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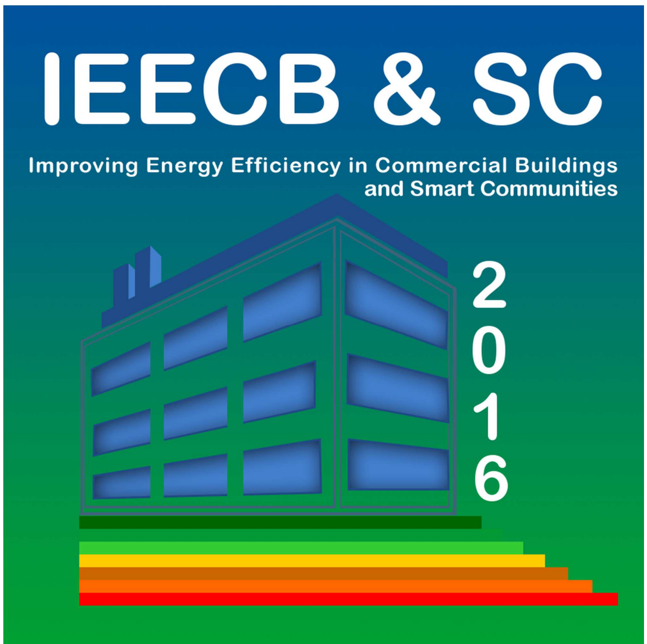
9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities

IEECB&SC'16

Paolo Bertoldi

2016



EUR 27993 EN

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9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities

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JRC Science Hub
https://ec.europa.eu/jrc

JRC102161

EUR 27993 EN

ISBN 978-92-79-59779-4 (PDF)

ISSN 1831-9424 (online)

doi:10.2790/290244 (online)

How to cite: Paolo Bertoldi; 9th International Conference Improving Energy Efficiency in

Commercial Buildings and Smart Communities; EUR 27993 EN; doi:10.2790/290244

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Integrated and sustainable energy concepts for urban neighbourhoods – A generic approach based on Austrian experiences

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Abstract

Larger Austrian cities are confronted with the necessity to develop new districts and to revitalise existing neighbourhoods. This process includes the development of new energy supply systems. The conventional solutions usually are gas grids for decentralised use on the one hand and district heating systems on the other hand. But both systems remain unsatisfactory: The simple gas supply is not in line with sustainability and GHG emission reduction goals, whereas district heating (with CHP as major source) is confronted with serious economic problems due to changes at the electricity markets and municipal utilities thus refuse to enlarge their district heating systems.

The paper derives a integrated approach to identify and to evaluate different energy concept options for neighbourhoods. The approach is characterised by the following points of reference:

- The (optimised) integration of energy demand and energy supply within the neighbourhood is seen as key success factor. Therefore the characteristics of energy demand are not interpreted as fixed design values but as variable parameter that can be influenced;
- The assessment of locally available renewable resources and infrastructures sets the basis for the identification of technically feasible options;
- The different technical and energy-economical energy concept options are assessed by means of a life-cycle cost analysis. This approach is widely used at the level of single buildings, but so far not well developed for the district level. This requires methodical adaptations and enhancements.
- The same applies for a consistent environmental assessment at the level of districts. Therefore various methodological approaches and performance indicators will be applied.

This generic approach was applied in the concept phase of the development of a new neighbourhood in the City of Vienna called Donaufeld. In this feasibility study several technical options for heat supply were developed together with experts within the administration of the city and the local energy supplier Wien Energie. Technical assessment and economical and environmental evaluation of several variants were carried out in order to have a holistic set of criteria as decision support. However, the assessment is not finished yet. The paper can draw preliminary results.

Finally, the paper draws conclusions on technical solutions and policy instruments that may be applied to enhance the implementation of sustainable energy concepts in new urban areas.

1 Background

Cities are facing the challenge of developing new districts and increasing the density of existing districts' due to constant urbanisation. In addition, the development of energy supply solutions for these city districts is part of this process. Conventional solutions are gas networks and the decentralised use of gas boilers in buildings or district heat supply - but both systems are unsatisfactory with regard to new urban areas. The increasing need for sustainability and the targets of reducing the greenhouse emissions are not in line with simple gas supply. Owing to the changes in the electricity market, district heating (with cogeneration as the main source) is confronted with serious economic problems recently. Hence, urban energy suppliers avoid expanding the district heating plants. In addition, district heat supply reaches its limits of economic efficiency at lower energy density in the supply areas. Moreover, the question rises whether it makes a good economic sense to have two infrastructures for heating and energy at decreasing heat consumption.

The city of Vienna faces a particularly big challenge. There are 1.77 million people living in Vienna at the moment (as of 2013) [1]. Forecasts say that the city will have more than 2 million inhabitants by 2028 already. This means an average increase of more than 15,000 people per year [2]. Therefore, numerous new districts are built in the "green fields" to meet the housing demand.

Hereby, the city sets great value on the sustainability of these development areas. In the course of the Smart City initiative [3], targets for living quality, conserving resources and innovation as well as the target values for CO2 emissions will be defined in accordance with the requirements of the Zurich 2000-watt society [4]. In order to achieve a sustainable and fair society, the city of Zurich has decided upon the 2000-watt model. According to this model, the known primary energy of 2,000 watt is sufficient for the continuous output of every human being, which equals a yearly energy demand of about 17,500 kWh per head. Thereby, about one fourth of this output (500 Watt primary energy) is available for housing purposes [5].

For the above reasons, the Municipal Department for Energy Planning (MA 20) of the city of Vienna commissioned a study to examine the technical energy supply solutions that are both environmental and economically viable for a concrete urban research area while taking account of local renewable energy sources. The research area is the city development area Donaufeld in the north of Vienna.

2 City development area Donaufeld

The city development area Donaufeld has a size of about 60 hectares and is located in Floridsdorf, the 21th district of Vienna. According to the guiding principles [6], the target is to develop an energy strategy that leads to an environment and climate friendly district. Thereby, not only a high-quality supply of green space and social infrastructure but also a city friendly, resource saving and environmentally compatible mobility concept plays a major role.

This area will be mostly used for residential buildings. There are plans to construct buildings on an area of 757,000 square metres and 6,000 apartments. A very dense development is intended with buildings having 5-7 upper floors.

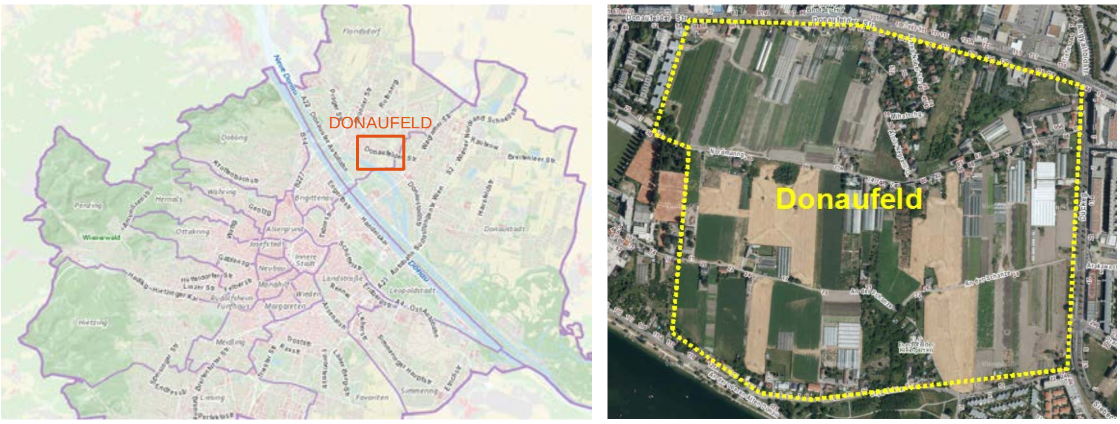

Figure 1: Overview and site plan of the city development area Donaufeld (Source: Guiding principles of Donaufeld, own additions)

The research area will be realised in three construction phases. The first construction phase is located southeast of the Donaufeld; the second construction phase is located in the North. Both are situated east of the grass strip and will be set up in the coming years. The third construction phase is located in the West of the green area and will probably only be built in the mid-2020s.

3 Methods

3.1 Study development process

It was the target of the project to develop possible energy supply solutions for the new district Donaufeld in consideration of local renewable energy resources, the examination of the technical feasibility as well as the environmental and economical evaluation. Moreover, it was aimed at involving essential stakeholders of the city of Vienna for new heat supply solutions. For this reason, a project advisory board was announced that includes institutions such as the wohnfonds_wien, the Municipal Department or Urban Renewal and Testing Agency for Residential Buildings (MA 25), the Energy Center of TINA Vienna, the urban energy supplier Wien Energie as well as the client MA 20. Wohnfonds_wien is the biggest property owner in Donaufeld and processes the urban developers' competition. The MA25 establishes criteria for housing subsidy. The MA20 together with Energy Center of the TINA Vienna have the task to set the framework in the city in order to reduce the use of energy and the CO2 emissions. However, Wien Energie is the main addressee of the study: the energy supplier's next step should be the implementation of the newly developed heat supply solution in concrete development areas.

At the beginning of the project, the members of the project advisory board were asked to submit proposals on how to create a sustainable heat supply for Donaufeld. After that, agreement on a shortlist of possible heat supply options was reached. During the following meetings of the project advisory board, the current status and the interim results were presented and discussed in order to keep the participants informed and give them the possibility to actively contribute their experience and know-how. Thus, the heat supply options could be adjusted to the Viennese general conditions and can expect a higher acceptance.

3.2 Calculating and dimensioning methods

The development of heat supply solutions is built on determining the level and density of energy demand as well as analysing the local energy resources. On the basis of the values found, the performance values for space heating and warm water were calculated. The size and the operating mode of the plant were defined according to the heat supply solution.

On the one hand, the energy demand definition is based on determining the maximum permissible core value of the heating demand and the expectable building compactness in the research area; on the other hand, it relies on internal surveys and measurements of buildings that are similar in size and built with a construction standard of about 2010 conducted by Wien Energie. In order to determine the hot water demand [7,8,9] and energy demand of households [10,11,12] further studies were taken into account.

The heat amount necessary to satisfy the demand for heating and hot water as well as the upstream losses up to the building's technical centre is the relevant factor to determine the heat demand. The system boundary of the value is comparable to the Q^*_H of room heating as well as the Q^*_{TW} of hot water according to the Austrian Standard (ÖNORM) H 5056 [13]. The core value's level for room heating is 35 kWh/m²a and 28 kWh/m²a for hot water (referring to the conditioned gross floor area). In comparison to the heating demand of a passive house (about 10 kWh/m²a), these values (called heat demand of the building in the project) seem to be relatively high (according to the general conditions of the Austrian Institute of Construction Engineering (OIB) guideline no. 6 [14] and referring to the conditioned gross floor demand). Regarding the heat demand of room heating, a higher interior temperature of 22°C and the losses of the building's facilities were also taken into account.

The research area and the surrounding exploitations were examined to define the local renewable energy resources. The study "Options for designing the Viennese energy systems in the future" (Ger. „Optionen für die Gestaltung des Wiener Energiesystems der Zukunft") [15] of the Vienna University of Technology (TU Wien) served as a basis for the examination. With respect to the energy resources mentioned in the study, the local circumstances were examined regarding renewable energy resources at first. A second limitation considered additional aspects specific to the project. The use of geothermal energy and solar energy is regarded as promising.

For the reason that this city development area almost entirely consists of residential buildings, there is no remarkable amount of waste heat within the research area (e.g. due to cooling systems of commercial areas) that could be included in the concept. Instead, big potential for waste heat lies outside of the research area, e.g. in buildings such as the indoor sporting arena "Albert-Schulz-Halle" or the shopping mall "Donauzentrum". These objects ware not taken into consideration, because their distance to the border of the research area is bigger than 500 metres and other city development areas are planned that are closer to those objects.

4 Results

4.1 List of energy supply solutions that have been examined in detail (shortlist)

The selection of energy supply options is divided into reference options, options with heat network (with/without district heating) and an option without heat network (see figure 4).

Reference options are those options that are normally used at the moment. On the one hand, there is the option of district heating connected to the building (**option 0**); on the other hand, there is the option of a gas boiler in every building (**option 4**). According to the requirements of the Viennese building regulations, however, heat supply must only be provided by a gas boiler. In order to reduce the CO2 emissions, solar thermal energy of 1 square meter collector surface per 100 square meters living space of the building has to be considered in the particular case.

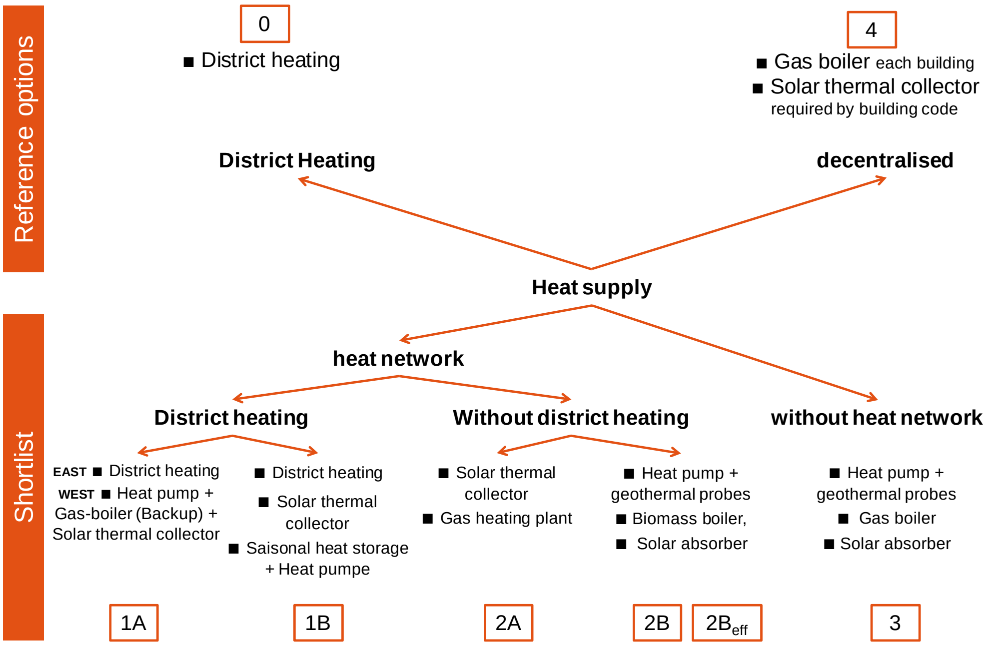

Figure 2: Shortlist of energy supply options (Source: own depiction)

Options including a heat network and district heating are divided as follows:

- Option 1A: Construction phase 1 and 2 (south of the green area) will be supplied with district heating. The supply of construction phase 3 (west of the green area) will be ensured with a heat pump on the building site and a central gas boiler to cover peak loads as well as solar thermal energy on the roof of the building.

- Option 1B: This option tries to reach a maximum coverage with solar thermal energy. The solar heat will be saved in one seasonal storage per construction phase. One heat pump per seasonal storage as well as district heating is available to cover the additional heat demand.

Options including a heat network without district heating are divided as follows:

- Option 2A: Solar thermal energy is intended on about 30% of the roof surface. The remaining heat demand will be supplied with central gas heating plants per construction phase.

- Option 2B: Option 2B implies small micro heat networks per every construction site. Heat is provided by heat pumps and geothermal probes. An exhaust air heat pump for buildings will be used for hot water. The electricity yield of the photovoltaic system on the roof will be directly utilised for the pump.

- Option 2Beff: Option 2Beff complies with option 2B, but has a reduced energy demand and thermal load by integrated ventilation systems with heat recovery.

Option 3 is planned without a heat network. Instead, one heat pump per construction site will be installed. The heating resources are geothermal probes as well as solar heating systems that can be used for the regeneration of geothermal probes during summer.

In the course of this study, the examination of a high number of technologies and supply systems was intended. Figure 5 provides an overview about the different possibilities to design the single options. It depicts the determinations for heat supply, heat networks, the temperature level of heat networks, ways of storage, hot water supply as well as the way of solar energy usage.

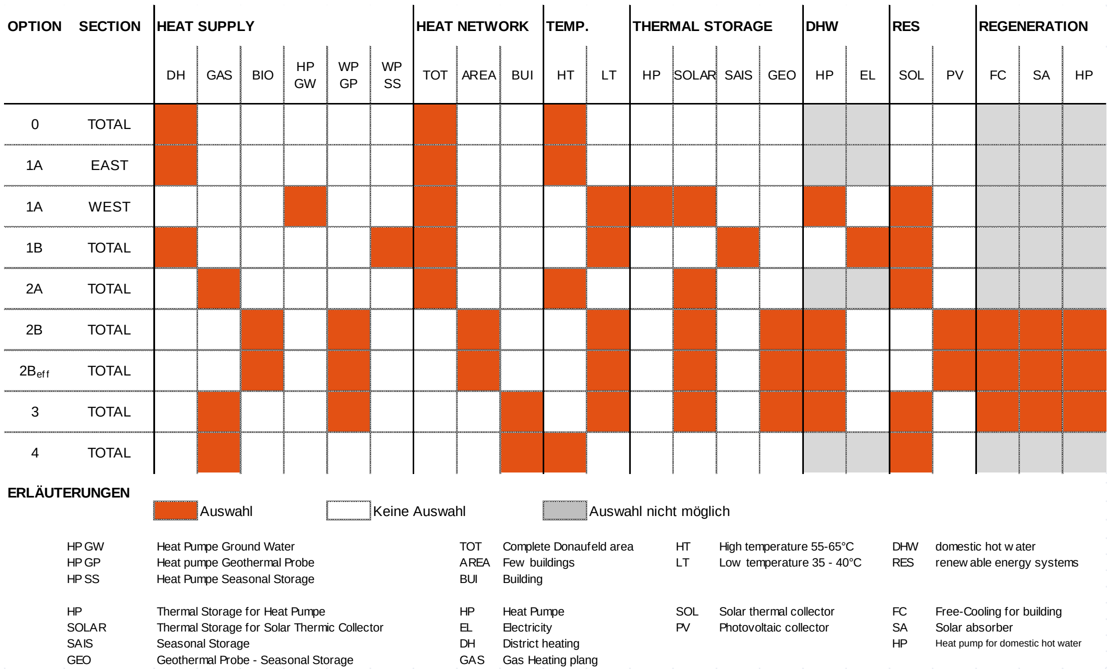

Figure 3: Overview about the different technologies of energy supply options (Source: own depiction)

With regard to the option using geothermal probes, heat supply for the building as well as the regeneration of the geothermal probes have to be considered. According to the concepts of option 2B, 2Beff and 3, which include fields of geothermal probes, it is necessary to balance the geothermal probes equally. That means that the energy amount used for room heating and hot water in winter has to be reproduced in summer. Otherwise, there is the threat of the soil cooling down in the long-term (up to the freezing of probes) and a decrease in the efficiency of the energy supply solutions [16].

In order to regenerate the geothermal probes, free cooling of the apartments as well as the introduction of heat from heat supply systems is intended. The following methods are examined to be used as heat supply systems: solar absorbers, reverse cycle heat exchangers (used as recovered heat), photovoltaic thermal collectors, thermal solar plants and hot water heat pumps. The decisive factors are their possible application in summer and low production costs for the heat. The concrete technologies for regeneration have not yet been finalised.

4.2 Environmental evaluation of energy supply solutions

The target of the environmental evaluation is to determine the necessary use of energy per energy supply option as well as the effects on the primary energy demand and the CO2 emissions.

The energy consumption per supply option is calculated by means of an annual balance based on the calculation methods according to the Austrian Standard (ÖNORM) H 506. The heat demand for room heating and hot water has already been defined (see chapter 3). According to the results, the losses due to heat distribution, heat storage as well as heat supply were calculated.

The energy efficiency parameters for heat supply were applied according to figure 6:

ENERGY SYSTEM		VAR 0	VAR 1A	VAR 1B	VAR 2A	VAR 2B	VAR 2BEFF	VAR 3	VAR 4
District heating heat exchanger	annual efficiency in %	98,50	98,50	98,50					
Gas boiler	annual efficiency in %		93,00		95,00			93,00	93,00
Water-to-water heat pump	seasonal performance factor		4,60	4,60		4,20	4,20	4,30	
Water-to-water heat pump (cascade)	seasonal performance factor		3,20						
Air-to-water heat pump	seasonal performance factor					3,20	3,20		
Solar thermal collector	Net heat gain in kWh/m²a (area of collector)		380,00	380,00	380,00			380,00	350,00
Photovoltaic collector	net electricity gain in kWh/m²a (area of collector)					135,00	135,00		
	effectiveness electricity in %					15,00	15,00		
Biomass boiler	annual efficiency in %					85,00	85,00		
Solar absorber	Net heat gain in kWh/m²a (area of collector)	just in period of regeneration of geothermal probe				390,00	390,00	390,00	

Figure 4: Energy efficiency parameters for energy supply systems of the single options (source: own depiction)

The results of the annual balance are final energy parameters of the respective energy supply option. In order to identify the CO2 emissions and primary energy parameters, the final energy was multiplied by the conversion factors in table 1:

Table 1: Conversion factors for primary energy and CO2 (source: OIB guiding principle 6, edition 2015; Wien Energie)

Source of energy	Primary energy factor	Primary energy factor renewable	Unit	CO2 emission parameter	Unit
Electricity	1.91	0.59	-	276	g/kWh
Gas	1.17	0.00	-	236	g/kWh
Fernwärme Wien (district heating)	0.33	0.06	-	20	g/kWh
Biomass	1.08	1.02	-	4	g/kWh

The values of the primary energy demand are preliminary results, as there might still be changes in the definition of the options. The area specific primary energy demand of the single options is between 21 and 75 kWh/m²a. The lowest primary energy demand (about 21 kWh/m²a) is caused by district heat supply (option 0). This value is enabled by a low primary energy factor of 0.33 for Fernwärme Wien (district heating). By contrast, the values for gas heating are the highest (option 4 and 2A). The options with heat pumps (2B, 2Beff and 3) have a specific primary energy demand between 40 and 50 kWh/m²a. Efficient heat pumps lay good foundations for a low primary energy value, whereas peak load boilers decrease this value. The options that use a mixture of district heating and heat pumps (option 1A and 1B) require around 30 kWh/m²a.

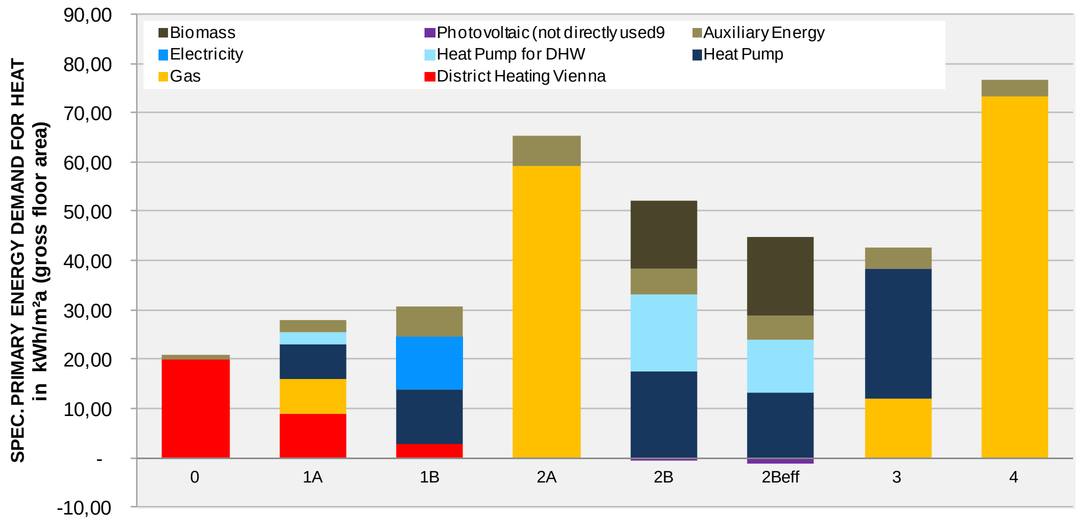

Figure 5: Area specific primary energy of the energy supply options (Source: own depiction)

A similar picture can be seen when evaluating the CO2 emissions of the research area (see figure 7). It also shows only preliminary results. In terms of this indicator, options with gas supply are responsible for the highest CO2 emissions; whereas options with district heating cause only very low emissions. In comparison to primary energy, options with biomass boilers (option 2B and 2Beff) achieve better value due to a low CO2 factor of 4 g/kWh.

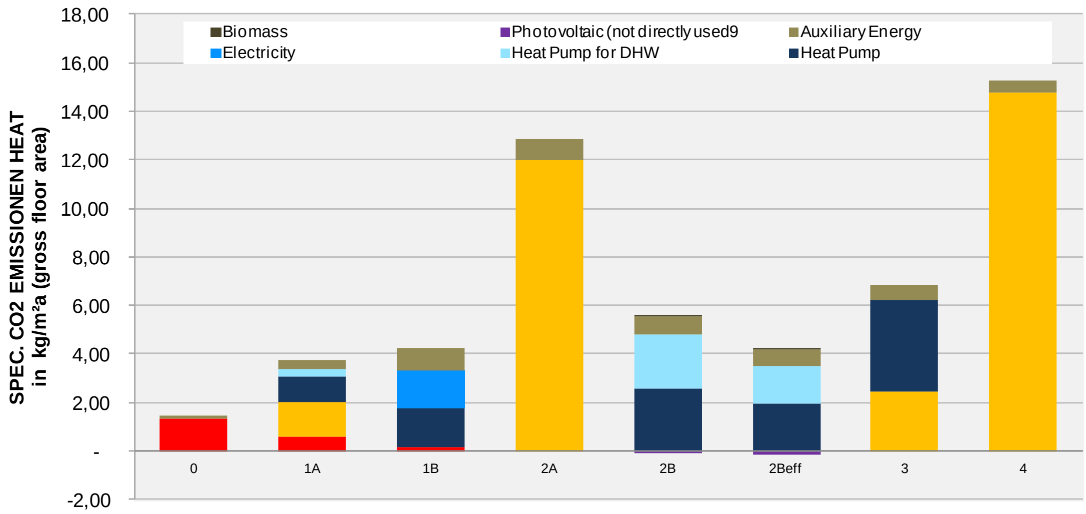

Figure 6: Area specific CO2 emissions of the energy supply options (source: own depiction)

In figure 8, the energy supply options were measured by the primary energy performance target of 500 W (based on the renewable share of primary energy). It shows that the options using mainly gas supply cannot keep the Smart City targets, as they already shortly fall below or even exceed the targets regarding the energy demand of room heating and hot water (RH+ WW). The values for the use of electricity in apartments (248 Watt/person primary energy performance) have not been considered here. The options using district heating as well as those using heat pumps, are significantly below the value of 500 W/person and can meet the target also when taking the electricity use of the apartments into account.

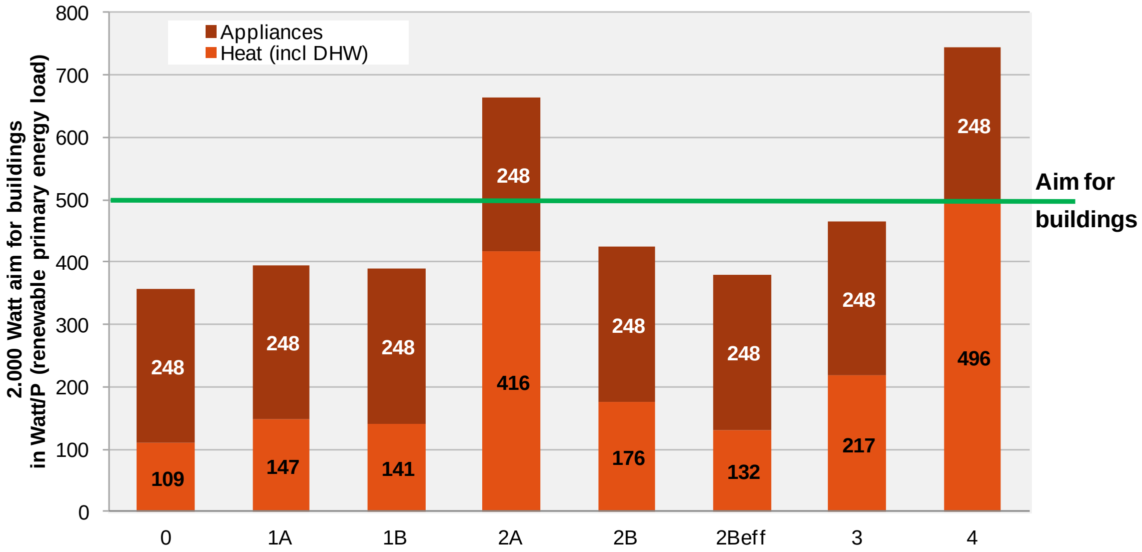

Figure 7: Orientation towards 500 Watt primary energy performance per person for living (source: own depiction)

4.3 Economical evaluation of energy supply solutions

The energy and fuel costs for gas and electricity were calculated on the basis of the grid usage rates according to the values of the Wiener Netze. The working price was attained and coordinated with Wien Energie. These specific energy and fuel costs are used as values for major customers. Figure 9 shows the range of energy and fuel costs for gas, electricity and biomass. The specific costs per energy supply solution depend on the required power and the energy consumption.

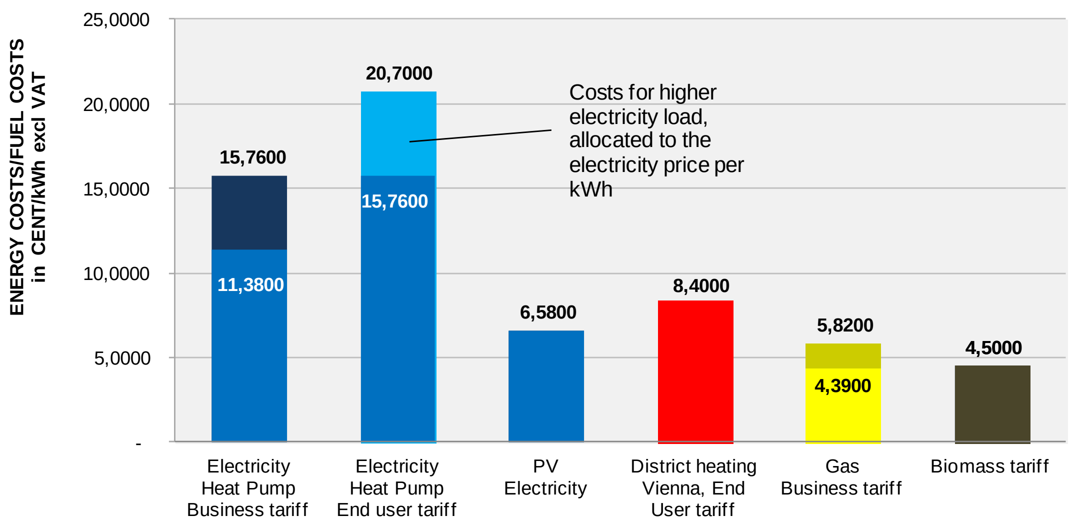

Figure 8: Range of energy tariffs for the different energy supply options (source: own depiction)

Comments on the specific energy and fuel costs in figure 8:

- The values include the working price and all details, but no value added tax (VAT).
- In case two values are set, these values make up for a range between the highest and lowest specific energy costs in dependence of the performance of the heat supply system as well as the energy consumption amount.

- In terms of electricity, there are differences between electricity for the heat pump and electricity for the apartment. Heat pump electricity is measured with a business rate, whereas the electricity for apartments is measured with an end customer tariff. For option 1B, which uses instantaneous water heaters, higher electricity tariffs can be expected due to a higher power demand. The arising costs are allocated to the specific energy costs.
- In terms of district heating, the tariff for property developers was applied. This tariff does already contain maintenance as well as reinvestment costs occurring after the expiration of the plant's operating life. In addition, management costs and rates of return on investment are included.

Because further detailing will be put into practice to get the most realistic cost values, investment costs as well as life-cycle costs are not determined yet. This next step will especially examine options 2B and 3. Derived from the results of preliminary examinations, peak load boilers and different solutions for regenerative heat were determined for option 2B and 3. Additionally, the option 2Beff with reduced energy demand in buildings was developed.

The next step will be to draw up the rough planning for a concrete area and the dimensioning of the plants. Based on concrete plants the costs relating to plants and heating will be determined. As a result, the investment and life-cycle costs will be updated. These working steps are to be completed in the spring of 2016.

5 Initial conclusions

The conclusions focus on the following three supply options: gas, district heating and heat pump (options 0, 2A, 2Beff, 3 and 4). Option 1B will be addressed when examining the investment and life-cycle costs. Option 1 A divides into two options: one with district heating (construction phase 1 and 2) and another one with heat pump and heat network (construction phase 3).

The options including heat pumps divide into solutions with a small local heat network (option 2B and 2Beff) and without a heat network (option 3), with option 2Beff having a lower energy demand.

5.1 Conclusions of environmental interest

In environmental terms, the decisive indicators are primary energy together with primary energy performance and CO2 emissions. The option with gas supply (option 4) has the highest values of primary energy and CO. The gas supply options (option 2A and 4) do not meet the Smart City targets of the city of Vienna and can thus be excluded from a future-oriented heat supply model.

The district heat supply option reaches the highest values for both indicators. Hence, district heating plays a leading role at the environmental level. In order to maintain the good environmental valuation, the low conversion factors for primary energy and CO2 must be continuously achieved in the future.

In case that heat supply is only based on heat pumps with geothermal probes or rather air as the source of energy, the options including heat pumps could lie level with district heating in environmental terms. Due to environmental reasons, however, a boiler based on gas or biomass is used to cover the peak load. Hence, the parameters for environmental valuation increase, except for the CO2 valuation of biomass boilers. In addition, it is necessary to produce regenerative heat when using geothermal probes to create a seasonal balance between heat extraction and heat introduction. This creates an additional energy demand that displays in the environmental valuation. From the environmental viewpoint, heat pumps are a meaningful way of heat supply. Nonetheless, it cannot keep up with the level of the district heating option because of the following reasons:

5.2 Conclusions of economical interest

The economical valuation has not been finalised yet, because the heat pump options are still undergoing a "reality check" for a concrete small supply area. Regardless of the examination, it is already possible to draw some preliminary conclusions.

The option with gas supply (option 4) has the lowest value for construction costs. The district heating option (option 0) offers low construction costs, too. In comparison to the other options, different system boundaries are applied here: the option with district heating does not consider the costs for heat generation, because a capacity expansion of district heat supply is included in the energy tariff.

The option that primarily uses solar thermal energy and seasonal storages (option 1B) has the highest construction costs. Therefore, it is possible to conclude that a heat supply by solar thermal energy only is not feasible in an area with such a high building density. The costs will be significantly increased due to the additional peak load coverage by heat pumps and district heating.

Regarding the heat pump options, it is crucial whether the peak load is covered by heat pumps and geothermal probes or by boilers. Peak load boilers can significantly reduce the construction costs. At this point, it is important to consider the disadvantages of fuel procurement and maintaining costs (biomass boiler) as well as the environmental effects (gas boiler). Moreover, the supply of regenerated heat in summer does burden the construction costs. In order to manage the fields of geothermal probes in a sustainable way, the regeneration of geothermal probes is mandatory. Since the waste heat from the buildings' effective space (free cooling of apartments) is too low, further heat supply plants have to be build that introduce heat to the geothermal probes. The usage of a hot water heat pump in a building with additional operating hours is cost-neutral regarding the construction, but increases the operating costs of the plant.

After the options with heat pumps have been analysed in a more explicit way, it will be possible to make a more detailed statement on the economical valuation.

This also applies to the life-cycle analysis. Nevertheless, the following results can already be anticipated: The gas option is the most economic option concerning the life-cycle costs. The high investment costs of the option with heat pumps and geothermal probes and the lower operating costs (especially low electricity costs) lead to a convergence of life-cycle costs between the option with heat pumps and district heating. Here, the extent of the convergence of district heating and energy supply by heating is dependent on the calculation parameters of the life-cycle analysis and the expected investment costs.

5.3 General conclusions

Heat supply by means of heat pumps and geothermal probes has higher construction costs than district heating and gas supply. These additional costs have to be covered during the construction phase of the building. However, they are difficult to cover as the existing upper limit for construction costs in the residential housing development promotion program in Vienna is already hard to meet at the moment. In the current system of housing development promotion these additional costs cannot be defrayed.

It is a system with higher investment costs for the energy supplier that cannot easily be covered by the current district heating tariff. Complete cost coverage would require a higher construction cost subsidy, which again cannot be easily implemented into the housing development promotion program.

These conditions lead to the consideration of new business models when regarding the abovementioned cases in order to enable the financing of initial investment. After all, options featuring heat pump solutions can also be used in smaller development areas and independent of district heating. Hence, it is possible to realise the presented plans without a "traditional" energy supplier.

In the course of the City of the Future project Smart Services "Smart Services for resource-optimised urban energy systems of city districts", possible solutions and concepts for business models of heat supply solutions with a high share of renewable energy sources are developed. Possible concepts are discussed with energy suppliers and other energy service providers. The final report will be ready in the fall of 2016.

From a technical point of view, the option with heat pumps is far more complex than a district heat supply solution. A heat supply concept with heat pumps considers several heat pumps, numerous geothermal probes that are distributed in the supply area, heating storages in the buildings and systems to regenerate the geothermal probes. The technologies for heat supply in the supply area are arranged in a decentralised way and demand higher management, maintenance and repair efforts.

At the same time, this means a higher degree of local added value. The financial resources for heat supply will be spent for the acquisition of energy sources, e.g. gas or oil, to a smaller share and be used to build and operate heat supply plants instead. In comparison to heat supply concepts such as district heating, the expenses for energy are significantly lower.

For now, heat supply in cities is mainly covered by district heating and gas boilers in the buildings. In areas where district heating and economically feasible possibilities for extension are currently available, it is still meaningful to use district heating. However, there are many areas without district heat supply. This can apply to existing buildings and city districts as well as newly build supply areas. For environmental reasons (and in order to achieve the Smart City targets), the new construction of a heat supply system based on gas supply does not contribute to the reduction of CO2 emissions and the primary energy demand in a sustainable way. At this point, it is expedient to provide alternative solution concepts. The option of heat supply by means of heat pumps and geothermal probes offers a meaningful concept for urban heat supply.

The concept including heat pumps and geothermal probes requires heat for the regeneration of the geothermal probes in summer. Thus, it is expedient to obtain cost-effective or costless waste heat directly in or near the supply area. In this way, the energy usage costs for regeneration can be minimised. This can be done by including commercial buildings into the systems, as they extract heat from the building in order to ensure comfort in summer in any case. However, this can also be companies in the research area that have been directly ordered to participate - when integrated into the supply concept they receive cost-effective cold in summer and deliver waste heat in return. Especially well-suited for this purpose are data centers, where heat is extracted 365 days a year in order to run the servers that can be used to regenerate the geothermal probes. In return, the data center receives cost-effective or costless cold from the geothermal probes that can be used for cooling.

Last but not least, an additional benefit of the heat pump solutions is the gain in comfort for the apartments: The first measure to generate regenerated heat in summer is free cooling of apartments. Thereby, the heat is extracted from the apartments and made available for the geothermal probes. In view of the hot summers in the last years, this solution offers a great benefit to the apartments. The costless temperature conditioning of apartments in summer provides a high level of comfort for the residents. This benefit should be considered in the overall evaluation of heat supply solutions.

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Covenant of Mayors Initiative an in-depth analysis of selected Sustainable Energy Action Plans (SEAPs)

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Abstract

In the frame of the European Commission's Covenant of Mayors Initiative an in-depth analysis of selected Sustainable Energy Action Plans (SEAPs) has been carried out by the Joint Research Centre of the European Commission. Based on a sample of 25 cities from different Member States of the European Union, the study seeks to identify and extract the common and most important characteristics on how local authorities across Europe develop and implement this mitigation policy. The strategy followed in elaborating the SEAPs has been investigated in terms of methodology, policies deployed, governance, external support, regional and national characteristics. By doing this, results are extracted as regard to strengths and weaknesses cities show in order to reduce their total GHG emissions by 2020.

Two types of Covenant signatories are considered: those which were already involved in climate, air quality, sustainability and energy plans at city level and adapted their plans to the Covenant requirements and those who engaged for the first time in sustainable climate and energy planning through the Covenant. Some important conclusions are drawn on the best practices, circumstances that favor the adoption and the implementation of local sustainable energy policies, the need of an external support for small municipalities to develop the SEAP, the relevance of joint efforts and the role of the Covenant Territorial Coordinators within the initiative.

1. Introduction: The Covenant of Mayors initiative: a tool helping cities to reduce CO_2 emissions and rethink the city to make it more sustainable

The Covenant of Mayors brings together local and regional authorities across Europe, who voluntary commit to implement sustainable climate and energy policies in their territories. The initiative, which currently involves more than 6 000 municipalities, was launched after the adoption in 2008 of the EU Climate and Energy Package. The Covenant's aim is to endorse and support the crucial role played by local authorities in mitigating the effects of climate change

The initiative relies on municipalities committing themselves to developing and implementing a Sustainable Energy Action Plan (SEAP). Each plan contains measures to reduce the municipality's energy-related emissions by at least 20 % by 2020 compared with the emissions calculated or measured in a baseline year. 1990 was recommended as baseline, but signatories may choose any other year, if that is the first one for which they can provide reliable data. SEAPs need to comply with the 10 key principles listed in Table 1.

Table 1 Ten key principles of the Covenant of Mayors initiative.

SEAP PRINCIPLES

SEAP approval by Municipal Council	Strong political support is essential to ensure the success of the process.
Commitment to GHG reduction	The SEAP must state clearly the greenhouse gas reduction target (at least 20 % by 2020).
BEI	The SEAP must include the results of the BEI, based on sound knowledge of the local situation in terms of energy and greenhouse gas emissions and covering the entire geographical area of the municipality.
Measures covering key sectors	Buildings (municipal, residential, tertiary), Transport.
Long and short-term actions	Goals until 2020 and detailed measures for the next three to five years.
Adaptation of municipal departments	Priority: identify a person/team to take responsibility for the plan, such as an energy and climate department connected to the Mayor's office.
Mobilisation of civil society	Describe how civil society has been involved in drawing up the SEAP and how they will be involved in its implementation and follow-up.
Financing	The SEAP should identify the key resources for funding the implementation of the plan.
Monitoring and reporting	'Monitoring Report' every second year following submission of the SEAP.
SEAP submission and filling the template	Municipalities should submit this within one year of joining. Uploaded in national language (or in English) + online SEAP template in English.

One of the initiative's main characteristics is its open and flexible character. Although signatories need to ensure that their scientific approach is basically sound, they have a certain degree of flexibility on technical aspects, such as:

- the approach taken to develop the BEI (i.e. the IPCC or LCA approach)
- the methodology used to measure or calculate energy consumption data
- the emission reporting unit (CO_2-equivalent or CO_2)
- the sectors covered among the key sectors established and beyond
- the approach to monitoring.[1]

It is worth noting that the Covenant is seen by the signatories not only as an energy-related initiative, but also as a way of developing local sustainable measures that will enable their city to achieve better urban planning and socioeconomic development. Energy saving, emission reduction and climate change mitigation are achieved as a result of a new organization of the local authority and to a deeper awareness among the public. SEAPs are also used in most of the participating municipalities as a tool in the design of the urban environment.

1 Guidebook: How to develop a sustainable energy action plan (SEAP). http://iet.jrc.ec.europa.eu/energyefficiency/publication/guidebook-how-develop-sustainable-energy-action-plan, 2010.

2. Methodology: Basis of the analysis developed for the 25 selected signatories

2.1 Objectives of the in-depth analysis

The aim of this study is to carry out an in-depth analysis of the SEAPs submitted by a selected number of cities and towns that have joined the Covenant of Mayors. The analysis comes six years after the launch of the Covenant and coincides with the start of the monitoring phase. The study can help identify the way cities in Europe are implementing energy measures to achieve their specific emission reduction target by 2020.

Table 2 Objectives of the study

Concrete objectives of the study
1. Identify a selected sample of cities joining the initiative, making sure that the study covers the full spectrum of the Covenant community
2. Understand cities' main strengths and weaknesses in developing their SEAPs
3. Highlight the key differences between countries, regions and European areas or between larger and smaller cities
4. Study the interaction and synergies with other related initiatives
5. Extract several best practices adopted by the selected cities*

* *see the full science for policy support report (Rivas et al, 2015)*

The conclusions may be used to draw up a proposal on how to improve the overall approach for SEAP development and implementation and how to step up the initiative. The proposal may refer to the method by which municipalities join, to improving online resources generated within the initiative, to providing more robust and comparable data, or to better identifying the monitoring requirements for new signatories.

2.2 Compiling the in-depth analysis sample

The purpose of the sample selection was to select a number of signatories that would cover the full spectrum of the Covenant community and provide representative SEAPs for different city sizes, countries and levels of economic development. Nine main factors were considered, as shown in Table 3, in order of priority.

Table 3 In-depth analysis sample criteria

	SAMPLE CRITERIA
1	**City size**, using the cities 2012 classification[2]. As most of the energy saving measures in key Covenant sectors such as local power generation and transport depend on city size, this is the

2 Cities in Europe. The new OECD-EC Definition. RF01/2012 http://ec.europa.eu/regional_policy/sources/docgener/focus/2012_01_city.pdf.

	main factor we considered when compiling the sample. According to assessment studies for the Covenant of Mayors *(Cerutti et al. 2013, Kona et al. 2015)*,[3] 88 % of the municipalities joining the Covenant are small and medium-sized towns so it is important that they are represented in the sample.
2	**Population covered** by the plan, in terms of country population and Covenant community. Although large urban cities represent 3% of the total number of signatories, they account for 56% of the total Covenant population.
3	**Member states** The aim was to have the maximum number of EU member states represented in the sample, taking into account not only the number of signatories per country but also the population covered
4	Regions (socioeconomic aspects)
5	**Participation in related initiatives** to determine if a previous involvement of a signatory in the implementation of a Covenant-related plan can generate mutual benefits for the city in question and for the Covenant movement as a whole. This study should identify ways of helping these cities to meet the Covenant's requirements without duplicating their work, as far as possible.
6	Support provided by a Covenant Territorial Coordinator (CTC) or not
7	Individual SEAPs and joint SEAPs (developed by two or more municipalities together)
8	Limiting factors: language, objectives of the plan outside of the Covenant's scope, lack of adaptation of pre-existing plans
9	Year of submission

Special cases: joint SEAPs and SEAPs coordinated by a Covenant Territorial Coordinator

To take into account lessons learnt during the initiative, such as the difficulties faced by smaller towns in complying with the Covenant requirements, different approaches were proposed: promote joint SEAPs[4] and SEAPs developed with the support of a Covenant Territorial Coordinator (CTC[5]), a role officially recognized by the European Commission.

Limitations

We encountered some restrictions when selecting the sample. For example, we had to exclude some good SEAPs from the list, including some examples of interesting measures, because the cities did not follow some of the Covenant's key principles, e.g. they did not adapt their long-term target to 2020

3 Covenant dataset established in May 2014, as described in 'Covenant of Mayors: Performance Indicators — 6-Year Assessment' (Kona et al 2015).

4 Quick Reference Guide — Joint sustainable energy action plan http://www.covenantofmayors.eu/IMG/pdf/Joint_SEAP_guide-2.pdf

5 Quick Reference Guide — Grouped SEAP analysis http://www.covenantofmayors.eu/IMG/pdf/Grouped_SEAP_analysis_guide.pdf.

or they rely on non-priority sectors like green areas and waste management for more than 10 % of their total reduction in greenhouse gases.

Figure 1 Geographical sample distribution. Own source

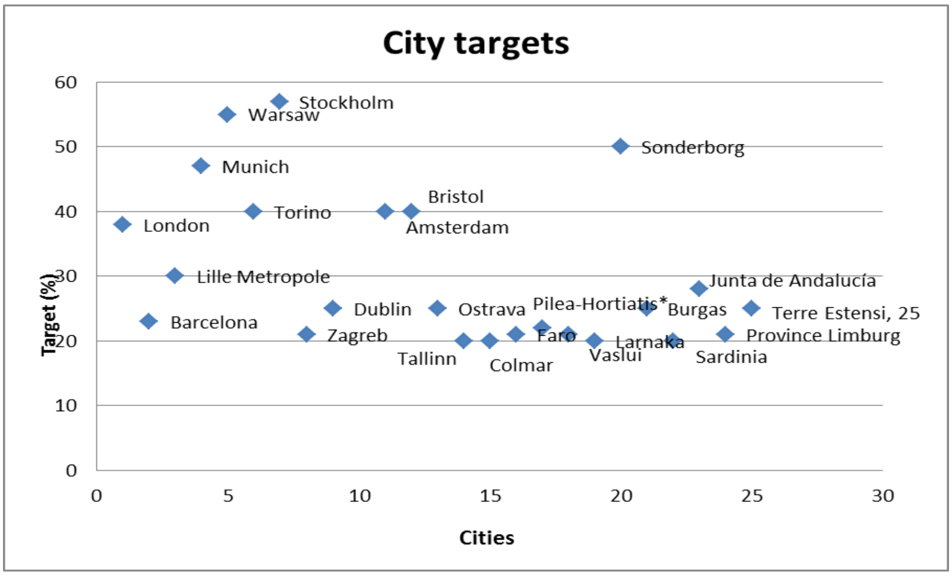
RESULTS

3.1 Basic data

3.1.1. 2020 Targets

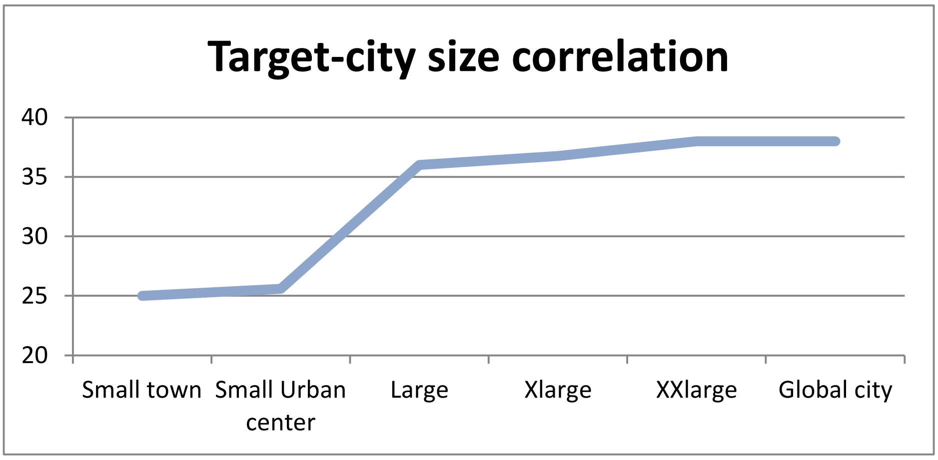
The signatories' selected targets seem to correlate closely with their size and whether or not they had pre-existing plans and initiatives in place. The total greenhouse gas reduction targets range from standard targets of 20 % (e.g. Dublin and Tallinn) to more ambitious targets (e.g. 57 % per capita for Stockholm and 47 % for Munich). 50 % of the signatories in the sample selected a reduction target of between 20 and 30 %. The mean target selected by the cities analyzed is 29.3 % and the median target is 25 %.

Figure 2 City CO_2 2020 reduction targets



With its 50 % reduction target, Sonderborg is a special case. Although being a small urban centre, it shows a very well developed strategy to achieve a low-carbon future.

Figure 3 CO2 target-city size correlation



Targets are mostly expressed in absolute terms. Only four of the signatories selected for the study (Stockholm, Barcelona, Colmar and of Pylaia-Chortiatis a) set a per capita reduction target. One reason why some signatories selected a per capita target may have been that they forecasted a significant increase in population. This was the case for Stockholm and Pilea-Hortiaris. For example, the population of Pylaia-Chortiatis almost doubled between 1991 and 2011 because of its proximity to the Thessaloniki urban area and its touristic location.

There is some variety in the types of targets proposed in the plans: a total of 11 signatories, (44 % of the sample) included energy savings and/or renewable energy source targets in their SEAPs. Some cities, such as Barcelona, Munich and Ostrava, did not set a specific energy saving target by a given year, but rely instead on a continuous reduction in energy consumption. Stockholm and Junta de Andalucía's plans base themselves on regional or national requirements in terms of energy savings. The rest of the plans set a preferred target of a 30 % reduction in energy savings by 2020 and a RES share of 26 %.

Table 3 Sample energy efficiency (EE) and renewable energy (RES) targets

City	EE target	RES target
Lille Métropole	13 % by 2020	6 % by 2020
Barcelona	No specific target but committed to a continuous reduction in energy consumption	
Munich	No specific target but committed to a continuous reduction in energy consumption	
Stockholm	National objectives by 2021	
Dublin	33 % by 2020	33 % by 2020
Amsterdam		30 % by 2025
Bristol	30 % by 2020	
Ostrava	No specific target but committed to a continuous reduction in energy consumption	
Larnaca	No specific target but committed to a continuous reduction in energy consumption	
Burgas	26 % by 2020	26 % by 2020
Junta de Andalucía	Regional objectives by 2020	

3.1.2. The existence of long- and short-term targets

City size seems to also have a bearing on whether the signatory sets long-term targets. In total, eight of the selected signatories set a long-term target. These were London, Munich, Turin, Dublin, Amsterdam, Bristol, Sonderborg and Stockholm. The objectives vary from a 50 % reduction by 2030 for Munich to Stockholm's fossil fuel-free by 2040 scenario.

Table 4 Long-term CO2 reduction targets

City	2030 target	2040 target	2050 target
London			80 %
Munich	50 %		
Turin			80 %
Stockholm		100 %	
Dublin	50 %		
Amsterdam		75 %	
Bristol			80 %
Sonderborg	100%		

3.1.3. Relation with other initiatives

In principle, cities that have already developed or implemented an energy, climate or environmental plan might seem advantaged when joining the Covenant initiative and complying with its requirements, but the reality shows that even in such cases, fulfilling the Covenant can be quite demanding. Participation in other initiatives certainly gives cities the skills and resources to commit to the Covenant's goals. For example, Barcelona implemented the initiative through pre-existing municipal departments. However, sometimes the objectives and procedures are different, forcing the city to make a significant effort to reconcile them. The synergies between the participation in others initiatives and the Covenant successful implementation might not be obvious.

In total, 15 of the signatories included in the sample are involved in mitigation-related initiatives or in networks such as Eurocities and Climate Alliance. The case of France and Germany are particularly noteworthy.

3.1.4. Involvement of the public and other stakeholders

This is one of the strong points shares by the SEAPs in the sample: the substantial importance given to the involvement of civil society in the plan. The consultation process is an important part of the whole SEAP process in all cases, in addition to specific measures under the 'Other sectors' section regarding social mobilization and awareness of citizens. Energy days, surveys, workshops and working groups are the main tools used by the signatories to involve not only the public but also the main stakeholders. In every city analyzed, at least three of the interest groups listed in Table 5 appear as players involved in the SEAP preparation process.

Table 5 Involvement of stakeholders Figures are in blue for cities with more than 10 stakeholders involved, in red for cities with more than 15, and in black for cities with less than 10 stakeholders)

Stakeholder	Number of cities involving the stakeholder
Local energy suppliers	15
Local transport companies	14
Private companies in general	12
Citizenship/consumers associations	17
Cities networks or other cities	6
Universities	7
Representatives of private companies active in EE and RES'	4
Representatives of civil servants	2
Trade unions	1
Regional government	11
National government	9
Local and/or regional energy agencies	12
Financial partners such as banks, funds or energy service companies (ESCOs)	6
Media	5
Environmental associations	7
Other local bodies	9
Industry/employers federations	5

The case of Sonderborg is especially instructive. The Sonderborg project involved more than 100 stakeholders from different sectors, who participated to create a concept which will drive the entire decarbonisation process. It is an outstanding example of how a local authority can take the lead in mobilising different stakeholders to find mutually advantageous solutions and transform the need to reduce greenhouse gas emissions into a growth opportunity for the community.

3.2 Baseline emission inventories (BEI)

3.2.1. Baseline year

The Covenant guidebook specifically recommends using 1990 as the reference year for calculating the emission reduction by 2020. Nevertheless, just 19.4 % of the total signatories of the Covenant were able to gather reliable data for that year, while four sample cities (Munich, Stockholm, Riga and Torino) provided a complete 1990 inventory. In general, cities with a longer tradition of dealing with energy and environmental matters could be expected to provide earlier robust data.

The most frequently chosen reference year was 2007 (40 % of the sample), followed by 2005 and 2008. The results match those gathered from the six-year assessment study.

3.2.2. Emission inventory calculation

The methodology used in the Covenant to calculate emission inventories allows participants to choose between the IPCC (Intergovernmental Panel on Climate Change) guidelines and the LCA (Life cycle assessment) approach. In order to make sure that the data produced under the Covenant were comparable, a conversion was proposed in 2013 using a unique conversion coefficient (0.885) considered to be representative for the direct emissions in LCA inventories.[6]

88 % of the sample used the IPPC approach to calculate the BEI data, while Munich, Stockholm and Tallinn used the LCA approach. Even if the LCA in principle is a more complete methodology, it takes considerable time and specialization, which is not always affordable for small municipalities developing their SEAP in-house. For cities like Munich, which already had climate and energy plans, most of the information needed for the calculations was already available in their records.

3.2.3. Emission reporting units

As illustrated above, the Covenant initiative guidelines' intended reporting units for city emissions are either the total CO_2 or the total CO_2-equivalent, which is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential over a 100-year timescale (IPCC, AR4, 2007). Carbon dioxide equivalents are commonly expressed as 'million metric tonnes of carbon dioxide equivalents' (MMTCO2Eq). The carbon dioxide equivalent for a gas is derived by multiplying the tonnes of the gas by its associated global warming potential.

Only 35 % of the cities included in the sample selected CO_2-equivalents as their reporting units. As with the previous Covenant reports, the CO_2 unit was expected to be selected more often for reporting due to the higher feasibility of the data collection.

3.2.4. Sectors covered and sectors missing in the BEI

Among all the emitting sectors in the urban environment, the following sectors are strongly recommended to be included when calculating the BEI:

1. municipal buildings, equipment and facilities and municipal public lighting;
2. tertiary (non-municipal) buildings, equipment and facilities;
3. residential buildings;
4. urban road transport (including the municipal fleet, public transport, private transport).

As not all signatories have detailed data for all sectors and energy carriers, a certain degree of flexibility is allowed in the online template for data collection.

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[6] Five-year assessment report. Covenant of Mayors.

The main aim is not to exclude signatories which, for various reasons (such as data confidentiality or the format of their statistics), may not have detailed data. The 'Buildings, equipment facilities and industries' sector has as its subsectors municipal buildings, tertiary buildings, residential buildings, public lighting and industry non-ETS (i.e. not covered by the emissions trading system), while the 'Transport' sector has as its subsectors municipal fleet, public transport and private transport. (Green cells are mandatory, white cells are optional). As only the data at the level of sector are mandatory, , the quality of the data provided varies significantly.

Twelve of the cities analyzed provided a properly completed BEI. Five common situations were identified:

1. cities not providing data for a particular sector.
2. cities not providing data by subsector, but only by sector. This was the case for Junta de Andalucía (CTC), Tallinn and Faro (transport);
3. cities providing subtotal data but not split by carrier, as in the case of Warsaw;
4. cities including the municipal sector within the total for the related sector (i.e. buildings or transport). This was the case for Amsterdam, while Burgas did the same for the tertiary sector;
5. the BEI includes data from other sectors, which are either explicitly not recommended (such as agriculture, airports, or optional (such as waste and water management). Barcelona, Lille Métropole, Sonderborg and Dublin included optional and non-recommended sectors.

Due to the lack of an exhaustive explanation of the methodology provided, it is not clear when and how these data are included. In certain cases, confidentiality issues or the use of national statistics which follow data structures different to the one proposed by the Covenant prevented the signatories from providing a complete and coherent BEI.

3.3 Sustainable energy action plans (SEAPs)

3.3.1. Preferred sectors in terms of CO2 reduction. Lack of data

As described in the BEI section, the requirements and data the signatories must provide or include in their SEAPs are quite flexible. This generates very diverse data.

This section aims to analyse the real weighting of the different sectors in the CO_2 reduction the signatories plan to achieve by 2020. However, as described before, the data provided by the cities in the online templates vary considerably.

The building sector (including municipal, tertiary and residential buildings) is **the preferred sector** for the signatories' estimated $\mathbf{CO_2}$ reduction by 2020**.** All signatories plan to carry out measures in this sector. This is in line with European and national policies (the Energy Performance of Buildings Directive and the Energy Efficiency Directive) and with the results of the six-year assessment report, which found that 44 % of the estimated total reduction relies on the building sector.

The second most popular sector by number of signatories was transport, closely followed by electricity production and heating and cooling, which were covered by three cities. However, by looking at the results in terms of population, as shown in Table 6, we find that transport and electricity production sector account for the same percentage.

Table 6. Preferred sector by population (*Amsterdam excluded from the calculation)

Sector preferred	Population	Percentage
Buildings	12 181 141	**64.1**
Transport	2 766 121	14.5
Electricity production	2 971 106	15.6
Heating/Cooling	1 022 908	5.5
Others	69 500	0.3
TOTAL	19 010 776	

The signatories in the sample took very diverse approaches on how to achieve the emission reduction. In most cases, signatories had one preferred sector that accounted for a high percentage of the reduction. By contrast, Warsaw, Vaslui and Junta de Andalucía achieved a balance between different sectors. For Junta de Andalucía, buildings and transport account for almost the same percentage. For Vaslui, the total data cover only two sectors, most probably because the emission reduction from heating and cooling was already accounted for under buildings. As stated above, just 2 % of the sample gives measures for the five basic sectors. Munich's SEAP bases 80 % of its total emission reduction on electricity production measures, while almost 85 % of Stockholm's overall target comes from district heating and cooling measures. Colmar was the only instance where the 'Others' sector (42 %) had the main contribution to its SEAP.

3.3.2. Examples of policy-related practices. Approaches taken by specific signatories.

As part of the study, policies, measures and good practices were highlighted by sector. The analysis divides policies and measures into main sectors such as buildings, city policy support, local energy production and transport. Nevertheless, there are cross-cutting policies and measures that cover different sectors. Innovation, Measurability and Replicability were the criteria selected. As an example:

Innovation: The whole Sondenborg area strongly demonstrates commitment to new energy and climate solutions through technology, financing involvement and learning platforms. Sonderborg uses its SEAP as a means of becoming a 'sustainable city', using smart energy and financing in city development.

Replicability: Covenant signatories regional standards to impose more stringent energy performance requirements than those applicable at national level. For example, cities like Amsterdam, Turin and Copenhagen have in place examples of city policy support that go beyond the requirements of national building codes not only for public buildings, but also for residential buildings.

Measurability: The energy saving concept ('ESK 2000') in Munich's plan involved systematically examining 50 % of the entire Munich municipal building stock over two years to identify potential for energy savings. The energy benchmarking helped to indicate an efficient course of action when carrying out the subsequent project phases.

3.4 Implementation and monitoring

One of the key principles of the Covenant of Mayors initiative is the need to track how the measures in the SEAP are being implemented. A qualitative report is sent every second year to the European Commission and a quantitative report is due every four years. The 25 SEAPs analyzed in this report were submitted at a time when the Covenant of Mayors was not yet providing guidance on how to report on SEAP implementation.

Therefore, the planning of an effective implementation with real monitoring plan seems to be a weak point. Twelve cities, i.e. less than 50 % of the sample, included a specific monitoring chapter. Similarly, less than half of those that provided a specific monitoring chapter included as part of it a real implementation or monitoring plan stating the methodology to be followed, players, timeline, etc. In most cases, we found just a vague indication about the mandatory reports provided for by the initiative (Lille Métropole, Turin, Tallinn). Five cities in the in-depth study (London, Sonderborg, Barcelona, Bristol and Munich) have genuinely well-defined implementation and monitoring systems. Barcelona and Munich are especially interesting in this respect.

CONCLUSIONS

Policy contribution

For most of the signatories, the Covenant of Mayors initiative is a structured way of implementing national regulations. The municipalities' policies benefit from the leverage of the European directives on the energy performance of buildings, energy services, energy efficiency and renewable energy sources. In response to these directives, EU countries drew up policy guidelines on energy efficiency in buildings and the end-use by consumers and it is normal that municipalities follow national strategies on these subjects. It was not uncommon to find similarities between the measures in the SEAPs analysed and those in national energy efficiency action plans. The signatories present the measures to achieve the target in a cross-sectoral way; most of the measures originate from European or national policies, with few innovative measures being presented. For example, Faro presented a package of solar power measures as its most important contribution towards energy savings; these measures are mostly based on transposed European directives. By contrast, in the absence of strong national policies for transport, signatories were much more diligent in developing their own measures for that sector. Larger cities tend to include promising measures in their SEAPs that represent a step up from the basic regulations. Larnaca provides a very good example of how to scale down national policies and tendencies to adapt them to the local level. Its plan was developed with strong support from the national energy agency.

Overall considerations

As described in previous sections, the in-depth analysis aims to identify how cities in Europe are tackling the challenge of achieving their specific emission reduction target by 2020. One of the main focuses of the study was to understand and highlight the main and most common **strengths and weaknesses** in the SEAPs **and suggest solutions on how to overcome the shortcomings**.

Strengths:

1. Many signatories include energy savings and RES targets in their plans, in addition to the Covenant requirement to set an emission reduction target. This shows that municipalities are in line with national and European policies. Also, setting partial targets makes it easier to monitor results in different areas of intervention.
2. Some signatories set a longer-term target, even going beyond the timescale of the Covenant of Mayors (e.g. to 2030 or even to 2050). This is considered a key success factor as it clearly shows the local authority's political commitment and gives a clear message to the public and local stakeholders on how the local authority wants to develop in the future, paving the way for more substantial investment in sustainable infrastructure.
3. The substantial importance given to involving civil society in the drafting of the plan is one of the strong points shared by the evaluated SEAPs.
4. Signatories use the SEAP not only as an energy planning instrument, but also as the basis for an all-encompassing approach to urban planning: a healthier environment, better quality of life, the creation of skilled and stable jobs that are not at risk of moving elsewhere; greater economic competitiveness and reducing energy dependence.
5. Covenant territorial coordinators (CTCs) are also playing an important role in helping cities and towns of different sizes to implement sustainable energy policies. The experience of multi-level governance, in the form of SEAPs coordinated by a CTC and joint SEAPs for groups of municipalities, has shown that small and medium-sized municipalities are able to communicate and work with stakeholders and calculate emission inventories more successfully at a broader regional level than at the local one.

Weaknesses:

1. Monitoring. The fact that municipalities have to be accountable and illustrate their progress makes the Covenant much more than a political statement; it is also a technical tool to improve energy performance. With the exception of London, Munich and Barcelona, most of the SEAPs analysed failed to document the implementation and monitoring phase in their plans (London continues to be one of the world's leading cities in measuring and reporting its direct and indirect CO_2 emission and assessing the progress of the Mayor's climate change and mitigation programmes on a yearly basis). However, one of the reasons why signatories failed to document the implementation and monitoring phrase may be because before May 2014 the Covenant of Mayors did not provide any specific monitoring guidelines.

2. Data inconsistency. In some cases, we found significant differences between the exhaustive and detailed information reported in the SEAP document and the poor information included in the SEAP template. This is especially true for cities that developed their plan under a different context to that of the Covenant (e.g. London, Amsterdam, Munich and Lille). The Covenant of Mayors needs to provide more guidance so that the Covenant is more compatible with existing initiatives, limiting duplication of work.

3. In most cases, local authorities count heavily on a favorable national or regional context for energy efficiency and renewable energy policies (e.g. availability of national incentives for building renovation, etc.). We have found that a significant proportion of signatories' estimated 2020 emission reductions are associated with measures decided at national and/or regional level, such as in the case of Turin and the Junta de Andalucía, or rely on funds allocated by the national government. To overcome this, municipalities need to identify possible financing schemes that could encourage private players to participate in public investments. Many municipalities need private sector investment in order to fund local sustainable energy strategies and programmes. Strengthening the relationship between the public and private sectors could also create new opportunities for securing additional sources of funding, such as European funds.

General conclusions

- The selected emission reduction target seems to be correlated with city size and the existence of previous plans and initiatives. Usually larger cities have higher targets, most likely because they are better placed to interact with big energy players and have more resources to plan major investments on sustainable infrastructure (see London, Stockholm, Dublin and Turin). In addition, the earlier a city committed to developing a climate and energy plan (e.g. Stockholm), the more ambitious its target for 2020. The example of Sonderborg, a medium-sized municipality with a very ambitious target, offers an alternative approach for similar municipalities on how to tackle the potential lack of resources by increasing synergies between stakeholders.

- Only the 'big cities' (i.e. global and large cities) have long-term targets for beyond 2020. However, smaller cities could also benefit from this approach, as it would give a clear indication of the city's vision in the longer term and possibly attract private investors.

- Plans developed after the launch of the Covenant and the publication of the guidebook generally do not have difficulties in complying with the requirements. This means that the guidelines are generally well understood and applied by the signatories and provide good guidance material on local energy planning, especially for newcomer cities.

- In principle, the emission calculation approach, i.e. selection of the emission reporting units and of the BEI (baseline emission inventory) year do not have a significant impact on the results of the SEAP. The selected areas of intervention have much more of an impact. Once a significant number of monitoring reports have been submitted, these aspects could be investigated further, to determine whether aspects like a city's regional and economic realities have a clear influence on the plan's success.

- The preferred sector in which the CO_2 reduction is to be achieved, confirming the results of the six-year assessment study,[4] is the buildings sector (64 %), followed by transport and electricity production (15 and 14 % respectively in per capita units). This is in line with European and national policies (the energy performance of buildings directive and the energy efficiency directive). In all cases where transport was the preferred sector, the city concerned was a global or large city.

- City size versus quality. Even if global and large cities have more developed and ambitious SEAPs supported by higher budgets and more diversified financial resources, the real effectiveness of plans may not be related to city size. Small municipalities present a more accurate evaluation of the reality of the city and may therefore produce more efficient measures. Small municipalities may also benefit from more direct contact with the public and stakeholders and run more successful awareness raising campaigns. City size has a strong impact on the characteristics of the SEAP.

- By contrast, we have found only minor national and regional differences, although the sample includes SEAPs from different geographical areas in Europe. There are, however, some differences in terms of the processes for SEAP development: SEAPs from northern and central Europe seem to count on greater cooperation by the municipal departments involved and on a collaborative or participative process with stakeholders. These aspects are generally less developed in SEAPs from southern Europe (e.g. Turin, Maracena (Junta de Andalucía), Faro). Future studies could look more closely at the differences between local energy plans across Europe, for example based on the national energy policy context (e.g. regulations and incentives) and the amount of decentralization of powers on energy issues.

- signatories that have already developed or implemented energy, climate or environmental plans could be at an advantage when joining the Covenant of Mayors initiative. A signatory's participation in other initiatives gives it the skills and resources to commit to the Covenant's goals (e.g. Barcelona, which used existing municipal departments to implement the initiative). However, sometimes the objectives and procedures of the Covenant and pre-existing initiatives are different, forcing the city to make a significant adaptation effort to reconcile the two. Moreover, in some cases the synergies between initiatives may not be obvious.

Recommendations

The conclusions of this report may serve as a basis for a proposal on how to improve the overall approach to drawing up and implementing SEAPs and on possibly expanding the initiative. Such a proposal would need to look at the following:

- the methodological process and the path to joining the initiative;
- the strengthening of structures and platforms generated as part of the initiative;
- ensuring more robust and more comparable data; (improving the data submission process)
- better monitoring requirements for new signatories.
- Interoperability with initiatives that are similar to the Covenant
- Key principles review. With the Covenant extended beyond 2020, a revision of the 10 key principles may be worth considering. This would need to ensure that the principles are relevant to a wider and more diverse Covenant community comprising a large number of small and medium-sized towns, where new models of multi-level governance are being tested with the involvement of covenant territorial coordinators.

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INVESTIGATING THE IMPACTS OF COMMUNITY ENERGY PROJECTS ON LOCAL STAKEHOLDERS

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Recent years have witnessed a growing interest in the transformation on how energy is generated and used to the benefit of man and the environment. Amongst many Green House Gas (GHG) emissions reduction strategies, community based Renewable Energy activities seem to have risen higher up in the UK public agenda. This paper therefore accentuates the importance of an appropriate research design for the investigation of the impacts of Community Renewable Energy Projects (CREPs) on local stakeholders in the UK. The role played by CREPs in contributing to building resilient and stronger community in the UK cannot be denied. In spite of these successes, there is an increasing debate on perceived CREPs outcomes and its impacts which are yet to be properly communicated. This research integrates the pragmatic paradigm (as the philosophical footing), inductive and deductive approaches and combination of both survey and case study data collection strategies in its design. Although the case study is still ongoing, data collected from questionnaire distributed to Community Energy Groups across the UK were analysed using appropriate statistical techniques. Among the main outcome of the analysed data, there is a lack of adequate communication on the gains and successes of CREPs to non-participants; and most UK community energy initiatives are located either in rural areas or in small towns away from large urban centres. The main conclusion of this paper was to communicate CREPs positive impacts on stakeholders on a UK wide scale. However, a number of important limitations need to be considered, first the findings are limited by the use of only survey data to highlight the effects of CREPs on stakeholders when the research design prescribed combination of both Survey and Case Study strategies, this is because the case study phase is still ongoing. It is believed that the outcome of this phase will provide sufficient clarification on CREPs impact on a UK wide scale. Again, with a small sample size, caution must be applied, as the findings might not be representative of the entire UK Community Energy Sector

Keywords: Community Energy Projects, Impacts, Local Stakeholders, UK

1 Introduction

The Conventional energy sources (coal, oil and gas) are almost depleted and the climate catastrophe caused by GHG associated with its usage has become a big threat to the existence of human and planet earth. The generation, sales and usage of energy from these sources also depends largely on a lengthy supply chain, huge investments on production facilities, and infrastructures which sometimes may lead trade partners and nations into conflicts (Weisser, 2007). The hurdle of meeting global demand for energy is enormous; there is however, an increasing need to explore sustainable ways this can be achieved (Hain et al., 2005). Consequently, the global energy system is now undergoing transformations especially in how energy is generated and consumed.

In Europe, different strategies have been put forward to curb these emissions, in order to achieve a 20% reduction from the 1990 baseline by 2020. Among the strategies proposed is rural community's involvement in Energy programmes and activities such as planning, generation, distribution, consumption and ownership. At present, the UK has made tremendous progress in this regards as evident in the increasing numbers of communities tailoring their energy needs to fit local resources available to them thereby becoming self-reliance. This localised energy system so far has contributed to a decline in rural urban migration in mostly the islands and other isolated communities across the UK.

Community Renewable Energy Project's (CREPs) contributions to the UK CO2 emission reduction target has become a key agenda in many UK sustainable Energy reports including the Department of Energy and Climate Change 'Community Energy Strategy' report (DECC, 2013). However, an understanding of the possible impacts these projects may have on individual stakeholders could scale up its uptake and further creates multiplier effects on UK CO2 emission reduction target. In order to properly communicate the above understanding, a relevant, appropriate and robust research methodology is required.

To date various methods have been developed and introduced to measure community energy impacts (Rogers et al., 2012, Warren and McFadyen, 2010, Rand and Clarke, 1991, Vine and Harris, 1990, Das et al., 1995) however, main focus has been on technical assessment of demand, supply, or related cost. Moreover, the methods are very generic and were not tailored to intrinsic individual against collective expectations of the local stakeholders which is the main focus of this paper.

The paper has been organised in the following way: first, a brief understanding of the various impacts CREPs may have on local stakeholders is presented, followed by a discussion on local stakeholders expectations. It then goes further to justify the importance of designing a robust methodology to investigate CREPs Impacts. From quantitative data collected, the analysis results, discussion and conclusions drawn are presented in the last section of the paper

2 Community Energy Projects and Local Stakeholders

This section first provides a brief discussion on socio-economic and environmental considerations of Community Renewable Energy Projects (CREPs) and Local Stakeholders being the main thrust of this paper

2.1 Community Energy Projects Impacts

The primary aim of setting up CREPs in the UK was to explore the possibility of using Renewable Energy resources to tackle local needs, build resilient and stronger community and further promote sustainable consumption of natural resources by helping the locals gain more understanding of the dangers of climate change.

CREPs being an evolving concept is understood differently in terms of meaning and application given that Renewable Energy (RE) resource availability varies from place to place, likewise the technology and governance structure for harnessing the resource (Cai et al., 2009). Also, the projects vary in terms of the capacity of energy generated which is a determining factor for socio-economic and environmental impact assessments (Frondel et al., 2010). According to Keyhani et al., (2010), investigating or appraising the socio-economic and environmental impacts of CREPs on the local stakeholders is not without a twist because most impacts assessment are based on the economic growth of an area

Economic growth resulting from business activities in a locality is often measured by the number of jobs generated or prevented as a result of that business activity (LOOTS, 1998), for example the economic value added locally (Bahri et.al. 2011). Aghion and Howitt (1994) however argued that amount of job created by economic growth does not translate to quality of employment opportunity. Weisbrod and Weisbrod (1997) warned that focusing assessment of project impacts on economic benefits alone disregards project whole life impact on the natural environment and social relations.

Furthermore Schreiber and Kuckshinrichs (2009) maintained that the approach is not holistic but adds that economic advancement however comes with social cohesion and improvements to the host community. It is however important to state that socio-economic and environmental impact assessment of CREPs is not about emphasising the negative project outcomes on the people and the environment but also to explore how the human-centred and sustainable local values and benefits generated by the project development can be maximised for the general wellbeing of the people (Berkhout et al, 2002). The common benefits identified in most CREPs projects include access to clean energy supply, human security (Aitken, 2010), local wealth creation, savings in energy bill, local skills development (Zahnd, and Kimber, 2009), job creation and larger community development (Wilkinson et.al, 2009) and so forth.

In as much as these benefits are important, their positive or negative impacts on stakeholders cannot be generalised (Omer, 2008). This is because, while investors are concerned with the functionality (optimal performance) of the project, the consumer on the other hand is concerned about the safety, reliability, social inclusion (or rejection) and whether general standard of living can be improved by these projects (Akorede et.al, 2010). However, by strategic early feasibility studies, different expectations and interests in the project can be identified and incorporated into the project risks management programme and managed using appropriate stakeholders management tools

2.2 Local Stakeholders Expectations

Generally, stakeholder management is a broad research area and cannot be exhaustively covered in this paper; however it is important for project participants to understand and adopt established tools and theories on stakeholders' management (Savage et.al, 1991; Harrison and Freeman, 1999; Kelada, 1999; Cleland, 1986). These tools can be adopted and used to check and control possible impacts unmet expectations of stakeholders could have had on the project. Campbell (1997) refers to stakeholders as persons with different expectations from a given project or business activities. El-Gohary et.al (2006) added that every project will affect lives, and that those whose lives are affected have the right to express their opinions which must be used to redirect project or business decisions. This includes those within and outside the project organisation or environment. Stakeholder identification, assessment and management therefore have become regular and essential strategy incorporated into the development processes in many projects (Kelada, 1999). A similar view is held by Wheeler and Sillanpa, (1998) studies which revealed that stakeholders are keen to know the many positive/negative benefits a new expansion and/or closure of business activities or projects can generate.

Above assertion aligns with CREPs core objectives which are to support and empower the local people to make decisions centred on their needs and also to ensure that the system is open to public scrutiny and accountability (Akorede et.al, 2010). However, indirect local stakeholder's needs are seldom recognised and prioritised in CREPs (Srivastava and Rehman, 2006). Rather, local investors and volunteers, regulatory bodies, commercial partners, contractors, equipment suppliers, funding organisations, local consumers and employees are the main stakeholders whose needs are recognised and prioritised by most CREPs development (Reddy and Painuly, 2004; Haralambopoulos and Polatidis, 2003; Downs, 2004).

It has been argued by Wüstenhagen et.al, (2007) that every project involves numerous stakeholders and their many expectations which must be considered holistically instead of isolating a few interest groups based on convenience. Stakeholders are people and people have lifestyles, interest, influence and motivations that cannot be ignored, in other words socio-economic and environmental value addition is a major stakeholder expectation that should be assessed at every phase of the project lifecycle. Drawing on above understanding of who stakeholders are, it is fair to say that successful CREPs delivery will depend largely on collaborations among the project teams with direct involvements in the projects and others with no direct involvement but whose ability to influence project outcomes cannot be summarily dismissed. Arguments put forward by Pomeroy and Douvere, (2008) suggests that stakeholder's identification and engagement has to be robust and should form an integral part of any organisations corporate and risk management strategy that must be reviewed periodically.

Zhang et.al, (2005) believes that local stakeholder's expectations and Community Renewable Energy projects objectives are two realities, but for the projects to satisfy all of the stakeholder's demands/expectations is impossibility. Blumsack, (2007) however suggests that the gains of CREPs can be assessed by measuring the Socio-economic and environmental outcomes of CREPs over Socio-economic and environmental project expectations. The next section briefly examines four different models of research design and presents a design adopted and employed for the investigation of CREPs gains and impacts on the local stakeholders.

3 Research Design

3.1 The principle of research design

Research design is a decision making process that is backed by a convincing empirical justification of why such process is best for the research (Hakim, 1987). It is thinking about the research and all the various dynamics and control mechanisms in carrying out acceptable research (Blaikie, 2009).This research seeks to answer the question of impacts of community energy ownership models on the nature and performance of community renewable energy projects (CREPS) in the UK, with particular focus on adopting a research design model for the investigation of the impacts of community renewable energy projects on local stakeholders in the UK.

In order to facilitate above investigations, four different models of research design and their various control process are examined, the models are: Saunders et.al (2009)'s Research Onions, Creswell (2009)'s Research Design Framework, Blaikie, (2007)'s Research Choices and Kagioglou et al (2000)'s Nested Model (see Table 1).

Table 1: Four research design models and the Control Procedure

Models of Research Design	**Research Procedures and Control Process**					
	1st Procedure	**2nd Procedure**	**3rd Procedure**	**4th Procedure**	**5th Procedure**	**6th Procedure**
Blaikie, (2007) Research Choices	Research Paradigms (Ontology, Epistemology)		Research Strategies (Inductive, Deductive, Retroductive ,Abductive)			
Creswell, (2009) Framework for Research	Philosophical Worldviews (Postpositivist,Constructivist,Transformative,Pragmatic)		Design and Strategies (Experiments, Ethnographies ,Explanatory Sequential)	Design /Choice (Qualitative, Quantitative, Mixed Methods)		Methods / Techniques (Questions, Data Collection, Data Analysis, Interpretation, Validation)
Kagioglou et al., (2000) Nested Research Model	Research Philosophies (Preunderstanding, Understanding)	Research Approaches (Case Study, Action Research)				Research Techniques (Questionnaire, Interviews, Workshops, Literature Review)
Saunders et al., (2009) Research Onions	Research Philosophies (Positivism, Realism, Interpretivism, Pragmatism)	Approaches (Deductive, Inductive)	Strategies (Experiment, Survey, Case Study, Action Research, Grounded Theory, Ethnography, Archival Research)	Choices (Mono Method, Mixed Method, Multi Method)	Time Horizons (Cross-Sectional, Longitudinal)	Techniques/ Procedures Data Collection Data Analysis

A careful consideration of above table shows the robustness of each research design model which can also serve as a guide for the adoption of a practical research design. The four models considered the philosophical standpoint as the first control procedure in research design, although with different terminologies such as philosophical worldview, research paradigm and or philosophies. Irrespective of the names assigned to this over-arching research element, its underlying emphasis is on the fact that basic believes of every researcher will eventually influences their actions, decisions and research directions.

The second control procedure being the research approaches is however missing in Creswell and Blaikie's Research design models respectively and captured by Saunders et.al, (2009) and Kagioglou et al., (2000). Moreover Creswell (2009)'s Research Design Framework, Blaikie, (2007)'s Research Choices and Kagioglou et al (2000)'s Nested Models were not exhaustive in covering all the control procedures by providing finer details and flexible options on how to progress with research from general assumptions to specific methods of theory formulation and testing. These aspects are however the strength of the Saunders et.al (2009) Onion.

That notwithstanding, it is important to note that the diversity and contradicting school of thought on appropriateness of one research design model over the other stems from the fact that ownership of truth about any given circumstances or subject matter is not an exclusive right of any model or researcher (Lincoln et.al., 2011; Denzin and Lincoln, 2009; Schwandt, 2001). The following section will cover the research design model and the control procedures adopted

3.2 Adopted Research Design: Research Onion Approach

The common mistake novice researchers make usually is to focus attention on designing a method for the research problem rather than focus on the research problems and tailor the methods (structure a plan) to fit into the research aims, and answer the research question. According to Cooper et al. (2006), research question is a major consideration when choosing research method(s) to use. Therefore having carefully examined the specific features in all the elements in each model, this research adopts the 'Research Onion' model by Saunders et.al (2009) shown in Figure 1 to bring about a comprehensive approach congruent to the investigation of the impacts of community energy projects on local stakeholders in the UK. Each element in the "onion" is carefully considered and modified where and when necessary to fit into the type of question established for the study.

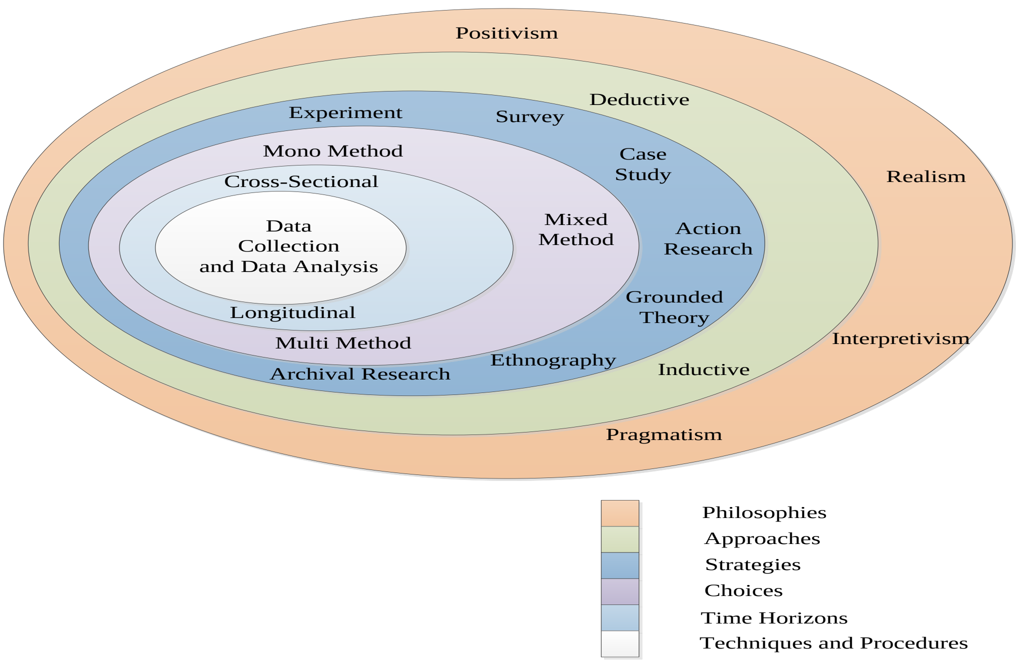

Figure 1: Research Onion, Saunders et.al (2009)

Many researchers have developed their methods and strategy successful by peeling through the layers in Saunders et al (2009)'s onion and adopting appropriate approaches, and strategies, thereby making choices within specific time horizons, before settling for data collection, analysis techniques, procedures and tools that reflects their overall research objectives. Drawing on above Onions design model (Figure 1), adopted components of the model found suitable to guide the investigation of the impacts of community energy projects on local stakeholders in the UK, is justified and presented in Figure 2 below. In addition, the adopted design aided the selection of appropriate data collection technique, the primary data collected is analysed and the results are discussed in section 4.

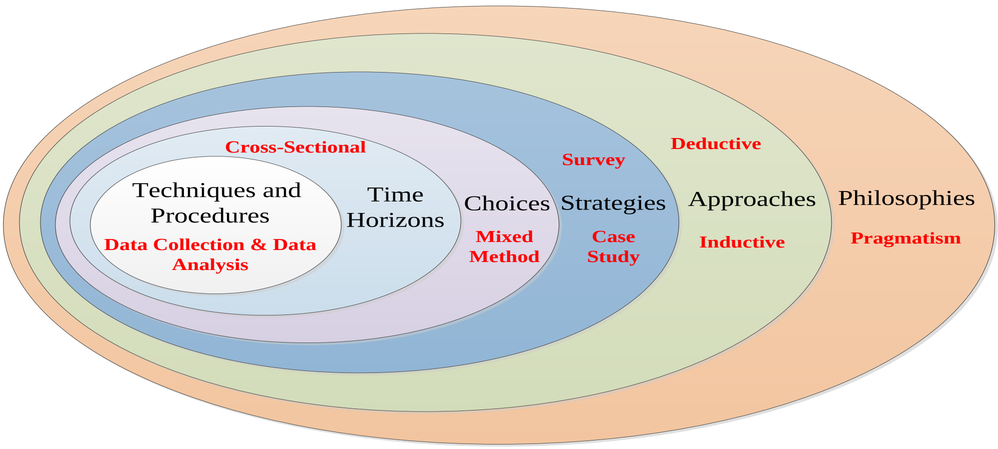

Figure 2: Research Design for this research

3.2.1 Research Philosophy: Pragmatism

From the first (philosophy) layer in Figure 1, the pragmatic paradigm is adopted as the philosophical footing for the study. This is because pragmatist researchers place emphasis on the research question (West, 1989), in this case - what impact (if any) does the Community Renewable Energy Projects (CREPs) have on the local stakeholders in the UK and How these impacts can be assessed?. The pragmatists employ every technique there is (qualitative, quantitative or combination of both assumptions) to understanding and answering research questions (Morgan, 2007).Furthermore, pragmatic philosophy emphasises understanding of real problems (actions of community energy projects organisers and the impacts generated) faced by real people (local stakeholders in the UK) (Joas, 1993). In addition the pragmatists are strong proponents of combination of two or more research paradigm in order to make up for drawbacks in individual paradigm (Rescher, 1999), by this a more appropriate approach, strategy and choices for research can be achieved (Feilzer, 2010).

3.2.2 Research Approaches: Deductive and Inductive

Based on above philosophical paradigm, inductive (qualitative), deductive (quantitative) or combination of both approaches can be used to advance the research (Ali and Birley, 1999). Therefore in order to approve or disprove existing theories on stakeholders influence on projects (Morse, 1991), the Socio-economic and environmental outcomes of CEP over Socio-economic and environmental project expectations were subjected to statistical tests (Deductive approach). These variables were derived from literatures and responses from questionnaire administered to various Community Energy Groups (CEGs) in the UK.

Furthermore, qualitative case study interview is planned for selected CREPs in Scotland alone (Inductive approach) where opinion of a smaller sample of practitioners and local stakeholders would be gauged as regards negative and positive impacts CREPs may have on the local economy. The inductive approach focuses more on providing interpretation to meanings each individual affected by the projects hold about the project but according to Bryman and Bell (2015), care less about generalisation. This is a divergent point of the inductive approach that necessitates combination of both Case Study and Survey to strengthen the entire research design

3.2.3 Research Strategy: Case Study and Survey

The Survey and Case study were chosen as the appropriate strategy for this study based on the following reasons: The survey research strategy is a popular and an efficient method for collecting significant amount of data from the target population through Questionnaire administration in a relatively inexpensive way (Andersson *et.al*., 1987), while Case study strategy is an effective way of answering the 'how' questions in research (Gillham, 2000). While Questionnaire administration was UK wide, Cases selected for this research are narrowed to Scotland since this research seeks to answer the question on how to assess the impacts of community renewable energy projects (CREPs) on local stakeholders in the UK, narrowing down will allow for in-depth study of CREPs impacts.

Furthermore, Scotland was chosen because the area benefits from variety of renewable wind, hydro and solar energy projects (CES, 2014). As a matter of fact, Scotland contributes over 12% to the UK overall RE capacity. Plans are already underway to boost this capacity further through exploring the Geothermal, Biomass, Offshore wind, Hydrogen fuel cell, Tidal and Wave Energy markets (Walker, 2008). Moreover, the ownership model (management system) of these projects and the nature of project (technology in use) vary which makes it necessary to measure the impacts of these fragmented variables. It is however important to state here that the process of arriving at the choice Scotland as a case study area was not very easy but considering the presence of substantial and diverse nature of CREPs and their ownership models were the key factors that favoured the area over other regions in the UK. The Case Study phase of the research is however still ongoing.

3.2.4 Research Choices: Mixed Methods

In order to make up for acknowledged limitations associated with using either quantitative or qualitative, the combination of both research choices is employed. In addition researches resulting from combination of these choices are highly rated, accepted for generalisation (Bazeley, 2002).

3.2.5 Research Time Horizon: Cross Sectional

This research is comparing different phenomena from CREPs in the UK and the researcher hopes to draw findings within the permissible time available for the research. Therefore the Cross sectional time horizon in the "Onion" time horizon layer sits well with this research

3.2.6 Research Techniques and Procedures

3.2.6.1 Data Collection

The survey samples for this research were Community Energy Groups (CEGs) selected and compiled from the Community Energy Projects database of Community Energy Scotland, England, Northern Ireland and Wales, this is because these four Nations make up the United Kingdom. Also, various type of Renewable Energy projects engaged in by the selected CEGs was considered to give wider perspectives to phenomena under investigation.

The survey questions were divided the four groups covering main themes under investigation. Group-A sought answers to some general demographic questions, while Groups B, and C probed into community renewable energy projects performance in the UK, and its social, economic and environmental implication on investors and local communities respectively. The last group (D) investigates the impacts of community ownership projects ownership models (CEPOM) on the performance of energy projects. The survey is now deactivated and data collected is undergoing various statistical tests.

3.2.6.2 Data Analysis and discussion

Survey respondents were asked to answer the 5 points Likert scale questions to the best of their recollection based on their most recent involvement in Community Energy projects. The choice of Likert scale as a response method for this survey is because it is widely used, easy for respondents to understand and makes quantification of responses easy (Laerhoven et al., 2004). Of the 65 or 59% respondents that completed the survey, only 63.08% provided the address of where their project is sited. Based on above statistics, England, Scotland and wales account for 51.22%, 46.34% and 2.44% respectively of respondents/projects geographical location.

4 DATA ANALYSIS AND RESULTS

4.1 CREPs Professionals Categorisation

Figure 3 represents respondents profile in terms of their expertise and job classification in the Renewable Energy Sector. The job classification was based on the various stages involved in the life cycle of the project thus: Experts working with Construction and Installation, Government/Regulatory Agencies, Support Service Providers, Operations and Maintenance Experts, Technical Designs and Equipment Manufacturing, Research, Planning and Development and Volunteer groups

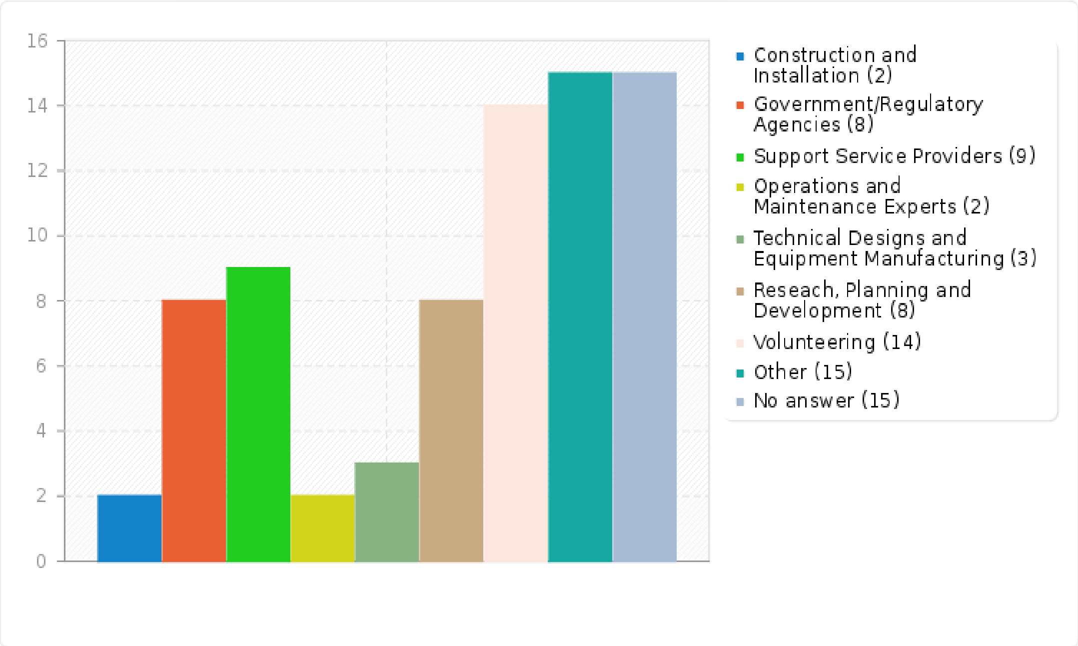

Figure 3: CREPs Professionals Categorisation

From above profile, it can be seen that 15% respondents did not specify their area of expertise, data from these people were not considered among valid responses, also the volunteer groups have similar percentage as non-response group, and volunteers are the main drivers of the UK community energy projects. They comprise mainly of retired professionals from various fields of endeavour trying to use their wealth of experience in contributing to the wellbeing of their immediate locality. The construction, installations and maintenance experts are very few with a 2% response rate; this signifies that the locals still rely on external technical skills to facilitate CREPs delivery.

4.2 Socio-economic and Environmental impacts of CREPs on Stakeholders

Twelve (12) social, eight (8) economic and nine (9) environmental possible impacts that CREPs may likely have on its stakeholders were identified from literature and included in the questionnaire. Survey respondents were asked to answer the 5 points Likert scale questions to the best of their recollection based on their most recent involvement in Community Energy projects. The mean ratings of the possible socio-economic and environmental impacts of CREPs by the respondents were used to analyse their level of agreement or disagreement to the potential impacts based on each respondent's level of understanding or recent involvement in any Community Renewable Project.

As shown in table 2, respondents identified increased local support, increased knowledge of renewables, local capacity building, and enhanced local skills as positive social impact of CREPs because they all have a mean rating of 4.00. The next important social impact was increased local acceptance closely followed by High pro-environmental behavioural change both with a mean rating of 3.90 and 3.70 respectively. Improved quality of indoor air had the lowest mean rating of 3.10

Table 2: Rating of Social impacts of CREPs on Stakeholders

Social impacts of CREPs on Stakeholders	Mean	Rank
Increased local support	4.00	1
Increase local acceptance	3.90	2
Increased knowledge of renewables	4.00	3
High pro-environmental behavioural change	3.70	4
Improved quality of indoor air	3.10	5
Greater local resource reliance	3.60	6
Scaled up local job creation	3.40	7
Reduction in rate of fuel poverty	3.60	8
Offers energy choices to the locals	3.50	9
Increased in local social activities	3.60	10
Local capacity building	4.00	11
Enhanced local skills	4.00	12

The results obtained from the rating of CREPs economic impacts (see table 3) shows that revenues generated from this projects are reinvested locally to boost local economic activities; this is evident in the mean rating of 3.70. Reinvested revenue further facilitates the diversification of the local economy and reliance on conventionally produced energy to other sustainable local businesses. A mean rating of 2.90 was assigned to "High prospects for local manufacturing". In other words the locals depend on external expertise for equipment manufacture, installations and maintenance.

Table 3: Rating of Economic impacts of CREPs on Stakeholders

Economic impacts of CREPs on Stakeholders	Mean	Rank
Increased local job creation	3.30	1
Reinvested revenue boosted local economic activities	3.70	2
Reinvested revenue diversified the local economy	3.60	3
High prospects for local manufacturing	2.90	4
Local energy market growth	3.40	5
High savings on energy bills	3.20	6
Less reliance on conventionally produced energy	3.60	7
Affordable and stable energy price	3.30	8

The environmental impacts of CREPs (Table 4) are not severe compared to conventional energy projects, alterations to the natural environment was rated 3.00 and this is common in mostly wind, and hydro projects. High carbon embedded material used during construction and upsetting effects of construction/maintenance traffic had a mean rating of 2.90 each. These are temporary environmental concerns during the construction phase of most CREPs projects

Table 4: Rating of Environmental impacts of CREPs on Stakeholders

Environmental impacts of CREPs on Stakeholders	Mean	Rank
Health risks from toxic chemical storage near site	2.30	1
Severe noise pollution	2.50	2
Alterations to the natural environment	3.00	3
High rate of wildlife fatalities	2.50	4
Conflicts in heritage protected landscapes	2.90	5
Reduction in tourism activities	2.40	6
High carbon embedded material used during construction	2.90	7
Displacement of residential and farmlands	2.60	8
Upsetting effects of construction/maintenance traffic	2.90	9

5 Discussion and Conclusions

This paper accentuates the importance of an appropriate research design for the investigation of the impacts of Community Renewable Energy Projects (CREPs) on local stakeholders in the UK. Having examined four different models of research design, the research onions seem appropriate, detailed and easy to understand and also reflect the researcher's ontological believes and consideration. These considerations bother on the questions set for the research and resources (time and money) available for this study.

Therefore, the research design for this paper, integrates the pragmatic paradigm as the philosophical footing, and combines both deductive and inductive approaches as its data collection strategy. The combination of these elements also further influences research directions and most importantly the researcher's approach to it – as the richness of research depends on approach adopted by the researcher. This study produced results which corroborate the findings of a great deal of the previous work in this field (Walker et al., 2010, Warren and Mc Fayden 2010, Maubach, 2013).

The results shows that diverse community groups are impacted by CREPs based on the various responsibilities undertaken directly or indirectly by these groups to ensure that local people accept and participate in small scale Renewable Energy projects and also benefit from positive environmental, social and economic outcomes of the project activities. This can be either temporary or permanent group of enthusiastic individuals generating, purchasing, managing energy and or promoting efficient use of energy.

Based on this multiple stakeholder's involvement in CREPs, it is important to clearly identify and classify impacts the projects may have on everyone involved and vice versa. This is important because while some interest Groups supports and aid successful project delivery, others do not. Likewise some project outcomes may not serve the interest of the common man. This is also needed to tackle the problems of the long term community leadership of energy projects in the future considering the continuous growing energy demand, changing market conditions and regulatory reforms which automatically place huge investment burdens on local owners.

While Socio-economic impacts are assessed based on Economic growth resulting from business activities (Table 3), environmental impact assessment on the other hand, is a key requirement at the pre-construction phase of most projects to ensure compliance with laws on Land Use, and the ecosystem, hence there are not many post construction environmental issues with CREPs (Table 4). It is basically CREPs using especially on and offshore wind, large solar farms, and hydro technologies that have direct environmental impacts on the local stakeholders.

Also, worthy of note is the lack of adequate publicity on the achievements of Community Renewable Energy Projects (CREPs) in the past thereby making the energy system unpopular (Walker and Devine-Wright, 2008). This according to DECC (2013) may be due in part or wholly to the fact that most community energy initiatives are located either in rural areas or in small towns away from large urban centres. For example in Scotland alone, over 200 CREPs are already installed in highlands and other remote places as at early 2014, (CES, 2014); but the socio-economic and environmental benefits (as indicated in tables 2,3 and 4) are not widely communicated.

In addition, several local investors (financial stakeholders) are not realising the anticipated return on their investments due to limited grid capacity, and severe levels of curtailment for which they are not compensated. This is out with their control, though some are looking to turn this into an opportunity to explore further, innovative technologies to realise the full potential of their installed capacity e.g. hydrogen. Among the main outcome of the analysed data, there is a lack of adequate communication on the gains and successes of CREPs to non-participants; and most UK community energy initiatives are located either in rural areas or in small towns away from large urban centres. The main conclusion of this paper was to communicate CREPs positive impacts on stakeholders on a UK wide scale. However, a number of important limitations need to be considered, first the findings are limited by the use of only survey data to highlight the effects of CREPs on stakeholders when the research design prescribed combination of both Survey and Case Study strategies, this is because the case study phase is still ongoing. It is believed that the outcome of this phase will provide sufficient clarification on CREPs impact on a UK wide scale. Again, with a small sample size, caution must be applied, as the findings might not be representative of the entire UK Community Energy Sector

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Integrated process of Ecosystem Services evaluation and urban planning. The experience of LIFE SAM4CP project towards sustainable and smart communities.

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Abstract

Evaluation of Ecosystem Services (ES) and related mapping tools and techniques can be used in urban planning and design to define sustainable land use strategies aimed to achieve resilience in urban planning.

The analysis of ES improves the ability of politicians, administrators, planners and stakeholders to define strategies of regeneration, ecologically and energy efficient oriented. Furthermore, it allows to reflect about the sustainability of urbanization and related environmental issues, bringing attention to social and economic aspects, too. The soil, as measurable value common good, is a source of energy, requires a strong reduction of its consumption and a good use of it.

The paper experienced the recent research innovations made by DIST for LIFE program SAM4CP, which integrates the process of planning and decision making with analysis and assessments of ES in order to support Municipalities to define policies and monitoring procedures oriented to limit the consumption of high quality soil. The process of evaluation and planning can also be adopted for urban resilient projects aimed at define successful methods for improving energy efficiency in communities and urban areas. The paper aims to present partial results of the project. A strong integration of evaluation and planning actions, providing multicriteria analysis techniques and adopting software (like InVEST) able to map the outcomes of the evaluation process and the inputs for the planning process will be discussed.

An indicator based approach is presented as the innovative tool to achieve land use efficiency, and resilience as the main paradigm to steer Co-planning Conference.

1 Introduction

In the Italian context few research activities related to land use planning are designated to introduce operative innovation over the traditional framework of systems and powers. The gap between the theoretical advancement of research on land use sustainability and its “real” application is affecting the practices. Nowadays, the environmental approach on land use planning is mainly referred to the bureaucratic procedure of plans approval rather than the construction of a knowledge system embedded with Strategic Environmental Assessment procedure. By the way great amount of skills are required to improve the technical framework for land use sustainability considering its practical application.

The LIFE project SAM4CP[1] made by DIST-Politecnico di Torino[2] aims to connect the scientific knowledge on Ecosystem Services (ES) allowing a better territorial decision mechanism. The project leads to include the ecological assessment of soil within its economic value also accounting alternative land-use scenario.

ES refers the conditions, process, and components of the natural environment that provide both tangible and intangible benefits for sustaining and fulfilling human life [1]; its measurement is codified by the publication of Costanza et al. *The value of the world’s ES and natural capital* (1997) which present an economic valuation of the goods and services that human population derive, directly or indirectly, from ecosystem functions. Recently, has emerged an important discussion concerning the definition of a common international classification of ES (CICES) [2].

Associated with the land use changes and the observation of the land take by new urbanization, the valuation of the ES help to enforce the decision making mechanism. The methodological evaluation of land use impacts, when defined by scientific standard procedures embedded on local plans construction, became a basic tool to define trade-offs between alternative uses and scenarios and thus being communicative with stakeholder (public and private ones).

Among others, specific phases of the project are aimed to define a scientific methodology to assess ES for local planning. In particular, the core of the project is to find benchmarks for planning evaluation, here intended as the thresholds for a Soil Quality Indicator (SQI) that holds the most important information for an efficient use. Efficiency, is due to the capacity of the soil to “fit with the use” without a permanent alteration that drastically decrease other potential uses. Related to this, is the possibility to achieve resilience over planning activities.

The definition of a SQI request a previous construction of ES assessment with a high technological degree of innovation over planning activities, which is mainly based on new ES mapping activity.

Three main phases of the LIFE project are designed to define such SQI and concerned to mapping and assessing ES:

- the identification of models for biophysics and economic evaluation of ES. With the legacy of the previous LIFE projects, some approaches were compared and evaluated by a preliminary research. This phase was aimed on pointing out a set of tools for ES economic and ecologic evaluation;
- the collection of input data for running the models to ES evaluation. This phase was crucial for launching and testing the software for ES evaluation. Input were collected primarily for the main functions defined by the project (carbon sequestration, water purification, contrast to soil erosion, maintenance of biodiversity, provision of habitat for pollinators; wood/fiber production; food production);
- the application of the model (production of preliminary output) and the evaluation of comparative results. In this phase two crucial sub-phases were requested:
    1. to find out the benchmark to test different result of research for specific ES evaluation;
    2. to evaluate and compare between them scenarios output.

[1]Title of the Project: Soil Administration Model for Community Profit. Project leader: Città Metropolitana di Torino responsible for the actions 3, 4 as well as a management and administrative management of the project; Partner (1): Politecnico di Torino – Interuniversity Department of Regional and Urban Studies and Planning; Partner (2):ISPRA – Istituto Superiore per la Protezione e la Ricerca Ambientale; Partner (3):CREA – Consiglio per la Ricerca in Agricoltura e l’Analisi dell’Economia Agraria.

[2]The DIST research group is composed by: Prof Carlo Alberto Barbieri (Scientific Responsable), Prof. Giuseppe Cinà, Prof. Angioletta Voghera; with an operative team of research fellows composed by Dr. Arch. Carolina Giaimo, Dr. Dafne Regis and Dr. Stefano Salata.

The testing of models through evaluation of input/output data is aimed to be prepared at launching the models using a case of study (which is the Municipality of Bruino in the metropolitan area of Tourin - Italy) and testing the full operability of ES assessment for the construction of a local land use plan.

Once ES are mapped and fully assessed by biophysical/economic sides the project aims to capture the “flows of value” that a land use variation produce to the initial stock. It is the “quality”, rather than the “quantity” of used soil to be analyzed because such information is crucial for a better integration of sustainable/resilient strategy of land use management in terms of energy systems: only a deep knowledge on ES flows supports strategies of mitigation and compensation for land transformation[3].

2 Resilience

The concepts of “sustainability”, “development” and “growth” required a re-contextualization of the socio-economic changes and dynamics taking place in the current global scenario.

In particular, the debate around climate changes – and related issues - prompt a change of the paradigm in the way planning cities is undertaken, with an emerging attention to resilience and adaptability of land use planning. The concept of resilience - initially used in the mechanical and metallurgical domains – became established in the sciences concerned with complex adaptive systems: biology, ecology, sociology, psychology. Since a few decades, it has also been used in town planning as the capability of a city to adapt to any external intervention, bothman-made or caused by climate change, in order to restore its own balance. The concept of resilience focuses attention on the dynamics of persistence and adaptation taking place within the observed system[4]. Furthermore, resilience is already the affirmation of a proactive approach that can be glimpsed or pursued[5].

Planning for increase urban resilience urges a significant renewal of planning activities with a view to new methods of acquiring knowledge and cope with existing issues, as well as adequately support the evaluation of planned land use scenarios.

A key element in planning for urban resilience and fostering the adaptive capacity of a city, is the development of environmental infrastructures (blue, green and slow) to build a new city around the "commons" (water, soil, green areas, energy , waste, mobility), their spaces and their management. This approach would trigger positive loops for the recycling of scarce resources and foster proactive policies, overcoming approaches of land use limitations[6]. For instance, actions for climate change mitigation require radical improvements in the functioning of a city, i.e. the use of both land and buildings through water and energy networks. Particularly, a strategy to mitigate climate change requires significant reductions in greenhouse gas emissions, but the development of a planning activity focused on greenhouse gas emission reduction require a good knowledge of soil properties that interact with the composition of gases on atmosphere.

The methodology adopted by SAM4CP entails several possible solutions to design urban settlements with the aim of minimising carbon emissions and improving the quality of public open spaces. The proposed analysis improves the knowledge about the ecological quality of the soil using ES assessment as the value of an ecological indicator for a context based area. The deeper the knowledge of ES value and spatial distribution, the greater the possibility that these features are properly considered as part of planning and urban design.

Moreover, SAM4CP addresses the issue of how the success of this “new paradigm” in plans, policies and projects, implies to the forms of organization and decision-making of the territorial government, using multilevel governance to engage all the various stakeholders involved in the dynamics of land use planning development. Through the tool of Co-planning Conference, SAM4CP is experimenting urban planning actions geared towards differentiation and synergy of institutional roles among various issues at different scales (regional, metropolitan and local levels).

3 Ecosystem Services Analysis

From systematic studies on surface and covers, to the complete assessment of urban transformation effects in all soil-related system, a huge amount of research deal with the question “what happened on topsoil, and under it, when a process of urbanization occurs" [7]. Despite this, few analyses are focused on environmental effect of land use change to ES provided by natural soils [8], especially the ones which requires integration across different disciplines [8].

Anyway, great deal of research is dedicated to estimate the single's environmental effect of land take process, especially using a specific ES as a proxy [9][10][11][12].

But even if ES approach clearly demonstrate that effect of land use change affect more than a single ecosystem [13][1], still persist a lack of technical assessment to introduce multidimensional indicators that hold different aspects of soil transformation (e.g. productive, natural, protective). Composite indicators on ES are far away from being rooted in scientific literature, but the demand for profound soil knowledge is high [14]. Reasons of such failure is that the creation of a SQI request a major interaction of scientists from other disciplines to achieve a broad holistic role in society; up to now the poor feedback between land use and soil related studies is limiting advancements[15].

3.1 The broad evaluation of Ecosystem Services

One of the most common approach of ES evaluation is the one that follow: *the total ecosystem services of each land use category can be obtained through multiplying the area of each land category by the value coefficient: ESV = ∑ (Ai • VCi) – where ESV is the estimated ecosystem service value (Euro•a-1), Ai is the area (ha) and VCiis the value coefficient (Euro•ha-1•a-1) for land use category "i"*[8].

The above mentioned definition, introduces the possibility to have an economic evaluation of ES. Even oversimplified [16][17]such possibility gives to public administration and planners the estimation of a stock and a variation value for environmental management through land use planning.
First exploration on ES values for specific land use/cover categories are reported on study "impact of urbanization on natural ecosystem service values: a comparative study"[18]. An example of output is given by Table 1 which present actual[3] economic values in euro for five major land use classes.

Table 1 ES value coefficient for each land use category

€ for hectares actualized					
services types	forest	grassland	agriculture	wetlands and water	barren
gas regulation	371,3	85,1	52,7	95,6	
climate regulation	286,1	95,6	94,0	932,4	
water regulation	338,9	85,1	63,1	1.904,5	3,2
soil formation and retention	413,4	206,6	154,8	90,7	2,4
waste treatment	138,6	138,6	173,4	1.929,7	0,8
biodiversity	345,3	115,1	75,3	264,2	35,6
food production	10,5	31,5	106,1	21,0	0,8
raw material	275,6	5,6	10,5	4,0	
recreation and cultural	135,3	4,0	0,8	523,6	0,8
total	2.314,9	767,2	730,7	5.765,9	43,7

Such approach was so long criticized by whom intended to state that it is not possible to fix pre-defined environmental values for land use classes, both because environmental goods are economically "intangible", and because it is impossible to commonly define a "price" without a site-specific situation.

And the critics was true, for the above mentioned reasons, but forgot to consider that the "fixed price" for land use categories is not defined to outline "which is the value of a specific ES" rather than to be used for comparative studies, to track the trend of growth or decrease associated to a land use variation. Indeed, when a land use change occur, the alteration to specific ES can be differentiated: the transformation of an agricultural field into an urban areas should decrease the "food production" capacity, but increase "biodiversity" because it alters surface adding huge green urban areas.

[3]Values in dollars per hectares were transformed in euro per hectares, with a coefficient of actualization of price of 0,7% here intended as the difference between inflation on 2005 and 2012. http://epp.eurostat.ec.europa.eu/inflation_dashboard/

The only way to holds all the complex system of information regarding land use variation is the association of a complete ES assessment to Land Use Change (LUC) scenario.

LUC allows to quantify the loss of ES as effect of change in cover or land uses[18]. Nowadays the creation of indicators for specific ES request a high account in research, especially for local planning [19][20]. But it is not the simple "quantification" of ES enough appropriate to support effective practices of land use planning: *the critical ways in which ecosystems support and enable human well-being are rarely captured in cost-benefit analysis for policy formulation and land use decision*-making [21].
It is important to remark that rather than absolute value, economic computation is useful to understand which is the present and future variation *between values* [22][23]. Such information gives better feedback to planners and politicians to steer local policies of land use transformation. Moreover, it is not the evaluation of a single's ES function to be helpful for a trade-off analysis, but a complete ES assessment.
When an overall computation of different ES values has been monitored, and not a single function, results appear consistent: … *results showed that, although a conventional, market-dominated approach to decision making chooses options to maximize agricultural values, these policies will reduce overall values (including those from other ES) from the landscape in many parts of the country; notably in upland areas (where agricultural intensification results in substantial net emissions of GHG) and around major cities (where losses of greenbelt land lower recreation values). In comparison, an approach that considers all of those ES for which robust economic values can be estimated yields net benefits in almost all areas, with the largest gains in areas of high population… Our analyses suggest that a targeted approach to land-use planning that recognizes both market goods and nonmarket ES would increase the net value of land to society by 20% on average, with considerably higher increases arising in certain locations*[22].

The statement imply that, especially the definition of local planning policies, require the construction of a "complex" and "integrated" knowledge framework which overwhelm the traditional approach of alternative land use scenarios: it is not an evaluation between productive and urban uses enough to understand at all if an efficient and resilient use is planned or not. This is why a SQI is necessary.

SQI is important because refers to "quality" rather than the "quantity" of soil affected by anthropic processes. The soil quality is the capacity of a soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health. It contributes to the investigation of several key ecosystem concerns: the productivity and sustainability of many ecosystems, the conservation of soil and water resources, the accumulation of persistent toxic substances, and the contribution of different land uses and covers to the global carbon cycle [24].Thus SQI is a fundamental key to achieve a better sustainable and resilient urban planning.

3.2 The case of study: methodology

The Municipality of Bruino is a small town (8.576 inhabitants) located south-west sector of the Città Metropolitana di Torino (north-west of Italy), it is a typical second ring Municiaplity, characterized by a rural landscape (52% of land is covered by agricultural uses, the 22% is covered by natural zones, and only the 24% is covered by the built up system, by which only 7% is covered to productive, commercial and public services areas) and a local productive/commercial economy. Urbanization had a strong development in the second part of the last century related to new residential areas and industrial districts.

In order to reduce the urban sprawl, a new Local Plan has been approved in July 2015, assuming the concept that "free soil" has an ES with a high value for environment and life quality in urban settlements and defining goals: limitation of soil consumption and construction of a local ecological network. Moreover, Municipality of Bruino is taking part as a key case study in LIFE activities, as a contribution to improve strategies already adopted and to enhance more the Local Land Use Plan.

The construction of ES values in the case of study has been reached using the software InVEST-Integrated Valuation of Ecosystem Services and Tradeoffs. The research presented considers the last release available (in 2015) of the InVEST model (version 3.1.0).

The software was used to estimate seven main ES: biodiversity, carbon sequestration, water purification, water yield, contrast to soil erosion, provision of habitat for pollinators; food production.

As introduced, the Municipality of Bruino (among other Municipalities) has been selected as a key case study in LIFE activities according to the letter of interest. The LIFE activity has to produce a variance of the Local Land Use Plan. This is why every model has been constructed to have a great deal of accuracy and precision for planning purposes: the challenge was not to use InVEST as a general tool for ES accountability, but to construct alternative scenarios of efficient land use planning for Co-planning phase.

The phase 1 of the project has been dedicated to run the software InVEST for each ES selected. In particular, actions were dedicated to:

- the construction dataset (using standard and ancillary data);
- the research of sources for input software values;
- the interpretation of output models.

Output of biophysical models were distributed on five per five meters cell, than associated economic values were founded.

Biophysical evaluation produces output per pixel expressed by (i) indexes or (ii) absolute quantities. The seven ES mapped by project were estimated using such units:

- index from 0 to 1 for Habitat Quality and Crop Pollinator;
- tons/pixel for Carbon Sequestration and Sediment Retention; mm/pixel for Water Yield; kg/pixel for Nutrient Retention;
- values form 0 to 8 for Land Capability Classification (Crop Production).

Subsequently, considering the previous LIFE+MGN (Making Good Natura)[4] project, the biophysical maps where used to associate economic values. Indeed, one of SAM4CP output is the estimation of economic values of soils on the base of their biophysical maps. With respect to this, a basic consideration have to be outlined: all estimated economic values are “potential” rather than “definitive” because they derived from market price of substitution/artificial production of a similar service which is normally provided by soil.

Table 2 Methodology for evaluation, adopted in the project LIFE SAM4CP

Ecosystem Function	Biophysical Value	Economic Value
Habitat Quality	The overall quality of the ecosystem (biodiversity) [index 0-1]	Cost of the “reproduction” of specific land uses that provides ES [20€/sq. m.]
Carbon Sequestration	Tons of sequestered carbon by soil [t/px]	Price for each ton of carbon stored [120€/mc]
Water Yeld	Liters of water removed by processes of evapotranspiration [mm/px]	Cost for removing water by artificial techniques as a construction of a lamination hydro-basin [12,6€/mc]
Nutrient Retention	Nitrates released into the water [kg/px]	Cost for the construction of green buffer zones useful to detention of nitrates [64€/kg]
Sediment Retention	Potential erosion avoided by soil [t/px]	Cost of rehabilitation of soil fertility, useful to the protection from erosion [22,8€/t]
Crop Pollinator	Gradient of optimal allocation for hives [index 0-1]	Average price of hive [44€/hive]
Crop Production	Productivity capacity [index 1-8]	Prices of specific crops [€/sq. m.]

[4]Project “Making Public Good Provision the Core Business of Nature 2000” (LIFE+11 ENV/IT/000168) coordinated by University Consortium (CURSA). For more information: http://www.cursa.it/ecms/uk/research/making_good_natura

While for ES with absolute values it is possible to define a price per unit, mistake arise when the economic value is associated to indexes. Even though with declared limitations, a “derived” value was still applied. An example is given by economic evaluation of biodiversity index. Such index was estimated from the price of “reproduction” of land uses that provides biodiversity in urban areas. Than the price of “substitution” (how does it cost to plant an urban forest?) was distributed using a linear function to all the land use categories. Therefore, all seven main ES were evaluated

Table 3 An example of ES assessment: Carbon sequestration

Land Use/Land Cover	Carbon Sequestration							
	t0		t1		Var (abs)		Var (%)	
	biophisic	economic	biophisic	economic	biophisic	economic	biophisic	economic
Continuous urban fabric (dense)	17,86	2.143,35	17,89	2.146,76	0,03	3,41	0,16%	0,16%
Continuous urban farbic (non dense)	366,20	43.943,55	762,49	91.498,28	396,29	47.554,73	108,22%	108,22%
Discontinuous urban fabric	7.727,02	927.242,68	7.634,46	916.134,86	-92,57	-11.107,82	-1,20%	-1,20%
Discontinuous urban fabric (sparse)	1.244,37	149.324,61	1.194,95	143.394,29	-49,42	-5.930,31	-3,97%	-3,97%
Industrial or commercial units (dense)	194,06	23.287,09	232,67	27.920,27	38,61	4.633,19	19,90%	19,90%
Industrial or commercial units (non dense)	64,44	7.732,93	71,90	8.627,87	7,46	894,94	11,57%	11,57%
Road and rail networks and associated land	2.486,12	298.334,91	2.433,22	291.986,99	-52,90	-6.347,92	-2,13%	-2,13%
Dumpsites (mine)	8,97	1.076,67	8,97	1.076,94	0,00	0,26	0,02%	0,02%
Dumpsites (deposits)	45,14	5.416,22	35,06	4.207,57	-10,07	-1.208,65	-22,32%	-22,32%
Construction sites	129,63	15.555,84	129,66	15.558,74	0,02	2,90	0,02%	0,02%
Unbuilded artificial soils	75,37	9.044,59	14,00	1.680,51	-61,37	-7.364,07	-81,42%	-81,42%
Artificial, non agricultural vegetated areas	157,03	18.843,36	47,63	5.715,78	-109,40	-13.127,58	-69,67%	-69,67%
Green areas	125,92	15.110,58	799,95	95.993,55	674,02	80.882,97	535,27%	535,27%
Urban parks	762,59	91.511,11	2.665,82	319.898,78	1.903,23	228.387,66	249,57%	249,57%
Uncoltivated urban areas	4.272,37	512.683,85	1.664,32	199.718,32	-2.608,05	- 312.965,53	-61,04%	-61,04%
Cemeteries	3,42	409,87	3,43	411,69	0,02	1,82	0,44%	0,44%
Sport and leisure facilities	289,72	34.765,95	289,98	34.797,88	0,27	31,93	0,09%	0,09%
Agricultural areas	9.261,19	1.111.343, 00	8.458,40	1.015.008, 15	-802,79	-96.334,85	-8,67%	-8,67%
Indifferentiated arable land	230,48	27.657,40	230,46	27.655,15	-0,02	-2,25	-0,01%	-0,01%
Vegetable crops	1,34	161,20	1,34	161,27	0,00	0,07	0,05%	0,05%
Vegetable crops (irrigated)	551,27	66.152,06	468,50	56.220,55	-82,76	-9.931,51	-15,01%	-15,01%
Permanentwoodagricu lture	89,75	10.770,08	89,78	10.773,24	0,03	3,16	0,03%	0,03%
Pastures	3,98	477,20	3,98	477,28	0,00	0,08	0,02%	0,02%
Agriculture/naturalland	743,53	89.223,18	702,12	84.254,89	-41,40	-4.968,29	-5,57%	-5,57%
Broad-leavedforest	1.524,66	182.959,00	1.398,34	167.800,22	-126,32	-15.158,79	-8,29%	-8,29%
Water courses (natural)	3,85	462,27	3,85	462,45	0,00	0,18	0,04%	0,04%
Water courses(artificial)	0,03	3,89	0,03	3,89	0,00	0,00	0,02%	0,02%
average/tot	30.380	3.645.636	29.363	3.523.586	-1.017,09	-122.050,2	-3,35%	-3,35%

Table 3 shows the ES valuation, for Carbon Sequestration function, of both biophysics/economic values. Such evaluation is a typical output of a context based analysis, derived by a distribution of values for all land use classes detected inside the case study. The assessment is defined by a LUC analysis, associated to an ES mapping of biophysical values applied to a t0 (which is the present land use/cover situation) and a t1 (which is the planned scenario of land use transformation). This simple comparative analysis between existent and planned land uses shows that each single category is affected by variation in the provision of the specific ES of Carbon Sequestration.

The evaluation shows that planned land uses decrease the total carbon stored on soil from 30.380 tons to 29.363 tons. Such carbon loss is equal to an economic decrease of more than 122.050 euro, with a rate of decreased value between existent and planned scenario of 3,35%. Moreover, the single variation, demonstrate that maximum decrease in values is concentrated on Uncoltivated urban areas (-2.608 tons stored), and that maximum growth due by the new Urban Parks (gain of 1.903 tons stored). Similar trends are registered for the decrease in value of Agricultural areas (- 802 tons) and the increase of Green generic areas (674 tons) or the Continuous urban fabric (non dense), which increase the value (of 396 tons).

These data are a good indicator of the plan strategy, because Bruino acts with a policy of land use “infilling”, converting the residual open spaces closed to the built up system into new urban low dense zones. Such transformation, is typically accompanied by the provision of new green urban zones, which guarantee a high degree of quality to urbanization.

In that case, even if the overall process of artificialization due by the panned scenario is equal to a growth rate of 5,56%, the decrease of the Carbon Sequestration service is “smaller” (-3,35%), because the planned LUC guarantee a low decrease or efficiency for the specific ES considered.

This is a typical trade-off between alternative function evaluated using one ES as a proxy, that demonstrates which is the lost benefit derived by a land use scenario. The assessment of such evaluations support a strategy of resilience during planning phase, because it allows to achieve better balances between sustainable land use functions. Therefore when efficiency is used as a proxy for better land use allocation, than resilience is provided.

4 How to balance trade-off among different values

As written before, one of the major task for accompanying planning decision is the indication of a SQI here intended as a multisystemic approach on ES.

Indeed, it is necessary to overcame the main limitation of a single ES analysis that quantifies only a single process in the total amount of processes regarding the land use transformation (in particular, it allows to quantify the single effect of a LUC over specific ES observed).

When a process of urbanization occurs, multiple processes are simultaneously happening. Considering only the plain variation of land covers by LUC it is normally possible guarantee a statistical information on land take trends. But related processes (e.g. the “sealing process” and its effect on hydrological cycle, rather than the alteration in the capacity of soils to support primary production) affects covers with different degree and effects on ecosystem and landscape[8].

Normally, when an agricultural field is urbanized, the productive capacity downgrades, and may be completely neglected in the future. For many reasons productive capacity is also the major indicator of soil quality considering the fact that i) land take affects mainly agricultural fields, ii) agricultural land has a high suitability for productivity capacity because of the high fertility of such soils, and iii) high fertility is associated to good geological characteristics and thus is generally considered a good proxy of “quality”.

Nevertheless, the reduction of the trade-off balance among different ES to a binary alternative between urban and agricultural values is flattening the possibility to really reach a complex system of knowledge on soil efficiency performance able to support planning activities. This is why SAM4CP considers all the main ES to define, with an indicator based approach, a set of rules or guidelines for best practices of sustainable land use aimed to increased soil resilience.

Within this target, a composite SQI has been tested to find a balance of trade-off among different ES, with a research focused on the definition of “patterns” where soil efficiency of ES is represented and interpreted as a qualitative support for the decision making process.

SQI was generated with a “weighted overlay” function associated to single’s output ES model. A weighted sum of cell for specific ES was launched with ArcMap version 10.2. InVEST model’s output generates a raster distribution of both positive and negative values. Indeed, to transform negative to positive, the weighted overlay uses the “conversion” for crop production, multiplying the value for – 1, and the water purification for –1 too.

The output was converted using a “raster to polygon” function for the cell field “value”; than normalization with a range from 0 to 1 has been applied using Excel (normalization function) with the .dbf file. Geographic distribution of values has been reached joining the table to a new shapefile called “multisystemic values”.

4.1 A Soil Quality Indicator as a proxy of efficiency

As introduced, SQI was prepared to outline a “pattern” characterization of the specific information provided by efficiency of each land use class.

In order to visualize the different “dimensions” of land uses, spider charts were designed: the vertices of the charts represent the selected ES variables for a multidimensional representation of efficiency of land uses. The representation by spider charts, shown by Figure 1, tends to hold together disjoint variables. We aimed to give an adequate representation of the “multidimensional” aspect driven by land use phenomena.

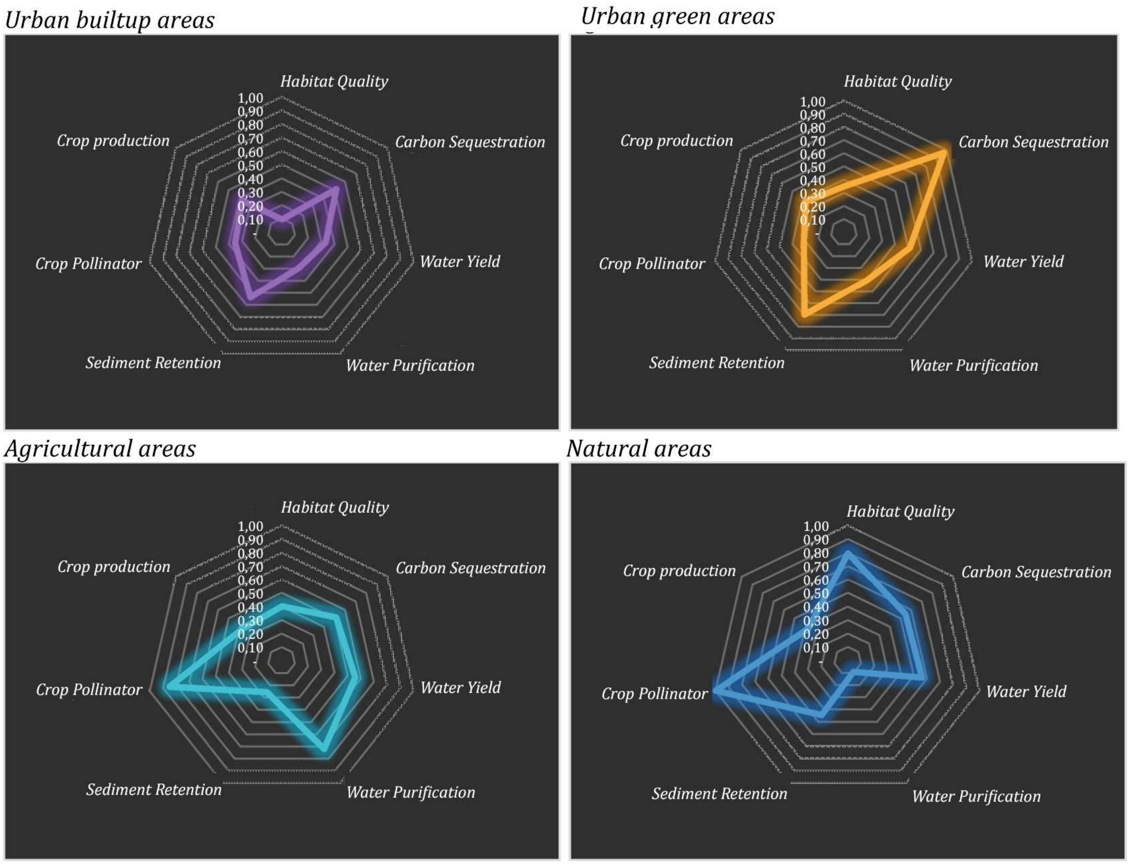

Figure 1 Land use efficiency patterns

As it is possible to see, significant different patterns are represented to the Figure.

Firstly, it has to be stated that the two values below the chart (Sediment retention and Water purification) represent the contribution of soil to produce erosion and water pollution, thus good performance are indicated by low values and viceversa. For all other functions low values correspond to low performance and viceversa.

Urban builded areas: the pattern shown an average ES performance clustered to che centre of the graph, whithout any specific cusp. It means that generally urban soil in Bruino performed low quality of ES, with a tendency to register higher performance for Carbon Sequestration, because the build-up system is “porous”, and such porosity does not affect the Carbon Sequestration function.

Urban Green areas: the pattern reveals that urban green areas play foundamental role for ES maintenance. The performance is generally high, only productive capacity is, obviously, lower than other ES. Maybe for geological reasons, those areas generate also erosion, but provides the higher values for carbon sequestration, and optimal values for water cycle regulation.

Agricultural areas: the pattern shows a general good performance of such land use for all ES, in particular the pollination service is high, due to the fact that some agricultural fields are optimal to nesting sites allocation. But also water cycle regulation and carbon sequestration have good values. Nevertheless, water pollution is critical, because the use of fertilization have great impact with the nutrient retention capacity.

Natural Areas: obviously this pattern shows the great feedback with Habitat Quality. It means that the overall ecological quality of this land use in Bruino provides good quality for all animal and vegetal species. But better results are achieved by impollination function. Also carbon sequestration and water cicle regulation is optimal, even if productive values are low.

And what about efficiency? Seems that the four observed land use categories generally demonstrate that none of considered ES is completely neglected by specific land use. In terms of comparative analysis, efficiency increases as long as the pattern covers a higher distribution on good qualities. By the way, it is pretty simple to recognize that the cluster of Urban builded areas is less efficient of the ones of Urban green areas. More the pattern shows a general good quality, and more the potential tradeoff between different functions during a planning phase have to “ponderate” how to achieve a good balance for newer scenarios.

Such kind of knowledge contributes to evaluate different options of mitigative/compensative actions for a sustainable land use transformation, also taking into account climate change mitigation policies aimed at increase the performances of soil to act as a carbon pool and as a filter for the general air quality.

5 Conclusions

The creation of a system of knowledge on ecological quality of soils, using ES assessment as a proxy for SQI, gives to planners and administrations the possibility to select sustainable targets for resilient policies and actions. The more ES knowledge and mapping is deep, the more such knowledge can really support land use planning activity and its operability with processes and projects of territorial governament.

By the way the assessment of soil quality is helpful for considering a single’s soil function, and thus select specific target of resilence, rather thanconsidering a cumulative evaluation based on a sum of different SQI, pursuing a general target of sustainability in planning.

Obviously, the construction of a composite indicator on SQI is dependent from the availability of a huge amount of datasets, and also their precision; nevertheless, the ecological assessment of soil is finalized to integrates planning procedures, in particular a target of SAM4CP is to bring into the phase of Co-planning Conference the evaluation of soils and its implication for the Strategic Environmental Assessment for planning policies definition.

The consensus building approach based on a deep knowledge of ES trends and dynamics is shading lights on some planning issues related to sustainability of land uses: only a qualitative knowledge, rather than quantitative, supports practices of mitigations or compensations for urbanization.

Bringing such approach into planning practicies means to improve the performances of land use resilient strategies, here intended as the possibility to achieve a long term land use efficiency by planning practices. If resilience is the capability of a city to adapt to any external intervention, both man-made or caused by climate change, in order to restore its own balance, than a indicator-based approach of the tradeoff among different function helps planners to reduce discretionary variables during decision-making phase.

Even if the approach is far away to be considered "easy", the presented methodology should support a real innovation for achieve a real sustainable land use management for local communities. More and more the issues of efficiency will bring into territorial governance new challenges: soil is a scarce resource, the competition for alternative use will certainly increase, because the global trend of population is growing. Within this perspective strategies of adaptations are required also for steering territorial policies. This is why, up to now, new methodologies of land use analyses for planning practices are welcome, even if not fully tested.

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Session Cities II

GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock

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Abstract

Energy efficient buildings' issue integrated into the district and CO_2 emission reduction strategies and policies is one of the main concerns in the European Union (EU). In order to achieve an effective impact, instead of just concentrating on the improvement in terms of energy efficiency to one particular building, this approach requires challenges to be solved in an entire municipality or an entire district. Accordingly, it is significant understanding the comprehensive residential building stock models in the urban environment able to promote a sustainable energy planning. In this paper we describe a new methodology based on two different modelling approaches top-down and bottom-up with the aim to evaluate the buildings energy consumption model of a municipality. This methodology is mainly based on information that is already available on building stock from the literature and data collection (i.e., technical department of municipality, web, energy auditors and others) which is later transferred into the Geographic information system (GIS). Into this in future studies GIS platform provides the information on energy performance in the whole city as well as creating the urban energy maps for assessing retrofitting scenarios and support decision making for policy implementation to achieve sustainable urban planning. This study is part of an ongoing Smart City research study, national cluster project named Zero Energy Buildings in Smart Urban Districts (EEB) and is tested in a medium sized town in the Piedmont region (Italy), and the results are discussed.

Keyword: Geographic Information System (GIS), Thermal Energy Consumption Model, Building Stock, Urban Scale

Introduction

Nowadays, there is an immense impact on energy demand and consequently GHG emissions due to the way that cities are acting and growing [1]. In Italy, the energy balance in 2013 has demonstrated a further reduction of the energy demand for about -1.9% compared to 2012 level. This trend is happening not just due to the economic crisis, but also to the result of the successful implementation of energy efficiency policies. Indeed, the end users of energy accounted for about 126.6 (Mtoe) with a reduction of 1% compared to 2012. It is noteworthy that only sector where the energy consumption has increased is the construction one (+ 5.6%) [2].

Particularly in the building sector, energy consumption is influenced by the spatial organization. Therefore, where the purpose is the assessment of globally achievable energy savings and the greenhouse gases reduced emissions, it is crucial to broaden the focus on the building stock at urban scale [3]. Accordingly, many different approaches and tools are developed for the spatial representation of energy demand, production and CO2 emissions such as a Geographical Information Systems (GIS). The implementation of spatial analysis through GIS tools can be important to manage, archive, analysis, and geo-referenced visualization of the energy data and to optimize the energy sources available on the territory [4].

It is required to understand the building energy performance in an entire district or municipality to achieve a sustainable energy planning strategies that speed up the energy renovation and energy efficiency procedure in needed existing buildings [6]. In fact, the Sustainable Energy Action Plan (SEAP) promoted by the European Commission brings up the strategies for realizing the greenhouse gas reductions required by 2020 for municipalities that have joined the Covenant of Mayors [5]. There are numerous approaches that have been conducted to evaluate the energy consumption model for a large building stock (i.e. Real monitored data [7] considering a cadastre found out from a big number of individual certifications [8] or Census data [9]). Accordingly, with the aim of the energy consumption reduction, many building energy regulations are approved (e.g. codes, standards, etc.) in most of the developed countries [10]. Several types of research have been carried out primarily in order to investigate the methodologies for single building's energy performance [11], [12] or for building stock [13]. In this study, the attention is focused on the residential building stock at urban scale.

There are two general methodologies to modelling energy use that are used for building sector: 'top-down' and 'bottom-up' methods. The top-down approach uses historic aggregate energy values reported by energy suppliers and estimates the energy consumption of housing stock as a function of top-level variables. These variables comprise macroeconomic indicators (e.g. unemployment, inflation and gross domestic product), energy price, and general climate. As this model is based on historical information, therefore, it is not adequate for the evaluating the impact of new technologies on energy consumption. The residential energy demand system for Spain [14] is an example of this kind of model. The bottom-up method accounts for the estimated or simulated energy consumption for a specific individual or group of houses. This approach involves two categories: the statistical method and the engineering method. The adaptive neural network technique that [15] applied to a building in Montreal and the conditional demand analysis model used by [16] for San Diego are two examples of statistical bottom-up models.

This work is focusing on a method for evaluating the thermal energy consumption of residential building stock in one of the municipality in Piedmont (Italy) "Settimo Torinese" which is, representing approximately 46875 inhabitants [21] based on GIS for mapping energy consumption profile. The main goal of this work is to show that the energy-efficient strategy for a Smart City of the future should start on its existing building stock.

Methodology

The methodology used in this study is based on the literature that is partly mentioned in the previous section where the models used for the energy assessment of existing residential buildings can be divided into two categories [17]:

- Top-Down models: energy-use data at urban scale are compared with climate variables, census results, and statistical surveys to determine average energy consumption for existing buildings. These models can compare different variables, but cannot distinguish spatial variations in energy consumption of a Municipality or a territory.
- Bottom-Up models: these models, at building scale, are used to evaluate the energy balance of a single building with high detail; together, a set of energy consumption models, can be combined to evaluate the energy consumption of blocks of buildings, districts or cities; to achieve a valid and high quality results at urban scale a large number of data which is explained in the next section related to the buildings is required. These models can be also used to evaluate energy savings model after building retrofits.

In this case, it has been implemented a hybrid approach where the single building models, derived by the bottom-up approach, were used to represent the energy consumption of residential buildings in a district or a city through a detailed spatial representation considering the heated volume, the period of construction, and the compactness of residential buildings. While the statistical models at urban scale, derived by the top-down approach, were used to validate the above energy buildings' models taking into account the spatial variability of the urban context, the socio-economic level, the type of users, the buildings' retrofit level and other important factors influencing the energy-use of buildings.

In the following paragraph the description of the data used for the bottom-up and top-down approaches is described. Particularly, the calibration of the two models has been made, introducing correction coefficients in the bottom-up approach at buildings scale to get the overall consumptions at Municipal scale as reported in the SEAP. These correction coefficients take into account the characteristics of the built heritage and the typical users influencing the energy consumptions (e.g. the buildings' retrofit level and the users' behavior).

Evaluation of thermal energy of residential buildings in large urban context

For the evaluation of Space heating energy consumption of residential buildings, it can be considered some advantageous indicators as a period of construction, compactness and density of the buildings [3], [18]. In this work has been considered the climate with the Heating Degree Days (HDD), the compactness of buildings with the surface to volume ratio (S/V) and the period of construction with different levels of the envelopes' thermal insulation and systems' efficiencies to calculate the energy consumption on existing buildings [19]. The sources of data needed are essential:

i) Energy-use data: Sustainable Energy Action Plan (SEAP), considering 2009 as a reference year for the case study [5]; ii) Buildings use, Heating Volume, Building Geometry: The Database Spatial Reference Entities (BDTRE) Piedmont, other information as the height of the buildings and the type of roof obtained from Lidar datasets, Digital Terrain Model of Piedmont Region (DTM) [20]; iii) Demographic data: The 2011 ISTAT at census section scale [21]; iv) Climate data: outdoor air temperature and the Heating Degree Days (HDD) by climatic ARPA database [22]. As the energy consumption considered in the "Action Plan for sustainable energy" referred to the year 2009, the model was taken into account the HDD for that year. It was considered the climatic data recorded at the Brandizzo Malone weather station, as the closest station in terms of geographical coordinates (45°10′37″ N, 7°50′08″ E, 192 (m s.l.m.) to Settimo Torinese (45°08′26″ N, 7°45′49″ E, 212 m s.l.m.).

For this research, the ArcGIS 10.2 is used to analysis energy consumption [25]. Considering the spatial distribution of the heated volumes, for residential buildings with different characteristics, the energy-use of the single buildings' models was applied on an urban scale. The 2011 ISTAT census data were also used to improve the models considering the average percentage of the heated volume, the type of buildings' envelope, systems' efficiency, the period of construction, and the number of inhabitants on census section scale. The proposed methodology can be divided into following steps:

1. The residential building stock has extracted from the Database Spatial Reference Entities (BDTRE) Piedmont [20];

2. The surface to volume ratio S/V_{real} has calculated (Figure 1(a)). This ratio is classified as Detached House S/V ≥ 0,72; Terrace house 0,57 ≤ S/V ≤ 0,71; Row house 0,46 ≤S/V ≤0,56; Tower S/V ≤ 0,45 [23], [24];

3. The construction period has attributed for every residential building (Figure 1(b)), where is classified as <1919; 1919-1945; 1946-1960; 1961-1970; 1971-1980; 1981-1990; 1991-2000; 2001-2005; >2005 [21];

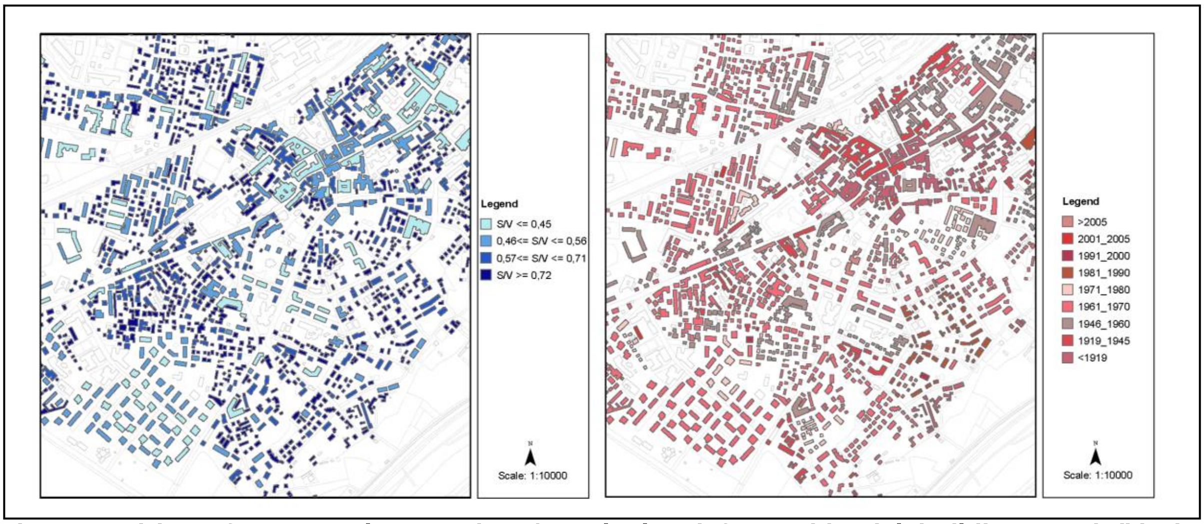

Figure 1, (a) surface to volume ratio S/V calculated for residential buildings and (b) the building construction period attributed for case study (elaborated by authors)

4. The energy demand has calculated using the model started from the model of Torino [24].

Comparing the bottom-up and top-down results, correction factors can be determined to calibrate the bottom up results to achieve good results at Municipal scale. The simplified models of space heating energy-use developed in the bottom-up approach do not take into account significant factors such as solar gains, indoor/outdoor air temperatures and, specially, the refurbishment of buildings. To consider these variables and to adapt the model to real energy consumption data, the model of the specific energy-use of buildings was multiplied by a correction factor and the demographic aspect [23].
For the city of Settimo Torinese, the energy consumption correlations have been defined starting from the model of Torino [24] corrected by the HDD (normalized on the average value of the Heating Degree Days of the last 10 years). These linear correlations used to simulate the energy-use EPgl (for space heating and domestic hot water production) as a function of the surface e to volume ratio S/V for Settimo Torinese are shown in Figure 2, where;

EPgl (kWh/m^2/y) = Slope (kWh/m/y). S/V (m^{-1}) + Constant (kWh/m^2/y)

The models consider the statistical percentage of the real heated volumes, the existence of uninhabited dwellings (the average value for Settimo Torinese is 0.83; from the census) and the correction factor = 1.19 depending on the different use and type of buildings while these values for Torino are respectively 0.94 and 1.04. The correction factors are average values for each city depending by the different territory, residential users, and buildings characteristics.

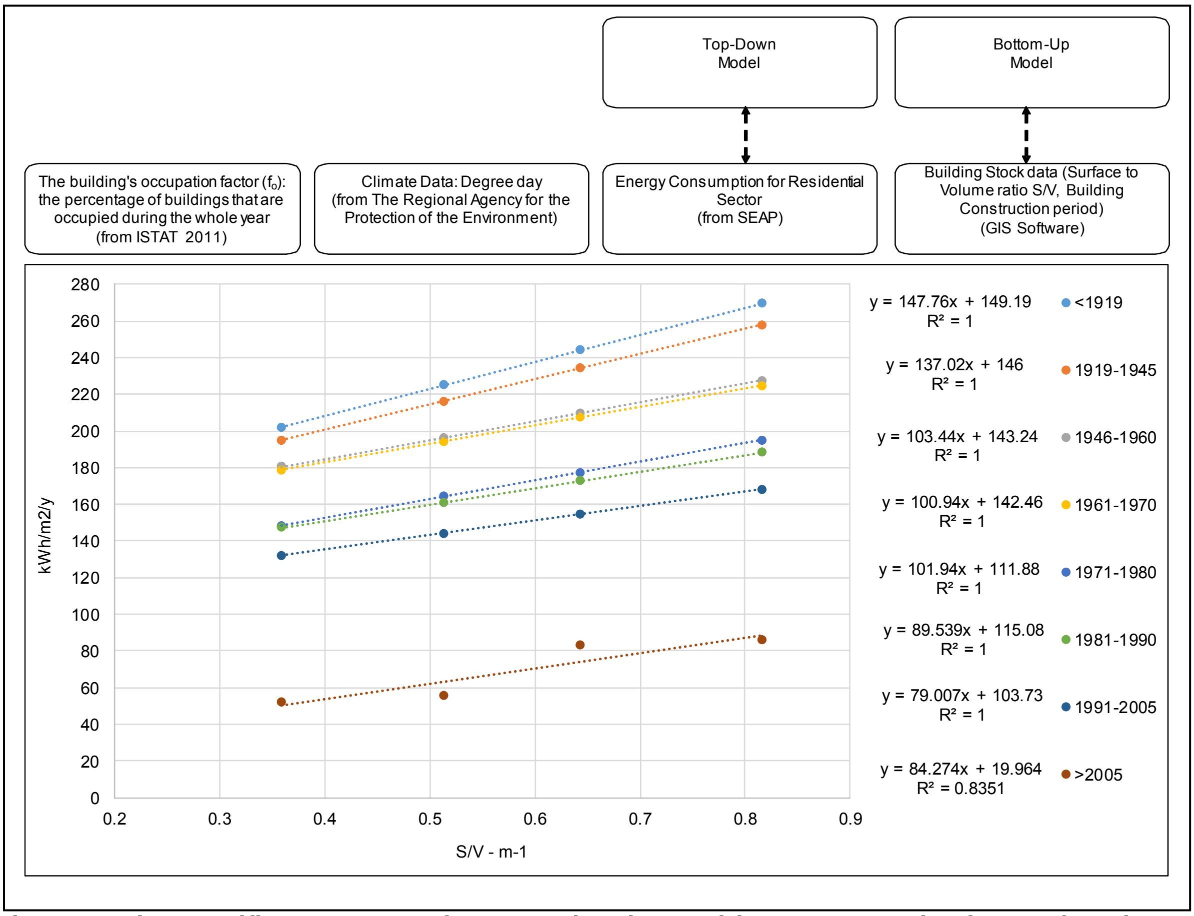

Figure 2. The specific energy-use for space heating and hot water production as function of the building construction period and the surface to volume ratio S/V for residential buildings for Settimo Torinese.

The specific energy-use EPgl for space heating and hot water production's model have a coefficient of determination R^2 =1 except in the case of construction period after 2005 (R^2 =0.8351), showing that the variation of energy-use can be explained as a function of the surface to volume ratio S/V for each period of construction. R^2 indicates how well the statistical model fits the data and, since the Torino model has been used [19], the coefficient of correlation for Settimo Torinese is equal to 1 by meaning that the regression line perfectly fits the data. The simplified linear equation models used to simulate the energy-use for the cities of Torino and Settimo torinese are defined in Table 1.

Table 1, Linear model of specific energy-use (kWh/m^2/y) for space heating and hot water production as function of surface to volume ratio S/V and period of construction for residential buildings in Torino and Settimo Torinese.

Buildings' construction period	Torino (2462 HDD)		Settimo Torinese (2926 HDD)	
	Slope kWh/m/y	Constant kWh/m^2/y	Slope kWh/m/y	Constant kWh/m^2/y
<1919	130.82	140.75	147.76	149.19
1919-1945	121.31	137.93	137.02	146
1946-1960	91.58	135.49	103.44	143.24
1961-1970	89.37	134.80	100.94	142.46
1971-1980	90.26	107.72	101.94	111.88
1981-1990	79.27	110.56	89.539	115.08
1991-2005	69.95	97.61	79.007	103.73
>2005	100.84	22.02	84.274	19.964

Results

Integrating the Top-down and Bottom-up models, it is obtained the average annual energy-use for space heating and hot water production equal to 218 kWh/m^2/y. In Figure 3 is shown the energy classes of the Piedmont Region [26] and the number of buildings belonging to those classes. The building more energy efficient is located in class B ($EP_{gl,\ average}$ = 68.25 kWh/m^2/y) with the construction period after year 2006 and the surface to volume ratio $S/V_{average}$ = 0.57 m^{-1}. While the building with less efficient class G ($EP_{gl,average}$ = 324.04 kWh/m²/y) are mostly belong to the construction period year <1919 and $S/V_{average}$ =1.33 m^{-1} with 1 floor.

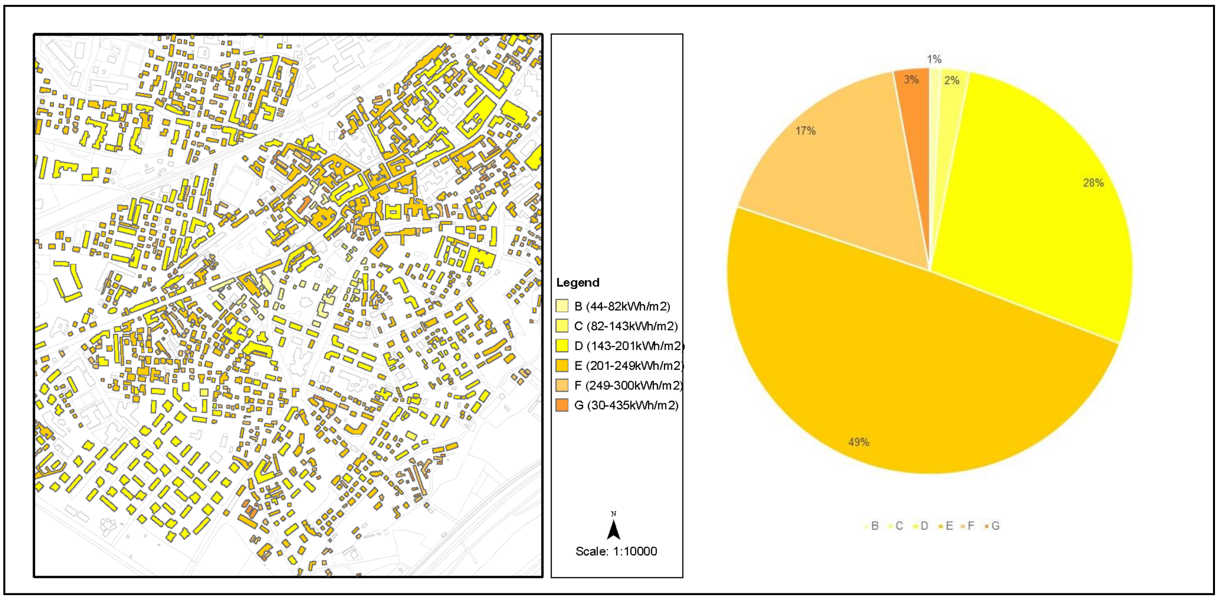

Figure 3, Energy efficiency classes kWh/m^2/y and the percentage number of buildings belonging to those classes.

As shown in Table 2, the number of buildings for different periods of construction and for energy certification classes (space heating and domestic hot water production), the more recent buildings belong to the better energy classes rather than older. It is happening due to the effective implementation of the energy efficiency policies and laws.

Table 2, Number of buildings for different periods of construction and for energy classes.

Energy efficiency classes kWh/m²/y	Construction period									Tot.
	< 1919	1919 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 - 2000	2001 - 2005	> 2006	
A+ < 27	-	-	-	-	-	-	-	-	-	-
A 27-43	-	-	-	-	-	-	-	-	-	-
B 44-81	-	-	-	-	-	-	-	-	25	25
C 82-142	-	-	-	-	-	-	20	8	38	66
D 143-200	1	2	68	240	181	149	103	59	1	804
E 201-248	36	66	332	816	125	51	2	5	-	1433
F 249-299	65	99	115	208	5	-	-	-	-	492
G 300-435	31	38	11	5	-	-	-	-	-	85
N.C. > 435	-	-	-	-	-	-	-	-	-	-
Tot.	133	205	526	1269	311	200	125	72	64	2905

Conclusion and future study

The European Directives, including the Energy Efficiency Directive 2012/27/EU [28], emphasize that big effort must be made by a Member States to optimize the use of energy sources. This can be achieved through an energy efficiency plan, setting several policy targets as reduction in EU greenhouse gas emissions, raising the share of EU energy consumption produced from renewable resources and energy efficiency improvement. Despite the great energy efficiency improvements in buildings, recent energy consumption data analyses show that these targets will unlikely is reached [27].

Therefore, the assessment of the residential building energy consumption at city/municipal scale is significant to achieve the energy efficiency goals in EU. The importance of the period of construction and shape factor of buildings is discussed, where more recent buildings belong to the greater energy classes due to the current effective implementation of the energy efficiency regulations. On the other hand, it can be obtained the same conclusion for the surface to volume ratio S/V: the single-family houses belong to the low energy classes, rather than the compact buildings, as towers.

Therefore, it is crucial to define a comprehensive profile model to understand the current state of the energy consumption for building stock. This paper began by calculating the energy consumption profile at the City Scale with the use of geographic information systems (GIS) that can significantly help in the planning of actions. The estimation of energy-use for each residential building of the case study was calculated through the methodology described. For the future study, it will compare the bottom-up measured energy consumption and the calculate one. Afterward, it will calculate the renovation rate for residential building stock, taking into account the social variables. Particularly, a multi-criteria decision-making will be applied to achieve a sustainable and smart energy planning as a method, which has fascinated the decision makers' attention for a long time [29].

Acknowledgment

The work included in this paper has been supported by the Research Project "Zero Energy Buildings in Smart Urban Districts".

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New 3D simulation methods for Urban Energy Planning

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Abstract

To develop planning scenarios for the development of the urban energy demand of buildings and the renewable supply options with heating and cooling network distribution, a large amount of data on the building stock, the buildings thermal properties, the network and supply infrastructure is needed. It is therefore very advisable to access the continuously growing data stock organized in geographical information systems that many cities use. If the data can be combined with simulation models of buildings and energy systems, very powerful analysis possibilities for an energetic and economic evaluation of scenarios arise. In this work, 3D models in CityGML format of the entire building stock of a city and even an entire region were used and enriched with building physics parameters to allow an automatized simulation of the thermal heating and cooling demand.

Within the workflow the building physics and building usage data are attributed from various sources such as census or cadaster data, from infrared thermography for the refurbishment status or from using on site surveys or crowd sourcing information. Depending on the analysis questions, an automated process of model generation using the modular simulation environment INSEL is carried out, resulting in either steady state monthly energy balances or dynamic single or multi-zone building models.

The method was applied to simulate scenarios of energy efficiency developments in a whole region with 34 municipalities, where every individual building was simulated and the results compared with the municipal total energy consumption. It could be shown that using advanced insulation standards varying for different building types the regional heating energy demand can be reduced by up to 58% and by 46% if a medium insulation standard is applied to all buildings.

Introduction

The research field of urban energy analysis is extremely important to reduce global CO_2 consumption. Deploying ICT helps to quantify and predict the urban energy demand. A range of simplified ICT tools address this topic with different scope of application and functionalities [1].

Urban energy modeling is computationally intensive, due to the increasing level of detail and amount of meta data attached. Either the processing power can be improved by implementing cloud-based or parallel computing solutions [2] or the urban models can be simplified [3]. The use of GIS is very useful to integrate and structure the large urban data set [4,5].

Virtual 3D city models generated from airborne laser scanner or photogrammetry technologies can provide an excellent dataset for bottom-up physical modelling, storing geometrical and semantic data of entire cities [6]. Based on such city models, several urban heat demand analyses have been recently carried out in some European cities like Berlin [7,8], Karlsruhe and Ludwigsburg [9], Trento and Ferrara [10].

Used for modelling a growing number of cities, regions and even countries (Germany), virtual 3D city models represent a powerful support for public authorities and engineering companies to tackle the urgently required energy transition. Among the 3D city model formats, the open standard CityGML stands out as the reference, providing an excellent and flexible spatial-semantic data structure for 3D geospatial visualization, multi-domain analysis and exploration. The CityGML data model is the basis of the new urban energy simulation platform SimStadt developed at the University of Applied Sciences Stuttgart during the last years. This platform aims to support urban planners and city managers with defining and coordinating low-carbon energy strategies for their cities, with a variety of multi-scale energy analyses. The platform integrates simulation algorithms and explores the potential of new data sources.

The input data quality is crucial for the accuracy of the results and several European projects dealing with urban data management are working on this issue, like INSPIRE [11] or SUNSHINE.

Investigating the impact of the different input variables on the result accuracy enables the identification of the most influential input data and the analysis of data uncertainty [12]. As a result, intelligent and adequate data collecting strategies can be designed, assigning resources to the most important parameters, while parameters with minor influence can be assessed with coherent benchmarking values.

Using as adequate data for the demand simulations as possible, the contributions of renewable energies to cover this demand can then be calculated. This requires the simulation of the energy provided by solar energy conversion system and to relate this energy produced to the demand of each building in question. This is particularly important when considering solar thermal energy use, which is currently only directly used by each building and usually not fed into heat distribution grid.

The scope of this paper is to determine energy efficiency strategies and the photovoltaic and solar thermal system potential at an urban and regional scale. A German county district with 34 municipalities was analyzed. The purpose was to determine what fraction of energy demand can be covered by renewables and which strategy has to be adopted to reach this aim. Two different strategies i.e. economic and technical are investigated. The potential analysis is carried out for each single building according to its specific roof shape, receiving solar irradiation, and heat demand. The heat demand of each building as well as solar irradiation is simulated by SimStadt, a java-based simulation platform.

Heat demand simulation

Within the space heating workflow the thermal energy demand of each building is calculated for which some basic data like year of construction, building typology as well as 3D geometry are available. Geometry data are provided in the CityGML data format, a SIG standard for modeling urban objects [13] The CityGML buildings can be modelled with different Levels of Details (LoDs). LoD1 models buildings as a cube with flat roofs, whereas LoD2 adds the details of roof shape. The workflows in SimStadt have the ability to work compatibly with different LoDs. To determine the space heating demand, weather data is also required. The monthly energy balance is then calculated according to DIN 18599-2.

The simulation results are classified in three building types, which is often used for climate protection concepts:

1. residential: (mainly private homes and multi-party houses)
2. public: (mainly public administration and community buildings)
3. industry, trade, commerce and services

Beside the status quo analysis of the current energy needs of districts, there are two simulation scenarios provided by SIMSTADT, called “Medium” and “Advanced” to calculate future building energy efficiency scenarios. Different building parameters are used for each scenario regarding the building physics characteristics such as heat conductivities and capacities of the different construction layers. For this all buildings are sorted into categories like single-family houses, multi- family houses etc. and year of construction. The data base is a building typology from the Institute IWU [14] in Germany.

The assumption for the “Medium” scenario is a standard refurbishment level corresponding to the German Energy Saving Ordinance 2009. The assumption for the “Advanced” scenario is a level of refurbishment which is similar to standards of passive houses, but without a ventilation system with heat recovery.

The following table 1 lists the heat transfer coefficients of building components used for the simulation of the two refurbishment scenarios. The values are applied depending on the building type and year of construction.

Table 1: Heat transfer coefficients of building components

Building component	U-Value status quo [W/(m2K)]	U-Value “medium” scenario [W/(m2K)]	U-Value “advanced” scenario [W/(m2K)]
Pitched roof	0,35 – 1,75	0,35 - 0,40	0,14
Flat roof / top ceiling	0,23 - 1,21	0,13 - 0,74	0,11
Wall	0,3 – 1,87	0,18 - 0,39	0,11 -0,14
Floor	0,31 – 2,66	0,23 - 0,49	0,18 - 0,26
Window	2,7 – 4,3	1,3 - 1,6	0,8 - 1,25

The simulation can be performed with different annual rates of refurbishment. For a given refurbishment rate, the buildings are then selected stochastically from different categories and year of construction. It is however possible to change these constraints manually if desired. Figure 1 shows the building distribution of the county Ludwigsburg sorted by build year as it is applied in SIMSTADT.

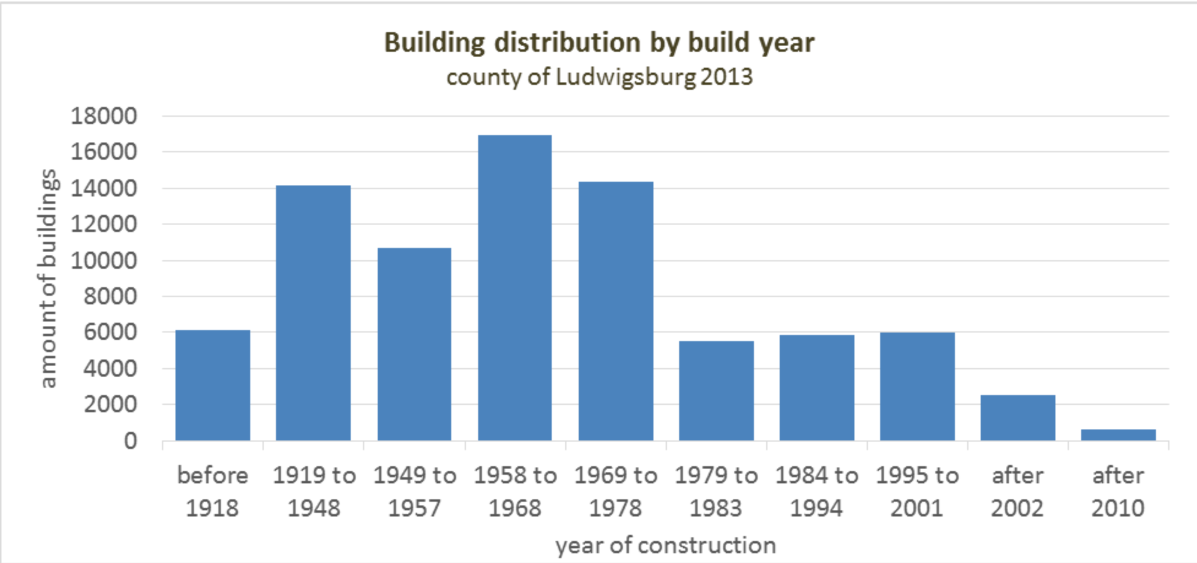

Figure 1: building distribution of county Ludwigsburg by build year

Definition of measures in climate protection concepts

An important part of climate protection concepts is the definition of strategies to decrease CO_2 emission. Initiatives to reduce the energy demand (e.g. of buildings) can lead to direct or indirect CO_2 savings. Another approach is to implement renewable energy supply systems to replace conventional systems, which can significantly lower CO_2 emissions too. Using the simulation results of SimStadt, it is possible to quantify the effect of CO_2 saving measures. The aim is to consolidate estimated effects of activities in the future. Hence, the principle is to extract relevant outcomes of SimStadt and combine them with key indicators of particular initiatives to calculate and predict feasible energy and CO_2 savings.

Case study integrated climate protection concept of county Ludwigsburg

The county of Ludwigsburg which is composed of 34 municipalities is located in the South-West of Germany with a total population of 521.633 inhabitants (2013). This number represents about 5 % of total population of the German federal state Baden-Württemberg. The total surface of the rural district is 68.682 ha with more than 55 % used agriculturally. Another 18 % is forest area, 16.500 ha of the county consists of settlement and traffic area and 4 % of the surface is water or other.

The county of Ludwigsburg commissioned an integrated climate protection concept in 2014 which has three main goals.

The first purpose of the county of Ludwigsburg is to determine potentials to reduce emissions and to design innovative projects to decrease or even avoid CO_2 emissions. This requires an energy status analysis to ascertain strengths and weaknesses. Laying the foundations for continuing CO_2 monitoring and determining the potentials of renewable energies shall be ensured too.

Another objective is to issue a realistic and viable package of measures forming a basis for a financing concept.

Thirdly, the rural district of Ludwigsburg strives to become climate-neutral until the year 2050 and to reduce the total CO_2 emission per capita in the county of Ludwigsburg below 2 tons.

SimStadt was used for the project to investigate the current status of energy demand, to evaluate prospective energy demand scenarios and to serve as an advance base to design concrete measures for action.

Simulation results and validation

The simulation process was performed for each municipality of the county Ludwigsburg. Following this, the results were accumulated for the whole administrative district.

Total heating energy demand

Figure 1 presents the total simulated heat demand of all buildings in each municipality. The two communities of Bietigheim and Vaihingen have a particularly high heat demand due to larger populations and higher amount of buildings in these administrative districts. The total county heating energy demand is 3.890.456 MWh/yr.

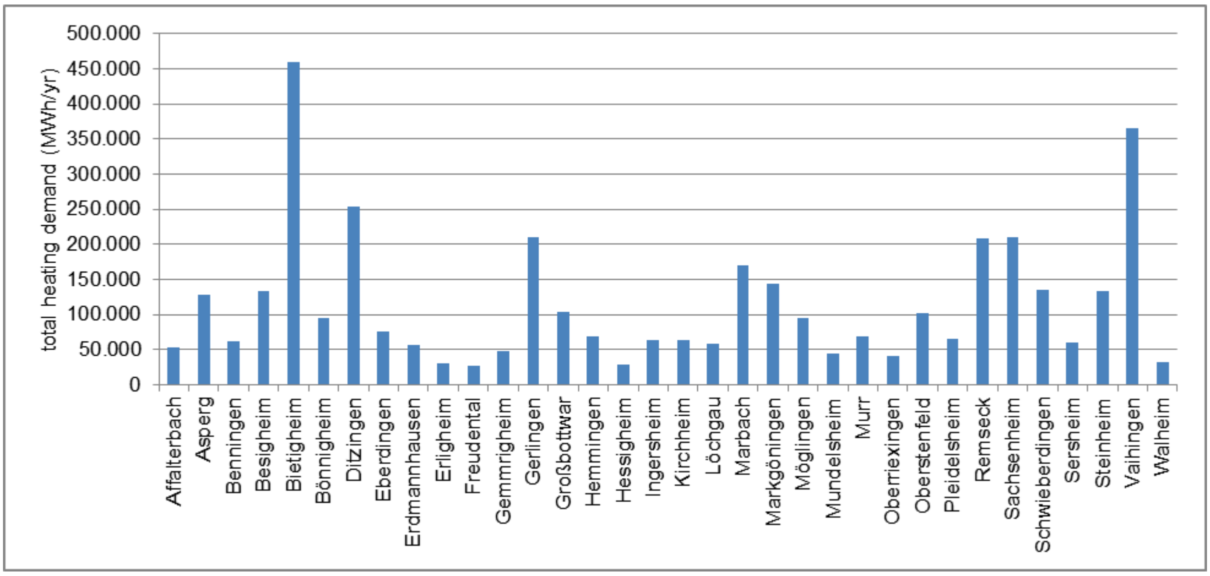

Figure 2: Total simulated annual heating energy demand of all buildings in 34 municipalities in the county of Ludwigsburg

A validation of the results could be made only for 6 municipalities, where heating energy consumption data were available. Therefore the analysis results are presented for these towns solely.

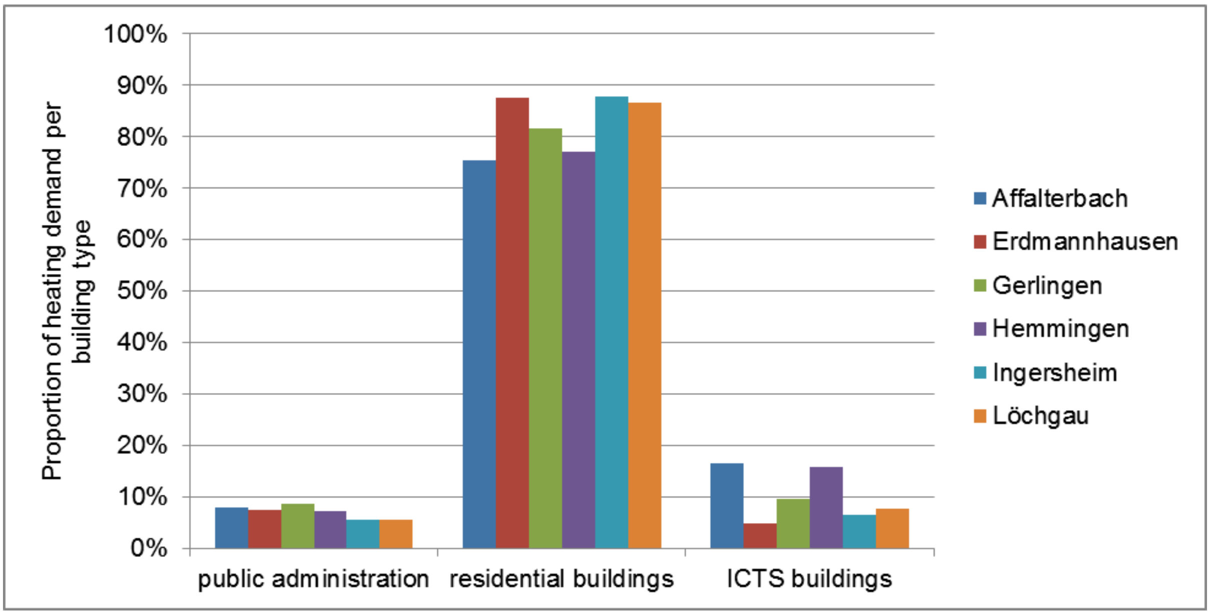

Figure 3: Percentage of heating energy demand per building type.

In all communities the highest energy demand is caused by residential buildings, which is typical for small and rural municipalities.

The approach to validate the data of the simulation process was to use gas supply bills or concession bills from the municipalities and compare them with the simulated energy demand results of Simstadt. An inquiry was directed to the communities to send their bills for evaluation. A challenge was to extract coherent data because the submitted concession bills differ by their dates (measurement year) and furthermore are often incomplete. However six concession bills of the year 2012 could be gathered and compared with the calculated heat energy demand by assuming an average conversion efficiency of the gas boilers of 85%.

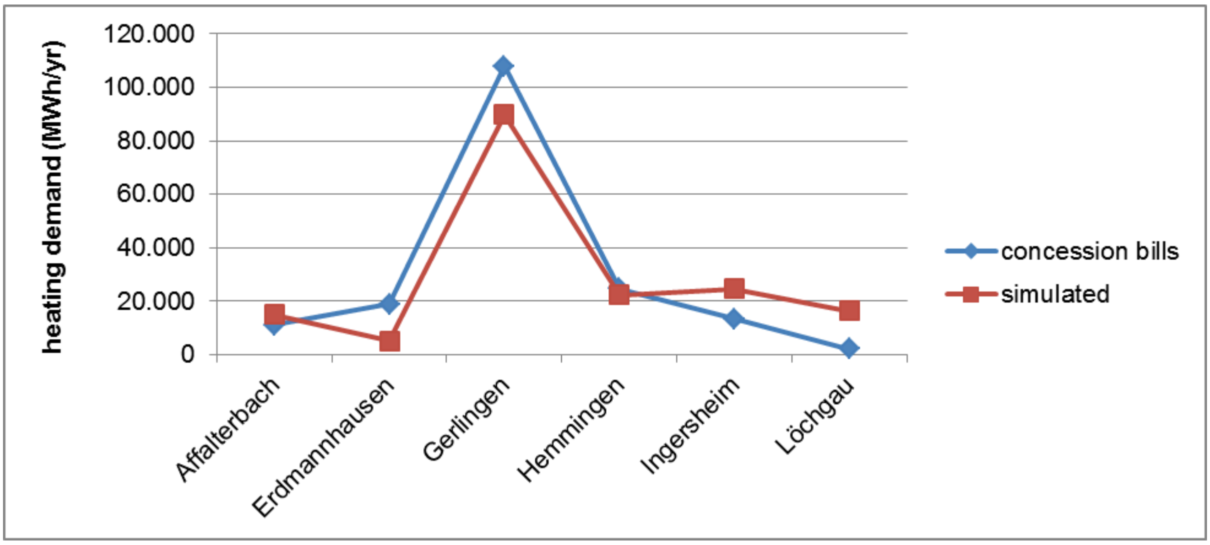

Figure 4: Comparison of simulated and real data for the buildings within the different municipalities that are heated with gas

From Figure 3 a correlation of the simulated and real data can be seen. The higher measured consumption in Gerlingen is due to energy-intensive industries which are located in this area. Also a bigger hospital is situated there, that could require more heating energy than simulated. In the small community of Löchgau a local glider airfield and several sport facilities may cause the deviations because of their relatively low heat demand.

In summary it can be stated that the simulated heating energy demand matches the real consumption data reasonable well and that the main deviations occur for non-residential buildings, where the use is not well known.

Specific heating energy demand

Overall an average heating demand of 125 kWh/m^2.yr for the status quo of all buildings was obtained. Applying the “Medium” and “Advanced” scenario, the demand drops to 67 kWh/m^2.yr respectively 52 kWh/m^2.yr.

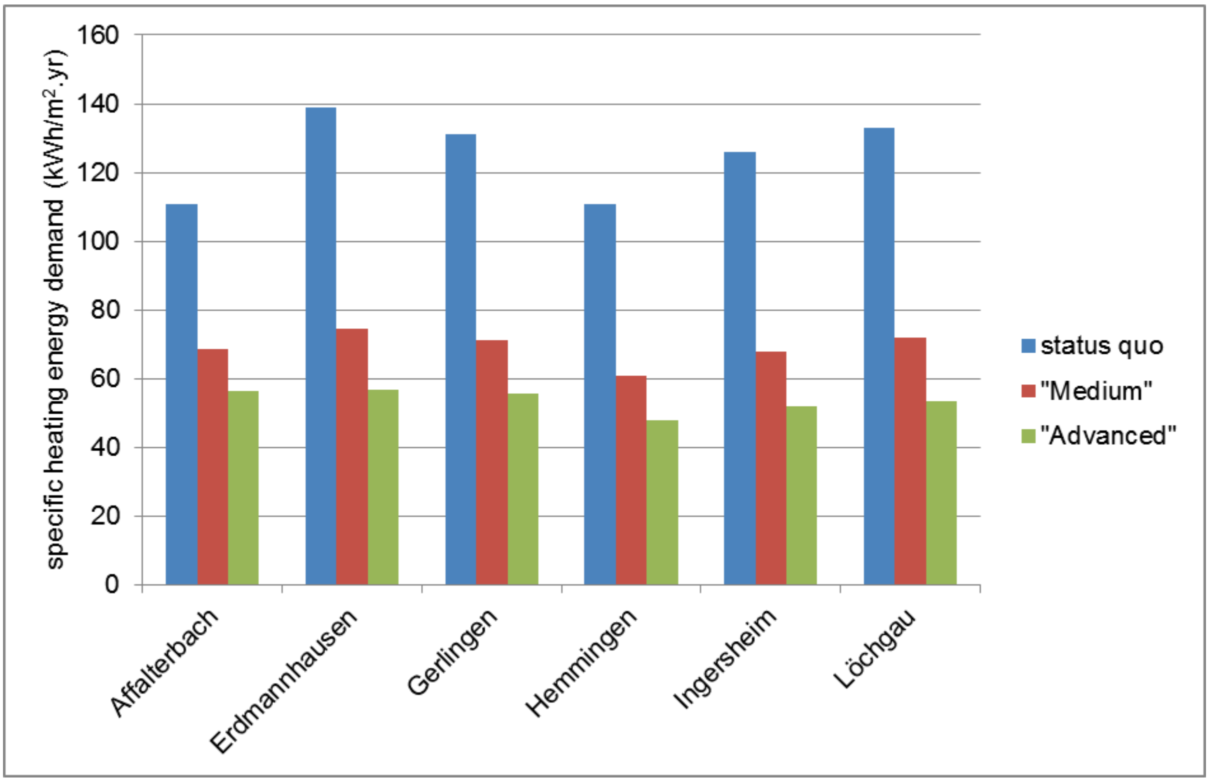

Figure 5: Simulated specific heating energy demand for different scenarios

Figure 5 shows the shift of the specific heat demand when applying the three simulation scenarios to the municipalities. The difference to the status quo scenario can be up to 58% for a high energy standard and 46% if a medium insulation standard is applied to all buildings. It is apparent in this figure that the difference between the status quo and the medium refurbishment scenario values is greater than among the medium and advanced scenario.

Figure 6 shows the simulated specific heat demands for each building sector.

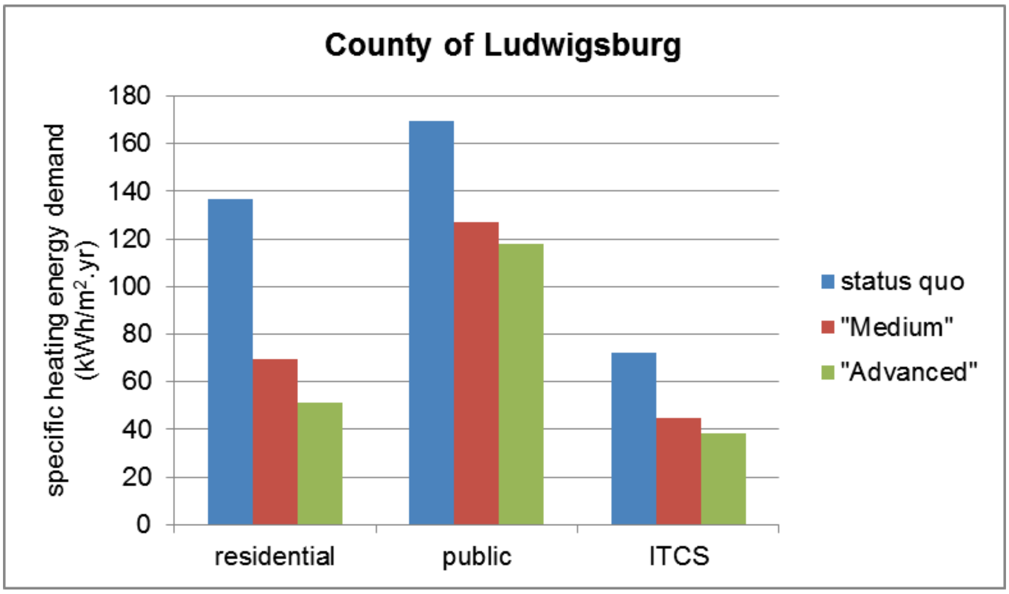

Figure 6: Specific heating energy demand scenarios for each sector

From the chart, it can be seen that the specific heat demand of public buildings does not decrease as much as for the residential and ITCS buildings. This is due to the fact that only for residential buildings thermal parameters for refurbishment scenarios are defined in the national data bases. For some buildings such as health care centers no scenarios could be calculated, for others with high surface areas or volumes the residential retrofit scenarios do not properly fit. A more detailed analysis of the specific heat demand of buildings of various types of use within a single municipality is shown in Figure 7.

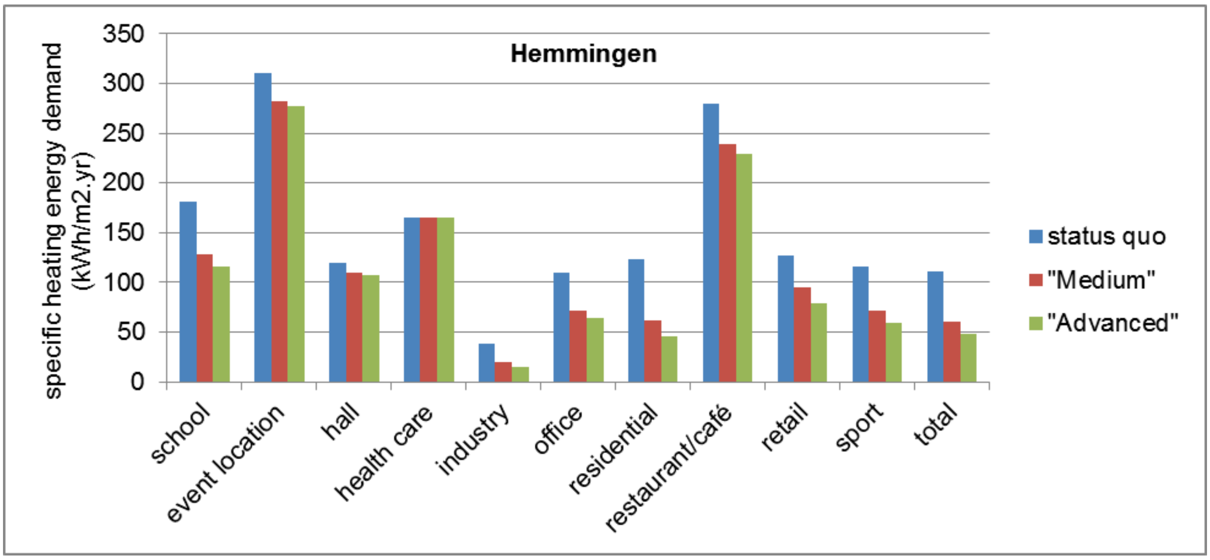

Figure 7: Specific heating energy demand of various building types in the non-residential sector

As an example Figure 7 displays an overview of Hemmingen. From this data it can be seen that event location buildings have a very high heat demand, which only declines slightly through the "Medium" and "Advanced" scenario. Further investigations need to examine more closely these results.

Derivation of measures and initiatives from the analysis of results

Based on the calculated energy demand and the determination of objectives for the rural district of Ludwigsburg, several categories of measures were defined. The aim was to provide approaches for decision makers in the municipalities to take action and support them during the execution of the climate protection concept. The measures are classified in: general actions, activities in the energy supply/renewable energy sector, economic activities, actions for private buildings, for mobility, for user behavior / education / consumption, activities within the sector public administration, public relation activities and consulting or citizen participation activities. Initiatives were designed and assigned to one of the categories. Each initiative is described in detail by a profile. The profile consists of a form to enter important indicators like target group, chances / barriers of progress, costs, energy CO_2 / energy savings etc. Further, key factors for costs and CO_2 savings were defined. In the following one of the initiatives is presented whose factors could be quantified.

Example: Using the Photovoltaic Potential

As an exemplary initiative the installation of PV systems shall be accelerated to exploit the existing potential. To support this process, the potential shall be communicated activating energy consultants, project managers and property owners of the county. The plan is to reduce CO_2 emissions by 2% every year. This measure was assigned to the energy supply/renewable energies activities.

The key indicator of this measure is the annual percentage of buildings which should be equipped with PV for achieving 2% CO_2 reduction "B_{PV}". The amount of energy saving "E_{yr}" (kWh/yr) needed for the 2% annual reduction of CO_2 emission and the average energy savings through PV for each building "S_a" (kWh/yr) are also required for this definition.. The annual energy saving is obtained from:

$E_{yr}= (M_{yr}/M_{kWh.yr}) \times 0.02$

The PV electricity production per building is simulated for building roof using the surface area, a user defined percentage of area coverage with PV and the roof orientation.

$S_a=E_{PV}/B_t$

The percentage of buildings to be equipped with PV is then calculated from:

$B_{PV}= (E_{yr} /S_a)/B_t \times 100$

From the Simstadt simulation results the indicator was calculated in the following way:

Listing of relevant variables to determine the key indicator

Variable	**Value of the example**	**description / Source**
M_{yr}	1.434.175 t/yr	Annual CO2 emissions calculated by SimStadt
$M_{kWh.yr}$	0,00069 t/kWh.yr	Substituted CO_2 of PV installations in Germany from environment ministry BMU
E_{PV}	670.000.000 kWh/yr	annual potential of PV electricity production calculated by SimStadt
B_t	82.930	total amount of relevant buildings recorded in SimStadt
E_{yr}	41.570.301 kWh/yr	Required PV production to achieve 2% savings $(M_{yr}/M_{kWh.yr}) \times 0.02$
S_a	8.079 kWh/yr	PV potential per building E_{PV}/B_t
$\mathbf{B_{PV}}$	**6,20%**	Annual percentage of buildings to be equipped with PV to reach 2% CO2 savings $(E_{yr} /S_a)/B_t \times 100$

An economic analysis of this measure was made too. On the one hand the annual savings "A_s" (€/yr) by avoiding the electricity costs was identified. On the other hand the annual costs to reduce CO_2 emissions by 2% "C_{CO2}" (€/yr) and the total investment costs "C_t" (€) were calculated. The calculations were done as follows:

$A_s=E_{PV} \times C_{ep}$

$C_{CO2}=E_{yr} \times C_{ft}$

$C_t=P_{PV} \times C_{kWp}$

After extracting the required results from Simstadt the indicators were calculated in the following way:

Listing of economic indicators and their parameter

Variable	**Value**	**description/ Source**
E_{PV}	670.000.000 kWh/yr	annual potential PV electricity gain calculated by SimStadt
C_{ep}	0,22 €/kWh	electricity price per kWh (Experience value)
A_s	**147.400.000 €/yr**	$A_s=E_{PV} \times C_{ep}$
E_{yr}	41.570.301 kWh/yr	amount of energy saving needed for an annual reduction of CO_2 emission by 2 % (calculated above)
C_{ft}	0,1231 €/kWh	feed-in tariff for small PV facilities http://www.bundesnetzagentur.de
C_{CO2}	**5.177.331 €/yr**	$C_{CO2}=E_{yr} \times C_{ft}$
P_{PV}	630.000 kWp	Total PV potential calculated by SimStadt
C_{kWp}	1,3 €/Wp	Average price for the installation of 1 kWp PV from Fraunhofer ISE [X]
C_t	**819.000.000 €**	$C_t=P_{PV} \times C_{kWp}$

Conclusions

Urban 3D models support climate protection concepts by allowing to quantify scenarios and measures to improve energy efficiency. The SimStadt platform was developed to couple urban data models with modular simulation tools. The study showed that the heating energy demand of a whole region can be simulated on a building by building scale. Depending on the level of refurbishment, the regional heating energy demand can be reduced significantly by applying the refurbishment scenarios. It is still very challenging to get enough municipal consumption data to seriously validate the simulation results, but previous detailed validation work on blocks of buildings demonstrates that the error between consumption and modeled yearly heating energy demand is less than 10%.

Using the Simstadt platform it is possible to evaluate policies on a municipal and regional level. With reliable input data, this work has shown that key indicators can be calculated as a basis for measures to be taken for regional climate protection concepts.

Acknowledgement

This work has been carried out in the framework of the national project SIMSTADT funded by the German Ministry of Economics and the development of a climate protection concept for the region Ludwigsburg in a consortium led by Drees & Sommer.

Nomenclature

GIS	Geographic information system
ICT	Information and communication technology
ITCS	industry, trade, commerce and services
PV	Photovoltaic

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GIS-based bottom-up approach to evaluate the energy demand for the SINFONIA district Innsbruck (AT)

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Abstract

In order to evaluate the impact of energy related measures in districts or cities in terms of the expected energy savings, it is necessary to calculate the actual energy demand (baseline) in these areas. This baseline is issued for a defined area for the city of Innsbruck as part of the EU project SINFONIA (Smart INitiative of cities Fully cOmmitted to iNvest in Advanced large-scaled energy solutions). The baseline includes the actual situation of the electricity and heat demand to represent the percentage change of the energy demand due to the implemented measures by SINFONIA. The basic information of all energy-related databases (geographic information and feature data) are collected, combined and linked, in accordance with the Austrian data protection law (DSG[1] 2000). A specially designed bottom-up model named “Energieraum Alpen” (EneRAlp) was applied on this database. The EneRAlp model was developed in accordance with the Austrian Energy Certificate (ÖNORM[2] EN ISO 13790 / ÖNORM B8110-6), which is used to balance the energy demand in buildings. The EneRAlp model includes the residential sector and partly the non-residential sector like offices, retail outlets and accommodations. The final target of the SINFONIA baseline was to calculate the entire building stock in relation to the energy demand. This paper describes the methodology of the EneRAlp bottom-up approach, the verification by using the consumption data and the results of the investigated SINFONIA district.

Introduction

The SINFONIA project is a five-year initiative to deploy large-scale, integrated and scalable energy solutions in mid-sized European cities. At the heart of the initiative is a unique cooperation between the cities of Bolzano and Innsbruck, working hand in hand to achieve 40 to 50% primary energy savings and increase the share of renewables by 20% in two pioneer districts. This will be done through an integrated set of measures combining the retrofitting of more than 100,000 m² of living surface, optimization of the electricity grid, and solutions for district heating and cooling [1].

The elaboration of the baseline is essential in order to evaluate the predefined goals and measures in the SINFONIA district. This paper represents the methodology of the baseline establishment and the energy related results of the investigated SINFONIA district.

The main object during the development of the EneRAlp baseline bottom-up approach in Feldkirch (federal state Vorarlberg, AT) [2] was to set up on standardized Austrian datasets. Consequently, it should be possible to apply the approach on every Austrian city or community with minimal modifications and extensions. Therefore, a pre-investigation of the available datasets of the different stakeholders (federal state, city / community, energy supplier …) was necessary. For the energy calculation module, a comprehensible approach of the Austrian Energy Certificate standard was selected. During the SINFONIA baseline preparation, the EneRAlp approach was reworked and adapted to local circumstances (federal state Tyrol, AT). Additionally, the calibration and verification of the calculated energy demand was refined in the project. In comparison to the study [3] in section 5.2 the described bottom-up model is based on the engineering method. The EneRAlp model uses the actual sample house data and can therefore be assigned to the technique “Samples” of the mentioned study.

SINFONIA stands for “Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy”. This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No 609019

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[1] DSG… Austrian data protection law
[2] ÖNORM…Austrian standard

Methodology

The following sections describe the data protection requirement, available datasets, calculation method (EneRAlp), calibration method and at least the building categorization for the result presentation.

Data Protection

Before the collecting process started, UIBK[3] developed special data contracts in accordance to the Austrian data protection law (DSG 2000) with all SINFONIA Innsbruck partners. Due to data security reasons, UIBK installed an independent data server, where all basic data sets are stored. The entire data handling and the baseline calculation are made on this secure data server. In accordance to the data protection law, no personalized information is processed for the preparation of the baseline. All energy relevant information is aggregated from the building level to the GIS-based (Geo Information System) 100 x 100 meter raster level which is provided by the Austrian statistic [4].

Data Sets

At the beginning of the baseline, UIBK collected all available specific data from the various SINFONIA Innsbruck partners (City of Innsbruck, IKB[4], TIGAS[5], NHT[6], IIG[7]). The data collection started before any other SINFONIA measure took action at the end of May 2015. The following table 1 shows all main datasets for the baseline calculation.

Table 1 Main datasets SINFONIA district

Main Datasets	Source
AGWR* Administrative Report buildings	Municipality Innsbruck
AGWR Administrative Report building units	Municipality Innsbruck
AGWR Administrative Report construction projects of buildings	Municipality Innsbruck
AGWR Administrative Report construction projects building units	Municipality Innsbruck
Digital Building polygons and address	Municipality Innsbruck
Surface and Terrain Model	Municipality Innsbruck
Electricity Consumption Data (Raster)	IKB
Gas Consumption Data (Raster)	TIGAS

*Austrian Federal Building and Dwelling Database; table source [5]

The above mentioned datasets consist of different sources. The main information is provided by the AGWR II (address, building and dwelling register) administrative report building units. This report has been evolved subsequently to the census in 2001, where the setup of the GWR Report (building and dwelling register) started, which includes the address data, buildings and building units and the structural data. In 2004, the GWR was extended with the address register, which leads to an authentic database of geocoded addresses. In March 2010, the Statistics Austria changed the system to AGWR II [6], which includes the following information: characteristics of the address of plots (street name, house number, geocoding, etc.), building characteristics, building function, building age, building height, areas (gross floor area, net floor area, etc.), floor-related information, type of heating system, type of supply systems (water, electricity, sewerage, natural gas, etc.), energy carrier and characteristics of the building units.

The digital building polygons provide information about the wall length and wall orientation which also helps to improve the calculation of the energy demand. The surface and terrain model implements

[3] UIBK…University Innsbruck
[4] IKB…Innsbrucker Kommunalbetrieb Aktiengesellschaft
[5] TIGAS…TIGAS-Erdgas Tirol GmbH
[6] NHT…Neue Heimat Tirol
[7] IIG…Immobiliengesellschaft der Stadt Innsbruck

further information. This model is calculated by flights using laser-scan technology. The database is required for the determination of the sea level and the building height. The consumption datasets (electricity, natural gas and district heating) are aggregated on the 100 x 100 m raster level.

EneRAlp Tool / Calculation Method

The baseline software tool "EneRAlp" [7], was partly developed for the Energy Master Plan [2] Feldkirch (AT) in collaboration with the company alpS GmbH and University of Innsbruck. The approach was adapted to the available datasets of the SINFONIA project partners (federation state, city, residential property developers, utilities …). The following figure 1 shows the software architecture.

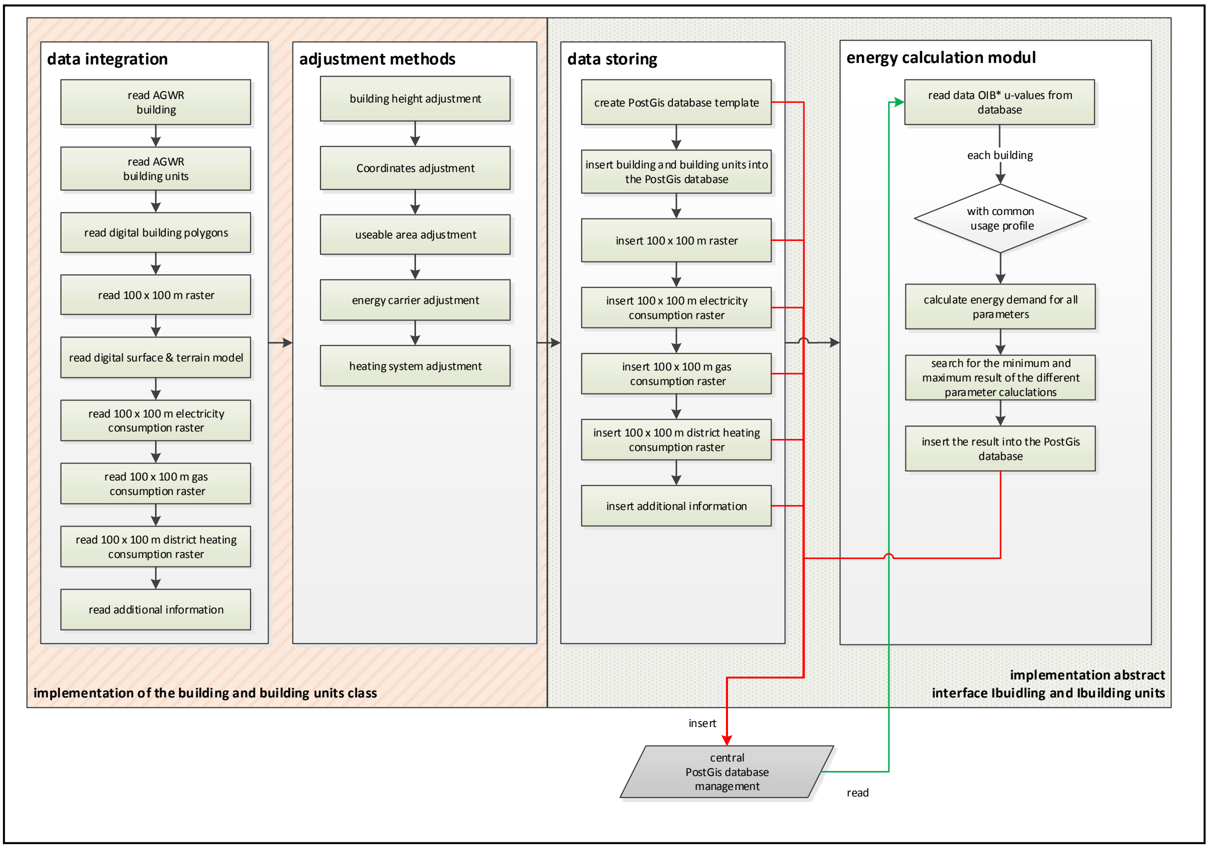

Figure 1 Software architecture [5]; *OIB…Österreichisches Institut für Bautechnik

The software tool consists of four sub-processes: data integration, adjustment methods, data storing and the energy calculation module. After the data collecting process, the datasets (table 1) were systematically integrated in the building and building unit classes. During the integration, the smart linking method connects all different information of the different datasets. The data classes (building and building unit classes) will be improved by corrective measures with the adjustment methods, which is done by comparing the individual information of the different datasets (i.e. data of laser scanning flights and number of building levels according to AGWR). After this process, building and building unit classes are the interface for the further sub-processes. With the basic database-template, a new Postgres[8] (PostGIS[9]) database is created. All relevant building data for the energy demand calculation are stored in this database. Corresponding to the Austrian data protection law, the required GIS 100 x 100 m raster is stored as well in the database.

The specially designed bottom-up energy calculating model was applied on this database. The energy calculation module was developed in accordance with the Austrian Energy Certificate, which is used to balance the energy demand in buildings. The energy model is based on the following Austrian

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[8] http://www.postgresql.org/, 2016.01.14
[9] http://postgis.net/, 2016.01.14

standards: ÖNORM EN ISO 13790 [8], ÖNORM B8110-5 [9], ÖNORM B8110-6 [10], ÖNORM H5056 [11], ÖNORM H5050 [12], OIB “Leitfaden” [13], OIB “Richtlinie 6“ [14]. All calculated results of the energy demand according to the energy certificate of each building are stored in the Postgres database.

Calibration Factor (fm) & Model Calibration

Due to the assumed parameters (window area, building capacitance, …) of the EneRAlp Model and a lack of information on the building level concerning the restoration measures, real user behavior, partly heated dwellings etc. the heat energy results have to be calibrated with the real heat energy consumption. For the calculated electricity demand, a calibration with the real electricity consumption is also necessary. UIBK developed in cooperation with the energy supplier companies (IKB, TIGAS) statistical methods to create calibration factors for the model calibration. Therefore, the following basic concept was used:

$$\text{fm}_{\text{(building category, building age)}} = \frac{\text{measured energy consumption}}{\text{calculated energy demand}}$$

In order to establish this concept on the heat demand of the residential buildings, it is important to distinguish between the various heat energy carriers (e.g. gas and logs) in the building. In some cases, the domestic hot water or space heating can be supplied by electricity energy. For this reason, a separation between space heating and domestic hot water is important. If the electricity energy supplier has the information about the consumption of the domestic hot water or space heating, it will be implemented in the evaluation. Additionally, the amount of electricity produced heat energy has to be considered by the electricity demand calibration. Due to the data protection of the consumption data, the statistical evaluation for the calibration factor was performed by the energy suppliers themselves. UIBK provided the calculated energy demand and analysis method, which was developed together with the supplier. Figure 2 gives an overview of the described process.

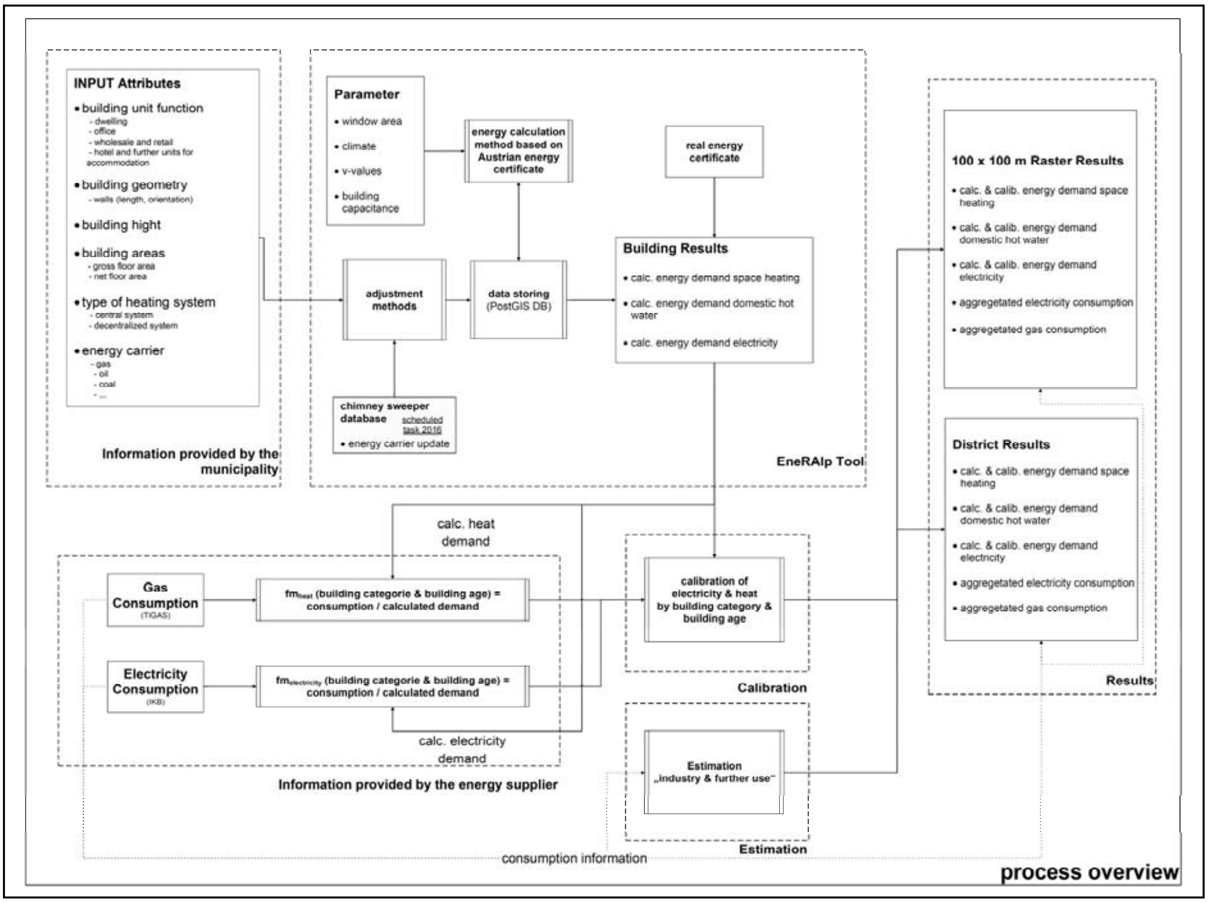

Figure 2 Process overview of baseline calculation [5]

These detailed correction factors (incl. restoration measures, user behavior, etc.) between grid-bounded energy consumption (gas, electricity) and the calculated energy demand, are used to calibrate the baseline calculation. After the calibration process, the energy demand of each building was aggregated on the district level for the final baseline balance. The estimation of the unknown units will be described in the section ”Calculated Final Energy Demand of all Buildings”. In addition, the sum of the measured energy consumption (gas, electricity, district heat) in the SINFONIA district was verified with the baseline results.

Building Categories

For a better overview of the building stock and the calculated energy results, a categorization of the building information was necessary. Based on the AGWR building unit information, the classification of the buildings was made as following:

Table 2 Building category

Building Sector	Building Category	Usage Category
Household	Single-Family House	1 dwelling (free standing building)
	Terrace House	1 dwelling (walls string together)
	Multi-Family House "Small"	2-4 dwellings
	Multi-Family House "Medium"	5-10 dwellings
	Multi-Family House "Large"	>10 dwellings
Mixed Use*	Mixed Use	Apartment, office, wholesale and retail, hotel and further units for accommodation, transport and communications, industry and storage, culture, leisure, education, healthcare, public buildings, other
Commercial	Commercial Building	Office, wholesale and retail, hotel and further units for accommodation
Industry	Industry	Industry and storage
Public Buildings	Public Buildings	Owner: federal government, federal state government, community, non-profit housing co-operatives and other public bodies
Further Use	Miscellaneous	Culture, leisure, education, health, agricultural use, transport and communications, churches, other religious buildings, residential areas for communities
Miscellaneous		Private garages, pseudo-physical structures (tents, caravans, …), other structures, attic space, basement area, traffic areas

*At least two different types of usage are available in the building; table source [5]

The category “households” was divided into several classifications, due to the considerable differences within its energy demand. The table above shows the distribution according to the number of dwellings within the concerned building. The category “mixed use” states that there are two or more different forms of utilization within one building. The building category “miscellaneous” comprises the two buildings sectors of “further use”, like religious buildings, agricultural used buildings etc. and “miscellaneous”, e.g. pseudo-physical structures (tents, caravans…) etc.

Results

This section represents the analyzed building stock and the evaluated energy demand in the SINFONIA district.

Building Stock Analysis

In total, within the SINFONIA-district border, there are 4,489 buildings with a useable area of 4,464,603 m². This amount of buildings is the base for the following energetically baseline survey.

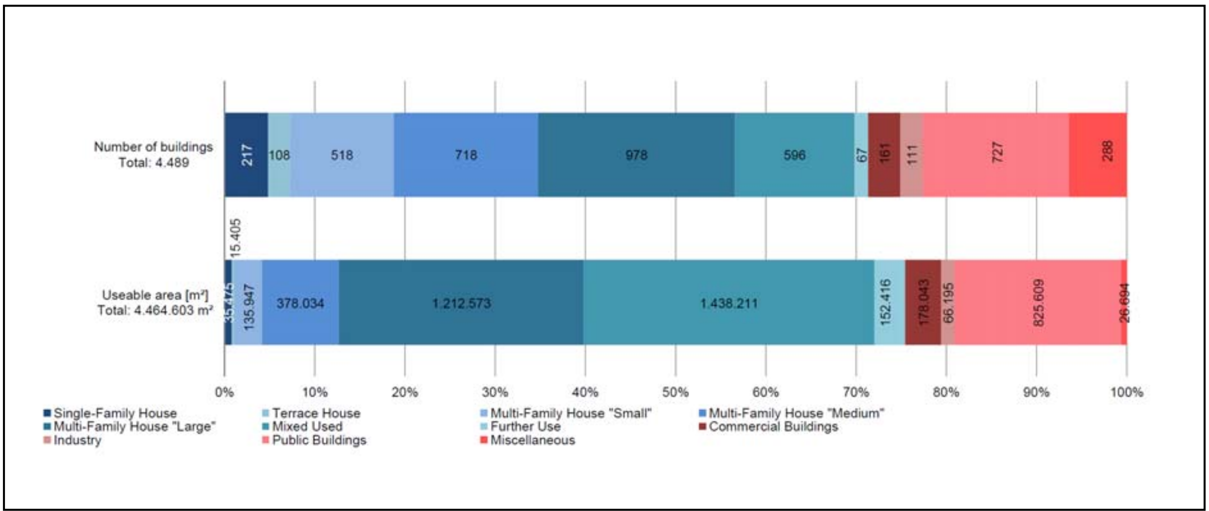

Figure 3 Number of buildings and useable area per category [5]

Figure 3 shows that the building sector “households”, with its five different sub-categories represents more than half of the buildings. Compared to the useable area, the building sector “households” covers about 40% of the total area. It is noticeable, that the building category “mixed categories” with 596 buildings represents a large percentage of the useable area. Within the SINFONIA district there are 31,603 households with – in total – 66,290 inhabitants. 86.7% of them are registered as permanent residents (primary residence). Compared to the living area per person of Austria (44.3 m²/ person) [15], the average specific useable area of 43 m²/ person of the SINFONIA district is similar.

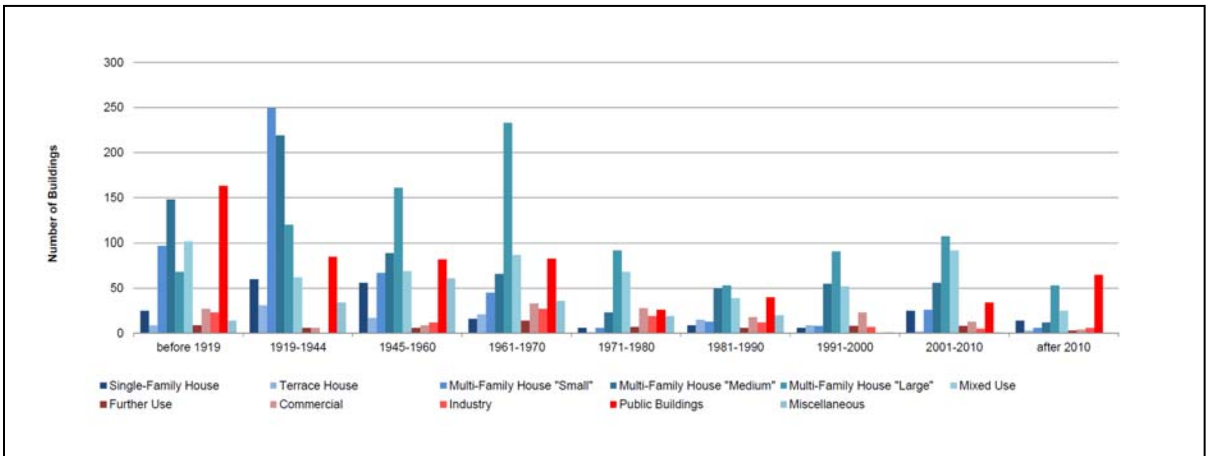

Figure 4 Building age per category [5]

Figure 4 shows the age structure of the buildings within the SINFONIA district. It can be seen that most of the small and medium multi-family houses were built in the interwar period from 1920 until 1944. Before 1919, the building period was determined by the construction of public buildings and medium multi-family houses. After the Second World War, the construction boom decreased for the first time. The second significant decrease was after 1970. The construction of public buildings remained the same for almost three building periods (from 1920 until 1970) before it decreased. The building period with the biggest construction boom was from 1920 until 1944. From 1961 until 1970 lots of large multi-family houses were built. Since 1971 the construction boom has been decreasing. The number of constructed medium multi-family houses constantly remained the same – apart from the 1980s. Worth mentioning is the increase in buildings with a mixed use within the period from 2001 until 2010.

Calculated and Calibrated Energy Demand of Residential Buildings

Figure 5 represents the calculated energy demands for space heating, domestic hot water and electricity for the residential buildings in the SINFONIA district.

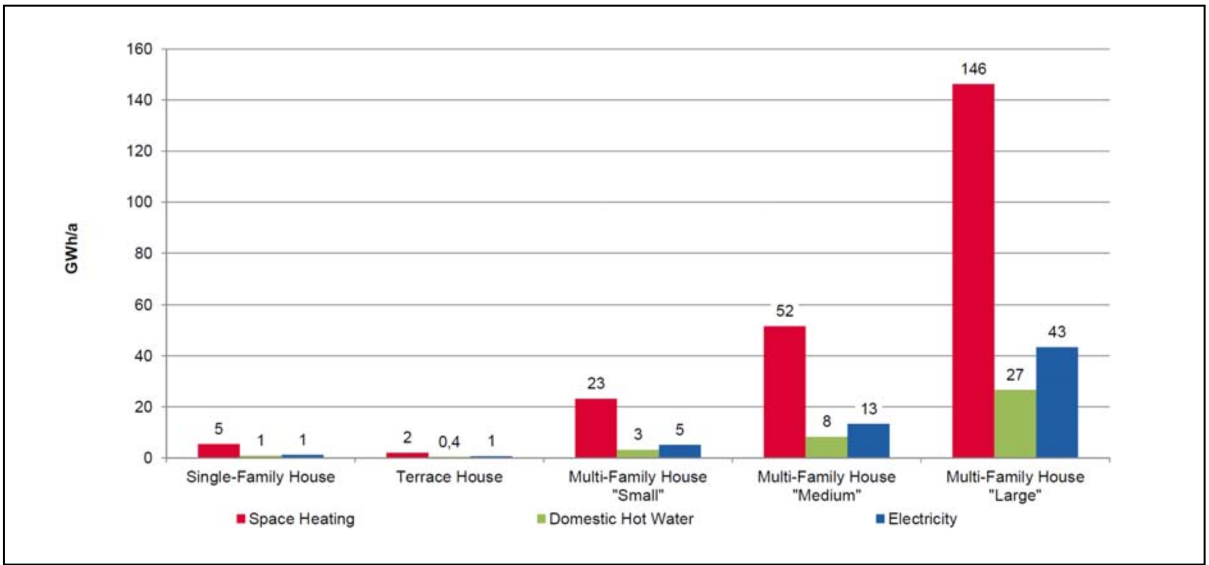

Figure 5 Calculated and calibrated energy demand of residential buildings [5]

Due to the building structure of the investigated region, the highest amount of energy is used by the "large" multi-family houses, which is specified as an apartment block with more than 10 dwellings. For this category, the total amount of buildings is 974 (figure 3) and the final energy demand is 215 GWh per year.

Specific Calculated and Calibrated Energy Demand of Residential Buildings

The following figure 6 shows the specific energy demand which is based on the heated useable area.

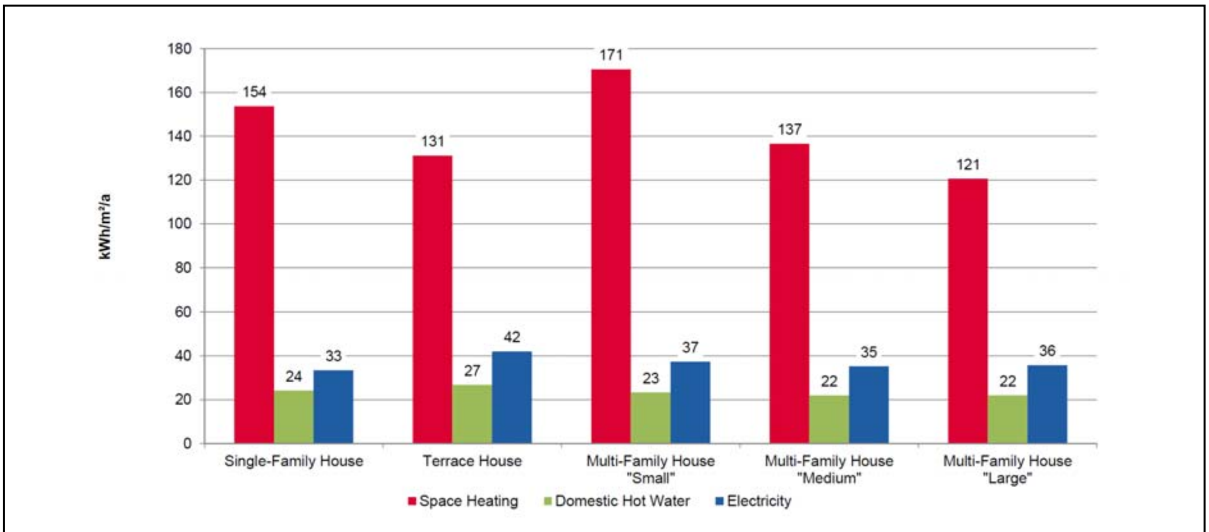

Figure 6 Specific calculated and calibrated energy demands of residential buildings [5]

In general, the specific energy demand decreases by the increase of the building size. Contrary to this approach, the diagram shows that the multi-family house “small” has the highest specific energy demand, which results from the age structure. Figure 4 shows that most “small” multi-family houses have been constructed in the period from 1919 until 1945.

Calculated Final Energy Demand of all Buildings

In addition to the residential buildings, the remaining building stock was calculated on different approaches. Table 3 shows the results of the final energy demand over the whole building stock.

Table 3 Final energy demand of all buildings

Category	**Final Energy Demand [GWh/a]**
Single-Family House	7
Terrace House	3
Multi-Family House “Small”	31
Multi-Family House “Medium”	73
Multi-Family House “Large”	216
Mixed Use	223
Commercial Buildings	71
Public Buildings	214
Industry	38
Further Use	33
TOTAL	**910**

Table source [5]

The table represents the final energy demand of all buildings in the SINFONIA district in GWh per year. The final energy demand contains the heat and electricity demand of each building type. The calculated results of the residential building stock were provided from the EneRAlp tool. The tool provides additionally partly the results for the mixed used, commercial and public buildings. The energy demand of the unknown units of these categories was specified with the average energy demand of the respective category by the useable area. Additionally, the electricity demand was verified with the IKB electricity consumption data 2014. The electricity consumption data were also used for the categories “further use” and “industry”. Due to missing information of the heat energy demand for the “further use”, the heat energy demand was estimated with the average overall of the heat energy demand (171 kWh/m²/a). Similar to the “further use”, the heat energy demand for the “industry” was calculated with the average specific heat energy need of 376 kWh/m²/a. This specific energy parameter was taken from the Sattler Study Vorarlberg [16], which includes 65 different industrial companies. The verification of the estimated energy demand of the grid bounded energy carrier (electricity, gas) was successfully performed. It was not possible to verify the non-bounded energy carrier (e.g. oil and biomass) due to non-existing data. The estimation of the unknown units was not possible to review due to a lack of information. Finally, a total final energy demand of 910 [GWh/a] is estimated for the SINFONIA district.

GIS-based Energy Demand Map

For the categories single family house, terrace house, multi-family house small, multi-family house medium, multi-family house large, mixed use[10] and public building[10] a GIS-based energy demand map was created. Due to the data protection law and the framework contract with the energy

[10] calculated part of the buildings (known profile)

suppliers (TIGAS, IKB), the calculated and calibrated energy information from the building level was aggregated to the 100 x 100 meter raster level. Figure 7 and figure 8 show the calibrated heat (space heating and domestic hot water) and electricity demand.

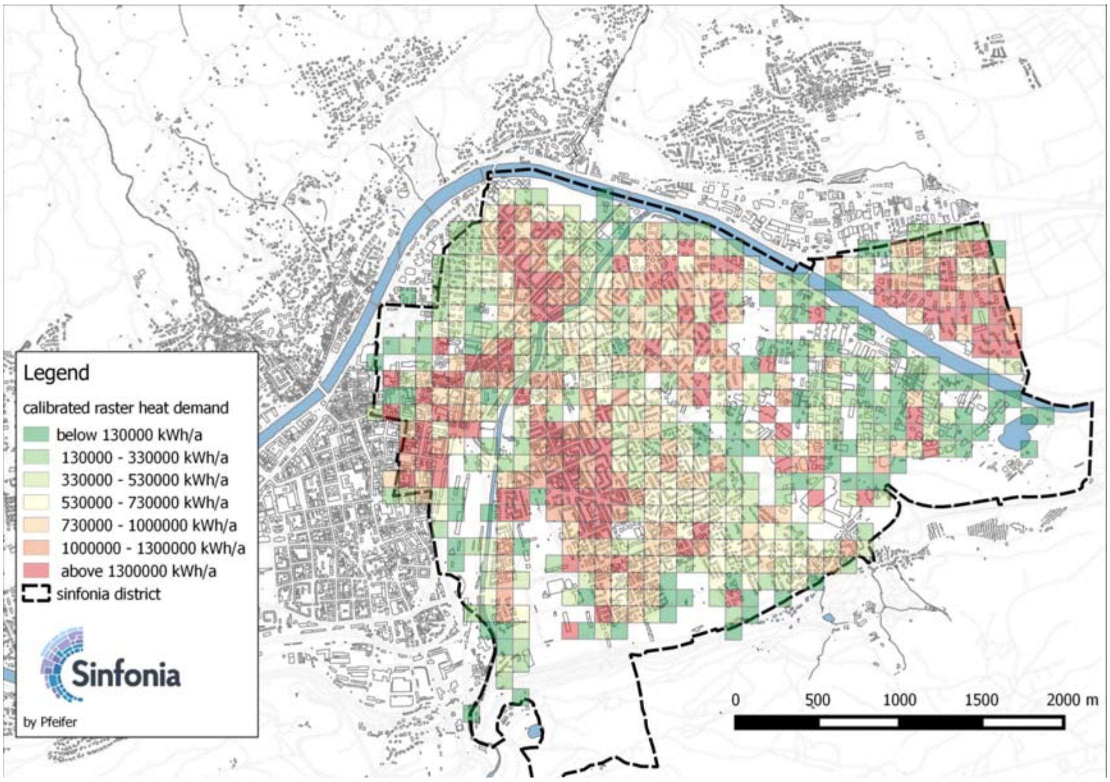

Figure 7 Heat demand of “residential”, “mixed use” and “public” buildings [5]

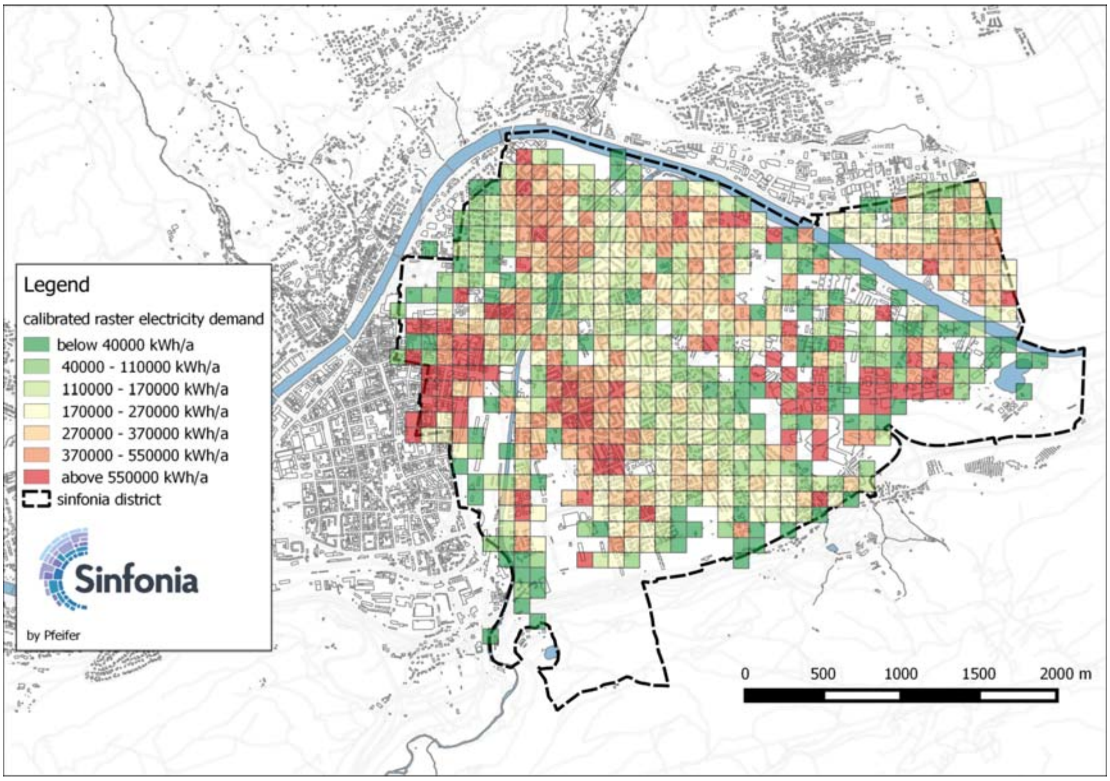

Figure 8 Electricity demand of “residential”, “mixed use” and “public” buildings [5]

Discussion and Conclusion

To evaluate the SINFONIA predefined goals and measures, it was necessary to build up on the GIS-based bottom-up approach. Based on the spatial analysis, measures can be localized and monitored during the whole project process. The major advantage of the GIS approach is the visualization of the different issues. For example it is very easy to check the basic datasets on their completeness. Discrepancies between data sets can be visualized, discussed and reworked with the data providers. The SINFONIA data pre-processing (four months), started a continuous data improvement process in the municipality Innsbruck. Even the energy suppliers built their information on GIS-based data sets which made it possible to aggregate the real energy consumption for the SINFONIA district.

Outcomes during the SINFONIA baseline establishment

It was important to start the data management process early enough in order to fulfill all data protection and data exchange laws. In Innsbruck, these discussions were very intense as data protection laws are rather strict and contracts had to be elaborated with all involved stakeholders to meet all legal requirements. Furthermore, the development of the secure server environment in accordance with the Austrian data protection law required additional resources.

The following main insights could be deduced during the adaption process to the SINFONIA district. Due to the variations of the data availability between the federal states Vorarlberg (Feldkirch[11]) and Tyrol (Innsbruck), no central database for the real energy certificates or for the chimney sweeper information (includes energy carrier, heating power) was existing. Other data differences were the independent GIS-based address database and the numbers of address per building polygon. For the real energy certificates it was necessary to collect every available certificate (246 certificates) of the different SINFONIA partners. The review of this energy certificate demonstrated that the successful implementation of the certificates was complicated. More than one address per certificate, different address spellings and various certificate generations made an implementation and evaluation for the SINFONIA district difficult. For future investigations based on the energy certificates, it is recommended to the federal state Tyrol to implement the final designed energy certificate database of the statistic Austria [17] in Tyrol. The advantage of this database is the direct link to the address information of the AGWR. A merger of the chimney sweeper database with the energy certificate database would be reasonable. With this adaptation, synergies of the different databases could be used, for example the information of energy carriers. The verification of the independent address database showed, that the GIS-based address coordinates match the building polygons better than the coordinates of the AGWR. Therefore, a coordinate update method for each building was implemented in the adjustment methods. In contrast to Tyrol, in Vorarlberg the GIS-based address database is already equalized with the AGWR coordinates and the number of the addresses per building polygon is not more than one. For the numbers of addresses per building polygon, an additional method to calculate the share value of each address per building polygon was necessary. This address share value of the building polygon was considered in the energy demand calculation. In the end, more adaptations were necessary than expected at the beginning of the project.

After the data adaption and the implementation to the local circumstances, the model calibration was performed. The calibration factors evaluation for the calculated energy demand showed a similar trend as in Feldkirch: The calculated heat demand of new buildings corresponded to the heat consumption. In contrast, the calculated heat energy demand of old buildings was overrated (as expected). In general, the calculated electricity demand of the model was underrated. For the final energy demand calculation it was a challenge to represent the entire building stock. It was therefore necessary to differentiate between the calculated building units (covered by the EneRAlp tool) and the unknown building units. For the unknown units, the verification of the estimation was difficult due to the lack of information.

[11] first investigation city of the "EneRAlp" tool

Future evaluation of the predefined goals and measures in the SINFONIA district

As already mentioned at the beginning of this paper, it is essential to evaluate the predefined goals and measures in the SINFONIA district in the future. In order to use the same correction values, it is a requirement to use the same data basis and calculation method. Consequently, the underlying model can be calibrated the same way so that the results are comparable. The calculation method has to be the same in order to compare the results from the beginning and from the end. If, in the future, the model will be changed, also the baseline has to be recalculated and recalibrated with the new model. Otherwise different results will be obtained.

Outlook

The municipality of Innsbruck decided to expand the SINFONIA baseline evaluation to the entire city. Therefore, the following three main issues should be investigated:

- chimney sweeper database
- expansion of information
- further development of calibration factors

The chimney sweeper database was not available for the SINFONIA baseline establishment. The actuality and completeness of the AGWR-based energy carrier´s information should be improved through the integration of the chimney sweeper database. The information for the industry and partly for the commercial units should be expanded with the commercial database of the federal state Tyrol. With the extension of the baseline, the sample for the statistical evaluation of the calibration factors increases. This means that further investigation on additional building characteristics can improve the calibration process for the baseline calculation.

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Session Cities III

Building Stock Modelling - A novel instrument for urban energy planning in the context of climate change

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Abstract

Cities and their building stock represent one of the largest energy consumer groups and emitters of greenhouse gases (GHG). The urban building stock, including commercial buildings, offers a large and mostly untapped potential for energy efficiency improvement and GHG mitigation. Urban development, building stock alterations, and building technology measures therefore play a major role in setting the framework to exploit these potentials. A way to describe possible building stock development pathways is through building stock modelling. Although there have been many different bottom-up approaches that model energy demand and GHG emissions as well as other aspects of urban development, they have not been fully integrated and are not giving community energy planners, urban planners and decision makers enough information to influence the development in specific areas and technological fields. The building stock model presented in this paper gives the possibility to model energy supply and demand of both the residential and non-residential building stock at the scale of individual buildings, taking into account both heating and cooling demand (and other energy services) of buildings of various types and age classes. The model allows for tapping into spatially differentiated potentials and to balance demand and supply and renewable energy source (RES) potentials at a local scale (typically small-scale neighbourhoods and hectares) to guide the planning and development of sustainable cities. It is shown that commercial buildings in particular play a key role in initiating thermal energy network approaches (e.g. local low-temperature networks).

Furthermore, the possibility to connect with other models e.g. through the Smart Urban Adapt (SUA) modelling platform, makes it possible to run a fully integrated, bottom-up simulation of different urban development scenarios and their impact on energy demand and GHG emissions taking into account all aspects of urban development. The SUA modelling platform provides a highly integrated model, taking into account energy, land use and urban design, in order to investigate the socio-economic drivers of energy consumption.

The results of a concrete case study revealed the benefit of integrating energy efficient commercial buildings with district energy systems that allow for tapping local potentials of renewable energy sources, for both heating and cooling.

Introduction

In European countries, the residential and commercial building stock account for around 40% of final energy demand and GHG emissions. In order to tackle these issues, both the European Union and Switzerland are implementing increasingly strict efficiency standards for new as well as existing buildings [1, 2] and have set ambitious reduction targets. The recent Paris Agreement to curb GHG emissions in order to limit global warming to a global average temperature increase well below 2°C further stresses the need to reduce GHG emissions, especially from buildings. The urban building stock, including commercial buildings, offers a large and mostly untapped potential for energy efficiency improvement and greenhouse gas mitigation. Urban development, building stock alterations, and building technology measures therefore play a major role in setting the framework to exploit these potentials.

Building stock models (BSM) offer a way to evaluate different pathways for the GHG emissions and energy demand reduction of a building stock of a city. Recent developments in building stock modeling focus on methodologies which simulate the energy demand and GHG emissions bottom-up [3]. There have been various bottom-up approaches that model energy demand and GHG as well as other aspects of urban development (see [3] and [4] for an overview), they have however not been fully integrated. Especially, [4] highlights recent advancements in BSM in describing the building stock more and more detailed. However, most BSM focus on describing the status quo and are limited in regard of the scenarios they are modelling. Therefore, they can describe general development pathways but do not give community energy planners, urban planners and decision makers enough information to influence the development in specific areas and technological fields.

The BSM presented in this paper gives the possibility to model energy supply and demand of both the residential and non-residential building stock at an individual building scale, taking into account heating but also cooling demand (and other energy services) of commercial and public buildings of various types and age classes. The model allows for tapping into spatially differentiated potentials and to balance demand and supply and renewable energy source (RES) potentials at a local scale (typically small-scale neighbourhoods and hectares) to guide the planning and development of sustainable cities and districts. The approach to a combined modeling of both heating and cooling demand described in this paper adds a new dimension to building stock modeling in that it enables the planning of traditional district heating networks or local low-temperature energy networks that combining heating and cooling systems across buildings.

Method

Model structure

In order to adequately address the information demands of urban planners and decision makers and to also take into account information at the local scale, we further develop the BSM proposed in [5, 6], which works at the building scale (Figure 1). The model, therefore, can deliver detailed results as well as take into account building specific information (such as building geometry or building usage) and local potentials for RES. Apart from conventional RES for heating such as heat pumps, solar thermal collectors or district heating, the model calculates heating as well as cooling demand respectively, which makes it possible to match local heating demand with available exhaust heat from datacenters, commercial spaces or other sources.

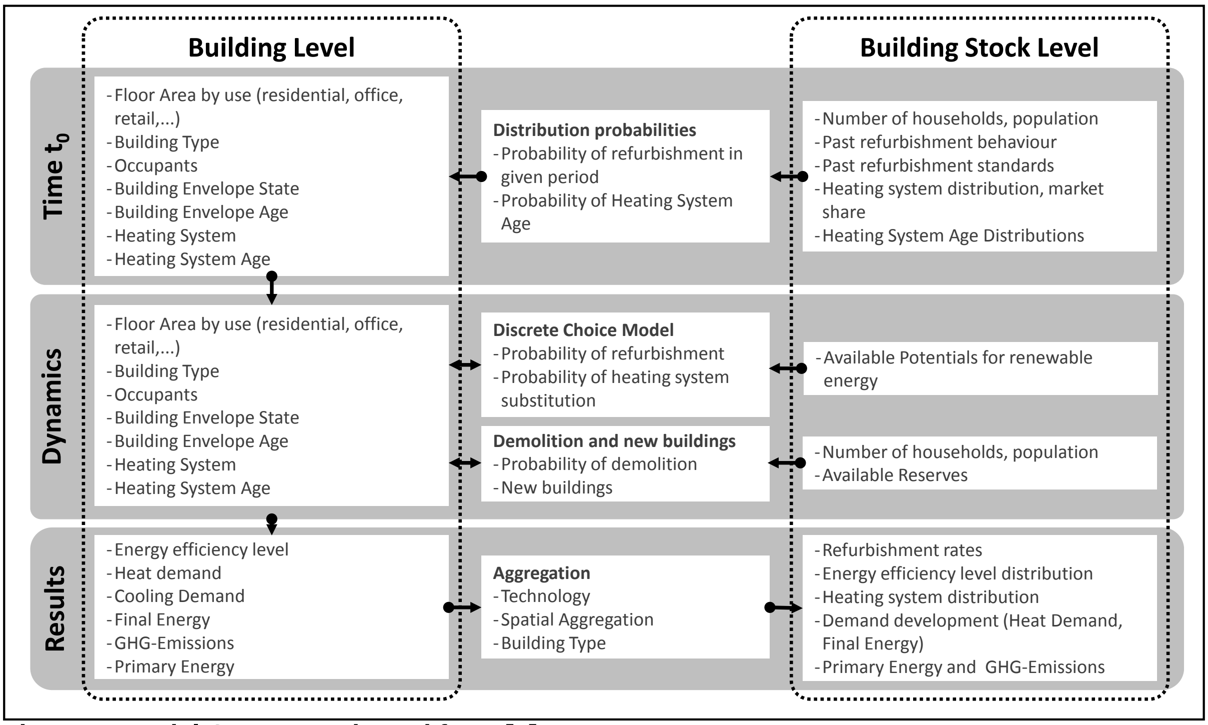

Figure 1: Model Concept, adapted from [5]

Building stock inventory

The initial inventory of buildings is based on the building registery of the city of Zürich [7]. This data is complemented with building geometry data from the 3D model of the city. Data gaps are filled with data from energy utilities, statistical data and assumptions at the building stock level.

The building stock development is described in three different parts; demolition and replacement, new construction, and refurbishment. Demolition is calculated based on statistical analysis of past demolition and a fitted survival function (see [5]) taking into account the area and building age. Protected buildings are excluded since they likely will not be torn down. The volume and geometry of the replacement building is then determined based on the available reserves according to the zoning law of the parcel of land in question. On unoccupied parcels, new buildings are added to the stock based on a probabilistic function that is compatible to aggregate construction rates. Building geometry and volume are again determined based on the zoning law, which allows for selecting the most suitable parcels first. For the refurbishment of the remaining existing stock, the model applies a discrete choice model described in [3], in order to model building refurbishment and heating system substitution decisions.

The model was developed in such a way that it is also possible to connect it to the interactive modelling platform Smart Urban Adapt (SUA) [8]. The SUA platform enables the integration and exchange of different urban development models. Through SUA, the BSM can be fed with detailed model results on the demolition and new construction activities through further models, such as FaLC (a Land use model, which models the demand development for housing and commercial space) and REIM (a real-estate investment decision model, which models decisions for new construction and demolition).

Heating Demand

Thermal demand for space heating and warm water is modeled based on the Swiss norm sia 380/1 [9], which is equivalent to EN 13790, for each building individually based on geometries from the city 3D-model. The heating system is determined initially based on data from the building register which is updated with data from the energy utility. The heating system substitution and building refurbishment are then modeled based on the discrete choice model (see [3] for detailed description of the choice model). The model differentiates between spatial zones with different potentials for RES (availability of HPs, solar potential), which affects the heating system substitution model and adjusts the choice-set accordingly. Initial U-values are chosen by the model according to the construction period of the building. The model then decides on when (according to a hazard rate function) and to what extend (based on a discrete choice model) each building component is refurbished. The U-values for the initial state are based on common construction practice in the past and the current building standard [2] for new construction. The refurbishment choice differentiates between three different standards based on the current construction norm [9]. Figure 2 shows the U-Values for new construction and refurbishment which were implemented in the model.

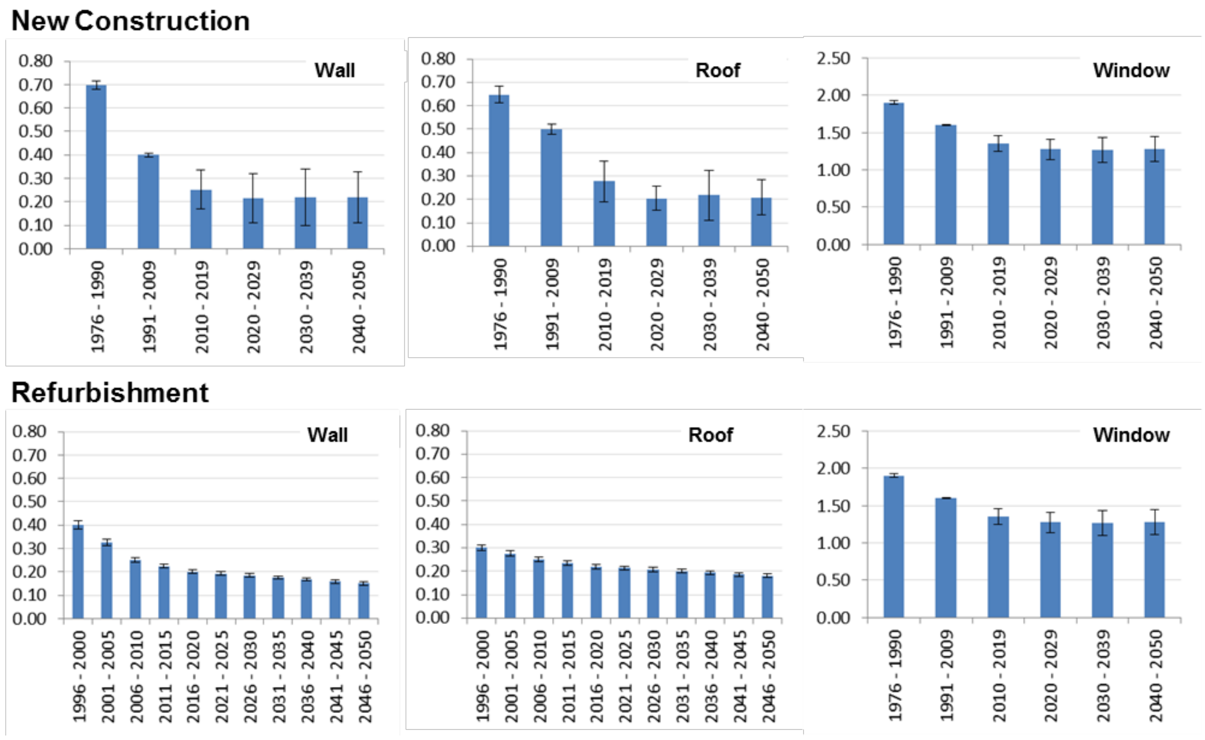

Figure 2: U-Values [W/m2/K] for the different building components and their distribution in the stock (Error bars) for the new construction and building refurbishment

Cooling Demand

Cooling demand calculation is divided into three categories (1) air conditioning (e.g. space cooling of offices, etc.), (2) commercial cooling (e.g. cooling demand from refrigerator cabinets in supermarkets) and (3) cooling of IT-equipment in datacenters. As these cooling demand categories entail different temperature levels and different demand drivers, varying modeling approaches were chosen.

Cooling demand for space cooling and air conditioning is based on three different factors; the energy reference area per building type (ERA), the diffusion rate of air conditioning units per building type (DR) and a building type and area specific cooling demand per reference area (Qc). The cooling demand of a building can then be calculated based on the following formula:

$$\text{Space Cooling Demand} = \text{ERA } [m^2] * \text{DR } [\%] * \text{Qc } [kWh_{th}/m^2] \quad (1)$$

Specific cooling demand (Qc) is specified based on expert interviews, literature, simulation results [10,11] and measurment results [12]. Qc is defined for office buildings, offices in other buildings, as well as retail buildings, whereas other building types were found to only very rarely have a cooling system installed and were therefore excluded in the case study.

Table 1 Specific space cooling demand according to building type in kWh_{th}/m^2

Building Type	1976 - 1990	1991 – 2009	>2010
Office – Finance & Insurance	80	70	60
Office – Administration / Other	60	50	40
Retail buildings	120	110	100

Commercial cooling demand was calculated in a way similar to the space cooling demand. The former is calculated for restaurants, hotels, retailers and wholesale. However, while the driver behind the space cooling demand is mainly the cooled floor area, the commercial cooling demand is determined based on the size of the company (in FTE – Fulltime equivalents) , the electricity demand for cooling per employee (E_{FTE}) and the efficiency of the cooling system (EER).

$$\text{Commercial Cooling Demand} = \text{FTE} * E_{FTE} * \text{EER} \quad (1)$$

Cooling demand of datacenters is not modeled by the BSM but directly included from data of the handful of large datacenters and spatially referenced to the datacenter location. Cooling demand for smaller server rooms are included via the space cooling demand.

Table 2 Specific commercial cooling demand according to Company type

Company Type	Electricity demand per employee (E_{FTE}) [MWh_{el}/FTE]	Efficiency of the cooling system (EER)
Wholesale	0.7	2.7
Retailers	1.7	3
Hotels	2.2	3
Restaurants	3.9	3

Results

The BSM described here was applied to a case study of the complete building stock of both residential and commercial buildings in a district of the city of Zürich. As the model uses building-specific, geo-referenced building data (from the building registry of Zurich [6]) results can be presented in maps as well as in graphs. Figure 3 shows the development of the energy reference area distributed over the city, the map clearly shows, that the new development of the city is mainly focused on the eastern and northern part of the city and that the historic core close to the lake will not increase significantly.

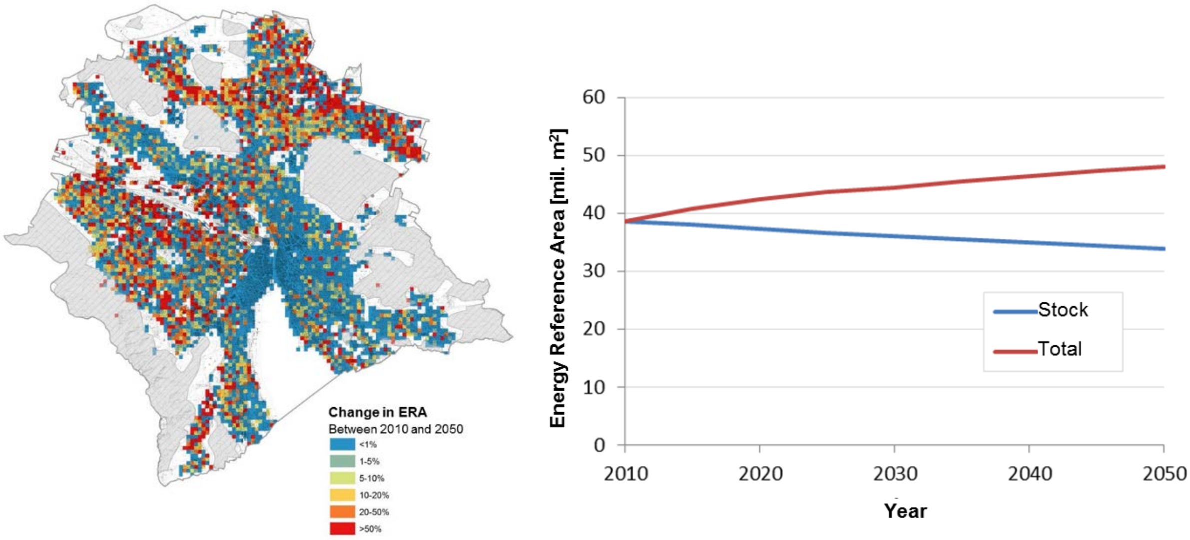

Figure 3 Development of the Energy Reference area

The distribution of the heat demand across Zürich in 2010 and its projection for 2050 is represented in Figure 4. In the scenario considered, it is apparent that areas with high heat demand are becoming less abundant alongside an overall general decrease in demand. Moreover, even though Figure 3 shows a significant increase of the building stock in the east and north of the city, this does not translate to a higher heating demand in 2050. On the contrary, the replacement of older with new and efficient buildings in combination with refurbishment of the rest of the stock, leads to a decrease of the total heat demand even in those areas. The highest heat demand will remain in the inner city in the historic core of the city, where mainly historically protected buildings are located, which are difficult to refurbish.

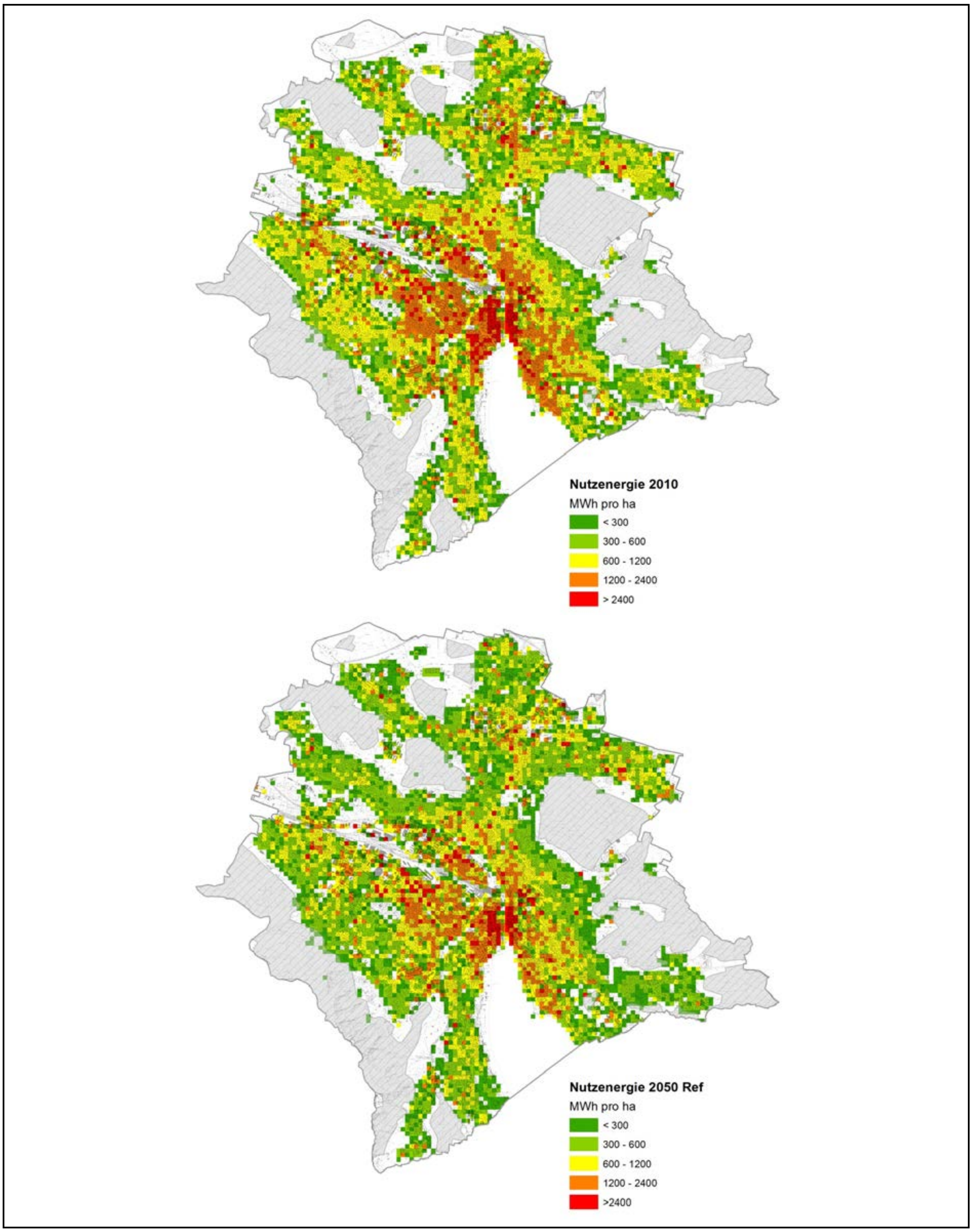

Figure 4 Heat demand development of the City of Zürich from 2010 (above) to 2050 (below)

The model results regarding heating demand were complemented with the implementation of the cooling demand module in the Zürich city district of Altstetten in the east of the city. The results in Figure 3 show that high heating demand areas also coincides with a high cooling demand. Such spots, mainly located in the historic nucleus of the district around the train station, would make ideal candidates for the implementation of local low-temperature combined heating and cooling networks.

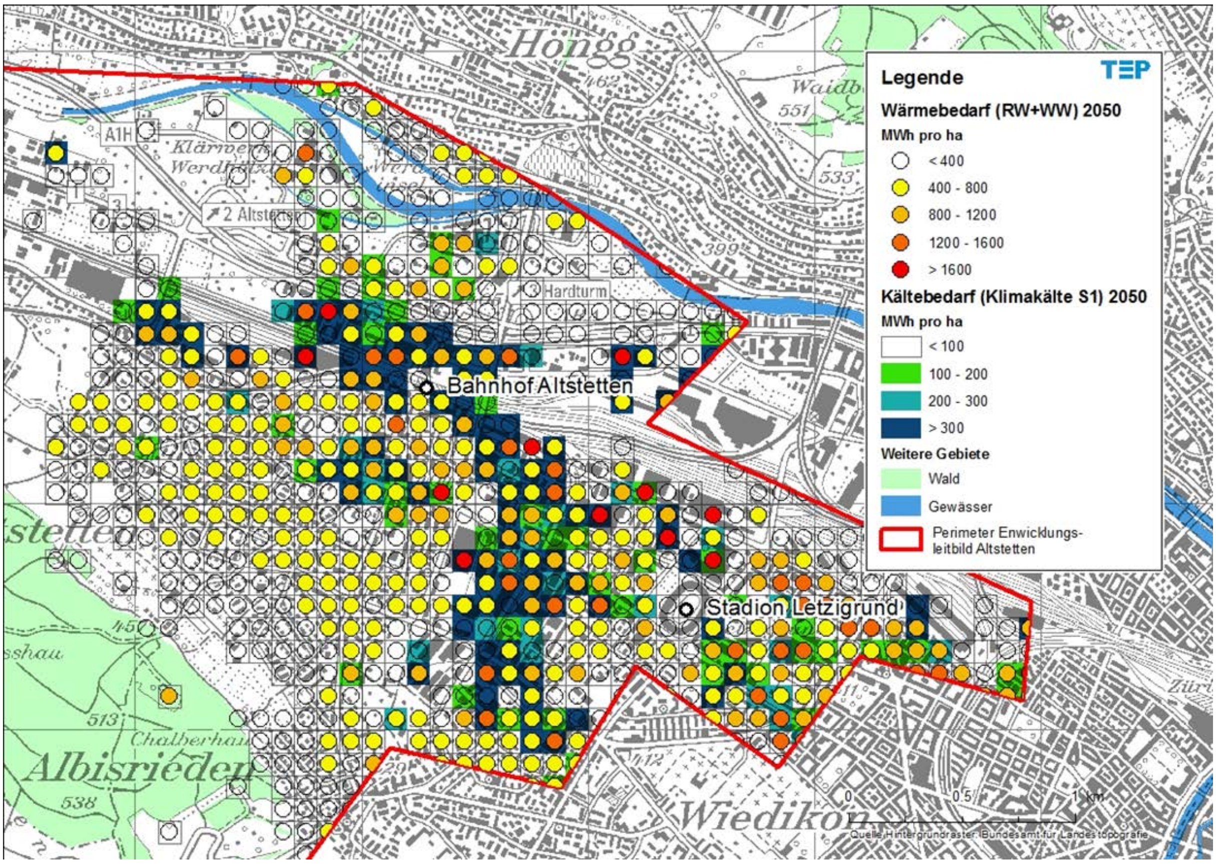

Figure 3 Heating (cyrcles) and cooling (squares) demand of the City of Zürich district Altstetten

Conclusion

The modeling approach described here for spatial, building-specific modeling of space heat and cooling demand offers energy planners and policy makers new insights into the building stock energy demand. Results from the model show both overall building stock level demand development as well as sufficient level of detail to be used in strategic urban energy planning. The results presented may be used both for the city to develop their overall energy strategy as well as by the municipal utilities for planning of energy networks (e.g. gas district or district heating extension as well as planning of local low temperature networks). This can be particularly useful toward the local spatial matching of heating and cooling demand, which is the foundation for planning low temperature energy networks such as those presented in [13; 6]. The transferability of the BSM to other cities is currently under investigation. Furthermore, the BSM is being extended to include not just heating and cooling demand but also other energy services as well as energy embodied in construction activities. The resulting model will allow the modelling of the complete energy demand and related environmental impact of a building stock during the entire lifecycle of the buildings. Moreover, through the integration in the modelling platform SUA, the model is able to integrate information form other models and model the urban development in even greater detail.

Acknowledgements

Results, underlying research and development summarized in this paper was predominantly enabled through data and financial contributions of the city of Zurich, own funding of TEP Energy and the Climate-KIC through the projects SUA and CREAM, which we gratefully acknowledge.

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Public-Private Partnerships in Microgrid Development

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At the COP21 Summit in December 2015, 195 nations committed to lowering GHG emissions and limiting global warming. Microgrids are an innovative technology to integrate renewable energy resources, reduce GHG emissions and improve resiliency against the adverse effects of climate change. However, individual stakeholders such as end-users, utilities, governments and Independent Power Producers (IPPs) are often unable to monetize and internalize sufficient benefits to justify the development cost of a Microgrid, which makes it necessary to partner up. This paper applies past research on Public-Private Partnerships (PPP) to Microgrid development. It finds that there are nine possible partnerships of public (government and utility) and private (end-user and IPP) stakeholders that can cooperate under various established PPP models, including service contracts, leases, Design-Build-Operate, concessions, Build-Operate-Transfer and Build-Own-Operate. Depending on the partner's preferred allocation of ownership, operation, investment and market risk, certain PPP models are more appropriate for each Microgrid in order to maximize internalized benefits and minimize complexity and transaction cost. The theoretic conclusions are validated with a case study of the Hunts Point Community Microgrid in the South Bronx of New York City. The case study demonstrates that a partnership between three or more stakeholders internalizes sufficient benefits to justify the total development cost and meet the sustainability and resiliency goals of the Microgrid.

1. Introduction

1.1 Relevance

At the COP21 Summit in December 2015, 195 nations committed to lowering GHG emissions to limit the adverse effects of climate change. In the US, the generation, transmission and distribution of electricity accounted for 31% of total GHG emissions in 2013, making the electricity sector the largest contributor to climate change. To limit global warming, both developed and developing nations must increase their share of renewable energy resources such as solar Photovoltaics, wind and hydro power. However, these intermittent resources alone cannot provide a stable energy supply and depend on other distributed energy resources (DER) to ensure stability, efficiency and resiliency.

Microgrids ("groups of interconnected loads and DER within clearly defined electrical boundaries […] that can connect and disconnect from the grid" [17]), are an innovative technology that integrates renewable energy resources into electrical distribution systems while providing additional benefits to public and private stakeholders [1]. Public benefits include improved resiliency, energy efficiency, and offset investment cost, while private customers benefit from reduced energy costs, improved system reliability and higher power quality [2,3]. However, integration of renewable energies and many other public benefits are difficult to monetize and compensate. Furthermore, the availability of financing sources and the ability to mitigate risks depends on the type of Microgrid owner [4,5]. As a result, ownership will have a "direct bearing on the decision to invest" [2].

PPPs ("arrangements whereby private parties participate in, or provide support for, the provision of infrastructure") [6] are a well-known approach to share ownership in infrastructure development with both public and private benefits [7]. Considerable research has been conducted regarding PPP ownership models. These lessons could potentially be applied in Microgrid development to help internalize more public and private benefits and thereby improve the viability of Microgrids [8].

1.2 State of Research

The research on Microgrids has traditionally focused on technical aspects, such as the optimal design, generation sources, capacities, controls and communication within Microgrids [9–11]. A critical factor in Microgrid design is the economic feasibility under uncertainty of cost and returns [12,13]. More and more research is focusing not just on returns, but also on the benefits of Microgrids to a variety of stakeholders. A methodological approach for Benefit-Cost-Analyses (BCA) of smart grids has been developed by the Electric Power Research Institute (EPRI) [4], who build on previous research and propose four categories of benefits: Economic, Reliability and Power Quality (RPQ), Environmental and Security and Safety. The proposed BCA is a ten-step approach that includes characterizing the project elements, function and characteristics, estimating and quantifying the benefits and comparing them to the associated costs. The New York State Energy Research and Development Authority (NYSERDA) finds that benefits and costs are not always incurred to the same stakeholders, and that ownership will have a “direct bearing on the decision to invest” [2]. Building on this research, Morris et al [1] developed a framework for the evaluation of costs and benefits of Microgrids, using functions to assign specific Microgrid benefits to various stakeholders. Based on the finding that “the division of benefits depends on the ownership model”, Morris et al [5] analyze different business models that aim to monetize these benefits by providing them as paid services to the other stakeholders. DNV KEMA [3] summarizes the characteristics, benefits and challenges of utility, single user, multi-user and hybrid Microgrids in Massachusetts, finding that the latter category “combines the best aspects of Distribution Company and private ownership”. Navgiant [14] and [15] analyzes various Microgrid case studies in New York State and concludes that not all benefit streams can be monetized and that “asset ownership has a significant impact on business model viability”.

1.3 Research Thesis and Questions

The previous research mentioned above indicates that Microgrid development is limited by the benefits an owner is able to internalize, as many benefit streams to other stakeholders cannot be monetized and compensated. This problem may be solved by sharing ownership between public and private stakeholders so that each party can contribute to and benefit from the Microgrid development. Public-Private Partnerships (PPPs) are a well-researched method to share ownership and benefits in the development of infrastructure. Therefore, the following research thesis is formulated:

“Microgrids could provide more benefits if more public and private stakeholders could internalize benefits by sharing ownership in Public-Private Partnership models.”

To validate this thesis, this paper addresses the following research questions:

1) What are the benefits of Microgrids and how do they relate to Microgrid ownership?
2) What is the current state of research on PPP ownership models?
3) How can PPP models be applied in Microgrid infrastructure projects?
4) How do different PPP models influence the stakeholder benefits in Microgrid development?
5) Can these findings be empirically validated in a case study of the Hunts Point Microgrid?

1.4 Methodology

The second chapter summarizes the concept of Microgrids. After establishing a common definition, the existing microgrid typologies are discussed. These are associated with different categories of benefits for public and private stakeholders, which are sometimes difficult to monetize and compensate. The difficult monetization of these benefits results in challenges to project viability depending on Microgrid ownership, which may be overcome through joint ownership in PPPs.

Therefore, in the third chapter, the principles of PPPs are presented. Comparing various definitions, the common characteristics of PPP infrastructure projects are formulated. The research findings on PPP ownership models are then summarized and discussed.

The fourth chapter addresses the application of these lessons in Microgrid development. First, it analyzes the applicability of the PPP approach to Microgrids based on common PPP infrastructure project characteristics. Second, it categorizes the public and private stakeholders in Microgrid development. Third, it discusses how the PPP models could be adapted to these stakeholders in order to better internalize the public and private benefits of Microgrids.

The fourth chapter summarizes the case study of the Hunts Point Community Microgrid and identifies stakeholders, development costs and benefits. After discussing applicable PPP models, the monetization of benefits in these models and the impact on project viability are being discussed.

The final chapter summarizes the findings and discusses the limitations and implications for research and practice. An outlook indicates the need for further research and anticipated developments in PPP Microgrid development.

2. Microgrids

2.1 Definition

The concept of a Microgrid is not entirely new, since small grids dominated the early electric power industry in the United States from 1880 to 1910 [16]. Small steam engines served just a few blocks, generated DC power but were very unreliable. Reliability was ultimately improved by connecting with other generators, but that was difficult at first due to little standardization in power frequency, synchronization and protection. In the 1960s, the development of generally accepted standards, larger generators with better economies of scale, more efficient and reliable transmission technology and public policy eventually led to a centralized grid that soon covered 95% of all electricity sold in the United States. More recently, however, the increasing interest in distributed generation, sustainable energy resources, power quality and reliability and public policy revived the concept of Microgrids.

Today, there is still no common definition of Microgrids. NYSERDA [17] and the US Department of Energy define a Microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity which can connect and disconnect from the surrounding utility grid and operate in both grid-connected or island mode”. Likewise, EPRI [16] defines a Microgrid as “a power system with distributed resources serving one or more customers that can operate as an independent electrical island from the bulk power system”. DNV KEMA [3] uses a more detailed definition with four characteristics: “A power distribution network comprising multiple electric loads and distributed energy resources, characterized by all of the following:

1. The ability to operate independently or in conjunction with a macro grid;
2. One or more points of common coupling (PCC) to the macro grid;
3. The ability to operate all DER, including load and energy storage components, in a controlled and coordinated fashion, either while connected to the macro grid or operating independently.
4. The ability to interact with the macro grid in real time, and thereby optimize system performance and operational savings.”

All of these definitions have in common that a Microgrid is “a group of interconnected loads and distributed energy resources (DER) that acts as a single controllable entity and can connect and disconnect from the grid”. Based on this definition, electrical networks that are always connected to the electrical grid or always operate as a grid island are not considered Microgrids for the purpose of this paper. Likewise, electrical systems that only serve one building are considered Nanogrids and not Microgrids.

2.2 Microgrid Typology

Microgrids that fall under the definition above can be categorized in various ways, including the type of distributed generation resources, the load size, the number of end users or the owner type. For the purpose of this paper, the categorization by Navigant [14] is utilized. Microgrids with one end user but several building loads are considered Campus Microgrids, while Microgrid with multiple end users are summarized as Community Microgrids. Within these categories, the Microgrids can be further differentiated by being owned by its end users, an independent third party, the government, the utility or a combination of these stakeholders, as illustrated in Figure 1:

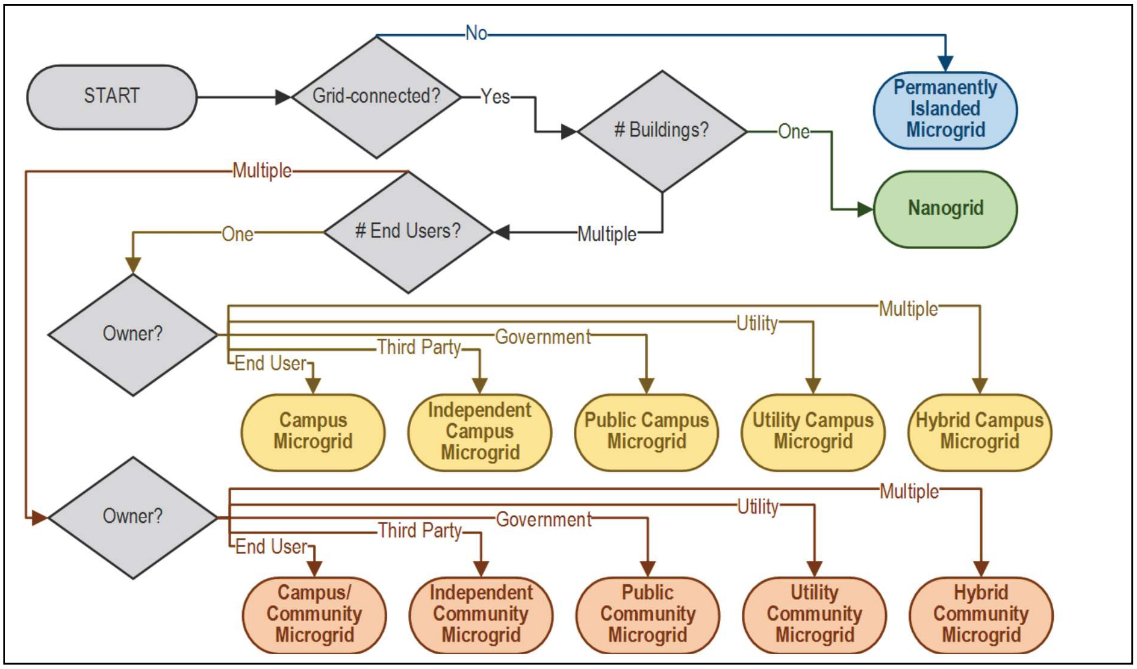

Figure 1: Microgrid Typology by Navigant [14]

2.3 Microgrid Stakeholders

The number of end users and the owner type have a large impact on the objective, design and operation of the Microgrid [4].

End-users are industrial, commercial or residential customers of electricity generated in the Microgrid, for which they pay electricity rates based on their energy consumption (kWh) or peak demand (kW) in a given time period. The maximum coincident demand determines the necessary capacity of the Microgrid and its generation and storage resources, while the total consumption influences the fuel usage and other operating costs. If end-users own the Microgrid, the objective is usually to reduce electricity costs and to improve the reliability and quality of their energy supply.

Third-party Microgrid owners, often referred to as **Independent Power Producers (IPP)** [1], can include private financiers interested in long-term investments, technology vendors looking to showcase their products, energy service providers with operating experience and various others. They are generally more interested in the risk-return profile of the Microgrid as an investment and the financial compensation for benefits by customers, utilities and the government.

Governments include various public agencies responsible for economic development, energy policy, emergency management, environmental protection, social welfare or owning public land. The interests in owning a Microgrid vary accordingly and generally include benefits for society as whole, including job creation, resiliency, sustainability, energy research and tax income.

Utilities are responsible for the transmission, distribution and/or generation of energy. Depending on the local policy, they may either be public agencies, regulated private companies or usually a combination of both. Utilities often have natural monopolies for the grid operation in a certain area, and therefore design and operate Microgrids to stabilize the electricity grid while reducing capital and operating costs.

Finally, Microgrids can be owned by a combination of these stakeholders for various reasons. For example, distribution utilities may, through regulation, be kept from owning generation equipment which is instead owned by end users or independent third parties. Stakeholders could also work together to share their experience and resources to be able to internalize all the public and private benefits a Microgrid provides.

2.4 Stakeholder Benefits

EPRI [4] defines benefits as “an impact […] that has a value to a firm, a household, or society in general”. They organize benefits into four categories: Economic, Reliability and Power Quality (RPQ), Environmental and Security and Safety. The same categories are adopted by NYSERDA [2] and DNV KEMA [3], who further differentiate direct and indirect economic benefits. Direct economic benefits include energy cost reductions, compensation for ancillary services (e.g. voltage and frequency control and black start capabilities) and generation capacity cost savings. Microgrids furthermore generate indirect economic benefits, such as reduced and deferred distribution cost, job creation and tax income. By operating in islanded mode and balancing loads and generation, Microgrids significantly improve the ROQ (mitigating voltage swells and sags, reducing distortion and unwanted harmonics etc.). Environmental benefits can be generated from higher efficiencies by utilizing waste heat in Combined Heat Power (CHP) systems and reducing GHG emissions and other pollutants. Finally, Microgrids can improve overall Security and Safety by providing safe havens for the community during regional power outages by operating independently from the macro grid in islanded mode.

These benefits can be allocated to the stakeholders discussed above in a Stakeholder-Benefit Matrix based on NYSERDA [17] and Morris et al. [1], as illustrated in Table 1.

	End-Users	**IPP**	**Utilities**	**Government**
Direct Economic Benefits				
Energy Cost Reduction	**X**			
Ancillary Services		**X**		
Generation Capacity Cost Savings			**X**	
Indirect Economic Benefits				
Distribution Capacity Cost Savings			**X**	
Job Creation/Tax Income				**X**
Reliability and Power Quality				
Improved Reliability	**X**			
Improved Power Quality	**X**	**X**		
Environmental Benefits				
CHP Fuel Savings		**X**	**X**	
Reduced (GHG) Emissions			**X**	**X**
Security and Safety Benefits				
Safe Haven During Outages	**X**			**X**

Table 1: Microgrid Benefits based on NYSERDA [17] and Morris et al. [1]

2.5 Monetization and Challenges

The stakeholders will design, develop and operate Microgrids so that they can internalize most of the benefits associated with them. User-owned Microgrids will be focused on “the opportunity to improve electric reliability and reduce or control the direct energy costs to participants” [2]. Utility-owned Microgrids might provide some of these benefits to their customers, but they will tend to have a larger focus on reliability and power quality for certain customers, ancillary services and demand response, reduced line losses and deferred capital investments. Government-owned Microgrids will put more emphasis on environmental and societal benefits. Finally, IPP-owned Microgrids will mostly provide benefits that generate revenues through negotiated Power-Purchase-Agreements (PPA) with electricity customers or ancillary and demand response services to the utility.

Each of these Microgrids might also generate benefits to other stakeholders and will seek compensation from these parties. However, “depending on the ownership model, only certain benefit streams may be monetized” [15]. For example, the immature markets for emissions credits make it difficult for non-utility Microgrids to capture the environmental value stream from emission reductions, resulting in uncompensated social benefits. Likewise, benefits provided to the interconnected utility grid, such as deferred capital expenditures or improved reliability, cannot be adequately monetized unless the Microgrid is owned by the utility itself [2].

This creates two major problems: First, Microgrid owners may choose not to provide all of the benefits they could theoretically generate, as they are missing a financial incentive to justify the additional costs. For example, Microgrid developers could choose to invest in a cogeneration technology that has lower GHG-emissions, but without financial compensation, they may decide to rather invest in a cheaper model that barely meets the current emission limits. Secondly, some Microgrids may not be built at all if the internalized benefits are not sufficient to make the project feasible without compensation for the benefits it could potentially provide to other stakeholders. For example, a Microgrid may have the potential to significantly improve the resiliency and sustainability of an area, but due to lack of subsidies for this shared public benefit, the private Microgrid developer does not have a business case to make the investment work financially.

As a result, it can be assumed that many beneficial Microgrids do not reach their full potential or are not built in the first place. There are various efforts to compensate selected benefits (e.g. compensation for ancillary services and demand response or financial subsidies for emission reductions and resiliency projects), but some benefits simply cannot be monetized adequately. As an alternative, it may therefore be worth considering to include all stakeholders in the development of the Microgrid. This would first incentivize each stakeholder to contribute his experience and resources and secondly allow each stakeholder to internalize the benefits the Microgrid provides. The hybrid Microgrids discussed above are a first step in this direction. But a true cooperation between all stakeholders is much more complex and should be based on prior experiences and research. Fortunately, there are various examples of stakeholder cooperation in complex infrastructure projects based on decades of research: PPPs.

3. Public-Private Partnerships

3.1 Definition

There is no commonly accepted definition of PPP, but often they are defined as “arrangements whereby private parties participate in, or provide support for, the provision of infrastructure” [6]. With these arrangements, the parties share “the skills and assets of each sector (public and private)” as well as “the risks and rewards potential in the delivery of a service and/or a facility” [18]. The term Private Finance Initiative (PFI) as a major type of PPP in the UK is often used interchangeably [19].

PPPs are used to realize public infrastructure and services more effectively and efficiently than under conventional procurement by allocating risks and optimizing the life cycle of planning, construction, financing, operation maintenance and liquidation [20]. The main objective is to improve value for money (VFM) through optimized “risk transfer, the long-term nature of contracts […], the use of an output specification, competition, performance measurements and incentives [and] private sector management skills” [21]. Positive impacts from PPP infrastructure provision are reduced costs, higher value for money, faster completion and an improved risk profile [22], while negative impacts arise from possible inexperience with PPP and higher participation cost and time for participants [23,24].

3.2 Project Characteristics

As indicated by the definition above, PPPs are generally characterized by an enduring partnership between public and private parties that share their resources, responsibilities and risks in order to provide public infrastructure and services [6]. Peter [25] identified five defining characteristics of this partnership:

1. The partnership involves two or more actors. At least one of these actors is a public entity and one is from the private sector.
2. Each participant is a principal with full negotiation authority and the ability to enter into binding agreements.
3. The partners establish an enduring and stable relationship with previously negotiated terms. This excludes any one-off or repeated transactions between public and private parties.
4. Each participant contributes material and immaterial resources (money, materials, knowledge, labor, authority) to the partnership.
5. The partners share the responsibility, the risks and the benefits from the project.

The second set of characteristics relates to the definition of public infrastructure and services that PPPs are used for. Grimsey and Lewis [26] specify that PPP may take the form of “construction or management of public sector infrastructure facilities by the private sector entity, or the provision of services (using infrastructure facilities) by the private sector entity to the community on behalf of a public sector body". Infrastructure projects can be divided into economic projects such as road, rail, bridges, airports, energy and telecommunication facilities as well as into social infrastructure such as hospitals, schools, prisons, water supply and sewerage [27]. Infrastructure projects share characteristics with other fixed investments, such as their duration, illiquidity, capital intensity and valuation, but they have to be provided or regulated by the public due to a number of inherent characteristics [26]:

1. They provide network services that integrate economic activity.
2. They offer public goods that are characterized by non-rivalry and non-excludability.
3. They generate positive and negative externalities to the public.
4. They are natural monopolies with economies of scale that only allow one provider.

PPPs are a modern approach to integrate the private sector in the provision of these services in order to benefit from higher efficiency, private competition, optimized risk allocation and private financing. Various PPP models have developed over time and in different countries that allow different degrees of private participation.

3.3 PPP Models

There are various forms of PPP models that differ with each country and project. As an attempt to categorize these models, Thomsen [28] differentiates common forms of PPP projects by the allocation of operation, ownership, investment and market risk as well as their average duration. He sorts these models by increasing private sector participation.

In **service contracts** for management, maintenance and operation, the private sector provides selected services for a fee while the public sector retains ownership, investment and market risk. These contracts are usually of short duration and the fees are based on negotiated performance criteria. In the case of maintenance contracts, the private partner may in some circumstances take responsibility and contribute financial funds. These service contracts are exclusively used for existing public facilities.

In **affermage/lease** arrangements, the private sector takes responsibility for existing facilities and personnel for a defined period of time, but does not assume ownership. Under a lease, the operator retains revenue collected from customers and pays a lease fee to the public partner, while in an affermage both partners share customer revenue [29]. Normally, the private party does not finance any new investments, unless the parties enter into a Lease-Develop-Operate (LDO) agreement [30].

In **Design-Build-Operate (DBO)** contracts, the ownership remains with the public sector, but the private party also provides design and construction services for new facilities before taking over operating responsibility and market risks. This model is intended to improve the efficiency and quality of new construction, as the private partner receives a combined fee for construction and operation. The public owner generally finances all investment cost, but in Design-Build-Operate-Maintain (DBOM) models, the private partner provides capital for maintenance-related improvements [30].

In a **concession**, the private operator is fully responsible for operation and investment of a new or existing facility during an extended period of time. The public sector retains full ownership and regulatory control over service terms and rates, but the private operator invoices customers directly and carries all market risks within the regulatory boundaries. The operator may either pay for the concession or receive a fee for the services provided.

In **Build-Operate-Transfer (BOT)** projects, the private partner owns a new facility during construction and a specified operating time before it is transferred to public ownership. During the operating period, he must generate sufficient revenues to service all debt and earn a return on investment before ownership reverts back to the public sector, which gains an operating facility without any investment. However, the public sector may pay a service fee or enter into a PPA or Bulk Supply Agreement (BSA) to compensate the private partner for public services. In an adaption of this approach, the Build-Own-Operate-Transfer (BOOT) model, the private partner has full legal ownership title, while in BOT the public partner retains some ownership interest and risk [31].

Finally, in **Buy-Build-Operate (BBO) and Build-Own-Operate (BOO)** projects, the private sector has full ownership and control of the facility and assumes almost all investment and market risks during design, construction and operation. In the first case, the public sector sells an existing facility to the private partner, who then rehabilitates and operates it indefinitely. In the second case, the private sector designs and builds a new facility and the public sector only purchases infrastructure services through a long-term agreement. This is the highest level of private participation in PPP before complete privatization, which does not constitute an enduring public-private relationship and therefore does not meet the criteria discussed above.

The PPP models are listed in Table 2, which is based on the original frameworks by Thomsen [28] and Benes and Stary [31].

<table>
<tr><th>Category</th><th>Model</th><th>O&M</th><th>Market Risk</th><th>Investor</th><th>Owner</th><th>Duration (years)</th></tr>
<tr><td rowspan="2">Service Contracts</td><td>Operation</td><td rowspan="11">Private</td><td rowspan="2">Public</td><td>Public</td><td rowspan="7">Public</td><td>1-2</td></tr>
<tr><td>Operation and Maintenance</td><td>‘Shared</td><td rowspan="2">3-5</td></tr>
<tr><td rowspan="2">Affermage/ Lease</td><td>Affermage/Lease</td><td rowspan="2">Shared</td><td>Public</td></tr>
<tr><td>Lease-Develop-Operate (LDO)</td><td>Shared</td><td>8-15</td></tr>
<tr><td rowspan="2">DBO</td><td>Design-Build-Operate (DBO)</td><td rowspan="7">Private</td><td>Public</td><td rowspan="7">20-30</td></tr>
<tr><td>Design-Build-Operate-Maintain (DBOM)</td><td>Shared</td></tr>
<tr><td>Concession</td><td>Concession</td><td rowspan="5">Private</td></tr>
<tr><td rowspan="2">BOT</td><td>Build-Operate-Transfer (BOT)</td><td rowspan="2">Private/ Public</td></tr>
<tr><td>Build-Own-Operate-Transfer (BOOT)</td></tr>
<tr><td rowspan="2">Private Ownership</td><td>Buy-Build-Operate (BBO)</td><td rowspan="2">Private</td></tr>
<tr><td>Build-Operate-Own (BOO)</td></tr>
</table>

Table 2: PPP Models based on Thomsen [28] and Benes and Stary [31]

4. PPP in Microgrid Development

4.1 Applicability

In order to apply PPP ownership models to Microgrid development, it is first necessary to determine if Microgrids are "public sector infrastructure facilities" [26]. Microgrids are without doubt fixed investments, as they consist of fixed generation, distribution, communication and control equipment that is capital-intensive, difficult to sell or valuate and therefore intended to remain in place for a long time. It is more controversial if Microgrids are also a public infrastructure facility, since many Microgrids are being developed without the involvement of the public sector. However, they can be considered part of the electric distribution network, which they partly replace or supplement, thereby providing network services that integrate economic activity. As any electric network, Microgrids are intended to be used exclusively by paying customers, but the generation capacity is calculated so that there is no rivalry for electricity by these customers. Furthermore, Microgrids generate public benefits (integration of renewable energies, energy resiliency for communities, reduction of GHG and other emissions) as well as potentially negative externalities (air and noise pollution, negative effects on the grid), which is why they are often publicly supervised and regulated. Finally, Microgrids depend on economies of scale by being the sole energy provider for an entire area (with backup of the grid). Installing several Microgrids in one place that compete for customers would make each of these Microgrids unprofitable. As they meet the criteria proposed by Grimsey/Lewis [26], Microgrids can be considered public infrastructure facilities.

4.2 Stakeholder Categorization

After establishing that Microgrids are indeed public infrastructure facilities, the next step is to determine who would be the public and private stakeholders that could establish an enduring relationship, in which each participant contributed resources and shares responsibility and risks [25].

As discussed above, Microgrids can be owned by end-users, IPPs, governments and utilities. Governments and their agencies belong without doubt to the public sector, while industrial, commercial and residential end-users are usually private. Exceptions are public universities, military bases and other public facilities, but in this case they share the same interests as private customers. IPPs generate a return on investment by generating electricity and providing paid services to public and private clients. Due to the profit-seeking nature of their business and their private ownership, they are considered a private stakeholder.

It remains controversial if utilities should be considered public or private. On the one hand, utilities are often privatized government-owned entities (which some consider a form of PPP by itself [31]). Furthermore, they are publicly regulated and serve a public purpose of providing electricity to customers in an area. On the other hand, utilities are now often owned by private shareholders with the purpose of generating profits with the generation and distribution of electricity as a product. Taking everything into consideration, utilities serve a public purpose of electricity provision (for profit or not), therefore they will be considered a semi-public entity for the purpose of this paper.

As a result, a Public-Private Partnership can either be established between the end-users/IPP and the utility/government. Partnerships only between a government agency and the utility or between the end-users and an IPP are not considered a PPP, since they do not include at least one public and one private actor. Since several public and private stakeholders can be involved on either side, this generates a matrix with nine possible combinations as illustrated in Table 3.

Public/Private	Utility	Government	Both
End-Users	Utility-User Microgrid	Government-User Microgrid	Government-Utility-User Microgrid
IPP	Utility-IPP Microgrid	Government-IPP Microgrid	Government-Utility-IPP Microgrid
Both	Utility-User-IPP Microgrid	Government-User-IPP Public Microgrid	Government-Utility-User-IPP Microgrid

Table 3: Microgrid Stakeholder Categorization

In order to form a PPP, all stakeholders must form an entity with full negotiation authority and the ability to enter into a binding agreement. IPPs usually form a consortium, in which they share ownership of a special entity and contribute their skills and resources, including construction, operation and financing. End-users may already belong to one entity, for example a university, or form a cooperative to build and operate the Microgrid. Utilities and governments often establish subsidiary companies to limit the financial exposure to the assets of this entity. In all cases, the public and private entity must contribute material and/or immaterial resources and share the risks and benefits of the Microgrid in order to establish a true PPP. This relationship is defined by the chosen Microgrid PPP model.

4.3 Microgrid PPP Models

Generally, any PPP model can potentially be chosen for a Microgrid development by negotiating the contract terms between the stakeholders to fit the intended purpose. However, some models are more appropriate for certain stakeholder combinations. IPPs will contribute experience in design, construction and operate, while end-users are more likely to take over long-term ownership of public assets. Utilities tend to have existing facilities or concessions that transfer to private operation, while governments often control land but lack operating experience.

Service contracts, affermages and leases are appropriate PPP models when the publicly-owned Microgrid infrastructure already exists and has been operated by the utility. This could be the case when a utility built a demonstration Microgrid to diversify its portfolio, but leases it to the end-users or contracts an experienced IPP to ensure efficient operation. The choice of model depends on whether the private party should take some market risks, provide own funds for maintenance and repairs and the intended duration of the partnership.

DBO models can be used for new Microgrid developments that are to remain in public ownership but are built and operated by a private party. These projects are often initiated by both the utility as concessionaire and the local government as land owner. IPPs could provide further experience and efficiency in construction and operation (DBO), while end-users with a long-term interest in the Microgrid could take responsibility for design, construction and operation and maintenance (DBOM).

Concessions can be given by the government to IPPs that provide financing, design, construction and operation, but are to be regulated in all key decisions by the government that maintains concession ownership. This would be a preferred model when the Microgrid customers are mostly residential and need to be protected from unjustified rate increases while not being able to own and operate the Microgrid themselves. As with DBO models, the duration of a concession is usually very long (20-30 years) to ensure a sufficient return for the private IPP.

BOT models are used when the government has the intention of developing a resilient Microgrid on public land, but has neither the funds nor the experience to build and operate it at the moment. As it might also be politically challenging to justify selling the land to a private party, the government instead allows it to build and operate the Microgrid with the condition that it reverts back to the public after a specified time period. The end-users with a long-term interest could take full ownership title during this period (BOOT), while a partnership with end-users and an IPP would require keeping stricter public control by retaining some ownership titles (BOT).

Finally, private ownership models such as BBO or BOO require the participation of both the end-users (to take long-term ownership) and an IPP (to ensure efficient operations). A BBO model would be appropriate if the utility has already put electrical infrastructure in the ground that will be bought by the private partners to save costs when developing and operating a Microgrid above ground. A BOO model would be suitable if the government currently owns the land and the utility has a concession for electricity distribution in the area, so a partnership between all parties is necessary to privately build, operate and own a Microgrid.

The PPP models most appropriate for each stakeholder combination are illustrated in Table 4:

Public/Private	**Utility**	**Government**	**Both**
End-Users	Affermage/Lease	BOOT	DBOM
IPP	O&M	Concession	DBO
Both	BBO	BOT	BOO

Table 4: Microgrid PPP Models

4.4 Stakeholder Benefits

In all the cases described in section 4.3, both public and private entities are involved in the ownership, construction or operation of a Microgrid. In this process, these stakeholders will attempt to generate the benefits they can monetize or internalize to make their involvement as profitable as possible. On the other hand, each party tries to avoid additional cost and risks from providing benefits they cannot monetize or internalize. Therefore, benefits are more likely to be provided in a Microgrid development if shared by several stakeholders. The resulting matrix in Table 5 illustrates that Microgrids several partners are likely to provide more benefits as these can be internalized by more stakeholders to make the development feasible. All four stakeholders are interested in improving resiliency and CHP fuel savings. However, while it is more likely that a Microgrid will be designed and operated to provide benefits to its stakeholders, the realization of these benefits depends on limiting additional complexity and transaction cost. Nevertheless, these partnerships can potentially help internalize benefits that cannot be monetized otherwise, and thereby make Microgrids more feasible and beneficial.

Partner	Utility	Government	Both
End-Users	Energy Cost Reduction Generation Cost Savings Distribution Cost Savings Improved Reliability Power Quality CHP Fuel Savings Reduced Emissions Safe Haven	Energy Cost Reduction Demand Response Job Creation Tax Income Improved Reliability Power Quality Reduced Emissions Safe Haven	Energy Cost Reduction Generation Cost Savings Distribution Cost Savings Job Creation Tax Income Improved Reliability Power Quality CHP Fuel Savings Reduced Emissions Safe Haven
IPP	Ancillary Services Generation Cost Savings Distribution Cost Savings Power Quality CHP Fuel Savings Reduced Emissions	Ancillary Services Job Creation Tax Income Power Quality CHP Fuel Savings Reduced Emissions Safe Haven	Ancillary Services Generation Cost Savings Job Creation Tax Income Power Quality CHP Fuel Savings Reduced Emissions Safe Haven
Both	Energy Cost Reduction Ancillary Services Generation Cost Savings Distribution Cost Savings Improved Reliability Power Quality CHP Fuel Savings Reduced Emissions Safe Haven	Energy Cost Reduction Ancillary Services Job Creation Tax Income Improved Reliability Power Quality CHP Fuel Savings Reduced Emissions Safe Haven	Energy Cost Reduction Ancillary Services Generation Cost Savings Distribution Cost Savings Job Creation Tax Income Improved Reliability Power Quality CHP Fuel Savings Reduced Emissions Safe Haven

Table 5: PPP Microgrid Benefits

5. Case Study: Hunts Point Community Microgrid

5.1 Project Summary

In 2015, the New York State Energy Research and Development Authority (NYSERDA) hosted the NY Prize Competition to support community Microgrid development. In the first stage, 83 applicants were awarded $100,000 to conduct studies on the feasibility, benefits and costs of proposed Microgrids. One of the projects that received funding is the Hunts Point Community Microgrid in New York City, which serves as a case study to demonstrate and discuss the findings of this paper.

The Hunts Point Food Distribution Center (FDC) in the South Bronx is one of the largest food distribution centers in the world. Three wholesale markets store, refrigerate and distribute 60% of New York City's meat, produce and fish, and are therefore considered critical facilities for the region's food security. The 329-acre site and the market buildings are owned by the City of New York (NYC) and administered by the NYC Economic Development Corporation (NYCEDC). The electricity and steam distribution utility at Hunts Point is Consolidated Edison, Inc (ConEd). The Hunts Point peninsula is home to a residential population of approximately 12,500 people with a median household family income of just $23,679 (2013 American Community Survey). Currently, neither the markets nor local refuge facilities have backup generation despite being partly located in a 100-year floodplain. Therefore, flooding or a regional power outage pose a considerable risk to the region's food supply and the local population.

A Microgrid at Hunts Point could help improve the resiliency, economic competitiveness and environmental sustainability of the Food Distribution Center and residential community. By generating electricity and steam on-site with diversified distributed energy resources (DER), the Microgrid could maintain power supply during a regional blackout. As the markets have significant refrigeration loads, a combined heat and power (CHP) facility with natural gas turbines could provide electricity and steam to drive central refrigeration chillers at the markets. The high efficiency of CHP and solar photovoltaics (PV) on the market rooftops could help reduce fuel consumption, GHG emissions and energy cost.

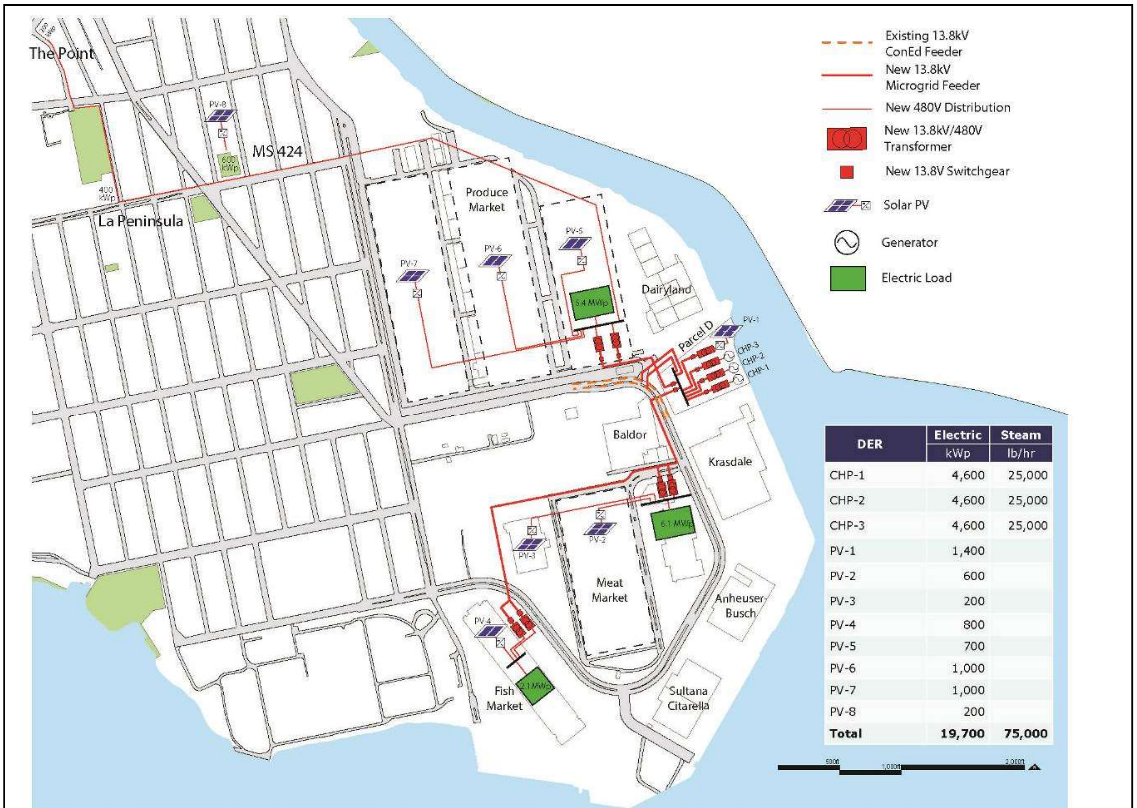

Figure 2: Hunts Point Community Microgrid

The proposed design in Figure 2 shows three 4.6 MW gas turbines, each generating 25,000 pound of steam per hour, that will be located on a currently undeveloped Parcel D in the Northeast of the Food Distribution Center. From a Point of Common Coupling at Parcel D, new 13.8 kV electrical feeders and steam pipes will serve the Produce, Meat and Fish Markets, where steam-driven chillers and electric chillers provide the required refrigeration load. Solar PV with a capacity of 5.8 MW will be installed on the market rooftops. A school and two community centers will be connected to the Microgrid via 480 V feeders and serve as refuge facilities during a regional power outage. The total development cost are estimated at $84 million. Annual operating and maintenance cost are $2.3 million, fuel expenses $4.7 million and emission damages $3.2 million. The total Microgrid development and operating cost over twenty years have a present value of $215 million at a discount rate of 7%.

5.**2 Stakeholders and Benefits**

The **end-users** of the Microgrid are the tenants of the three cooperative food markets as well as the three community refuge facilities. The main benefit of a Microgrid for these stakeholders is the substantial resiliency improvement through local generation, which protects revenues, inventory and jobs at the markets and provides a safe haven for the local population during a regional outage. Microgrid customers will also directly benefit from reduced energy cost thanks to the efficiency of CHP and solar PV. These cost savings will contribute to keeping Hunts Point a competitive location for the wholesale markets and their tenants. Finally, the control and communication equipment of the Microgrid could help reducing voltage and frequency problems of the utility grid and provide a better local power quality. However, as the grid's power quality is already high at Hunts Point, this benefit is minimal.

During normal operation, the Microgrid is connected to the **ConEdison** grid and able to export excess electricity to the grid, thereby deferring generation capacity investments of the utility. The Microgrid could potentially help deferring distribution capacity investments, but a new substation has been recently completed and the benefit is minimal. Since Hunts Point is within both the ConEd electricity and gas service territories, the reduced electricity sales are partly compensated by increased demand for natural gas to run the CHP turbines. Finally, ConEd can claim the CHP fuel savings and lower GHG emissions to meet statewide grid requirements on sustainability, renewable energies and emissions.

The FDC and the market buildings are owned by the **City of New York (NYC)** and administered by the NYC Economic Development Corporation (NYCEDC). These governmental stakeholders act as landlord in order to advance public objectives. This includes the preservation of more than 6,000 jobs in one of the least affluent Congressional Districts of the United States and providing a safe haven for the Hunts Point residential community. Furthermore, the CHP fuel savings and low energy costs are competitive factors to keep small businesses and tax income in New York State.

Finally, an **IPP** could help financing, building and operating the Microgrid. Neither the end-users nor the City of New York have experience with Microgrids, while ConEd as the distribution utility is not allowed to own generation equipment. An IPP such as the New York Power Authority (NYPA) or private energy service companies (ESCO) could potentially contribute private equity, development experience and operational efficiency. In return, the IPP would make profits from ancillary services and electricity sales to ConEd, retain a share of the energy costs savings from CHP fuel savings. As the power quality is already high, it cannot charge customers for higher power quality.

The benefits named above can be valued based on the Benefit-Cost-Analysis (BCA) model for NY Prize by NYSERDA and Industrial Economics, Incorporated [32]. The total benefits amount to $240 million over twenty years at a discount rate of 7%. Therefore, the project has a benefit-cost-ratio (BCR) of 1.13 with an internal rate of return of 6.4% if all benefits can be monetized or internalized. The costs and benefits of the Hunts Point Community Microgrid are illustrated in Figure 3.

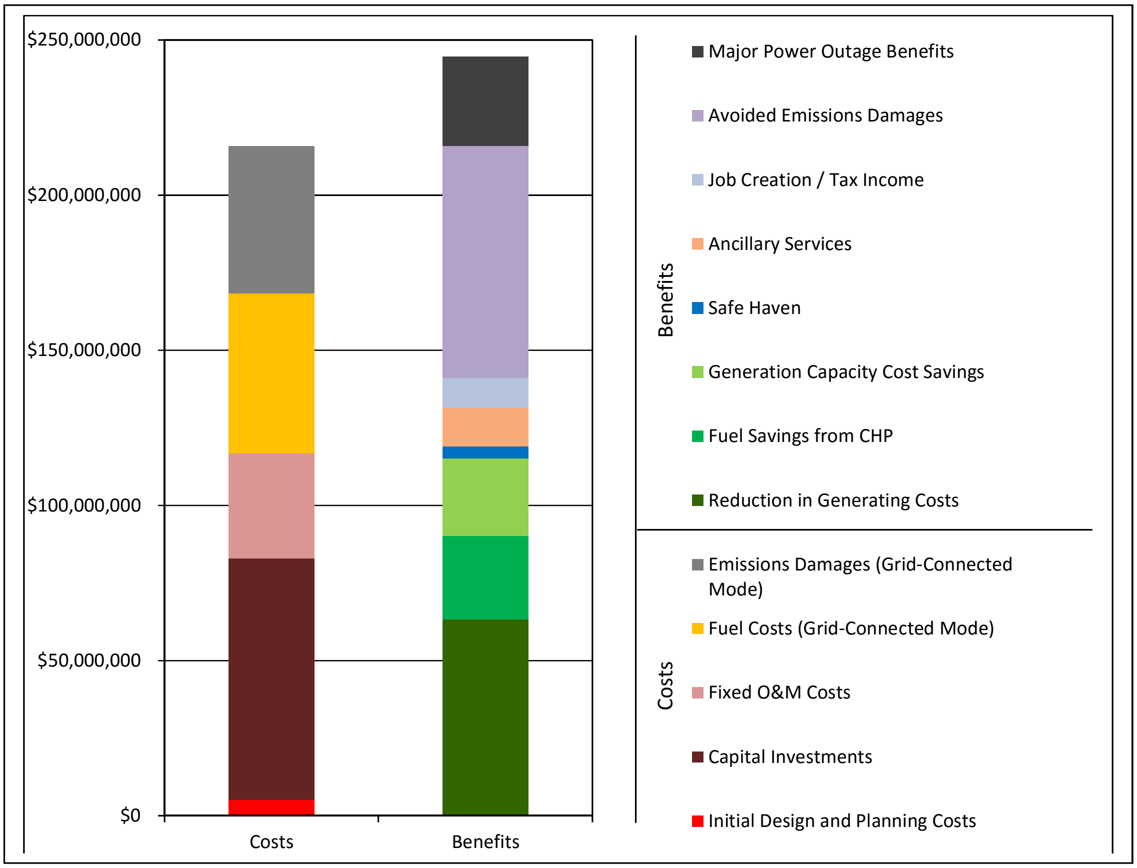

Figure 3: Hunts Point Costs and Benefits based on [32]

5.3 PPP Models

When considering appropriate PPP Models, the circumstances and objectives of the Microgrid have to be taken into consideration. The Hunts Point Community Microgrid will be developed with entirely new generation and distribution infrastructure, thereby ruling out service contracts, affermages and leases that depend on existing infrastructure. The three wholesale markets as end-users and the City of New York as landowner have to be part of the Microgrid development in order to ensure base demand and development rights, therefore DBO and BBO models are not applicable either. However, neither the Markets nor the City have experience with Microgrid development and operation to form a BOOT, therefore they need to partner with ConEd (DBOM), an IPP (BOT) or both (BOO). ConEd would facilitate the interconnection with the grid and contribute its experience with distribution and billing of electricity and steam. A private IPP would also offer experience in construction and operation of Microgrid as well as private equity and financing. The potential PPP models are summarized in Table 6 below.

Public/Private	ConEd	City of New York	Both
Markets	x	x	DBOM
IPP	x	x	x
Both	x	BOT	BOO

Table 6: Hunts Point Community Microgrid PPP Models

In a BOT model, the City of New York and the three wholesale markets would partner with an IPP to build and operate the Microgrid before transferring it back to public ownership upon a specific operating time, since the City of New York already owns the land and market buildings. The Markets have a vested interest in a resilient and affordable energy supply, but neither the capital nor the experience to own and operate the Microgrid. Both could be provided by an IPP in return for entering into a Power-Purchase Agreement (PPA) to buy electricity at reduced but fixed rates, which generates a return on investment (ROI) for the IPP during the specified term.

In a DBOM model, the City of New York and the Markets would partner with ConEd instead of an IPP in order to ensure public interests. The City of New York would provide the land and development capital, the utility its experience with design, construction, distribution and billing and the Markets could take responsibility for operation and maintenance of the generating assets. While this facilitates grid interconnection, community support and demand-based operation, it remains questionable if the Markets have the capacity and experience to operate both CHP turbines and refrigeration chillers.

In a BOO model, this problem would be resolved by partnering with both the IPP to build and operate the Microgrid generating assets and the utility to manage interconnection, distribution and billing. The City of New York would retain ownership of the land, while the Microgrid will be privately owned by the IPP and the Markets who would share all investment and market risks. Public interests would be protected by public ownership of land as well as the participation of ConEd as a publicly regulated utility. The Markets would agree to share energy cost savings with the IPP in return for limiting their operational and financial commitment. As all four stakeholders work closely together, the ownership of the Microgrid does not have to revert back to the public sector.

5.4 Stakeholder Benefits

Comparing these three PPP Models for the Hunts Point Community Microgrid requires a closer look at the benefits that could be internalized in each model. In all three models, CHP and solar PV generation would improve reliability during outages and generate cost savings from fuel efficiency. This protects Market revenues, inventory and jobs, and provides a safe haven for the residential community. Furthermore, any Microgrid that reduces grid demand helps the utility defer generation and distribution investments and reduce GHG emissions. The participation of ConEd would enable the Microgrid to internalize the value streams from reducing generation capacity costs, saving fuel and lowering GHG emissions. Likewise, the participation of an IPP in a BOT or BOO Microgrid would reduce the cost and improve the quality of construction, operation and maintenance while allowing the IPP to monetize ancillary services and CHP fuel savings. Summing up individual partner benefits, a BOT would be able to internalize $167 million, a DBOM $215 million and a BOO the full $240 million of potential benefits. Naturally, these benefits come with additional complexity and transaction costs. Furthermore, the distribution of benefits between the stakeholders is not certain. Comparing these benefits with the development cost of $215 million shows that only a partnership with DBOM or BOO partnership allows the stakeholders to internalize sufficient benefits to justify the total development cost of the Microgrid.

	Markets	**IPP**	**ConEd**	**NYC**
Direct Economic Benefits				
Energy Cost Reduction	**$65M**			
Ancillary Services		**$12M**		
Generation Capacity Cost Savings			**$25M**	
Indirect Economic Benefits				
Distribution Capacity Cost Savings			**$0**	
Job Creation/Tax Income				**$10M**
Reliability and Power Quality				
Improved Reliability	**$28M**			
Improved Power Quality	**$0**	**$0**		
Environmental Benefits				
CHP Fuel Savings		**$13M**	**$13M**	
Reduced (GHG) Emissions			**$35M**	**$35M**
Security and Safety Benefits				
Safe Haven During Outages	**$2M**			**$2M**
	$95M	**$25M**	**$73M**	**$47M**

Table 7: Hunts Point Stakeholder Benefits

6. Conclusion

6.1 Summary of Findings

This paper defines Microgrids as “a group of interconnected loads and distributed energy resources (DER) that acts as a single controllable entity and can connect and disconnect from the grid”. Microgrids can be categorized by their main stakeholders, including end-users, utilities, governments and Independent Power Producers (IPPs). Each of these stakeholders can monetize and internalize some but not all of the benefits a Microgrid provides, including direct and indirect economic, reliability and power quality, environmental and security and safety benefits. Therefore, it may be necessary to partner with other stakeholders in order to internalize more benefits and make the Microgrid development feasible. A well-researched form of partnership are Public-Private Partnerships (PPP), which are defined as “arrangements whereby private parties participate in, or provide support for, the provision of infrastructure”. Depending on the preferred allocation of ownership, operation, investment and market risk to each partner, there are various PPP models from leases and concessions to build-operate-transfer (BOT), design-build-operate (DBO) and build-own-operate (BOO). Microgrids could potentially be developed with the utility and/or government as public partners and end-users and/or IPPs as private partners. In total, there are nine possible combinations of public and private stakeholders in Microgrid development. Some PPP models are more appropriate for certain Microgrids that others based on the contributions and expectations of each participating stakeholder. Depending on the partner’s preferred allocation of ownership, operation, investment and market risk, certain PPP models are more appropriate for each Microgrid in order to maximize internalized benefits and minimize complexity and transaction cost. The theoretic conclusions are validated with a case study of the Hunts Point Community Microgrid in the South Bronx of New York City. Here, three critical wholesale food markets, the residential community and the public landowner of the Food Distribution Center could choose to cooperate with the utility and/or an IPP to build and operate a resilient and sustainable Microgrid. The case study demonstrates that a partnership between three or more stakeholders internalizes sufficient benefits to justify the total development cost and meet the sustainability and resiliency goals of the Microgrid.

6.2 Limitations and Implications for Research and Practice

The findings in this study are based on an in-depth literature analysis of Microgrids and PPPs that was used to analyze the applicability, stakeholders, PPP models and potential benefits of Microgrid PPPs. The theoretic findings were demonstrated on one case study that is not representative of the great variety of Microgrids. Therefore, a more extensive empirical study should be conducted to validate

- if Microgrids have been developed successfully as PPPs,
- whether there are any more key stakeholders to be considered,
- which PPP model is best suited for which stakeholders, and
- which of the potential benefits are actually being generated.

For end-users, developers, utilities and governments, this research may nevertheless indicate that partnerships with the other stakeholders should be considered in order to make Microgrids more feasible or beneficial. The PPP models and benefits mentioned in this paper could serve as a basis to discuss potential forms of cooperation, in which every partner could contribute resources, share risks and internalize more benefits. Microgrids remain a very innovative technology with limited experience on all sides, therefore intensified cooperation could help advance this field for the common good.

6.3 Outlook

In times of global warming and climate change, Microgrids will become increasingly important for reducing GHG emissions while providing resiliency during natural disasters. The experience from various pilot projects and studies will make Microgrids cheaper, more efficient, less bureaucratic and easier to finance, to which PPPs may contribute significantly. Valuable lessons have been learned from PPP projects in other sectors that can be transferred to Microgrid development, especially regarding risk allocation, project finance and procurement. When combining progress in both areas, PPPs in Microgrid development could be a small but meaningful contribution to meeting the climate goals that were agreed on at the COP21.

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Lessons Learnt from an Urban Community: the "Concerto AL Piano" experience

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Abstract

The European project *Concerto AL Piano* is aimed at demonstrating the economic and social benefits in investing in energy saving and renewable energy in urban regeneration. The project includes a mix of interventions: the renovation of existing social housing, the construction of new eco-buildings and the provision of a cogeneration district heating, integrated in the urban environment. [1]

The sustainability goals of Concerto AL Piano can be summarised as follows:
- high reduction of fossil fuel consumption in existing renovated buildings;
- integration of renewable energies at the urban village scale;
- district heating and co-generation as a network for the urban village;
- local team to promote the information campaign on the energy conservation scheme;
- municipal energy management and retrofit programme.

The completion of urban voids, with the creation of the New Eco-Village, improves the perception and the endowment of the district that would be otherwise incomplete.

This paper focuses on the main achievements and lessons learnt from this demonstration project at the urban scale to promote a smart urban community. The lessons are categorised under a series of "P" which can be seen as key ingredients for the success of a smart and sustainable strategy. The P of Project / Planning / Process / Partnership / Promotion / Product / Performance / Prolongation are the keywords of this dissertation on lessons learnt from converting an urban district into a Smart Urban Community. [2]

Introduction

Concerto AL Piano, in Alessandria at the NW of Italy, is one of the 58 integrated energy demonstration sites promoted by the European Commission within the 6th and 7th Framework Programme. The project has upgraded the energy profile of a whole urban district through:
- renovation of 300 existing dwellings, up to 50% reduction of energy consumption;
- energy conservation scheme for 3,000 dwellings, and energy retrofitting over 48,000 m^2;
- 104 new dwellings and 50 apartments for elderly people adopting minimal space heating standards.

Concerto AL Piano had a strong effect on the urban regeneration of the whole district. Such ambitious projects, managed by a partnership between local government, private companies and university research, served as a model for the urban regeneration process, which became a key action in the Strategic Energy Action Plan (SEAP).

With regards to performance, what undoubtedly has undergone significant transformation is the energy balance of the neighborhood. The energy consumption of existing buildings was reduced by around 40% while the new settlement represents the next generation of buildings, aiming to reduce energy consumption even with unusual typological solutions, like a micro-climatic atrium.

Three main demonstration actions are developed in Concerto AL Piano:

a. RETROFIT _ Energy Retrofitting at the district level
The Energy Retrofit Programme aimed at providing the Concerto district with an energy conservation scheme for 3000 dwellings, based on announcements in local newspapers and letters addressed to the inhabitants. A 20% of the audited buildings (48,000 m2) were retrofitted following the scheme. Over the global retrofit investment, inhabitants were asked to contribute up to the 65% of the energy rehabilitation costs. This was organised through local community tenders that have increased the popularity and penetration of the Energy Retrofit Programme at the city level.

b. RENEW _ Energy Renovation of the existing village

The existing social housing village was needing an urgent energy retrofit, due to the lack of thermal insulation and a very degradated envelope. Then, a deep renovation of 300 dwellings took place, with the aim of reaching up to 50% reduction of the specific energy consumption. The complete refurbishment of 11 buildings belonging to the Social Housing Agency incorporated a wide range of measures: external insulation; air tight windows and ventilation control; greenhouses and glazed balconies; individual heat meters and thermostatic valves; district heating system with cogeneration. A visible refurbishment involved the whole building envelopes, retrofitted using external fiber-wood insulation. Existing windows were replaced with new double glass, low emission and high performance windows. The south facades have been equipped with passive greenhouses to provide solar gains in winter, thus reducing energy consumptions for space heating.

c. NEW _ New Construction of a low-energy village

The new low-energy village includes 104 dwellings and the elderly house for other 50 dwellings, adopting minimal space heating and DHW standards. In addition these dwellings make use of renewable energy: 200 m^2 of water solar collectors; 50 kWp of photovoltaic systems. The design of four micro-climatic buildings is based on the *atrium* solution: two building blocks are linked together by transparent atrium to determine an intermediate and more comfortable winte climate. The use of environmental friendly materials, the reduced fossil fuels consumption for space heating and sanitary hot water, and the implementation of a large set of measures to save and reuse water, recycle waste, limit the traffic speed, provide an improvement of the local environment. A newly built district heating network provides the heating and electricity in co-generation. One of the demonstration issues consists of showing the inhabitants how a central power station could appropriately fit in a populated residential district. A plant remote control system drives the cogenerator to adapt its power output following the heat demand, granting the highest possible efficiency. A remote control room gets each day the production data, with 15 minutes scansion, as well as any eventual out of order signal.

At the end of the 8 years project cycle, from design to monitoring, the coordinating team of Concerto AL Piano could focus on the main achievements from this demonstration project to promote a smart urban community. The lessons learnt can be helpful for new projects and for a wide application of sustainable principles on an urban scale.

1. Project

from Nearly Zero to Net Zero Energy

Concerto AL Piano, as all other Concerto projects, was a precursor of the complex dispute between Nearly vs. Net zero energy into the real practice of an urban project.

Undoubtedly, Concerto AL Piano has represented an experience of smart urban community for Alessandria by promoting an innovative regeneration of an urban site, with a mix of refurbishment and new construction of residential and non-residential buildings, representing the complexity of our urban situations. The several projects incorporate innovative energy technologies and contribute to the environmental quality, as well as to the quality of life, thermal comfort, lighting and ventilation of indoors, since eco-buildings are better buildings for the occupants.

The results achieved by Concerto AL Piano can be easily summarised in the following table and in the related shankey diagram, showing the energy saving on the district scale. The energy consumption of existing buildings was reduced by a maximum of 48% that could be obtained for all dwellings with fine-tuning of heating systems. New micro-climatic buildings reduce energy needs at 38 kWh/m^{2}y, even with unusual typological solutions for housing (building atrium). Although these results are lower than expected, we can consider this an example of low-energy district. [3]

Under a more comprehensive perspective, when starting Concerto AL Piano the more ambitious goal of a Net Zero Energy district was pursued. [4] The districts aimed at having a total renewable energy provision, based on a biomass district heating as auxiliary system. However, we learned that solving the energy use and emissions at the building level could not be achieved in a cost effective way, without approaching energy demand and supply at the same time. We suddendly recognised that sufficiency was a key concept to achieve through optimisation of the energy demand versus the supply of renewable energies. Urban sufficiency is a stimulating concept. If efficiency means achieving the same end use with the least amount of resources; sufficiency means limiting the consumption of resources to the real essential, minumum needs. The real challenge is to set the appropriate minimum levels of needs without compromising the quality of life [5].

1. Social Housing settlement before and after energy renovation

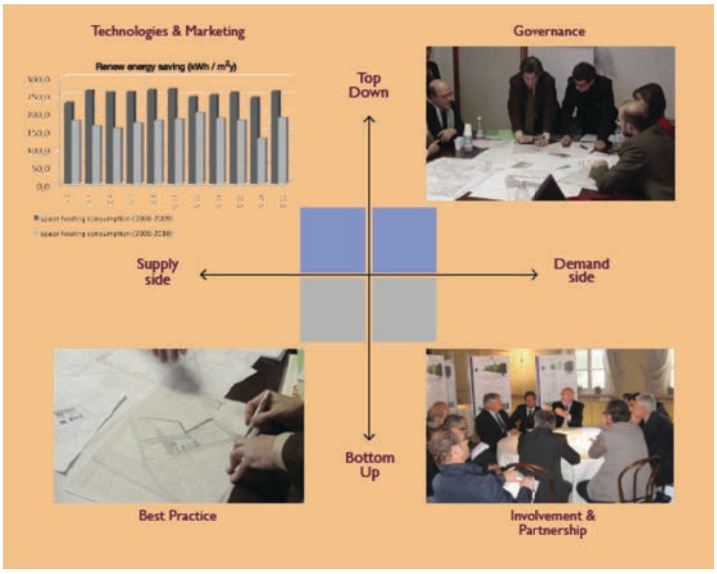
Three key recommendations can be proposed, based on lessons learnt:
- projects and approaches either focusing on one side of the picture, i.e. building technologies, renewable technologies, or energy network systems, are uncoherent.
- *Energy Sufficiency* concepts can limit the consumption of resources to the real essential needs, at feasible levels
- *Net Zero Energy* concepts, only providing renewable energies without minimising energy needs, can be inconsistent and contradictory

2. Planning

from strategic plans to tactical discontinuities

The Urban Pilot Projects, as well as the European Integrated Projects (IP) put the focus on "sustainability" addressed on several levels: a new way, not exclusively technical, to deal with the inner multi-disciplinarity of projects. Urban Demonstration Projects, such as Concerto, are major tactical projects in the complexity of the city. The integrated management of these projects needs a huge team effort that should last up to ten years at very high intensity. The fertilization of experiences between local leaders, professionals, builders, industries, and not lastly citizens is a strong point of the integrated methodology that has been implemented in Concerto AL Piano.

A relevant step of Concerto AL Piano was its scaling-up from a limited, although visible, demonstration project (tactical) to a wide-spread strategic plan, the so called Sustainable Energy Action Plan (SEAP), initiated by the City of Alessandria few years after the project start. The SEAP initiative directly involves City Mayors, who commit to go beyond the EU target of reducing CO^2 emissions of more than 20% by 2020 [6]. The initiative is having a considerable success all over Europe, but particularly in Italy, with more than 3000 signatory cities (about 52% of the total participants in Europe). In order to respect the commitments of the covenant and adopt an effective plan, the creation a Local Team was crucial. This team was able not only to involve all stakeholders in the SEAP, but also to integrate previous experiences, best practices, and on-going demonstration projects in the field of sustainable urban regeneration.



2. Alessandria Sustainable Energy Action Plan

Here, the role of Concerto AL Piano was crucial. The involvement of Alessandria, who signed the Covenant among the first cities in Europe, started from the network of stakeholders shaped by Concerto AL Piano. The application of urban renovation methods, the collaborative design approach, the workshops based on scenarios from the building to neighborhood up to the city scale, were the essential methodologies for the SEAP elaboration. The research team of Politecnico di Torino supported the city of Alessandria in the integration between the european demonstrative project Concerto AL Piano and the adoption of the SEAP [7].

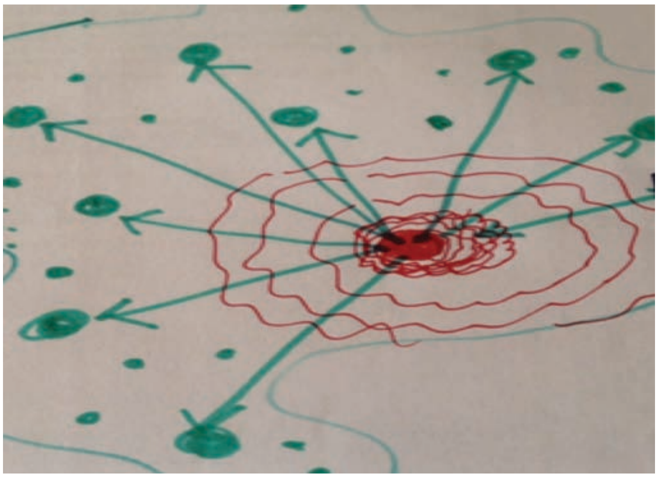
Three key recommendations can be formulated based on lessons learnt:
- *tactical discontinuities* are essential breakthroughs in the more-of-the-same urban experiences;
- *scaling-up*: move from local demonstration projects to strategic plans on a city scale;
- *keeping the momentum* of strategic plans, such SEAPs, in accordance with local demonstration projects, requires an extraordinary, rarely reached effort and commitment by all stakeholders.

3. Process

from one acupuncture to multiple *eco-punctures*:

The acupuncture is a well known concept in urban planning [8]. It provides the ground for the tactical action versus the strategical approach. When we started Concerto AL Piano it was very clear that our approach was not a strategical, but a tactical one: making a number of minimal acupunctures in the tissue of the urban grid to reverse, reconnect, and regenerate the area.

Since the topic is the environmental regeneration of an urban area, we changed the expression acupuncture into *eco-puncture* that better symbolize the effort devoted to the environmental regeneration [9]. We have learned that one eco-puncture is not enough to make the process visible and irreversible. Multiple eco-punctures were made, in various sectors and areas of the same districts to overcome the inertia and introduce innovation, in the existing social housing, in a new eco-village, in promoting and supporting energy retrofitting by private housing owners, in supporting the new cogeneration district heating, in taking-off the new elderly housing: many eco-punctures, many meaningful tactical steps to make the change happen.



3. eco-punctures on regeneration area

Urban regeneration projects are, above all, long processes. These are slow enough to be, sometimes, counterproductive and to lose the original innovative outlook. Researchers have to fight againts the entropy of the trend, which is one of the most disruptive factor affecting the original ambitions and targets. An example in Concerto AL Piano consisted in the building energy efficiency performance. At the design stage, the selected levels were highly ambitious in comparison with the 2006 regulation levels. During the following years, stricter levels of energy consumption in buildings were in contradiction with the unchanged initial design requirements, and the lenght of the building process accentuated such discrepancy: projects get old, while regulations are progressing. Only a strong effort project managers and coordinators was able to reset the initial targets, already reached by the improved regulation, to enlower energy consumption indexes, enlower U values, and to ameliorate the overall performances.

Three key recommendations can be proposed, based on lessons learnt:
- a *scientific guide* must support the local autority, or the public body, to strengthen the role and committment to targets;
- *countinuous, simplified assessment* of the process/project development at preliminary stages via basic tools, in addition to post-design evaluations and post-occupancy monitoring;
- *social monitoring*, in addition to environmental and energy monitoring, in order to reach a comprehensive assessment.

4. Partnership

from single players to multiple stakeholders

The need of a strong urban partnership is a well known concept in urban projects and it is a basic condition of all Concerto projects, from which the name itself originates. In Concerto AL Piano every step of the process has been a concertated step, from the very first ideas and applications to the very last reformulations and amendements. Concerto AL Piano has improved the process of urban revitalisation by involving the local community. The participation of stakeholders and citizens in planning and decision making has provided a longer lasting solution to urban problems. Innovative methods were used to address economic, environmental and social issues, while bringing in the local community.

From the very beginning, Concerto AL Piano aimed at providing the public decision makers, the developers, the professionals and citizens with a "Sustainable Urban Project" for Alessandria. A Scenario Workshop has been the basis for the selection of the regeneration topics, the technological solutions, and the urban action plan. The Scenario Workshop involved 40 among the city officers, professionals, builders, citizens' representatives. It took place on a full day devoted to facilitate the discussion and selection of actions, within a number of possible futures for the Concerto district. Compared to more conventional methods, this Scenario Workshop allowed to identify and discuss the similarities and differences in the perception of problems and their possible solutions between the different role groups involved. It helped generating new ideas and guidelines for action and regeneration initiatives to be undertaken in the short and medium term. Based on the results of the Scenario Workshop, the urban proposal was shaped and the further steps were planned. [10]

4. Scenario Workshop on Concerto Action Plan _ Alessandria

We could retorically state that a perfect match was reached between public and private - the so called PPP - but our independent role gives us the opportunity to focus on the lessons learnt and on what was wrong, more than on what was right. A key lesson we have learnt suggests to make this public-private partnership flexible enough to make easy changes in the private coalition when problems occur (and they will occur) by easy decisions of the leading public body. To exemplify, most of construction delays of Concerto AL Piano, due to the rising economic crisis, were essentially caused by the late engagement of the Alessandria private builders, concerned to start works without solid market guarantees on selling apartments once built. As a consequence, the urban demonstration was twofold: the public (city and social housing agency) completed its construction and rehabilitation works much earlier than the private development remained uncompleted for years, giving to the whole site and inhabitants a long and persistent low liveability. This could have been avoided through a more flexible engagement and substitution within the partnership, allowing internal bids and easy replacement of builders, that could take the place of those escaping risks.

Based on lessons learnt, three key recommendations can be proposed:
- the *public-private partnership* is essential;
- the public must lead;
- *flexibility* must be incorporated in consortium agreements and immediately implemented when problems occur.

5. Promotion

from builders' involvement to communities' involvement

Urban demonstration projects are long-term processes, that may last ten years, despite enormous efforts of involved teams, managing difficulties. They require an extraordinary commitment and team-work for cities. Concerto AL Piano, in its lifetime, has dealt with three City Mayors, four construction companies have withdrawn, and three different energy suppliers took responsibility for the co-generation district heating. In urban pilot projects, builders are still among the main players, having to make investments and test innovative solutions, but a durable political commitment, high competence and risk acceptance are essential components from the very beginning, in conjunction with a strong public awareness and community involvement.

To examplify the effectiveness of promotion initiatives among the community, the kick-off meeting of Concerto AL Piano can be summarised. It took place on July 2-3, 2008, in occasion of the first *Partners Meeting* with the associated communities. During the first day a short visit of the Concerto AL Piano district was carried out, followed by a sightseeing of the so-called *Photovoltaic Village*. In the evening there was a get together between major local and regional stakeholders and representatives of the associated communities. The peculiarity of the second day was that the meeting was held in a public place, namely a highly populated square in the city centre of Alessandria. A further feature was the very high participation of the local public administration, including the Mayor. The meeting started with an opening speech of the Mayor, followed by presentations of the activities of the Concerto AL Piano project in the demonstration site Alessandria and in the associated communities. [11]

Apart from the kick-off contents, the novelty was represented by the context: the public square where the conference was held and the attactiveness of this *setting* for the public. People around the square have been brought into the context of the urban pilot project through a truthful exposure to a conference that was not intended to be for the public, but intentionally *within the public*.

5. Community Awareness: the conference on the public square in Alessandria

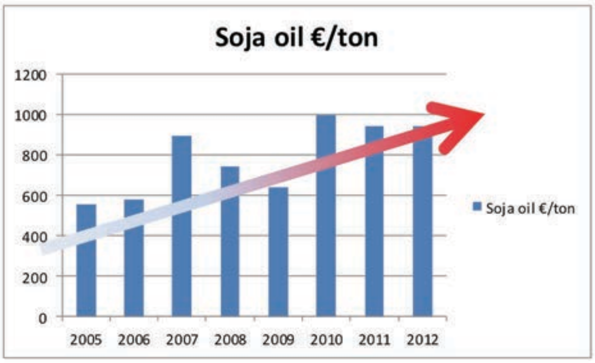
Based on the lessons learnt, three key recommendations on *promotion* issues can be proposed:
- do not ask people to come, but *go to people*: innovative city settings for promoting urban projects can enhance the perception and the awareness within the local community;
- involve *associated cities* in demo: having more communities involved in a local pilot project improves the partnership and sharing of the initiatives;
- when regeneration happens in a district, former inhabitants are happy to come back to live in their original neighborhood.

6. Product

from technological solutions to holistic solutions

For many years, demonstration projects at the bulding and urban level were mostly designed to develop, demonstrate, validate technological solutions, at the building or district level. Currently, urban projects have scaled-up, becoming increasingly more comprehensive and holistic. Integrated energy solutions are among the most challenging achievements in a smart urban community. This was also true for Concerto AL Piano, looking for a good combination of energy demand reduction with renewable energies as auxiliary components.

The catalogue of renewable technologies in the project included: passive solar, solar thermal, solar photovoltaic and biomass district heating. All solutions were implemented, in various configurations and architectural integrations, with the exception of the biomass that had to be reconsidered. The change in fuel of the district energy system was caused by the new regulation of the Piedmont Region, who could not approve the biomass solution in the urban context. Prevalent winds would have brought the combustion products into the city centre, and the admitted levels of pollution could not be respected with the best available technologies. The local regulation requires unrealistic particulate limits. In terms of total particulate limit in the exhaust gases, the Regulation Authority called for 10 mg/Nm^3 at 5% O^2 [12]. Respecting this limit at any time is unrealistic with the best engines and extremely dangerous because of penal consequences for the owner and technology provider. We illustrated this situation to the local and regional authorities, supported by international experts, but they kept the line. We believe the windless weather of North Italy (Val Padana) and its high pollution levels were at the base of this rigid position againts the biomass exploitation. To be noticed, the regulation (DGR 46-11968) was not in effect when we entered the project and designed the plant in 2007. However, Concerto AL Piano had to comply with the lack of authorisation to find an alternative solution. In addition, the price of vegetable oil (soja oil) doubled, boosting up from 500 to 1.000 €/ton and this was another element that was reassuring both promoters and technology providers on the risks the original solution would have incurred. [13]



6. Cost of biomass (vegetal oil)

The doubled price produced a dramatic economical effect, and reduced the operation margin below zero. It is not a matter of better or worse financial return. With such a price, the owner chooses to stop the plant because when running he loses more money than when stopping it. As a consequece, the biomass plant was not feasible any more, and the alternative solution had to be identified, namely in a natural gas district heating system with co-generation.

Based on the lessons learnt, three key recommendations can be proposed:
- integrated, holistic solutions are to be achieved in smart urban communities;
- sometimes, new available technologies cannot allow the achievement of environmental targets;
- air quality in urban context is a major concern and energy solutions that cannot comply with its improvement are to be considered inappropriate

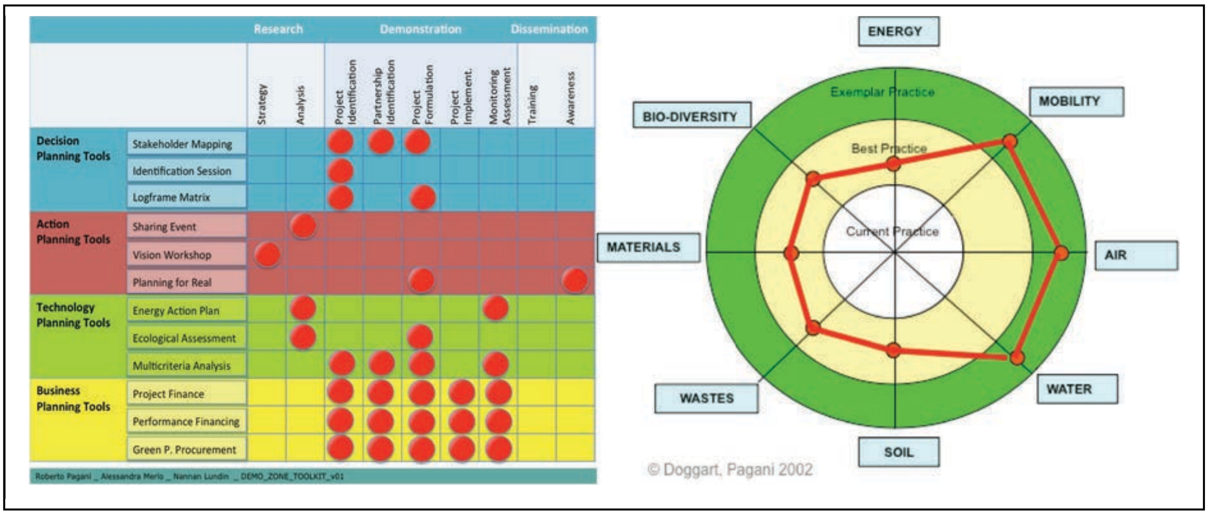
7. Performance

from individual experts tools to a Toolkit for Demo Zones

Performance evaluation helps understanding strengths and weaknesses of a comprehensive urban project that hosts a number of functions on the urban, district and building scale. Concerto AL Piano worked on a multi-level performance evaluation: from site-assessment to building energy monitoring; from the overall environmental quality to indoor comfort. All layers have specific expert tools for the analysis and evaluation and for all topics the most appropriate tools were selected. In particular, careful analyses were conducted on the quality of the urban project in relation with energy and environmental sustainability, health and comfort of indoor and outdoor environment. The quality of an urban project must also be assessed in relation to the available resources, to the level of site upgrading and to the upgaded social opportunities. Scoring methods may not fully comprehend the complexity of urban processes, but their indicators can at least provide evidence of the impact of changes. By means of an iterative process, these tools allow to progressively improve the result of each assessment topic (sustanaibility, health, accessibility, comfort, etc.).

Many tools are normally used in Europe in demonstration and pilot projects to facilitate decision-making and design processes. Based on the conceptual framework adopted by Concerto AL Piano [14], an innovative Toolkit got inspired and was independently elaborated in the framework of the EU-China cooperation, with the contribution of expertise from previous EU demonstration projects.

Tools were carefully selected among the most recurrent in urban demonstration processes, giving to them a categorization and structure. The matrix consists of the main demonstration phases (horizontal) and four tools categories (vertical): decision planning, action planning, technology planning, and business planning. Each tool category includes three fundamental, well-grounded tools giving a total of 12 tools to assist urban demo-projects. The demo phases include the three main steps of any demonstration project, as recognised in EU project frameworks: Research, Demonstration, Dissemination, as well as the sub-steps of each of the previous macro-phases. Based on this categorisation of tools across various steps of demonstration processes, a matrix of preferential applications was compiled to guide users to better understand the comprehensiveness of the Toolkit. A detailed illustration of the Toolkit for Demo-Zones is presented in the references [15].



7. Matrix of the Toolkit for Demo Zones [15].

Based on the lessons learnt, three key recommendations on *performance* issues can be proposed:
- urban demonstration projects are pilot schemes where methods must be used to lead processes and get innovative results
- project benchmarking and performance assessment are key process steps to address the general and specific targets of an urban community project
- the Toolkit for Demo-Zones helps in adopting the appropriate methods and tools to govern the various project steps and to formulate comprehensive decisions

8. Prolongation

from managing the projects to managing the change

As previously emphasised, Concerto AL Piano is characterised by a comprehensive approach involving administrators, planners, investors and users. It can be regarded as a significant training effort at the city and neighbourhood level. During the planning phase, a number of consultations and workshops have been carried out. A Local Community Task Force has been created for sharing and assessing the project, at each stage of implementation: it is constituted by city managers, citizens and associations, experts, promoters and builders. Through the coordinating team, training to architects, planners and urban managers was provided from the very beginning of the project by means of workshops and focus groups.

Concerto AL Piano became the topic of an intensive training activity, involving the students of the School of Architecture of Politecnico Torino. It has been studied as a *best practice* of sustainable architecture in all its components: energy saving, bioclimatic architecture, natural building materials, and involvement of inhabitants in urban regeneration. The students were committed in a *learning by doing* experience aimed at re-thinking and re-designing Concerto, and exploring different planning solutions.

The training method consisted in a Scenario Workshop, simulating in classroom the urban regeneration planning. Students were divided into *role groups*: Administrators, Inhabitants, Experts, and Investors. Each role group analysed strenghts and weaknesses, opportunities and risks of the urban area, from its role's point of view. New groups were formed, mixing roles and starting a discussion between different stakeholders, in order to establish guidelines and targets for the urban regeneration plan, that are shared and voted from administrators, inhabitants, experts and investors. Thanks to this *role game,* the students had the experience of the complexity of Concerto projects, and understood the importance of cooperation in a sustainable urban process. Finally, the students went back to their role of *young architects* to develop their own urban regeneration project.

8. Training on Concerto AL Piano _ School of Architecture

Both the experience of the Local Task Force and the Students' Training have been the real good practices that we can reckon as titles of Concerto AL Piano. Through the Task Force, a long-lasting effect on urban decision making and the perdurance of its influence has been granted. Through Concerto, a step forward in stakeholders involvement was reached from which the local community does not come back. In addition, what has been touched on with the students' training is more *durable and doable* than any other actions: the prolongation and perpetuation of the effects along the time and professional carrier of each single student. The real added value of Concerto.

Based on the lessons learnt, three key recommendations on *prolongation* issues can be proposed:
- Concerto dynamics, innovative decision making, local task force, are marking local communities from which it is impossible to go back;
- *learning by doing*, experimenting, coaching with a demonstration project is an asset for education;
- *P = prolongation* is perhaps the most effective result of Concerto AL Piano.

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Session Cities IV

Campus and Community Energy Master Planning in North America based on European Best Practice

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Abstract

Integrated community energy systems (ICES) take advantage of cross-sectorial opportunities in the areas of land use, infrastructure, building, water and sanitation, transportation and waste to curb energy demand and reduce greenhouse gas emissions at the local level, while increasing energy security, enhancing the quality of life and realizing financial benefits for residents. While current practice of Urban Planning for neighborhoods or entire communities is mostly focusing on land use, public space, infrastructure and transportation, energy planning in much of North America is often reduced to a building by building approach.

This paper describes the approach taken to develop realistic, implementable and truly Integrated Community, Campus or Neighborhood Energy Master Plans (IEMP). The goal of IEMPs must be to seamlessly address the community's entire energy value chain starting from the end usage, through energy service distribution and conversion, back up to all forms of primary fuel used both on and off site. The IEMP includes recommendations that optimize investments and other measures between end-use efficiency, energy distribution in the City or on the Campus and energy supply choices, including fuel and renewable options. The IEMP systematically addresses all of the following questions in a balanced way:

- Do solutions meet acceptable reliability standards?
- How much energy is really needed by the final end-uses?
- Are greenhouse gas emissions minimized?
- Do solutions meet acceptable financial returns?

IEMP recommendations are being assessed and ultimately prioritized according to the following loading order:

1. Maximize end-use energy efficiency
2. Maximize electrical and thermal distribution efficiencies
3. Maximize heat recovery including the use of CHP
4. Selectively implement thermal and electrical renewable supplies

Introduction

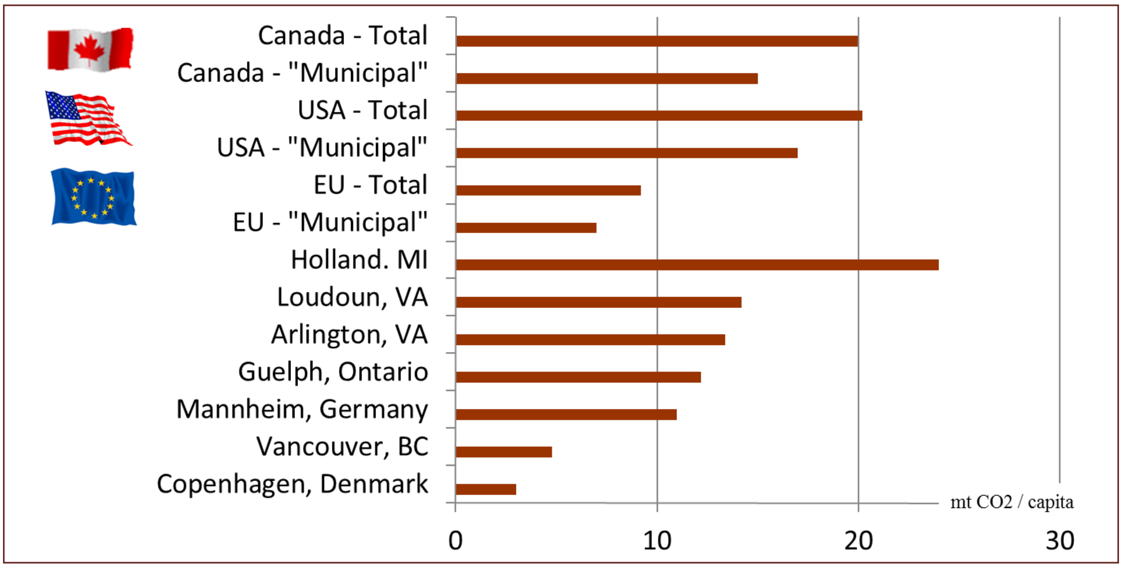
The 2015 United Nations Climate Change Conference, held in Paris, France, from 30 November to 12 December 2015 concluded with an agreement between all 195 participating member states and the European Union that calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st century. In the adopted version of the Paris Agreement, the parties will also "pursue efforts to" limit the temperature increase to 1.5°C. The 1.5°C goal will require zero emissions sometime between 2030 and 2050. [1]

The C40, a network of the world's megacities committed to addressing climate change is publishing their greenhouse gas emission reduction goals, measures and progress [2]. Copenhagen in Denmark is one of the few major cities with a clear short term goal of being carbon neutral by 2025. Currently

Copenhagen's CO_2 emission is at 2.5 metric tons per capita [3]. By contrast the US uses around 17.6 tons per capita [4].

Comparable data on the energy related emissions for cities around the world that can be systematically used for assessing the effectiveness of management strategies is relatively difficult to find. Using a number of sources, the Authors developed the following chart [4] to give an indication of the range of emissions for some selected communities in North America and Europe between about 2006 and 2010.

Figure 1 – Indicative Per Capita Emissions for Selected Countries and Communities



The national totals include all sources of emissions, the "municipal" and community level is an estimate of the energy related emissions in the urban environment. In the intervening years, the USA has seen overall reductions of about 10% largely due to switching from coal to gas for power generation. Similarly, some regions like Ontario have dramatically changed power generating mix away from coal.

What is important is this chart is the range of comparable performance. The EU municipal footprint is roughly half that of the USA or Canada. Where a reasonable comparison between communities can be made, a similar ratio emerges. The City of Holland, Michigan can be compared with Mannheim, Germany, in that it has a high percentage of coal fired power and significant industry. The per capita emissions of Holland are about 24 mt compared to about 11 mt for Mannheim. In a similar way, if the industrial emissions are extracted from Mannheim, the remaining emissions are about 7 mt/capita or half those of Arlington, Virginia, a comparable sized community with minimal industry and similar power mix. Vancouver, with nearly 100% carbon free (hydro) electricity, has per capita emissions substantially higher than Copenhagen, which still relies on fossil fuel for a substantial part of its power.

These comments underline the importance of drilling down into the details of the differences between emissions indexes, but highlight the substantial differences between comparable communities on either side of the Atlantic. There are multiple factors, all of which interplay with each other. The best practice driving the lower emissions in many EU Cities can be traced back to a greater degree of integration of energy as a key factor in overall urban planning and policy.

These include:

- More compact multi-use neighborhood design to facilitate walkable neighborhoods and effective mass transit reducing both building and transportation energy use
- Systematic implementation of higher energy efficiency standards for new construction and renovations
- Ensuring transparency of building energy performance through energy performance labelling as a normal part of the real-estate marketplace
- Widespread implementation of municipal district energy systems, facilitating economically viable implementation of cogeneration, waste heat recovery, bio-fueled heat sources among other thermal supply possibilities.

- Metering and control systems that measure and manage electrical, thermal and water systems in an integrated fashion
- Institutional structures at the municipal level that manage energy sourcing supply and use at the municipal level.
- Integration of industrial energy use and waste into the overall municipal energy service planning
- Systematic measurement and reporting of energy performance to maintain and enhance community engagement and adjust plans as needed
- Long-term EU and national policies aimed at systematically improving energy efficiency, fuel supply flexibility, and more recently, emissions reductions.

By contract, the energy related aspects of a North America municipality have been largely controlled by outside institutions. States and Provinces control building codes affecting new construction. Utilities tend to be regional, highly regulated and operate within their "power" or "natural gas" silo. District Energy is virtually unknown, and where it does exist is often seen as a relic of the past rather than a tool of future efficiency. As a result, municipal energy programs are often small scale, focusing on publicly owned buildings, community outreach and education and a relatively small number of voluntary efficient building and vehicle projects. While valuable to raise awareness, these lack the scale to transform the energy performance to global best practices, which are normally found in the EU.

Despite these challenges, a growing number of US and Canadian municipalities and Universities are developing energy and climate action plans that seek to scale up the economic, employment and environmental benefits of large scale energy performance transformation.

In order to have real impact and achieve rapid and drastic change, it is not sufficient to improve the energy efficiency of a community, campus or neighborhood one building or one vehicle at a time. It requires the development and implementation of truly integrated and transformational master plans that tackle energy efficiency and integration on a larger scale.

Approach to IEMPs

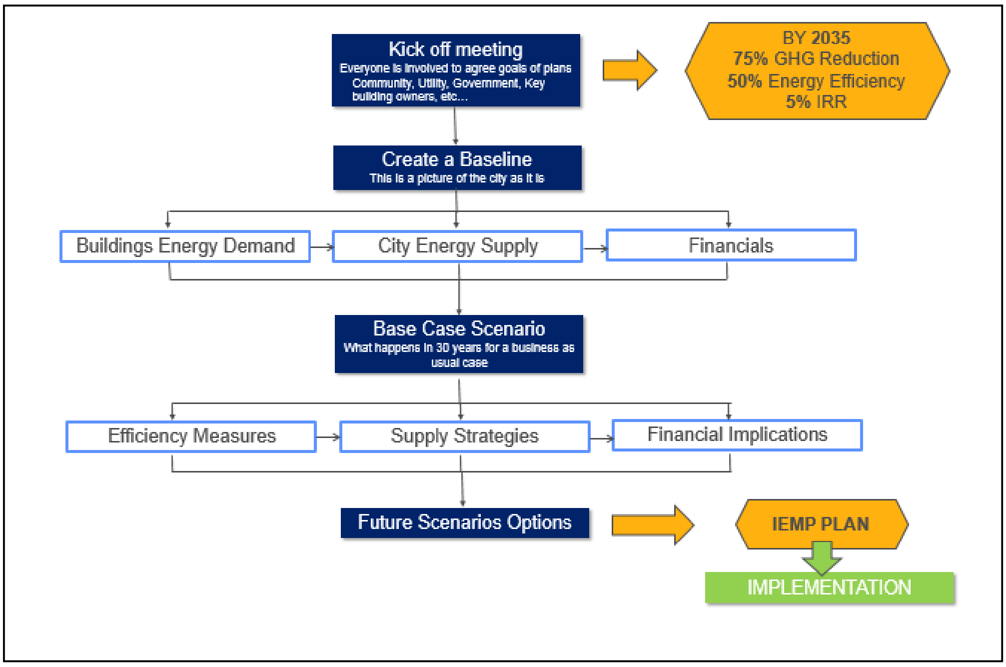
The work plan described in this paper, outlines the process to create a Decision Grade – Integrated Energy Master Plan (IEMP). In order for an energy master plan to be effective in its development and implementation it is important to ensure that there is buy in from the community as a whole, this includes government, utilities, community groups, building owners and facility managers.

In the first kick off meeting representatives of all these people are present and goals for energy use reductions, GHG reductions, investment returns, and other factors such as employment or supply security, along with a timeline for the plan are decided. These goals will guide the process throughout its lifetime. The goals are a clear statement of the community's desired outcomes over a 20 to 30-year period. An integrated energy master plan (IEMP) relies on data to make decisions. The IEMP will include an assessment of the technical feasibility and economic attractiveness of integrating energy efficient transportation, industry and buildings with efficient distribution and clean and efficient energy supply.

It is crucial that the IEMP is at a level of detail sufficient to make directional investment and organizational decisions and requests. These would be subject to final validation as part of the normal management and financial due diligence process prior to implementation.

The development of the IEMP has to be a highly interactive process between the community stakeholders and consultants. The IEMP Project Working Team (PWT) will always include representatives from community staff and local population and consultants, as well as other key stakeholders, such as the local utilities, and regional policymakers. It is also crucial that all key stakeholders are seen as active project team members and be involved in the process. The PWT should be considered the governance authority for the IEMP, giving directional guidance. This direct engagement ensures that the resulting IEMP will be fully "owned" by the members who will have the task to implement the plan, as well as the users that will benefit from it.

Figure 2 – General IEMP Flow Chart Process.



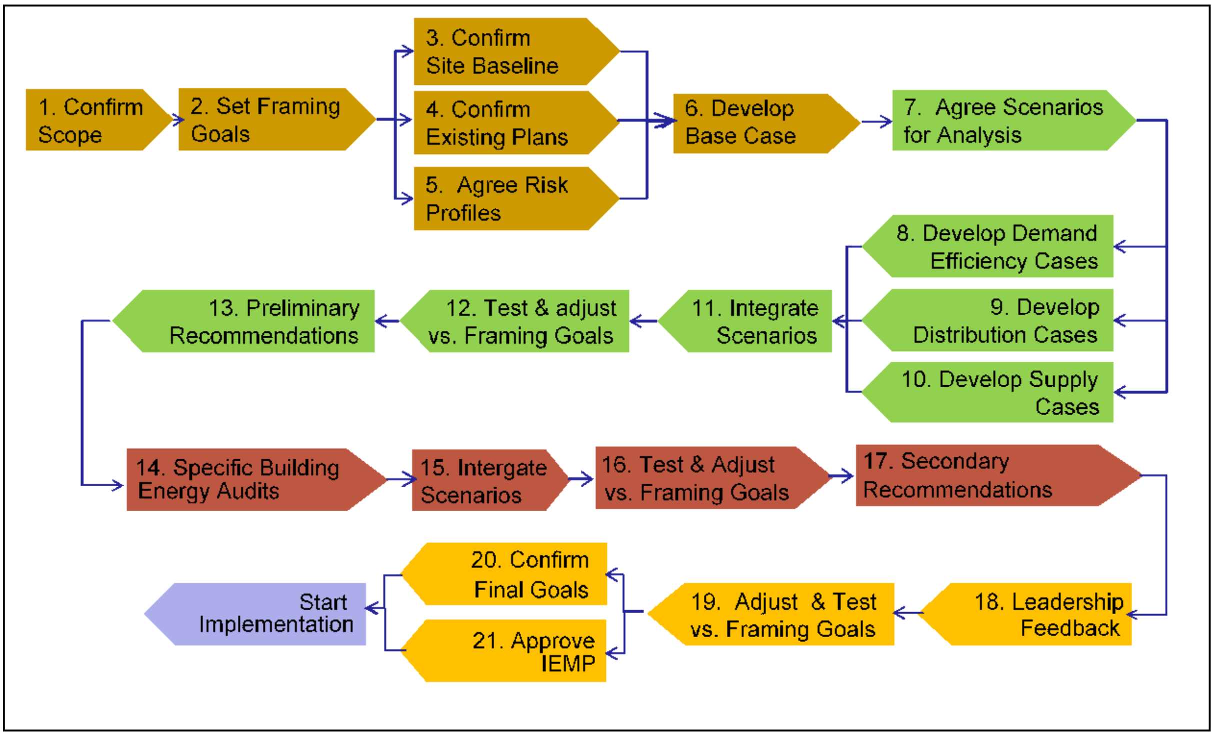
The flow chart shown in Figure 2 represents a general approach for creating integrated energy master plans (IEMP). This approach has been developed over 20 years and applied to numerous communities and campuses in North America. The approach recognizes the elements of EU best practice outlined earlier that have successfully created comparably more efficient communities.

In general, there are the following phased during the development of the IEMP:

1. Agreement on Framing Goals and Creation of Baseline
2. Development and Review of Base Case Scenario
3. Development of Future Scenario Options and detailed technical, environmental, and economic analysis including policy and institutional aspects.

The flow chart in Figure 3 represents the IEMP process step-by-step. Steps 1 – 7 form Phase 1 and conclude in agreed scenarios for the analysis. Steps 8 – 13 form Phase 2 and conclude in preliminary recommendations. Steps 14 – 17 are optional if more specific and individual building assessments are desired or required once the initial recommendations have been presented. Steps 18 – 21 form Phase 3 of the IEMP and conclude in the selection of the most beneficial scenario and approval of a final IEMP.

Figure 3 – Step-by-Step Flow Chart for IEMP Approach.



Project Kick-Off Meeting & Framing Goals

(Figure 1 – Steps 1-2)

A draft work plan for the IEMP will be developed during these steps for review and alignment during a first milestone meeting. During this first milestone meeting, the members of the PWT will be confirmed, and all should be present if possible. All available documentation and data provided to the team will be reviewed and assessed for completeness. A site tour and visual inspection (including photos) will also be included as part of this meeting.

The project Vision and Framing Goals that will guide the IEMP development and recommendations will be established. The Vision should be a concise statement clearly iterating the client's (community, city, university, college, etc.) ultimate goal in undertaking the IEMP project. The Framing Goals should reflect local requirements and expectations for economic development and also consider anticipated growth and growth potential.

The Framing Goals will cover all of the City's or University's desired results in the areas of Economic Development, Reliability, Energy Efficiency, Environmental Performance, Economic Performance and in the case of an academic institution, Educational Value.

In some communities these are based on global benchmarking. Guelph, Ontario used Stockholm as its emissions' benchmark, Holland Michigan used Mannheim, and Arlington, Virginia used Copenhagen. A major community college in Ohio used a pool of Austrian Colleges and Universities as a performance benchmark to establish its campus goals. Using global benchmarks is still relatively rare in North America, which often results in targets that fall well short of what is clearly achievable. A key part of the consulting role is to challenge the community to embrace world-class performance, while recognizing their potential attainability.

Any previous studies, along with current land-use and infrastructure planning are reviewed in the context of the IEMP Framing Goals and included in its development, where applicable. Last but not least, the kick-off establishes a comprehensive list of data requirements.

Base Case Review

(Figure 1 – Steps 3-6)

Following the review of available data at the Kick-off Meeting, and possibly additional data gathering as needed to fill gaps, a Baseline Assessment will be prepared showing the current energy picture for the community or University. This Baseline will include a combination of specific and generalized, or proforma, modelling and mapping of the energy use in all buildings, industrial facilities and other end-use functions such as street lighting. This can range from a few tens of buildings on a campus to many thousands in a city. This will be integrated with models of the thermal and electrical distribution systems and the current fuel supply. Transportation energy use is estimated from all available data on individual and mass transit vehicles and journeys. This Baseline will then be benchmarked at the building, vehicle, journey and community level against local best-in-class examples from the U.S., Canada and global best-in-class, typically from the EU.

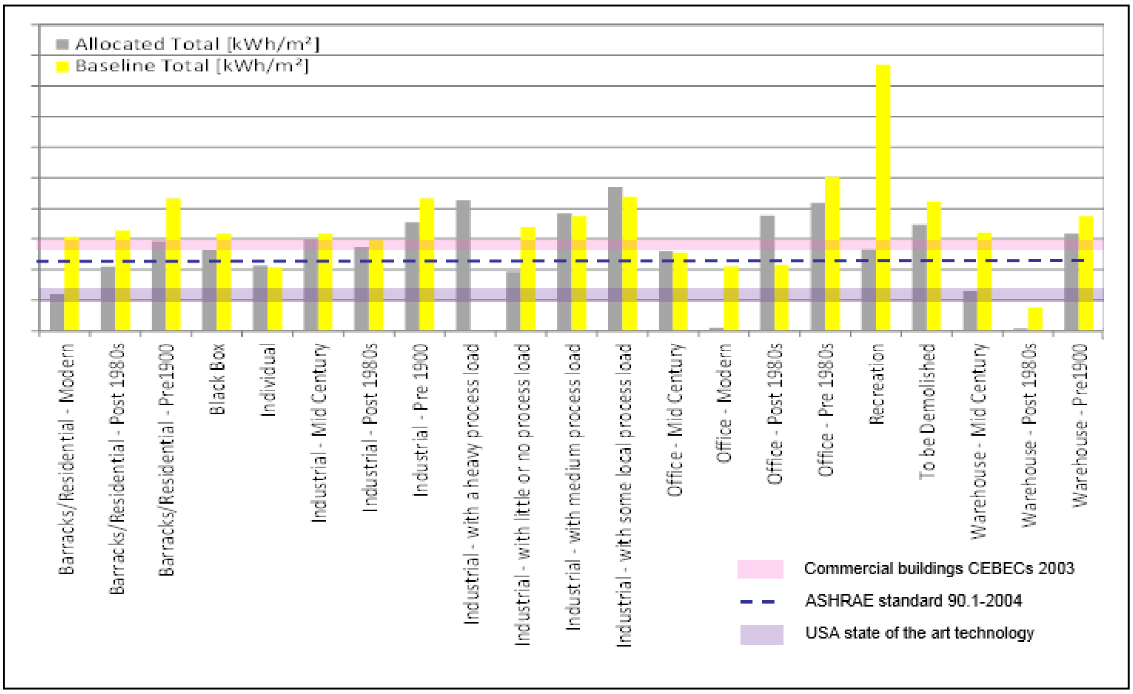
In the next step, a business-as-usual forecast will be developed covering the same time horizon as the IEMP. This assumes the community's approaches to supply, distribution and use of energy will remain as it is today. This is the IEMP Base Case. It will take into account any relevant plans for demolition, new construction and other spatial plans. It also includes an assessment of the impact of expected economic development and employment of energy use especially in industry commerce and transportation. The Base Case also includes an assessment of the potential energy and carbon pricing risks, typically using a lower and higher outlook evaluation based on current market values and normal rates inflation. The Base Case will act as the reference against which all alternative scenarios and recommendations can be measured in terms of efficiency, investments and emissions.

Generalized Modeling & Mapping of Building Energy Use

Generalized modelling plays an important part in creating a basis for analyzing the city's energy needs as well as trialing efficiency measures to see how far they contribute the Community Framing Goals. Generalized energy modelling still requires complex energy models for each building type, but a relatively small number of them. The community could consist of hundreds of thousands of buildings. It would be impossible and unnecessary to model each individually. The building stock is divided into similar functional categories, such as office, hospital, single family home and so on. It is also important to divide these categories further into age of building. In most communities there will have been development waves where the community has grown, therefore it can be quite clear what age category most buildings fall into. It is also important at this point to consider the building codes that were in place over the age of the town and categorize building types accordingly. This helps to give more detail to the generalized models and create age categories.

Once the categories have been decided generalized energy models are built. These are built with the same precision as an individual building model would be but instead of exact data given by drawings or specifications, the inputs are calculated assuming the building was built to code at the time, generalized schedules are made using studies for that type of building. Each building is adjusted to fit with the climate of the city and the general assumptions made about the building. All models are then run under the weather file closest to the city or campus and the data is collated. The energy use calculated by the energy model can be output divided by use types within the building (heating, lighting, cooling etc.) this is useful for further matching and calibrating to any available metered data. In future phases of the IEMP specific energy conservation measures cam be added to the models to calculate potential energy savings. Figure 4 shows an example of generalized modeling results with 20+ building categories from a complex large-scale military facility with over 120 buildings.

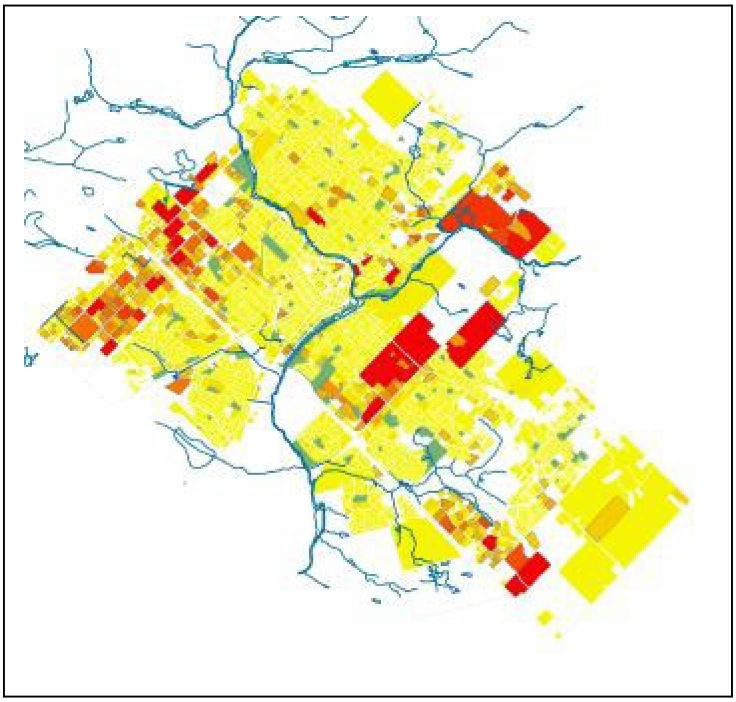
Figure 4 – Generalized modeling data against allocated data and benchmarked.



Communities are large and encompass many buildings, and statistical laws apply. Generalized modelling works well because it can be assumed that the worst performing buildings in a category will be equalized by the better performing buildings in the same category. For community-level IEMP this analysis makes sense. Obviously, as the IEMP move into implementation certain groupings may need more detailed modelling. As was the case in the City of Guelph, Ontario, when a community decides to incentivize single family home renovation, generalized modelling will again be applied but with the categories widened to accommodate more variations.

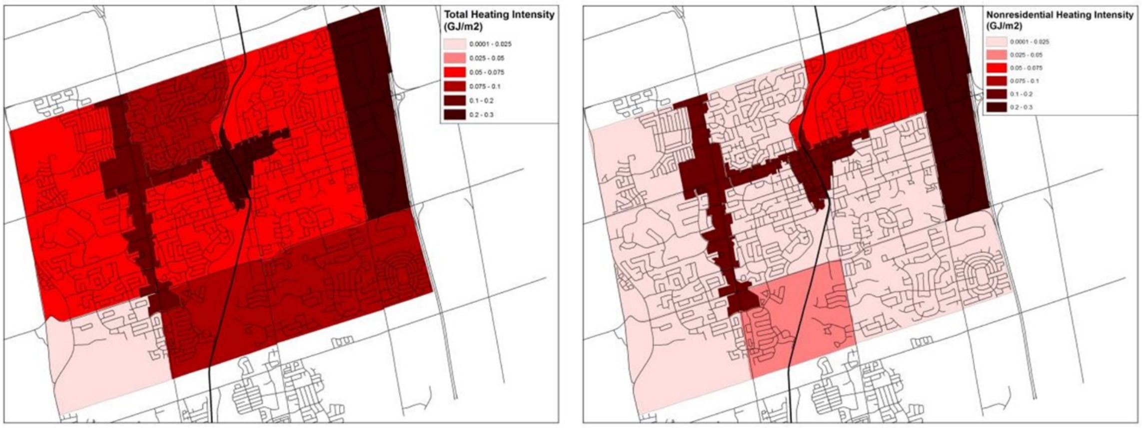
Generalized modelling creates the basic building bricks for energy mapping. This mapping can be used to visualize this data as detailed as per parcel or building. These maps can help the team to pin point areas of energy density. Figure 5 shows an example of this energy mapping for the City of Guelph. Each parcel in the GIS data represents a building, each parcel was given its allotted baseline annual heating energy in MWh taken from the generalized modelling and the results have been mapped. The lighter yellow is lower heating energy the dark red is high heating energy.

Figure 5 – Thermal map of the baseline heating energy for the city of Guelph.



This parcel based modelling can be aggregated to identify neighborhood energy use. Figure 6 shows areal heating intensity for the Town of Newmarket, Ontario for energy planning districts (neighborhoods) used to develop the municipal IEMP.

Figure 6 – Example of Heat Mapping by Neighborhood and User Class



The map on the left show the total heating intensity, the one of the right separates out non-residential heating needs. These maps formed the basis to ultimately recommend the implementation of new district heating services in three neighborhoods of the community.

Future Scenario Development

(Figure 1 – Steps 7-13)

Following completion of the Base Case, a number of possible integrated scenarios will be developed to be postulated for further detailed analysis. Each distinct scenario will be an integrated balance of energy use, distribution and supply. The technical and economic assessment of each scenario is detailed enough to allow the merits and challenges of each to be clearly evaluated. Most importantly the degree to which the various scenarios meet the Framing Goals will be analyzed. The Scenario best fitting ***all*** the Framing Goals will form the basis of the IEMP recommendations.

In developing the Scenarios, Energy Conservations Measures (ECMs) will be developed and modelled for each building type across the building inventory of the community. Similarly, the ECMs for transportation energy use which include rethinking neighborhood design and transport mode choices will be modelled. The expected industrial and heavy commercial energy use for both building and process functions will have ECM's applied and modeled.

The energy distribution options will be modelled as well and will be timed and sized to be consistent with the ECM modelling results. Finally, energy supply portfolio alternatives will be integrated into this analysis and will be modelled for each scenario, once again being timed and sized to match the ECM modelling results. Options for renewable supply (Solar PV, wind, etc.) will typically be included in the overall integration model in to assess their effectiveness in any scenario. It is critical to follow the loading order, as outlined before: first, energy efficiency; second, energy reuse/recovery, and third, renewable energy options. Each fully-integrated scenario will be analyzed relative to the Base Case, including the lower and higher pricing outlooks, in terms of energy balance, emissions balance, investments and financial key performance indicators. They will also be assessed in their contribution to economic development including such things as local employment and inbound investment.

The results of each scenario will be compared against all of the Framing Goals. The scenarios may then be adjusted depending on the degree to which they match the Framing Goals, striving to find the best match. Alternatively, the result of the analysis may conclude that one or more Framing Goals are fundamentally unrealistic and may need to be adjusted, provided that the overall Vision for the project is not significantly jeopardized. The scenario that yields results closest to the Framing Goals will form the basis of the IEMP Preliminary Recommendations. These recommendations will be summarized and presented in a highly-detailed integrated format, and will include, at minimum, the following elements:

- Building efficiency measures for all buildings from beginning to the end of the plan for each building category
- Transportation efficiency measures
- Industrial efficiency measures
- Heating and cooling distribution structure
- Electricity distribution infrastructure
- Evolution of utility and on-site thermal energy supply portfolio
- Evolution of utility and on-site power supply portfolio
- Customized energy and other utility services for specific customer groups such as industry
- Institutional structure of energy services supplies to the site including ownership along with regulation of quality and prices
- Policy or incentive structure to ensure efficiency and supply expectations are met
- Policy or incentive-based energy zoning structure to ensure customer connections, especially as it related to thermal services.
- Energy performance measurement, oversight and reporting and community engagement

Large Scale Energy Audits

(Figure 2 – Steps 14-17)

Once the generalized IEMP has been established, some groupings of buildings in the city may be identified for more specific assessment. This is typically in cases where one or more buildings are significant energy objects, do not necessarily fit in any of the general building categories or where anomalies from the generalized modeling cannot be explained. It may also be where a community is planning a short term modification or renovation and the IEMP needs to be more specific in this particular case in order to provide concrete advice or guidance to inform urgent design decisions.

Once complete, the results from these detailed audits will be transferred into the integrated recommendations, with adjustments being made to the existing generalized Scenarios. The revised community integration will be assessed to determine if they still meet or exceed the Framing Goals. ECMs may be added or removed at an individual building level in order to achieve the best overall results for the IEMP. The final modelled results for these buildings will then be incorporated into the integration workbook tool, allowing for the full economic analysis to be completed, now including the detailed building energy audits.

This mixture of using individual building models and generalized modelling techniques can help validate the modelling assumptions in the generalized IEMP. This also creates specific role models for other similar buildings as the plan proliferates across the community or campus. It will provide a solid database for future renovations and building commissioning. Ensuring that the ECMs are applied to the building inventory as recommended will not only enhance the effectiveness of the IEMP through on-going efficiency measurement verification and operational diagnostics, but this will also ensure that the buildings operate at optimum levels for their expected lifetime.

Final Recommendations and Business Case

Once the IEMP integration is complete, a detailed summary will be compiled and used to guide a comprehensive Leadership Review. This should be a high-level meeting including all relevant stakeholders and decision makers. The results of the various scenarios and options are reviewed along with a preliminary recommendation by the PWT. These recommendations will be finalized following community leadership and stakeholder feedback.

The next step would then be the formal approval of the IEMP by the community leadership (See Figure 2 – Step 21). For a municipal IEMP plan, this would typically be a formal vote to approve by the elected leadership. At this point the IEMP will be considered final and the process towards implementation should begin as soon as possible in order to maintain positive momentum.

Because the IEMP is developed on a year-by-year basis and includes financial analysis, market structure and policy evolution, it should be a relatively simple next step to create an actionable implementation plan. It is important to understand that the integrated energy master plan with its recommendations is a well-rounded menu, and not a buffet. The implementation of single measures is not validated in its own, but whether it supports the achievement of the IEMP framing goals and targets in their entirety. A comprehensive and truly integrated IEMP plan typically recommends transformational measures that lead to energy use and greenhouse gas emission reductions of 50% and more in a typical North American community with sound economics.

IEMP Example - Community

Guelph Ontario Community Energy Plan and District Energy Strategy (2006 – ongoing)

In 2006 the authors worked with the City of Guelph, Ontario to complete their ground-breaking Community Energy Plan (CEP), following the approach outlined above. From the start of the CEP process, the targets and implementation was actively benchmarked against German, Swedish and Danish best practices. The CEP was unanimously adopted by the City Council in 2007 as the energy policy for the City through to 2031 and beyond. [6]

The Vison for the plan was as follows:

Guelph will create a healthy, reliable and sustainable energy future by continually increasing the effectiveness of how we use and manage our energy and water resources

The overarching goals were:

- Guelph would be recognized as a location of choice for investment
- Guelph will offer a variety of reliable, competitive energy, water, and transport services will be available to all
- Energy use per capita and resulting greenhouse gas emissions will be less than the current global average
- Energy and water use per capita will be less than comparable Canadian cities
- All publicly funded investments will visibly contribute to meeting CEP goals

The specific Framing Goals were:

- Competitive energy services as measured by cost for key customer classes
- 50% less energy use per capita
- 60% less GHG emissions per capita
- Population grows by 50% using less energy than today

The initial CEP (or IEMP in the context of this paper) recommended a comprehensive set of implementation sub-strategies:

- Enhanced building efficiency
    - All construction – new and retrofit
- Energy Performance Labels
    - All construction – national pilot
- Transport efficiency
    - Urban design and vehicle choices
- Heat recovery and integration
    - New District Heating infrastructure
    - Industrial and other sources
- Clean & Renewable Supply
    - Biomass and Solar Photovoltaic in large scale
- Extensive Combined Heat & Power
    - New energy services supply company

The details are clearly beyond the scope of this summary paper.

Beginning in 2013, the community launched the detailed CEP sub-strategy to develop developing Guelph's detailed District Energy Strategic Plan [7]. The process use was similar to that described for a community wide IEMP, but more specifically focused on the creation of a new district heating and cooling system, along with associated institutional and market structures.

Guelph is the first city in North America to announce and publish a plan for a city-wide thermal energy network, allowing for multiple buildings to connect and share a central energy supply. Within a few years, the goal is for the new thermal utility to serve the entire Downtown, a major new Industrial Park and some satellite growth nodes. Within 20 years, the goal is for the District Energy system to serve at least 50% of the City's heating needs and a large part of the cooling needs.

All aspects of the District Energy Plan including investment and institutional approaches, as well as technical implementation, were benchmarked against Danish and German best practices.

As part of the CEP the District Energy Strategic Plan is a key step toward creating a reliable and sustainable energy future for the community and sets a path to improve how thermal energy—heating and cooling—is generated, delivered and used throughout the community.

In January 2014, Guelph formally announced that they are beginning to build North America's first city-wide district energy network [8]. The first few hundred meters of the Downtown network was completed in late-2013 connecting an arena and a major entertainment center, with connection to neighboring residential and non-residential buildings expected shortly.

In 2013, the Ontario Government announced a new energy planning policy for the Province that gives an elevated role to municipal energy and climate plans. They specifically cited Guelph as an example of best practice for other cities to follow.

IEMP Example - College

Sheridan College Integrated Energy and Climate Master Plan (2011-2012)

Sheridan College, Ontario, Canada has 2.1 million square feet of buildings on two campuses in the cities of Oakville and Brampton. It is developing a new campus in Mississauga. Significant growth is expected on all three campuses. In 2012, the Office for Sustainability and the authors jointly developed an Integrated Energy & Climate Master Plan (IECMP) to substantially reduce long-term economic and environmental risks surrounding energy use at the College looking forward to 2030. The academic goal of the IECMP was to use Sheridan as a 'living laboratory' to develop curricula and become a Canadian Centre of Excellence in energy and climate planning and implementation.

The IECMP took a fully integrated view of Sheridan's energy use under different efficiency, distribution and supply scenarios to arrive at the final recommendations. In 2011, Sheridan spent $4.4M on natural gas and electricity, a 42% increase since 2005. This was forecast to rise to between $7.5M and $10.6M by 2030 depending on the potential risk outlook used. Energy caused 9,700 metric tons of GHG emissions in 2010, creating an additional annual cost risk of over $200,000. Sheridan's energy use was typical by US and Canadian levels, but between 40% and 100% higher than comparable EU colleges. Final targets were established using German A-rated levels as guiding benchmarks.

Using similar detailed computer modelling and mapping, the impact of different efficiency retrofits and improved energy management practices were assessed, along with the possibilities for more efficient thermal and electrical energy distribution and alternative energy supply options.

The IECMP recommends investing $31M over the coming 5-7 years in a plan for comprehensive energy and greenhouse gas reduction solutions on all three campuses. The investment plan comprises campus-wide control and metering, building efficiency retrofits, upgraded and expanded heating and cooling distribution, on-site heat and power generation and extensive solar PV applications. To ensure these investments deliver their full potential, the IECMP also recommends measures to engage the entire college population – students, staff and faculty – in energy and climate management on a continuing basis. New campuses and buildings will be built to at least LEED Gold standards with energy performance separately specified to meet systematic global best practices, even if these are higher than LEED goals. The plan was approved in 2013, and then validated by an independent third party, and is expected to deliver the following results within a decade.

- Reduction in primary energy use of 65%
- Reduction of greenhouse gas emissions by 47%
- Internal Rate of Return on the IECMP investment portfolio of between 14% and 15%
- World-class sustainability, energy & climate educational programs

Implementation is underway on both major campuses following the recommendations of the ICEMP.

Conclusions

1. The systematic IEMP process outlined in this paper creates credible, cost effective pathways for North American communities to achieve at least 50% energy productivity gains within 15 to 20 years.
2. Integrated energy master plans (IEMPs) are a powerful tool to help communities understand and manage their energy usages.

3. By identifying value and challenges at all points in the energy value chain, the IEMP process assists in creating approaches where the investment, resources and benefit are appropriately aligned.
4. Using both local and global performance benchmarking raises the confidence of leadership that apparently breakthrough goals are more achievable than they may first appear.
5. Best practice benchmarking that includes institutional and investment comparison accelerate effective implementation and reduces overall implementation cost.
6. Global best-practice benchmarking underlines the potential cost and other competitive risks a community or college may face if it fails to operate its energy systems at world-class standards.
7. While many of the best-practices discussed in this paper are from the EU, many EU cities would benefit from a systematic municipal energy approach outlined in this paper. This could be an example of “reverse engineering” to create a new level of systematic planning.
8. An IEMP needs to be fully integrated with buy-in from the community leadership and stakeholders. Successful implementation happens over the course of several years or even decades and must be owned by all stakeholders and the community at large.
9. The IEMP relies on analysis and benchmarking to make decisions, not on opinions or emotions. It is crucial that all recommendations and decisions are based on valid data and thorough analysis that withstands questioning and attacks from critics.
10. An IEMP should be understood as a living and lived roadmap that must be translated into multiple actionable secondary plans.
11. The relatively few communities and colleges in Canada and the USA that actively team with EU counterparts to create and implement mutually beneficial breakthrough energy plans indicate an area for further development at many levels.

Much of Europe went through a major energy transformation between 1975 and 2000, which effectively doubled the energy productivity of most of industrialized Europe. North America is going through a similar transformation now a generation later. The approach described is largely a formalization of the ad hoc approaches used by more successful examples of European transformation. Europe is now facing another energy transformation that is calling for a further doubling of energy productivity in the coming 10 to 20 years. In many ways this is a greater challenge than that faced by the USA and Canada and will require detailed systematic strategic energy planning. Very few European Cities or Universities have an approved and resourced IEMP of the type described in the paper. Without such a plan, the probability of meeting the new transformational targets, as exemplified in the German “Energiewende” among others, falls significantly. The formalized IEMP approach we have found so effective will be a powerful basis to develop these plans. While the targets are different on either side of the Atlantic, the planning and implementation process challenges are the same. In effect, the challenge for today’s EU energy planners is to recreate the transformational thinking and spirit of the previous generation and get results in a much shorter timescale. Without IEMPs this will not happen. It may be time for Europe to relearn its history.

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Achieving greater energy efficiency through the transition from Net Zero Energy Buildings to Net Zero Energy Settlements

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Abstract

The transition from NZE buildings to NZE settlements requires the optimum management of the energy loads and resources through the application of solutions for the distribution network, energy storage and micro-grid control on a district level, and through an optimum climatic management of the open spaces. The development and implementation of a comprehensive, cost-effective system for Net Zero Energy (NZE) settlements is composed of innovative solutions for the building envelope, for building energy generation and management, and for energy management at the settlement level. The developed solutions will be implemented in four different demonstration projects throughout the EU, with varying climates and building types, while the results of their implementation will be monitored and analyzed. The aim of the NZE settlements' development is to achieve a reduction of operational energy usage to an average of 0-20 kWh/m2 per year and the reduction of the investment costs for the development of the system by at least 16% compared to current costs, through the employment of an approach of mass customization that will reduce "balance of system" costs. This research is carried out in the framework of a project called "ZERO PLUS" funded by the EU under the H2020 programme. In this paper, the overview and objectives of the ZERO PLUS project are presented. The case studies and technologies involved are described. The approach that will be followed in order to achieve the project goals is analysed.

Introduction

Buildings and settlements are nowadays increasingly expected to meet higher and potentially more complex levels of performance. They should be sustainable, use zero-net energy, be healthy and comfortable, grid-friendly, yet economical to build and maintain. The European Union (EU) has adopted the new 2030 Framework for climate and energy [1] which goes beyond the 2020 targets and aims at:

- a 40% cut in greenhouse gas emissions compared to 1990 levels
- at least a 27% share of renewable energy consumption
- at least 27% energy savings compared with the business-as-usual scenario

Taking into account that the building stock is responsible for a major percentage of GHG emissions it is evident that it should achieve even higher reductions and that the energy consumption and GHG emissions of new buildings need to be close to zero to be able to achieve these ambitious targets. The concept and obligation of Net Zero Energy Buildings (NZEBs) has become increasingly more important as the recast of the European Performance of Buildings Directive (EPBD) requires all new buildings to be "nearly zero energy" buildings (nZEB) by 2020, including existing buildings undergoing major renovations. The EPBD defines a nearly Zero-Energy Building as follows: "A nearly Zero-Energy Building is a "building that has a very high energy performance… [ ]. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby." Acknowledging the variety in building culture and climate throughout the EU, the EPBD does not prescribe a uniform approach for implementing nearly Zero-Energy Buildings and neither does it describe a calculation methodology for the energy balance [2].

Net zero energy communities are the next frontier in energy efficiency and sustainability. NZE Settlements with a reduced carbon footprint will play a key role in fulfilling EU's ambitious GHG reduction target aiming at drastic reductions in domestic greenhouse gas (GHG) emissions of 80% by 2050 compared to 1990 levels [3] as well as the climate change targets according to the EU strategy on adaptation to climate change which sets out a framework and mechanisms for taking the EU's preparedness for current and future climate impacts to a new level [4]. Achieving net zero at the settlement scale presents unique challenges as well as opportunities. NZE settlements should be places of advanced social progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account. They will also support the efficient use of natural resources, economic efficiency and the energy efficiency in new and existing buildings[5, 6]. The main shortcomings in the current roadmap towards NZE Buildings and Settlements are:

- Large discrepancies in targets and fulfilments among EU Member States [7]
- The use of energy efficient technologies in combination with the various energy production technologies (solar, wind and other sources of energy) to attain nearly zero-energy behavior result to a significant cost burden for the building/ settlement [7, 8]
- Delays in smart/micro grid integration that can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability, thus ensuring effective optimization of resources at neighbourhood and district level.

Significant efforts have been put into quantifying and bridging the energy, financial and environmental gaps that exist between the cost optimal combinations of energy technologies and NZEB. The aforementioned efforts show that while various innovative passive and active smart and even low cost technologies are available, their successful and optimal integration is still missing. Furthermore, although there are now some examples of NZEBs already built, which show that they are achievable there exist very few cases in Europe demonstrating the NZE concept at distinct level.

ZERO PLUS: “Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology” is an EU project in which a comprehensive, cost-effective modular system for Net Zero Energy (NZE) settlements is being developed, implemented and demonstrated in a series of case studies across the EU. In this paper, the energy, environmental and socioeconomic objectives of the ZERO PLUS project are presented as well as the methodology to achieve these objectives. The case studies and technologies involved are described. The ZERO PLUS project is coordinated by the National and Kaposistrian University of Athens.

Energy, environmental and socioeconomic objectives

The goal of the ZERO-PLUS project is to provide the market with an innovative, yet readily implementable system for NZE residential neighborhoods that will significantly reduce their costs. In effect, the project has the following six main objectives:

1. Reduce the operational energy usage in residential buildings to an average of 0-20 kWh/m2 per year, compared with the current average of 70-230 kWh/m2energy per year. The reduced energy consumption will be attained through the application of a number of technologies, including highly efficient insulation, heating and lighting, as well as automated Building Energy Management Systems (BEMS) in four selected case studies of 5300 m2of buildings.
2. Generate at least 50kWh/m2 renewable energy per year, on average, in the NZE settlement. This objective will be attained through the integration in the settlement of innovativeenergy production technologies such as Linear Fresnel Reflectors, advanced building integrated photovoltaics (biPV) and advanced wind driven energy production systems.
3. Reduce the cost of NZE settlements by at least 16%, compared with current costs. This cost reduction will be achieved through a strategy of mass customization. To achieve this objective, a modular building system will be developed that is customized and optimized according to the specific requirements of each building and settlement, yet is implemented through cost-effective industrialized processes.

1. Transit from single NZE buildings to NZE settlements, in which the energy loads and resources are optimally managed. This objective will be attained through the application of solutions for the distribution network, energy storage and micro grid control on a district level, as well as through an optimum climatic management of the open spaces in the settlement.

2. Achieve a market uptake of the solutions developed in ZERO-PLUS by the year 2018. This will be achieved through the demonstration of the solutions in four different real-life case studies across the EU under different climatic conditions, and through the dissemination and exploitation of the results of these case studies, based on a comprehensive market analysis and business plan.

3. Support the shift towards resource-efficient, low-carbon and climate-resilient buildings and districts, by enhancing the role of Europe's construction industry in the reduction of the EU's carbon footprint by almost 77kgrCO2/m2 with a total 408 tonnes CO2 offset for all ZERO-PLUS case studies.

Overall approach and methodology

The challenge of significantly reducing the costs of NZE settlements will be achieved through the implementation of three parallel strategies:

- Increasing the efficiency of the components directly providing the energy conservation and energy generation in the NZE settlement.
- Reducing the "balance of system" costs through efficient production and installation processes.
- Reducing operational costs through better management of the loads and resources on a district scale rather than on the scale of a single building.

In order to achieve the objectives described in the previous section a work plan has been set up including the following activities:

- State of the Art on NZE and Positive Energy Settlements: Initial Preparation and Collection of Data in the Four Demonstration Sites
- Development of an innovative Process Information Modelling (PIM) approach which will be implemented for the planning, simulation and optimization of the off-site production and onsite assembly activities and for the integration of innovative building envelope components
- Design and optimization of solutions applied on the building scale, for on-site and nearby-generation of renewable energy, for energy conservation systems, for building energy management systems and for highly efficient heating ventilation and air conditioning systems
- Design and optimization of solutions for net-zero energy neighbourhoods at the district scale.
- Integrated Design and Optimisation of the Zero Energy Settlements providing integrated solutions based on the outcomes of the three previous activities,which are adapted to the local climate and site, using energy optimisation techniques and Life Cycle Assessment (LCA) approaches
- Verification of the performance of the solutions through a building commissioning process and their implementation in demonstration projects.
- Monitoring of the settlements and verification of the energy performance, development and implementation of solutions for automated and cost-effective maintenance of the installed equipment, and an analysis and minimization of the differences between predicted and actual energy performance
- Accelerating significantly the speed at which NZE buildings and their systems are taken up by the market and end users.

These activities will be implemented by an international consortium, composed of 16 partners from the academia and the industry, who will work together in a number of areas. More information can be found on the ZERO PLUS website: http://www.zeroplus.org/

The ZERO PLUS technologies

The ZERO-PLUS system is an optimized, integrated, readily implementable system for cost-optimal NZE settlements constituted by a number of advanced, beyond the state of the art, energy technologies (Figure 1).System components are customized and optimized for each case-study. Standardized interfaces allow for flexibility of the system and optimized collective performance, as different components can be interchanged or adjusted. The energy technologies composing the ZERO-PLUS system are divided into the following five main categories:

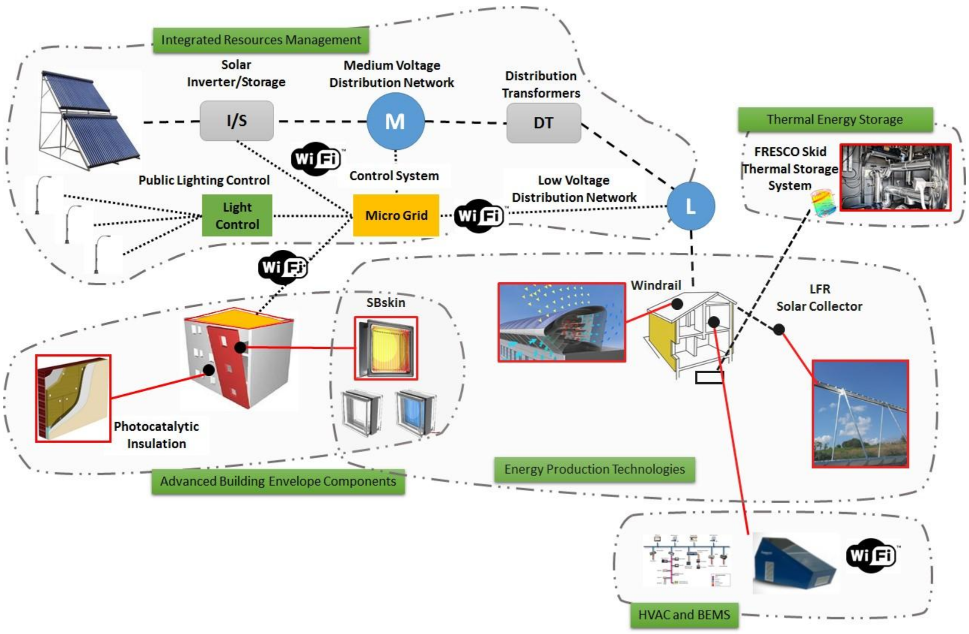

Figure 1: Synoptic diagram of the components of the proposed system

Envelope Components. Innovative, composite cool- thermal insulating material based on the new generation of extruded polystyrene (XPS) will be installed on the building envelope. The component provides, through one light composite material, improved vapour permeability (lower water vapour diffusion resistance factor μ) and cool materials properties which contribute to lowering the demand for cooling, GHG emissions and mitigating the UHI. The final layer is either a) a ceramic tile (for flat surfaces) with high solar reflectance and either high or low emissivity coefficient that makes it appropriate for a variety of climatic conditions or b) a coating with high solar reflectance (for vertical surfaces), infrared emittance and photocatalytic properties that apart from the cool material benefits has also self cleaning properties. Thus, the material is lighter and is suitable for new and existing buildings; it minimizes the construction costs because of the decrease in the required layers and the easier construction method.

Heating Ventilation and Air-Conditioning. Compact solar thermal driven air-conditioning systems will be exploited to meet the cooling demand and, where possible, the heating demand of the buildings. This technology is based on a new solar Desiccant Evaporative Cooling concept. The smallest unit has a solar collector surface of about 2 m2, providing the necessary electricity to drive the system, and gives 2.7 kW of cooling power, while the maximum power absorbed is 150W. Furthermore, Wireless Sensors Networks coupled with model based predictive control algorithms will enable indoor comfort management by the building occupants but also the interconnection with the integrated resources management component.

Energy production. Three innovative energy production technologies will be considered for the ZERO-PLUS system. The first energy technology is precast, dry-assembled and pre-stressed translucent biPV glass components made of Dye Sensitized Solar Cells (DSC) capable of performing as an active and passive system simultaneously. These cells will be applied to translucent building façades and roof installations. The second technology is a compact Linear Fresnel Reflector (LFR) for polygenerative applications based on solar energy concentration. The possibility of a tight coupling of flat PV panels on the reverse side of the mirrors allows for flexibility in energy generation. Finally,WindRail®, a building-based modular wind turbine system will be considered. The system efficiently harnesses the energy of the wind, by exploiting the pressure differences around the building and the solar radiation to generate electricity. WindRail® modules are designed to also enable integration of other building based technical solutions such as HVAC systems.

Thermal storage. A complete and integrated solution for the storage of heat coming from high performance solar fields and its transformation into cold by absorption chillers will also be part of the system. A thermal storage system composed of pressurised oil storage, temperature sensors, inverter pumps and 3way valves will be used to help manage the temperature and to maximize the storage efficiency. The system is designed to increase the overall efficiency of the whole system and to control the hot fluid feed into the chillers according to the quantity of available energy. An integrated control system verifies the density of energy stored and gives the signals to control the solar collector tracking system.

Integrated Energy Resources Management. Medium Voltage (MV) and Low Voltage (LV) distribution networks with micro grid capabilities will be combined with public lighting control and solar inverter/storage. This integrated system will provide the capacity to safely integrate more renewable energy sources, smart buildings and distributed generators into the network; deliver power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; use automatic grid reconfiguration to prevent or restore outages (self-healing capabilities), and enable users to have greater control over their electricity consumption and to actively participate in the electricity market.

The ZERO PLUS case studies

The ZERO-PLUS system will be developed, implemented and demonstrated in four settlements across the EU. The settlements have varying climates, micro-climates and building types thus maximising the possible impact on the building industry and market uptake of the solutions. The four case studies are described below:

Peyia, Cyprus. The settlement is situated on the outskirts of Peyia a village in the south-west region of Cyprus. The site is a hillside adjacent to a pine forest and very close to the Sea. The residential part of the development includes 123 autonomous plots spread in 323,608m2 of total land area. In the framework of ZERO-PLUS two autonomous plots of approximately 1,700m2, including individual houses with an area of about 500m2, will be constructed and monitored. In parallel, the main open spaces of the settlement and in particular the main square and the area around it will be constructed to improve microclimatic conditions.

Voreppe, France. The French case study is located in Veroppe, a small town15 km North-West of Grenoble. The ZERO-PLUS case study is an apartment building of around 1400 m² of inhabited area consisting of 20 dwellings for social renting. It is integrated in a larger program including 28 additional dwellings for social selling.

Novafeltria, Italy. The Italian settlement is located in a residential- commercial area of Novafeltria in the Rimini province. The total area dedicated to the Italian NZE settlement, including public spaces, is approximately of 30,000 m2. This area will include four residential single-family villas of total gross area of 130 m2 each distributed into an approximately rectangular ground sub-lot of more than 400 m2.

Derwenthorpe, York, UK. Derwenthorpe is a mixed tenure community in the outskirts of York which when complete in 2019, will consist of around 500 new family homes. The scheme is being built in four phases; the first phase of 64 homes was completed in 2013. Through ZERO-PLUS three properties will be transformed into near zero energy homes. The properties will be located in Phase Four of the development, and will demonstrate the next generation of low energy and low carbon homes.

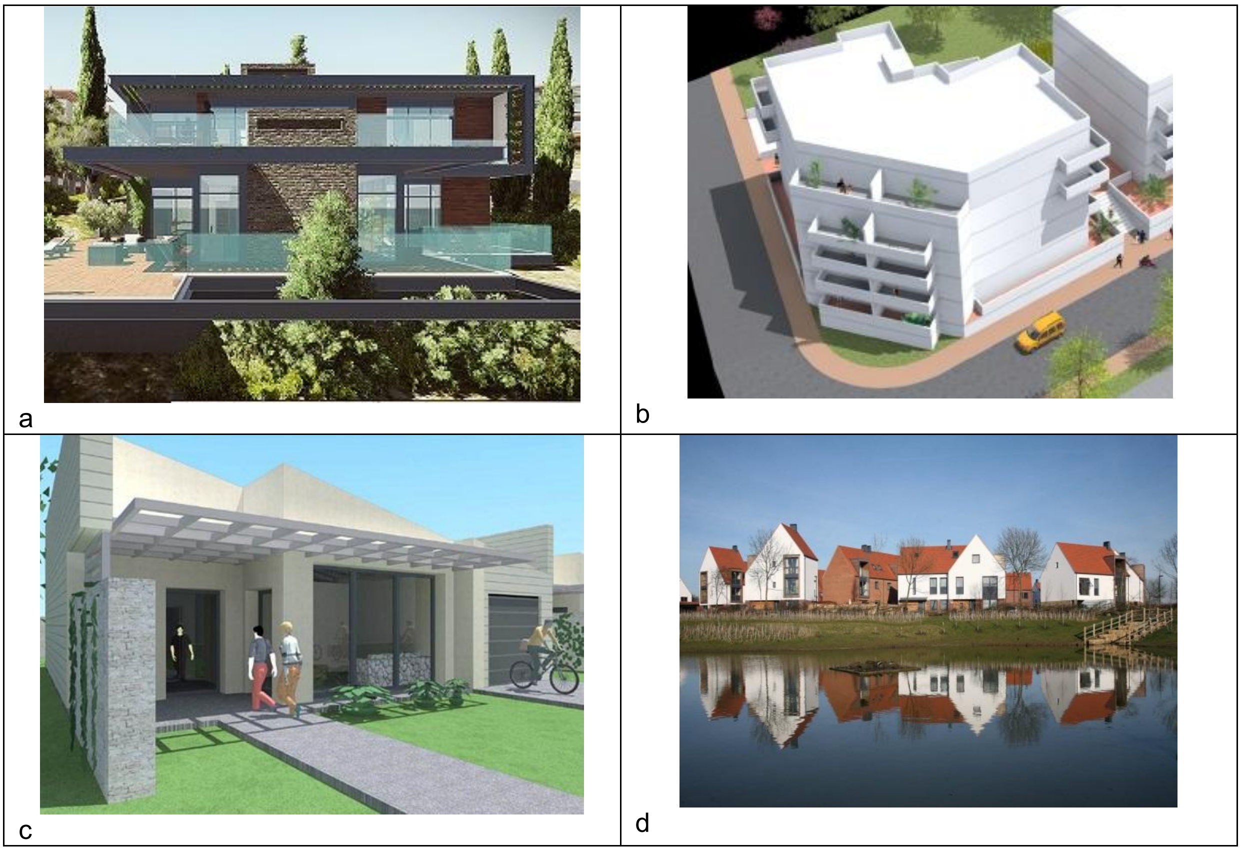

Figure 2: ZERO-PLUS case studies in a) Cyprus, b) France, c) Italy, d) UK.

Conclusions

At present and during the following years the building design community and building professionals in general will be challenged by mandatory codes and standards that aim to improve the buildings energy and environmental performance in order to achieve the targets of EU's energy efficiency and environmental policies like the 2030 targets and the objectives of the climate strategy as laid down in the low carbon economy roadmap 2050. The ZEB principle is anticipated to contribute significantly towards the achievement of the future smart cities, envisioned by the European Union and promoted through its regulatory framework. The Horizon 2020 project "Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology" (Acronym: pictureZERO-PLUS) described in this paper, meets the challenge to develop a comprehensive, cost-effective modular system for Net Zero Energy (NZE) settlements to implement and demonstrate it in a series of real life case studies across the EU.

Acknowledgments

This work has received funding from the European Union Horizon 2020 Programme in the framework of the "ZERO PLUS project: Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology", under grant agreement n° 678407.

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Operational Efficiency of the UK Community Energy Ownership Models

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Abstract

Community Renewable Energy Projects (CREPs) are emerging form of energy governance system that have contributed substantially to a reduction in the global threat posed by Climate Change and Energy security. However, an understanding of the relationships or impacts of operational efficiency of the various Community Energy Project Ownership Models (CEPOM) on successful delivery of CREPs in the UK could generate more positive impacts. It is important to conceptualize these relationships theoretically in a framework so as to further enlighten Community Energy Groups (CEGs) on how aspects of their individual CEPOM's operations/activities can be improved for effective CREPs delivery. Therefore, the main thrust of this paper is to present a theoretical framework that captures the link between efficient CEPOM and CREPs optimal performance. Three theoretical concepts are employed in the development of a theoretical framework that connects groups of effective ownership model indicators to aspects of the model improvement and their impacts on CREPs Outcome.

The framework highlights the importance of competent internal management structures, availability of project administration and management expertise and timely external supports for the UK community energy groups as a precursor to organizing successful CREPs with optimal performance in line with expected environmental, social and economic outcome.It is expected that the conceptual framework will assist CEGs to systematically accommodate any unforeseen institutional deficiencies within their traditional approaches to CREPs development.

Keywords: Community, Renewable Energy Projects, Ownership Models, Operational Efficiency, UK.

1 Introduction

The subject of community (local) involvement in Renewable Energy activities is one of the most active areas in energy research today (Walker and Devine-Wright, 2008). Place-based activities towards environmental sustainability are not new, although the approaches are different (Slack, 1990, Schreuer and Weismeier-Sammer, 2010). Emphasis on such activities in present times tends to be more on Community Renewable Energy Projects (CREPs). According to Alvial-Palavicino et al. (2011), CREPs are integral part of an overall global micro renewable energy generation program aimed at decentralizing the sustainable generation and consumption of environmental goods. There is no doubt that major decisions on energy investments are taken centrally by the national Government of most countries (Sperling et al., 2011). The Centralized Energy Systems (CES) has been criticized by Bouffard and Kirschen (2008) for failing to recognize that people are keen and eager to become part of the system and to understand how things works and not be mere economic logs. Moreover the system is exposed to intermittent interruptions due to its lengthy and complicated supply chain (Alanne and Saari, 2006).

Manfren et al. (2011) submit that irrespective of the controversies associated with CES, the system does not impede local involvement in Renewable Energy (RE) activities and that local authorities and municipal councils still controls environmental and climate issues (Bouffard and Kirschen, 2008, McLaren Loring, 2007) in some parts of Europe.

The case of Denmark is a typical example, where local authorities promoted the Danish citizen's participation in implementing and owning energy projects in the late 1970s (McLaren Loring, 2007). The Danish energy sector road map targets the year 2050 to generate all her energy from renewables. In the meantime, a quarter of all the electricity consumed in Denmark is from wind owned by the community (McLaren Loring, 2007). Evidently, 80% of these wind energy systems is owned locally through community partnership (Devine-Wright, 2005), putting Denmark as one of the World leaders in wind energy development.

Similarly, Germany is determined to switch to renewable for at least 80% of her total energy demand before the year 2050 (Lehr et.al, 2012). Approximately 8% of Germany's energy consumption was from Renewable sources as at late 2005 (Ringel, 2006). This achievement was traceable to the competing commitments of the community groups. Spain on the other hand recorded a 14% contribution to its total energy demand from renewables in spite of the prolonged domination and monopolization of the sector by larger Energy companies (González et.al, 2007).In the UK, it appears that the newly introduced Renewable Obligation (RO) supports centrally governed energy system (Connor, 2003). That notwithstanding, locally organized energy has delivered 508MW of Energy to many homes and businesses in Scotland alone as at late 2015 (Young and Georgieva 2015), and the multiplier effects which includes reduction of community carbon foot prints, could lead to attainment of UK's carbon emissions reduction targets.

While a variety of definitions of the term Community Energy (CE) have been suggested (Walker and Devine-Wright, 2008, MacQueen et al., 2001, DECC, 2014), this paper will use the definition suggested by the UK Department for Energy and Climate (DECC). DECC (2014), sum up Community Energy to mean diverse groups and the various responsibilities undertaken by the groups to ensure that local people accept and participate in small scale Renewable Energy projects and also benefit from positive environmental, social and economic outcomes of the project activities. This can be either temporary or permanent group of enthusiastic individuals generating, purchasing, managing energy and or promoting efficient use of energy.

From the above definition, it can be deduced that local participation and leadership in Energy matters is an important aspect to deploy renewables towards the fulfilment of global carbon emission reduction pledges by many Nations. This paper therefore present a theoretical framework that captures the link between efficient CEPOM and CREPs optimal performance in the UK. Throughout this paper the term CREPs, CEPOM, CEGs and CREPO will refer to Community Renewable Energy Projects, Community Energy Projects Ownership Models, Community Energy Groups and Community Renewable Energy Projects Outcome respectively. The following sections in this paper will describe the methodology, present reviews on CREPs, CEPOM and further discuss the importance and use of the theoretical framework.

2 Methodology

In order to develop a theoretical framework for operational efficiency of the UK Community Energy Project Ownership Models (CEPOM), literatures on factors affecting project success and the various Models deployed were reviewed. Drawing on the reviews, a list of recommended indicators for effective project operations was defined. These indicators are then organized under aspects of CEPOM that can affect CREPs performance. Lastly, the group of indicators are used to developed a framework to support future operational activities of Community Energy Groups in the UK

3 Review on Community Ownership of Energy Projects and Models Employed

According to McKee (2007), community ownership implies a change in management control, rights, and privileges over an asset, infrastructure, and services from a centrally governed authority to a relatively more decentralized market and people oriented authority in the form of a long, free or short lease. Research by Fafchamps, and Quisumbing, (2002) indicates that proper local community engagement in ownership and management of public assets can yield positive benefits. In the energy sector, citizen's ownership of energy projects can be traceable to energy revolution in Denmark and Germany (Rechsteiner, 2008). Prior to this revolution, European Energy policies were designed to foster the fossil fuel dominated Centralised Energy System (da Graça Carvalho, 2012).

Walker and Devine-Wright, (2008) summarized that the different forms of community-led and community based ownership of energy projects are aimed towards establishment of a unique process of energy sector governance that fosters Citizen's participation, acceptance of the projects and creation of awareness on dangers of Green House Gas (GHG) emissions. In spite of the uniqueness of Community Ownership of CREPs (Walker and Devine-Wright, 2008, Walker and Simcock, 2012), It still faces criticism. Bolinger (2001) raised concerns about the future of the energy market, in particular the future uncertainties within the Renewable Energy market and its long term performance. He revealed that if the community becomes leading figure in provision of energy services without competition, this according to him could lead the Community Energy Groups into influencing the prices of energy and becoming reluctance towards changing market demand.

In another study, Schreuer and Weismeier-Sammer (2010) pointed out that so far, there is no empirical evidence on the best Community owned REP, in other words ownership and governance model of CREPs depends on several factors. Ownership models for setting up rural electrification have been in used in Germany since early 20th century (Shamsuzzoha et al., 2012). The models usually comprise network of professionals, volunteers, interested individuals and investors with a shared vision of getting involved in the planning, organization, implementation and ownership of Renewable Energy Projects (Walker and Devine-Wright, 2008).

These models are numerous and as such, not all would be covered in this paper, however, the legal models commonly and widely used in setting up energy projects within the UK and other EU states would be identified for this study. The popular forms of partial or full CREPs ownership range from an individual's ownership of a solar panel on a domestic building to commercially organized Social Enterprise, Cooperatives, Development Trusts, Community Charities and Community Interest Companies. The selected models reviewed in this paper are as contained in the UK Community Energy strategy report published by Department for Energy and Climate (DECC, 2014).

Regardless of the ownership structure, whether it is designed and organized to give full ownership of projects to the community, (Khan et.al, 2007), or just sense of ownership (Schreuer and Weismeier-Sammer, 2010), the models are overwhelmingly recognized as a platform for achieving an overarching goals of CREPs which includes helping the locals reduce energy use, tackle climate change, and end fuel poverty amongst many other benefits.

Projects goals and objectives can easily be achieved when the organizational management system and their operational activities are aligned to the overall project objectives (Hsueh and Yan, 2011, Bailis et al., 2007). Furthermore, it can be argued that in the process of delivering CREPs, local participation, derived benefits, models of ownership and cost of project vary from place to place.

These varying features make it difficult to conclude that a particular model is more effective than another in delivering successful CREPs and moreover a template for periodic review and assessment of CEPOM operational activities is missing in research. The various models identified above are briefly examined below.

3.1 Community Energy Project Ownership Models (CEPOM) operational features

Social Enterprise (SE) Model is regarded as being innovative in breaking new grounds in business. It is registered either as a not-for-profit or for-profit organization. Its core principles however is centered on ensuring that the socio-economic and environmental needs of the people they represent are met. They achieve this by engaging in people centered and community oriented activities, services and projects. According to Mulgan et al. (2007), SE is the best model for building a successful collaboration with external entrepreneurs for the benefit of the community. Bridgstock et.al, (2010) reports that there are approximately over 50,000 SE in the UK with annual turnover of £26.7billion. However, there are no clear literatures on how shareholding, CREPs execution and other activities are conducted in SE. Similarly, the cooperative ownership model seem to share some objectives with the SE model in the area of service delivery to its members. This objective also aligns well with CREPs principles of keeping development, operations, ownership and benefits of the project within the community. The social values and core principles of the cooperative model encourages equal rights and opportunity in decision making and profit sharing amongst participants based on one man one voting right. It is not surprising that the model has been the most adopted and widely employed for community ownership of REP.

According to (Willis and Willis, 2012), membership strength of Cooperatives all over the UK is over 900 million while about 90million locals are gainfully employed by these Cooperatives as at 2014. It is important to state that there are no convincing empirical evidence to proof the availability of sufficient technical, administrative and project management capacity to undertake CREPs using this model. In other words the cooperative model may be relying on external experts for CREPs delivery.

In contrast to the Cooperative model, Community Trust (also known as Development trust in Scotland) does not emphasize equal rights among members but however supports local investors and non-investors alike to benefit from the CREPs. It functions as a medium for attracting wider environmental, social and economic CREPs gains to the entire community. The model is structured such that no individual or group can lay claim its ownership. The daily administration and decision making are preserves of a democratically elected board of trustee (BOT). Development Trusts have been at the fore front of promoting Scotland's Community Energy activities (CES, 2014), but not without grants and other supports from the Scottish Community and Renewable Energy Schemes (CARE). The next model is the Community Interest Company. In the UK, Community Interest Companies (CIC) are not registered as charity but have the status of a not-for-profit organization. CIC relies more on external funding for its operations and uses the funds generated to pursue both commercial and social objectives of the community. According to Chew (2010), this aspects of CIC operations have post great risk to its existence. However, its activities are closely regulated by an independently registered assessor. As with cooperative model above, there are also no empirical evidence on local skill availability in CIC for CREPs execution. The last model of ownership identified for this study is the Community Charities (normally in the form of a Housing Association) that acts on behalf of low income group. They assist members in securing affordable accommodation in Estates managed by the association, and meeting any other special needs of this category of tenants. According to Saunders et al. (2012), the law, permits tenants to be accepted into the membership cadre and even governing board of the association through democratic means. Egmond et al. (2006) also opined that a well-organized board can access loans to execute projects for the benefits of other tenants in the estates. However, these models have shortcomings which are detailed in the section below

3.2 Common CEPOM Pitfalls that necessitates framework Development

Drawing on DECC (2014)'s definition of CREPs, the focus of each ownership model should be to keep the development, operations, ownership and benefits of the CREPs within the community and to also encourage equal rights and opportunity amongst participants , as these are some of the main attractions for local participants. A careful study of the cooperative model revealed that the organizational, structural and operational efficiency of the model is one of the key determinants of its success in CREPs delivery (Bender, 1999; Viardot, 2013). This however does not mean that there are no drawbacks in deploying the model. While the Cooperatives model promotes equal rights, opportunity and profit sharing (among many other incentives), above several other models, it is however criticized for being associated with huge administrative burden (Schreuer and Weismeier-Sammer, 2010). Recently, some Community Energy representatives and support providers in the UK revealed that lack of data, easy access to finance, grid connectivity and planning consent are the major limitations faced by all the models (CES, 2016; CEE, 2016). Furthermore, Harnmeyer et al. (2015) reported that generally, CREPs is characterized by a prolonged preplanning activities. This view supports Warren and McFayden (2010)'s assertions that the main challenges confronting CEGs in the sector is in the area of securing funds and planning permissions for CREPs development.

On the other hand, Parthan et.al, (2010); DECC, (2014) and Walker et.al, (2010) maintained that CEGs can overcome these challenges by partnering with private developers in addition to the provision of favorable financial and policy supports by the Government (Walker et.al, 2007). It is fair to say that, until these drawbacks are addressed, commercial developers will continue to dominate the Renewable Energy market. One way to address these drawbacks is by identifying each model's efficiency indicators and the key aspects of the ownership models that can be enhanced. There are a number of these indicators that can influence the operational efficiency of CEPOM. These indicators according to (Zhao et al., 2010, McLaren Loring, 2007), although not exhaustive are listed below:

1. Competitive Business Case
2. Control over Principal/Agent interest
3. Access to Grants/ Funding for the Project

4. Risk Management Skills/Strategies
5. Identification of Local needs
6. Track records of Directors
7. Knowledge of the Sector
8. Incentive Programs
9. Extensive Feasibility Studies
10. Project scope definition
11. Procurement approach
12. Site(Land)ownership
13. Project Management expertise
14. Market share
15. Access to industry information/practices
16. Favorable Regulatory Frameworks
17. Expert advice on emerging trends
18. Local membership route/criteria
19. Equipment supply and maintenance
20. Availability of local skills/expertise
21. Contractor selection criteria
22. Project Environment
23. Communication Management

The CEPOM efficiency indicators listed above are further classified into three groups thus: Organizational Management related, Project related and External indicators. One may argue the basis for such classifications; the above classification is based on the aspects of CEPOM enhancement it addresses, although most of the classified indicators are interrelated and depend on each other to be relevant, the impact of each in enhancing CEPOM's efficiency is unique. For instance, some aspects of external factors may not necessarily constitute risk to Partnership model as it does to the Community Interest Company Model. This is because complementary skills, competence and experience in the industry are major considerations in a partnership business relationship. Also, the incentive programme (as part of Management and Board of Trustee enhancer) can equally influence the construction and administration of project operations. It is important to state that the classification is meant to draw attention of Community Energy Groups (CEGs) in the UK to the importance of a formidable internal top management and project team with vested knowledge of external local and global barriers and drivers of effective Community Energy Project ownership. On this premise, the need for the development of a theoretical framework that captures all the indicators and their impacts on the various ownership models is important. It is expected that the framework will be an improvement to aspects of current models deployed for CREPs delivery in the UK. The framework is presented and discussed in the next section

4 Theoretical Framework Development and use

Conventionally, every project is said to be distinctively different based on the peculiarity of its location, client, the project team and so on (Andersen et al., 2006). This is entirely true of CREPs; the risk appetite, administrative procedures and the process of organizing start-up funds vary greatly. Furthermore, most CREPs are unable to supply their local area with electricity generated from the projects because CEGs are not registered as energy suppliers in the UK. Consequently, the local authorities and elected members could become resistant if they don't feel involved.

This theoretical framework therefore is based on the considerations for setting up ownership models that can overcome these challenges. The considerations rely primarily on the owner's, consumer's and investor's interest such as tax exemption, access to clean electricity, bill reduction, and self-sufficiency; and community benefits like job creation, climate resilience and GHG emission reduction.

Although the Cooperative model has overwhelmingly become the most attractive model for organizing CREPs in Europe, the positive attributes of the model could be combined with outlined CEPOM enhancement indicators to further strengthen other models for effective CREPs delivery. In particular, the theoretical framework (See Figure 1 below) is developed for the enhancement of the UK CREPs ownership models. It is to be used by CEGs whose ownership model is constituted legally for non-profit distribution and whose operations are within a defined geographical location. This is because these groups of people are mainly volunteers who face challenges of raising funds to start up or sustain projects.

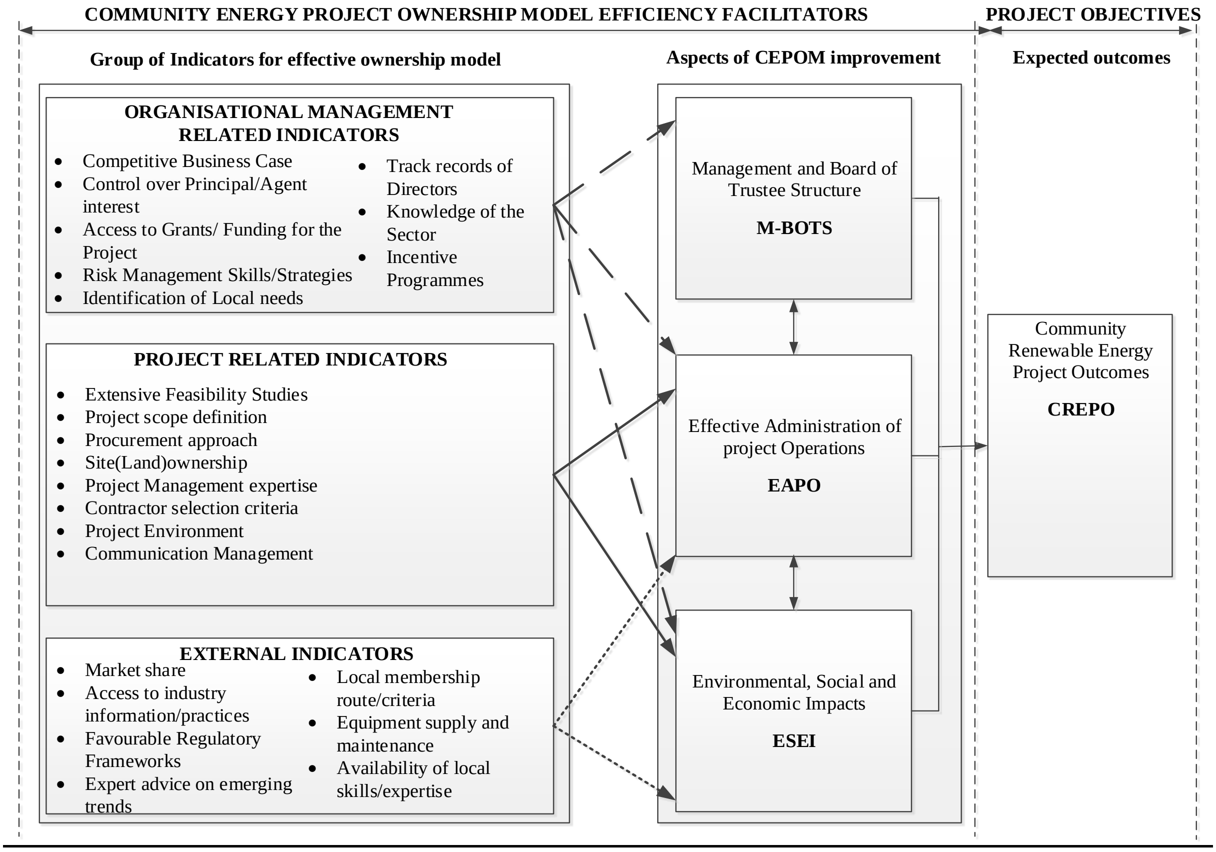

Figure 1: Theoretical Framework for enhancing Models of CREPs ownership

The framework above highlights the connections between group of CEPOM enhancement indicators, aspects and CREPs outcomes. The Community Renewable Energy Project outcomes (CREPO) is presented here as the objective of the CEPOM improvement process, while Management and Board of Trustee Structure (M-BOTS), Effective Administration of project Operations (EAPO), Environmental, Social and Economic Impacts (ESEI) are considered as CEPOM enhancement facilitators. The various groups of CEPOM enhancement indicators, aspects of enhancement and expected project outcomes are discussed in subsequent sections.

4.1 Discussion on components of the Theoretical Framework

4.1.1 Organizational Management Related Indicators

Since CREPs is an emerging energy governance system, the ownership models are vulnerable to internal management failure that may result from incompetent management and project teams. Management incompetence on the other hand may be caused by external influences such as lack of adequate technical support, funding, and unfavorable regulatory regime. CEPOM as an organizational setting for CREPs development and management thrives on a formidable and competent top management structure. Although in most CREPs, top managers, shareholders and funders are not part of the daily running of CREP operations, they however have significant power to influence major decisions.

Cooper and Kleinschmidt (1986) stated that every project is a product of someone's idea, but before the idea can be appreciated by potential investors and sponsors, it must be developed into a structured and convincing business case. According to Dyllick and Hockerts (2002), a good business case should be able to communicate the project needs as well as expected returns on investment. In addition, as a fundamental principle of setting up community organizations, the representatives of the local people (agents, e.g. CEGs Board of Directors) are expected to put community interest before self-interest.

There are instances where an agent (a board member) working for a principal (Community Energy Group) may be tempted to undermine the collective interest of the community since there are no personal incentives accruing to the agent. This is possible in partially owned or partnership models of ownership (Feiock et.al, 2009). Partial ownership models is common in wind energy projects where the community is allowed to own a few turbine in a large wind turbine site developed and managed by commercial developers. The incentive to the commercial company is the access to community land while the community benefits from energy generated from their turbine. Obviously one would not expect the commercial company to provide more support to the community turbine over theirs. Interestingly, CREPs conceived and implemented to meet local needs such as population (Dasgupta, 1995), fuel poverty reduction (Foster et.al, 2000), and social cohesion (Del Río and Burguillo, 2008), tends to attract more local acceptance which is a sure way to building local resilience.

The management and Board of Trustee of the model therefore must show the will power to check principal/Agent interest among top managers and ensure the project is profitable, and financially stable. Effective management of project operations and capacity to deal with bureaucratic obstacles is also an important attribute deserving of the top managers. Above all, members of the model are expected to be experts in Renewable Energy Sector with essential project management skills.

4.1.2 Project Related Indicators

The group of indicators for determining successful project delivery according to Bowen et al. (1997) varies based on the technical features of project. For instance, there are multidimensional approaches to procuring CREPs, while technology procurement is straight forward, the consulting, professional and specialists services procurements costs a lot (CEH, 2016), particularly when there are no capability in the organization to provide these services. Depending on project specification and duration, the costs of keeping specialist/professional service providers may extend Pay Back Period in situations where the bidders lead the pricing instead of working with project budget.

Furthermore, for CREPs to be delivered within expected time, costs and quality, the initial investment decisions should be based on access to accurate industry and project information (Fritz, 1984). This is where feasibility studies covering sector and specific project risks, investor's need, project specifications, market and sector analysis becomes necessary. The ability of the CEGs to develop convincing business case is a function of in-depth feasibility studies (Dalton et.al, 2009). Likewise, project participants must understand that the project environment is not just about the project site (Kelsey et.al, 2001), but entails organizational, cultural, political, social and the physical environment (Youker, 1992). According to Foxon et.al, (2005), most wind energy developers in the UK do not rely on turbines manufactured locally. Large wind turbines with generation capacity above 100Kw to 1MW of electricity are imported from either the US, Spain, Germany, India, Denmark or France. Often times, the installers are dispatched from foreign manufacturers to work abroad. Working in a different country requires an understanding of the local project environment.

Another important environmental consideration for CREPs delivery is land ownership. Community land ownership related obstacles are not common in the UK because the UK land reform legislation (Dwyer, 2011) confers rights on communities to own and manage land for the benefit of the community. This rights favors community and not commercial owners, however before the approvals is granted for community projects, justifiable local contributions and convincing business case is required by the Ministerial approvals board. This further reinforces the importance of business case. The construction process of CREPs comprises a long supply chain of equipment manufacturers, installers, designers, developers and so on. It is also the most important phase of the project as soon as planning permission and funding is secured. Therefore any involvement of locals in this phase will place heavy demand on local skills and the respective ownership model top management. It is the responsibility of the top managers of these models to ensure there is sufficient technical, administrative and project management capacity to undertake CREPs. Also, the choice of a contractor in a conventional construction project is determined by the contractor's competence in delivering the project within a specified cost, time and expected quality (TCQ). On the contrary, CREPs in addition to TCQ also emphasizes that the project must be environmentally friendly, socially cohesive, economically viable and sustainable for the locals.

4.1.3 External Indicators

These groups of indicators have indirect, yet very critical impacts on the functionality of CEPOMs and the performance of CREPs in the UK. The CREPs sector depends largely on external grants and funds for its programs, this means that for the market to be fully established and sustained, the sources of supply of grants and funds must be guaranteed, because a prolonged cut in cash flow can render the project moribund. Also, increasing technology innovations, national regulations, legislations and changing market conditions have long term implications on the survival and outcome of the project. Although full local ownership of the project is emphasized in CREPs, the increasing project demands highlighted above have compelled the local community's dependence on external inputs to fully achieve project goals. Worthy of note is the fact that the CREPs sector is becoming highly competitive, therefore an understanding of indicative financial performance of the project over a period of time can provide insights on competitive market advantage or otherwise. Again the continuous growth of the CREPs sector depends on consistency of regulatory frameworks because excessive tax burdens can interrupt project operations (DECC, 2014). The UK Government have been supportive in this regards by admitting CEGs activities and projects into the Enterprise Investment Schemes (EIS) and Social Investment Tax Relief (SITR). The major incentive of belonging to these schemes is that members are exempted from paying full business tax (Wüstenhagen et.al, 2007). Unfortunately, there are plans by the UK Government to exclude CREPs from the scheme in 2016. CEGs are putting forward strong case and resistance to continue in the scheme (Horne, 2015). If at the end the Government succeeds in excluding CEGs from the schemes, there will be a decline in scale of local participation in CREPs. Whilst the inputs of external commercial and technical experts is appreciated in promoting CREPs, the gradual diffusion of CEPOM with the practices, methods and procedures of these external aid providers must be checked to ensure that both local members of the Energy Groups and non-members are not neglected.

4.1.4 Aspects of CEPOM Improvement

The aspects of CEPOM improvement (Management and Board of Trustee Structure – M-BOTS, Effective Administration of Project Operations – EAPO, and Environmental, Social and Economic Impacts – ESEI) may be similar for all models. The importance of each indicator (Organizational Management related, Community Renewable Energy Project related and External influences) varies from one ownership model to another. It is expected that Community Energy Groups (CEG) will make necessary adjustments (introduce local conditions congruent to the project) into their chosen model before organizing CREPs. However, the framework is only a guide to CEG on what aspects of the model to prioritize. The practicality of the framework would be further validated as the research progresses, it is expected that many more indicators and aspects of CEPOM improvement maybe identified from survey and interviews to be conducted in the coming months

4.1.5 CREP outcomes (CREPO)

CREPs underpinned by sustainable long term investment plans could scale up local businesses and investments. In addition, the returns on investment from the projects are used for projects to meet other community needs other than energy over and above development of local skills and job creation. It is also important to clarify that the key aspects of the ownership models can only be enhanced when the various enhancement indicators are holistically considered and responded to by the top management

5 Conclusion

This paper proposes a theoretical framework for the enhancement of the UK CREPs ownership models. In particular, the framework is designed for use by CEGs whose ownership model is constituted legally for non-profit distribution and whose operations are within a defined geographical location. This is based on the author's assumption that these groups of people lack innovative solutions to their organizational and project management operations in addition to the fact that template for periodic review and assessment of CEPOM operational activities is not common in research. Drawing on the reviews of factors affecting project success and the various Models deployed for CREPs development in the UK, Three theoretical concepts are employed in the development of a theoretical framework that connects groups of effective ownership model indicators to aspects of the model improvement and their impacts on CREPs Outcome. The framework highlights the importance of competent internal management structures, availability of project administration and management expertise and timely external supports for the UK community energy groups as a precursor to organizing successful CREPs with optimal performance in line with expected environmental, social and economic outcome. It is expected that the conceptual framework will assist CEGs to systematically accommodate any unforeseen institutional deficiencies within their traditional approaches to CREPs development. This paper is part of an ongoing PhD research; therefore further work will be focused on collection and analysis of primary data to refine or validate the Framework.

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Crowdfunding in the energy sector: a smart financing and empowering tool for citizens and communities?

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Abstract

Crowdfunding in the energy sector responds to the pressing need of improving access to capital to support worldwide transition to a sustainable, low-carbon economy and to the spread of community energy approaches, conductive of greater participation of citizens and communities in distributed renewable energy projects. Crowdfunding platforms are empowering financing tool as besides pooling capital as factor of production can turn consumers and citizens into participatory actors, as well as investors. They are thus potentially able to expand the applicability of shared ownership and civic approaches in energy investments, aggregating financial resources as well as people on specific energy projects. This is an exploratory study into the nature of this emerging sector presenting results of the first worldwide systematic review of energy crowdfunding platforms. A particular attention is given to the structures of investors' involvement and benefits in order to gauge to which extent crowdfunding has been used as a participatory tool, to support community energy and, more widely, participation of citizens to energy projects. Evidence presented shows an emerging and empowering financial tool for investments in the energy sector. Initially developed as a socio-technical practice for shared ownership and community energy approaches, it is already showing signs of scaling up and of turning into a new viable business model for distributed energy investments.

1. Introduction

Crowdfunding is an innovative form of alternative finance which allows a project, an organization or a company to raise money from the general public for seed finance, products development or social causes through open calls via the internet. It is a relatively new phenomenon, mainly driven by the reduced access to capital for new investments to citizens and firms due to the financial crisis since the second half of the 2000s and to the possibility to reach a large public with a relatively low cost thanks to the web. Despite its novelty it is becoming a valuable alternative source of funding for entrepreneurs and innovators [1], increasingly recognised by institutions [2-5] and has recently attracted the interest of academic scholars. The academic literature on the topic is only nascent, with most of the peer reviewed research so far focused on investigating crowdfunding from a business and management point of view, with a particular attention to the role of crowdfunding in financing the development and growth of small and medium-sized enterprises, such as start-ups and innovative ventures. Several contributions have analysed either entrepreneurs incentives to use crowdfunding [6, 7] or sponsors' motivations to invest [8-11], or the dynamics behind success and failure of crowdfunded ventures [7, 12-14]. This paper takes a different perspective by assessing the potential of crowdfunding as innovative financing tool in a specific sector: the energy industry. It does so by providing the first worldwide systematic review of energy crowdfunding platforms with the objective of providing a reference analysis to policy makers, regulators as well as finance, energy industry and general public stakeholders about the state of art of this emerging sector.

The use of crowdfunding in the energy sector begins in 2012 as response to reduced investments (both governmental and private) into the transition to decarbonized energy systems [15] and to the spread of community energy approaches, conductive of greater participation of citizens and communities in distributed renewable energy projects. The strong transformation in the energy systems since the late 90s (due to restructuring and liberalisation of the industry on one hand and the need to decarbonize energy systems by increasing the proportion of renewable distributed generation on the other) has allowed smaller size investments (than centralized generation plants) and the entrance in the energy market of new generators and investors (including citizens, local authorities, small firms) previously set outside of the industry mainly dominated by large energy companies [16]. Decentralised energy is now part of governments' and societies' 'localism' agenda, as citizens, communities, firms, local authorities and other public sector organizations can become energy producers and not only 'passive' users of a service delivered. As such, they could fully harness benefits and incomes originating from energy investments implemented in their premises and territory. Indeed, the last decade has seen the increasing development of community energy and shared ownership approaches for investments in the energy sector worldwide [17-20]. These approaches are new business models and structures conductive of greater participation of citizens and communities in energy projects, as such are a form of democratization of energy investments and policy. However, it has been pointed out how such community led schemes are often under-resourced [21] and lacking of sufficient access to finance to scale up activities [22].

A distinctive feature of crowdfunding, besides pooling capital as factor of production, is its potential of turning consumers and citizens into participatory actors, as well as investors [6-8]. Such characteristics make crowdfunding platforms a potentially powerful tool to expand the applicability of participatory approaches in energy investments, as it can aggregate financial resources as well as people on specific energy projects. However, the benefit for the investor of the participation in the crowdfunding mechanism can change considerably according to the type of crowdfunding model chosen and the type of projects proposed [6]. Therefore, the aim of this paper is to provide a thorough analysis of the application of crowdfunding to the energy sector by looking at how the different crowdfunding models have been used, for which type of projects and how they have performed to date. A particular attention is given to the structures of investors' involvement and benefits in order to gauge to which extent crowdfunding has been used as a participatory tool, to support community energy and, more widely, participation of citizens to energy projects.

The paper sets the context in Section 2 by providing an introduction to crowdfunding including an overview of different crowdfunding models and of recent market developments. In Section 3 the methodology used for data gathering is described. Section 4 presents results of the worldwide review of energy crowdfunding platforms. Section 5 concludes with discussion of the findings.

2. What is crowdfunding

The concept of raising money through general public is not new in socio-economic systems (e.g. fundraising is a well-developed practice in the not-for-profit sector [23]) and crowdfunding falls within a wider group of financing options (including microfinance and impact investing) which have emerged over time as alternative finance mechanisms [24].

What specifically characterizes crowdfunding is the use of internet and dedicated web platforms to raise money. This has been made possible by the widespread adoption of information and communication technology (ICT) and the progressive increasing use of technology-enabled social networks to interact and connect online[1]. Crowdfunding campaigns are based on web platforms where projects are presented to the public and beneficiaries of the funding can communicate and engage with their community of potential donors or investors, and through which people can donate or invest money. As highlighted by several contributions [7, 26, 27], crowdfunding is a financing evolution of crowdsourcing, through which needed services, ideas or content are developed by soliciting contributions from a large group of people, and especially from an online community, rather than from traditional employees or suppliers [27]). As in the case of crowdsourcing, it provides a way for people to directly connect to projects proponents, without standard financial intermediaries [14]. Crowdfunding is thus a form of democratization and disintermediation of financing made possible by the use of internet and social networks which allow people and potential investors to directly browse and investigate investment options. As such it can be an empowerment tool, positioning people at the centre of economic and financial processes. This process is made easier in energy related initiatives by the smaller size of investments in new energy technologies based on renewable sources.

Crowdfunding is not only an alternative source of funding for entrepreneurs and project proponents, allowing to raise funds for projects that could find hard to be financed through institutional channels. Crowdfunding platforms are also powerful communication tools, as they allow full transparency and open communication on projects, enabling investors, stakeholders and communities to engage with the project proponents, get involved and monitor progress over time. Crowdfunding has in fact increasingly been used to test new products and to launch marketing campaigns, as consumers and investors can not only benefit from rewards offered by project proponents, but also actively participate to online communities, sharing information and providing suggestions [8, 14]. Indeed, it has been suggested that it is rightly the social information and the possibility of direct interaction between project proponents and potential investors which mainly determines the success of crowdfunding campaigns [14, 28].

Crowdfunding models and market developments

There exists several types of crowdfunding models and several classifications have been produced by previous contributions [1, 3, 5, 29]. For the purpose of this study crowdfunding platforms are grouped in two overarching categories (Figure 1), which differentiate themselves on the basis of the relationship between those who provide financial resources and those that receive the funds (i.e. recipients):

1. Non-financial or donation crowdfunding, where individuals' contributions are not associated with a financial return and;
2. Financial or investing crowdfunding, where financial instruments are sold in relation to companies assets and/or financial performance.

Non-financial crowdfunding can be pure calls for *donations* which are given without expectation of any financial returns or benefit, thus relying on altruistic motives. Typical donation campaigns are run for charitable or public interest causes. Another form of non-financial crowdfunding is the *reward based* model where individuals provide capital to support a project in exchange for some kind of benefit or award; such award could also be the product that will be produced with the capital collected (typical examples are musicians who raise funds to record an album in exchange of the copy of the album once released). Reward based crowdfunding has also been used extensively by businesses and innovators, often as a tool to assess demand for a new potential product or service by raising on crowdfunding platforms capital for pilot design and production. Examples of renown reward platforms are Kickstarter and Indigogo based in the USA; e.g. Kickstarter alone raised in 2014 more than half billion dollars from over 3 million of investors and has launched extremely successful campaigns such as Oculus Rift (which raised over $2 million) and Pebble (which raised over $10millions) [30].

[1] As of January 2014 it is reported that around 74% of online adults use social networking sites. 25. Pew Research Center, *Social Networking Fact Sheet*, in *Available at: http://www.pewinternet.org/fact-sheets/social-networking-fact-sheet/*. 2014.

The main financial crowdfunding models are *lending* and *equity based*. With lending crowdfunding funders receive a debt instrument that specifies future terms of payment, usually a fixed rate of interest. Lending platforms can be peer-to-peer (i.e. lending among individuals) or peer-to-business (i.e. lending to support a business activity). With equity crowdfunding funders receive an equity instrument or a profit sharing arrangement. In this case investors have a stake in the company financed and can participate of business activities and risks. The returns on the investment are dependent on the company's performance, thus potentially higher than the case of lending, but also accompanied with a higher risk.

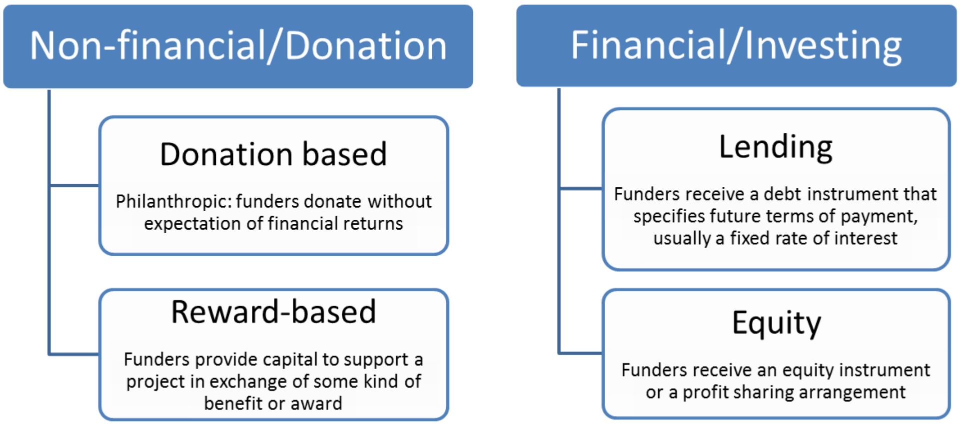

Figure 1. Overview of major crowdfunding models
Source: Author's elaboration

Apart from some pioneering initiatives in the early 2000's (such as lending platform Zopa in the UK in 2005, equity crowdfunding platform ASSOB in Australia in 2006 or reward crowdfunding platform Produzioni dal Basso in Italy in 2005)[2] crowdfunding appears as a wider phenomenon around 2008, when reward platforms such as Indigogo or Kickstarter[3] have been launched. Since then the crowdfunding market has been steadily growing overtime. The number of platforms has been dramatically increasing worldwide as well as the funding volume, moving from about $53 million in 2010 to over $16 billion in 2014 (Figure 2).

[2] http://www.zopa.com/, https://www.assob.com.au/, https://www.produzionidalbasso.com/
[3] https://www.indiegogo.com/, https://www.kickstarter.com/

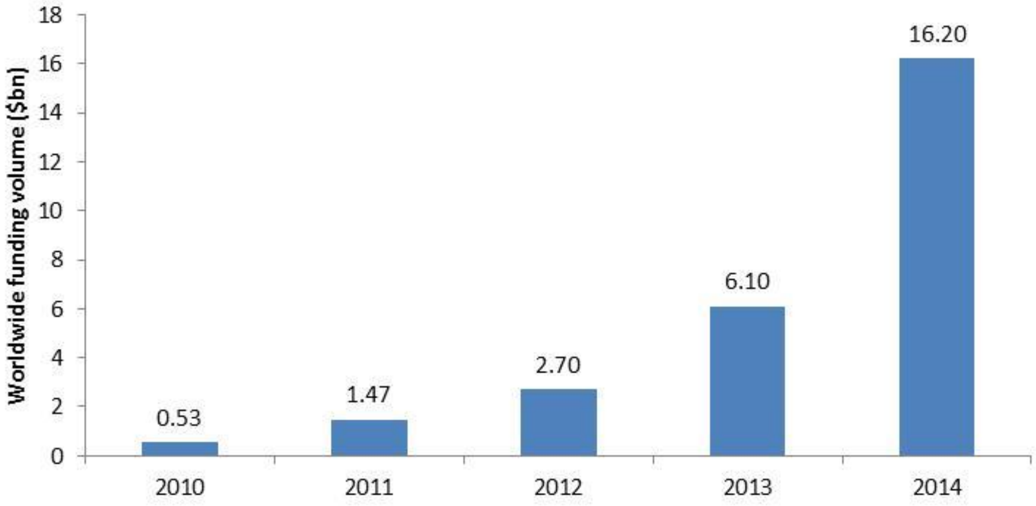

Figure 2. Crowdfunding volume worldwide in $billion
Source: [1, 31]

North America and Europe are the major markets, but the Asian market is quickly growing experiencing an increase in funding volume of 320% in 2014 (Figure 3).

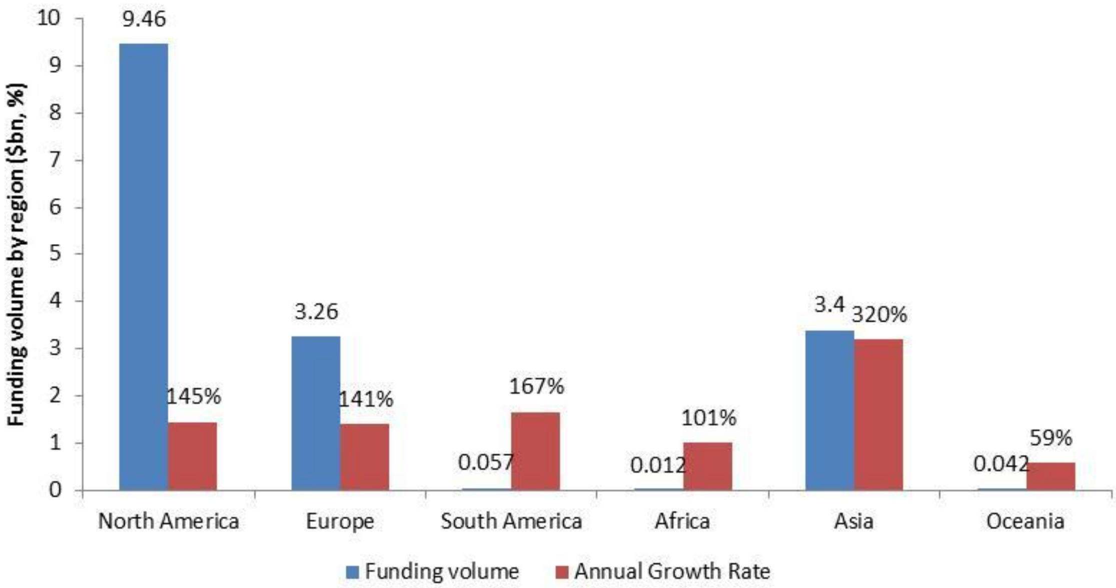

Figure 3. Crowdfunding volumes by region in $ billion, 2014
Source: [1]

The lending-based model has the largest market share and has grown most rapidly, followed by donation and reward-based crowdfunding. Equity-based as well as more novel models such as hybrid and royalty based ones are recently gaining more traction (Figure 4).

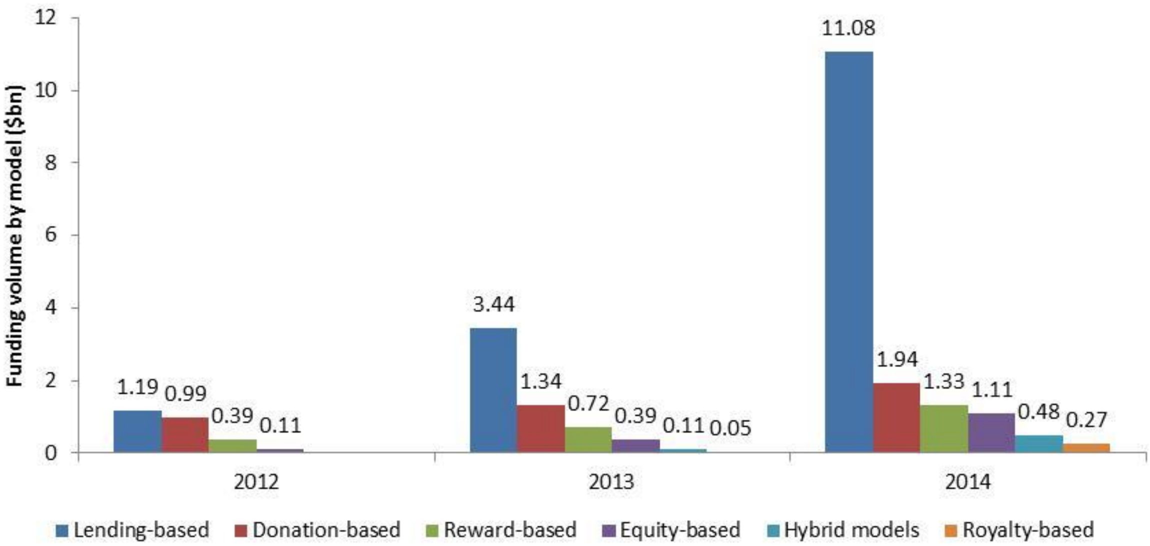

Figure 4. Funding volumes by crowdfunding model, $ billion, 2014

Note: Hybrid models are platforms that offer one or more crowdfunding models on a single platform. With royalty-based model funders receive a royalty interest derived from intellectual property of the fundraising company.

3. Data and methods

The goal of this paper is to provide a systematic review of the use of crowdfunding in the energy sector. It is an exploratory empirical study of the nature of this emerging sector for which almost none evidence has been provided yet. Thus the data gathered and their analysis rather than testing formal hypothesis have the main objective of providing evidence base for future assessments and theory building. Indeed, systematic reviews are increasingly used to provide robust evidence to policy making in several sectors, including energy [32, 33]. They have to be based on explicit and transparent methodologies (which also need to be replicable and updatable) for searching and synthesising available primary research and data [34, 35]. For the purpose of this study the systematic review of energy crowdfunding is based on [34]:

- A clear definition of the scope of the analysis;
- A systematic and exhaustive searching of the available literature;
- The application of explicit criteria for the inclusion or exclusion of studies and data;
- An objective summary and synthesis of the results.

The scope of the review is eliciting evidence on the use of crowdfunding in the energy sector, with particular attention at how it has been declined across different models and how it has been performing to date. Peer reviewed primary research in this specific field is almost inexistent, thus major sources of information have been grey literature, crowdfunding platforms and websites.

Energy crowdfunding platforms have been searched for and selected through analysis of online grey literature [36-40] and systematic web browsing running Boolean keyword searches for the terms ‘energy’, ‘renewables’, ‘crowdfunding’, ‘community shares, ‘equity’, ‘solar’, ‘wind’, ‘biomass’, ‘energy efficiency’, ‘shared ownership’ . The platforms identified and included in the review have at least one project focused on energy and, if not active yet, express clear focus on the energy sector in their mission. Such systematic review has allowed identifying 42 energy related platforms worldwide. Through close read of information provided on the platforms and searches of related online literature (including crowdfunding and energy related online magazines and conferences proceedings) a data set has been constructed with platforms' descriptive data and characteristics including: country of origin, date of launch, crowdfunding model, technology focus, number of projects, money raised, benefits and returns offered to the investors. Then information and material published for each project on all active platforms (i.e. the material on each project web page) has been closed read to build up a data base of 389 energy crowdfunding campaigns, accounting for several variables including: project name; location; technology type; opening and closing date of the campaign; target and amount of money raised; type of investment offered; returns guaranteed. When information given on the platform website or on a specific project page were not sufficient, online keyword searching were run to search for additional evidence on online grey literature. Data gathered provide a static picture of the sector in October 2015, but the methodology and database produced are potentially updatable to account for progress over time of the market. The results of the systematic review are synthesized and analysed in the next sections.

4. Crowdfunding in the energy sector

The application of crowdfunding to the energy sector has been relatively recent, within the short lifetime of the crowdfunding sector itself which appeared as a wide phenomenon around 2008 when platforms such as Indigogo or Kickstarter[4] have been launched. Table 1 lists the forty two platforms searched for and identified worldwide. Apart from the pioneering experience of the German platform GreenVesting launched in the 2009, the first relevant platforms and campaigns have begun to appear in 2012 (the non-energy specific platforms such as Milaap and Microgenius despite being launched in 2010 and 2011 have both been publishing energy related projects only in 2015). Since then the number of initiatives and platforms have been increasing overtime. By October 2015 twenty nine energy crowdfunding platforms were active with projects online and thirteen new platforms were in the pipeline.

[4] https://www.indiegogo.com/, https://www.kickstarter.com/

Table 1. Platforms overview: country, launch date and technology focus

Platform	Country	Launch	Platform Focus	Technology focus
GreenVesting	Germany	2009	Renewables	Solar
Milaap	India	2010	General	Solar
Microgenius	United Kingdom	2011	General	Mix
Lumo	France	2012	Renewables	Mix
Crowdener.gy	Germany	2012	Renewables	Solar
WindCentrale	Netherlands	2012	Renewables	Wind
Greencrowd	Netherlands	2012	Renewables	Mix
Abundance Generation	United Kingdom	2012	Renewables	Mix
SunFunder	USA/Tanzania	2012	Renewable	Solar
Bettervest	Germany	2013	Renewables and energy efficiency	Mix (Mostly Energy Efficiency)
Econeers	Germany	2013	Renewables	Mix
GreenXmoney	Germany	2013	Renewables	Mix
We share Solar	Netherlands	2013	Renewables	Solar
Gen Community	United Kingdom	2013	Renewables	Mix
Trillion Fund	United Kingdom	2013	Renewables	Mix
CollectiveSun	USA	2013	Renewables	Solar
Divvy	USA	2013	Renewables	Mix
Mosaic	USA	2013	Renewables	Solar
Village Power	USA	2013	Renewables	Mix
Enerfip	France	2014	Renewables	Mix
Lendosphere	France	2014	Renewables	Mix
LeihDeinerUmweltGeld	Germany	2014	Renewables	Mix
DuurzaamInvesteren	Netherlands	2014	Renewables	Mix
Veolis	Switzerland	2014	General	Mix
Solar Schools	United Kingdom	2014	Renewables	Solar
Clean Reach	USA	2014	Renewables	Ocean energy
Re-Volv	USA	2014	Renewables	Solar
Coopernico	Portugal	2015	Renewables	Mix
GridShare	USA	2015	Renewables	Mix
Citizenergy	Europe	Non active	Renewables	Mix
Joukon Voima	Finland	Non active	Renewables	Mix
Crowd2win	France	Non active	Renewables	Mix
Benoolend	France	Non active	Renewables	Solar for rural electrification
Babyloan/Total	France	Non active	General	Rural electrification
GreenCrowding	Germany	Non active	Renewables	Mix
Ecomill	Italy	Non active	Renewables	Mix
Fundera	Italy	Non active	Renewables	Mix
Trine	Sweden	Non active	Renewables	Solar for rural electrification
Crowdgeneration	United Kingdom	Non active	Renewables	All
EnergyDonwell	United Kingdom	Non active	Renewables	Mix
Palmetto Direct	United Kingdom	Non active	Renewables	Mix
CrowdEnergy	USA	Non active	Renewables	Ocean energy

Note: 'Launch' is the online launch date of the first energy project on the platform, despite several platforms have been reported to be conceived couple of years before the date of launch of the first campaign. Unique exceptions in the list are Milaap and Microgenius General platforms: platform launch date is reported, but their first energy related campaigns have been launched in 2015.

Europe, in particular Germany, United Kingdom and the Netherlands have been the initiators of the sector in 2012, with USA following in 2013 and currently hosting the highest number of energy related platforms (Table 2).

Table 2. Number of platforms per country

	USA	Germany	United Kingdom	Netherlands	France	Switzerland	Portugal	Italy	Finland	Sweden	India
Active platforms	8	6	5	4	3	1	1	-	-	-	1
Forthcoming platforms	1	1	3	-	3	-	-	2	1	1	-

Crowdfunding in the energy sector is currently associated with and serves only clean energy investments, with most of the platforms specifically focused on renewable energy (the few non-thematic platforms listed in Table 1 have also published renewable energy projects). Platforms generally offer investments in renewables energy projects from a mix of technologies, including solar photovoltaics, wind, biomass, hydropower and, in some cases, in energy technologies startups or energy related technological research and development projects. Investments in energy efficiency projects are much less common, apart from one German platform, Bettervest, which is almost totally concentrated on them. Some platforms are instead focused on a specific renewable technology, usually structuring their project scouting and communication strategy explicitly targeted on the renewable technology chosen.

How are different crowdfunding models applied?

Over 80% of the active platforms are financial/investing platforms (twenty four out of twenty nine – see Table 3) with the remaining 20% dedicated to non-financial/donation models (Figure 5). Of the financial ones a good majority have adopted some sort of declination of the lending model (14 out of 24), some the equity/community share model (6 out of 24) and the remaining have adopted an hybrid model allowing investors to choose among different types of investing options (debt instruments, bonds, company equity or shares in local cooperatives).

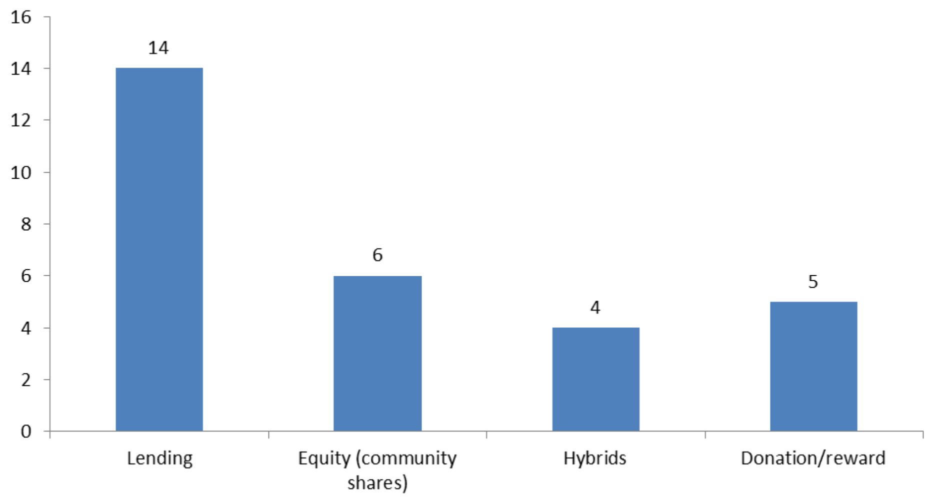

Figure 5. Number of energy crowdfunding platforms per model
Source: Author's elaboration

But let's have a closer look: Table 3 and 4 show how the twenty nine active energy crowdfunding platforms are differentiated across models and how investors' benefits change according to the model chosen.

The *lending platforms* in this context are all 'peer to business' meaning that, according to the definition above, some money is lent through the platform by the investor to support an energy related business or activity. Investments in renewable energy projects (and in few cases in energy efficiency projects) are solicited online by the platform providing the investor with a debt instrument which is then repaid and remunerated over time as a function of the revenues generated by the project. Payments of revenues are often administered by the platform itself which, in this case, acts as a sort of financial intermediary between the project developers and the wider investors (e.g. Abundance Generation, We Share Solar, Mosaic). In some cases the remuneration is variable as a function of the revenues accruing from the sale of the electricity generated by the renewable project, which vary due to both the fluctuations in the generation itself (e.g. solar, wind are intermittent and variable renewable power) and the variability of electricity selling price. In other cases the remuneration guaranteed is fixed.

All lending platforms' mission and communication strategy emphasize the ethical and environmental dimension of the initiative; a quick browsing of slogans on platforms' websites provides the best evidence for it:

- "*Investments that build a better world*", Abundance Generation[5]
- "*Working together for a better future. Crowdfunding for energy efficiency and green technologies*", Econeers[6]
- "*Enerfip, la plateforme de financement participatif pour la transition énergétique*", Enerfip[7]

However, some platforms have a stronger ethical/social connotation, either in the type of investments they offer or/and in the way they structure investors' involvement and returns. To give some examples:

- Collective Sun mainly supports solar projects development for non-profit entities, such as schools, churches, community centres and so on;
- SunFunder's mission is to unlock solar energy in emerging and developing countries to improve access to energy and rural electrification;
- Lendosphere offers higher returns to investors living in the area of the project, thus emphasizing the importance of the involvement local community in the project.

The ethical return is somehow a novelty in the energy sector, where the least cost option has been the driver since the development of the industry at the beginning of the 20th century, when scale economies made the sector a monopoly of large utilities. Today the new technical conditions make energy generation affordable for a large community of investors, including those in search of non monetary remuneration.

[5] https://www.abundanceinvestment.com/
[6] https://www.econeers.de/
[7] https://enerfip.fr/

Table 3. Financial active platforms

FINANCIAL			
Platform	**Model**	**Investor's benefit**	**Country**
Abundance Generation	Lending	% of the revenue or profit generated by the projects	United Kingdom
DuurzaamInvesteren	Lending	% of the revenue or profit generated by the projects	Netherlands
Econeers	Lending	% of the revenue or profit generated by the projects	Germany
GreenVesting	Lending	% of the revenue or profit generated by the projects	Germany
Lumo	Lending	% of the revenue or profit generated by the project, plus use of the electricity generated	France
Mosaic	Lending	% of the revenue or profit generated by the projects	USA
We share Solar	Lending	% of the revenue or profit generated by the projects	Netherlands
Lendosphere	Lending	% of the revenue or profit generated by the projects (higher % returns for investors living in the project area)	France
Enerfip	Lending	% of the revenue or profit generated by the project	France
Bettervest	Lending	% of the revenue or profit generated by the projects	Germany
GreenXmoney	Lending	% of the revenue or profit generated by the projects	Germany
LeihDeinerUmweltGeld	Lending	% of the revenue or profit generated by the projects	Germany
CollectiveSun	Lending (for no profit projects)	% of the revenue or profit generated by the project	USA
SunFunder	Lending (for rural electricifaction)	% of the revenue or profit generated by the project	USA/Tanzania
Crowdener.gy	Equity (Community Shares)	Financial returns proportional to the share owned	Germany
Gen Community	Equity (Community Shares)	Financial returns proportional to the share owned, plus surplus income reinvested in the community	United Kingdom
Microgenius	Equity (Community Shares)	Financial returns proportional to the shares owned	United Kingdom
WindCentrale	Equity (Community Shares)	Financial returns proportional to the share owned, plus use of the electricity generated	Netherlands
Village Power	Equity (Community Shares)	Financial returns proportional to the share owned	USA
Coopernico	Equity (Community Shares)	Financial returns proportional to the share owned	Portugal
Trillion Fund	Hybrid (Lending, Equity, Community Shares)	Returns vary in accordance to the finacial tool choosen (bonds, community shares, equity, funds)	United Kingdom
Greencrowd	Hybrid (Lending, Equity)	Returns vary in accordance to the finacial tool choosen (loan or equity)	Netherlands
Veolis	Hybrid (Lending , Reward)	Benefits vary: % of the revenue or profit generated by the projects (Lending) or rewards provided (Reward)	Switzerland
GridShare	Hybrid (Lending, Equity, Reward)	Benefit vary: % of the revenue or profit generated by the projects (Lending), dividends (Equity) or rewards provided (Reward)	USA

The *equity crowdfunding* platforms active in the energy sector generally offer a form of *community shares*, usually for investments in renewables projects: investors give money in exchange of shares of the legal entity making a specific investment (usually a company or a cooperative), as such benefiting from returns on the investment itself through dividend payments and acquiring rights to participate to the legal entity activities (which vary according to the form of the legal entity, e.g.

generally higher in the case of cooperatives [41]). In the case of renewable generation and energy efficiency revenues accrue respectively from the sale of the electricity produced and the savings on the electricity bills.

Most of these platforms have a strong focus on community based projects, with a strong geographical characterization and with the explicit aim of increasing and improving the participation of local communities and citizens in the renewable energy investments accruing in their territories. Platforms such as Gen Community, Microgenius, WindCentrale, Village Power and Crowdener.gy explicitly shape their mission as well as scout and structure their projects in order to empower communities by offering them a stake and voting rights in the legal entities (usually cooperatives) making the renewable energy investment. Gen Community's projects also encompass a sort of revolving fund[8] which allow to reinvest surplus income from the project into other activities of community interest. WindCentrale also offers to investors the use of the electricity generated by the wind farms thanks to a partnership with an energy supplier [42].

Finally *hybrid platforms* allow investors to choose among different types of investing options: debt instruments, bonds, company equity or shares in local cooperatives. Each of the four hybrid platforms listed have its own peculiarity. Veolis is a lending platform, which has also launched some reward based campaigns to support energy technologies startups or energy related R&D activities. Greencrowd is also structured as a lending platform, mainly raising from online investors loan to finance the construction phase of renewable energy projects; however, it also offers equity instruments to finance initial development costs and/or to fund the equity component of a renewable investment funded through project financing. In this context equity is offered as a higher risk but higher return investment. Grid share offers a combination of loan, equity and reward, within the same projects. However, from the evidence presented online it is difficult to gauge whether the platforms is fully operational as very limited money has been raised to date and none of the projects has been funded. Trillion Fund instead looks as a successful case of hybrid platforms (see also Section 2.3). On Trillion Fund investors can browse among several types of investments, including:

- lending instruments such as bonds and funds (issued respectively by renewable energy company or investment funds) and direct loan to renewable energy projects.
- Community shares: shares in co-operatives or firms serving a community purpose.
- Equity investments: Trillion Fund is the first platform to have launched a pure equity crowdfunding campaign, offering shares to capitalize Triodos Renewables, a renewable energy company developing projects across the UK.

In this case the platform acts as an intermediary, thus being responsible only for the crowdfunding campaign; payments of returns to the investment are then managed autonomously by the proponent of the project i.e. company, cooperative or investment fund.

[8] A revolving fund is a legal 'vehicle' e.g. a company or a cooperative, which funds local energy investments (by which is also repaid) whose returns are further invested in local carbon reduction investments and community activities.

Table 4. Non-financial platforms

NON FINANCIAL			
Platform	**Model**	**Investor's benefit**	**Country**
Milaap	Lending (for social value projects)	Loan without interests or repaiment - high social value project	India
Re-Volv	Donation (plus Revolving Fund)	No monetary returns for investors. The lease payments are reinvested in a revolving fund, the Solar Seed Fund, to further finance community-based solar projects	USA
Clean Reach	Donation	No monetary returns for investors. Money collected are used for testing new technologies and organize thematic events	USA
Solar Schools	Donation	No monetary returns for investors. Money collected are used by a chiarity to install photovoltaic plants on UK schools	United Kingdom
Divvy	Donation/Reward	No monetary returns. Rewards provided	USA

Five of the active platforms are *non-financial/donation* (Table 4), four of which are strongly socially oriented, providing renewable energy projects to communities and no-profit in their respective countries, and one aiming at raising funds to support technological development in ocean energy (Clean Reach).

How have they performed?

Such high variability of crowdfunding models adopted raises the question of how have the different platforms performed to date. Is there a model more successful than another? What is the success rate[9] of the projects? Is success affected by the returns offered and/or by other factors such as e.g. the ethical/social mission of the projects? Let's begin by looking at the evidence gathered on projects published to date by each active platform (data summarized in Table 5). Platforms performances differ quite substantially, in terms of both number of projects and amount of money raised. This is certainly an indication of how young and fragmented this sector still is. However, it is possible to highlight some initial trends out of the gathered evidence.

[9] The success rate is the percentage of the published projects which get successfully funded.

Table 5. Performance of active platforms

Platform	Model	Number of projects	Success rate	Average returns	Money raised €
Abundance Generation	Lending	23	61%	7.49%	13,526,367
Mosaic	Lending	20	NA	NA	5,785,414
LeihDeinerUmweltGeld	Lending	19	89%	5.25%	4,029,050
Econeers	Lending	10	90%	5.34%	3,915,150
DuurzaamInvesteren	Lending	9	78%	5.68%	2,892,000
Bettervest	Lending	31	90%	7.21%	1,774,240
Lendosphere	Lending	16	94%	5.42%	1,446,990
We share Solar	Lending	8	63%	5.75%	1,075,574
GreenVesting	Lending	9	100%	5.33%	970,950
GreenXmoney	Lending	13	85%	4.54%	277,550
Lumo	Lending	6	67%	3.00%	185,000
Enerfip	Lending	1	100%	NA	60,000
CollectiveSun	Lending (for no profit projects)	4	75%	6.20%	254,769
SunFunder	Lending (for rural electricifaction)	34	100%	3.52%	986,238
Trillion Fund	Hybrid (Lending, Equity, Community Shares)	29	97%	7.60%	102,095,794
Greencrowd	Hybrid (Lending, Equity)	23	96%	4.88%	2,097,040
Veolis	Hybrid (Lending , Reward)	3	100%	2.50%	77,498
GridShare	Hybrid (Lending, Equity, Reward)	14	0%	6.38%	54,874
WindCentrale	Equity (Community Shares)	9	NA	3-8%	14,300,000
Village Power	Equity (Community Shares)	13	62%	NA	5,202,674
Gen Community	Equity (Community Shares)	2	100%	7.00%	1,351,516
Microgenius	Equity (Community Shares)	2	100%	NA	1,436,458
Coopernico	Equity (Community Shares)	7	86%	NA	267,600
Crowdener.gy	Equity (Community Shares)	5	80%	NA	181,800
Solar Schools	Donation	65	82%	-	691,976
Re-Volv	Donation (plus Revolving Fund)	3	100%	-	106,448
Divvy	Donation/Reward	4	50%	-	10,423
Clean Reach	Donation	6	0%	-	5,698
Milaap	Lending (for social value projects)	15	NA	-	338

Notes:

- Success rate is the percentage of the published projects which get successfully funded.

- Money raised figure is the result of the sum of money raised in each single project published online. The survey thus assume that figures published by platforms for each project are accurate and factual.
- Money raised figures for Mosaic and WindCentrale are taken from websites and grey literature, as information and data of specific projects is not available online.
- Trillion Fund figure for money raised presented is conservative as three successful 'Fund' projects are not added to the figure as data not available online.

When data are aggregated by country, focusing on the most active in the sector (Table 6), United Kingdom stand out as the market leader, in terms of number of projects and money raised (both total amount raised and average project size). This is not surprising, considering United Kingdom leadership in the wider European crowdfunding market (accounting for market share of over 74% [24]). Netherland follows, with the next highest figures in terms of money raised, then USA and Germany whose numbers fall in a similar range.

Table 6. Performance by country

Country	Number of projects	Money raised €	Average raised per project €	Average returns by country	Number of platforms
France	23	1,691,990	73,565	4.21%	3
Germany	87	11,148,740	128,146	5.53%	6
USA	98	12,406,537	126,597	6.29%	8
Netherland	49	20,364,614	415,604	5.58%	4
United Kingdom	121	118,234,845	977,147	7.36%	5

Table 7 instead presents data aggregated by crowdfunding model. Lending platforms have been publishing the highest number of projects to date, which could have been expected considering they account for about 60% of the active platforms. However, equity/community shares and hybrids platforms seem to have better performed in terms of money raised (both total amount and average project size). Average returns offered to investors are comparable between lending and hybrid platforms and slightly higher for equity/community shares projects (which is again expected, as usually equity is remunerated at higher rates than debt). Thus, these data seems to show that despite lending platforms are the mostly implemented, they tend to attract smaller size projects and raise lower amount of money overall.

Table 7. Performance by crowdfunding model

Model	Number of projects	number of funded projects	Money raised €	Average raised per project €	Average returns
Lending	203	153	37,179,291	243,002	5.39%
Equity (community shares)	38	31	22,740,049	733,550	7.00%
Hybrids	66	53	104,325,206	1,968,400	5.34%
Donation/reward	93	58	814,883	14,050	-

Note: 'Number of projects' figure for Hybrid platforms does not include three Trillion Fund successful 'Fund' projects for which data on amount of money raised is not available online.

However, a closer look reveals that the data presented above are strongly affected by the performance of two specific platforms: Trillion Fund in the United Kingdom and WindCentrale in the Netherlands. Indeed, Trillion Fund significantly outperforms to at least an order of magnitude all other energy crowdfunding platforms across the world (Table 5), thus being the main contributor of United Kingdom leadership in the sector. Similarly WindCentrale is the largest platform in the Netherlands and the second biggest in Europe (Table 8), comparable only to Abundance Generation (second biggest platform in the United Kingdom - Table 5).

Table 8. WindCentrale performance

WindCentrale	
Money raised €	14,300,000
Number of projects	9
Average return	3-8%
Average raised per project €	1,588,889

Moreover, disaggregating Trillion Fund performance data across their different project types (Table 9) it is quite striking to notice how the majority of the money has been raised through their lending projects, i.e. loans and funds issued by renewable energy company or investment funds. Average returns for such type of investments are also higher than average lending platforms returns (just above 5%).

Table 9. Trillion Fund performance, by project type (all UK based)

Trillion Fund	Equity	Community shares	Loan	Fund
Money raised €	4,747,208	6,972,470	34,017,910	56,358,206
Number of projects	1	9	13	3
Average return	9.5	5.29%	7.34%	15.13%
Average raised per project €	4,747,208	774,719	2,616,762	18,786,069

Note: Successful ‘Fund’ projects are in reality six, but three have not been included as data on amount of money raised is not available online.

Moving Trillion Fund lending projects from the hybrid model group to the lending one (Table 10) leads to very different results than above in terms of energy crowdfunding models’ performances: lending model is not only the more frequently applied by energy crowdfunding platforms, but it’s also the best performing. Table 10 clearly shows how lending projects have been the highest in numbers, raised the largest amount of money (over 75% of the total raised to date) and for largest average project size. Returns offered are also the highest, although the 9.29% figure in Table 10 is slightly biased upper ward by the Trillion Fund’s average returns to funds of 15.13%, without which average returns would stay around 6% (thus still slightly lower than equity/community shares’ returns).

Table 10. Performance by crowdfunding model – accounting for Trillion Fund lending projects

Model	Number of projects	Money raised €	Average raised per project €	Average returns
Lending (with Trillion Fund's lending projects)	219	127,555,407	768,406	9.29%
Equity (community shares)	38	22,740,049	733,550	7.00%
Hybrids (no Trillion Fund's lending projects)	40	13,949,090	348,727	4.58%
Donation/reward	93	814,883	14,050	-

Compared to the financial platforms, donation/reward initiatives have raised much less money, but for a good number of projects overall. They sit in a fairly different category. In this contexts crowdfunding campaigns are smaller in size than in financial platforms as they are generally used to raise funds for rather small renewable energy projects, such as small/medium solar energy plants on schools roofs or solar for rural electrification projects (e.g. in the case of Milaap, the currently open campaigns would finance solar lamps for women empowerment in India and have set targets between a minimum of 80$ and a maximum of 250$).

The most successful of these platforms, e.g. Milaap (15 projects published in the first month of activity, August 2015) and Solar School (65 published projects, 53 of which successfully funded), offer very homogenous and replicable projects (i.e. solar lamps in the case of Milaap; solar projects on schools roofs mobilizing the interest of parents, local businesses, former students and wider local community in the case of Solar Schools) which allows them to raise money from a high number of similar small projects.

How does it compare with the wider crowdfunding sector?

Overall the energy crowdfunding sector has raised about €165millions since 2012, which accounts for only 0,75% of the crowdfunding funding volume cumulated worldwide roughly over the same period of time (i.e. almost €23billions) [1]. However it is interesting to notice that, despite being a still quite small market, the size of energy crowdfunding campaigns is almost double than the average wider worldwide crowdfunding (Figure 6). And this pattern is consistent across all models.

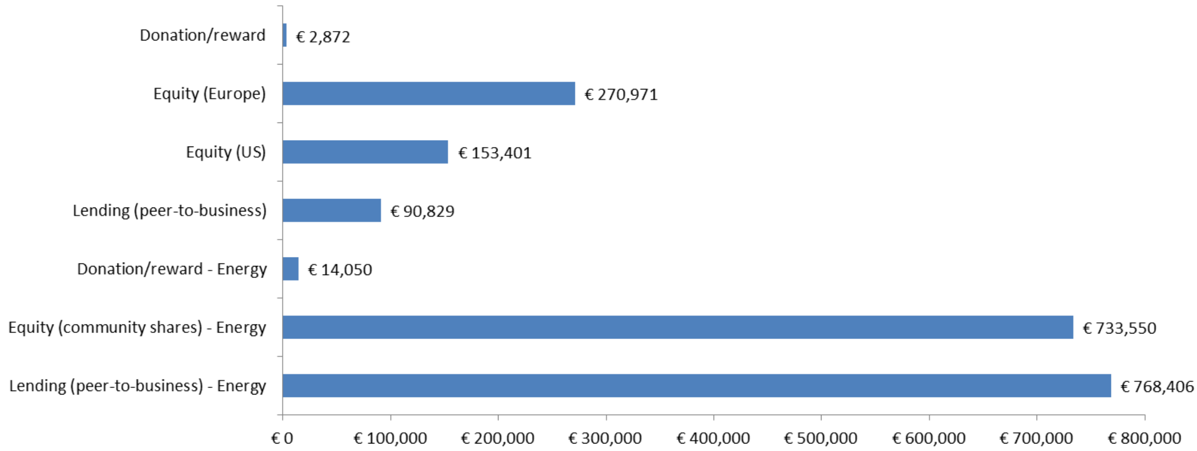

Figure 6. Comparing average crowdfunding campaign size, by model
Source: Author's elaboration, (Massolution, 2015)

Moreover, the energy crowdfunding campaigns are also on average more successful. Figure 7 shows much higher success rates) for energy crowdfunding projects than wider crowdfunding averages, and across all models. The only exception are lending based campaigns showing the highest success rate (around 90% and above), mainly due to the popularity of peer-to-peer microloans (which have the highest success rate across all campaigns). However, the peer-to-peer microloan model has not been used in the energy sector to date, thus such figure is not directly comparable with the success rate of lending projects in the energy sector, which are instead peer-to-business. When lending in the real estate market (which is instead peer-to-business) is taken as a more realistic benchmark, energy crowdfunding sector still outperforms the average global trend. Similarly, donation/reward and equity/community shares projects are also very successful in the energy sector. Success rate of the latter is particularly striking if compared with wider equity projects success rate (which is expectable due to the fact that they tend to be focused on innovative start-up businesses offering highly risky and volatile returns) and, even more striking, with equity projects in the real estate sector (which is instead characterized by less risky investment with relatively stable and foreseeable returns, such as the energy sector). A discussion of some of the potential drivers of such higher success rate are presented in Section 4.

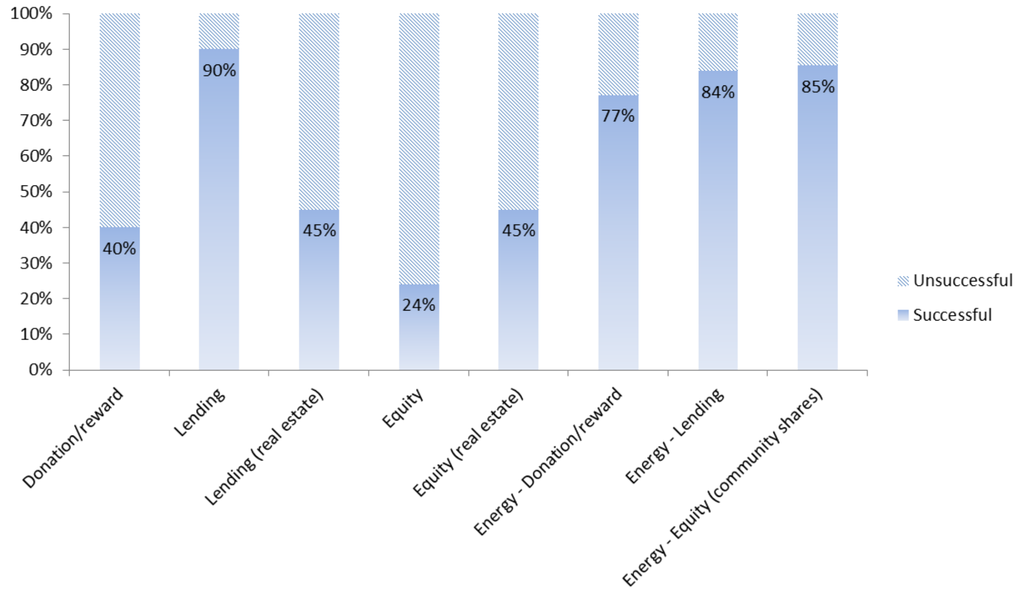

Figure 7. Comparing average success rate, by model
Source: Author's elaboration, (Massolution, 2015)

5. Discussion and conclusion

The analysis of the evidence gathered on energy crowdfunding platforms pictures a very new, but quite dynamic sector. The crowdfunding tool has been applied in most of its forms, ranging from peer-to-business lending to pure donation platforms. The strong environmental mission is a common place, with all platforms focusing on clean energy projects and most of them explicitly shaping their project scouting and communication strategy emphasising the ethical dimension of the initiative.

Indeed, the use of crowdfunding in the energy sector has begun as a fairly niche application to grass root and community energy projects, with the explicit aim of increasing participation of citizens in renewable energy investment. First ground-breaking campaigns are those launched by platforms such as WindCentrale (Netherlands), which in 2013 managed to raise €1.3 million in less than 13 hours from 1700 households in the Netherlands to finance a community owned wind turbine [42, 43]. More recently platforms such as Lendhosphere (France), LeihDeinerUmweltGeld (Germany), DuurzaamInvesteren (Netherlands) or Village Power (USA) have managed to successfully raise millions of euros in renewable energy projects with explicit community and local focus. Through crowdfunding platforms a company, a local authority or a community developing a renewable generation plant or an energy efficiency measure can not only raise capital but also involve citizens and other stakeholders in the investment, allowing them to invest, become shareholders and benefit from the return on the investment itself.

However, the systematic review has also shown how equity/community shares (the most participatory crowdfunding model, as investors buy shares in local energy projects) is not currently the most popular nor the most performing. Lending platforms, which bring forward 'third party' business models (where investor give money to a third party making the investment [44]) are instead the mostly used in crowdfunding and raised the largest amount of money to date.

Moreover, evidence presented in previous sections also shows how energy crowdfunding platforms, while maintaining their environmental and clean energy focus, have already been moving from niche, grass root initiatives into larger projects and collaborations with energy private sector and institutional finance. Results from a recent European survey among projects proponents (Figure 8) highlight how the majority of projects have been developed by private sector stakeholders, either limited companies or energy service companies [45]. In other words, crowdfunding has been used by energy project developers to finance their new investments in the sector.

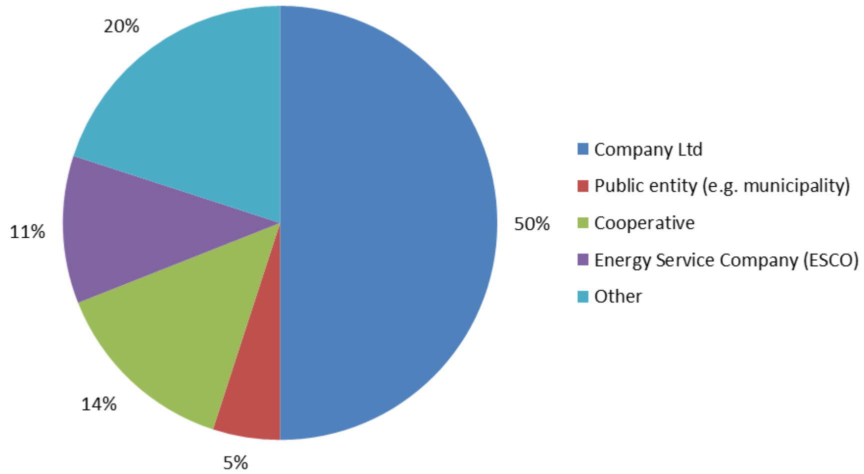

Figure 8. Company structure of projects proponents
Source: Author's elaboration, (Klaes, 2015)

Nonetheless, despite bringing forward less participatory business approaches than community shares for the implementation of renewables and energy efficiency measures, lending platforms still allow people to invest in green energy projects in a disintermediated manner (as they can transparently choose where to invest and do it directly) and for small amount of money. They thus provide the possibility to those interested in investing in clean energy, but without suitable conditions (e.g. lack of sufficient capital or of a suitable area to develop the project) to directly contribute to CO_2 emissions reduction and benefit from the returns on the investment. A clear example is Abundance Generation (United Kingdom), which is allowing citizens to invest in solar or wind plants with as little as £5 investment since 2012 [46].

Such environmental and social connotation of energy crowdfunding platforms is likely to be one of the main determinants of higher success rate to energy crowdfunding campaigns than worldwide averages, in particular when compared to potentially less environmentally and socially characterized businesses such as real estate, where the driver to invest is likely to mainly be the financial returns offered. Available evidence shows that in the energy sector funding from local population is more easily raised, and potentially lower returns is counterbalanced by the possibility of being involved in the project with some sort of participation or control rights [19, 47]. Moreover, recent studies have shown how, in other sectors, crowdfunding initiatives that are structured as non-profit organizations tend to be more successful than other in achieving fundraising targets [12]. However, this is definitely not the only driver for energy crowdfunding investor. Most of the platforms use financial models, thus offering quite interesting monetary returns on the investments, on average in the 4% to 7% range.

Further work would be needed to analyse in higher details the profile of energy crowdfunding investors and the drivers behind their investment decisions: in particular, are more the social and environmental commitments or the financial returns driving investment decisions? Unfortunately data on investors profile and behaviour are owned by platforms under strict privacy controls and the sector is relatively young, thus publicly available analysis on this topic is still limited. Nonetheless, some initial evidence can be drawn from experience shared by some platforms. An analysis from a leading UK energy crowdfunding platform (Abundance Generation) points out that about 34% of their target investors are the so called ‘ethical investors’ (those that actively consider the impact of their investment activities, thus motivated by the ‘green value’ of the investment), but over 50% are ‘financial planners’ (experienced investors, who plan for their financial futures, thus less motivated by the sustainability cause and more by the returns on the investment and the possibility to choose among additional and novel investment options) (Abundance Generation, 2014). This UK experience seems to indicate that returns on the investments play a considerable role in making energy crowdfunding investments attractive. On the other hand, at the recent Energy Crowdfunding Conference (London, 5th November 2015) several platforms’ representatives (among those Trine and Lendosphere) have emphasized the importance of communicating social and environmental impacts of investments to acquire investors and guarantee high success rates to their projects (Energy Crowdfunding Conference, 2015). Lendosphere also stated the success of their strategy of offering higher returns to people geographically closer to the project, which has to date allowed them to raise about 50% of the money among local people (Blais, 2015).

In conclusion, crowdfunding in energy is a novel sector, with large room for innovation, testing and standardization of business models (both for platforms themselves and projects launched on them). It is a highly innovative sector characterized by flexible and dynamic firm structures to keep the pace with fast market developments. Initially developed as a socio-technical practice in a niche, it is already showing signs of scaling up and is turning into a new business model, which could help in fostering and scaling up sustainable solutions in the future [48, 49]. As wider crowdfunding (which, despite beginning as a grass root phenomenon, has quickly scaled up and has been increasingly used by established businesses to finance growth and expansion activities [14, 50]) the energy crowdfunding sector is already moving from small/medium locally characterized energy projects to larger projects, from energy cooperatives to private sector led campaigns often launched to support the expansion of renewable energy companies rather than single projects (in particular in the United Kingdom). For example, Trillion Fund performance to date highlights the important role of structured finance and more institutional investors for scaling up the sector: over 50% of the total funding volume of worldwide energy crowdfunding sector (about €165 millions) has been raised only by 16 loan and fund campaigns launched by Trillion Fund in the last couple of years. Whether grass root, community approaches will coexists with more structured finance instruments in the scaling up of the sector is an open question to which we will get an answer only in the years to come.

ACKNOWLEDGEMENTS

Research funding from the Marie Curie Fellowship LocalEnergy (FP7-PEOPLE-2012-IEF, GA-331081) is gratefully acknowledged.

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Session Lighting

A lighting retrofit intervention for energy savings and comfort optimization in an industrial building

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Abstract

The paper reports a case study regarding a retrofit intervention realized in a factory located in Nola, Naples (Italy). The intervention consists in the substitution of old luminaires with LED and in the installation of a smart and open control system. The goal of the customer was, on one hand to increase the efficiency of lighting system, in order to reduce energy consumptions and, on the other hand, to improve luminous environment quality to guarantee appropriate comfort conditions to workers. Furthermore considering system's dimensions and its characteristics it was necessary to simplify maintenance activities.

1. Introduction

In recent years lighting design approach has widely changed. On one hand the growing interest in environmental pollution, natural sources depletion and energy waste reduction has directed designers to experiment technical solutions able to maximize energy savings. On the other hand, researches' results about light effects on human wellbeing have driven technicians to look for new design criteria in order to build luminous environments tailored to people needs.

Finding a balance between energy savings and comfort optimization is fundamental in specific applications: offices, factories, educational buildings, hospitals. In these cases lighting energy costs can be very relevant due to the amount of installed luminaires and of system's operating hours. Furthermore people often spend the most part of the day in these workplaces, consequently light can have a consistent impact on their wellbeing. Researches demonstrate that light influences health [1], circadian rhythm regulation [2], mood and consequently productivity [3].

Nowadays available technologies allow to design advanced dynamic lighting systems, the characteristics of which can be continuously changed, in order to achieve a balance between energy costs reduction and comfort conditions optimization. For example the use of LED sources makes possible to vary not only luminaires' emitted flux, but also spectral power distribution; modern strategies of integration between daylight and electric light allow to maximize daylight entering in buildings and at the same time to control daylight glare or overheating; installation of advanced control systems permits to modify systems' configuration depending on changeable requirements and to simplify maintenance activities.

Factories represent an interesting research and application field, in order to experiment potentialities of new lighting technologies. In these buildings energy consumptions can be very high due to systems' dimensions and it is fundamental to control workers' comfort conditions that are proverbially uncomfortable. Moreover data referred to operating conditions of industrial buildings' systems are lacking. Generally researches focus on offices or educational buildings, especially when considering effects of control systems installation [4].

The paper reports a case study regarding a lighting retrofit intervention realized in a factory located in Nola, Naples, Italy (Latitude 40° 55' 33 N, Longitude 14° 31' 41 E), owned by Finmeccanica Global Services S.p.A. (a Real Estate of Finmeccanica S.p.A.) and used by Finmeccanica S.p.A - Aerostructures Division. It is a building about 52000 m^2 wide, equipped with a significant amount of

lamps (1371 400W metal halide lamps) and characterized by high annual energy consumptions (about 4.92 GWh).
Finmeccanica Global Services meant to reduce lighting energy consumptions and asked the substitution of old luminaires with more efficient ones. New lighting fixtures had to be installed at the same position of old ones, in order to avoid actions on wiring and reduce intervention costs.
Furthermore the customer required the improvement of workers' visual comfort. The old system was static and not provided by dimmable luminaires. Despite users' tasks are several and require different light levels to be performed, wherever in the factory lighting conditions were the same. It was not possible to regulate emitted luminous flux and to define in each working area the most suitable light levels depending on specific tasks.
The customer specified that production activities may vary a lot depending on business workload and consequently, both working hours and indoor spaces distribution can vary on the basis of production needs. For this reason he considered essential to install a flexible system able to be adapted depending on changeable requirements. If it was necessary to relocate a manufacturing activity from a factory's part to another, it would be possible to reset luminous scenario in the considered area and fulfill requirements characteristic of the specific task.
At the same time the management of the system should be more simple as possible. Each area manager, who directs a particular production activity, should be able to change light levels of a single zone, in order to guarantee the best lighting conditions for workers, without interfere with other areas.
Furthermore it was necessary to consider that, due to manufacturing typologies, indoor environmental pollution is considerable, determining the necessity of continuous luminaires' cleanliness and, given the mounting height and the amount of installed lighting fixtures, high maintenance costs.
In brief, customer needs were energy savings, quality of luminous environment, flexibility of the system and simplification of maintenance activities. Given that, the identified design solution was the installation of energy efficient LED light sources and of a smart and flexible control system that allows to adapt lighting characteristics to changeable customer requirements. Installed LED luminaires and control system were provided by Melchioni.
Department of Industrial Engineering of University of Naples Federico II cooperated with Finmeccanica Global Services, providing a scientific and technical support to decisional process before retrofit intervention, considering both visual comfort and energy savings requirements.
At present the new system is installed and Finmeccanica Global Servcices, Melchioni and University of Naples continues to cooperate in commissioning phase, in order to optimize system performances.
Following paragraphs describe the case-study, the old system and the new one. A specific section deals with the description of tasks performed in the factory and on the analysis necessary to identify for each manufacturing activity the most suitable lighting conditions.
Finally, considering that commissioning is in progress, analyses performed in this phase are described in Paragraphs 7.1 and 7.2.

2. Case study

The case study is a factory located in Nola, Naples, Italy (Latitude 40° 55' 33 N, Longitude 14° 31' 41 E). It is part of an industrial complex owned by Finmeccanica Global Services S.p.A. and used by Finmeccanica S.p.A.- Aerostructures Division to manufacture elementary parts of aircrafts.
The building is about 52000 m^2, it is 181 m wide, 289 m long. It is equipped with a shed roof (the maximum height of the building is 15.5 m) and its longitudinal axis is 39° North-oriented.

Figure 1 reports factory's plan and sections.

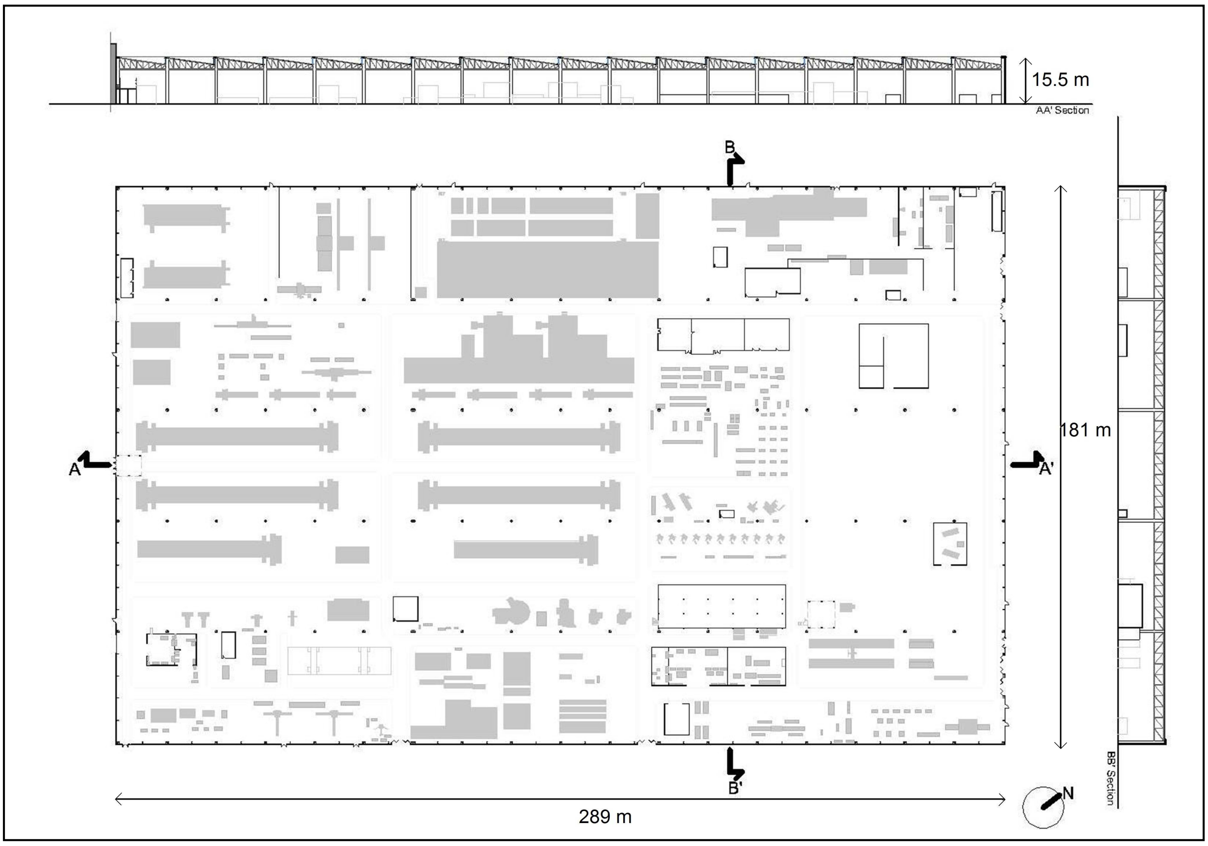

Figure 1: Factory plan and sections

The building was provided by 1371 industrial reflectors, equipped with 400 W metal halide lamps characterized by 3500 K Correlated Color Temperature (CCT). Luminaires are placed in twenty rows in longitudinal direction, at a distance of 9 m. In cross direction the distance between lamps is generally equal to 4 m, but, in some cases (see Figure 3) it is doubled.

Lighting system's operating hours can change during the year according to production needs. During 2015 twenty 8-hours work shifts per week were performed: 3 per day from Monday to Saturday and 2 on Sunday. Considering these conditions, lighting systems worked for 8344 hours per year. In this condition the old system determines annual energy consumptions equal to 4.92 GWh corresponding to CO_2 emissions equal to $2.34 \cdot 10^6$ t.

3. Analysis of working activities and definition of related requirements

In order to define requirements the new system has to fulfill, it was necessary a careful analysis of the working activities.

In the factory aircrafts' components are produced. In more detail prismatic pieces are obtained thanks to several processes: thermal treatment, countouring, pressing and calibration, shavings' removal from slabs, extrusion or pressing of elements of aluminum and titanium alloy, parts' assembly.

Figure 2 and Table 1 summarize and classify each factory area depending on definition and requirements according to European Standard EN 12464-1 [5]. In Table 1 the first column reports a number that allows to identify the considered area in Figure 2. Areas 24 and 27 are not reported in Table 1, because they are occupied by box offices equipped with specific lighting fixtures. Column 4,5,6 and 7 report Maintained Illuminance (E_m), Unified Glare Rating (UGR), Illuminance uniformity (U_0) and Color rendering Index (CRI) respectively.

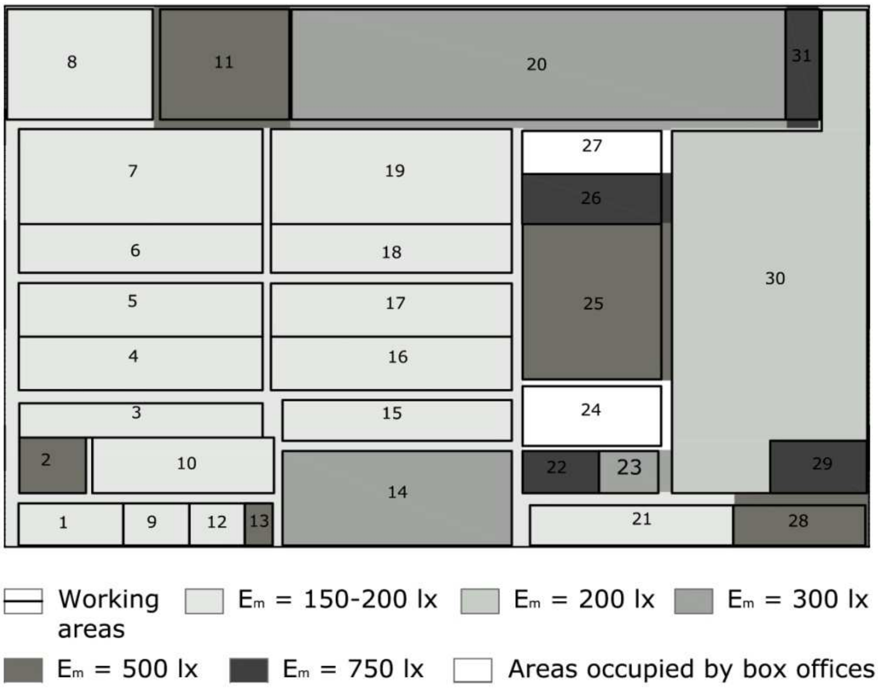

Figure 2: Working areas classified depending on task illuminance

Table 1: Requirements related to different task areas

Reference to Figure 2	Name	Manufacturing activities definition according to EN 12464-1	E_m [lx]	UGR	U_0	CRI
1	Mechanical processing area 2 and Mecfond area	5.22 Rolling mills, iron and steel work / 5.22.2- 5.22.3 Production plants with occasional or continuous manual operation	150-200	28-25	0.4-0.6	40-80
3	Contouring area					
4	Single gantry 9A area					
5	Dual gantry 5A-6A area					
6	Dual gantry 1A-2A area					
7	Mechanical processing area 1 and measuring area					
8	High speed jobs area					
9	Hufford LAF area					
10	Mechanical processing area 3					
12	Hufford A12 area					
15	Work center area					
16	Single gantry 10A					
17	Dual gantry 7A-8A					
18	Dual gantry 3A-4A					

19	Milling machine area					
21	Printing press area					
30	Shipping area	5.4 Store rooms, cold stores / 5.4.1 Store and stockrooms	200	25	0.4	60
14	Thermal treatments area	5.18 Metal working and processing / 5.18.2 Drop forging	300	25	0.6	80
20	Galvanising area	5.18 Metal working and processing / 5.18.12 Galvanising	300	25	0.6	80
23	Profiling area	5.22 Rolling mills, iron and steel work / 5.22.6 Mill train; coiler; shear line	300	25	0.6	40
2	Calibration and tuning area	5.18 Metal working and processing / 5.18.5 Precision machining: tolerance < 0.1 mm	500	19	0.7	80
11	Surface finishing area					
13	Mandrini area					
25	Mechanical processing area 2					
28	Deflashing area					
22	Calibration and adjusting area	5.18 Metal working and processing / 5.18.6 Scribing; inspection	750	19	0.7	80
26	Dea area					
29	Painting area	5.18 Metal working and processing / 5.18.13 Surface preparation and painting	750	25	0.7	80
31	Test and imprint area	5.18 Metal working and processing / 5.18.6 Scribing; inspection	750	19	0.7	80

As it was previously mentioned, working activities can be relocated depending on production needs. Consequently the new system must fulfill in each area of the factory the highest requirements indicated in Table 1. In this way it is always possible to guarantee in each zone the highest comfort conditions prescribed by regulations, regarding industrial activities. On the basis of this consideration, the requirements reported in Table 2 were defined.

Table 2: Requirements new system has to fulfill

E_m [lx]	500
UGR	19
U_0	0.7
CRI	80

As for E_m, the highest limit defined by EN 12464-1 [5] was 750 lx. Instead, in Table 2 is indicated a value of 500 lx. This happens because where high precision manufacturing activities are performed, machineries or working tables are provided by integrative lighting.

4. Luminaires substitution

Old industrial reflectors equipped with metal halide lamps were replaced by two types of LED luminaires, based on remote phosphors technology. Figure 3 reports photometry of chosen luminaires and Table 3 related technical characteristics declared by the manufacturing.

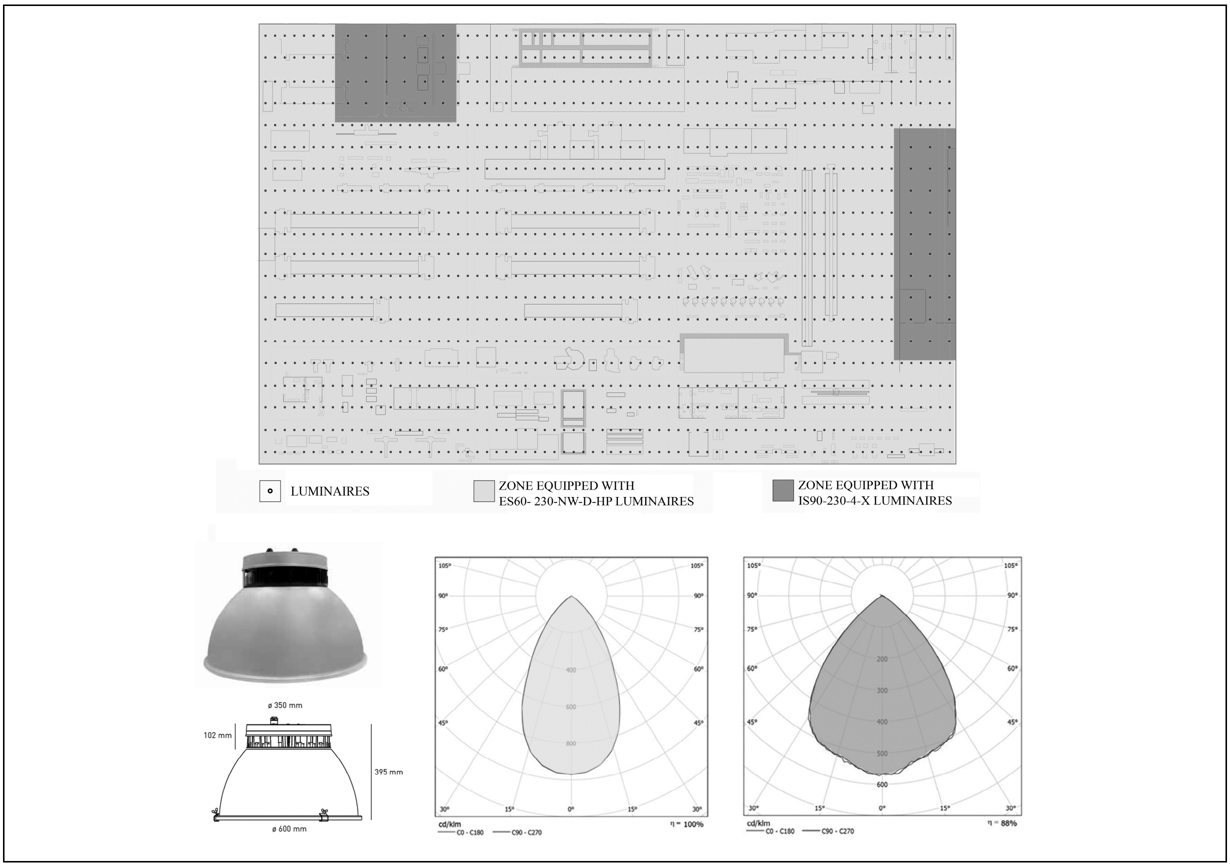

Figure 3: Factory plan and luminaires' characteristics

Table 3: Technical characteristics of installed luminaires

Nominal power	230 W
Luminous efficacy	110 lm/W
Correlated Color Temperature (CCT)	4000 K
Color Rendering Index (CRI)	80
Half-peak divergency	60° - 90°
Service life	> 50000 h
Operating Temperature	- 20°C / 45°C
"Blue light hazard" risk group	Exempt

Two luminaires' typologies are characterized by the same values for each technical characteristic except for photometry, due to the variation of the distance between luminaires in cross direction, imposed by the old system (see Figure 3). Indeed, for zones where luminaires are disposed at a distance of 9 m (longitudinal direction) and 8 m (cross direction), a larger beam spread guarantees a more uniform light distribution at workplane height.

On field measurements were performed, in order to verify luminaires compliance with regulations requirements previously mentioned. In more detail the following parameters were measured:

a) average horizontal illuminance (E_m), illuminance uniformity (U_0), spectral power distribution, Color Rendering Index (CRI) and Correlated Color Temperature (CCT), in order to characterize luminaires and evaluate environmental luminous effects;
b) average horizontal illuminance and absorbed power related to different operating conditions (full capacity, dimmed at 70%, 50%, 30%), in order to define energy consumptions when luminous flux is dimmed;
c) average luminance of luminaire (L_{avr45}) related to a 45° angle of view and the solid angle subtended by light source (Ω), in order to verify the safety as regards "Blue light hazard".

For measurements purposes, in order to evaluate average illuminances and illuminance uniformity, a completely empty test area equipped with luminaires mounted at a distance of 9 m in longitudinal

direction and 4 m in cross one was set. Indeed in the factory, the presence of machineries would obstacle measurements.
In order to measure illuminances, a squared-meshed measuring grid was determined. The grid was composed by 7*10 points, the distance between points was always 2 m and illuminances were measured at a distance to the floor equal to 0.85 m. The dimensions and characteristics of analysis grid allow to obtain a survey more accurate than how required by Appendix A of EN12464-1 [5].
Results of measurements are reported in Figure 4, 5, 6 and in Table 4.

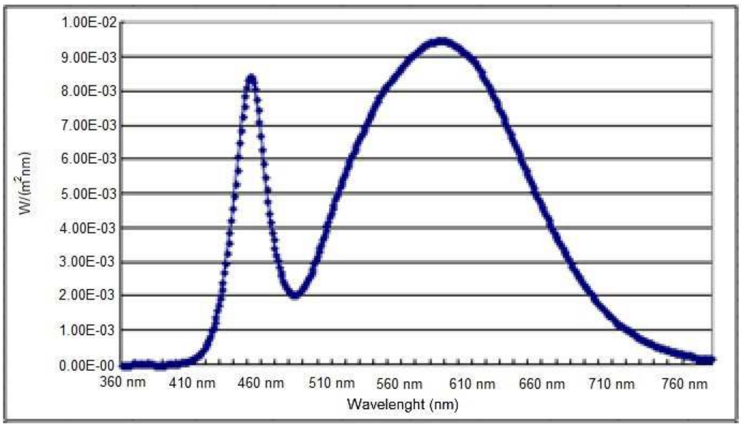

Figure 4: Spectral irradiance

Table 4: On field measurements data

E_m	601.7 lx
U_0	0.838
CRI	80
CCT	3780 K

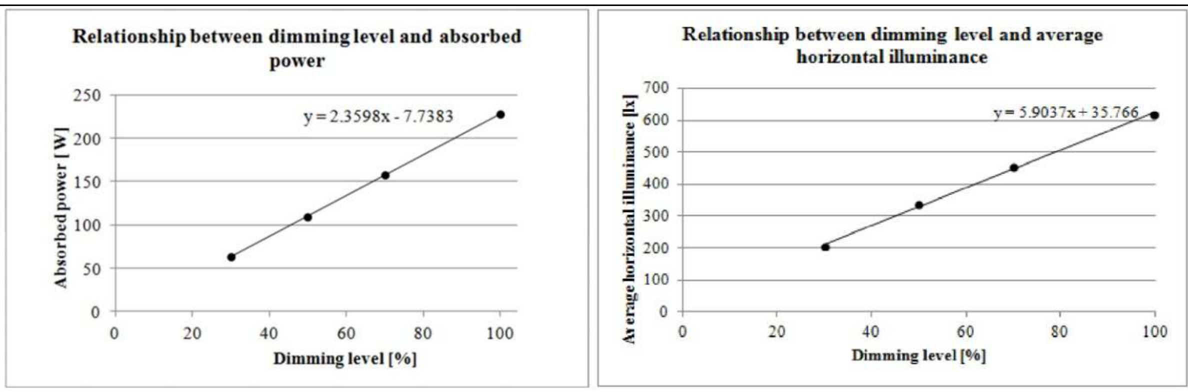

Figure 5: Relationship between dimming level and absorbed power and between dimming level and average horizontal illuminance.

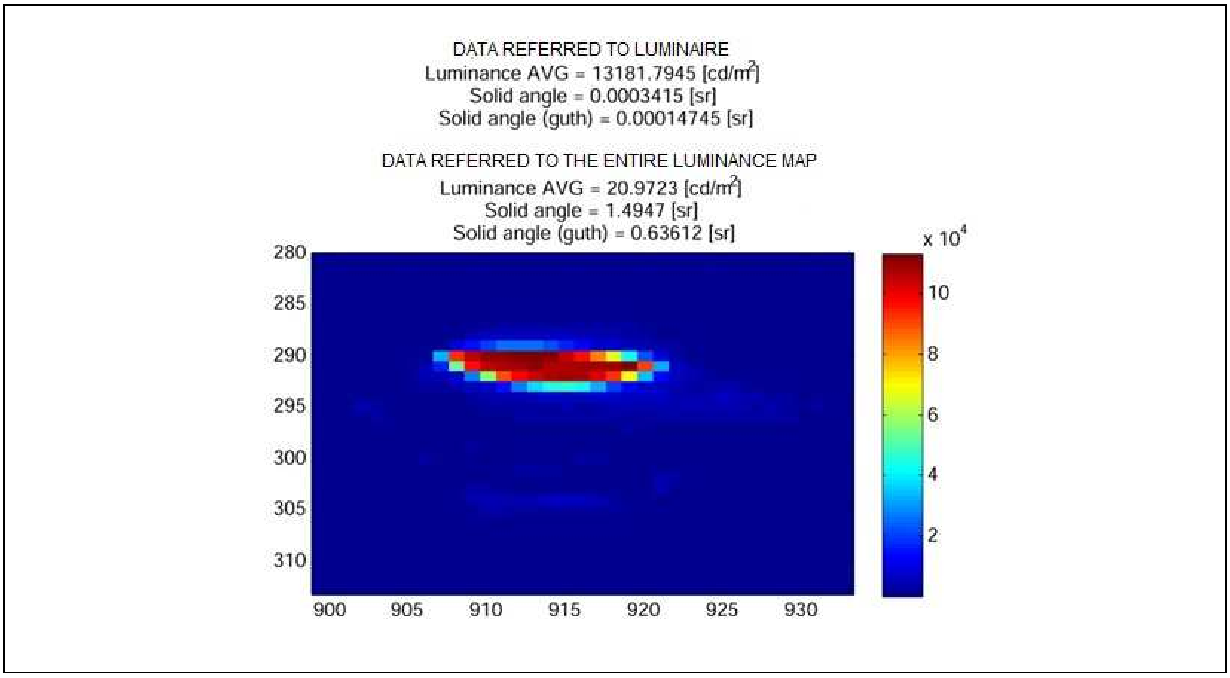

Figure 6: Luminance measurements

In order to verify the safety as regards "Blue light hazard" according to the EN62471 Standard [6], starting from spectral irradiance [W/m^{-2} nm^{-1}] and luminance [cd m^{-2}] measurements, spectral radiance [W m^{-2} $sr^{-1}nm^{-1}$] was obtained thanks to numerical processing. Then obtained distribution was weighed on the blue light hazard spectral weighting function $B(\lambda)$, in order to obtain effective radiance of blue light L_B.

Measurements were performed at the eyes' level of an ideal observer that looks at the luminous source, considering a 45° angle of view (height from the floor equal to 1.60 m). In this condition, related angle size is 0.032 rad, consequently source cannot be considered small according to [6].

Measured average luminance was equal to 13182 cd m^{-2} and calculated L_B is equal to 5.71 W m^{-2} sr^{-1}. These data confirm that luminaires can be classified as belonging to the Risk group "Exempt".

Measurements agree with data reported by Melchioni technical data sheets and demonstrates that requirements indicated in Table 3 are fulfilled, guaranteeing workers' comfort conditions. Measurements were repeated also in an area where luminaires were mounted with a cross distance of 9 m and requirements were achieved as well.

Chosen luminaires allow to obtain illuminances higher than 500 lx. This choice depends on maintenance issues. Given the manufacturing typologies, environment is strongly polluted. Due to the amount of luminaires, costs of regular cleanliness activities would be higher than energy costs obtained emitting a higher luminous flux in order to account for dirt accumulation.

In order to evaluate glare risks, Dialux software was used to calculate UGR values. An analysis grid, composed by 285*176 points (50160 points), with following parameters was set:

- user's height = 1.6 m;
- user's considered view directions = 0°, 90° ,180° and 270°;
- angle between view direction and horizontal plane = 0°.

Calculated maximum value was 19.

5. Control system installation

Melchioni also provided a smart and flexible control system called Light Care. It is a web-based system that allows to monitor and optimize luminaires functioning. It is based on a Client-Server architecture, it is very flexible and independently controls each luminaire, allowing to differently set its emitted flux. Each luminaire is indeed linked to a HUB and can be managed and controlled by a

whatever PC connected to a local network or to Internet (by cable or by Wi-Fi), simply by accessing to Light Care portal. In this way the system can be controlled also by Melchioni head office, in order to help customer in maintenance activities.
Figure 7 reports a synthetic scheme of system's functioning.

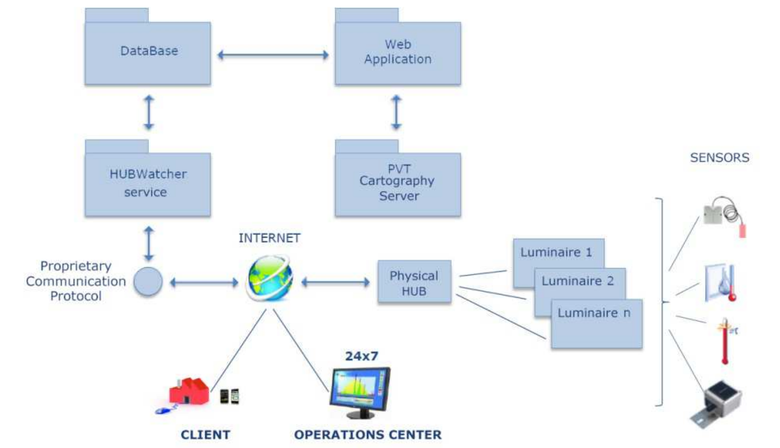

Figure 7: Scheme of control system's functioning

The control system allows to adapt lighting configuration to different and changeable requirements: lighting levels can be modified on the basis of pre-set scenarios and through a time scheduling or by the aid of sensors in order to maximize energy savings and comfort conditions; system's maintenance is greatly simplified and improved as well. The control automatically monitors each luminaire registering in real time the following data:

- Power (kW)
- Energy consumptions since system activation (kWh)
- Daily energy consumptions (kWh)
- Energy savings since system activation (kWh)
- Daily energy savings (kWh)
- Dimming level (%)
- Operating condition (On, Off, Maintenance)
- Operating temperature (° C)

On the basis of the monitored data it is possible to derive personalized statistical reports about luminaires' functioning. Moreover it is possible to set security parameters in order to preserve each luminaire. When the system registers values higher than security limits, it shows a warning message in order to activate maintenance activities. It is possible to set an automatic emitted flux reduction in case of irregular consumption or overheating.
A user-friendly interface allows to simply update system's configuration. Screenshot of the system's interface are represented in Figure 8.

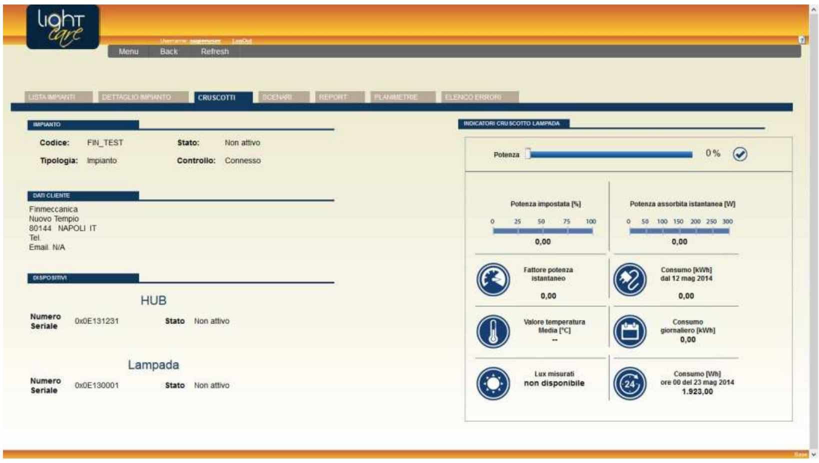

Figure 8: Control system' interface

6. Comparison between the old system and the new one

Figure 9 reports isolux plan calculated with Dialux software and referred to new system when all luminaires are switch on at full capacity.

Optical characteristics of considered surfaces are modeled as following:

- reflectance of internal walls equal to 50%;
- reflectance of ceiling equal to 50%;
- reflectance of floor equal to 30%;
- reflectance of outside ground equal to 20%;
- visual transmittance of glazing equal to 80%.

In order to account for indoor pollution levels, as for glazing a dirty factor equal to 50% was considered. Maintenance factor was assumed equal to 0.9.

Calculated illuminances are lower than measured ones because of the shading effect of machineries modeled in Dialux.

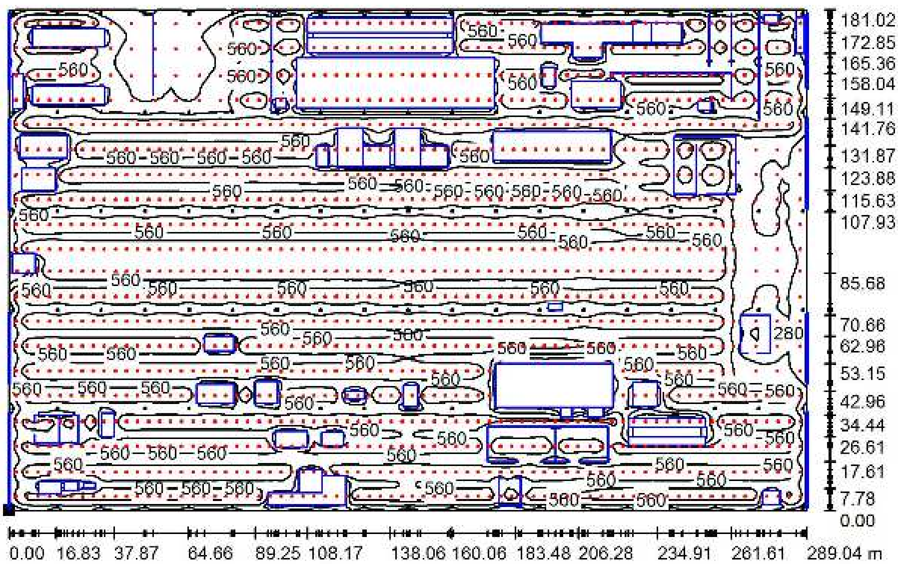

Figure 9: Isolux plan: all luminaires emit 100% of total flux

Table 5 compares systems' characteristics before and after retrofit intervention.

Table 5: System's characteristics before and after retrofit intervention

	Before	**After**
Amount of luminaires	1371	1371
Nominal power of each luminaire	400 W	230 W
Actual power of each luminaire	430 W	228 W
Working hours per year	8344 h	8344 h
System total power	589.53 kW	312.59 kW
Annual energy consumptions	4.92 GWh	2.61 GWh
Annual CO_2 emissions	$2.34 \cdot 10^6$ t	$1.24 \cdot 10^6$ t

Energy consumptions and CO_2 emissions are considerably reduced. In more detail thanks to LED installation annual energy savings and annual CO_2 reduction equal to about 50% are achieved.
Figure 10 and 11 represent the factory before and after retrofit intervention.

Figure 10: System before retrofit intervention

Figure 11: System after retrofit intervention

7. Further development

As it was previously mentioned, at present commissioning is in progress. Following paragraphs show analyses so far performed in order to optimize energy performance of system. On one hand, starting from regulation requirements reported in Table 1, a light scenario able to guarantee for each zone required task illuminance was searched for. On the other hand, considering the possibility to integrate photosensors in the control system, an in depth evaluation of indoor daylight availability was carried out.

7.1 Optimization on the basis of task illuminance requirements

As reported in Paragraph 3, illuminances lower than 500 lx were prescribed by regulations for many manufacturing activities. Given a specific configuration of working areas, it would be possible to gather luminaires together and to differently dim them, in order to obtain illuminances required by regulations at each task area, saving energy.

As reported in Table 1, according to [5] manufacturing activities entirely belong to two different categories identified as "Metal working and processing" and "Rolling mills, iron and steel work". Indeed EN 12464-1 does not report a specific paragraph referred to aircrafts' components production and, during commissioning, Finmeccanica S.p.A. – Aerostructures Division managers expressed their concern about this issue. They fear regulations do not always specifically describe actual activities performed in Nola factory. For this reason, in order to guarantee comfort levels appropriate to the specific case, new lighting requirements were defined.

In more detail, where EN 12464-1 requires 150-200 lx, a task illuminance of 300 lx was asked for. This decision derives from the consideration that, despite workers operate machineries through displays, sometimes they need to consult drawings or papers and, for this task, 150 lx is considered a not adequate illuminance level.

Moreover, as for "Profiling area" (n. 23 in Figure 2), an increasing of task illuminance to 500 lx was asked for, because in some cases manufacturing process is not completely automated and human intervention is needed.

Finally, as for "Calibration and adjusting area" (n. 22 in Figure 2) and "Painting area" (n. 29 in Figure 2), a reduction to 500 lx was asked for because, on the contrary, production process is completely automated. Figure 12 classifies factory areas depending on illuminance requirements based on previous considerations.

On the basis of these requirements, a light scenario able to fulfill them was identified through the use of Dialux software. Luminaires are gathered together in different control groups. In order to define dimming levels specific of each control group, it was necessary to account for different issues:

1. luminaires that are located on a single task area are not always mounted at the same distance. For example, cross distance between luminaires in the "shipping area" (n° 30) is sometimes 4 m and sometimes 8 m. Considering that, for this area average illuminance equal to 200 lx is requested, it is necessary to identify two different control groups, in order to guarantee illuminance uniformity;
2. due to luminaires beam spread and mounting height, lit area of each luminaire is wide;
3. due to system's characteristics, where cross distance between luminaires is equal to 8 m, sometimes it is not possible to achieve an average illuminance equal to 500 lx, if machineries shade luminaires' luminous flux. If the activities located in this area required such illuminance levels and high machineries are installed (like the present working configuration), integrative lighting should be implemented.

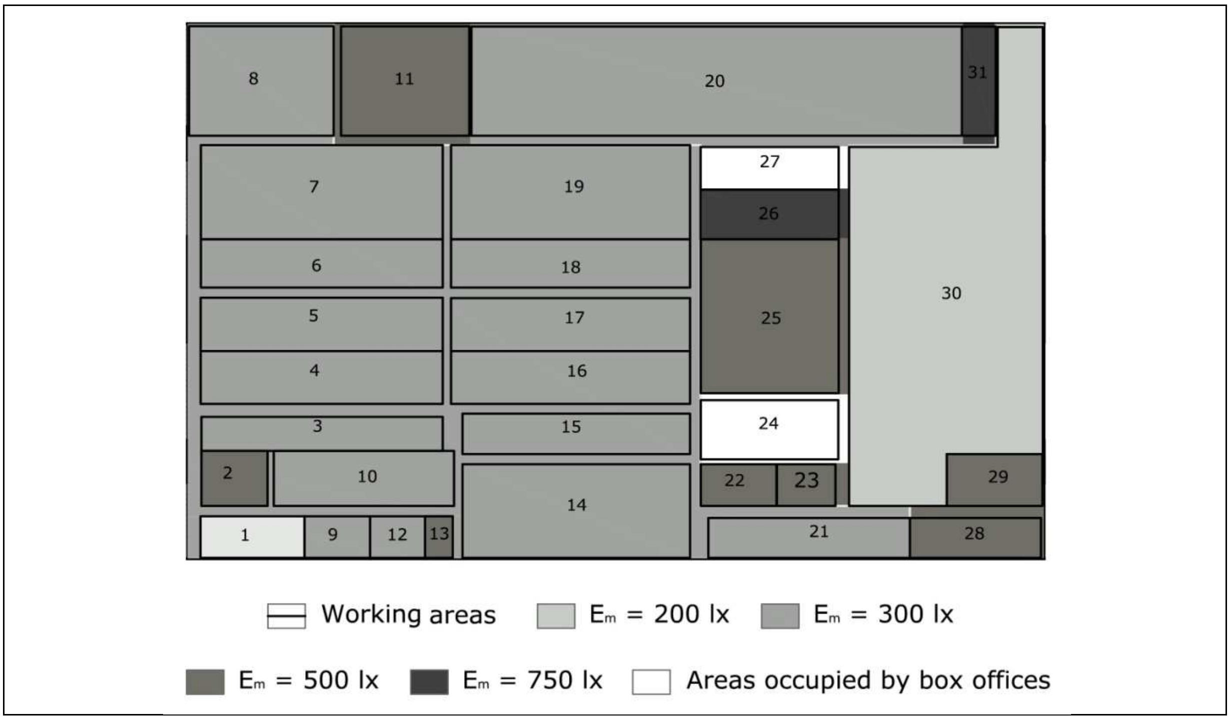

Figure 12: Working areas classified depending on Finmeccanica S.p.A illuminance requirements

On the basis of these premises, control groups are identified as illustrated in Figure 13.

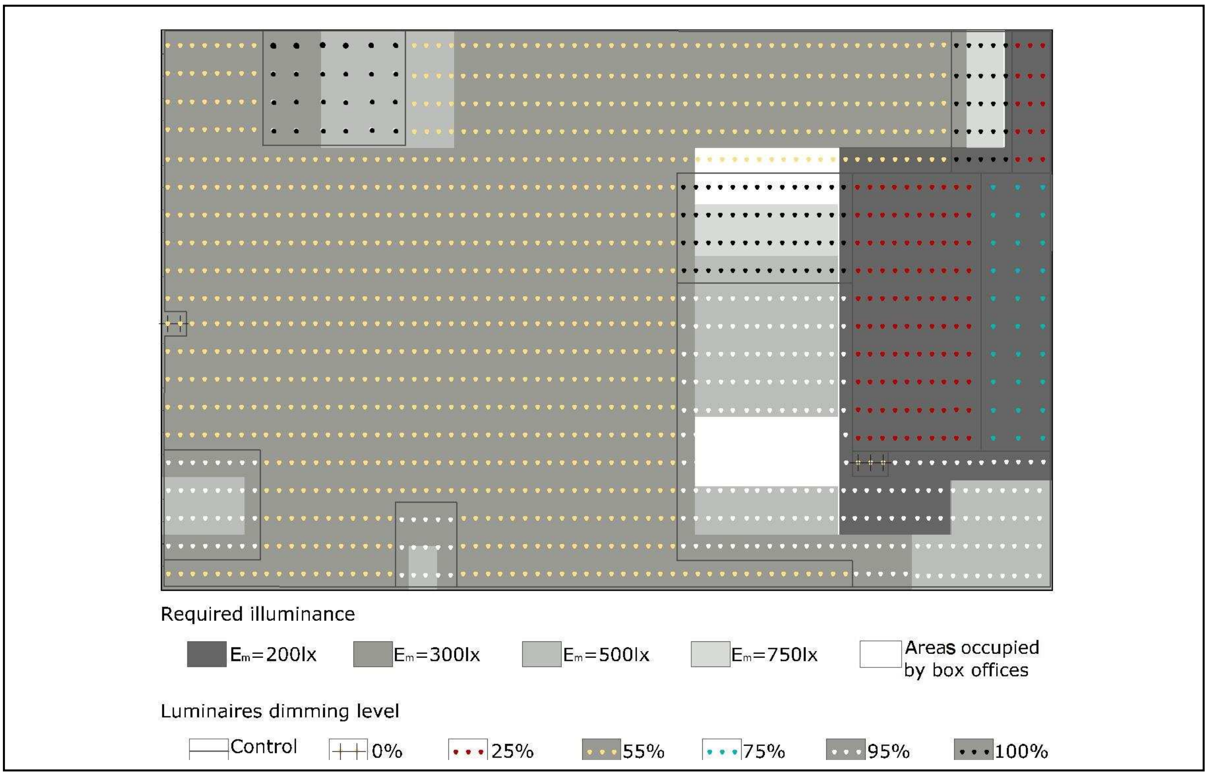

Figure 13: Control groups distribution

Table 6 reports for each control group the number of luminaires, the dimming level necessary to obtain required illuminance at workplane and the correspondent power absorbed by each luminaire. The power related to each dimming level is deduced from Figure 5.

Table 6: Control groups dimming levels

Number of luminaires	Dimming level [%]	Correspondent absorbed power [W]
5	0	0
115	25	51
874	55	122
30	75	169
242	95	216
105	100	228

As it can be inferred from Figure 14, in order to obtain required task illuminances, control areas (indicated with black lines) do not always correspond to task areas (represented with grayscale hatches). This occurs because it is necessary to account for issues previously mentioned (changeable distance between luminaires, influence areas, etc).

Moreover, some luminaires should be turned off because their flux is shaded by box offices. On the contrary, some luminaires mounted on box offices, shorter than the other constructions, should be turned on in order to guarantee illuminance levels in adjacent areas. This happens because of the present distribution of working activities. An indoor reorganization of the spaces could determine different system setting.

In Figure 14 illuminance distribution at workplane is represented and for each task area E_m achieved values are reported.

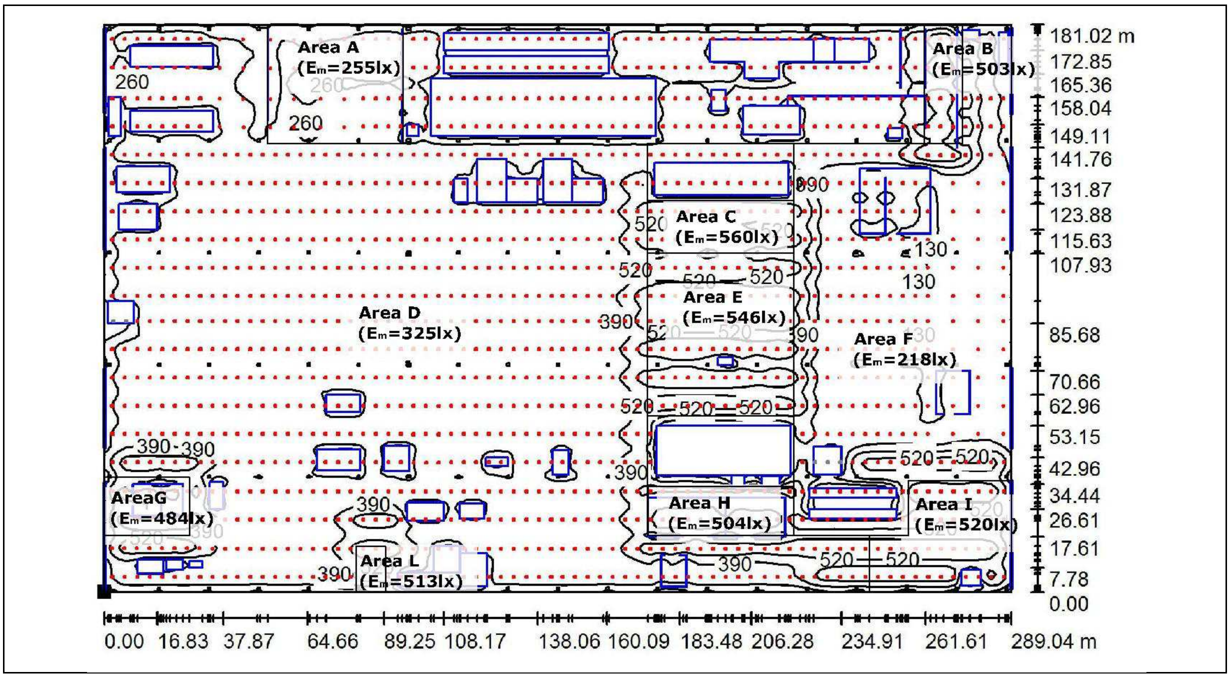

Figure 14: Isolux plan: each control group is differently dimmed

The described system's configuration determines annual energy consumptions equal to 1.62 GWh. It determines energy savings equal to 37.94% compared to system set at full capacity.

7.2 Optimization on the basis of daylight provision

The installed control system would allow to manage luminaires according to signals produced by photosensors. In order to evaluate the advantages linked to this technical solution, the evaluation of indoor daylight availability was performed; Daylight Autonomy (DA) and Useful Daylight Illuminance

(UDI) were calculated. DA represents the percentage of the occupied times of the year when the minimum illuminance requirement at a calculation point is met by daylight alone [7].
UDI is the percentage of time in a year during which the illuminance registered in a point on the workplane ranges from 100 to 2000 lx. These illuminance levels are considered sufficient to carry out visual tasks. Actually UDI results in four metrics:

- the percentages of the occupied times of the year when daylight illuminance values are lower than 100 lx and daylight is insufficient to visual task;
- the percentages of the occupied times of the year when daylight illuminance values are comprised between 100 lx and task illuminance and daylight have to be integrated by electric light;
- the percentages of the occupied times of the year when daylight illuminance values are comprised between task illuminance and 2000 lx and daylight is sufficient to perform visual task;
- the percentages of the occupied times of the year when daylight illuminance values are higher than 2000 lx and daylight levels are likely to produce visual or thermal discomfort, or both [8].

Indoor daylight contribution is determined by windows belonging to the two cross walls and by saw-tooth windows located in the roof. Each shed is glazed except the first towards South which is opaque.
Dynamic daylight simulations were performed with DIVA (3.0.0.6 version), a daylight analysis tool developed at the Graduate School of Design at Harvard University and now distributed by Solemma LLC.
Optic characteristics of considered surfaces are modeled as described in paragraph 6. Glazing's visual transmission is considered equal to 40% in order to account for indoor pollution levels.
An analysis grid, located at 0.85 m from the floor, composed of 600 calculation points located at a distance of 9 m one from another was considered. Other 17 calculation points were located at the height of each one of the shed except of the opaque one, in order to simulate open-loop photosensors.
Simulations were performed considering that the building was occupied 24 hours a day from Monday to Saturday and 16 hours a day on Sunday, as reported in Paragraph 2.
Table 7 reports calculation parameters.

Table 7: simulation parameters [9]

Ambient bounces	Ambient divisions	Ambient super samples	Ambient resolution	Ambient accuracy
7	1500	100	300	0.05

In order to evaluate the potentialities of a system based on photosensors, Daylight Autonomy (DA) was calculated for each point of the analysis grid. Task illuminances considered for DA evaluation are those indicated in Figure 12. DA values are represented in Figure 15. Moreover, for some representative calculation points, Useful Daylight Illuminance (UDI) levels are calculated as shown in Figure 16.

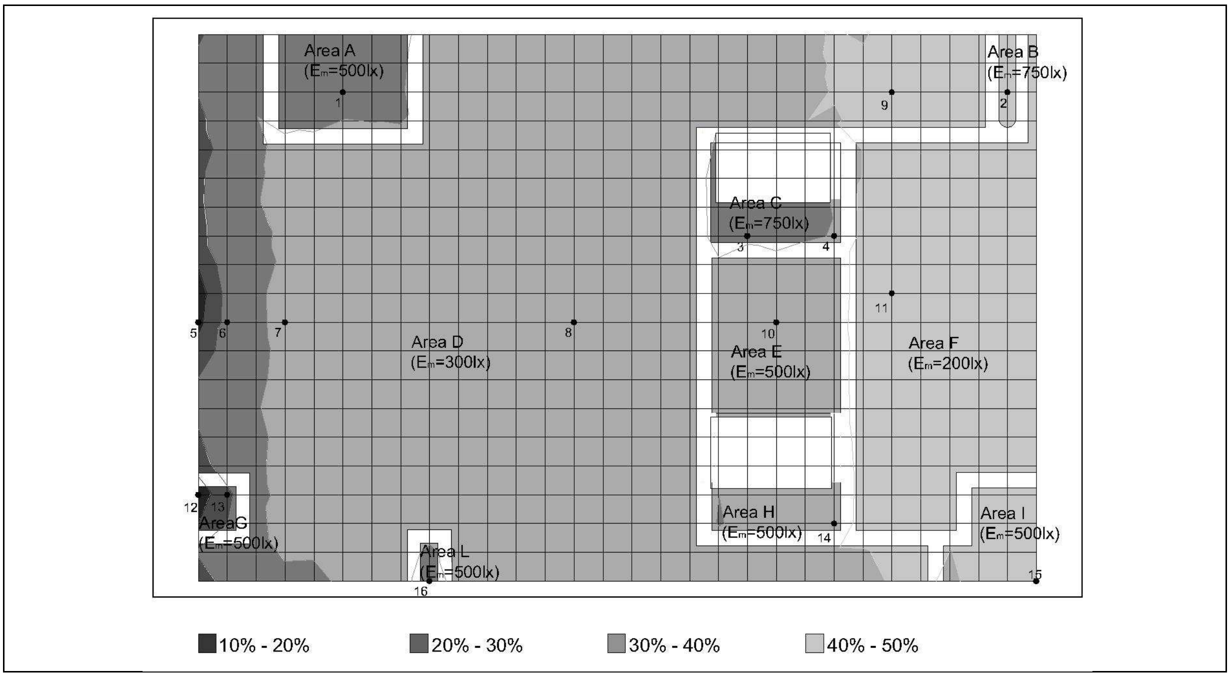

Figure 15: DA grayscale plan

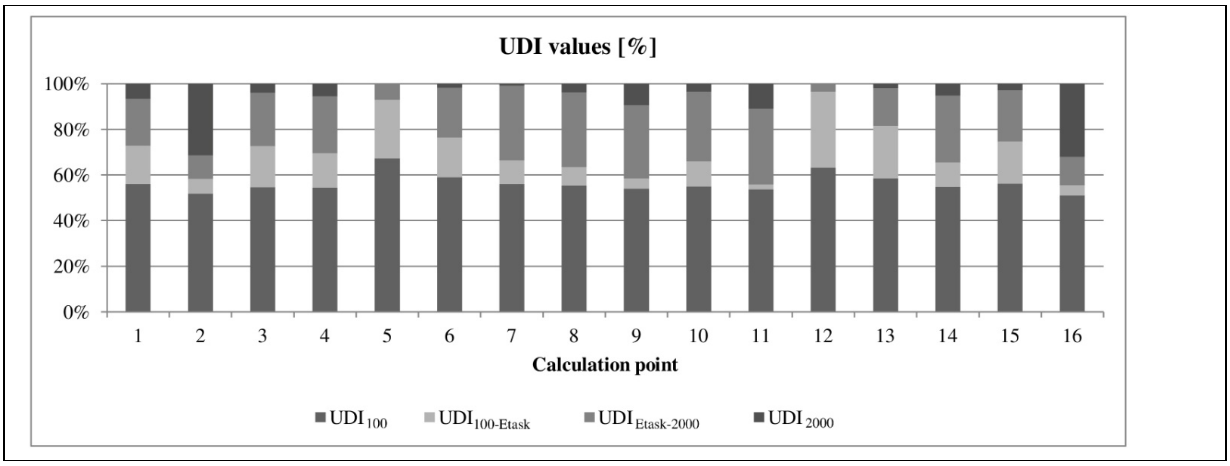

Figure 16: UDI values

As it can be inferred from Figure 15, DA assumes values comprised between 30% and 50% in the most of considered areas. The South zone is more disadvantaged then the others. This demonstrates that daylight contribution of side windows is negligible compared to that of saw-tooth windows. Indeed DA assumes lower values in the area corresponding to the opaque shed (see points 5 and 6).

Obviously DA assumes highest values when required illuminance is lower (see "Shipping area").

As for UDI values, Figure 16 demonstrates that generally risks of discomfort due to daylight illuminance values higher than 2000 lx are negligible. Annual percentage for which daylight illuminance is comprised between 100 lx and task illuminance varies between 2% and 33% depending on the specific area.

Considering results of daylight analysis, the use of an open-loop dimming daylight-linked control system is likely to determine relevant additional energy savings.

Cross-checking data of Figure 13 and Figure 15 it can be deduced that areas characterized by the same task illuminance does not receive the same amount of daylight. For this reason, control groups previously defined are further partialized as reported in Figure 17, in order to account for indoor daylight availability.

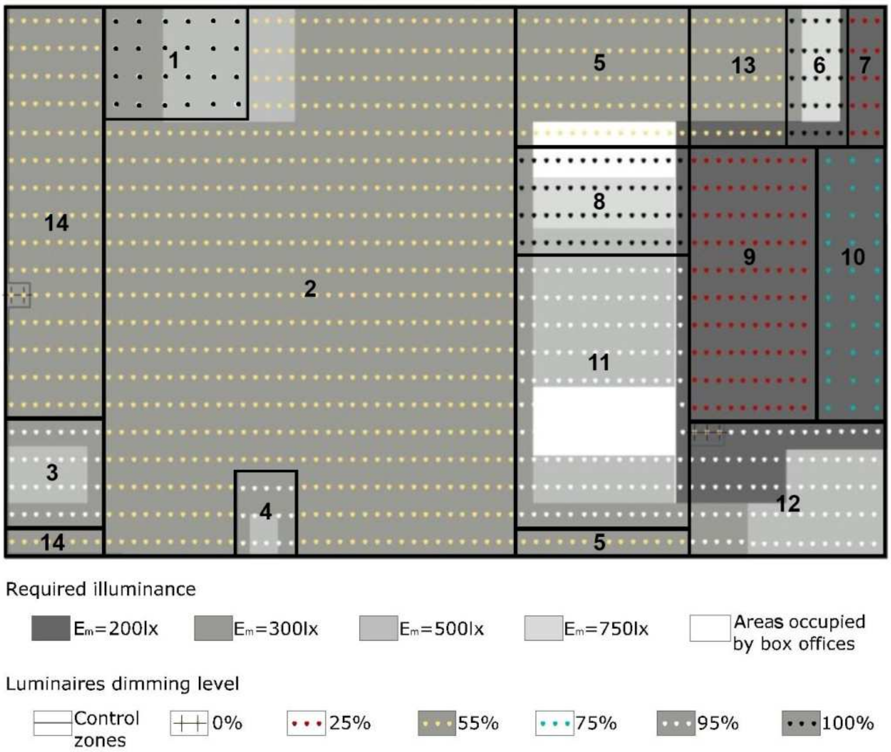

Figure 17: Control groups defined cross-checking data obtained by task analysis and DA evaluation

It was supposed that each one of the considered luminaires groups was managed by a photosensor located at the height of the shed corresponding to the center of the controlled area. For each controlled zone the most disadvantageous calculation point (i.e. the point receiving the lowest amount of daylight during the year) was identified. Then the relationship between the illluminance at this point and the photosensor illuminance was studied (see Figure 18).

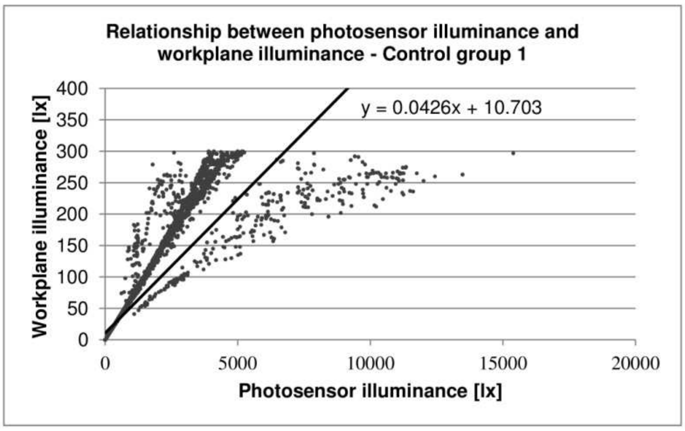

Figure 18: The relationship between photosensor illuminance and the workplane illuminance observed for control group 1

In this way the best fit linear function that represents the ratio between photosensor illuminance and workplane illuminance was identified. Then, thanks to the function equation, it was possible to model the open-loop control algorithm, as described in Figure 19.

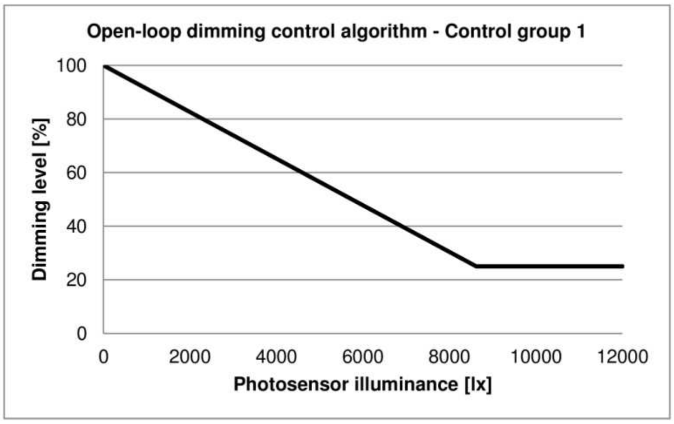

Figure 19: Open-loop control algorithm related to control group 1

For each control group a minimum dimming level equal to 25% was established on the basis of measurements reported in Figure 5. On the contrary the maximum dimming level was different for each group and it was inferred from Table 6. For example, luminaires belonging to the control group 2 (see Figure 17) will be dimmed from 25% to 55%.

Groups 7 and 9 will be not dynamically dimmed because the analysis of tasks (see Paragraph 7.1) prescribed for these luminaires a dimming level equal to 25%.

Knowing photosensor illuminance variations during the year thanks to the dynamic daylight simulation, on the basis of the modeled open-loop control algorithm and of the relationship between dimming level and absorbed power (see Figure 5), it was possible to evaluate system's energy consumptions. Calculations demonstrated that the use of such a control could determine annual energy consumptions equal to 1.20 GWh, obtaining energy savings equal to 54.16% compared to the system operating at full capacity.

However the assessment of energy savings is strictly influenced by the simplifications of the used calculation model. In this evaluation photosensors' spatial and spectral responses were neglected; photosensors were modeled as luxmeters and the photosensor signal was assimilated to illuminance at the photosensor; dynamic simulations time-step were 1 hour and consequently photosensors time delay was not considered; power absorbed by auxiliary electronic components was not evaluated.

Simulated data should be on-field verified by monitoring the actual functioning of a system after the installation of photosensors, in order to evaluate energy savings, correctly calibrate the control, evaluate the possibility to further partialize the system and observe workers' reaction to the automated control.

8. Conclusions

The paper describes a lighting retrofit intervention regarding a factory located in Nola, Naples, Italy. The intervention consisted in the substitution of old metal halide lamps with more efficient LED sources and in the installation of a smart and flexible control system able to independently manage each luminaire. Presented results derive from the cooperation work of Finmeccanica Global Services (intervention customer), Melchioni (the company that provides new system) and University of Naples (technical and scientific advisor). The goals of the intervention were to reduce system's energy consumptions, to improve workers comfort conditions and to simplify maintenance activities.

An in-depth analysis of manufacturing activities was performed and related design requirements were identified on the basis of EN 12464-1 Standard [5], in order to guarantee workers' visual comfort. E_m, U_0 and CRI values were measured to test the quality of chosen luminaires. Moreover the safety as regards "Blue light hazard" was verified through field spectral measurements.

As it was described in the paper, the new system allows to reduce energy consumptions from 4.92 GWh to 2.61 GWh.

Furthermore the installed control system, thanks to a user-friendly graphic interface allows to continuously monitor the operating conditions of each luminaire, simplifying maintenance activities.
At present commissioning is in progress and the paper also reported analyses so far carried out in order to identify strategies to optimize the functioning of the system.
Due to the production needs, in the factory working activities can be reorganized and the spatial distribution of spaces can be changed. For this reason, given a specific indoor configuration, it is possible to gather luminaires together in order to differently light working areas and to obtain for each one of them appropriate workplane illuminance levels. The application of such a technical solution, considering the actual factory configuration, could allow to achieve energy savings equal to 37.94% compared with the system at its full capacity.
Dynamic daylight simulations allowed to evaluate the advantage to install photosensors, in order to automate lighting control on the basis of indoor daylight provision. Simulation results demonstrated that photosensors installation and dimming control could allow to obtain additional energy savings equal to 16.22%, compared with the abovementioned solution.
However as it was previously reported simulated savings are influenced by simplification of calculation model and consumptions should be on field verified.
The further development of this work is the practical application of technical solutions presented in paragraphs 7.1 and 7.2. Illuminance levels calculated on the basis of the partialization of the system could be verified by on field measurements. The advantage of photosensors' installation should be proved. The performances of the system should be evaluated on the basis of its capability to maintain prescribed illuminance at workplane according to photosensors detection, continuously monitoring illuminance at workplane and measuring absorbed power at the same time.
Furthermore it could be interesting to examine workers' opinions about system functioning through the use of a questionnaire.

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Sustainable outdoor lighting for reducing energy and light waste

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Abstract

The lack of lighting planning for internal and external illumination of buildings contributes to wasting energy and to the issue of light pollution. This will be demonstrated with research from the ground and by analysis of images, taken with detectors on satellites, the International Space Station or planes. Besides large area floodlighting from airports or sports facilities, facade illumination is the most important contributor. The effects of malpractice versus sustainable lighting planning solutions will be demonstrated with some examples in cities like Bonn, Strasbourg, Athens and Thessaloniki. Further examples in the countryside will demonstrate lighting practice in the German star park Biosphere Reserve Rhön. facade lighting planning, considering optimal alignment, the intensity and the colour quality of the illumination, will contribute to reducing light pollution and thus waste of energy and will increase human comfort at the same time.

Experience shows that unilateral promoting energy efficiency will finally result in more extended use of energy, which is known as rebound effect. In addition the small size and long lifetime of the modern solid state lighting will result in an increased use even in remote places thereby emitting more artificial light into the natural night. This does not only affect the energy use, but also the biological rhythms of animals and human beings.

More interdisciplinary criteria for a sustainable lighting with reduced light pollution will be discussed based on the observations including data provided by the EU-network "Loss of the Night"-Network (EU-COST Action ES1204 LoNNe).

1 Introduction

Light pollution is obtrusive artificial light, which brightens the natural lighting conditions. Three different effects of artificial light at night (ALAN) are disturbing: glare, light trespass in non-target areas and sky glow, the brightening of the atmosphere by scattered light. The worldwide brightening of the nightscape is increasing by a rate of about 6% per year [1]. Skyglow is enlightening the atmosphere far beyond cities borders by a range hundreds of times larger than was the case before using artificial light [2].

Light pollution is not only an annoyance, but an ecological hazard. Sustainable lighting planning is an important tool to avoid obtrusive ALAN and to save energy at the same time. Over 60% of invertebrates and 30% vertebrate organism inhabit the nightscape and have fine-tuned senses, adapted to night time environment [1]. Light pollution can interfere with the circadian and seasonal behaviour, disrupt ecosystems, reduce ecosystem services, e.g. night time pollination and water clearance and is a major risk for biodiversity [e.g. 1, 3]. Many studies clearly indicate adverse health effects due to the suppression of melatonin [e.g. 4, 5].

The EU-COST Action 'Loss of the Night Network (LoNNe, ES1204) aims to improve knowledge of the multiple effects of increasing artificial illumination worldwide. Lighting planning, innovations in technology and policy are urgently required to address the impact of artificial lighting on the natural environment, biodiversity, ecosystems, human health and society, and to identify potential corrective measures.

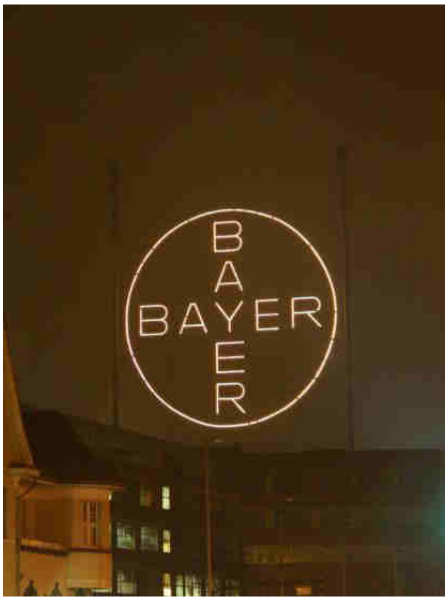
The lighting planning within the commercial and public building sector is an important assignment to combine energy efficiency, ecological compatibility and human wellbeing and comfort.

Here we demonstrate the impact of mainly horizontally emitted lighting on birds and of disturbed ecosystem services. Some examples of measurements of vertical illuminances from Greece are discussed. Then we demonstrate with some examples how upward emissions of architectural lighting are even visible from space. Finally, we will offer cost-effective solutions for lighting planning in order to reduce the negative impact of ALAN and lower the energy consumption.

2 Examples for ecological constraints with ALAN

2.1. Bird collision with emission through illuminated structures

In Germany long-time studies on the collision of migrating birds with the illuminated advertising Bayer cross in Leverkusen have been made between 1964 and 1999 by Hermann Brombach from the NABU Leverkusen [6]. The Bayer cross has a diameter of 51 m and was illuminated through 1712 40 W incandescent bulbs, that have been exchanged to 5 W LED bulbs in 2009. Brombach counted 1964 – 1979 an annual mean of 28.5 dead birds. Since 1980 the cross is switched off during bird migration time in March/April and September/October during night between 22 and 4 o'clock and the mean annual number of dead birds 1983 – 1999 had decreased to only 1.8.



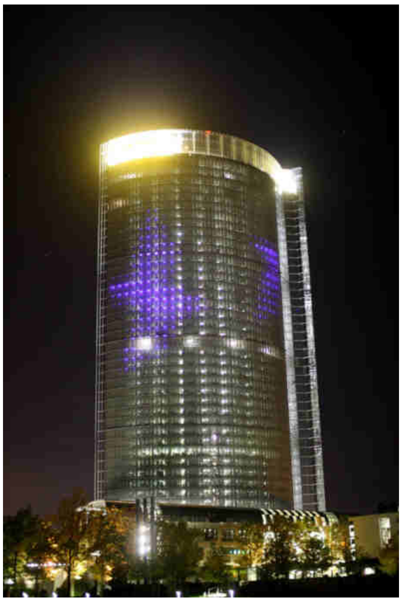


Fig. 1. (left): The Bayer cross in Leverkusen, Fig. 2 (right): The Posttower in Bonn

Haupt [7] observed bird collisions with the illuminated Post Tower in Bonn, a 162 m high building with 41 storeys, which is surrounded by glass facades. The facades are illuminated with 2000 fluorescent tubes in the colors blue, yellow, red and 142 beamers with changing colors with altogether 75 000 W. Further beamers illuminate the top and the advertising sign and waste light towards the sky which is visible especially with low clouds. During one year Haupt detected about 1000 birds that collided with the illuminated facade. From these results, the owner of the building took action, but results of this reduction have not yet been published.

In Toronto, Canada, volunteers of the Fatal Light Awareness Program (FLAP) have collected migrating birds that were killed or injured by collisions with 16 illuminated buildings during night [7]. Switching off the lights at night mainly during the migration periods reduced the number of killed birds considerably. The reduction of the artificial lighting in the late night reduces the energy bill of the 16 buildings in Toronto by $ 3 200 000 and CO_2 emissions by 34800 tons [8].

Therefore a compromise between glass and non-glass surfaces should be used to reduce energy use during day by using daylight as far as possible. But during night the reduction of reflections and light emissions protect nature and reduce energy consumption.

2.2. An example of disturbed ecosystems

At the Elbe Philharmonic Hall in Hamburg the Hafen City is the largest European urban regeneration area. Old port warehouses of Hamburg are being replaced with offices, hotels, shops, official buildings, and residential areas. The bridge spider *Larioinides sclopetarius* which is an extremely successful species in colonising urban habitats propagates at the Hafen City 300 times faster compared to its natural habitat. Open concrete, lack of trees for birds and superabundance of food, due to water emerging insects, which are massively attracted to the light of the buildings are optimal conditions for the spider propagation [9]. Cobwebs and spiders are an annoyance to the residents and the costs for cleaning add up to maintenance expenses.

3 Examples of facade illumination from Greece

There are a lot of outdoor lighting applications where the luminance on building facades or signs are exceeding the limits defined in CIE 150 [10] or EN 12464-2:2007 [11]. Using a luminance meter (Konica Minolta LS-100) several luminance measurements were performed on building facades in two major cities of Greece, Athens and Thessaloniki. Table 1 shows the luminance measurements on various building facades and signs while figures 6 to 9 show the measured facades and signs. The urban content of the Greek cities consists of buildings like the selected ones meaning that luminance on the facades of buildings in Greek cities is exceeding the European norms.

Table 1. Luminance measurements of building facades and signs using luminance meter (Konica Minolta LS-100) while the observer was opposite of the building.

Type	Luminance (cd/m^2)	Environ. zone	Limit EN 12464-2 (cd/m^2)
Building A	145 (area with white color)	E3	10
Building A	65 (area with the flowers' image)	E3	10
Building B	24.5 (part of the facade with cold color temperature)	E3	10
Building B	31.5 (part of the facade with warm color temperature)	E3	10
Sign A	1590	E2	400
Sign B	5041	E4	1000

Fig. 3: Building of Onassis Cultural Center (Building A). It is located near the center of Athens, at Syggrou Avenue. It is located adjusted near residential suburbs (medium district brightness area) thus at an E3 environmental zone.

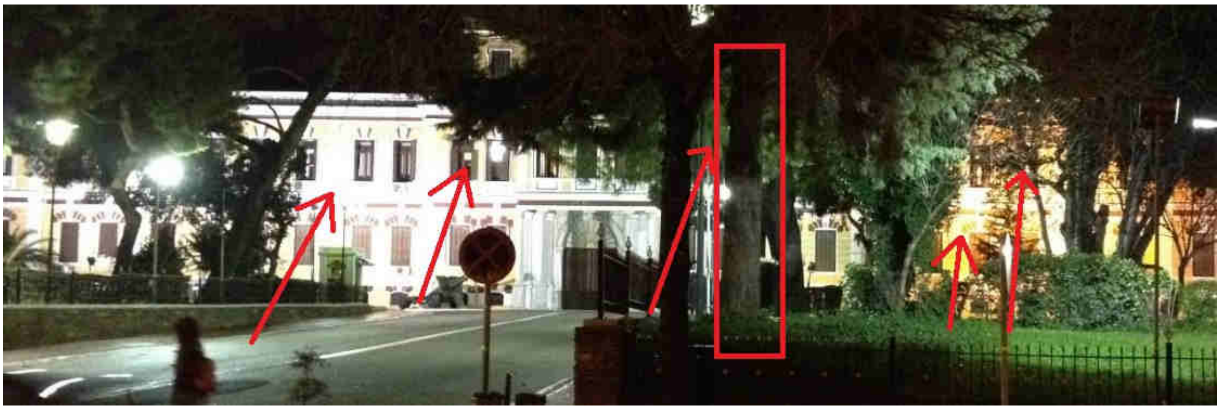


Fig. 4: Building of Memorial of third Corps Army (Building B). It is located near the center of Thessaloniki, at Stratou Avenue. It is located adjusted near residential suburbs (medium district brightness area) thus at an E3 environmental zone.

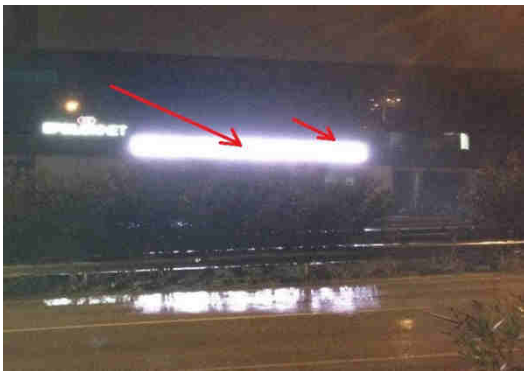


Fig. 5: Sign of private company building (Sign A). It is located outside the city of Thessaloniki. It is located adjusted near residential rural areas (low district brightness area) thus at an E2 environmental zone.

Fig. 6: Sign of private company (Sign B). It is located at the center of the city of Thessaloniki. It is located in commercial area (high district brightness area) thus at an E4 environmental zone.

4 Observing light emission from above

4.1 Architectural lighting

The upward artificial light can be detected with satellites from space. Partly this is unavoidable light reflected diffusely from illuminated streets or places. But partly it is directly emitted light that must be considered as wasted light because it is emitted without use into the sky. From 1992 till 2012 these lights have been detected with the Operational Linescan System on the satellites of the Defense Meteorological Satellite Program (DMSP) with a limited angular resolution of about 5 km and limited dynamic range [12]. Therefore the individual sources of light emission could not be separated and the overpasses were in the early evening (at 19:30). A higher spatial resolution (750 m) and higher dynamics have the data of the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-Orbiting Partnership satellite since 2012 and which is available to the public on a monthly interval [13]. The spectral sensitivity of the detector is between wavelengths of 500 nm and 900 nm. The observations in central Europe are made in the early morning hours (at 01:30), therefore at a time when at least in Germany many activities have stopped and artificial lighting is reduced.

An even higher spatial resolution in the range of 10 – 20 m can be achieved by the astronauts on board of the International Space Station depending on the viewing angle towards earth and the focal length of the camera lens used [14]. As these pictures are taken with standard digital reflex cameras

Nikon D3S, they also provide color information in blue (420-500 nm), green (500-590 nm) and red (590-650 nm).

Using images taken with long focal lengths, individual light sources can be distinguished. The highest spatial resolution of 1 m can be achieved with pictures taken at night from a plane e.g. over the cities of Berlin [15] and Linz, Austria [16].

Kuechly et al. [14] determined from the flights over Berlin that 31.6 % of the visible upward light emission is due to street lighting and 15.6% due to industrial, commercial or service areas.

Satellite pictures from many cities present bright individual spots. We have taken a closer - though only qualitative - look at pictures taken by the astronauts on the ISS of cities identified by the authors. These pictures were overlaid on GoogleEarth data to determine the position of the bright point sources. The individual light sources were identified using either local knowledge or information from Google Maps.

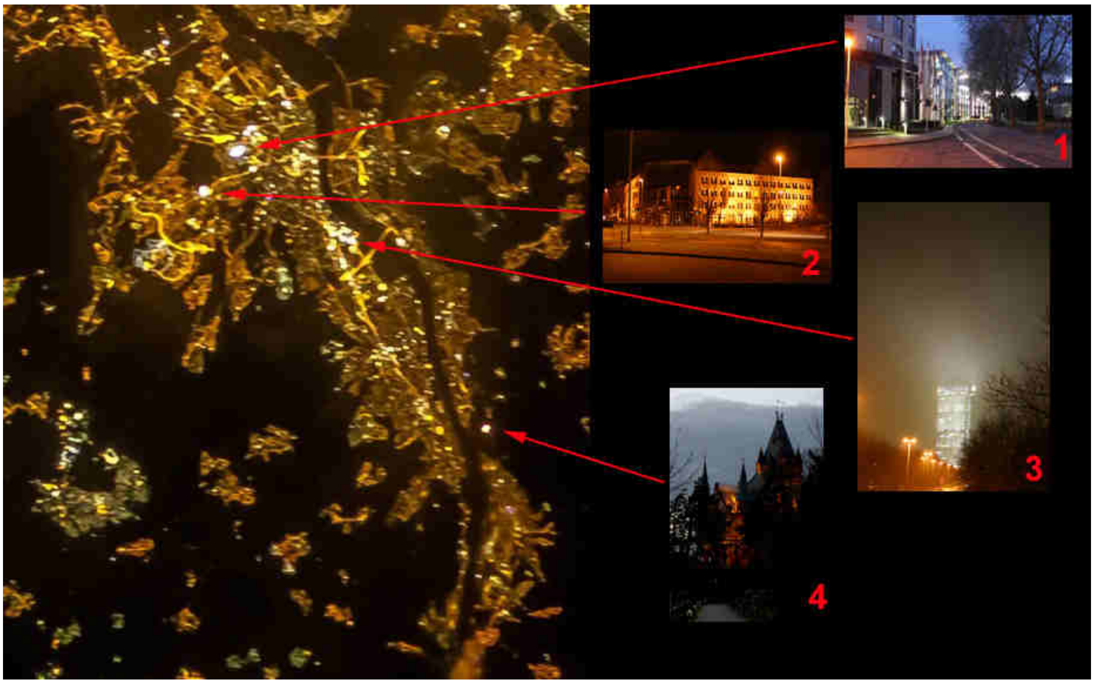


Fig. 7: ISS picture of Bonn and some of the bright identified structures (see text)

Bonn in Germany was identified on the picture ISS034-E-5938 taken on 2012-12-08 at 21:39 with a focal length of 180 mm (fig. 7). Buildings lit by floodlight are brightest:

- Business Centers Rochusstr. (2 in fig. 7), Am Probsthof/Bornheimer Str. (1),
- Administrative center around Posttower (3) and United Nations Campus
- Drachenburg is a building illuminated with floodlights on the roof within the Nature Park Siebengebirge (4)

Strasbourg, France, is on the image ISS030-E-274365, which was taken on 2012-02-21 at 20:08 with a focal length of 400 mm (fig. 8). The following bright spots could be identified:

- Many extended illuminated sports areas.
- Parking of supermarket (4 in fig. 8)
- Others are due to facade illuminations in the centre of the city (2)
- Brightly illuminated cultural buildings like Musée d’Art Moderne et Contemporain (1)
- Passerelle des Deux Rives illuminated pedestrian bridge (3) over the Rhine River, brighter illuminated through floodlights than the main street to the North.

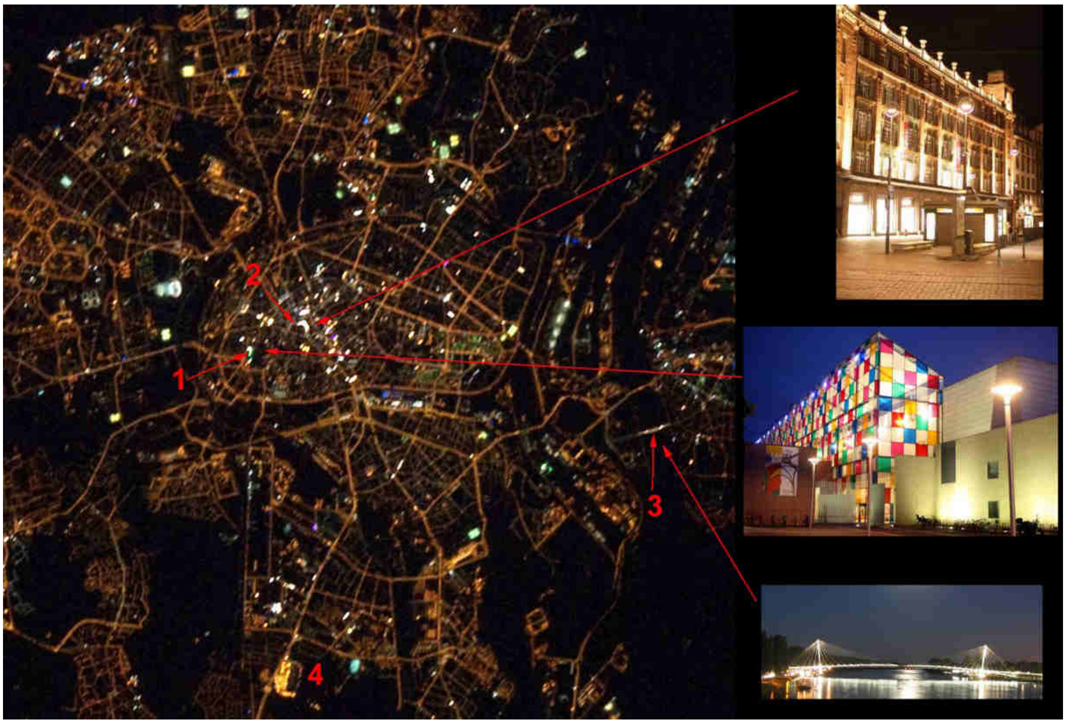


Fig. 8: Strasbourg as seen from the ISS, with some bright structures identified (see text). Picture 3: Passerelle des Deux Rives is from Wikimedia

Another interesting illumination could be detected on the VIIRS data in the UNESCO biosphere reserve Rhön which in 2014 was designated as an International Darks Sky reserve according to the criteria of the International Dark Sky Association. Under the dark skies of this region, a far reaching bright light dome over the small village of Brüchs in the most northern part of Bavaria was detected (1 in fig. 9). When getting closer, a church illuminated with two 400 W floodlights was visible with most light passing by the church into the sky. Nearby is a Special Protected Area for birds according to EU regulations. The village has about 100 inhabitants and more energy was used to illuminate the church than the public lighting in the road of the village. This light was visible on the VIIRS satellite data and appeared brighter than the light of the nearby village Fladungen with 2180 inhabitants. After the intervention of the star park administration, the church was switched off in 2013 and is no longer visible in later data.

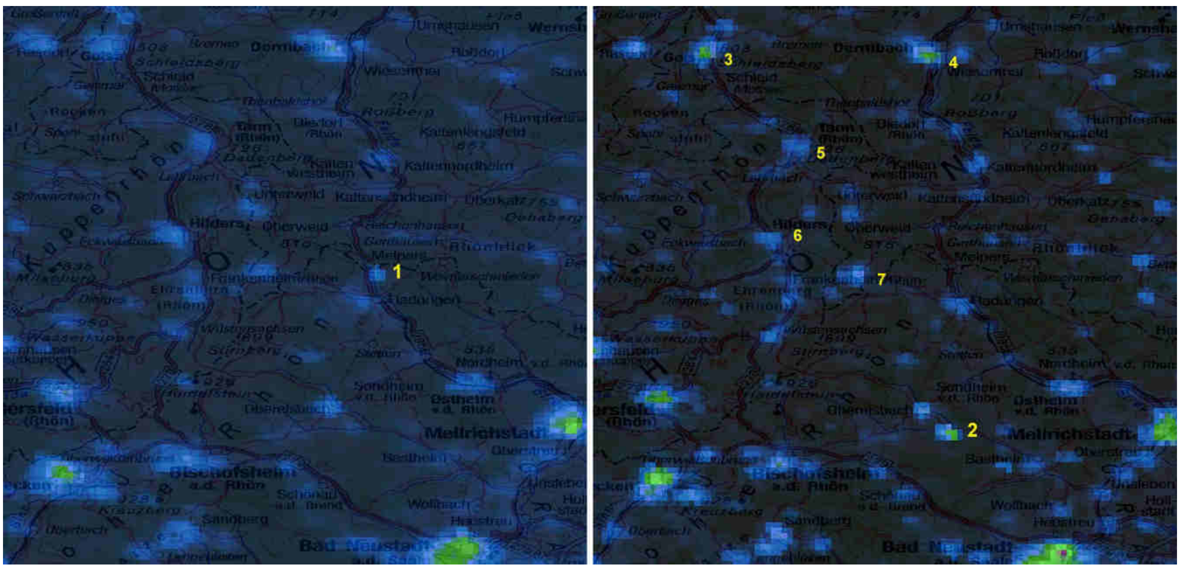


Fig. 9: VIIRS data from 2012 (left) and 2014 (right) from the Rhön, more details in the text

These data show also that communities in the former East German communities are brighter lit than those in the western part. The communities in Thuringia Geisa (3, 4677 inhabitants), Dermbach (4, 3050 inh.) and Frankenheim (7, 1134 inh.) emit more light upward than similar or larger communities in Hesse, the former western part: Tann (5, 4446 inh.) und Hilders (6, 4600 inh.). This is due to more modern illumination installed after the reunification, partly due to commercial or industrial areas outside of the settlements and partly to the use of less efficient light guidance or no reductions during the late night hours. A similar result that east German communities are brighter lit than west Germans has been obtained by Kyba et al [14] using data for whole Germany.

4.2 Street lighting

Only on high resolution pictures (e.g. from flights) it is easily possible to distinguish street and architectural lighting. Then it is even possible to distinguish indirectly reflected light from the street and direct light from the street luminaires. While in street lighting it is easier to calculate the corresponding upward artificial light in facade lighting is more difficult.

For example in street lighting, considering as 100 W the average electric power for each luminaire, with an average luminaire efficiency 80 lm/W, i.e. 8000 lm of luminous flux per luminaire, it is concluded that the 56 million luminaires operated in the EU25 [17] emit roughly 450 billion lumens to the environment. A realistic estimation is that the upward light ratio ULR of those luminaires is at least 2.5%. Thus, over 11 billion of ineffective lumens are emitted directly to the night sky. This light is added to the one that is emitted downwards (DLOR) and reflected upwards from the asphalt and the buildings and trees in the surroundings. Supposing that the average reflectance of the surroundings is the same with the 7% reflectance of the most common asphalt CIE R3 it is concluded that 32 billion more lumens are reflected to the sky. Thus 43 billion lumens (direct and reflected) are directed to the sky.

On the other hand the main difficulties to estimate the corresponding upward flux for facade lighting are:

- No estimation of number of luminaires for facade lighting
- No real data for power of the luminaires, luminous efficacy, lamp type etc.
- It is impossible to gather data for the placement of this type of luminaires meaning the ULR depending the aiming, orientation or guidance of light.

In general, the European Norm EN13201-2 categorizes the street luminaires in 6 luminous intensity classes (G1 to G6) depending on their emission at the angles 70^o, 80^o, 90^o and above 95^o from the vertical. Most of the modern luminaires with LED or conventional lamps are classified in Class G3. Older luminaires which represent the vast majority of the existing installed ones belong to the upward emitting classes G1, G2 and G3 (ULR≥0). These classes do not limit the light emission at the angle of 70^o and above 90^o. However in facade lighting there are no European Norms regarding either the categorization or the placement of luminaires for the facade lighting.

As can be seen from the satellite pictures architectural lighting contributes considerably to the upward light. However, the lack of data for facade lighting regarding light pollution is a major factor for the main inability to prevent the waste of energy and the unwanted light flux upwards to the sky.

5 Possible solutions

With the following measures it will be possible to reduce energy waste of artificial lighting and light pollution.

5.1. Orientation/Guidance of light:

As can be seen in the pictures from above, floodlights with broad angle beams illuminate a facade homogenously but often are not installed correctly that a lot of light passes by the object to be illuminated into the sky. This can be reduced by using accentuated light with smaller beam diameters. Other problems are the ground recessed luminaires, as they emit the light upward and if they have asymmetric emission they must be installed correctly. They are glaring to people passing by and the glasses of these luminaires become quickly scratched and then emit light diffusely upwards. Another method to direct the light correctly is the use of shades in front of the floodlights which prevents light passing by the object to be illuminated. This GOBO technique is used e.g. for the facade illumination of the buildings in the city of Lucerne, Switzerland, avoids the illumination of the sky and protects habitats of birds [18].

Another method to reduce diffuse reflections from a facade towards the sky was proposed by Gălăţanu [19]. In a typical situation a facade is illuminated with narrow beam projectors from below (fig. 10). We introduce some virtual calculation planes to calculate the light distribution to an observer on the ground (VIP – Virtual Inferior Plane), and towards the sky (VSP – Virtual Superior Plane) using DIALux (fig. 11). Due to the diffuse reflection – even when light is incident nearly tangent – the light distribution is symmetrical in the Virtual Vertical Plane (VVP). The illuminance values are given in table 2 and one recognizes that the downward light towards the observer and the upward light towards the sky (generating light pollution) are the same.

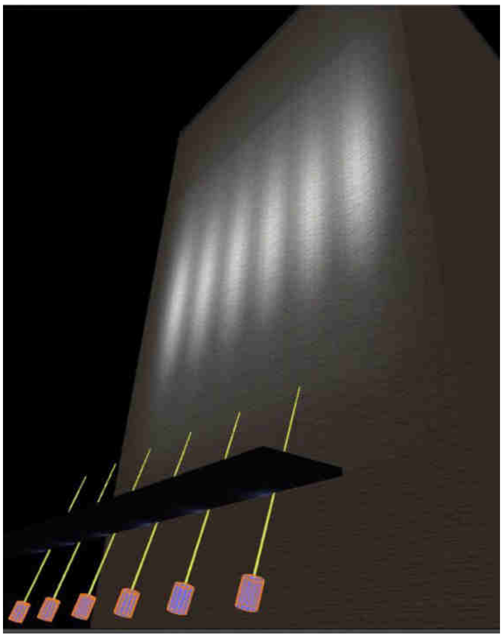


Fig. 10: Lighting scene of the façade

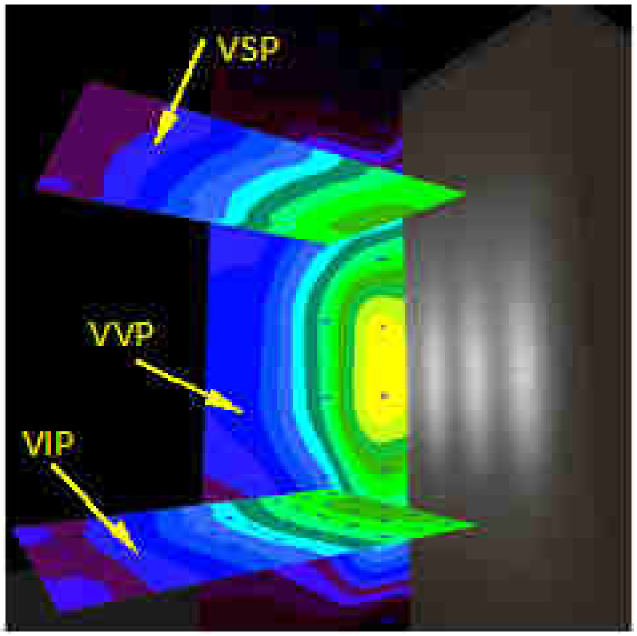


Fig. 11: Virtual calculation planes

Table 2 – The quantitative results for symmetrical (diffuse) reflection of the facade

Parameters (Lux)	**Virtual Superior Plane (VSP)**	**Virtual Inferior Plane (VIP)**	**Asymmetrical Factor (VSP/VIP)**
Average Illuminance	3.97	3.92	1.01
Maximum Illuminance	7.44	7.41	1.00

If an asymmetric micro profile could be attached to the facade, it is possible to change the situation. While in [19] a prismatic profile was analyzed, we propose here a cylindrical micro profile (fig. 12). The quantitative results demonstrate a considerable reduction of the upward light and therefore light pollution (table 3). In fig. 13, the Virtual Vertical Plane (VVP) also illustrates a much more favorable asymmetry of the reflection.

Table 3 – The reduction of the upward light for asymmetrical (diffuse) reflection of the facade

Parameters (Lux)	**Virtual Superior Plane (VSP)**	**Virtual Inferior Plane (VIP)**	**Asymmetrical Factor (VSP/VIP)**
Average Illuminance	2.08	5.57	0.37
Maximum Illuminance	3.37	13.2	0.25

The increase of the average illuminance from 3.92 lx to 5.57 lx at the observer in VIP gives the possibility to reduce the installed luminous flux by the ratio 3.92/5.57 = 0.703. This will also result in an additional reduction of the average illuminance of VSP to 0.703 * 2.08 lx = 1.46 lx. Compared to the initial value of 3.92 lx this corresponds to a reduction of upward light by 63 % and an energy saving of 29.7%.

Even if one is forced to use usual construction material for the facade, it is possible to reduce light pollution by modifying the diffuse reflection. The presented micro profile can be realised technological easily on site, using two centimeter steep plaster extrusion for example.

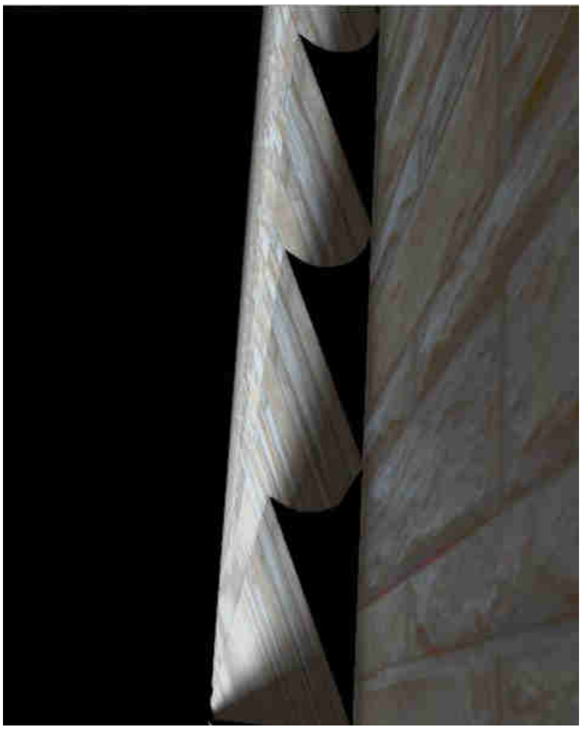


Fig. 12: The cylindrical micro profile on the facade

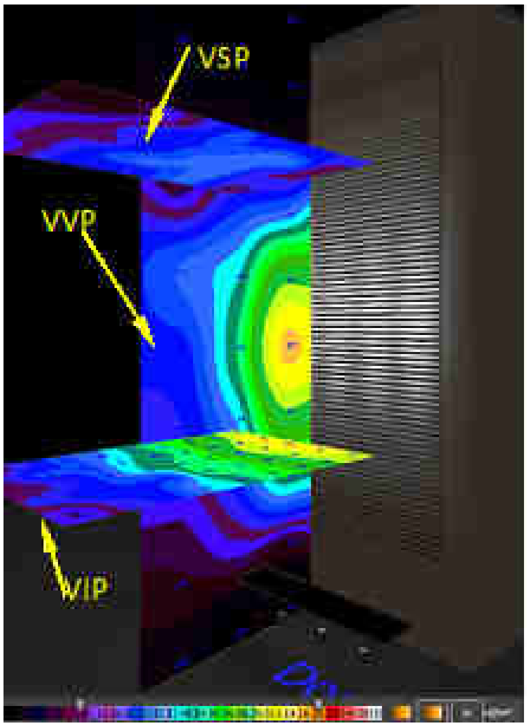


Fig. 13: The asymmetrical diffuse reflection of the facade

5. 2. Intensity of light

The CIE Technical Report 150 [10] and EN [11] give limits on the vertical illuminance in different zones from natural (E1) to urban (E4) surroundings. These values are from 2 to 25 lx which after curfew should amount to 0 (E1) to 5 lx (E4). The luminance of illuminated building facades should not be higher than 0 (in E1) to 25 cd/m² (E4) which is already a very high value, considering that typical street lighting is 1 – 2 cd/m², Lucerne has defined a maximum value of 15 cd/m² [18]. These differences of brightness should be reduced to not disturb the dark adaption of the human eyes. This should also be applied to the luminance values of signs which can be in the range from 50 cd/m² (in E1) to 1000 cd/m² in E4. A luminance of 730 cd/m² is already considered as disturbing [20] and Lucerne [18] has defined a maximum luminance for self-luminous signs of 110 cd/m².

The German “Lichtimmissionsrichtlinie” (LAI) [21] allows maximum vertical illuminance of windows: of 1 – 15 lux before 22 o’clock and 0 – 5 lux afterwards, depending on the zoning. These limits are relatively high compared to the illuminance of winter full moon on a horizontal plane of about 0.3 lx and the illuminance onto windows as measured in Switzerland is mostly under 0.2 lx [22].

5.3. Adaptive reduction of light

Adaptive lighting or switch off is the most effective method to reduce energy consumption though artificial lighting. The French government released a regulation within the environmental law “Grenelle de l’environnement” to reduce energy waste by reducing light pollution [23]. For this reason: advertisement has to be switched off between 01:00 and 06:00, interior lighting of offices has to be switched off 1 hour after the last use, facade illumination has to be switched off after 01:00, shopping windows have to be switched of between 01:00 and 07:00. The government estimates that 250 000 tons CO_2 could be avoided and the electricity consumption of 750 000 households saved.

5.4. Lighting colour

Although the human eye becomes more sensitive to blue light under mesopic lighting levels, and the human vision is improved, it is not recommended to use cooler color temperatures due to the harmful effects of the inherent blue light content to the human health (melatonin suppression) as well as insect attraction or negative impact on circadian rhythms of animals [24]. Therefore warm colors with reduced blue content should be preferred in outdoor use.

6 Conclusions

It is possible to reduce the waste of light and energy in façade illumination and street lighting considerably by directing light accurately towards the aim that shall be illuminated and reducing the lighting amount during late night hours when only few light is needed.

Thanks:
The ISS Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center and the VIIRS data due to: Image and Data processing by NOAA's National Geophysical Data Center.
We would like to thank for support through the EU-COST Action ‘Loss of the Night Network (LoNNe, ES1204).

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When should LED be used in a lighting upgrade?

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Abstract

LED technology is considered by many to be a silver bullet which will deliver the most efficient lighting solution. Historically, the same sales pitch was given for T5 and compact fluorescent. New technology is exciting and everyone wants to join in the revolution, so it can be difficult for the client and the designer to curb their enthusiasm long enough to really examine whether this is really the best solution for their space.

When deciding on what technology to use the designer must first identify the functional requirements of the space and then make sure the technology satisfies for those requirements. Discussion points are drawn from case studies of implemented upgrade designs from the last 18 months, which provide examples of a range of lighting requirements. We will detail the reasons why a designer of a lighting upgrade would choose to upgrade to LED, and why they would not.

Keywords

Lighting, upgrade, design, energy, efficient, methodology, LED, illuminance, lumens, lighting quality, lighting uniformity, glare

Introduction

Designing and implementing an energy efficiency upgrade of a building presents unique opportunities and challenges. No design is perfect and the building's use can change over time. The processes involved in a lighting upgrade provide the opportunity to identify imperfections in the existing system and rectify them. Through time spent using and maintaining the existing system, clients gain a clearer understanding of their needs; they know its flaws. Their energy bills tell their own story which the client has been attending to for the life of the building.

In this way the task of the designer for an energy efficiency upgrade differs from the task for a new build. As with a the design of a new installation the brief from the client is of primary importance, but in an upgrade the client speaks from experience and with very clear drivers in mind which are learned from experience with their building. At a minimum the new system must work as well as the old system.

The rapid advance of lighting technology has created a very fertile market for energy efficiency upgrades across all lighting applications, which has in turn created a significant lighting upgrade industry with a strong focus on selling the latest technology as a replacement for whatever came before. Unfortunately, this technology driven process has tended to lead to an over-simplification of lighting design. Thus compact fluorescents were uniformly used as substitutes for incandescent lamps, T5 replacement kits used to replace T8 lamps and LEDs used as drop-in replacements for all lamp types, often with very poor outcomes in terms of lighting quality. This discredits lighting upgrades and risks creating market cynicism and resistance to valid new technologies.

It is disappointingly easy to find examples of poor lighting upgrade design decisions in the everyday urban environment. Consider the example shown in Figure 1, which shows retrofitted feature lighting for a sign - which is now scarcely visible. It is reasonable to assume that the original lighting for this sign which announces the position of a highly regarded institution was well designed and implemented in the first instance. Along comes an energy efficiency upgrade and with no thought to the purpose of the sign lighting the original down lights are replaced with an LED version. While they have achieved their energy saving goal the perpetrator of this upgrade has failed to realise that the original down lights were asymmetrical wall washing downlights and have installed downward pointing symmetrical beam down lights. The result, as can be seen in Figure 1, is a sign lit with narrow, vertical beams of light making the sign harder to read instead of easier. This is one example of many where no consideration of design has resulted in a poor lighting outcome.

Figure 1: Sign suffering from poorly implemented lighting energy efficiency upgrade. For reference, the sign is barely visible just below the dark band at the top of the wall.

Consider also early adopters of T5 retrofit tubes who found the power factor in their buildings increased enormously and contrary to expectations were landed with higher energy bills instead of lower.

LED retrofit tubes are also offenders in this area because once again early versions of LED retrofit tubes did not meet expectations. Maintenance managers across Australia are having to replace the tubes only 4-5 years after installation instead of the promised 10 years because while the tubes saved energy they did not provide enough light over the life of the installation.

Methodology

There are well defined and long practiced methodologies within the construction industry for establishing good designs and ensuring they are well implemented.

Within this paper we present a best practice project methodology and how it should be applied in the context of a retrofit to achieve the best possible outcomes for both lighting quality and energy efficiency. This methodology encompasses:

- Designing for recommended illuminance levels as opposed to recreating what is already there
- Designing for good uniformity and glare control
- Reviewing luminaires with due diligence
- Ensuring that the installation and commissioning are completed correctly
- Following up after practical completion to ensure the system continues to fulfill requirements

These concepts merge design for energy efficiency with design for good lighting.

The discussion points of this paper are drawn from case studies of a series of implemented upgrade designs in local community centres from the last 18 months.

Data collection stage - Functional requirements brief (FRB)

When an engineer first engages with their client the first step should be to understand their objectives.

The project Functional Requirements Briefs (FRBs) are compiled from client interviews. This process is critical to achieving the best quality and functionality outcome. The FRB should document key stages of the project including thoroughly detailed requirements for testing, witness testing and tuning. These are crucial steps which are often left out because the project runs out of time or budget, but facilitate the provision of a more efficient lighting design when they are implemented.

Clients should review the FRB until it receives their full approval and backing. The FRB is used as the basis for design decisions, specification requirements and commissioning and testing target. The specification will describe the requirements of the design and installation to the contractor in such a way as to ensure that the requirements of the FRB are fulfilled.

Data collection stage – site visit

The design engineer must visit the site prior to upgrades to provide a baseline with which to compare lighting levels as well as a basis for subsequent luminaire selection and placement. This should include a count and identification of the existing lights, documentation of the existing lighting control system and measurement of illuminance levels throughout the site using a calibrated illuminance meter. The site visit can occur during the same period or before the FRB is written.

Analysis of existing conditions

The existing *average illuminance* should be calculated for each space on site using illuminance levels from the site visits. *The existing average Illuminance* should be adjusted by a *maintenance factor* to allow for the age of the existing lamps so estimate of the initial average illuminance. This can then be compared to the recommendations in the appropriate national standards.

Data sheets and IES files are obtained for the existing luminaire (or equivalent) and examined to get an idea of the initial lumens of the existing luminaire. The difference between 1) the existing illuminance levels that have been measured on site and 2) the illuminance levels recommended for that space type are calculated and that figure used as a multiplier to calculate the likely lumen output needed in a luminaire to achieve the recommended lux level. This information is used to select a potential replacement luminaire with some confidence that the recommended illuminance will be achieved.

The same process is conducted for uniformity. If the existing uniformity is poor; consideration should be given to an alternative diffuser, mounting or luminaire.

One advantage a lighting upgrade has over a new build is that the colour and texture of furnishings is more likely to be known. Lower than expected illuminance or poor uniformity may be a result of dark coloured furnishings or high partitions. Before any design decisions are made this issue should be discussed with the client. Are there plans to change the colour of the carpet or furniture? Is there adequate budget to move or add luminaires, or must the upgrade be a one for one replacement?

Beam spreads of the prospective new luminaires should be reviewed to check if they match or improve on the uniformity in the space, or make it worse.

Having collected plenty of data on the existing lighting system, design decisions can now be made with a clear idea of the likely outcome

Luminaire selection

Many energy efficiency lighting upgrades involve matching the existing luminaire with an equivalent but more efficient version and replacing it on a one for one basis with little regard to the lighting outcome. A more holistic approach needs to be applied in order to ensure that the lighting needs of the space are being addressed with a good quality lighting design.

It is helpful to build a small simulation of a representative area from the site, or if the site is small, the whole site. The resultant simulation can be used to verify the calculations made earlier and similarly the earlier calculations are used as a reference to ensure that all the variable values entered in the simulation are correct. We use AGi32[1] which is a standard lighting modelling software package.

Specification

A clear and detailed specification must be written covering all stages of the project to ensure the contractor understands all the requirements expected of them. The specification should adhere to the requirements of the FRB and include detailed descriptions of

- Equipment requirements including their minimum energy performance requirements. Any obsolete equipment should be removed from specification templates

- Minimum warranty periods for equipment
- Targets for maintained average illuminance and uniformity in each space type
- Lighting control functional requirements eg: sensor run on times, sensor sensitivity and switching requirements
- Commissioning and testing requirements including a commissioning plan that follows CIBSE[2] or ASHRAE[3] guidelines, clear and detailed test sheets, allowance for detailed testing, witness testing and defect rectification
- A 12 month defects period starting from practical completion
- A 12 month tuning period starting from the completion of rectification of defects arising from witness testing
- Requirements for a waste disposal plan, especially any possibly toxic waste such as paint
- Requirements for recycling batteries, metals and plastics.

The specification should also require that an independent commissioning agent (ICA) is engaged for the project.

If required, clear and detailed lighting upgrade plans are drawn to ensure that luminaires are installed in the expected places.

These details will enable the contractor to tender a price that will cover all requirements, and be a guide to them as they are purchasing, installing, commissioning and testing the equipment and the lighting system.

Commissioning and testing

An independent commissioning agent (ICA) should be engaged to provide a commissioning plan and drive the commissioning and testing process. The ICA will attend witness tests to verify all the testing done by the contractor and provide a report at the end of the project for the client.

This is the stage of the project where the early work on the FRB and the specification come to fruition. If the FRB and specification have achieved their job the contractor should find the instructions clear and be able to use set targets for commissioning and testing the lighting system.

During testing the contractor should fill in detailed test sheets and when they are satisfied that the system is running according to specification they provide a copy of the test sheets to the ICA and notify them they are ready for witness testing.

Witness testing involves repeating a small proportion of the tests to ensure they are repeatable and to verify to the ICA and the client that the installation and commissioned system are operating according to the requirements of the specification.

There are always defects discovered during the witness tests and the ICA compiles a list of defects for the contractor to fix. When the contractor has fixed the defects another witness test is held to verify that they have been fixed and the ICA signs off the defects. Typically a percentage of the contractor's fee is withheld until the defects are fixed and verified.

Tuning

A tuning period is conducted after the defects from the witness test have been rectified. The tuning period involves working with the contractors, building operators and occupants to achieve maximum comfort and understanding of operating the building systems.

In terms of lighting this is a time for training the building occupants in how to run the lighting controls, adjusting run on times, sensor sensitivity or positions and dimming values as required.

Testing conducted by a contractor and witness tested by the lighting designer does not find all the issues. A well conducted tuning period takes the opportunity to liaise with occupants to ensure that the lighting system is functioning properly and in a way that suits the occupants.

Tuning is usually conducted quarterly, that is four times within the 12 month period. Occupants are surveyed to ensure they are happy with the lighting system and the controls. Sensors timing out when rooms are still occupied, unforeseen glare issues or individual health issues can all be discovered and addressed in this way.

If the occupants report that they are comfortable with the lighting system it may be an opportunity to push the envelope particularly with regards to control. Perhaps the sensor run on times can be wound down to reduce lighting power use after hours and the margin between illuminance set points and recommended illuminance levels shaved in the PE cells for an increase in daylight harvesting.

Case studies

Luminaire Selection Case Studies

The following two case studies are taken from work at a central city community centre. This community centre underwent a lighting energy efficiency upgrade from which a number of examples on the choice of lighting technology can be drawn. The design work occurred in 2013 and was implemented in early 2014. The existing lighting system comprised mainly 2x36W T8 linear fluorescent troffers with warm white tubes running on electronic control gear. A number of twin 26W CFL down lights and were also in use in corridors and meeting rooms.

Both examples represent the simplest form of upgrade, i.e. a like-for-like replacement. They also illustrate the importance of selecting the correct luminaire in order to achieve the correct illuminance, uniformity and lighting colour.

Illuminance and uniformity were verified via simulation using IES files in both cases, leading to a successful outcome for both projects.

CFL down lights

In late 2013 when this project was being developed, LED down lights had been a potential upgrade option for some time but were just beginning to become affordable. The specification of LED down lights for the site Centre was a result of using the above methodology to compare the functionality of CFL down lights compared with LED down lights. We found that a 2x26W CFL down light could be replaced with a 19W LED down light with a similar beam distribution and light output.

The 19W LED downlight achieves the same light output for a radically lower wattage by two mechanisms:

1. The LED light source is more efficient, at 103 lm/W versus the CFL at 63 lm/W
2. The point source nature of the LED results in 100% of the light output from the LED being available, as opposed to only 52% of the light from the CFLs being available from the luminaire.

The data from the IES files indicates that CFL down lights are very inefficient. In fact, replacing a CFL down light with an LED down light can reduce lighting power by more than 60%. A simulation of the corridors confirmed that using the 19W LED down light would achieve recommended illuminance. Given all these advantages stacked up against the poor efficiency of the CFL down light the authors now consider CFL down lights to be obsolete and LED down lights a viable and efficient alternative.

T8 linear fluorescent

Also installed at this community centre were 2x36W T8 warm white recessed troffers with direct indirect perforated metal diffusers. These were replaced with 1x36W T8 cool white fluorescent recessed troffers with flat panel diffusers. The new single tube luminaires were engineered with a much more efficient reflector and diffuser than the existing twin tube luminaires. The cool white colour tubes blended better with the daylight component in the offices and were more conducive to office work.

Simulations in AGi32 indicated that most rooms would achieve recommended illuminance levels. Occupancy sensors were also installed to switch lights off when spaces where not occupied.

At this site, energy savings of 146,000 kWh per annum were achieved at the same time as meeting the Australian standards for illuminance levels. The lighting quality was improved because the distribution of light from the flat panels was wider than the indirect system which pushed more light onto ceilings and walls, and there were no glare problems because the prismatic flat panel disperses light at an appropriate angle for office work.

Figure 2: Original 2x36W T8 warm white recessed troffer at Griffin Centre

Figure 3 1x36W T8 cool white recessed troffer at Griffin Centre after upgrade

Specification Case Study

The following case studies demonstrate how research and thoughtful design decisions put into a specification can affect the outcome of a project. The first case study describes a project which was positively affected by the specification of frosted LED tubes and the second case study describes the result when the specification was taken out of the process and clear LED tubes were mistakenly installed. Not only is a specification necessary, but it also needs to be implemented.

Suburban Community Hub #1

The design work for this site occurred in 2014 and the upgrade installed in early 2015. When the client insisted that we specify LED retrofit tubes to be installed in their fluorescent luminaires we analysed the quality of several brands of LED tubes and calculated the resultant illuminance levels. Simulations confirmed our expectation of a drop of approximately 25% in average maintained illuminance. Since beam distribution of a frosted LED tube was more similar to a fluorescent tube than in a clear tube, we included the requirement that the LED tubes be supplied with a frosted diffuser for all luminaires whether they were a bare batten or a diffused fitting. Where calculations indicated that the frosted LED tube retrofit would drop illuminance below recommended levels extra luminaires where specified for installation into that space.

Figure 4 demonstrates the outcome of retrofitting clear LED tubes into fluorescent fittings with and without diffusers. The photo-metrics of a clear LED tube are not compatible with diffusers which are designed to disperse a fluorescent tube, and without any diffuser the LEDs are uncomfortably glary.

Figure 4: Reduction in glare from clear LED tubes behind fluorescent diffuser (left) versus exposed bare tubes (right)

Figure 5 shows the same room at Suburban Community Hub #1, before and after the upgrade showing the distribution of light on the ceiling is the same. Note the camera and photographer are the same but the photo on the left was taken in daylight while the photo on the right was taken at night. There is no discernable difference in colour to the naked eye.

Figure 5 Suburban Community Hub #1 archive room fluorescent battens before (left) and after (right) upgrade

Suburban Community Centre #2 – Squash Courts

This community centre was upgraded in 2015 for the same client as the other community centres. Once again the client required LED retrofit tubes to be installed in their fluorescent luminaires. The equipment specification was not followed instead clear LED tubes were supplied and installed. The result was high levels of glare. The resultant lighting performance was unacceptable especially in the squash courts.

Squash players complained of stroboscopic effects caused by the ball passing through the very directional light from the LEDs along uneven lighting distribution on the courts. After the clear tubes were replaced with frosted tubes and the stroboscopic effect vanished. The striations in the beam distribution shown in Figure 6 demonstrates the directionality of the LED beam when no diffusion is used.

Figure 6 Beam distribution of un-diffused clear LED tube shows up on the squash courts change room wall

Witness testing later revealed that the illuminance levels did not meet recommended levels in the squash courts. The addition of 2 well-designed purpose built LED battens in each court raised illuminance levels to a more acceptable level.

Figure 7 Suburban Community Centre #2 squash courts before (left) and after (right) the upgrade

Commissioning and Testing Case Studies

The following case study demonstrates how when time is allowed for thorough commissioning and testing, (and tuning) design issues which were not known at the beginning of the process can be identified and solutions found.

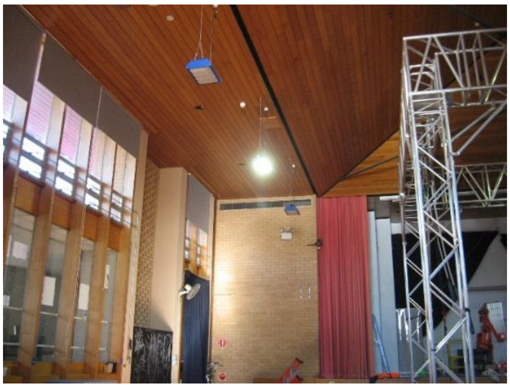
Health and Wellbeing Centre – LED high bays in a circus hall

This Health and Wellbeing Centre underwent a lighting upgrade in 2014. One of the tenants there was a circus troupe who ran circus training in the main hall. The hall was lit mainly by 400W mercury vapour high bays with bowl shaped prismatic diffusers over the opening of the fitting. The ceiling height varied in the space. The height around the perimeter was 6m and in the centre the ceiling reached up to 12m. The luminaires were mounted at 5m. The lighting was very dim. The space was predominantly lit by daylight during the day and was very dim at night. The tenants were not concerned by the lack of light but were keen to have new lighting because the mounting height in the space made it so difficult to change lamps that 2 lamps had failed and most of them had such depreciated lumens that they should have been changed long ago. With this in mind we explored the options for long life light sources and of course LED was a front runner.

Figure 8 Original luminaire in circus hall

We simulated the space using AGi32 and found that 135W LED high bays achieved the correct illuminance. We selected an LED high bay with well-designed beam angles to manage glare and the simulations indicated that the glare index for these luminaires was suitable. However the glare index simulation is designed for an occupant looking on the horizontal plane. It quickly became apparent that glare was a problem in this space. In tenant feedback sessions it was revealed that when the circus performers looked up to juggle or in the middle of tumbling they became dazzled and disoriented by the new lights.

Figure 9: Witness test of new LED high bays in circus hall



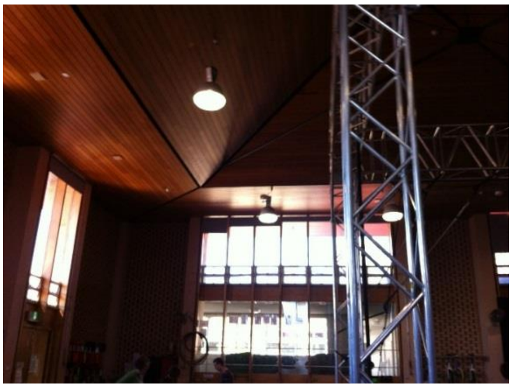
Due to good planning there was time allotted to testing and witness testing for this project as well as a 12 month tuning period after practical completion. There followed then a series of collaborative attempts to address the issue. There was no problem getting contractors to site to work on the issue because they were already attending site as part of the detailed witness testing and tuning periods the specification had required them to allow for in their tenders.

Opal diffusers were rigged up to cover the LEDs, but due to the design of the LED luminaire the diffuser had to hang a little below the LED board and the resultant side light was still a glare issue from the other side of the room. Also, the lights were just too bright. Had the LEDs been dimmable the installation of a dimming system may have solved the problem, but this was still very early days for LED luminaire development and there were no dimmable high bays available in Australia at the time.

Our detailed design process had considered and simulated a number of technology options from several manufacturers. Consequently the LED high bays were removed and instead we had pulse start metal halide high bays installed with new bowl shaped diffusers and 250W long life dual arc lamps. These performed more efficiently than the mercury vapour lamps of course and provided the target maintained illuminance.

The need for a long life light source was addressed by using a dual arc lamp. The dual arc lamp has an advertised service life of 40,000 hours, which is double the life of most metal halides and nearly as long as many LEDs. This is achieved because of the dual arc construction which effectively doubles the life of the lamp. Each time the lamp is switched on the arcs alternate so that the maintenance curve of the lamp is roughly the same for both arcs.

Figure 10: 250W metal halide high bays in circus hall



The problems encountered in this space were dealt with as part of a general attitude of consultation and refinement in a well planned project that allowed for detailed design work and ongoing testing. The client was made aware from the beginning that access would be required not just for installation but for testing and tuning. Because the entire project team had allowed the time and budget for the rectification of issues arising from testing, the outcomes of the project in the hall were successful. A trial and error engineering process ultimately allowed for the correct solution to be implemented.

As shown by our experiences at Health and Wellbeing Centre and at Community Centre #2, the process of testing reveals any defects in the design and the defect period provides the time to address them. Not allowing this time risks the quality of any installation because testing always occurs at the end of the project and there is frequently no time allowed to rectify them. Similarly insufficient testing risks faults remaining undetected only to become a source of inefficiency, cost or irritation later on.

Discussion

Cutting through the sales speak

The lighting designer's pallet should include both emerging technologies such as LED and proven technologies such as fluorescent and metal halide and luminaires should only be proposed for a design after a process of due diligence and testing.

Sales literature is designed to sell product and is an inadequate basis for selection of a fitting. If a product appears to have potential, the designer needs to conduct due diligence. This should commence by requesting the IES file from the manufacturer and viewing it using IES reader software such as AGi32 or Photometric Toolbox. Through using this simple methodology it can be clearly seen which emerging technology luminaire has the equivalent lumens of a luminaire using proven technology and which one is making exaggerated claims. If there is no IES file available this is a warning sign that the luminaire has not been tested for approval for use against any standards

The figures in photometric test reports should also be approached with caution. It is a good idea to verify that the test report has been produced in an appropriately rated laboratory and that the luminaire has undergone all the required tests for approval for use in your country.

The importance of commissioning and testing

A thorough and well documented commissioning and testing process must include witness testing to verify the test results can be repeated. This process is key to achieving the targets originally set out in the FRB. By holding the contractor accountable and going on site in person to witness tests this process ensures that the contractor meets all their obligations with regards to completing the work to a high standard. Without the allocation of time and funds for testing and rectification, defects and design errors would go unnoticed by the building owner until they began to receive complaints from their tenants.

Witness testing will also verify when targets have been successfully met. Illuminance measurements taken during testing in the corridor of the central city community centre verified that there was ample light for the space after the LED down lights were installed. Also illuminance measurements of suspect rooms at the site revealed that an extra luminaire was required in only 4 rooms where the existing luminaire spacing was insufficient to meet the recommended illuminance levels with a single tube luminaire when a lot more were suspected.

If the tuning has been well planned and implemented the result will be a finely tuned lighting system that meets occupant and client expectations and is highly efficient. For example the tuning period at the site of the central city community centre in the 1st case study resulted in sensor times being wound back in offices from 30 minutes to 20 minutes with no complaints from the tenants. At the site of the health and wellbeing centre in the 5th case study, the tuning period allowed an extended period to fine tune a fairly complex commissioning process involving the performance of sensors which were operating both lights and HVAC.

Conclusion

A close relationship with the client and a whole of project engagement are key to achieving the good outcomes for the building. This relationship empowers the designer to participate in the planning of the project and provide expert advice from the beginning to the end of the project. If the client feels that the designer really listens to their needs and pays attention to the details the designer can work with the client towards a common goal.

When this relationship fails it leads to disappointing outcomes. When this relationship works it leads to good results for everybody.

The individual lessons learned from the case studies in this paper are that

- Commissioning and testing are crucial to implementing a successful and efficient lighting design
- Through liaison with the building manager and occupants the tuning process
    - Provides the opportunity to fine tune a design
    - allows further efficiencies to be implemented
- The designer should
    - Consider the individual issues of a space in order to design an appropriate lighting system
    - Consider the appropriateness of the light source and luminaire for each application
    - Always use a diffuser of some kind over LEDs
- CFL down lights should be considered extinct. The use of quality LED down lights to replace CFL down lights should be standard practice.
- A design using single T8 fluorescent lamps at appropriate spacing's is still very efficient and may be appropriate in some cases
- A design using long life metal halide may be more appropriate than LED in some cases.

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Flicker, buzz, instability, and poor low-end performance: understanding and overcoming LED lighting dimming challenges

Author: Sam Woodward

Lutron Electronics Ltd.

Abstract

A decade ago the debate amongst the visitors around Light&Building was about whether LED would ever become a viable light source. Four years ago the discussion had moved on to whether LED would become the dominant light source. Now in 2016 it's achieved both of these, but with this revolution have come significant challenges: there isn't a consultant, electrician or specifier that hasn't encountered severe performance problems when deploying LED light sources. Flicker, poor-low-end-behaviour, noise (both electrical and audible), nuisance circuit-breaker-tripping, and even premature failure are all issues that plague projects.

Yet there are real practical solutions, and careful planning can prevent expensive disasters!

This presentation will investigate why it is that LEDs can be challenging to control, looking in depth at the technical aspects of phase-chopping dimming, inrush current issues, inductive, capacitive and resistive load types, and the plethora of low-voltage protocols which are common in lighting control within a smart-building context, and then suggests a number of real-world strategies for achieving success with LED control.

Performance Challenges of LEDs – the need for Standards and Testing

LED lighting systems are different from incandescent lamps. The various parts of an LED system, including the “light-engine”, the driver, and the dimmer, all interact in electrically-complex ways, unlike a resistive lamp. These complex interactions can result in flicker and other undesirable performance issues, which may vary considerably between different models of lamps when used with different models of dimmer. As LEDs become the dominant light-source, designers need to have confidence that the whole system will fulfil the promises of LED: efficient, aesthetically pleasing performance, over a long lifetime.

The challenge in Europe is that whilst there are many standards for product *safety* which apply to lamps and fixtures, there are no industry standards by which to ensure the *compatibility* of light-sources and dimmers.

This means that the only way a designer can be certain that a system will work is to *test* each combination of lamp and dimmer, as different combinations will yield different performance.

Verifying compatibility must go far beyond a simple “look and see” test for dimming, as invisible issues such as inrush currents, power-factor problems, or electrical and audible noise, may variously affect both performance and system life.

The upcoming “lamp ban” legislation in the EU, due to come into effect for directional halogen lamps in September 2016, and for non-directional halogen lamps in September 2018, increases the urgency of finding a reliable workflow for deployment of LED systems.

The Role of LED Drivers

The part of the overall LED system which has most effect on performance is the “driver”. The “driver”, also known as the Electronic Control Gear, or E.C.G. is the part of the system which converts the incoming line voltage (typically 230V AC mains) into the low-voltage required by the LED array.

The nearly instantaneous response of LEDs to changing current makes them highly susceptible to flicker [1], especially compared to incandescent sources. One of the most important LED driver features (regardless of whether the driver is constant current or constant voltage) is the quality and consistency of the DC output voltage of the driver.

There are many types of driver, including Constant Current (used for driving LEDs in a series string with a fixed current to determine the brightness), and Constant Voltage (used for driving LED tape, where the exact length, and therefore the total number of LEDs to be powered, is unknown prior to installation).

Constant current and constant voltage drivers are NOT interchangeable, and it is the electrical requirements and the design of the LED load that determines which driver is appropriate. Often this is application-based, but it is still the configuration of the LEDs that determines if a constant current or a constant voltage driver is needed. Drivers are sometimes manufactured to operate specific LED devices or modules, while others can be configured to operate most commonly available LEDs. Generally, it is up to the fixture manufacturer to specify the proper driver type to be used. The selection of an appropriate driver is not limited to just making sure it matches the LED module being used. The driver is the primary component that determines the best-possible dimming capabilities of the LED lamp or fixture. Furthermore, the LED driver is one source of potential failure for the LED fixture. The long-life benefits of LEDs are significantly reduced if the driver is not specifically designed for an equally long life. Beyond compatibility with the LED load, LED drivers must be selected to fit the mechanical constraints of the fixture.

In the case of a retro-fit lamp, the driver circuity is most likely to be built into the lamp housing itself, and is therefore often overlooked. However, just as with fixture drivers, this crucial circuit is responsible for the response of the lamp to mains-borne transients, and to ensuring that if a chopped-AC sine-wave (from a dimmer) is used then the LED chips themselves do not flicker. The variety in circuit designs for this driver, combined with the cost-pressure applied by market forces affecting this commodity product, have the combined result that there is considerable performance inconsistency between lamps from different manufacturers, and even between different models from the same vendor.

Methods of Dimming LED Drivers

There are two methods to control an LED driver, and the right type must be selected according to the design of the driver [2]:

a) Dimming the mains supply to the driver, also known as phase-cutting
b) Using a driver that accepts a fixed mains supply, and also a low-voltage control signal, such as DALI or DMX. The low-voltage signal is used to instruct the driver how much power to deliver to the load.

Phase Cutting Dimming

There are two types of phase-cutting dimming: leading-edge (known in the USA as forward-phase), and trailing-edge (known in the USA as reverse phase). The leading-edge dimmer is most common in Europe, being commonly created as a simple triac-based circuit, recognizable by the inclusion of a large choke (or inductor) which is used to suppress EMI emissions, enabling compliance with the CE requirements.

Figure 1: Phase Chopping Dimming

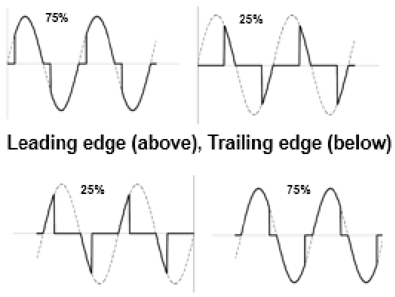

Figure 1: phase-chopping dimming: leading edge (top), trailing-edge (bottom)

Different LED circuits vary in their compatibility: some being only compatible with leading-edge dimming, some being only compatible with trailing-edge dimming, and some being compatible with either method. There is no common rule-of-thumb that can be used, and once again extensive testing is the only way of establishing the optimum method, assuming that the lamps are dimmable at all, which many are not.

To optimize the chances of project success it is therefore also recommended to deploy phase-adaptive dimmers, which are those whose circuit design can be software-selected to produce either a leading-edge or a trailing-edge output.

When using mains-dimming, where part of the waveform is missing, the remaining power may be insufficient to enable the driver circuit to operate. This is another common source of flicker, when dimming to low-levels.

Older dimmer circuit designs usually require a “minimum load”, typically around 40W, in order for the triac-gate to be kept open during dimming. With LED loads very often less than this, and therefore the minimum load requirements of the dimmer are not met. Part of the compatibility testing process must verify this parameter, as often success can be achieved when multiple lamps are used, even if they are still below 40W in total.

Examples of LED Driver Compatibility Testing Regimes for Phase-Chopping Dimming

As established above, the need for testing to go beyond the simple “look and see” test for compatibility, and to implement a more rigorous set of performance tests is crucial. Such testing is time-consuming, but in the absence of performance standards it is the only route to achieving success in the real-world conditions of a building project. Such testing should therefore include items as shown in the table below.

Tests

Electrical Tests	Aesthetic Tests
• Repetitive Peak Current • Inrush Current • RMS Current • Average Current • Power Factor & Current vs. Voltage • Off-State Leakage • Repetitive Voltage Ring-Up • Dimming Curve • Minimum number of lamps required for stable dimming • Is a synthetic load required in parallel for stable dimming	– High end & low end voltage – High end & low end light level – High end dead travel – Low end dead travel – “Steppy” dimming – Flicker – Shimmer – Does not turn off – Buzzing – Start time at low end – Pop-on (lamp comes on to a bright level part-way through a level-raise) – Popcorn (lamps come on one by one at different times)

Table 1. Testing regime: source: Lutron Electronics Inc, Coopersburg, USA

Figure 2: measuring repetitive inrush currents. Source: Lutron Electronics, Coopersburg, USA.

LED Dimming with Low Voltage Protocols

Greater success can be achieved using a driver, matched to the load in terms of its output voltage and current rating, which takes a fixed mains supply along with a low-voltage signal which gives instruction to the driver circuit to indicate what proportion of the output power should be applied to the load.

Such instruction is communicated via a protocol such as DALI, DMX or a varying analogue voltage.

These techniques are less prone to flicker. Some protocols, such as DALI, offer greater immunity to electrical interference than others, such as 0-10V control. Other proprietary protocols exist, which give increased stability. Flicker issues when using these are usually down to a mismatch between the driver and the LED load.

Summary

In the absence of standardization the route to success with retro-fit LED dimming relies on extensive testing. The good news is that this data is freely available [3] to specifiers to make informed decisions, but the challenge to our industry is to educate that it is imperative for testing to go far beyond a quick "look and see"

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[3] www.lutron.com/ledtool (website contains a free searchable database of LED test results)

Session Building Example

Best practice commercial buildings from Upper Austria

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OÖ Energiesparverband

Abstract

Since the mid-90s, the government of Upper Austria has prioritised energy efficiency and renewable energy. Renewable energy currently supplies 34% of the total primary energy demand in the region. The share of renewables in the energy mix was achieved through comprehensive regional energy action plans that laid the foundation for more than a decade of steady progress.

To achieve its ambitious goals, Upper Austria has developed policy packages for different target groups. These packages consist of financial incentives, legislation to mandate installation obligations, and promotional activities. The OÖ Energiesparverband is in charge of implementing many of these programmes and providing related services.

Upper Austria is a leading European region in sustainable buildings. Due to consistent policies, today there are more than 1,000 buildings meeting passive building standard and several thousand "lowest energy buildings". This development started in the residential sector but in recent years a number of best practice commercial buildings were established showcasing innovative technologies.

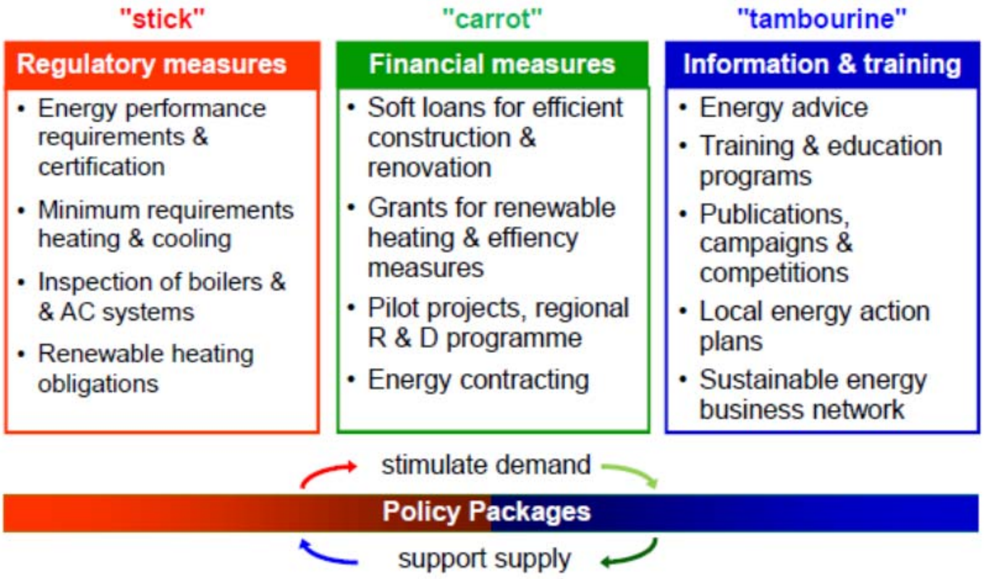
Background

Since the mid-90s, the government of Upper Austria has prioritised energy efficiency and renewable energy. Renewable energy currently supplies 34% of the total primary energy demand in the region. The share of renewables in the energy mix was achieved through comprehensive regional energy action plans that laid the foundation for more than a decade of steady progress. Building upon the success of its policies to date, Upper Austria has set a target to meet 100% of its electricity and space heat demand by renewable energy sources and to reduce energy consumption for heating by 39% and CO_2 emissions by 65% by 2030.

To achieve its ambitious goals, Upper Austria has developed policy packages for different target groups. These packages consist of financial incentives (mostly investment grants), legislation to mandate installation obligations, and promotional activities (energy advice, outreach campaigns, training, etc.). The different types of support mechanisms can be thought of, respectively, as carrots, sticks, and tambourines. The OÖ Energiesparverband is in charge of implementing many of these programmes and providing related services.

The OÖ Energiesparverband also manages the "Ökoenergie-Cluster", the network of renewable energy and energy efficiency companies in the state. There are currently 170 companies and institutions in the network, which employ more than 9,300 people and generate annual revenues of more than 2.3 billion Euro. The network members represent the full spectrum of sustainable energy products and services and high-efficiency building technologies. In recent years, companies in these fields have experienced strong growth and have added more than 500 new jobs in the region.

Upper Austria is a leading European region in sustainable buildings. Due to consistent policies, today there are more than 1,000 buildings meeting passive building standard and several thousand "lowest energy buildings". This development started in the residential sector but in recent years a number of best practice commercial buildings were established showcasing innovative technologies.



Upper Austria's sustainable energy strategy – example sustainable buildings

Case Study1: Energiewerkstatt Consulting

Project Details

EWS Consulting is a privately-owned energy consulting company with 42 employees. The company combines professional expertise on all issues related to wind energy and is primarily active in Austria and on an international scale in the planning of renewable energy projects. Due to the growth of the company, there was a need to enlarge and adapt the existing office building. In 2012, the company doubled its floor space by adding an annexe to the existing building.

The main objective was to construct a “positive-energy” office building that would offer the occupants comfortable and enjoyable working space and that would function in a sustainable way for years to come. Environment-friendly, natural and sustainable building materials were prioritised in the elaboration of this project. Moreover, the company’s owners are not only dedicated to making the business’ buildings energy-efficient, but strive to minimise the company’s overall ecological footprint.

This building not only generates more electricity annually than it requires, but 100% of its heat and electricity demand is supplied by renewable and low carbon-emitting sources. The installation of a 20.5 kW lithium battery permits the building to store its generated electricity and access it when required.

Technical Details

- Approach: To build a "positive-energy building"
- Construction typology: Heavyweight construction with thermal-insulating blocks (bricks)
- U-values W/m^{2}K: overall average 0.21; main walls 0.15-0.17; roof 0.09-0.14; windows 0.68-0.84 with an average of 0.75.

- Air tightness: 0.60 air changes/h at P=50 Pa
- Ventilation: Mechanical ventilation with heat recovery
- Passive heating strategies: building orientation, maximal use of incoming solar radiation through large windows.
- Passive cooling strategies: exterior blinds on windows, maximizing thermal inertial through heavyweight construction.
- Final energy demand: 60.4 kWh/m^{2}y (gross area)
- Energy rating: Energy performance indicator (for heat) (HWB-ref) of 9 kWh/m^{2}y (Upper Austria Energy Performance Certificate)
- PV installed capacity: 14.5 kWp (stand alone system)
- Solar thermal installed capacity 22 m^2
- Biomass installed capacity: 20 kW
- Annual RES generation: 100% coverage of energy demand (space heating, DHW and electricity)

Case Study2: Lighthouse 1 – Schachinger

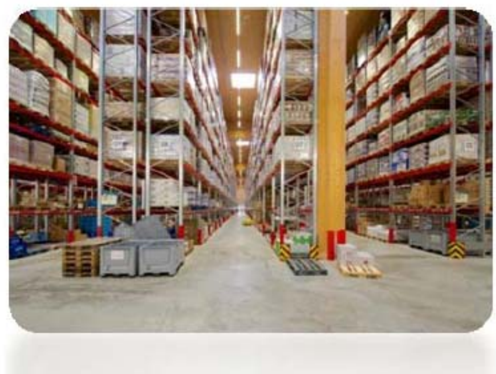
Project Details

Schachinger Logistik is an Austrian family-owned logistics business with headquarters in Upper Austria. The company owns a fleet of 100 trucks, buildings with a total of 400,000 m^2 floor area and employs over 500 people throughout its 15 locations. In 2013, owing to the strong forward thinking of the company's management, Schachinger became a true pioneer in its field through the construction of "Lighthouse 1" - a very large passive building warehouse and office building - at its logistics park in Hörsching.

Inaugurated in September 2013, the 11,790 m^2 wood construction comprises a warehouse, a distribution centre and a 3-storey office wing. Lighthouse 1's energy demand is 60% lower than that of Schachinger's most recently built logistics building. These savings were achieved through a combination of high thermal insulation of the building shell and efficient energy systems. The project's overall investment of around 9 million Euro represents only 6% higher costs than the company's previous conventionally-built building. Lighthouse 1 is now one of Europe's most sustainable high-bay warehouses. In 2015, a 400 kWp PV-system was installed on the building's roof. It will generate around 65% of the building's yearly electricity demand.

Technical Details

- Construction typology: Timber construction set on a low-carbon cement foundation.
- U-values W/m^{2}K: walls 0.16-0.19; roof 0.14; windows 0.84
- Air tightness: 0.12 air changes/h at P=50 Pa
- Ventilation: Mechanical ventilation with heat and humidity recovery
- Passive heating and cooling strategies: natural ventilation when weather is adequate
- Primary energy demand: 28 kWh/m^{2}y
- Final energy demand: 10.7 kWh/m^{2}y
- CO_2 annual emissions: 133 tonnes CO_2/y
- Energy rating: Energy performance indicator (for heat) (HWB) of 8.9 kWh/m^{2}y (office wing) and 10.3 kWh/m^{2}y (warehouse) (Upper Austria Energy Performance Certificate)
- PV installed capacity: 400 kWp
- Other RES capacity: around 375 kW groundwater heat pumps
- Annual RES generation: 100% coverage of electricity and heat demand



Case Study3: Hagenberg Sports Centre

Project Details

The Hagenberg Sports Centre is a multi-service sports facility in Hagenberg im Mühlkreis, a rural municipality in the north of Upper Austria. The single, rectangular-shaped building contains a 23 x 44 meter gymnasium, a 9 meter-high climbing wall, a spectator section and other related-use areas. It offers a variety of indoor and outdoor leisure activities to a population of around 14,000 inhabitants.

This building is the first passive house sports centre in Austria and acts as a showcase example that large public buildings can achieve passive house standards without additional costs. The sports centre was inaugurated in 2012 after a construction period of only 14 months. The pellet boiler and solar thermal system permit a 95% coverage of annual space heating and DHW energy needs. The PV installation generates the equivalent of around 33% of the building's yearly electricity needs.

The energy and cost goals were achieved thanks to a holistic approach and strategic planning from the very first steps of the project's development. Without compromising comfort or services, the building's design has led to a 70% saving in energy costs compared to a conventional sports centre construction. Furthermore, the detailed monitoring suggests that the predicted energy savings will be exceeded. The sports centre currently meets passive house criteria, but there are plans to pursue this even further and to bring it to "plus energy" status by expanding the PV installation.

Technical Details

- Approach: Passive house design and technology
- Construction typology: The sections of the building that are in contact with the ground are made of concrete. All other sections (including the flat, multi-level roof), are lightweight wood constructions.
- U-values W/m^2K: overall average: 0.17; reinforced concrete walls 0.15; flat wood construction roof 0.10; windows approx. 1.05.
- Air tightness: 0.60 changes per hour at P=50 Pa, measured with a blower-door test.
- Ventilation: Mechanical ventilation with heat recovery
- Passive heating strategies: South-facing orientation with windows concentrated on the west, south and east façades.
- Passive cooling strategies: Horizontal and vertical overhangs on windows, automatic blinds, natural ventilation at night, a green roof and a thermal activated heat dissipation system in the ground floor.
- Final energy demand: 61.78 kWh/m^2y
- CO_2 annual emissions: reduction of 75 tonnes CO_2 per year compared to a standard built sports centre (savings of 25.8 kg CO_2/m^2y)
- Energy rating: Energy performance indicator (for heat) (HWB) of 5.3 kWh/m^2y (Upper Austria Energy Performance Certificate)
- PV installed capacity: 10 kWp (grid-connected)
- Solar thermal system: $20m^2$ with 3,000 litre buffer system
- Biomass installed capacity: 32 kW

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Lessons from the Leading Edge: What Drives Australia's most Efficient Buildings?

Dr Paul Bannister,

Energy Action (Australia) Pty Ltd

Abstract

When the Australian Building Greenhouse Rating scheme (latterly renamed NABERS Energy for Offices) was launched in 1999, it is established a 5 star scale where 1 star was poor, 2.5 stars average and 5 stars exceptional. At the time, it was thought that 4 stars was a reasonable upper benchmark for achievement for conventional technology office buildings, while 4.5 stars was seen as a stretch target and 5 stars was seen as the domain of deep green, "alternative" buildings. In the 16 years since then, entire portfolios of mainstream office buildings have upgraded their average performance to above 4.5 stars, and there are many examples of 5 star buildings. Indeed, it has become necessary to introduce a 6th star – at 50% the emissions intensity of 5 stars, and there is already a conventional office building performing at that level.

Obviously, there has been a massive transformation in the Australian office market over this period and many lessons have been learnt. In this paper, a review of data and three case study examples are used to identify the characteristics of a 5.5 and 6 star buildings. It is identified that high performance is best correlated with simple and essentially conventional good design, with high quality commissioning, tuning and operations, rather than "deep green" or even particularly innovative design. The possible next steps of efficiency are discussed in the light of these results.

Introduction

Australia has achieved a unique level of success with its application of the operational energy efficiency rating NABERS Energy to the base building (landlord operated) services of commercial office buildings. Indeed, over the period 2006-2014, the average base building rating is estimated to have risen from 2.9 stars to 4.2 stars (Figure 1), corresponding to an emissions reduction in excess of 30%. This is particularly remarkable given that by 2014 the coverage of the office market above 2000m^2 was close to complete, due to the implementation of mandatory ratings since 2011. While this in itself is a significant achievement, the primary topic of this paper is to examine the performance of the buildings in the 5.5-6 star range, which have only appeared since 2010, as shown in Figure 2. To put this in context, when the scheme was created in 1999, 4.5 stars was thought to be the highest rating likely to be achieved by a conventional office; 5.5 stars represents a reduction in emissions intensity of roughly 40% from 4.5 stars and 6 stars approximately 60%. Furthermore, 6 stars represents a reduction in emissions intensity of 75% from the 1999 average building emissions intensity.

The question arises therefore as to what distinguishes buildings at this upper tier of performance: is it innovation, expensive investments in efficiency or just good design delivered and operated well? This paper seeks to explore this question by reviewing some of the data associated with this upper echelon of buildings and by reviewing case-studies of actual buildings.

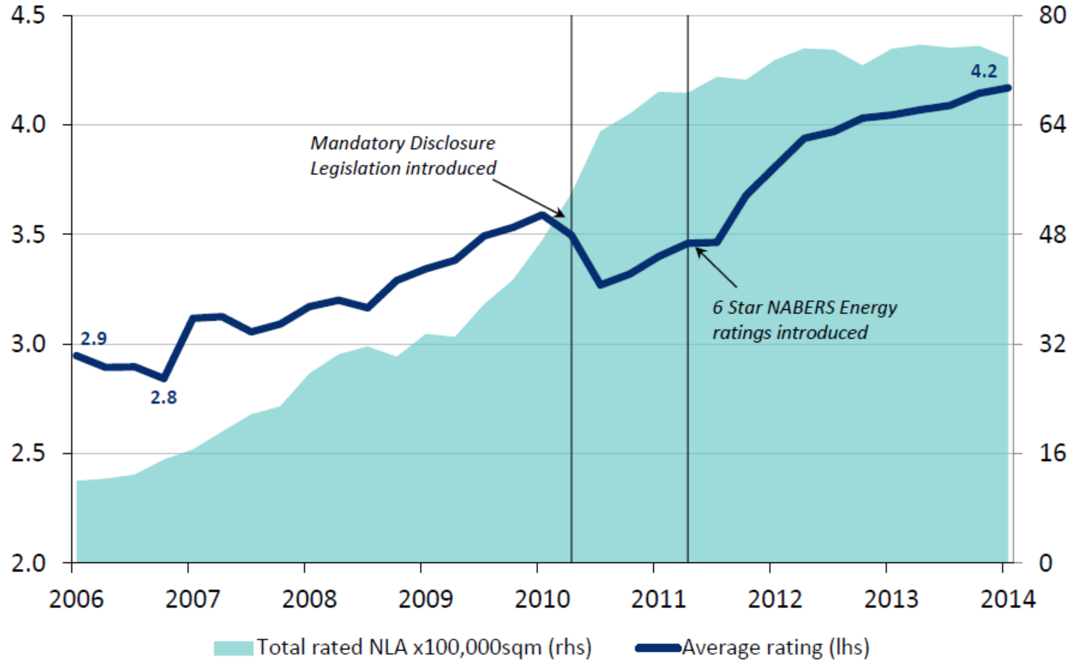

Figure 1. Total rated area and average NABERS rating. Source: IPD 2014.

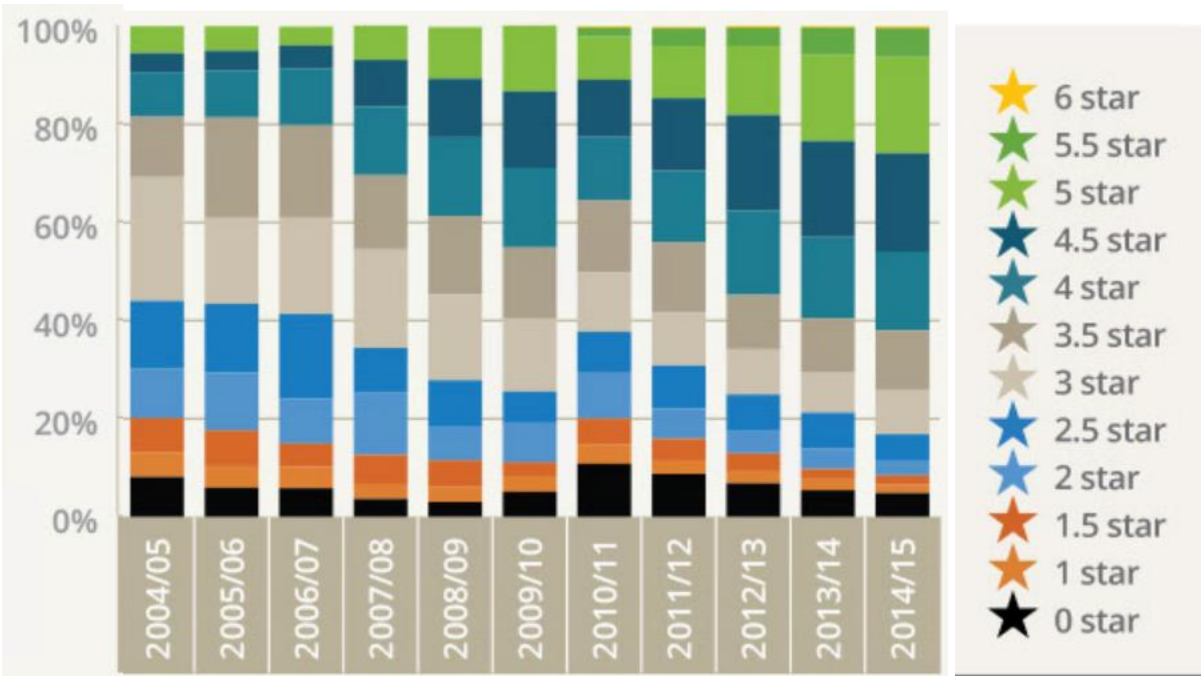

Figure 2. NABERS ratings (without GreenPower) distribution over the past decade. The significant increase in 5 star and higher ratings in the past 5 years is visible. (Adapted from NABERS 2014 annual report).

What is the base building?

The definition of "base building" within NABERS was built on the basis of common industry practice for energy metering in Australian office buildings. The key components of base building energy use are as follows:

- All energy use associated with the general heating, ventilation and air-conditioning system provided to service the office areas of the building. This includes central plant (e.g. boilers, chillers) all the way through to on-floor plant (fan coil units, local electric reheats)
- Light and power to non-lettable spaces (which includes the entry foyer, most lift lobbies, back of house and base-building amenities)
- Lifts (excluding lifts installed within a tenancy by the tenant)
- External lighting
- Car park lighting and ventilation, where car parks are provided for the sole use of tenants.
- All other services provided for general use of the tenants (most often this is a condenser water loop provided for tenants to attach supplementary air-conditioning to)
- Domestic hot water provided centrally and/or to base building amenities. (Local domestic hot water within tenant spaces is not captured with the rating).
- Fuel use for back-up generators

These services typically account for around half of the emissions of an average building. The balance is related to the provision of light and power for the tenancies.

An example of the end-use breakdown of a 5 star NABERS office base building is shown in Figure 3 below. While obviously this building represents a particular climate location and HVAC type, the general proportions are typical, with around 60% of the energy being HVAC and the balance being common area light and power and lifts[1].

It is clear therefore that a high NABERS rating must achieve superlative performance in HVAC energy efficiency; other factors, such as common area light and power and lifts play a still important but secondary role in determining the rating outcome.

[1] Lift energy in this building is, however, unusually high; for most buildings lifts represent only 5-15% of base building energy.

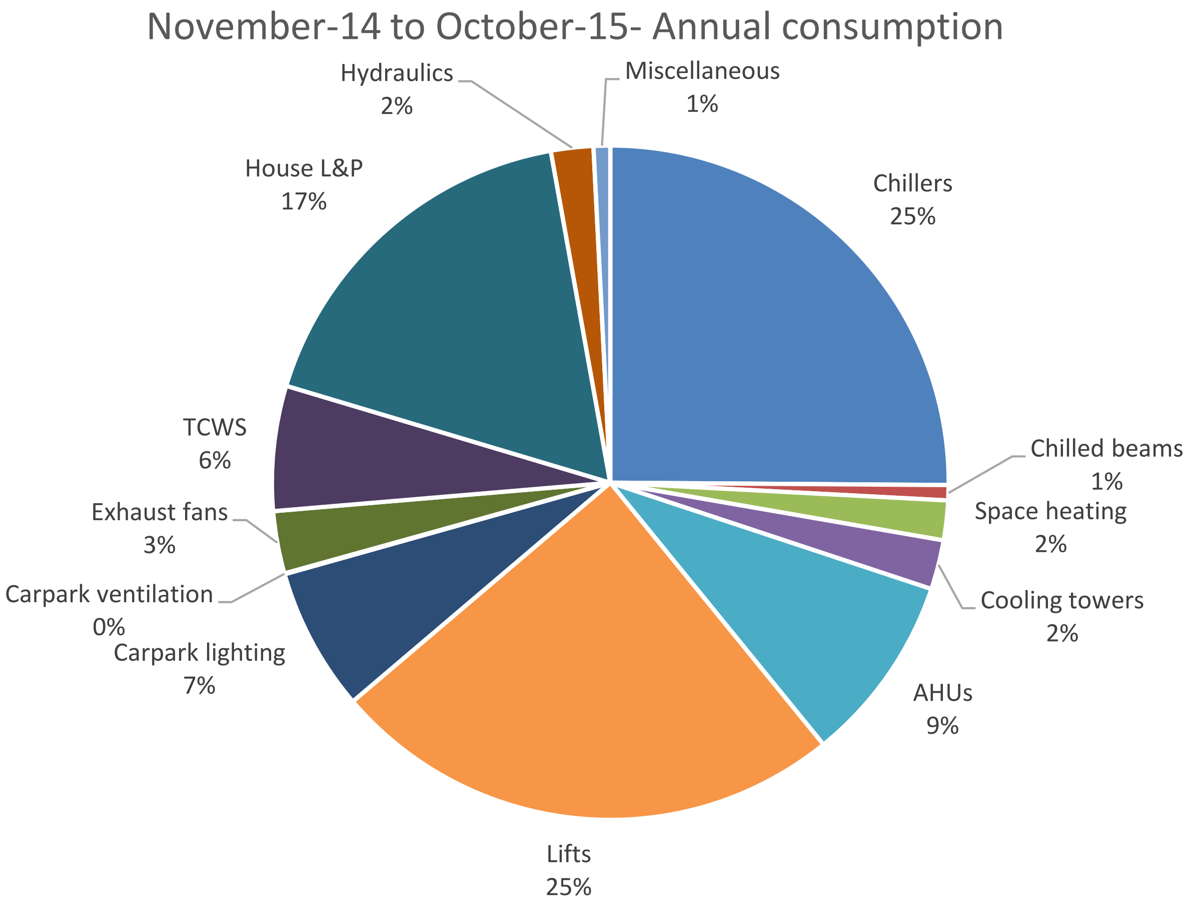

Figure 3. Electricity end-use breakdown for a 5 star hybrid passive chilled beam/VAV base building in Sydney. Total electricity consumption is 72kWh/m². Gas use for this building, which covers space heating, reheat and most domestic hot water, comprises a further 43kWh/m². TCWS = Tenant condenser water system.

How efficient are these high ratings, really?

The level of stringency required by 5 and 6 star ratings is documented in Table 1. It can be seen that the stringency is significantly climate dependent, reflecting the influence of cooling demand; the warmer centres have significantly higher benchmarks than the cooler centres. Using Sydney as a baseline example, 6 stars corresponds to energy use in the region of 40kWh/m² for base building services. The relativity of climates between Australia and Europe is shown in Figure 4.

Location	5 stars, all electric (kWh/m^2)	5 stars, 80% electric 20% gas (kWh/m^2)	6 stars, all electric (kWh/m^2)	6 stars, 80% electric 20% gas (kWh/m^2)
Brisbane	100	119	50	59.5
Sydney	86.4	102	43.2	51
Perth	75.8	89.6	37.9	44.8
Melbourne	52.7	63.4	26.3	31.7
Canberra	53.7	63.3	26.8	31.6

Table 1. Energy equivalents for 5 and 6 star ratings in major Australian cities. 5.5 stars is the mid-point between 5 and 6 stars. Figures are based on 55 hours per week operation. The higher energy figures for mixed fuel buildings reflects the fact that NABERS is based on greenhouse gas emissions, which in Australia are typically 3-5 times higher for electricity than gas.

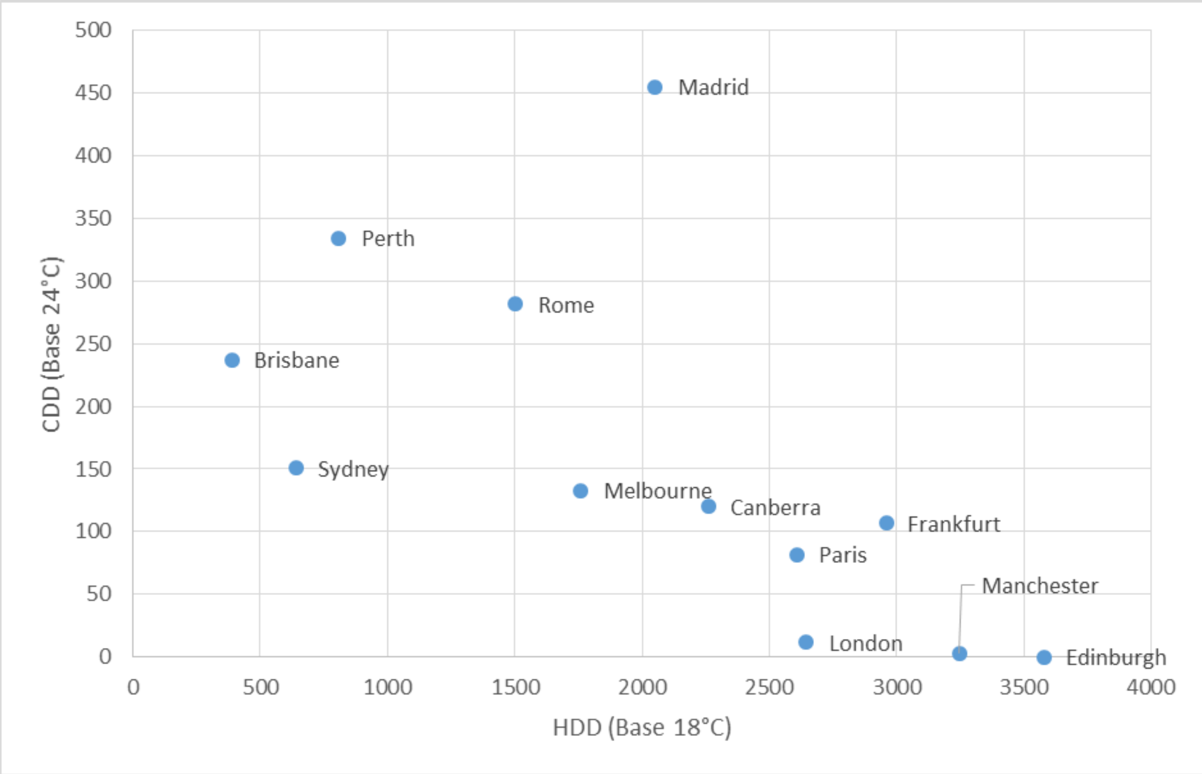

Figure 4. Climate comparison of Australian and EU cities.

Why have owners been pushing for higher ratings?

The drivers for higher base building ratings originate from the nature of the base building/tenancy split. The key benefit of this split is that the base building rating is comprised of items that are essentially under the direct control of the landlord, with only second-order influence from the nature and operations of tenancies. In Australia this also corresponds to the normal boundary for utility metering. This means it is possible for a building to be considered as having – and continuing to have – a particular NABERS rating, independently of the tenants. As a result, the base building rating can be used in procurement by tenants seeking a high performance building, as indeed has become commonplace in the Australian market. The market leaders in this context were the various State governments and the Commonwealth government, which introduced requirements for minimum NABERS base building ratings for properties they are tenanting, typically at 4.5 Stars. This is a very easy procurement exercise for a tenant as it involves no effort on their part, because the onus for improvement is entirely on the landlord. The requirement of minimum NABERS base building ratings by larger corporates has become relatively commonplace following the government procurement initiative in this area.

The expectation that a building will become easier to lease – to a higher quality tenant on a longer than average lease – has created a significant market driver for owners, as much as by fear of losing market position as by any other mechanism. In this context, the cost of efficiency upgrade is no longer set against the saved energy (the benefits of which typically flow through to tenants via net leasing practices, anyway) but against the rental revenue retained or gained by having a building that is more competitive. As rental is often more than 10 times energy cost, this is a major motivator which can modify efficiency upgrade behaviour radically from standard practice, and indeed has done so. In this sense, efficiency has been reprioritised from a low-priority cost-benefit item to a desirable core value for a property, comparable to good carpet, a marbled foyer or other items that are considered mandatory in the profiling of a building. Evidence of this can be seen in Figure 5, which shows that in the prime market at least, high NABERS ratings correlate with higher overall commercial returns. These higher returns have a significant impact on the building's capital valuation, which in turn increases the availability of finance.

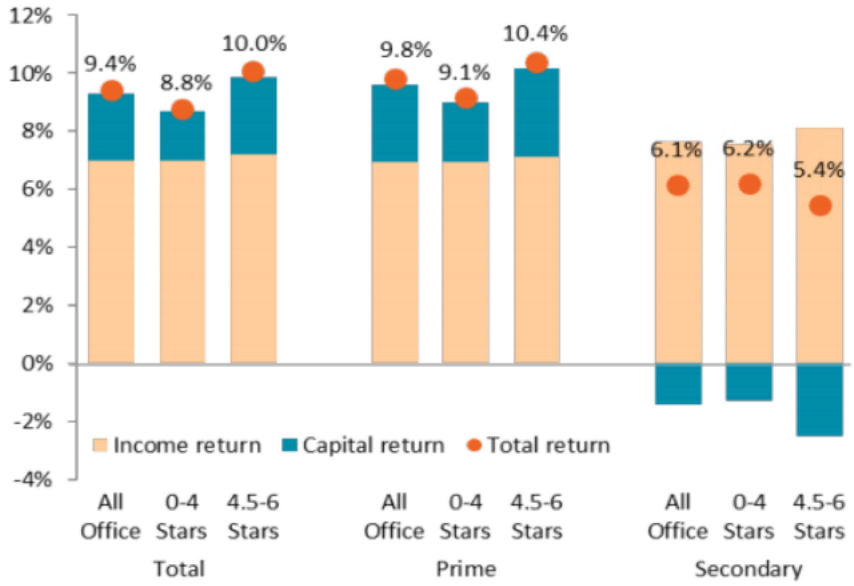

Figure 5. Relationship between NABERS Rating and commercial return for CBD offices. Source IPD 2013.

There remains however the interesting question of why, when Government agencies continue to only seek 4.5 star ratings, are landlords upgrading their buildings further? The only well-defined requirement above this level is within the Property Council of Australia Quality Matrix (PCA 2011), which as of 2012 has specified a minimum 5 star NABERS rating for premium quality office space. However this only applies to the very top end of the market and is not formally assessed. It has to be concluded that further improvement beyond 5 stars is ahead of market demand, rather than in response to market demand. This appears to be the result of two drivers:

1. Achievement of a high rating is seen as inherently prestigious, a marked change from the traditionally secondary importance accorded to efficiency in most markets. In some cases this is underpinned by corporate goals for net zero or net positive greenhouse positions in the mid-term future, which may reflect a perception that this position will be good for business as well as the environment.

2. As the 4.5 star criterion was set more than 10 years ago, there is an expectation that this will be increased at some stage; as a result higher ratings are seen as a risk mitigation for the future.

The population of 5.5 and 6 star buildings

The NABERS website (www.nabers.gov.au) provides a database of current accredited NABERS ratings. Based on data accessed in early December 2015, there were four buildings rated at 6 stars and 60 buildings rated at 5.5 stars, excluding buildings that achieved these ratings by use of GreenPower[2]. Of these, the author's organisation has obtained data or worked on one 6 star building and twenty one 5.5 star buildings, enabling a marginally deeper characterisation of these:

- Age: The vast majority of the buildings in the sample were constructed relatively recently, typically within the last 7 years, as shown in Figure 6. Only 3 of the 22 buildings sampled were refurbishments of older buildings; all the rest were new-built.

- Size: The buildings within the sample were all above 10,000m² and predominantly in the region of 10,000-40,000m², as shown in Figure 7. This broadly reflects the general population of buildings that use the NABERS base building rating.

[2] GreenPower is certified zero greenhouse electricity. Buildings that use GreenPower get a benefit to the NABERS Rating due to the zero emission supply, but also have to declare the rating ignoring the impact of this supply choice.

- GreenStar[3]: Of the 21 buildings for which the GreenStar status was known, 6 were not rated, 2 were rated at 4 stars (the minimum accredited rating), 6 were rated at 5 Stars and 7 were rated at 6 stars (the maximum rating).

- HVAC systems: The dominant HVAC system type was variable air volume (11 of 18 buildings with known HVAC), followed by active chilled beams (4 of 18, at least one of which was hybrid active chilled beam/VAV) and passive chilled beams (3 of 18). All are fully air-conditioned and none have natural ventilation or mixed mode operation for any significant space. All bar one of the sample buildings used water-cooled chillers.

- Cogeneration or trigeneration: 7 of 19 buildings within the sample had cogeneration or trigeneration (generally trigeneration)[4].

- PV Systems: Only 2 of 16 buildings of known PV status had significant PV systems installed.

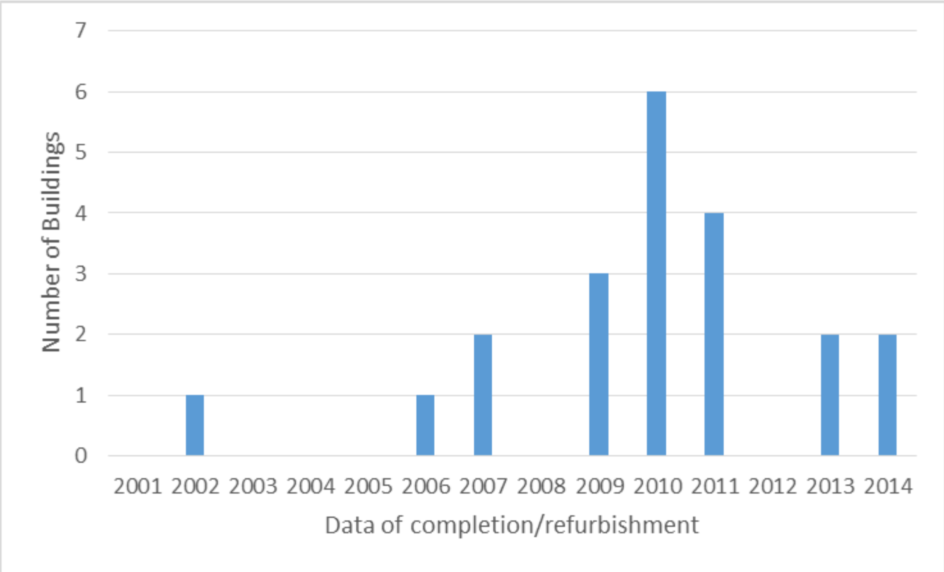

Figure 6. Completion/refurbishment date of sample 5.5 and 6 star buildings.

[3] GreenStar is Australia's broad-based sustainability design rating, similar to BREEAM or LEED. See www.gbca.org.au.

[4] Note that in Australia, the grid electricity emissions for most states are in the region of 1-1.4kg/kWh, meaning that even in the absence of effective heat recovery gas generators have a lower greenhouse impact than grid electricity. As NABERS ratings are calculated on the basis of greenhouse emissions, this has a direct impact on ratings, albeit generally only in the region of 0.5 stars.

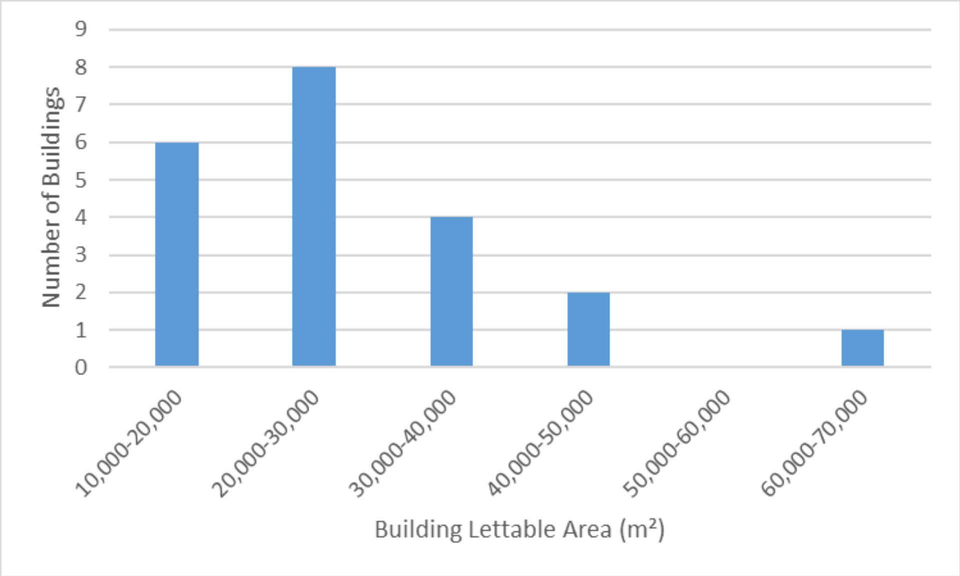

Figure 7. Lettable area of sample 5.5 and 6 star buildings. No buildings below 10,000m² were present in the sample.

In review, it can be seen that the high rating buildings are typically:

- Recent buildings with a strong focus on sustainability in construction/refurbishment, as evidenced by age and the high number of GreenStar ratings
- Mainstream, fully air-conditioned buildings typically using VAV or chilled beam technologies and water cooled chillers
- Split on the issue of cogeneration/trigeneration, with a significant number of buildings with and without these technologies
- Not subject to a significant amount of on-site renewable generation

Importantly, the mainstream nature of the buildings means that these results are being achieved without comprise to the commercial expectations of the tenant population.

Case Study Examples

To further characterise these high performing buildings, three brief case studies are provided below.

Case Study 1: Sirius Building, Canberra

The Sirius Building is a 46,000m² 10 story building in Canberra housing the Australian Government Department of Health and Aging as sole tenant. The building is owned by Mirvac Property and was the first NABERS Energy for Offices Base Building rating to achieve 6 stars for a major office building.

When originally specified, the intention of the building design was to meet the 4.5 star procurement requirement of the Australian Government as tenant. The design team response was a low temperature variable air volume HVAC system, using multiple small AHUs to service segments of the façade without the need for reheat plus separate AHUs servicing the building core. High efficiency magnetic bearing chillers were used plus conventional boilers. The building, which has a large (approximately 4,600m²) floor plate with significant exposure to the north and west, was designed with extensive shading and solar control glazing.

During the design development of the building the simulation results predicted a performance in excess of 20% better than 5 stars, a result which at the time was taken as being adequate to indicate 4.5 star performance but not necessarily credible as a prediction of performance beyond 5 stars, as at that stage no similar building had achieved such a rating. However the building achieved 5.5 stars in post construction performance and was tuned by the owners to 6 stars over a period of several years through the implementation of energy efficiency initiatives including LED lights and chiller plant optimisation technology in conjunction with focused facility management including night audits and detailed performance monitoring.

In 2014, Mirvac elected to add 80kW of PV cells to the roof, this system generates circa 100,000 KWh pa and supplies approximately 10% of base building consumption. Notably, there is roof space for considerably more PV capacity, so higher performance is still possible[5].

From a market perspective, the Sirius building is an exceptional example of what can be achieved with highly focussed facility management and a relatively conventional design without the need to resort to expensive technologies like cogeneration or trigeneration and without the need to move to newer technologies such as chilled beams. Furthermore, it also is an illustration of what can be achieved with PV in the mid-rise sector of the office market.

Figure 8. Sirius Building, Canberra. The shaded western façade is visible to the right; lighter shading on the northern façade is visible to the left.

[5] Note that the PV system only contributed approximately 5,000 KWh to the first 6 Star rating, the vast majority of the performance improvement was through operational management & tuning and the chiller plant optimisation and lighting projects.

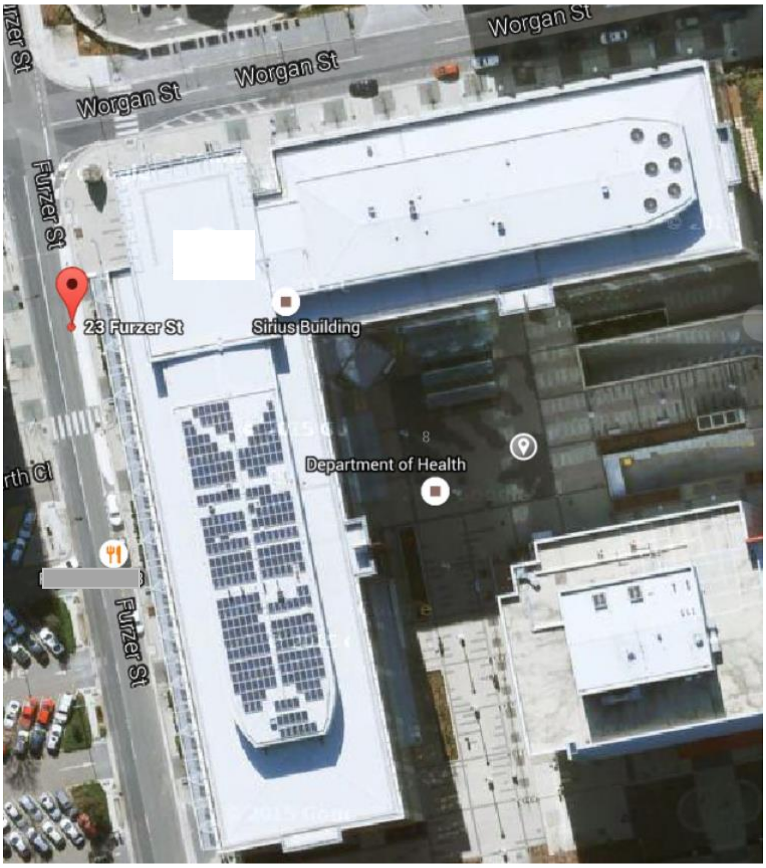

Figure 9. Sirius building aerial view showing the extent of the current 80kW PV array.

Case Study 2: 747 Collins St, Melbourne

747 Collins St in Melbourne is a 38,174 m^2, 16 storey building on the western side of the Melbourne central business district. Completed in 2012, the building is owned by CIMB and leased solely by the Australian Federal Government.

The building façade is of a conventional high-performance glazed design with limited shading. HVAC for the building is variable air-volume with water cooled chillers and conventional boilers. Separate air handlers are used for each façade and the centre zones. The building's key innovation is the use of gas fired micro-turbines (3x300kW$_e$) connected to an absorption chiller (450 kW$_{th}$) and the heating system. Unlike many cogeneration and trigeneration projects in Australia, the modularity and high turndown of the microturbines has meant that the system has been in operation since the building was opened, with long hours of operation[6]. This is particularly important in Melbourne, where the greenhouse gas coefficient for electricity is approximately six times larger than that for gas, due to the dominance of brown coal for electricity generation in the state.

[6] The majority of cogeneration and trigeneration projects in commercial buildings in Australia have used single large reciprocating generators, which typically cannot operate below 50% electrical capacity. As many of these projects have been oversized, they often struggle to meet minimum load for large parts of the year. As a result, many such installations have been mothballed.

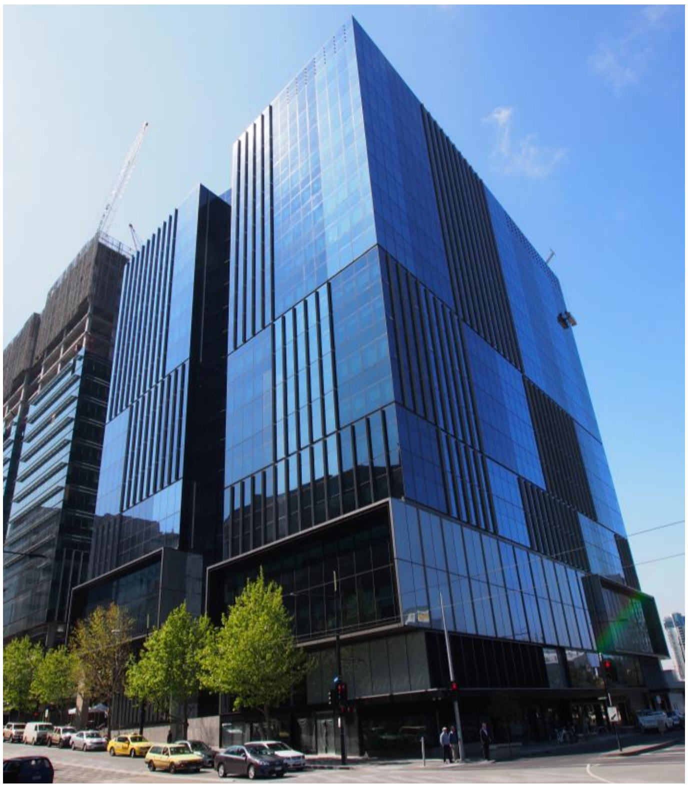

Figure 10. 747 Collins St, Melbourne.

The building was originally delivered at 5 stars and has since been tuned to 5.5 stars (5.84 as at November 2015). Projects are underway to potentially take the building to 6 stars, including further building tuning and a PV array.

Case Study 3: 30 The Bond, Sydney

30 The Bond in Sydney is a 19,700m², 9 storey building on the western side of Sydney's Central Business District and is owned and managed by DEXUS Property Group.

The building, which was opened in 2005, was consciously designed to be exceptional, being amongst other things one of the first buildings to be rated under the GreenStar environmental rating scheme (5 stars) and the first large scale application of passive chilled beams in Australia. With a large west facing façade, the building has automatic exterior blinds as well as naturally ventilated meeting spaces to shield the conditioned area from solar gains. The building also uses a large atrium with connection to a quarried rock face as a return air plenum.

Beyond the use of passive chilled beams, the HVAC servicing is relatively conventional, using simple chilled water/reheat dehumidification to an outside air ventilation system with limited recirculation, conventional boilers and water cooled fixed speed centrifugal chillers operating at high temperature for the chilled beams and low temperature for dehumidification. The building does not have cogeneration or PV cells. The relative simplicity of the design has been a strength for the building as some next-generation chilled beam designs in Australia attempted far more complex central plant design without any notable benefit, and with the issue of increased control and operational complexity.

Figure 11. 30 The Bond, Sydney. This is the main façade of the building, and faces west.

The building was originally designed to achieve a 5 Star NABERS rating, which it achieved shortly after occupancy, making it the first recipient of this rating. DEXUS's focus on sustainability has resulted in a progressive improvement in the building's rating from 2010 to achieve its current rating of 5.5 stars

From a market perspective, 30 The Bond is an excellent representative of the first phase of high performance office building design in Australia, being built at a time when there were no precedents for 5 stars. At the time it was believed that 5 stars could only be achieved by departing from design norms, and the building's success as the first 5 stars NABERS building validated this strategy.

Where Next? – Options for the Next Generation of 6 Star Buildings

HVAC

Given that VAV is the dominant HVAC system in the Australian office sector, the current tranche of high performing VAV buildings is an indication that the majority of savings within the current design paradigm have probably already been taken. This suggests that further improvement in this building type will need to rely on building envelope enhancements or new technological innovations within components. The role of indirect evaporative cooling as an enhancement for buildings in drier climates is one such potential innovation.

For chilled beam systems, given the relatively small number of these systems in the market and their short history in Australia, there is a good argument that there is further maturation of design possible. Notably, chilled beam buildings in Australia have yet to fully coordinate central plant design, with most designs using a chilled water/reheat design for dehumidification rather than other potentially more efficient technologies such as dessicant wheels or even chilled water/air bypass systems. This is of critical importance as chilled beam systems in Australia require significant levels of dehumidification. Furthermore, many chilled beam buildings in Australia use low temperature chilled water mixed up to beam temperatures rather than operating dedicated high temperature chiller plant, thereby losing the potentially significant chiller efficiency benefit of high temperature operation.

While 30 The Bond is a good example of careful architectural/ façade design integration, this is not necessarily typical, and many chilled beam building designs are compromised by poorly managed façade heat gains. Thus improvements in façade design could be a significant next step for this technology.

It is also noted that there are some underfloor displacement system buildings expected to reach the 5.5 star region. This technology is still fairly immature in the Australian market and has significant scope for further improvement into the high star ratings.

Overall, there is complementary scope for improvement between the optimisation of conventional technologies and design and the maturation and normalisation of newer approaches. It should be expected that the future population of 6 star buildings will reflect a mix of these approaches.

Architectural Design

As noted above, management of façade loads and the integration of façade design with mechanical design needs is still a weak area in Australian buildings. Anecdotally, there is some evidence that buildings with better managed facades – or in well-shaded CBD locations – are over-represented in the higher star ratings. This indicates this is likely to be an area in which further improvements can be made.

A further anecdotal observation is that there are a significant number of large floor plate (in excess of 2000m² per storey) buildings in the higher star rating population. It is possible that this trend – which also reflects a general industry preference for larger contiguous floorplates to enhance workplace communication – could assist in delivering further high rated buildings, due to the reduced surface are to volume ratio

Cogeneration and Trigeneration

The role of these technologies in high rated buildings is currently ambiguous. This is because there is a relatively high failure rate of this type of design, most commonly due to lack of base load to permit continuous operation of the generator. Note that this is significantly affected by the fact that in NSW and Victoria, the tenants will generally have their own utility supplies and thus not be able to be serviced by the generation system, thereby removing a key potential electrical load[7]. Furthermore, as Australia has moved to large scale export of LNG, domestic gas prices have risen significantly and are expected to rise further, detracting from the economics of such systems.

A further issue is that throughout much of temperate Australia – and certainly all cities Sydney and south – the actual heating and cooling loads are relatively small in a well-managed building, so that often it can be difficult to make full use of waste heat. This detracts from the emissions benefits of on-site generation and exposes a significant risk that as the Australian electricity market becomes less emissions intensive, the benefits of on-site generation will recede.

Photovoltaics

There is significant potential for expansion of the use of PV on high performing buildings where site conditions permit, making use of the high generation potential of this technology in the sunny Australian climate, as shown in Table 2, and as evidenced by the low penetration of such systems in the sample data.

State	City	Annual Output kWh/year per kW
NSW	Sydney	1378
ACT	Canberra	1533
QLD	Brisbane	1528
VIC	Melbourne	1345
WA	Perth	1630
SA	Adelaide	1500
TAS	Hobart	1198
NT	Darwin	1640

Table 2. Annual generation per installed kW for well oriented unshaded PV installations in Australia.

[7] In other states, tenants are provided electricity via a landlord-owned micro-grid, thereby providing a better base load for generation operation. This option has recently become available in NSW and Victoria.

While there is significant activity in this field in Australia – solar has a direct commercial payback of 5-8 years on suitable sites, which is more attractive than some common investments in HVAC efficiency – the degree of impact available has to be kept in perspective. For instance, if one were to take the Sirius Building as an example, an additional 100kW of solar would be expected to generate approximately 150,000kWh which would only constitute 3kWh/m² relative to the 6 star equivalent electrical consumption of 27kWh/m². As a result the potential impact of PV on building ratings is significant only for low to medium rise buildings.

Summary of Opportunities for New Office Buildings

From the above it is clear that the opportunities for new buildings lie in:

- Improved façade design and architectural/mechanical coordination
- Technological innovation with VAV systems
- Design improvement and maturation for less common system types such as chilled beams and displacement ventilation
- Strategic use of cogeneration and trigeneration, focussed on key locations where costs, grid emissions factors and building loads are favourable
- Additional use of PV, but only as an incremental benefit.

Conclusions

The NABERS scheme in Australia has been successful in driving significant improvement in the average efficiency of the office market in the area of landlord services, with average emissions intensity having dropped by more than 30% in the period 2006-2015.

The key driver of this change has been the ability of tenants to request a base building rating as a procurement requirement when seeking space for lease. This creates a market for energy efficient buildings that values efficiency as a fundamental indicator of building quality rather than merely a cost-benefit analysis between energy costs and investment. This is supported by empirical evidence which shows that high NABERS Rated buildings have better commercial returns.

However, there is an increasing cohort of buildings rating at 5.5 and 6 stars, achieving emissions reductions of 25%-50% relative to 5 stars which is the highest nominated requirement for buildings. These buildings are leading rather than following the market and appear to be driven by a degree of competition and a perception of prestige associated with leading the market.

The current population of 5.5 and 6 stars has been reviewed and shown to comprise of mainstream fully air-conditioned buildings using VAV or chilled beam technologies, with a fairly even mix of the use or otherwise of cogeneration and trigeneration. The buildings reviewed were generally built in the last 10 years with a specific environmental brief.

Profiles of three leading examples of 5.5 and 6 star rated buildings have been used to demonstrate that these are practical, real-world buildings with conventional tenants and designs that are more representative of good design and operation than experimentation with technology or on occupants. This highlights a key practical lesson from the Australian experience, which is that high efficiency performance does not require high risk in design or operation or any compromise in service.

Looking forward to new developments, it is evident that there is further scope for improvement of building facades and architectural/mechanical integration as arguably the lead opportunity. While the dominant VAV technology is probably well optimised, newer technologies such as chilled beam and underfloor displacement are still comparatively immature and show potential for further improvement in design and operation. Cogeneration and trigeneration have potential in specific circumstances but are limited by a range of factors. PV has significant potential for further application, and is a rapidly expanding field, but the potential impacts on overall performance are incremental rather than transformative.

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How the renovation of government-owned listed buildings can contribute to achieve both cultural and energy efficiency goals

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Abstract

Many European cities host a large stock of culturally-protected buildings that keeps growing. Governments tend to own and use some of the most valuable among them. They could be interested over time in improving the energy efficiency of these heritage assets, so conflicts with their conservation may arise in doing it.

Meanwhile, the EU legal framework avoids tackling with this problem. Regarding those buildings which are both owned and occupied by public bodies, the Energy Efficiency Directive (27/2012/EU) imposes some renovation targets to national governments, but allows them to exempt listed buildings from the mentioned requirement.

This flexibility mechanism may lead to inaction in energy renovation, and eventually, to a loss of competitiveness of heritage buildings as real-estate assets, due to worse indoor comfort conditions and higher operational costs compared to those of other -new or renovated- non-heritage buildings. This poses an additional threat to a group of buildings that often faces the pressure of the market in city centres with rising land values.

The theoretical framework presented in this paper will show how the main conflicts between the conservation of a building's cultural value and its energy efficiency improvement lay on the complexity of taking that cultural value into consideration when assessing the cost-effectiveness of the available alternatives for upgrading. Later, we will assess the rate of inclusion of heritage buildings in the Spanish programme for the renovation of government-owned-and-occupied buildings. Finally, we will draw some general conclusions on how public bodies can contribute to their cultural and energy efficiency targets at the same time when managing their assets.

Introduction

At least since the end of the 1970s, West European governments support policies aimed at increasing the energy performance of the building stock in their countries. Some of these buildings are owned and occupied by central governments. Making economically efficient improvements in publicly-owned buildings saves taxpayer's resources when reducing energy-related expenses. But the energy renovation of state-owned buildings has a more important role: it serves as a demonstration tool to develop a market for the energy renovation of buildings, and to engage the private sector in improving the energy performance of its real-estate assets.

Part of both the existing private and publicly-owned building stocks consist of heritage assets. Central Governments often own a large proportion of these listed buildings for historic reasons (they were commissioned or seized by them at a given point in time), as well as a consequence of active policies aimed at protecting those buildings by purchasing them.

A current EU-wide mandate to renovate buildings owned and occupied by central governments allows Member States to exempt those which are legally protected for cultural reasons from compliance with the scheme if it puts their conservation at risk.

That renovation mandate is the starting point of this paper, which explores the theoretical and practical basis for the mentioned exemption in order to support it or proposing better alternatives. First, it is important to remember the goals of public buildings renovation schemes –briefly mentioned before- as well as those of cultural protection policies. Also, the implicit assumptions often presented when dealing with this topic should be put into question: it is often stated that the works to improve the energy performance of heritage buildings may pose a risk for their conservation, but we have not found any assessment regarding the effect of a possible worse-than-average energy performance, - due to a lack of improvement works for conservation reasons- on their occupation and, as a consequence, on their conservation. This will be the main topic of the first, theoretical part of this paper.

Also, there are two more common implicit assumptions for which there is a lack of real data to support them. The first of them is that a listed building is, or not, harder to renovate than a building without cultural value, without any possible intermediate situation. The second is that, nowadays, their small number compared with the whole building stock does not make them critical to achieve energy and climate change mitigation policy goals.

The second part of this paper deals with the latter statement. Publicly available data will be used to discover which of the buildings owned and occupied by the Spanish Central Government in Madrid have probably been excluded from the European mandate because of their legal protection. The number of buildings found and their aggregate area will be compared with the figures of the part of the stock in which that mandate is applied. Finally, we will draw some conclusions and propose further research needs.

The regulatory framework: the 'exemplary role of public bodies' buildings'

As mentioned before, an EU-wide mandate for the energy renovation of public buildings is the starting point of this research. The 2012/27/EU Directive on Energy Efficiency (which will be referred as the EED) [1] includes two requirements related to buildings that are, at the same time, owned and used by the Central Governments of the EU's member states:

1. A mandatory renovation target (Article 5): Member States must renovate 3% of the total heated or cooled area of the aforementioned buildings every year.
2. Also, the Directive introduces some criteria regarding public procurement (Article 6), which involve energy performance requirements for buildings rented or bought by Central Governments.

Buildings renovated under the first mentioned mandate, as well as those rented or acquired under the second, must reach a minimum energy performance requirement. This requirement has already been set by each Member State under a previous norm called the 2010/31/EU Directive on the Energy Performance of Buildings (hereafter EPBD) [2]. There are national or regional requirements for both new buildings and renovations, voluntarily carried out, which affect parts or components of the building that are relevant to its level of energy consumption.

Both the EED's renovation scheme for public buildings, and the energy performance standards from the EPBD (used by the former as a reference), have been developed for a reason. A renovation target for public buildings is mainly an instrument aimed at giving momentum to the renovation market or, in other words, designed to let the public sector generate the externalities produced by first-movers, a role that is avoided by the private sector because of its inherent financial risk [3]. It complements another instrument, the standards put in place by the EPBD, which can be interpreted as a way of reducing the cost of information involved in assessing and carrying out an energy renovation, although its effect on the discount rate applied by consumers is often cited against this tool [4].

Exemption of protected buildings because of their cultural value

The Directive 2012/27/EU allows Member States to decide whether or not to exempt heritage buildings for the public buildings renovation schemes that it mandates, if trying to upgrade their energy performance to the required level could harm their cultural value. That required level has been previously set, as mentioned before, by each Member State in accordance with the 2010/31/EU

Directive (EPBD). The fact is that the EPBD already allows the same possible exemption for any listed building under renovation[1], publicly or privately owned.

Therefore if, under the mentioned provision in the EPBD, the building regulations of a Member State already allowed energy renovations of listed buildings not to strictly obey the energy performance requirements included in these regulations, there would be no need to allow the exclusion of listed buildings from the renovation programmes mandated by the 2012/27/EU Directive. In other words, if a listed building from the public sector were included in a renovation programme that implies renovating it to comply with its country's building regulations on energy, the latter would be applied to an extent that it did not damage the cultural value of the building.

Obviously, it is quite different to make public buildings comply with those regulations (if these regulations include some exemptions for listed buildings, even doing nothing can be deemed as compliant) than to make them comply with the minimum energy performance standards set in these regulations (an additional exemption has then to be added). The 2012/27/EU mandates to *"[…] meet at least the minimum energy performance requirements that it [a central government] has set in application of Article 4 of Directive 2010/31/EU*" a wording that does not offer any clear answer, so an explicit exemption is included in the EED.

Moreover, provided that heritage buildings are not near to represent a very high percentage of the building stock owned and occupied by governments, it would have been easier, if desired, just to postpone their renovation by prioritizing the improvement of non-protected buildings. After all, 'only' a 3% of the total under-performing area has to be renovated each year, so it would take many years just to complete the renovation of the non-listed group.

Therefore, it is hard to argue that the exemption included in the EED regarding public buildings renovation programmes is the most efficient way to avoid damaging heritage assets. Some commentators [5] suggest that this calculation of the annual rate is the key to understand the exemption for listed buildings: as the 3% annual target is calculated yearly over the remaining area that does not comply with the minimum energy standards in place, the inclusion of a backlog of listed buildings that may have compliance problems, widens the total area taken into account and, therefore, the area that must be renovated every year.

The European Commission's initial proposal for the current Energy Efficiency Directive [6] did not foresee any exemption for the renovation of listed, publicly-owned and occupied buildings. It was later included during its adoption process in the European Parliament. The MEP's proposals [7] ranged from stating a mere exemption to accompanying it with a specific renovation programme for listed buildings. That special programme did not appear in the final version of the Directive, probably due to the lack of competences in cultural matters offered by the Treaty on the Functioning of the European Union [8].

The previous paragraphs question the convenience of exempting listed buildings from the EED's public buildings renovation programmes as a way of assuring their conservation. In addition, they show some that here may be an incentive to exempt as many buildings as possible, and try to explain why the EU had limited powers to develop more elaborated solutions. The following section deals with the reasons and implications of the exemption itself, regardless of the norm that includes it.

A theoretical framework to the exemptions of listed buildings from complying with minimum levels of energy performance

More often than not, conflicts between minimum energy performance requisites and the conservation of cultural assets are summarized in a pair of arguments or situations:

- Either it is not possible to improve the energy performance of the building while keeping its cultural significance;

[1] It must be remembered that the EPBD does not mandate any renovation, but it sets energy performance standards for energy renovations that are already going to be carried out.

- or it is possible to improve the energy performance of the building without damaging its cultural features, but the extra effort required comes at a cost.

The exemptions included in the EPBD and EED Directives that have been mentioned in previous sections are aimed at the first scenario. This kind of exemption makes sense: given that legally protected heritage buildings are supposed to hold a large cultural value to Society, and that it cannot be translated to monetary terms to perform a cost-benefit analysis [9], it is safer to avoid any risk and make the energy savings or GHG emissions reductions required by policy anywhere else.

Actually, these exemptions do not protect heritage buildings from being damaged: that is the mission of their legal (cultural) protection. These exemptions just make it possible to comply with the building regulations and the legal cultural protection at the same time, accommodating both legal bodies.

It also must be taken into account that, as energy performance standards move towards a standalone requisite of non-locally-produced-renewable-energy consumption by square meter and year, it will become easier, when dealing with listed buildings, to offset the limited potential in some parts or elements produced by conservation needs. This can be done either by making a bigger effort regarding other parts or systems less sensible for the cultural conservation, or even by taking some technical systems out of the building, and sharing them with the surrounding blocks. In this context, the second scenario mentioned before, namely the extra cost of energy renovation related to heritage preservation, will probably grow in importance over the years at the expense of the first one.

When the energy renovation of a specific listed building is possible but more costly due to heritage conservation efforts, it is currently possible to exempt that building from compliance anyway. This exemption is not based on the cultural value of the building itself (in fact, it is a consequence of it), but in the fact that compliance with energy performance standards is conditional to an economic viability principle, as expressed in the 2010/31/EU Directive (Article 7, paragraph 1). Therefore, if costs are higher than usual, that principle could be used -if reflected in the corresponding national building regulation- to justify an exemption.

At first glance and taking into account only their aggregated effects, the current legal answers to the two mentioned problems do not have a negative impact on welfare: first, the conservation of cultural assets is a priority, so any improvement in the energy performance of these buildings must be compatible with their protection, even if this makes it impossible to comply with the minimum requirements set by the EPBD. Second, if it is possible to comply with the EPBD's requirements in a compatible way, but getting to these efficiency levels makes the renovation too expensive to be profitable, those agents performing the mentioned renovation may legally decide not to strictly comply with the EPBD. Therefore, a loss of cultural capital is avoided and consumers are not forced to make investments that may not be profitable for them.

Nevertheless, if the energy renovation of listed buildings in a compatible way with protection were as straightforward -and had the same costs- as those of a renovation in the absence of legal protection, it would be beneficial for owners and occupiers and social goals such as climate change would be a bit easier to reach.. The following section deals with the opportunity cost of cultural legal protection, regarding the energy performance of buildings, and with the case for public intervention.

Opportunity cost of heritage protection related to energy efficiency

Even though these measures do not worsen any agent’s situation, it is apparent that, in absence of the legal protection that impedes or makes more expensive to reach a given energy performance level, its occupant and owners would have enjoyed the benefits of that level of performance, at least at lower costs. Those benefits can be presented as follows:

- First, the energy renovation of a building reduces the energy consumption –and probably the GHG emissions – related to the initial comfort level. This limits energy costs and improves the classification of the building if its occupier is subject to an environmental certification programme.

- Second, works aimed at improving the energy performance of a building tend to produce some indirect effects such as better internal comfort conditions or economies of scope when improving other features, (e.g. accessibility). At the same time, some studies show a derived improvement in worker's performance and a positive impact in the organization's public image.

So in partially or totally renouncing to those benefits, or when paying more than average to obtain them, owners and occupiers are bearing with an opportunity cost, or with a real extra cost. Those are costs of heritage conservation. Who benefits from that conservation? Maybe those occupiers and owners do, just because of their personal enjoyment or the actual income produced by cultural significance of the building. But a larger group of people benefits too, especially those individuals who find a cultural significance in the building and, in some cases, business people and workers whose economic activity is partially based on exploiting that interest, such as the tourist sector and nearby shops to the cultural asset, without owning the building or contributing to its conservation. Those two effects are defined by the literature on economics as *public social goods* and *positive externalities*, which are *market failures* [10]. In both cases someone is bearing with all costs but not reaping all benefits, so he or she will tend to under-produce the source of those benefits. Market failures make public intervention reasonable, even from the stricter point of view.

Governments can contribute to reduce the costs related to energy efficiency and heritage conservation mentioned before. This can be done by investing or easing the development of compatible and cheaper renovation technologies and procedures for heritage buildings, along with the provision of better information to all stakeholders, including that information derived from pilot renovations[2] . A good example of this kind of policy is the funding available in the European research Framework Programmes for projects on this topic such as the well-known 3ENCULT and EFFESUS [11].

Therefore, among the benefits of increasing the energy performance of a publicly-owned and occupied building to a given level, the positive effects on the renovation markets for heritage buildings should also be taken into account. Sadly, there is little data on the size of that prospect market, so this is a difficult task to perform.

But there are other costs and benefits of those renovations that might be taken into account at some point in the future: is it harmless for conservation to let these buildings lag behind in their energy performance? The last question to pose would be if the energy performance requirements for conventional existing buildings and for the listed ones should be the same. The latter is part of an ongoing investigation by the authors that will be published soon.

The energy renovation of a heritage building as a requirement for its conservation

In the former approach it was supposed that the only risk for heritage conservation related to the energy performance of the building was the potential damage derived from renovation works. Now, a wider, -hypothetical- approach is taken.

International Charters on heritage conservation [12] tend to highlight the importance of keeping buildings in –a compatible- use. This can be argued at both theoretical (because of its link with the cultural significance of the building) and practical level (the conservation expenses allow both the regular use of the building and its cultural conservation, so it is more efficient than conserving the building as an exhibition piece).

If, in the future, some energy-related features of new buildings -such as comfort standards, cost of operation or environmental class- became crucial for their occupiers (including public bodies), the energy renovation of existing buildings will be needed for their survival. Non-listed buildings can be demolished, but heritage buildings must be conserved and it would be unsustainable to keep a large share of them out of use.

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[2] As the R&D activities and pilot programmes involve positive externalities and both these externalities and a hypothetical, current lack of information to agents represent market failures, they can justify the choice of the mentioned type of public intervention

Therefore in that case, improving the energy performance of listed buildings would become a goal of conservation policies, and some of the additional costs compared to conventional buildings would probably have to be borne by their budgets. As mentioned before, governments tend to have a larger proportion of listed buildings in their portfolio than average, so the financial impact for them would probably be larger than usual as well.

This is a good reason to increase the pace of technology and market development for that specific market, in order to lower costs and reduce the stock to be intervened. But again, there is little data regarding the size and the characteristics of the listed part of the stock to assess and support that claim. In the final section the listed buildings occupied and owned by the Spanish government in Madrid that have not been included in the renovation scheme mandated by the EED are examined in order to propose some improvements to that program.

Madrid's case-study

The previous sections were focused on those situations when improving the energy performance of heritage buildings is not possible or involves additional costs. It was also mentioned that it often seems that not reaching a high level of energy performance in the renovation of listed buildings has no relevant impact of the achievement of energy efficiency or climate change mitigation programmes.

In the following pages the stock of listed buildings owned and occupied by the Spanish Central Government is assessed by comparing their weight to that of not protected buildings. Later, in the final section, we will draw some general conclusions.

Sources of information and method

In July 2015, an updated list of assets subject to the EED's mandate for the renovation of government-owned buildings was published [12]. Spain's latest National Energy Efficiency Action Plan [13] states that heritage buildings have been excluded from the renovation programme and put in a dedicated register, but the latter has not been made public yet. Military buildings are also put in a separate, reserved registry.

The access to the register of the Spanish central government's estate (General Inventory of Assets and Rights of the State) is restricted [14]. Nevertheless, a "Transparency Portal" website [15] was recently launched, and it includes a list of the real-estate assets publicly owned[3] and linked to each Ministry in the aforementioned Inventory. Though this may represent a fraction of the government's total estate, it is probably similar to the initial list used to select those buildings subject to the public bodies' renovation programme.

Both lists have been inserted in a Geographic Information System recently developed by the authors to study Madrid's building stock, and that contains information related to the level of protection, occupation and physical features of each parcel. If we exclude partially-owned buildings, assets used by third parties and residential buildings, we can approximate the number of whole buildings that have been excluded because of being listed, or at least, the number of parcels from the cadastre that include heritage buildings, that have been excluded. Then, analyses on their renovation potential can be carried out as a means to develop a method for the Spanish Administration. The first goal has been achieved here, and work on the second one is still being carried out.

Size of the excluded stock

The list of buildings subject to the EED's renovation scheme, made public by the Spanish Government includes 50 cadastral parcels with listed buildings that meet the criteria described before (wholly owned and occupied by government, without residential use). In the following table, the first column shows the total conditioned area subject to the renovation scheme across the whole country; the second and third columns show the number of listed buildings in Madrid that are included, along

[3] It includes ownership or "real rights"

with their aggregated area. The fourth and fifth columns show a total of 121, not residential, listed buildings in Madrid which the Transparency Portal associates with each Ministry that do not appear in the renovation scheme list – probably as a result of the possibility of excluding them- along with their aggregated area. The latter figure is not declared as 'conditioned' area, but can be used as a proxy. We don't take into account buildings which are just part of conservation areas ('colonia') nor those whose level of protection hardly involves the physical conservation of any original part ('volumétrico' and 'ambiental' categories)

Table 1. Number of listed buildings and their aggregated area included or not in the Spanish renovation scheme under the EED

	Total area included (All Spain)	Included parcels with listed builds. in Madrid		Excluded parcels with listed builds.in Madrid	
Ministry	**Sq metres**	**No**	**Sq metres**	**No**	**Sq metres**
Employment	1,935,057+	4*	20,835*	2	59,996
Education, Culture and Sports	459,676	10*	37,437*	20	282,760[4]
Economy and Competitiveness	918,965	11	73,454	7*	89,668*
Finance and Public Administrations	1,547,279	7	97,151	4	26,125
Foreign Affairs	6,743	1	5,046	6	64,980
Agriculture, Food and Environment	142,674	3	51,568	3*	27,908*
Development / Infrastructures	243,951	2*	26,035*	2*	10,292*
Justice	20,889	1	5,428	10	76,815
Health, Social Services and Equality	343,031	1*	1,800*	1	9,462
Interior / Homeland Security	4,949,122	5	24,286	3	19,244
Industry, Energy and Tourism	312,086	0	0	0*	0*
Presidency	124,674	1	74,638[5]	2	7,436
Defense	-	-	-	19	652,996[6]
*Shared buildings 'Nuevos Ministerios' – PºCastellana 67 'Pº Alfonso XII 3-5' 'C/Alcalá, 56 / C/Valenzuela, 3' 'C/Rios Rosas,23 / C/Cristóbal Bordiú, 34' 'C/Príncipe de Vergara, 54'		4	86.251 (of 262.353)	1	10.747

[4] The inventories show an aggregate surface for the Ministry's headquarters which comprises three buildings: the building in C/Los Madrazo is not protected, so its 11,137 square meters declared in the transparency portal (although they are not measured in the same way than in the renovation inventory) have been deducted. The opposite happens to two listed, large buildings from the National Distance Education University. They have been counted as one entry but their built surface is not included in the aggregated figure shown.

[5] The figure is for the *Moncloa* complex (the presidential office and residence) which is wholly protected although it holds some buildings without cultural value.

[6] This figure includes the 'Gomez Ulla' Military Hospital, with 261.502 square metres, and the 'General Arteaga' Military Base, with 175.849 square metres. The number of listed buildings includes some elements from the 'Campamento' Military Base that is currently being redeveloped; As a consequence there is not related, accurate data available on their area, so that area is not included in the aggregated figure.

Own formulation using publicly available data provided by the Council of Madrid, the Transparency Portal and the Spanish Ministry of Industry, Energy and Tourism.

As it can be seen above, the total exclusion of heritage buildings announced by the NEEAP did not materialise. But the criteria followed excluding only some listed buildings was heterogeneous: for some ministries the heritage-related area excluded is not significant when compared with the total area under the mandate (see for example the Ministry for Employment); but in other cases (such as the Ministries for Foreign Affairs or Justice) the option to exclude heritage assets has a large impact on the actual built area that they must renovate each year.

Also, it can be seen that a relatively small number of heritage, shared buildings, make up a large portion of the built area in Madrid that we are assessing. Nevertheless, the way these buildings are treated changes from one Ministry to another. An outstanding situation is presented by the *Nuevos Ministerios* building, a large complex of 185.000 square metres from the middle of the 20th century with an intermediate level of protection, and which houses four ministries, but only one of them has included its part of the building in its renovation target

These situations show that the list is a work in progress, but it also may well contribute to make a case for the harmonization of the selection criteria applied by each Ministry.

Conclusions

Under the 2010/31/EU Energy Efficiency of Buildings Directive, Member Estates can exclude from their national building regulations on energy those works for which complying with the regulations could harm heritage buildings. Alternatively, if compliance is possible but at a greater cost than average, the exclusion can also be authorized, without breaking the EU law.

Nevertheless, the mentioned conflicts between energy renovation and heritage conservation can be limited to specific systems and components of a building, leaving room for further opportunities of conventional renovation of other elements of the asset.

The 2012/27/EU Directive on Energy Efficiency provides a mandatory building renovation programme for public bodies that affects government-owned and occupied buildings in every member state. These governments may exclude heritage buildings from these schemes if the compliance with the Directive puts their conservation at risk.

In this paper, a proxy to the list of heritage buildings excluded by the Spanish government was found. Although many heritage buildings were kept in the renovation programme, the aggregated area of some ministries' excluded buildings was relevant compared with the total of listed and non-listed buildings included in the mentioned programme.

The exclusion option mentioned in the EED does not offer any additional protection regarding the exclusions that are already incorporated in some national building regulations, as it happens with the *Código Técnico de la Edificación* [Spanish Technical Building Code]. Moreover, the EED's option is designed for whole buildings but not for specific conflicting systems and elements. Under this approach a building that cannot be fully upgraded has to be excluded as a whole, wasting its remaining potential for conventional renovation. It is also possible to lower the total, annual renovation target by excluding heritage buildings.

Therefore, in the first place, it is proposed to scrap the mentioned provision in the EED for the exclusion of heritage buildings. This involves clarifying some other articles from the same directive, related to the minimum renovation rate for public bodies' buildings. Namely, the current mandate to renovate these buildings to '*meet at least the minimum energy performance requirements that it* [each government] has *set in application of Article 4 of Directive 2010/31/EU'* should be replaced by a mandate to comply with the national building regulations derived from that article. This could be useful to assure that applying any exemption included in these regulations to a heritage building (for example, allowing it to reach an energy efficiency level below the general requirements related to article 4 from the EPBD) does not make its renovation, less ambitious tan average, incompliant with the renovation mandate of the EED.

This would often increase the total area that a government has to renovate each year. But, on the other hand, these governments could compute the total area of a heritage building as renovated, even if the renovation was only partial, for conservation reasons provided in their national building regulations. This would prove to be useful for the European Commission, as a means to check the way that the exemptions offered in the EPBD are used in each country, in order to apply these conclusions to the periodic revisions of that Directive.

The inclusion of more demanding improvements in mainstream renovation programmes

Also, in the medium term, the energy renovation of heritage buildings could become a key element for the economic sustainability of their conservation because it could affect their effective occupation. Not all heritage real-estate assets are made of ancient and fragile building systems, so broader pilot renovation schemes for heritage buildings could be launched, leaving demonstration projects funded by R&D programmes to specific, more contentious categories of buildings. These renovations programmes should deal with those parts of heritage buildings whose energy renovation is more complex, and probably more expensive, to carry out.

Mainstream schemes for the renovation of governmental buildings, as these from the EED, pose a great opportunity for this task, mut governments have to be encouraged to carry out these special works. Given the supposed lack of competences from the EU in heritage-related matters, the simplest option is to allow these renovations to count more than the conventional ones towards each government annual renovation targets in the existing scheme.

Although this solution is far from perfect, the extra cost communicated by governments to justify each ‘heritage bonus’ could be compared to the average costs included in their cost-optimal calculation. This experience would provide the European Commission with rich data and with a deeper knowledge about the energy renovation of heritage buildings.

Acknowledgments

We thank the anonymous reviewer for his/her constructive comments.

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Session
Building Automation I

European certification method for assessing the building automation impact on energy efficiency in buildings

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Relevant Topics: *Control Systems, IoT and Building Energy Management Systems (BEMS); Policies and Programmes (local, national or International); Energy and facility management, energy services; Building envelope, passive techniques and HVAC*

Keywords: *Building Automation, EN15232, Certification, Optimization, Life Cycle*

Abstract:

Building automation controls play an important role for the efficient and sustainable operation of the building. The building sustainable performance depends on the building structure, the building technical systems and the building users. The building automation impacts each one of them. Its role is especially important in operations aiming for sustained energy-efficient control of building systems:

- by identifying and eliminating energy waste
- by using energy only in the amount, at the place and at the time it is needed
- by implementing the right control function level for the right application at the right place

The innovation proposition is to evaluate the BACS (Building Automation Controls System) systematically and universally against a classification standard (in this case EN15232) using the eu.bac methodology and tool. eu.bac is the European Building Automation and Controls Industry Association.

The eu.bac methodology offers a very simple and fast way to benchmark the BACS and to identify improvement potential without a detailed energy analysis. The outcome of this standardized assessment clearly points out the potential rating increase that could be achieved with improved control strategies for each specific function. The methodology includes continuous evaluation of key performance indicators (KPIs) which signal that the building systems are managed at their most sustainable energy-efficient level while maintaining indoor comfort closely related to building occupants' satisfaction, health and productivity.

If BACS were properly designed, installed, commissioned and operated, making use of all economically viable control-related energy-savings opportunities, the average savings per commercial/public building would be of the order of 37%.

For more information visit www.eubac.org

Introduction

Buildings are the biggest energy consumer in the world and present the biggest potential for improving energy efficiency and reducing CO_2 emissions. Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU (Source: *EU Commission site January 2016*) Furthermore, commercial and public buildings in urban areas are the fastest growing energy consuming sectors. The commercial building sector is a key area where the CO_2 reduction could be achieved in a cost-effective manner. Therefore all involved actors need to take all necessary steps to disseminate good practice, foster investments in energy efficiency and provide sustainable technical solutions. This includes behaviour changes in how companies, architects, urban planners and building operators invest, design and operate non-residential buildings.

Building sustainable performance depends on the building structure/envelope, the building technical systems and the building users. The building automation impacts each one of them, for instance:

- Controls of shading and thermo-active building systems as parts of the building envelope
- Controls and integration of building technical systems, traditionally HVAC and lighting; building automation is the "brain" and the "command center" for the building systems.
- Aid in efficient building operation as per design specifications and current facility requirements

Building automation controls play a significant role in the operation of the building and offer vast potential for low-cost improvement measures in existing buildings.

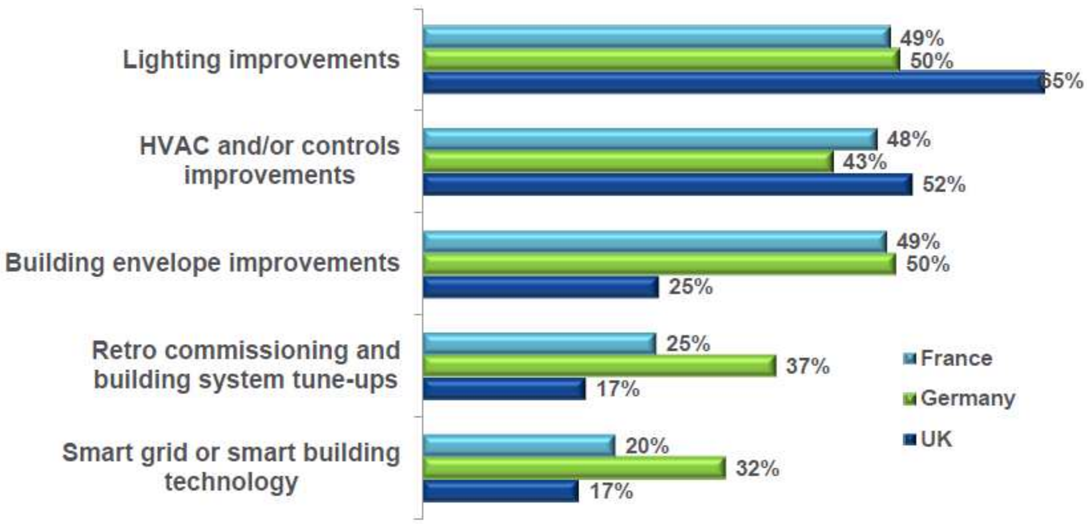


Figure 1: Levels of adoption of energy efficiency measures (Source: Energy Efficiency Indicator Survey 2013, Institute for Building Efficiency)

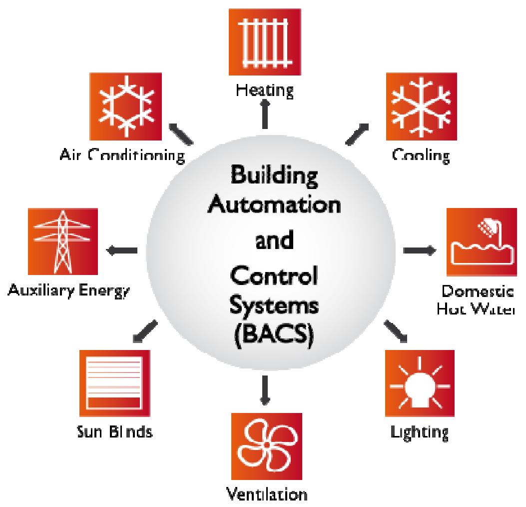
Lighting and HVAC controls and improvements rank as the top two energy efficiency measures being implemented globally. Many energy-efficient building technologies are widely available today and can reduce carbon emissions at a low or negative net cost. [1]

At the same time the assessment of the impact of the building automation controls is not considered comprehensively enough in current building certification systems, such as LEED, BREEAM, DNGB, etc. It is very often overlooked in the design phase and not adequately utilized in the operation phase. Energy models also do not simulate control strategies.

To ensure the life cycle efficiency of the building the building automation controls must be designed, installed, commissioned, operated and maintained properly.

Buildings, occupants and their needs

The primary purpose of a building is the provision of space for working and living, a place of comfort and safety.



Building automation is the automatic centralized control of a building's heating, ventilation and air conditioning, lighting and other systems through a Building Automation and Controls System (BACS). Thus it is used to control the indoor environment, to create a safe and comfortable space for the occupants. It binds all relevant systems together through less- or more- efficient controls strategies.

BACS control according to design specification which must follow current facility requirements. Current facility requirements change during the life of the building influenced by factors such as change in use, operational priorities, technology development and regulatory requirements.

- Is the BACS designed to support the energy efficiency goals of the building owner?
- How energy efficient is your BACS?
- Does the installed BACS control according to specification?
- How do the users interact with the BACS?
- Is the full potential of the installed BACS being used?

The eu.bac assessment method could help you find the answers to the above questions. Moreover, this methodology offers an *uncomplicated and effective* way to benchmark the BACS and to identify improvement potential without a detailed energy analysis. The outcome of this standardized assessment shows the gap between the actual functionality and the optimal control functions for the specific system. It clearly points out the improvement potential and prospective rating increase that could be achieved with better control strategies for each specific function and field of use.

eu.bac is the European Building Automation and Controls Industry Association [2]. It was established in 2003 with the goals:

- to promote the adoption of European legislation and its associated standard EN15232
- to ensure BACS systems are specified at an adequate level,
- to endorse a scientifically proven BACS audit process for assessment in new and existing buildings which will certify its current condition with the respective BACS label

The eu.bac vision is: "A world where energy-efficiency and sustainability in every building is achieved through the optimal application of building controls, automation systems and services."

Impact of BACS: Evolution from legislation to certification

Effective measures for preventing energy waste are described in the European standard EN 15232: Energy Performance of Buildings – Impact of Building Automation, Controls and Building Management [3]. The central principle in this standard is to allocate higher ratings for demand-based control and operation of the energy-consuming systems. Energy in the form of heating, cooling, conditioned air and lighting should only be provided when there is a demand on the user side. Usage and thus, in large part, the users should dictate when and how much energy must be consumed.

Demand-driven control reflects the needs of the controlled space as a better energy saving solution over schedule-based control solutions. Sensors continuously monitor conditions in the controlled space, they provide real-time feedback to the controller which adjusts the generation and distribution path to match the actual demand and occupancy of the building. Systems with consistent, automatic identification of needs with, for example, presence detectors and a room control which effectively communicate their demand to the central control logic for the main plant, achieve the highest energy efficiency class.

EN15232 specifies methods to assess the impact of Building Automation and Control System (BACS) and Technical Building Management (TBM) functions on the energy performance of buildings, and a method to define minimum requirements of these functions to be implemented in buildings of different complexities. TBM provides information for operation, maintenance and management of buildings especially for energy management – trending and alarming capabilities and detection of unnecessary energy use.

EN 15232 defines different efficiency classes for BACS as follows:

- Class D corresponds to non-energy efficient BACS. Buildings with such systems shall be retrofitted. New buildings shall not be equipped with such systems.
- Class C corresponds to standard BACS used as a reference level in EN 15232 calculations with "1" as energy consumption factor.
- Class B corresponds to advanced BACS and some specific TBM functions (e.g. networked room automation, energy monitoring)
- Class A corresponds to high energy performance BACS and TBM (e.g. networked room automation with automatic demand control)

The potential savings for thermal and electrical energy can be calculated for each class based on the building type and building purpose. The values of the energy class C are used as the reference for comparing the efficiency.

	Thermal energy				Electrical energy			
Class	D	C	B	A	D	C	B	A
Offices	1,51	1	0,80	0,70	1,10	1	0,93	0,87
Lecture hall	1,24	1	0,75	0,50	1,06	1	0,94	0,89
Education	1,20	1	0,88	0,80	1,07	1	0,93	0,86
Hospitals	1,31	1	0,91	0,86	1,05	1	0,98	0,96
Hotels	1,31	1	0,85	0,68	1,07	1	0,95	0,90
Restaurants	1,23	1	0,77	0,68	1,04	1	0,96	0,92
Wholesale & retail	1,56	1	0,73	0,60	1,08	1	0,95	0,91
Residential	1,10	1	0,88	0,81	1,08	1	0,93	0,92

The reference is set at 1 for class "C" standard BACS, then efficiency factors are used to present the deviations in energy consumption for the other BACS efficiency classes. For example, by using class A, 30 % of the thermal energy can be saved in offices.

Figure 2: Overall BACS efficiency factors (Source: EN15232, 2012)

The impact of BACS functions on the energy efficiency of a building can be determined by comparing two energy demand calculations for a building using various building automation functions.

EN 15232 is one of the set of standards arising from the European Energy Performance of Buildings Directive (EPBD) prepared by **CEN (C**omité **E**uropéen de **N**ormalisation **–** European committee for standardization) and commissioned by the European Community.

Drawing on the profound knowledge and experience of control experts eu.bac has transferred the EN15232 requirements into a practical method for assessment of BACS. The method was scientifically tested by Dresden University of Technology. The assessment involves periodic eu.bac system audits as well as ongoing monitoring of eu.bac KPIs. eu.bac has also prepared the certification procedure and test method for the audits as well as the training and accreditation for the Auditors.

eu.bac Methodology

The eu.bac System Method will assure the users a level of performance of their systems, as defined in the EU directives and relevant EN standards. The acknowledgement of the certification is the eu.bac System Certificate that expresses conformity with EU directives, quality EN standards, and the eu.bac System Technical Recommendations. It rates the system efficiency and creates trust and transparency to the benefit of building owners and occupants.

The BACS evaluation is based on a points system and is normalised to a 0–100 scale. Using points provides a flexible and multi-value scale. Individual control functions are allocated different amounts of points depending on their relative importance for the BACS energy efficiency. As described above, the assignment of points directly relates to functions listed in the EN 15232:2012 standard.

			Definition of classes							
			Residential				Non residential			
			D	C	B	A	D	C	B	A
AUTOMATIC CONTROL										
1	HEATING CONTROL									
1.1	Emission control									
		The control system is installed at the emitter or room level, for case 1 one system can control several rooms								
	0	No automatic control								
	1	Central automatic control								
	2	Individual room control								
	3	Individual room control with communication								
	4	Individual room control with communication and presence control								

Figure 3: Function classification list (Source: EN15232, 2012)

Thus the relative importance of each of the applications (e.g. Emission Control application) is established, assigning them a multiplication factor to create an overall summary assessment that is relevant to the section in question of a typical building.

A typical building contains rooms/spaces, several air-handling units (AHU), a central plant. These may have various pieces of equipment that are controlled through different control functions. In the eu.bac assessment tool each space, AHU, heating distribution network, heating plant, etc. is described in one row. To be able to make an accurate classification different weightings are applied to them. Weighting factors are given as a relative value to compare equipment of different sizes or spaces with different operating schedules. For technical building management (TBM), the area covered by the respective BACS is used in the calculation.

Moreover, the tool is capable to weigh up the applications differently for different types of buildings. The selection of building type is used to assign importance factors for all the different applications in the different sections. The weighting factors were modelled and tested in collaboration with the Technical University of Dresden.

The eu.bac method considers the following types of buildings:

- Office
- Data Centre
- Education
- Hospital
- Hotel
- Retail
- Restaurant
- Residential Building

The type of building determines the relative importance of BACS functionality for the following applications:

- heating control,
- domestic hot water control,
- cooling control,
- ventilation and air-conditioning control

- lighting control
- shading control
- technical building management

In addition, the eu.bac method evaluates the use of Key Performance Indicators, certain extended functionality, and/or certified products that contribute to high energy performance.

The methodology could also be used in the simulation of concrete examples, i.e. to demonstrate the new, improved rating if the recommended installations and optimisations were implemented.

There are some rules included in EN 15232:2012 that allow for missing functionality and functionality that has no substantial impact (< 5%) regarding the amount of energy used for Heating, Cooling, Ventilation, DHW, Lighting or Blinds. These rules are taken into consideration when calculating the final assessment results. As an example, if there is no cooling system installed in the building, the cooling control functionality will not be considered and the actual importance factor will become 0.

The eu.bac Technical Recommendations document describes the different functionality options for each application in more detail and advises how to check that functionality during the audit.

Audit

The eu.bac System audit following the eu.bac methodology is carried out by eu.bac authorised Auditors. Each auditor must complete official eu.bac training with a final test. Upon successful completion and after the eu.bac acceptance of their first audit, the auditor is listed officially as an accredited eu.bac System Auditor. The Auditors maintain their status through conducting audits on a regular basis and through participation in continuous professional development offered by eu.bac. The audit reports submitted by the Auditors are checked independently by two members of the eu.bac System Quality Assurance Panel. On their acceptance/approval, eu.bac issues the certificate that officially publishes the achieved rating level.

eu.bac Auditors use the eu.bac assessment tool and the Technical Recommendations document when performing an audit in a building. The assessment checklist contains six main sections for recording the specific information related to the different applications of control functions for: Rooms, Air Handling Units (AHU), Heating, Cooling, Domestic Hot Water (DHW) and TBM.

eu.bac System Inspection Check-list v25

Rooms

Type of room (name)	Number of rooms of this type	Room area (m2)	Total room area (m2)	Estimated run time (%)	Weighted area/run time	Information missing?	Heating 1.1 Emission Control									
							NO HEATING	Name of associated heating distribution network	1.1.0 No automatic control	1.1.1 Central automatic control	1.1.2 Individual room control	1.1.3 Individual room control with communication	1.1.4 Individual room control with communication and presence control	2.2.2.3 KPIR.c	SUMMARY POINTS	POINTS/area/run time
									0	0	1	2	3			
Exhibition Hall	1	2224	2224	36%	800.64			System 102					1	0	3	1.079
Training Room	1	83	83	35%	29.05			System 102					1	0	3	0.039
Open Plan Office 2 fl	1	869	869	42%	364.98			System 101					1	0	3	0.492

Figure 4: eu.bac System audit checklist excerpt (Source: eu.bac, 2015)

In addition there is a Notes section where the Auditors record specific observations during the walk through the building as well as descriptions of tests conducted to verify specific control functions.

The results from the audit for the different control applications are calculated and the eu.bac System classification level is displayed according to the total achieved points score. An example summary page is shown on the next page.

The potential additional points that could have been achieved with better control strategies for each control application are shown in a separate section. This section is extremely useful in the analysis and recommendations phase of the audit.

eu.bac european building automation controls association

Import data from a v24 Check-list

eu.bac System Inspection Check-list v25

BUILDING FACTS					
Building name					
Building address	Business District	Country	DE	Postcode	Frankfurt
Building built year	2012				
Building type	Office				
Building owner	Real Estate				
Building contact person	John White				
Assessment date	20.04.2015				
Inspector name	James Black				
Status of inspection	Preliminary				

POINTS AND CLASS SUMMARY					POINTS	
Section	Description	Importance	Actual Imp.	Norm. Score	Result	<5%
1	Heating control	10	10.00	96.30	**18**	
2	Domestic hot water supply control	2	2.00	100.00	**4**	
3	Cooling control	10	10.00	97.55	**18**	
4	Ventilation and air conditioning control	10	10.00	96.75	**18**	
5	Lighting control	5	5.00	100.00	**9**	
6	Blind control	5%	0.00	0.00	**0**	
7	Technical building management	10	10.00	100.00	**19**	
8	eu.bac Key Performance Indicators	5%	2.70	2.44	**0**	
9	eu.bac Extended Functionality	5%	2.70	70.18	**4**	
10	eu.bac Certified Products	3%	1.62	0.00	**0**	
NORMALIZED TOTAL (0-100)			54.02		**89**	
			eu.bac System (E–AA):		**AA**	

DECLARED BUILDING AREA	
Total room area (m2)	6,008
Supervised area by TBM (m2)	6,008

Compare

Print Report

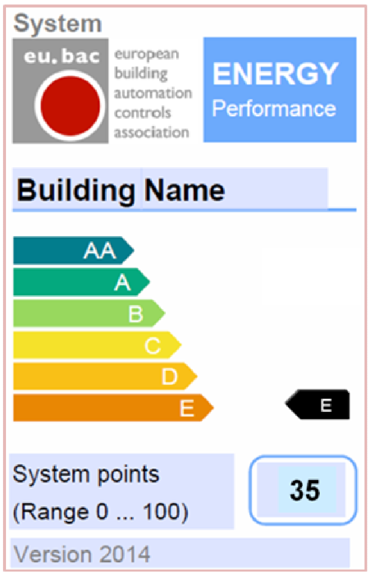
Send Report

INFORMATION MISSING?			Errors?	
SUMMARY	NO			
AHUs	NO		NO	
Heating	NO		NO	
Cooling	NO		NO	
Rooms	NO		NO	
DHW	NO		NO	
TBM	NO		NO	

Figure 5: eu.bac System audit checklist summary (Source: eu.bac, 2015)

eu.bac Label and Classification System

eu.bac established the AA/A/B/C/D/E classification scheme for all eu.bac related product certifications as well as the eu.bac System certification with the AA rating being the best. The eu.bac certificate and allocation of points to the corresponding levels is depicted below:



Level	Points
AA	85-100
A	75-84
B	65-74
C	55-64
D	45-54
E	0-44

Figure 6: eu.bac System label (Source: eu.bac, 2015)

The eu.bac System Label assures the BACS has been assessed according to EN15232 and highlights the potential to control the building systems in the most energy-efficient way.

Based on the calculation methods described in EN 15232 [1], conclusions can be drawn regarding the potential for energy savings. An improvement of 10 points corresponds to energy savings of approximately 5%. These values, of course, depend very much on the individual object to be evaluated and should be considered as reference values.

The eu.bac label sustains the energy-efficient control of building systems. The certificate is valid for 3 years. Subsequent recertification will be required in order to keep or improve the given rating. When KPIs have already been in use the recertification would focus only on identified deficiencies and on areas where modifications to the building or the BACS have occurred.

eu.bac System Key Performance Indicators (KPIs)

The eu.bac method includes continuous, automated evaluation of key performance indicators (KPIs) which prove that the building systems are controlled at their most sustainable energy-efficient level while maintaining indoor comfort closely related to building occupants' satisfaction, health and productivity. The kPIs are self-adapting to modifications in operational parameters, e.g. if the operator changes the temperature setpoint, the kPI using this value in the calculation will adapt automatically the allowed deviation within a defined range.

eu.bac System KPIs detect any deficiencies in the control of energy-consuming technical equipment in the building. A simple traffic light evaluation (green, yellow, red) allows first level diagnostic without consulting complicated trend curves.

Example KPI

KPIR.c:	Room / Zone air temperature (heating comfort supervision)
KPI explanation:	Detects “temperature” condition (e.g. overheated) of room/zone – in relation to actual set point (+ 0.5 K) and “heating controls output > 0”
KPI function:	= (PIRh.i + PIRh.j) / PIRh.a

Daily evaluation:
- green: value ≤ 0.1
- yellow: value between "> 0.1 and ≤ 0.2"
- red: value > 0.2

KPI Evaluation: Number of days where ((daily values > 0.1) > 20% of supervision period

- red = number of days > 20% of supervision period
- yellow = number of days > 10% of supervision period
- green = else ();

The key performance indicators enable ongoing assessment of the performance of the building automation system and its components. With the help of these indicators, operators can detect and optimise settings that differ from actual requirements. For energy consultants, they also constitute a reliable data source and are the basis for energy optimisation. The basic principle here is: The greater the level of instrumentation and the finer the resolution, the more accurate the information, the more precise the control of the indoor environment; the more individual control the occupant has on his/her immediate environment.

Building lifecycle

The eu.bac System method supports energy efficiency goals through all building phases. eu.bac audits help save energy and reduce operating costs and ensure efficient and sustained operation throughout the entire life cycle. The installed BACS functionality is checked periodically. In this way, deviations from design during commissioning or deviations from current requirements can be identified, allowing corrections to be made.

The entry point to apply the eu.bac System method could be anywhere in the life-cycle for new or existing buildings as depicted in the next figure.

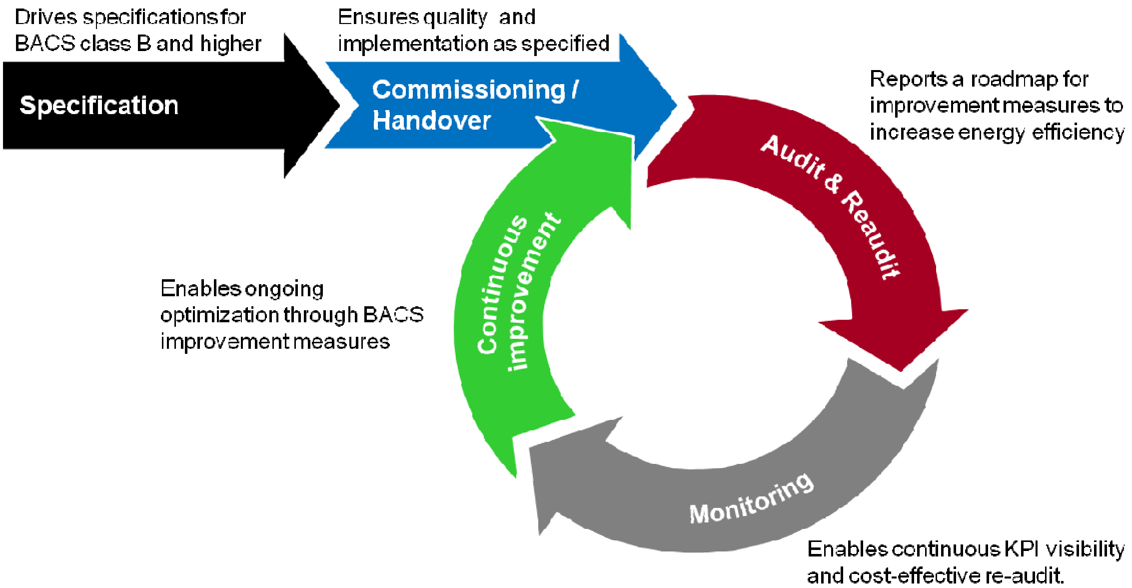


Figure 7: eu.bac System for new and existing buildings (Source: eu.bac, 2015)

In design phase, the eu.bac System method supports best possible specification of BACS through the selection of building automation and control functions according to their targeted impact on the building's energy efficiency performance. During commissioning and handover, the functionality of the installed BACS is uniformly documented, and the proof of "as designed" functionality is provided. In existing buildings, the periodical structured evaluation of current functionality enables sustainable operation through recording of energy savings potential and continuous monitoring and adaptation.

Benefits

The energy efficiency gains supported with a higher eu.bac System rating throughout the building life are depicted in the following figure. For instance, if the installed BACS in a building has the standard class C, recurring eu.bac audits combined with proper maintenance would sustain the energy-efficient control in the building according to this installed BACS level. If, however, the BACS would be upgraded to a higher class, this would enable a substantial reduction in energy consumption.

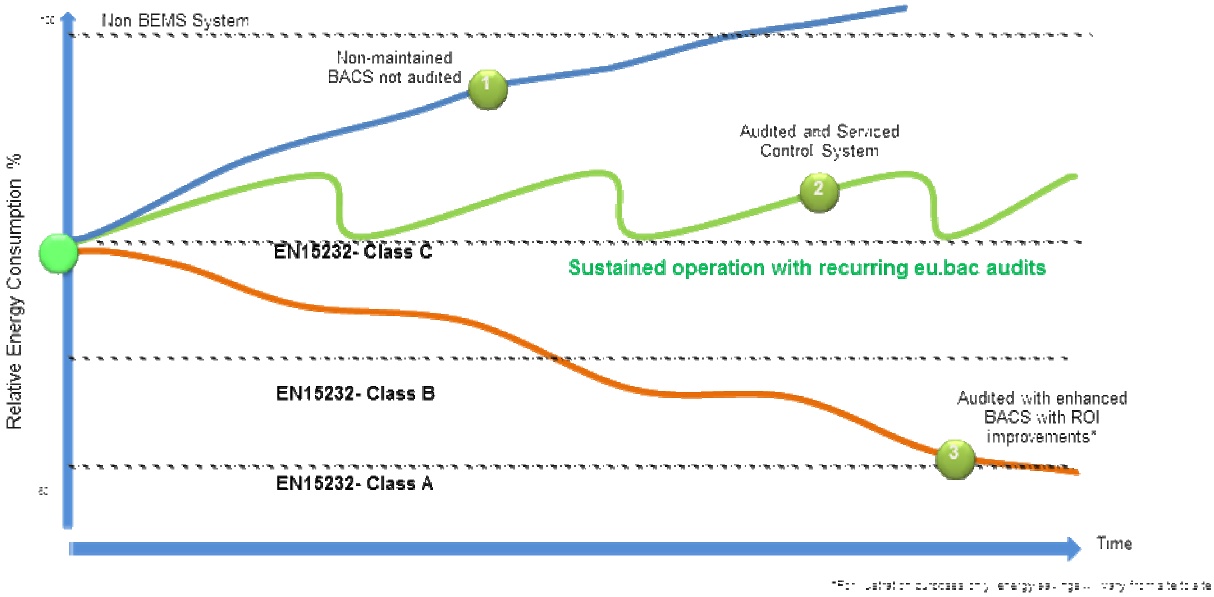


Figure 8: eu.bac System audits sustain the energy-efficient control of building systems (Source: eu.bac, 2015)

In summary, the major stakeholders within the building industry could expect the following main benefits of using the eu.bac System method:

Building Owner - Operator

- increased building value through best practice energy-efficient control solutions
- reduced operating costs through ongoing improvements and re-certification
- maximized tenant retention and rental through good maintenance practices

Engineering Consultants

- a tool to design and simulate best practice efficient control strategies according to EN15232
- eu.bac audits as additional consulting services to validate BACS effectiveness
- assistance in identification of optimization measures

System Installers – Maintenance Providers

- transparency that BACS is installed effectively to EN15232
- regular audits and implementation of recommended improvements
- prove ongoing energy efficiency

Current market introduction

eu.bac audits have been conducted in over 100 buildings throughout Europe. There are trained eu.bac Auditors in Germany, France, United Kingdom, Switzerland, Spain, Austria, Italy, Belgium, Denmark and Turkey. eu.bac System Partners, such as VDMA, ACR, BCIA support the local rollout activities including localized Auditor trainings. The following graph shows the distribution of audit results per efficiency level.

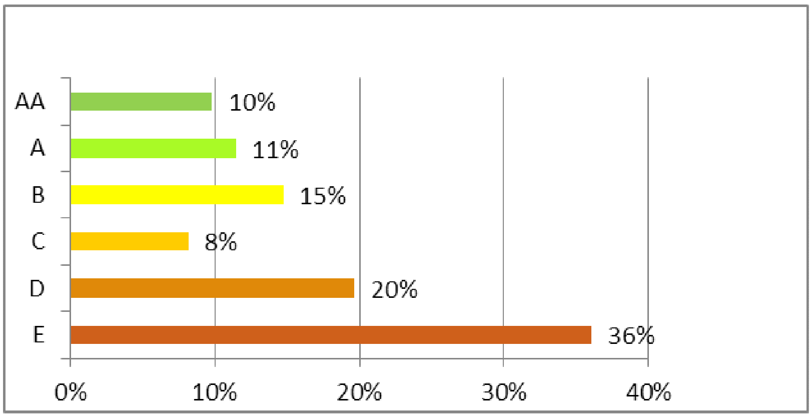


Figure 9: Audit results per efficiency level (Source: eu.bac, 2015)

The results vary from 33 points (label F) to 86 points (label AA). The lowest results come mainly from existing buildings. The high ratings (label A and AA) are achieved in buildings where special attention was paid to sustainability during design and construction. Most of these buildings are also LEED or DGNB certified and attained high ratings under those certification systems as well.

The current status with over 50% of systems being rated below level C indicates high potential for improvement towards better energy efficiency.

Conclusion

Energy reduction in buildings may be achieved by a wide range of engineering approaches, e.g. mixed-mode ventilation, solar heating, 'micro-CHP' and phase-change media for heat or cooling storage. In a modern building with integrated renewable energy systems, the plant will require sophisticated control techniques to achieve efficiency, more akin to automobile engine management than traditional HVAC control sequences.

Building control systems will have to provide holistic control of a building not just in the thermal environment but also in the control of lighting, particularly the balance between natural and artificial light; in adopting increasingly sophisticated techniques for interaction with building occupants; in assisting fault detection and diagnostics through real-time monitoring; in making the building a "smart" element within the Smart Grid and the Smart City.

Well-designed building automation can return control to the users (the ultimate point in recognising the needs of everyone) and can also monitor the way they are doing so and advise them if it could be done better, for example to reduce energy use.

We are in the age of design for a sustainable future. To achieve a sustainable future involves the design of control systems for our buildings and building services so that comfort is achieved with minimum energy. The prerequisite for energy efficiency at a desired level of comfort is an intelligent building automation system that provides the required energy in the right quantity at the right time and at the right place.

State-of-the-art building automation systems enable energy-efficient and sustainable building operation. eu.bac has developed a manufacturer-independent standardised assessment method that can evaluate and classify the extent this capability has been used.

The eu.bac System Method will assure the user a level of performance of their systems, as defined in the EU directives and relevant EN standards. The acknowledgement of the certification is the eu.bac System Certificate that expresses conformity with EU directives, quality EN standards, and the eu.bac System Technical Recommendations. It rates the system efficiency and creates trust and transparency to the benefit of building owners and occupants.

Effective control of the heating, ventilating and air conditioning systems in a building is essential to provide a productive, healthy and safe working environment for the occupants. Without a properly functioning BMS, the activities carried out in the building will be disadvantaged. Along with good building design and efficient HVAC plant, the BACS plays a vital role in the prevention of energy waste and reducing the environmental impact of the building.

If BACS were properly designed, installed, commissioned and operated, making use of all economically viable control-related energy-savings opportunities, the average savings per commercial/public building would be in the order of 37%, or 3.4 GT (gigatonnes) CO_2 by 2035. [4]

References

[1] Energy Efficiency Indicator Survey 2013, Institute for Building Efficiency

[2] eu.bac: www.eubac.org: European Building Automation Controls Association

[3] EN15232:2012: Energy performance of buildings — Impact of Building Automation, Controls and Building Management.

[4] The scope for energy and CO_2 savings in the EU through the use of building automation technology, European Copper Institute, 2014

How can EU policy frameworks best capture the potential for energy savings in the EU through the use of building automation technology?

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Abstract

The potential for energy savings from building automation and controls (BACS) in European service sector buildings has been estimated to be 20.3% of their total energy consumption, equal to 50 Mtoe/year in 2035 and worth €56 bn per annum. These savings are highly cost effective, with savings outweighing investments by a factor ~18, but they do not materialise due to several non-financial market barriers. Despite these, up until recently the topic has had relatively little policy attention.

The launch of the EU's Energy Union strategy and review of the Ecodesign, Energy Efficiency and Energy Performance in Buildings Directives has provided an opportunity to remedy this omission. But what blend of policy instruments is needed to deliver the potential? Can a single Directive be used to meet the needs or is a coherent strategy required, drawing upon policy measures made operable through more than one Directive?

This paper reports the findings of a thorough investigation into these issues. It begins by considering the specific barriers that need to be addressed and then maps these to the articles within the various extant Directives in their current form to see which could be applied to address the constraints. It finds that multiple actions are required to access the savings but they can be broadly categorised into a need to promote greater adoption of BACS coupled with an equally important need to improve the quality of design, installation and operation of the BACS systems. The analysis further finds that at the very least proactive implementation of measures within the Energy Performance in Buildings (EPBD) and the Ecodesign Directives are needed, but furthermore the Energy Efficiency Directive could play a huge role to provide stable finance at scale and to help address quality in the supply chain. Alternatively, the EPBD could be amended (mostly through strengthening the Article 8 provisions on technical systems) to deliver a large part of the savings with complementary support from the Ecodesign Directive. Either way it is clear that much more proactive policy attention is required for these savings to be realised and that a policy development and implementation approach, which breaks down current policy silos will be necessary for success.

1. Introduction

The policy case for taking proactive action on the promotion of effective building automation and controls (BACS) strategies within European buildings is overwhelming and yet the topic has received relatively little policy focus in the EU to date. Recent studies and standardisation efforts [1,2] have found that the potential energy savings from proper deployment and use of building automation and controls are huge and would deliver a sizable contribution to the EU's broader energy, climate and socio-economic policy objectives.

In particular, action on making the current policy frameworks more supportive of unlocking the large-scale savings of BACS contributes to several dimensions of the Commission's Energy Union strategy:

- Energy security: if the savings from BACS would be realised today, they would improve Europe's energy independence by 3 to 5 percentage points, from currently 49.5% to 53-55%.
- Energy efficiency and moderation of demand: the savings potential from BACS equates to a 15-22% reduction in the total energy consumption in European buildings.

Furthermore, the above savings are highly cost-effective, with estimated benefits being ~18 times higher than costs for service sector buildings (and ~9 times, but for residential buildings), and thus clearly merit consideration in the context of the EU's Efficiency First[1] principle.

Even more significant are the potential contributions towards climate change mitigation. More effective BACS strategies across all EU building types are estimated to offer annual emissions reduction

[1] The 'Energy Efficiency First' principle is set out in the Commission's Energy Union text [3]

potential of from 260 to 419 million tons of CO_2 by 2028 as a result of reducing Europe's demand for fuel combustion by from 8-13%.

Realisation of these savings are estimated to result in the creation of between two and three hundred thousand direct jobs by 2030 across the EU. Many of these jobs will be for trained installers, for whom it will be necessary to establish competence requirements supported by accreditation and certification. In addition, up to further 3.7 million of indirect jobs would be created (1.1% of EU GDP saved and reinvested in other sectors with average employment rates per unit of GDP) [4].

Given the tremendous scale and multiple win nature of this value proposition it is appropriate to explore what policy frameworks are needed to realise the potential from BACS and how this fits with the existing EU policy structures.

2. Value Proposition of Building Automation and Controls

2.1 Scope of current technologies

Modern building automation technology brings the electromechanical hardware of sensors, actuators and thermostats together with information and communication technology ICT hardware such as controllers/outstations, programmers and central facilities such as personal computers (PCs) and data displays. Collectively these can be combined with appropriate software to provide building energy management systems (BEMS) for service sector (non-residential) buildings; however, it is important to understand that varying degrees of integration and sophistication are used and that the most appropriate system will vary in response to the building and usage characteristics. In this paper we use the term BACS when referring to the overall suite of BAT/BEMS solutions. Its important to understand though that effective BACS can be quite simple, for example, the more spaces where the demand for heat delivery is sensed and controlled individually – rather than as an aggregate – the greater the savings. The same systems should also employ optimum start and weather sensing to avoid heating coming on unnecessarily early or staying on too long. The same principles are used in service sector building systems but will be more complex and will also control all other energy using functions (lighting, HVAC, hot water, etc.).

2.2 Vast untapped energy and GHG emission saving potential

According to a recent study [1], greater adoption and improved operation of building automation technologies and controls (BACS) across all EU building types could progressively result in estimated savings of up to 150 Mtoe (1,745 TWh) per year by 2028. This is 22% of all building energy consumption and ~9% of total final energy consumption of the entire European Union. Furthermore it corresponds to an abatement potential of up to 419 $MtCO_2$ per year.

For service sector buildings alone, the potential annual energy savings peak in 2035 at 49.7 Mtoe (578 TWh), which is 20.3% of all EU service sector building energy consumption. The cumulative savings potential in final energy consumption is 742 Mtoe by 2030. This is 14.8% of the cumulative service sector building energy consumption and corresponds to an abatement potential of up to 140 $MtCO_2$ per year.

However, this Optimal Scenario is predicated on a rational and perfectly functioning market, where all cost-effective energy savings opportunities are invested in and without serious constraints to effective service delivery. In a more realistic depiction of the potential to deliver additional savings beyond business-as-usual, savings ramp up progressively to reach 13% of the building energy consumption by 2035 – still over 5% of the European Union's entire energy consumption. For service sector buildings, annual energy savings peak in 2035 at 40 Mtoe, which is 16.5% of all EU service sector building energy consumption. This latter Realistic Scenario assumes that all the recommended actions outlined in the study are implemented and that BACS are procured, installed and operated accordingly, see Figure 1.

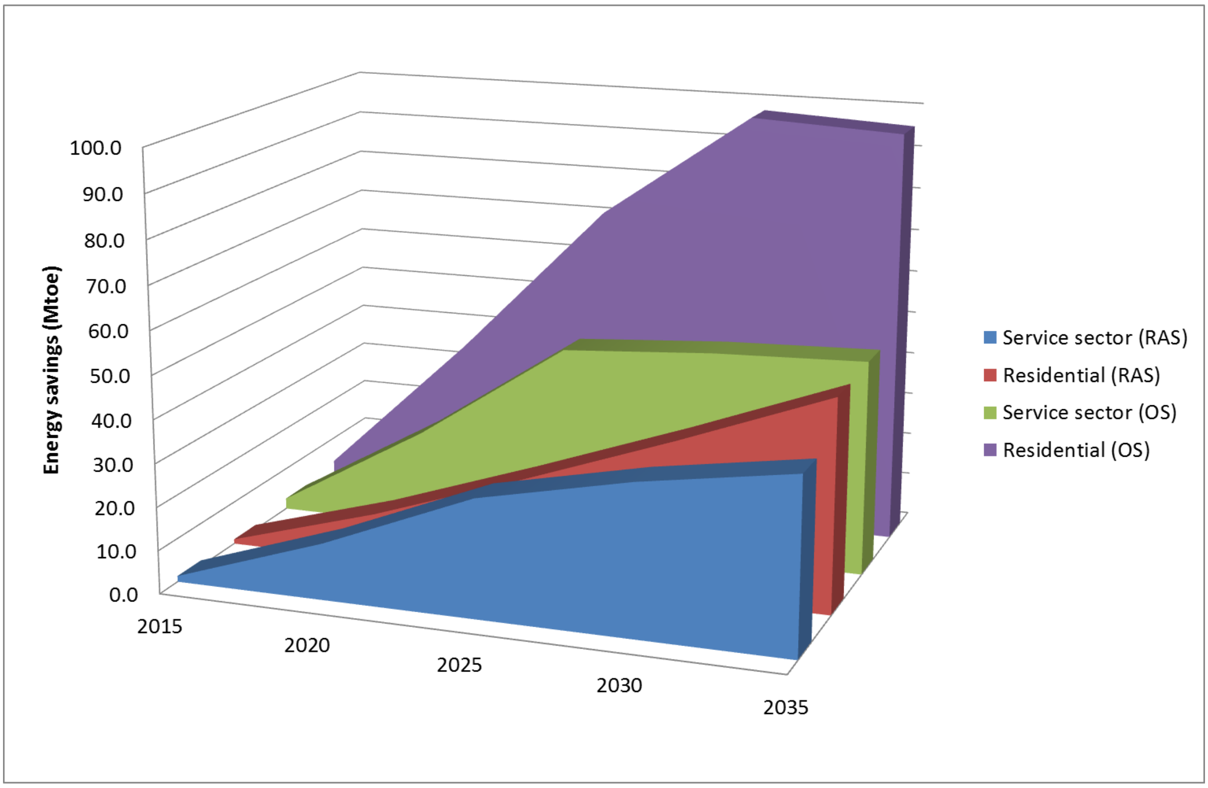

Figure 1. Building energy savings under the Recommended Action Scenario (RAS) and Optimal Scenario (OS) for European residential and service sector buildings compared with the Reference Scenario

These two scenarios lead to from 1,000 to 2,100 Mtoe of cumulative energy savings to 2035 compared to a business as usual scenario. This equates to estimated cumulative CO_2 savings of from 3.4 to 5.9 gigatonnes over the same period, with annual CO_2 savings peaking at between 260 and 419 million tonnes.

Over the scenario period (2015−2035) of the Optimum Scenario, some €192 billion of extra investments in BACS and related services are needed to deliver these savings, at an average of €9.6 billion per year across all building types. Large as these incremental investments are, they are nine times less than the value of the resulting savings in energy bills, which total €2 088 billion over the period, at an average of €104. billion per year. Over the same scenario period for the Realistic Scenario, some €136 billion of extra investments in BACS and related services are needed to deliver these savings, at an average of €6.2 billion per year. These incremental investments are almost 11 times less than the value of the resulting savings in energy bills, which total €1 187 billion, at an average of €53.9 billion per year.

To comprehend the scale of the opportunity it is informative to compare the value proposition of building automated technology and controls with other means of delivering energy services which already receive strong support from EU Member States (MS) and the Commission.

EU Member States are required to ensure the implementation of smart metering under EU energy market legislation in the Third Energy Package. MS are currently rolling out smart meters with an average 3% energy saving per installation[2] at a projected investment cost of €55bn by 2020 for a

[2] To date, Member States have committed to rolling out close to 200 million smart meters for electricity and 45 million for gas by 2020 at a total potential investment of €45 billion. By 2020, it is expected that almost 72% of European consumers will have a smart meter for electricity while 40% will have one for gas.

While cost estimates vary, the cost of a smart metering system averages between €200 and €250 per customer and are expected to deliver benefits of €160 for gas and €309 for electricity per metering benefit of €69bn, which equates to a benefit-cost ratio of 1.25. By contrast it is projected that were there to be a broad-based EU-wide deployment of good quality building automated technology and controls in EU buildings that the expected savings would amount to €1,187bn by 2035 for an investment of €136bn [1]. This amounts to average savings of ~20% per installation and gives a benefit-cost ratio of 8.7, i.e. seven times greater than for smart meters.

With support from the Renewable Energy Directive the EU Wind Energy Association estimates that wind power capacity installed by the end of 2014 would, in a normal wind year, produce 284 TWh of electricity, enough to cover 10.2% of the EU's electricity consumption[3]. The average cost of generation is ~€5.6c/kWh[4]. By contrast a large scale roll out of good quality building automated technology and controls is projected to deliver energy savings equivalent to 5.2% of EU total energy consumption by 2035 at an average cost of €1.1c/kWh-saved[2]. Even were it to be assumed that all these savings were for thermal energy and a primary to final energy factor of 2.5 to be applied to the value of wind power, the equivalent cost of wind generated energy would be over twice as high as the projected cost of energy savings through building automated technology and controls.

2.3 Cost Optimality and Quick Wins

Detailled analyses have shown that BACS solutions are among the set of cost-optimal measures that will produce economically viable energy savings, almost independently of the quality of the building envelope and the occupant user profile. In service buildings, energy consumption reductions by 10, 20, or even more than 50 percent are reported [5]. These assessments show that enhancing the automation, control and supervision functions in a building with one efficiency factor level (as defined in EN 15232 [2]) will often improve the Energy Performance of Buildings Directive (EPBD) building energy performance certificate (EPC) classification by one class. However, few of the Member States cost-optimality submissions to the EPBD for the derivation of cost optimal building codes have included any proper assessment of the opportunities presented by BACS – rather, very aggregate numbers have been used if at all.

On top of being a cost-optimal measure, BACS require relatively low investments and can be implemented without the need for the building to be taken out of service. Building owners that find themselves constrained to postpone major energy-related renovations (for reasons of occupation or budget constraints), can already benefit from investing in improving the operation efficiency of their energy services equipment. These BACS will still provide a valuable function and deliver energy savings if at a later stage the owner decides to completely renovate the building envelope. Importantly BACS provide a cost-optimal option whenever the envelope cannot be transitioned to state-of-the-art performance levels, for example when cultural of historic factors prevent intrusive actions.

3. Problems and barriers to savings from BACS

3.1 General problem

Ineffective control of energy-using systems such as heating, cooling, ventilation and lighting is endemic in Europe's buildings. Spaces are heated when it is not necessary, lighting is left on, ventilation operates continuously at maximum capacity, etc. The resulting energy wastage is vast, and thus a considerable potential for savings is presented.

In principle, modern building automated controls comprise a significant part of the solution, providing the possibility to control each of these elements individually and as a whole. Furthermore, they can

point with, on average, 3% energy savings. Source: Cost-benefit analysis and state of play of Smart Metering Deployment in the EU-27, Commission Working Document S WD(2014) 189 final, http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1403084595595&uri=SWD:2014:189:FIN%20

[3] This is about 3.6% of EU primary energy consumption assuming a 2.5 final to primary energy conversion factor

[4] Figures taken or derived from the European Wind Energy Association statistics for 2014, http://www.ewea.org/statistics/

respond to demand (need), and via ICT they can analyse building energy-using systems, diagnose problematic control issues as they occur and make intelligent responses to rectify them.

This is the promise − but reality has yet to match it fully. On average, building automated control technology when it is deployed saves much less than it should on account of numerous design, installation, commissioning, monitoring and operational failures. There are a variety of reasons for this, but the key theme is the need for control solutions that work better with people and the way they use and operate buildings.

3.2 Specific problems

Analysis conducted in support of this paper has identified various market barriers and failures that limit the opportunity for effective BACS adoption in both residential and service buildings. Moreover, most BACS that are installed are poorly managed and not working as well as they should, such that overall it is thought that about 90% of commercial and public building floor space is inadequately or poorly controlled. It is important to appreciate that these two problems are related, since disappointing quality and reliability does not build confidence in the value proposition of BACS and is therefore a barrier for uptake in its own right.

Market barriers and failures affecting BACS uptake

The building services controls industry in Europe has developed relatively slowly compared with other industries that use microprocessor-based technologies and communications. This is due to a number of reasons, of which the principal ones are:

- A lack of general awareness, understanding and appreciation of the options and the value proposition of BACS
- Slow response from HVAC equipment manufacturers to incorporate advances into their packaged controls and communications
- A lack of common standards enabling building management systems (BMS)/BEMS suppliers to develop more universal products
- A poor standard of client briefing and technical specification, resulting in lowest-cost solutions regardless of the effect and leading to selection on the basis of lowest capital cost rather than highest value in operation
- The economic situation depressing demand, although perversely the economic situation would result in greater uptake of BACS if clients were aware of the cost-benefits that can be achieved

Poor quality of the delivered savings

BACS often fail to deliver their full potential because those specifying the system have limited understanding of how it will be operated and have little experience of operating the systems they have specified. In general, there is a need to move to a market where consultants, contractors and suppliers are selected on the basis of their ability to demonstrate that they understand how the BACS will be used in operation, rather than just on their design experience.

Problems may arise because of:

- An inadequate potential for the building energy system to be properly controlled, i.e. the system is not controllable
- The different control systems applied to specific components or elements not always being interoperable and having conflicting control regimes
- The wide range of user interfaces available, and situations where users have no access to the control systems, often resulting in systems being overridden manually

These problems are compounded by a lack of appropriate training for building operations and maintenance teams with respect to the operation of building service engineering systems and the BACS that are intended to control and monitor them.

Addressing these issues is not principally a hardware issue: in many cases, especially for the more complex non-residential buildings, the whole manner in which controls are procured, designed and specified, installed, commissioned and managed within building services is in need of improvement, with the right incentives to deliver appropriate technical and organisational capacities, resulting in better facilities management for energy efficiency. The effective deployment of controls will thus be as much an organisational challenge as a technical challenge.

Integrated design

There is a division between HVAC design and electrical design in some European countries, e.g. Germany. If the design engineers and consultants for HVAC design and for electrical design do not work together on the specifications it may not be possible to specify BACS that fulfil the holistic approach set out in EN15232. BACS at room automation level combines the control for HVAC and electrical controls and need to work in an integrated manner.

3.3 Drivers for the problem

Efficiency efforts are focused on building fabric and installed equipment, not control

Energy renovation of existing buildings is not an easy task. Buildings, and the stakeholders involved with them, are complex. This introduces additional barriers beyond those that would apply to the adoption and use of any standard energy-efficient product. Split incentives may separate the economic incentive for energy savings from those that procure services. These split incentives move the focus for renovations towards improving the efficiency of the building fabric and the installed equipment and may neglect the real energy performance of the building in use.

Poor implementation often goes undetected

For example, if heating and cooling set-points are too close, such that air conditioning cools a space while it is simultaneously being heated, users will not necessarily be aware of what is happening and are unlikely to complain unless thermal comfort is also affected. This all-too-common situation illustrates just one of the many implementation and operational failures that can occur and remain undetected with building energy controls, no matter what their degree of sophistication. Monitoring real performance and running diagnostics to detect faults and waste is a key need, requiring both

(i) the installation of appropriate technology and

(ii) the organisational structures and capacity to monitor faults and follow up with remedial action.

The process of continuous commissioning, one example of the type of structures that are needed, implies a more profound service delivery than the simple installation and commissioning of building automated controls.

4. Trends and policy objectives

4.1 Market trends

Penetration of modern BACS and management systems is projected to rise from 26% of all service sector floor area today to 40% by 2028 without further policy intervention. This business-as-usual scenario leaves a vast potential of energy savings and CO_2 emission reduction untapped.

4.2 Gaps in the existing policy framework

There are many gaps in the existing policy framework that could be addressed to help realise the potential savings from effective BACS implementation and uptake. The focus of this analysis is on the Directives which most concern BACS and/or are under review, namely: the Energy Performance of Buildings Directive (EPBD), the Energy Efficiency Directive (EED), and the and Ecodesign Directive (ED). Overall the analysis shows that the existing EU policy framework contains plenty of levers and opportunities that could be applied to the promotion of BACS and that could treat almost all the ideal policy package needs. In practice though very little of this has actually been applied to the realisation of cost effective savings from BACS.

This is mostly because these policy levers are aimed at addressing a number of horizontal energy savings opportunities of which BACS is but one (albeit one with a very large unexploited savings potential). In principle the approach taken with the existing measures might appear to make sense i.e. a policymaker might ask why one should be prescriptive about the means of reaching a savings objective if any number of measures are eligible and could meet the objective. However, the reality is that the vagueness about how to address the savings coupled with the lack of appreciation of the scale of opportunity posed by BACS means that the topic simply hasn't received the attention it deserves, neither in Community-wide policy packages nor in Member States implementation plans.

5. Policy options

5.1 An ideal policy framework for BACS

An ideal policy package on the one hand needs to drive demand for effective BACS installations to overcome market barriers and failures. On the other it needs to stimulate improvements in the practical design, specification and operation of BACS to ensure they deliver the savings potential in practice. It is important to appreciate that these two aspects are related, however, as addressing the quality and reliability of savings delivered through BACS will also help drive future demand by building market confidence in the value proposition of BACS. There is therefore a feedback between these two objectives.

5.2 The objectives of an ideal policy package

Table 1 summarises the needs that the ideal policy package needs to address as identified in the barrier and needs analysis.

Table 1 - Measures needed to support energy savings from BACS within an ideal legal framework

Enhancing visibility	a) Standardisation - ensuring currency and adequacy of all BACS technical and professional standards b) Product labelling based on quality/functionality and whether or not performance is certified so that no controls system can be installed without the procurer knowing its impact on the building energy performance and the potential to save energy from adoption of the best BACS systems and that no building ownership/occupation transfer can occur without the impact of the BACS being made clear to the new party c) Accreditation & certification of services - giving visibility/recognition to high quality BACS services (design, specification, installation, commissioning and re/continuous commissioning)
Promotion of awareness and value proposition	Awareness raising among: Policy makers (at EU and Member State level), Facility Managers, Building owners, Company boards, Building Services Engineering sector
Capacity building	a) training and certification of accredited controls engineers b) development of continuous commissioning markets for more complex buildings and portfolios c) development of continuous/regular re- commissioning services
Enhancing useability	a) ensuring controllability of HVAC, lighting b) ensuring interoperability of all HVAC, lighting and controls c) ensuring user friendliness of BACS d) ensuring products are available for all needs e.g. that are sympathetic with traditional building furnishings and styles as well as modern systems

	e) ensuring products/services include automatic failure alerts (e.g. simultaneous heating/cooling of the same space) f) improving the automatic diagnostic capabilities of BACS and the systems they are designed to operate
Minimum requirements	a) ensuring that the BACS in all new build, major renovation or replacement of the BACS meet minimum energy performance requirements b) ensuring BACS professional parties meet minimum quality requirements
Funding, finance and incentives	a) Ensuring adequate programmatic funding is available to fund all the programmatic activity needed (i.e. the steps outlined above) b) Ensuring incentives and finance are in place to raise capacity in the BACS supply chain c) Ensuring incentives/finance mechanisms of an adequate scale are in place to help remove the incremental first cost barrier associated with good quality energy savings BACS equipment and services - at least in early years of market development

5.3 Measures to drive demand

Driving demand can be done through a mixture of mandatory provisions, procurement specifications, incentives and awareness raising measures, see Table 2. Demand can also be raised by improving the reliability of delivered savings which is addressed separately in the next paragraph.

Table 2 – Measures to drive demand

Mandatory measures	• Building codes • Ecodesign regulations • Energy performance certification • Mandatory inspections • Sub-metering or monitoring requirements • Professional qualification requirements • Installed system requirements
Incentives	• Support through utility EE financed programmes • Tax incentives • Direct state incentives
Procurement specifications	• Binding public sector requirements • Strong encouragement for private sector requirements
Awareness raising	• National/EU communication campaigns • Professional services networks • Corporate sustainability reporting (CSR) networks

5.4 Measures to improve the quality of delivered savings

Equally important to measures aimed at driving up demand are those aimed at improving the reliability of savings from BACS. Indeed the two are strongly related as the autonomous market demand for

BACS will rise if the quality (reliability) of assured savings increases. Part of the process to raise the quality of delivered savings through BACS involves measures to raise the technical capacity of those involved in the supply and delivery of the savings i.e. of: the BACS systems specifiers, the HVAC and lighting systems specifiers, installers, commissioners and operators (e.g. facility managers). Just as important are the management cultures and systems put in place among end-using facilities. In order for investment in such services to increase, however, the value proposition of investing in a reliable system to manage and verify energy savings through BACS needs to be clearly articulated among decision makers so that sustained resources are made available to ensure this occurs. Addressing the organisational cultural challenge this implies is therefore also a key need. Policies are required that will help address these issues as summarised in Table 3.

Table 3 – Measures to improve quality of BACS energy savings

Trouble shooting	• Continuous commissioning • Regular audits • Improving automatic diagnostics
Certification	• of BACS components and systems • of specifiers and installers
Training	• of facility managers • of building service engineers
Increase organisational prioritisation	Raising awareness: • of the value proposition of BACS including at board level • of the need to monitor and verify actual performance
Strengthen standardisation	• Complete standards and check/improve applicability • Increase usability and awareness of the standards

6. Leveraging the existing EU policy frameworks

There are four EU Directives that address energy efficiency (Figure 2). All four of these Directives have either undergone a recent review (Edodesign [6] and Energy Labelling Directives) or are currently under review (Energy Performance in Buildings Directive [7] and the Energy Efficiency Directives [8]). This section summarises the relevance these policy instruments have for the promotion of energy savings via BACS, identifies gaps that could be addressed to promote the effective use of BACS and makes recommendations on each.

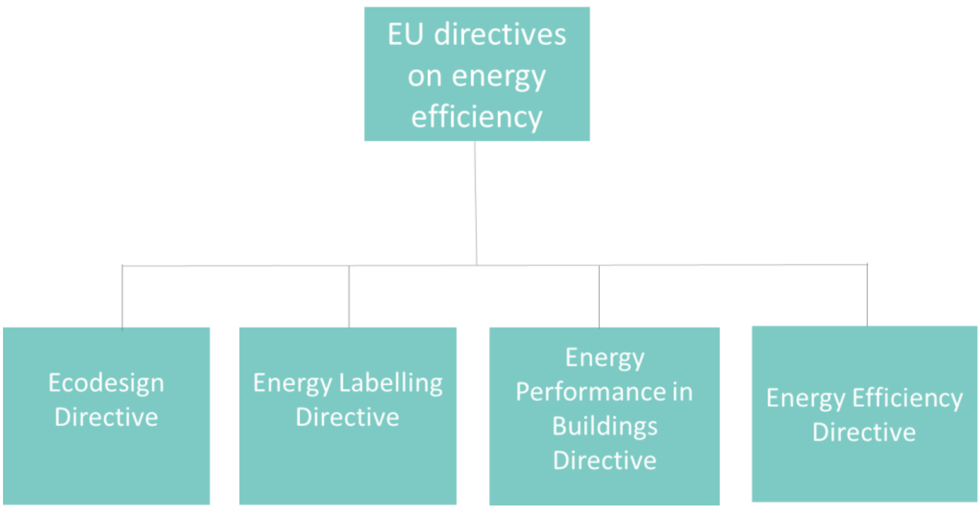

Figure 2. The four EU energy efficiency Directives

6.1 Energy Performance in Buildings Directive (recast)

Provisions for BACS in building codes

Analysis of national building codes indicates that a blend of overarching whole building energy performance requirements combined with minimum functionality prescriptions for individual BACS options will result in surer delivery of cost-effective energy savings from BACS than simply relying on a whole building energy requirement; however, most current codes in the EU do not set specific requirements for BACS. This is despite the provisions of Article 8 of the EPBD which specifies that Member States (MS) should develop requirements for technical building systems and specifically mentions (a) heating systems; (b) hot water systems; (c) air-conditioning systems; and (d) large ventilation systems. BACS are not specifically mentioned in this list but rather the article states "Member States may furthermore encourage, where appropriate, the installation of active control systems such as automation, control and monitoring systems that aim to save energy". Thus while MS are required to specify measures for the building energy systems that BACS control they are not for the BACS themselves. For this reason and the fact that the value propostion and regulatory options are not sufficiently well-known and explored probably explains why very few MS have currently set BACS requirements in their buidling codes.

Cost optimality assessment

As for the cost optimality assessment process in the EPBD, case studies conducted to support the analysis behind this paper clearly show this method is currently not being applied properly by MS and as a result cost-effective energy savings options using BACS are either not being considered at all when assessing the cost-optimality of energy performance codes or are being aggregated with other options in such a way that the true benefits are not properly accounted for. This results in both, a reduced appreciation of how much BACS can contribute to energy savings objectives and in sub-optimal building codes. Both issues should therefore be addressed in future cost-optimality assessments.

Energy Performance Certificates

It should be viable to determine Energy Performance Certificates (EPCs) both through asset and operational ratings and then use the difference between the two to determine the adequacy of the control strategy once occupancy effects are accounted for. If a large gap is found (i.e. the operational rating is significantly worse than the occupancy adjusted asset rating) it would imply a failure in the control strategy. Several MS already use EPC determinations based on both asset and operational energy ratings so in this case it would be a simple step to add this additional aspect. This in turn would allow direct recommendations to be given to the building owner/occupiers with respect to the control strategy. At present this is a very limited, or non-existent, focus of the recommendations given via the EPCs of how to improve building energy performance via BACS so there is clearly an opportunity to improve the quality and usefulness of the EPCs in this regard.

Financial Incentives and Market Barriers

Without having assessed each of existing MS schemes in detail the evidence indicates:

- There is a patchwork of incentive schemes in place and many EU states have no measures
- The scope of application of the existing schemes varies considerably in terms of building types so that very few economies have measures in place for all types of new and existing buildings
- The scope of application with respect to BACS is often (usually) unclear and would require a more detailed investigation to assess; however, many of the schemes would appear not to apply to BACS
- None of the schemes are explicitly targeted at BACS as their primary focus.

Recommendations on how MS should implement the EPBD with respect to BACS

Given the above it is recommended that EU Member States:

a) Ensure whole building (new build or renovation) energy performance requirements are complemented by minimum requirements for BACS to ensure that building services are deploying cost-effective control strategies

b) Ensure BACS are included in the calculation of whole building (new build or renovation) energy performance in a sufficient level of detail to capture the diversity of outcomes and to reward good practice so that their contribution can be properly accounted for in delivering prescribed whole building or renovation performance levels

c) Ensure BACS are also properly taken into account in the determination of rankings for energy performance certificates and that BACS options are included and proposed among the set of options recommended to improve performance

d) Ensure that the cost optimal methodological assessment used to define or justify the codes in place includes a proper assessment of BACS differentiated by their various levels of functionality and that these are not aggregated with other options that might be less cost effective to implement

e) Consider amending the application of EPCs to analyse the difference between asset and operational ratings and using this to provide direct guidance on the need to improve the BACS/control strategy (as discussed in the EPC section above)

f) Consider the implementation of targeted BACS financial support mechanisms under the auspices of Article 10 on financial incentives (if not through this then through the EED Article 7 – see below)

g) For those MS that are implementing the alternative compliance pathway to Article 14 on Inspection of Heating Systems and Article 16 on Inspection of Cooling Systems consider the development of BACS deployment and quality support mechanisms as a low cost altervative to achieve equivalent savings.

How should the Commission implement the EPBD with respect to BACS?

Most of the potential power of the EPBD to produce cost-effective savings through BACS is currently untapped. To help address this it would be helpful were the Commission to:

a) Encourage MS to complement whole building (new build or renovation) energy performance requirements with minimum requirements for BACS to ensure that building services are deploying cost-effective control strategies. This could be done through strengthening the Article 8 requirements on technical building systems.

b) Ensure BACS are included in MS calculations of whole building (new build or renovation) energy performance in a sufficient level of detail to capture the diversity of outcomes and to reward good practice so that their contribution can be properly accounted for in delivering prescribed whole building or renovation performance levels

c) Encourage MS to take BACS properly into account in the determination of rankings for energy performance certificates and to include BACS options among the set of options recommended to improve performance

d) Ensure that the cost optimal methodological assessment used to define or justify the codes at MS level includes a proper assessment of BACS differentiated by their various levels of functionality and that these are not aggregated with other options that might be less cost effective to implement

e) Develop guidelines regarding the design of programmatic actions to stimulate savings through BACS as an alternative means of complying with Article 14 requirements

f) Develop guidelines on how best to treat BACS within EPCs

g) Encourage MS to consider partially satisfying Article 10(2) requirements regarding financial support measures with measures that target effective BACS deployment

h) Encourage MS following alternitive compliance pathways to the inspection of heating and coolling systems under Article 14 and 15 to develop BACS support mechanisms that aim to achieve (at least) equivalent energy savings

i) Encourage MS to amend their application of EPCs to analyse the difference between asset and operational ratings and using this to provide direct guidance on the need to improve the BACS/control strategy (as discussed in the EPC section above). If necessary, trial this concept and support the development of analytical tools to support this process.

In general it can be said that while provisions requiring the use of adequate controls in new buildings and renovations are necessary to stimulate uptake of energy-saving controls, there needs to be much greater reflection regarding how they should be framed and specified to ensure that they are clear, usable and encourage good practice. It is therefore recommended that an expert task force be established to prepare guidelines on these specifications and to review/critique existing specifications. To ensure that the recommendations reflect real application, the task force should include review from practitioners who would be expected to use the requirements and not just from experts in the control industry or researchers. Once clarity on the optimal regulatory specifications has been established, EU Member States should move to implement them fully in their building codes and to monitor implementation experience to ensure desired results are being achieved, making informed adjustments if not. The European Commission could facilitate coordination of this process.

6.2 Energy Efficiency Directive

The EED has a great many articles that could be applied to strongly promote energy savings through BACS. However, at present there is very little evidence in MS submissions via the National Energy Efficiency Action Plans (NEEAPS) or other documents that they are applying these provisions to the realisation of savings through BACS. In particular, the provisions for Energy Efficiency Obligation (EEO) schemes under Article 7 could be implemented to provide the necessary funding for training, certification/accreditation and for BACS deployment.

Article 7 on Energy Efficiency Obligation schemes

Article 7 specifies that Member States:

- shall set up an energy efficiency obligation scheme to ensure that energy distributors and/or retail energy sales companies achieve a cumulative end-use energy savings target by 31 December 2020, at least equivalent to achieving new savings each year from 1 January 2014 to 31 December 2020 of 1.5 % of the annual energy sales to final customers of all energy distributors or all retail energy sales companies by volume, averaged over the most recent three-year period prior to 1 January 2013
- may exclude from the calculation all or part of the sales, by volume, of energy used in industrial activities listed in Annex I to Directive 2003/87/EC; and transport fuels
- may allow savings achieved in the energy transformation, distribution and transmission sectors, including efficient District Heating/Cooling infrastructure, or due to individual actions implemented since 31 December 2008 to count towards the target's attainment
- shall publish the energy savings achieved by each obligated party annually

This is probably the most promising EU policy instrument that could be apllied to help fund the deployment of good quality BACS and also provide funding for strengthening of the supply chain (i.e. funding for accreditation and certification schemes for professionals involved in the specification, installation and commissioning of BACS). This is because BACS would constitute one of the most cost-effective means of meeting the energy savings requirements and becasue funding through EEOs is recovered through the energy tariffs and hence is independent of government budget allocations and taxation. Thus, while Articles 10, 14 & 15 of the EED could be used to help increase deployment of high quality BACS they are less likely to have large scale secure funding as they are reliant on central revenue raising and hence are less likely to be able to support actions at the scale the opportunity merits. Funding is raised through EEOs by recycling part of the benefits in energy bill cost reduction and hence is directly linked to the impact the measures produce. It can (and should) be structured to have a favourabel cost-benefit ratio for final consumers. Were there to be a targeted effort to use EEOs to support the deployment of high quality BACS, covering incremental costs of the technology, roll-out costs, strengthening the supply chain (through training, certification and accrediation) and paying for monitoring, verification and enforecement (MV&E) to ensure intended results are being attained in practice, it would be one of the most viable and cost-effective means for MS to satisfy their Article 7 requirements.

Article 4 on Building Renovations

Article 4 specifies that MS shall establish a long-term strategy for mobilising investment in the renovation of the national building stock. This strategy shall encompass:

a) an overview of the national building stock based, as appropriate, on statistical sampling;
b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;
c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;
d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;
e) an evidence-based estimate of expected energy savings and wider benefits

Article 5 - Exemplary role of public bodies' buildings

In this article MS shall ensure from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least EPBD minimum code levels. MS may opt for an alternative approach whereby they take other measures, including deep renovations and measures for behavioural change of occupants, to achieve equivalent savings in central government buildings by 2020. MS shall encourage public bodies, inc. at regional and local level, and social housing bodies governed by public law to: adopt energy efficiency plans; implement energy management; use ESCOs/EPCs to finance renovations and implement EE plans.

In principle this article could be implemented in such a way that best practice in BACS is one of the first options applied. This could be deployed at a faster rate than 3% per year and have the same impact as major renovations and hence could be used an an alternative or complementary compliance pathway. The Commission could provide explicit guidance about how this could be done and considered within MS proposals.

The role of BACS merits being considered and promoted within the scope of fulfilment of these two articles. At present it is hidden within many options to renovate buldings and is therefore not subject to the dedicated support it needs.

Article 16 on the Availabiliity of qualification, accreditation and certification schemes

Article 16 requires Member State to considers that where the national level of technical competence, objectivity and reliability is insufficient, it shall ensure that, by 31 December 2014, certification and/or accreditation schemes and/or equivalent qualification schemes, including, where necessary, suitable training programmes, become or are available for providers of energy services, energy audits, energy managers and installers of energy-related building elements as defined in Article 2(9) of Directive 2010/31/EU.

A clear need to strengthen the technical competence of those involved in the design, specification, installation and commissioning of BACS has been identified, such that eu.bac the EU industry association for BACS has developed their own voluntary certification initiative [9]. MS and the EU sould consider either supporting these or developing complementary programmes to ensure that the required technical comptences are present to an adequate degree and are easy to identify by service procurers. Article 16 presents an ideal vehcile for supporting this process.

6.3 Eco-design Directive

The Ecodesign directive sets specific minimum and generic requirements for the ecodesign characteristics of products. Energy Labelling allows the difference in energy performance to be measured and displayed to end-users and others in the supply chain. While it is correct that the majority of BACS savings potentials are not achievable via measures that could be implemented under the Ecodesign Directive, however, even if only the most miniscule fraction would be achieved, BACS leapfrog other products currently envisaged.

In the current WP2015-2017 methodology the criteria to assess the eligibility for product groups under Ecodesign are:

a) The potential for design-related improvement options;
b) The remaining space for product differentiation (competition);
c) The appropriateness to target the isolated product (versus the system that integrates it).

With respect to points a) and b) there are clearly functionality and performance differences between different BACS. As the potential for energy savings depends on these design differences, there is a significant savings potential related to product design.

With respect to point c), the energy performance of the system (in casu the building services) depends directly on the quality of the BACS that controls it.

Policy instruments that target BACS as a system are certainly needed in addition to any Ecodesign measure and will most likely lead to substantially greater savings, however, the criterion that should be applied to assess the eligibility for BACS under Ecodesign is: will the inclusion of BACS within the 2015-17 plan lead to a process or measures that produce greater savings than products currently in the top of the list?

On this point one can anticipate that the simple action of including BACS within the Ecodesign process will help to clarify to the EC's satisfaction what potential there is for savings under BACS and what part of these could be realised by actions directly on the product (via Ecodesign policy measures) as opposed to what part needs to be addressed under other directives or instruments.

Explicit Ecodesign measures that could apply to BACS products directly include:

- Requirements on interoperability (i.e. to ensure or encourage products to use open communication and control standards so that they can work with the maximum proportion of HVAC and other energy services equipment)
- Requirements on functionality (i.e. to ensure or encourage products to have sufficient functionality to enable significant savings to occur)
- Requirements on usability (i.e. to ensure or encourage products to be more user friendly, perhaps through adoption of common user interface templates in line with industry best practice, but also (depending on the product type) to provide alerts when extreme energy losses occur (e.g. when the same zone is being heated and cooled))
- Development of a common performance classification scheme leading to requirements on the disclosure of the classification perhaps via labelling or a rating disclosure process (either as components or within a larger system classification scheme)
- Requirements on the sensitivity and permitted tolerances of BACS
- As a stimuli to repeat commissioning via a requirement for an inbuilt alarm when a set period has passed since the last system commissioning

Each of these would be expected to lead to energy savings, either directly or indirectly, that would comfortably exceed the savings projected for other product groups currently considered. Were it possible to develop a mandatory EU-wide energy performance classification scheme for BACS, under either Ecodesign information requirements or energy labelling requirements, this would greatly foster dissemination of awareness regarding the distinction in performance between different BACS solutions and could greatly foster promotion of the value proposition and good practice in the market.

Most critically requirements on standardised measurement and reporting of BACS technical characteristcs can be set via Ecodesign and energy labelling and this will facilitate making the correct choice of product for the application.

There is the perception that the energy savings potential of improved BACS will be covered via addressing the controls for other product groups, such as boilers (Lot 1), water heaters (Lot 2), smart appliances (Lot 33), and lighting systems (Lot 27). Although a certain overlap does exist (with the exception of smart appliances, that deliver none of the potential savings of BACS), it only covers 9% of the entire energy savings potential of BACS. As shown in Figure 3, annual savings of 137.6 Mtoe are not accessible via regulation on the controls of other targeted product groups.

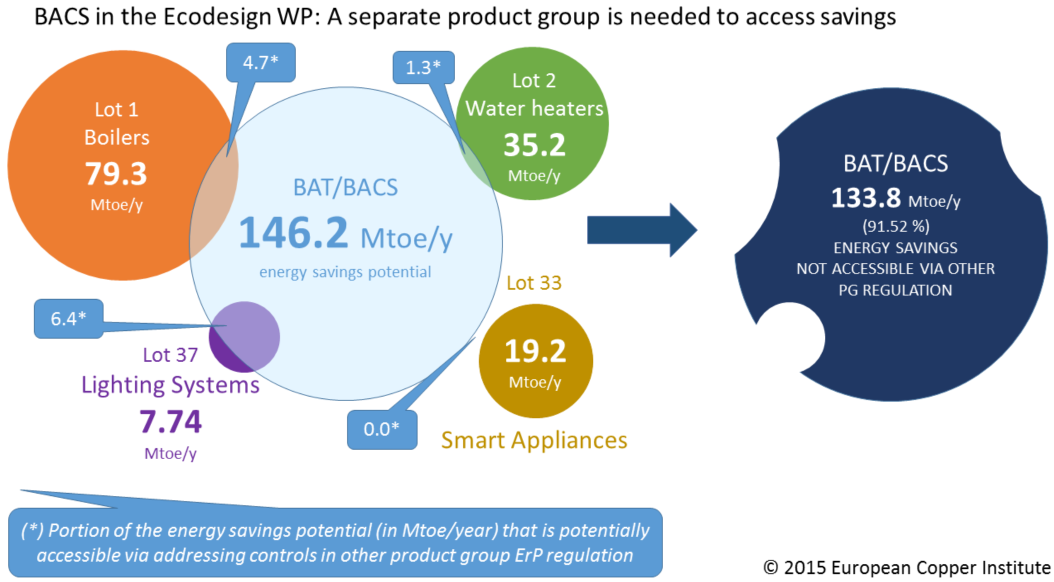

Figure 3. BACS energy savings that are not currently tapped through Ecodesign implementing measures

It is therefore recommended that Ecodesign and/or labelling requirements be developed for BACS to help support the implementation of the other policy measures mentioned in this paper. See [10] for a fuller discussion of this issue.

Conclusions

About 10% of all EU energy consumption is being wasted through the non-optimised control of European buildings of which a large part is in service sector buildings. In principle this can be saved through the adequate deployment and operation of building energy controls with building automated technology; however, many barriers remain to be overcome for these savings to be realised at scale. A variety of policy and programmatic recommendations have been proposed which can help to realise a large part of this savings potential. These build where possible on strengthening the implementation of the Energy Performance of Buildings and the Energy Efficiency Directives at the EU and Member State level and through the use of Ecodesign and energy labelling requirements to help make the quality of BACs more visible to the market place. Critically realisation of these savings will require efforts at a major scale supported by very substantial financial resources and incentives; however, as the value of the benefits outweigh the costs by an average of almost 11 to one over the lifetime of the installations this constitutes a high cost-effective investment and one that therefore merits much greater policy attention than it has received thus far. It also requires the development of a joined-up policy strategy where the contribution that specific aspects of existing yet distinct EU Directives on energy efficiency are recognised and implemented to achieve a common aim. At the institutional level this may need the establishment of a BACS working party that operates across the Directives in order to ensure desk officers and MS committee representatives understand the contributions that their specific regulatory foci can make to a collectively beneficial outcome.

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Energy performance contracting, the royal road to increasing the competitive advantage of businesses by improving energy efficiency

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Abstract:

Energy efficiency in buildings is a politically recognized contributor to the European Union`s (EU) climate and energy targets for 2020, 2030 and 2050. According to 2013 statistics residential buildings account for three quarters of EU`s floor area, while non- residential buildings account for the remaining quarter. With regard to final energy consumption the situation is different with non-residential buildings responsible for roughly one third of the final energy consumption of EU`s building stock.[1]

For facilitating the uptake of energy efficiency improvements a large private sector (ESCOs), providing energy efficiency services, has developed in Europe, over the last 30 years. One of the most common used contracting method provided by these companies is Energy Performance Contracting (EPC). Even though EPC has been around for decades, the trend analysis of the energy services market shows that this type of contracting is still underrepresented in the private sector.[2] This situation is despite its growing success in the public sector and despite the fact that energy costs can account for up to a fifth of the average business' expenditure.[3]

To what extent this potential can be exploited depends on the EPC providers` ability to demonstrate the multiple benefits and key advantages beyond energy savings such as improved health and productivity of employees (due to better indoor environment quality), increased property value, released funds to reinvest in the core business as well as evoked cost and value based competitive advantage. All this while at the same time minimizing the environmental impact and supporting the EU`s climate and energy targets.

Understanding Competitive Advantage

Competition is at the core of the success or failure of firms. Competition determines the appropriateness a firm's activities that can contribute to its performance. Competitive strategy is the search for a favourable competitive position in an industry, the fundamental arena in which competition occurs. [4]

There can be many types of competitive advantages including the firm's cost structure, product offerings, distribution network and customer support. Competitive advantages give a company an edge over its rivals and an ability to generate greater value for the firm and its shareholders. The more sustainable the competitive advantage, the more difficult it is for competitors to neutralize the advantage. The poster references on an achievable cost advantage through lower energy cost as well as a potential differential advantage. A differential advantage is created when a firm's products or services differ from its competitors and are seen as better or more sustainable than a competitor's products or services by customers. [5]

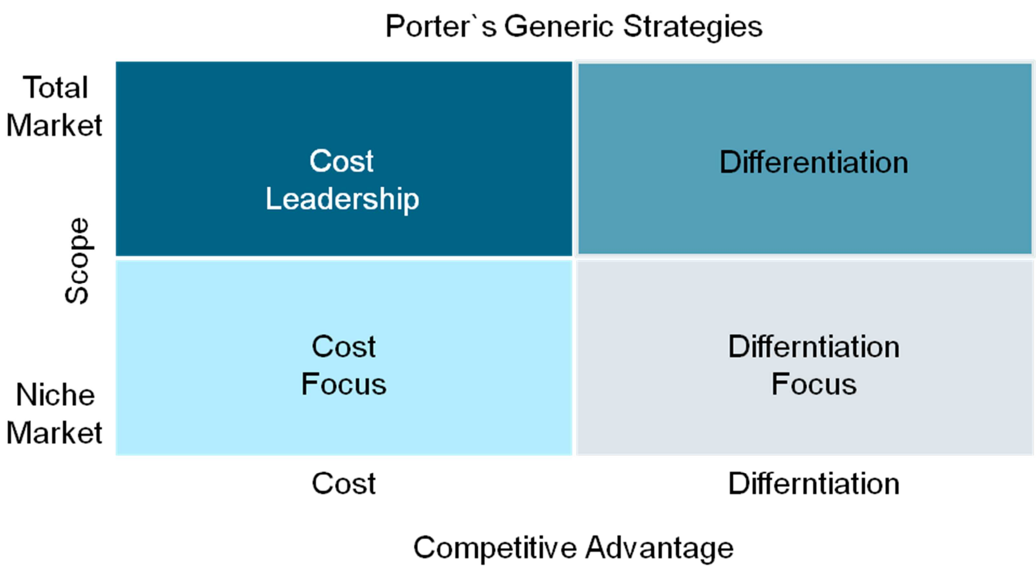

Figure 1 The basic model of competitive advantage [6]

Energy efficiency respectively energy cost reduction can support a company's competitive advantage to a certain extent (motivations to invest in energy efficiency)

There are several possible motivations for investing in energy efficiency: the desire to reduce energy costs; the need to comply with legislation; or simply the desire to be, and be seen to be, a good corporate citizen. The strongest business motivation for energy-efficient investment is, of course, pay-back from energy cost savings and the constant improvement of the cost position in comparison with the competition.

The strongest business motivation for energy-efficient investment is, of course, pay- back from energy cost savings. The second, however, is the availability of affordable methods of investing, which allows the user to pay for the equipment at a similar rate that energy cost savings are accruing. But what are typical examples of such energy-efficient technologies for the private sector?

Office technology is the fastest growing energy user in offices, currently accounting for around 15% of total office energy consumption, and set to double by 2020.[7]

However, it is in the very high power consumption computing locations – data centres, processing centres, server farms – that lower power, lower heat emission CPU technology is making a real contribution to energy saving. Analysis from Gartner has noted that the global IT industry generates as much carbon emissions as the global airline industry.[8]

In this case, air conditioning technology – itself the single biggest consumer of energy in the average business – may be best upgraded to the greener alternative whilst other work is also happening. So planning across several technologies – perhaps air conditioning, lighting, security, IT, and more – is becoming increasingly paramount, with the result that supporting finance arrangements often need to be able to encompass all these elements.

Heating, ventilation and air conditioning (HVAC) is relevant to both the office and the industrial context. Much more significant, however, for industrial organizations' energy-saving initiatives are drives and motors. Energy-efficient upgrades in the industrial context also require careful planning. Drives of various sorts, whether they are part of a production line, turning a printing press or moving chemicals, are typically a major focus for energy-efficient upgrades in industry, as they are major consumers of power, and can therefore provide rapid payback from energy cost savings.

However, companies investing in energy-efficient equipment need to think about the subject of energy performance management. Most investors in energy-efficient equipment will have constructed, often with expert help from the technologists themselves, a return on investment (ROI) model, where energy cost savings pay for the investment over a given period, e.g. Performance Contracting.

However, the reliability of such ROI models is only robust where their various dependencies are well understood and managed. [9]

European businesses are evidently serious about investing in energy-efficient technology, with a substantial proportion having already done so. The spend-to-save argument, where energy cost savings offset the cost of the equipment over time, is certainly compelling. But this argument is not strong enough to boost energy efficiency where it should be.

Beside the common sales argumentation (Energy-, Cost-, and CO_2 savings) a much more powerful lever for stimulating the energy efficiency business is required.

According to a study of Accenture and UN Global compact leading CEOs understand sustainability and energy efficiency an opportunity for innovation, competitive advantage, differentiation and growth.[10]

Keeping this in mind the approach to energy and sustainability should begin with a thorough understanding of the customer`s needs, goals and mandates.

ESCO potential customers face rising operating costs reduced financial resources, degrading infrastructure, new energy and environmental sustainability goals and legislation, and a constantly changing energy market. They struggle to find and implement practical solutions to address these complex issues. For this reason, the ability to provide solutions that help customers capitalize on trends and gain competitive advantages represents a significant opportunity for a business. The fundamental precondition for that is to understand the customers industry and business processes.

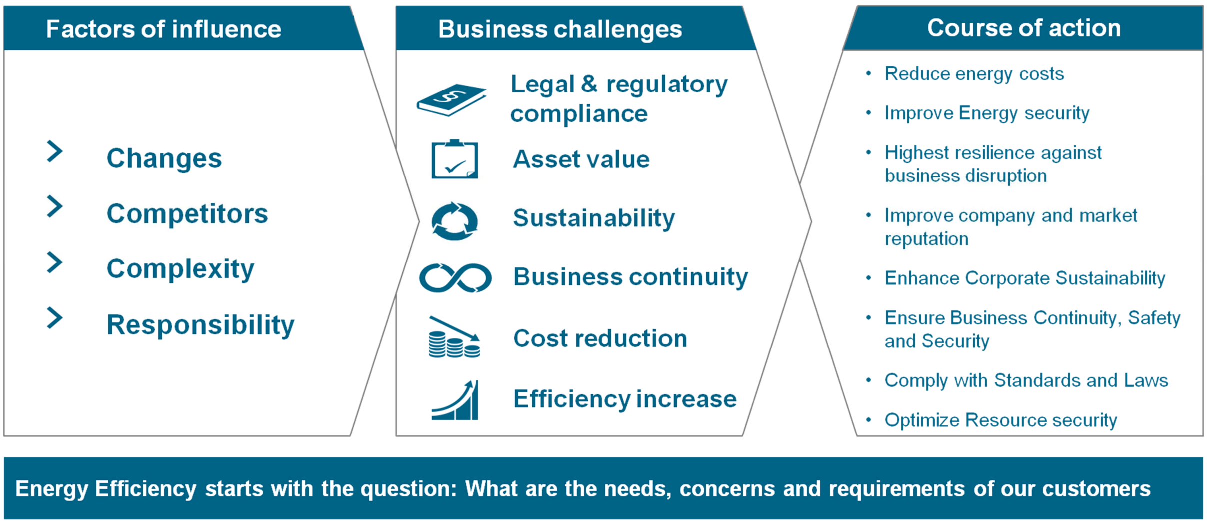

Figure 2 Gain an in-depth understanding of your customer's business pain points

After fully understanding the customer's priorities, you determine where your customer should enter in a well-defined flexible and scalable process, which can be tailored to the customer's individual situation. In an ideal manner this process is structured in five stages.

A comprehensive consulting-, service- and solution process is prerequisite to exploit the full potential of energy efficiency to support a company's competitive advantage

Phase 1: Strategy and Planning

During the Strategy & Planning phase, work with the customer to develop actionable, strategic plans that meet its legislative and corporate mandates and energy and sustainability goals. The phase begins with transparency — understanding where they are today (a baseline). Already here it is important to identify the customer's return on investment and funding requirements as well as its competitive situation.

Phase 2: Evaluation & Assessment

Next, you should move to Evaluation & Assessment. Using the established strategies and plans as a guide, identify improvement areas, financial options and available utility incentives and then calculate the financial metrics. As a result you will get the roadmap for program implementation.

Phase 3: Implementation

Based on the Program Implementation track record, customers can rest assured that you deliver their projects on time, within budget and at the quality level they need. If you can in addition assist with funding option for capital intensive implementations you will secure an advantage over the competition.

Phase 4: Service and Optimization

Ongoing Services & Optimization offerings are needed to continually improve the new baseline and maintain the customer's investment, a commitment that separates you from some of your competitors. A proven backward and forward capability history will be a strong proof that you truly stick with your customers for the life of their buildings and infrastructure.

Phase 5: Measurement and Reporting

The Measurement & Reporting phase deploys information management technology to ensure savings goals are met and further improvements are identified. Deliverables include monitoring, measuring/quantifying and reporting on performance.

Throughout each of the five phases, Continuous Data Analysis is an extremely important underlying component for delivering value to customers. Excelling in this area will reinforce the message that you can do more than just collect data.

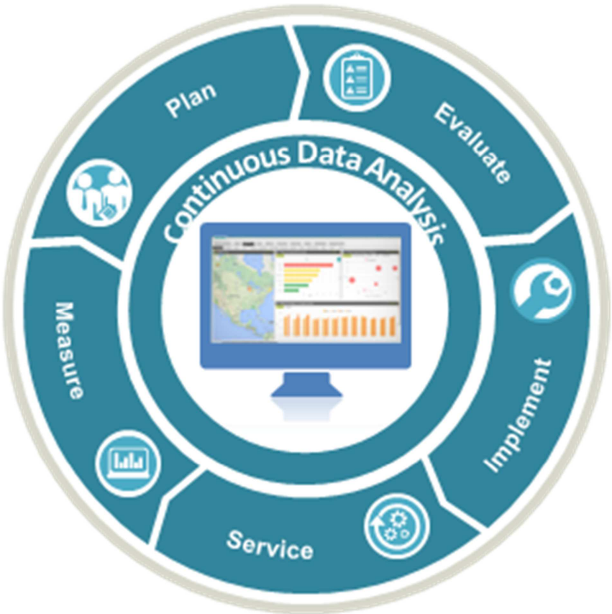

Figure 3 Recommended Consulting, Service and Solution Process for Energy Efficiency measures

In order to deliver optimal results, an important integration between energy efficiency, energy supply, compliance and sustainability must take place in each of the five phases of the customer relationship lifecycle. These categories combine to create a comprehensive and powerful offering set for your customers. If only one or two of these categories are addressed, the customer is neglecting opportunities that can be greatly beneficial. Moreover, you are incapable to reveal the addressed relationship between savings / margin improvement and a competitive advantage. [11]

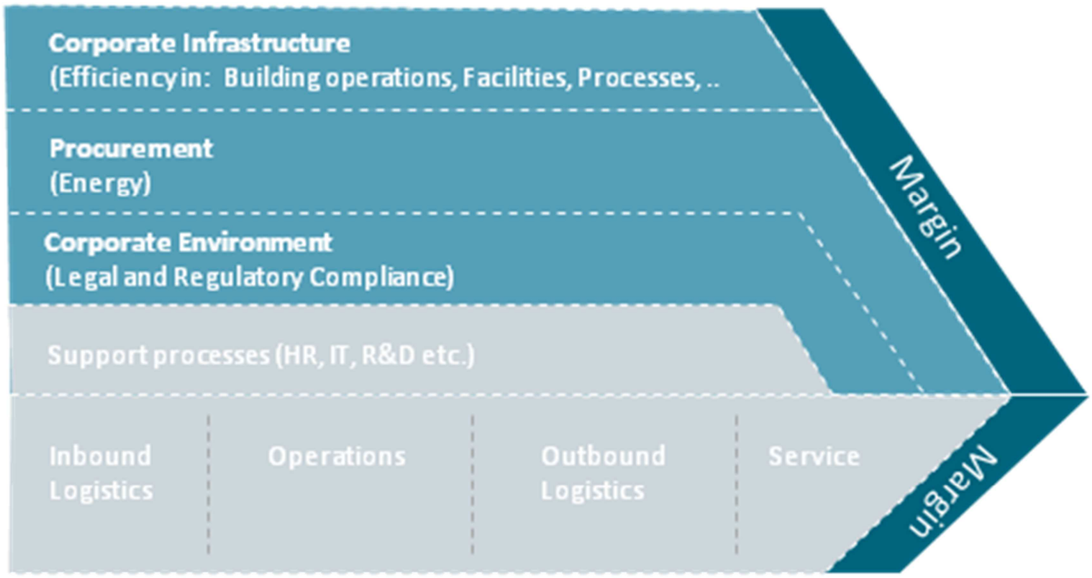

Figure 4 Energy related advisory and investments in energy efficiency measures improves margin and thus increase competitive advantage [12]

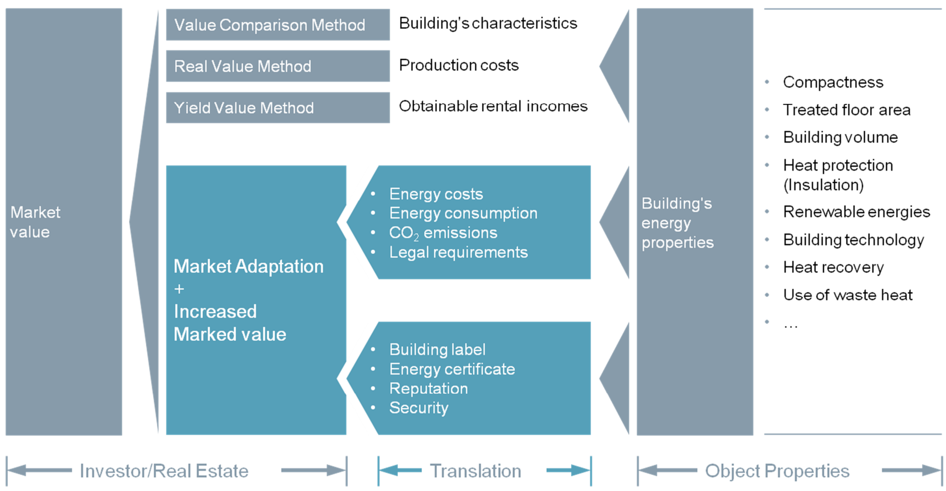

Figure 5 The shift from cost to opportunity: Example Commercial Real Estate [13]

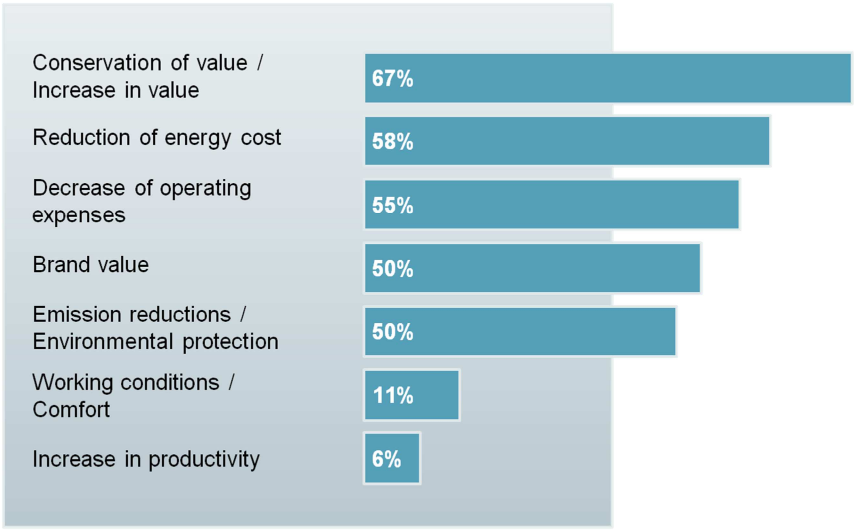

Figure 6 Objectives of energy efficiency and enhancement in value as well as cost reduction [14]

Private owned and public-sector companies which improved their cost and value proposition within their industry through energy efficiency measures

Berlin	Solution	Achievements
▪ 76 locations/~200 Buildings ▪ Energy cost (base line) € 7.6 million ▪ Guaranteed savings by contract ▪ Reduction of energy consumption in large building complexes respectively building pools ▪ Implementation, controlling and maintenance of energy saving measures ▪ Rights of proprietary and usage of the systems	▪ Modernisation or new installation of process control technology ▪ Upgrade of control cabinets to enhance or introduce digital system control ▪ Installation of combined heat and power ▪ Boiler replacement ▪ Carbon dioxide emissions reduction ▪ Replacement of energy-intensive lighting ▪ Optimization of ventilation systems and air condition installation	1. Decrease of the energy costs of 18% per annum 2. Minimization of the CO_2-emission of 25% 3. Immediately participation of the saving with 8% 4. Decrease of the transaction costs through building pools 5. Continuous optimization with transparent costs and efficiency

Figure 7 EPC Reference, Siemens Building Technologies, 2010

Johannesbad Fachklinik	Solution	Achievements
▪ Group wide cost reduction program and standards in advance of the EED ▪ Restructuring of technical infrastructure for the group within 4 years time to improve the property value ▪ Energy cost savings (>1,500,000 € reached in 2017) ▪ Reducing maintenance and repairs with respect to new technical infrastructure	15 Energy Efficiency projects, thereof **5** Energy Saving Performance Contracts Group wide auditing strategy IT-platform based building automation Energy Efficiency Directive advisory services	1. Optimized Energy Supply – Approx 300k € savings 2. Cost savings: Up to now 1,100,000 € 3. CO_2 reduction 5,100t 2013 until present

Figure 8 EPC Reference, Siemens Building Technologies, 2015

BMW	Solution	Achievements
▪ Automotive Industry ▪ Contracting period 10 years	▪ Waste heat utilization form the Aluminum melting and feed in the heating network ▪ Extension of the power house with a Combined Heat and Power Unit	▪ Reduction of CO2-Emissions 9.000 t / year ▪ Energy cost savings ca. € 2.000.000 / year

Figure 9 EPC Reference, Siemens Building Technologies, 2015

Concluding remark

The energy and sustainability market has evolved significantly over the past ten years. It's a core organizational competency that's necessary to remain competitive and enhance organizational value.

Companies in all verticals are striving to achieve sustainability, energy-consumption and cost-reduction targets, while facing:

- Resource and capital constraints;
- Lack of internal in-depth energy knowledge;
- Aging infrastructure;
- Constantly changing energy market.

As a consequence they are seeking an "end-to-end" solution that combines supply- and demand-side offerings to meet all of their energy and sustainability needs. This creates the necessity of an integrated approach beginning with consulting and lasts for the life of the customer's asset. The path to success – creating transparency, raising awareness and improving efficiency is prerequisite. To explain and demonstrate the relation between cost and CO_2 reductions and a competitive advantage is in the discretion of the energy service provider.

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Session
Building Automation II

Synthesis and Refinement of Artificial HVAC Sensor Data Intended for Supervised Learning in Data-Driven AFDD Techniques

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Abstract

Up to 20% of the total energy used in developing countries is consumed within HVAC systems [1] with between 15-50% of this consumption being attributed to faulty operation [2,3,4]. Yu et al.[5] cite a UK survey conducted in 2000 which found prompt detection and diagnosis of HVAC faults can reduced the average plant consumption by more than 10-35%, similarly, in their analysis of VAV systems Lee 2010 [6] found considerable HVAC energy savings could be made through the adoption of Automated Fault Detection and Diagnostics (AFDD). Many approaches to HVAC AFDD have been developed [5], but the commercial viability of many of these techniques still needs to be thoroughly investigated. Labelled fault data is an essential for assessing and comparing the frequency of false alarms or detection success rates. It already known that historical system data is unavailable and inadequate for this purpose [6,7] leaving simulation of faults using real plant [8] or software [7] as the only alternative.

This paper proposes a scheme for the procurement and preparation of synthetic BEMS data in which faults are present using the IES-VE. This data is intended primarily for supervised learning in data-driven approaches but is also suitable for the testing of all HVAC AFDD methods. We identify and describe the characteristics good quality the training data should have suggesting that fault observability should be considered when classifying (labelling) fault data. We suggest that the use of skewed data sets are permissible for the purposes of training data-driven classifiers and that brute-force simulation is a reasonable way of comprehensively sampling the typical operational envelope of many common systems. We conclude with a short discussion on our approach.

Introduction

AFDD has been underutilised in commercial HVAC applications [2,9], perhaps due to the required effort and perceived lack of returns in developing such a tool [6]. Bruton 2014 [4] states the use of AFDD will develop as a necessary tool for HVAC recommissioning citing the following reasons; 1) There are increasing financial and environmental pressures to reduce energy wastage, 2) More complex diagnostic tools are required to cope with increasingly sophisticated plant, 3) Emerging technologies such as wireless sensor networks make implementation evermore feasible. The Simulation Enhanced Integrated Systems for Model-based Intelligent Control(s) Project (EINSTEIN) is a European funded project which aims to develop and deploy a prototype building operation optimisation framework. A key aspect of EINSTEIN is to explore more sophisticated AFDD techniques than are currently used in existing BEMS however, since undertaking the project we have encountered issues in procuring historical building fault data for the testing of AFDD methods. In our experience BEMS data is only archived for around one to two weeks and there is typically an absence of accurate fault labelling with a strong possibility of unlabeled faults hiding within historical data. This paper outlines the philosophy and approach we have taken to procure labelled fault data for the training of data-driven AFDD techniques in EINSTEIN.

1. Fault Classification Scheme for HVAC Operation

Data-driven AFDD methods detect and identify faults at discrete time t using real valued data taken through the regular and synchronous sampling of a system's sensors $\mathbf{s}(t) = [s_0(t), s_1(t), ..]^T$. This is converted into a set of n features $\mathbf{x}(t) = [x_0(t), x_1(t), ..x_n(t)]^T$ for input into a classifier $\mathbf{x}(t) = f(\mathbf{s}(t))$. Fault identification is a classification problem where a classifier is used to map the feature space $g: \mathbf{x} \mapsto y$ into a finite number of prediction categories $y \in \{0,1,2..\}$ where $y = 0$ indicates a non-faulty operation prediction and $y = i$ indicates a prediction that fault type i has occurred. This is illustrated in (figure 1) using the notation $X_{y_{val}} \equiv \{x \in X_U | g(x) = y_{val}\}$ where X_U corresponds to the system's entire operational envelope. This categorisation topology of the featurespace is time independent. Fault detection can be viewed as the simpler binary classification problem where all of the fault prediction region are grouped into one $X_{fault} = X_1 \cup X_2 \cup ..$. An AFDD algorithm monitors a system's feature space trajectory, checking for incursions into the fault prediction regions by feeding sensor data through the classifier $(g \circ f): s \mapsto y$.

Classification ambiguity is undesirable therefore every point of the feature space should correspond exclusively a single prediction category, that is to say no classification regions should overlap i.e. $\emptyset = \{X_i \cap X_j | i \neq j\}$. Faulty plant generally exhibits both faulty operation and non-faulty operation since faults may not always affect the system for example; the effects of the chiller breakdown are unlikely to be observed during periods when the system is in heating mode and the chiller is non-operational. Fault prediction regions should therefore only correspond to detectable faulty operation which is distinguishable from baseline operation. Similarly two different fault types might sometimes produce the same symptoms making them indistinguishable in featurespace. Regions of feature space in which multiple fault regions overlap can be considered as distinct fault regions in their own right, as would all any regions corresponding to multiple faults acting simultaneously.

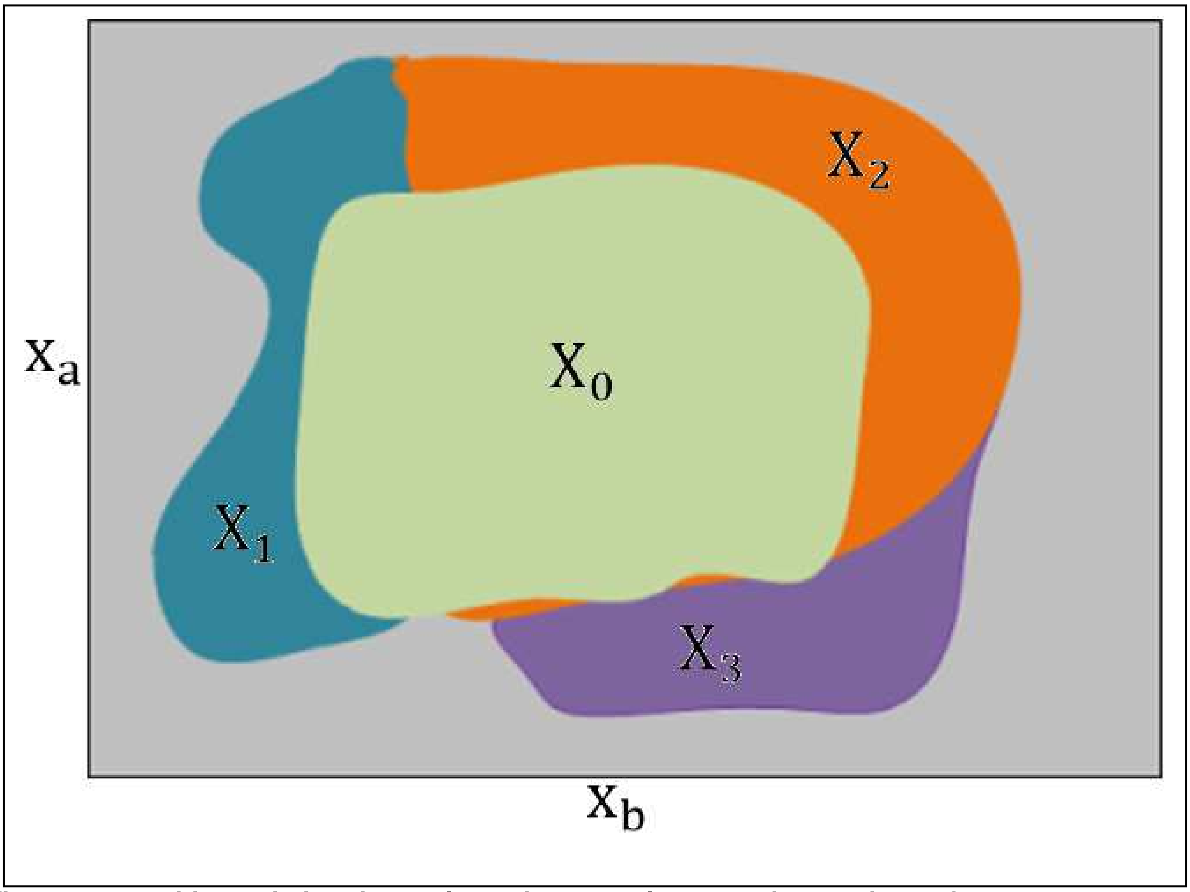

figure 1: Graphic Depicting the Faulty and Non-Faulty Operation Regions of Feature Space

2. Desirable Characteristics of Labelled Fault Data

The different types of data-driven classifier (e.g. Artificial Neural Networks, Support Vector Machines, Random Forests etc...) are essentially parameterised functions capable of representing the prediction boundaries in $\mathbb{R}^n$ featurespace. A data-driven classifier's prediction boundaries are optimised through supervised learning, where the classifier's parameter values adjusted to minimise the classifier's prediction error on a training dataset $\mathbf{D}_{train}$ in which each data point $\mathbf{x}_i$ is labelled with the correct prediction category y_i.

$$D_{train} = \{(\mathbf{x}_i, y_i) | \mathbf{x}_i \in \mathbb{R}^n, y_i \in \{0,1,2..\}\}_{i=1}^{N_{epoch}}$$

A classifier's performance is highly dependent on the quality of the data used to train it. There are a number of characteristics good quality training data should possess; first and foremost the labeling of the data should be accurate preferably using fault labels corresponding to detectable faults only as outlined in the former section. Exhaustive sampling of the feature space particularly around the boundary regions can ensure that class boundaries are positioned accurately with little margin for uncertainty, furthermore an even spread or distribution of points insures that the classifier accuracy is even across the feature space and not bias towards a particularly dense cluster of points. Training data should have diversity or spread of data and even distribution, however these are difficult to obtain if the dimension of the feature space is high and if the data procurement method suffers from sampling bias. We anticipate that high dimensionality issue is alleviated for fault detection in most systems for two reasons; many features are typically correlated and therefore data points lie within or around a much lower dimensional subspace in the feature space (as found using principle component analysis), secondly, most of a system's operational envelope corresponds to atypical system behavior which is unlikely to ever be encountered, comprehensive sampling can therefore be limited to typical or reasonable operating region.

3. The Procurement of Raw Fault Data using the IES-VE

Data-driven AFDD techniques can be used with proactive testing [8], this involve intentionally seeding adverse system problems in real plant while training data is collected however, this may be time consuming and prohibit since in could result in the damage of equipment, simulation is therefore the only method for the procurement of training data in many cases [7]. We have developed a utility which produces large volumes of artificial sensor data from AHU simulations subjected to common operational faults using the IES-VE software package.

The IES-VE software suite allows users to import or construct a geometrical model of the client building on a 3D canvas using the ModelIT module. All time varying simulation inputs are defined as profiles and added to the profile database within the ApPro module (figure 2). An alternative module ApHVAC is provided for the modelling of HVAC plant (figure 3). Users can define air and waterside loop configurations assigning the profiles which drive the plant serving them. The IES-VE was originally intended as a building design tool simulating idealised control for compliance, but it is now also being used for the simulation of building operation for instance, freeform profiles permits the import of actual plant sensor data to drive realistic calibrated building models. We have used IES-VE to simulate both normal and faulty operation of a number of typical AHU configurations.

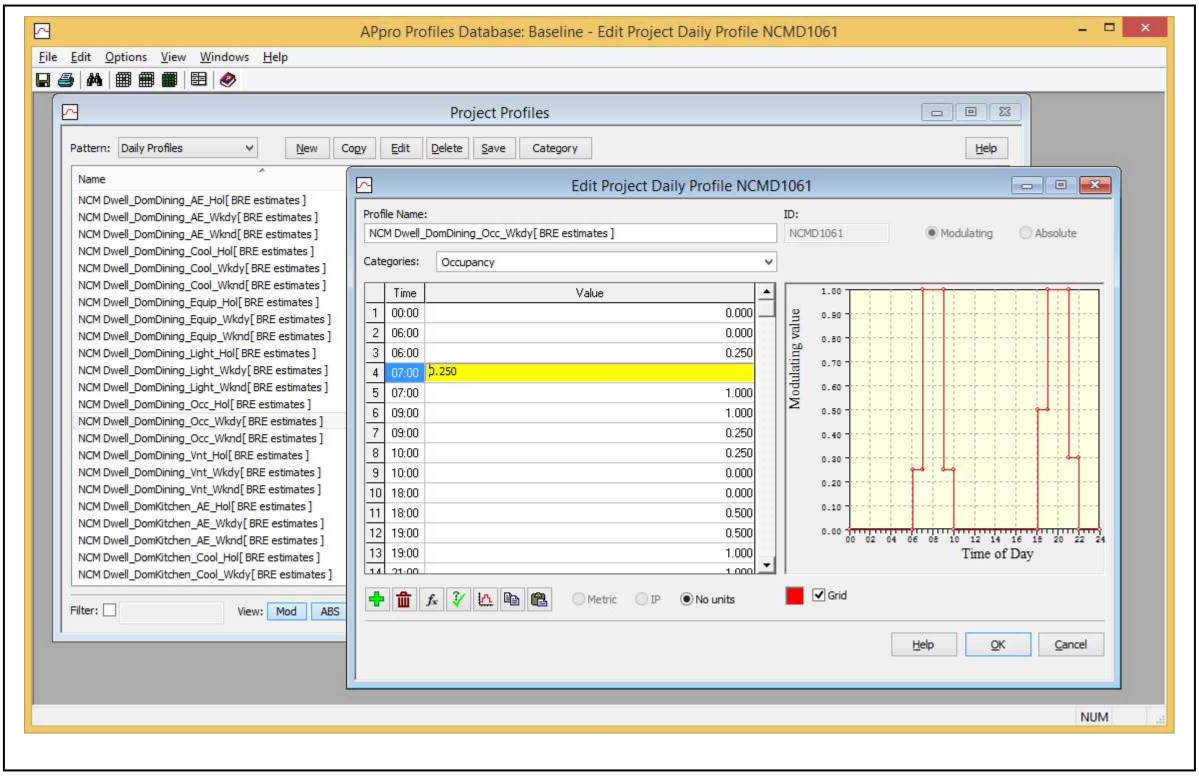

figure 2: **Profile Editing using IES-VE's ApPro**

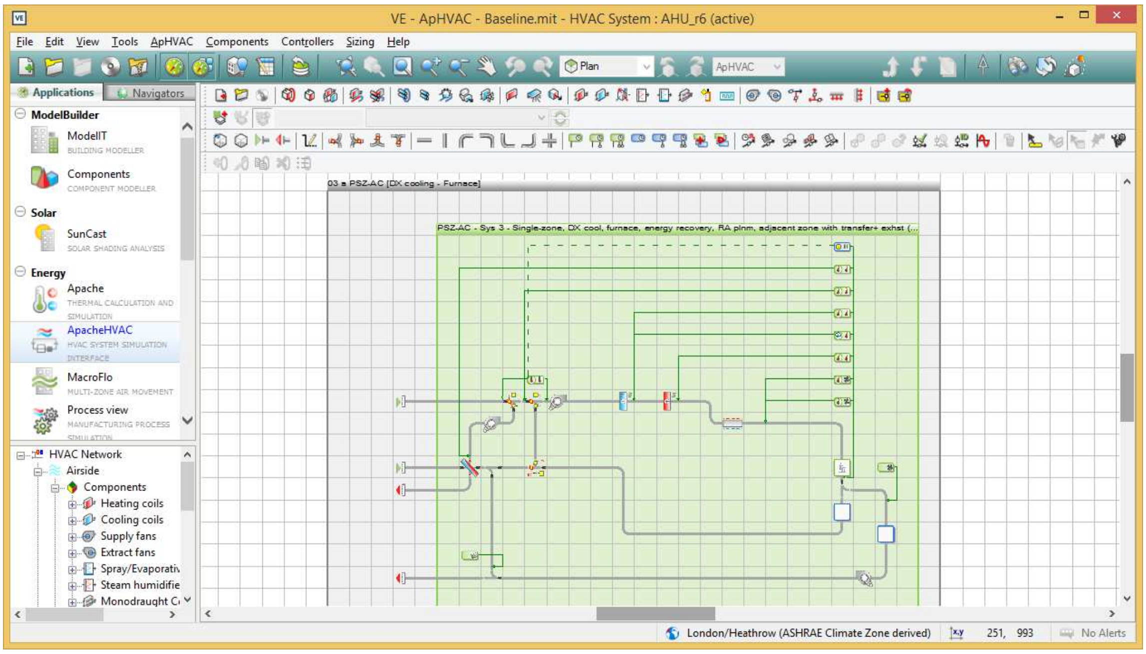

figure 3: **AHU editing in IES-VE's ApHVAC**

3.1. Simulating Building Operation using IES-VE

Standard IES-VE models simulate HVAC plant functioning as intended, these can be used for the procurement of sensor data representing the non-faulty operation of equipment. A baseline model of a building and plant is first set up, this simulates arbitrary operation of the system over a three month period with results output at 6 minute reporting intervals. The baseline model is then cloned, producing multiple variant models in which the operational input parameters (profiles) are randomly perturbed to produce a set of results files corresponding to system operation over a wide range of the system's non-faulty envelope. The raw sensor data is extracted from the results files and added to a database for storage. The variant models can be generated and simulated repeatedly to produce a very large and diverse dataset.

3.2. Simulating Faulty Building Operation using IES-VE

Little in terms of research has been conducted in the area of modelling strategies for common HVAC faults using building design software [7,10]. The IESVE suite does not cater for the explicit modelling of equipment faults however, its robust first principles core engine (as opposed to more data driven tools), permits implicit fault simulation using the two strategies presented in [7] namely, extending the model and the perturbation of free form profiles which drive the simulation. These techniques are applied to produce a set of baseline models corresponding to faulty operation from which sensor data can be procured in the same way section 3.1 describes. A new baseline model is required to simulate every individual type of system fault which may occur as well as every combination of faults which can occur. This is extremely time intensive and so far we have limited ourselves to the detection of the most common faults in the systems we have studied.

4. The Refinement of Fault Data

Post processing of the raw simulated sensor data taken from the IES-VE simulations is required to put it into the form suitable for data-driven fault classifiers described in section 2. Sections 4.1 and 4.2 present a simple approached for the accurate labelling and balancing of data respectively. This approach may also be used to put data procured from any source into the form we desire provide that; the presence of all faults in the data are known and the data set represents a comprehensive coverage the system's operational feature space envelope.

4.1. Labelling of Fault Data

The volume occupied by a cloud of data points in a multi-dimensional feature space can be found using the technique of kernel density estimation (KDE). A Gaussian kernel is placed over each data point so that the sum of the kernels correspond to a normalised density distribution of the dataset. Next a tolerance is chosen between zero and the peak height of the selected kernel, every point of the feature space which produces a larger value when sampled in the density distribution function is considered to be inside the region of data points. We apply this technique to detect and address any overlap between the different classes of points.

Initially, the labels for the raw simulation data points simply correspond to the faults that were present in the system from which produced them. All data samples in which no faults are present can be immediately labelled as belonging to the non-faulty operation region of feature space. Next we consider the detectability in all of the data in which faulty operation is present discarding and data points in which a fault is present but undetectable. KDE is used to identify the volume of the feature space which corresponds to non-faulty operation X_0. Any data points procured from faulty plant simulations which are found to reside in the non-faulty operation region of feature space are discarded.

Similarly, we can iterate over the fault classes and check for overlap between them. When overlap between two fault categories is identified, all points in the overlapping region are put into a new category corresponding to a prediction region in which the classifier is uncertain of which individual fault is present. This may be undesirable and indicates that different features should be selected to make faults more resolvable.

4.2. Balancing of Fault Data

Data-driven fault classifiers should be ideally be trained using data spread evenly across the typical operational envelope of the system. This is typically not a characteristic of the data procured from the variant simulations and consequently, we discard (undersample) a proportion of data points located in the denser sampling regions of the feature space. Kernel density estimation can again be used to determine which data points to discard after the fault labelling process or alternatively this can be done when forming the density functions during the labelling procedure. The later approach works as follows, before adding a new kernel to the density function we sample the current semi-constructed density function at the location of the new data point (corresponding to the new kernel). If the semi-constructed density function returns a value which is too large - for instance the height of two kernels, we discard the data point and do not add the new kernel to our density function.

Concluding Remarks

A computational approach to fault modelling like the one we have outlined in this paper shows promise in being able to produce large volumes of reliable data quickly. This can be used to compare the detection rate and frequency of false alarms in different classifiers, allowing progression of the AFDD aspect of EINSTEIN. Further study is needed in evaluating the use of this data for the training of data-driven AFDD classifiers which are to be deployed on real buildings, since we acknowledge there is typically a large disparity between data procured from real plant and simulated data.

This paper takes the view that data-driven fault classifiers should be trained using data spread evenly across the typical operational envelope of the system, this results in class imbalance when the $\mathbb{R}^n$ dimensional volumes of feature space corresponding to the different fault categories vary dramatically in size. We note this may contravene some widely reported guidelines which states this can lead to poor performance in data-driven classifiers however, we share the view of (Batista et al. 2004 [11]) who find skewed classes may be permissible when there is no overlap between the different classes of points - something we addressed by the design of our labelling scheme.

Our approach samples the classification of a feature space through simulating the time evolution of HVAC plant, in effect we are sampling along numerous paths or trajectory through the space. Considering a HVAC system as a group of attractors in featurespace, it is conceivable that this approach inevitably leads to extreme sampling bias, something we have explicitly stated we would like to avoid. We can offer two explanations for this; (i) the most sampled regions will correspond to the system's typical operational envelope which is the region of interest, (ii) hysteresis effects and the slower nature of building dynamics dictated that it is necessary to simulate (precondition) for a long period prior to sampling.

Acknowledgments

The EINSTEIN project acknowledges the support received from the European Union's FP7 program through the Marie Curie Industry-Academia Partnerships and Pathways (IAPP) program, under grant agreement no: 611012

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Cloud Enabled Smart Controller for Non-Domestic Building

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Abstract

In this work, a cloud enabled WSN based smart controller for non-domestic buildings has been developed. The smart controller maintains a comfortable environment by using three random neural network (RNN) models i.e., HVAC Control, predicted mean vote (PMV) Setpoint Estimator, and Occupancy Estimator. Wireless sensor nodes for monitoring the indoor environment of the building (CO_2, temperature, humidity and light intensity) and inlet air from the HVAC (CO_2, temperature, humidity) have also been developed. A RNN occupancy estimator calculates the number of occupants inside the building by monitoring temperature and CO_2 concentrations of the HVAC inlet air and indoor environment of the room. A RNN PMV setpoint estimator calculates the PMV based setpoints for heating and cooling. Moreover, the smart controller controls ventilation, heating and cooling of the building by using a RNN HVAC control model. The RNN HVAC controller can maintain user defined setpoints for heating/cooling or PMV based setpoints, and it is integrated with a cloud platform using a gateway. Indoor building environment data and HVAC control variables were displayed on the dedicated web portal and training of RNN models and data storage was performed in real-time on a cloud platform. The trained smart controller was tested in the Glasgow Caledonian University (GCU) environment chamber and the accuracy of occupancy estimation was 78.5%. The smart controller was capable of turning off the HVAC when the room was unoccupied which also reduced the energy consumption up to 19.8%.

Introduction

In 2010, buildings consume 32% (24% for residential and 8% for commercial) of the global final energy consumption, 19% of total energy related CO_2 emissions and 51% of total electricity consumption [1]. Total Energy consumption in commercial building for heating is 33% and 32% for cooling [1]. In 2008, the Climate Change Act sets the target to reduce 34% of CO_2 emission by 2020 and 80% by 2050 as compared to 1990 [2]. The target of reducing the CO_2 emission is impossible to achieve without reducing CO_2 emission in buildings. This can be done by developing controllers for HVAC systems so that they can consume less energy without compromising the occupants comfort.

Nowadays people spend more than 90% of their lives in buildings therefore indoor comfort is very necessary. After 1973/74 energy crisis the need for Building Energy Management Systems (BEMS) emerged and many improvements have been done in BEMS with the advancement in computer technology, and telecommunications. The aim of BEMS is to ensure indoor comfort for building occupants and at the same time to reduce the energy consumption. For this, BEMS monitors and controls different environmental parameters of the building with different sensors and actuators placed in the building.

Wireless sensor networks are replacing hard wired sensors in BEMS due to recent advancement in wireless communication, sensor design and low power microcontrollers [3]. WSNs are low cost and can easily be installed without major retrofitting in existing buildings. WSN have limited processing power and memory due to which limited intelligence can be embedded in WSN. The random neural networks (RNN) are used to embed intelligence in the low cost WSN. However, the training algorithms for RNN requires large memory and high computational power. Cloud computing technology is relatively new technology and it offers greater processing power and memory for data storage/representation. An integration of cloud with WSN is very attractive for BEMS. There are very few applications of cloud enabled WSN for building thermal comfort control applications.

HVAC (heating, ventilation and air conditioning control) is an integral part of the BEMS. Thermal behaviour of a building is effected by the presence of occupants in terms of heat gains and occupants thermal comfort requirements. In most of the buildings, fixed occupancy schedule is used for HVAC control. Fixed occupancy schedule based HVAC control is often used because of its simplicity. However, energy consumption by these methods can be high due to unnecessary heating/cooling the building when it is unoccupied. Correct occupancy estimation can enable HVAC to respond to the change in ventilation demands and minimise energy consumption without compromising the occupant comfort [4]. The results showed that occupancy estimation can reduce energy consumption by 10% to 56% [5],[6],[7],[8]. Correct occupancy information in building control has a significant energy saving potential [9]. If BEMS is capable of correct estimation of occupancy, it can reduce energy consumption by switching off HVAC or lights when the rooms are unoccupied.

In this work, we have developed a cloud enabled WSN based smart controller for the HVAC. The cloud computing platform is used for training the RNN models and data storage. The RNN models for occupancy estimation, PMV based setpoint estimation and HVAC control are embedded in base station to maintain comfortable indoor environment. Wireless sensor nodes for monitoring the indoor environment (Temperature, CO_2, Humidity and Light intensity) and for monitoring the inlet air of the HVAC (Temperature, Humidity, CO_2) are developed. The base station is interfaced with a gateway for cloud interfacing and for data representation on web portal. The smart control detects the occupancy and turns off the HVAC when the room is unoccupied in order to reduce the energy consumption. The main contributions of this work are:

1. Implementation of RNN-based smart controller on low cost Moteino mega board (16 kB RAM) [10].
2. The trained RNN models for smart controller are integrated in the base station. Following RNN models are integrated in the base station:
   - 2.1 RNN-based occupancy estimator by using the information available in standard HVAC system without compromising the user privacy. The model uses CO_2 concentrations in HVAC duct and room, temperature of HVAC inlet air and room air, and actuation signal of inlet air to estimate the number of occupants.
   - 2.2 PMV-based heating/cooling set point estimator using RNN.
   - 2.3 RNN-based HVAC controller that can maintain user defined/PMV-based set points for heating, cooling, and ventilation.
3. The performance of smart controller is tested in the environment chamber to measure the savings in energy consumption.
4. Integration of WSN with cloud platform for data storage, data representation and training of RNN models.

Related Work

BEMS should learn from user preferences in order to reduce energy consumption while maintaining comfortable indoor environment. This requires feedback from the user through touch screen interfaces, web portals, pc based interface, mobile phones etc. [11], [12]. In [13], the authors proposed multi-agent systems that accommodates occupant's preferences and coordinates it with building system devices to achieve maximum occupant comfort and reduced energy consumption. In [14], an agent based model was developed for modelling the behavior of occupants and then covariance graph models were used for real-time estimation of the number of occupants. A hierarchical multi-agent control system was developed in [15], which used particle swarm optimization (PSO) for optimization task. The control objectives were achieved by using four types of agents which coordinates with each other. In the ThinkHome project [16], the occupant behavior was tracked using RFID tags. The goal of this project was to achieve occupant comfort and reduce energy consumption in residential building by controlling HVAC, and lighting/shading. In [17], the self-programming thermostat was proposed which used occupancy data (i.e. pattern of leaving and returning home) to regulate the building environment.

The support vector machine (SVM), artificial neural networks (ANN), and Hidden Markov Model (HMM) were compared for occupancy estimation in large scale sensor network test bed in [18]. Due to the open environment of testbed it was found that only CO_2 and acoustic parameters have the correlation with the number of occupants. The selected inputs for training were : CO_2FD2 - 1st order shifter difference of CO_2 i.e., $CO_2(t(i))-CO_2(t(i-2))$, CO_2 $-MA-20min$ - 20 minutes of moving average of CO_2, CO_2Out -

the outdoor CO_2 values, CO_2Diff the difference between indoor and outdoor CO_2, acoustics, 1st order shifter difference of acoustics and PIR. The accuracy of ANN and SVM were approximately 75 % but they generated the noisy signals while the accuracy of HMM was also around 75% but it gave smoother results with less noise. However, in one of the dataset the accuracy of HMM was reduced to 58%.

In [19], the occupant behavior pattern model and weather forecasting model were integrated with non-linear model predictive control. The semi Markov Model for occupancy estimation was developed based on CO_2 values, lighting, motion and acoustics. The experiment results showed that an accuracy for occupancy estimation was around 80 % and energy consumption was reduced by 17.8%. In [4], the radial basis function neural networks was used for occupancy estimation. The sensor nodes were developed for measuring the CO_2, light, sound, temperature, humidity and motion. The accuracy of occupancy estimation was 87.62% for the self-estimation test and 64.83% for cross estimation.

HMM, SVM and autoregressive HMM (ARHMM) were compared for occupancy estimation for up to 7 people in [20]. The features used for occupancy estimation were: PIR1-for detecting the motion in room1, PIR2-3 for detecting the motion in room 2 and room 3, difference of indoor CO_2 and outdoor CO_2, first order differential of CO_2, 2^{nd} order differential of CO_2, humidity and first order differential of humidity. The accuracy of occupancy estimations with HMM, SVM and ARHMM were 79.63%, 77.6% and 80.76% respectively.

The parametric identification (P) technique, nonparametric identification (NP) technique, SVM and ANN were compared for occupancy estimation in KTH test lab [21]. Statistical correlation between CO_2 levels, temperature and actuation signal was exploited for estimating the occupancy. The experiment results showed that accuracy of P technique was 0.88, 0.882 for nonparametric identification technique, 0.826 for SVM and 0.811 for ANN. The room was reported empty for 1% of the times when the room was occupied with proposed P and NP technique. The room was reported occupied when the room was empty for 0.7% of the times.

In [22], implementation of cloud based model predictive thermostatic control of commercial building was presented. SCADA system received temperature information from the wireless thermostats, weather forecast from the NOAA webserver and send optimal zone temperature setpoints. The system assumes the fixed occupancy schedules. Metabolic rates for office workers and heat gains from equipment were used for calculating the loads. SCADA system makes call to Matlab and General Electric optimization software for determining the optimal setpoints.

Random Neural Networks

Gelenbe [23][24] proposed the new class of Artificial Neural Network (ANN) as Random Neural Network (RNN) in which signals are either +1 or -1. RNN is a black box learning technique which is based on concepts of probability theory applied to Markovian queuing theory. Applications of RNN were reported for modelling, optimization, pattern recognition and communication [25]. RNN is also used for function approximation. The feed-forward Bipolar random neural network (BRNN) and the clamped RNN (CRNN) can approximate any continuous function bounded on set [0,1] [26]. This works is further extended to check the limit of RNN architecture for function approximation in [27]. The authors showed that RNN can approximate the function of s variables with s +2 hidden layers.

The image processing problem is also addressed by RNN which includes texture modelling [28], texture classification [29],image segmentation of magnetic resonance imaging [30] and ultrasound images [31], image enhancement and fusion [32], and video compression [33,34]. RNN are easier to implement on hardware as their neurons can be represented by simple counters [35][36]. Abdelbaki in [37], compared the performance of the RNN with Artifcial Neural Networks (ANN) for unseen patterns not covered in the training data and found that RNN accurately measured the output while ANN failed to predict accurate output. Similarly in [38], the authors compared RNN with ANN and showed that training time for RNN is greater than ANN but RNN outperformed ANN during run-time phase in total calculation time. The authors further showed that RNN have strong generalization capability for the patterns not covered in training phase. ANNs are sensitive to the number of hidden neurons and due to over-training problem the ANN memorizes the input patterns but gives poor generalization for new inputs.

In RNN shown in Figure 1, signal travels in the form of impulse between the neurons. If the receiving signal has positive potential (+1) it represents excitation, and if the potential of the input signal is negative (-1) it represents inhibition to the receiving neuron. Each neuron *i* in the random neural network has a state $k_i(t)$ which represents the potential at time *t.* This potential $k_i(t)$ is represented by non-negative integer. If $k_i(t)>0$ then neuron *i* is in excited state and if $k_i(t)=0$ then neuron *i* is in idle state.

When neuron *i* is in excited state it transmits impulse according to the poisson rate r_i. The transmitted neuron can reach neuron *j* as excitation signal with probability $p^+(i,j)$ or as inhibitory signal with probability $p^-(i,j)$, or can leave the network with probability *d(i)* such that

$$d(i) + \sum_{j=1}^{N}[p^+(i,j) + p^-(i,j)] = 1 \ \forall i \tag{1}$$

where

$$w^+(i,j) = r_i p^+(i,j) \geq 0 \tag{2}$$

$$w^-(i,j) = r_i p^-(i,j) \geq 0 \tag{3}$$

combining (1)-(3)

$$r_i = \left(1 - d(i)\right)^{-1} \sum_{j=1}^{N}[w^+(i,j) + w^-(i,j)] \tag{4}$$

The firing rate between the neuron is represented by $r_i = \sum_{j=1}^{N}[w^+(i,j) + w^-(i,j)]$. As '$w$' matrices are the product of firing rate and probabilities, therefore these matrices always hold non-negative values. External positive or negative signal can also reach neuron *I* at poisson rate Λ_i and λ_i respectively. When positive signal is received at neuron i its potential $k_i(t)$ will increase to +1. If neuron *i* is in excitation state and it receives negative signal the potential of neuron *i* will decrease to zero. Arrival of negative signal will have no effect on neuron *i* if its potential is already 0. The description of symbols used is given in Table 1.

Consider the vector **K(t)=** $(k_1(t), \ldots\ldots\ldots k_n(t))$ where $k_i(t)$ is the potential of neuron *i* and n is the total number of neurons in the network. Let **K** is continuous time Markov process. The stationary distribution of **K** is represented as:

$$\lim_{t \to \infty} \Pr(K(t) = (k_1(t) \ldots \ldots \ldots k_n(t)) = \prod_{i=1}^{n}(1 - q_i) q_i^{ki} \tag{5}$$

For each node *i* $\quad q_i = \frac{G_i^+}{r_i + G_i^-}$ (6)

Where

$$G_i^+ = \Lambda_i + \sum_{j=1}^{n} q_j \ w_{(j,i)}^+ \tag{7}$$

$$G_i^- = \lambda_i + \sum_{j=1}^{n} q_j \ w_{(j,i)}^- \tag{8}$$

For three layer network, q_i for each layer is calculated as

$$q_{i \in I} = \frac{\Lambda_i}{r_i + \lambda_i} \qquad where\ I\ is\ Input\ Layer \tag{9}$$

$$q_{h \in H} = \frac{\sum_{i \in I} q_i w_{(i,h)}^+}{r_h + \sum_{i \in I} q_i w_{(i,h)}^-} \qquad H\ is\ hidden\ layer \tag{10}$$

$$q_{o \in O} = \frac{\sum_{h \in H} q_h w_{(h,o)}^+}{r_h + \sum_{h \in H} q_h w_{(h,o)}^-} \qquad O\ is\ output\ layer \tag{11}$$

Figure- 1 Random Neural Network

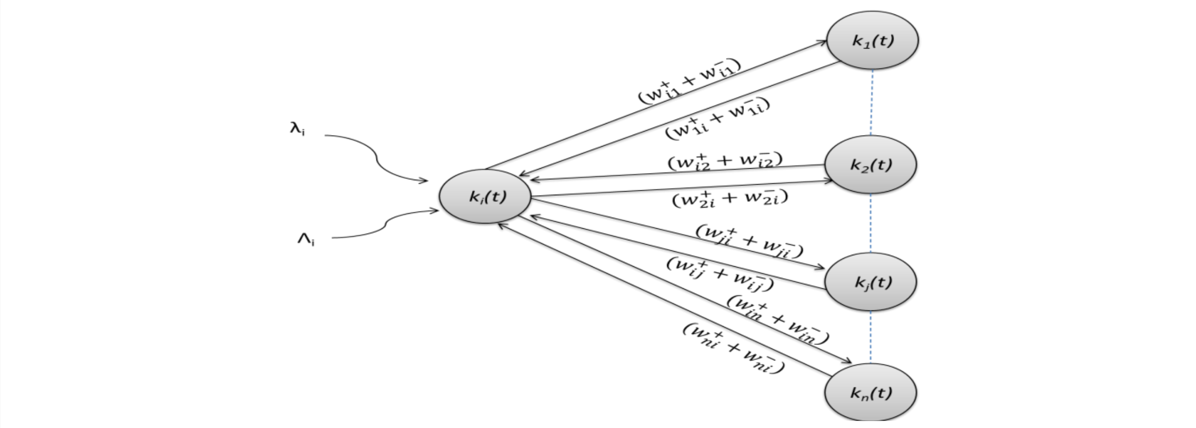


Table 1: RNN Symbols

RNN Symbol	
Symbol	***Description***
q_i	Probability neuron *i* excited at time t
$p^+(i, j)$	Probability neuron *j* receives positive signal from neuron *i*
$p^-(i, j)$	Probability neuron *j* receives negative signal from neuron *i*
r_i	Firing rate of neuron i
Λ_i	Arrival rate of external positive signals
λ_i	Arrival rate of external negative signals
$d(i)$	Probability a signal from neuron departs from the network
$k_i(t)$	Potential of neuron *i* at time *t*

Training Algorithm for RNN : Hybird Particle Swarm Optimization with Sequential Quadratic Programming

Many researchers have used a Gradient Descent (GD) algorithm [39] for learning the weights of an RNN model. The GD algorithm is relatively easy to implement but zigzag behaviour may cause it to be stuck near a local minimum for the problems with multiple local minima. The evolutionary algorithms are used for solving optimization problem. These techniques are better than gradient base techniques as they do not get stuck in local minima. The Particle Swarm Optimization (PSO) algorithm performs well in finding the global minimum but it might be slow to converge to the global minimum while in the presence of multiple local minima, Sequential Quadratic Programming (SQP) optimization method [40] usually converges to local minima. The problem of slow convergence of PSO and local minima problem of SQP optimization is addressed by the hybridization of PSO and SQP optimization algorithm [41].

In this paper, we used a hybrid Particle Swarm Optimization with Sequential Quadratic Programming (PSO-SQP) algorithm for RNN training first proposed in [42]. First, RNN is trained with PSO algorithm to find the global minima, and then based on feasible start point from Adaptive Inertia Weight-Particle Swarm Optimization Algorithm (AIW-PSO) [43], SQP optimization algorithm converges to global minima. The position vector for PSO is formulated as Xsd = $[w_{ih}^{+L1}\ w_{ih}^{+L2}\ w_{ih}^{-L1}\ w_{ih}^{-L2}]$, w_{ih}^{+L1} is positive interconnection weights between node i of layer 0 and node h of layer 1. Similarly, w_{ih}^{-L1} is negative interconnection weights between node i of layer 0 and node h of layer 1. The details of hybrid PSO-SQP algorithm are given in [41].

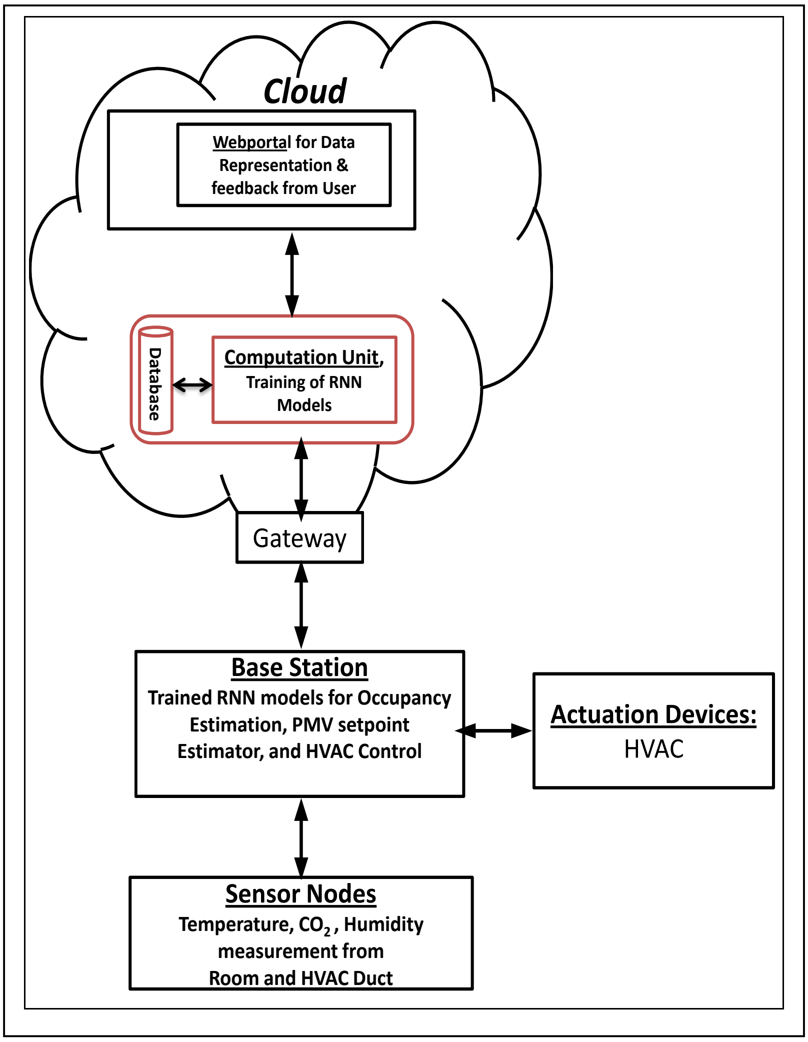
Architecture of Cloud Enabled Smart Controller for HVAC

The smart controller has modular architecture and is easily expandable. The basic modules for the smart controller are: base station, environment monitoring sensor node, HVAC duct sensor node, gateway, and cloud platform for data representation, storage and RNN model training. The architecture of the cloud enabled smart controller is shown in Figure 2.

Environment Monitoring Sensor Node

The environment monitoring sensor node is developed with Moteino R4 board which have 2KB of RAM and 32 KB of program memory. The sensor node monitors the light intensity, temperature, humidity and CO_2 inside the room. The DHT22 sensor is used for monitoring temperature and humidity, whereas COZIR sensor is used for monitoring CO_2 values and photoresistor sensor is used for monitoring the light. The sensor node transmits the information to the base station using RFM 69W transceiver at 915 MHz. The environment monitoring sensor node is shown in Figure 3 a.

Figure 2: Architecture of Cloud Enabled Smart Controller for HVAC



HVAC Duct Sensor Node

HVAC duct sensor nodes monitors the inlet air of the HVAC coming from the HVAC duct. The sensor node monitors CO_2, temperature and humidity of the inlet air coming from the HVAC duct. The sensor node is developed with same board and sensors used for environment monitoring sensor node. The HVAC duct sensor node is shown in Figure 3b.

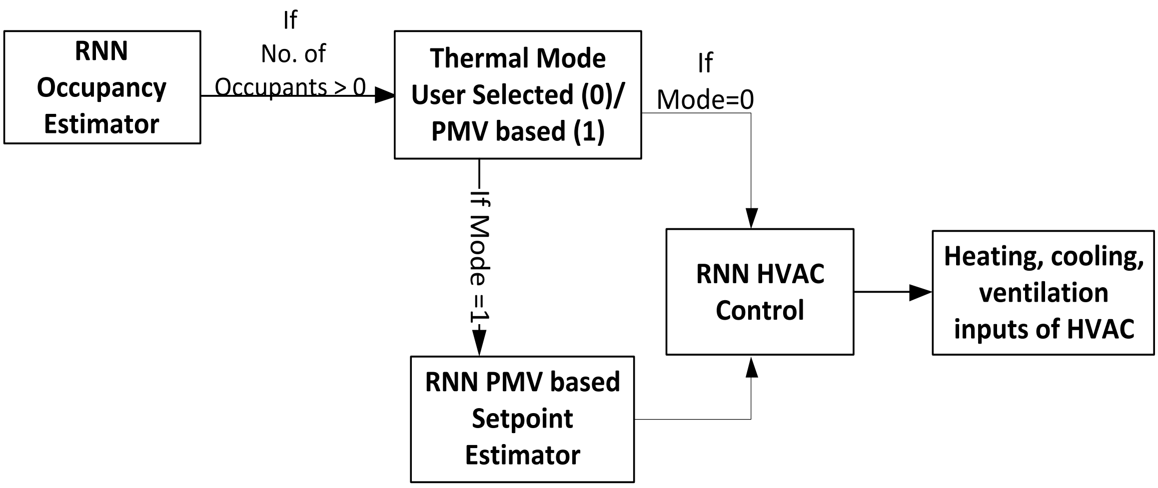
Base Station

The base station is implemented with Moteino Mega board [10] which have 16KB RAM and 128 KB of program memory. It receives information from the environment monitoring sensor node and HVAC duct sensor node and controls the actuators of the HVAC. The base station uploads the data of sensor nodes to the web portal through gateway. RNN models are trained on cloud platform and weights of trained RNN models are transferred to base station. The control algorithm is implemented with multiple RNN models integrated on the base stations i.e. RNN occupancy estimator, RNN PMV based setpoint Estimator, RNN HVAC control model. The control structure of smart controller is shown in Figure 4.

Figure 3: (a) Environment monitoring Sensor Node (b) HVAC Duct Sensor Node

(a) (b)

Figure 4: Control Structure of Smart Controller



RNN Occupancy Estimator:

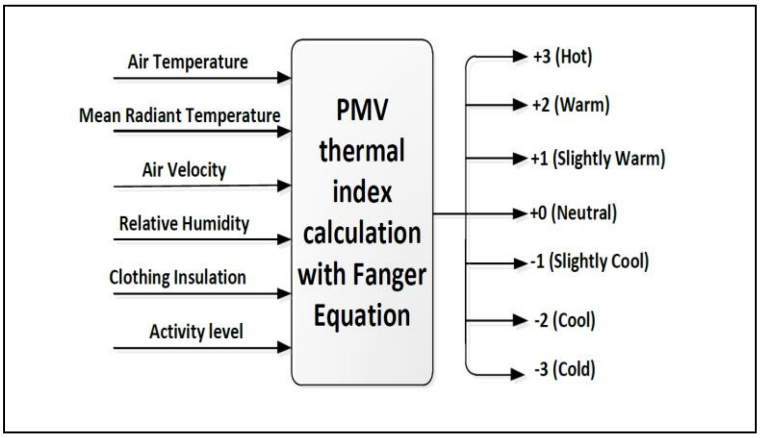
The RNN model is used for estimating the number of occupants. The RNN occupancy estimator calculates the number of occupants inside the room by using CO_2 and temperature values received from the environment monitoring sensor node and HVAC duct sensor node. The RNN model is trained with the dataset collected from the environment test chamber located in Glasgow Caledonian University. The RNN model have four neurons in the input layer, five neurons in the hidden layer and one neuron in the output layer. Inputs for the RNN model are: 1) CO_2 concentration in the room, 2) temperature of the room, 3) CO_2 concentration in the HVAC duct, 4) temperature of the air coming from the HVAC duct and output of the RNN model is the number of occupants. The RNN model is trained with the hybrid PSO-SQP and MSE is 2.55 e-02.

RNN PMV Setpoint Estimator

Fanger in [44], developed the iterative general thermal comfort equation which calculates thermal comfort index corresponding to thermal environment variables i.e. air temperature, mean radiant temperature, relative humidity, air velocity and two personal dependent variables i.e., insulation of clothing person is wearing and activity level of the person. Fanger developed seven point index of comfort/discomfort which is dependent on six variables as shown in Figure 5. PMV index is computed by iteratively solving the equations until the maximum number of iterations are achieved or required accuracy is achieved. The iterative solving of these equation take long computation time and may not be possible to implement on low power, low memory embedded system for real time applications. The ANN model has been used for determining the PMV index in [45]. The least square support vector machine based approach has also been applied to determine the PMV index in [46].The authors in [45], simplified the neural network model for PMV estimation by assuming air velocity, clothing insulation, and metabolic rate to be constant. The results showed that PMV-ANN model achieved more accuracy than [46] with shorter execution time.

In this work, training data set is generated by using Fanger equation for PMV. To reduce the human interference, we assumed the typical office environment. Therefore, clothing insulation of 0.8, metabolic rate of 1.1, and air velocity of 0.15 m/s are assumed to be constant. After generating training dataset, RNN is trained with PMV and humidity as an input and temperature as an output. A 2-4-1 RNN is trained with hybrid PSO-SQP training algorithm. In this work, PMV of -0.1,-0.3,-0.5 is tested for heating setpoint and PMV of 0.3, 0.5 and 0.7 is tested for cooling set point. The RNN PMV based setpoint estimator is implemented on the base station. The estimated setpoints from the RNN model will be used by RNN HVAC control model for controlling the HVAC. In this work, when PMV value of -0.5 is selected the estimated setpoints for temperature are varied between 22.34°C and 22.47°C.

Figure 5: PMV Thermal Index



RNN HVAC Control

RNN model is trained for maintaining comfortable indoor environment by controlling the heating, cooling and ventilation of HVAC. The cooling setpoints (25 ^{o}C,26 ^{o}C,27 ^{o}C ,28 ^{o}C) and heating setpoints (19^{o}C, 20 ^{o}C,21 ^{o}C,22 ^{o}C ,23 ^{o}C) are varied by occupant to train the controller. In this way, RNN model learns user preferences for heating, cooling and ventilation. A 5-7-3 RNN controller with 5 neurons in the input layer, 7 neurons in the hidden layer and 3 neurons in the output layer is trained with (PSO-SQP) training algorithm.

To avoid fluctuation in heating, cooling and ventilation multiple thresholds are implemented.

1. The room is allowed to heat up to the required heating set point and heating will not be turned on again until the room temperature reaches 1^{o}C below heating set point.

2. The room is allowed to cool up to the required cooling set point and heating will not be turned on again until the room temperature reaches 1^{o}C above cooling set point.

3. Ventilation is turned on when CO_2 values are higher than 800 ppm and will be turned off until CO_2 values reaches below 750ppm.

Cloud Services

The base station of WSN is interfaced with the cloud platform through gateway using Global System for Mobile Communication (GSM) module. The gateway stores the data in the database and web portal is updated after every 15 minutes. Training of RNN models is done on a cloud platform and trained weights of RNN are transferred to the base station through gateway. For each sensor node, the web portal (http://sensors.traceallglobal.com/) displays Node ID, upload time in milli seconds (the time sensor node is powered), light intensity, CO_2 concentrations, temperature, humidity, dewpoint temperature, data receiving time, motion sensor, heating setpoint, cooling setpoint, heating output for HVAC, cooling output for HVAC, ventilation output for HVAC, and number of occupants in the room.

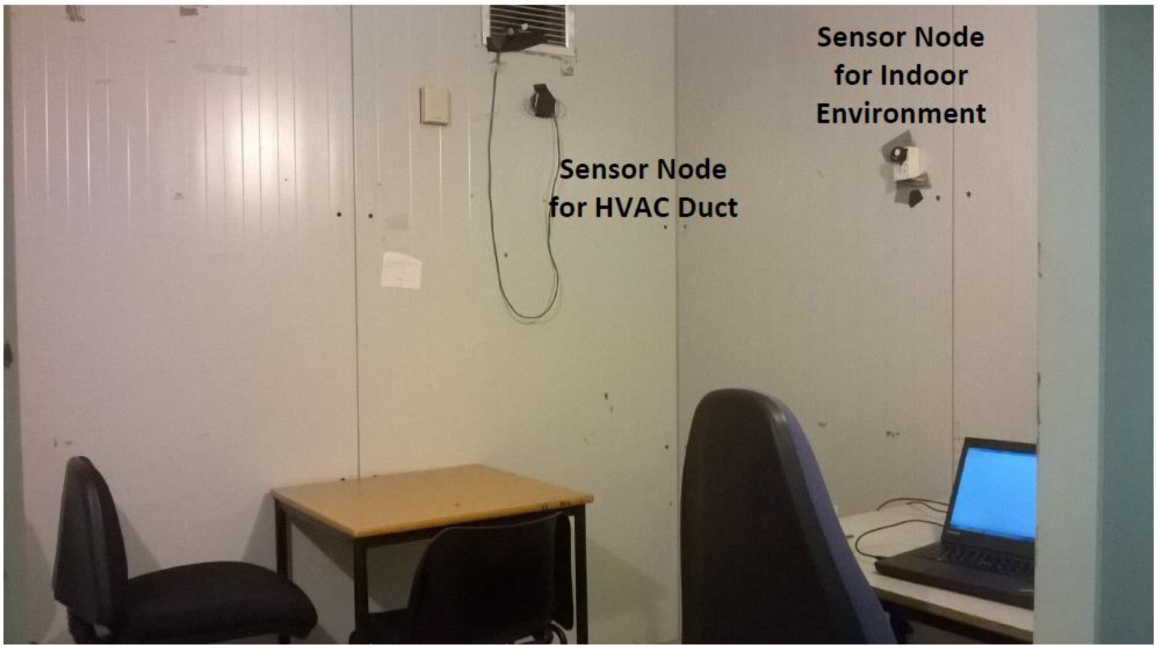
Results

The performance of the smart controller is evaluated by testing it in the environment test chamber located at Glasgow Caledonian University. The smart controller estimates the occupancy and if the room is occupied it maintains the indoor environment of the test chamber according to the user preferences. The smart controller maintains PMV based setpoints for heating/cooling and if the user is not satisfied with PMV based setpoints, it can maintain user defined setpoints for heating/cooling.

Environment Test Chamber

The dimensions of environment test chamber are 3.65m x 2.43m x 2.43 m. The test chamber has dedicated HVAC that humidify/dehumidify, heat/cool the chamber between 5 ^{o}C and 40 ^{o}C. Inside the environment chamber, there are two sensor nodes one for HVAC duct (monitoring inlet air CO_2, Temperature and Humidity) and one for monitoring the environment of the chamber. The HVAC circulates the air in the environment chamber. The base station is connected with control panel of the environment chamber to turn on/off heater, cooler and ventilation. The indoor view of the environment test chamber is shown in Figure 6.

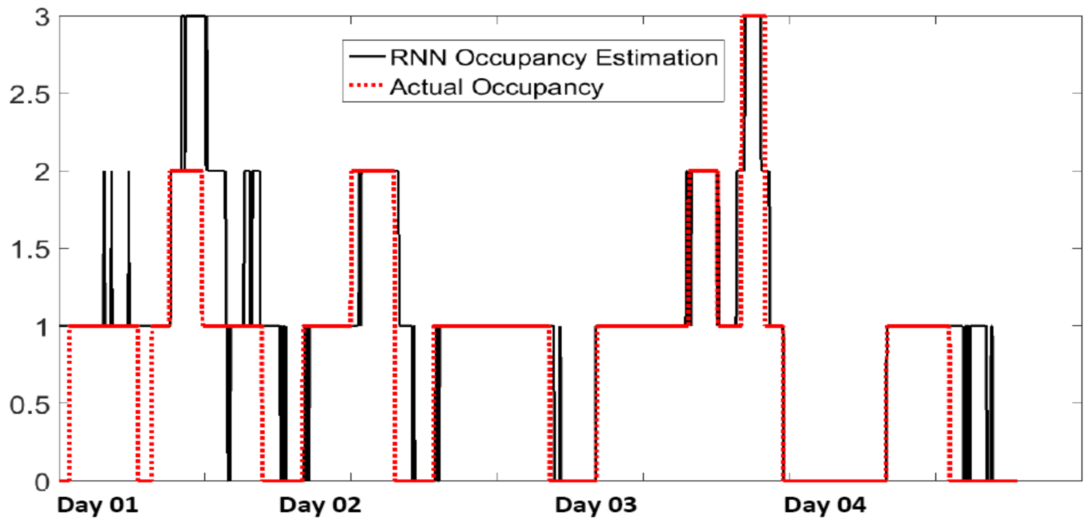
Figure 6: Indoor View of the Environment Test Chamber



Occupancy Estimation with RNN

CO_2 concentrations increases in the environment chamber when the chamber is occupied but CO_2 concentrations drops slowly when the occupant leaves the room due to this non-linear behavior the occupancy estimation is a very challenging task. The occupancy estimation with RNN model is tested in the environment chamber for five days between 10:00 AM to 06:00 PM. The environment test chamber was occupied up to 3 persons during the test. The ground truth values for number of occupants were recorded manually to calculate the accuracy. The experiment results are shown in Figure 7. The accuracy of the occupancy estimation with RNN model is 78.5% (i.e. when occupancy estimation with RNN is equal to the actual occupancy inside the test chamber).

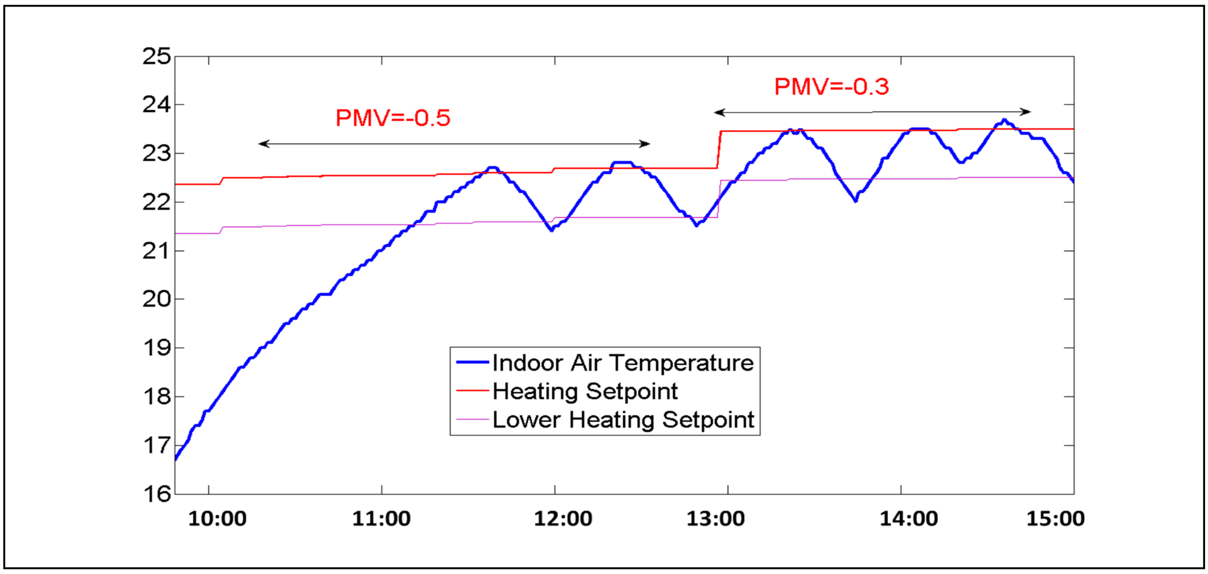
Figure 7: Occupancy Estimation with RNN in Environment Test Chamber



HVAC Control

The smart controller can maintain the PMV based heating/cooling setpoints and user defined heating/cooling setpoints. The upper threshold for heating setpoint and lower threshold for heating setpoint is implemented. The HVAC turns on the heating to reach the upper threshold of the heating setpoint for test chamber and heating remains turned off until reaching the lower threshold for the heating setpoint (i.e. heating setpoint -1°C). The performance of the smart controller was evaluated for maintaining the PMV based heating setpoints in the environment test chamber. During the test, the PMV based heating setpoints were varied between 22.15 °C and 23.5 °C. The indoor air temperature of the test chamber along with the heating setpoint and lower heating setpoint is shown in Figure 8.

Figure 8: Indoor air temperature of the environment chamber for maintaining the PMV based heating setpoints.



Comparison of Energy Consumption

Energy consumption of HVAC with RNN based smart controller is compared with energy consumption of simple thermostat. The smart controller maintains the heating/cooling setpoint if smart controller detects the occupancy using RNN occupancy estimator. The setpoint for heating was 23 °C and for cooling was 26 °C during the test. Occupancy patterns were kept same both for smart controller and simple thermostats. The occupancy estimation with RNN is shown in Figure 9 and indoor air temperature of the test chamber is shown in Figure 10. Energy consumption of the smart controller was 30.16 kWh, while energy consumption of simple thermostat was 36.12 kWh. The smart controller consumes 19.76% less energy than simple thermostat. Simple thermostats maintained the air temperature between the heating and cooling setpoint during 10:00 hrs to 18:00 hrs whereas smart controller turned on the HVAC at 10:30 AM and switched off the HVAC at 16:00 hrs as room was unoccupied during rest of the time.

Conclusion

In this paper, the cloud enabled smart controller for BEMS is presented. Sensor nodes for monitoring the indoor environment of building and HVAC duct are developed with low power Moteino boards. The smart controller is developed by integrating multiple RNN models trained for occupancy estimation, estimation of PMV based heating/cooling setpoints, and HVAC control on base station. RNN based smart controller is interfaced with cloud platform through gateway. Environmental parameters of the test chamber and control parameters of the HVAC are uploaded on the web portal. The computational requirement for training the RNN models is high whereas the base station has limited processing power. This shortcoming has been addressed by training the RNN models on cloud. The trained RNN models are then implemented on base station to take the control decisions locally. The performance of the smart controller is evaluated by testing it in the environment test chamber. The results showed that occupancy estimation with RNN is 78.5% accurate and energy consumption of the smart controller is 19.8% less than simple thermostat.

Figure 9: Occupancy Estimation with RNN in Environment Test Chamber for Comparison of Energy Consumption.

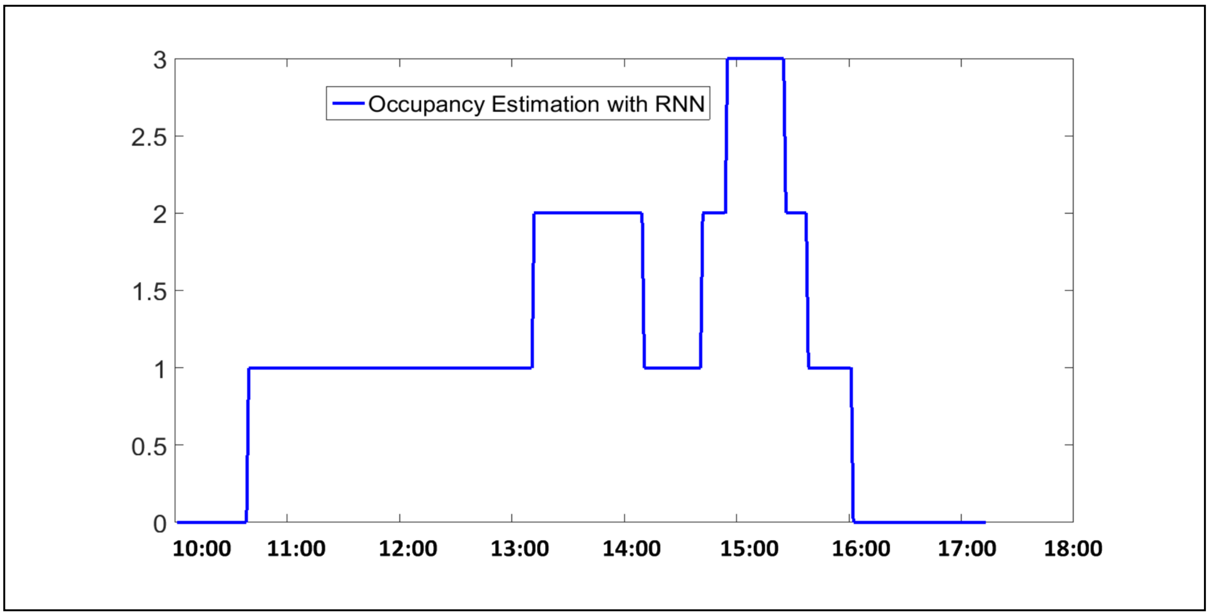
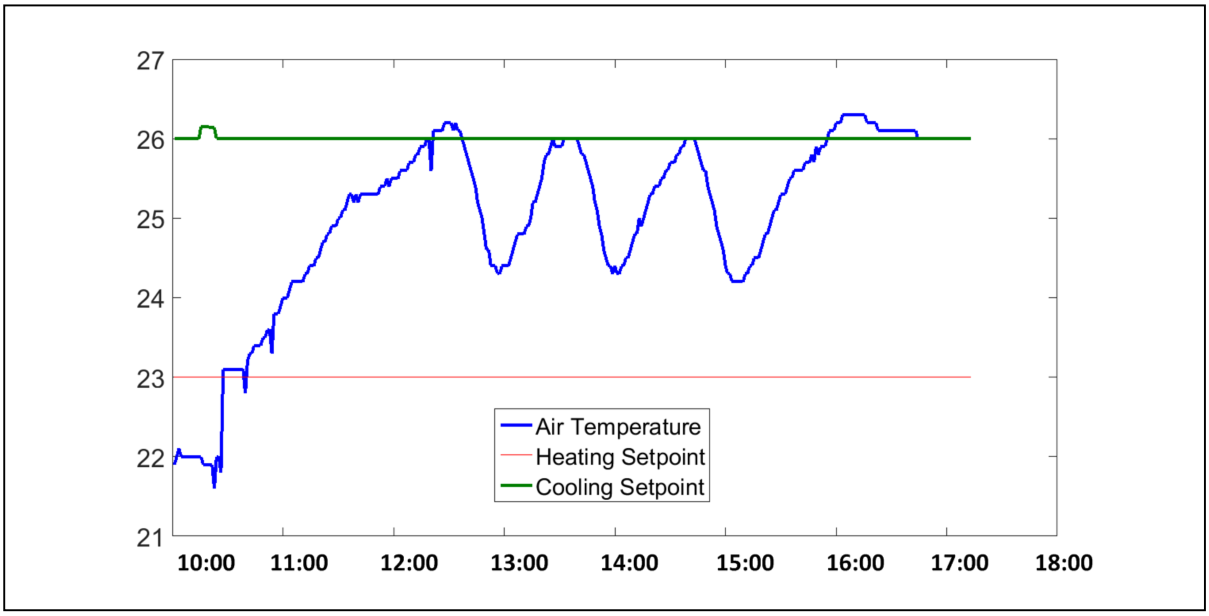


Figure 10: Occupancy Estimation with RNN in Environment Test Chamber for Comparison of Energy Consumption



Acknowledgments

The authors acknowledge support from the Innovate UK and CENSIS Innovation Centre. CO_2 Sensors were provided by GSS Ltd

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Can Energy Efficiency Services in buildings be seen as a Cleantechnology ?

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Keywords: ***Energy Efficiency services, University college PXL, Hasselt, Paradigm shift,***

Abstract

The debate on energy and sustainability is of main interest. Special attention and priority is continuously given to avoid CO_2 emission in view of energy production, use and/or conversion. The heating of buildings, both public and private, is a large energy end-user.

Since the beginning of 1960 environmental technologies have been developed into clean technologies with a focus on reducing environmental impacts during the whole life cycle. Moreover nowadays industrial symbiosis is setup to exchange materials in a closed loop (C2C) in combination with energy optimization.

Energy Efficiency Services in buildings focus on a lower and flexible, energy consumption in combination with renewable sources. The connected buildings (particular and industrial) are the start of urban (energy) symbiosis in smart cities and thus can be seen as an expression of clean technology (renewable energy, closed loops and decentralized). The positive impacts will be a climate friendly energy production and consumption. Due to this way of organizing, buildings are no longer the problem, but are the solution to solve the (energy) problem.

1. Introduction

In this paper the parallelism between Energy Efficiency Services (EES) in buildings and the actual clean technology is illustrated.
First, we discuss the actual energy needs for the heating of buildings, both public and private, in combination with the present greenhouse gasses (GHG) emissions. In the past one often used trias energetica principles in order to improve the energy efficiency (and thus lower the GHG) (strictly spoken this is the use of end of pipe technology). Nowadays we see across all industries a trend moving towards services, and dematerialised consumption. In this context EES and their variants can be seen as subset of Product Services System (PSS). Indeed, these project are output driven as the services (light, heat, ….) are important and the accompagnied business models are based on the cost benefits during the Total Life Cycle.
EES applied to buildings can therefore be seen as an expression of clean technology (main characteristics are renewable energy, closed loops and decentralized). Due to this way of organizing, buildings are no longer the problem, but are the solution to solve the (energy) problem.

2. Energy

Since the industrial revolution in the 18th century the energy management has moved from short CO_2 cycle towards a long cycle CO_2 cycle (as the local biomass and local sustainable energy resources were no longer sufficient and men start to use fossil fuels). The rapidly increasing use of fossil fuels has led to a concentration of more than 400 ppm for CO_2 in the atmosphere. Although the IR absorption of water vapour is more efficient, the importance as greenhouse gases depends both on their concentration and on their absorption of IR radiation. As the atmospheric life time of water vapour is very short in comparison to CO_2, the increase of carbon dioxide has contributed more than 72 % of the enhanced greenhouse effect to date [1].

In 2007, European heads of state and government stressed the need to increase energy efficiency. Recently the EU has also articulated a long term goal for 2050 and the European commission [2] has decided within the 2030 Framework for Climate and Energy to increase the goals in comparison to 2020 targets namely: -40 % GHG emissions (20%), 27 renewable energy (20 %), 27 % Energy Efficiency (20) and, 15 % interconnection (10%) [2].

Belgium (together with Germany and Sweden) have somewhat ambitious (exceeding 10 %) reducing targets in both primary and final energy. Despite reduction in both primary and final energy consumption in these three countries, further efforts will be necessary until 2020 to achieve faster reduction [3].

Energy can be divided into delivered energy, useful energy and final energy services. In view of the use of energy we distinguish at least for different types: heating of buildings, energy in industrial processes, transport, and power/light.

In this paper we will focus on the energy dealing with buildings.

3. Buildings

The heating of buildings, both public and private, is a large energy end-user in addition the share of buildings in the greenhouse emissions is significant (6, 5 % direct and 12 % indirect) worldwide [4,5].

The 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive are the EU's main legislation when it comes to reducing the energy consumption of buildings. The Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020. All new public buildings must be nearly zero-energy by 2018 [2].

It is clear that the transition towards a more sustainable energy supply will affect the landscape of residential and rural areas as well as industrial sites. Because of the large scale deployment and effective integration of distributed and renewable energy sources (wind energy, photo voltaic cells (small and large); the transport via power lines, the eventually CO_2 capture and storage.

The ecological footprint is very high in Flanders mainly because of the high CO_2 emissions (inefficient private and public building and too much traffic because of the rural architecture of (small) cities [6].

In Flanders the CO_2 emissions in buildings has increased between 1990 and 2009 with 17 % [6] This is caused by increase of habitants together with the decrease of the numbers of persons in one family (from an average of 2,98 in 1970 into 2,3 in 2009). The EEA [3] stated in her recent report that Belgium is not on track in view energy consumption neither on achieving the GHG emissions targets. The target on the share of renewable in final energy consumption is achieved. In the province of Limburg (Flemish part of Flanders), the aim has been set at 2050, with a 30% reduction in greenhouse gas (GHG) emissions by 2020. It was estimated that over 20% of the yearly regional GHG emissions were related to domestic heating and cooling and another 5-7% to that of public and (semi)commercial buildings. But we notice also positive trends. A lot of habitants and companies make efforts in view of energy savings and sustainable energy, but a lot of progress is still possible.

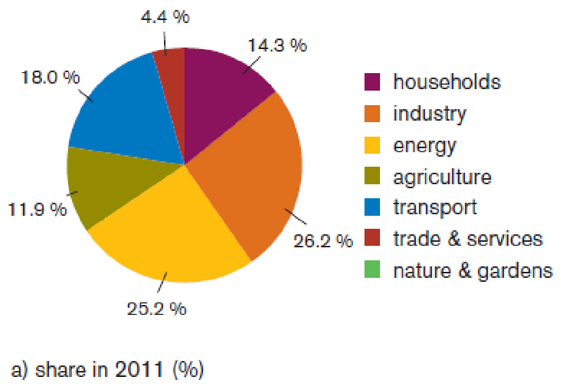

Figure 1 CO_2 emission in Flanders [6]

4. Technology

The environmental technology has already modified strongly since the first development in the early 60's of the previous century.
The first environmental technologies, designed as "end of pipe" technologies, moved towards clean technologies with a focus on reducing environmental impacts during the whole life cycle [7].

Clean technology is often defined as "Clean technologies are any product, service or process that delivers value using limited or zero non-renewable resources and/or creates significantly less waste than conventional offerings" [8].

At this moment Clean technologies are divided into six subcategories: environmentally-friendly energy and energy storage, circular economy, sustainable water management, sustainable mobility, resource and material efficiency and energy efficiency [9].

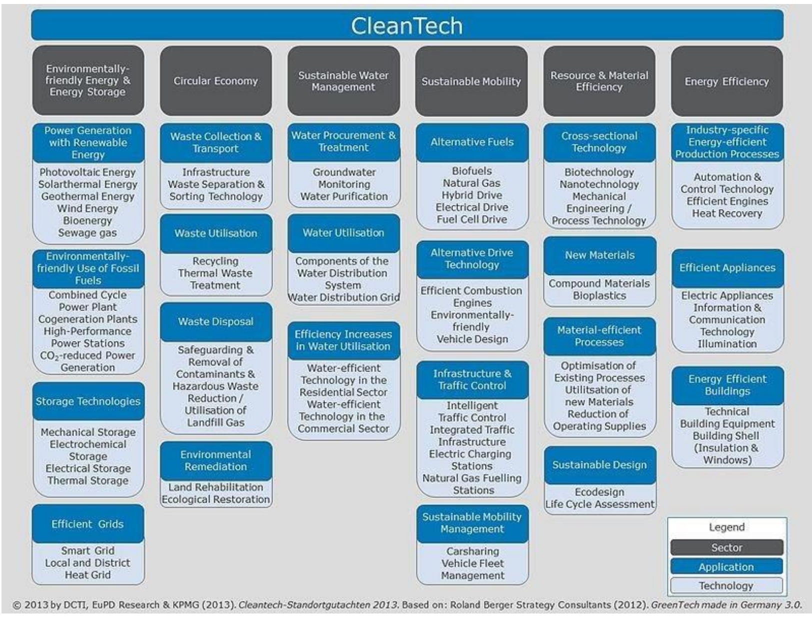

Figure 2 CleanTech categories [9]

The most recent evolution in environmental technologies is directed towards interaction between different industrial processes namely the industrial symbiosis: the waste from one industrial plant might be the input for another process [10].

Besides industrial symbiosis there is also a trend to develop urban symbiosis projects [11]. This can be a strategy to create a more efficient metabolism of the cities. In addition new urban areas will/must be created. These areas provide scope for experimentation regarding novel infrastructures as well as new products/services. Many cities have started their metamorphosis into a new city model. These cities will not only connect services, utilities and road to internet, but the smart cities will manage their energy, material flows (including waste and urban mining), logistics and traffic. One of the positive impacts will be a decentralized, climate friendly energy production and consumption.

Due to this way of organizing, buildings are no longer the problem but are the solution to solve the (energy) problem. As they fit with the main characteristics namely

- Renewable energy
- Closed loops (as much and as many as possible) products
- Decentralised

they can be seen as an application of clean technology.

Energy Efficiency for buildings and his variants (see further) can thus be seen as an implementation of the principle of Clean Technology. Special attention must be given so that all instruments and approaches applied to promote building energy efficiency should be coordinated to ensure that they are pulling in the same direction.

5. Business models.

Across all industries, there is large evidence that these new clean technologies are having a major impact on business models. In addition changes also occur at the consumption level, by moving the demand for products and services for more dematerialised consumption. Consequently there are calls for a new sustainable business models. Bocken[12] developed eight sustainable business models archetypes. One group with particular attention are known as Product Services Systems (PSS) [13]. These PSS business strive to present value propositions that simultaneously meet economic, ecological and social needs economy (see fig. 3). They have been recognized as a concept that can help from a classical linear economy (product) towards circular economy (service, function).

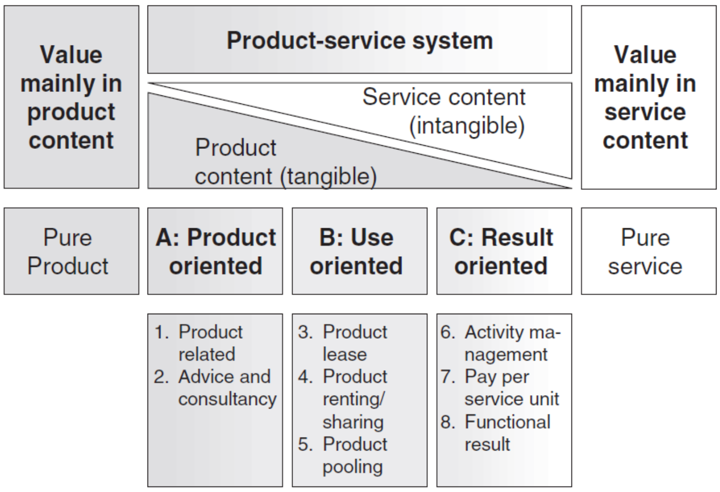

Figure 3 PSS subcategories [13]

Community is an important topic in this evolution. We need to evaluate from good projects into integrated cluster of smart activities.

The energy efficiency for buildings can be improved by replacing existing installation with actual technologies and accurate control systems. But often the use of the trias energetica [14] is not sufficient in order to get the (climate, environmental) goals.

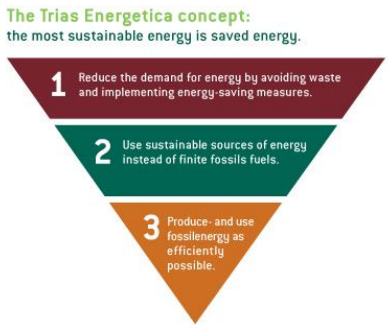

Figure 4 Trias energetica [14]

Our society is technocratic and innovation driven. The technique is often seen as the cause of the pollution. On the other hand there is also hope that the technology can be the solution for a sustainable society. So EES and his variants (solar ESC, ESC, EPC, Smart EPC, CR-EPC, ….) [15,16] (See fig. 5) can be seen as an implementation of the principles of clean technology and as a sub-set of the PSS family focussed on energy services provision [17]. In this PSS context, the service provider is often stimulated to use and maintain any related products properly, increasing both efficiency and effectiveness, which leads to several potential sustainability such as

- Lower materials and energy consumption during production and use
- Extensions of the manufacturers responsibility for the product in the use and the end-of-live phase
- Development of more durable and use-intensive products
- Easier upgrading to more eco-efficient technologies

The PSS accelerate transition towards a post fossil society.

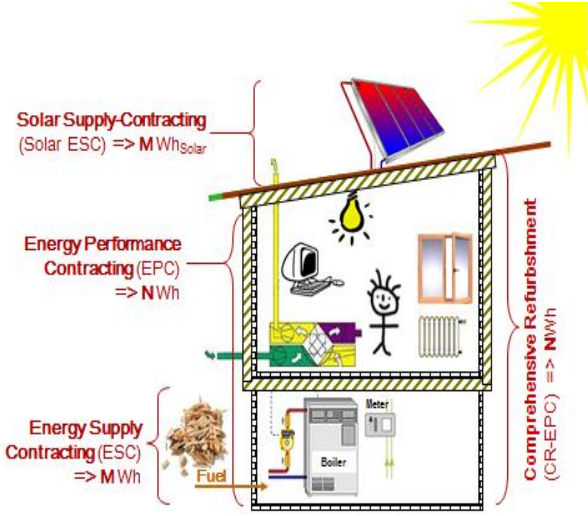

Figure 5 Different possibilities for EES [15]

6. Case

6.1. Introduction

At this moment in Flanders the hospital OPZ in Rekem has realised the first ESCO project to reduce their energy bill, maintain their technical installations, and guarantee comfort. Indeed although sustainable building has evolved to a more mainstream concept, it soon became apparent that even building professionals often lacked specific knowledge and insights. Therefor the PXL University Colleges has customized a postgraduate with the strong interaction of several dedicated stakeholders. The collaboration between early adapters and the steering committee is important and helps to develop the "ESCo" market. The PXL has recently started an EES project for its own buildings and the students of the PG EES, having a public or private professional background, taking different initiatives, several projects (private and public) are in the pipeline. The PG EES is definitely a catalyst for more EES projects in our region. The Energy Quick Scans, as a first step in our EES for PXL, is illustrated in this case.

Participation is seen as pre-requisite for achieving sustainable development. It is one of the buzzwords that has entered the sustainability discourse (SD), but lacks a more differentiated use and application.

Higher educations (HEI), seen as a key player in the promotion of SD are making advancements in SD implementation (e.g. in terms of campus greening, curriculum renewal and research orientations). Stakeholder groups of HEI can be classified by internal/external, individual/collective, academic/non-academic, but as well the government or other substantial supporters the main stakeholders [18]. The University College PXL has taken the initiative to organise a customized postgraduate. It is developed with the strong interaction of several dedicated stakeholders: BELESCO (association Belgium), Infrax (a public ESCo), Encon (a private ESCo), Dubolim (sustainable building) and the (local) government the province Limburg [19].

6.2 Curriculum Postgraduate Energy efficiency services.

Although sustainable building has evolved to a more mainstream concept, it soon became apparent that even building professionals often lacked specific knowledge and insights [19].

There are three obliged modules in this course

1) Energy efficiency services dealing with buildings (with special attention towards the iterative project cycles including the topics audits, measurements and verification and the role for facilitator). Also the link between building and mobility is a subject, as well as attention for monuments.

2) In the second module the life cycle costing is the main subject. In addition the aspects of circular economy as well as the green value/added value are explained.

3) Communication.
Special attention towards in- and external communication in combination with change management strategy.

6.3 (present) Output

The University College PXL recently decided to start a preliminary EPC study for their own existing buildings. The goals of the preliminary EPC study are

- The potential of the energy savings in the main technical domain
  - HVAC (heating, ventilation, cooling)
  - Lighting
  - Isolation of the outher shell (roof, wall, window and door).
- The determination of the perimeter of the investment. Different scenarios can be considered
- Determination of the duration of the EPC contract (including maintance as wel), in view of the financial scheme versus the total investment
- The development of a financial plan and the evaluation of the financial profitability of the EPC project

The energy quickscans performed in view of this preliminary study, will clarify the potential in the mentioned technical domains. Production, distribution, emission en regulation will be considered in view of HVAC optimization. For relighting both relamping and automation will be calculated. In case of isolation of the outer shell, there will be a focus on the several construction components. Special attention will be given for these measurements with a reasonable payback time (typical max. 15 years). The energy efficiency options will be analyzed and put into an investment matrix.

In addition participation of academic and non-academic staff is foreseen in view of present knowledge but also in order to improve the support and to communicate the non-energy benefits. This PG is also a catalyst for other (public) project in the neighborhood. The City of Hasselt Hasselt signed the covenant of majors 2020 and made the commitment to reduce the CO_2-emissions with 20 % in 2020 and to achieve the target on the share of renewables in final energy consumption (13 %). But as a consequence of this PG and the debate, sustainability is strongly incorporated in the procurement for their new city office. Geothermal heating pumps, PV installations, green roofs and low energy lighting will be incorporated. The excellent isolation and energy values meet and even surpass the nearly zero-energy criteria for buildings of The Energy Performance of Buildings Directive of the EU, even though the criteria has only to be met in 2018.

7. Conclusion

Progressing towards several climate and energy targets at the same time presents a number of co-benefits. For example, the significant deployment of renewable energy between 2005 and 2012 resulted in GHG emissions savings and to a certain extent, a reduction in primary energy consumption, through the replacement of less efficient fossil fuels plants. Additional efforts will be necessary on implementing and enforcing existing policies and in overcoming common barriers associated with EES (high investment capital costs, lack of information,…). EES can help to decarbonize the energy sector and make the energy transition successful. (trends and in the EU)
In combination with the integrated environmental assessment [20] of the use of materials in buildings (based on monetised indicators), we can counter the strong demand for energy and material resources if combined with new sustainable business models.

In addition connected houses have the potential to be vastly more energy efficient, reducing direct cost for consumers as well as mitigating economically damaging environmental degradation [21].

This specific approach of the postgraduate EES deals with a "built on" (extra sustainability courses) as well as with a built-in approach (an integration of sustainability in research and campus development).

This PG EES is a catalyst for more projects in our region: in other words, it can contribute to develop the "ESCo-market" and to overcome the several barriers. Therefore governments need to be responsive to the rapid changes and challenges. They need to adapt and continuously evolve in order to co-create public value with private and public sectors.

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Who's in Control: A Look at Control Systems Characteristics, Energy and Roles in Net Zero Buildings

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Abstract

This report summarizes the findings from the commercial building research: Zero Net Energy[1] (ZNE) Controls: *Characteristics, Energy Impacts and Lessons,* conducted by New Buildings Institute (NBI) on behalf of The Continental Association of Building Automation (CABA) in 2015. The research examined the perspectives on controls from design firms responsible for 23 buildings, operators of six buildings and occupants of seven buildings.

The approach in this summary is to distill the project and information down, yet maintain the high-level and critical aspects of the findings. A full report of the project with extensive detail on the survey participant's responses is also available.

Control systems can deliver important benefits that support the owner and occupants as well as goals of reduced energy use in buildings. This research found that while controls are considered highly critical to energy performance there are often installation, communication and integration issues. Decreased cost of sensors is driving greater inclusion of controls across multiple systems and operators now need greater knowledge and skills in interconnectivity and controls. With the increasing role of controls the controls contractor needs to become a first-tier part of projects. These, and other, control-related trends and recommendations for paths to high performance buildings are presented in this summary report.

Background

In 2014 The Continental Association of Building Automation (CABA) commissioned New Buildings Institute (NBI) to conduct research on controls in Zero Net Energy commercial buildings. ZNE buildings are an emerging trend in response to energy efficiency and carbon reduction policies, as well as market interest in 'green and sustainable' environments. NBI's last decade of work in building performance outcomes and ZNE buildings identified a gap in information concerning the control systems applied in these leading edge buildings. The outcomes of this collaborative research project can help fill that gap and enable a better understanding for the building and energy industry. The findings can help: manufacturers target improvements; design teams better integrate controls and work with contractors more effectively; and utilities identify program priorities leading to a next generation of buildings on the path to zero. The research was conducted from December 2014 to September 2015.

The work was guided by a Steering Committee representing a cross-section of providers in the energy and building controls marketplace. Representatives from each organization joined NBI and CABA on regular collaboration calls to guide the research scope and ensure it met project objectives. **Figure 1** shows the 18 companies and organizations that were on the Steering Committee and supported this project [1].

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[1] ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy. Also called Net Zero Energy or Zero Energy buildings. Buildings without renewable energy but with equivalent low-energy use may be termed Net Zero 'Ready'.

Figure 1: Project Steering Committee and Funders

Introduction

Controls – Controls – Controls! This aspect of commercial buildings has been frequently cited as the linchpin to creating, and maintaining, buildings that perform for comfort and for optimum energy use. The building and system-level controls can be a cornerstone that secures performance, or a weak link that creates challenges for design teams and operators. It is now possible for a high-performance building to integrate and optimize all of its major functions [2]. ZNE buildings are at the forefront of energy efficient design and operations, yet little is known regarding energy-related control systems in these advanced structures. This project focused on the control aspects in 23 ZNE buildings.

Key Objectives

The objective was to characterize monitoring and control systems in zero net energy buildings focused on three key areas from the designer and user experience. The three key objectives were:

1. **The Design, Selection and the System**. What did they choose and why? What were the selection criteria, method, and the actual attributes of the control system installed at a set of ZNE buildings? What lessons can they share to increase good design integration and performance outcomes of controls?
2. **The Energy Impact**. What energy performance are these ZNE buildings able to target and obtain? Can we identify savings attributed to various control systems or within the whole building energy use? How important to low energy targets were various systems in these buildings?
3. **The Use and User Experience**. How are controls being operated, what is effective, and what is lacking? What are the perspectives and experience of the operators and occupants? What is needed for best outcomes in performance? What are the most desired and applied functions? What training/experience is needed to operate the controls?

Methodology

The research approach was based on utilization of existing lists of ZNE buildings in the NBI *Getting to Zero Database*[2] and the findings in the *2014 Getting to Zero Status Update*[3] [3]. These represent the most comprehensive list of ZNE buildings in North America and include varying degrees of information on the building characteristics, technologies, energy use, and owner perspectives on ZNE. The research team and Steering Committee identified the priority building types and reviewed the areas of inquiry for the surveys. The surveys were conducted in person, via phone and/or through an online link. The research team identified an initial target list of over 60 projects and design teams and did extensive outreach to get the research target of 20+ building projects.

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[2] The Getting to Zero Database is a publicly available resource with information and case studies on ZNE buildings. http://newbuildings.org/getting-to-zero-database

[3] http://newbuildings.org//2014-zne-update

Surveys

Survey questions included yes/no, ranking, multiple choice, with the ability to select more than one response in some cases, and narrative response. Many questions were narrative response and all questions allowed comments. The research was targeted to parties responsible for the selection, operation and utilization of the control systems. The research sample included design firms (architect and engineering), design team surveys of 23 buildings, operator surveys of six buildings, and 130 occupant surveys from seven buildings. The survey instrument included over 100 customized questions for the design teams and operators. The occupant survey had ten questions, and responses were anonymous. It focused on the awareness of the occupant of energy targets, their engagement and experience with control systems, and their desire for greater or less ability to control energy using features.

Drivers of Change

The building industry has seen a dramatic rise of connectivity and monitoring that includes energy and equipment performance assessment. This extends well beyond the historical use of whole building monitoring and now includes discrete building systems, individual equipment and even each plug outlet. The boundary for controls is also expanding beyond the building as distributed generation (renewables or other onsite generation), demand response (controlling equipment use through price or demand signals), and onsite storage (renewable generation integrated batteries) become parts of the new bilateral transaction of energy with utilities and other providers of services.

These trends are driven in part by dramatic reduction in the costs of sensors and the rise of wireless and direct digital controls (DDC). This in turn is tied to trends from: the Internet of Things (IoT), original equipment manufacturer (OEM) integration of these low cost sensors, the rise of LED technologies, gains in universal communications protocols, fault detection and diagnostics, and the widening use of computers and handheld devices for data access, management, and system control.

An additional, and significant trend is the interest and insistence of people on two contemporary topics: a) individual control and data access and b) the environmental character of their work or retail space. These interests merge in the area of controls where today's most highly desired young-tech work spaces reflect, and advertise, these features. A 'green' work space often includes control for natural ventilation, shading variations, daylight and lighting responsiveness customized at the individual light fixture, thermal control or feedback regarding comfort, and lobby displays of the building energy status and awards.

Defining ZNE

There are a variety of definitions in use pertaining to very low and net zero energy buildings [4] and classifications [5]. For this study the project team used Zero Net Energy because it is in use in California and in the largest studies of ZNE buildings in North America [ibid 3]. This controls study included both 'verified' (documented ZNE performance) and 'emerging' (striving for) ZNE buildings and, where relevant, this distinction is made. The terms used to determine if a building is ZNE are as follows:

- **Zero Net Energy (ZNE) Buildings** – Buildings with greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy.
- **Net** – The energy used by the building is completely (or more) replaced by energy produced by on site renewable sources so the building's 'net' energy use is zero. Energy use and production are constantly changing so net is calculated as an average over 12 months.
- **Energy** – All energy (electric, gas, steam, liquid fuel, etc.) consumed at the building interior and exterior (typically lights metered with the building, such as entry lights, walkways, signage, etc.[4]).
- **Energy Use Intensity (EUI)** – In order to normalize the various fuels in a building, the energy for both use and production/generation are converted to thousands (k) of British Thermal Units (Btu)

[4] Parking lot lighting or other larger outdoor energy use is often separately metered and not part of the building energy use.

and then divided by the square feet (sf) of the building with 'yr' representing the 12 month period of data. EUI is the most commonly used metric of building energy use or performance and allows benchmarking and comparisons of buildings.

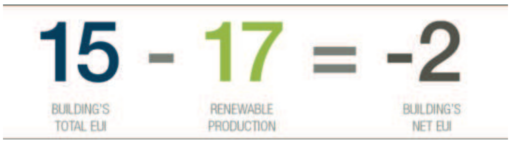

Figure 2: Example Calculation for Zero Net Energy

Explanation of Figure 2 calculation: **15** (12 months of building's total energy use in kBtu/sf/yr) – **17** (12 months of onsite renewable production[5] in kBtu/sf/yr) = **-2** (building's net EUI in kBtu/sf/yr). Since the 'net' is zero or less it is a ZNE building.

Metric Conversion: *Most countries world use the metric system for measurement and reporting, and that convention/system of units is that the energy use for all fuels is converted to kWh and summed and then divided by the building square meters. In the above example it would be:* ***Buildings Total EUI 47 – 54 Renewable Product = -6 Net EUI in kWh/m²/yr.***

The Buildings and People

The initial part of the research established the characteristics of the buildings and the survey respondents. Research participants were selected based on their role in designing or operating a specific ZNE building. The building type selection was due to the transferability to a wide range of buildings. The following characterizations apply to the buildings and the research participants:

- The study set of 23 buildings are primarily 10,000 – 100,000+ square feet and composed of offices and higher education buildings. A courthouse, two laboratories, a library and a museum as well as a few buildings of smaller size are also represented.
- The majority of buildings in the study are located in California due to the high concentration of ZNE buildings located there but the full set of buildings represents a range of climates.
- The design firm participants had extensive experience in the two primary building types (office and higher education) and have worked on an average of four ZNE buildings.
- Contrary to standard practice, these designers set energy and green building targets) and maintain ongoing tracking and feedback on post-occupancy energy use and operations.

[5] Renewable Production may be called Renewable Production Intensity or RPI

Table 1: Energy Goals Indicated by Project

Building ID	Zero Net Energy	LEED Certified	Living Building Challenge	Zero Net Electric	Carbon Neutral	Architecture 2030 Compliant	Zero Net Energy Ready
A	■						
B	■		■				
D	■	■					
E				■			
F	■	■	■		■		
G							■
H	■	■					
I	■						
J	■						
K	■	■		■	■		
L	■	■			■		
M	■	■				■	
N	■		■			■	
O	■	■	■				
P	■			■			
R	■	■		■	■	■	
S	■		■	■			
T	■	■	■				
U		■		■			
V	■						
W	■						

Controls and Integration

One of the primary goals of this project was to characterize the controls technology and strategies used in ZNE buildings within the consideration that controls are, of course, dependent on what systems are used in the building.

Controls and Integration Summary

- The vast majority (91%) of the buildings use control systems that integrate multiple end-uses.
- Most (67%) of the buildings have an integrated whole-building control system to address all major end-uses. Only a few (9%) have no whole-building controls architecture with controls only at the end-use level. These buildings tend to be smaller and use simpler design approaches. **Figure 5** shows the extent of system level controls integration.
- Despite the preponderance of integrated controls, the controls sequences are not everything: fully 74 percent of the buildings surveyed rely on the occupant for some part of the success of the controls operations.
- Most buildings used a combination of automated and manual controls to adjust the building's environment, e.g., when occupants manually open windows, the HVAC zonal programming is overridden until the window is shut.
- Light switches are still more prevalent than occupancy sensors, but intelligent light switches are becoming more common.
- Some buildings have light switches whose default setting is "off," and are programmed so that that the lights must be manually turned on and then will eventually turn themselves back off.
- Daylighting controls are an integral part of high performance buildings. The project used the range of daylighting controls shown in

Table 2: Major Lighting Controls Strategies [6]

Strategy	Definition	Relevant Technologies
Occupancy	Adjustment of light levels according to the presence of occupants	Occupancy sensors, time clocks, energy management system
Daylighting	Adjustment of light levels automatically in response to the presence of natural light	Photosensors, time clocks*
Personal tuning	Adjustment of individual light levels by occupants according to their personal preferences; applies, for example, to private offices, workstation-specific lighting in open-plan offices, and classrooms	Dimmers, wireless on-off switches, bi-level switches, computer-based controls, pre-set scene selection
Institutional tuning	(1) Adjustment of light levels through commissioning and technology to meet location-specific needs or building policies; or (2) provision of switches or controls for areas or groups of occupants; examples of the former include high-end trim dimming (also known as ballast tuning or reduction of ballast factor), task tuning, and lumen maintenance	Dimmable ballasts, on-off or dimmer switches for non-personal lighting

**Time clocks are often used for daylighting control in exterior applications, and could be used in interior spaces but rarely are.*

- Glare control and shading must be done properly to realize the benefits of daylighting. Most designers used fixed elements (overhangs, louvers) or manual roller shades.
- Interior shades or blinds were used in over half of the projects (52% - 12 projects) toward their energy reduction and occupant comfort goals, and 34 percent of these (four projects) applied automation to the shades or blinds. Figure 3 and Figure 4 show the strategies used for shading and glare control.

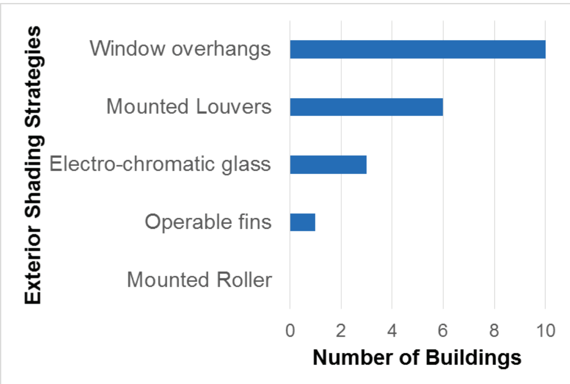

Figure 3: Exterior Shading Strategies

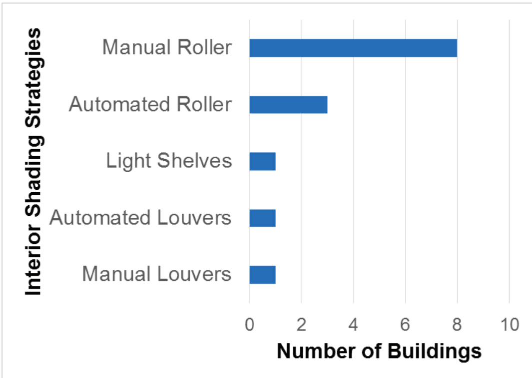

Figure 4: Interior Shading Strategies

- Automated shading was selected to improve thermal controllability and energy savings according to the design teams.
- Plug load controls, a relatively new entry into the building and system-level controls world, was recognized as an energy use factor that is typically outside of the hands of the design firm.
- While 64 percent of the projects included plug load controls, with most using a variety of controls solutions to address plug load energy use, it still was identified as challenging to get right. In high

performance buildings with highly efficient major systems (HVAC, lighting, etc.), this challenge is more critical due to the increased proportion of total energy used by plug loads.

- The highest-performing buildings have engaged operators and occupants standing on the shoulders of intelligent and integrated controls systems.

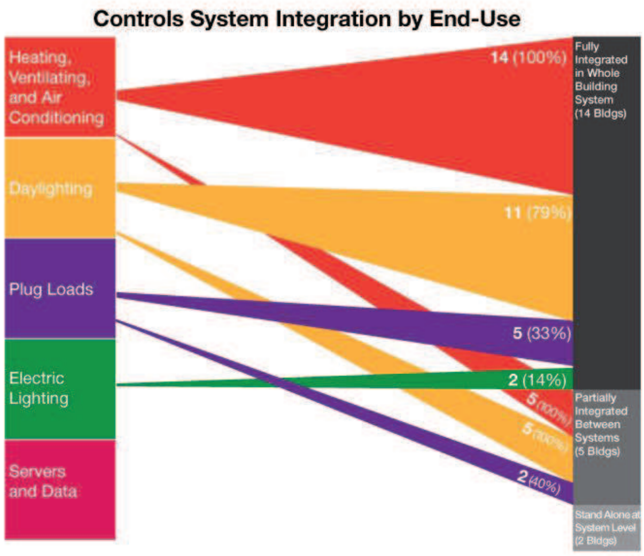

Figure 5: Extent of End-Use Controls Integration Use

Control Design Selection Process

Feedback from this section of the study made it clear that designing a ZNE building involves rigid execution of the design intent, thorough documentation, specifications and detailed sequence of operations, while still allowing for a great deal of built in flexibility when it comes to implementation, and ultimately, building operation. While this survey demonstrated that there are plenty of commonalities in approaches to achieving a ZNE goal, it also demonstrated that how one ultimately implements a ZNE design is built on experience and approaches can vary.

Selection Summary

- A vast majority (86%) selected prior experience with the vendors system is a top criteria, ahead of 57 percent that chose price (**Figure 6**).

Figure 6: Designers Criteria for Selecting a Controls Vendor/Subcontractor

- Selection of the controls typically falls to the engineer of record, with some input from the building owner and an assortment of subcontractors.

- Early identification and communication of energy goals was critical to the design and selection process of the controls.
- Most (66%) of respondents say that the attributes of the user interface and preference setting were very important or critical to ensuring proper use by the operator.
- The use of open source versus proprietary communication protocols does not appear to limit the selection process for building controls, nor does the use of open source protocols mitigate integration issues in the field.
- Despite the focus on performance and the qualification of the design and construction teams associated with these projects, incorrect installation of controls systems in the field is the greatest reason for excessive follow-up, followed by integration issues (**Figure 7**).

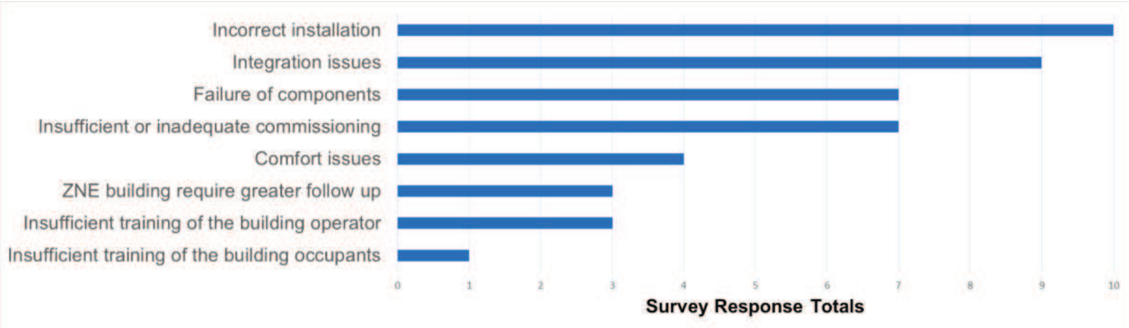

Figure 7: Reasons for Controls Follow up by Design Team

User Experience

While we have seen the market for ZNE continue to grow, the building industry still has a long way to go in order to formally acknowledge the role that the building operator plays in determining the success of a project, and in providing them with the tools they need in order to see greater market penetration of ZNE buildings.

Operator Survey Summary

- All of the participants agreed that the building operator should be brought into the design process as early as possible, and should be involved in all sequence development efforts as well as the commissioning process (only one in six of the respondents on these buildings was involved at the design phase). Not only will this facilitate a smoother startup process, but will also allow the operator to understand the design intent behind the key strategies and systems. As noted by one of the operators, they are the ones "who have to understand how to use the systems every day and have to ultimately buy into owning the system."
- The building operator's relationship with the control vendor is essential to ensuring that the building is operated in an optimal manner. This relationship involves frequent communication, especially in the first year of operation when the operator and vendor have to work as a team to troubleshoot problems and implement solutions. In several cases, a control integrator contributed significantly to this process.
- While training is important, there was not a consistent approach to formal training that these operators had gone through, nor was there a common professional development path that led them to their current position. Most of the training was characterized as happening informally on-the-ground, with a heavy reliance on the Operations and Maintenance (O&M) Manual and the Commissioning process and report.
- The building operator is responsible for compiling a System Support or Procedure Manual, which is important to ensuring the persistence of efficient operations and ensuring that the project is meeting its performance goals.

- Five of the six operators surveyed agreed that the value of investing in controls for these buildings is increasing. Similarly, four of the six agreed that a building designed with numerous passive systems did not reduce the scope of controls needed to effectively operate the building.

Occupant Survey Summary

As greater focus is placed on the role of occupants in the energy outcomes of buildings, it is increasingly important for design teams to consider their interactions with the building and its control systems. For the most part, occupants felt satisfied with the electric lighting controls featured in these buildings where 65 percent are 'neutral' or 'about right'. The findings also point to an important call for greater controllability in regards to shading and glare with 38 percent wanting 'somewhat more' or 'more control' shading and glare controllability (Figure 8).

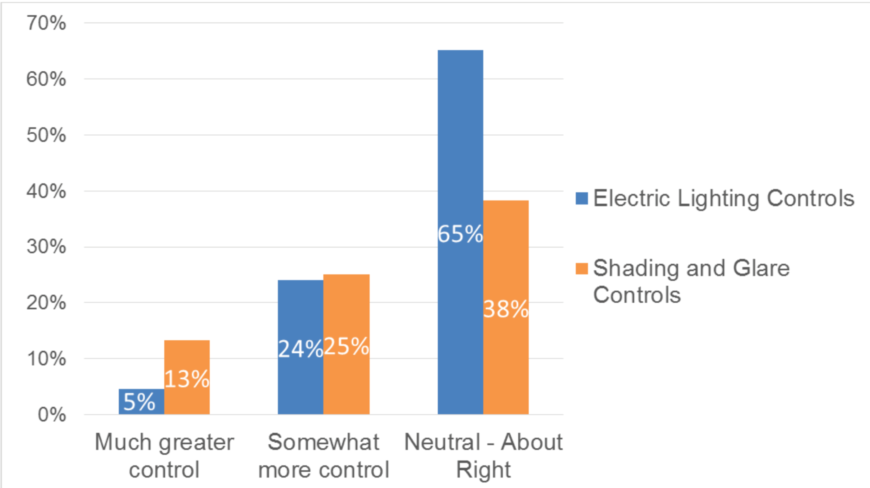

Figure 8: Occupant Interest in Interaction with Lighting and Shade Controls

Given the energy performance goals of these projects and the feedback provided by the occupants surveyed, it appears that the design teams and building operators have for the most part successfully walked the line between automation and reliance on the building occupants to interact with the systems in providing healthy and comfortable interior environments. Below is the summary of the occupant surveys:

- Occupants are very satisfied with the quality of light in their spaces.
- In providing ample daylighting and views, it is important to allow occupants to have the ability to control shading elements in response to glare.
- The level of satisfaction with the lighting and daylighting, regardless of control access, was quite high in these buildings with 70 percent in the moderate to very satisfied category with its characteristics. With regard to daylighting, a noteworthy 75 percent of occupants indicated that they were moderately or very satisfied with the daylighting system and characteristics.
- Occupants responded favorably to the ventilation strategies featured in these buildings, including natural ventilation and dedicated outdoor air systems.
- The heating systems and strategies appeared to be well regarded, while more occupants expressed a desire to more finely control cooling in their zones.
- The plug load controls don't appear to be problematic or obtrusive for most of the building occupants.

Energy Findings

Getting to Zero is strongly facilitated by the leadership, experience and technical design knowledge of firms that have worked on numerous low and zero energy buildings. The research set of 23 buildings reflect leading practitioners in both architecture and engineering, as well as owners that support or mandate a low-energy building. During the conceptual and pre-design stage, the fundamental program for the building is established, which, in the case of these buildings, included aggressively-low energy use outcomes. These firms knew these outcomes were feasible, not fantasy, and 100 percent of the participants considered setting early energy targets as key to the design process and outcomes

While some buildings have actual metered data of their Energy Use Intensity others are based on their targets as shown in Figure 9.

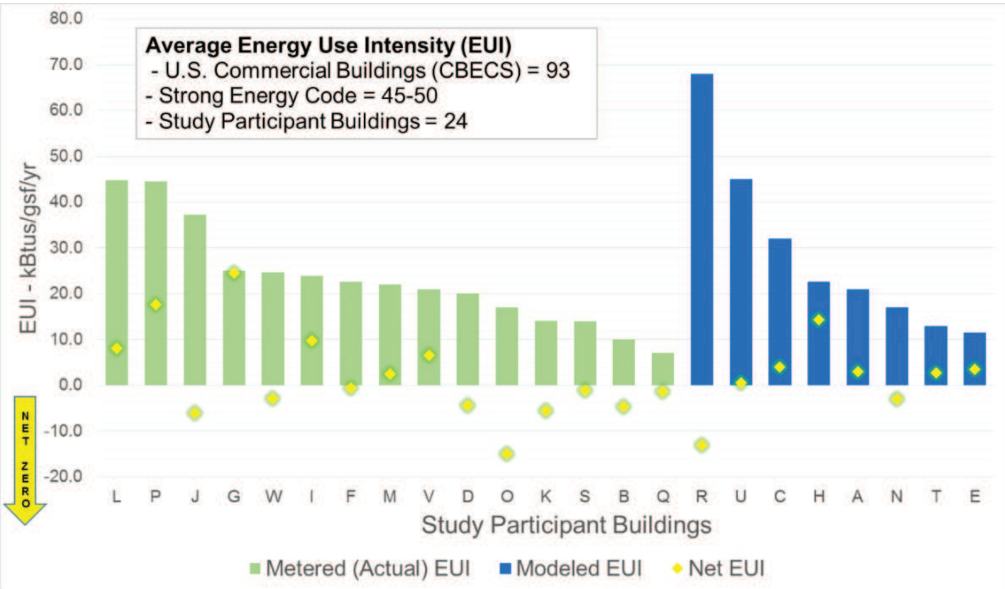

Figure 9: Energy Use Intensity (EUI) of Participant Buildings

Metric Conversion: *The EUIs above in kWh/m²/yr. (per square meter basis with all fuels converted to kWh) would be: US Avg. (CBECS) = 293, Strong Energy Code = 158, Participant Buildings Average = 76*

It should be noted that not all buildings that target ZNE will reach that outcome as ongoing building commissioning, weather variables, and occupancy and hours of operations affect a project's ability to meet targets, but the design and ongoing effort usually result in exemplary energy performance.

Energy Findings Summary

Whole Building Energy Aspects

- The energy use (modeled and metered) of these buildings collectively is an average EUI of just 24 kBtu/sf/yr (258 kBtu/sq.meter/yr) or approximately and that drops to an average EUI of just 19 kBtu/sf/yr (237 kBtu/sq.meter/yr) when the two lab buildings are not in the average. This is half that of a building built to strong energy code levels[6] and 75% less than the US national average is 93 kBtu/sf/yr (1000 kBtu/sq.meter/yr).

[6] There is a wide range of energy codes in the U.S. with the strongest energy codes (IECC 2013, IgCC, Title 24 California) resulting in code buildings that are very energy efficient. These codes are also on paths to get to zero energy standards over the next decade.

- The projects primarily used a High Performance or a LEED building as the baseline.
- Most firms utilized more than one energy modeling software and noted that for radiant heating/cooling systems and natural ventilation, Integrated Environmental Solutions (IES) and Thermal Analysis Simulation (TAS) software provided improved analysis.
- New resources are emerging to support dynamic simulation models for building energy and control systems but are not yet known or in use by practioners [7].
- The buildings' high efficiency HVAC systems - such as ground source and air source heat pumps, radiant heating and cooling distribution and Variable Refrigerant Volume systems – are cited as key, after building siting and envelope design, to the low energy use of these buildings.

System Energy Aspects

- Average metered Lighting Power Density (LPD) was .35 watts per sf (40-60 percent less than code) and modeled plug load targets were .65 watts per sf (60 percent less than standard baselines).
- System-level contribution to the projected whole building energy savings ranged from 6 percent to greater than 15 percent (**Figure 10**):
    - ***Lighting Controls***. Selected as > 15% and never less than 11% of the whole building savings, with daylighting controls as the most common reference.
    - ***HVAC Controls***. Selected as >15% of the whole building savings. HVAC strategies were passive strategies first, with controls for natural ventilation, night flush and thermal set point controls, and then to optimize the mechanical system control and monitoring.
    - ***Shades or Blinds.*** 33% of those with shades or blinds said this strategy "Contributed to thermal energy savings in the model sufficient to reduce the HVAC system size."
    - ***Plug Load Controls.*** Selected as either >15% or 6-10% of whole building savings.

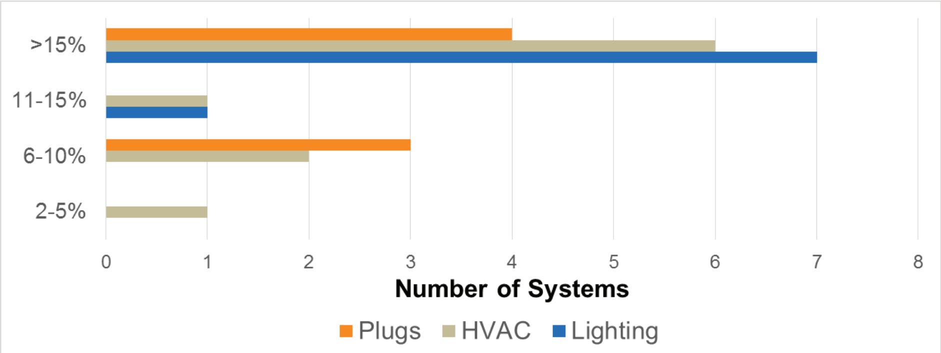

Figure 10: Whole Building Energy Savings per Controlled System

Occupant Energy Role

The Occupant's role in energy savings was considered a key factor to getting low energy outcomes by the majority of participants.

- All of the projects employed, or plan, the use of a public energy dashboard as one method to try to influence occupants' attention to the building's energy performance.
- Nearly three-quarters (74%) of the design team projects included occupant direct engagement, with controls including light levels, window operations, thermal settings, and plug load management.

- The occupant should not be solely responsible for optimizing system settings or remembering to turn them off. Designers usually incorporated a default reset for systems with occupant access to controls, while approximately one-quarter of the projects kept the system controls autonomous.
- Occupant education and ongoing connection with the building performance and their impacts through such methods as emails, signage, and even gamifying energy use were the most frequently cited non-control strategies.

Discussion

This section discusses the takeaways and conclusions from the study and presents some recommendations to improve the role of controls in high performance and ZNE buildings. .

Controls at the Nexus of Performance

As the built environment continues to move toward lower energy use, controls become a more critical and nuanced aspect of achieving and maintaining energy and operational expectations. There is a renewed focus on passive design strategies as a foundation for getting to low and zero net energy buildings, while at the same time the world of abundant sensors, wireless technology and automation is accelerating. In parallel, policy makers and utilities [8] are looking to buildings to reduce carbon emissions from power generation and to shift to other models of energy production and distribution by 2030 [9]. The nexus of these market, policy and technology factors occurs in zero net energy buildings, where the interplay of design, technology, control, operations and occupants affect the end performance.

The set of buildings in this study are 23 leading edge designs incorporating a range of strategies and technologies that share a common intent to minimize energy use and get to zero net energy performance. Their design teams also share many common perspectives on the value of, and role of, controls. Every project design firm selected controls and early energy targets as very important or critical to getting to ZNE. They also universally agreed that every single project “has some controls problems.” The reasons were not focused on any specific product, but rather on the process to ‘get it right’ and installation issues. While some suggested simplifying things and avoiding as much automation and points of failure as possible, the majority said system integration, extensive metering, automation, granular levels of data and feedback are here to stay and are beneficial to the process.

Solutions in New Roles and Old Relationships

From both the design team and the operators’ perspective, the solutions lie in an increased need for the controls contractor and the building operator to be more actively engaged with the design early, during commissioning and after occupancy. A more robust scope for the controls contractor that includes responsibility for extensive commissioning, sequence documentation, and longer term availability post-occupancy may seem like a pipe-dream during budget development, but there are losses in real money and confidence in controls lost without this extended role. Since prior experience with the controls system is the top basis for their selecting a vendor (86%), even over price (57%), both the design firm and vendor are vested in creating a successful relationship and outcome.

In the current process, operators often run the building through a series of trial and errors with no formal training. They cite the failure of components as the main reason for ongoing call backs with the design team – another costly factor for both parties – while the majority of respondents found most issues associated with poor installation, lack of commissioning, and improper settings. These are matters that could be reduced or resolved with more connection between design, controls and operator pre- and post-occupancy. In these ways, ZNE buildings mirror all buildings – getting system sequences and controls commissioned correctly can be the Achilles heel of building performance. But ZNE buildings have more high performance systems, integrated energy production, and tend toward greater system integration, metering, monitoring and feedback as their standard practice. Due to this, research participants identified a new role that some called “Controls Integrator” while others noted a “ZNE Commissioning Agent.” Both titles identify an emerging role for a multi-system and controls expert that has continuity of the building performance outcomes for both energy use and production, from design through to occupancy.

Zero Net Energy Driven by Good Design, High Performance Systems and Shading

These buildings are designed to, and in many cases documented at, energy use levels 50 percent less than most new buildings today and over 75 percent less than the average existing buildings, with renewables making up the small balance of energy needs. Getting to Zero is an integrated approach that begins with applying a good site orientation, envelope design and passive strategies to reduce energy needs, followed by the mechanical systems and their controls to drive the next layer of savings[7]. The HVAC systems in these buildings tend toward high performance with radiant heating and cooling, ground and air source heat pumps and variable refrigeration flow systems. Ventilation is most frequently provided through manual and automated windows (natural ventilation) and/or dedicated outside air systems (**Figure 11**). Lighting is always integrated with both daylight design strategies and controls, resulting in lighting power densities that are 40-60 percent less than a code building.

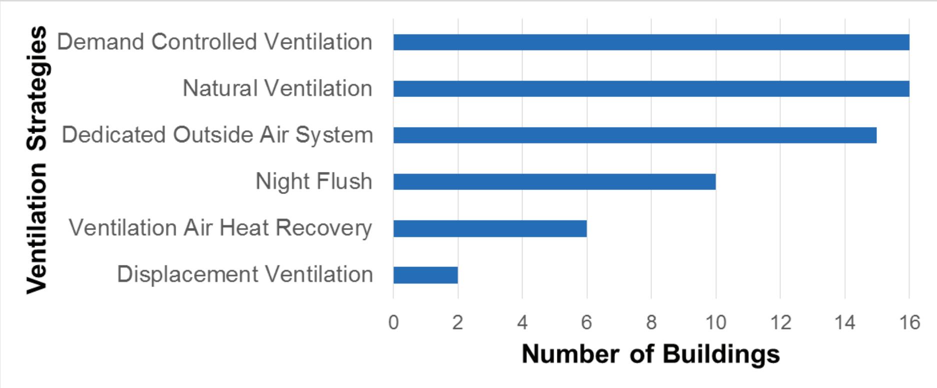

Figure 11: Ventilation Strategies

The pursuit of reducing occupant-driven plug load energy remains a challenge, but well over half of the projects incorporated some control technologies such as smart power strips, outlet level controls or centralized power management, and 100 percent of them incorporated energy-use dashboards and occupant feedback. The majority of design firms attributed HVAC, lighting and plugs each with having a greater than 15 percent impact on the energy savings, so the success of the control of these systems means the success of the energy goals. Interior shades and blinds are an old ally for controlling glare and heat, but they are having some renaissance with new designs and automation beyond simply a draw cord randomly applied (or not) by the occupant. Over half of the projects included interior shades or blinds with manual and/or automated controls driven by thermal energy and occupant comfort benefits according to the design firms.

Occupants are a New Operator

The role of occupants on energy outcomes has never been greater. Although designers and operators see the value and importance of all system and building level controls increasing, despite reductions in baseline energy use, the occupant impact remains a wildcard. Fully 74 percent of the buildings rely on the occupant for some part of the controls success, from roles with operable windows and blinds to plug load controls and energy awareness campaigns. But occupants must not be left to their own devices completely. The study found a strong participant message to allow engagement with building systems combined with “Design for Off”™ through a hybrid of manual + controls where systems return to a default triggered by time or sensor and messaging[8]. Yet nearly 70 percent of the occupant respondents said they do not receive any communications on the topic of their role in reducing energy consumption in their

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[7] Exterior shading, and in one case electro-chromatic glass, as a part of the envelope design, were credited in the energy section questions as being a major strategy toward reducing the mechanical cooling system size.

[8] “Design for Off” was developed and trademarked by Ecotope and referenced by several projects

building, further indicating a gap from design intent to operations and occupancy.

These buildings had generally very high levels of occupant satisfaction, regardless of control access, with the lighting and the daylighting (70% and 75% respectively) the indoor air quality and heating (63% and 57% respectively), and plug load controls (45%) while cooling had a high unsatisfied response (40%) (**Figure 12**). A majority of the respondents did want some degree of greater control modified by comments that a bit more would go a long way. For ZNE buildings, perhaps more so than standard buildings, a flaw in design or control can adversely impact the public perception of these leading buildings. While some owners were hesitant to survey occupants, either due to interruption of their primary work or to avoid soliciting feedback that might be negative and/or warrant action and investment, others recognized that learning of and resolving problems has great benefits. The occupants, according to one design firm, are the best building 'sensors' and we need their perspective to tune the building controls. Both the design teams and the occupants recognized that in today's buildings with extensive plug loads and changing work and occupancy patterns the occupant is now an operator.

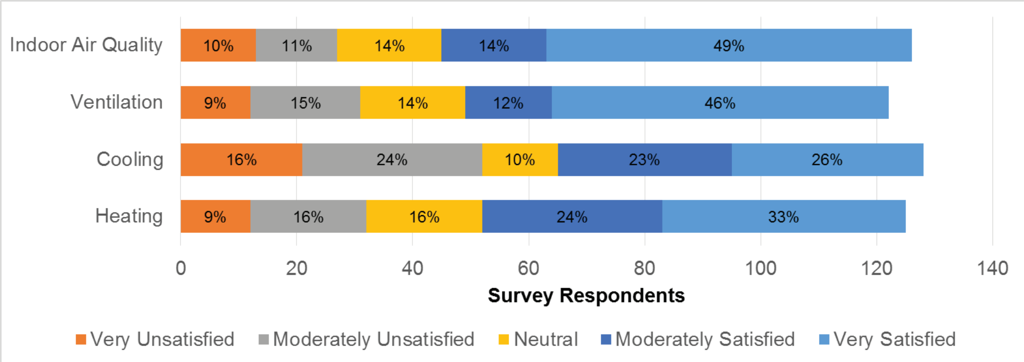

Figure 12: Occupant Satisfaction with HVAC Systems and Characteristics

Game Changers Include Integration, Engagement and a New Utility World

The survey included a blank section, or open ended question in interviews, in response to a question on emerging or game-changing trends for building controls. The results are grouped around three main themes, with a few outliers. First, the area of **Integrated and Low Cost Control Systems** was widely referenced as the major change currently in process and seen as on a trajectory of increased adoption. This included integrating more end-uses, greater wired and wireless connectivity between sensors and controls, greater data available from a single system sensor (e.g., light levels, occupancy and temperature), network interties and automation of the control management. Protocol standardization was cited as a trend that supports this area of change. 'Intelligent' or smart buildings leverage information technology to lower the costs of and speed the attainment of business and energy goals. IT is changing the way building controls systems are designed, installed and managed and that creates risks and significant opportunities [10].

Also notable were the responses regarding **adaptive controls** that learn and respond (adapt) to occupant-based needs and preferences. The residential thermostat "Nest" was cited as an example, but the use of 'artificial intelligence' in commercial buildings was described as a key missing piece. Adaptive controls were also mentioned with the integration of external real time weather sensors.

The second group of trends focused on **Occupant and Operator Engagement** through more extensive monitoring and feedback. Universal adoption of energy dashboards in these buildings was a first step, but participants noted trends for more graphical and intuitive user interfaces with key performance indicators, simpler monitoring accessible for smaller buildings and retrofits, and fault detection and diagnostics (FDD) embedded in equipment at the manufacturer. Occupant cues to open/close windows, turn off receptacle-based equipment, and relate energy use to higher values and goals based on dashboards, computer programs, smart phone apps, wearable technology (e.g., smart watches) or other visual messaging were also forms of engagement and trends.

Changes in the world of **Utility Programs and Pricing** was cited by a few respondents as a game-changer. Demand response programs with price signals for time of use or reductions at peak can alter the controls strategy. Most of these buildings now have bi-directional transactions (buying and selling) of energy with the utility company. The growth of distributed generation (located at multiple sites and owned by a wide variety of entities) due to increased renewables on buildings and the daily/seasonal variations in energy production and use are creating new load curves for utilities and reassessments of their base infrastructure and commodity pricing. Since energy costs are a key factor in the analysis of getting to zero, utility decisions can change the formula for what makes sense when and where.

Lastly, a set of trends were seen as noteworthy that overlap with the three groups but are worth noting individually. They are technologies growing in part due to ZNE targets: a) **Direct Current** (DC) building systems, b) **onsite energy storage** and c) **robotics**.

Industry Implications and Recommendations

When looking at the conclusions of this study, the findings need to be parsed by control-type and audience. The new world of integrated sensors, metering, monitoring and controls is not 'simple,' nor is the industry that manufacturers these systems, designs, builds, operates, owns or occupies buildings. Add in the energy industry and policy and political dispositions, and you have a matrix of factors and entities looking to find a blend of financial prosperity coupled with environmental stewardship. The implications lie in the interests of the reader, yet there are clear messages that apply across industries.

The complexity of controls in both quantity and derived data means a new learning curve and new players with controls expertise. The attention on energy efficiency of buildings as a carbon-reduction strategy is only going to increase from the few to the many, and the impacts will spread from components to construction, from program to performance requirements. This ZNE world is not a disconnected world, standing alone with its solar panels and wall packs of batteries – it is a community of buildings and leaders interacting within a new web of energy exchange. That these current buildings have demonstrated that ZNE is real, and that it brings benefits beyond energy, will only accelerate the need for innovative controls from the widget to the whole building.

Recommendations

Industry should move beyond products to performance-based services and find ways to help transition a much larger scale set of knowledge, skills and application of strategies and technologies to get all buildings to low and zero net energy. This report scratches the surface of the fast moving industry of control integration in buildings and increased drivers for energy efficiency. Greater investigation of bridging the design to operations gap, the training issues and new roles for control contractors and operators, occupant interest and impact of controls engagement, and the trade-offs of simplicity versus increased data and feedback are all called out from this research. There are five clear areas that repeat through the research that serve as recommendations to help move the current trend of controls integration toward a much greater likelihood of increased and ongoing energy performance and user satisfaction. These are:

1. **Prioritize Passive Strategies.** Prioritize passive strategies first during design then layer in controls to optimize the whole building outcomes.
2. **Integrate the Controls Contractor.** The controls contractor needs to be a primary team from design through occupancy.
3. **Increase Operator Training and Support.** Bring controls training and improved hand-off documentation to the operators and provide ongoing connectivity with the design team and controls contractor.
4. **Occupants are Operators but Default Settings Need to be the Backup.** Provide occupants with energy use engagement and control access with a 'hybrid' system that returns controls to default settings and "Off".

5. **Build Industry Awareness and Knowledge of Emerging Trends**. Increase industry awareness and knowledge of a) integrated, wireless and adaptive controls, b) user feedback and dashboards, c) DC systems and renewable integration, d) utility load management, price and program issues, and e) policy drivers toward low and zero net energy buildings through outreach, education, marketing, workshops, industry publications and programs.

Working on these recommendations through the chain of building and controls manufacturing, design, operations and influencing programs and policies will help smooth the path to performance. As the trend of low cost interconnectivity continues, the real estate ownership, management and energy efficiency industries have a collective need to harness a landslide of control evolution and occupant expectations toward buildings that operate elegantly, efficiently and in an environmentally sound manner. Based upon the advances in design and operations of this elite class of ultra-high performance ZNE buildings, coupled with attention the buildings sector is getting from entrepreneur and tech startups in the Silicon Valley, we anticipate the pace of change in the controls industry to accelerate even more rapidly in the coming decade. It is our hope that this study provides some stepping stones for effective controls in the next generation of ZNE buildings.

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Session
Policies & Programmes I

Design for Performance not compliance: making measured energy in-use the objective for new office buildings

Robert Cohen[1], Paul Bannister[2] and Bill Bordass[3]

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Abstract

The paper describes the transformation that has taken place over the last 15 years in the energy efficiency of new office buildings constructed in Australia and considers if and how countries across Europe could follow suit. The success in Australia has been greatest for the **'base building'**: the energy used by the heating, ventilation, air-conditioning (HVAC) and hot water supplies serving the whole building, together with all other energy uses in the common parts, including the lifts. Base building performance is determined by the building's design, its construction, HVAC services, controls, commissioning and management - all things the developer, designer, procurement and delivery team and operations and maintenance people can be responsible for. The Australian approach embraces a '*design for performance*' culture, supported by the NABERS[1] 'Commitment Agreement', where developers and their teams sign up to an in-use performance target. The process is underpinned by advanced simulation, strategic sub-metering and fine-tuning post occupation to help eliminate wasteful deviations.

The requirement of the EU Energy Performance of Buildings Directive for a non-residential building to be given an energy performance certificate when it is constructed, sold or let has stimulated a robust debate in all European countries about the relative merits of calculated asset ratings and measured operational ratings. For new buildings and major refurbishments, the paramount objective of a Commitment Agreement is to bring the two together. It requires the design process to predict how much energy the base building is expected to use when occupied. This then becomes the target for in-use performance (subject to codified adjustments for weather and the hours of occupancy of each tenant) and is verified by the direct measurements of sub-meters.

Introduction

In the 1990s, the Property Environment Group[2] in the UK identified a vicious circle of blame that conspired to undermine the environmental performance of the UK's prime office buildings. Since then, the energy efficiency of new rented office buildings in Australia has been transformed, while problems persist in the UK, and we suspect elsewhere in Europe. At the turn of the century, new office base buildings in Australia were no more energy efficient than typical existing ones. Over the last fifteen years, there has been a remarkable transformation in their energy efficiency, while existing building performance has also improved markedly.

In 1999, New South Wales introduced a voluntary system (the Australian Building Greenhouse Rating, ABGR), to measure and benchmark the CO_2 emissions arising from the energy use of office buildings. The system included procedures and benchmarks for 1). whole buildings, 2). "base buildings" (the landlord's services), and 3). tenancies. Over the years, this developed into a national rating scheme and became part of NABERS (www.nabers.gov.au/public/WebPages/Home.aspx).

A Base Building Rating

Base building performance is determined by the building's design, its construction, and its HVAC services, controls, commissioning and management - all things the developer, designer, procurement

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[1] NABERS (the National Australian Built Environment Rating System) covers energy, water, indoor environment and waste. It is based 100% on measured performance outcomes. The **NABERS Energy** rating scheme has enjoyed particular success in driving improvement in energy performance of larger prime office **base buildings** in Australia, for which it is now mandated (on sale or let) by the Building Energy Efficiency Disclosure Act 2010. NABERS is also available, but less widely used, for office tenant ratings, whole office buildings, and for shopping centres, hotels and data centres.

[2] The Property Environment Group was set up in London by the consultancy Environmental Governance in 1998 to bring together investors, developers, contractors and occupiers to share sustainability-related information and support and break down the vicious circles obstructing development of more sustainable buildings.

and delivery team and operations and maintenance people can be responsible for. It has been demonstrated that, provided occupancy hours are taken into account, other aspects of tenant activity have a relatively small influence on measured base building performance. By providing information where the agency exists to improve it, the base building rating allows landlords to demonstrate how good and well-managed their buildings are. Today, most new prime office buildings in Australia have what Europeans would call excellent energy efficiency, as measured by their operational base building energy use. This is now reflected in property values, creating a virtuous circle where landlords compete to offer lettable space with a better operational rating. Observers in Europe can draw two conclusions:

1. First, it is remarkable that we actually know this situation to be true. This is because Australia has a robust and credible way to measure and verify the base building operational energy performance of all large commercial offices. And these outcomes are publicly disclosed.
2. Second, it has proved possible to make dramatic improvements in the in-use energy efficiency of new office buildings over this 15 year period.

New office buildings across Europe have not followed the same trajectory, though we cannot be precise about this, because base buildings are not clearly defined, nor is their in-use energy performance routinely benchmarked. However, evidence suggests that base building services in recently-completed UK prime offices use typically twice as much energy per m^2 as their Australian counterparts, and possibly up to four times as much as the market-leading Australian buildings.

Design for Compliance vs Design for Performance

There are no intrinsic physical reasons why base building energy performance in new European offices cannot be as good as it is in Australia. However, the absence of a disclosure culture has contributed to Europe falling behind (1); while the design of new offices is rarely informed by feedback from real-world measurements. Instead, although the '*design for compliance'* regime that is the norm across Europe largely targets the energy performance of the same "regulated loads" as the base building metric, it focuses on modelled theoretical results, not predicting and then achieving in-use performance outcomes.

By contrast, Australia has pioneered a '*design for performance*' culture. Developers and their teams sign up to – and then follow - a "Commitment Agreement" protocol[3] to design, construct and manage new office buildings to agreed levels of actual in-use energy performance, at least for the base building. By using the process, and learning from the experience, Australian teams can now design, build, commission and operate office buildings that routinely achieve measured performance in line with design intent, albeit after some (essential) fine-tuning. How can Europe catch up?

How Australia Achieved Market Transformation

Measurement and verification standard for base building energy use

In Australia, metering generally follows the landlord/tenant split in responsibility for management and control (see Figure 1); an arrangement that the base building rating has reinforced[4]. One set of utility meters measures the landlord's services: energy used by the heating, hot water, ventilation and air-conditioning serving the whole building, together with all other services in the common parts, and so directly feeds into the **base building rating.** Separate utility meters measure energy used by each tenant (typically for their lighting, small power and ICT), feeding into **tenant ratings**[5]. Whole building ratings can be used to meet mandatory disclosure requirements where base building performance cannot itself be measured. In addition to the base building rating, the Building Energy Efficiency Certificate required by the Building Energy Efficiency Disclosure Act[1] requires a tenancy lighting assessment[6]. In practice, it is the base building rating that has enjoyed stellar success and attracted much international attention.

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[3] http://www.nabers.gov.au/public/WebPages/DocumentHandler.ashx?docType=2&id=26&attId=0

[4] When Australia was looking for an office building energy performance rating system in the late 1990s, this was the situation in two major States: New South Wales and Victoria. With hindsight, it is fair to say that they struck lucky: the metering coincides with the agency of the landlord to influence and control energy efficiency.

[5] In Australia, there is currently no drive from Government at any level to make tenancy ratings mandatory; the voluntary CitySwitch program is driving activity in this area: www.cityswitch.net.au

[6] The mandatory tenancy lighting assessment is not part of NABERS. It reflects the energy efficiency potential of the installation - not its actual energy use, as this is not under the control of the landlord.

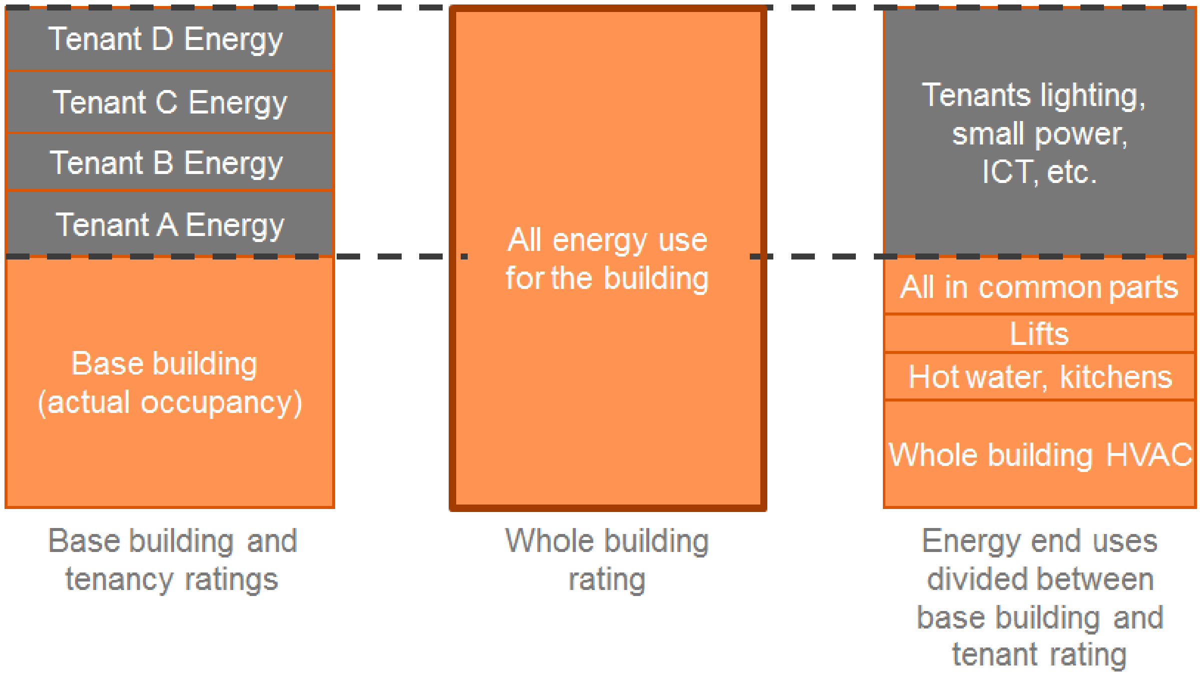

Figure 1 – Different scopes of different energy performance ratings

NABERS Energy motivates performance improvement by using a star scale. When first introduced, 2.5 stars was median performance and 5 stars was the highest possible rating. Recently the scale was extended to 6 stars[7]. The market transformation made possible by metering arrangements has actually come about because major office occupiers can now specify the performance they want. Federal and State governments set the ball rolling, saying they would only rent buildings that rated 4.5 stars or better. Some corporates followed suit. In 2006, the imperative for new build to be energy efficient was sealed when the Property Council of Australia stated that, to qualify for the Prime or grade A office categories, a minimum 4.5 star base building energy rating would be required (increased to 5 stars in 2012 for new build). The equivalent, for example in the UK, would be for the BCO specification (2) to require excellent energy efficiency, based on measured in-use performance.

The fact that market credibility of energy efficiency was now being driven by investment-grade measured in-use outcomes created a challenge for developers of new office buildings: how to attract pre-lets and underwrite their investment? Clearly, they needed to promise a guaranteed level of base building operational performance to investors and tenants. This implied two things: first an ability to deliver energy efficient base buildings and secondly an independent process to authorise developers to make their claims and give them credibility in the market.

Necessity was the mother of invention. In 2002, the NABERS Commitment Agreement was conceived, a process to help ensure that new offices could operate at their target energy efficiency level. Now virtually all new offices in Australia achieve at least 4.5 stars, with developers starting to target 5.5 and 6 stars. Commitment Agreements must take a substantial part of the credit for this transformation, not just for the individual projects, but perhaps more importantly for helping to educate the industry generally.

In summary, whilst the Australian process was assisted by the prevalence of base building metering at the outset, the market transformation in Australia has occurred through a virtuous circle of drivers:

- Commitment Agreements, empowering developers to deliver good performance
- the promise of a guaranteed level of base building performance enabling developers to attract prospective tenants and investors
- major office occupiers becoming inspired to specify the performance they want
- market credibility, resulting from investment-grade measurements of in-use energy performance, summarised in a simple star rating.

[7] 6 stars is half-way from 5 stars to net zero carbon. It is important to recognise that an absolute scale like this would enable Europe's nearly zero energy new buildings ambition to be realised in reality as well as theory.

What does a Commitment Agreement entail?

The Commitment Agreement requires the developer to:

- design and construct and commission the premises to operate at the target energy performance level
- provide written notice of the Commitment Agreement to all consultants and contractors involved in the design, construction, commissioning and management of the premises
- include in agreements to lease and in leases with all tenants a clause that discloses the Commitment Agreement
- provide data to allow the operational performance to be verified after 12 months of full occupation (if the commitment rating is not achieved by then, a 12-month extension is allowed for further fine tuning before the rating is published)
- use best endeavours to achieve and maintain the commitment rating for the duration of the lease
- provide the tenants with annual updates of the performance rating for the premises.

It also has some technical requirements:

- advanced simulation of the design, which can reliably predict actual operational energy use for individual sub-meters
- design reviews by independent experts
- the rating must be reported to the scheme administrator once it has been measured.

Extended commissioning and post occupancy fine tuning against expected performance is invariably necessary to achieve target performance.

Although commitment agreements manifest in contracts between the developer and the New South Wales Government (which manages NABERS on behalf of the Australian government), the intention is to use transparency and reputational pressure to encourage fulfilment of the agreement rather than legal enforcement. All commitment agreements are published on the NABERS web site, together with their status (achieved, pending, overdue, not achieved, terminated).

Figure 2 is a schematic representation of how Design for Performance differs from Design for Compliance. The two columns on the left represent compliance predictions of base building energy use, assuming respectively standard and expected occupancy and activities. The middle column shows a more realistic prediction of the same metric using advanced simulation and assuming realistic levels of occupancy and hours of use. A key attribute of the advanced simulation is to model HVAC plant and controls simultaneously with dynamic thermal modelling of heating and cooling loads. The two columns on the right of Figure 2 represent metered energy use, before and after fine tuning, illustrating how fine tuning can bring the measured energy use more into line with the predictions of the advanced modelling.

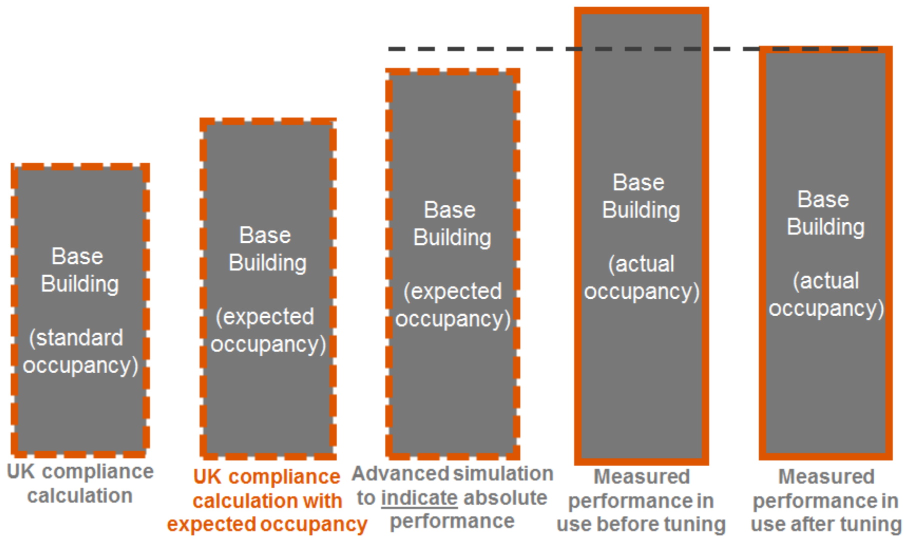

Figure 2 – Base building energy use: predicted vs measured (illustrative)

Figure 3 illustrates how strategically located sub-meters can capture the energy consumption of each significant end use and allow it to be compared with the predictions of the simulation model. Deviations may be due to inappropriate assumptions in the model or unexpectedly poor plant efficiency, control or management. The process enables engineers to identify the causes and to fine tune the plant, the controls, or the model, to allow any wasteful deviations to be addressed.

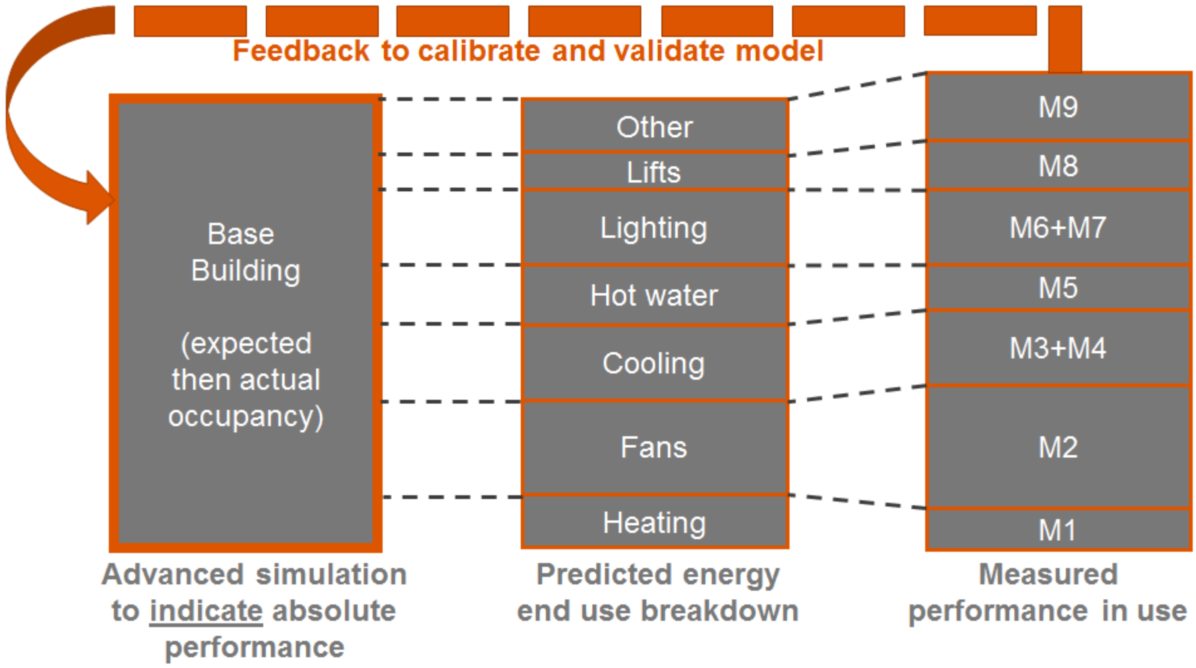

Figure 3 – Base building energy use: setting targets for individual sub-meters

For successful delivery of NABERS outcomes, monitoring and tuning during the Defects Liability Period (DLP), and beyond until full occupancy, has been found to be essential. Typically this includes:

- establishment of building and subsystem targets based on simulation
- monthly monitoring reports comparing sub-metered performance to simulated predictions
- at least 4 tuning exercises during DLP, each including a detailed review of BMS operation
- continued commissioning activity to identify and rectify commissioning defects
- contractual retentions on the builder and mechanical contractor based on NABERS performance (i.e. NABERS performance failure is treated as a defect)
- end-of-period formal assessment of NABERS Rating prior to contractual release.

History of Commitment Agreements in Australia

Since starting in 2002, a total of 147 Commitment Agreements have been signed for base buildings. Annual totals have fluctuated significantly over this period, peaking between 2008 and 2013; and with fewer just recently, see Figure 4. This probably relates to changes in construction activity, together with increased confidence by the industry that it can build high performing buildings that can achieve good NABERS ratings without oversight.

Figure 5 shows that the vast majority of buildings with Commitment Agreements have targeted 4.5 or 5 stars. This reflects a number of factors:

- 4.5 stars is still the benchmark requirement for Government departments, so many projects aim to reach this rating, and no more. However, it should be noted that when Commitment Agreements started, 4.5 stars was genuinely a “stretch” rating, with no track record of it ever having been achieved in use.
- 5 stars has in recent years become the new informal benchmark for “high performance”, but only in the past 3-4 years has it been achieved regularly.
- 5.5 stars (and higher) is relatively uncommon today, with industry knowledge of how to deliver it not well established, so making it a greater risk as a commitment. Nevertheless, several projects that committed to 5 stars have gone on to achieve 5.5 stars, indicating some conservatism and risk management on the part of developers and designers.

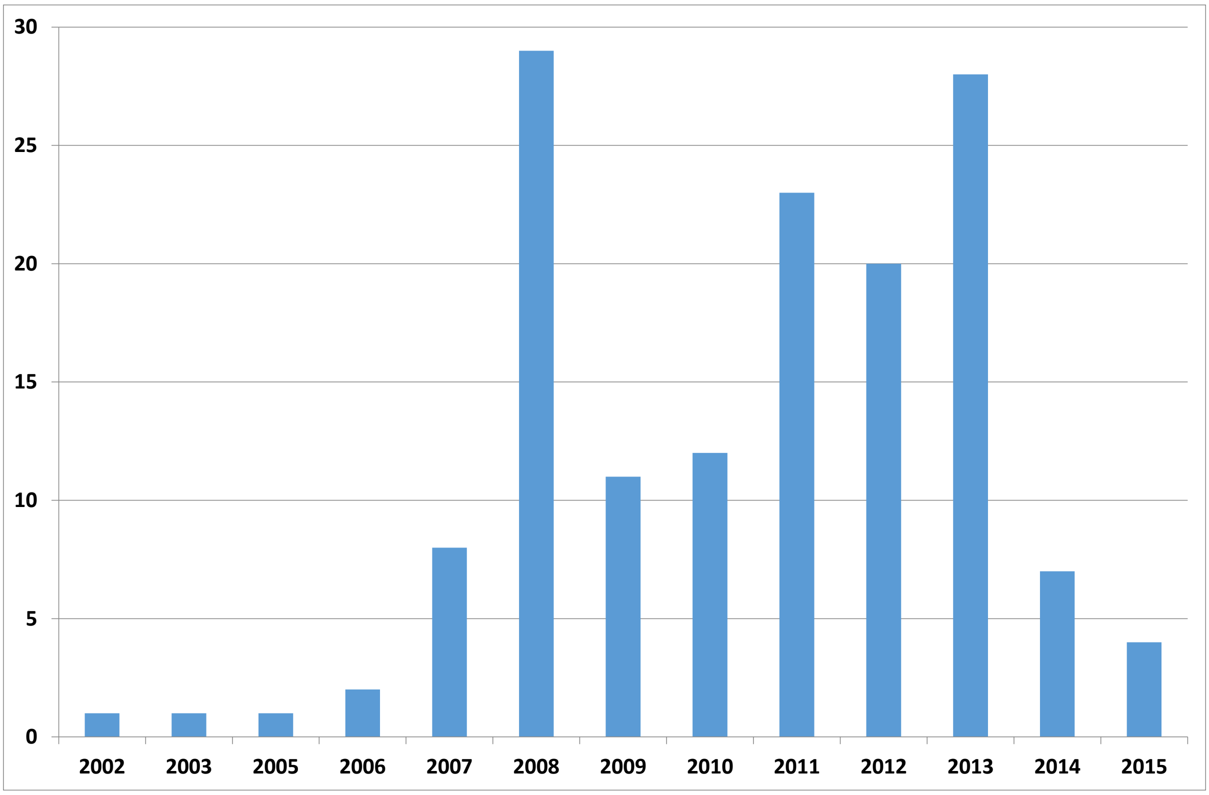

Figure 4 – Numbers of office base building Commitment Agreements by year

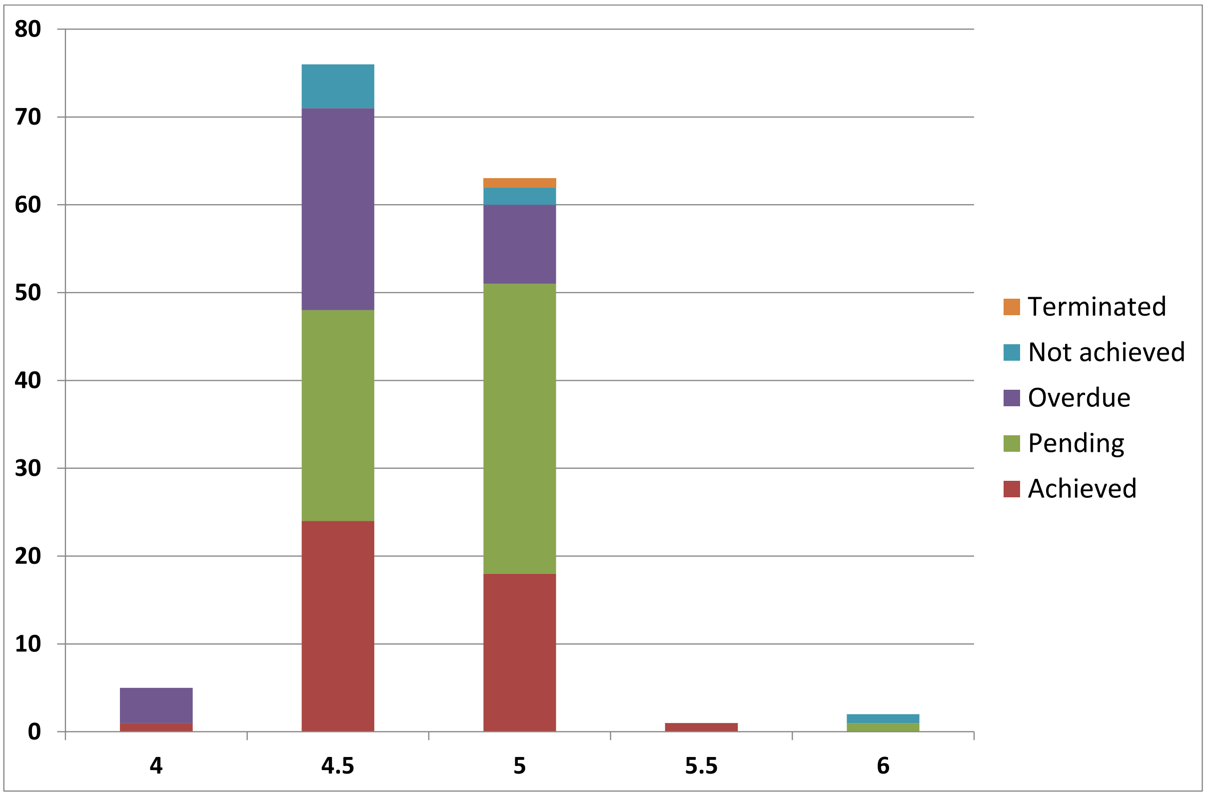

Figure 5 – Number of office base building Commitment Agreements by target

As Figure 5 shows, one new building has achieved 5.5 stars. This is significant in that 5.5 star performance requires almost four times less energy than 2.5 stars, the average performance of

Australian office buildings in 1998. In other words, a 5.5 star building is now achieving the "Factor 4" hypothesised as possible by Amory Lovins et al back in 1998 (3).

Existing Buildings

Energy performance ratings for Australia's existing stock of larger office buildings have also improved markedly since the ABGR was introduced. Figure 6 shows data from IPD (4) covering the period 2006-14. The right hand axis and filled area show how the use of NABERS for existing buildings has grown enormously, with total area rated annually increasing from 1.5 million m^2 in 2006 to 7 million m^2 in 2014. National data collected by Government (5) states that over 77% of the national office building market has now been rated with NABERS Energy for offices at some point – about 18 million out of 23 million m^2.

The average base building rating is shown by the thick blue line and left hand axis of Figure 6. When introduced in 1999, the average rating was 2.5 stars and excellent practice 5 stars (at the time deemed unattainable). The average rating had risen to 2.9 stars in 2006 and 3.6 stars by 2010, so transparency about energy performance was clearly driving significant activity to improve efficiency. This evidence led to the federal government introducing in 2010 the Building Energy Efficiency Disclosure Act, to mandate disclosure of base building ratings on sale or let of premises over 2,000 m^2. With poorer performers forced to declare their ratings, the area-weighted average dipped from 3.6 to 3.3 stars, but recovered within two years. The NABERS Administrator then introduced the 6 star level (categorised as "market leading performance"), challenging the industry to be yet more ambitious. The average rating has since continued to rise, reaching 4.2 stars by June 2014 - equivalent to a 32% reduction in emissions for the whole stock over the 8 years of this graph.

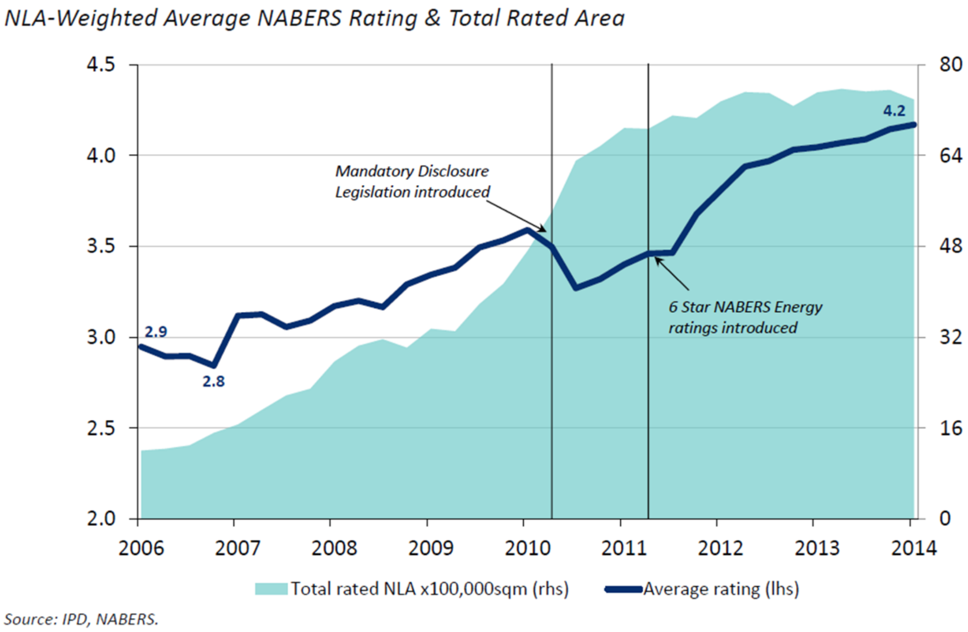

Figure 6 – Office base building ratings: improving penetration and outcomes

Figure 7 shows the current number of base building ratings at each star level for the 921 existing offices held in NABERS' database at November 2015. Over half the ratings are 4.5 star or better, with the mode rating (203 buildings) 5 stars ("Excellent performance"). Although 70 buildings are rated 5.5 stars and 12 are 6 stars, these numbers reduce to 60 and 4 respectively without GreenPower[8].

[8] GreenPower is certified zero carbon electricity. Buildings that use it get a better NABERS Rating due to the zero emission supply, but they also have to declare their ratings ignoring the impact of this supply choice.

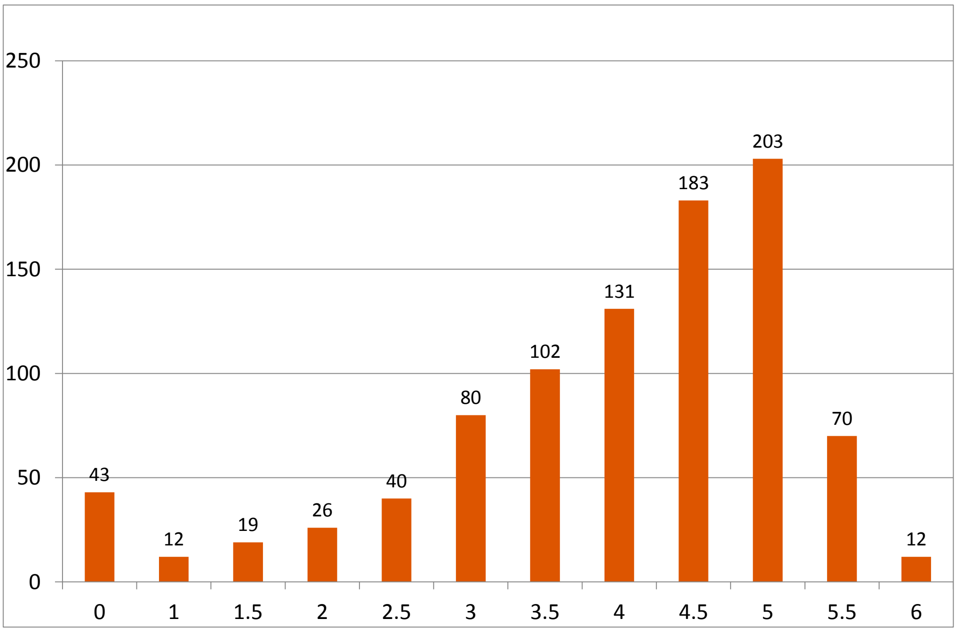

Figure 7 – Number of base building ratings by star rating (November 2015)

How Does the Energy Efficiency of European Offices Compare?

Some Existing Initiatives

There are three main ways that market leaders in the UK attempt to achieve exemplary energy performance for new office buildings or major refurbishments:

1. setting targets “beyond Building Regulations compliance”
2. setting a target whole building operational rating[9]
3. signing up to the Low Carbon Workplace[10] (LCW)-ready scheme.

The first is clearly wedded to a design for compliance culture and never associated with explicit real outcomes. The second and third focus on operational outcomes, but for whole building energy use, which is likely to be a bigger challenge than base building energy (as more parties are involved), though it avoids any doubts about which energy is in scope (and casts the net wider), and suitable metering for verification is much more likely to be available.

Measuring and benchmarking base building energy use

The market transformation success for office base buildings in Australia led the Better Buildings Partnership (BBP) in 2012 to commission Verco and UBT to develop a Landlord Energy Rating[11] (LER), an investment-grade base building rating scheme for existing UK offices akin to the NABERS system in Australia. In 2013, prototype tests of the resulting Excel software on eighty of the BBP members’ existing buildings exposed challenges with the configuration and sub-metering of building services systems in many existing UK office buildings[12]. Detailed case studies were then made of four of these buildings to understand these underlying issues in more depth, and to provide calibration checks on the simpler rating approach that had to be used on most of the sample (in order to keep costs down). We have no data on how the characteristics of prime office base buildings in Australia (size, type of construction, hours of operation, occupancy, etc.) compare with those in the UK market, although we suspect there are more similarities than differences.

[9] http://www.willmottdixon.co.uk/projects/building-a-prosperous-future-for-keynsham
[10] https://www.carbontrust.com/client-services/advice/business-advice/low-carbon-workplace/
[11] http://www.betterbuildingspartnership.co.uk/our-priorities/measuring-reporting/landlord-energy-rating
[12] In 2006-07, UBT had developed a Landlord’s Energy Statement (LES) and an associated Tenant Energy Review (TER) with the British Property Federation, see http://www.les-ter.org. This low-cost method was intended to support the UK Government’s proposed extension of Display Energy Certificates (DECs) to commercial buildings, which in the event never happened. The inconsistent boundary between landlord and tenant energy use in different buildings made simple benchmarking of the LES and TER impossible.

The findings caused the BBP to explore a different path towards the successful outcomes achieved in Australia: to focus on new buildings, where it was potentially possible to design out the obstacles of engineering services and sub-metering configurations encountered in the existing stock, and to:

- demonstrate that energy efficient operation can be achieved in new buildings
- ensure that new stock does not 'add to the existing problem'
- identify exemplar pathways for improving the existing stock.

Base Building Energy Performance of New Prime Offices in Europe

For the purposes of this paper, we have made a comparison between offices in London and Melbourne. London is typically cooler, both in summer and winter, so buildings require a little more heating and a little less cooling. Figure 8 makes direct comparison of base building energy performance ratings of offices in London and Melbourne. The line shows the relationship between kWhe/m^{2}NLA/yr[13] and the NABERS star level for Victoria. At the poor end of the scale, 1 star equates to over 200 kWhe/m^2, at the excellent end, 5 stars represents around 50 kWhe/m^2/yr. The ranges for each city indicate the spectrum of performance, from least to most energy efficient. Most new offices in Melbourne achieve 4.5 stars (70 kWhe/m^2/yr) or better, with the best at 5.5 stars (40 kWhe/m^2/yr).

Where do new UK offices sit on Figure 8? We cannot say precisely, because UK base building operational performance is not measured. However, the 2013 tests of the LER found that base building energy use averaged 160 kWhe/m^2/yr, four times as much as the best in Melbourne. The detailed case studies were scattered around that level, giving some confidence in the value.

The LER assessments were mostly for existing buildings. However, from this and other evidence, it seems likely that the range for new build stretches to at least 160 kWhe/m^2/yr, the average for existing buildings. From other confidential data sources, the best prime office base buildings in the UK currently seem to reach 60-80 kWhe/m^2/yr, similar to the 4.5 star minimum standard in Melbourne. So the best end of the UK new building range seems to need nearly twice as much energy as the best in Melbourne, and the poorer end four times as much.

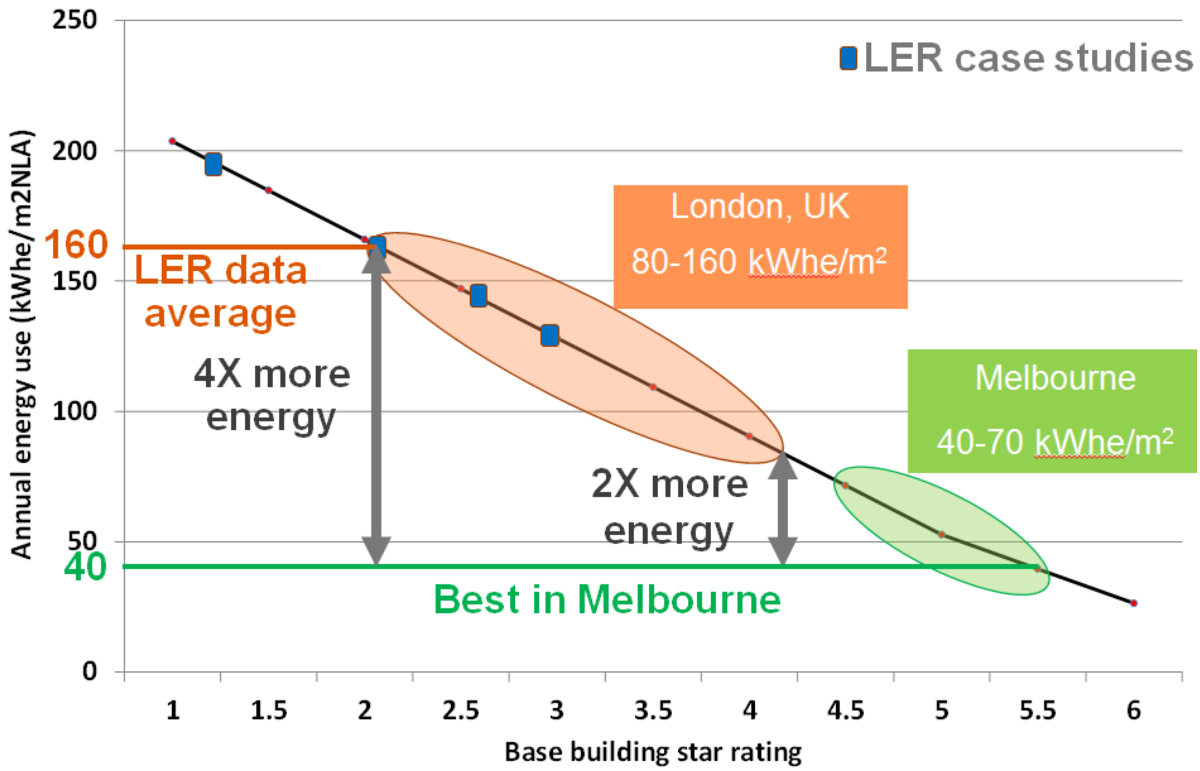

Figure 8 – Base building energy use for new offices in London and Melbourne

[13] kWhe is the "electricity equivalent" of total energy use: kWh of electricity are added to kWh of any fuel multiplied by 0.4 and kWh of hot or chilled water multiplied by 0.5. NLA is net lettable floor area.

Importance of single responsibility for base building services

An important reason for the Australian success is that the developer and then the landlord can "own" base building performance, and have authority of control over HVAC services in tenanted areas (apart from special equipment added by the tenants). In the UK this is not always technically possible, particularly in top end Central London offices. Why? Because developers and landlords are pushing onto tenants the installation, operation, maintenance, control and metering of what would be base building plant in Australia. This results in an apparent (but fictitious) saving in the cost of installation, operation and maintenance of landlord's services - perhaps with lower service charges, but with tenants incurring extra direct costs. More worryingly, the lack of a common control strategy and the division of responsibility for what should be managed as base building services can lead to highly inefficient energy use, with the landlord becoming a "dumb" provider of hot and chilled water (and sometimes primary air) to tenants. The differences can be enormous, at worst with landlord's services operating 24/7, whether or not they are really needed.

Some London tenants allegedly prefer these arrangements, taking in-house more control of the services in their spaces. However, this preference may be solely cultural: it seems unlikely that their technical requirements are much different from those in Sydney (indeed some of the occupiers and activities are identical). Some tenants may feel more secure under such arrangements, but may be unaware of the scale of the energy and carbon penalties; and the potential CSR embarrassment if evidence emerged that their base buildings used much more energy per m^2 than was demonstrably necessary in efficient and well-managed prime offices.

Feasibility of Commitment Agreements in the UK

An extensive group of industry stakeholders[14] is currently undertaking a study of the potential to introduce to the UK the '*design for performance*' concept and a Commitment Agreement protocol, supported by a base building rating method. There is a strong expectation that the Australian model can map directly onto second tier property here, where many tenants are happy to get on with their business and leave servicing the building to the landlord. Evidence from building performance studies (6) also suggests that energy efficient performance and high levels of occupant satisfaction are not in conflict, but can be achieved simultaneously as complementary outcomes of good briefing, design and management. Given the huge energy efficiency benefits arising from single-actor control of HVAC services in Australia, the top end of the UK office market might want to consider it too. UBT also hopes to promote Commitment Agreements in all sectors, and not just offices.

Compatibility of Base Building ratings with the EPBD

The EPBD recast (7) Annex 1 paragraph 1 says:

*"The energy performance of a building shall be determined on the basis of the calculated **or actual** annual energy that is consumed in order to meet the different needs associated with its **typical** use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs."*

The focus on 'heating energy needs and cooling energy needs' seems to have led EC lawyers to take the view that all energy certificates must be based on an asset rating, and to justify saying this disallows the use of whole building utility meter data to determine the energy performance.

It is apparent that the Annex 1.1 wording is compatible with the definition of the NABERS Base Building rating, which is closely based on the measured energy use for heating, cooling and hot water (or a prediction of the same until the building has been in operation for a year with at least 75% of full occupancy). It may therefore be tenable that EC lawyers can endorse a NABERS-style measured (and predicted) base building rating as being compliant with Annex 1.1. The key semantic challenge is

[14] The feasibility study is backed by the Better Buildings Partnership (BBP) and is being funded and overseen by: British Land, Legal & General Property, Stanhope, TH Real Estate, Laing O'Rourke, NG Bailey and the energy simulation company EDSL. UBT is co-funding the public interest aspects of the project. The study also has the support of DECC, BCO, BPF, UK-GBC and CIBSE. The study team is led by Verco and includes BSRIA, Arup and UBT. For the Australian review, and consideration of the feasibility of Commitment Agreements in the UK, the team is being assisted by Energy Action, Canberra.

to understand that a Base Building rating should be based on metered energy use once the building is occupied, ie it is a type of operational rating, but it is not the operational rating most people in Europe associate with the term ie based on the whole building energy use measured by utility meters. The latter can be deemed by lawyers to be inconsistent with Annex 1.1, whereas the former cannot.

The words 'typical use' in Annex 1.1 above can also sometimes be claimed to imply an asset rating, but a measured base building rating does effectively benchmark "typical use" by adjusting the benchmark 1) for the actual weather during the measured period (compared with typical weather) and 2) for the building's actual hours of use (compared with typical use).

So the EPBD recast seems to allow EU countries to deploy NABERS-style measured base building ratings, but Member States have not taken the opportunity to do so. This may be partly because the CEN Standards which relate to the EPBD do not explicitly offer this option, despite it being explicit in Annex 1.1. An extensive market study commissioned by the EC in the context of the common Voluntary Certification Scheme (VCS), which is required by Article 11.9 of the EPBD recast, highlighted stakeholder appetite for measured ratings and suggests that allowing a measured base building rating to be an option for the VCS would be strongly supported by stakeholders in the real estate market. For this to happen, the new CEN Standards for the EPBD recast need to recognise the measured base building rating option implied by Annex 1.1.

Achieving 4.5 Stars in the UK: a Commitment Agreement Challenge

Given it is routine in Australia for new office base buildings to be 4.5 stars or better, what does 4.5 stars energy performance look like in a UK context? The most used benchmarks for offices in the UK are contained in Energy Consumption Guide 19 (8), known as ECON 19. Figure 9 shows the Good Practice benchmark for a Type 3 office (air-conditioned, open plan) base building. It equates to nearly 120 kWhe/m^2/yr, placing it at around 3.2 stars if in Melbourne. Figure 9 also shows the measured base building performance of one of the most energy efficient air-conditioned offices known to the authors, at just over 100 kWhe/m^2/yr, or 3.7 stars. To achieve the 4.5 stars target in the UK, base building energy use would need to be about 72 kWhe/m^2/yr. While this might appear daunting, the speculated improvement from the 3.7 star building in Figure 9 is almost all due to lower space heating, which seems more than feasible, given much evidence, e.g. (9), that the fuel needed for heating has decreased substantially since ECON 19 was published.

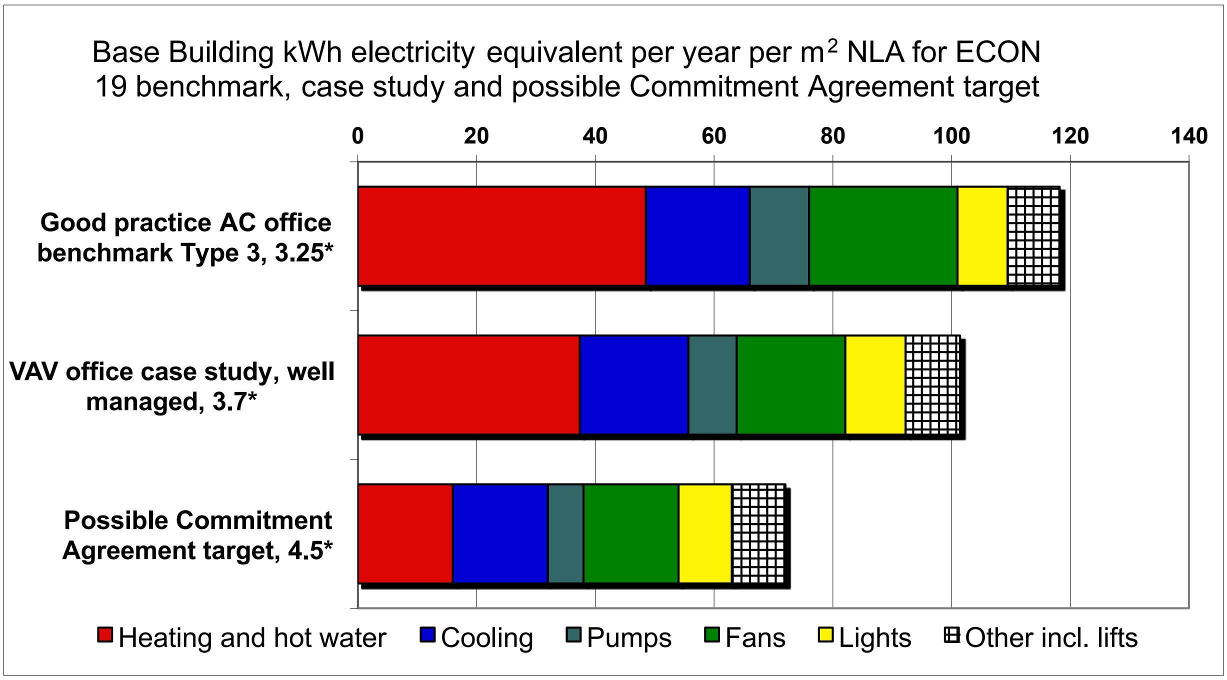

Figure 9 – Base building 4.5 star energy use vs ECON 19 Type 3 Good Practice

(Energy Consumption Guide 19 gives Typical and Good Practice benchmarks for 4 office building types: naturally ventilated cellular (1) and open plan (2), air-conditioned standard (3) and prestige (4))

Conclusions

The energy performance of new prime office base buildings in Australia has been transformed over the last 15 years. Primary drivers have been:

- a base building energy in-use measurement standard and rating system
- a Commitment Agreement process that has helped teams to target in-use performance realistically, and then deliver it
- major office occupiers deciding to specify the energy performance they want.

NABERS base building ratings and their mandatory disclosure are fundamental to the way commercial buildings are managed in Australia, strongly influence investment decisions for existing and new buildings and have a significant impact in the management of major investment property portfolios, including which buildings are bought and sold (5). Research indicates that higher NABERS Energy ratings enhance property values, reduce vacancy rates and increase yield (10).

As investors in property in Europe show ever more interest in sustainability as a driver of asset value, measured operational energy use is becoming increasingly material data (11). A key lesson here is that a government can effectively support the achievement of energy performance outcomes in the private sector by mandating transparency (which removes uncertainty and information asymmetries) and creating one independent, robust and authoritative system which enables credible information to be collected and communicated effectively.

In Australia, the alignment of operational energy efficiency with lettability and thereby shareholder value in commercial property has created a virtuous circle between policy objectives and market forces. In Europe, in spite of there being more energy-related legislation for buildings, data on the expected base building energy performance of new office buildings, in a form which could then be validated by in-use measurements, is not produced. It is not surprising therefore that markets in Europe are not driving the spectacular improvements in base building energy efficiency that are being witnessed by the Australian market.

There are no intrinsic physical reasons why new offices in Europe cannot perform as well as Australia's. However, base building energy in use is neither measured nor targeted; the design of energy efficient offices is rarely informed by feedback from real world measurements; and a design-for compliance culture, lack of energy performance disclosure, and confused responsibilities have contributed to the EU falling behind. As a result, it seems plausible that on average new prime offices across the EU may be using twice as much energy per m^2 for base building services as their Australian counterparts.

The Commitment Agreement process appears to be a promising avenue for European countries to explore further, probably with pilot studies that apply some key ingredients of the process to real building projects. Harking back to the Property Environment Group's circle of blame, developers may say they need tenants sufficiently committed to rent space in truly energy efficient buildings before it is worth their while creating them. But with the increasing interest of investors in operational energy use, market demand for an energy efficient 'product' can be established as soon as an investment-grade measurement and rating system is in place to prove it. The EU can get to that position quickly, by learning from Australia's experience. An ambitious but realistic goal would be for a scheme to be in place for the 2020 roll out of 'nearly zero energy' new buildings, as required by Article 9.1(a) of the EPBD recast (7). New offices could then begin to offer what the energy efficiency claim 'says on the tin'.

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Investing in Building Energy Efficiency to preserve Natural Capital and Human Capital

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Abstract

Energy efficient buildings are central to addressing diminishing resources and transitioning to a green economy. Carnegie Mellon University's Center for Building Performance and Diagnostics has developed a critical approach to triple bottom line calculations that integrates the economic, environmental and human cost benefits of energy efficiency to accelerate investments in high performance building technologies. Quantifying the 'financial' capital costs and benefits as a first bottom line are well known NPV techniques, but the second 'natural' capital calculations and the third 'human' capital calculations are still emerging.

To advance a 2nd bottom line that can be translated into Corporate Sustainability Reporting, the CMU team has been developing a methodology for capturing the environmental benefits of reducing electricity demand towards sustaining air and water resources. These calculations are based on three levels of information - electricity fuel sources and power plant quality, the respective air pollution and water consumption consequences, and emerging valuation incentives for pollution reduction. The calculation is built for greenhouse gases - CO2, CH4, SOx, NOx - as well as particulates and water use, given three global scenarios – an emerging economy (India), economies with mid-level sustainability goals (US), and economies in the forefront of defining climate change policies (EU). The capital saved by avoiding the environmental impacts of electricity use based on fuel source and mix are added to the value of the kilowatt-hour of electricity saved in a second bottom line calculation.

The team also continues to refine the third bottom line calculation, capturing field and laboratory research findings that link high performance building design decisions to human health and individual and organizational productivity. This presentation will demonstrate how the integration of the second and third bottom line can shorten payback periods from 17 years to 13 years to months, paybacks that are critical to inspiring strategic building investments in the quality of the built environment.

Introduction

The market adoption of energy efficient retrofits in commercial buildings can be accelerated if professionals and decision-makers are informed about the full range of benefits from these investments. While energy payback analyses can reduce overall system costs and increase the return on the investment, net present value (NPV) calculations can be critical for overcoming first-least-cost decision-making patterns that prevent owners and tenants from investing in high performance retrofits. The addition of triple bottom line (TBL) calculations that capture the economic, environmental and human cost benefits (i.e. profit, planet and people) offer life cycle arguments for investments that save energy and improve the quality of the indoor environment for the workers. The challenge for TBL calculations however, is the quantification of environmental and human gains, including health, productivity, and organizational performance. This paper proposes a new methodology to create TBL justifications for three climate responsive façade investments – daylight dimming, daylight redirection and dynamic external shading.

For each investment, the first cost per employee (employees being the critical unit of health and productivity) was evaluated against the 15-year life-cycle benefits in a TBL calculation. The first bottom line relates to the known cost-benefits of energy and facility management savings resulting from the retrofit. The second bottom line relates to the environmental cost-benefits that are directly linked to electric energy savings: reductions in CO_2, CH_4, SO_X, NO_X, particulates, and water. The third bottom line relates to the human cost benefits that are directly linked to health and productivity benefits identified from laboratory and field studies. The iterative and cumulative NPV, return on investment (ROI), and simple payback calculations for each retrofit provides professionals and manufacturers arguments for investment in energy retrofits that improve the quality of the indoor environment for workers.

TBL framework for building investments

In recent years, sustainability has become part of the mainstream business approach for many organizations (Yakhou, 2012). Managers find themselves frequently challenged by customers and the market on how they are measuring and managing economic, environmental and social commitments and accomplishments. Leading corporations have addressed the demand for greater transparency by adopting different forms of sustainability accounting, from voluntary disclosures such as greenhouse gas accounting, to reports on corporate sustainability initiatives that comply with guidelines such as those under the Global Reporting Initiative (Bennett, Schaltegger, & Zvezdov, 2013).

The early phase of sustainability accounting aligned more with 'environmental accounting', focused on the relevance of environment to business and operations (Bennett & Roux, 2011). The building industry has been in the forefront of embracing sustainability through green building certifications like the U.S. Green Building Council's Leadership in Energy and Environmental Design®, the Living Building Challenge, and the Architecture 2030 challenge, that requires new buildings, developments, and major renovations to be carbon neutral by 2030 (Architecture2030, 2015). In adopting these goals, designers are beginning to use life cycle impact assessments of building materials as critical factors for design decisions and selection of materials. Until recently, however, the impact of built environment on the building occupant's health and well being has been qualitative, without economic metrics that can be used by the decision maker (Bennett et al., 2013).

The definitions of design for comfort, health, and well-being of the building occupant is often driven by market demands and building codes (World Green Building Council, 2013). Workers spend more than 40 hours a week in the workplace in the US, where the minimum thermal (temperature, humidity levels), lighting (light levels on the work surface, in shared spaces), air (acceptable CO2 and other contaminant levels), acoustic and spatial requirements for the operation of the space, are prescribed by building codes (Muldavin, 2010) (Bendewald et al., 2014). With companies spending as much as 100 times the resources on employee salaries than what they spend on building operations and maintenance, any investment that improves the indoor environmental conditions, and increases occupant health and productivity, will impact the organization's bottom line (Loftness et al., 2005) (Terrapin, 2012).

The triple bottom line (TBL) reporting framework and the more recent Integrated Bottom Line (IBL) encompass all three dimensions of sustainability – financial, natural (environmental) and human (social) capital (Elkington, 1997). Yet their applicability in building investments is not well defined. Introduced by Elkington in 1997, the triple bottom line is critical to sustainability, guiding organizations to not only care for the economic "bottom-line" performance, but the environmental and social performance as well (Elkington, 1997). The first, economic bottom line is inclusive of the physical capital invested, like machinery, and the financial capital of operations and maintenance (Elkington, 1997). The second bottom line is the organization's "planet" account that measures how environmentally responsive the company is relative to our collective natural capital (Slaper, 2011). It includes the identification of environmental costs and gains within conventional systems and the creation of new ways of valuation to encourage environmental performance (Henriques & Richardson, 2004). Lastly, the third bottom line is the organization's "people" account which measures the social value created by the operations of the company and its facilities (Gong, 2013). The social capital captures the value of human capital, in the form of health and performance (Elkington, 1997).

This paper proposes the adoption of a triple bottom line approach for evaluating a building investment, by evaluating not only the financial performance of the investment, but also the environmental and human performance to provide a holistic analysis. This approach will help quantify how investments in high performance systems relate to environmental responsibility and increased worker health and productivity, providing the opportunity to transform qualitative relationships into quantitative values.

Approach for capturing the three capitals in building investments

To demonstrate the new methodology, the research team completed TBL justifications for investing in three low and medium cost façade retrofits. The calculation is founded on the United Nations ICLEI Triple Bottom Line standards, in which benefits are categorized in one of three categories (1) Financial capital (Economic) (2) Natural capital (Environmental) and (3) Human capital (Equity), also often discussed as the three P's (1) Profit (2) Planet and (3) People. In brief, the first bottom line financial capital calculations capture the economic cost-benefits of energy and facility management savings resulting from each of the retrofit actions. The second bottom line, natural capital calculation is built for four greenhouse gases CO_2, CH_4, SOx, NOx , as well as particulates and water use, given three global scenarios – an emerging economy (India), economies with mid-level sustainability goals (US), and economies in the forefront of defining climate change policies (EU). The third bottom line captures the human benefits that are linked to improved thermal, lighting, and air quality, drawn from the ongoing work of Carnegie Mellon's CBPD that links the quality of the built environment to health and productivity outcomes.

For each retrofit option, the first cost per employee (the critical unit of health and productivity) was evaluated against a 15-year life-cycle calculation. Given the identified range of façade and lighting investments, costs were collected from both literature and direct communications with manufacturers and professionals specifying façade, lighting and daylighting components and systems. U.S. market prices were used for this paper, acknowledging that the costs of these retrofits may vary significantly based on existing conditions in the building, variations in the product and labor market, and planned intentions of the building owner to upgrade their buildings. For this study, the project team collected average technology and labor costs for each retrofit recommendation assuming a medium size office of 50,000 square feet on 3 floors with 250 employees.

A focus on the Second bottom line 'natural capital' benefits

The CMU team has been developing a methodology for capturing the environmental benefits of reducing electricity demand for sustaining air and water resources, a critical component of the second bottom line. These calculations are based on three levels of information - electricity fuel sources and power plant quality, the respective air pollution and water consumption consequences, and emerging valuation incentives for pollution reduction. This section elaborates on the critical data required to complete a natural capital cost-benefit calculation.

The transition to a green economy in recent years has made resource efficiency and the move to a low-carbon society important global issues(EEA, 2015)(UNEP, 2015). The EU has been in the forefront of defining medium and long-term goals relative to resource efficiency and GHG emission reduction to ensure the world does not exceed a 2 degree C maximum set by international agreement (Fraunhofer ISI, 2015). The resulting 2050 climate policy goals include de-carbonization of the energy supply and greater GHG emission cuts by reducing the reliance on fossil fuels (EEA, 2015). The environmental cost savings from the EU policies can provide emerging economies like India, and economies with mid-level sustainability goals, the ability to compare national and international benchmarks.

The energy supply sector, which includes generation of electricity and heat, contributes to 40 percent of the global CO_2 emissions. Almost three quarters of that come from six major economies (figure 1 and 2) (Foster & Bedrosyan, 2014). A majority of these emissions occur at the point of combustion, and are caused by the burning of fossil fuels, industrial waste and non-renewable waste to generate electricity. Investments that promote efficient use of energy are therefore critical to limiting GHG and other pollutant emissions at the source of power generation. Yet conservation receives little consideration compared to de-carbonization of the energy supply (Fraunhofer ISI, 2015).

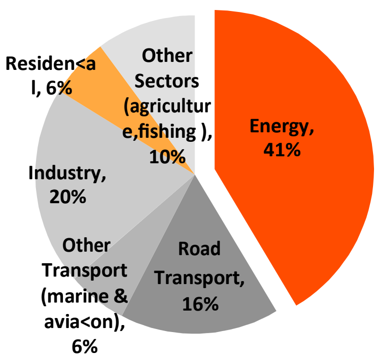

Figure 1: CO2 Emissions by sector (IEA, 2015)

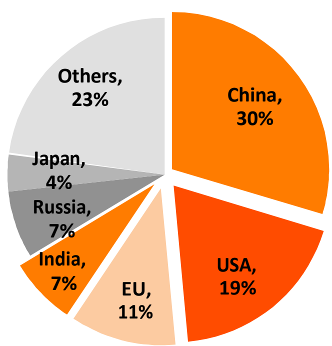

Figure 2: CO2 emissions by country attributable to the energy sector (IEA, 2015)

The carbon content of the fuel used for electricity generation has a direct impact on GHG and air pollutants. Global trends in the fuels used for electricity generation reveal the ongoing dominance of coal worldwide, even though it is diminishing in the US and Europe (figure 3) (IEA, 2011). Coal is considered to be a dirty source of energy as it is by far the largest contributor to energy related CO_2 emissions (Foster & Bedrosyan, 2014). With the availability of cleaner sources of energy such as natural gas and renewables, a decline in the quantity of coal for power generation is projected (figure 4).

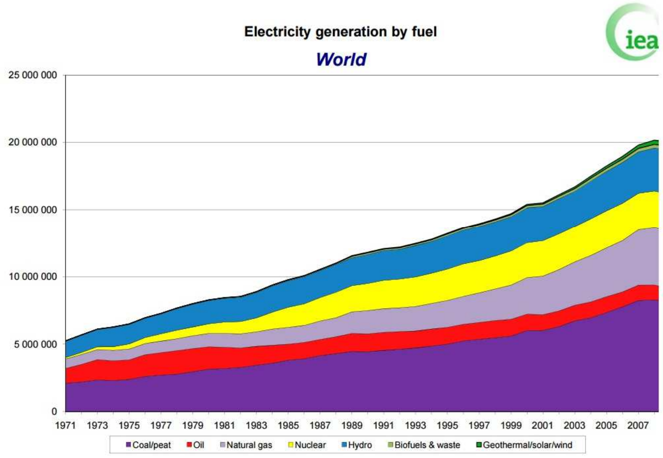

Figure 3: World electricity generation by fuel till 2009 (IEA, 2011)

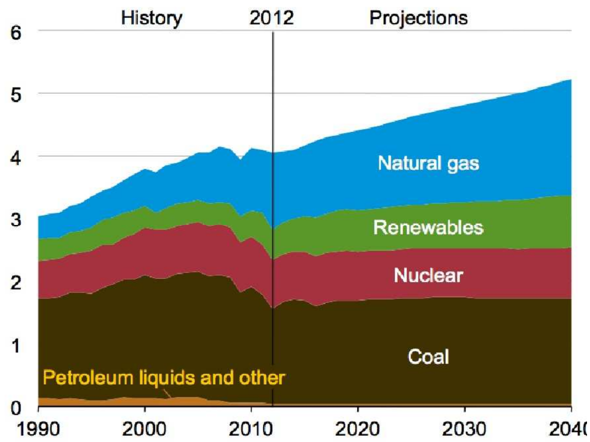

Figure 4: Decline in use of coal for electricity generation in the US market (U.S. Energy Information Administration, 2013)

Each country's specific fuel mix impacts their greenhouse gas (GHG) and pollutant emissions. The fuel mix in different countries reveals variability in the percentage of coal used for electricity generation (figure 5), ordered from the cleanest to the dirtiest source mix. In the case of emerging economies represented by India, 61% of the mix was dominated by coal (Kate & Ian, 2015) (Vasudha Foundation, 2014), followed by a 40% for the US and 27% for the EU.

Fuel Mix for electricity generation by country

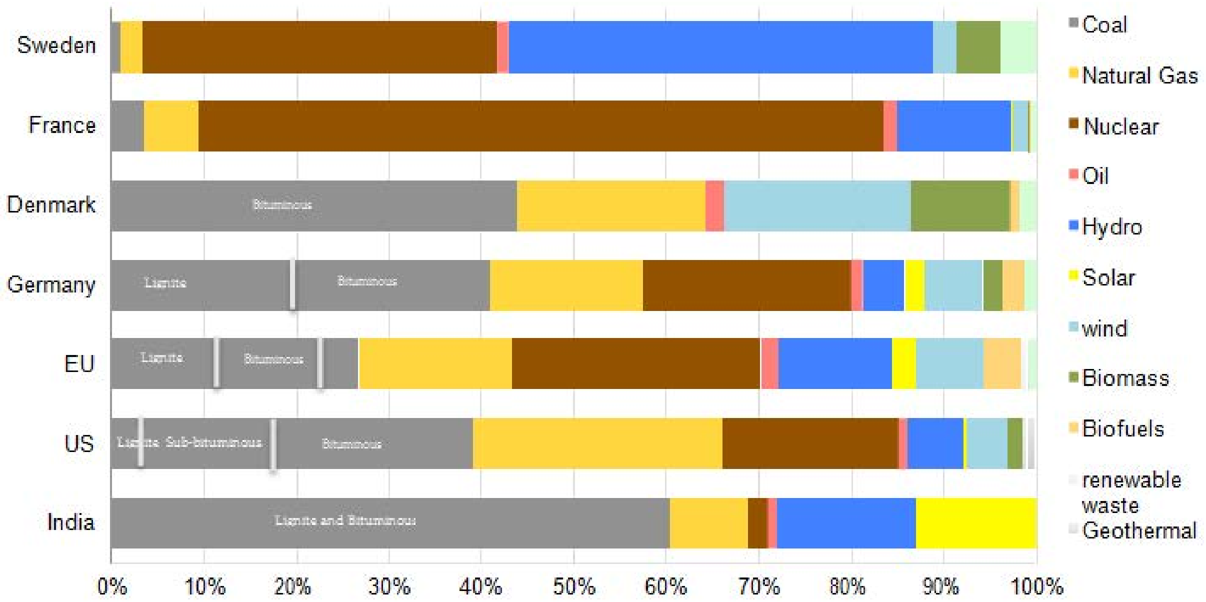

Figure 5: Dirtiest to the cleanest fuel mix by country (Srivastava, 2016)

Even where a downward trend in the use of coal is projected, the type of coal used for electricity generation can have a significant impact on the amount of emissions from the power plant. The type of coal accounts for a significant variation in carbon content that governs power plant GHG emissions (Garg, Kazunari, & Pulles, 2006). For example, in the year 2008, US electric power generation facilities used 49.5% sub-bituminous coal, 44% bituminous, and 6.5% lignite in the total tonnage used (October, 2010). CO2 emissions output is when higher qualities of coal are used compared to the coal fired power plants that burn lower quality coal like lignite (Figure 6, Cai et al, 2012). In combination with power plant combustion efficiencies, this variation in the CO_2 emission outputs from the different types of coal used for electricity generation is also evident at the country level (figure 7). For example India has the highest CO_2 emission output per kilowatt-hour of electricity due to the use of low quality coal (Cropper et al., 2012).

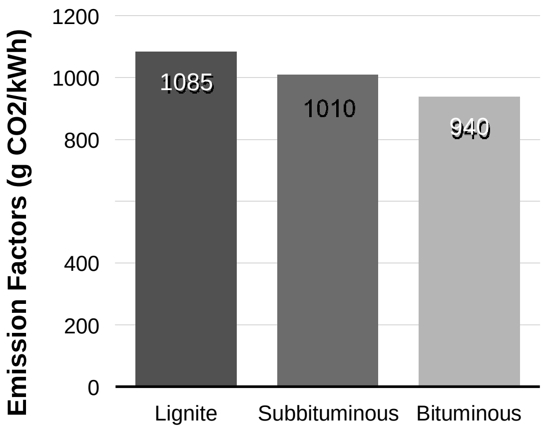

Figure 6: CO2 Emissions by type of coal/ kWh of electricity in the US (Cai et al,2012)

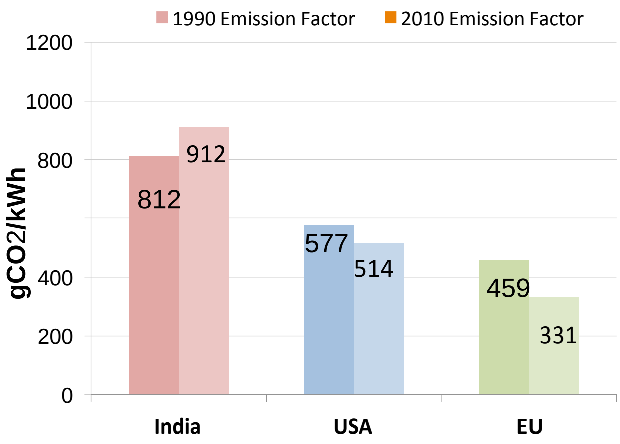

Figure 7: CO2 Emission/ kWh of electricity given variations in coal type and generation efficiencies (IEA,2012c).

The combination of coal quality, combustion technology, and operating conditions of a power plant determine other emissions from power plants beyond carbon (figure 8). In the US, coal fired power plants are the largest sources of sulfur dioxide (SO_x) emissions. The use of emission control equipment - flue gas desulfurization (FGD) scrubbers - has significantly reduced the SO_x emission levels (EIA, 2011). Regardless of coal type ,type, power plants that have scrubbers have substantially lower SOx emissions than unscrubbed coal-fired plants (figure 8), providing another tier of pollution savings for emerging economies and economies with mid-level sustainability goals as they shift away from dirty sources of electricity generation.

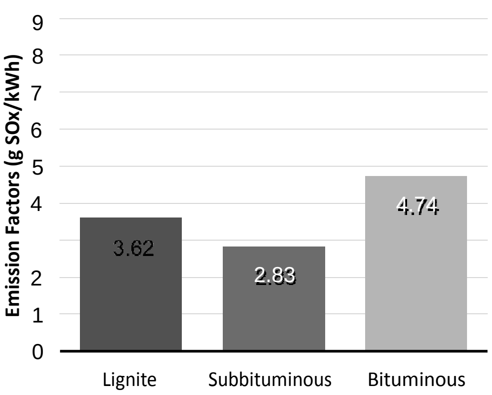

Figure 8: SOx Emissions by type of coal per kWh of electricity in the US

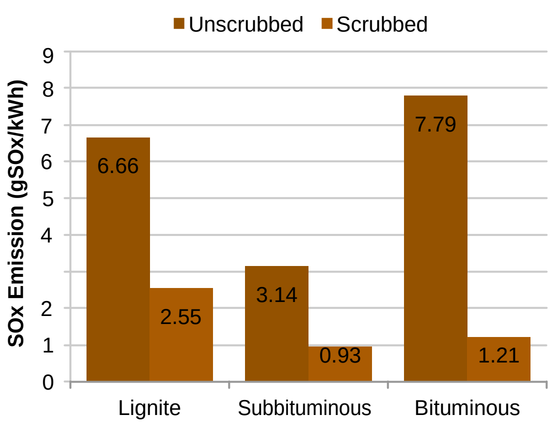

Figure 9: SOx Emissions by type of coal & emission control equipment (EIA, 2011)

The air pollutants emission from power plants affect human health, flora and fauna, and contribute to global climate change that negatively impact natural disasters, agricultural cycles, and more. In addition to air pollution, it is acknowledged that electric power generation can cause several other externalities (EIA, 1995) that are not part of this natural capital savings calculations. For instance, water quality issues that impact aquatic populations and land use values that are affected by solid, liquid and nuclear wastes could be considered in the future iterations.

This TBL methodology captures the impact of fuel sources and mix for electricity generation and the power plant quality for selected greenhouse gases and pollutants - CO_2, CH_4, SOx, NOx, PM2.5 and water use - for which quantifiable data is available. These are pollutants that cause a majority of the environmental damages that arise from burning fossil fuels to generate electricity (Kats & Capital, 2003) and are known contributors to global warming. These pollutants are also known to cause respiratory illness, cancers, and developmental impairment, increasingly quantified by the international community (Venema and Barg, 2003) but not included in this second bottom line. The environmental calculations also do not include the environmental costs or benefits of the materials and assemblies installed and those discarded, a calculation typically captured in life cycle assessment. This is a “gate to gate” assessment of reductions in selected outcomes of power generation, is quantified to represent the environmental savings attributable to energy efficient retrofits.

The last dataset used to calculate the ‘natural capital’ savings is monetary valuation for the selected air pollutants, greenhouse gases and water use for electric power generation set by different countries and international treaties. An example of such a valuation is the social cost of carbon (SC CO_2) developed by the US EPA and other federal agencies to evaluate the climate benefits of national rulemaking. The dollar value represents the benefits or the value of damages avoided for a small emission reduction (EPA, 2013)(EIA, 1995)(Goodkind & Polasky, 2013). Summarizing the downstream externality reduction benefits of each kilowatt hour of electricity saved at the site, Figure 10 illustrates CO2, SOx, NOx, PM2.5 and Water benefits for three global scenarios – an emerging economy (India), economies with mid-level sustainability goals (US), and economies in the forefront of defining climate change policies (EU), given US valuations for pollution reductions but international power sources and generation effectiveness (Figure 10).

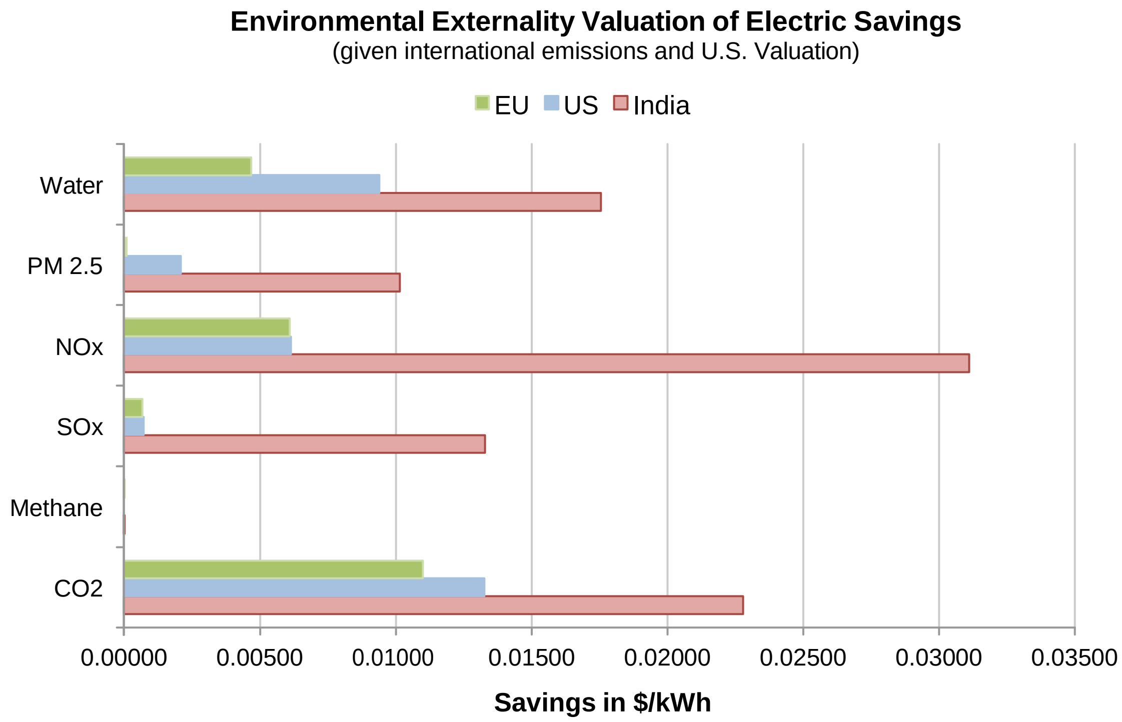

Figure 5: Range of environmental values for avoidance of selected outcomes for three global scenarios – an emerging economy (India), economies with mid-level sustainability goals (US), and economies in the forefront of defining climate change policies (EU) (Srivastava,2016).

In a second bottom line calculation, the capital saved by avoiding the environmental impacts of electricity use, based on fuel source and mix, plant efficiencies and scrubbers, for selected emissions and pollutants at the power plant have been added to each kilowatt-hour of electricity saved. At present, emerging economies place NO value on the externalities associated with power generation, whereas EU's commitment to reduction in GHG emissions may place a much higher value than shown on the US normalized chart above.

A quick introduction to third bottom line human capital savings

A third bottom line calculation is critical to capturing the human cost-benefits offered by energy retrofit investments that also improve indoor environmental quality for the occupants of buildings. To understand the performance benefits beyond energy, it is critical to identify published laboratory and field research that statistically link indoor environmental quality with human health and productivity. The CMU Center for Building Performance and Diagnostics has a long-term research effort focused on identifying published health, productivity, and organizational benefits of high performance buildings in a database entitled BIDS – Building Investment Decision Support Tool. Selected studies that link the three high performance building investments to human outcomes are deployed in the third bottom line calculations . Figure 11 captures two examples of research summaries that link advanced energy retrofits and human benefits that have been included in the calculations.

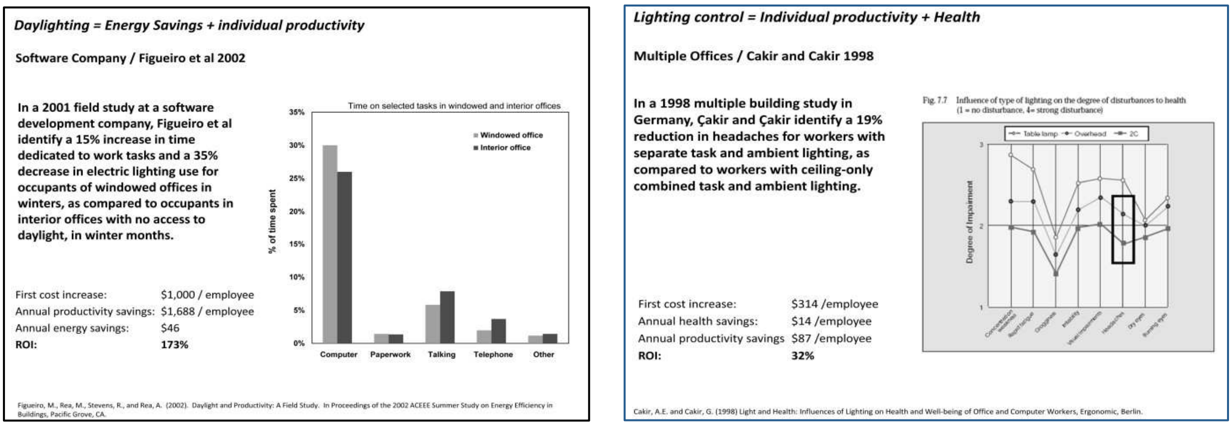

Figure 11: Research summaries linking lighting investments to human health & productivity

Triple bottom line calculations rapidly accelerates return on investment

To demonstrate the TBL methodology, CMU's Center for Building Performance and Diagnostics (CBPD) research team continues to explore the best high performance building retrofit options that would match first costs with energy and carbon savings, pent-up maintenance needs, and human health and performance benefits. Based on existing U.S. commercial building stock analyses, the research team identified façade and lighting retrofit actions that would yield substantial reductions in electric energy use, with additional environmental and human cost benefits. CMU's CBPD has also undertaken extensive field studies (POE) in federal workplaces over a 10-year period and identified a number of conditions contributing to high lighting energy use (CBPD, 2009). Finally, the CBPD participated in the development of the Pennsylvania Action Plan for Climate Change (PA-DEP, 2009), identifying façade and lighting retrofits as critical in the range of building improvements that can have a significant impact on energy use and the associated pollutant levels in Pennsylvania. A number of key lighting retrofit strategies were identified in this detailed cost-benefit study for the State: lowering lighting power density, upgrading lamps and fixtures, maximizing daylight utilization, and adding advanced controls. From this mix, three retrofit investments have been selected to illustrate the impact of triple bottom line calculations on rethinking return on investment.

The first retrofit action to be assessed through a triple bottom line iterative calculation is the introduction of dimming ballasts to maximize the use of daylighting in office environments. Even with tinted glazing, the addition of **daylight dimming in perimeter workspaces** yields up to 35% lighting energy savings (Verderber & Rubinstein, 1984) In addition, daylight dimming will help to reduce the over lighting of workstations, given the significant shift to computer based tasks in the workplace.

The second retrofit action assessed is the addition of clerestory light shelves, in combination with daylight harvesting controls to maximize daylight and view, minimize glare and brightness contrast, and minimize energy use. An 'inverted' fixed light louver for clerestory windows in highly glazed facades increases the depth of influence of daylighting and enhances views. The shift to full spectrum daylight has a measured influence on human health and reduced absenteeism (Thayer, 1995); and natural changes in light levels regulate melatonin production that in turn synchronize circadian rhythms and stabilize our sleep cycles (Figueiro and Rea, 2010). Furthermore, productivity improvements of up to 6.7% have been attributed to access to windows and outdoor views (Heschong et al., 2002; Figueiro et al., 2002). Finally, light redirection louvers help to manage brightness contrast by reflecting light to the ceiling and back on the window wall, with a measured performance improvement at visual tasks by at least 3% (Osterhaus & Bailey, 1992).

The third retrofit action assessed is window **shading to avoid overheating in summer**. While modern office design has been synonymous with sleek glass towers, todays design community is rediscovering the power of facades articulated by fins, louvers, and screens as well as the highest performing dynamic shading devices. Dynamic shading devices can be daily or seasonally adjusted to reflect sunlight when required, while allowing effective daylight penetration and solar gain during the winter (Lechner, 2009). Awnings can be made of synthetic fabrics that are fade resistant, water repellant and require less maintenance than they have historically required. Fixed overhangs, horizontal louvers and fins, and dynamic awnings are each effective additions to modern facades, providing shade with daylight, without diminishing our views with dark glass, eggcrate shading and scrim layers. The use of adjustable awnings as a shading device can reduce solar heat gain and associated cooling loads in the summer by up to 65% on south-facing windows, 77% on west-facing windows and 20-25% total cooling energy savings (DOE, 2012; Nagy et al., 2000). The human benefits of light shelves include the value of glare control for productivity and health previously identified, as well as the benefits of shading for improved thermal comfort in summer. In a 1998 controlled experiment, Witterseh identifies a 54% increase in mathematics accuracy and a 3.5% typing improvement when subjects feel thermally comfortable, rather than too warm, in quiet office conditions (Witterseh, 2001).

The Triple Bottom Line life-cycle benefits of each of the retrofit actions are presented in three successive "return on investment" calculations to offer decision-makers the choice of where they are willing to draw the line: at 'hard' economic cost benefits in the first bottom line; environmental cost-benefits that may be legislated or incentivized in the second bottom line; and the human cost-benefits that should drive standards and investments in buildings in the third bottom line. The successive ROI and payback in years for these three retrofit actions are persuasive, especially when human capital is included in the decision (Table 1).

Table 1: TBL calculation for an economy with mid-level sustainability goals

		Dimming Ballasts	Install Light Louvers	Awnings for shade
Financial Capital Savings	**First cost per employee**	$180	$400	$330*
	Annual Energy savings:			
	Energy Savings (%)	35%	35%	20%
	Energy savings per employee	$48	$50	$20
	ROI (Financial)	**26%**	**12%**	**6%**
	Payback in years	3.75	< 8.5	17
Natural Capital Savings	Given Annual Energy savings in kWh	475	475	195
	Annual Environmental Benefits:			
	Air pollution emissions (CO2, SOX, NOX = $.051/kwH)	$10.6	$10.6	$4
	Water Savings ($0.02/kwh)	$4.5	$4.5	$2
	ROI (Financial + Natural)	**35%**	**16%**	**8%**
	Payback in years	< 3	< 6.5	< 13
Human Capital Savings	**Annual Human Benefits**			
	Productivity increase (0, 1,4%)	$0	$450	$545
	Reduction in absenteeism (15%)	$115	$115	$115
	ROI (Financial + Natural + Human)	**100%**	**158%**	**208%**
	Payback in years	2	< 1.25	< 1

If one-year carrying costs is the extent of the company's leadership ability, the installation of dimming ballasts has the highest return on investment (26% ROI financial capital only), followed by the addition of 'inverted' light louvers in the clerestory area of highly glazed facades to increase the penetration of daylight (12% ROI). The environmental benefits of reducing electricity use for these retrofit actions mirror the energy benefits, so the priorities remain the same while the ROI's get stronger. These environmental savings are most substantial for emerging economies that rely on dirty fuel mixes for power generation (figure 12). The human health and productivity benefits of each of these retrofit actions, however, realign the investment priorities given the benefits of light shelves and shading for the quality of the indoor environment to support human health and productivity.

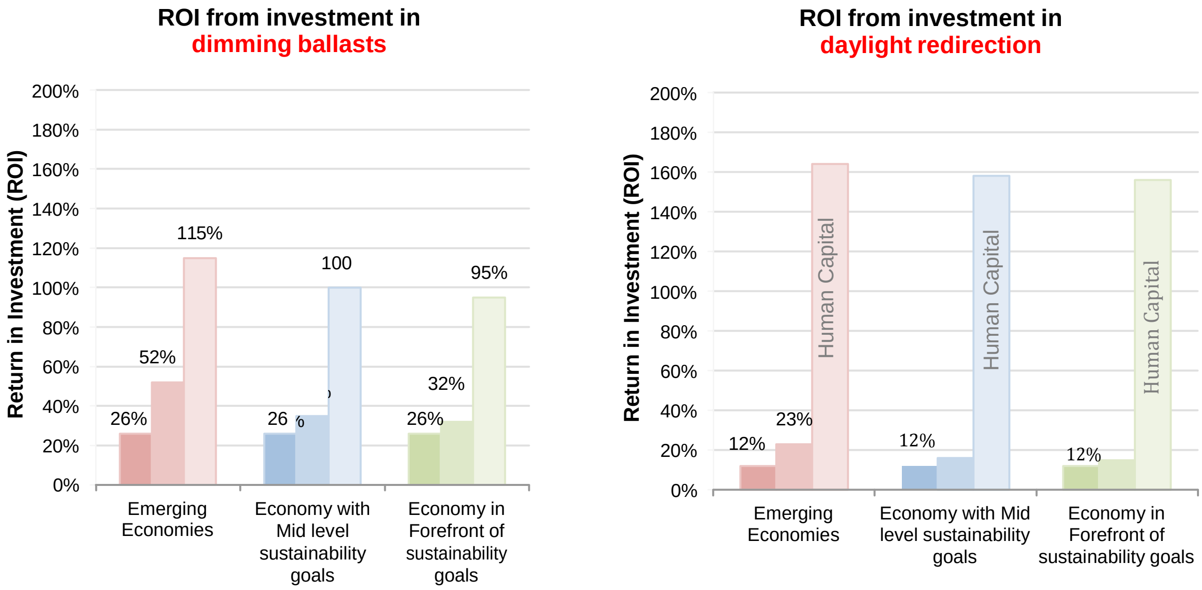

Figure 12: ROI for three energy retrofit investments based on financial, natural and human cost-benefits for three fuel mix economies.

Discussion

Carnegie Mellon's studies of facade retrofits revealed that with energy savings ranging from 15-45%, simple paybacks will be from 2-17 years - if only energy savings are included in the life cycle calculation. However, when the environmental benefits of electricity savings are included, paybacks are faster at 3-13 years. Most strikingly, when human benefits identified in controlled research are included - from reduced headaches and absenteeism to improved task performance or productivity, paybacks for investments in daylighting and lighting retrofits in US offices are less than 2 years.

The addition of environmental benefits accelerate payback of the investment, and can be monetized if the organization is required to meet energy reduction goals of city, state or federal mandates or the organization will be disclosing baseline energy use and annual accomplishments for Energy Portfolio or 2030 commitments; or the organization has made sustainability a centerpiece of their market growth. The second bottom line may not be applicable if electricity is generated from a clean source.

The human health and productivity benefits of lighting and daylighting retrofits are the most compelling arguments for action and shift the return on investments from 6% with paybacks of 17 years to 400% and immediate payback.

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Flexibility of the CEN AND ISO STANDARDS ON ENERGY PERFORMANCE OF BUILDINGS ASSESMENT PROCEDURES supporting the sustainable and smart communities

Jaap Hogeling

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Abstract

The Recast-EPBD[1] requires an update of the current (2007/2008) set of CEN-EPB standards. This update work started in 2012 and will result in a new set of CEN-EPB standards.. Where possible this work will be done parallel with ISO. This project is based on EU-Mandate 480. This mandate accepted by CEN, requires a really out of the box thinking approach of the standard developers. This project is coordinated by CENTC371 the "Program Committee on EPBD" and is considered to be a step forward in progressing towards European Energy Codes for Buildings. This second generation of EPB standards aims on more comprehensive standards, a clear split between informative text in Technical Reports and normative text in Standards, attached excel files to illustrate the calculation procedures etc.. The EPB[2] set of standards and technical reports will support the holistic approach needed for the Nearly Zero Energy Buildings (nZEB) and high performance energy renovation of the existing building stock.

The modular structure of EPB standards is flexible in order to take into account national, regional and regional choices. An approach has been introduced, via the so-called Annex A and B in all EPB standards. Annex B is an informative Annex and includes all default values, choices and options needed to use the standard. Normative Annex A includes empty tables for these needed values, choices and options, this empty template shall be used by National Standard Bodies (NSB) or recognized local, regional or national authorities to declare these values, choices and options to be followed under their jurisdiction. This approach allows maximal flexibility and transparency in applying the EPB standards. If published by the NSB's these filled in Annex conform Annex A are indicated as National Annex to the EPB standard. The flexible approach included in these EPB standards, sometimes criticized, but allowing maximal freedom in innovative design approaches, able to demonstrate the impact of smart energy infrastructures as expected in future smart communities.

Formal Voting drafts of all EPB standards are expected to be ready by mid-2016. After the EPB standards are accepted and finalized the publication by the NSB's in the beginning of 2017.seems possible.

Keywords: EU Energy Performance Buildings Directive; CEN ISO Standards; EPBD; smart energy infrastructures

1. Introduction

Analyses regarding the use of the in 2007/2008 published set of CEN-EPB[3] standards and the requirements set out in the recast-EPBD showed the clear need for a second EU mandate to CEN in order to improve these standards. The revision will improve the accessibility, transparency, comparability and objectivity of the energy performance assessment in the Member States, as mentioned in the EPBD.

The "first generation" CEN-EPB standards were implemented in many EU Member States "in a practical way". Typically: partly copied in "all in one" national standards or national legal documents, mixed with national procedures, boundary conditions and input data.

For a more direct implementation of the EPB standards in the national and regional building regulations, it is necessary to reformulate the content of these standards so that they become unambiguous (the actual harmonized procedures), with a clear and explicit overview of the choices, boundary conditions and input data

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[1] EPBD: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings.
Recast-EPBD: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings; (recast).

[2] In this paper EPB stands for "Energy Performance of Buildings" the D for the EU-Directive is intentional deleted in relation to the standards. The EU-directive is of great importance for the EU-member states however these CEN standards could become ISO standards as well and it is more appropriate to use just EPB.

that can or needs to be defined at national or regional level. This implies that the current set of CEN-EPB standards is improved and expanded on the basis of the recast-EPBD.
The standards shall be flexible enough to allow for necessary national and regional differentiation to facilitate EU Member States implementation. Such national or regional choices remain necessary, due to differences in climate, culture & building tradition, building typologies, building regulation, existing energy infrastructure, policy and/or legal frameworks.

2. Work in progress, the last phase of the work on the EPB standards

The EPB standards have been developed by the following CEN/TC's:

- TC 089 Thermal performance of buildings and building components;
- TC 156 Ventilation for buildings;
- TC 169 Light and lighting systems;
- TC 228 Heating systems for buildings;
- TC 247 Building automation, control and building management;
- TC 371 Project Committee on Energy Performance of Buildings.

These TC's are responsible for the technical content of EPB standards to be developed or revised. CEN/TC 371, the overall responsible coordinating committee, also ensuring that the timetable will be met and that the basic principles and rules, the modular approach and the foreseen improvements of the current set of EPB standards, are in line with the targets indicated and meeting the expectations of the end users.
CEN/TC 371 formulated common Basic Principles (CEN/TS 16628:2014) on the required quality, accuracy, usability and consistency and a common format for EPB standards, including a systematic, hierarchic and procedural description of options, input/output variables and relations with other standards and elaborated a unique hierarchic system for the EPB standards.
CEN/TC 371 [4] prepared the Basic Principles (BP) and the supporting Detailed Technical Rules (DTR) (CEN/TS 16629:2014), as basis and guidance for the total set.
The work carried out in CENTC371 and CENTC89 is done under the Vienna Agreement with CEN-lead. This means that these standards are developed in cooperation with ISO/TC163 and 205 and are going to be published as EN/ISO standards in the ISO52000-series.

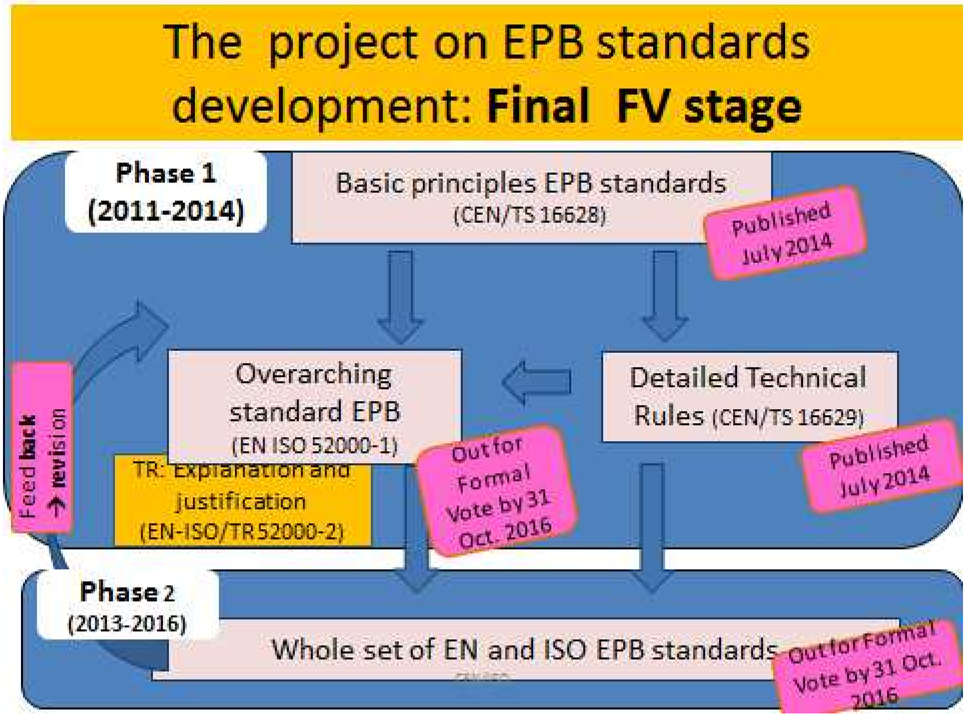


Figure 1 Current status

3. The Principles

The mandate M/480 explicitly requests for identification and prioritisation of items for revision and gaps in the current set of standards in consultation with the EU member states (MS).

The following, general principles are valid for the set of EPB standards :

1. The complexity of the building energy performance calculation requires a good documentation and justification of the procedures. Informative text is required but it will be separated from actual normative procedures to avoid

[4] CEN/TS 16628:2014 Energy Performance of Buildings - Basic Principles for the set of EPBD standards
CEN/TS 16629:2014 Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards

confusion and unpractical heavy documents. Therefore, each EPB standard (or sometimes a close connected set of) shall be accompanied by a Technical Report where all related informative material will be concentrated.[5]

2. The complexity of the building energy performance calculation requires also a very good coordination and testing of each calculation module. Therefore, each EPB standard shall be accompanied by a spread-sheet where the proposed calculation algorithms and data input/output are tested and proved to be consistent. A Software Tool team checks the calculation modules of the total set of EPB standards. With this excel based software it will be possible to assure that the in/output files of the various connected EPB standards are valid.

4. The deliverables of CENTC371

4.1 CEN/TS Basic Principles

CEN/TS 16628:2014 Energy Performance of Buildings - Basic Principles for the set of EPBD standards. This TS provides a record of the rationale, background information and all choices made in designing the EPB package. These basic principles are based on the analysis of the weak points within the first generation EPB package and on an evaluation of requirements by the Regulating Authorities and the outcome of the IEE-project CENSE (see http://www.buildup.eu and http://www.iee-cense.eu/).

The TS Basic Principles provides guidance on the required quality, accuracy, usability and consistency of each standard and the rationalisation of different options given in the standards, providing a balance between the accuracy and level of detail, on one hand, and the simplicity and availability of input data, on the other.

4.2 CEN/TS Detailed Technical Rules

CEN/TS 16629:2014 Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards. This TS is based on the CEN/TS BP and provides mandatory detailed technical rules to be followed in the preparation of each individual EPB standard. This is in addition to the CEN drafting rules and complementary to the Overarching Standard (former prEN15603 and current draft-ISO 52000-1) in this article indicated as OAS. The OAS, containing the common terms, definitions and symbols and the overall modular structure for the set of EPB standards. The DTR gives a common format for each standard, including a systematic and hierarchic structure to pinpoint the position of the standard within the framework of EPB standards and procedural description of options, input/output variables.

The CEN/TS DTR includes guidance for:

-a clear separation of the procedures, options and default data to be provided as default CEN option in an annex B but also allowing for national or regional choices conform the normative annex A of each of the EPB standard (where appropriate);

-a specification of the input data, also indicating the source of the data if this is the output calculated according to another EPB standard or related product standard;

-a specification of the intended output that is intended to provide the energy performance assessment results, the related data necessary for their proper interpretation and use, and all relevant information documenting the relevant boundary conditions and calculation or measurement steps.

-an informative CEN Technical Report, accompanying each standard[6], according to a common structure, comprising at least the results of internal validation tests (such as spread sheet calculations for testing and demonstrating the procedures), examples and background information. Almost all informative parts of EPB standards will be in these technical reports.

4.3 Energy performance of buildings-Overarching standard EPB; the former FprEN 15603: 2014 and current draft EN-ISO 52000-1 (expected out for Formal Vote at ISO and CEN level around October 2016)

This standard (OAS) specifies a general framework for the assessment of the overall energy use of a building, and the calculation of energy ratings in terms of primary energy, using data from other EPB standards, providing methods for calculating the energy use of services within a building (heating, cooling, humidification, dehumidification, domestic hot water, ventilation, and lighting). This assessment is not limited to the building alone, but takes into account the wider environmental impact of the energy supply chain.

The OAS handles the framework of the overall energy performance of a building, covering inter alia:

1. common terms, definitions and symbols;
2. building and system boundaries;
3. building partitioning;
4. unambiguous set of overall equations on energy used, delivered, produced and/or exported at the building site, near-by and distant;

[5] Either as a separate TR or if very limited as an informative annex to the standard. It is also possible that a TR will cover more standards.

[6] This to significantly reduce the length of the standards and strengthen their focus, thus facilitating the adoption (including translation) in national/regional regulations.

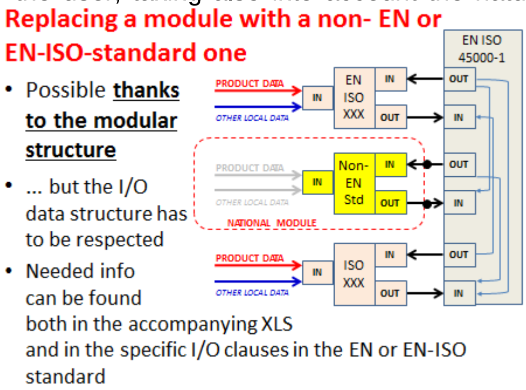
5. unambiguous set of overall equations and input-output relations, linking the various elements relevant for the assessment of the overall energy performance of buildings which are treated in separate standards;
6. general requirements to standards dealing with partial calculation periods;
7. general rules in setting out alternative calculation routes according to the calculation scope and requirements;
8. rules for the combination of different partitioning, thermal zoning and service areas.

The OAS provides a systematic, clear and comprehensive, continuous and modular overall structure on the integrated energy performance of buildings, unlocking all standards related to the energy performance of buildings.

The overall framework provided by the OAS will work as the "***Backbone***" (see figure 2) of the set of EPB standards, it facilitates a step-by-step implementation by the user, taking also into account the nature of each procedure identifying the typical type of user. More information is given in a Technical Report accompanying the OAS. The justification for the defaults and options are provided in this TR (draft TR 52000-2).

Current (February 2016) status: this prEN ISO 1 passed the enquiry. The enquiry results have been processed. The Formal Voting is expected at the by end of October 2016. After the standard is accepted publication by the beginning of 2017 possible.

The flexibility approach by replacing CEN standard modules by custom made modules as illustrated in 2.



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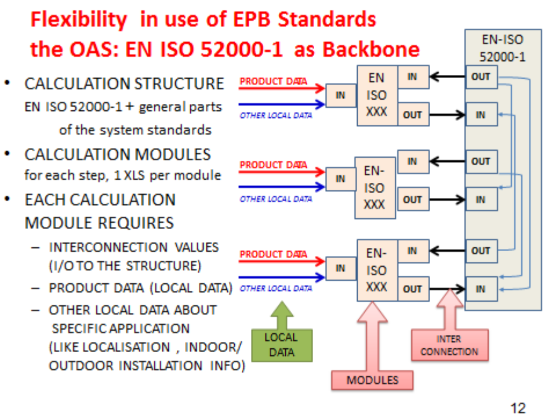


Figure 2 The OAS as backbone for the set of EPB standards

This flexible approach is supporting the sustainable and smart communities. The way modules can be handled and the unambiguous set of overall equations on energy used, delivered, produced and/or exported at the building site, near-by and distant allow the flexibility needed to support the development of smart grids and local energy communities.

4.4 Draft EN ISO TR 52000-2 (former prCEN/TR 15615:2014) Energy Performance of buildings - Accompanying Technical Report.

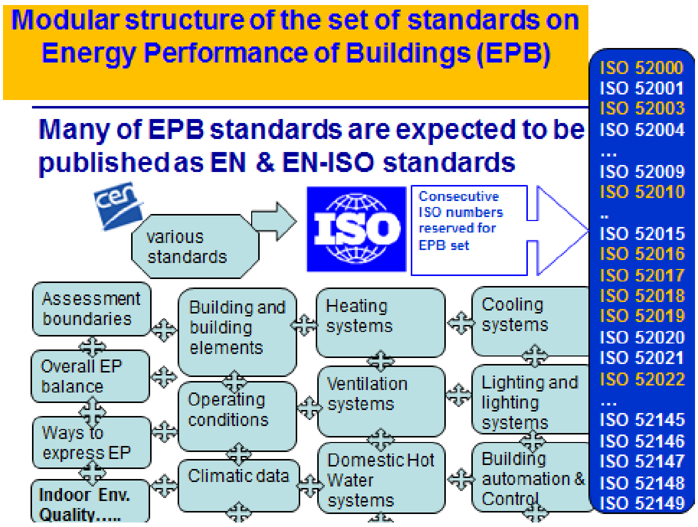
This draft-TR contains information to support the correct understanding, use and national implementation of this standard.
This draft is expected to be published at the same time as the OAS.

5. Hierarchic numbering system - Modular structure

The setup of a coherent and hierarchically numbered system of EPB standards is a requirement. Given the fact that not all standards will be ready for parallel ISO enquiry or publication and that standard numbering system in CEN doesn't allow this, a modular structure has been developed, allowing for addressing documents given hierarchic positioning in that structure. By adding the identification code of a specific cell of the modular structure (see Figure 3 & 4) the purpose of a standard (and/or specific clauses of the standard) can be identified easily.

Figure 3 Overarching Modular structure and connected ISO numbering

Overarching		Building (as such)		Technical Building Systems										
	Descriptions		Descriptions		Descriptions	Heating	Cooling	Ventilation	Humidification	Dehumidification	Domestic Hot water	Lighting	Building automation & control	PV, wind, ..
sub	M1	sub	M2	sub		M3	M4	M5	M6	M7	M8	M9	M10	M11
1	General	1	General	1	General									
2	Common terms and definitions; symbols, units and subscripts	2	Building Energy Needs	2	Needs									
3	Applications	3	(Free) Indoor Conditions without Systems	3	Maximum Load and Power									



4	Ways to Express Energy Performance	4	Ways to Express Energy Performance	**4**	Ways to Express Energy Performance									
5	Building Functions and Building Boundaries	5	Heat Transfer by Transmission	**5**	Emission & control									
6	Building Occupancy and Operating Conditions	6	Heat Transfer by Infiltration and Ventilation	**6**	Distribution & control									
7	Aggregation of Energy Services and Energy Carriers	7	Internal Heat Gains	**7**	Storage & control									
8	Building Partitioning	8	Solar Heat Gains	**8**	Generation & control									

9	Calculated Energy Performance	**9**	Building Dynamics (thermal mass)	**9**	Load dispatching and operating conditions										
10	Measured Energy Performance	**10**	Measured Energy Performance	**10**	Measured Energy Performance										
11	Inspection	**11**	Inspection	**11**	Inspection										
12	Ways to Express Indoor Comfort			**12**	BMS										
13	External Environment Conditions														
14	Economic Calculation														

The shaded modules are not applicable

Fig. 4 – The overarching modular structure of EPB standards; this Table 1 from the OAS illustrates the position of this standard (in casu M1-1 - M1-3, M1-5, M1-7 – M1-10), within the modular structure of the set of EPB standards

6. Calculation tool and Module description

The complexity of the building energy performance calculation requires also a very good coordination and testing of each calculation module to ensure coherence and the software-proof of the set of EPB standards. Therefore, each EPB standard shall be accompanied by a spread sheet in which the proposed calculation algorithms and data input/output are tested and proved coherent.

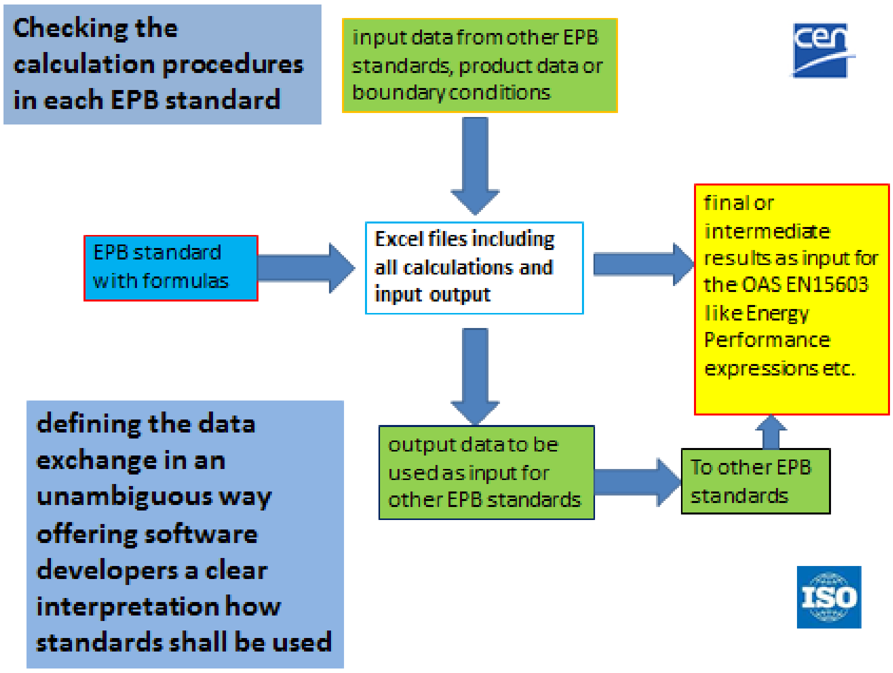


Figure 5 Software check of the excel sheets of the EPB standards

7. How the EPB standards interacts with the relevant product standards

Saving energy in the build environment requires not only that products consuming electricity and fuels are designed to be intrinsically more energy efficient. The interaction of a product with the rest of the system or installation in a building into which it is fitted plays an important role. This appears obvious for a number of product categories such as building equipment for ventilation, heating, cooling, lighting, control and automation. With the increasing application of electronic and communication technologies, this is also increasingly true for many other products, used in buildings but not considered as EPB related, that become ‘smart’ and ‘networked’, and can be controlled through wider systems (IoT). When EU-policies such as the Ecodesign Directive use a too narrow product-based view, products are considered irrespective if their surroundings and tested in standard conditions. If only their technical efficiency is considered, this approach may look straightforward but misses the savings that can be expected from ensuring that the product is also correctly sized, fitted and controlled to render its service optimally in a well-designed building installation. While it may be difficult to reach an EU regulation of systems under product policies, it may be possible to find creative ways for tackling at least a part of the energy savings.

On one hand we have the Ecodesign Directive requiring through EU regulation minimal energy performances of energy using products. On the other side we have the EPBD where the EU Member States are obliged to require minimal target values for the energy performance of buildings, also having specific requirements for the overall thermal performance and the energy performances of the heating, ventilation lighting and cooling systems

The CEN expert teams working on the different EPB-system standards checked if the product data available on basis of product standards and/or related EU regulations are sufficient as input for their system standards. At the same moment the CEN and ISO product Technical Committees and/or experts have to be convinced that using the EPB system approach, to describe and test the products, is the most efficient way to ensure effective energy performance targets for products, systems and finally the buildings (figure 6).

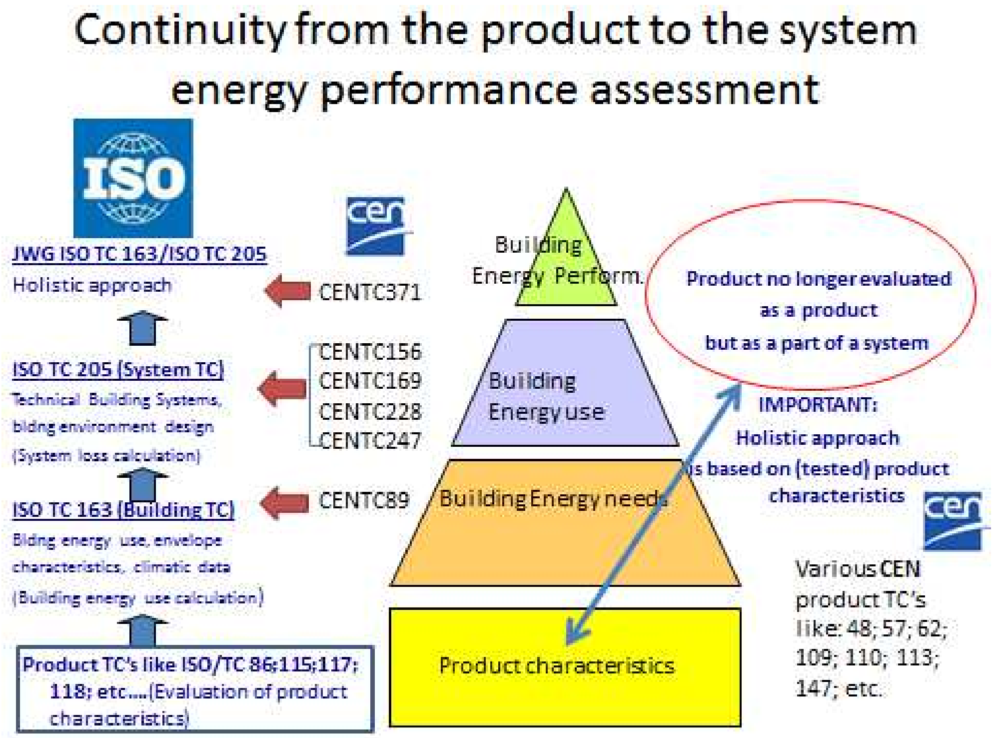


Figure 6 Products not longer evaluated as products but as part of the system where the interaction between product and system related CEN and ISO TC's is illustrated.

The holistic approach to buildings developed by the CEN in cooperation with ISO TC 163/205 Joint Working Group (JWG) and as a result of the EU mandate has opened new opportunities and challenges to the built-environment industry. While much of the detailed development has been done within CEN and for the EU, the intent has always been to extend the results through the Vienna Agreement to ISO. Figure 6 shows the ISO related perspective of the pyramid that illustrates the Holistic Approach to Buildings in a slightly altered and emphasized manner. One will note that the emphasis is on the very bottom and therefore "base" of the structure namely the product information required to support everything needed to move up the pyramid to the ultimate goal of building performance characterization One will note in the figure the intent is evaluate products not individually but as part of the system. This is not done lightly and will require a different paradigm from the companies and organizations involved

8. Co-operation with ISO

An active process of interaction for the overarching type of standards through the JWG of ISO TC 163 & 205, for the other CEN-EPB standards via the different WG's of ISO TC 163 and ISO TC 205. Experts in the ISO and CEN teams are working on these standards, with the ultimate goal to agree on EN-ISO standards. A challenge given the geographic and other differences in the building sector. For several EPB standards under some of the CEN TC's the cooperation with ISO is still informal. This means that for these standards no parallel voting is expected before 2017. Current parallel voting on EN-ISO EPB standards is expected for the OAS-type standards and the building thermal performance related standards as developed under ISO/TC 163. These ISO standards are indicated like EN-ISO 520xx-1 (see also figure 3) and the connected Technical Reports as CEN-ISO TR 520xx-2. Several (11 of the 52) first generation EBP standards are already EN-ISO standards. They have been developed under the Vienna Agreement. Revision of these standards requires co-operation with the responsible ISO/TC. The central co-ordination of the preparation of a set of international standards on the energy performance of buildings at the ISO level is in the hands of ISO /TC 163/WG 4, *Joint Working Group of ISO TC 163 and TC 205 on energy performance of buildings using a holistic approach*. The main leading and active experts in CEN and ISO are among the main leading and active members of this ISO Joint Working Group. This co-operation with ISO aims to avoid serious duplication of work, to avoid incompatibilities in input product data, procedures and (output) energy performance data related to buildings and systems.

Session

Policies & Programmes II

Lessons learned from NABERS and Energy Star - relevance to next iteration of EPBD?

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Abstract

The Energy Star and NABERS (National Australian Built Environmental Rating Scheme) building energy performance rating systems were developed in parallel in the US and Australia and share many common elements, including the use of statistical benchmarking based on real buildings to form the underlying basis of the systems. Both systems have now been in operation for 15 years or more, and it is useful to compare and contrast these systems to understand the differences and similarities in approach. In both cases, after years of refinement as a voluntary initiative, the two systems are now the basis for mandatory rating and disclosure schemes in each country.

In this paper, the two approaches will be compared from both an implementation and technical perspective. Energy Star performance ratings for offices are compared with the relevant NABERS ratings to determine the differences and similarities in the following key aspects of their operation: input data types (e.g. area, hours, climate) and measurement approach, underlying datasets used for benchmarks and comparison, weather and other normalization factors, fundamental performance metric (e.g. primary energy vs greenhouse gas), actual stringency of rating for climates common to both tools, rating scale approach and use, market impact, and administration.

The purpose of this review is to facilitate insights into the practicalities of the comparison of efficiency benchmarks from one country to another, as well as to highlight the possible directions either tool, or any new tool in another country, could take to improve international compatibility and comparability. The widespread use and acceptance of commercial building operational ratings may have relevance to future revisions to the European Energy Performance of Buildings Directive (EPBD), as policy makers work to understand and resolve the performance gap highlighted by many buildings consuming significantly more energy than a calculated asset rating would predict.

Introduction

Building energy performance rating and benchmarking[1], meaning utilizing energy consumption data for the purposes of comparing a building to its peers, has expanded worldwide as a policy tool intended to encourage identification and reduction of energy waste. The rating systems, programs, and policies have evolved significantly in the past few years as a result of continuous feedback, first from voluntary precursor programs and then from data collected from participating buildings. Across the United States (US), Europe, and Australia, mandatory benchmarking requirements and disclosure laws are creating additional data beyond the voluntary precursors. This paper compares and contrasts the approaches in the US and Australia, where the schemes began as voluntary initiatives and have evolved to mandatory policies covering parts of the market in both jurisdictions.

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[1] The terms "benchmarks," "benchmarking" and "rating" are not always understood the same way in different regions. For the purpose of this paper, a "benchmark" refers to any data collected on any metric that is meant to enable a comparison. Energy Use Intensity (EUI, or energy use per floor area) is a benchmark, and regular collection of this benchmark is "benchmarking." A "rating" is more specific, and simplifies things by attempting to clarify the conclusion drawn from the benchmarking comparison. The Energy Star score and NABERS stars are examples of ratings.

Building energy performance rating is the act of collecting building energy use information and comparing that information to the energy use of other, similar buildings (real, averaged, or estimated) for the purposes of drawing conclusions about a building's energy efficiency. There is a wide variety of types of building energy rating schemes currently in use around the world. The ratings may be based on actual usage data (operational ratings) or physical building characteristics and assumed operations (asset ratings), and may be focused on the whole building energy performance, or parts of the building where different stakeholders have decision-making and investment authority (IPEEC 2014, Leipziger 2013). This paper focuses solely on the energy benchmarking and rating of the operational performance of large buildings in the US and Australia.

Building benchmarking and rating policies are often accompanied by requirements for the disclosure of the benchmark results at a point in time, either calendar-based (annually or less frequent) or event-based (lease or sale). The requirements are to provide the benchmark results to enable the interested parties to make some comparison to other buildings and understand the larger context of the energy use of the building and associated costs. The requirement may specify an energy intensity metric (energy per unit space) or a building energy rating.

Evolution of Rating Systems in the two countries

United States

In the absence of federal policy, benchmarking laws are being rapidly adopted across the United States at the sub-national level, particularly by large cities. Since 2007, 15 U.S. cities, two states, and one county have created rules requiring energy benchmarking for privately owned commercial and/or multifamily residential property. Roughly half of these rules were adopted in the past four years, a bellwether for strong and sustained interest by policymakers.

Adopted policies vary significantly in design, including policy scope (the types and sizes of buildings required to comply); compliance timeframes; benchmarking quality control measures; and information reporting and disclosure requirements. Yet they also share core design elements that provide strong continuity across jurisdictions. All of the adopted policies require use of the Energy Star Portfolio Manager tool, and most adopted policies require benchmarking to be conducted annually (the exceptions are the states of California and Washington, though these states may be modifying their requirements).

Launched by the U.S. Environmental Protection Agency (EPA) in 1999 as a key tool of the voluntary Energy Star Buildings initiative, Portfolio Manager is a free, online energy benchmarking software tool. It calculates a whole building energy efficiency rating of “1” to “100” for common commercial building types and multifamily buildings based on 12 months of energy usage data and basic information about building occupancy and operations. As of the end of 2012, it was used to benchmark more than 300,000 buildings totaling more than 30 billion square feet (approximately 2.8 billion square meters) of space, (USEPA 2013). Portfolio Manager is by far the most widely used benchmarking software tool in America, with the 30 billion square feet representing approximately 42% of all U.S commercial building floor area. U.S. policymakers have consistently chosen to leverage Portfolio Manager in benchmarking laws in part because of its widespread, voluntary usage in the real estate marketplace.

The current landscape of U.S. benchmarking policies is summarized in the figure 1.

The state of California adopted its benchmarking policy in 2007, the first such policy in the United States. It requires benchmarking for commercial buildings greater than 5,000 square feet (approximately 460 square meters) involved in a sale, financing, or full-building lease transaction. Benchmarking information must be reported to the State and disclosed to the prospective transaction counterparty. The state delayed implementation of its policy several times, and in 2015, passed a suite of changes to the policy, most notably allowing the implementing agency broad flexibility in changing the program and likely converting the “time of sale or lease” requirement for benchmarking to an annual requirement.

District of Columbia: The District of Columbia adopted its benchmarking policy in 2008. It was the first U.S. policy to require the public disclosure of benchmarking information. It requires annual benchmarking for commercial and residential buildings greater than 50,000 square feet (approximately 4,600 square meters). Benchmarking information must be reported annually to the

District, which posts it on a public website. The rate of compliance is 83%, according to a District report published in February 2014.

New York, NY: The City of New York adopted its benchmarking policy in 2009. It requires annual benchmarking for residential and commercial buildings greater than 50,000 square feet. Benchmarking information must be reported annually to the City, which posts it on a public website. The rate of compliance is 84%, according to a City report published in September 2014.

Numerous other large cities around the US have adopted similar policies in recent years as shown above in Figure 1, and details on the various requirements can be found at the regularly updated website: www.buildingrating.org

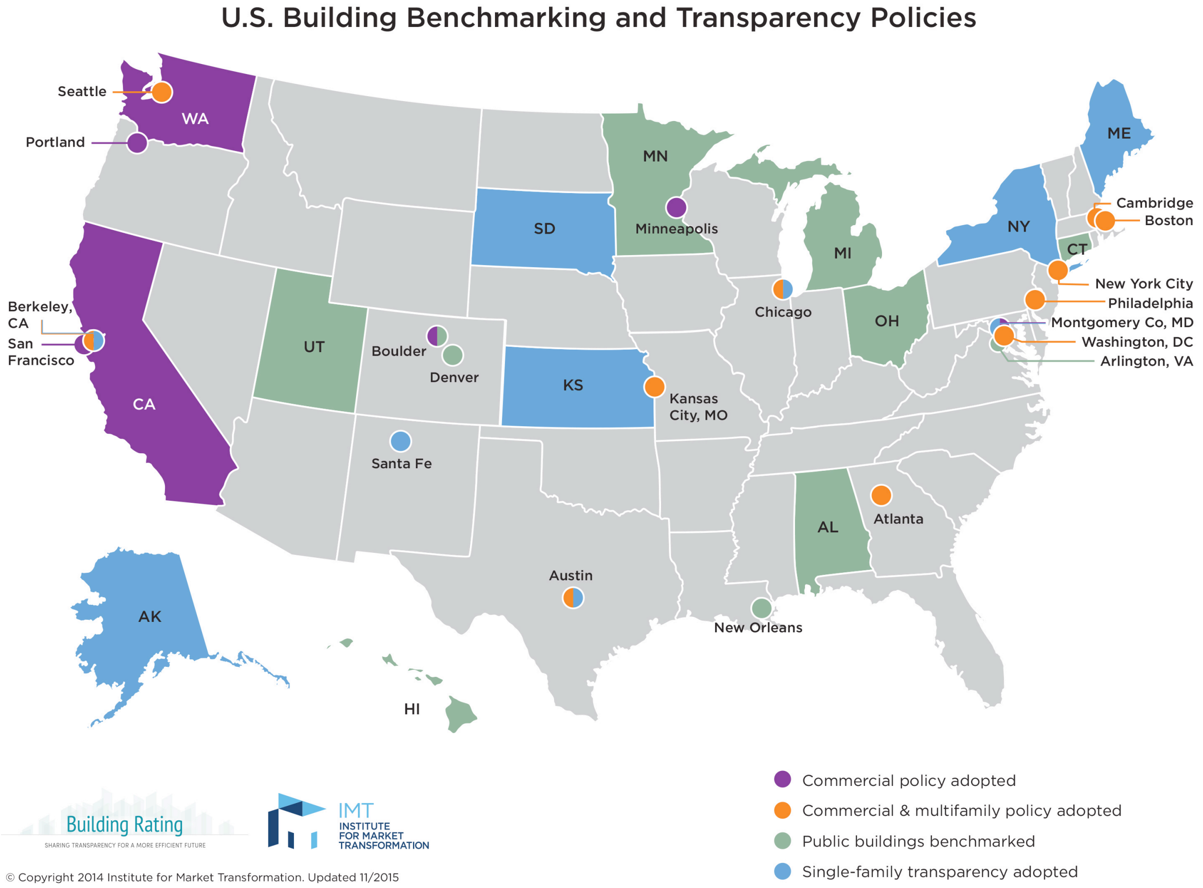

Figure 1. Benchmarking Policies and Programs in the United States. (BuildingRating.org 2015)

Australia

Australia requires disclosure of the current energy rating of commercial office buildings in the event of the sale or lease of more than 2000m^2. Enacted in 2010 and named the Building Energy Efficiency Disclosure Act, the law created the Commercial Building Disclosure (CBD) program which requires the use of the NABERS (National Australian Built Environment Rating System) tool to for covered buildings.

NABERS was created by the New South Wales government in 2005 and evolved out of a predecessor program called the Australian Building Greenhouse Rating (ABGR) created six years earlier. Significant development effort on the system was expended when it was a voluntary program. The tool produces a rating from “1” to “6” stars (initially five, and advanced levels of achievement have been added to distinguish the highest performers for office water and energy use). The rating is calculated from 12 months of performance data that is converted to greenhouse gas emissions, and accommodations are made for energy source, building size, type, and usage, and climate. The program is now managed by the NABERS National Administrator, in the NSW Office of Environment and Heritage. NABERS also operates in New Zealand, under licence from the NABERS National Administrator.

NABERS is distinct worldwide in offering building ratings for whole buildings and tenancies, and base building ratings for the areas controlled by the landlord. The base building covers the common areas and central building systems, whereas the tenancy rating covers tenant-occupied spaces. The most common type of NABERS rating is for the base building, and this is the basis for many policies in place in Australia, including the mandatory CBD.

The NABERS tool has expanded in scope beyond offices to include shopping centers, homes, hotels, and data-centers, and can also benchmark water usage (whole building only) for most of these building types. In offices the program can also assess waste and indoor environment quality. It should be noted that the NABERS program is distinct from green building rating systems for new construction, such as the Green Star program from the Australia Green Building Council.

The CBD program requires the use of the NABERS tool to produce a Building Energy Efficiency Certificate. The Certificate contains a whole-building or base-building NABERS rating (NABERS provides for separate ratings for either the whole building, or just base building or tenant space), a tenancy lighting efficiency assessment, and general energy efficiency recommendations. CBD accredits assessors to produce the Certificates and submit them on behalf of building owners. The law requires the rating to cover the base building, unless it is impossible to distinguish the base building energy consumption from tenant-controlled consumption, in which case a whole-building rating is sufficient. The Certificates are valid for up to 12 months, or until the NABERS rating referenced expires.

Pre-mandate market penetration and effectiveness

Comparing voluntary implementation and results from the Energy Star program before New York City passed a mandatory requirement and similar statistics from Australia before the enactment of the CBD program show similar market penetration and results.

- 60 percent of Australian office space was benchmarked before it became mandatory (Bannister, 2012). At the equivalent time before the NYC law became effective, the US benchmarked office space was somewhere between 40 to 50 percent (EPA, 2010).
- In late 2012, 11.1 million square meters, or 66 percent of Australian office space was benchmarked (NSWOEH, 2012), while the US reports about the same penetration, with 834 million square meters (EPA, 2013).
- Office buildings repeatedly benchmarking in the US and Australia show nine percent improvements in energy efficiency[2] (NSWOEH, 2012 and EPA, 2012).
- Highly rated Australian offices attain rent premiums of up to three percent and show value premiums of two to nine percent, while low rated offices have up to nine percent lower rents. (Newell, McFarlane, and Kok, 2011). Multiple studies on Energy Star and LEED buildings show rent premiums of two to nine percent and value premiums of six to 31 percent (IBE 2012).

The mandatory benchmarking requirements in Australia and major U.S. cities are increasing the use of the benchmarking programs. Additional research the effect of benchmarking is being conducted based on the new datasets being created as result of these policies.

Initial Results of Mandatory Policies in the U.S.

The individual or collective impact of U.S. benchmarking policies on energy efficiency, carbon reduction, real estate valuation, and other areas is beginning to be analyzed. A recent study by U.S. researchers suggested that the benchmarking policies of four cities resulted in a statistically

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[2] For the US, the improvement is in the whole building energy performance, while for Australia it is just base building performance.

significant 2% reduction in utility expenditures per square foot (Palmer and Walls 2014). Previous analysis by the USEPA (Oct 2012) indicated that general use of Portfolio Manager is correlated with demonstrable energy savings in buildings over time.

Initial Results of the Australian Requirement

The first-year results for the CBD program were released in 2013 and covered the period from November 2011 to November 2012. Because the requirements are triggered by sale or lease, compliance rates are not directly comparable to policies requiring annual reporting as in some U.S. jurisdictions, but some buildings do update their Certificates on a rolling basis (DoRET 2013). In the first year, 1250 Certificates were issued covering 850 buildings. Eighty-nine percent of the net-lettable-area of the buildings rated was covered by a base building rating, leaving only 11 percent covered by a whole building rating (DoRET 2013).

Second Year results

The second year of the program ending November 2013 resulted in 1,081 Certificates covering 862 buildings (DoI 2014). Interestingly the average star rating stayed nearly identical at 3.03 for the second year compared to 3.04 in the first. In the second year, 91 percent of the net-lettable-area received base building ratings and the remainder received whole building ratings (DoI 2014).

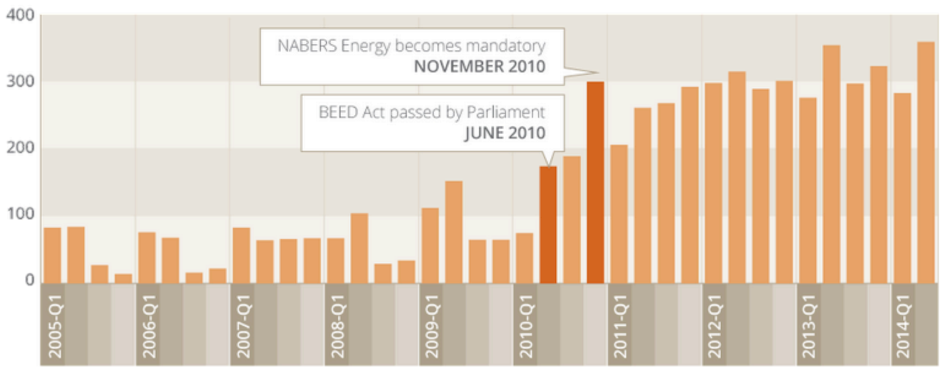

Figure 2. Quarterly Growth of Office Ratings in Australia. (NABERS 2014)

NABERS and Energy Star Compared

Basics

Both NABERS and Energy Star provide intensity metrics in terms of source energy use or greenhouse gas emissions per unit area for buildings over a one-year period. Both programs normalize for weather and occupancy, so that comparisons across locations and occupancy levels are possible. Both programs convert that normalized intensity metric into building type specific rating so performance can be evaluated by an interested third party.

While both programs target commercial buildings, in reality they evaluate different things. Energy Star evaluates whole building energy performance, and as a result the benchmarks and ratings produced by the program speak very effectively to the overall impact of a building. The downside of the whole building focus is that separating the owner and tenant contributions to that overall impact is impossible. An office building with inefficiently operated central mechanical systems that also happens to have tenants with relatively low energy demands may attain the same rating as highly efficient and optimized building with extremely demanding tenants. Certainly the program normalizes for occupant density, computer density, and special space use cases to counteract this possibility, but because it depends on assumptions made for the whole building, less extreme cases of these variations could easily impact ratings.

NABERS structurally addresses this potential by having separate ratings for base building, tenants, and whole buildings; though in reality the vast majority of rated buildings are base building ratings. It is important to view these ratings within that context and to be wary of extrapolating base building performance to whole building performance.

This flexibility afforded to NABERS by separately rating base buildings and tenancies has enabled the development of policies targeting those segments and potentially contributed to market penetration and passage of the national benchmarking requirements. Owners and operators do not have to contend with data access or quality issues when producing the required benchmarks because the data used is their own.

Energy Star utilizes source (primary) energy intensity, meaning it considers the energy intensity of the fuel generation as well as the energy usage on site, to compare to a range of source energy intensities of that same building type across the country. From that comparison, the program produces the 1 to 100 score that roughly represents the performance percentile that building attains. Energy Star certifications are awarded when a qualified third party verifies this rating and the rating is over 75, representing top quartile for the building type. Not all building types can attain an Energy Star score or certifications, but many building types can utilize the tool to generate a normalized source energy intensity.

The NABERS program undertakes a similar process to normalize a greenhouse gas intensity metric (which accounts for the fuel source similarly to source energy) for weather and occupancy, and compares that number to the associated intensities for that building type according to the NABERS dataset. Intensity metrics are binned and the bins are assigned star ratings, from 1 to 6 stars. Market leading performance is generally signified by 4 or above stars, and 6 stars represents meeting a high performance intensity metric established by the program administrators. Average performance is considered to be around 3 stars. Half stars can be awarded, and official scores must be produced by verified third parties called assessors.

Structure and Data

When considering the structure of either benchmarking program, it is extremely important to understand the resources and constraint that directed their evolution. For example, the availability of trusted data sources on building energy consumption determined the initial building types that the program targeted, and the type of information commonly available to the user of the system determined the inputs requested.

Underlying datasets used for benchmarks & comparison, and associated building types

Energy Star utilizes data from the U.S. Department of Energy's periodic Commercial Buildings Energy Consumption Survey (CBECS)[3] in most building types to create the benchmarks and scores. The most recent full version of this survey included performance information from 2003, but the 2013 version of the survey is being released in 2016. Where CBECS does not include information on a particular building type, the EPA has utilized industry surveys to provide performance comparison, often partnering with an industry association.

NABERS utilizes industry surveys for all of its external data collection, as there is not a similar building energy consumption survey conducted by the Australian government.

NABERS does not cover the plethora of building types that the Energy Star program does, but NABERS covers far more than just energy in the building types it does cover. Energy Star focuses on energy, as the name would suggest, but also can provide water intensity metrics for offices and several other building types.

Energy Star certainly benefitted from the existence of the CBECS survey in the states, which has allowed for expansive coverage of many building types. The existence of the survey, and the data collected during the survey also influenced how the benchmarking process was crafted, and therefore the inputs required for benchmarking consistency. Table 2 shows the inputs required for physical building characteristics to create an Energy Star rating for an office building.

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[3] See http://www.eia.gov/consumption/commercial/

Table 1 Energy Star Building Types and External Data Sources

Building Types	Benchmark source
Data Center	EPA Survey
Hospital (General Medical and Surgical)	ASHE Survey
Hotel	CBECS 2003
K-12 School	CBECS 2003
Medical Office	CBECS 2003
Multifamily Housing	Fannie Mae Survey
Office (covers office, bank branch, financial office, and courthouse)	CBECS 2003
Parking	Engineering Assumptions
Residence Hall/ Dormitory	CBECS 1999
Retail Store (covers retail and wholesale club/supercenter)	CBECS 2003
Senior Care Community	Industry Survey
Supermarket/Grocery Store	CBECS 2003
Swimming Pool	Engineering Assumptions
Warehouse (covers distribution center, non-refrigerated warehouse, and refrigerated warehouse)	CBECS 2003
Wastewater Treatment Plant	AwwaRF Survey
Worship Facility	CBECS 2003

Table 2. Inputs required for an Energy Star Rating for Office Buildings

Field	Notes
Name	
Address	City, State, Post Code, Country
Year Built	
Primary Function	Office, Retail, etc
Construction Status	Is the building completed or still being built? Energy Star allows for use in the design phase of a building.
Gross Floor Area	
Property Structure	Part of Building, Single Building, or Multi-building Property.
Federal property? Y/N	Federal properties have specific requirements.
Property ID (optional)	Custom IDs, Federal and City IDs, Third Party IDs
Parking Lot Size	This triggers additional inputs about parking lots.
Partially and completely enclosed garage sizes	This triggers additional inputs about parking lots.

In comparison, NABERS requests and requires far fewer inputs of physical building characteristics to create a rating. These inputs are basically only the name, address, and net lettable area (a different metric than the gross floor area used by Energy Star), although there are extensive rules that cover many of the secondary factors and features to ensure a consistent basis of comparison. It is certain that both the expansiveness of the Energy Star program and the simplicity of the NABERS program in these respects arise from the design decisions made by the program creators, and both lead to advantages and disadvantages for the program users. These are features, not bugs, in the respective programs.

In terms of energy data inputs required to create a benchmark, the same design philosophy is evident in both programs. Table 3 shows all the possible energy related inputs to the Energy Star program. In comparison, the NABERS program again requests far fewer. The energy data inputs for NABERS can be found in Table 4

Table 3 Energy related inputs for Energy Star rating

Category	Field	Notes
Usage Details	Gross Floor Area	
	% Occupancy	Annual average.
	Weekly Operating Hours	At least 50% occupied and no AHAC.
	Number of Workers (on main shift)	
	Number of Computers	
	% Area that can be heated.	
	% Area that can be cooled.	
Energy Usage Type	Electricity	Grid, On-site Solar, On-site Wind
	Natural Gas	
	District Steam	
	District Hot Water	
	District Chilled Water	Electric driven chiller, absorption chiller using natural gas, engine-drive chiller using natural gas, other
	Propane and Liquid Propane	
	Fuel Oil (no. 1, 2, 4, 5, or 6)	
	Diesel (no. 2)	
	Kerosene	
	Wood	
	Coal (bituminous and anthracite)	
	Coke	
Energy Data Per Meter	Start Date	
	End Date	
	Usage	
	Cost	Optional

Table 4 Energy related inputs for NABERS Energy rating

Category	Field	Notes
Energy Usage Type	Net Lettable Area	Net Lettable Area is typically 85% of gross conditioned area, but can vary widely dependent upon the design of the common areas of the building
	Hours Per Week	Assessed based on lease requirements and after hours requests for the base building rating and based on hours above 20% occupancy for whole building ratings
	# of Computers	Used for whole building and tenancy ratings. Not used for base building ratings
	Electricity	Includes all external utility energy supplies, net of on-site renewables such as solar. District chilled water and hot water covered by conversion to an effective utility quantity
	Natural Gas	
	Diesel Oil	
	Coal	
Energy Data Input	12 Months Total Consumption	
	% Green Power	GreenPower is 100% renewable energy supply obtained contractually via the grid. Ratings indicate performance with and without GreenPower.

Minimum Input Data Required for NABERS Energy Rating

To create a NABERS Office rating, the following is necessary:

- 12 months energy consumption data (ie bills for electricity, gas, diesel etc)
- Location (postcode)
- Net Lettable Area of your office premises in m^2 (shown on survey diagrams or lease documents)
- Number of computers
- Hours of occupancy

Another nuance is found in the minimum usages requirements of building use for the systems to produce a rating. While the NABERS program has no stated minimum occupancy, hours in operation or other limitation[4], the Energy Star program requires at least 30 hours per week of operation and sets a minimum building size at 5,000 square feet. Both programs require 12 months of energy data to produce an energy rating.

The approach to accounting for occupancy is also a distinction. Energy Star considers the average annual occupancy as a single percentage input, and explicitly instructs users not to account for after-hours air conditioning requirements (AHAC). NABERS strives to rate the building by "hours of comfort" provided, meaning AHAC hours are included.

Rating results for the same office building under both approaches

A simple comparison of the output of both systems

In order to understand the relative stringency of the scales, it is necessary to attempt to compare NABERS and Energy Star outcomes for a building of similar performance in a similar climate. For this exercise, we have selected a building of known NABERS performance in Sydney and translated it to the US environment for assessment under Energy Star.

San Diego was found to be the most comparable city in US in terms of climate to Sydney based on a comparison of Heating Degree Days (HDD), Cooling Degree Days (CDD), Dry Bulb (DB) temperature and Wet Bulb (WB) temperature. Los Angeles was the second best match. The detailed summary of these three cities are as follows.

Table 5 Australia/US Climate Comparison

	Sydney	San Diego	Los Angeles
Total annual HDD @ 15.5°C base	323	153	244
Total annual CDD @ 15.5°C base	1497	1555	1254
Average annual DB temperature (monthly high/monthly low) (°C)	21.7/13.8	20.9/14.2	22.1/13.2
Average annual WB temperature (°C)	15.4	14.0	13.7

[4] In the design of NABERS, the minimum building size is considered to be self-limiting based on industry demand, and minimum hours are considered unnecessary as lower hours will cause the rating to drop, creating a disincentive for rating.

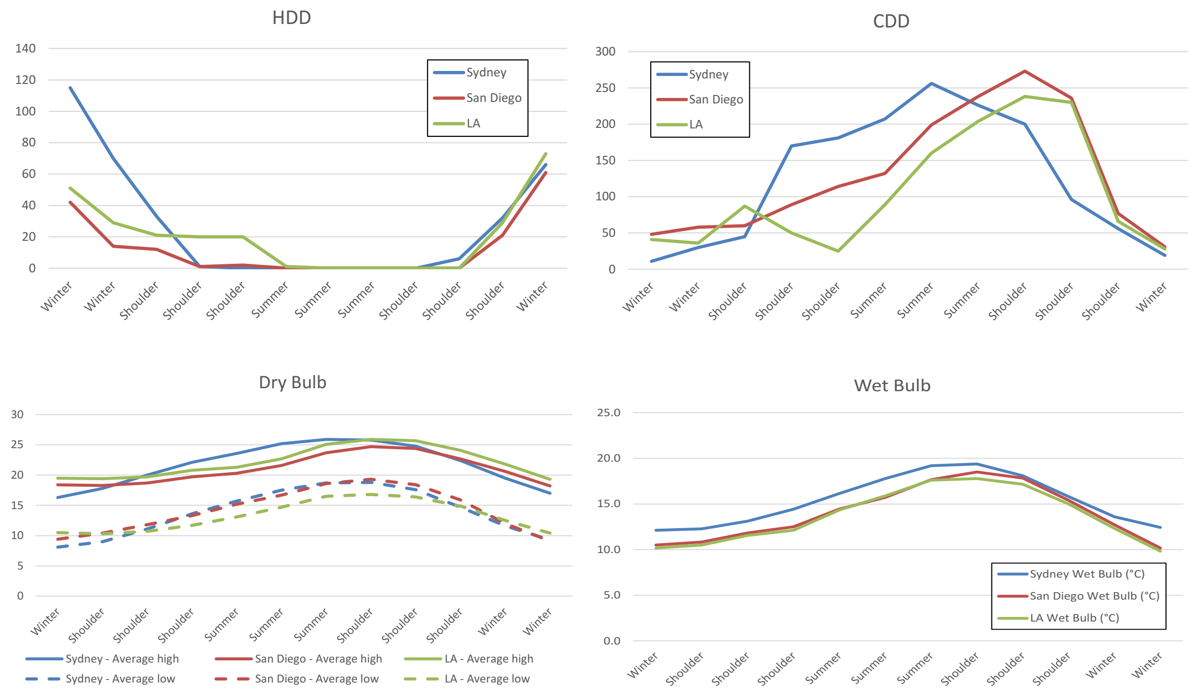

Figure 3. Climate Comparison

The comparison on the WB temperature shows that Sydney has a 2°C higher WB temperature in most of the year than San Diego and L.A, indicating more active cooling energy to be consumed in Sydney. As office buildings in Sydney are cooling dominated, this would tend to disadvantage a Sydney building relative to the same building and energy use judged against the other climates.

Input comparison

Most of the NABERS inputs can be directly used by Energy Star, however the following items require some extra consideration before entering the values:

- Rating type: NABERS has clear segregation on the base building, tenant and whole building ratings. Energy Star focuses on the quantity of the building – partial, one building or more than one building.
- Area: Net Lettable Area is used for NABERS, while Gross Floor Area is for Energy Star. A 15% difference between these figures has been allowed for.
- Car park: NABERS assessment includes car parks where these are provided for tenant use, with no compensating adjustments to the rating. Energy Star requires the following inputs for car park (if ticked): Open parking lot size, partially enclosed parking garage size, completely enclosed parking garage size, and whether if there is supplemental heating.
- Retail area: If not office or office supporting area, the retail area should be excluded in NABERS. However, stores smaller than 5,000ft² should be included with the main office use under Energy Star. For these stores, Energy Star requires the following inputs: Gross floor area, weekly operating hours, number of: workers on main shift, computers, cash registers, refrigeration/freezer units,
- Occupancy: NABERS requires the spaces to be individually verified by leases or other confirmations throughout the rating period, while Energy Star only needs a percentage input. There is a risk of methodological differences in this area, but this was not investigated for this study.
- Hours: Similar to occupancy, NABERS requires the tenants to be individually verified by lease or other confirmations throughout the rating period, then weighted by the tenants' area.

Energy Star uses only a single input. Again, there is potential for methodological differences in this area but this was no investigated for this study.

We have created a sample building to test these two rating schemes. The building information is entered into both systems as below:

Table 6. Sample building characteristics

	NABERS	Energy Star
Address	Sydney, NSW 2000	Hillcrest, CA 92108
Property use	Office	Office
Number of buildings	*n/a*	One
Rating type	Whole building	*n/a*
Construction status	*n/a*	Existing
Year built	*n/a*	2007
Area	22,557 m² NLA	26,538 m² GFA
Occupancy	22,557 m² based on leases	100% single input
Parking	No	No
Data Centre	No	No
Retail	No	No
Hours	46.1 hr/wk based on leases	46.1 hr/wk single input
Number of workers on shift	*n/a*	1000
Number of computers	949	949
% can be heated	*n/a*	50% or more
% can be cooled	*n/a*	50% or more

Energy inputs and rating outputs comparison

Based on the same building information, we have used our single line calculate to compute the thresholds for the building to reach 2.5, 4.0, 5.0, 5.5 and 6.0 stars under the different fuel mix conditions (80%-20% electricity to gas ratio, 90%-10% and 100%-0%). Then the consumption has been used in Energy Star to calculate the corresponding outcomes under each scenario.

It can be seen that there is a linear relation between the scale, with a NABERS rating of 4 corresponding roughly to a qualifying Energy Star score of 75. This closely reflects the original position under NABERS whereby 4 stars was considered to be a good score. However, with movements in the market, scores of 4.5 stars and higher have become common, corresponding to scores of 85-90 under Energy Star. The small number of NABERS rated buildings that have achieved 6 stars, however, are “off the scale” for Energy Star, which has a maximum of 100. Note in this context that the extrapolation of the NABERS scale is theoretically capable of rating zero emissions on its existing scale; this does not appear possible with Energy Star because of the percentile scale.

Table 7. Energy consumption for different scenarios

Fuel mixture (based on equivalent MJ)	Electricity consumed (kWh)	Gas consumed (MJ)	NABERS	Energy Star
80% - 20%	6,425,000	5,782,500	2.5	41
90% - 10%	6,645,000	2,658,000	2.5	42
100% - 0%	6,820,000	-	2.5	43
80% - 20%	4,410,000	3,969,000	4.0	73
90% - 10%	4,550,000	1,820,000	4.0	74
100% - 0%	4,680,000	-	4.0	75
80% - 20%	3,060,000	2,754,000	5.0	91
90% - 10%	3,160,000	1,264,000	5.0	92
100% - 0%	3,250,000	-	5.0	92
80% - 20%	2,295,000	2,065,500	5.5	97
90% - 10%	2,370,000	948,000	5.5	98
100% - 0%	2,440,000	-	5.5	98
80% - 20%	1,530,000	1,377,000	6.0	100
90% - 10%	1,580,000	632,000	6.0	100
100% - 0%	1,620,000	-	6.0	100

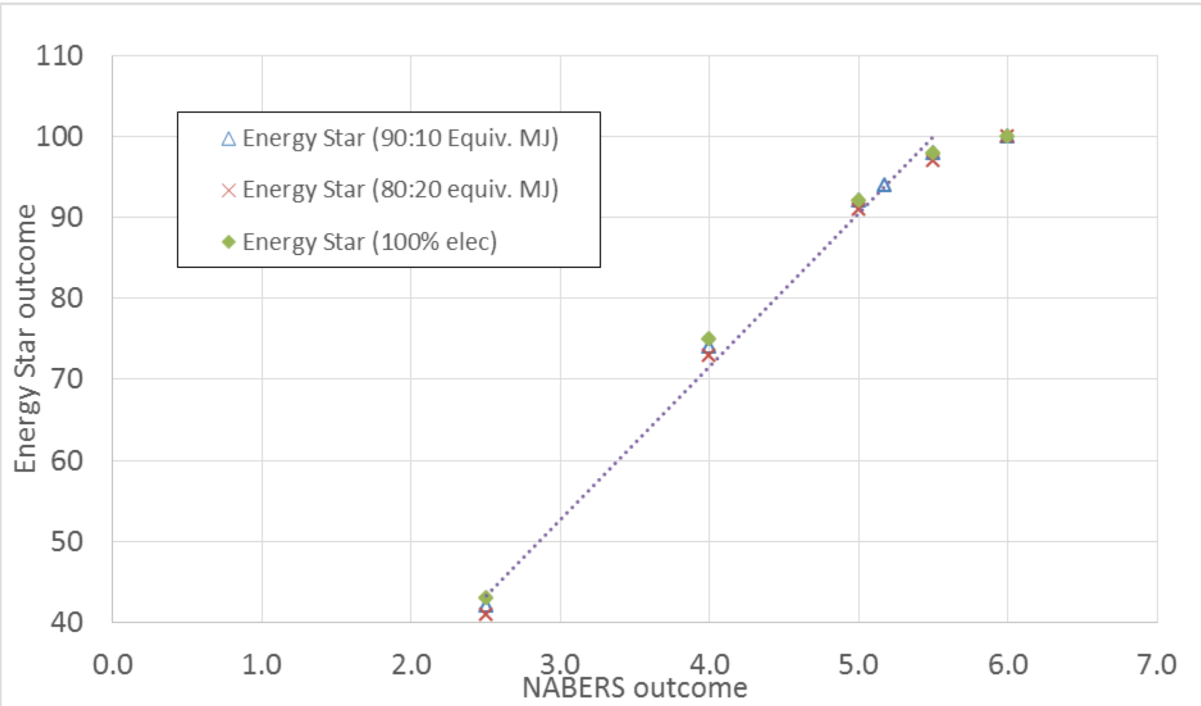

Figure 4. Comparison of NABERS and Energy Star ratings of a Sydney building translated to the San Diego climate. Note that Energy Star under the Los Angeles climate was essentially identical, indicating that this comparison is fairly robust to climate.

Discussion

International comparability

There is growing interest in international comparison of building energy performance, in part to understand trends toward energy and climate policy goals, as well as to understand policy effectiveness. A number of international efforts to compare simple, unadjusted building energy or carbon intensity have been underway: through ULI Greenprint, a 2015 IEA/IPEEC Building Energy Performance Metrics report, and work currently underway through the C40 Network of Megacities (ULI 2015, IPEEC 2015), but there is an acknowledgement in many of these efforts to have some type of international rating scheme to adjust for differences in how buildings are used. The US and

Australian initiatives are often recognized as the most advanced toward this need for simple yet technically valid normalization.

Possibly the most striking aspect of the comparison of these two rating systems is that, in spite of many differences in detail, the underlying comparability of the ratings is actually very good, with an apparent congruence in the assessment of good practice between the two scales in the example. This indicates that establishment of a viable rating can take different paths and use significantly different levels of project resourcing and yet still achieve essentially the same assessment of building performance. Perhaps an eventual cross-borders understanding of building is perhaps more achievable than is commonly thought.

Similarities and Differences

It is also significant that while NABERS uses a base building rating and credits a significant part of its success to the matching of the base building rating to the domain of control of the landlord, Energy Star has been successful in rating the whole building as a combination of base buildings and tenants. It is not fully clear from available data, therefore, whether the base building rating approach carries significant benefits that merit the additional complexity that the assessment of energy use along this boundary entails. This is also significant as the ability of NABERS to expand to other countries has been significantly limited by the availability of base building energy data. However, insufficient directly comparable data is available on the relative success of these two systems to enable a specific conclusion to be reached on the relative merits of these approaches. A full study of this question would need to consider a broad range of factors, including:

- What is the mix of multi-tenant to single tenant buildings in each country, and the relative success of each system in each sub-population?
- What are the overall efficiency improvements that have been achieved on a comparable basis, i.e. including tenancy energy for NABERS and looking at base building energy for Energy Star.
- What are the differences in upper end performance achieved? Is either system better at generating genuine innovation in high performance?
- What have the resourcing requirements been for the two programs, and how have these differed?

What is clear from the data is that both systems have been successful in the assessment and improvement of building performance. This indicates that irrespective of whether a base building or whole building approach is used, having any form of performance based rating is worthwhile.

Dealing with changing building efficiency

Both systems have started with a scale determined from a historical dataset. Given the success of both systems in achieving population-level improvements, it is worthwhile to question whether the scales require updating. NABERS has adopted the position that it is not updating its scale but has extended the scale. As a result, the fact that the average rating has risen significantly can be absorbed by the availability of ever higher ratings. This is possible as a result of the fact that the NABERS scale works all the way through to zero emissions; it has also been accompanied by an increase in market expectations as to what is meant by high efficiency. In scales such as Energy Star that achieve maximum rating before zero emissions are reached, there is a stronger technical argument for updating of the scale, as ultimately the original scale may lose its power as a modifier of behavior; alternatively, the scale may, like NABERS, need to be extended beyond its current upper rating.

Implications for European Policy Makers

The Australian and US initiatives have been evolving from voluntary, gradual market uptake initiatives to mandatory policies over the past twenty-five years, while in most cases, European member states went straight to mandatory rating and certification as required by the initial Energy Performance of Buildings Directive. This gradual evolution allowed for a different type of market acceptance and regular adjustment before widespread mandates.

The experience in the two countries has shown major market transformation success with the rating and benchmarking policies, and the widespread common operational performance ratings is demonstrating substantial energy savings as a result.

The most notable evidence of market transformation may be the percentage of benchmarked buildings within a portfolio of an institutional real estate company. Some owners and Real Estate Investment Trusts can claim extremely high levels of benchmarking. Similarly, the market penetration of benchmarking in non-institutional real estate market segments. This would suggest to EU policy makers that perhaps tailoring existing building rating requirements to market segments can impact overall program success.

Conclusions

Both the Energy Star and NABERS rating systems have evolved from government developed but real estate industry supported voluntary initiatives, which have become the basis for mandatory policies in each country. Both initiatives have shown major success, and have lessons that are relevant in the US and Australia, and beyond.

It is not yet possible to compare the relative success levels of the two initiatives because there is not comparable data, but both initiatives are clearly having significant market impacts. NABERS has strong buy in from the building owner community and a powerful market transformation mechanism for the building owners, but lacks a similar impact on tenants. Energy Star inherently encourages a more holistic approach that may drive more balanced outcomes between owners and tenants, and avoids the issues of demarcation that complicate NABERS. However, it also lacks some of the market transformation mechanism that drives NABERS.

There is much that can be learned from the NABERS experience with base building ratings, which address the end-uses and areas that an owner/manager can control, and allows for commitment agreements for a "guaranteed" level of performance. Energy Star has become a very widely used tool, now the basis for benchmarking and transparency policies throughout the US, and recently adapted for use in Canada.

Major differences of base building vs. whole building ratings raises remaining questions – the US is looking to develop separate tenant rating, while UK is currently looking at separate landlord/base building ratings. It is unclear how these will work or how quickly they can be launched due to data availability challenges.

The success of both the Energy Star and NABERS schemes show that the act of measurement and rating is power irrespective of the detail; suitability of individual systems is likely to come down to the local market context.

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Energy efficiency in public buildings under the EU Cohesion Policy in the 2007-2013 programming period – insights from the ex post evaluation

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Abstract

This paper presents the findings of the ex post evaluation of EU Cohesion Policy support to energy efficiency investment in public and residential buildings financed by the European Regional Development Fund (ERDF) and the Cohesion Fund (CF) during the 2007-2013 programming period. Over the period, the allocation under EU Cohesion Policy broadly dedicated to energy efficiency (a new area of Cohesion Policy expenditure) increased significantly from the initial allocation, with a net overall increase of 45% and reached over EUR 6 billion, representing a 2% share of the total combined budget of ERDF and CF.

This paper evaluates the rationale for intervention and the types of mechanisms used, as well as early evidence of the effectiveness of investments in energy efficiency in public buildings. It includes results from the quantitative and qualitative analysis of the 48 operational programmes (OPs) across the EU Member States which had the highest financial allocations to the priority theme entitled "Energy efficiency, co-generation, energy management". Operational details are presented on the basis of six in-depth case studies (the UK, Lithuania, Poland, Hungary, Greece, and the cross-border programme between Slovenia and Italy).

The findings point to an important role for non-energy considerations in the design of energy efficiency interventions, and differences (and weaknesses) in the strategies adopted by Managing Authorities, including in their responses to the economic crisis of 2008. The authors identify policy implications for the current EU Cohesion Policy programming period (2014-2020), relating to, among other issues, project selection criteria, audit requirements, the relationship between EU and national sources of finance, and the potential importance of project development assistance. The conclusions drawn from the evaluation are applicable to a range of public policy tools in the field of energy efficiency.

1. Introduction

Context

The EU's regional policy is the main investment policy to support growth in Europe. It is delivered through investment funds of which two, the European Regional Development Fund (ERDF) and the Cohesion Fund (CF), were able to support energy efficiency in buildings in the 2007-2013 programming period. In 2014, the Directorate-General for Regional and Urban Policy (DG REGIO) of the European Commission, responsible for regional policy, commissioned an ex post evaluation of Cohesion Policy programmes 2007-2013, focusing on the ERDF and CF. One of the work packages of the evaluation covered energy efficiency in public and residential buildings. The evaluation under this package was conducted between December 2014 and October 2015, by the authors of this paper and other country and energy efficiency experts. The aim of this paper is to present the results from the evaluation with a focus on findings relevant to energy efficiency in public buildings [1].

Methodology and challenges

This paper presents the findings of our evaluation which was implemented through the following phases:

(i) a background review covering literature on the rationale for energy efficiency investments in buildings by the public sector, existing evaluations of energy efficiency expenditure under the ERDF and CF, an analysis of national funding for energy efficiency in EU Member States, and an initial assessment of the data available on relevant expenditure in operational programmes;

(ii) examination by country experts of 48 operational programmes (OPs) [2], selected by the European Commission on the basis of the level of funds they allocated to the designated priority theme “Energy efficiency, co-generation, energy management”; this exercise was based on desk research followed by interviews with relevant Managing Authorities. Seven of the 48 programmes identified as having relatively large allocations to the priority theme proved, on closer examination, not to have supported energy efficiency projects in public or residential buildings. The evaluators therefore concentrated on assessing the remaining 41 programmes.

(iii) detailed case studies based on desk research and interviews with the stakeholders of 6 operational programmes with aspects of particular interest in relation to energy efficiency in public and residential buildings, in Poland, Hungary, Lithuania, Greece, the UK, and the cross-border Italy/Slovenia programme;

(iv) based on results from the earlier phases, identification of good and bad practices, as well as policy implications, and the development of conclusions, which were then tested at a workshop with stakeholders involved in the implementation of support to energy efficiency investments.

The nature and comparability of data recorded by operational programmes posed some challenges for this evaluation; there were time delays in reporting outputs, results and impacts, and the priority theme of “Energy efficiency, co-generation, energy management” did not separately identify energy efficiency investments in public buildings and residential buildings, but also included other types of energy investments (for example, combined heat and power production using renewable energy sources or the introduction of cross-border energy management). At the same time, some OPs supported energy efficiency in public and residential buildings under other priority themes. It has not been possible to identify all of these interventions and therefore no complete financial data is available. Detailed data concerning interventions was not always available in OPs and Annual Implementation Reports [3]. Therefore, the research depended strongly on the input from Managing Authorities and other national stakeholders, which itself was variable in quality: it was not always possible to find interviewees who had sufficient knowledge of the 2007-2013 period..

Structure of this paper

This paper is structured as follows:

- The second section provides an overview of the support provided to energy efficiency in buildings under the Cohesion Policy and other public schemes between 2007 and 2013.
- In the third section, the reasons for public support to energy efficiency in public buildings as stated in the literature and the evaluated OPs are presented.
- In the fourth section we present our findings on the interventions analysed: their types, underlying strategies, and the institutional set-up.
- The fifth section is dedicated to the achievements identified in the form of both direct outputs and wider results and impacts.
- The final section contains summary conclusions and a number of recommendations with relevance to the current and future programming period under the Cohesion Policy and potentially also to other public policy targeting energy efficiency investment.

Acknowledgements

The authors would like to thank Jean-Sébastien Broc (École des Mines de Nantes) and Robert Harmsen (Utrecht University) for their critical comments, revisions and support throughout the evaluation process. This paper is based on work funded by the European Commission.

2. Overview of support to energy efficiency in buildings in 2007-2013

Public financial support to energy efficiency investment in public buildings over the examined period came from three major sources: the EU, European countries and supranational organisations. A general overview of each is presented below.

EU Cohesion Policy

Under the 2007-2013 programming period of the Cohesion Policy, energy efficiency in public buildings was mainly supported under the “energy efficiency, co-generation, energy management” priority theme, although other priority themes also included some investment related to the energy efficiency improvement in buildings. At that time energy efficiency was still a relatively novel area of investment, although growing in relevance as Member States progressed in their implementation of the wider EU regulatory framework (namely directive 2002/91/EC on the energy performance of buildings and directive 2006/32/EC on energy end-use efficiency and energy services). The Cohesion Policy framework and its implementing measures were prepared before the European Council emphasized the need to increase energy efficiency in the EU as part of the new climate and energy targets to be achieved by 2020 [4]; although additional flexibility for spending on energy efficiency was provided in 2009, partly in response to concerns about the economic crisis.

Total ERDF/CF allocations to the “Energy efficiency, co-generation, energy management” priority theme for the 2007-2013 programming period in EU-27 amounted to EUR 6.1 billion – 2% of the total ERDF/CF allocated by operational programmes. It is estimated, bearing in mind the caveats on the data mentioned in previous sections, that EUR 3.4 billion were allocated to support energy efficiency in public and residential buildings. It did not prove possible to disaggregate this figure in order to retrieve an estimate on the allocation to support energy efficiency in public buildings only.

Expenditure (funding spent) on the priority theme “energy efficiency, co-generation and energy management” for the EU-27 amounted to EUR 4.7 billion by the end of 2014. The intensity of allocation (funding allocated) for the priority theme, calculated as the ratio of EU allocation for the priority theme and the total EU allocation per Member State, was the highest in Lithuania and Italy, while there were no allocations for the priority theme in Cyprus and Denmark. More detailed information on the priority theme “Energy efficiency, co-generation, energy management” per Member States is presented in Table 1 below.

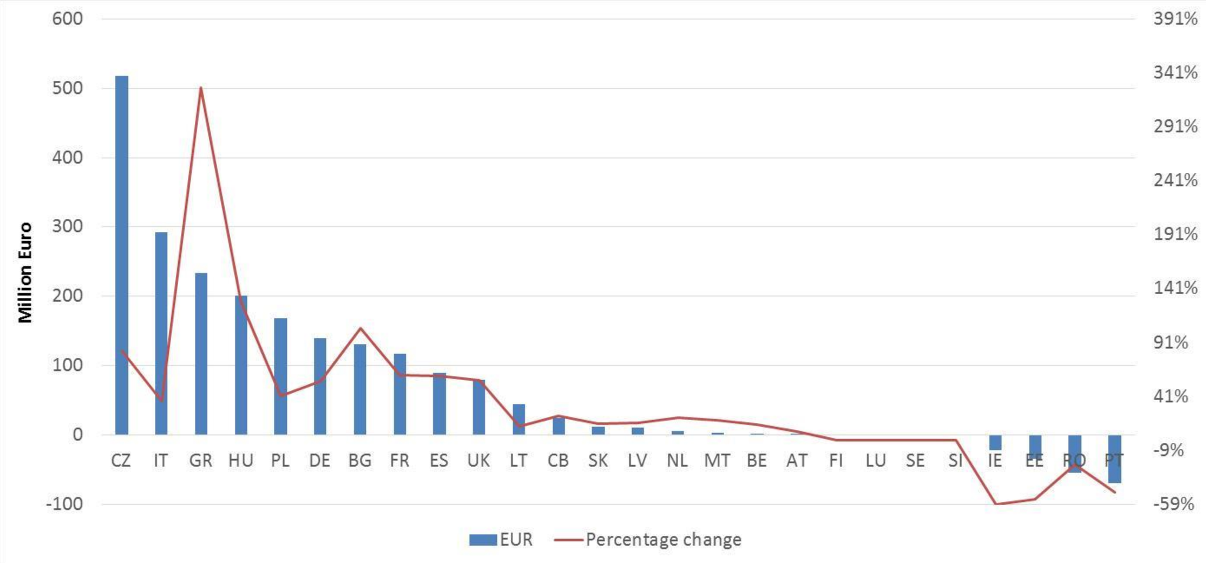
Table 1: Key information on ERDF/CF investment for the "energy efficiency, co-generation and energy management" priority theme at the Member State level at the end of 2013

Member States	Allocation (mln EUR)	Intensity of ERDF/CF (%)	Total projects (mln EUR)	Selection of projects (ratio of funds committed to funds allocated to this priority theme)
Czech Republic	1,140	5%	710	62%
Italy	1,087	5%	838	77%
Poland	578	1%	633	109%
Germany	391	2%	473	121%
Lithuania	374	7%	467	125%
Hungary	358	2%	385	108%
Greece	304	2%	838	275%
France	298	4%	373	125%
Bulgaria	257	5%	194	75%
Spain	237	1%	50	21%
UK	221	4%	153	69%
Romania	198	1%	104	52%
Interreg (transnational)	127	2%	216	170%
Slovenia	106	3%	142	135%
Slovakia	91	1%	98	108%
Portugal	77	1%	52	67%
Latvia	70	2%	187	267%
Netherlands	34	4%	28	81%
Estonia	29	1%	29	100%
Finland	24	2%	13	54%
Malta	19	3%	8	43%
Belgium	16	2%	10	61%
Ireland	16	4%	16	104%
Sweden	9	1%	1	12%
Austria	6	1%	18	299%
Luxemburg	1	2%	2	368%
Cyprus	0	0%	0	0%
Denmark	0	0%	0	0%
EU27 and Interreg	**6,067**	**2%**	**6,038**	**100%**

Source: IEEP, Ramboll (2015) based on monitoring data on ERDF/CF investments provided by the European Commission

The allocations shown in Table 1 were arrived at after initial the allocations to energy efficiency had evolved in the course of the programming period. The monitoring data showed that the financial allocations for the “energy efficiency, co-generation and energy management priority theme” changed substantially in the majority of Member States during the 2007-2013 programming period. In absolute terms, most (17) Member States increased their allocations, as did the transnational cooperation programmes; 4 Member States (Ireland, Estonia, Romania and Portugal) decreased their allocations; while allocations remained unchanged in 4 Member States (Finland, Luxembourg, Sweden and Slovenia, see Figure 1) [5].Overall the total allocations increased by EUR 1.9 billion, (45%). In absolute terms the increase was most substantial for the Czech Republic, where, compared to 2008, an extra EUR 518 million was allocated by the end of 2014 (see Figure 1).

Figure 1: Change in total allocation for the relevant priority theme in all Member States between 2008 and 2014 (EUR)



Source: IEEP, Ramboll (2015) based on monitoring data on ERDF/CF investments provided by the European Commission

According to the Managing Authorities of the relevant OPs, the majority of the additional financial allocations to the relevant priority theme were channelled into energy efficiency interventions in public or residential buildings. They cited the main driver to be a high demand for energy efficiency investments by eligible beneficiaries resulting from a range of factors not always related to energy savings; absorption of the available funding, and reductions in national public expenditure, appear to have been relevant.

An interesting case for the allocation increase was identified under the Hungarian Environment and Energy OP. The Hungarian programme significantly increased support for energy efficiency in public buildings in order to absorb underspends from another OP and to respond to the very high demand for support for energy efficiency [6]. While flexibility in programme design can help to ensure that funds are invested in accordance with current real priorities and opportunities (particularly when economic circumstances have changed significantly from the point at which the initial programme documentation was written), there are risks that in some cases it can simply be a means to ensure that funds are spent (e.g. on building refurbishment), rather than that they are spent well in delivering the programme’s original objectives.

National and supranational schemes of support

To better understand Cohesion Policy support to energy efficiency in public buildings, it is important to analyse it in the context of other public funding in Member States for relevant energy efficiency projects. We identified 129 mechanisms supporting energy efficiency in public and residential buildings in the EU-27 between 2007 and 2013. Out of that number one third supported investments in public buildings. This includes 16 schemes that supported both residential and public buildings (for instance, the Italian Kyoto Rotation Fund and Slovakia's Ekofund Programme). Some mechanisms provided also support for commercial buildings. The support was predominantly provided in form of grants.

Seventeen Member States (Belgium, Bulgaria, Cyprus, Estonia, Finland, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Romania, Slovenia, Slovakia, and UK) had introduced financing mechanisms targeted at public buildings. Some of these financing schemes supported only specific types of public buildings. For instance, education institutions received support in Germany (Future Investment Act) and Greece (energy upgrading of existing school buildings). The mechanisms we identified were mostly funded from state budgets but supra-national institutions also played an important role. For instance, in Hungary, only one financing mechanism targeted energy efficiency in public buildings (funded by the European Bank for Reconstruction and Development). In addition to the EBRD, supra-national or extra-EU institutions involved in the financing included the European Investment Bank (EIB), the UN Global Environment Fund (GEF) and grants from the European Economic Area (EEA) and Norway. Seven Member States (Bulgaria, Poland, Czech Republic, Estonia, Hungary, Latvia and Lithuania) used funds generated by the sale of Assigned Amount Units (AAUs) under the Kyoto Protocol and created Green Investment Schemes to provide support for energy efficiency in public and residential buildings. Furthermore, some Member States used money from Power Plant Decommissioning Funds to support energy efficiency in public and residential buildings. These included the Bulgarian grants under the Kozloduy International Decommissioning Support Fund (KIDSF), the Slovak SLOVSEFF facility co-financed by the Bohunice International Decommissioning Support Fund, and the Lithuanian Ignalina Programme for 2007-2013.

As in the case of the Cohesion Policy allocations, the mechanisms were subject to significant change in many countries over the period. This occurred partly in response to the development of EU and national policy and legislation on energy efficiency, in particular measures to implement the Energy Efficiency Directive and the Energy Performance in Buildings Directive, and partly as a result of downward pressure on overall public expenditure.

Concrete financial information could not be found for all the Member States, but for the sake of illustration, the roughly estimated cumulative funding for both public and residential buildings in 9 Member States (Bulgaria, Czech Republic, Greece, Hungary, Lithuania, Poland, Romania, Slovenia and the UK) amounted to some EUR 7.2 billion [7]. The comparison of the wider public funding identified in these 9 Member States to the ERDF/CF allocations showed a varied picture. In some cases Cohesion Policy funds provided an important contribution to total support for energy efficiency in buildings, in other cases they played a rather limited role in comparison with other policy instruments.

We noted that in the 2007-2013 programming period the synergies between the Cohesion Policy funds, other EU and international funding programmes or technical assistance support mechanisms (e.g. ELENA) and national public funding (e.g. Green Investment Schemes) for energy efficiency in public and residential buildings were generally not exploited, and in some cases the schemes overlapped and competed.

3. The reasons for funding energy efficiency in public buildings

As part of the evaluation we examined the rationale for public support to energy efficiency in buildings.

First, we analysed selected positions from the relevant literature [1]. The review indicates that the main rationales for public support to energy efficiency improvements, including in both residential and public buildings, are well understood and clearly described. The identified economic, social and environmental benefits (primary and secondary) linked to public support for energy efficiency investments in public buildings are summarised in Table 2 below.

Table 2: Overview of benefits of public support to energy efficiency

	A - Primary benefits	B - Secondary benefits or co-benefits
Economic	Less expenditure on energy allows for more efficient allocation of resources ensuring that further cost efficient energy efficiency measures are adopted Economic benefits associated with improved energy security, including reduced vulnerability to price shocks and supply constraints, reduced energy imports and improved trade balance	Macro-economic benefits including energy efficiency as part of a stimulus package Exemplary role for public building investment
Social		Employment Reduced fuel poverty/ Increased health benefits from improved heating Health benefits from improved air quality
Environmental	Contribution to climate change mitigation through reduced CO_2 emissions from fossil fuel energy	Reduced pressure on environmental resources from energy infrastructure Improved air quality

Source: IEEP, Ramboll (2015) based on literature review

Next, we compared the reasons identified in the literature review with those included in the OPs. The analysis of the 41 of the 48 selected OPs which in practice invested in energy efficiency in buildings showed that the potential primary benefits of energy efficiency were reflected. The selected OPs referred to aims of climate change mitigation, energy security and cost savings. Also clear references to EU climate and energy policy were made. In particular, the so-called 20-20-20 targets were mentioned. The exemplar role of public buildings was not widely promoted although several programmes (particularly in France, the UK and Germany) identified this as part of their rationale for investment.

It should be noted that the potential benefits for energy efficiency identified in the programme documentation were in most cases not specific to public buildings. They related to energy efficiency in general. Moreover, access to finance became an urgent issue due to the financial crisis. The importance of energy saving interventions in public buildings increased as a result.

Interestingly, case by case examination exposed important inconsistencies in the stated and implicit rationales (e.g. bias towards investment in public buildings in order to reduce future public expenditure rather than greenhouse gas emissions). It can be partly explained by the short-term opportunistic drivers, and partly by the fact that at the time when Managing Authorities initially developed the OPs, experience in the use of ERDF/CF funds for energy efficiency was lacking. Many programming authorities had limited understanding of energy efficiency in buildings and found it difficult to define a clear strategy and rationale for investments. Over the period there has been a steep learning curve for the Managing Authorities and their partners in designing interventions for energy efficiency in buildings.

Support to public buildings was more common than for residential buildings. A majority of the selected OPs from the EU-12 and a minority of the selected OPs from the EU-15 targeted public buildings. The reasons behind the choices of types of supported buildings were not well justified in the programme documentation. When they were provided, such justifications often lacked consistency with the types of buildings targeted in practice and did not always clearly link to the EU policy and legal framework relevant to energy efficiency in force.

Most Managing Authorities preferred grant schemes over loans or any other forms of financial engineering instruments to support energy efficiency in buildings. The selection of the form of support was based on pragmatic reasons, rather than on an analysis of the specific needs and market imperfections. The use of financial engineering instruments required a more rigorous intervention design than in case of grants, and met with a great degree of reluctance, especially from Managing Authorities with limited experience of this sort of funding vehicle.

Further in this paper we will describe how the rationales evoked by the OP Managing Authorities translated into the corresponding investment strategies.

4. Interventions for ERDF/CF support to energy efficiency in buildings

The types of intervention funded

Of the 41 programmes from the sample which funded investments in public and residential buildings, nearly all (38) included some support for investments in public buildings. The public buildings supported included, among others, public administration buildings, schools, nurseries, hospitals, sports facilities, cultural institutions and buildings occupied by NGOs, and a host of other, primarily municipal buildings (for residential buildings these covered primarily multi-family houses and social housing).

Support to energy efficiency interventions in buildings was provided for a wide range of measures such as:

- Thermal insulation of the building shell (walls, roof, windows)
- Improvements to the heating system (e.g. boiler exchange)
- Lighting systems
- Energy management and control systems
- Air ventilation.

The 41 OPs differed to the extent to which the energy efficiency measures were all-encompassing. Some OPs provided funds for single measures while others provided funds for deep renovations of entire buildings (e.g. the UK London OP the German Lower Saxony OP and the Polish Pomorskie OP). Support within the six case studies also targeted a wide range of energy efficiency interventions, with a note-worthy approach implemented in the London OP that stands out from other examples thanks to its innovative edge. One project funded in the London programme, through loans from the London Energy Efficiency Fund (LEEF), involved investment at the Tate, a major public art gallery. Total investment of GBP 260 million (approximately EUR 360 million) included GBP 18 million from LEEF (EUR 25 million), and has funded innovative energy efficient gallery-standard lighting; the use of waste heat recovery from an electricity sub-station; and bore-hole cooling using the River Thames. Considerable potential exists for making use of the technical understanding developed under this project to help similar investments in other cultural venues worldwide.

In addition to the physical energy efficiency interventions, in some cases support was also provided for the preparation of energy efficiency projects. For example the Polish Infrastructure and Environment OP stopped support for physical energy efficiency interventions in public buildings in 2013, and financial support was directed to the preparation of local low-carbon growth plans. The plans provide a roadmap for energy efficiency interventions in both public and private sector for communes, identifying the most pressing needs in terms of energy efficiency [8].

As noted above, the support provided generally took the form of non-repayable grants. Where grants were used, Managing Authorities seem to have found it difficult initially to judge the level of co-financing which should be made available; in some cases, very high co-financing rates were offered (up to 100%), particularly for public buildings. In other cases, co-financing rates were significantly increased following initially slow take-up, leading to a change from lack of interest among the targeted beneficiaries to significant over-subscription.

While there are strong arguments in principle for the use of loans rather than grants for energy efficiency investments, particularly those with a clear perspective of an early payback of investment costs through reduced energy costs, Managing Authorities were in general reluctant to use them. A number of reasons were cited, including constraints on public authorities taking on loan commitments in the case of public buildings and administrative complexity for the Managing Authorities. Nevertheless, detailed analysis of loan mechanisms suggest that it is possible to overcome these difficulties and design interventions which can generate significant benefits at a lower final cost to the public sector. For instance under the London OP007-2013, the use of a loan fund led to public sector and not-for-profit sector organisations paying careful attention to the need to ensure that savings from future energy bills were available to repay the loans, which in turn led to more careful planning of projects. Moreover the effort made by the managers of the loan funds to work with potential applicants to develop projects seems to have ensured a high quality of projects, with potentially valuable lessons on energy efficiency investments, capable of wider dissemination. These benefits are additional to the increased efficiency of funding.

The strategic underpinning of energy efficiency investments

In addition to a general weakness in defining an explicit rationale for energy efficiency investments in public buildings (see section 3), OPs managers also found it difficult to establish a clear strategy for their interventions in this area. In particular, there was little attempt to show how ERDF/CF investments were integrated into, and formed a relevant contribution to, wider national strategies to meet EU and national energy efficiency targets. This can be explained by the fact that at the time the OPs were designed before 2007, with the EU 2020 climate and energy targets only adopted subsequently. There was therefore in some Member States a low level of national strategic orientation on energy efficiency at the start of the programme period. While there were positive examples of programmes which stated a broader contribution to the development of a self-sustaining energy efficiency dynamic (for example, the development of a more capable energy efficiency services sector; or improvements in public understanding of energy efficiency; or the role of public buildings as exemplars), it was not always clear how these were followed through in the detailed design of interventions.

The lack of strategic planning was stark, among other examples, in the case of the Polish Infrastructure and Environment OP. In the eyes of the Managing Authority and beneficiaries, strategic planning was lacking in the 2007-2013 programming period. No coherent action plan was developed across the country, as the communes, poviats and regions usually included energy efficiency interventions in their strategic documents related to different topics without coordination between each other. Energy efficiency investment plans were addressed in the regional strategies in a haphazard way and they were usually too general to provide concrete guidance and an investment plan. This weakness was addressed by the Managing Authority in the course of programming period. The support was shifted from physical intervention to strategic planning and investment documentation. This adjustment was expected to have paved the way for more effective energy efficiency investment developed under 2014-2020 programming period.

Governance of interventions

The governance structures behind the supported energy efficiency investment in public buildings varied in line with the broader governance structures of the OPs, rather than as a reflection of different approaches to energy efficiency as a policy issue. However, there was some evidence of a pattern that Managing Authorities sought to overcome their own lack of familiarity with energy efficiency investments by making use of intermediate bodies, and implementing bodies (including bodies charged with administering loan funds).

Structures can be seen to be more complex where the JESSICA (Joint European Support for Sustainable Investment in City Areas) mechanism was used [9]. The body acting as a holding fund manager was usually a bank but in the case of London, companies specialised in fund management were employed for this purpose [10].

Project selection criteria were often loosely defined and not well-understood by potential applicants. The most frequently-used criteria referred, unsurprisingly, to energy savings. Energy audits were used as a means of assessing energy savings in only 17 out of the 41 programmes studied in detail; and their use, and that of Energy Performance Certificates, was partly determined by the level of familiarity of public authorities and the construction industry with them. In some cases, however, the use of energy audits by ERDF/CF programmes has been beneficial in encouraging their use in the property market more generally. An overview of project selection criteria used in 5 analysed OPs that allocated the most to energy efficiency in public and residential buildings is presented in Table 3 below.

Table 3: Project Selection Criteria in five analysed OPs with the highest estimated allocation to energy efficiency in public and residential buildings

Name of the OP	Minimum energy reduction	Energy audit	Cost-effective-ness of investment	Contribution to national / regional objectives	Compliance with energy effic.standards	Use of innov. technology	Mini-mum project value	Use of alternative energy sources
Czech-Rep. Environment	No	No	Yes	Yes	No	Yes	No	No
Lithuania Promotion of Cohesion	No	Yes	No	Yes	No	No	No	No
Hungary Environment & Energy	Yes	No	Yes	No	Yes	No	No	No
Italy RES & Energy Saving	No	No	No	No	No	No	No	No
Slovenia Env.&Transport Infrastr.	Yes	No	No	Yes	Yes	Yes	No	Yes

Accompanying measures, including training for both programme authorities and beneficiaries, were included in most of the programmes studied; and some programmes have shown particular strengths in terms of addressing a wider information gap and behavioural challenges associated with energy efficiency policy, although detailed evidence of outcomes on this, as on many other aspects, remains scarce.

5. Achievements of ERDF/CF support to energy efficiency in buildings

While achievements have been made through energy efficiency investments in public buildings in the 2007-2013 programming period, these achievements are only partially captured by the programmes' monitoring systems. The achievements in all subject areas under Cohesion Policy in the period 2007-2013 were measured with the use of the output, result and impact indicators [11] reported on by Managing Authorities, which varied between programmes and Member States. The extent to which these indicators were designed appropriately to capture evidence of energy efficiency achievements in each evaluated OP, was variable and inconsistent. While some set up several relevant indicators and reported on achievements, others did not report on any relevant indicators, despite providing financial support to energy efficiency investments in public buildings. This section presents the main achievements captured by the indicators.

Outputs

The most widely used output indicators show the number of relevant projects/operations. Specific output indicators captured for example "number of thermo-modernised buildings" or "number of communes with Low-carbon Growth Plans" as in the Polish OP Infrastructure and Environment. Other relevant indicators are more generic, as was the case in the German Saxony OP with the output indicator "the number of projects for environmental protection, in particular for CO_2 reduction and energy efficiency increase, noise reduction and climate adaptation". Targets for the indicators measuring the number of interventions ranged from 6 in the German Saxony-Anhalt OP to 46,920 in the Romanian Regional OP.

In total the reviewed programmes reported on 117,000 interventions related to energy efficiency in public and residential buildings. These programmes managed to achieve 82% of their target levels in this respect by 2013. A vast majority of the OPs supported public building and the highest number of interventions have been conducted in residential buildings under only 5 OPs: The Greek Competitiveness & Entrepreneurship OP (39,210 'energetically modernised households' and 36,669 'replaced energy intensive appliances'), the German Saxony OP (20,781 projects), the Greek Macedonia-Thrace OP (6,280 'energetically modernised households'), the Greek Attica OP (4,594 'energetically modernised households') and the Romanian Regional OP (2,836 'energetically modernised apartments').

One might expect that the size and number of projects supported is linked to the justifications provided for funding. On one hand, larger projects that involve comprehensive renovations of public buildings could be expected to be related to funding justifications that stress the exemplar role of the public sector or fostering regional innovation. Smaller projects, on the other hand, that involve less comprehensive renovations (e.g. a simple boiler or air conditioner exchange) would tend to go better with support to residential buildings, and be associated with funding justifications that stress the need to reduce fuel poverty and increase thermal comfort. The evidence does not allow confirmation or rejection of this expectation: of the 8 OPs that cited the exemplar role of the public sector as a funding justification, few focused their support on a big number of projects. Three of them (the Greek Attica, Macedonia-Thrace and Competitiveness & Entrepreneurship OPs) even supported more than 1,000 projects each. In contrast, the UK London OP and German Lower Saxony OP supported only a small number of deeper renovation projects, yet did not cite the exemplar role of the public sector as a justification for funding. This further supports the findings (presented in section 3) that the rationales presented in the OPs had little concrete implication for the implementation and achievements.

Results

Among the result indicators, "reduction of energy consumption" and "reduction of greenhouse gas emissions" were used most frequently, allowing for comparisons across programmes. The forty one selected OPs used seven different (types of) result indicators. Of these seven indicators, the two used most frequently are the reduction of energy consumption or an equivalent formulation (27 OPs out of 41 OPs) and the reduction of greenhouse gas emissions (20 OPs out of 41 OPs).

The programmes reviewed reported on reductions of energy consumption in the magnitude of 2,904 GWh per annum and of reductions of greenhouse gas emissions of 1,454 kilo tonnes of CO_2 equivalent per annum as a result of, among others, energy efficiency interventions. These achievements constitute the progress reported by the 27 OPs that used reduction of energy consumption and the 20 OPs that used reduction of greenhouse gas emissions as indicators to capture the achievements of energy efficiency in public and residential buildings. Compared to the targets set, these programmes managed to achieve 62% of their energy reduction and 23% of their emissions reduction targets by 2013. It should be noted, that of the 2,904 GWh per annum only 1,438 GWh can be directly attributed to energy efficiency interventions in public and residential buildings. The energy savings of the 15 OPs that supported energy efficiency interventions in public and residential buildings but did not measure energy savings are not included in this figure. The same reasoning applies to emissions reduction, where 826.4 kilo tonnes of CO_2 equivalent per annum can be directly attributed to energy efficiency interventions in buildings and the emissions reductions of the 21 OPs that did not report on them are not included in the figure.

Evidence from the interviews conducted in the course of our study indicated that the results were influenced by a range of behavioural and cultural factors.

A comparison of achievements across programmes can be made for the two most frequently used result indicators; however the findings need to be treated with care. The comparison shows that both the targets set and the achievements reported vary significantly across programmes, independently of how much was allocated to and spent on energy efficiency in buildings. This suggests that Managing Authorities faced difficulties in setting realistic targets mainly due to the fact that the energy efficiency investment in buildings was still a novel area for them. However, the differences across programmes might be exaggerated by the fact that Managing Authorities did not use standard procedures for measuring and monitoring project results. Especially in the area of energy and emissions measurements, different measuring procedures can lead to widely diverging results. Not too much weight should therefore be placed on the differences found across programmes.

Overall we identified a number of improvements of energy efficiency in public buildings funded from the ERDF/CF over the 2007-2013 programming period. For instance under the Lithuanian Promotion of Cohesion programme modernisation of public buildings was more successful than renovation of multi–apartment buildings (the latter was negatively affected by the economic crisis as well as a principal-agent problem). By the end of 2014, 864 public buildings were modernised (101,6% of the target value). For public buildings, the result indicator “Amount of energy saved in modernised public buildings (GWh)” was used, with a target value of 200 GWh. By the end of 2014, 236.6 GWh of energy had been saved as a result of energy efficiency investments in public buildings (118.3% of the target value). According to preliminary data from the Annual Implementation Report of 2014, an energy efficiency increase of over 69% has been achieved in modernised multi–apartment buildings which represents 231.8% of the target value; although for a significantly lower number of buildings than planned.

Under the Polish Infrastructure and Environment programme 413 public buildings were thermo-modernised by the end of 2014. The projects resulted in reduced CO_2 emission and energy savings, but the result indicator target values were not achieved. Nevertheless, according to the experts, even if the target values were met, energy efficiency projects in public buildings would have only a negligible impact in terms of overall energy savings and CO_2 emissions. This contrasts with the ambitions of the Managing Authority to create results in terms of energy saved and greenhouse gas emissions which would help fulfil the requirements stemming from EU and international laws with the energy efficiency interventions in public buildings supported by the CF.

Managing Authorities provided a range of reasons for not setting or not achieving targets. These reasons include, among others, difficulties in estimating what would constitute a realistic target, difficulties reporting on progress made, slow deployment of funds, and a time lag in reporting on projects, particularly in relation to energy savings.

Cost effectiveness calculations

Cost-effectiveness calculations using available monitoring data reveals seemingly large variances across programmes. Despite some comparability issues for the available 2013 expenditure data [12], the information can be used to construct a cost-effectiveness ratio of how much energy in MWh was saved for every EUR 1,000 spent. The reduction of energy consumption in GWh per year (reported by 13 of the 16 OPs using a specific result indicator on the reduction of energy consumption) was compared to the estimated amount of funds spent on energy efficiency interventions by these OPs. The calculations indicate that the cost-effectiveness of interventions for these 13 OPs varies substantially. It ranges from less than 0.4 MWh saved per EUR 1,000 spent in the Lithuanian Promotion of Cohesion OP and the Czech Environment OP to approximately 10 MWh per EUR 1,000 spent in the French Nord-Pas-de-Calais and French Aquitaine OPs. However, it is important to stress that the interventions often include non-energy related investment; therefore (without a clear and standardised indicator) such comparisons need to be handled with care.

Differences in energy efficiency measures, units of analysis and reporting practices make a comparative analysis based on the available monitoring data meaningless. At first sight the calculations presented above suggest that the French OPs were significantly more cost-effective, especially if one takes into account the differences in input costs in these countries. However, it is likely that the observed variations are to a large extent due to a lack of standardised framework for calculating costs and benefits. First, the type of energy efficiency measures (e.g. thermal insulation, space heating, space cooling, domestic hot water, ventilation systems, lighting etc.) covered by the expenditure data are not always known, which makes any general comparison difficult. Second, the expenditure data and the outcome data need to cover the same set of activities. This is not the case in the Lithuanian Promotion of Cohesion OP, for instance, where the result indicator measures the reduction of energy consumption in public buildings, while expenditure data encompasses both public and residential buildings. Third, the reporting practice and frequency vary between programmes. For instance, in the Polish programmes energy reductions are measured and reported one year after completion of a project, while in the Greek programmes the energy reduction is reported based on theoretical values already before project completion, therefore failing to account for a potential optimism bias in project design.

Evaluating and comparing the cost-effectiveness of the interventions would therefore require a detailed and standardised data collection and reporting framework, which was not available. Finally, even if such a framework existed, the usefulness of the comparisons would be limited by the fact that not all interventions pursue the objective of reducing energy consumption in the same context. Some programmes invested in expensive demonstration projects, in which the absolute reduction of energy consumption was of secondary importance as such. For instance, the German Lower Saxony OP supported four deep renovations of public buildings and comparing the cost-effectiveness of such pilot demonstration project with programmes that invested into a large number of small but effective measures does not do justice to the former. As a result, comparing the cost-effectiveness of ERDF/CF investments in energy efficiency based on monitoring data does not appropriately reflect the full range of objectives pursued.

Impacts and other achievements

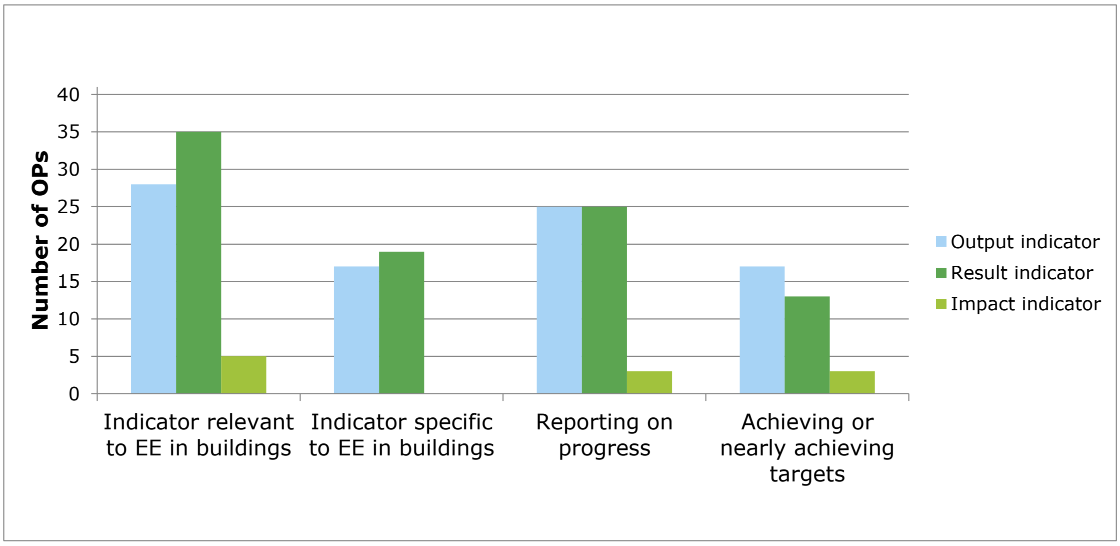
Impact indicators that capture the effects of interventions at the level of the whole economy were used only by a minority of programmes. From the sample of 41 selected OPs, 5 programmes used an impact indicator relevant to energy efficiency in buildings (e.g. energy intensity of GDP in kgoe per 1,000 EUR in GDP, used by the Lithuanian Promotion of Cohesion OP), out of which 3 OPs reported on progress made by the end of 2013. All 3 OPs achieved or exceeded their target. From the information available in the programme documentation it was not possible to assess to what extent these achievements can be attributed to the energy efficiency investments in public buildings.

Some additional achievements were attained, including increased awareness among both policy-makers and beneficiaries of energy efficiency. Although they are not captured by the monitoring systems, these achievements are highly relevant given that energy efficiency in buildings was a relatively new area of intervention in the ERDF/CF.

Overview

Overall, the use of relevant and/or specific indicators of achievements in energy efficiency in public and residential buildings is not consistent across programmes. An analysis of the monitoring data for the 2007-2013 programming period indicates that not all programmes used an output, result and/or impact indicator relevant for energy efficiency interventions in buildings (i.e. capturing achievements of energy efficiency interventions, including in buildings but possibly in other intervention areas as well). Moreover, very few programmes used an indicator that was specific to energy efficiency in buildings (i.e. capturing only the achievements of energy efficiency interventions in buildings), even fewer used indicators relevant to public buildings only. Instead, a wide array of heterogeneous and in some cases unspecific indicators were used (see Figure 3). This weakness in design of the framework underpinning the OPs affected comparability of the OPs and has been to some extent addressed in the current programming period.

Figure 2: Number of OPs using relevant targets and reporting on achievement



Source: IEEP, Ramboll (2015) based on in-depth review of selected Operational Programmes

As a result, no complete picture can be provided of achievements across programmes. This is a consequence of the weaknesses of the monitoring systems, which often lack specific indicators, set unrealistic target values and failed to measure the achievements of project interventions. There is a strong demand by Managing Authorities for clear guidance on how to set adequate targets and measure achievements in this policy area.

6. Summary and policy implications

Despite significant shortcomings in data availability, the evaluators collected a wide range of findings relevant to the investment in energy efficiency in public buildings under the previous programming period of the EU Cohesion Policy. Nonetheless the quantitative data on public building interventions was usually available only in aggregation with data on residential buildings, and even with data on investments in cogeneration and energy management. The total of ERDF/CF allocations to public and residential buildings over 2007-2013 period was quite substantial from the outset, and for several reasons including implications of the economic crisis, increased significantly over the course of the programmes to reach around EUR 3.4 billion.

In terms of the reasons behind the energy efficiency investment in public buildings, the quality of the stated rationales in the operational programmes examined was rather poor. Key outcomes mentioned included climate change, energy security, and reduced costs; but there was little detailed analysis of specific market failures, and little explicit argumentation for the choice of mechanism (for example, grants as opposed to loans), or the choice of buildings targeted (with a majority of the programmes studied referring to general benefits of energy efficiency investment, rather than issues specific to public buildings). These findings can be partly attributed to the novelty of the eligibility of these investments for ERDF/CF support, and to the context of the rapidly-developing EU legal framework and national strategies for energy efficiency. In general, the broad range of objectives to which energy efficiency investment can contribute has been an important argument in favour of allocating public funding. It seems however that this broad range of objectives can make it more difficult for public authorities to set clear success criteria, and design transparent evaluation mechanisms.

Of the 41 programmes from the sample which funded investments in public and residential buildings, nearly all included support for energy efficiency investments in public buildings. The support was provided through grants with high co-financing rates (up to 100%). The Managing Authorities were reluctant to use loans due to the administrative complexity and constrained loan-taking capacity of the potential beneficiaries.

The governance structures used by operational programmes varied significantly; but there was some evidence of a pattern that Managing Authorities sought to overcome their own lack of familiarity with energy efficiency investments by making use of intermediate bodies, and implementing bodies (including bodies charged with administering loan funds).

Project selection criteria were often loosely defined; the most frequently-used criteria referred to energy savings. Energy audits were used as a means of assessing energy savings in only 17 out of the 41 OPs studied in detail; and their use, and that of Energy Performance Certificates, was partly determined by the level of familiarity of public authorities and the construction industry with them. In some cases, the use of energy audits by ERDF/CF programmes has been beneficial in encouraging their use in the property market more generally.

Accompanying measures, including training for both programme authorities and beneficiaries, were included in most of the OPs studied; and some programmes have shown particular strengths in terms of addressing a wider information gap and behavioural challenges associated with energy efficiency policy, although detailed evidence of outcomes on this, as on many other aspects, remains scarce.

The evidence on achievements in terms of indicators of energy efficiency in public buildings in the 2007-2013 programming period provides an incomplete and mixed picture. It is mainly due to the variable extent to which the indicators reported on by Managing Authorities were designed appropriately to capture evidence of achievements. Not all programmes used indicators that were able to report on energy efficiency impacts specifically from public buildings; and many did not include indicators that were specific to buildings at all. Overall, the ERDF/CF support to energy efficiency in buildings over the period was beneficial and delivered physical outputs although not always in a cost-effective manner. The overall cost of interventions in relation to the potential energy savings was relatively high, but it can be considered a part of a broader learning process.

Our findings point to a number of policy implications, in particular:

1. **There is a need for operational programmes to set a clear rationale for their interventions, and in doing so to take account of the wider context of energy efficiency policy, including the scale of ambitions, and the types of national and regional funding support mechanisms available.**

Programmes with a robust and clearly expressed rationale, which is then translated into a clear strategy for how ERDF/CF interventions will tackle the challenge of energy efficiency, seem to have a better chance of success and to be able to adjust interventions effectively in the light of experience. A careful focus by programming authorities on assessing the nature of energy efficiency challenges in the context of broader interventions at EU, national and regional level is recommended. It is important to identify the specific contribution that ERDF/CF support can make to overcoming particular market failures or weaknesses in the broader policy framework, or to facilitate the development of a self-sustaining energy efficiency sector. Interventions should be designed clearly showing how the targeted contributions are to be achieved cost-effectively, with a clear understanding of the incentives created. This could be improved through an increased focus on coordination with National Energy Efficiency Action Plans, which should be reflected in the Partnership Agreements in which the Member States outline how the European Structural and Investment Funds (ESI funds), including ERDF/CF, will be spent at national level.

2. **The choice of intervention mechanism should be carefully considered, and supported by a clear rationale. Very generous levels of grant financing for public authorities, beyond the level necessary to fund well-justified projects, should be avoided. However, grants may be particularly well-suited to deep energy efficiency interventions where beneficiaries may face uncertainty about the pace and scale of payback of the investment.**

The analysis of OPs suggests that, in addition to the lack of a clear rationale identified above, there was often little explicit consideration of the most appropriate form of instrument, or, within instruments, the most appropriate gearing of support. This in turn may have compromised in some cases cost-efficiency of the delivery of public benefits from support to energy efficiency investments. Extremely generous grants (providing up to 100% support) were used in some cases, rather than potentially more efficient loans, grant-loan combinations, energy audits or awareness raising schemes or other approaches. Therefore OPs should develop a robust and clear rationale for choosing the preferred type of instrument and for the method of implementation.

3. Synergies with national and private funding need to be ensured

It would be beneficial to use the complementarity of different available funding sources to leverage energy efficiency investment for a range of beneficiaries and types of interventions. This could be achieved through a coordinated set up of schemes that would eventually demarcate or target different categories and subcategories of beneficiaries and investment types. The complexity of the national funding picture from the point of view of potential beneficiaries was, in some programmes, a constraint on applicants coming forward with projects for ERDF/CF support. There is clearly a risk that applicants choose to delay investments while they decide which of the schemes is the most advantageous available to them. Consideration should be given to ensuring, through well-publicised information portals or other mechanisms (although not necessarily through the use of ERDF/CF funds), greater awareness of the map of coordinated schemes available. The set of principles set in the new Cohesion Policy package offers a promising framework in this respect; it stipulates that EU funds should support policy implementation, but that the majority of climate related investment should be private sector funded, and/or through energy providers; that Member States and regions should ensure that public funding complements and leverages private investments and does not crowd them out; and that market mechanisms such as energy efficiency obligations schemes or energy service companies (ESCOs), etc. should be considered before public funding as an option to create value for energy savings. Moreover the Common Strategic Framework (Annex I to the Common Provisions Regulation (CPR) [13] sets out the obligation for Member States and, where appropriate, regions to "ensure that the interventions supported through the ESI Funds are complementary

4. Programme authorities should actively examine loans and other mechanisms (such as energy service contracts) as a more cost-efficient means of supporting energy efficiency. The development of "off-the-shelf" templates for such instruments can be of significant value to programme authorities.

There is a need for a more explicitly targeted approach to the design of interventions. In particular, the form or support (or financing mechanism) should be chosen with care. For residential buildings, a higher ratio of grant funding (as compared to loans) may be more appropriate for home-owners in fuel poverty. For public buildings, however, the risks involved in channeling generous levels of support to public authorities are significant: it may represent a dilution of the primary intended impacts of ERDF/CF support in order to maximise beneficial impacts on current and future public expenditure. It may also weaken the exemplar role of such investments, by removing the need to demonstrate that energy efficiency investments are self-financing over the medium term and it may make public authorities reluctant to make energy efficiency investments from their own resources while they await the next opportunity to apply for generous ERDF/CF instruments. There may be particular institutional constraints present in some Member States which make it difficult to use loans (for example, constraints were identified on the ability of municipalities in Poland to enter into multi-annual loan commitments). However, as noted above, such weaknesses in the policy framework should ideally be addressed at their source, rather than through reliance on ERDF/CF funding, in this case for example, by finding a mechanism to enable loan commitments on an "invest to save" basis. Vehicles such as energy service companies (ESCO), or other approaches which rely on private sector funding to deliver energy savings, could also be considered. In the 2014-2020 programming period, Managing Authorities are allowed to provide support through a combination of financial engineering instruments with grants, and to structure such instruments using Energy Performance Contracting (EPC). Under more market oriented approaches of this kind, the role of non-repayable grants would be significantly reduced; and (as with all instrument choices) be based on market failures and investment needs identified in the ex-ante assessment.

Future policy developments driven by the Commission will aim at encouraging the Member States to prioritize energy efficiency in their policies, especially in terms of energy efficiency of building sectors that offers huge potential for improvement. As announced in the Energy Union communication [14]: "the Commission will support ways to simplify access to existing financing and offer "off-the-shelf" financing templates for financial engineering instruments to the European Structural and Investment Funds Managing Authorities and interested stakeholders, promote new financing schemes based on risk and revenue sharing, develop new financing techniques and support in terms of technical assistance. Financial support needs to be combined with technical support to help aggregate small-scale projects into larger programmes which can drive down transaction costs and attract the private sector at scale". The Common Provisions Regulation providing common rules applicable among other to ERDF/CF in the programming period 2013-2020 introduced a basis for "off-the-shelf" instrument specifically targeting energy efficiency in building sector known as the Renovation Loan. These instruments should be ready-to-use for a swift roll-out; their terms and conditions are pre-defined by the Commission. The conclusions of the evaluation confirm that the Commission's plans go in the right direction, while the bulk of work will need to be done at national, regional and local levels.

5. Careful attention should be paid to project selection criteria in order to maximise the effectiveness of funding in delivering policy objectives, and to avoid the risks of perverse incentives.

Project selection criteria should be appropriate to the objectives of interventions; should be transparent and well-understood by potential applicants; and should be constructed so as to avoid risks of perverse incentives. The effects of inadequate project selection criteria could be observed for example under the Polish Infrastructure and Environment programme which included a minimum grant level which led to portfolio applications from groups of municipalities with little coherent collective logic, leading in practice to significant management and information exchange difficulties. In future, project evaluation could involve, among others, specific criteria related to energy financing. The amount of energy saved compared with a baseline scenario should be accounted for, and the criteria should be designed to foster deep renovation projects in line with the Directive on Energy Performance of Buildings [15].

6. To ensure standardised and relevant monitoring, indicators should be set and approaches to measure them should be explained

The results available from monitoring systems for 2007-2013 programmes did not provide fine grained information about energy efficiency investment in public and residential buildings. They were also difficult to compare between programmes and in many cases failed to provide information that was relevant to the rationale for interventions. In future, Managing Authorities could be encouraged to present their specific rationale for support to energy efficiency in buildings. Those specific rationales should then be used to develop programme specific indicators capable of providing information on the success with which the programme meets its objectives, which could be reported on alongside common indicators. The agreed common indicators 2014-2020 for energy efficiency investments encourage more standardisation of the reporting of results and impacts. There is potential for more guidance to be offered to Managing Authorities by energy efficiency policy experts on appropriate approaches to reporting.

7. Supporting measures (such as capacity-building, training, and information campaigns) can play an important role, particularly where the types of intervention made available are new to the Member State or region. Specific attention should be given to project development assistance, where its availability would increase the effectiveness of European investments and improve the capacity of beneficiaries, for example in structuring larger and more aggregated projects.

Energy efficiency of buildings was an unprecedented type of investment for most of the Managing Authorities. They struggled therefore to ensure sufficient knowledge and know-how to design and implement programmes efficiently. Moreover, beneficiaries generally lacked understanding and knowledge about small-scale financing options for energy efficiency investments. Some programmes provided advice and a cooperative approach to the development of projects (for example the London Energy Efficiency Fund); others (for example, the Polish Infrastructure and Environment OP) provided funding for the early stages of project development. If wider spread, project development assistance facilities and capacity building schemes provided to public and private project promoters such as public/private infrastructure operators or ESCOs, will advance innovative, bankable and sustainable energy efficiency investments under Cohesion Policy. Some project development assistance vehicles introduced in the 2007-2013 period will be continued over the 2014-2020 programming period. These include: the European Local Energy Assistance (ELENA) and Joint Assistance to Support Projects in European Regions (JASPERS). Moreover under the Horizon2020 programme, project development assistance can also be provided to sustainable energy project promoters. These facilities can be used as examples for Managing Authorities for setting-up similar facilities at the Member State or Regional level. Moreover, as mentioned above the Common Provisions Regulation (art. 59) allows earmarking of part of ERDF/CF funding for technical assistance, at the initiative of the Member States.

8. The competencies of programme authorities in the area of energy efficiency investment should be reinforced; they should ensure (through recruitment, training, or the use of external expertise) that they can draw on the right level of understanding of energy efficiency investment in buildings and its context.

The employees of institutions managing and implementing operational programmes did not always have the knowledge and expertise to ensure good design and effective implementation of energy efficiency schemes of support. Also, the administrative capacity and technical expertise for implementing financial engineering instruments varies considerably across the EU. In future, to streamline energy efficiency investment in priority areas, it is essential that relevant staff have the right skills and understanding of the practical and contextual aspects of energy efficiency investment in buildings. In some cases, involvement of external experts to support the Managing Authorities could be envisaged. This area for improvement has been already tackled to some extent by the Common Provisions Regulation framing the programming period 2014-2020. Member States will be allowed to use ERDF/CF to improve their institutional capabilities and to help develop and implement the operational programmes. Article 59 of the Common Provisions Regulation allows support for actions that cover 'preparation, management, monitoring, evaluation, information and communication, networking, complaint resolution, and control and audit'.

9. The use of energy efficiency audits should be the norm for ERDF/CF investment in this area.

Varying approaches were observed to the use of energy audits, to a large extent influenced by the extent to which they were a well-understood instrument in the Member State in question. Some programmes chose not to make use of them, some programmes made use of them as a matter of course, and others (for example, the Greek Competitiveness and Entrepreneurship OP) made a positive choice to require them. The latter led to an improved understanding of the instrument in the construction sector. Overall it is found that energy audits can help to ensure rigour both in the assessment of project applications, and also in the evaluation of the impacts of investment on energy use and associated CO_2 emissions. Their use should therefore be the norm, except where there are overriding reasons against. One example of such reasons is avoiding complexity of paperwork for small value interventions.

10. The exemplar role of public buildings should be further promoted

As noted above, the potential role of public buildings as exemplars is an important potential justification for focusing investment on them (it is also stipulated in the Directive on Energy Performance of Buildings). Where investment is focused on public buildings, it is important to make use of this exemplar role. A first step is to ensure that they provide either a convincing demonstration of the financial benefits of energy efficiency investment (which is more consistent with the use of loan mechanisms) or a demonstration of the potential for deep renovation (which is more consistent with grant mechanisms, as suggested above). In either case, it is important to consider how information about the investment will be disseminated effectively, and used to promote wider understanding of the benefits and potential of energy efficiency interventions. This approach is in line with the Energy Efficiency Directive's introduction of specific renovation targets for central government buildings [16], and the Directive on Energy Performance of Buildings requiring energy performance certificates to be issued for and displayed by public buildings frequently visited by the public. Apart from the promotion of energy

11. **Good inter-agency communications are important, particularly between Managing Authorities and agencies responsible for energy policy, in order to ensure that the delivery of cohesion policy and energy efficiency policy objectives is mutually reinforcing.**

The most successful schemes could be found in the Member States where communication between different public governance levels was relatively well developed. In future Managing Authorities could reinforce their cooperation with national and, if possible, local energy agencies. They should involve institutions and organisations with a good understanding of incentives and likely responses of the owners of public and residential buildings in the design and, where appropriate, implementation of programmes.

References

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Can be downloaded at:
http://ec.europa.eu/regional_policy/sources/docgener/evaluation/pdf/expost2013/wp8_final_report.pdf

[2] 48 operational programmes subjected to the evaluation; 6 OPs selected for case studies are marked in bold.

COUNTRY CODE	OPERATIONAL PROGRAMME - IDENTIFICATION NUMBER	OPERATIONAL PROGRAMME - TITLE
BG	2007BG161PO001	Operational Programme Regional Development
BG	2007BG161PO003	Operational Programme Development of the Competitiveness of the Bulgarian Economy
CB	2007CB163PO005	Programa Operativo FEDER Cooperación Transfronteriza España-Portugal
CB	**2007CB163PO036**	**Programma per la cooperazione transfrontaliera Italia-Slovenia 2007-2013 MODIFICATO 2**
CB	2007CB163PO040	Interreg IV A programme de cooperation transfrontaliere France (Manche) - Angleterre 2007-2013
CB	2007CB163PO055	North Sea Region Programme 2007-2013
CB	2007CB163PO061	Central Europe 2007-2013
CZ	2007CZ161PO004	OP Podnikání a inovace
CZ	2007CZ161PO006	OP Životní prostředí
DE	2007DE161PO004	Operationelles Programm EFRE Sachsen 2007-2013
DE	2007DE161PO007	Operationelles Programm EFRE Sachsen-Anhalt 2007-2013
DE	2007DE162PO004	Operationelles Programm EFRE Berlin 2007-2013
DE	2007DE162PO007	Operationelles Programm EFRE Nordrhein-Westfalen 2007-2013
DE	2007DE162PO010	Operationelles Programm EFRE Niedersachsen (ohne Region Lüneburg) 2007-2013
ES	2007ES161PO008	Programa Operativo FEDER de Andalucía
FR	2007FR162PO001	Programme opérationnel FEDER AQUITAINE
FR	2007FR162PO015	Programme opérationnel FEDER LORRAINE
FR	2007FR162PO017	Programme opérationnel FEDER NORD PAS-DE-CALAIS
FR	2007FR162PO018	Programme opérationnel FEDER PICARDIE
GR	**2007GR161PO001**	**Ανταγωνιστικότητα και Επιχειρηματικότητα**
GR	2007GR161PO005	Περιβάλλον - Αειφόρος Ανάπτυξη
GR	2007GR161PO006	Αττική

COUNTRY CODE	OPERATIONAL PROGRAMME - IDENTIFICATION NUMBER	OPERATIONAL PROGRAMME - TITLE
GR	2007GR161PO008	Μακεδονία - Θράκη
HU	**2007HU161PO002**	**Operational Programme for Environment and Energy**
IT	2007IT161PO002	Programma Operativo Interregionale "Energie rinnovabili e risparmio energetico" 2007-2013
IT	2007IT161PO004	Pon Istruzione FESR - Ambienti per l'apprendimento. Proposta di variazione dei tassi di cofinanziamento tra assi.
IT	2007IT161PO008	POR Calabria FESR 2007 - 2013
IT	2007IT161PO009	Por Campania FESR
IT	2007IT161PO011	Por Sicilia FESR
IT	2007IT162PO006	POR FESR 2007-2013 Lombardia
IT	2007IT162PO011	PO Regione Piemonte FESR - versione 5
IT	2007IT162PO015	Por Veneto FESR
IT	2007IT162PO016	Por Sardegna ST FESR
LT	**2007LT161PO001**	**2007-2013 m. Sanglaudos skatinimo veiksmų programa**
LT	2007LT161PO002	2007-2013 m. Ekonomikos augimo veiksmų programa
PL	**2007PL161PO002**	**Program Operacyjny Infrastruktura i Środowisko**
PL	2007PL161PO008	Regionalny Program Operacyjny Województwa Lubuskiego
PL	2007PL161PO013	Regionalny Program Operacyjny Województwa Podkarpackiego
PL	2007PL161PO015	Regionalny Program Operacyjny Województwa Pomorskiego
PL	2007PL161PO017	Regionalny Program Operacyjny Województwa Wielkopolskiego
RO	2007RO161PO001	Regional Operational Programme
RO	2007RO161PO002	Sectoral Operational Programme Increase of Economic Competitiveness
RO	2007RO161PO004	Sectoral Operational Programme Environment
SI	2007SI161PO002	Operativni program razvoja okoljske in prometne infrastrukture za obdobje 2007 - 2013
UK	2007UK161PO002	West Wales and the Valleys ERDF Convergence programme
UK	2007UK162PO004	East of England ERDF Regional Competitiveness and Employment programme
UK	**2007UK162PO006**	**London England ERDF Regional Competitiveness and Employment Programme**
UK	2007UK162PO008	North West England ERDF Regional Competitiveness and Employment Operational Programme

[3] Annual Implementation Report is a report on the implementation of the operational programme that a management authority was due to submit every year to the European Commission. This

obligation stems from Article 67 of the Council Regulation (EC) No 1083/2006 of 11 July 2006 laying down general provisions on the European Regional Development Fund, the European Social Fund and the Cohesion Fund and repealing Regulation (EC) No 1260/1999, OJ L 210, 31.7.2006.

[4] Presidency Conclusions of the European Council of 8/9 March 2007, doc. 7224/1/07 REV 1, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf

[5] Information on financial figures on 2013 and 2014 ERDF/CF allocations was also collected from Managing Authorities within WP13. Due to the differences of the data sources there are discrepancies between the financial figures on ERDF/CF allocations for 2013 as reported in the Commission's SFC system and the WP13 database. The main information source on financial figures used throughout this evaluation was the European Commission's SFC Monitoring System; the financial figures on 2013 ERDF/CF allocations were based on the SCF system and not the data collected under WP13. There were no allocations for the relevant priority theme in Cyprus and Denmark.

[6] National Development Agency, *National Strategy Report of Hungary* [Nemzeti Stratégiai Jelentés], 2012

[7] The estimated cumulative allocations for energy efficiency measures in public and residential buildings in these 9 Member States should be treated with caution as data cannot be considered fully reliable and the calculations are rough estimates which often use approximation.

[8] Jędrzejewska-Kozłowska B., *Low-carbon grwoth plans – an opportunity for development of the communes* [Plany gospodarki niskoemisyjnej szansą rozwoju gmin], 'Czysta Energia' nr 2(162)/2015

[9] JESSICA (Joint European Support for Sustainable Investment in City Areas) is a European Commission initiative supported by the EIB and the Council of Europe Development Bank (CEB). It is designed to support investments in long term sustainable urban development in the context of cohesion policy.

[10] Fi compass, *London Green Fund, Case study*, Conducted by t33, University of Strathclyde – EPRC and Spatial Foresight, 2014. Can be downloaded here: https://www.fi-compass.eu/sites/default/files/publications/case-study_london-green-fund_uk.pdf

[11] Outputs are goods and services produced, usually measured in physical or monetary units. Results are direct and immediate effect on direct and final beneficiaries brought about by a programme. Impacts are long-term effects including effects beyond the direct and immediate effects

[12] The allocation data for each OP contained in the WP13 "geography of expenditure" dataset differ from the allocation data in the Commission's SFC system used throughout this evaluation.

[13] Regulation (EU) No 1303/2013 of the European Parliament and of the Council of 17 December 2013 laying down common provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund, the European Agricultural Fund for Rural Development and the European Maritime and Fisheries Fund and laying down general provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund and the European Maritime and Fisheries Fund and repealing Council Regulation (EC) No 1083/2006, OJ L 347, 20.12.2013. Can be downloaded here: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32013R1303

[14] European Commission, *A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*, COM(2015)80 final, February 2015. Can be downloaded here: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2015%3A80%3AFIN

[15] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, OJ L 153, 18.6.2010. Can be downloaded here: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

[16] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, OJ L 315, 14.11.2012. Can be downloaded here: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF

Who does what with data? A WICKED approach to energy strategies

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Abstract

Working with Infrastructure Creation of Knowledge and Energy strategy Development (WICKED) is a UK-based research project seeking energy solutions for different retail market segments. Stakeholders include landlords, tenants, and owner-occupiers. Through cooperative research, WICKED investigates clusters of technical, legal, and organisational challenges faced by retail organisations, including those with smart meters and energy managers (the “data rich”) and those without (the “data poor”). Within this context, this paper provides a snapshot of the existing energy data and analytics practices of six partners. Partners include four retail tenants (a multi-national, full-service department store; a home improvement chain; a café chain; and an electronics retailer) and two landlords/managing agents (a property owner of UK community shopping centres, and a managing agent for a budget shopping centre). Where available, it uses quantitative data from partners to provides a glimpse of current energy analytics within organisations. Using interviews with staff, it provides new information on the organisational context of energy management according to a 4C’s “concern”, “capacity” and “conditions” with “communities” framework. These cases show that the data rich and poor will need different energy management solutions to maximize their energy efficiency and behavioral opportunities. The data rich may hire third-party experts to turn numbers into knowledge, and then discover the need for further communications strategies to engage staff. The data poor, on the other hand, can engage staff through a program of participatory monitoring and evaluation, using interactive handheld devices. The paper concludes that further investigation is needed into how organisational cultures frame employee duties, behaviours, and expectations, particularly with regard to data and analytics.

Introduction

It has been well-understood for some decades that energy use in existing buildings is a major source of greenhouse gas (GHG) emissions, and that there is significant potential for energy savings in retrofitting existing buildings [1, 2]. Reductions in emissions on the scale required to stabilise the global climate cannot be achieved without major change in the patterns of energy use across the entire building stock. Although change at this scale requires modifications in both technologies and organisational practices, research is dominated by technological approaches [3-5], and towards disciplines and activities that continue this trajectory [6]. Where social science research does exist, it is skewed towards households [7-11] rather than businesses. Approximately 18% of UK green house gas (GHG) emissions come from energy use in non-domestic buildings [12]. By one estimate, this rises to 34% if both operational and “capital” GHG emissions (direct and indirect emissions from construction works, services, materials, transport, and products) are included [13]. Yet research in non-domestic buildings accounts for less than 10% of the end use energy demand research portfolio in the UK [14, 15]. Broadening the understanding of the socio-technical processes and constraints that affect the dynamics of change in non-domestic buildings is of critical national and global importance.

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[1] Authorship for this paper is based on contributions to the analysis and interpretation of these particular cases. The project overall is a joint effort which includes the work of other colleagues at Oxford University including Peter Grindrod (Maths), Malcolm McCulloch (Engineering), Susan Bright (Law), and Julia Patrick (ECI). Suggested author order for citation is: Janda, Wallom, Granell, & Layberry.

To bolster research in this area, in 2014 the UK Engineering and Physical Sciences Research Council (EPSRC) funded six new projects on energy management in non-domestic buildings. This paper is funded by one of these projects. The project is called WICKED (Working with Infrastructure, Creation of Knowledge, and Energy strategy Development) and is designed to learn from real world situations, focusing on energy strategy development in the retail sector. The acronym WICKED draws on Rittel and Webber's [16] conceptualisation of complex problems that defy simplistic or straightforward planning responses as 'wicked', or tricky. Improving the building stock needs to address both the technical challenges involved in upgrading the physical infrastructure and also the social challenges of organisational decision-making [17].

The retail sector is vital to the economy, diverse, and facing a number of challenges. Retailers range from multinational corporations to small independent stores, selling everything from antiques to frozen yoghurt. Stakeholders include landlords, tenants, and owner-occupiers. Across the sector, energy costs and requirements for understanding, displaying, and reporting energy use are increasing. Meanwhile organisations face competing pressures to "go local", support staff development, and keep prices down. Because of this diversity, retail energy management creates a "wicked" problem, where solutions to challenges are contentious and multi-faceted. The Working with Infrastructure Creation of Knowledge and Energy strategy Development (WICKED) project provides energy solutions for different retail market segments. Through cooperative research, WICKED investigates clusters of technical, legal, and organisational challenges faced by retail groups, including those with smart meters and energy managers (the "data rich") and those without (the "data poor"). In partnership with energy suppliers, retailers, landlords, SMEs, and Oxford University, WICKED develops actionable energy and business insights by combining (1) top-down big data analytics, (2) middle-out organisational research, and (3) new bottom-up data. Building on this interdisciplinary evidence base, WICKED co-designs market-ready energy strategies to fit the retail sector's diverse needs. The project uses a segmented socio-technical model to explore challenges faced by six different types of stakeholders in the retail market: data rich and data poor owner-occupiers, landlords, and tenants.

The UK retail sector contains a number of large organisations that have well-known and highly publicized sustainability programmes. For example Sainsbury, Tesco, Morrison, and Marks & Spencer all have sustainability plans that incorporate carbon reductions [18-21]. These initiatives are supported by the British Retail Consortium (BRC), which is the leading trade organization for the retail industry [22]. Its members include approximately 200 retailers and food service companies, including a number of multi-national firms headquartered outside the UK (e.g., McDonalds, Ikea, and Starbucks). It also partners with trade associations (e.g., the British Council of Shopping Centres) and other groups providing services to retailers (e.g., banks, landlords, distribution companies, accountants, etc.). Independently and in partnership with the UK Department of Energy and Climate Change, the BRC has produced a number of initiatives to assist with and learn from its members' efforts, resulting in reports about increasing resource efficiency [23], workshops [24], and policy guidance [25]. Despite this activity, energy costs and requirements for understanding, displaying, and reporting energy use are increasing across many building sectors, including retail. Meanwhile organisations face competing pressures to "go local", support staff development, and keep prices down. Because of this diversity, retail energy management creates a "wicked" problem, where solutions to challenges are contentious and multi-faceted.

The paper begins with a discussion of WICKED's approach to the problem of energy management in the retail sector and non-domestic organizations, describing WICKED's novel socio-technical and interdisciplinary approach to the sector. Within this context, this paper provides a snapshot of the existing energy data and analytics practices of six different partners. Partners include four retail tenants (a multi-national, full-service department store; a home improvement chain; a café chain; and an electronics retailer) and two landlords/managing agents (a property owner of UK community shopping centres, and a managing agent for a budget shopping centre). Using interviews with staff, it provides new information on the organisational context of energy management according to a "concern", "capacity" and "conditions" framework. Combined with quantitative data from 5 partners, it provides a glimpse of current energy analytics within organisations and proposes novel additional analyses beyond current practice. These cases show that the data rich and poor will need different energy management solutions to maximize their energy efficiency and behavioral opportunities. The data rich may hire third-party experts to turn numbers into knowledge, and then discover the need for further communications strategies to engage staff. The data poor, on the other hand, can engage staff through a program of participatory monitoring and evaluation, using interactive handheld devices. The paper concludes that further investigation is needed into how organisational cultures frame employee duties, behaviours, and expectations, particularly with regard to data and analytics.

A WICKED Approach

This section first describes the sociotechnical segmentation model used to characterize different stakeholders and participants in the retail market. Next, it describes the energy behavior change model used in the research to frame why and how these participants engage in energy strategy development. We use these frames to think about how well the cases described in this paper represent the broader retail sector, and how further data might be gathered to create additional insights.

Socio-technical segmentation

WICKED introduces a segmented socio-technical approach to work with and learn from different configurations of building energy data and ownership in the existing UK non-domestic stock [26]. This segmentation model (see Table 1) uses the concepts of "data rich" and "data poor" to identify and map energy-related infrastructure, as well as barriers to and opportunities for change.

We define "data rich" as a Platonic ideal archetype: an organization that is able to gather, analyze, and use energy data to manage its premises in perfect harmony with its core strategy and central concerns. The reality is somewhat messier and inexact. Real organizations fitting this category will have lots of data—generally achieved through automatic meter reading (AMR)—and an energy manager of some description. In contrast, a "data poor" organization is one without access to real-time data and lacking the in-house analytical capacity to measure, map, and understand energy issues.

This typology is a heuristic model designed to help define and categorize research assumptions about the nature and distribution of firms and organizations with respect to energy issues. Three vertical categories recognize that there are three kinds of ownership types in the market: owner-occupiers, landlords, and tenants, each of which is subject to a different kind of legal infrastructure. The horizontal categories split these three ownership types into data rich and data poor bins, resulting in a typology of six different firm types.

Table 1. Socio-technical segmentation of the UK non-domestic stock

Segmentation of the UK Non-Domestic Market	Owner Occupied	Leased Space	
		Landlords	Tenants
Data Rich (e.g., an organization with AMR and an energy manager)	A	B	C
Data Poor (e.g., an organization with legacy meters and no energy analysis)	D	E	F

Janda, Bottrill et al. [27] used this approach to focus on "data poor" tenants and owner-occupiers (Types D & F). The current research aims to "fill in" the table further by concentrating on "data rich" tenants (Type C) and "data poor" landlords (Type E). It also goes beyond the survey methods used in Janda et al. [27] to incorporate interview data and quantitative data (where available). This broader approach enables us to learn both within disciplinary approaches and across them.

Organizational Potential

In addition to the infrastructural variation noted above, organizations also vary in the extent to which they are willing and able to engage in energy management practices at different levels within and across the organization.

Previous research [28, 29] has recognized that different organizations engage in the same types of energy efficiency practices, whereas similar organizations may do different things. Based on these findings, the researchers developed a “3Cs” framework that suggests that energy efficiency and conservation actions in organisations depend on the level of “concern” within the organisation about efficiency relative to other business goals; the “capacity” of the organisation to take action; and the real-world physical and technical “conditions” of the premises that are to be acted upon. The presence or absence of these three variables can be used to recognise variation within organisations and potentially map different policy approaches to encourage energy efficiency or conservation. This characterization also suggests that there is not one kind of firm; there may be at least eight different kinds.

In [9], Janda augmented the 3Cs framework with a “building communities” approach, based on [30]. This paper further develops the framework from 3C’s to 4C’s, as shown in Table 2.

Table 2: 4C’s framework: Concern, Capacity, Conditions within a Community

<table>
<tr><td></td><td></td><td colspan="3">3Cs</td></tr>
<tr><td></td><td>Analytical Level</td><td>Concern
(factors that shape attention to energy)</td><td>Conditions
(factors that shape where energy actions occur)</td><td>Capacity
(factors that moderate abilities to take energy actions)</td></tr>
<tr><td rowspan="5">Building Communities
(grey area, neither organizational nor individual)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Organization</td><td>Legislative requirements, leases</td><td>Building retrofit opportunities, thermostat setpoints, standard operational hours, provision of space & equipment</td><td>Energy management structure; job titles & responsibilities; feedback & data availability; granularity of data</td></tr>
<tr><td>Workgroup</td><td>Workstyles</td><td>Clothing choices, (e.g., “casual Fridays”), activities outside “normal” hours</td><td>Peer pressure & social practices; workgroup dynamics</td></tr>
<tr><td>Individual</td><td>Attitudes, beliefs, habits, values</td><td>Use of task lights, computers, auxiliary heating/cooling devices; extra plug loads; operation of blinds / windows</td><td>Presence or absence of champions; expertise & understanding of systems; interest in and ability to act on feedback</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

Axon et al. [30] propose a “building communities” framework that accommodates the perspectives of building stakeholders, the physical context in which they interact, as well as the legal, policy, and market frameworks that shape their interactions.

Axon et al.'s concept of a building community is built around the idea of "communities of practice" (CoP). A CoP is a system of relationships between people, activities and their outside world developing over time and interconnected with other CoPs, which themselves can be found within businesses, across businesses and other organisational and professional structures [31, 32]. The concept of CoP also has implications for knowledge management and its codification [33, 34]. Such communities can be either geographically coherent and organisationally diverse (e.g., a multi-tenanted office building or shopping mall); or organisationally coherent and geographically diverse (e.g., a fleet of Marks & Spencer stores). The themes included in Axon et al.'s research are (1) legal and property aspects of improving energy performance; (2) policy context and organisational response; and (3) technology adoption and environmental performance. The levels of analysis recognize that building communities are affected simultaneously by the general context in which the community is situated (e.g. the building standards and resource costs in a particular country); as well as company-level expectations and building-level specifics.

One benefit of a "building communities" frame is that it moves beyond the usual levels of analysis that tend to take account of either "organizations" or "users." It recognizes that employees are both a part of and apart from the organization in which they work. Employees have to do their jobs, but in many organizational contexts, they have some agency over their actions that their employers do not completely control. Organizations govern some, but not all, of the actions their employees take, and even though inductions and protocols can help frame expectations that employees have about their work practices, employees can still disagree with corporate policies, particularly in their own areas of expertise. Similarly, organizations are a part of and apart from a larger market and social context for the goods and services they are providing. This kind of multilevel analysis is inspired by and reflective of other forms of multi-level research, including transitions theory [35] and recent work on construction and innovation in the management literature. Hoffman and Henn [36], for instance, identify social and psychological barriers to green buildings at three levels: individual, organizational, and institutional. The 4C's framework illuminates the presence and importance of multi-level influences, reflecting previous research that organizational change and innovation can occur from the top-down [37], bottom-up [38], or middle-out [39-41]. Moreover, such changes are likely to be more successful if the organization recognizes the need to integrate these levels [42].

Methods

WICKED has collected quantitative and qualitative data from stakeholders engaged in the UK retail sector. Quantitative data of various shapes and sizes has been obtained from six partners. This gives us a snapshot of the raw data, metadata, analytical processes, and issues that different market participants are currently working with. In addition some fine-grained quantitative data has been collected for two additional partners sampled at shorter intervals (1 or 5 seconds) than utility meters provide (typically 15 or 30-minute intervals). This gives us an opportunity to examine whether the data that "smart" utility meters provide is at a sufficient level of detail for all energy management decisions.

In addition to the case studies represented below, qualitative data have been gathered through interviews with 33 representatives of 23 different organisations, including property owners, retailers, letting and property management companies, energy management companies, law firms and legal experts, and industry intermediaries and associations. The interviews are supplemented by document analysis of company strategy reports and reviews of policy documents and industry reports.

Case Studies

This paper combines insights from the qualitative and quantitative data gathering and analysis. It therefore focuses mainly on cases where both quantitative and qualitative data are available, and frames these using the 4C framework presented above. These cases are summarized in Table 3.

Table 3: Case Study Description

Case	Company Description	Quantitative Data Gathered	Qualitative Data Gathered
1	European electronics company with a work force of 40,000	30 minute readings of the electricity consumed by 663 British shops during April	Interview with energy manager; review of external strategy

	employees in 3,000 stores spanning 11 countries	2013 to October 2014. Meta-data includes store type and postcode, but not floor area.	documents and website.
2	Full-line food and clothing retailer, with approximately 800 stores throughout the UK and another 300 stores in 40 overseas locations.	Hourly readings of electricity from 526 British stores from 1 July, 2014 to 30 June, 2015. Meta-data includes floor area, opening hours, occupancy and temperature.	Multiple interviews with energy management team, head of property; review of internal and external strategy documents.
3	A UK high street and online retailer with over 130 million customers and a network of 740 stores.	30-minute readings of the electricity consumed by 59 British stores from 31 March, 2012 to 31 March, 2014. A second batch of 30 minute resolution gas readings for 264 stores during 5 years from 31/08/2010 to 31/08/2015.	Interview with energy manager; review of external strategy documents and website.
4	Two-storey shopping centre opened in 1965 containing 91 units. Owned by a UK real-estate investment trust and managed by a national property management company.	No digital data available. High-resolution data collection discussed, but monitoring devices could not be indemnified sufficiently to be installed on the premises.	Two interviews with store managers (the first left and was replaced by a second); site visit; review of external strategy documents and website.
5	3-storey shopping mall opened in 1976, with 101 stores. Owned by UK community-focused retail property company.	30 minute readings of the electricity consumed by 1 shopping centre over 5 years (10-6-2011 to 8-6-2015). No meta-data available.	Interviews with energy management team; onsite visit to gather high-resolution data; review of external strategy documents
6	Chain of cafes owned by a larger hospitality company. One café addressed in context of a landlord/managing agent for a large London shopping centre.	No utility metered data given to project. 1-second high resolution data collected by 3rd party WICKED affiliate.	Interview with energy manager of hospitality company; interviews with local café manager, shopping centre manager, and managing agent.

Biases in the work

Data availability and inference

As we are not omniscient, we can only report on the data our partners shared and what our partners *told* us they were doing with their data. Therefore, this paper provides a somewhat grainy snapshot of the challenges and activities ongoing in our partners' companies. They (or their 3rd party affiliates) may be engaged in or in the process of pursuing other analyses that they did not discuss with us. Data analysis is a moving target, and so is data collection. This paper reflects what we learned between July 1 2014-June 30 2016.

In all cases, the quantitative data that we have been given is incomplete in various ways. We asked for data from across their entire portfolios, but we received a subset of these data. Interviews across a larger number of partners indicate that “getting” and “sharing” data is easier in some stores within a portfolio than in others for a variety of reasons. Partners are starting to digitize their portfolios, but getting store information (both metadata and energy data) online and keeping it up to date across hundreds of properties is difficult. Local managers may have the ability to make changes to the premises without reporting these changes to the energy team. Further, meters and monitors fail. Across 100s of stores, at any given time there are missing data, broken meters, and anomalies to correct.

Finally, we partnered with companies, we did not audit them. We asked for information that was easy for partners to share. If a company keeps electricity and gas records in separate databases, for instance, or if one source is digitized and the other is not, we might have received only part of the data that are available in-house. Data we received from some partners extended over multiple years and covered both electricity and gas. Data from other companies was more limited, but this may be an indicator of the company’s willingness or ability to share, rather than their absolute knowledge of their own stock.

The qualitative and quantitative data in this study were gathered in an iterative fashion by two different teams. Sometimes the interviews preceded data collection, sometimes vice versa. Although both the quantitative and qualitative teams shared information with each other, different questions evolved which required further discussion with partners. There was only so far we could pursue these additional questions. As further questions evolved from the combined analysis, we treated each evolution as an opportunity for further study only if the topic was of interest to the partner.

Case Study Sampling

Additional bias exists because of the small sample size, and its reliance on a convenience sample. Our findings are, therefore, not representative of the entire sector. They are not even representative of our own socio-technical model of the sector (Table 4). Our case studies show that our sample to date has not adequately captured the owner-occupiers (Types A and D in Table 4) in the market. Most of our interviews have been with larger retail organizations, which our interviews show prefer to be tenants rather than owner-occupiers. Their business model focuses on their core business—selling food and consumer goods—rather than upkeeping the physical properties that contain their businesses. These organizations mainly (but not exclusively) pair with large property landlords.

Table 4: Overlay of Case Studies and Socio-Technical Model

Segmentation of the UK Non-Domestic Market	Owner Occupied	Leased Space	
		Landlords	Tenants
Data Rich (e.g., an organization with AMR and an energy manager)	A	B Case 5	C Cases 1, 2, 3
Data Poor (e.g., an organization with legacy meters and no energy analysis)	D	E Case 4	F Case 6

Results

We present the results of the research in three sections—concern, capacity, and conditions—according to the 4C’s organizational potential model previously introduced. In keeping with [9] and [10], we focus on multi-level elements of organizational research. Even though the organizations we interviewed are coherent legal entities – a building “community” with a brand identity, unified on one level by name and purpose—our results show that companies operate across a diverse portfolio of properties, and there are significant variations both within companies (e.g., board room vs. energy team vs. store managers vs. employees) and across them.

Variation in Concern

The idea of energy management was not new to any of our interviewees or case studies. However, each of the 6 organizations in our cases engaged in this topic in a different ways. This section describes first the various energy topics that our partners address in their portfolios, then the ways in which these topics manifest in practice.

Different Energy Topics

At the organizational level, all of the cases had some form of sustainability statement on their website. This reflects the general external pressure for organizations of all kinds, not just retailers, to participate in corporate social responsibility activities [43]. The extent to which energy management plays a role in this set of concerns, however, varied. Energy management can mean many things, and each of our partners participated in a unique subset of the possible topics that "energy management" denotes. All partners were interested in reducing "out of hours" energy consumption, looking to minimize energy use in the hours their stores are not in service. Beyond this, organizations were (un)concerned about a variety of other energy aspects. For example, only one of our four retailers we talked to was interested in engaging their landlords through the mechanism of green leases. This retailer, M&S, has made a particular point of adding green leases to their sustainability toolkit. Research has shown that green leases are generally led by landlords and particularly popular in office buildings [44], but the landlords in the retail sector are not pushing this particular form of inter-organizational governance. Only one of our partners (Case 2) was considering innovative forms of energy supply, in this case, biofuels. None of the cases were seriously considering rolling out demand response strategies, although one interviewee mentioned an early stage pilot project.

Heterogeneous Practices

In terms of taking action on expressed concerns, there is a long distance between stating a corporate policy and enacting it. Across our cases, we found a number of instances where organizational infrastructures did not necessarily match the high level concerns. For example, several energy managers expressed frustration with the ways in which internal accounting mechanisms and pre-set thresholds for capital projects did not allow for upgrades that would otherwise seem reasonable. One interviewee told us that his company had a 12-month payback period, so he could not implement an improved lighting roll-out that would have had a 14-month payback. Another energy manager from a different company described how his company's capital expenditure spreadsheet did not account for increases or volatility in energy prices.

Variation in capacity

Capacity in the 4C's framework refers to the human and organizational effort allocated to the problem of energy efficiency. This effort can be allocated internally (e.g., staff members with time dedicated to these issues) or externally (e.g., 3rd parties hired in for specific expertise). On one level, the capacity of the retail sector is very coherent. In all cases, energy management is understaffed relative to the scale of the problem. For example, a recent Major Energy Users Council (MEUC) survey [45] found that 75% of respondents said they have at least one staff member responsible for energy, but the rest have not allocated staff time to manage energy concerns. 62% of respondents had a clearly defined energy reduction strategy for their business, but the remainder did not. These results indicate gaps in organizational capacity to manage energy, even amongst self-defined major energy users.

Internal capacity

All of the organizations we interviewed, as well as our case studies, showed varying levels of effort devoted to the task of improving energy management. Most, but not all, of our cases had an energy manager. This energy manager is typically responsible for overseeing the entire portfolio of stores, which represents hundreds of stores. In case 6, for instance, the staff member responsible for energy is also responsible for water and waste in over 1000 premises. In all cases, the "energy manager" operated in a "1-to-many" context, rather than a "1-to-1" relationship, like a store manager. While this slightly distant relationship provides the ability to learn from multiple cases, it does not enhance the ability to understand what is happening "on the ground". The energy manager can usually only see what the data tell him or her.

In a few cases (notably Cases 2 & 3), the energy manager also had direct contact and ongoing contact with the store managers. In both these cases, the organizations had hired in third-party software providers to help push energy information to the store managers. The energy manager for Case 3, for example, together with a 3rd party software provider, designed special portals for store managers to be able to see the feedback for their stores on a tablet. Case 2 (also in combination with a 3rd party) took feedback even further: store managers could see the feedback, and there was also an advertising campaign to increase energy awareness amongst store employees, as well as encouragement to exchange energy and environmental topics between employees on a special social media platform designed for the retailer.

For most cases, however, the energy information stayed with the energy manager. The premises in case 6, for instance, have "smart" meters but the meters send their data to a central location and are not pushed back out to the stores. As a part of a pilot test of new monitoring equipment in a shopping center, a WICKED affiliate working provided auxiliary metering on top of the smart meter in one of these stores to extract the information from the meters locally, upload it to a server, and display it back to the shopping center managers and store managers.

External capacity

The discussion above shows that even where energy managers are present in an organization, they rely strongly on external expertise and hire third parties to provide data management, analytics, and display services. These capabilities are not provided "in house" but instead are provided by consultants who may work entirely off-site or, in some cases, be embedded within the organization. In Case 2, the consultants work on kind of a "secondment" basis, where they work in the headquarters of the company and have an access badge to the premises. Compared to "normal" employees, however, their badge is a different color, which distinguishes them from the store managers and others who are "core" employees. Interviewees in these situations were very committed to the work they did for their host organizations. One interviewee opined about a database which accurately contained all the details of the energy-consuming equipment in every store, even as he discussed the difficulty with gathering this information, particularly as an outsider. On a day-to day basis, the store managers are seen as delivering the strategic "core" of the organization's operations, whereas energy management is still seen as peripheral [46]. Store managers have considerable power to make independent decisions regarding sales displays and promotions, which includes adding feature lighting. Although these decisions may impact energy use, the store managers are not required to notify the energy managers or their team of making such changes. Their goal is to maximize sales, not minimize energy use.

Variation in Conditions

This set of variables in the 4C's model relates to the physical and technical conditions present in each portfolio, which extends to the presence and absence of meters and data. A perfect portfolio would have the database envisioned by the consultant in Case 2 above: an accurate and complete accounting of every energy-consuming item in every store, updated in real time and without flaws, matched perfectly with energy data at sufficient spatial and temporal resolution to be able to problem-solve deviations. Further, these deviations would be automatically detected and flagged by smart algorithms, which could learn over time what is and is not a genuine problem. Ideally, it would also have an accurate representation of the physical attributes of the buildings (size, composition, orientation, location, building quality) in the portfolio, as well as some operational data about the activity in the buildings (opening hours, footfall, etc.).

The ideal database envisioned above is far from the reality. Most existing databases are incomplete, some (such as Case 4) are largely non-existent. The shopping center manager in Case 4, like most "data poor", has a box of paid and neatly filed gas and electricity bills rather than an active database of information. Where databases do exist, the energy and building level data are often in separate spreadsheets that are matched only on an ad hoc basis. The norm is energy managers operating mainly with energy data, set at arm's length from 100s of stores, often without a complete list of the building-level data, let along equipment or appliance-level data. In our investigations we found common problems which include: heterogeneous building stocks; evolving data practices; and some difficulties in relating the stocks and data to each other, let alone to problem-solving.

Heterogeneous stock

Internally, the organizations identify their stock in different ways for business purposes. Case 1 had 9 different internal definitions for “store type”, whereas Case 2’s database used only three categories, and Case 3 used two. From an energy perspective, these business classifications add some meaning but do not provide a sufficient technical basis for an internal benchmarking scheme.

At the building level, some organizations had hired a 3rd party to check and aggregate the asset-level data through the lens of the EU-wide Energy Performance Certificate (EPC) level-data. Most cases, however, did not link their EPCs with their metered data. Interviewees mentioned concerns about the quality of EPC data as an accurate benchmark. However, aside from normalizing for building size and sometimes climate zone, little work has been done within companies to benchmark for building quality. The problems addressed by energy managers is often limited to pinpointing and troubleshooting “out of hours” energy use, rather than looking for retrofit opportunities within the building portfolio.

‘Smart’ meters and imperfections

In all cases, the metered data were imperfect. Meters and monitors fail. Across 100s of stores, at any given time there are missing data, broken meters, and anomalies to either correct or remove, lest they skew the analysis. In Cases 1 and 3, for example, respectively 3% and 2% of the meter readings were inaccurate. In Case 2, however, close to 30% of the electricity readings were null values.

Other flaws in the data set may also exist, but are difficult to filter out without gaining a better idea of the expected performance and consumption norms. This process of looking for anomalies can be automated, but it is unclear to what extent either the retailers or the 3rd party manager is actively engaged in fine-tuning the analysis to assist with granular assessment of the meters themselves [47]. Close attention over time to fine details and fluctuations may or may not be part of the data package purchased from a 3rd party provider.

Beyond assessing the individual streams of metered gas and electricity data, braiding these and other streams into a joint “energy” profile has been challenging. Some stores are all electric; others have both gas and electricity, but the gas data may not have the same level of resolution or time stamp as the electricity data. These variations complicate combining the data sets and analyzing them in tandem.

Discussion and Conclusions

This paper presented and discussed findings from the first 18 months of WICKED, a 2-year research project on energy management in the UK retail sector. We presented the conceptual basis for the project and introduced a 4C’s (concern, capacity, and conditions across communities) framework for understanding the behaviour of firms. We discussed available data from 6 case studies: 4 data rich and 2 data poor. These cases show that retailers are not a homogenous group. As a result, one size does not fit all: the data rich and poor will need different energy management solutions. Smart meters will not solve everything: further analysis is necessary to turn numbers into knowledge. How organisational cultures frame employee duties, behaviours, and expectations requires further investigation.

The project results to date show that there is still a lot of room for improvement in the retail sector within the realms of data, organizations, and buildings. This is most obvious in Case 4, where the technical infrastructure of a budget shopping centre does not provide detailed access to real-time energy information for its manager. This is a fairly common problem in the retail sector, as evidenced by British Land—the UK’s largest listed owner and manager of retail space--posting a case study about adding automatic meter-reading to its retail properties as recently as 2013-14 [48]. Energy management is not a top priority in the retail sector [49], and moving this item up the organizational agenda is a difficult task. The cases show us not just that similar stores are different, but also that the available data could be better contextualized, cleaned, and possibly used to pinpoint meters that are faulty. As energy data acquisition and use becomes more commonplace, meter maintenance and data quality control will need to be added to the ongoing processes of "standard practice" for all commercial organizations if they wish to use their information to best effect.

Across the cases, there are two "solutions" that look like they will be helpful in resolving some of the issues across the retail sector, particularly in terms of energy accounting and accountability. One is standardization of data identifiers and variables, and the second is development of flexible smart-er monitors to assist with new meter locations, participant education and engagement. Our initial explorations suggest that some protocols regarding energy data availability and meter functionality may be useful. More work is needed to understand how energy managers in "data rich" firms actually use the data that they have, and whether additional meta-data may be needed. "Data poor" firms will need to access additional data, and as Case 6 showed, local managers of "data rich" firms can use these devices to get detailed information at the local level, if this has not been provided centrally.

A 4C's framework helps to clarify socio-technical challenges and opportunities at different operational levels within firms. Broadly, the results confirm that interdisciplinary, multi-level problem-solving is important, particularly in the real world. From the perspective of each disciplinary approach in the project, there are some problems that are visible and interesting, others that are obdurate to the tools used by that discipline. An example is the indication of broken or malfunctioning meters in Cases 1-3. From a data analytics perspective, data should be clean and regular, so faulty information streams should be discarded to ensure that "the system" is represented in a functional form. From an energy and management perspective, however, these malfunctioning meters represent real buildings that require some kind of physical intervention (e.g., meters need fixing or replacement) for their data to play a useful role in energy management. The question of how often meters (whether smart or not) fail, who knows when or if they do, and how they should be fixed is a problem that presents an additional opportunity (or challenge) to energy managers on the ground. Better data and analytics can illuminate this challenge, but engineering (stuff) and organizational effort (staff) are required to fix it.

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Session

Policies & Programmes III

Energy Saving Cost Curves as a tool for policy development - case study of the German building stock

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Abstract

The building sector within the EU accounts for about 40% of final energy use and one-third of greenhouse gas emissions. Buildings therefore should play an important role in meeting the EU climate targets. Using the example of Germany, the largest economy of the EU, this paper sets out the methodology for appraising the contribution that comprehensive building renovations, comprising both fabric insulation and heating system upgrades, can make towards decreasing energy use. A dynamic bottom-up simulation model, the Invert/EE-Lab model, evaluates the effects of three scenarios of economic and regulatory incentives for three different renovation packages oriented towards the standards defined by the German building code (EnEv) as well as the support programmes of the KfW development bank. Results are presented visually through Energy Saving Cost Curves which communicate the monetary costs (or savings) and the energy savings for 16 building categories that represent the entirety of the German building stock. The Energy Saving Cost Curves developed in this paper represent the investors' perspective to 2030. Under the Business As Usual scenario, the total cost effective energy savings potential amounts to 60 TWh/a, avoids 1.1 bn€/a in energy costs, and comprises most of the non-residential building categories and the oldest residential buildings built before 1948. Increasing the level of subsidy in the High Subsidy scenario results in an almost doubling of cost-effective savings to 118 TWh/a while increasing energy cost savings to 1.9 bn€/a. Energy Saving Cost Curves provide a means to compare the impact of different policy options from the perspective of the investor for different building categories, and can thereby feed directly into the design of renovation strategies -whether at national, regional or city level- under a wide variety of conditions and taking into consideration economic parameters ranging from subsidies and energy prices, to transaction costs, learning curves and discount rates.

Introduction

In order to curb climate change, the European Union (EU) has set a long-term aim to reduce greenhouse gas (GHG) emissions by 80-95% below 1990 levels by 2050. The EU has proposed a 40% goal for the reduction of GHG emissions by 2030, together with targets of 27% for both renewable energy and improved energy efficiency. Buildings play an important role in meeting the EU climate targets, in particular in Germany, the largest economy of the EU, where the building sector accounts for 40% of final energy use and for about one-third of GHG emissions.

Adopted as part of the Energiewende (Energy Transition) in 2010/2011, the Federal Government has set national goals to reduce energy consumption for heating by 20% by 2020 and non-renewable primary energy consumption for space heating and hot water by 80% by 2050, compared to 2008 levels. In addition, it aims for a 14% share of heating and cooling generated from renewable sources by 2020. Energy efficiency is the second pillar of the Energiewende and has been higher on the political agenda ever since the revision of the Renewable Energy Sources Act (EEG) was adopted in 2014. Currently, however, Germany is not on track to achieve its 2020 GHG emissions reduction target of 40%. In the 2013 report to the European Commission on GHG emissions projections and national programmes, the Federal Government reported a projected 33-35% CO_2 reduction.

In this context, this paper analyses the potential and related costs of energy savings in the German building sector. Thus, the core research questions of this paper are:

- What are costs and benefits for achieving cost effective energy savings in the building stock?
- How can energy saving cost curves (ESCC's) be developed as a policy support tool? / What is the usefulness of ESCC's as a policy support tool?
- Which results and conclusions can we derive from the application of ESCC's to the case of Germany?

After this introduction we explain the methodology developed and applied in this paper. Section 0 documents the input regarding the building stock and cost related data for the case of Germany. In section 0 we present the main results in form of Energy Saving Cost Curves under various scenario assumptions. Finally, we discuss the results and derive conclusions (section 0).

Methodology

General approach

In order to develop energy saving cost curves for the building stock – and thus to better understand the impact of different policies on the economic attractiveness of renovating different types of buildings – the following steps were undertaken:

1. Consider the current stock of buildings and factor in stock changes (e.g. demolitions, conversions) over the modelling period to 2030; Stock changes are modelled via Weibull distributions of buildings and building components (see model description Invert/EE-Lab below in section 0). The stock of buildings is structured in different building segments j.
2. Define a number of different renovation packages i, resulting in various levels of improvement in the building's energy performance.
3. Calculate delivered energy demand ($q_{i,j}$) in kWh/yr of each reference building in the building segment j after renovation with package i by means of the corresponding module in Invert/EE-Lab. This calculation module is based on the standard monthly, stationary energy balance approach defined in EN13790. Calculate energy savings per building $\Delta q_{i,j}$ as the difference of the delivered energy demand for each renovation package i and the energy demand of the reference system (assuming a building renovation without thermal improvement of the building envelope and a natural gas condensing boiler as a reference system);

$$\Delta q_{i,j} = q_{i,j} - q_{ref,j}$$

4. Calculate levelized costs of heating energy service c for these renovation packages i and different building segments j in €/yr based on the database, final energy demand (q) and economic evaluation module of Invert/EE-Lab.

$$c_{i,j} = \frac{IC_{i,j} \cdot \alpha + O\&M}{a_j} + q_{i,j} \cdot \overline{p}_{i,j}$$

With

$IC_{i,j}$	Investment costs of renovation package i in building class j (€)
α	Capital recovery factor
O&M	Operation and maintenance (€/yr)
$q_{i,j}$	Delivered energy demand for renovation package i and building segments j (kWh/yr)
$\overline{p}_{i,j}$	discounted average energy price during the considered time period (depreciation time) for the renovation package i and building class j (€/kWh)

5. Calculate additional costs $\Delta C_{i,j}$ (€/yr) for heating energy service in building class j with renovation package i compared to reference renovation package.

$$\Delta C_{i,j} = C_{i,j} - C_{ref,j}$$

6. Define a set of economic parameters affecting the cost effectiveness from the perspective of the investor (e.g. energy prices, interest rate or development of investment costs). These can be varied in order to generate different scenarios (see section 0).

7. Identify and select the least cost renovation package i* for each building segment j.

$$C_j^* = \min_i \left(C_{i,j} \right)$$

8. Calculate costs of energy savings for those least cost renovation packages* as the ratio of additional costs and energy savings;

$$\Delta c_j^* = \frac{\Delta C_j^*}{\Delta q_j^*}$$

9. Plot the data on an Energy Saving Cost Curve by representing every relevant renovation package and building class combination as a bar where Δc_j^* represents the height and ΔQ_j^* the width of the bars, ranking the bars by the costs of energy savings and starting with those bars with lowest costs on the left hand side, where ΔQ_j^* represents the total energy savings in the building segment j, by taking into account the number of buildings n_j and the cumulated renovation rate from 2014-2030 ρ_j in the building segment j.

$$\Delta Q_j^* = \Delta q_j^* \cdot n_j \cdot \rho_j$$

In this step, a clustering of building segments is carried out in order to allow a reasonable graphical representation.

10. Calculate additional indicators like overall investments, bundling of renovation measures etc

Applied models

The Invert/EE-Lab model

The Invert/EE-Lab model is a dynamic bottom-up simulation tool that evaluates the effects of different promotion schemes (in particular different settings of economic and regulatory incentives) on the energy carrier use, CO_2 reductions and costs for RES-H and renovation support policies. Furthermore, Invert/EE-Lab is designed to simulate different scenarios (energy carrier prices, insulation, consumer behaviours) and their impact on future trends of renewable as well as conventional energy use on a national and regional level.

The development of the model Invert/EE-Lab has started in 2002. Since then, the model has been used in more than 30 projects in more than 15 countries and has been extended to EU-28 (+Serbia) in the IEE project ENTRANZE (www.entranze.eu). The basic idea of the model is to describe the building stock, heating, cooling and hot water systems on a very detailed level, calculate related energy needs and delivered energy, determine reinvestment cycles and new investment of building components and technologies and simulate the decisions of various agents (i.e. owner types) in case that an investment decision is due for a specific building segment.

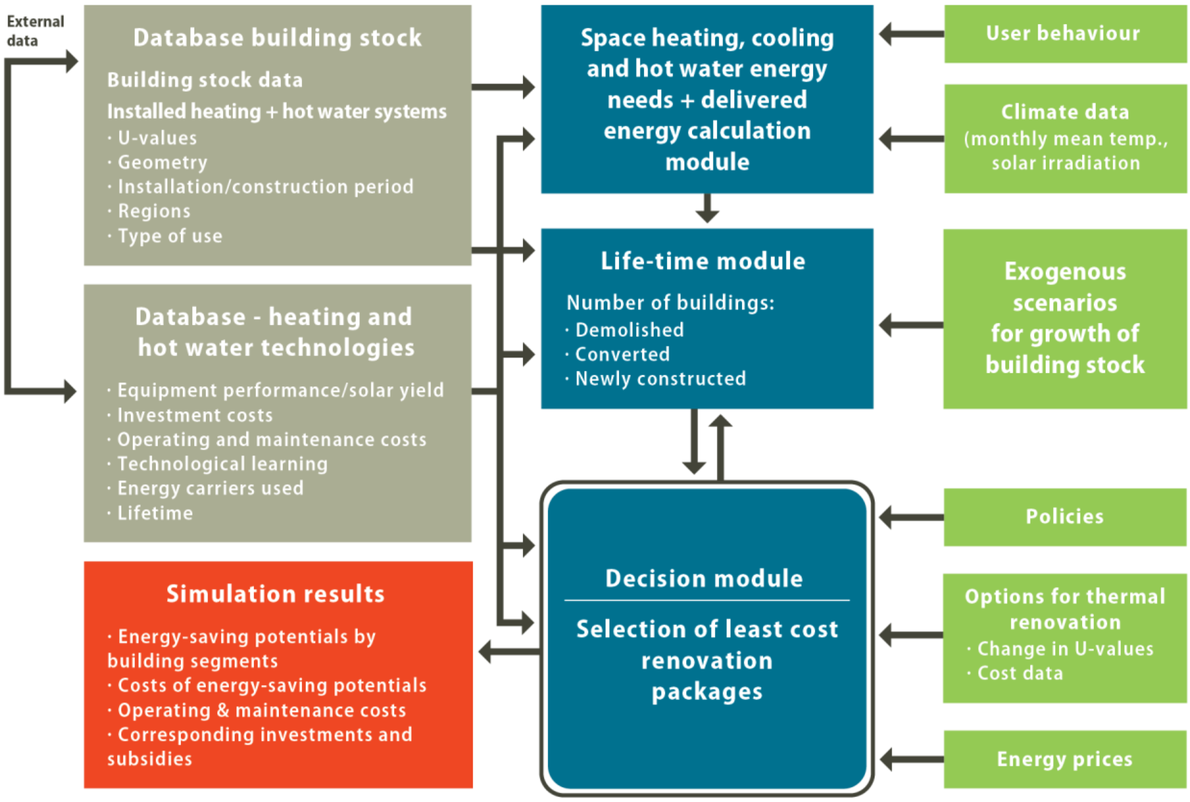

Figure 1: Structure of the Invert/EE-Lab model as applied in this study for deriving Energy-Saving Cost Curves

Sources: Müller 2014, Kranzl et al 2014

The energy needs and demand calculation module implemented in the Invert/EE-Lab model uses a monthly energy balance, quasi-steady-state approach [3], [4], [5], [6], [7]) enhanced by explicitly distinguishing between using and non-using days and in case for ventilation between average day (16 hours) and night (8 hours) outside air temperatures. Buildings are implemented as single zone buildings. Behavioural aspects, such as dependency of the energy needs for heating on the thermal quality of the building envelope or the heated area of dwellings are implemented based on [8], [9], [10]. A more detailed description of the model is given in [11], [12].

The building stock database used by the Invert/EE-Lab model clusters the different buildings based on a set of properties. The top level, our so called “building category” level, summarizes buildings based on fundamental building characteristic such as type of usage or size (in terms of dwellings of residential buildings). All policies implemented into the model can be defined for all building categories differently. For the performed calculations, the Austrian building stock has been clustered to four building categories for residential building (single family homes, row houses and double family homes, small multifamily houses and large apartment buildings) as well as 12 clusters for non-residential buildings. At the second building structure level, the “building classes” level, summarizes buildings that belong to the same top-level class and have the same energy needs, defined by the following criteria: geometry, types and properties of the building façade elements and mechanical ventilation system, climate region and user profiles. The lowest level of the used hierarchical buildings structure represents the “building segments” level. This level finally clusters all buildings that belong to the same building class, have the same heat supply and distribution system and belong to the same region-type. Our dataset for Germany includes in the base year 4459 thousand building segments, i.e. reference buildings (see Figure 2).

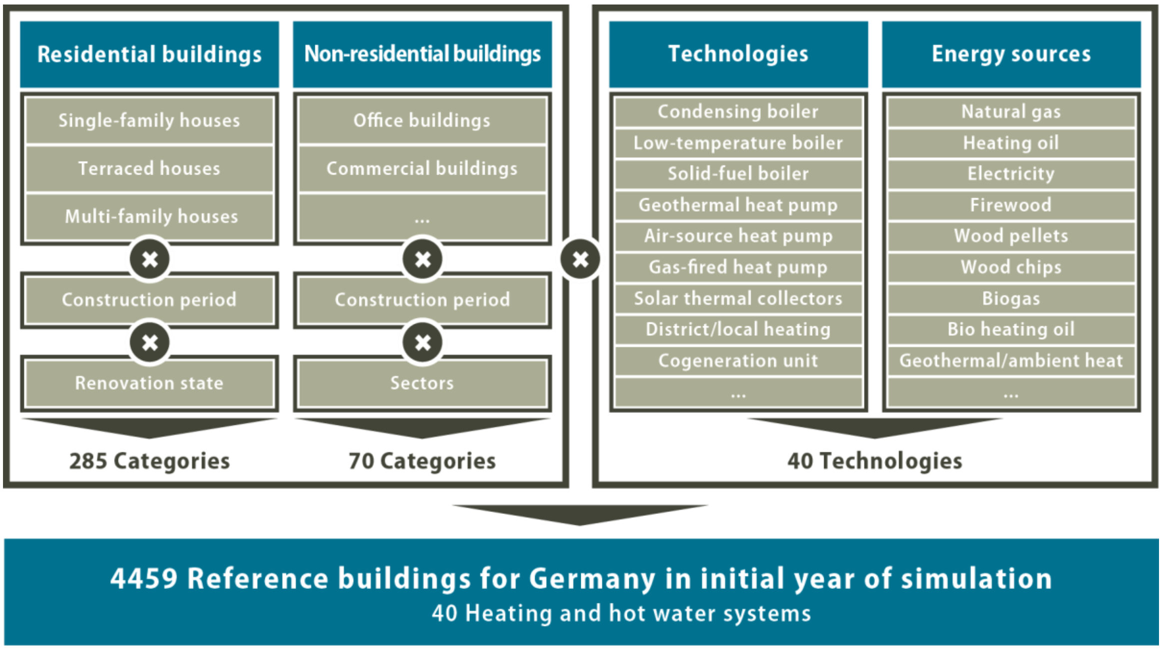

Figure 2. Definition of German Reference Buildings

ESCC Plot Tool

The tool for deriving Energy Saving Cost Curves (ESCC) makes use of the results derived from the model Invert/EE-Lab. The ESCC plot tool has been developed by BPIE as an add-on to the Invert/EE-Lab with the purpose of displaying the results in the form of ESCC’s.

The tool utilizes the standardized format of delivered Invert/EE-Lab’s model outputs that are used as inputs to the BPIE ESCC tool. Each scenario outputs are printed in spreadsheets of 40 columns (results for each building segment and related renovation measure) by 120,000 rows, each of them representing a building segment and related renovation measures. In order for these inputs to be interpreted and presented graphically, an excel vba code was developed. The code aggregates input by building category and vintage in order to display the weighted average renovation costs and energy savings for each building category. The aggregated values are plotted according to the Marginal Energy Saving Cost Curve format with energy costs or savings on the vertical axis and energy savings on the horizontal axis. Additionally, the tool aggregates and provides the shares of renovation depths for envelope measures, heating technologies used, total investment requirements and the total value of subsidies.

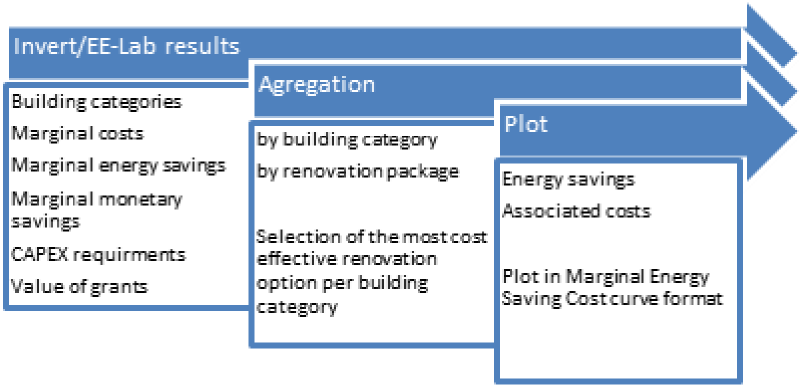

Figure 3. Process of deriving energy saving cost curves in this paper

System boundaries and methodological aspects

- We included the following technologies in our analysis:
    - Space heating and hot water systems: Solar thermal collectors, PV and heat pumps. Natural gas condensing boilers were taken into account as reference system. District heating and biomass heating systems were excluded from the analysis because this would have required a spatial disaggregation (in case of district heating) and biomass potential restrictions (in case of biomass) with additional methodological challenges and distortions in developing the energy saving cost curves.
    - Renovation of the building envelope: different insulation thicknesses of ceiling, façade and floor as well as window replacement. Three different renovation depths were taken into account.
  - Not every feasible energy saving measure has been considered in this study. For example, the important role that district heating, co-generation (heating and electricity) and tri-generation (heating, cooling and electricity) can play in reducing GHG emissions has not been explored.
- Only comprehensive renovations which result in installation of both fabric and heating measures are considered. Such renovations can be effected in one stage, or alternatively in a number of carefully planned and co-ordinated stages. Partial renovations are not considered. Additional savings, not shown in the scenarios, will be achieved in cases where only the heating system or certain building components (e.g. windows) are replaced.
- All scenarios run to 2030. This is a sufficiently long timescale for the full impact of policies to be witnessed; yet not so long as to necessitate unrealistic assumptions to be made about longer term technological developments and evolution of costs/prices that may radically change the economic landscape for building renovation. Clearly, within the period to 2030, it would only be possible to renovate a proportion of the existing stock, so the results presented below should not be considered as being the limits of what can be achieved in terms of energy savings and GHG emissions reductions from the existing building stock.[1]

  The results present the full impact of the renovations undertaken under a particular scenario through to 2030, rather than an annualised rate. For example, the quoted energy savings will occur from 2030 onwards, once the full complement of buildings has been renovated. The

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[1] In the model Invert/EE-Lab the renovation rate is derived based on the lifetime of buildings and building components and the corresponding age structure of the building stock. Thus, different age categories show different renovations rates. The cumulated share of renovated buildings in the period from 2015-2030 varies between about 15% and 37% for different building segments. This is equivalent to an annual renovation rate from below 1% for newer building segments and up to 2.3% for older building segments.

investments and subsidies represent the total requirement for all renovations to 2030, but at today's prices (reduced according to the learning curve applicable under a given scenario). Likewise, net savings (which might be negative or positive) cover the energy cost savings over the lifetime of the measures, minus the total investor contribution to the investment.

- Within each building category there are a range of buildings, some of which will be more suitable to renovation than others. The results plotted in the results section represent an average across that building category. If a building category is cost effective overall, it does not necessarily mean that comprehensive renovation of all buildings of that type will be cost effective. Likewise, a building category that is overall not cost effective may include some buildings which are cost effective to renovate under the given set of economic conditions.

Scenario settings and basic assumptions

In order to generate different possible views of the future, a number of economic factors that are relevant to investors have been identified and used as variables in the generation of different scenarios. These are described and summarised in Table 2.

Technological learning reflects the cost reduction due to technology diffusion and as a result of increased volumes of sales. Historical evidence of such reductions is plentiful, with perhaps the best known example being the reduction in the cost of photovoltaic panels (PV). In the model, the following learning, in form of cost reduction, is used. As can be seen, they are differentiated according to technology, reflecting its maturity. In deriving learning effects, we took into account relevant recent literature, in particular [13], [14], [15].

Table 1: Cost reduction applied for specific technologies

Technology	**Cost reduction in 2030 compared to today's prices**		
Scenario assumption	*low*	*central*	*high*
Solar thermal	3%	6%	9%
PV	13%	25%	38%
Heat pumps	3%	6%	9%
Ambitious renovation of building envelope	8%	15%	23%
Moderate renovation of building envelope	5%	10%	15%

The cost effectiveness from the investors' perspective is estimated in a number of different scenarios based on permutations of economic factors, to illustrate different policy measures that government might reasonably consider applying to stimulate the renovation market. The selected scenario parameter variations are described in Table 2 and Table 3.

Table 2: Overview of scenario variables

Item	Description	Scenario variables	
Subsidy level for building envelope measures	Grants, implicit value of loan, or other external financial support as a % of total capital investment	low	0%
		central	10-25% (R1= 0%; R2 =10%; R3 = 25%)
		high	20%-35% (R1 = 0%; R2 = 20%; R3 = 35%)
Subsidy level for heating and hot water system measures		low	0%
		central	10-20%
		high	25%-40%
Transaction costs	Costs associated with preparatory work, planning costs, approvals, etc., including staff time, expressed as a % of total capital investment	central	5%
Discount rate	Cost of borrowing to finance energy saving investment	low	2%
		central	4%
Learning and cost reduction until 2030	The impact of future price reductions resulting from factors such as increased sales volumes, more efficient installation procedures, improved productivity or R&D resulting in new and better ways of saving energy	central	6-25%
Energy price increase until 2030	Increase in the real retail price of energy from 2015 to 2030	central	1.1% /year

Building stock and cost related input data

Building stock data

The starting point for the analysis is the categorisation of the German building stock according to a number of representative building typologies. Figure 2 shows the disaggregation as used in the model. In total, 4459 reference building segments are differentiated according to the physical characteristics of the building structure and the installed heating systems. The level of building classes is relevant for the differentiation of the energy performance of building envelopes. Residential buildings are represented by 285 different classes, non-residential buildings by 70 classes. Building classes are distinguished in terms of building type (e.g. single-family houses, apartment buildings, office buildings, etc.), as well as construction period and presence of existing renovation measures.

The resulting building typology has been applied in previous studies and scientific analysis by Fraunhofer ISI and TU-Wien ([16] [17], [18], [19].

For the presentation of the results, buildings are aggregated in the following categories shown in Figure 4, which shows the final energy demand for space heating and domestic hot water in the year 2014[2].

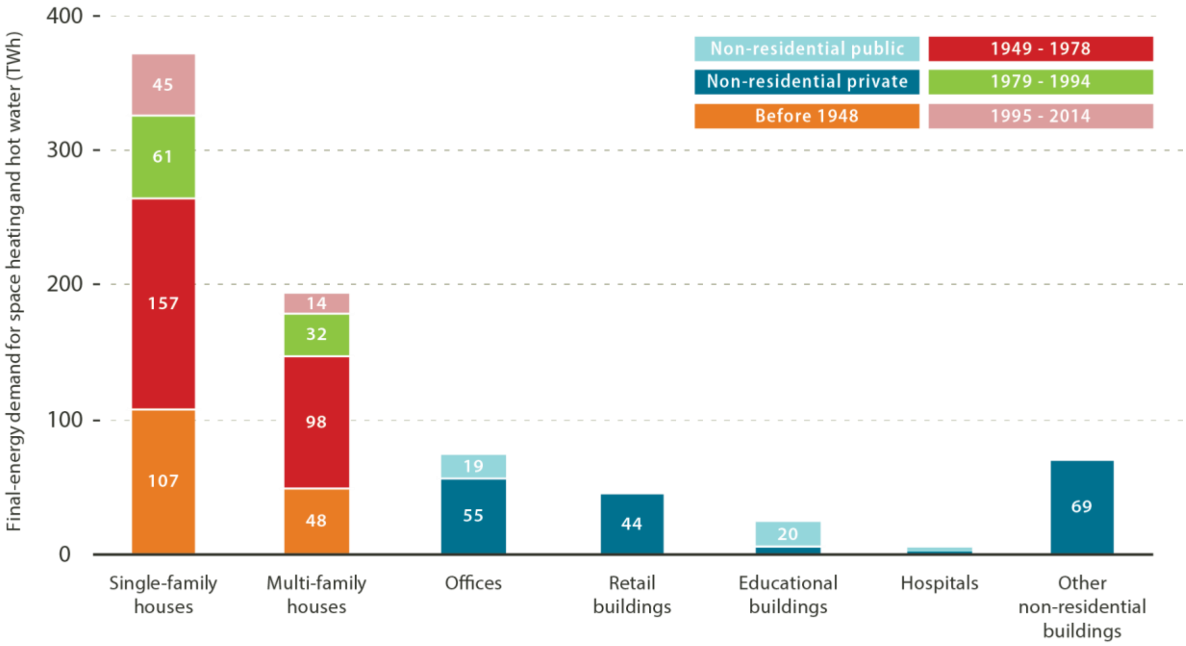

Figure 4: Final annual energy demand for space heating and hot water clustered in the building categories used within this project

The target value for the ***Standard*** refurbishment package assessed in this study is defined by the requirements of the *Energy Saving Ordinance* on existing buildings in case of major renovation. The ***Moderate*** refurbishment package meets the target of a *KfW efficiency house 100* with regard to the energy performance of the building envelope, while the ***Ambitious*** package corresponds approximately to the highest *KfW efficiency house 55* level of performance. Figure 5 illustrates the relationship between the efficiency standards relevant to this analysis.

[2] Since the data on buildings are partly based on the year 2010, results for 2014 have been extrapolated applying the Invert/EE-Lab simulation model and calibrated with the end-use energy balance.

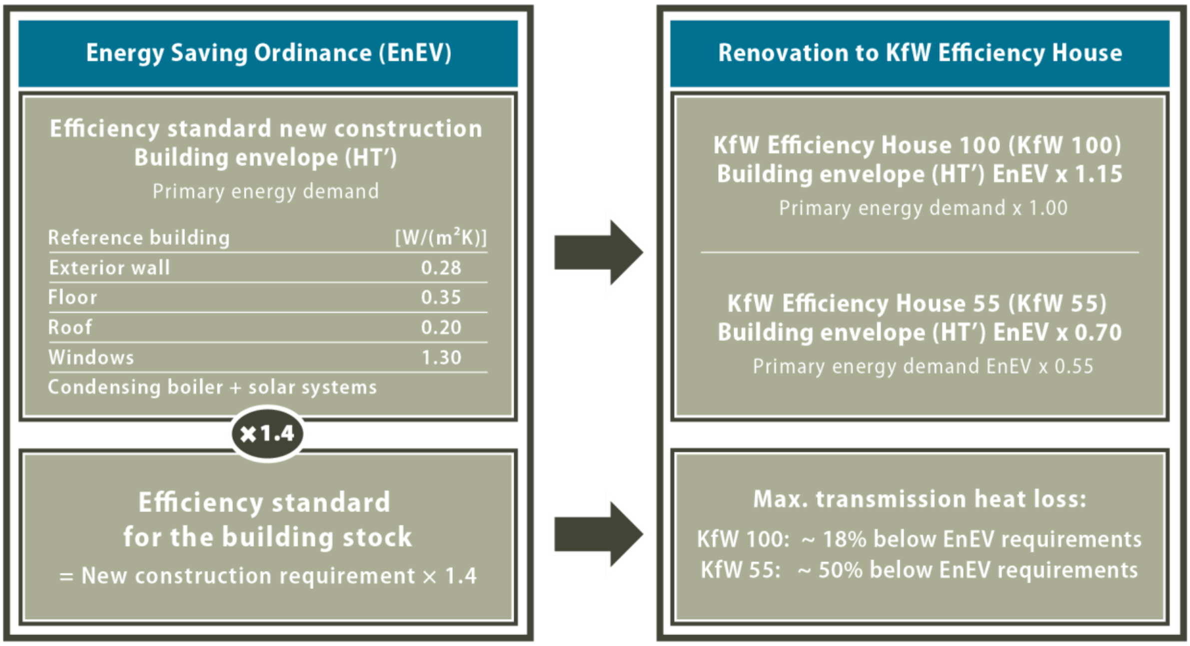

Figure 5: Relevant efficiency standards defined by the German building code and the KfW efficiency houses within the support programme of KfW

Efficiency standards and renovation packages

This study analyses the energetic refurbishment of the German building stock to meet three different efficiency standards. The standards to be achieved are oriented towards the requirements defined by the German building code (Energy Savings Ordinance, EnEv) as well as the support programmes of the KfW Development Bank[3]. Relevant for measures targeting the energy performance of the building envelope is the maximum value of specific transmission heat losses (HT ') which reflects a measure of the overall thermal performance of the building envelope.

For ease of reference, we have adopted the following shorthand description for the three renovation levels: Standard renovation package R1, moderate renovation package R2, ambitious renovation package R3. The refurbishment packages for achieving the respective standards are determined for each reference building dependent on the initial energy performance. In order to achieve the defined standards, there are degrees of freedom in the choice of building components to be retrofitted as well as in the applied level of insulation thickness and windows quality. Therefore, an optimisation model is used to determine the specific refurbishment packages for each reference building while minimising the required investments, [18].

[3] The KfW programme *Energy Efficient refurbishment* provides grants, or soft loans with repayment bonuses, for refurbishment to the so-called *KfW efficiency houses.* The financial support depends on the achieved energy performance level.

Required investments for renovation packages – building envelope

Figure 6 distinguishes potential efficiency measures applied to the building envelope according to specific investments per surface area of each building component in relation to the thickness of the insulation material[4] and in relation to the U-Value for window replacement, respectively.

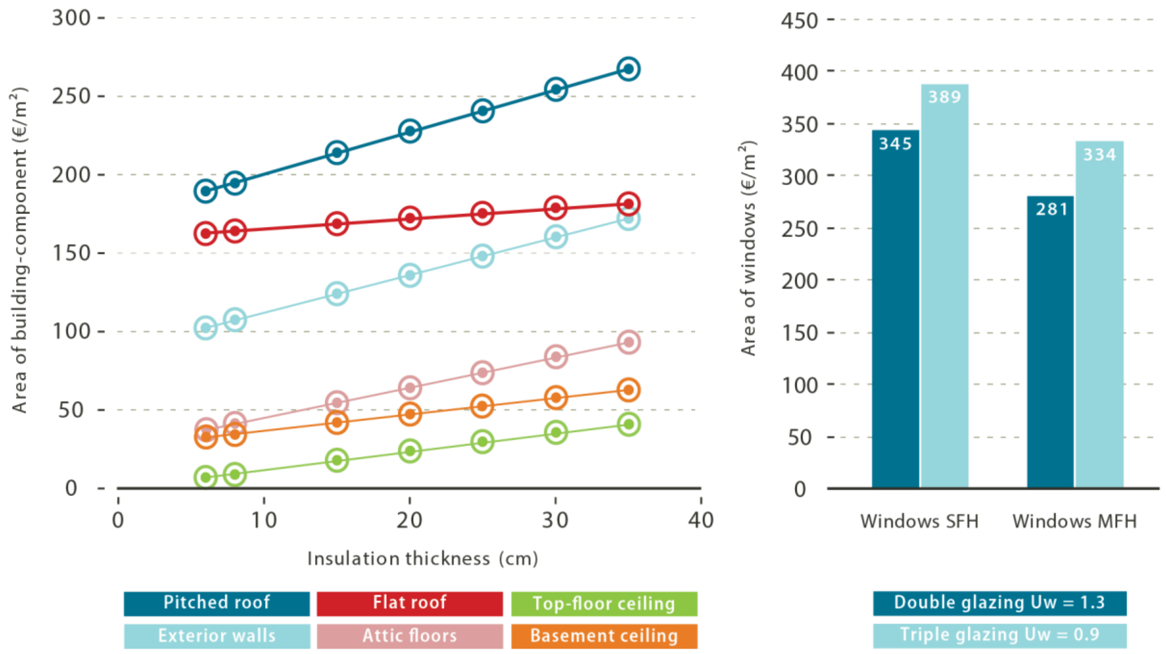

Figure 6: Specific investments of a range of energy efficiency measures on the building envelope, based on an average of different insulation products available for each application

Source: [20]

The illustrated values represent the investments in terms of a full cost calculation for the energy retrofits, including material, transport and labour costs. The data are based on the evaluation of projects that have actually been implemented, while various insulation materials have been converted to an equivalent insulation thickness with a thermal conductivity value amounting to 0.035 W/(m*K) (Hinz 2011).

The cost effectiveness of the energy retrofit depends significantly on whether the investment includes concurrent implementation of energy retrofit measures alongside maintenance measures such as essential replacement of a building component (e.g. roof repair[5]). Assuming such works are undertaken simultaneously, only the additional efficiency measures are taken into consideration in the evaluation of the cost-effectiveness of building renovation.

The resulting specific investment costs for the renovation packages needed to achieve the three efficiency standards considered in this analysis for the reference buildings are taken from [18]. Non-

[4] The thicknesses discussed here do not refer to a specific type of insulation, but instead are based on an average across a range of products available on the market.

[5] For a detailed description of the conventional retrofit measures that would in any case be implemented (regardless of an energy retrofit or a normal refurbishment), please refer to Hinz (2011).

energetic investments account for 32 % of the total investment for the *Standard Renovation* package on average, weighted by floor area.

The area-weighted average investments of the renovation packages per m^2 of gross floor space are shown in Figure 7. The total investment cost, including maintenance measures, for the “moderate” package is on average 30% higher than the cost of the “standard” package. For the “ambitious” renovation package, investments costs more than double on average compared to the “standard” package.

It should be noted that the values shown below only include the investments for measures on the building envelope, excluding the heat supply system.

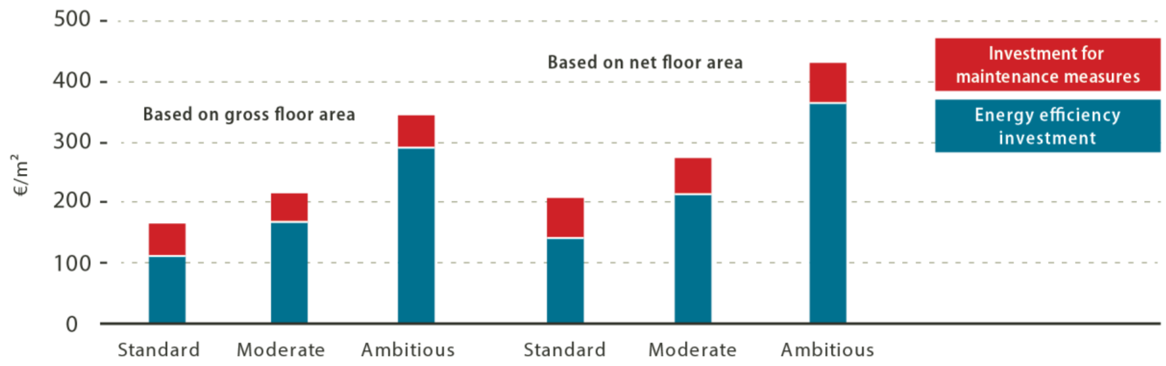

Figure 7: Renovation investments based on floor area

Results: Energy Saving cost curves

In the following, we will present the resulting energy saving cost curves for three cases (according to the assumptions documented in Table 3), followed by an overview of sensitivity calculations, resulting from a variation of each of the parameters listed in Table 2.

Table 3: Overview of scenario parameters applied in the scenarios

Scenario	Subsidies	Transaction costs	Discount rate	Cost decrease to 2030	Energy price increase to 2030
Business as usual	10-25%	5%	4%	6-25%	1.1% /year
Low subsidies	0%	5%	4%	6-25%	1.1% /year
High subsidies	20-40%	5%	4%	6-25%	1.1% /year
Low interest rate	10-25%	5%	2%	6-25%	1.1% /year

Scenario 1: Business as Usual

This scenario assumes the prevailing *central* economic conditions in Table 2 are maintained throughout the period in question. Under the Business as Usual scenario just over half of the building categories are located above the line and thus not cost-effective (without consideration of the co-benefit). Non-residential building categories hold the most cost-effective potential for retrofits, notably hospitals, educational facilities, retail and private offices. It is noteworthy that, within the residential sector, only older dwellings built before 1948 exhibit a cost-effective potential for renovation – these are the ones with the highest specific energy demand, as illustrated in Figure 8. However, it should be recalled that we consider full renovation packages only. There would undoubtedly be single measures or partial renovations that deliver cost-effective benefits, even though they would achieve lower savings. Assuming investors only take up cost-effective renovations, the total investment required amounts to €97 billion, of which €19 billion is public subsidy. When co-benefits are valued in the economic appraisal, total investment increases to €235 billion, of which subsidies account for €41bn[6].

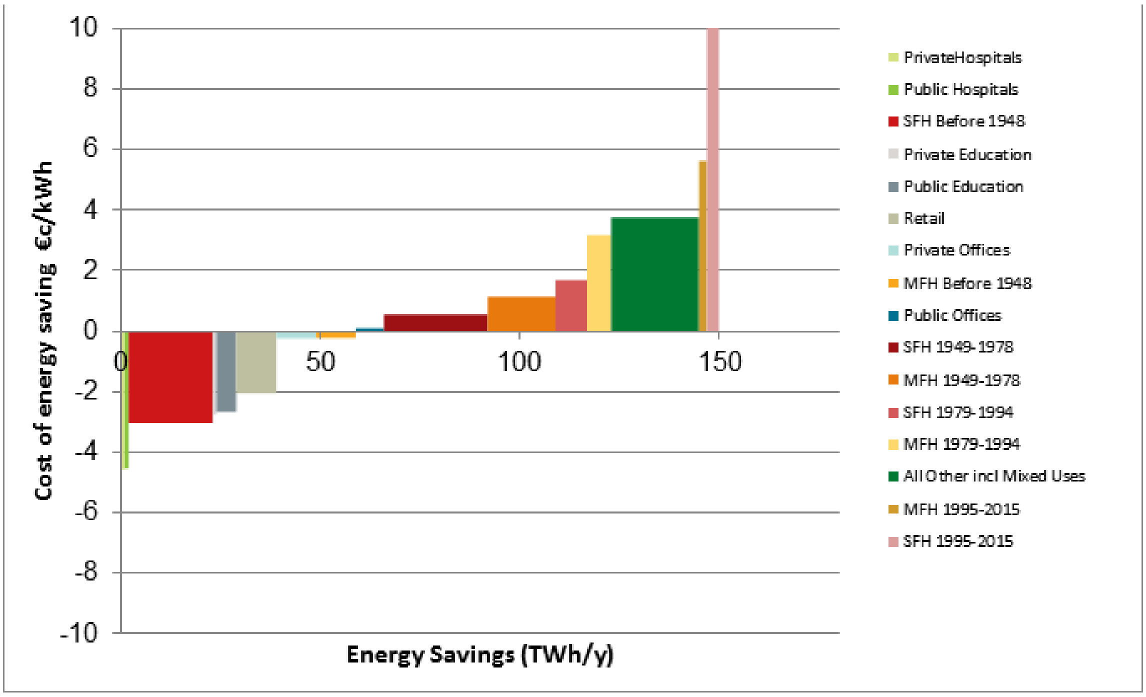

Figure 8: ESCC– Business as Usual scenario

[6] Subsidies are related to the level of investment. They do not rise in exact proportion to the investment, since the mix of measures changes according to the specific input parameters, and different measures attract different levels of subsidy – see table 6.

Scenario 2 and 3: No Subsidies vs. High Subsidies

In this section, we show the results under low subsidies (i.e. no subsidies, Figure 9) and under high subsidies (Figure 10)[7]. The first scenario shows the impact of current subsidies. Without these subsidies (and no change in other framework conditions) a considerably smaller amount of energy savings would be economic, only 28% of the overall potential compared to 40% in the BAU scenario. The result also shows that the current subsidies do not only trigger renovation activities, but also contribute to avoiding lock-in effects: The type of implemented renovation activities in the "no-subsidy scenario" is less ambitious and thus locks these buildings for more ambitious renovation packages until 2050.

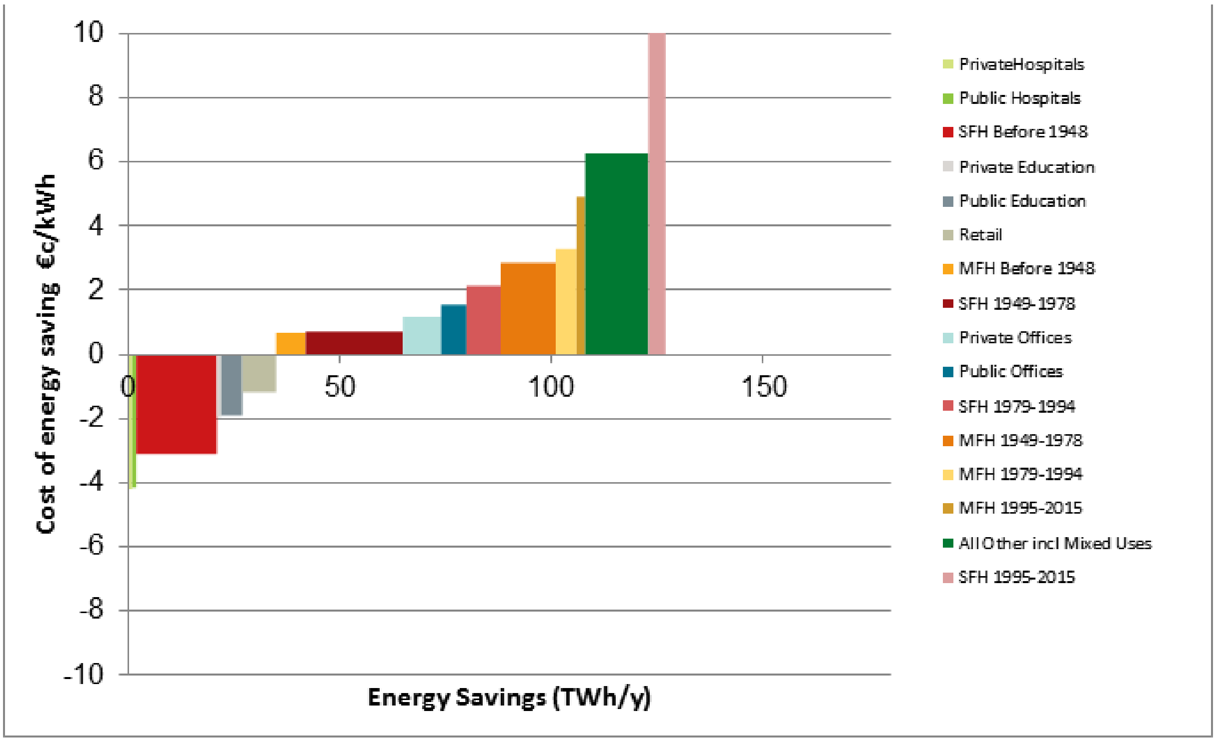

Figure 9: ESCC– No Subsidy scenario

Compared to the Business as Usual scenario, the additional incentive in the High Subsidy scenario is to increase the level of subsidies to the *high* values seen in Table 3, namely for fabric measures: R1 = 0%; R2 = 20%; R3 = 35% and for space heating and hot water systems 25-40%.

The impact of applying the higher subsidy rates can immediately be seen. Compared to the Business as Usual, there is a general shift down (i.e. more cost-effective) and right (i.e. higher energy savings) in the Energy-Saving Cost Curve. The following additional building categories become cost-effective: public offices and residential buildings (both single and multifamily) constructed in the period 1949-1978. Total energy savings increase from 150 TWh/year to 167 TWh/year (not including the co-benefit). The fact that net savings across all building categories are positive, at €1.2 billion, means that a "bundling" approach of transferring the surplus from cost-effective buildings to the non-cost-effective ones could achieve the total energy saving potential in a way that delivers net cost savings for all building category owners. Clearly, the higher subsidy rate comes at a higher cost to the public purse – up from €50 billion in the Business as Usual scenario to €106 billion in this High Subsidy scenario.

[7] Taking into account the values documented in Table 3.

However, the challenge is also to avoid free-rider effects: Those buildings with already quite negative energy saving costs also receive the increased subsidies leading to even higher profit from building renovation. In order to reduce the impact on public budgets and increase the probability that increased subsidies will be realized such free-rider effects should be avoided. This could be achieved by mandatory bundling of projects or tendering.

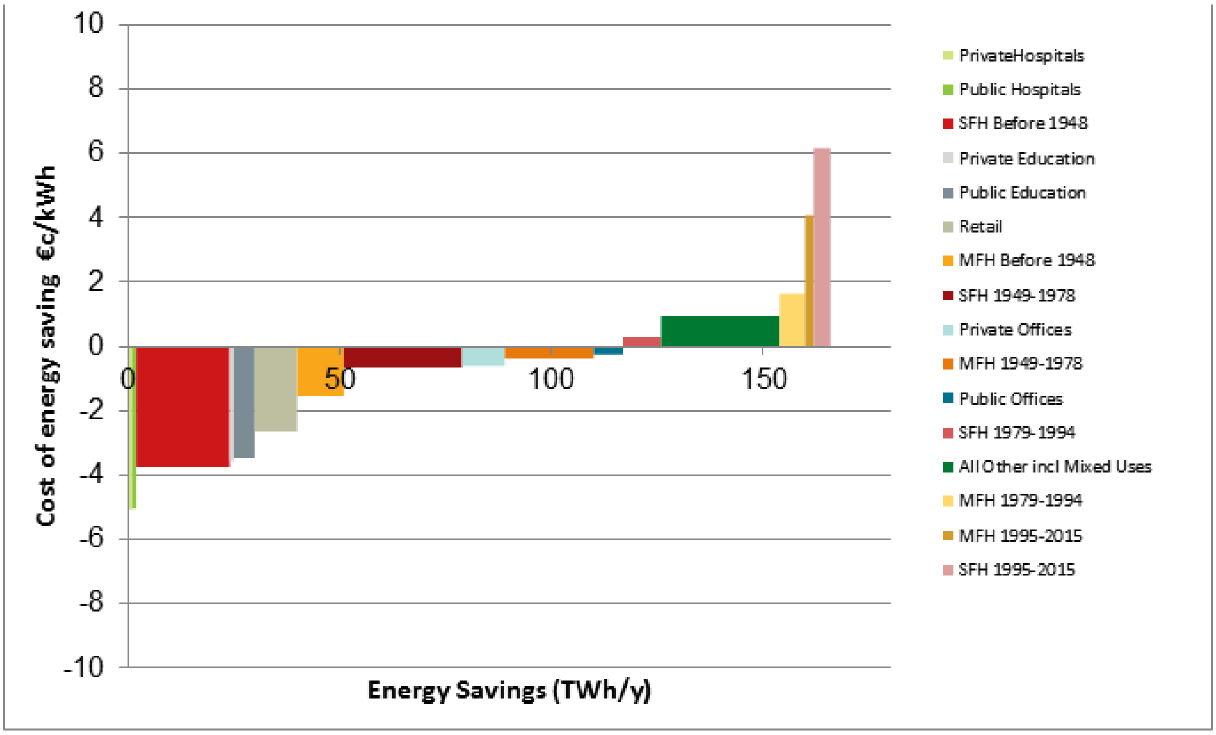

Figure 10: ESCC– High Subsidy scenario

Scenario 4: Low discount rate

The following scenario shows the impact of a low discount rate on the ESCC. A high uncertainty is related to the discount rate which is applied by investors. Currently, we can observe very low market discount rates. Some building owners may have money on their bank accounts with practically 0% real discount rate. Thus, if investors, the banking sector, pension funds etc. would identify the potential of thermal building renovation not necessarily as highly profitable but highly secure investment with still positive rate of return (e.g. 2% as suggested in this case), this could lead to a huge increase of economic energy saving potential compared to the central scenario: About 125 TWh, which is more than three quarters of the potential in this scenario is cost effective and more than 90% of the potential is achievable with costs below 0.2c/kWh energy saving.

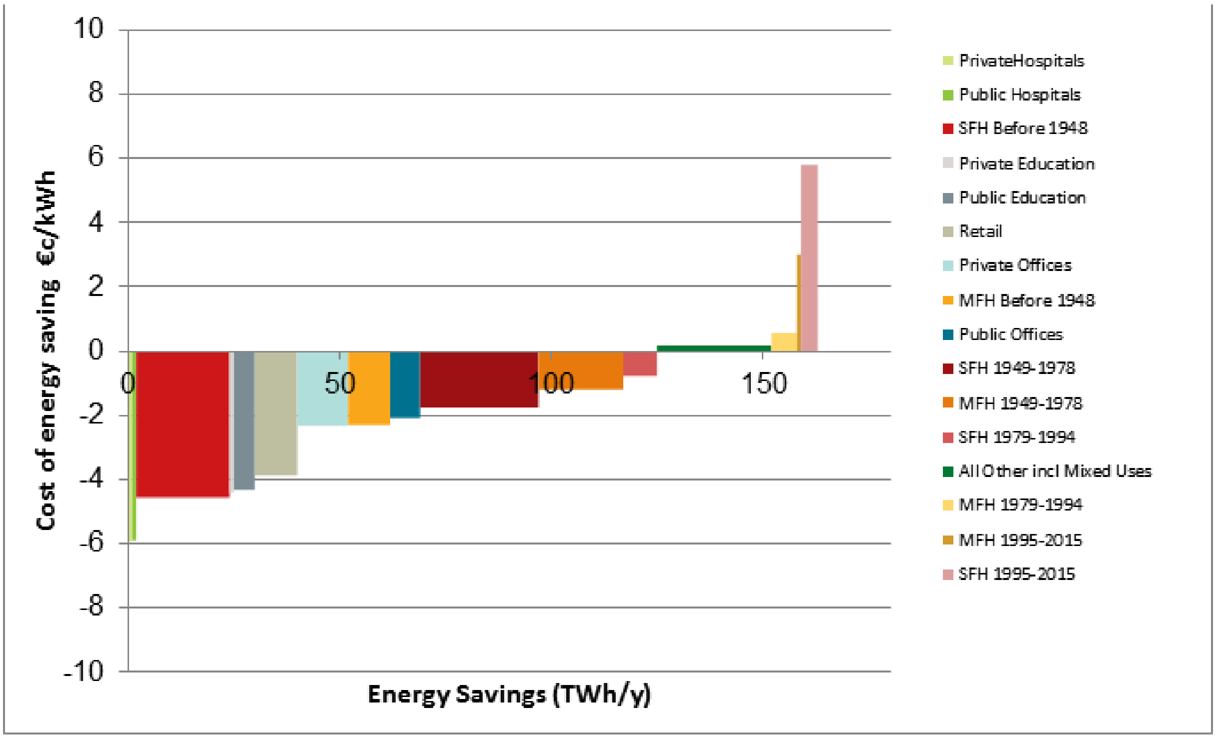

Figure 11: ESCC– Low discount rate scenario

Discussion

The level of ambition of renovation is heavily influenced by policies rather than by the market. Without the right policy signals, there is a serious risk that the building owners and investors will continue to focus on shallow renovations. These shallow renovations might effectively lock out the potential for the full energy potential to be realised, and, with it, a loss of economic benefit to building owners and the wider German economy. In the worst case, over half of all renovations could be shallow, whereas in the best case, over 70% could be deep;

Total annual energy savings of up to 180 TWh could be achieved by 2030, through a dedicated programme focused on deep renovation. This represents approximately 16% of current energy use in the building stock;

Non-residential buildings are generally more cost-effective to renovate than residential buildings; Among the residential buildings, those constructed prior to 1948, both single-family and multi-family, are the most cost-effective to renovate; The energy saving potential across all non-residential buildings is broadly equivalent to that across single-family houses of all age categories;

The least cost-effective building categories to renovate are the newer residential buildings, built to higher energy performance standards. One would not expect these new buildings to be renovated in substantial numbers in the period to 2030;

Total investment requirements over the period to 2030 vary considerably, between €100 billion and €500 billion, according to scenario, depending on whether co-benefit is included, and whether all buildings or only the cost-effective sectors are considered. This shows the big impact in investment – up to a factor of 5 – that choice of policy levers can have on the market for building renovation;

Establishment of a fund which bundles investments with varying cost effectiveness can substantially increase the overall level of renovation;

The greatest level of energy savings, and financial return to investors, would be achieved through a combination of financial/fiscal measures such as subsidies and energy prices, together with soft measures that reduce costs for investors by creating more favourable market conditions.

There is a limited pool of funds to be allocated under the German energy efficiency fund. In order to stimulate optimal investment and overcome the issue of free riders, a bundling approach is proposed. The bundling policy of the grant-making scheme would aim to transfer surplus economic gains from building categories with a high energy savings potential to building categories whose economic benefit is marginally negative. In this way, financial returns to free riders who have the financial capacity to undertake energy efficiency renovations are limited, and the surplus savings are distributed to beneficiaries who would otherwise be unable to do so. Our approach is indicated by a focus on financial transfers between building categories, but a renovations programme adopting this approach should also be taking into account social factors, which are excluded from the scope of our analysis. Through the bundling approach, the sharing of economic gains from the renovation of the most cost effective categories will allow borderline cost effective buildings to engage in renovation activities and maximise the overall energy savings. In practical terms, owners with investment capacity of buildings with significant economic energy savings potential would through the bundling approach receive smaller subsidies (either as direct payments, or low interest loans) compared to owners of buildings who also have significant energy savings potential but are only marginally uneconomic.

The economic evaluation of the subsidy levels under the KfW requirements should pass through a centralised system that will allow for a readjustment of the grant according to the bundling approach and based on the registered economic status and energy savings potential of the participating owners and buildings. Attention should be placed in the structure of the bundling system and its adjustment criteria in order to avoid irrational and socially unacceptable transfers of funds.

Several methodological aspects should be considered carefully in the interpretation of our work:

The energy saving cost curve developed in this paper represents the investors' perspective. A change in the side conditions (e.g. energy prices, subsidies, taxation) affects the economic viability of various renovation packages and thus might lead to a change in the least cost option for the investor. Thus, this approach allows the policy maker to assess the energy saving potential which can be exploited at certain cost levels and under various side conditions. This leads to the fact that a change e.g. in subsidies shifts not only the cost level of the energy saving cost curves (i.e. the height of the bars) but might also change the energy saving potential (i.e. the width of the bars).

While we think that this methodology is a very useful approach to show the impact of policy instruments and other side conditions on the economic viability of energy saving potentials, it is not possible to get the full energy saving potential, including the stepwise marginal additional renovation measures which exist to improve the energy performance of the building stock. A comparison of our results with another methodological approach for deriving energy saving cost curves or also CO2 abatement cost curves in the building stock would be very interesting and is left for further research work.

The definition of the reference system has an impact on the results. We only took into account the part of the building stock which has to be renovated due to lifetime restrictions until 2030. Thus, it is valid to assume that a renovation measure without any thermal improvement can serve as a reference system. However, we could also assume a thermal improvement according to the building codes as a reference system and only take into account those measures going beyond this reference renovation level. However, this analysis was beyond the scope of the work in this paper.

We focused on measures showing the impact of full renovation packages, i.e. renovation of the building envelope (including all building envelope components) and the space heating and hot water system. However, one could also think of measures including only certain parts of such full renovation packages, in particular only replacing the space heating and hot water system without a renovation of the building envelope. These measures also were not taken into account in this paper.

The numerous reference buildings taken into account in the input data and the modelling framework were aggregated to a limited number of building clusters. This was mainly done in order to allow for a clear and manageable visualisation of the energy saving cost curves. However, we are aware that the building clusters are not completely homogenous. This means that within each building cluster there are buildings with lower energy saving costs and buildings with higher energy saving costs. Thus, the way how we clustered the large number of reference buildings has an impact on the average values shown in the graphs.

Acknowledgements

This work was carried out within the project "Renovating Germany's Building Stock – An Economic Appraisal from the Investors' Perspective", funded by the European Climate Foundation and coordinated by BPIE.

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Efficiency potentials of building technologies and their contribution to the energy and climate change mitigation goals

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Abstract

Building technologies such as lighting, ventilation, cooling, heating, and others are most relevant contributors of energy consumption in commercial and public buildings. Likewise building technologies are key to tap efficiency potentials in these kinds of buildings. A wide variety of measures is needed to tap these potentials, as revealed by a study that involved numerous experts from various disciplines and technological areas. About 150 different measures were identified, categorized, and characterized in terms of their technical performance and field of applicability. To quantify their aggregated potential on a national level these measures were integrated in an energy and building stock model. Potentials are derived from the difference between a reference and an efficiency scenario. It was found that efficiency is increased by 25% at the final energy level and by 30% at the primary energy level. Greenhouse gas (GHG) emissions are reduced even more (by about 40%), due to substitution effects towards non-renewable energy sources. Results show that all kinds of measures in all technological areas contribute to this efficiency gain and GHG emission reduction: more efficient components and systems, controls, building automation, energy management and optimization, add-on measures, and energy carrier substitution etc. It is emphasized that efficiency measures are available at all phases of a building's lifetime: conceptual design, planning, investment decision, installation, commissioning, and operation. We conclude that building technology efficiency measures prominently contribute to the goals of the Swiss Energy Strategy and that adequate policy instruments should be implemented to tap these potentials.

Introduction

As part of the Energy Strategy 2050 of the Swiss Confederation, the building sector continues to offer high potential to reduce energy consumption and GHG emissions (GHGE) through upgrading thermal insulation and substituting energy sources from fossil fuels with renewable alternatives. There is great additional potential, however, in the area of energy efficient technological advances in buildings. The purpose of this study is to create a foundation for the implementation of measures in the field of building technology to work towards fulfilling the goals of the Energy Strategy.

To better understand the contribution to the overall energy demand of public and commercial buildings, the energy use of lighting, ventilation, cooling, and miscellaneous building processes were defined, assessed, validated and evaluated in a study commissioned by the Bundesamt fur Energie (BFE), or Swiss Federal Office of Energy [1]. The energy reduction potentials were assessed based on four criteria. First, the effect on final energy requirement, second the amount of primary energy used, third the amount of non-renewable primary energy used, and fourth the GHGE. The emissions reductions potentials were then reported as CO_2 equivalents in order for the information to be incorporated into the national scheme.

Methods

The basis for this study is a list of building efficiency measures generated by around 30 professional and industry associations that have joined together to form the Konferenz der Gebäudetechnik-Verbände (KGTV), or Conference of Building Technology Associations. Their aim is to implement the roadmap laid out by the 2050 Energy Strategy and to provide a platform to exchange information and ideas on various building technologies. This list of measures was categorized into themed packages that were validated and updated through consultation with experts in the field of energy. To model the impact of these measures on energy consumption and GHGE until the year 2050, two scenarios were developed.

The reference, or "business as usual" scenario (Ref) describes the expected development of building measures and efficiency gains that would be implemented even without additional instruments.

Programs such as EnergieSwiss already implement federal regulations that are part of the Energy Strategy, for example.

The efficiency scenario (Eff) incorporates additional incentives and requirements in the form of market instruments and building measures that greatly increase efficiency. These measures include the substitution of renewable energy sources for heating and hot water, retrofitting low-energy technologies onto buildings, increasing the efficiency of ventilation systems, and modifying lighting systems.

The effects of proposed technological changes on a building efficiency model were then tested to compare different measures and packages in the two scenarios.

Comparing the energy reduction potentials of the different packages was the end result of this study. The untapped potential for energy efficiency in the field of building technology is the difference in GHGE reductions between these two scenarios measured until the year 2050. Some of the measures are already being implemented through existing building efficiency improvement programs and so, although they may offer great advantages, their potential will appear to be reduced in this study.

Evaluation of the state of the Swiss building stock

The proposed building technology measures are assigned to model structures. The effects are modeled using the Building Stock Model (BSM) [2] and the ex-post analysis TEP Tertiary model [3] that focusses on building technology. The models are based on numerous statistical databases (inter alia on the Swiss building and apartment registry as well as the Swiss company registry and are calibrated for use throughout Switzerland using overall energy statistics. The resulting situation is then presented in tabular and graphical form.

Calculation of aggregate energy and GHGE reduction potential

The BSM is complimented by upstream and downstream calculations and estimations to calculate energy over two scenarios. The results are then presented in a way that allows prioritization of the measures based on the GHGE reduction potential.

System boundaries

The present analysis considers measures that may be permanently installed on or in new buildings within the period up until the year 2050. Uses covered include room heating and cooling, hot water, ventilation, lighting, security, etc. The KGTV also includes building automation (BA), which is normally not considered as an energy use per se, but a technology that controls the aforementioned systems in order to maximize their benefit and to minimize their energy consumption. BA is here considered a connecting technology that can be used as a measure of efficiency. Combined heat and power generation systems are considered separately within this study. The study excludes household lighting, appliances, information technology equipment (ICT), entertainment areas, office equipment, industry-specific applications such as cooking, large health care equipment, process cooling systems, and industrial processes. In certain cases, the separation between a building and equipment therein is fluid and so these divisions also must be considered.

Model assumptions

The BSM was run using a combination of calculated energy savings based on a list of assumptions relevant to each efficiency measure package. Each measure within these packages was assessed separately as to how extensively it could be applied in the different scenarios. Within each scenario, there is variation in the implementation level as these vary in regards to different building types. Further, the measures were characterized based on the time period in which they should be re-assessed, their associated specific efficiency increase, and if this applies to reductions in the installed capacity (IC) or full load hours (FLH). The assumptions associated with four measure categories, namely lighting, air conditioning, ventilation, and general building technologies, are discussed and presented here in detail. The remaining categories (space heating, water heating, etc.) are further discussed in the original study [1] and additional information can be found therein.

Lighting

Within the scope of this study [1], the permanent lighting fixtures of buildings are considered in the 'lighting' category. Efficient lighting is achieved through measures such as LED installation, illuminance adjustment, demand management, and timed lighting systems. The assumptions for this category are shown in Table 1.

Table 1. Model assumptions for level of implementation, renewal cycle, and specific efficiency increase of building lighting efficiency measures and packages. Efficiency improvements refer to the state of the art in 2010.

Measures	Implementation level			Renewal Cycle	Specific efficiency increase	
	2010	2050 Ref	2050 Eff	(years)		Reference[a]
Main area lighting	0–7 %	0–21 %	2–35 %	20	10-15 %	IC
Efficient lighting	1–3 %	30–32 %	47–50 %	20	> 35 %	IC/FLH
Retrofit LED bulbs	0–7 %	49–56 %	54–64 %	5	30 %	IC
Adaptive illuminance and flux tracking	0–23 %	3–13 %	12–34 %	20	5-10 %	IC
On-demand control	0–5 %	25–35 %	43–56 %	20	5-25 %	FLH
Daylight-based interior lights	0–0 %	11–18 %	33–38 %	25	50 % [c]	FLH
Swarm regulation	0–7 %	1–6 %	3–16 %	20	50 % [b]	FLH

a: energy conservation refers to full load hours (FLH) or installed capacity (IC)

b: in the relevant room type

c: in areas exposed to sunlight

Source: Jakob et al. 2016 [1]

Ventilation

For the purposes of this study, the power consumption of ventilation systems is not considered to include the power that is used to heat or cool the air, but instead tracks the energy used to circulate air and to add or remove moisture from it. This includes electricity for fans and motors, and the energy demand is reliant on factors such as airflow velocities, pressure losses in air treatment, fan efficiency, and air flow rate. The cooling and heating of air is considered separately and discussed in detail in the main text [1]. Table 2 lists the assumptions used in the modelling of ventilation system changes to reduce energy use.

Table 2. Model assumptions about penetration, renewal cycle and specific efficiency improvement for the measures and packages used to improve ventilation.

Measures	Implementation level			Renewal Cycle	Specific efficiency increase	
	2010	2050 Ref	2050 Eff	(years)		Reference[a]
Updating existing systems [e]	38–90 %	86–95 %	84–91 %	25	50-70 %[c]	IC
Increasing monoblock size	11–16 %	21–28 %	39–56 %	25	20 %[d]	IC
Optimized air distribution	0–0 %	<5 %	23–43 %	28	5 %[d]	IC
Efficient fans	6–12 %	22–28 %	45–63 %	15	10 %[d]	IC
Efficient filters	0–7 %	17–22 %	39–58 %		6-10 %	IC
On-demand flow control	3–12 %	12–20 %	31–38 %	20	5-15 %	FLH
Optimized ventilation equipment	5–21 %	24–29 %	36–49 %	20	1 %[d]	IC
Time control optimization	8–31 %	13–21 %	29–53 %	EM [b]	15 %	FLH
Air flow rate adjustment	4–13 %	23–28 %	45–63 %		9 %[c]	IC
On-demand humidification	3–5 %	1–14 %	5–14 %	20	2 %	FLH

a: energy conservation refers to full load hours (FLH) or installed capacity (IC)

b: energy optimization measures (EM) are carried out periodically

c: Compared to ventilation systems with 2400 Pa pressure loss

d: Compared to ventilation systems with 1200 Pa pressure loss

e: Depends on construction date

Source: Jakob et al. 2016 [1]

Air conditioning

Measures that influence air conditioning are concerned with the cooling of rooms and the associated increase in comfort. This process is generally modelled for office buildings, but the large lecture halls of teaching institutions as well as laboratories were also included. The associated assumptions for use in the model are shown in Table 3.

Table 3. Model assumptions for level of implementation, renewal cycle, and specific efficiency increase of building air conditioning measures and packages. Efficiency improvements refer to the state of the art in 2010.

Measures	Implementation level [b]			Renewal Cycle	Specific efficiency increase	
	2010	2050 Ref	2050 Eff	(years)		Reference[a]
Efficient cooling	6–8 %	17–25 %	34–46 %	20	13 %	IC
Variable cold water temperature	0–8 %	0–20 %	0–47 %	25	5–20 %	FLH
Variable recooling temperature	0–7 %	0–16 %	0–40 %	20	15–30 %	FLH
Hybrid recooler	0–11 %	0–18 %	0–44 %	20	10 %	FLH
Free cooling	0–7 %	0–17 %	0–42 %	20	10–20 %	FLH
EM and BA cooling	2–12 %	11–21 %	33–63 %	EM [c]	5–15 %	FLH
Optimized mixed air ratio in ventilation [d]	0–0 %	0–8 %	0–8 %	10	5 %	IC

a: energy conservation refers to full load hours (FLH) or installed capacity (IC)

b: including rooms with little penetration, as measure usually not applicable

c: energy optimization measures (EM) are carried out periodically

d: relevant for retail space

Source: Jakob et al. 2016 [1]

Various building technologies

This category of measures includes a variety of other building management processes such as electronic locking systems, monitoring systems, fire protection systems, uninterrupted power supply (UPS) and transformers. The assumptions for the category's use in the models are shown in Table 4.

Table 4. Model assumptions for level of implementation, renewal cycle, and specific efficiency increase of general building measures and packages. Efficiency improvements refer to the state of the art in 2010.

Measures	Implementation level			Renewal Cycle	Specific efficiency increase	
	2010	2050 Ref	2050 Eff	(years)		Reference[a]
General building processes	8–14 %	18–21 %	41–44 %	10	17–43 %	IC & FLH
Pumps and power supply	10–12 %	17–24 %	39–47 %	20	14–60 %	IC & FLH
Energy efficient lift technology	14–16 %	30–37 %	48–56 %	20	8–42 %	IC
Energy efficient lift improvements	20–30 %	38–49 %	52–65 %	20	5–10 %	IC

a: energy conservation refers to full load hours (FLH) or installed capacity (IC)

Source: Jakob et al. 2016 [1]

Results

The development of energy demand and GHG emissions in the two scenarios

Irrespective of the increased growth of the building sector in Switzerland due to population and economic growth, GHGE associated with the business as usual scenario is predicted to drop well below 2010 levels by 2050. This is due to improvements in building insulation and building systems. Still, the Eff scenario predicts even greater energy savings, along with significantly lower GHGE (Figure 1).

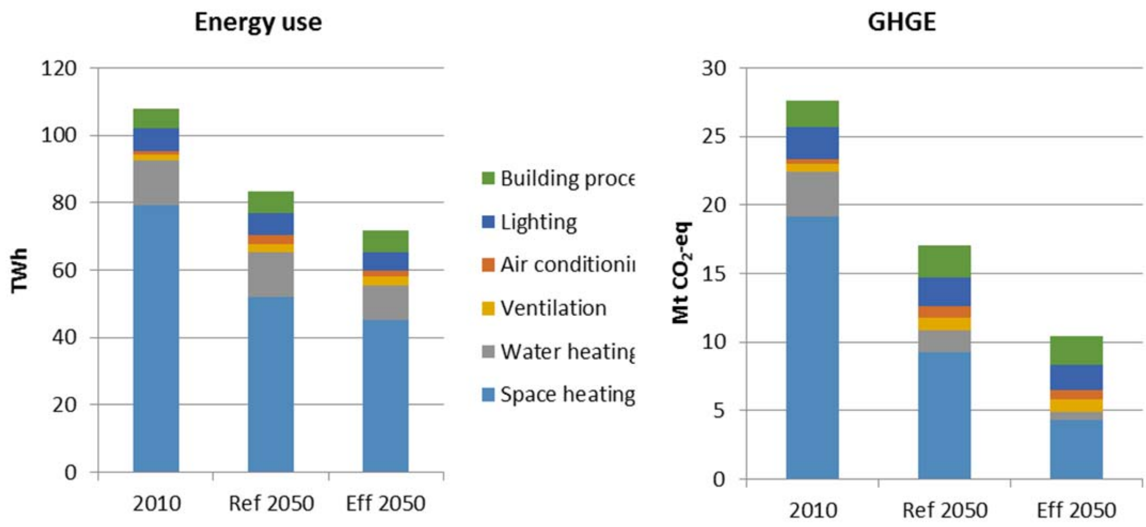

Figure 1. Final energy use and GHGE in the Swiss building stock including environmental heat in the current state, and two future scenarios.

Source: Jakob et al. 2016 [1]

Energy efficiency and emissions reduction potential

The reduction in total final energy (EE) demand in the Eff scenario is approximately 18 TWh, with an associated reduction of 21.0 TWh in total primary energy (PE_{total}) (Table 5). The reduction in primary non-renewable energy ($PE_{n.e.}$) is even more drastic; 29.2 TWh. This amounts to a reduction of 6.6 Mt CO_2-eq in GHGE. When compared to the Ref scenario, this result shows a reduction in PE of 17%, a $PE_{n.e.}$ of 38%, with an EE reduction of 14%.

The results in Table 5 and Table 6 show that implementation of various energy efficient packages ane their component measures will have varying degrees of effect on the overall energy use reduction in the Swiss building stock in the Eff scenario. The greatest reduction in energy use are associated with space heating (57% of EE reduction and 76% of GHGE, representing 5.0 Mt CO_2-eq). Figure 1 demonstrates that this energy-intensive process is responsible for the majority of energy use in buildings and therefore presents some of the greatest potential for efficiency improvements. Water heating is the next energy-intensive process, followed by lighting, air conditioning, and general building processes. These additional categories variably affect the reductions in EE, PE_{total}, $PE_{n.e.}$ and GHGE and so their effectiveness depends on the particular technologies employed. Compared to the energy-intensive activities, improvements in general building processes and ventilation have negligible effects on the energy use reduction.

For an assessment of how district heating changes can greatly reduce the energetic demands of an entire zone within an urban setting, see Jakob et al. (2013) [3]. By modelling the possible coupling of cooling and heating of buildings in the older centre of the City of Zürich, the authors demonstrate great potential in the two most influential categories of efficiency measures.

Table 5. Potential reduction in EE, $PE_{total,}$ $PE_{n.e.}$ and GHGE in the Ref and Eff scenarios.

	EE	**PE_{total}**	**$PE_{n.\ e.}$**	**GHGE**
	TWh	TWh	TWh	Mt CO_2-eq
Current state 2010	**107.8**	**148.9**	**121.9**	**27.6**
Reference scenario 2050	**83.4**	**121.9**	**77.7**	**17.0**
Space heating[a]	-6.8	-12.4	-22.0	-5.0
Water heating	-3.1	-4.3	-4.1	-0.9
Ventilation	0.0	0.0	0.0	0.0
Air conditioning	-0.6	-1.3	-0.9	-0.2
Lighting	-0.9	-1.9	-1.4	-0.3
Building processes	-0.5	-1.2	-0.8	-0.2
Potential energy use reduction of Eff 2050 [b]	**-11.8**	**-21.0**	**-29.2**	**-6.6**
	-14%	-17%	-38%	-39%
Efficient scenario 2050	**71.6**	**100.9**	**48.5**	**10.5**

[a] including updating ventilation systems to reduce thermal demand

[b] compared to Ref scenario

Source: Jakob et al. 2016 [1]

Table 6. Share of energy savings (ie. exploitable potential) by type of measure.

	EE	GHGE
Space heating	57 %	76%
Water heating	26 %	14%
Ventilation	0 %	0%
Air conditioning	5 %	3%
Lighting	7 %	5%
Building processes	4 %	3%
Total (%)	100 %	100%
Total (TWh, Mt CO_2-eq)	11.8 TWh	6.6 Mt CO_2-eq

Source: Jakob et al. 2016 [1]

Marginal efficiency improvements

In order to consider the effects of building improvements outside hot water and space heating, their effects were isolated and the results displayed in Table 7. The contribution of measures to the reduction of energy use was divided between effects on installed capacity and full load hours for the categories of ventilation, air conditioning, lighting, and general building processes. In the Ref scenario, the focus of building lighting and general processes is on increasing efficiency of installed capacity. In regards to cooling, the emphasis is on full load hours. In other words, energy consumption throughout the year can be more influenced by regulating the installed capacity as opposed to measures that are only applied during the hottest periods.

Table 7 demonstrates the importance of incorporating efficient systems and energy-efficient equipment into the planning and design of new buildings and renovation of older ones. Additionally, it stresses the need to design building control systems that allow enough control to reduce full load hours as much as possible. This can be achieved through appropriate BA systems that can be adjusted through responsible management practices.

Table 7. Shares in the savings in 2050 Eff scenario (compared to Ref) broken down by type of measures: reduction of installed capacity and reducing full-load hours.

	Contribution to reduction		
	Installed capacity	Full load hours	Total
Ventilation	51 %	49 %	100 %
Air conditioning	18 %	82 %	100 %
Lighting	60 %	40 %	100 %
Building processes	70 %	30 %	100 %
Total efficiency measures (excluding space heating and hot water)	**51 %**	**49 %**	**100 %**

Source: Jakob et al. 2016 [1]

Conclusion

The following general conclusions can be drawn from this study:

1. Space heating and water heating represent the areas with the greatest potential reduce GHGE by increasing the energy efficiency of buildings and through the substitution of fossil fuels with renewable sources of primary energy (e.g. wood and heat pumps). Technologies like district heating are more likely to be applied in urban areas. Reducing thermal demand of buildings can further these reductions. For additional information, see Jakob et al. (203) [3].
2. Installation of efficient ventilation equipment with associated on-demand and energetically-optimized technologies compensate for the increased electricity consumption by additional ventilation systems required in the process of heat recovery.
3. Energy use by air conditioning can be improved through optimization of new and already installed systems. This can be achieved through coordination of pumps, use of efficient chillers, and free cooling techniques.
4. The installation of LED lighting will greatly increase efficiency, but this is already implemented in the Ref scenario. Significant energy reductions can be made through energy-efficient lighting technologies and measures to better regulate the timing and intensity of lighting.
5. We recognize the general importance of regulatory and on-demand control measures through optimized energy use and building automation.

Through the involvement of industry representatives and building technology experts, this study aimed to establish a well-coordinated mix of instruments to be applied in the Swiss building stock. These measures must be individually- analyzed and set at appropriate levels in order to maximize the energy efficiency benefits across the entire system. The introduction of these measures into the existing stock can be realized through policy instruments such as regulations, information in various forms including norms and standards, education and training on the supply and on the demand side, and the networking of actors at different levels. The implementation of these measures is to be supported by encouraging a transition to renewable sources of energy within the building landscape. By supporting these approaches, it will be possible to implement the measures outlined in this report and to fully exploit the reported energy efficiency potentials. However, the involvement of stakeholders at all levels of planning and execution is required for this program's success.

Acknowledgements

We would like to thank the Swiss federal Office of energy (BFE), KGTV, and the numerous experts involved in Jakob et al. (2016) [1].

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A business-oriented roadmap towards the implementation of circular integrated facades.

Merging the interests of supply and demand stakeholders in the construction industry through long-term collaboration models.

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0. Abstract

The challenge of transitioning towards circular economic models requires a broad reorganization of processes and responsibilities throughout the construction supply chain. Such reorganization can no longer be solely conceptualized by academics in diverse manufacturing fields, but must be developed and grounded with the involvement of business-oriented industry partners who represent the interests and concerns of real supply and demand side stakeholders. The shift towards circular development starts at a strategic level, by identifying the business potential of models that extend collaboration, reinforce customer loyalty for suppliers and optimize performance-oriented services for clients. This strategic decision must then trickle down their respective organizations to include all technical, administrative and executive teams and facilitate the creation of product-service combinations.

Alternative ownership and financing models are emerging, in line with the principles of circular economies. These models are based on lower initial capital investments, material ownership retention by suppliers, and the delivery of buildings as living, dynamic and adaptable platforms, as opposed to current enclosed and static constructions. The business processes underlying such a shift in industrial culture can accelerate the rate and effectiveness of energy- and resource-efficient building renovations, by applying the principles of constant vitalization of systems and components, thus future-proofing buildings and extending their potential service-life indefinitely.

This paper will describe a foundation roadmap towards the implementation of circular, integrated façade systems, based on our team's experience developing a pilot project with the involvement of leading industry partners in the Netherlands. The process will be described in sequence: starting with the creation of a pilot supply chain and consortium; working through the integration of independent technologies into physical and digital product packages which allow (de)centralized control and management of smart, interconnected, performance-delivering products; and finishing with the new business scheme and value proposition created by long-term collaboration between suppliers and clients.

1. Introduction

In our conceptual foundation paper “Integrated Facades as a Product-Service System - Business process innovation to accelerate integral product implementation” [3], scheduled to be published in the following edition of the Journal of Façade Design and Engineering, we established that the linear supply and procurement process currently dominating the construction industry hinders the transition towards energy efficiency in buildings by delaying the implementation of innovative technological products. This paper will propose a schematic strategy to practically adopt circular economic practices in the industry by examining our team’s ongoing pilot project for a leasable façade system on a landmark building in the campus of Delft’s University of Technology (TU Delft).

Figure 1. Building complex of the EWI Faculty, TU Delft *(left)*. Diagram showing location of the IFPSS pilot project on the north face of the complex’s low-rise *(right).*

(Azcarate-Aguerre, 2015)

The unsustainable characteristics of a linear construction process

The increasing negative impact of linear economic models has been identified and documented by large organizations, think tanks and corporate task-teams such as the Ellen MacArthur Foundation [14] and the Salterbaxter MSL group [18]. These effects have special repercussions for the construction industry—characterized by an intensive use of materials and energy—affecting the business activities of stakeholders across the entire value chain. We will start by identifying some of the main actors in this supply structure, and breaking down the detrimental effects of the “take-make-dispose” mentality on the roles of each party within the value chain:

a. *Manufacturers and suppliers* of facades and façade-integrated systems can be categorized, in their majority, as small and medium enterprises with a relatively small number of employees and limited financial resources [6]. Such companies are especially vulnerable to fluctuations in the price and availability of raw materials and the intensifying financial cycles of the last few decades. Evidence of the financial challenges presented to these companies by linear contracting methods based on the regular acquisition of new projects can be found in the aftermath of the Global Financial Crisis of 2008, when 25% of VMRG's members (the Dutch metal façade industry branch organization) ceased operations between the years of 2009 and 2014 due to bankruptcy, acquisitions or mergers [22]

b. *Real estate developers and managers* have to accommodate for increasingly frequent changes in user models, spatial distribution, building safety and indoor climate regulations and other occupational demands brought about by technological innovation, economic cycles and social trends. High vacancy rates, especially affecting the commercial real estate sector [8], are the result of accelerating technical or perceived obsolescence, as facilities managers frequently decide to move to a new building which caters to the organization's changing needs instead of committing resources to the renovation or adaptation of existing facilities.

c. *Planners and architects* have to stay up-to-date on upcoming and complex technological systems in order to comply with increasingly demanding regulations on building performance, quality and comfort. The degree of specialization required has led to the development of specific educational programs which deal with different aspects of construction technologies, as well as a series of certification systems such as LEED in the US, BREEAM in the UK and NL, and DGNB in Germany, among others. The rising depth and complexity of these systems, exacerbated by the lack of continuity and proper cross-disciplinary communication between project teams and collaborating companies across projects, causes high planning and design costs and in some cases disappointing or underperforming results [19].

d. *Investors and financial institutions* have become reluctant to traditional real estate investments after the Subprime Mortgage Crisis of 2007 that lead to the Global Financial Crisis in 2008. The safety of property-backed investments is now more carefully assessed on a case-by-case basis. The depreciation of technological systems, the energetic efficiency of the construction, and its flexibility to change and accommodate new user requirements have all become important factors when evaluating the attractiveness of a portfolio [17].

e. *Utility companies* are under increasing pressure to make new investments in sources of clean energy and new, more efficient distribution infrastructure. The decentralized production of heat and power through building integrated technologies has positive effects on the overall footprint of construction projects, but can have disruptive consequences for energy service and utility companies who have to accommodate and balance these production sources within a general energy grid and market [10].

f. *Regulatory bodies* have to analyze and implement strategies on a wide range of scales to deal with new challenges. On a global scale, access to raw materials, especially in the case of rare-earth metals and other scarce elements, is likely to become one of the main geopolitical debates of the 21st century. On a building scale, the regulation of building materials and technological systems to provide optimum technical performance, minimum embodied energy and maximum re-usability and recyclability is a matter of debate and on-going research.

In the face of such environmental and economic challenges, and in an atmosphere of increasing (global) competition and product commoditization, a number of stakeholders across diverse manufacturing and service industries have started to explore new strategies to make their business both more sustainable and more profitable by focusing on services that extend the efficiency and value of their products. This trend has been recognized by some authors [5] [16], and is considered as a conceptual and practical inspiration for the strategic goals of our current project. By engaging representatives from many of the groups mentioned above, our team has created a testing environment for the discussion of transition possibilities towards long-term, performance-based contracting.

2. Proposition

Performance contracting for multifunctional, integrated building envelopes

The evolution from a linear to a circular industry relies on significant structural changes on two fronts: On one side, it requires the technical development of product-service combinations which will create a long-term relation between supplier and client; on the other hand, it demands a fundamental shift in business and management processes which will facilitate the administrative, financial and logistic application of such performance-based contracts.

Integrated facades as a service-delivery tool

Products leased under a performance-based agreement should deliver a certain set of capabilities or performances to the client. The more critical these processes are to the client's activities (and the more accurately they can be measured) the higher the value held by the product-service combination [4]. Traditional facades, while performing an important number of services to a construction—such as protection against climate, noise and pollutants, ventilation, humidity control, fire safety and others—do not effectually deliver a concrete and measurable performance, as they are only part of a larger system of services and installations which control the indoor climate of the building.

Integrated multi-functional facades, which support a number of decentralized services, can expand the function of the building envelope and in certain cases encase virtually all systems responsible for the building's indoor comfort. This is especially true since certain constants such as spatial distribution, architectural design, orientation, user behavior and others cannot be radically altered within an existing building environment without redesigning the entire structure. Integrated facades can therefore replace centralized systems such as ventilation, humidity control, heating, cooling, energy production and storage, lighting, electric and ICT supply lines, etc., and are constantly expanding the range and effectiveness of their offerings [13] [15].

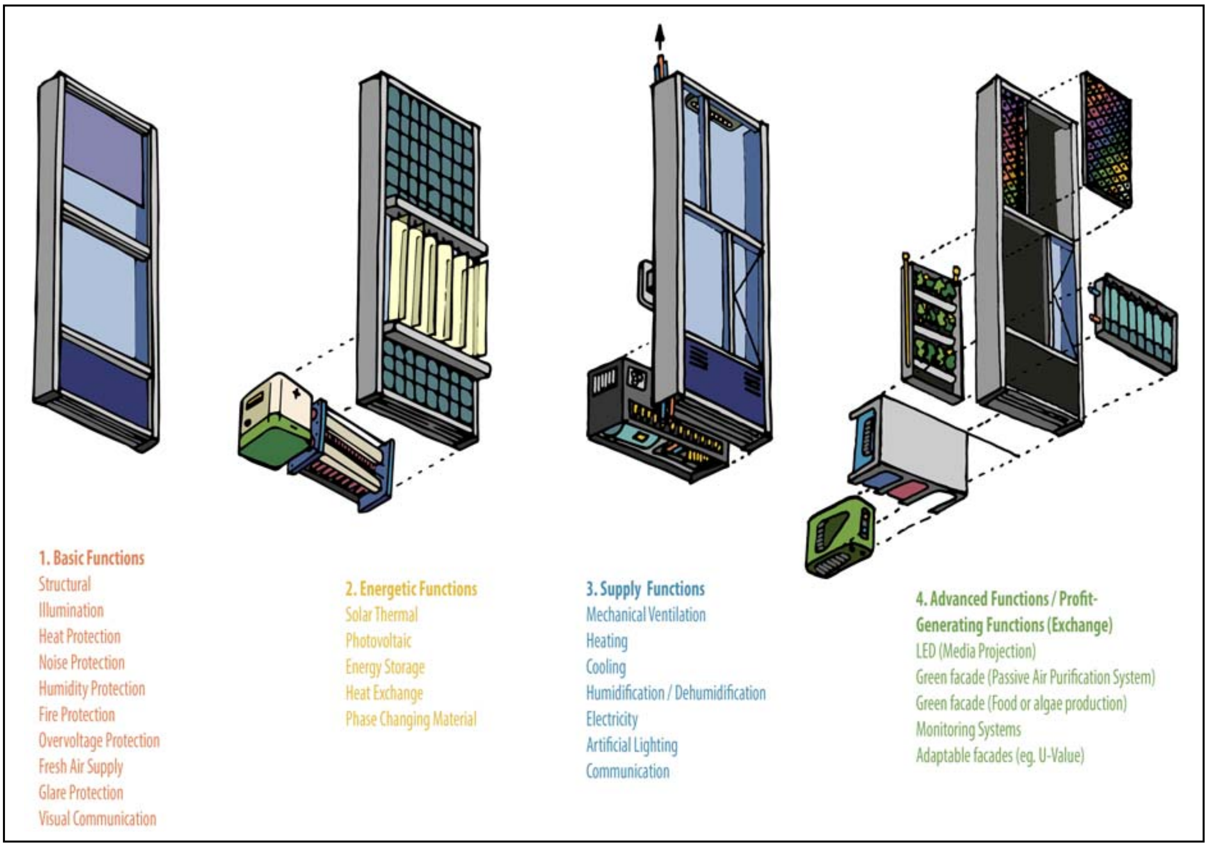

Figure 2. Service-oriented façade-integrated product combinations for multi-functional building envelopes

(Azcarate-Aguerre, 2015)

This means integrated facades can function as a consolidated system (envelope modules including a series of functional products and services [Figure 2]) that delivers a final, measurable performance (indoor quality, illumination and energy balance) to support a building's operation. This in turn enables them to become part of a Product-Service System (PSS) package in which the manufacturer, or facade fabricator, acquires a series of components from sub-suppliers, and assembles them into a complete functional product through which can be delivered a constant performance to the client through installation, maintenance, replacement and removal / reprocessing of components.

A number of integrated facade concepts have been presented, as prototypes, by teams of leading suppliers and fabricators, and their performance has been analyzed in studies such as [21]. Alcoa's "Next Active Façade, Schüco's "E2 Façade" and Wicona's "TEmotion Façade" are examples of functioning integrated envelope concepts which offer diverse degrees of service-delivery potential. The fact that none of these systems has managed to generate a considerable impact in the construction industry could be attributed to the traditional, linear business model through which they are being offered to clients. With a higher cost per square meter and a higher degree of technical complexity (regarded as a higher risk of possible failure) clients have not yet identified the value of decentralized facade concepts, while the perceived design limitations of such modular systems results in them being unattractive to architects who might therefore be reluctant to include them in their designs.

The circular business potential of product-service systems

Hugo Spowers, CEO of Riversimple mobility solutions, a UK-based fuel-cell car leasing company, describes business development in a circular economy as the design of a system in which "All (business) drivers are completely aligned with the interests of the customer, driving (the business) to minimize resource consumption" [20].

In a Product-Service System suppliers and clients form an ongoing symbiotic collaboration in which some of the processes necessary for the customer's activities are constantly delivered and maintained by the product supplier and service provider. This closed relationship, based on shared goals and benefits, naturally leads to a more careful use of resources (as waste results in loses for both parties) and a positive and incremental innovation curve (as improving systems and processes results in shared gains). A Product-Service System approach to building facades, therefore, could generate a closed financial loop for capital resources invested in the building components, and a closed material loop in which the supplier retains property of the materials and uses them to fabricate the next generation of products [Figure 2].

The shift from simple product manufacturing to complex performance delivery opens a new market for producers of technology (frequently the drivers of innovation) to compete, generating value not only from the immediate sale of their products, but from the long-term service delivered by such products. This, on its own, is a financially attractive transition, as the profit margin for services—generally between 8 and 12%—is between two and three times larger than that for products: 2 to 4% [4].

On top of this margin increase, manufacturers can lock out competition by establishing a deeper relationship with their clients. In the current model, where procurement is based on the lower initial cost of interchangeable products, one manufacturer could be perceived as similar to any other. However, in a procurement structure based on Total Cost of Ownership, which includes initial construction, management and operation, and demolition expenses, manufacturers and the products they offer become unique and their service range a source of added value [5]. This allows producers to establish specific manufacturing and servicing strategies balancing initial production quality, frequency and intensity of maintenance work, expected service-life and a number of other industrial parameters. Their involvement throughout the entire life-cycle of the building, and their responsibility to deliver a constant performance based on the combination of products and services, forces them to optimize their resource input (while still delivering the expected performance) in order to maximize their profit.

Clients also benefit from this model, as they outsource activities which are not central to their core business processes (such as, for example, a banking institution owning and maintaining the façade of their corporate headquarters). They also avoid the uncertainties related to material costs, peak expenses due to major renovations, or productivity issues derived from the under-performance of the building, and instead pay a periodic service fee dependent on the regularity and quality of the service delivered.

External partners are also involved in this circular business model. A central financing body (a bank or a branch of the manufacturer organization in the case of large corporations) will provide capital to bridge the gap between products manufactured today and services paid tomorrow, and will act as backer or guarantor in the event of a service provider bankruptcy or any other eventuality. Third-party service providers (such as transport companies, external monitors, specialized maintenance teams, etc.) can be involved in the business loop to provide products or services which cannot be offered cost-effectively by the manufacturer, taking advantage of specific industrial experiences and economies of scale.

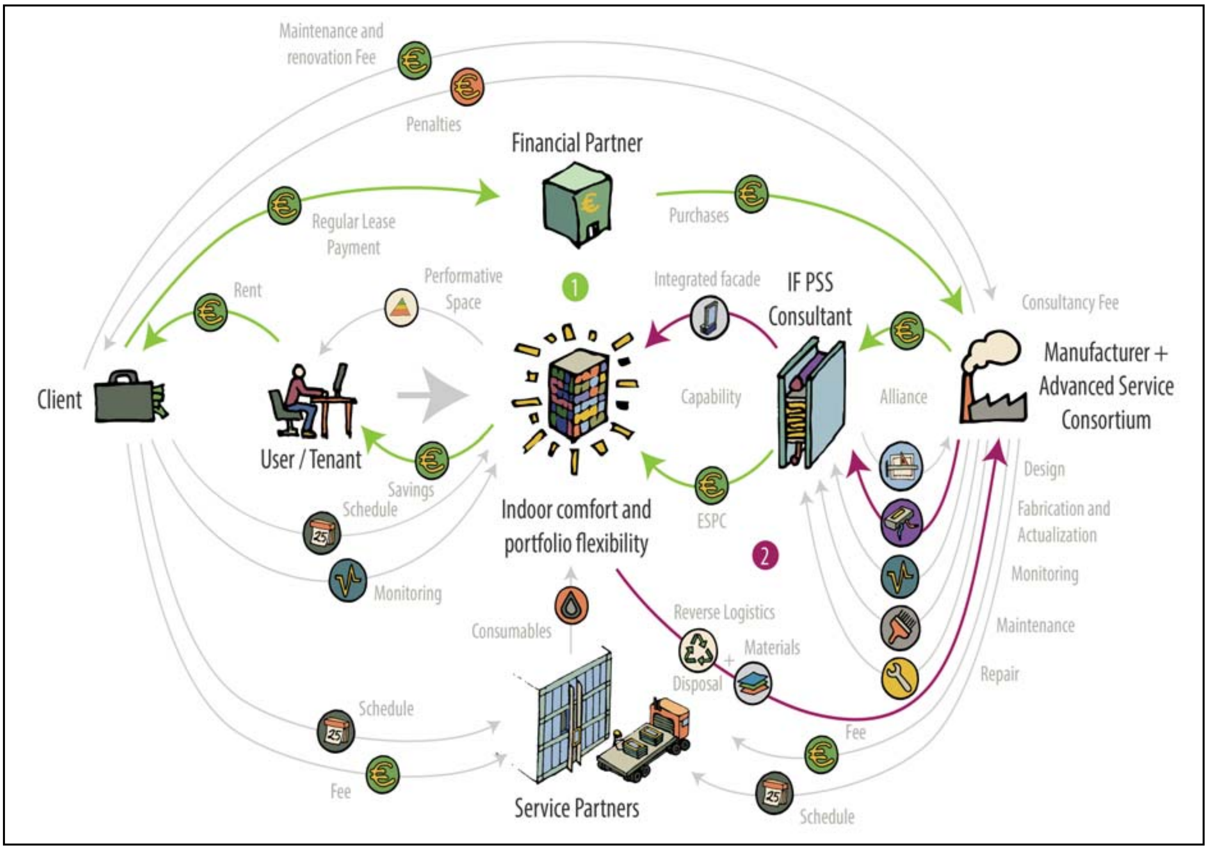

Figure 3. Diagram of circular business network for the delivery of integrated facades within a product-service system. *(1) Closed financial loop (2) Closed material loop*

(Azcarate-Aguerre, 2015). Inspired by [4].

Pilot project: Foundation roadmap toward an integrated façade system

Setting up a model collaboration team for a leasable façade mock-up

Well-documented examples of transportation, appliance and electronics manufacturing companies re-focusing their activities on the provision of advanced services are becoming increasingly available thanks to the dissemination efforts of organizations like the Ellen MacArthur Foundation. However, the construction industry is still far behind in adapting the supply chain and establishing the legal framework within which such new business models would operate. Specific examples can be found of independent building components being acquired through service-inclusive contracts [19], but such cases are still few and seldom apply to complex integrated systems which combine more than one final supplier. With the intention of testing our ideas and bringing the discussion forward among relevant decision-makers and stakeholders in the Dutch market, we organized the development of a pilot project with real parameters on a physical location.

As in the case of a Design, Build, Finance, Maintain and Operate (DBFMO) contract, the project is undertaken by a consortium made up of contractors, subcontractors and system suppliers, supported by experienced engineering, legal and financial advisors. For this project a consortium was created and divided into three main groups, with the intention of simulating the supply chain and information flow in an actual construction project. Information exchange and evaluation links have been created to reproduce the transition from a short-term project-delivery-based to a long-term service-based collaboration. The three teams can be broadly described as: *Project Management team:* The core team of the "Integrated Facades as a PSS" project acted as a centralized consultant, translating the functional needs of the demand parties into technical packages from the supply partners. *Supply Team:* A coordination team composed of VMRG / AluEco and facade fabricator Alkondor will overview the executive design, supply chain and construction process. *Demand Team:* The demand team is divided into Client organization—TU Delft's Facilities Management and Real Estate group (FMVG in Dutch)—and End-users (facilities managers, members and decision-makers of the EWI faculty). The End-user group will provide input on the current problems of the EWI building, especially with regards to indoor comfort.

Design and engineering process

A series of discussion meetings and workshops were organized with supply and demand stakeholders to identify key design aspects such as building requirements, integral product packages, current service offerings and risks and potentials of long-term collaboration. FMVG, the real estate and facilities management group of TU Delft, offered the building of the EWI faculty as testing ground to develop a physical pilot project.

The EWI (faculty) building is a modernist construction completed in the late 60's. It has a double-façade system (pioneering for its time) made up of two panes of unitary panels made primarily of glass and steel. After almost 50 years of continuous operation the building is reaching the end of its originally built-in service life: indoor comfort and air quality are below current standards, underperforming building services and installations cause high energy and maintenance costs, and the building envelope offers poor insulation and suffers constant leakages and air draughts. The facilities management organization has calculated that, per square meter, yearly expenses in maintenance and operation costs for the EWI building are as high as twice those attributed to their newer, comparable buildings [9]. A significant portion of these expenses can be attributed to the performance of the façade, as the poor energetic performance of the envelope results in a particulalry high demand for thermal energy, and the age of the façade components require a specific and labor-intensive maintenance schedule. The building offers an ideal experimentation site due to its modular, unitized construction, while it represents a huge portfolio of university buildings constructed in the decades of the 1960's and 1970's, and which constitute a large potential renovation market of millions of square meters in the Netherlands and tens of millions across Europe [7].

The supplier consortium, coordinated by our academic team and VMRG's project development team, commited to engineering a series of four panels which would reflect the state-of-the-art of building envelope and façade-integrated technologies, to replace a section of the orginial façade and test its effect on the overall performance of the building. The design and engineering of this mock-up project would target the development of "Technical product-service combinations" mentioned earlier in section [2. Proposition]. Sequenced from left to right [Figure 1], these four panels (made of interchangeable modular components) would address a variety of functional requirements and levels of desired investment. The design of these panels followed a sequence in the number and complexity of services delivered and the intended length of the contract, starting with a simple "Low-cost Panel 1", intended to extend the service-life of the building for an additional ten to fifteen years before a more extensive renovation, followed by a "Supply services and energy generation Panel 2" [Figure 4] intended to support or replace centralized building services, and finally "High-end Panels 3 and 4" intended to showcase advanced systems and technologies such as self-supporting vegetation panels, LED media screens, high-wind-velocity solar shading, among others.

The interchangeability of components was a dominating topic throughout the engineering process. Looking at the building envelope as a platform for the integration of distinct (and constantly evolving) technologies, we aimed to facilitate an ongoing vitalization process, converting the building into a flexible, adaptable core structure capable of housing a diversity of users and activities over time [11].

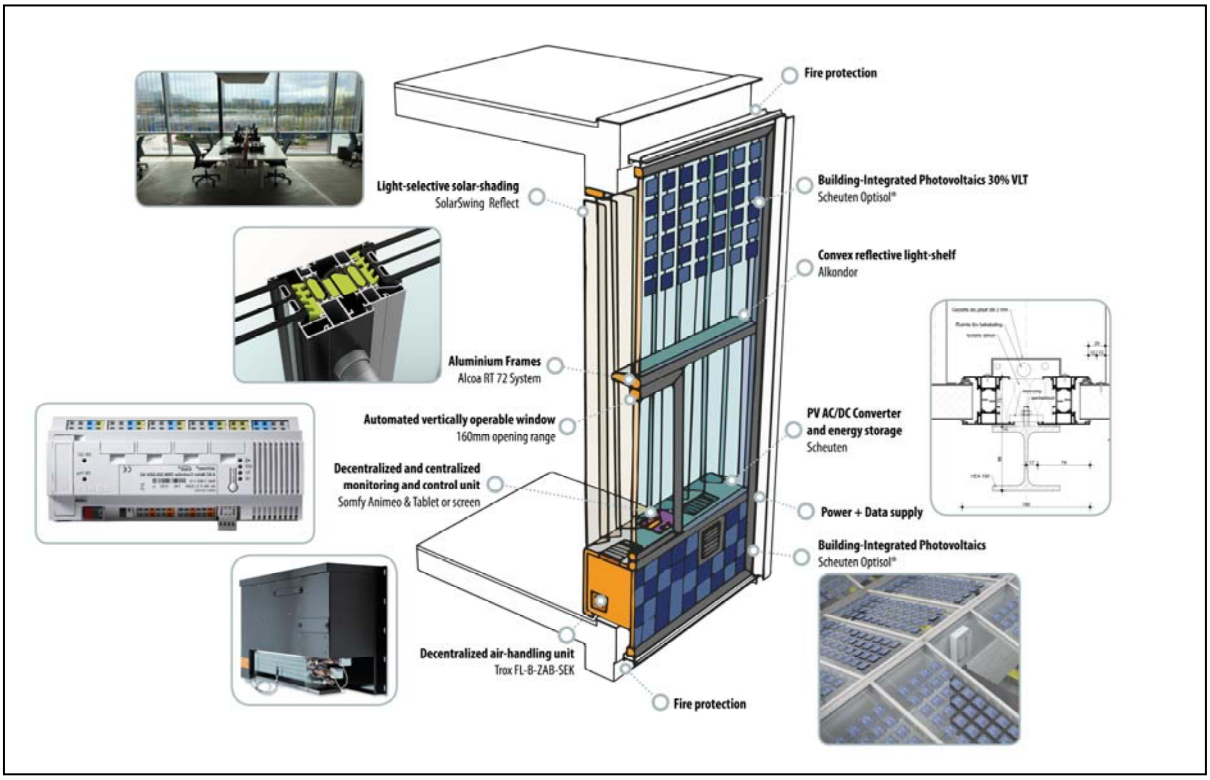

Figure 4. Sketch of integrated Panel B, including energy generation and storage technologies, decentralized air-handling systems and automated window operation

*(*Azcarate-Aguerre, 2015).

Developing a schematic business case for leasable façade systems

Manufacturers who desire to offer extended life-cycle services need to build a new body of experience on the processes and costs related not only to the fabrication of a product, but to the operation, maintenance, replacement, upgrade and eventual proper disposal of the unit. Suppliers, who until now are used to selling their products in a one-time transaction and then moving on to the next project (except for certain guarantees and liabilities held related to the proper functioning of the system), must now extend their activities to constantly collaborate with their customers on the upkeep of an ongoing technical service. The first challenge, when developing an initial schematic business model for leasable façade components, is to help manufacturers understand the series of extra steps that will be demanded from them, the risks and benefits these might imply, and their associated potential strategic advantages.

Additional supplier activities will be distributed along the project process: A deeper involvement with the client and planning team will be required in the preliminary design stages to propose the best technical solution for specific functional challenges; The installation, monitoring and maintenance of systems must be performaned by a multidisciplinarily trained team in order to guarantee ongoing performance delivery; A reverse logistics chain must be established to facilitate the end-of-service reprocessing of old components, and enable the extraction of materials to fabricate new products. While some of the suppliers in our consortium were familiar with certain service components in their traditional sales contract (such as maintenance and cleaning), few of them had any experience with the later processes such as the upgrading of units through new-generation parts replacement, or the re-claiming of their products at the end of their service-life in order to break them apart and extract subcomponents or raw materials for reuse/recycling.

On the demand side, real estate developers and facilities managers also need to develop their understanding of their own business processes and their current allocation of resources. Our experience so far has taught us that few business operators have a full understanding of the individual performance of components within their buildings, and lack the specific monitoring capacity to separate expenses related to heat loss because of a poorly-performing façade from the general energetic consumption of the facilities. Creating new business cases is difficult due to a general lack of current performance benchmarks in most facilities. Additionally, client organizations lack information on their current building envelope scenarios which can be compared against the results proposed by the supplier consortium through their product-service combination.

It is generally accepted by our project partners that the assumption presented above regarding the advantages of continuous life-cycle services could result in new business models for suppliers and clients. In order to further develop this schematic business proposition we must explore in more detail the technical and financial possibiltities of each individual company, identify their potential for service delivery and reverse logistics, and work out a short and mid-term plan for their transition. Up until this point in the project, we consider the involvement of such diverse stakeholders in our project team a success, as it shows that strategic decision-makers throughout the industry recognize the potential value of new business strategies.

4. Evaluation

Partner feedback and future steps

Our team's current task is that of advising both supply and demand actors within our partner network on the development of process maps which will improve their understanding of crucial aspects of their business and how these may be affected by a transition to circular economics. These areas include financial and material resource allocation, technical maintenance tasks and schedules (which could be redistributed among stakeholders) and internal and external conditions which can lead to significant changes to their products or building portfolio. In this final section of the paper we will describe some of the preliminary comments we have received from industry partners, and present an overview of challenges that remain to be solved.

a. *Manufacturers and suppliers* see the benefits of establishing long-term contracts with their clients; they are interested in the financial stability of ongoing projects as opposed to their current business model in which they must constantly seek new projects. They also recognize the value of being involved earlier in the design and planning stages, when their technical expertise and knowledge of their system range can lead to a better overall building design and more effective performance of their products.

On the negative side, few of them are ready to establish a reverse logistic chain as they lack the facilities and knowledge to break apart old products and extract useful components or valuable materials. Also, recent drops in the price of commodities such as raw materials and oil render the prospect of material ownership retention less attractive than it was at the start of our project when such prices were at the end of over a decade of constant increase. Some suppliers are also strategically and administratively unprepared to face the logistic challenges of service-delivery: They lack the trained human resources to provide maintenance of systems and keep a close relation with clients, and they lack the technical knowledge to fully assess risk related to their products performing below the expected levels [12].

b. *Real estate developers and managers (client organizations)* are eager to explore new models of responsibility distribution. They assign an added value to the prospect of outsourcing technical management of building systems, and an even higher value to the expanded flexibility offered by exchangeable building components. The shift towards project financing based on Total Cost of Ownership calculations from supplier consortia is also attractive to their financial overview and yearly cash-flows.

Examining the risks, client organizations are concerned about the proper distribution of responsibilities and the response of suppliers to underperforming systems, negative user behavior or failure. The development of new contracts will be a major topic for this stakeholder group. Also, the large number of systems in a building, and the interdependence between them in relation to their performance, means that careful monitoring will have to be maintained, and collaboration not only between suppliers and clients but among suppliers themselves will have to be enforced in order to avoid conflict.

c. *Investors and financial institutions* recognize not only the business advantages but also the strategic benefits of turning their focus towards more sustainable investments with a longer and healthier service-life [1]. They are probably the organizations which are better prepared to make this transition, as they already have experience with financing long-term leasing contracts for other types of equipment, and are familiar with the advantages of investments backed by technological components. Standardization of building components (which is already the case with a number of façade-integrated technologies) supports the case for this type of investment, as they improve the liquidity of these assets and improve the financial feasibility of the project.

   Emergency procedures will have to be developed to deal with eventualities such as the bankruptcy of a service-providing company or extreme under-performance of services compared to planned benchmarks. However, such protocols already exist in the financial industry, and their adaptation to the business outlined above should require no more than routine recalculations.

It is important to note that, due to time restrictions, we had to limit the scope of the product selection process to technologies which are currently available in the market. In the case of a market-scale project suppliers would most likely want to redesign and engineer their products to adapt to the new demands of an extended service contract. The integration of systems from different suppliers, on both a physical and a digital level, has been an engineering challenge and will surely form the basis for future research and development in academia and industry. The preliminary conclusions presented in this paper will be further developed by our team in the following year; the pilot project is currently in the late engineering stages and is scheduled to be completed by the end of spring 2016.

A number of questions remain open concerning the details and feasibility of a more developed business model, but we are convinced that the steps described above will move the discussion forward toward a more applicable stage. With the engagement and enthusiasm of both academic and industrial partners the transition towards a circular construction economy can progress from theory to practice in the not-too-distant future.

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Session

Retail Buildings & Health Care I

Interactions of retrofitted shopping centres with local energy grids

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Abstract

In sustainable development of city structures, increasing power consumption requires maintaining power grid safety and reliability with less mismatching between electricity generation and demand. Power grid fluctuations in both power demand and generation induce an effort to supplementary setting on conventional production units and efforts to maintain grid stability. Hence, nowadays with the trend towards more complex, flexible and dynamic systems as well the higher penetration of distributed and decentralized renewable energy systems, the issue of peak reduction of demand/generation mismatch has gained importance. Shopping malls, often centrally located in urban districts, have high energy savings and carbon emissions reduction potential due to their large lighting loads, high population density and hence, a large air conditioning demand. At the same time, shopping malls cover important surface areas and are reference points in urban districts for citizens, with possibilities to provide services to both the grids and the community.

Considering typical shopping malls high impact on modern society [1], the project addresses their transformation as lighthouses of energy efficient architectures and systems as well as assessment transparency. It has the objective to re-conceptualize shopping malls through deep retrofitting, develop a systemic approach made of technologies and solution sets as well as methods and tools to support their implementation and to assess their impact in a life cycle approach. The concept is based on a systemic performance-driven approach including: integrated design process guidelines, integrative modelling environment, energy-economic evaluation tools, lean construction and management procedures, continuous commissioning approach, environmental and socio-cultural impact assessment.

The Systemic Retrofitting Approach (SRA) allows to achieve the foreseen targets: up to factor 4 reduction of energy demand, power peaks shaving and 50% increased share of renewable energy source favoured by the intelligent energy management and effective storage. This paper studies for 3 different locations in Europe the interaction between shopping centres and the electrical grids to which they are connected with the objective to identify key aspects which allow improving the current interaction and identifying the capacities that these types of buildings could give as suppliers/providers of services to the local energy grid. The results will help to optimize renewable energy production integrated in shopping centres by being able to optimize self-consumption, reducing the energy need to generate and deliver additional electricity and allow the participation of the end-users in the management of energy with grid providers.

Introduction

The focus of this project is on existing shopping malls to be refurbished and buildings with a different original function, redesigned to become shopping malls. Wholesales&Retail buildings represent 28% of the total non-residential building stock, accounting for approximately 157 Mtoe in 2005 [2].

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In sustainable development of city structures, increasing power consumption requires maintaining power grid safety and reliability with less mismatching between electricity generation and demand [3]. Power grid fluctuations in both power demand and generation induce an effort to supplementary setting on conventional production units and efforts to maintain grid stability. Hence, nowadays with the trend towards more complex, flexible and dynamic systems as well the higher penetration of distributed and centralized renewable energy systems, the issue of peak reduction of demand/generation mismatch has gained importance [4]. Shopping malls have high energy savings and carbon emissions reduction potential due to their large electrical and thermal loads. At the same time, shopping malls cover important surface areas and are a reference point for citizens, with possibilities to provide services to both the grids and the community [5;6].

Objectives

This paper studies the impact of different retrofitting solutions for shopping centres on the electrical grids to which they are connected (the load curves) with the objective to identify key aspects which allow improving the current interaction. It has the objective to re-conceptualize shopping malls through deep retrofitting, develop a systemic approach made of technologies and solution sets as well as methods and tools to support their implementation and to assess their impact in a life cycle approach. The concept is based on a systemic performance-driven approach including: integrated design process guidelines, integrative modelling environment, energy-economic evaluation tools, lean construction and management procedures, continuous commissioning approach, environmental and socio-cultural impact assessment. The results were collected in a tool box with solution-sets having high replication potential and methods to implement them in different climates and urban contexts and for different building operative features (energy conservation challenge because of the external load) and functions (energy conservation challenge because of the internal loads).The results will allow the participation of the end-users in the management of energy with grid providers.

Method

The methodology involves firstly a characterization of shopping centres with respect to load profiles, climate, urban and energy contexts, among other aspects which condition the interaction between building and grid.

Methodology followed consists of four steps:

1 Definition of parameters which characterize the building, the building context and the interaction of building with grid.

- The characterization of the reference buildings and the building context is based mainly on the parameters defined in [7]. Most significant parameters have been included in a questionnaire delivered to the reference buildings owners/managers. This questionnaire intended to compile the relevant information from building (size, type, schedule and consumption profile), energy supply characteristics, included the grid capacity and evaluate the possibility for connection modification. The questions included were analyzed with detail in order to be able to get suitable information from the minimum number of points in order to persuade owners/managers in its reply.

- For the characterization of building-grid interaction, it was considered indicators described in [8]. In the case of Valladolid reference shopping centre, an energy grid analyzer was also utilized for measuring the quality of supply electricity fed by the grid to the building. This building is located in an urban context, the city centre, with likely high degree of grid saturation; therefore, it is assumed that this building represents the worst conditions, while the other reference buildings could have better conditions.

2 Characterization of shopping centres by the analysis of the data compiled in questionnaires.

3 Definition of the potential of shopping centres as energy service and identification of the best solutions for each shopping centre. Once the diagnosis of shopping centres is done, it can identify constrains and potentials of buildings for being exploited as energy service. Then, it is possible to propose a set of solutions according to the previous premises by each shopping centre (on site RES, Energy Storage, Peak Shaving and Energy Saving), see also [9;10;11;12].

4 Evaluation of the impact that energy solutions would produce on the local grid in case they were applied in shopping centres through Load Match and Grid Interaction (LMGI) indexes. The procedure for this analysis consists of:

- Generation of generic energy profiles for each reference building.

  - Generic energy profiles of the current situation of the reference shopping centres using EnergyPlus were created based on simplified models of commercial building and locations (three types of climatic conditions/weather files) [13]. Since the DOE reference building depends also on the US climate zone, we chose the reference building related to the US climate zone most similar to the one where it is located. This just leads to different wall constructions, design days and electricity source and emission factors. Subsequently, typical days for three different seasons (summer, winter and middle-season) were generated. The profile is adjusted to the location of reference buildings once it is introduced the climate characteristics of the places where they are located. Since, profiles are shown in Wh/m^2, they are adapted to the real surface of the supermarket and retail areas; these represented the baseline scenario.

- Evaluation of the energy generation and energy saving potential for the set of solutions proposed by each shopping centre.

  - Energy generation for RES (Renewable Energy Systems) solutions (PV and wind) is evaluated with TRNSYS [14]. For the capacity of PV, it was taken into account the available surface of each building, the climate and own restrictions of the building (shadow effect for surrounding building). For the case of the wind energy, it has estimated the production of energy taking into account a size of the turbine suitable to each building, the climate and the own restrictions of the building (e.g. location in urban context). Energy generation profile associated to the cogeneration is evaluated with EnergyPlus, assuming a 30% of efficiency based on thermal efficiency [13].

  - The energy profile of buildings associated with the incorporation of efficient solutions (HVAC, Lighting, Envelope and Refrigeration) was calculated with EnergyPlus in line with the most ambitious settings defined in [15].

    - <u>Envelope</u>
      - Reduce air changes to 0.6 hr^{-1}
      - Add night natural ventilation: $3hr^{-1}$
      - Double insulation thickness
      - Modify window: U-value glazing=0,8;U-value frame=0,6
    - <u>Lighting</u>
      - Reduce light density to 4.5 W/m^2 in shops and 3 W/m^2 for common areas (and others)
    - <u>HVAC</u>
      - Modify Heating equipment efficiency to 95%
      - Modify Cooling equipment efficiency to COP=6
    - <u>Refrigeration</u>

        - Reduce refrigeration power to 40% of initial installed power

- Calculation of Load Match and Grid Interaction indexes (LMGI) for the baseline and the solutions with RES alone and with RES plus one of the energy efficiency measures at the time.

Results

With the information collected and analyzed, it was possible to identify the potential as possible improvement actions in the interaction between the buildings and the grid, with solutions divided by on site RES, Cogeneration, Energy Storage, Peak shaving and Energy saving solutions. With the information available it has been possible to calculate the most relevant KPIs identified for the solutions proposed trying to understand how different solutions influence in the interaction between the shopping centres and the electrical grid.

The selection of solutions to provide services to the grid (e.g., increase matching during lack of electricity or use electricity during time of excess) is based on the characterization of building (available surface, energy consumption share and energy profile), environment context (climate, normative), grid capacity (current level of saturation and generation profile) and quality (non-existence of interferences in the proper operation of the system of energy supply) in order to detect the potential of building but also to note if the expansion of the capacity of the grid and especially to the use of renewable energies can produce stress for the grid.

Below is a list of potential solutions to provide services to the grid divided in five categories: on-site RES, Energy Storage, Peak shaving of demand curve and Energy saving solutions.

- On site RES
    - Photovoltaic energy
    - Wind energy
    - Cogeneration
- Energy storage
    - Power
        - Backup power
        - Primary power
        - Hybrid H2-battery
    - Transport
        - Hydrogen refueling station for customer
        - Hydrogen bus refueling
        - Material handling vehicle refueling
- Peak shaving of demand curve
    - Energy supply options
    - Shifting of loads using flexibility or system operation
- Energy saving solutions
    - Envelope
        - Solar shading
        - Green integration
        - Reflective coating
        - Natural ventilation

- Lighting
  - Daylighting
  - Replacement of inefficient lighting equipment
  - Lighting control
- HVAC systems
  - Energy efficiency equipment and components
  - Energy flux strategy and recovery
  - Equipment control and management
- Refrigeration
  - Reduction of refrigeration heat gains
  - Reduction of refrigeration heat load
  - General setting and operation rules

Based on the assessment of the context, the demand and the generation profiles, potential improvements of reference shopping centres are identified below.

Results for reference shopping centre in Valladolid

- The electricity demand of the Valladolid shopping centre is mainly due to the lighting, HVAC systems (radiant floor fed by air/water heat pumps) and the energy consumption of the refrigerators used for the conservation of the products. This gives an idea in where is possible to act to reduce the electricity consumption of the shopping centre.
- The demand profile shows a clear correlated character with the timetable during the market working day. Thus, the highest values are produced from 9:00 to 16:00, although there is a minimum consumption mainly due to the refrigerators outside of working hours.
- The cooling systems are old and undersized because, following the air temperature analysis and the users and clients comments, the comfort levels are not reached a lot of times. Furthermore, the low air-tightness, owing to building status, causes elevated energy consumption and it is a constraint for achieving the comfort conditions.
- Existing lighting systems are old and non-efficient in contrast to the modern lamps and luminaires in the marketplace.
- There is no energy management system for programming the control strategies so as to deal with the energy management.
- Results obtained with the grid analyzer reveal that:
  - The results of the analysis of the main electrical parameters in the supply indicate the lack of network quality problems, during the metering period.
  - Elevated reactive energy consumption has been detected.. This penalizes into the bills from the supplier.
  - Great values in the harmonics 5 and 7 have been detected due to non-linear loads (luminaires, fans…). This could influence the quality of the grid in terms of disturbances.
- There are no renewable systems for the electricity generation connected to the distribution grid of the market which affect regulations with regard to the renewable installation typical to each distribution line.
- The urban environment and the presence of buildings in the surroundings limit the installation of the photovoltaic and wind turbines. Besides that, the historical character of the building is a determinant too. However, high levels of radiation make solar panels a potential solution for this building.

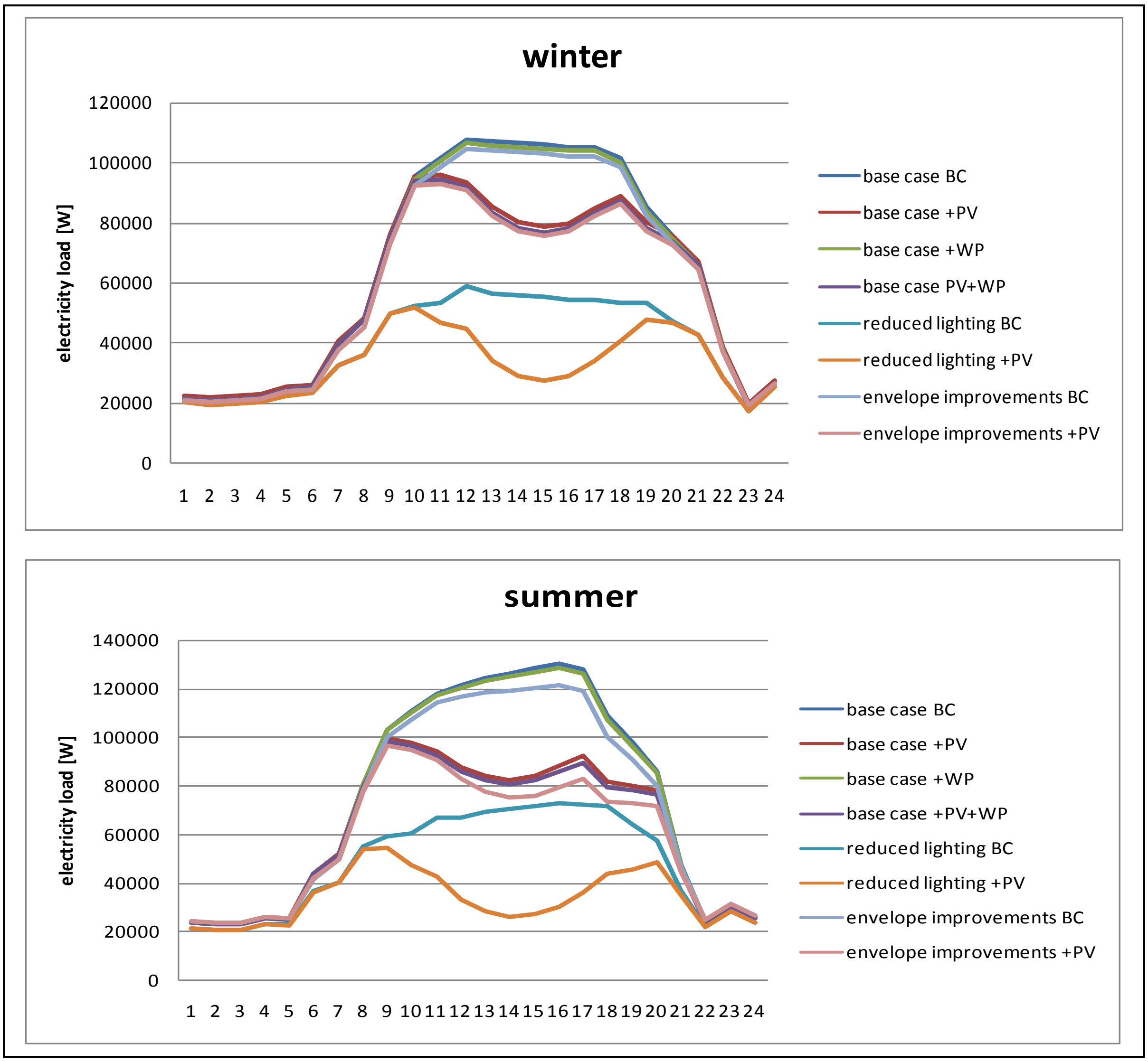

Figure 1 Results for winter and summer season for Valladolid

Results for reference shopping centre in Catania

- The energy consumption at the Catania reference shopping centre is dominated by the lighting that accounts for 41% of the buildings predicted consumption.
- Following lighting, the consumption is equally distributed between refrigeration and HVAC.
- All these services, even lighting, have greater consumptions in the summer months.
- The electricity demand profiles for each month indicates correlation with season as well as opening hours of the building.
    - Daily: the consumption peaks are reached during the central hours of the days, toward the early afternoon (i.e., 2pm) during the winter months and in the later afternoon (4pm) during the summer months. The summer peak is associated with the peak in cooling and refrigeration needs
    - Monthly. There is a strong correlation with the month of the year. During the summer months the consumptions are approximately 20% higher due mainly to the elevated electricity cooling need. The months with the highest and lowest consumptions are July and December.

- Assessing the present building situation we noticed
  - Envelope: structural elements could be improved including wall and window transmittance, exploitation of daylight, use of natural/hybrid ventilation
  - Active:
    - BMS to control and manage conditions (e.g., setting, presence, lux level) and energy fluxes (including improved efficiencies in the heat recovery system)
    - Improved refrigeration systems
    - Efficient artificial lighting systems
- Load management: management of loads and generation matching (also with batteries) to increase self-consumption and take advantage of favorable tariffs

RES: limited exploitation of on-site RES that should be considered (e.g., PV, solar thermal collectors or min-wind turbine). Additional areas (e.g. parking shadings) were not considered.

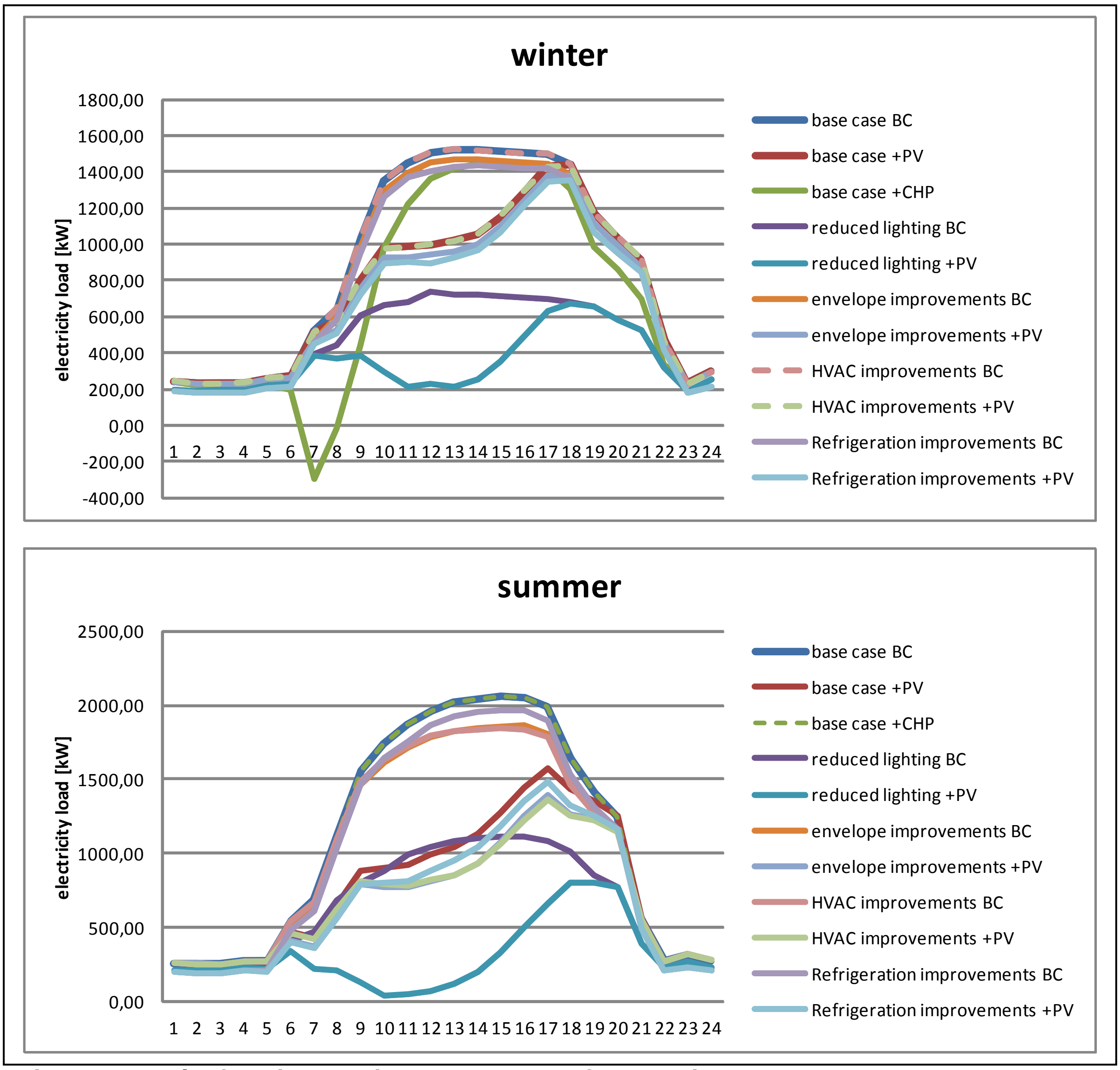

Figure 2 Results for winter and summer season for Catania

Results for reference shopping centre in Trondheim

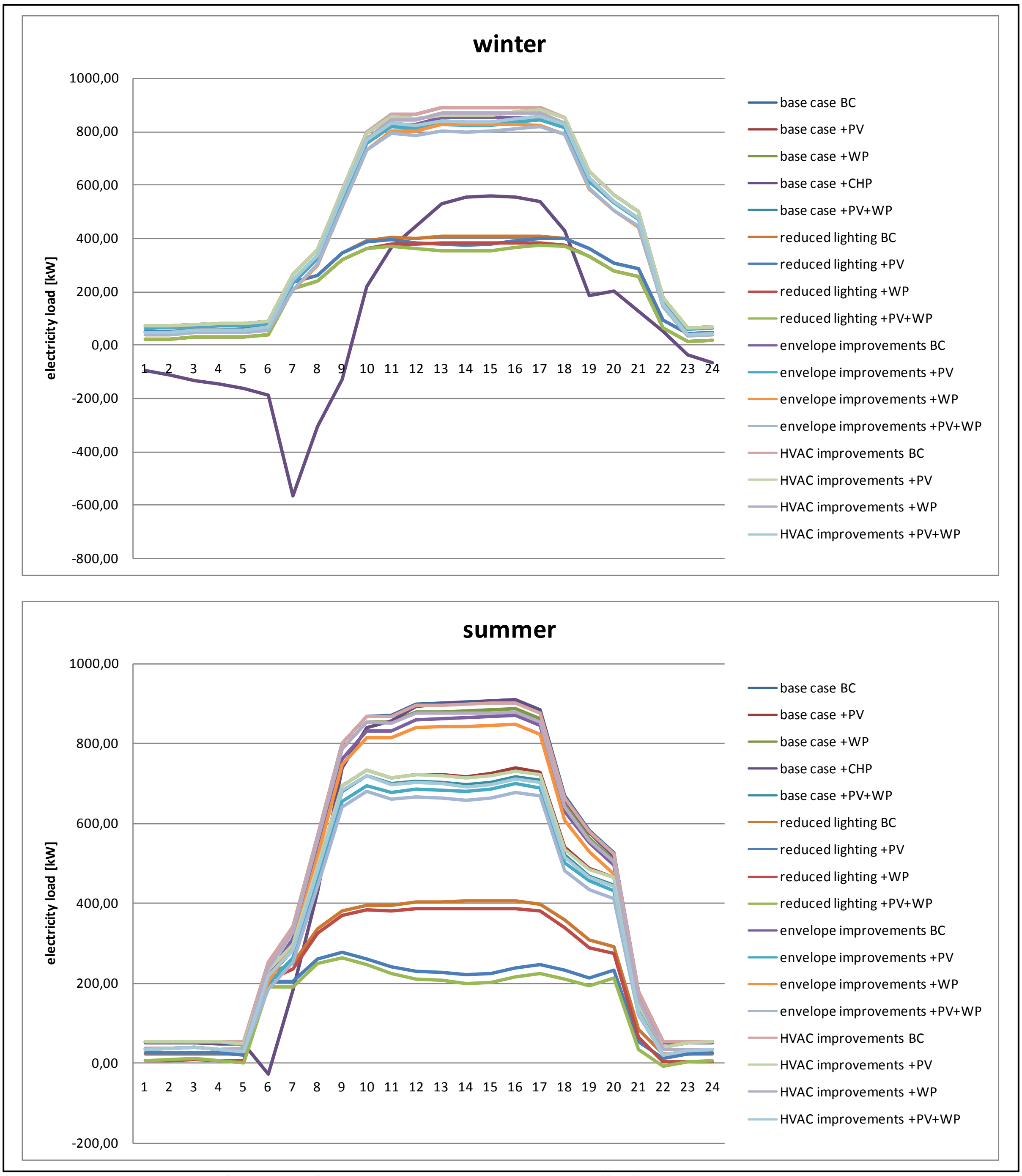

Figure 3 Results for winter and summer season for Trondheim

- The electricity demand of shopping malls in Trondheim is mainly due to lighting and appliances and HVAC. This gives an idea in where the potential lies to reduce the electricity consumption of the shopping centre.
- The demand profile shows a clear correlated character with the timetable during the working hours. Thus, the highest values are produced from 9:00 to 16:00, although there is a minimum consumption mainly due to lighting and appliances outside working hours.
- There are no renewable systems for the electricity generation connected to the distribution grid of the market which affect regulations with regard to the renewable installation typical to each distribution line.

- The urban environment and the presence of mainly low-rise buildings in the surroundings favour the installation of the photovoltaic and possibly wind turbines.

Discussion

The focus of this project is on existing shopping malls to be refurbished and buildings with a different set of solutions. Based on generic building models solution sets were adjusted to local situations. There are several aspects no linked with the own building and grid that constitute constraints or potential to the exploitation of shopping mall to provide an energy service. Among others, the most important contexts are:

- Climatology
- Urban
- Energy grid

Climatology context

The weather conditions affects ~~to~~ the consumption of electricity of the shopping centres. For example during extremely hot summer periods, there is a tendency of increased electricity consumption because of the air conditioning equipment, on the other hand in periods of strong cold mainly in winter, there is an increased in power consumption as a result of heating equipment (especially if the equipment are electric). Favorable climates also increase the potential of exploitation of natural resources, therefore potentially favoring the use of natural ventilation and natural lighting, reducing the need for mechanical/artificial systems and consequently the electricity consumption and carbon footprint.

There is a great opportunity in many cases to improve the energy behaviour of the shopping centre producing its own electricity through RES systems which take advantage of the weather conditions, and thus reduce the dependency from the grid. For evaluating the capacities of shopping malls for incorporating RES, it is necessary to evaluate climate parameters. For PV systems radiation and peak sun hours are critical elements. The solar radiation on the surface is fundamental to determine the potential production, and the time distribution; additionally, the solar radiation on each building surfaces is important to understand the shadow created by the surrounding elements. For wind turbines, the wind speed is the potential wind speed expected in a completely flat and open, typically specified 30 meters above the soil, independently of the roughness. However, attention must be paid to the fluctuation and variability of conditions.

Urban context

Three types of urban context are considered: Urban context, suburban context and isolated context. Each location is characterized by specific conditions that affect the expansion of the capacity of the grid and especially to the use of renewable energies.

- Urban context: the network capacity is often saturated because of the need to ensure energy supply to all users of a city, which can limit the installation of new power generation sources. In the case grid admits new energy power, it is needed to evaluate if the network may have reached maximum capacity permitted for renewable power. Normative usually fixes limits to this type of energy in order to avoid producing quality problems in network such as interruptions affecting energy availability due to the dependence of climatology conditions and disturbances in the wave associated to the own facilities of RES. Furthermore, the installation of solar panels may be limited by the shading produced by the surrounding buildings or by the limited space available. The application of wind turbines is restricted by the low wind speed achieved in cities and regulations.

- Suburban and isolated context: The installation of solar panels and wind turbines are promising in this context for the great availability of space as well as the excellent weather conditions (exposure to sun and wind). In these locations, the installation of RES could cover the shopping mall energy demand, especially for certain periods of time. In the case of isolated areas, which refer to small municipalities and industrial parks, the requirement for the installation of grid-connected renewable is the proximity of a network connection.

Energy grid context

The characterization of the energy grid context of a specific location is useful to understand how the electricity is generated, what is the typical expected profiled time of abundance or scarcity of electricity, the legislative framework and the tariffs. This information is useful to propose solutions for how shopping malls could provide potential services to the grid. Once the energy context is characterized it is possible to evaluate investment in RES, storage, peak shaving, peak shifting that could be considered a service from the shopping mall to the grid while also benefitting the mall. The normative trajectory of each country, and even in each region, has conditioned the electricity profile of a location. This information can provide a general idea of the reliability in new business around renewable energies.

Based on load matching and grid interaction indicators the results are shown in Table 1 and 2. It can be seen that energy supply options (PV, WP and CHP) have a very large influence. CHP is especially in Trondheim resulting in large LMavg factors (in summer and in winter). The retrofitting solutions concerning improvements (lighting, envelope, HVAC, refrigeration) combined with PV show highest LMavg values for reduced lighting loads (LG) in all three cases. The load match indicator is sensitive to the time resolution considered, i.e. the higher the time resolution, the higher is the load match and vice versa.

Table 1 Load matching indicators (LMavg) for the three cases

LMavg		**base case (BC)**			**improvements**			
					Reduce lighting (LG)	**Envelope (EN)**	**HVAC**	**Refrigeration (RF)**
		+PV	**+WP**	**+CHP**	**+PV**	**+PV**	**+PV**	**+PV**
Valladolid	winter	6%	2%	9%	12%	7%		
	midseason	13%	2%	15%	24%	14%		
	summer	19%	2%	20%	32%	20%		
Trondheim	winter	0.7 %	14.7 %	138.5 %	1.5 %	0.7 %	0.7 %	
	midseason	5.3 %	12.1 %	9.3 %	11.0 %	12.9 %	12.3 %	
	summer	12.6 %	13.4 %	66.2 %	26.0 %	5.5 %	5.3 %	
Catania	winter	9,7 %		20,9 %	19,7 %	10,2 %	9,7 %	10,4 %
	midseason	14,5 %		6,0 %	27,4 %	15,4 %	14,8 %	15,6 %
	summer	20,2 %		0,5 %	36,4 %	22,0 %	21,8 %	21,5 %

Table 2 Grid interaction (GI) for the three cases

GI		**base case (BC)**			**improvements**			
					Reduced lighting (LG)	**Envelope (EN)**	**HVAC**	**Refrigeration (RF)**
		+PV	**+WP**	**+PV**	**+PV**	**+PV**	**+PV**	**+PV**
Valladolid	winter	30%	34%	31%	21%	31%		
	midseason	24%	34%	24%	25%	23%		
	summer	30%	34%	30%	20%	28%		
Trondheim	winter	39.3 %	40.9 %	57.6 %	38.2 %	39.6 %	39.3 %	
	midseason	40.0 %	41.3 %	45.3 %	37.6 %	40.0 %	40.0 %	
	summer	40.5 %	41.6 %	41.7 %	37.9 %	40.3 %	40.6 %	
Catania	winter	29,7 %	n.a.	39,3 %	24,2 %	29,4 %	29,7 %	30,5 %
	midseason	27,7 %	n.a.	35,9 %	24,8 %	26,7 %	27,4 %	28,7 %
	summer	29,4 %	n.a.	36,6 %	28,6 %	28,0 %	28,0 %	30,3 %

Conclusions

After studying 3 reference shopping centres throughout Europe it was possible to verify that there is a significant potential for improvement in the interaction between the centres and the power grid. Moreover, key aspects which allow improvements of the current interaction and the capacities that these types of buildings could give as suppliers/providers of services to the grid were identified and quantified.

- The replacement of low efficiency, old or bad dimensioned components, such as lighting or HVAC systems, allow to improve the energy efficiency of the building, in this way there is a great potential of improvement in terms of electrical reduction.
- This is also possible through the improvement of the enclosures reducing the thermal losses and thus the electrical consumption of HVAC systems and through control and management systems which allow to manage the demand in each period of time optimizing the way in which the shopping centre consumes/distributes the electricity, all these measures allow to reduce the electrical consumption of the shopping centre in terms of lighting, heating, cooling, etc.
- Other alternatives such as the energy storage allow to store energy in case a surplus of energy in renewables energies or when the grid is in "valley period" with low electricity demand and then use it in periods when is needed by the shopping centre itself or by injecting it back to the grid in peak periods.
- With the integration of renewables is possible to reduce the energy consumption and thus the electrical demand from the grid to which the shopping centre is connected through self-consumption.
- Cogeneration systems are also very useful in terms of self-consumption and reduction of demand from the grid, producing at the same time electricity and thermal energy which allow also to decrease the electrical consumption in case of electrical HVAC systems.

The results will help to optimize solar energy production integrated in shopping centres, by being able to optimize self-consumption, reducing the energy need to generate and deliver additional electricity through while also being able to benefit from injecting the surplus of energy into the grid. Additionally, the match between production and demand could be improved by modifying some of the flexible demand profiles and using excess electricity for additional services (e.g., e-vehicle charging station or hydrogen production) and in general exploiting times of low (i.e., overproduction) electricity prices. Therefore, shopping centres have high potential in contributing to the solution and assisting in managing the issue that have arose regarding RES integration, energy management and grid support. It would be interesting to analyze the load match according to the electricity price slots. For example in Italy and in Spain, the cost of electricity is lower over the weekends and at night

Acknowledgements

The research leading to these results has received funding from the European Community Seventh Framework Programme (FP7/2007-2013) under grant agreement n. 608678.

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Smart shopping centers, controlled emission: rooftop PV power generation for a clean metropolitan city Dhaka, Bangladesh

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Abstract

Dhaka, one of the fastest growing cities in the world has around 500 shopping centres, which use unstable electricity supply from the national grid. A medium size shopping centre having 50 shops consumes about 320kWh every day during the daytime business hours between 8am to 5pm. This study proposes a sustainable alternative to replace fossil fuel based electricity consumptions by using rooftop solar panels as renewable energy source. A standard daily load demand estimated by surveying twenty shopping centres at different locations in Dhaka city and the optimal rooftop PV power system designed and financial analysis carried out using the HOMER software. The proposed grid tied 110 kWp PV system with 30% capital subsidy, 50% soft loan and 20% investor equity can supply electricity at a cost of USD 0.0382/kWh. The rooftop system consisting 180kW generic flat plate PV and 60kW converter produces 262,000kWh of electricity a year. Because of the complex demand pattern around 22,000kWh electricity are to be purchased from the grid every year and 75,000kWh can be sold back to the grid. The initial subsidized cost for the PV power generation system is USD 133,500 and project net present cost is USD 95,174. While saving substantial amount on the electricity cost and reducing pressure on the country's limited generation capacity, the 500 installed rooftop PV systems can save 60,000 metric tons of carbon dioxide into the atmosphere. The same model of smart shopping centres can be applied in all the urban areas of the country.

Keywords
Sustainable alternative; Rooftop solar panels; Smart shopping centre

1 Introduction

Dhaka the capital of Bangladesh is one of the most populated and fast growing cities in the world with a population of 5.6 million [1]. The city suffers from the unstable supply of electricity as the country has one of the lowest per capita electricity consumption (259 kWh) in the world [2]. Although no published data is available regarding the actual number of shopping centres in Dhaka city, it is assumed that there are approximately 500 shopping centres of varying sizes from 3,500 to 890,000 square meters in 92 administrative wards [3]. For example, Samrat Shopping Complex is one of the smallest and the Jamuna Future Park is the biggest one in Dhaka. Most of the shopping centres are open six or seven day a week from 9am to 9pm and use the electricity from the national grid. Because of unreliable supply they use either their own centrally connected diesel generators for big shopping centres or individual generating units by every shop for small ones. Bangladesh adopted its complete Renewable Energy Policy in 2008 [4] having the objective to harness the potential of renewable resources and dissemination of technologies by encouraging and facilitating both public and private sector investment, hence to promote clean energy for CDM with a set target of achieving ten percent of its electricity production from renewables by 2020 [5]. This study proposes a sustainable alternative for the 500 shopping centers to replace their fossil fuel based electricity consumptions by using rooftop solar panels as renewable energy source to combat the national power crisis and to create a clean and smart Dhaka city.

1.1 Renewable energy trends in Bangladesh

As the country's fossil fuel resources are very limited and it is heavily reliant on the imported resources for electricity production, government put some initiatives in place to move towards renewables. Apart from the remarkable success in standalone Solar Home Systems (SHS) there are not many successes to highlight. Total installed renewable energy (RE) capacity is around 105MW [6], of which almost 96MW comes from standalone SHSs [7] spreading all over the country. Most of the RE projects already implemented and planned for future are off-grid mode. Study [8] show that Bangladesh has high potential for grid connected PV electricity generation. To tackle the energy shortfall by increasing the RE generation in all the rapid growing divisional cities energy ministry introduced a new regulation, which compels all the new buildings to generate at least 3% of their load demand from the rooftop solar PV [9] as a pre-requisite to get supply from the national grid. None of these solar PV systems are connected to the grid as because there is no clear policy guideline regarding the feed in tariff (FIT). Performances of these systems and owners satisfaction have not been studied yet. However, according to the national 'renewable energy policy 2008', the sustainable energy development agency (SEDA) should develop financing mechanisms and facilities by using grant, subsidy and/or carbon/CDM fund for public and private sector investments in all forms of sustainable energy generations [4].

Domestic and commercial buildings in Bangladesh have flat rooftops, which are suitable for easy installation of solar PV panels. There is a gap in research regarding the use of the flat rooftops in the country to produce electricity using the solar energy with in the existing policy framework. Therefore, the current study focuses on using the shopping center's rooftops to produce electricity from solar PV systems for their own use and selling the available excess electricity to the grid in Dhaka city.

2 Methodologies

For this study, commercial or residential buildings having at least 20 or more shops with variety of trades are treated as shopping centres. For different types of data, i.e., number of shops, types of business and day time load profile, twenty representative shopping centres of different sizes were selected from each of the five administrative zones of both Dhaka City Corporation North and South [10]. Structured interviews were conducted with the management committee of each study shopping centre during the period of February and March 2015. To maintain appropriate ethical issues, name of the shopping centres studied and management committees interviewed are not mentioned anywhere in this paper. Based on the collected data a representative shopping centre containing 50 different sizes of shops was modelled with detailed load profile serving from 8am to 5pm (Table 1). Shops are categorized into three different types (food shops, general stores and service shops) covering the whole range of trades. The running hours estimated for every electrical item in this study (Table 1) are the average values to cover the seasonal variations.

Table 1: Load assessment for the model shopping centre in Dhaka

Type of shop	Number	Load requirements	Running hours	Total load
Food shop (café, restaurant)	5	8 Florescent bulbs @ 20wt each 1 TV @ 100wt 1 Computer @40wt 1 Air conditioning* unit @ 800wt 2 Refrigerator @ 120wt each 1 Microwave* @ 1000wt each 2 Kettle* @800wt each 1 Toaster* @ 250wt 1 coffee machine @ 250wt	8 6 6 6 8 2 3 2 4	85.70kWh
General store (Stationaries, Clothing, Jewellers)	25	10 Florescent bulbs @ 20wt each 4 Electric fans @ 80wt each 1 TV @ 100wt	8 8 6 8	127.00kWh

		1 Computer @ 40wt		
Service shops (Communicat-ion, Tailors)	20	1 TV @ 100wt 6 Florescent bulbs @ 20wt each 2 Electric fans @ 80wt each	8 8 8	60.80kWh
All shops	1 Music player @ 60wt x 6 hours x 50 shops 1 Mobile Charger @ 0.5wt x 5 hours x 50 shops Shop sign boards @ 80wt x 5 hours x 50 shops Shopping center's own outer sign, internal lighting and cooling –@ 2000wt x 5 hours			48.13kWh
Total				321.63kWh
* Can be replaced by the usages of other electrical appliances, i.e. cooker				

To analyse the proposed rooftop solar PV system and its performance a grid-connected system was designed (Figure 1) using 'HOMER pro' software [11]. The net present cost (NPC) was analysed to study the feasibility of the system. The designed system was a standalone grid connected one, with no generator backup and no storage facility. Power supply or any power outage during the evening hours (5pm to 9pm) is out of the scope of this study.

The quantity HOMER uses to represent the lifecycle cost of the system is the total net present cost (NPC), which includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. Therefore, NPC includes the initial capital cost of the system components, the cost of component replacements that occur within the project lifetime, the cost of maintenance, and the cost of purchasing power from the grid. The revenue from the sales of power to the grid reduces the total NPC. Although the levelized cost of energy (LCOE) is often a convenient metric to justify the suitability of a power generating system, HOMER uses the total NPC instead as its primary economic figure of merit. In its optimization process, for example, HOMER ranks the system configurations according to NPC rather than the LCOE.

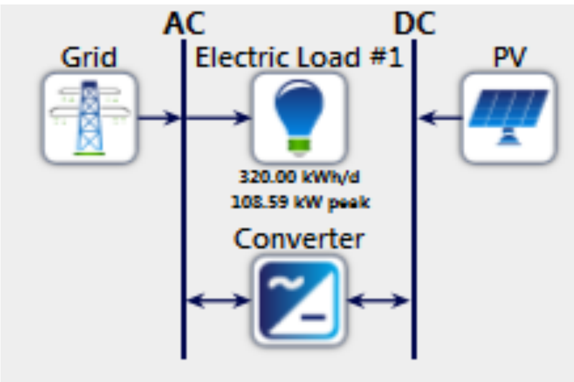

Figure 1: Schematic diagram of the grid connected rooftop solar PV system

The following equation was used to calculate the total net present cost using HOMER:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF\ (i,\ R_{proj})} \quad \ldots \qquad (1)$$

Where $C_{ann,tot}$ is the total annualized cost, i the annual real interest rate (the discount rate), R_{proj} the project lifetime, and CRF(*i*.N) is the capital recovery factor, given by the equation:

$$\mathrm{CRF}(i,\mathrm{N}) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad \ldots\ldots \quad (2)$$

Where, i is the annual real interest rate and N is the number of years.
The following equation to calculate the levelized cost of energy (COE):

$$\mathrm{COE} = \frac{C_{\mathrm{ann,tot}}}{E_{\mathrm{prim}} + E_{\mathrm{def}} + E_{\mathrm{grid,sales}}} \quad \ldots\ldots \quad (3)$$

Where, $C_{\mathrm{ann,tot}}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{\mathrm{grid;sales}}$ is the amount of energy sold to the grid. The denominator in equation (3) is an expression of the total amount of useful energy that the system produces per year. The levelized cost of energy is therefore the average cost per kilowatt-hour (kWh) of useful electrical energy produced by the system.

Both the subsidized and non-subsidized approaches as '30% capital subsidy plus 50% soft loan and 20% equity' or '50% soft loan and 50% equity' were applied for capital investment analysis. A fixed cost of either USD 21,000 or USD 30,000 was applied (Table 3) to cover the system installation, metering and wiring expenditures along with the cost of components. Cost of different system components, replacement and operation and maintenance used in this study are shown in Table 2.

Table 2: Cost of components, replacement, operation and maintenance

Generic flat plate PV initial investment cost (USD/kW)	750
Generic flat plate PV replacement cost (USD/kW)	500
Generic system converter initial investment cost (USD/kW)	300
Generic system converter replacement cost (USD/kW)	200
Solar PV and converter maintenance cost (USD/kW/yr.)	15
Rooftop system operation and maintenance cost (USD/yr.)	2000

The NREL solar radiation database [12] linked to HOMER menu was used to calculate the energy production from the PV system and the monthly average global horizontal irradiance for the study area presented in Figure 2. Various optimization and sensitivity variables were applied to obtain the optimal system configuration (Table 3) for this study.

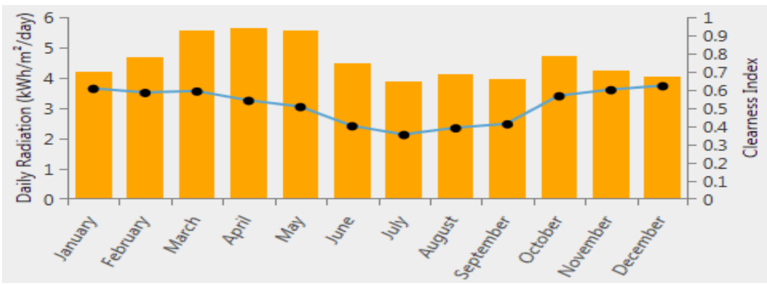

Figure 2: Monthly average global solar horizontal irradiance (GHI) for Dhaka

Table 3: Sensitivity and optimization variables

Item	Value	Item	Value
Size of PV array (kW)	140, 180, 220, 240	PV life (years)	20, 25
Converter size (kW)	40, 50, 60, 70	Interest rate	5%, 6%, 8%
Capacity shortage (%)	0, 5, 8, 10	Capital subsidy	0%, 30%
Grid power purchase price (USD/kWh)	0.10	Grid power sale price (USD/kWh)	0.10
Converter life (year)	5, 10, 15	Fixed cost (USD)	21,000; 30,000

PV derating factor (%)	60, 80	Renewable (%)	70, 80, 90, 100

3 Results and Discussion

The model shopping centre consumes approximately 320kWh of electricity on average between 8am to 5pm everyday (Table 1) and the detail load profiles illustrated in Figure 3. The average hourly load requirements vary between 20kW to 62kW, with the lowest in the morning and highest in the afternoon and the monthly highest is in the month of August (Figure 3).

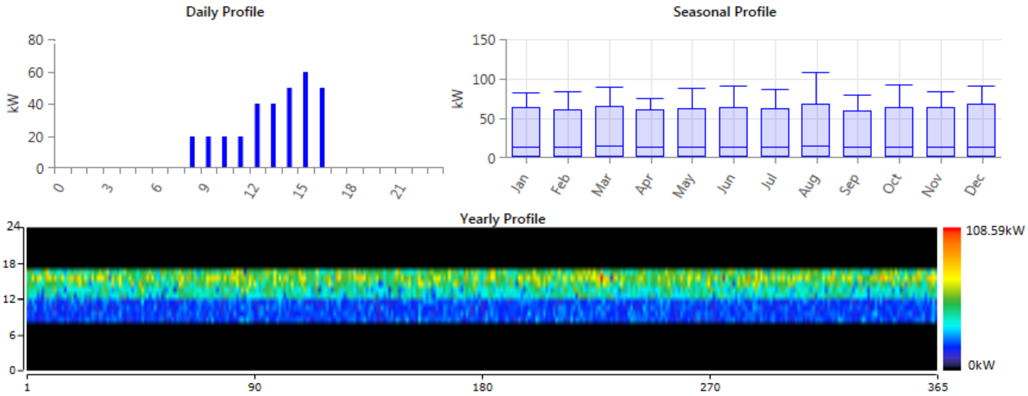

Figure 3: Daily, seasonal and yearly load profile

Homer applied 922 simulations and suggested 36 feasible PV systems considering all the optimization and sensitivity variables, economic constrain and seasonal load profiles. The optimal system architecture was the combination of 180kW PV and 60kW converter, which produces 262,622kWh electricity every year serving almost 92% of this load requirement (Table 4). This system produces energy well above the yearly requirement (approximately 117,394kWh) of the model shopping centre. However, because of the complex energy demand pattern and seasonal variation in solar resources it purchases 22,023kWh electricity every year while selling 75,866kWh back to the grid (Table 4; Figure 5). This winning system, which we analysed further in-depth was featured with 30% capital subsidy and 6% interest on soft loan along with the fixed project cost of USD 21,000.

Architecture		Cost				PV	Grid	
PV (kW)	Converter (kW)	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Production	Energy Purchased	Energy Sold
180	60.0	$0.0382	$95,174	-$2,965	$133,500	262,622	22,023	75,866
180	60.0	$0.0545	$135,674	-$2,965	$174,000	262,622	22,023	75,866
180	60.0	$0.0418	$104,174	-$2,965	$142,500	262,622	22,023	75,866
180	60.0	$0.0581	$144,674	-$2,965	$183,000	262,622	22,023	75,866
180	60.0	$0.0380	$94,751	-$1,373	$112,500	262,622	22,023	75,866
180	60.0	$0.0543	$135,251	-$1,373	$153,000	262,622	22,023	75,866

Figure 4: HOMER generated PV system architecture and performance

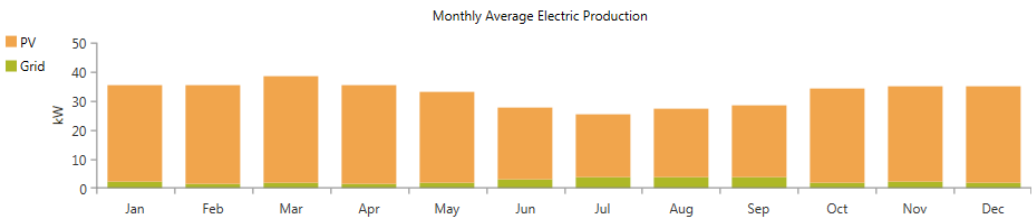

Figure 5: Electricity produced by the PV system and power purchased from the grid

Table 4: Monthly and annual net energy sales to the grid

Month	Energy purchased (kWh)	Energy Sold (kWh)	Net energy purchased (kWh)	Peak Demand (kW)	Energy charge (USD)
Jan	1692.1	6623.8	-4931.7	63.668	493.17
Feb	966.51	6157.7	-5191.2	52.106	519.12
Mar	1315	7246.9	-5931.9	55.407	593.19
Apr	1230	7352.9	-6122.8	60.485	612.28
May	1494.4	7594.6	-6100.2	57.265	610.02
Jun	2293.5	5689.5	-3396.0	71.207	339.60
July	2728.7	4845.7	-2117.0	68.562	211.70
Aug	2839.4	5099.3	-2259.9	98.617	225.99
Sep	2750.0	5103.6	-2353.6	61.463	235.36
Oct	1524.8	7079.4	-5554.6	59.863	555.46
Nov	1615.6	6578.5	-4962.9	71.011	555.46
Dec	1572.6	6494.3	-4921.8	65.638	492.18
Annual	***22023***	***75866***	***-53844***	***98.617***	***5384.40***

Considering the economic profiles HOMER ranked the system at the top with the best NPC of USD 95,174 while considering subsidized (30%) capital cost for this system USD 135,500 and COE USD 0.0382/kWh (Figure 4; Table 5). For the same system configuration without any capital subsidy COE is USD 0.0545/kWh (Figure 4). Although the system's performance remains the same, its initial capital cost is USD 174,000 and NPC is USD 135,674 (Table 5).

Table 5: Subsidized and non-subsidized PV systems financial details

	Component	Capital (USD)	Replacement (USD)	O&M (USD)	Salvage (USD)	Total (USD)
System with 30% Capital Subsidy	PV	94,500	0	23,270.00	0	117,770
	Grid	0	0	-69,606.00	0	-69,606
	Converter	18,000	5091.30	3,878.30	-958.23	26,011
	Other	21,000	0	0	0	21,000
	System	***133,500***	***5,091.30***	***42,459.00***	***-958.23***	***95,174***
System with no Capital Subsidy	PV	135,000	0	23,270.00	0	158,269
	Grid	0	0	-69,606.00	0	-69,606
	Converter	18,000	5,091.30	3,878.30	-958.23	26,011
	Other	21,000	0	0	0	21,000
	System	***174,000***	***5091.30***	***-42,459.00***	***-958.23***	***135,674***

The optimal PV system is capable of serving the year round AC primary load demand of the shopping centre between the designated hours of the day (Figure 6) while approximately only 8% to be purchased from the grid (Figure 5 & 7). Figure 7 clearly shows the efficiency of the system comparing the primary load requirement, system power generation, grid purchase and sales to grid.

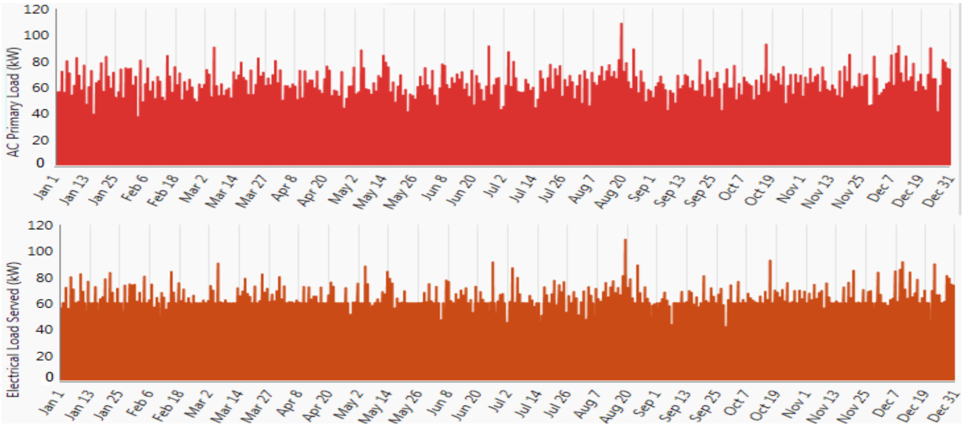

Figure 6: Monthly AC primary load and load served by the PV system

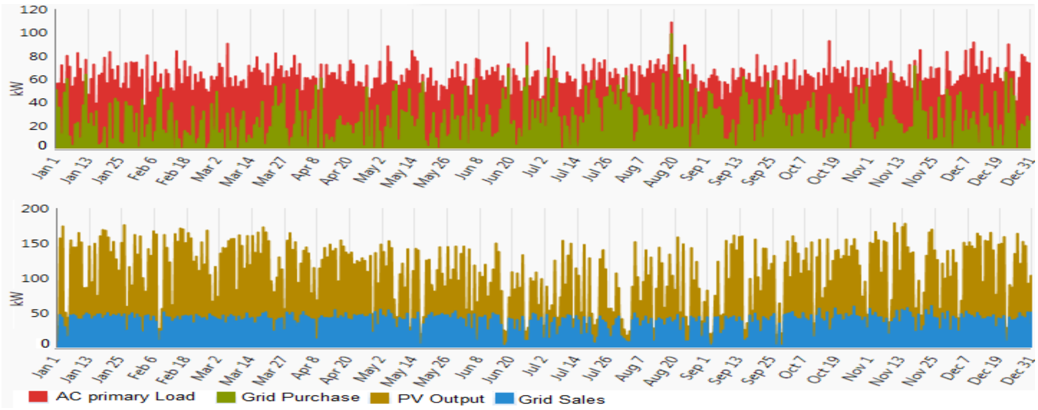

Figure 7: Monthly primary load requirements, power generation by PV, power sales to grid and purchase from grid

Analyzing the time series seasonal resources and system performance data HOMER explains the complex nature of power generation and load served by the PV system and electricity sales and purchase to/from the grid. For example, as in Figure 8 & 9, because of different primary load requirements by the model shopping centre and variations in global solar irradiance over Dhaka (0.90kW/m2 and 0.22kW/m2) during the same date (the 18th) and time (1pm) of two different months of winter and summer (January and July) the proposed system's performance varies a lot. During that particular hour in January PV system produces 168kW electricity and serves a primary load of 52.8kW while selling 7.19kW to the grid. The values are 30.86kW, 24.6kW and 3.17kW respectively for the month of July. However, HOMER summarizes the monthly profile of the system (Table 4), which we use to determine the performance and financial viability of the system.

Date	Time	Global Solar (kW/m2)	Generic flat plate PV Power Output (kW)	AC Primary Load (kW)	Grid Purchases (kW)	Grid Sales (kW)	Total Electrical Load Served (kW)	Renewable Penetration (%)	Excess Electrical Production (kW)	Total Renewable Power Output (kW)	Inverter Power Input (kW)
Jan 18	11:00 AM	0.80	153.65	22.76	0.00	37.24	60.00	256.09	86.99	153.65	66.67
Jan 18	12:00 PM	0.88	165.35	23.44	0.00	36.56	60.00	275.58	98.68	165.35	66.67
Jan 18	1:00 PM	0.90	168.92	52.81	0.00	7.19	60.00	281.53	102.25	168.92	66.67
Jan 18	2:00 PM	0.79	150.88	36.71	0.00	23.29	60.00	251.47	84.22	150.88	66.67
Jan 18	3:00 PM	0.59	116.15	62.47	2.47	0.00	62.47	185.94	49.48	116.15	66.67
Jan 18	4:00 PM	0.37	75.71	64.64	4.64	0.00	64.64	117.14	9.05	75.71	66.67
Jan 18	5:00 PM	0.22	57.22	43.43	0.00	8.07	51.50	111.11	0.00	57.22	57.22
Jan 18	6:00 PM	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan 18	7:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 8: PV system performance in January

Date	Time	Global Solar (kW/m2)	Generic flat plate PV Power Output (kW)	AC Primary Load (kW)	Grid Purchases (kW)	Grid Sales (kW)	Total Electrical Load Served (kW)	Renewable Penetration (%)	Excess Electrical Production (kW)	Total Renewable Power Output (kW)
Jul 18	11:00 AI	0.24	33.13	22.84	0.00	6.98	29.82	111.11	0.00	33.13
Jul 18	12:00 PI	0.23	32.57	26.16	0.00	3.16	29.31	111.11	0.00	32.57
Jul 18	1:00 PM	0.22	30.86	24.60	0.00	3.17	27.77	111.11	0.00	30.86
Jul 18	2:00 PM	0.24	33.80	29.13	0.00	1.30	30.42	111.11	0.00	33.80
Jul 18	3:00 PM	0.23	32.01	61.77	32.96	0.00	61.77	51.82	0.00	32.01
Jul 18	4:00 PM	0.10	13.62	66.08	53.82	0.00	66.08	20.61	0.00	13.62
Jul 18	5:00 PM	0.09	12.70	48.41	36.97	0.00	48.41	26.24	0.00	12.70
Jul 18	6:00 PM	0.09	11.91	0.00	0.00	10.72	10.72	111.11	0.00	11.91
Jul 18	7:00 PM	0.01	1.32	0.00	0.00	1.19	1.19	111.11	0.00	1.32

Figure 9: PV system performance in July

The proposed optimal PV system, combination of 180kW PV and 60kW converter offers the best NPC with lowest possible capital investment compare to the other possible system combinations suggested by HOMER (Figure 10).

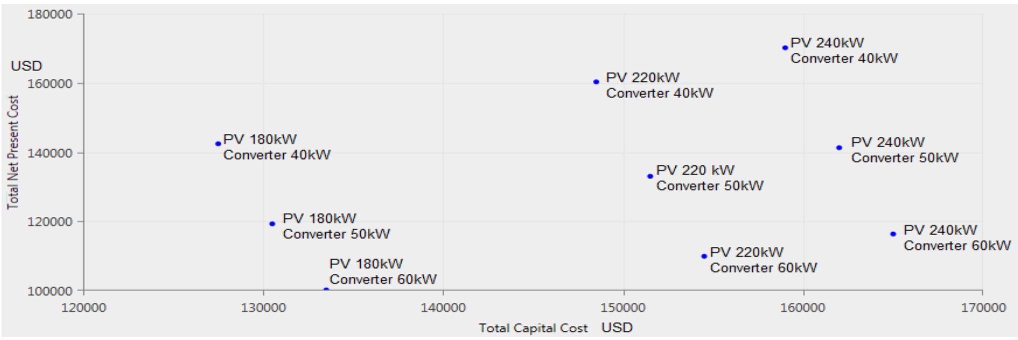

Figure 10: Optimization plot for possible PV system configurations

Cost of small scale commercial electricity supplied by the grid is around USD 0.07 to USD 0.09/kWh in Bangladesh [13]. While using the electricity from the proposed PV system at a lower cost (USD 0.0382/kWh) businesses will save money and at the same time will earn from the power sales to the grid. Study [8] show that a grid connected PV system can generate electricity at a cost of USD 0.15/kWh with no capital subsidy applied and including all the cost of land acquisition and infrastructure development.

Amount of emission reduced by the proposed PV system depends on the type of conventional energy it replaces. HOMER suggests that yearly 34,000kg of carbon dioxide, 147kg sulphur dioxide and 72kg nitrogen oxide can be reduced using the proposed PV system. Having installed such PV system in all shopping centres Dhaka city can reduce at least 60,000 metric tons of carbon dioxide it to its atmosphere while reducing tremendous pressure on the national grid and thus this can be the most sustainable approach towards a smarter city.

3.1 Problems to overcome

Some shopping centres may not have enough rooftop space to install the required capacity of solar PV array. During the interview the shopping centre management committee expressed their interest to use the available nearby building rooftops as a long-term lease or rent. Although, the renewable energy policy is in place but the implementation has not been very encouraging so far. Government needs to create transparent and easy accessible subsidy funds for this purpose. Moreover, clear guidelines are essential for commercial banks regarding the soft loan in such RE projects. Encouraging feed-in-tariff (FIT) or power purchase agreement (PPI) regulations should be added in the national renewable energy policy.

Updating the existing renewable policies to meet the above points and good application practice is the key to attract investors in such ventures. Study [14] outlines that the policy attributes of most countries become more similar in the policy types applied (dominance of feed-in tariffs) and in their scope of implementation (differentiation for installation sizes and ‘stacking’ of multiple instruments). Mathewes et. al., [15], highlight that the issue of public vs. private financing is not yet adequately explored and discuss the ways in which private financing could be mobilized to drive the energy industrial revolution that is needed if climate change mitigation is to succeed. However, there is consensus among policy makers that the transition to a low carbon economy will not happen without the involvement of private institutional investors [16, 17].

Conclusion

The recent increase in PV usages and decline in price globally creates the momentum for shifting from the conventional fuel based power generation to PV based renewable energy solutions. This is a good opportunity especially for the countries suffering acute energy crisis. Where large-scale institutional investment may not be possible immediately for RE projects in countries like Bangladesh, small-scale affordable innovative projects can offload the burden of the fossil fuel dependency. The proposed PV system can be standardized and replicated to attain a level of economies of scale where the recommended subsidy can be eliminated in future. Rooftop PV power generation systems installed on all shopping canters in greater Dhaka can make the city cleaner and smarter.

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Improving Energy Efficiency in Existing Health Care Facilities

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Abstract

It is estimated that more than 70% of commercial and public buildings still standing in 2050 will have already been constructed. Therefore, enhancing energy performance in existing facilities becomes an imperative need. Indeed, public and private sector organisations seek to reduce energy consumption while achieving carbon emission and operational cost savings through refurbishment and retrofitting interventions. The impact of these projects is crucial especially for organisations managing estates of significant size, such as the National Health Service (NHS) in the UK which occupies 28.4 million square metres, excluding primary care premises.

This paper aims to explore the challenges of improving energy efficiency in existing health care facilities by utilising secondary quantitative and primary qualitative information. Initially, the study provides a critical review of recent and current developments in the sector in order to establish an understanding of the appraisal, planning and delivery of such projects. Then, various obstacles are identified associated with the procurement of refurbishment and retrofitting projects, financing energy efficiency measures and implementation complexity of energy saving schemes. The paper proposes the need for a holistic approach which focuses on the entire estate rather than individual facilities. Such an approach would facilitate the development of energy efficiency programmes offering guaranteed energy savings and value for money. The complexity involved could be dealt with by improved process transparency and excellence in project management.

Key Words

Energy; Efficiency; NHS; Project Management; Refurbishment

Introduction

In line with the current call for sustainable development, improving energy efficiency in commercial buildings has been supported by many governments worldwide. Building regulations and other statutory requirements are constantly reviewed and amended to enable the achievement of energy efficiency targets for new developments. In March 2007, the Heads of States and Governments of the 27 EU Member States adopted a binding target of increasing energy efficiency to achieve a reduction of 20% of total energy use (below 2005 levels); 20% reduction of Greenhouse Gases (14% below 2005 emissions) and a 20% contribution of Renewable Energies to total energy use (11.5% above 2005 contribution) [1]. A year later, the Climate Change Act (CCA) was passed in the UK setting a 2050 target to reduce emissions by at least 80% in 2050 from 1990 levels. Given that building facilities are responsible for 40% of energy consumption and 36% of EU CO_2 emissions, the energy performance of buildings is highly critical to the achievement of these targets [2]. Accordingly, building regulations and other statutory requirements have been constantly reviewed and amended to enable the achievement of energy efficiency targets for new build developments. However, the potential of retrofitting and energy-efficiency upgrade projects has also been highlighted, with studies suggesting that these projects can result in buildings as energy efficient as new facilities developed according to best practice for low-energy buildings [3]. This presents a significant opportunity but also, given that in the UK it is estimated that 70% of existing commercial and public buildings property still expected to be standing in 2050 [4], a pure necessity.

Improving the energy performance of existing commercial buildings can be facilitated by various policies and measures which broadly fall into three main categories [5]. These include direct interventions through public policies and minimum standards, instruments that promote price reduction incentives and schemes that aim at raising the awareness about energy related issues. However, as highlighted by [6], notwithstanding energy efficiency measures investing in building energy-efficiency upgrades is ultimately a business decision. This decision is based on the comparison between the expected return on energy efficiency upgrades and the returns earned from other investment opportunities competing for the organisation's capital. For commercial and public buildings in particular, this decision is further influenced by various factors external to the organisation such as the economy, technological advances, government policy and the service providers industry.

Today, it is acknowledged that retrofitting of commercial buildings can result in substantial reductions in energy use and can be achieved at acceptable costs [3]. Still, many authors have suggested looking away from financial benefits and considering further possible drivers pushing positive reaction according to energy saving action [7]. Additionally, to accurately evaluate the economic effectiveness of an energy efficiency programme there is a need to measure energy consumption before and after the energy upgrade project. However, according to the [8] and [9] this is particularly challenging since often, energy consumption is calculated and not measured and as a result it does not take into consideration rebound effects, free rider effects, reduced savings due to insufficient technical quality or users behaviour. The latter has been also emphasised by [10] and [5] who suggest that the impact of energy behaviours is usually neglected although it has been referred as being as significant as that from technological solutions. These, together with the unique characteristics and needs of a specific building [11] are some of the challenges in developing a robust and comprehensive retrofit strategy. Other challenges include managing the supply chain, addressing the poor quality of workmanship, the possibility of technical failure and dealing with disturbance [12].

Removing the barriers that hinder the uptake of renovation measures is a prerequisite to realising the energy saving potential of retrofitting and energy-efficiency upgrade projects. Barriers could be financial, administrative or related to the capacity of the service providers to support decision making [12]. An investigation of these barriers would allow organisations to deal with challenges and improve energy efficiency in existing buildings. This would present an opportunity especially for organisations managing estates of significant size, such as the National Health Service (NHS) in the UK which occupies 28.4 million square metres, excluding primary care premises [13]. Indeed, the UK Green Investment Bank [14] suggests that potential annual savings for the NHS through energy efficiency measures could be £150m per annum. This would be very critical as these savings could be invested in improved patient care. This paper aims at identifying and investigating the challenges of improving energy efficiency in existing Health Care facilities. It presents the findings of an exploratory research being undertaken in the UK. The paper starts with an overview of the Health Care sector in the UK and the relevant energy reduction strategies. It proceeds to describe the main aspects of research methodology and then discuss the main findings. It concludes with a summary of the key issues discussed and recommendations for further research in the area of energy efficiency in the UK Health Sector.

The UK's Carbon Targets

The UK government has taken steps to limit the emission of greenhouse gases, including signing up to the Kyoto Protocol in 1995. More recently, the Climate Change Act (CCA) was passed in the UK in 2008 in order to develop an economically credible emissions reduction path. The CCA includes a 2050 target committing the UK to reduce carbon emissions, gradually as indicated in Table 1, by at least 80% in 2050 from 1990 levels.

Table 1: Climate Change Act Targets

Year	% Carbon Emission Reduction Below Base Year
2020	34%
2025	50%
2050	>80%

The CCA is a response to the European Union Directive 2012/27/EU. The Directive calls for all EU Member States to establish a "long-term strategy beyond 2020 for mobilising investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock" for both private and public sectors [15]. With this in mind and such drastic emission reductions required, a holistic, cost effective approach should be taken. A sustainable culture should be embedded within large organisations, such as the NHS. These organisations could be the primary focus of the government and relevant initiatives, as this is where energy efficiency measures will be most effective and where the most radical changes will be observed.

However, there are many challenges including increased workload, expanding estates and portfolios, as well as a lack of capital [16]. Also, at present there is a consensus that the UK government is not fully committed to energy performance and reducing emissions. This is down to the axing of funding for the energy saving programme Green Deal and the revision of energy subsidies including Feed-in Tariffs and the Renewable Obligation scheme. The energy cuts are even more unwelcome given the Paris Climate Conference – Conference of Parties 21 (COP 21) in December 2015 where 195 countries, including the UK, adopted the first universal, legally binding global climate deal. The main aim of COP21 is to restrict rising global average temperatures to below 2°C by the end of the century. Emission reduction targets will be achieved through short-term commitments called Intended Nationally Determined Contributions (INDCs). The INDCs could give the UK government an opportunity to provide support to organisations and act as a global leader for COP21.

NHS and Carbon Targets

The NHS is the largest employer in Europe, with over 1.3 million staff and deals with over 1 million patients every 36 hours [17]. A report published by the NHS' Sustainable Development Unit (SDU) detailed that the NHS' Carbon footprint baseline was 22.8 $MtCO_2e$, down from 25.7 $MtCO_2e$. This equates to an 11% reduction against a 2007 baseline, overachieving on a 10% target. In order to hit the 2020 34% reduction CCA target, the NHS' carbon footprint will have to be decreased by a further 6.6 $MtCO_2e$. [18] The emissions for NHS England and the respective targets are displayed graphically in Figure 1.

Figure 1: NHS England Carbon Footprint [18]

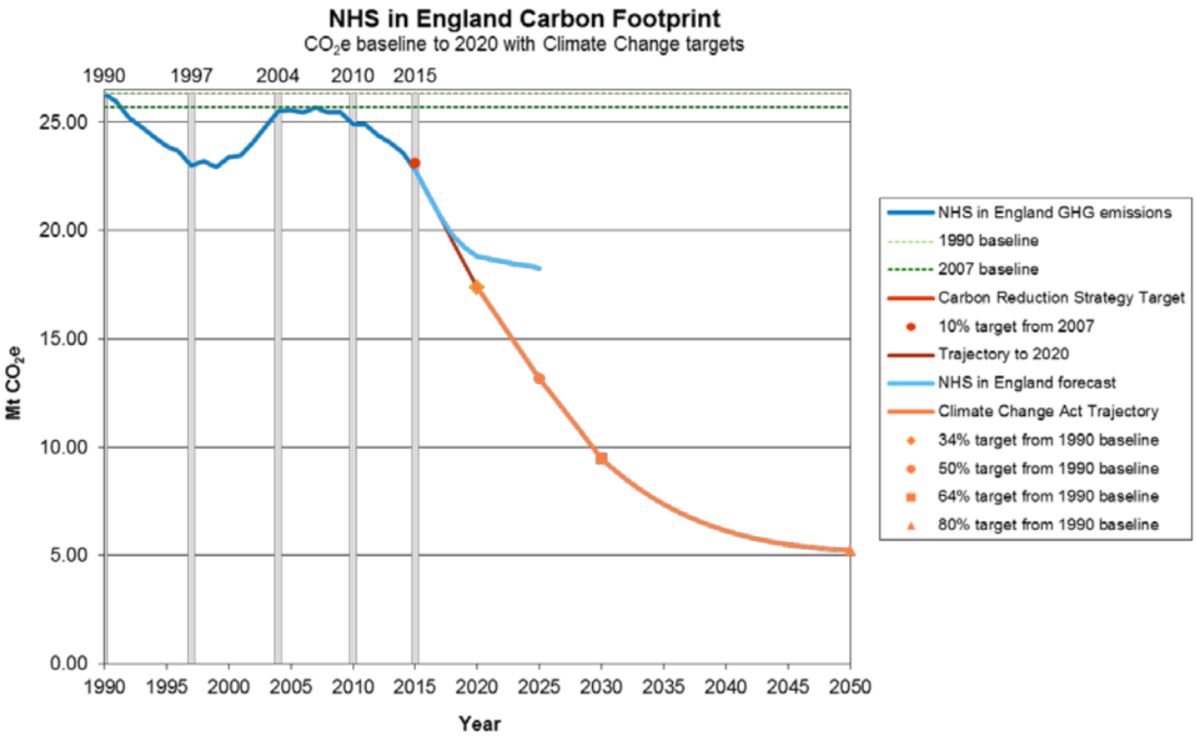

Figure 1 demonstrates clearly how challenging it will be for the NHS to achieve the 2050 target, especially as the forecast does not follow the trajectory to 2020 for the CCA target. Having the 80% 2050 reduction target was a start, but work needs to be done now on how that target is going to be met. A common approach that could be shared and rolled out nationwide would be most efficient, with uptake and success being easily monitored. Going forward, if NHS Trusts are constructing new sites/buildings, they will be installing energy efficient lighting, heating systems as it is standard practice. However with 70% of commercial and public buildings in 2050 having already been constructed, retrofitting measures need to be taken. This will be undoubtedly a significant cost element and a lot of care will need to be taken not to disrupt the hospital business; however it simply has to be done if the 2050 target is to be achieved.

The Sustainable Development Strategy for the Health, Public Health and Social Care System 2014-2020 was launched in January 2014. It describes the vision for a sustainable health and care system by reducing carbon emissions, protecting natural resources, preparing communities for extreme weather events and promoting healthy lifestyles and environments. [19] Having a Sustainable Development Management Plan (SDMP) which has been approved by the board is an essential part of the Sustainable Development Strategy. A SDMP is an important document to aid NHS Trusts meet carbon reduction targets and make efficiency savings. The information in Table 2 was compiled using 2014/2015 Estates Return Information Collection (ERIC) data. The ERIC database includes data submitted by 241 NHS Trusts.

Table 2: NHS SDMP Figures

	Board Approved Sustainable Development Management Plan (SDMP)	**Carbon Reduction Target**
Response	Yes – **170 Trusts**	1. No target included in plan – **18 Trusts**
		2. Target included but not on track to be met – **57 Trusts**
	No – **71 Trusts**	3. On track to meet target – **103 Trusts**
		4. No Sustainable Development Management Plan or Carbon reduction Plan – **63 Trusts**

Guidance for creating a SDMP was issued in December 2011 by the NHS SDU. As per Table 2, 170 out of 241 Trusts equates to 70.5% uptake. However, only 42.7% of the Trusts included are on track to meet their Carbon Reduction Target. 57 Trusts have a Carbon Reduction Target included in their SDMP that is not on track to be met, however it is not known how far off the target they are. Overall, over one third of NHS Trusts do not have a board approved sustainable development management plan or a carbon reduction target within their SDMP. These results are rather surprising given that the importance of the SDMP has been highlighted extensively by the NHS SDU and reveal that the use of the Plan among NHS Trusts needs to be further promoted. Indeed, the adoption of an SDMP and its monitoring could result in a systematic approach towards the common goals of carbon reduction. However, although SDMPs are required to be set up by individual NHS Trusts, the development of a more detailed implementation strategy and target monitoring policy would enable the NHS SDU to focus on performance and progress against the agreed targets.

Research Methodology

The research study presented in this paper aims to identify and investigate the challenges of improving energy efficiency in existing Healthcare facilities. Epistemologically, the research is mostly interpretive, accepting that knowledge can be developed through different interpretations of the same phenomenon [20]. Establishing a general understanding of the NHS setting, carbon and energy reduction targets was possible through a literature review. The use of secondary quantitative data was also necessary in order to define more effectively the research problem. This aspect of the study represents the positivistic element of the research.

Still, to explore the challenges of improving energy efficiency in existing Healthcare facilities the research had to focus on the decision making process of organisations implementing energy efficient measures and examine the impact of these on the reduction of energy use. To this end, there was a requirement to examine the perception of key actors involved in the decision making process of Health Care Trusts. This means that the conditions under which decisions are made had to be examined in order for the understanding of the phenomenon to be established in its context. This according to [21] justifies the selection of an interpretive epistemological position. Additionally, [22] emphasise that one of the major qualities of interpretive research is its capability of answering not only the questions asked, but also providing answers to research questions not originally asked. This approach ensured that important factors which perhaps were not identified in the literature, or considered to be negligible, were not overlooked.

The research adopts a triangulation approach in the process of data collection and analysis. The benefits of triangulation in exploratory studies have been widely emphasised. It can increase data validity, address shortcomings of individual methods, provide a wider scope of data and facilitate investigating complex themes [23, 24]. Following the analysis of the secondary quantitative information, data collection was carried out in three stages. First a qualitative questionnaire study was undertaken eliciting information from NHS trusts regarding the implementation of any energy efficiency measures. The questionnaire is included in Appendix 1 of this paper and was submitted to 25 NHS Trusts as a Freedom for Information request. As such, the response was reasonably high, with 17 out of 25 questionnaires returned by the time this paper was written. The second stage included conducting a total of 5 unstructured interviews with Asset Managers and Heads of Estates in order to probe further into the barriers hindering the uptake of these measures. The issues and themes included in the unstructured interviews were similar to those included in the questionnaire. Finally, the research employed a case study to investigate some of the challenges NHS Foundation Trusts could face when looking at the feasibility, overall impact and implementation of energy efficiency projects.

Data Analysis

Primary and secondary data has been used to compile this paper. Data analysis of ERIC information was undertaken as well as questionnaires being issued (Appendix A) to Trusts and interviews with NHS staff being carried out.

NHS Trust Questionnaire

Of the questionnaires completed, the following results were calculated:

Table 3: NHS Trust Questionnaire Result

Technology/Energy Efficiency Measure Listed	% of Participants Listed Technology
Combined Heat and Power (CHP)	40%
Heating/cooling system optimised	53%
Lighting	73%
New windows/insulation	47%
Solar PV	27%
Behaviour change programme	27%
BMS Improvement	20%

Lighting was the most popular technology that has been implemented, which is not surprising considering the low payback periods and reduced maintenance costs due to longer lifetimes than conventional lamps. CHP is also popular, again not surprising as hospitals have a large heat and electricity demand. HVAC system optimisation and window replacement/insulation of buildings projects have been implemented by approximately half of the Trusts questioned. However, window replacement or insulation could be improved through different avenues instead of an energy efficiency programme, possibly from capital works or ageing building fabric which would enhance uptake.

It is predicted that Solar PV will have less of an uptake due to the likelihood of Feed-in Tariffs being reduced by the UK government in early 2016. Regarding behaviour change programmes, it is anticipated that more NHS Trusts will be looking to implement such a scheme when having adopted particular energy efficiency measures. Interaction with staff to take simple actions such as turning off lights or closing doors would a positive result on energy consumption for no cost. If a lighting project is undertaken, the new lights should be more efficient; however, the full efficiency potential will not be realised if the lights are left turned on in unoccupied areas. Staff engagement is key and buy in from employees and building users must be achieved.

Interestingly, regarding obstacles to energy efficiency schemes, a third of participants mentioned funding/financing projects and 13% procurement as a possible hindrance.

Also, 62% of participants have a board approved SDMP, with 61% of these Trusts on track to meet the Carbon reduction target.

ERIC Data Analysis

Using ERIC data, tables 4, 5 and 6 have been composed.

Table 4: NHS England Energy Consumption Comparison (Electricity)

2012/2013 Electricity Consumption (GWh)	2013/2014 Electricity Consumption (GWh)	2014/2015 Electricity Consumption (GWh)
2,641	2,445	2,175

Table 5: NHS England Energy Consumption Comparison (Gas)

2012/2013 Gas Consumption (GWh)	2013/2014 Gas Consumption (GWh)	2014/2015 Gas Consumption (GWh)
7,224	6,984	6,702

Note that the electricity consumption figures in Tables 4, 5 and 6 do not include renewables.

Table 6: NHS England Energy Consumption Trend

2012/2013 Energy Consumption: Gas + Electricity (GWh)	2013/2014 Energy Consumption: Gas + Electricity (GWh)	2014/2015 Energy Consumption: Gas + Electricity (GWh)
9,865	9,429	8,877

Table 7: NHS England Energy Cost Comparison

2012/2013 Total Energy Cost	2013/2014 Total Energy Cost	2014/2015 Total Energy Cost
£520,059,359	£541,158,201	£498,329,537

As can be seen in tables 4, 5 and 6, energy consumption has fallen year on year, however table 7 shows that energy cost rose between 2012/2013 and 2013/2014. This could indicate an increase in energy costs or use but could also suggest issues with reporting accuracy. The latter would be a particularly crucial issue that needs to be addressed given that reliable monitoring is the foundation for improving energy performance and efficiency.

NHS Trust Interviews

Further to questionnaires and the use of ERIC data, an interview was held to find out information about the Energy Sustainability Project implemented by an NHS Foundation Trust operating in West Midlands running five main hospital facilities of relatively significant size. The Trust had to meet budget reduction and carbon emission targets, so a project was identified and delivered to give guaranteed energy cost and carbon savings. In 2011/2012, the Trust's total annual energy spend was circa £5.2m with carbon emissions of 28,200 tCO_2e.

The following schemes were carried out:

- Lighting
- Pipework insulation
- Fixed and variable speed drives
- Refrigeration controls
- Energy display meters
- Pump replacement

- Solar PV

The Energy Sustainability Project was very successful, with an 18% reduction in energy spend and the carbon reduction target being exceeded.

An interview was also conducted with an NHS Trust operating in the North West England. The trust implemented energy efficiency measures including 3,000 T8 and T12 lamps being replaced by LED equivalent, a new main chiller and removal of electric heaters. The energy policy was also updated and the results can be seen in Table 7 below, based on ERIC data:

Table 7: Energy efficiency measures results

2013/2014 Electricity Consumption (kWh)	2014/2015 Electricity Consumption (kWh)	Difference in Electricity Consumption: 2014/2015 – 2014/2013 (kWh)
6,820,316	5,400,987	-1,419,329

Note that a CHP was also installed which contributes to a reduction in electricity consumption. Also, not only will the reduced energy costs give a saving, but operational costs will also be reduced e.g. less maintenance or more reliable plant. The ERIC data reinforces the need for accurate reporting. If a Trust regularly monitors energy consumption and submits readings to utility suppliers, the bills are not generated using estimated readings, ensuring bills are accurate and overcharging does not occur. On the other hand if energy consumption is not monitored from before an energy project is started, improvements through efficiency cannot be truly measured. This is in accordance with suggestions made by [8] and has a significant effect on assessing return on investment of energy efficiency measures implementation. However, it has to be noted that monitoring energy consumption is not the only requirement in order to assess the effectiveness of an energy upgrade project. Indeed, as highlighted by [9] and [10] the task is naturally difficult to perform accurately due to many factors such as insufficient technical quality or user behaviour, which is why a guaranteed savings scheme is favoured. In this instance, if a Trust does not make the expected savings, the Energy Service Company (ESCo) will make up the shortfall. If savings are overachieved, savings are usually split between the ESCo and Trusts, dependant on the pre-installation agreement.

Meeting NHS Sustainability Targets

In order for carbon reduction targets to be achieved, a common goal needs to be established, which has already been done in the UK via the CCA. A knowledge campaign would be also useful in order to ensure organisations and respective decision makers are aware of targets and associated legislation. Generally, these steps have been taken, however the next step is implementation and it is down to each organisation and how they manage resources to achieve the targets. This is arguably the most difficult part of the process, especially within large organisations such as the NHS. A process/guidance should be implemented such as the NHS' Sustainable Development Strategy. The difficulty lies with ensuring each part of the organisation cooperates. As above, the NHS created a Sustainable Development Strategy, with a SDMP being one of the cornerstones of the strategy. However, only 170 out of a possible 241 Trusts have a SDMP in place. Once a process has been rolled out, it can be difficult to implement. The SDMP should be of a high standard with carbon reduction targets included, as it will be a reference for future projects and work. Note that the carbon reduction targets should be based on the SMART criteria. Once the SDMP has been approved by the board of the Trust, business cases can then be submitted and respective work/projects started. Once the projects to reduce emissions have been completed, monitoring and verification will be carried out. This is to ascertain whether the project has been successful and to what degree. For example, if a lighting scheme has been carried out, electricity consumption figures would be evaluated and compared with pre-scheme data. If the project has been successful, it could be used as an example for other Trusts that could look at carrying out similar work.

It is worth noting that the SDU will be publishing a new marginal abatement cost (MAC) curve and a report on the sustainability return on investment (ROI) which will detail potential carbon and financial savings. The publications are scheduled for release in summer 2016. [18]

Implementing a Cost Reduction and Efficiency Saving Scheme

The best way for a sustainable strategy to be successful is to stick to the process that has been established i.e. work to achieve targets within SDMP. If a Trust has not compiled and committed to a SDMP, the NHS SDU should investigate why this is. It may be the case that the Trust needs support or does not have adequate resources. When considering how the targets should be met, a holistic approach should be taken. Each site within a Trust needs to be included for consideration, not solely large hospitals. It should be remembered that no two Trusts are the same, with different building uses within each Trust. This is a particularly important aspect and major challenge of any retrofitting strategy [11]. For example, a hospital operates 24/7, but a community site may only operate 8 hours per day for 5 days a week. For optimum efficiency and results, NHS Trusts should base the project on the following steps:

1. Desktop assessment

The desktop assessment would consist of gathering energy consumption data to establish what the baseline for each site is. Targets (SMART) would be confirmed and timescales would be estimated.

2. Options Identification

Following on from the desktop assessment, energy audits/surveys would be completed for each site within the NHS Trust. Utility bills would also be examined to determine the unit cost of each utility. An evaluation of possible energy saving technologies would be completed and reviewed based on cost, payback period and value for money to give a prioritised list of options. This would allow the assessment of the business decision, as suggested by [6], and facilitate the procurement of similar energy saving initiatives.

3. Funding approach and procurement

The Trust will then decide how the project(s) will be funded. This will be either be self-funded, third party funded or the Trust may receive grant funding. Given the various challenges [16], another option is to use an ESCo who will guarantee energy savings. Sometimes the ESCo will offer an energy performance contract which entails implementing the energy saving measures at no upfront cost to the Trust, with the ESCo being repaid through energy savings. The contract is usually around 15 years long, with the Trust solely gaining savings once the contract terminates.

4. Installation of energy saving measures

The chosen energy conservation measures should be installed into the Trust’s buildings. Project management is a key aspect and a programme should be agreed from the outset. Once the measures are installed and passed practical completion, the project moves into the operational phase and the savings start.

5. Behavioural change programme

The NHS’ biggest asset is the staff. Staff can contribute to making hospitals and associated sites more energy efficient without compromise to patient care. Through simple actions, a culture can be embedded within the Trust to reduce energy wastage. Relationships between different departments within the Trust can also be enhanced due to increased communication. It is estimated that Trusts can experience energy cost savings of up to 6%. This suggestion confirms views put forward by [10] and [5] who claim that the impact of energy behaviours could be of equal importance to the implementation of technological solutions. The simple actions to enable savings include:

- Turning off unused equipment
- Switching off lights
- Closing doors

A behaviour change programme to engage staff and encourage them to take simple actions has proven not only to reduce energy costs and contribute to the major potential savings estimated by [14] but also improve patient experience with fewer incidences of sleep disruption.

6. Monitor Performance

The meter readings should be collected monthly to monitor the performance of the scheme. If an ESCo has been used, they should monitor and verify the energy savings. If the savings are equal or exceed the guaranteed savings, everything is in order. If the savings are below the guaranteed level, the ESCo will pay the Trust the difference.

Conclusion

To conclude, more than 70% of commercial and public buildings standing in 2050 will have already been constructed, strengthening the need for an enhanced energy performance in existing facilities. This holds particular true for organisations managing large estates, such as the National Health Service (NHS) in the UK and becomes a crucial factor in determining the future sustainability of and quality of healthcare services. To date, many NHS Trusts have attempted to reduce energy consumption and carbon emissions via developing and implementing refurbishment and retrofitting policies. Success has been achieved to some extent; however, a holistic approach is required for more widespread cost savings, compliance with emission targets and increased sustainability. Centrally planned policies and announced reforms should be followed by appropriate action plans and formal, robust, systematic monitoring. This paper investigated the barriers and challenges faced by NHS Trusts in order to suggest a step by step approach in managing energy efficiency upgrade projects. It revealed that implementation issues will still exist, especially given potential budget cuts, lack of resources, time constraints and procurement processes. Therefore, to reduce energy consumption and carbon emissions, investment in energy efficiency measures should be continuously supported by governmental interventions and importantly be seen as a non-financial investment.

Acknowledgements

This research has been funded by Innovate UK (Project ref: 509527)

Subscripts

CCA	Climate Change Act
CCC	Committee on Climate Change
COP 21	Conference of Parties 21
ERIC	Estates Return Information Collection
ESCo	Energy Service Company
HEFT	Heart of England NHS Foundation Trust
INDC	Intended Nationally Determined Contribution
MAC	Marginal Abatement Cost
NHS	National Health Service
ROI	Return on Investment
SDMP	Sustainable Development Management Plan
SDU	Sustainable Development Unit

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Appendix A

1. Name of Trust:

2. Total Trust occupied floor area (m^2)

3. Name of each site within the Trust and respective occupied floor areas (m^2)

4. What was the Carbon Footprint for the Trust in 1990? I.e. baseline for Climate Change Act targets ($kgCO_2e$)

5. What was the Trust's Carbon Footprint for 2014/2015? ($kgCO_2e$)

6. Has the Trust carried out any measures/work to ensure the 2020 Climate Change Act target will be met? Has any work been carried out to reduce energy consumption, and if so, what has been done?

7. What measures/work is the Trust planning to do in the future to ensure Climate Change Act targets are met?

8. How does the Trust plan to fund and procure future project that will reduce the Carbon Footprint/energy consumption?

9. Does the Trust currently work with any companies or consultancy firms in order to reduce the Carbon Footprint and/or energy consumption? If so, what is the name of the firm and what work have they carried out? If applicable, please email James a copy of the case study, or attach with this response

10. Would you like to know the findings from this exercise and are you willing to be contacted regarding the information you have provided in this questionnaire?

11. Contact details:

12. Date Completed:

Reducing hospital electricity use: an end-use perspective

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Abstract

Hospitals are an energy intensive building type for which high energy costs and sector carbon targets increasingly prompt attempts to reduce operational energy use. But evidence is sparse and generic one-fits all solutions are problematic due to the complexity and the differing specifications of hospitals. This study therefore focusses on departments as unit of analysis. Five department types (operating theatres, laboratories, day clinics, imaging departments and wards) with differing energy intensities, operating hours and at different stages within the patient pathway are investigated across three case study hospitals of different building age and size (11 departments in total). Detailed audits of installations and use are undertaken to attribute measured departmental electricity use to different end-uses. It is found that lighting loads are dominant in low energy intensity department types, while intensive department types have high loads for specialist ventilation and laboratory equipment. Resulting energy reduction strategies consequently need to take account of these differing challenges, for which an analysis of contributing factors as suggested for example by CIBSE TM22 proved useful. The use of floor area weighted operating hours is proposed as metric for hospitals and other complex buildings which may be beneficial in understanding end-use contributions to total energy use and in highlighting the after-hours switch off potential of building parts in otherwise continuously operating environments.

Context

Acute hospitals are complex buildings with unique energy requirements that exceed those of many other non-domestic building types [1]: They are occupied 24/7 by a large number of people, many of whom are vulnerable. Medical requirements necessitate strict control of the thermal environment and of indoor air parameters, especially in operating theatres and treatment rooms. Specialist medical equipment, sterilization, laundries and food preparation further increase energy use [2].

Given the crucial role of acute hospitals in providing health care to populations, the management of hospital energy demand has long been considered of little importance. Facilities management strategies tended to concentrate on the reliable running of building and building services (including in case of emergencies such as black outs) and the compliance with strict health and safety and other clinical requirements [3]. But high energy costs as well as climate change legislation, in some countries as specific as sector carbon targets, are increasingly prompting attempts to reduce hospital energy use [4]. It is also increasingly recognized that health and climate change are linked. The 2015 Lancet commission on health and climate change argues that tackling climate change could be ‘the biggest global health opportunity of the 21st century' [5].

In the UK, hospitals are operated by the tax-funded National Health Service (NHS). The carbon footprint of the NHS and associated authorities amounts to about 32 million tons of CO2 equivalent per year and accounts for 40% of all public sector emissions in England [6]. In line with the UK Climate Change Act 2008, the NHS commits to reducing its total emissions, of which 15% are from energy use in buildings, by 28% by 2020 against the 2013 level and in the long term by 80% until 2050 (ibid). The NHS Sustainable Development Unit, a government agency with the mission to promote sustainable development in the NHS, proclaims that ‘Our business is health and we have a moral duty to act on health threats and to manage future demand on the health service [7]'.

Strategies to reduce the energy use of existing hospital buildings are various. Primarily, they include technical measures such as the retrofitting of fabric insulation and updates to lighting installations as well as to pumps, motors, lifts and space conditioning equipment. Salix Finance, a government arm's length organization providing much of the funding for energy saving projects to NHS Trusts in England, Scotland and Wales, list combined heat and power, heat recovery and LED lighting as most commissioned technologies within the NHS between 2012 and 2014 [8]. Increasingly, wider organizational carbon management as well as building energy management strategies such as energy audit and post occupancy evaluation and behavior change are also being considered [9].

Apart from the access to funding, energy demand reduction efforts in hospitals are constrained by a lack of available evidence to benchmarks efficiencies at building or systems level and help identify reduction opportunities. Generic one-fits all solutions are further problematic due to the complexity and the differing set-ups of hospitals [10 - 12]. It is in this vein, that this study seeks to make its contribution: It focusses on departments as unit of analysis. Five department types (operating theatres, laboratories, day clinics, imaging departments and wards) with differing energy intensities, operating hours and at different stages within the patient pathway are investigated across three case study hospitals of different building age and size (11 departments in total). Detailed audits of installations and use are undertaken to attribute measured departmental electricity use to different end-uses. The contributing factors driving lighting energy use are analyzed in more detail based on CIBSE TM22 and implications for facilities management strategies aiming to improve building performance will be discussed.

Literature on energy end-uses in hospitals

Despite the availability of numerous high-level guidance documents on energy efficient hospitals (see EnCO2de 2015, p. 87 for an overview of UK documents [9]), the available evidence on actual energy use across a vastly heterogeneous building type remains sparse. Whole building energy consumption data as well as performance benchmarks are increasingly becoming available, in the UK for example through the Department of Health's 'Estates Return Information Collection (ERIC)' which annually publishes energy consumption figures and site characteristics for all of their premises. But information on the relevance of different energy end-uses, important for the identification of how building performance improvements could be achieved [13], remain very rare.

In the UK, the Energy Consumption Guide 72 on energy consumption in hospitals from 1996 [14] contains some typical and good practice values for different end-uses. The figures were, however, based on small samples and some engineering judgement and may also in parts be somehow dated now. A review of the academic as well as other literature relevant to energy management in health care further revealed 10 studies which identify the relevance of different energy end-uses in hospitals through audits (Figure 1, [15 – 24]). Scope, employed methodologies and quality of the reporting vary widely; presenting some challenges for systematic meta-analysis. Frequently, there are for example differences between the reported end-uses and what is encompassed within each term [25 -26].

Overall, it appears that except in tropical climates energy demand is dominated by space heating and hot water consumption, commonly from fossil fuels. This is line with an analysis of ERIC statistics showing that fossil fuel consumption accounts for two thirds of total energy consumption in UK hospitals (see also [27]). About two thirds of a hospital's electricity consumption occur locally through lighting, plug loads such as IT or medical equipment or through food preparation. The remaining third (more in tropical climates) is accounted for by the provision of building services, in particular cooling, ventilation, compressed gases and elevators.

This study focusses on departments as unit of analysis to account for the variety of processes on-going in hospitals. Perhaps with the exception of operating theatres, which have been researched some more due to their energy intensity (for example Balaras et al. [28]) few studies have attempted to link hospital energy demand specifically to the clinical processes and departments underlying them. In a study of two US hospitals, Rabanimotlagh et al. [29] identify the number of radiological imaging series performed to be a driver of electricity use. In a large UK consultancy project studying outpatient departments, Bacon [30] further argues that clinical activity decisively determines space use and therewith the design of healthcare facilities with important (albeit more indirect) implications for energy use. But no study is known to these authors which systematically compares the relevance of different energy end-uses for a number of prevalent department types in hospitals.

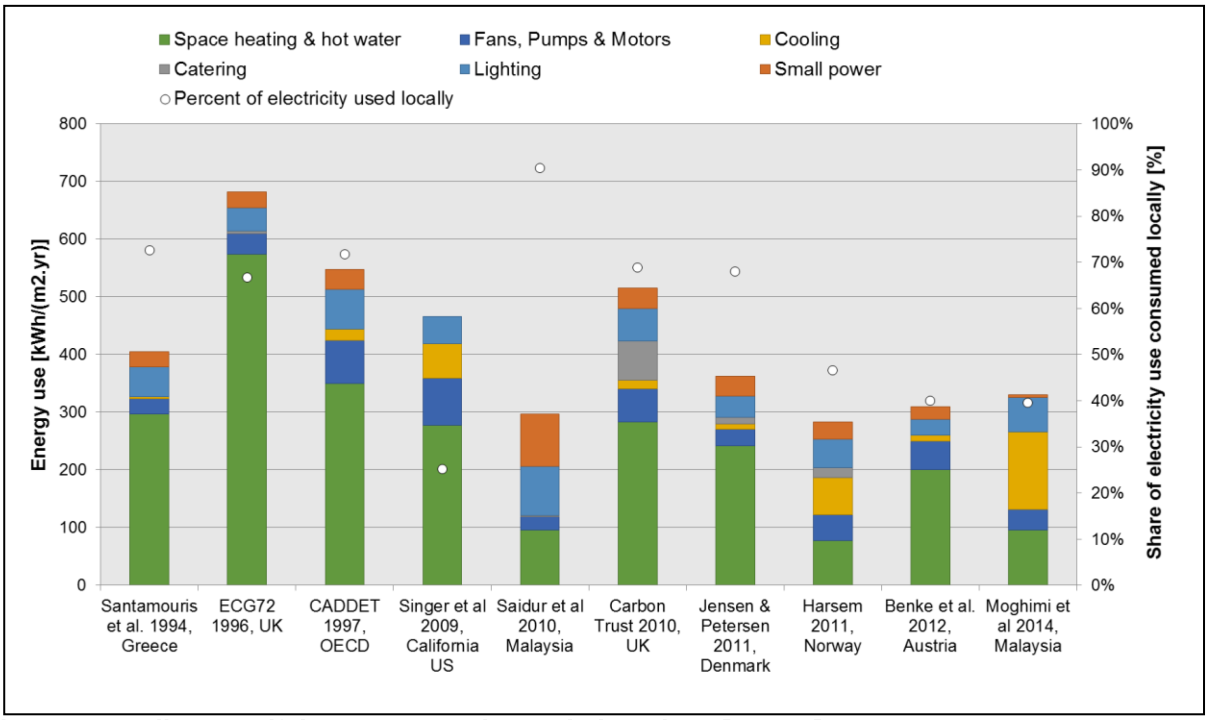

Figure 1: Studies specifying energy end-uses in hospitals [15 - 24]

Methodology of this study

Scope of the study

This study focusses on electricity due to its higher costs to the NHS compared to natural gas. It further restricts itself to the analysis of local electricity demands, i.e. lighting, catering and all types of small power consumption. Electricity use for ventilation, pumping and medical gas services, could not be assessed since it is often a central service, which can only with difficulty be attributed to separate spaces within a building. Finally, the study focusses on general acute hospitals as they occupy 60% of the total floor area within the NHS according to ERIC data.

Research design

Subject to access constraints and the collaboration interest shown by NHS trusts, three case study hospitals are selected using a purposeful maximum variation sampling strategy [31] in line with the exploratory aim of the study (abbreviated in the following as RLH, NUH and KCH). The sampling criteria relevant for diversity were identified from literature review and scoping activities to be hospital age and resulting built form (expected to yield a variety in the implementation of building services) and hospital size (expected to influence extent and realization of service delivery).

The unit of analysis for this study is an individual department. Five department types prevalent in general acute hospitals were selected for analysis reflecting variety in electricity intensity and operating hours: imaging departments, laboratories, operating theatres, day clinics and wards. They selected pathways therewith represented different stages along the patient pathway within an acute hospital: from the diagnosis of an illness (through imaging or the analysis of blood or other body fluid samples in a hospital's pathology laboratory); via its treatment (exemplified here through surgery in an operating theatre and the day treatment for specific conditions such as cancer or kidney malfunctions); to the inpatient care on wards. More information on each department type can be found in the first author’s PhD thesis [32].

Given the abundance of possible clinical pathways, this approach excluded many relevant hospital department types while the selection nevertheless allowed for some understanding of hospitals from a healthcare perspective. Other hospital departments with relevant energy intensities such as sterile services or those where access constraints impeded data collection, for example in accident and emergency services, were also excluded from the study in accordance with the resources available to the project. At least two departments of each type were investigated to increase external validity, as well as at least three departments in each hospital to allow for a literal replication of building features.

Data collection

The study employs quantitative data collection methods to analyze the local electricity use in different hospital buildings and departments. Following a review of available methodologies, the understanding of local electricity use is primarily built from two components which are used to complement and validate each [26, 33]: a departmental level **electricity use profile** (top-down) and a **bottom-up end-use model** based on a detailed audit of lighting and appliances use. Further details on the measurement and analysis of the departmental electricity use profiles is published elsewhere [27], this paper will therefore focus on a description of the bottom-up end-use models.

Within the **bottom-up model**, the electricity use (W_i) of each item is determined as suggested by CIBSE TM54 [34] for small power equipment. For lights, parasitic consumption for controls and emergency lighting is taken into account based on departmental floor area [35]. Item electricity use (W_i) is calculated as the product of the item's average power consumption during operation (P_i) and the duration of its use (t_i), both of which are investigated. Additionally, average item power draw outside of operation (N_i) (often referred to a stand-by although terminologies are not clear) has to be accounted for in some items. The departmental electricity use is understood as sum of the electricity use of all individual items.

(1) $W_i = P_i * t_i + N_i * (8760 \text{ [h/yr]} - t_i)$

Such an approach focuses on average electricity usage and disregards peak power consumption which (although of interest for load shifting strategies and for power system stability in hospital areas such as imaging) seems less relevant to an initial understanding of the comparative relevance of different energy end-uses across departments. More complex estimations for lighting or local heating and cooling electricity consumption were likewise disregarded because it was felt that the study's main challenge is from the collection and the uncertainty of the necessary data inputs (see also [36]), so keeping them to a minimum seemed preferable.

The data inputs into the bottom-up end-uses models are obtained through detailed lighting and appliances audits. Field et al. [26] and in more detail Mortimer et al. [33] have described methodologies to assess the end-use energy consumption of non-domestic buildings based on site-visits including the room-to-room inspection of the building, visual inspections of installed loads and consultations with staff as well as the analysis of secondary data on plant item and equipment listings, equipment ratings and time-schedule information. Accordingly, the collection of input data in this study takes place in two phases for each department: on site and as desk research.

On site, a room-by-room inspection of the area covered by the metered electricity data is carried out recording information on:

- type of use and reported duration of use of each room;
- lighting installations (identified based on lamp type and size, type of control gear and if in doubt light color and strike time) and lighting controls;
- HVAC installations and controls;
- windows and their operability;
- equipment items (including name plate ratings if available) and their use schedules
- spot-measurements of appliance wattage where possible; and
- the operational state of all items during the researcher's visit.

While information on the inventory is primarily observed or extracted from documentation, much of the duration of use information is reported by staff. In the literature, paper-based self-administered surveys are used to extract such information (e.g. [37]) but are found impractical in the dynamic hospital context where staff were rarely based in one space only. In addition, some of the more intense clinical areas such as labs and theatres are subject to strict health and safety regulations and introducing additional paper does not seem appropriate. A researcher-led approach asking a limited number of questions face to face to extract durations of room and equipment use is therefore preferred. Statements are validated against each other and followed up if inconsistent.

In a second step, the average power consumption of all items is determined in desk research based on information from literature for the specific piece of equipment or equipment type. If information on average consumption is unavailable, estimates are based on power ratings according to the respective plate rating or the equipment manual, taking into account that plate ratings provide measures of maximum as opposed to average consumptions. It is appreciated that the relation between average and peak power consumption can vary widely for different loads [38], but for want of better evidence it is relied on the following heuristics: For office equipment, CIBSE state that actual power consumption is about 10 - 25% of the nameplate rating [39]. For hospital equipment in particular, Hosni et al. [40] hold that for items with nameplate ratings up to 1000 W, the average consumption will be between 25% and 50% of the plate.

Other reasons further complicated data collection in the hospital context, among them the irregular nature of processes making it difficult for clinical staff to describe typical events and average durations of use, or the transient nature of the employment in some departments resulting in limited knowledge of local customs. To allow for some sensitivity analysis of the bottom-up model, the quality of each data input was coded (see [36] for details of the coding procedure) and the impact of the uncertainty in the most relevant items was explored.

Data analysis

To disaggregate the measured electricity use and understand the contribution of individual end-uses, representations of departmental electricity use were created based on the detailed audits of lighting and appliance use. A number of criteria were defined to establish the validity of these bottom-up electricity use model representations in the face of uncertain data inputs (see Table 1 for definitions):

1. Modelled annual electricity intensities per floor area were required to compare to measured values within the range of 20 to 30% as specified by Mortimer according to Liddiard [41].
2. Modelled and measured baseloads were expected to compare within a similar range.
3. The interpretation of load diversities needed to prove comprehensive with respect to the developed understanding of departmental processes: They were expected to be higher for departments with varied processes using much different equipment (in particular theatres) or equipment with a varied power output (hemodialysis) while departments with consistent equipment use such as laboratories or imaging departments (X-ray power use excluded) were expected to have diversity factors tending towards one.

In addition, lighting intensities were modelled based on the established lighting installations and compared to lux level measurements in some departments. Detailed model results were further interpreted in comparison to departments of the same type and in the context of available literature.

Failure to meet the above criteria was understood to require further investigation as to the source of the discrepancy, both at the desk and on the ground iteratively improving the model representation of the department. Table 2 provides an overview of the resulting validity characteristics for each department as well as a list of major uncertainties, which may be from either models or measurements.

Table 1: Definition of variables for model validity criteria

Variable	Definition
Base load (Modelled)	Base loads were modelled as stand-by loads plus active loads with annual operating hours exceeding 6570 h/yr.
Base load (Measured)	In measured data, base loads were defined as the mean of the minimum power readings recorded in each 24 hour period.
Total installed load (Modelled)	Sum of average power consumption of all recorded installed loads
Peak load (Measured)	Mean of the maximum power readings recorded in each 24 hour period
Load diversity	Total modelled installed load over measured peak load

Generally, the models complied well with the measured data according to the criteria listed above - with the exception of the KCH ward where some important base load components appeared to remain unaccounted for in the model (highlighted in grey in Table 2). The load diversity of the KCH ward also seemed with 1.4 rather low, providing further evidence that the model representation of this department should be used with caution only. A limited understanding of heating and cooling energy use by the installed split system was suspected to be the main reason for the modelling uncertainty. The load diversity of the NUH laboratory was also above expectations (1.7). Such issue may however be explained by the fact that the laboratory model covered the whole of the pathology department showing a much higher diversity of use than the investigated area at KCH.

Table 2: Validity of bottom-up representations of departmental electricity use

Department	**Modelled over measured**		**Load diversity**	**Key uncertainties (from modelling in normal font or measurement in italics)**
	Annual [kWh/(m²*yr)]	**Base load [W/m²]**		
NUH Imaging	101%	106%	1.9	• *Uncertainties around which areas & services were included in the sub-meter*[1] • Duration of use and power consumption of split units • Actual power consumption of analogue imaging processors
RLH Imaging	118%	71%	2.4	• Duration of use of reporting rooms which are shared with other departments
KCH Laboratory	99%	110%	1.0	• Power consumption of track system • (Stand-by) Consumption of automated analyzers • Duration of use and power consumption of split units
NUH Laboratory	88%	81%	1.7	• Power consumption of cold room • (Stand-by) Consumption of automated analyzers • Duration of use of IT equipment in specimen reception
RLH Main Theatres	103%	92%	1.7	• Actual operating hours at each theatre • Durations of use for medical equipment items generally • Actual loads from intensive medical equipment and those items hard to identify
NUH Main Theatres	103%	96%	1.4	• Actual loads of theatre panels and hard to identify medical equipment
RLH Day Theatres	122%	84%	1.5	• Actual loads from intensive medical equipment and those items hard to identify • Durations of use for medical equipment items generally
RLH Outpatients	117%	72%	1.3	• *Issues with metering suspected but could not be clarified despite collaboration with facilities management*
KCH Outpatients	99%	75%	1.9	• Duration of use and power consumption of split units

[1] The department had repeatedly been refurbished over the last decades resulting in changes to circuit and distribution board layouts. According to the responsible electrician, some loads within the X-ray area now ran through other distribution boards while the X-ray board included lighting loads in other areas. The exact determination of which circuits were served by which board resulted impossible due to a lack of documentation and the continuous operation of the department preventing experimental determinations of attributions through powering down boards sequentially out of hours.

KCH General Ward	98%	61%	1.4	• Duration of use and power consumption of split units • Operating hours for lighting in rooms where day light is available • Major unaccounted base load contribution and exaggerated installed load
NUH General Ward	110%	94%	2.0	• Operating hours for lighting in rooms where day light is available • Bedpan washer power consumption and duration of use

On the whole, the electricity models seemed to provide reasonable representations of departmental electricity usage. Some confidence could hence be had in end-use splits and saving potential estimates from operational changes on their basis. The next section will present a comparative analysis of electricity end-uses in different department types.

Findings

Local electricity use in different department types

Both annual electrical consumptions and the significance of different end-uses varied widely across different hospital department types (Figure 2). Intensive departments such as theatres and laboratory departments used on average roughly three times more electricity than wards, outpatient departments and imaging departments (excluding imaging equipment on three phase supply).

The former group i.e. operating theatre departments and laboratories used most of their electricity for ultraclean ventilation (UCV) and medical equipment or automated analyzers (also coded as medical equipment). Lower intensity department types were dominated by lighting loads. The RLH hemodialysis department (outpatients) was an exception here due to the extensive use of dialysis machines. Notably is also the higher local electricity use for cooling at KCH due to the provision of split systems, while cooling loads are met largely by central chillers otherwise.

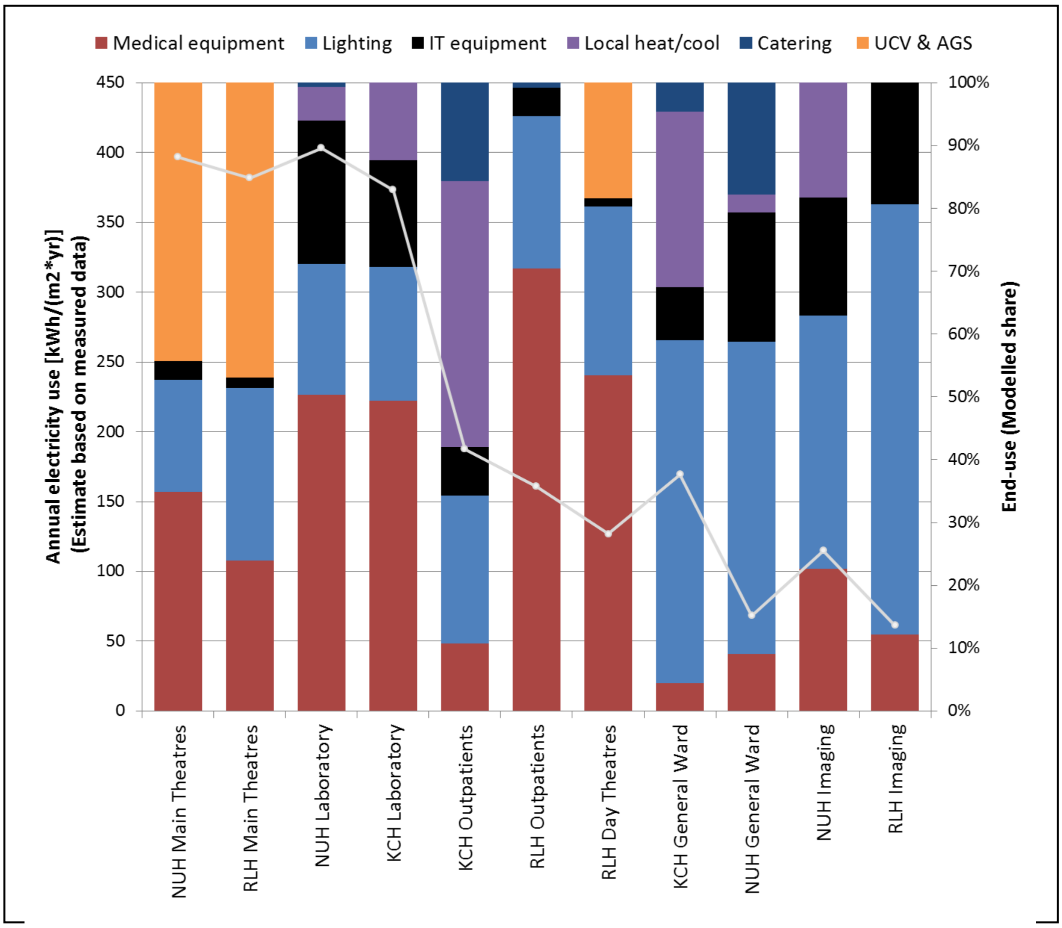

Figure 2: Local electricity use for all departments

The figure presents two information items for each case study department (x-axis): Firstly, a prediction of the annual electricity intensity based on four weeks of measured data, represented by the white line corresponding to the left y-axis. And secondly, the relevance of respective end-uses for each department type based on modelled data. The absolute consumption is scaled to represent 100% in each department so the relevance of different end-uses can be compared across departments. UCV stands for ultraclean ventilation, AGS stands for anesthetic gas scavenging; both are specialist ventilation services relevant in operating theatres.

Overall, the findings were in reasonable agreement with the limited available evidence on end-use relevance for hospitals as a whole. An analysis of Figure 1 showed that lighting loads were dominant over equipment loads in entire hospitals on average. This suggested that non-energy intensive department types played a major role within the make-up of a building's total energy performance, an interpretation that was substantiated by the fact that wards accounted for a significant proportion of space in general acute hospitals [42].

Lighting energy use and service provision

In order to identify opportunities for reducing energy consumption from selected end-uses, specifically ventilation and lighting, it is recommended to break down the respective energy use into contributing factors [13]. The following section will do so for the lighting electricity use in two of the above departments, while drawing on relevant benchmarks available for energy end-use components in hospitals. Lighting was selected for discussion here because it was found to be comparatively independent of building design and system age. Only window design was important in areas with daylight and replacement cycles influenced installed lighting technologies.

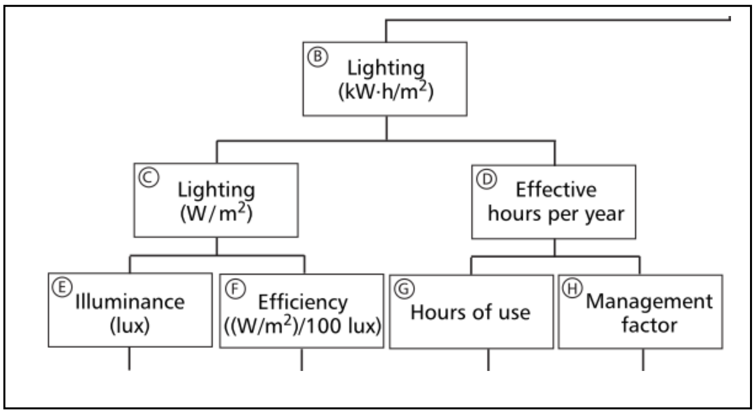

Figure 3: Analysis of lighting energy consumption and service provision according to CIBSE TM22 (from Appendix 2, [25])

According to CIBSE, illuminance levels, the efficiency of the lighting system as well as hours of use and a management factor summarizing issues of lighting control have hence been identified as main drivers for lighting energy use[2] (Figure 3). Ideally, benchmarks for all contributing factors (each box in Figure 3) are available to help the analysis of building and system level performance. For acute hospitals, the following values (discussed from the bottom upwards) may be indicative:

E) Illuminance levels for health care premises are prescribed in BS EN 12464-1:2011 [43]. Notably, the differentiation of illuminance requirements for different room types and activities is very detailed and outperforms any comparable evidence for energy metrics in availability. Typical illuminance levels range between 100lux as general lighting on wards and 1000lux for treatment in examination rooms and operating theatres.

2 According to an updated version of the TM22 tree diagram published by the Technology Strategy Board, load control from dimmable lights is also increasingly relevant, but will not be discussed here.

F) If no further details are known, the National Calculation Methodology (NCM, [44]) for buildings other than dwellings in England and Wales recommends lighting efficiencies of 6.2 W/(m2*100 lux) in spaces other than offices, storage or industrial spaces. 3 W/(m2*100 lux) could be used for efficient installations also in health care, as suggested for offices in CIBSE Guide F [39] and ECG19 [45].

G) In a first instance, the hours of use of a hospital department may be concluded from its opening hours. Especially for areas with continuous operation such as laboratories or wards, this assumption may overestimate actual use significantly, as the case discussed below will exemplify.

H) The management factor for lighting relates primarily to the installed means of lighting control. A value of 1 is typically assumed for manual light switching, while photoelectric day light sensors or occupant sensors may reduce this value to 0.9 each or 0.85 in combination (CIBSE Guide F [39] Table 9.4).

At a more aggregate level, lighting load (C) and effective usage hours per year (D) become relevant. Here, this study may contribute the in-situ metrics collected for the 11 investigated departments as basis for the further development of these box benchmarks (Figure 4). The average lighting efficiency was 16 W/m2, with little coherent differentiation between high intensity and low intensity department types. As expected, operating theatres did however stand out with higher power densities. These findings compared well but overall on the lower side with the default benchmark values for hospitals presented in BS EN 15193:2007 [35], which range between 15W/m2 and 35W/m2 depending amongst others on the color rendering properties of the installation and the level of special attention to health issues.

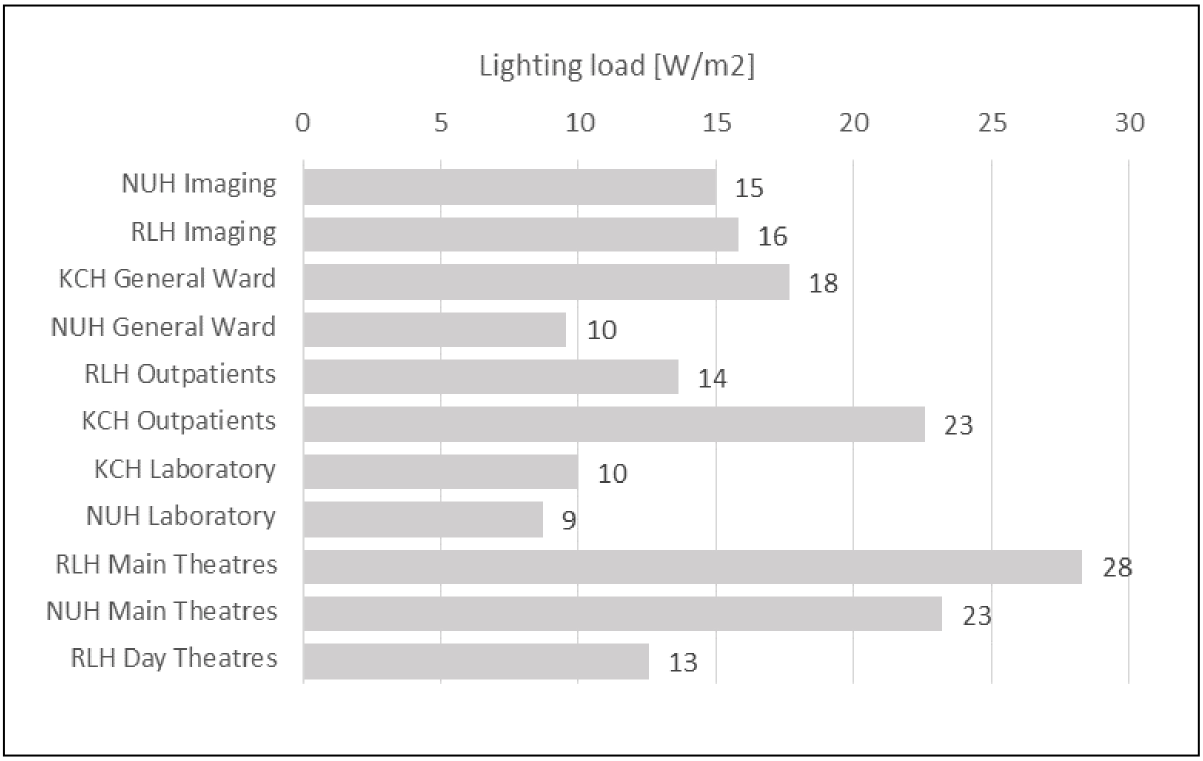

Figure 4: Departmental lighting loads

As for effective usage hours per year, the case investigation revealed that both the over- and the underestimation of actual usage hours may result in a biased evaluation of departmental lighting performance as demonstrated in the following for two quite different department types. For the KCH Outpatient department it could be shown that longer effective operating hours due to preparations and after hour cleaning activities resulted in a 10% higher lighting energy use than originally expected based on standard assumptions (Figure 5).

In complex departments and those with continuous operating hours, such as laboratories, however the analysis was less straightforward. The expected lighting load (Table 3) based on standard service provision benchmarks as discussed above vastly exceeded the actual load expected according to the audit results which were reconciled with available measurement data. The structure of the analyzed pathology department could be identified as driver of this discrepancy: apart from a continuously operating main laboratory, the department also contained a number of office spaces with shorter operating hours (and differing illuminance requirements). Understanding such variations in space use proved crucial for modelling and energy management and will be further discussed in the next section below.

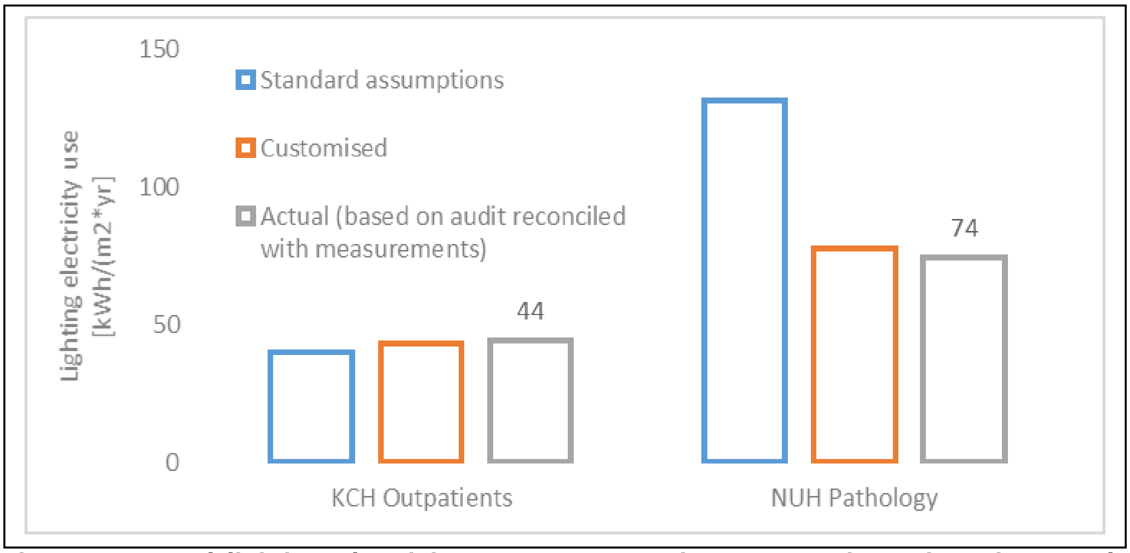

Figure 5: Actual lighting electricity use as opposed to expected use based on analysis of drivers for two case departments

Table 3: CIBSE TM22 analysis of lighting energy use

Case	Scenario	Illuminance [lux]	Efficiency [W/(m2*100lux]	Hours of use	Management factor
KCH Outpatients					
	Standard assumptions	300	6.2	2080	1
	Customised	307	6.2	2270	1
NUH Pathology	Standard assumptions	500	3	8760	1
	Customised	372	3	6957	1

The customized hours of use are based on floor area weighted operating hours for the department, taking into account the likely operation of each room as following:

$$\frac{\sum \text{Room annual operating hours } (h/yr) \cdot \text{Room floor area } (m^2)}{\text{Department floor area } (m^2)}$$

As for total lighting energy use, all departments were found to exceed the good practice lighting benchmarks presented in ECG72 of 20 kWh/(m2*yr) for acute hospitals [14]. It will however seem that, given a design lighting load of at least 15 W/m2 according to BS EN 15193:2007 [35], this benchmark may be little realistic. The average lighting energy use across all departments in this study was 63 kWh/(m2*yr), while a indicative good practice typical benchmark based on the 25percentile may range around 45 kWh/(m2*yr). This figure is however severely limited by the small sample size of this study, while the above analysis suggested that a more detailed analysis of local service provision will likely result in a more meaningful benchmark anyway, given the heterogeneous nature of clinical processes across a hospital.

Discussion and conclusions

The presented study has highlighted a number of issues relevant to the building performance evaluation in existing hospitals and other complex building types. Firstly, it was argued that due to the differing energy intensities of clinical processes and building service requirements, the analysis of hospital energy performance needs to look beyond entire buildings and consider departments or other sub-spaces as unit of analysis in order to understand building use and develop meaningful strategies to reduce energy consumption.

Secondly, in measuring electricity use at a sub-building level, it is paramount to correctly identify the areas and circuits served by distinct distribution boards or the services included in sub-meter data available on building or energy management systems. Hospitals, however, are dynamic environments which continuously evolve to meet the changing requirements of health service provision. This may result in changes to circuit and distribution board layouts, which in combination with a lack of documentation and the continuous operation of many departments (preventing experimental determinations of attributions through powering down boards sequentially out of hours) may limit the usefulness of sub-metering results. Previously also reported by Janda et al. [46], this finding highlights the importance of careful primary data collection efforts to make sure it is understood what is being measured and reported in building performance studies.

It was further suggested that in complex buildings, such as hospitals but surely also industrial facilities with continuous production processes or research laboratories, the estimation of effective usage hours across the entire building can be problematic. Guidance documents on energy management generally stress the need to break buildings down, for example into areas with different uses, operating hours and tenancy arrangements [39]. In complex buildings, floor area weighted operating hours may be one alternative metric which could be beneficial in highlighting the diversity of use across a building. The level of detail may not need to go down to room level in practice, for facilities management purposes a more indicative understanding of the use of space across a complex building may be sufficient. It could in any case point towards untapped energy efficiency potentials not only with respect to lighting use, but more importantly also for HVAC systems.

Timer settings for lighting, mechanical ventilation and heating set-points in spaces that are likely to be unoccupied for a significant number of operating hours, such as outpatient departments or day theatres, could benefit from such an improved understanding of space use and operating hours in hospitals. Given the sensitive and demand driven nature of health care, the options for and the effectiveness of manual override should also be explored in the context of timers and other centralized controls to building services in hospitals.

At a methodological level, the study also highlighted some of the difficulties for built environment research in hospitals. In particular, more data on the actual energy consumption of and the heat loads from both major and small medical equipment will be useful in the optimization of existing hospital buildings and the design of new facilities. The current study was somehow limited by the small number of investigated buildings and departments as well by restrictions to the monitoring of sensitive medical or laboratory equipment and access difficulties resulting in opportunistic auditing, i.e. the lighting and appliance audits were arranged when convenient for the respective department in an attempt to minimize disruption and increase research participation. Consequently, data collection took place at different times during weekdays or weekends, mornings or afternoons, somehow restricting the replicability of audit results.

For future projects in health care, increased collaboration between interested clinicians and technical personal is recommended to reduce access difficulties and identify viable options to reduce the energy use of existing hospitals while improving their overall performance in the service of staff and patients, in particularly also with respect to overheating issues. Methodologies to attribute central energy requirements to disparate spaces within complex buildings will also help to improve building performance models and therewith reduce the performance gap. Despite the above limitations this study offers some valuable insights into an area where little data is currently publically available.

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Session

Retail Buildings & Health Care II

How Does Energy Efficiency Work? Shopping Malls in Istanbul

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Abstract

In Turkey, building sector constitutes 35% of the total and 49% of the electrical energy consumption in 2013. One of the main reason for this situation can be stated as the increase in the number of buildings especially the commercial ones. In 2015, it is declared that totally 358 shopping malls exist in Turkey. From the current malls, more than 100 are in Istanbul.

The main objectives of the study are to give an overview of shopping malls in Turkey, to identify energy consumption figures of selected shopping malls in Istanbul and to provide recommendations for the implementation and promotion of the energy efficiency instruments.

For this purpose, seven shopping malls were visited. Their energy consumption figures and current energy efficiency studies were gathered in order to observe energy-efficiency awareness in shopping malls and to get an overview of current energy consumption patterns as well as energy efficiency measures that they prefer to apply. Some pilot projects realized and planned by these visited shopping malls were presented to give recommendations for the promotion of energy efficiency. It is observed that natural gas and electricity are mostly used as an energy resources. The natural gas and electricity consumptions of the visited malls are collected for different areas (common, leasable or both). Hence, yearly natural gas/electricity consumption per square meter could not be comparable. It is seen that natural gas is mostly used in winter while electricity is used in the summer seasons. In fact, on top of fixed electricity consumption, cooling loads creates an additional requirement for electricity. Thus, in order to decrease natural gas and electricity usage, energy efficiency improvements on HVAC and lighting systems in which energy is used intensively, have utmost importance.

Introduction

A shopping mall can be defined as a collection of many retail shops and common areas that is managed as a single facility. The European wholesale and retail sector contributes with around 11% of the European Union's (EU) Gross Domestic Product (GDP). Within the retail sector, shopping malls are important because of their structural complexity, high potential of energy savings together with carbon emissions reduction and also their importance and influence in shopping tendencies and lifestyle of the people within the country. When shopping malls are considered, achieving sustainable solutions which yields high energy savings with cost effectiveness as well as appropriate payback period for the sector. There is more than 122 million m^2 shopping mall gross leasable area in EU28 comprising Norway, with the area larger than 5,000m^2. As compared to residential sector, the renovation rate of shopping malls is approximately three times higher. The final consumption of the shopping malls in EU28 was 32.2 TWh in 2013. European yearly specific energy consumption per square meter for shopping malls is estimated as 272 kWh/m^2. The common energy carriers for shopping malls are electricity and natural gas [1].

Turkey which is a candidate country for EU has also increasing number of shopping malls due to population growth in urban areas and being a touristic country. Figure 1 represents the number of shopping malls between 1988 and 2015 which are provided by Shopping Mall Investor Foundation (AYD) and The Association of Real Estate and Real Estate Investment Companies (GYODER) [2-5].

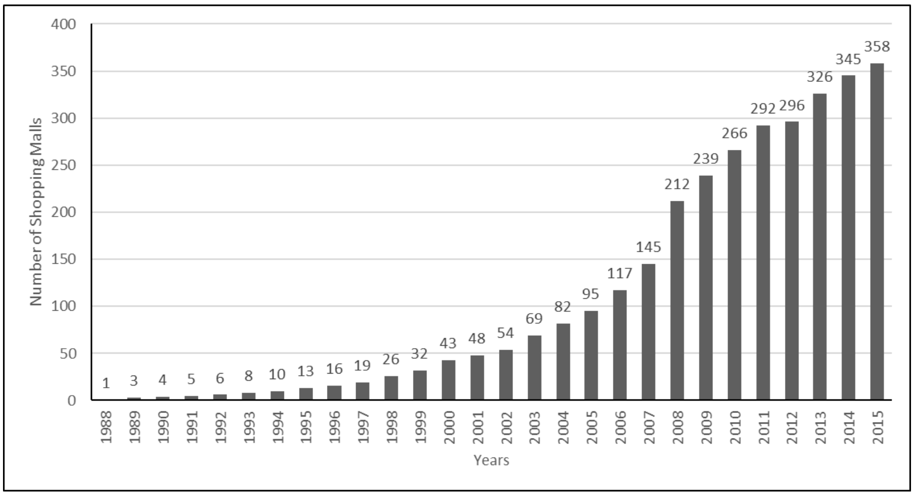

Figure 1. Number of shopping malls in Turkey (1988-2015) [2-5]

According to GYODER, total leasable areas of shopping malls in Turkey between 2006 and 2014, changes approximately from 3,093,000 m^2 to 9,700,000 m^2 as can be seen in Figure 2 [3,6]. In other words, the increase in total leasable area in 2014 as compared to 2006 is nearly 214%. Additionally, the average yearly increase rate of total leasable area is about 16%.

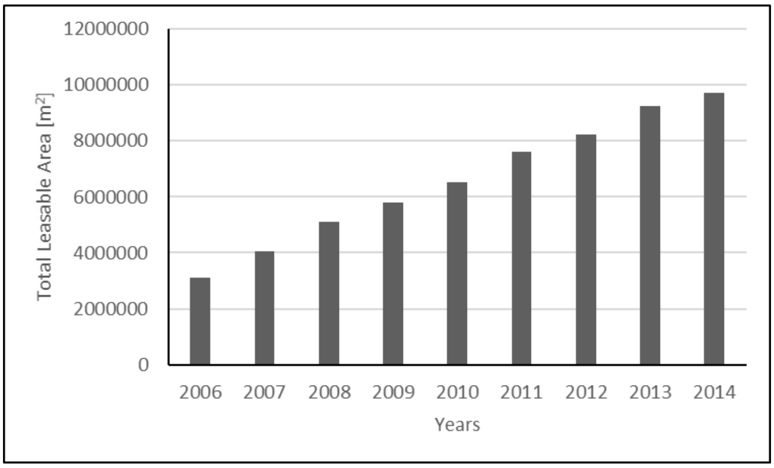

Figure 2. Total leasable area of shopping malls in Turkey (2006-2014) [3,6]

It is declared by AYD at the end of 2015 that there are totally 358 shopping malls in which more than 100 of them are in Istanbul. It is projected that 17 new shopping malls is going to be built between 2016 and 2017. Otherwise stated, considering both total number and increase rate of shopping malls, Istanbul can be assumed as a good example to represent general situation of shopping malls in Turkey.

The share of Turkish building sector (comprising both residential and commercial) comprises 35% of the total and 49% of the electrical energy consumption in 2013, which are higher than the industry sector [7]. One of the main reason for this situation can be stated as the increase in the number of buildings especially the commercial ones. Among commercial buildings shopping malls are of great importance due to increase in their numbers, high energy requirement (heating, ventilation and air conditioning – HVAC, lighting systems etc.), changes in shopping styles of Turkish people from bazaar to shopping malls. The main objective of the study is to get an overview of current energy consumption patterns as well as energy efficiency measures that they prefer to apply for the selected shopping malls in Istanbul together with providing recommendations for the implementation and promotion of the energy efficiency instruments.

Method

In the scope of the study, provided energy consumption figures and energy efficiency implementations in Istanbul were gathered for the selected shopping malls. For this purpose, the method of the study can be summarized as follows:

- A survey as presented in Figure 3 consisting of area, energy mix, yearly energy consumption figures and conducted energy efficiency projects was prepared and sent to energy managers of most popular 13 shopping malls.
- Among 13 shopping malls, 7 of them which are appropriate according to their willingness to share required amount of information and their data quality were selected with the age of 3 to 16 years.
- Selected shopping malls were visited and the required data were collected.
- The obtained data were presented.
- Primary energy consumption and carbon dioxide (CO_2) emissions of the selected malls were calculated by using BS EN 15603:2008 “Energy Performance of Buildings – Overall Energy Use and Definition of Energy Ratings” [8].

Name:	
Area figures (m²):	
Total construction area:	
Leasable area:	
Other shared areas: (corridors, parking places, etc):	
Energy Mix: (electricity, natural gas, others)	
Yearly consumption figures:	**(please state for which area this figures are given)**
Electricity (kWh/year):	
Natural Gas (m³/year):	
TOTAL (kWh/year):	
TOTAL/m² (kWh/m²/year):	
EE projects:	
On which system(s):	
EE saving potential: (as a percentage and/or related cost saving):	
Payback period:	

Figure 3. Conducted energy survey

Results and Discussion

In this section, evaluation of obtained data for the selected shopping malls, yearly energy consumption tendencies for sample shopping mall and their energy efficiency studies were explained.

Evaluation of Obtained Data for the Selected Shopping Malls

Data consumptions were collected from the selected shopping malls on the basis of the prepared survey. Table 1 represents both collected and calculated data according to performed surveys.

Table 1. Summary information for the selected shopping malls

	A	B	C	D	E	F	G
Area [m²]:							
Total construction	67.000	187.500	272.000	119.000	48.400	59.000	85.000
Leasable	40.000	88.000	104.917	42.000	35.330	20.000	32.000
Other	27.000	-	-	77.000	13.070	39.000	53.000
Energy Mix:	Natural Gas, Electricity	Natural Gas, Electricity	Natural Gas, Electricity	Natural Gas, Electricity	Natural Gas, Electricity	Natural Gas, Electricity	Natural Gas, Electricity
Yearly Consumption [kWh/m² year]:							
Natural Gas*	162.7	22.8	4.9	58.5	68.1	26.4	4.0
Electricity	371.9	281.1	182.3	255.5	1142.4	700.0	84.9
TOTAL	534.6	303.9	187.2	314.0	1210.5	726.4	88.9
Primary Energy Consumption [MWh/year]:**	97.3	180.3	165.9	110.1	50.6	47.1	15.2
CO_2 Emission [Tone/year]*:**	18.4	33.7	31.0	20.7	9.5	8.8	2.8

*1000 m^3 Natural Gas x 0.825 / 0.000086 = 1 kWh
** Natural Gas [kWh/year] x 1.36 + Electricity [kWh/year] x 3.31 = Primary Energy Consumption [kWh/year]
*** Natural Gas [MWh/year] x 0.277 [Tone/MWh] + Electricity [MWh/year] x 0.617 [Tone/MWh] = CO_2 Emissions [Tone/year]

As seen in Table 1 in the selected shopping malls, the main energy resources are natural gas and electricity. Natural gas is usually used for heating purposes and for meeting cooling and lighting system energy requirements electricity is used. Due to the placement of natural gas and electricity meters, the obtained data for the abovementioned malls are for common or leasable or total areas. For the calculation of yearly (kWh/m²year) and primary energy consumptions (MWh/year), the relevant areas are used. Since CO_2 emissions are caused by buildings in Turkey and also the energy consumptions of malls are significant among buildings, CO_2 emissions from primary energy consumptions were calculated.

Yearly Energy Consumption Tendency of Shopping Mall A

As all selected shopping malls are located in Istanbul with same climatic conditions, to represent yearly energy consumption tendencies for natural gas and electricity, shopping mall A was chosen as an example. Figure 4 and Figure 5 shows the monthly natural gas and electricity consumptions, respectively. Although natural consumption tendency is for total area, electricity consumption one is for common areas.

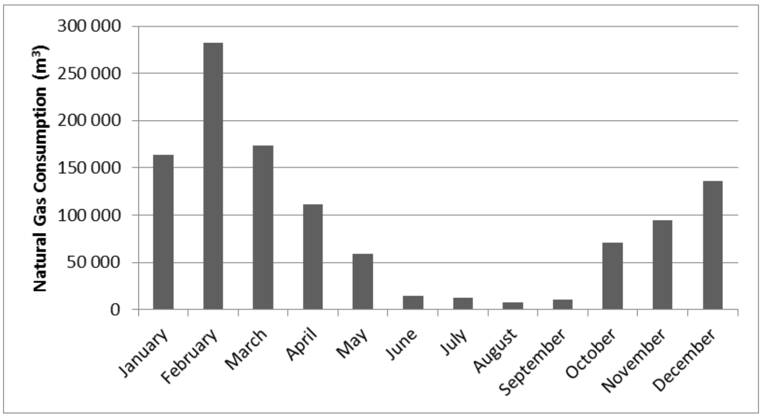

Figure 4. Monthly natural gas consumption tendency of shopping mall A (2010)

As can be seen in Figure 4, for Istanbul, the natural gas consumptions of January, February and March constitute large portion of the yearly total gas consumption. For summer season, natural gas can be used for other purposes such as hot water, cooking etc.

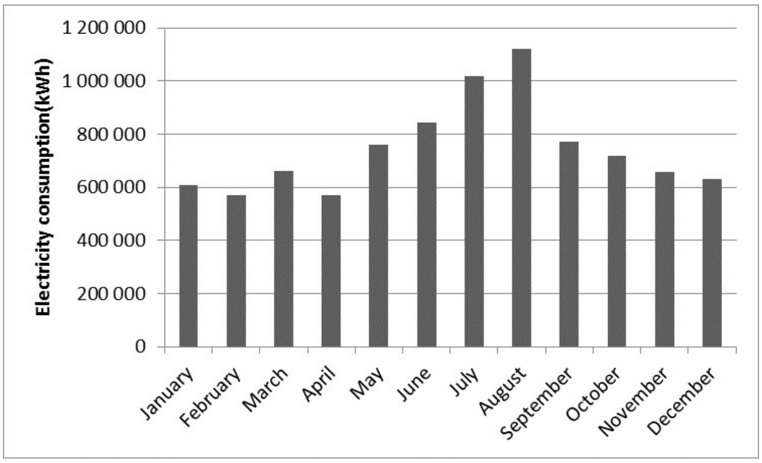

Figure 5. Monthly electricity consumption tendency of shopping mall A (2010)

According to Figure 5, electricity consumption for summer season increases as the cooling load increases. For the other months, nearly similar amount of electricity is used for mainly lighting, electric motor etc. It is observed that the same tendency is also valid for the other visited shopping malls, hence the other obtained figures are not shown.

Energy Efficiency Studies

In this section conducted and planned energy efficiency measures that were provided by the selected malls as a response to survey question regarding energy-efficiency projects are explained as follows (in other words all results were provided by the shopping malls' representative):

Shopping Mall A:

- The temperature of hot water at the entrance of the boiler is increased by means of sun collectors in 2011. Totally 36,391 m^3 natural gas was saved yearly. As a result of this implementation, the payback period was calculated approximately 5 years.
- In the common areas, 35% of electrical energy is consumed by lighting appliances. For this reason, the existing 2x26 W Compact Fluorescent Lamps (CFL) were replaced with 18.5W LED Luminaires in these areas. The expected energy saving ratio is calculated approximately as 70%.
- Special clothes are designed for security personnel working outside entrances in order to decrease the loads of electric heaters. By this way, about 350,000 kWh/year electricity were saved and the payback period of this implementation was calculated as 2 years.

Shopping Mall C:

- In order to decrease heat losses, the pipes and valves at boiler exit, were isolated. The payback period for this measure was calculated as 1.75 years.

Shopping Mall D:

- It is planned to use a special chemical in heating/cooling systems since it is stated that this new chemical can carry 5 times more energy as compared to water. The payback period is estimated as 1 year.

Shopping Mall F:

- It is planned to decrease energy consumption for the mall via various energy efficiency improvements and the estimated payback period is 7.2 years.

- Also it is intended to improve air conditioning systems with a payback period of 4.7 years.

Conclusions and Recommendations

The main results and recommendations which can be concluded after this study in spite of all difficulties that were met during the survey are listed below:

- Since the collected natural gas and electricity consumptions are either leasable or common or both areas, it could not be significant to compare all selected malls with each other in terms of yearly energy consumption per square meter. For this reason, energy efficiency audit studies are crucial for collecting similar type of data to compare shopping malls with each other. According to Turkish Energy Efficiency Law, commercial, service and public buildings with a construction area greater than 20,000 m^2 or having energy consumptions greater than 500 Tones Oil Equivalent (TOE) should hire energy managers to perform energy efficiency related studies [9]. On the other hand, there is no requirement and standard format to collect energy consumption figures for these types of buildings. In order to have comparable and reliable data, continuous and regular collection of energy consumption data with specified format should be mandatory to set a database for buildings.

- On the basis of building energy performance regulation, starting from 2009, all new buildings should have their energy performance certification to get building use permit, to rent or to sell. Nevertheless, as declared by Ministry of Environment and Urbanism, up to May 2017 all existing buildings should have energy performance certificate if they have construction area greater than 1,000 m^2. Up to 2012, 10 existing and 82 new shopping malls acquired energy performance certificate [10]. By this way, the control of energy efficiency studies and data collection could be easier.

- The composition of selected shopping malls is different as they include different types of facilities like sports center, cinema, food court etc. for their conditions. Thus, their energy mix (natural gas and electricity usage proportions) varies from each other.

- In recent years, the climate change causes the increase in cooling loads in buildings. Hence, usage of air conditioning systems increases the electricity demand even the cities like Istanbul with moderate climatic condition. In order to develop energy and environment related reference values for buildings, geographical location, climatic condition, demographic parameters etc. should be taken into account.

- Turkeys' dependency on imported energy resources is about 75% [11]. In addition, the energy intensity for Turkey is targeted to decrease 20% in 2023 as compared to 2011 [12]. For this reason, energy efficiency measures for reducing both natural and electricity consumptions in shopping malls are highly important. Since the payback periods are feasible, most of the implementations could concern mainly HVAC and lighting installations which can be considered as energy intensive systems.

- While a shopping mall are intended to be built, the insulation of building envelope, lighting systems with maximum daylight usage (reducing the requirement for artificial lighting), increase in the usage of alternative and renewable energy resources (heat pump, solar and wind systems etc.) should be taken into account.

After the publication of Energy Efficiency Law, while designing and building shopping malls, energy efficiency and environmental issues have been considered among main criteria. For instance, concepts of green, energy efficient, intelligent buildings have become more popular. Nonetheless, the controls and penalties for energy and environment requirements in existing buildings should be strictly applied. With this perspective, energy, economy and environmental gains will be improved.

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CommONEnergy – Transforming shopping malls into lighthouses of energy efficient architectures

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Abstract

Shopping centres or malls have been invented in the 1920´s in the United States and represent the modern version of a historical market place with their collection of independent retail stores, services, and parking area. Over the whole of Europe there are thousands of retail outlets contributing with around 11% of the EU's GDP and standing for almost 30% of the non-residential building stock. The European wholesale and retail sector therefore represents a high potential in terms of energy savings and carbon emissions reductions, meaning also a contribution to reaching the long-term environmental and energy goals of the EU.

The EU-funded project CommONEnergy aims at re-conceptualise shopping malls through deep retrofitting utilising an holistic systemic approach involving innovative technologies and solution sets as well as methods and tools to support their implementation. In order to gain an understanding of the current shopping mall building stock, the article reports on the data gathering of this project. Shopping mall features in the EU-28 and Norway are analysed based on an extensive literature survey and on a broad and detailed data collection process.

Compared to the current renovation rate of around 1% of the whole building stock in Europe, the annual renovation rate of shopping malls is a fourfold and creates a window of opportunities for implementing energy saving measures. Furthermore, the calculated total final energy consumption of shopping centres with a gross leasable area of 119.2 million m^2 in the EU28, including Norway and Switzerland is estimated to be 32.2 TWh.

The gathered results serve as basis for developing more advanced solutions in evaluating the energy drivers encouraging deep energy retrofitting and for decision making among European and national authorities.

Introduction

The European wholesale and retail sector is the big marketplace of Europe, contributing with around 11% of the EU's GDP [1]. Therefore, sustainability of the retail sector may significantly contribute to reaching the long-term environmental and energy goals of the EU. Within the retail sector, shopping centres are of particular interest due to their structural complexity and multi-stakeholders decisional process, to their high potential of energy savings and carbon emissions reduction, as well as to their importance and influence in shopping tendencies and lifestyle.

The EU-funded project CommONEnergy focuses on reducing the energy consumption in EU shopping malls. In order to gain an understanding of the current shopping mall building stock, features in the EU-28 and Norway are analysed based on an extensive literature survey and on a broad and detailed data collection process.[1] Special attention goes to an extensive analyse defining main drivers associated with deep energy retrofitting of shopping malls.

It has been a long way from medieval markets, Middle Eastern bazars and 18th century arcades to modern shopping centres as we know today. The 1950s, the 1960's and 70's established the shopping centre as the most dominant retail form in Western Europe. By the end of the 1970's they covered a retail space of 25 million m^2. Today, there is more than 112.1 million m^2 shopping centre gross leasable area (GLA) in the EU28, including Norway. This means 6.7 percent of all retail and wholesale buildings in Europe are shopping centres [2].

Setting the scene

Shopping centres vary in their functions, typologies, forms and size as well as the (shopping) trip purpose. In order to be able to consider the shopping centre building stock as one segment, shopping centre definition was defined as *"A formation of one or more retail buildings comprising units and 'communal' areas which are planned and managed as a single entity related in its location, size and type of shops to the trade area that it serves. The centre has 1) a retail complex containing several stores or units and 2) a minimum gross leasable area (GLA) of 5,000 m^2 except some specific types of shopping centres, e.g. market halls."* [3]

Beside the criteria defining the building typology of shopping centres, further criteria are needed to put them into their social and environmental context. These (location, type of development, the size and the GLA, the type of anchor stores and the trip purpose) are shown in Table 1.

Table 1: Shopping centre criteria regarding social and environmental context

Location	Type of development	Size	GLA (m^2)	Anchor store	Trip purpose
Town Centre Shopping/ urban	Neighbourhood centre/ community centre	Small shopping centres	5,000 – 19,999 m^2	Supermarket or hypermarket	Convenience shopping

[1] The results are presented in an interactive online data mapper available at www.commonenergyproject.eu/data_mapper.html

	Speciality centre (market halls, historical buildings, other)		Usually 5,000 m^2 and above	Traditional markets, tourist shops	Leisure, convenience shopping
Out-of-Town Shopping/ suburban	Retail Park and Factory Outlets		5,000 – 30,000 m^2	None	Household shopping, Comparison shopping, leisure
	Regional centre	Medium/ large shopping centres	20,000 – 79,999 m^2	One or more department stores	Comparison shopping
	Super-regional centre	Very large shopping centres	80,000 m^2 and above	Several department stores, entertainment centres	Comparison shopping, leisure

Source: CommONEnergy

In Europe, the share of residential building floor area is 75% while the non-residential buildings make up 25% [4]. Non-residential buildings comprise a more heterogeneous and complex sector compared to the residential buildings due to variations in usage pattern, energy intensity and construction techniques.

In the European directive on the energy performance of buildings [5], the non-residential building sector is divided into the following sub-categories: wholesale and retail, offices, educational facilities, hotels and restaurants, hospitals, sports facilities and others.

The wholesale and retail category is very heterogeneous and the floor area per sub-category cannot be found in the literature. However, based on statistics from the International Council for Shopping Centres (ICSC), supplementary data from the Building Performance Institute Europe (BPIE) and the EU project ENTRANZE [6], the GLA of shopping centres, with a breakdown per country, can be obtained (see Figure 1).

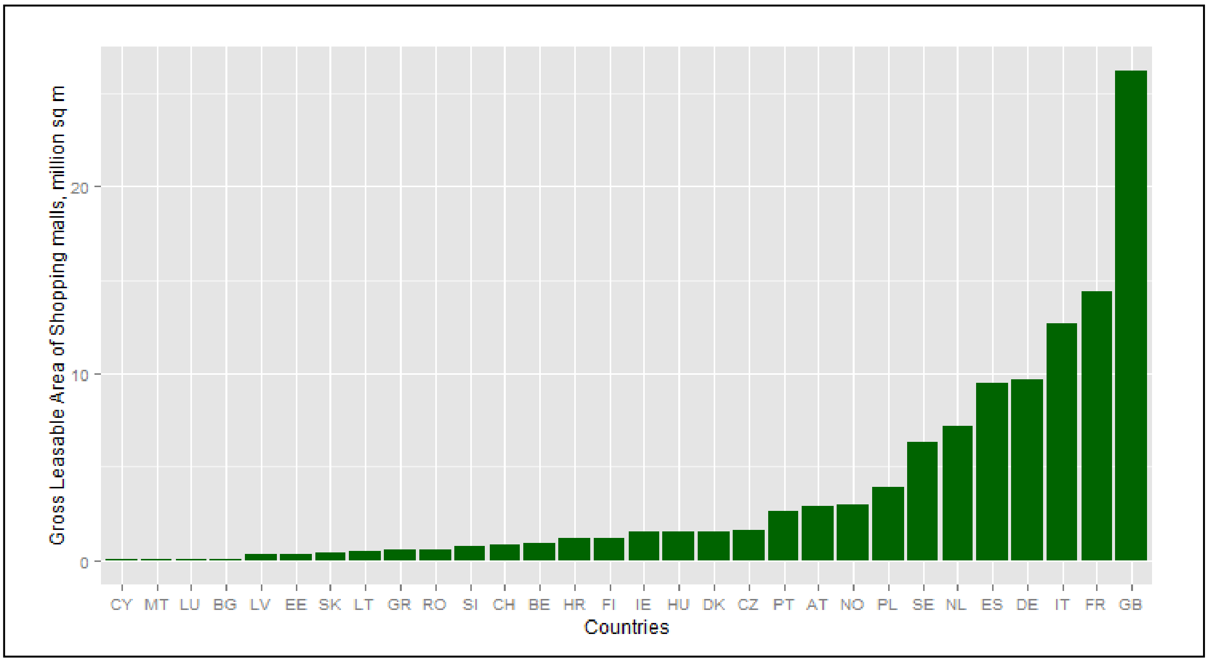

Figure 1: Gross Leasable Area of shopping centres

Source: CommONEnergy, based on ICSC, 2014, [Million m^2] larger than 5.000 m² in the EU-28 and Norway

The largest shopping centre gross leasable area is located in UK (26.2 Million m^2) followed by France (14.4 Million m^2) and Italy (12.7 Million m^2). These countries account for approximately 46% of the total shopping malls gross leasable area (GLA) in EU-28 and Norway.

Being a very dynamic sector, the GLA of the shopping centres varies from country to country, where the growth and market saturation is influenced by different parameters such as demographic development and consumer incomes, cultural preferences, difficulties in obtaining government permits, planning policies and dominant presence of other retail formats.

Shopping centres GLA per capita and development of shopping centres sales growth are used as quantitative criteria to analyse the market saturation and development. The shopping centres with the largest GLA per capita can be found in Sweden, followed by Norway, the Netherlands and the UK (see Figure 2). These countries are among those with the highest market saturation. Thus, there is only limited activity in relation to the development of new centres in these countries. However, in Central and Eastern European (CEE) countries, the shopping centre market is still young and growing. This means that in Western European countries, emphasis should be put on extensions, upgrades and renovations, while in the CEE countries new energy efficient buildings should be the main scope.

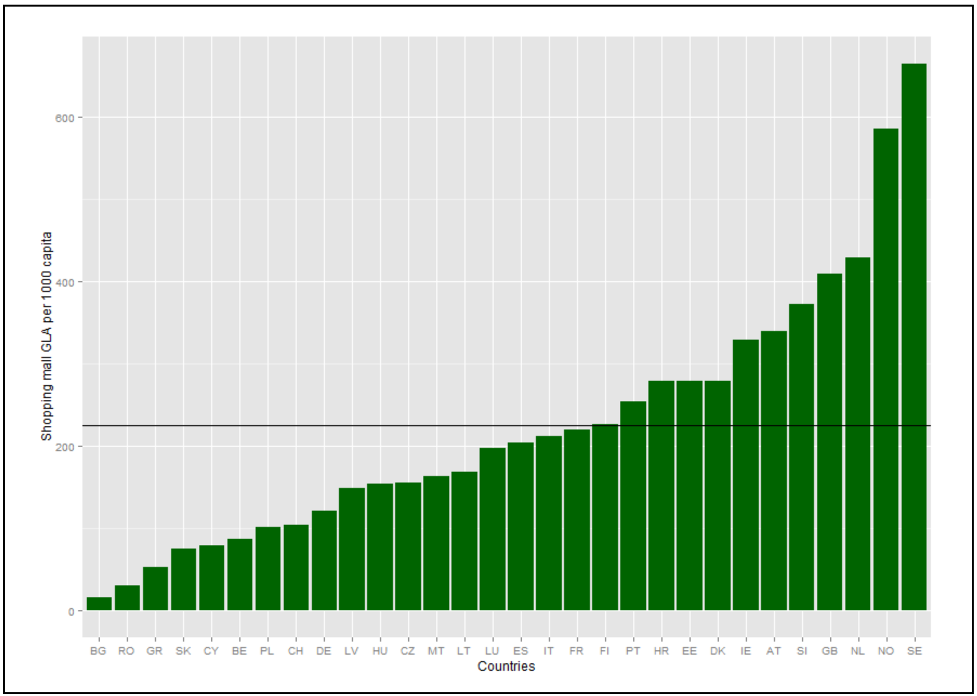

Figure 2: Shopping centre GLA per 1000 capita in EU-28 + Norway and Switzerland; the black line indicates the mean

Source: CommONEnergy, based on ICSC, 2014a and Eurostat, 2014

Bottom-up approach on total energy consumption estimation

Data on the time span between the construction of 3400 shopping malls and their renovation year [7] lead to a robust estimate of the annual renovation rate of 4.4%. This rate is confirmed by representatives from the shopping centre sector, clarifying that this is mainly because of the trend to update the buildings according to modern lifestyles. Compared to the current renovation rate of around 1% of the whole building stock in Europe [4] the annual renovation rate of shopping malls is very high and creates a window of opportunities for implementing energy saving measures.

The total energy consumption of the whole shopping centre building stock in all EU-28 and Norway has not been calculated so far. While in the residential buildings, energy is mainly consumed by heating, cooling, hot water, cooking and appliances [4], in the shopping centres it is mainly used for store lighting, ventilation, heating and air-conditioning and food refrigeration [8].

The composition of the energy consumption varies from one retailer to another. Non-food retailers have a different share of energy use compared to food retailers. For example, the electricity consumption of appliances in electronics stores is higher than in other kinds of shops, such as furniture- or do-it-yourself-stores, which are more dependent on lighting [8].

An analysis of the specific energy consumption was carried out and specific energy uses per shop category comparable to existing research [9] were found, as shown in Table 2. The anchor stores (i.e. stores prominently located in a shopping mall to attract customers who are then expected to patronise the other shops in the mall) are significantly larger than other stores and have – on average – lower specific energy consumption.

Table 2: Mean floor area and specific energy use in different shop categories

	Anchor Stores	Clothing	Hobby	Home	Supermarket	Other Services	Not categorised
Number of shops	(14)	89	6	15	8	90	31
Mean floor area [m²]	(3205)	421	241	645	824	174	318
Mean spec. energy use, [kWh/m²a]	(158)	180	206	244	456	385	288

Source: CommONEnergy - calculation based in an anonymous shopping centre. Note that "anchor stores" are not a separate category and subsumed in the other categories.

To make estimations and develop energy consumption patterns for shopping centres, it is essential to have an overview on the store composition per GLA of shopping centres in Europe.

To do this, the sustainability reports of several real estate companies and their shopping centres have been analysed. The energy consumption per square meter of 132 shopping centres and their GLA throughout seven European countries was taken from these reports. In addition, the store composition of 159 shopping centres was identified. The aggregate is presented in Table 3. As shown, the larger a shopping centre is, the larger is the clothing and hobby GLA, the smaller is the GLA of supermarkets and not categorised shops. The GLA of home stores as well as other services shows no clear trend. In general, home and clothing stores account for more than two thirds of the GLA, followed by supermarkets. The other store categories have small portions of the GLA.

Table 3: Store composition [%] per GLA of 159 shopping centres in Europe

	Clothing	Hobby	Home	Supermarket	Other Services	Not categorised
Small shopping centre	26%	1%	35%	20%	11%	6%
Medium shopping centre	33%	1%	34%	17%	9%	6%
Large shopping centre	36%	2%	39%	12%	8%	5%
Very large shopping centre	36%	2%	33%	9%	10%	5%
Total average	32%	1%	35%	16%	9%	6%

Source: CommONEnergy - calculation based on raw data from Steen & Strøm (2012), Unibail-Rodamco (2013), ECE (2013), Intu Group (2013), Britishland (2014), IGD (2014) and an anonymous shopping centre.

The constructive configuration and the installed technology also influence the energy consumption of shopping centres and are mainly given by the building typology. There is no typical configuration of shopping centres and no quantitative data on this issue available, making a robust estimation on installed technologies impossible. Shopping centres are individually designed and equipped, depending on main surrounding geographic, economic, social and technological conditions.

By using the data of the specific energy demand per GLA and shop category, the total energy consumption per country was calculated. Therefore, by using the results presented in Table 2 and Table 3, the specific energy consumption of shopping centres was calculated as first step. Table 4 shows these results, specifically the energy consumption per square meter of shopping centres. The energy consumption of shops varies – on average – from 228 to 280 kWh/m²a. As expected, the specific energy consumption is decreasing where the size of the shopping centre is increasing. The common area comprises hallways, resting places, sanitary facilities, technical and cleaning rooms, the centre management, security facilities as well as other auxiliary areas. This energy consumption of the common area was calculated - 117 kWh/m²a. The total final energy consumption (shops plus common area) per GLA varies from 257 to 309 kWh/m²a GLA with an average consumption of 290 kWh/m²a GLA.

Table 4: Specific Energy consumption [kWh/m^{2}a] of shopping centres

	Specific energy consumption of shops [kWh/m^{2}a]	Specific energy consumption of the common area[2][kWh/m^{2}a]	Total specific energy consumption per GLA [kWh/m^{2}a]
Small shopping centre	280	117	309
Medium shopping centre	263	117	292
Large shopping centre	248	117	278
Very large shopping centre	228	117	257
Total average	261	117	290

Source: CommONEnergy - calculation based on raw data from Steen & Strøm (2012), Unibail-Rodamco (2013), ECE (2013), Intu Group (2013), Britishland (2014), IGD (2014) and an anonymous shopping centre; note that the common area data is not available per shopping centre size; data does not include energy used for mobility

As a next step, the total energy consumption of shopping centres per country was calculated.[3] Based on the data collected by applying a bottom-up approach, the total final energy consumption of shopping centres (without mobility) in the EU28, including Norway and Switzerland, is estimated to be 32.2 TWh.

Obviously, the total energy consumption per country is closely linked to the country's GLA. The UK, Germany, Spain, France and Italy have in descending order the largest energy consumption. These five countries account for 54% of the total energy consumption of the total 30 countries (see Figure 3).

[2] The specific energy consumption of the common area is constant over all shopping centres sizes. No breakdown available.

[3] The reader should keep in mind that no reference value is available; neither for single countries nor for Europe. This is also true for the superior building category wholesale and retail.

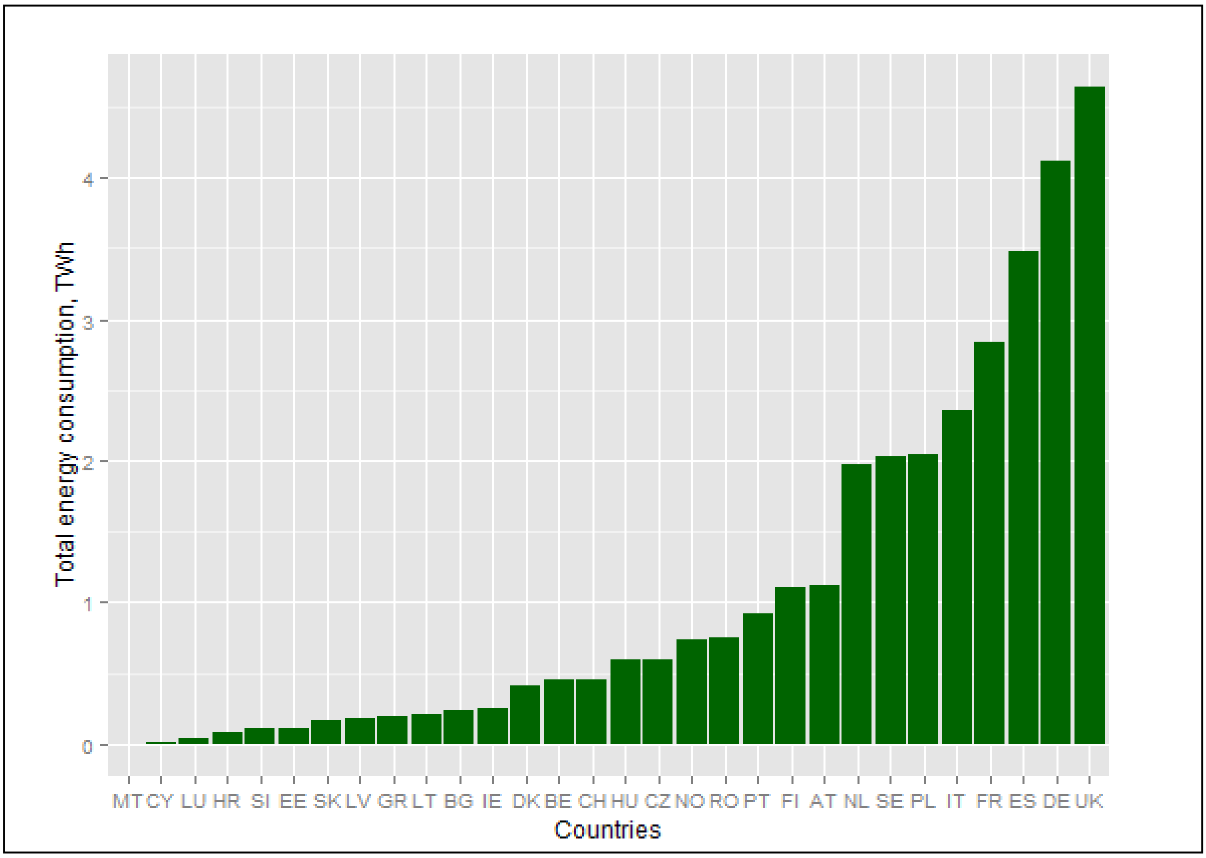

Figure 3: Total final energy consumption in EU shopping centre buildings

Source: CommONEnergy, without energy used for mobility

Based on the calculated total final energy consumption in the EU shopping centre buildings (see Figure 3) and on the energy consumption divided by energy carrier in non-residential building stock, a rough estimation of the final energy consumption subdivided by energy carriers in shopping centres was carried out. The predominant energy carriers in the European shopping centre sector are electricity (46%) and fossil fuels (42%). District heating and biomass account for approximately 10% and 2%, respectively. Data on other renewable energy sources are not available.

The CommONEnergy project has shown the relation between market growth and gross leasable area. Mature markets are usually related to low sales growth rates at large GLA per capita. In general, for non-mature markets it is the opposite way round. This concept is now being extended to energy consumption of shopping centres. Figure 4 is plotting sales growth against GLA per capita. In addition, the bubble size shows the annual energy consumption of shopping centres in TWh per year.

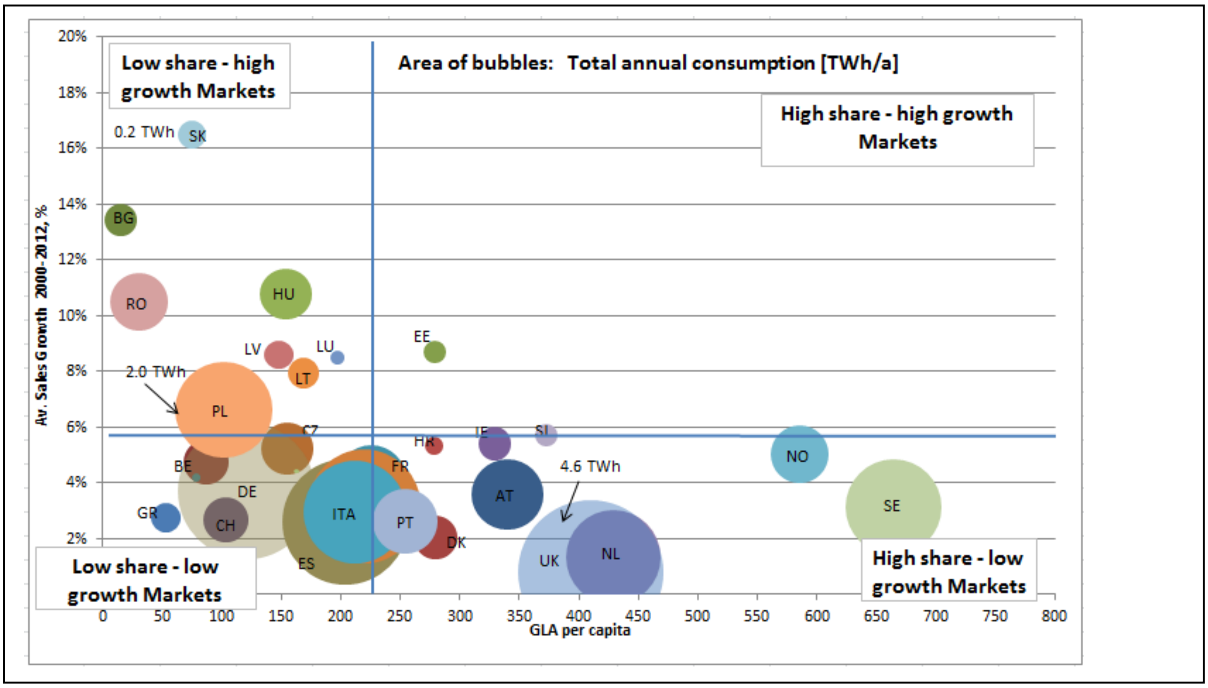

Figure 4: Average Sales Growth 2000-2012 and GLA per Capita

Source: CommONEnergy, the area of bubbles indicate the total annual energy consumption, blue lines indicate the mean values

While markets with high sales growth rates are mainly marked by new construction, refurbishment plays a minor role, which is also confirmed by the building age. Redeveloping existing buildings towards energy efficient shopping centres is the main challenge for countries with these traits.

Countries with low sales growth rates and high GLA per capita, considered as mature markets, will see only limited activity in relation to the development of new centres. However, these countries, namely Austria, Denmark, Finland, the Netherlands, Ireland, Norway, Portugal, Sweden and the United Kingdom, account for 41.2% of the total energy consumption. As there is a high retrofitting potential, they provide a huge energy saving potential related to the building renovation activities.

The situation in countries with low sales growth rates and low GLA per capita is quite ambivalent and varies from country to country. Moreover, many countries are very close to the average, whether in sales growth or in GLA per capita. This is the case for Czech Republic, France, Italy and Spain. Some others have strict regulations limiting the GLA per capita and others, such as Greece, face difficult economic conditions. Nevertheless, this part accounts for the largest portion of the total energy consumption (45.0%) and offers opportunities for both new constructed shopping centre as well as renovations.

From a more general point of view, it can be concluded that countries with low sales growth – most of them mature markets – offer the highest potential for retrofitting measures in existing shopping centres. These countries account for 86.2% of the total annual energy consumption and offer high potential for energy savings via increasing efficiency. Nevertheless, it is important to spread knowledge about energy efficient and sustainable shopping centres among all countries to avoid previous mistakes in developing markets, such as technological lock-ins and inefficient use of energy.

Building code analysis shows that most countries in Europe have implemented performance regulations. A number of them combine performance-based regulations with prescriptive requirements. In countries that have shifted their regulations to performance, there is often a significant dependence on traditional solutions. This is mostly due to the convenience of applying current building methodologies, and to a lack of appropriate technology solutions or knowledge.

Functional patterns and socio-cultural aspects

Shopping centres are designed to achieve maximum customer satisfaction. The understanding of typical functional patterns has therefore customer needs as its staring point. However, a comprehensive research on functional patterns should involve other stakeholders as well. These main stakeholder groups - customers, tenants, management and community - have different but interconnecting roles. For tenants and managers it is a main priority encouraging customers to choose their shopping centre. The primary factors which influence customers when they choose where to do their shopping are the location, physical environment, the range of products available and the tenant mix (see Figure 5). [2]

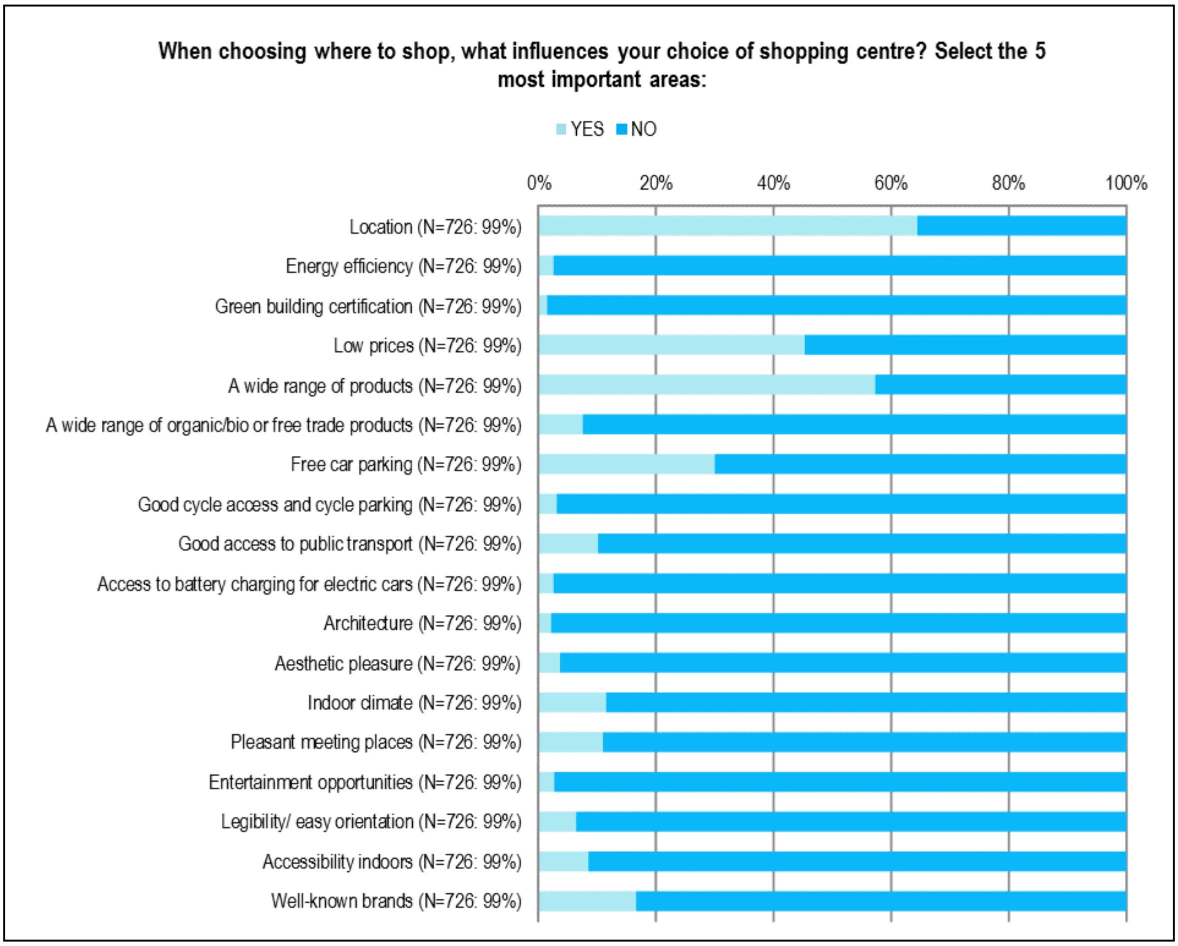

Figure 5: Customers questionnaire: When choosing where to shop, what influences your choice of shopping centre?

Source: CommONEnergy

For customers, a shopping trip to a shopping centre may become multipurpose, providing one solution to a number of retail and entertainment needs, and therefore tenants benefit from customer traffic which is not necessarily generated by them. Owners and managers support the activities of customers and tenants. They aim to continually improve attractiveness for customers; this in turn leads to sales maximisation for the tenants and profits for management and owners. Shopping centre attractiveness affects the price of rental spaces and how effectively the shopping centre is able to get its tenants to cooperate in marketing efforts. An effective retrofit must therefore take into account the need to provide attractive solutions for customers, which in turn leads to the maximisation of profits for management and tenants.

The success of a shopping centre also depends on the community around it. A shopping centre provides jobs and services, but it may cause as well a negative impact on existing structures within the community, such as local embedded retail and transport system. A sustainable retrofit should therefore take into account the needs of the surrounding community.

Functional patterns provide a framework to understand the activities within the shopping centre and its relationship with the surrounding environment on a day to day basis. This information should be taken into account when planning the deep retrofitting of shopping centres, because shopping centres are not just technical systems. Instead, they are social systems whose everyday functional patterns are based on supporting customer needs and desires, and thereby defining the retail success of tenants, owners and managers.

Shopping centre architecture is designed for a specific end-use-function, supporting retail needs which in turn lead to customer satisfaction. Within the framework of technology, functionality and aesthetic quality which supports this end-use-function, there is clear potential for energy savings.

Shopping centres have a strong demand for flexible interior spaces, enabling to adapt according to the tenant’s request. This flexibility is challenging the architectural and aesthetic quality in shopping centres. The conventional patchwork of solutions implemented in shopping centres over time may potentially reduce customer satisfaction. The fact that customer satisfaction remains at the core of running a successful shopping centre (see Figure 6), makes as well owners and managers rate improving architecture and design as one of the main motivations for upgrading a shopping centre [2]. Sustainable shopping centres of the future should therefore include architectural and aesthetic quality with focus on legibility, durability and energy use.

Figure 6: Areas to be addressed when considering upgrading the shopping centre

Source: CommONEnergy - owners and managers (green) and tenants (orange) answers to question "What are the most important areas to be addressed when considering upgrading the shopping centre?"

Technology, functionality and flexibility should not be allowed to dominate at the cost of good architecture. Integrated design requires consideration and improvement of all systems simultaneously; this will allow the implementation of optimal solutions that are sustainable in the present and will continue to be so in the future.

Reflecting on the socio-cultural aspects in the framework of implementing energy saving measures, a change in the planning of shopping centres refurbishment is proposed. Due to the high complexity and the large number of people involved, an integral planning approach, referring to the entire life cycle of a shopping centre, is recommended. At an early stage of the planning process, an integral planning team consisting of not only technical experts, but also main stakeholders, such as tenants, municipal authorities and the local community, should be involved in the decision making process.

Main drivers for deep energy retrofits of shopping centres

There is an enormous potential for energy savings due to very high renovation rate of 4.4% [3]. This state of constant flux offers the advantage of regular opportunities to improve energy related measures such as lighting, HVAC, the building envelope or the building management system. These measures can lead to significant energy reductions and indoor environmental quality (IEQ) improvements. Considering this, there are a number of drivers encouraging deep energy retrofitting. For the CommONEnergy-project, three types of drivers were analysed: direct drivers, indirect drivers and potential drivers. [10]

Direct drivers

The direct drivers have a direct link to energy retrofits actually to happen. They may be seen as actively and directly influencing energy use reductions in shopping centres today.

- The need to reduce energy use in shopping centres is in itself a driver based on the needs to reduce operational and overhead costs.
- Improving thermal and visual comfort are drivers inducing the improvement of lighting and thermal aspects related mainly to the envelope, HVAC system and lighting devices.
- More user-friendly systems to control and maintain (such as a more efficient building-management system, or the implementation of demand response systems) are a driver especially because of the greater management and flexibility that could in turn lead to economic benefits.
- Lack of knowledge among stakeholder levels is a barrier to energy use reductions. On the other hand, increasing knowledge on energy use in shopping centres on stakeholder level is a potential driver for energy efficient upgrades. Increasing user awareness might for example be achieved through the use of certification and actual energy monitoring systems. It is important that certification systems can measure improvements and account for the changes in the building and its operations which occur much more frequently in shopping centres than in other building types.
- Costs associated with retrofitting could be considered both drivers and barriers. Reducing overhead and operational costs may be considered a driver for energy retrofitting. However, if the costs of implementing energy efficient measures outweigh the costs achieved by energy use reductions, then the measures will not be implemented.

Indirect drivers

Indirect drivers provide support or background to direct drivers. For example, changing shopping habits and user behaviour influences the non-energy related retrofitting activity. These retrofitting actions may affect energy use in shopping centres and have the potential to be associated with energy retrofits. Customers are not demanding energy use reductions in shopping centres and as long as there is no direct demand, shopping habits cannot be considered drivers. Owners, managers and tenants are not pushed by customer demand to take direct actions and, as long as their profits remain stable or continue to increase, this will hardly change. Increasing consumer awareness may put pressure on the industry to increase their actions aimed at energy use reductions.

Size has a direct effect on energy use and therefore changes in user behaviour influence shopping centre size. Existing shopping centres are not expected to decrease in size due to the aforementioned trend. Shopping centres are continuously increasing in size due to changing shopping habits and an even wider range of activities, such as eating, meeting, sports and cinema. This requires more space and potentially affects shopping centre energy use. Customer behaviour can thus be seen to influence the kind of shopping centres being built or rebuilt, but only as indirect driver.

Potential drivers

Potential drivers are drivers which are not actually causing an effect at the moment, but with a certain set of circumstances in place they have the potential to become direct drivers. An example of a potential driver is the tenant knowledge. Tenants know little about in-store energy use and have a lack of engagement about energy issues. Owners and managers see a potential for reducing energy use in shopping centres through a collaboration with tenants. This is due to two main factors: firstly, tenants are the major cause of energy use in shopping centres, and secondly, tenants have a high degree of independent control over their in-store energy use. Informing tenants about how lighting, ventilation and building design (all direct drivers for energy use reduction) affect their in-store energy use (energy bills), will allow owners and managers to roll out energy saving measures.

The CommONEnergy research shows that social aspects such as customer satisfaction, tenant knowledge or retail profits and organisational structures have major implications for shopping centre retrofitting, and may operate as drivers or barrier for energy use reductions. However, it is within the technical challenges that the major drivers for energy use reductions are found. Shopping centres are complex buildings, which are subject to regular change, have complicated layouts, sophisticated utility plants and a high concentration of customer and workers.

Due to audits of reference shopping centres throughout Europe and literature research, the main areas of energy use inefficiencies were identified: lighting, HVAC measures, plug-loads and refrigeration, and lastly architecture and design. The need to achieve energy use reductions within these four areas may be considered a major driver for energy retrofitting in shopping centres. [11]

Addressing the complexity of performance requirements and next steps

When defining the relevance of performance indicators, legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context also come into play.

As a result of the underlining complexity of performance requirements in shopping centres, it may also be useful to distinguish causes of energy use within a functional sub-division (i.e. energy divided by the functions for which it is used by end use or supply system), and an organisational sub-divisions, distinguished by who pays for the energy and thus related to billing practice, tenant agreements, and contracts with energy supply carrier companies.

Conversions to primary energy, or CO_2 equivalents are typically performed on the supply side according to the type of energy carriers. This has been followed in the economic evaluation and a list of analysis variables has been developed for assessing the energy reduction of different shopping centres in Europe. These have been grouped according to different level of efficacy to define several energy saving measures. The primary energy and the energy uses for heating, cooling and electricity use have been calculated.

The calculation of the total primary energy of the reference shopping centres showed that measures with the largest saving potential are the reduction of the installed power density of lighting and appliances. Furthermore, a cost analysis of single measures shows positive net present value for measures such as adapting lighting, infiltration, thermal bridges and the increase of the indoor operative summer temperature. However, it is recommended to combine measures. More advanced solution sets should now be developed taking this first evaluation of energy drivers into account and adjusted to each specific building.

Next steps of the project, CommONEnergy Work Package 4 - Solutions for enhancing energy efficiency, will include more detailed analysis focused on combined technologies.

Conclusions

Shopping centres are complex buildings which are subject to regular change, have complicated layouts, sophisticated utility plants, and a high concentration of customers, workers and stakeholders with different perspectives and expectations. The research showed that the more we know about the social and technical systems within the shopping centres and the greater the communication between the systems, the more efficient the everyday running of shopping centres will become.

The main areas of energy use inefficiencies were identified: lighting, HVAC measures, plug-loads and refrigeration, and architecture and design. The need to achieve energy use reductions within these areas may be considered as a major driver for energy retrofitting in shopping centres. Architecture and design touch on a wide number of issues which have implications for the broader understanding of sustainability, and therefore include issues such as accessibility, ergonomics and safety.

Reducing costs associated with energy use may be a driver for energy retrofitting, but since costs associated with retrofitting are considered barriers, it was approached in a net present value evaluation. This to ensure that the costs of implementing energy efficient measures were not outweighing the savings achieved by energy use reductions.

The primary energy and the energy use for heating, cooling and electricity use have been calculated as well. The calculation of the total primary energy of the selected shopping centres showed that the measures for reduction of the installed power density of lighting and appliances have the largest potential savings.

In order to meet current customer trends, shopping centres are renovated more frequently than other buildings, which correspond to a renovation rate of 4.4%. This is very high compared with other building categories (generally with a renovation rate lower than 1%), and offers the opportunity to implement measures towards increased energy efficiency faster than in other buildings. Efforts to improve energy efficiency and provide sustainable solutions for shopping centres must take this state of constant flux into account, by providing systems that may be easily moved, reused or redeveloped.

If not yet applied, it is highly recommended that member states implement a performance based approach to every building category, taking example from the best-practice existing building codes and calculation methodologies. This holds true for shopping centres, the wholesale and retail sector as well as the whole building stock. It is also recommended to introduce energy efficiency standards for new construction, retrofit and operation, specifically designed for shopping centres or, in more general terms, for commercial buildings. Implemented according to the European Energy Performance of Buildings Directive (2010/31/EU), these standards serve to reduce both energy demand and greenhouse gas emissions of shopping centres. Moreover, voluntary or mandatory green building certificates and sustainability assessment schemes may contribute in making shopping centres more environmental friendly.

In light of the ongoing review of the European building related legislation (the so called EPBD) and the needs of the shopping centre industry, the project results may serve as a comprehensive basis for decision making among European stakeholders.

Acknowledgment

This work and the presented findings are based on the FP7-Project "Re-conceptualize shopping malls from consumerism to energy conservation", funded by the European Commission (Grant Agreement No. 608678, www.commonenergyproject.eu).

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EcoShopping: Energy efficient retrofitting solutions for retail buildings – a review of best practice.

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Abstract

The “EcoShopping” project aims to produce a practical holistic retrofitting solution for commercial buildings, reduce primary energy consumption to less than 80 kWh/(m^2.year) and increase the proportion of Renewable Energy Systems (RES) to more than 50%.

The project intends to use and integrate available products and technologies; along with a network to accurately monitor the environmental and occupancy parameters to allow the Building Management System to have better control of the building and fully exploit the thermal mass.

The study concluded that:

- Building codes lay down minimum performance levels for building fabric elements and services.
- The energy performance of non-domestic building as designed should be calculated holistically by the use of approved software. The software should then be used to for quantifying options; in conjunction with first step an EN 16247 energy audit.
- Best Practice for Technology areas was identified as lying within the EU Green Public Procurement (GPP) criteria and the UK’s Energy Technology List (ETL).
- Controls are one of the most effective solutions in realising energy savings, and EN 15232 should be used.
- Best practice guidance for low carbon refurbishment and daylighting has been identified.
- The UK Microgeneration Certification Scheme (‘MCS’) has a method for estimating the electricity generated from installed PV systems. However, no performance criteria for wind turbines and Micro-hydro systems were found.
- The energy consumption of lifts, escalators or moving walks should also be addressed; as these are often ignored by building codes. Best practice, in the form of CIBSE guide D: Transportation systems in buildings, has just been published.

Keywords ECOSHOPPING: energy efficient, retrofitting, commercial buildings, Retail sector, retail mall, shopping mall.

Introduction

The “EcoShopping” project (http://ecoshopping-project.eu/) aims to produce a systematic methodology and cost effective solutions for retrofitting commercial buildings within the EU, especially Hungary and the Balkan states. This is to be achieved by improving the insulation and lighting systems; integrating additional RES based HVAC systems; exploiting the building as thermal storage (“mass”); developing an intelligent automation control unit; and improving maintenance and commissioning technologies. The energy efficiency of the commercial building is expected to be enhanced by about 58%.

The “EcoShopping” platform will integrate the existing HVAC systems, such as heating, ventilation, air conditioning, etc.; and interoperate with other ICT- based subsystems (e.g. for security, protection, gas-detection, safety and comfort). The control and management of automation systems will be based on advanced algorithms where the platform will be capable of learning from previous operations and situations. This will be achieved by means of a semi-automatic process of retraining from Internet-based repositories, which allows configuration, personalization and dynamic adaptation to the characteristics of the building and the weather.

The overall objectives of the project are:

- To produce a systematic methodology and cost effective solutions for retrofitting commercial buildings by:
    - Investigating a retrofitting solution with innovative thermal insulation solutions and Day lighting technologies.
    - Integrating the Intelligent Automation Unit (IAU) concept with a Mobile Robot.
    - Developing a solution for automatically identifying and predicting failures; and inefficiencies in HVAC system performance.
- To embody the results in a case study which will:
    - Demonstrate an RES direct powered DC variable speed heat pump and increase the Building Thermal Mass with a view to reducing the energy consumption.
    - Target primary energy consumption and reduce to less than 80 kWh/(m^2.year).
    - Increase the proportion of RES (Renewable Energy Sources) to more than 50%.
- To carry out a continuous assessment throughout the entire project.

At this point it should be noted that the RES direct powered DC variable speed heat pump is being proposed as a demonstration technology but in itself should perform to the good practice level identified as in work package 2.

The phasing of the project is shown in figure 1 and this paper will introduce the project, the case study and present the results of Work Package 2. The project is budget is 4.10 million €; started in September 2013 with a duration of 4 years.

The EcoShopping consortium

The consortium consists of:

- EnergoSys Inc (Hungary);
- Fraunhofer Institute for Digital Media Technology IDMT (Germany);
- Solintel M&P (Spain);
- Austrian Institute of Technology (AIT);
- Intelligent Sensing Anywhere (ISA - Portugal);
- Novamina (Croatia);
- IZNAB Sp. z o.o.(Poland);
- GeoClimaDesign (GCD - Germany);
- National Research Council (CNR - Italy);
- Symelec (Spain);
- Building Research Establishment (BRE – UK);
- R.E.D. s.r.l. (Italy);
- Yaşar University (Turkey);
- National Taiwan University of Science and Technology (NTUST);
- LaGross Ltd.(Hungary);
- Ancodarq (Spain).

This consortium gives the project a wide range of expertise in terms of the construction processes and technology areas.

The project is Co-funded by the European Commission within the 7th Framework Programme but has its own website and marketing with the following logo:

The retail prospective for this project is provided by continuous dialog with the owners of the mall and the retailers that occupy it.

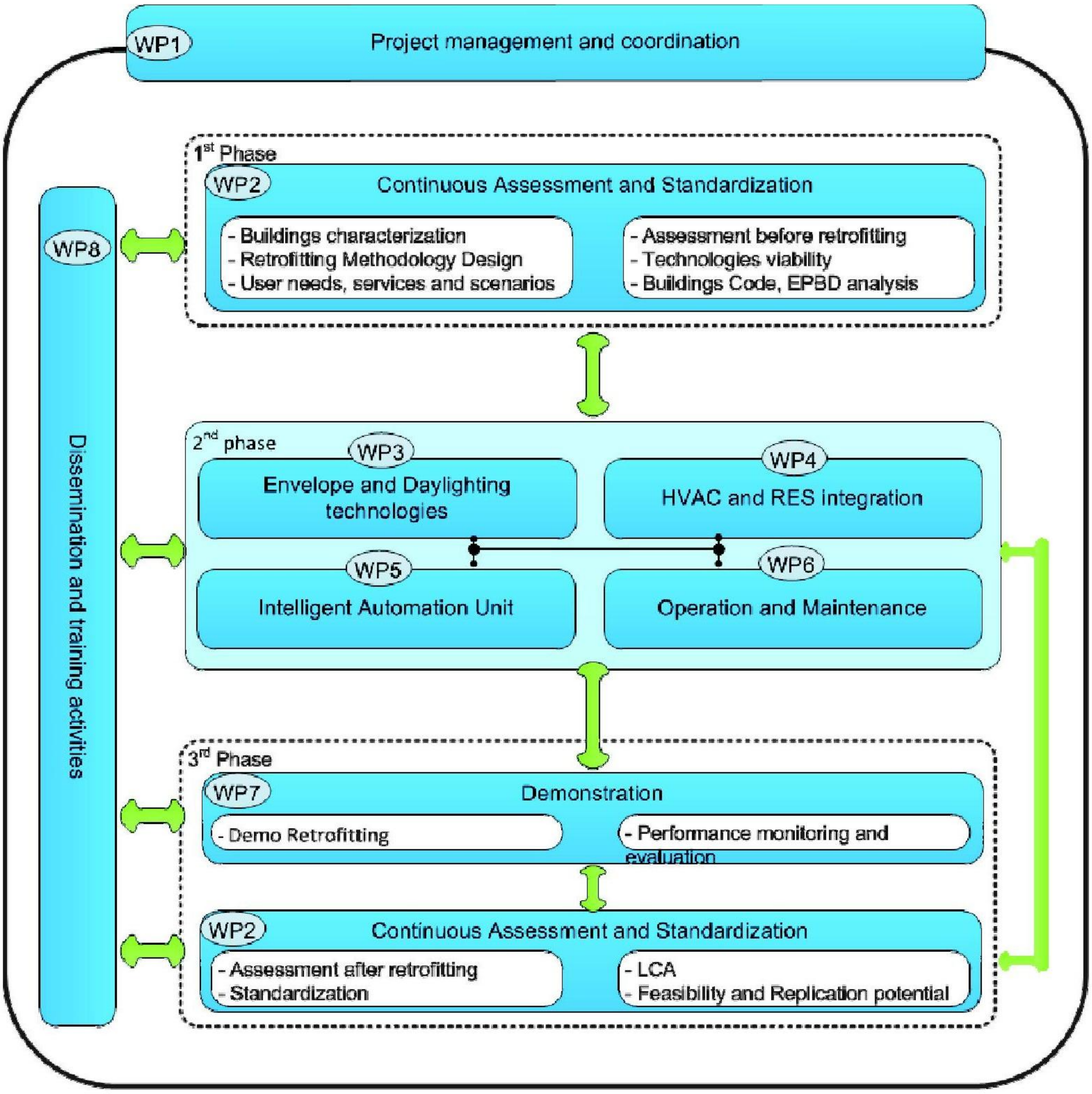

Figure1. EcoShopping work packages and phasing

The case study

The IKVA Shopping Centre is a retail mall in the city of Sopron in Győr-Moson-Sopron County of Hungary. It was built in 1979 and has approximately 3,700 square meters leasable area. The IKVA, due its larger department store size and downtown location, is ideally suited to meet the demands of larger retailers. The retail area mainly consists of large open spaces with only a few pillars, which allows a variety of uses.

It is located within the city centre, in the outskirts of the Castle district which is historic and a tourist area. The IKVA was built within the framework of a large scale urban development plan together with the Fenyő Shopping Centre next to it. It is a freestanding building but is linked with an open passageway to the Fenyő Shopping Centre. Access from the parking lot and also from street level is by a pedestrian ramp and staircases. From the bridge there is a direct access to the retail space on the ground floor. There is an open hallway around the ground level store floor. A wide pedestrian passageway leads directly from the south to the Shopping Centre.

Operation times of 0800-1900 for 220 working days plus 0800-1300 for 52 days gives a total of 2680 operational hours per annum.

The building has 2 main sections:

- Common area, which consists of 2 storeys with an open parking lot on ground level, and
- Service/office area with 3 storeys and a basement.

Geometry of the building follows functional separation with service and visitor access well separated. The building has a reinforced skeleton structure, 25 cm thick reinforced concrete envelope with a maximum height of 14.90 m; and a flat roof with bituminous waterproofing and polystyrene insulation.

There is no insulation on the external walls, which together with the large aluminium frame single-glazed portals in common areas, results in a high overall heat transfer coefficient.

Pre-retrofit building assessment
The building survey has identified the following systems:

- Heating system: 3 Viessmann Vitodens condensing boilers.
- Cooling system: local split air conditioners.
- DHW: only some local, electrical water heaters.
- Ventilation: 2 AHUs, but these are operated only in summer, 2 hours per day. The heating pipe for heat exchanger of AHU was cut off so the AHU has no heating capability.
- Lighting system: Mainly fluorescent lighting with some tungsten. Many of the fittings are inoperative.
- There is only the basic level of control (on/off for time control plus thermostats) with maintenance staff carrying out this function.

Please note that the Viessmann boilers are relatively new and if replaced this would be on the grounds of demonstrating new or more efficient technologies, not the business case.

Energy usage and calculations
Natural gas and electricity consumption was collected for the last 3 years:

- Natural gas: ~ 30.000 m^3/annum;
- Electricity: ~124.000 kWh/year.

The first step was to carry out a static energy model calculation in accordance with Hungarian legislation **[1]** which is harmonised with the EPBD **[2]**.

The calculation expresses the primary energy consumption of the heating, domestic hot water, cooling, ventilation and lighting systems.

The primary energy factors in Hungary are: e=2.5 for electricity, e=1.0 for natural gas.

Static calculation

Primary energy consumption per systems:

- Heating: 93.71 kWh/(m^2.year);
- Cooling: 11.49 kWh/(m^2.year);
- Lighting: 62.5 kWh/(m^2.year).

The Primary energy consumption was calculated as 167.7 kWh/(m^2.year) which gave an E rating on the Energy Performance Certification (EPC).

When comparing the actual to modelled consumption the following observations were made:

- Calculated natural gas consumption is 31.400 m^3/year; which is close to the real consumption (30.000 m^3/year).
- Calculated electricity consumption for lighting and HVAC is 96.000 kWh/year. The real energy consumption much higher (124.000 kWh/year), this was attributed to the additional usage of office equipment, IT technology, etc.

Target value for the IKVA case study is 80 kWh/(m^2.year); which is just over a 50% reduction in energy usage and would result in an EPC rating of an “A”. The consortium using the results from the modelling, and in consultation with the owners, have chosen what they consider is an ambitious target but one that is thought to be achievable.

Work Package 2: Continuous assessment and standardisation

The first deliverable was an assessment of national building codes; EPBD implementation; performance standards and good practice **[3]**. This report compares and analyses the national building codes/EBPD implementation and best practices for non-domestic buildings from the European countries (Austria, Croatia, Germany, Hungary, Italy, Poland, Portugal, Spain and the UK) within the project. The first version of the report was published in January 2014 and has been revised in March 2014 and October 2015 to reflect any changes in regulation and best practice.

Data collection
Each of the partners was tasked with completing a pro-forma which was designed to capture the following:

- The countries’ building energy code and is it mandatory?
- Implementation of the code and mandatory standards.
- Compliance software and targets.
- Requirements in the building code for the building envelope, especially insulation, thermal bridging, pressure testing and overheating.
- Requirements in the building code for the Heating, Ventilation and Air Conditioning (HVAC) systems.
- Requirements in the building code for Domestic Hot Water (DHW).
- Requirements in the building code for the lighting systems.
- Day-lighting requirements of the building code and how is it specified?
- Requirements in the building code for the use of renewables.

Next EPBD implementation was addressed by looking at the following:

- EBPD governance and implementation.
- Are Energy Performance Certificates (EPCs) an operational or asset rating?
- Is the software compatible with that used for building code compliance?
- Are there any other requirements?

Then best practice was examined in each country by asking:

- Is best practice regulated or encouraged through any other means?
- Is the uptake of renewables supported by other government initiatives?

Finally related standards were looked at such as:

- Those that allow electrical connections between renewable energy sources and the electrical grid.
- National regulations related to the procedures of authorization, certification and concession of the transportation and distribution of energy.
- Technical specifications and certification requirements for renewable energy systems.
- Grid obligations of buying the generated renewable energy.
- Mandatory regulation about buying the energy from an existing district heating.
- Any regulation about the thermal reserves in heating/cooling installations.

The data was collected and fully referenced for each of partner countries. Appendix 1 of this paper shows the completed data collection pro-forma for Hungary. Each countries collected data was captured in the final report as an appendix and in this case Appendix 4 for Hungary.

Analysis and observations

Each of countries building codes, EBPD implementation and good practice were compared. The conclusion was that all the building codes lay down minimum levels of performance for building fabric elements and building services; but not renewables. The codes do not attempt to prompt best practice in any way.

The energy performance of non-domestic buildings as designed is normally calculated holistically by the use of approved software. In the majority of countries the same software is used for both building regulation compliance and the production of EPCs. Because the software is country specific, normally due the local climate and construction data it uses, and therefore it should be the Hungarian software used to assess the design options and overall performance parameters of the building. At this point we should note that regulatory software provides a theoretical assessment of the asset but under standardised 'driving conditions' typical of that type of building in that location. While the operational ratings, which are based on energy bills, is nearly always higher (can be more than double) due to non-standard hours of operation, occupancy patterns and unregulated loads, such as IT and office equipment; if the retail building had food store(s) refrigeration will also be a contribution factor.

To truly understand how a building uses energy, it is necessary to know something about how the building has been designed itself and about how it is used; this requires both an asset rating and an operational energy rating. The difference between these ratings – or between the predicted and actual performance of buildings – is known as the 'performance gap' **[4]** and should be taken into account when assessing the design.

Best Practice for Technology areas was identified as lying within either:

- the EU Green Public Procurement (GPP) criteria **[5]**, or
- the UK's Enhanced Capital Allowance (ECA) scheme and its Energy Technology List (ETL) **[6]**.

Other countries do not seem to be as far advanced down the best practice specification route as the UK; although this may change with the forthcoming implementation of Ecodesign and Eco labelling initiatives. These however are yet to be fully implemented so the best sources of best practice are currently public procurement standards and those in support of government policy vehicles such as tax breaks or feed-in-tariffs.

Best practice and standards to be used on the EcoShopping project

In this section we look at how the best practice specifications and standards identified can be transferred to the EcoShopping project.

Building fabric

In the context of the project it is proposed that the best fabric u-values identified being used as the backstop (minimum) performance levels – see Table 1. Any enhancement of these will be terms of the cost-effectiveness of the increased thermal performance.

HVAC services

It is proposed that a renewable powered heat pump is used as are part of the refurbishment to demonstrate this technology. Therefore, the performance should match or exceed those laid down in the criteria of the GPP or ETL to ensure best practice. These criteria lay down best practice performance for Heat pumps, in terms of a Coefficient Of Performance (COP) in Heating mode and an Energy Efficiency Ratio (EER) in Cooling mode for the following technologies:

- Air source: gas engine driven split and multi-split (including variable refrigerant flow);
- Air Source: Packaged Heat Pumps;
- Air Source: Split and Multi-Split (including Variable Refrigerant Flow) Heat Pumps;
- Air Source: Air to Water Heat Pumps;
- Ground Source: Brine to Water Heat Pumps;
- Water Source: Split and Multi-Split (including Variable Refrigerant Flow) Heat Pumps.

Fabric element	Characteristic	Austria	Croatia	Germany	Hungary	Italy	Poland	Portugal	Spain	Turkey	UK	Best values
Roof/ceiling	U-value - W/m^{2}K	0.20-0.40	0.30-0.40	0.20-0.35	0.25	0.29-0.38	0.20-0.70	0.40-0.50	0.19-0.50	0.25-0.45	0.16-0.25	**0.16**
Wall	U-value - W/m^{2}K	0.35-0.90	0.45-0.75	0.28-0.35	0.45-0.50	0.33-0.62	0.25-1.00	0.50-0.70	0.25-0.94	0.40-0.70	0.28-0.35	**0.25**
Floor	U-value - W/m^{2}K	0.40	0.50-0.80	0.35	0.25-0.50	0.32-0.65	0.25-1.50	0.40-0.50	0.31-0.53	0.40-0.70	0.22-0.25	**0.22**
Windows, roof windows, roof lights, curtain walling and pedestrian doors	U-value - W/m^{2}K	1.40-2.50	1.80-3.00	1.30-2.7	1.60-2.50	2.00-4.60	1.30-1.80	3.30-3.40	1.2-5.7	2.4	1.60-2.20	**1.20**
Vehicle access and similar large doors	U-value - W/m^{2}K	2.50	2.9	1.80-2.90	1.80	N/A	1.70	N/A	N/A	N/A	1.50	**1.50**
High usage entrance doors	U-value - W/m^{2}K	2.50	2.9	1.80-2.90	N/A	N/A	1.70	N/A	N/A	N/A	3.50	**1.70**

Table 1: U values (in W/m^{2}K) for each of the participating countries in terms of the major building elements.

The ETL also contains criteria for Heat pump dehumidifiers; Heat pump driven air curtains and CO_2 Heat Pumps for Domestic Hot Water Heating.

As well as Heat pumps and associated technologies the ETL contains best practice criteria for:

- Air to air energy recovery;
- Automatic monitoring and targeting equipment;
- Boilers and boiler equipment;
- Combined heat and power (CHP):
- Compressed air;
- Heat pumps;
- Heating, ventilation and air conditioning (HVAC) equipment;
- Lighting;
- Pipe insulation;
- Motors and drives;
- Solar thermal system
- Refrigeration equipment;
- Uninterruptible power supplies;
- Warm air and radiant heaters.

An example of the criteria is shown in Table 2.

Product Category	Heating mode (COP)	Cooling mode (EER)
Water source: single split (non-VRF) heat pumps	>3.70	>3.30
Water source: dual split (non-VRF) heat pumps	>3.70	>3.30
Water source: multi-split (non-VRF) heat pumps	>3.70	>3.30
Water source: split or multi-split variable refrigerant flow (VRF) heat pumps	>4.10	>3.50

Table 2: UK ETL performance criteria for Water source: split and multi-split (including variable refrigerant flow) Heat Pumps.

Building Controls

The report and the documents it references **[7]** recognise that the control of energy in non-domestic buildings is generally poor, despite the availability of a range of tried and tested systems incorporating both mature and innovative technologies. The installation of HVAC zone controls, optimising controllers (for Wet Heating Systems) and lighting controls is encouraged by the building codes, but their specifications are basic. As controls are one of the most effective solutions in realising energy savings, they should always be part of a refurbishment.

The relatively new European standard EN 15232 on the Energy performance of buildings — Impact of Building Automation, Controls and Building Management **[8]**, should be used as the methodology for estimating their effect.

EN 15232 has a series of classes describing the energy performance – see Figure 2.

To put this into context Class C is what would be required by the current UK building regulations published in November 2013 **[9].**

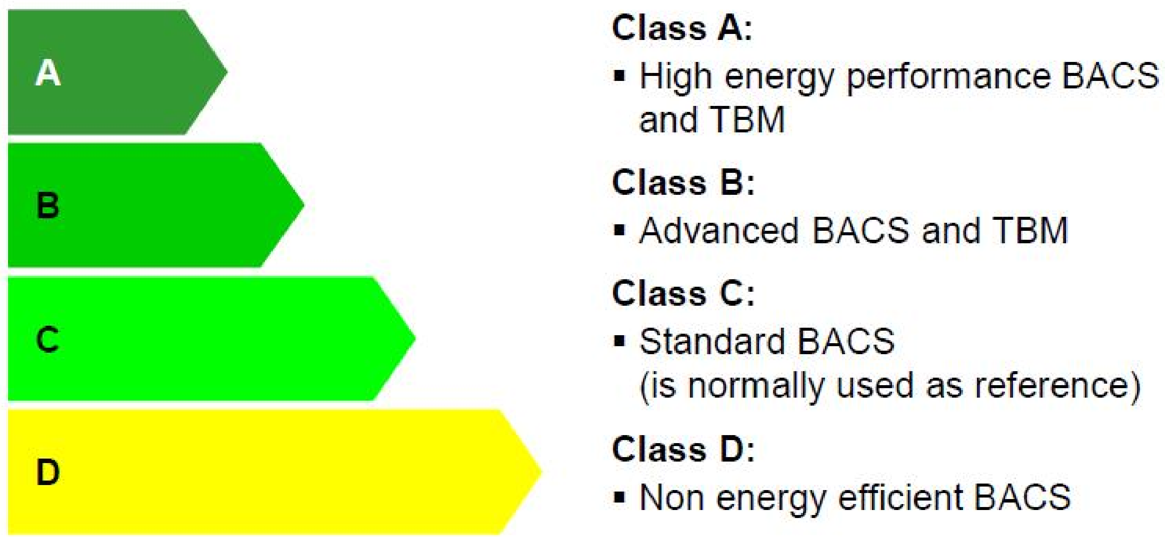

Figure 2: Energy performance classes

Note: Building Automation and Controls Systems (BACS) and Technical Building Management Systems (TBM) in the UK are known as Building Management System (BMS) and Building Energy Management System (BEMS) respectively.

The UK Energy Technology List (ETL) currently has criteria for:

- Heating, Ventilation and Air Conditioning (HVAC) controls (now Building Environment Zone Controls);
- Hot Water Systems Optimising controls (now Heating Management Controllers);
- Lighting controls; and
- Variable Speed Drives (VSDs).

The ETL Building Environment Zone Controls criteria are close to representing good practice when all the criteria are imposed. The criteria above fall slightly short in that summer/winter change over functionality and a requirement for 365 day programming, as defined in BS EN 15500 **[10]**, have not been included. Joining these together would represent good practice and a specification based on this would probably meet the requirements of Class B of EN 15232, a step up from the building codes but this still falling short of the most efficient operation of a building.

The indicative savings that can be achieved from the implementation of the EN 15232 classes are shown in the table 3. This considers Class D of the standard as the baseline; the reason for this is that the majority of buildings will be at this level or below.

If we look at the wholesale and trade service buildings line we can see that fitting Class C controls could realise 36% savings, whilst an additional 17% can be achieved through Class B controls. Pre-programmable BEMs would satisfy the Class B criteria but in order to achieve Class A of the standard, programmable BEMs would be required and then the final 9% of energy savings may be realised.

The standard indicates that approximately 62% of savings for a retail building can be achieved by fitting EN 15232 Class A controls (a programmable BEMs) which would achieve the target for the Eco Shopping building without other measures. The indicative savings are based on a large number of case studies from all over Europe, including ones from the UK's Energy Efficiency Best Practice programme (EEBPp).

Lighting controls are also included within the ETL but are technology specific; the specification covers products that are specifically designed to switch electric lighting on or off, and/or to dim its output. In addition to the functionality covered by the Building Environment Zone Controls described above, lighting controls cover presence detection and daylight detection – with and without dimming. The result is that these could be used as off the shelf specifications for the building control systems.

Non-residential building types	% savings from D			
	D	C (Reference)	B	A
	Non energy efficient	**Standard**	Advanced	High energy performance
Offices	0.00	34	47	54
Lecture hall	0.00	19	40	60
Education buildings (schools)	0.00	17	27	33
Hospitals	0.00	24	31	34
Hotels	0.00	24	35	48
Restaurants	0.00	19	37	45
Wholesale and retail trade service buildings	**0.00**	**36**	**53**	**62**
Other types: - sport facilities - storage - industrial buildings		N/A		
* These values highly depend on heating / cooling demand for ventilation.				

Table 3: Indicatives savings for increasing the class of building controls from Class D of EN 15232

Building Controls and zoning
The way a non-domestic building is subdivided into zones will influence the predictions of energy performance and how you set up the control of the building. Therefore, the zoning rules must be applied when assessing a non-domestic building for controls. The end result of the zoning process should be a set of zones where each is distinguished from all others in contact with it by differences in one or more of the following:

- The activity attached to it;
- The HVAC system which serves it;
- The lighting system within it;
- The access to daylight (through windows or roof-lights).

To this end, the suggested zoning process within a given floor plate is as follows:

1. Divide the floor into separate physical areas, bounded by physical boundaries, such as structural walls or other permanent elements.
2. If any part of an area is served by a different HVAC or lighting system, create a separate area bounded by the extent of those services.
3. If any part of an area has a different activity taking place in it, create a separate area for each activity.
4. Divide each resulting area into “zones”, each receiving significantly different amounts of daylight, defined by boundaries which are:

    a. At a distance of 6m from an external wall containing at least 20% glazing;
    b. At a distance of 1.5 room heights beyond the edge of an array of roof-lights if the area of the roof-lights is at least 10% of the floor area;
    c. If any resulting zone is less than 3m wide, absorb it within surrounding zones;
    d. If any resulting zones overlap, use your discretion to allocate the overlap to one or more of the zones.

An example of this approach is given in Figure 3. Once the zoning has been carried out consideration can be given to placement of sensors (temperature, occupancy and light levels) with a view to controlling these zones in terms of the services provided.

Daylighting Standards
The only comprehensive standard found, for non-domestic buildings, was the British Code of Practice for daylighting BS 8206-2 **[11]**. This standard gives recommendations regarding design for daylight in buildings, which include electric lighting design when used in conjunction with daylight.

BS 8206-2 describes good practice in daylighting design and presents criteria intended to enhance the well-being and satisfaction of people in buildings; these recognise that the aims of good lighting go beyond achieving minimum illumination for task performance.

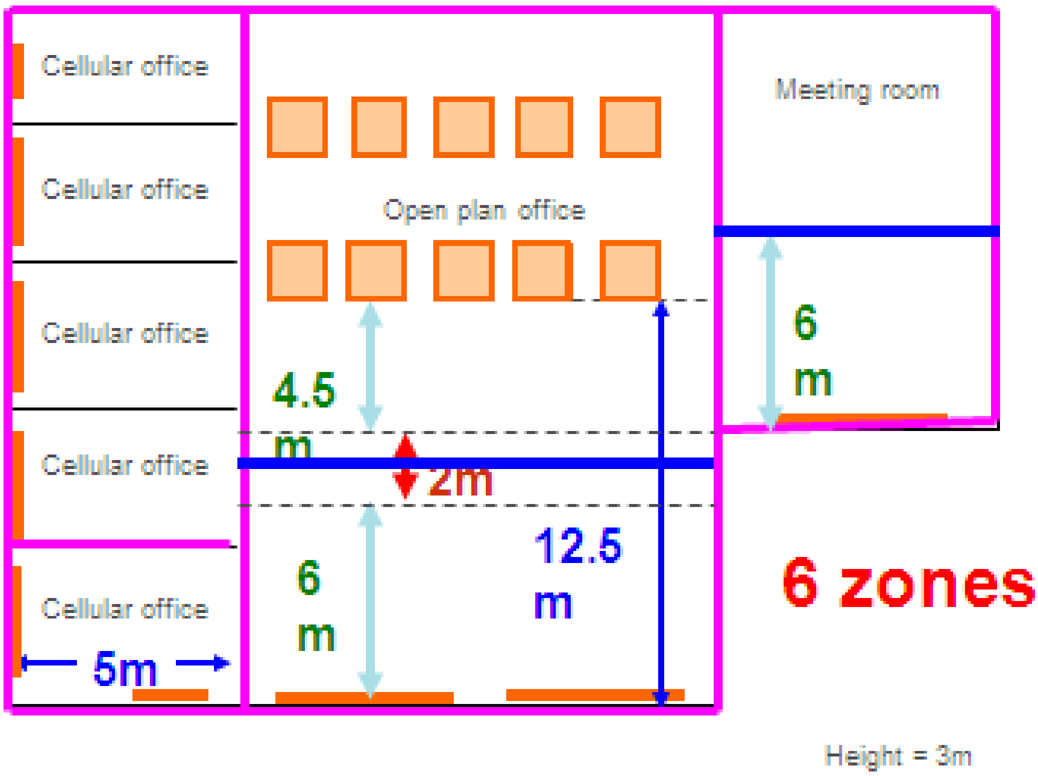

Figure 3: an example of a small office zoned by activity and then daylighting

This revision of BS 8206-2 has been prepared to take account of the publication of two European standards (EN 12464-1 **[12]** and EN 15193 **[13]**). In particular, some of the manual calculations that appeared in the 1992 edition have been omitted and a new annex on climate-based daylight modelling has been added along with a new clause on daylighting and health.

Simple graphical and numerical methods are given for testing whether the criteria are satisfied, but these are not exclusive and computer methods may be used in practice. Sunlight and skylight data are given.

In addition a new BRE guide **[14]** provides essential guidance on how to achieve effective and energy-efficient retail lighting and new CIBSE guide 10 provides designers with guidance on lighting for the built environment **[15]**.

Energy auditing and whole building energy savings
There is also a need to carry out an energy audit in order to identify the most appropriate technology areas for any refurbishment.

There is a new European standard for energy auditing **[16]** which should be used to identify opportunities for savings and barriers to implementation. Then the data collected can also be used to create meaningful improvement targets through the application of data analysis **[17]**.

For a case study such as this it is essential that the methodologies are comparable with those already in use and that technologies match or exceed best practice criteria already published. In addition, producing auditable numbers is essential to showing transparency in how the energy savings claimed are justified.
However, refurbishment is not treated consistently and for major works it is suggested the EU GPP criteria of an 20% improvement on the building regulations for new build is aimed for or at least the same performance as the minimum new build criteria, as laid out in the building codes, is reached.

If this is not technically feasible a minimum performance increase, such as achieving a final rating in the top quartile of energy performance should be considered. The top quartile level defined by analysing the database of Energy Performance Certificate (EPC) ratings within the country in which the non-domestic building is situated.

From earlier you can see that this project is far more ambitious and aims for an EPC “A” rating.

Phase	Low Carbon Refurbishment Process	Page	RIBA Work Stages[3]
Prepare	Commit to a low carbon refurbishment	7	**Preparation**
	Establish a low carbon vision for the refurbishment	7	A Appraisal
	Develop a low carbon outline brief	7	
	Establish the current carbon footprint of the building	8	B Design brief
	Set carbon targets for the refurbishment	8	
	Undertake a pre-refurbishment assessment	9	
	Consult stakeholders	10	
	Consider a budget for low carbon elements	10	
	Appoint a carbon champion	11	
	Choose an appropriate design team	11	**Design**
	Empower the design team	12	C Concept
Design	Keep the low carbon theme up front	13	D Design development
	Develop an integrated low carbon design	13	
	Encourage exploration of a wide range of low carbon options	14	
	Allow flexibility in design	15	
	Use energy modelling data	16	E Technical design
	Use whole life costing to support low carbon solutions	17	
	Manage the budget and scope	17	
	Approve the integrated design	18	
	Include targets in contracting arrangements	18	**Pre-construction**
Construct	Ensure effective project management	19	F Production information G Tender documentation
	Choose an appropriate contractor and subcontractors	19	H Tender action
	Get buy-in from site workers	19	**Construction**
	Monitor site progress against objectives	20	J Mobilisation
	Ensure high quality commissioning	20	K Construction to practical completion
	Set up energy monitoring	20	
Use	Make sure the occupants understand the building	21	**Post practical completion**
	Make sure the building operator understands the building	21	L Post practical completion
	Conduct a post-occupancy evaluation	22	
	Check energy use and comfort conditions and make changes	22	
	Make the most of the low carbon building	22	

Figure 4: Good practice roadmap for the Low Carbon refurbishment process
Best practice guidance on the design process

Best practice guidance on low carbon refurbishment of non-domestic buildings has also been identified; this covers both the refurbishment process and the use of renewable technologies **[18]**. The guidance is structured around a roadmap for the refurbishment process, identifying the key intervention points during the preparation, design, construction and use phases of the project – Figure 4.

Best practice for renewables
For renewables, the ETL has best practice performance criteria for Heat pumps; Solar Thermal; Combined Heat and Power; Biomass boilers and room-heaters.

The UK Feed-in Tariff (FIT) for generating electricity on-site [**19]**, Renewable Heat Incentive (RHI) **[20]** and the Microgeneration Certification Scheme ('MCS') **[21]** contains technology requirements for:

- Solar thermal systems;
- Solar PV systems;
- Small and micro wind turbines;
- Heat pump systems;
- Biomass systems;
- CHP;
- Micro-hydro systems;
- Bespoke Building Integrated Photovoltaic (PV) Products.

These give full product specifications to the current EN and ISO standards and have performance criteria based on these.

For example, MCS includes minimum performance requirements for heat pumps (COPs) and biomass (efficiency) and every MCS installation standard includes a methodology for estimating the annual energy performance of renewable energy systems. In addition, PV has the MCS Guide to the installation of PV systems which contains a method for estimating the annual electricity generated (AC) in kWh/year of the installed system.

Lift, escalator and moving walk energy consumption
The European Community publishes Energy Directives, which in turn give rise in to changes to the Building codes or Regulations. Only passing mention is made of the energy consumption of lifts, escalators or moving walks. This is in part due to the small energy demand (averaging about 5%) made by vertical transportation equipment compared to a building's total energy consumption and in part to the fact that the lift industry (generally) provides energy efficient products. Examples include counterbalanced lifts and auto-start escalators and moving walks. However, as the energy usage of buildings reduces the proportional due to the use of lifts and escalators becomes more significant.

Equipment standards
Lifts only move vertically and occasionally on an incline. Escalators move on an incline and moving walks move both horizontally and on the incline.

Escalators/moving walks fall under the European Machinery Directive **[22]**; are factory built and the manufacturer is responsible for compliance with any regulations. They also have close control on all energy aspects and can offer a range of products for which it is possible to declare a precise energy take.

Lifts fall under the European Lift Directive **[23]**; are assembled on site from a number of manufactured components and the installer is responsible for compliance with any regulations. Although the installer can select energy efficient components the quality of the installation and the way a building is operated significantly affect energy consumption.

The International Standards Organisation, Technical Committee ISO/TC 178, Lifts, escalators and moving walks, Working Group 10 have created and published three standards in the ISO 25745 family, under the general title Energy Performance of Lifts, Escalators and Moving Walks:

- Part 1: Energy Measurement and verification
- Part 2: Energy Calculation and Classification for Lifts (Elevators)
- Part 3: Energy Calculation and Classification for Escalators and Moving Walks

The standard BS EN ISO 25745-1: 2012 Energy Performance of Lifts, Escalators and Moving Walks — Part 1: Energy Measurement and Verification provides an agreed international method of energy measurement for lifts **[24]**.

The standard BS EN ISO 25745-2: 2014 Energy performance of lifts, escalators and moving walks — Part 2: Energy calculation and classification for lifts (elevators) provides an internationally agreed colour coded set of performance levels for running, idle and standby for lifts **[25]**.

The standard BS EN ISO 25745-3: 2014 Energy performance of lifts, escalators and moving walks — Part 3: Energy calculation and classification for escalators and moving walks provides an internationally agreed method to estimate the energy consumption **[26]**

Best practice
This is dealt with in the newly published (September 2015) CIBE guide D: Transportation systems in buildings **[27]**; in particular chapter 13 deals with the energy consumptions of lifts, escalator and moving walks.

It draws the conclusions that:

- Traction lifts have always been energy efficient as a result of their counter-balanced design. Today, lifts with regenerative VVVF (variable speed, variable-voltage, and variable-frequency) drives are even more so.

- Hydraulic lifts have been less efficient, but recently they have been installed with energy accumulators to capture the down movement energy and some suppliers now use VVVF flow control systems.

- The ISO classification system for lifts using the Performance Levels for running and standby are robust and specific to each individual lift in a specific building. The ISO Class is less robust as it is uniquely linked to the number of operations per day. When these change so does the class.

- With Escalators and moving walks; auto-start control can considerably reduce, and slow speed operation can reduce, energy consumption.

- The classification system for escalators and moving walks only addresses the no load condition against a set of reference installations. In time the reference values will change as technology and physical configurations progress.

- The BREEAM Credit system is important to encourage an energy efficient building.

Conclusion
This study identifies that building regulations and their associated codes lay down minimum levels of performance for non-domestic buildings but do not attempt to prompt best practice. These include minimum performance (“backstop”) requirements for building fabric elements and building services; the exception being true renewables, i.e. solar, hydro and wind based technologies, where there were generally no performance criteria. This may change in the near future with recast Energy Performance of Buildings Directive (EPBD) [2]; especially article 9 on Nearly Zero Carbon Buildings (NZEBs) but progress in this area, so far, has been slow.

This EcoShopping project aims to at least match the best of these backstop U-values for all of the building fabric elements and exceeded them wherever possible. The building codes approach the energy performance of non-domestic building holistically where the overall performance of the building as designed is calculated by the use of approved software. This gives an asset rating which is then deemed as a pass or fail when compared to the performance level required by the individual building code, normally in terms of a target kWh/(m^2.year).

The Primary energy consumption of the case study building was calculated as being 167.7 kWh/(m^2.year); which gave an E rating on the Hungarian Energy Performance Certification (EPC) scale. The target value for the IKVA case study is 80 kWh/(m^2.year); which equates to an approximately 50% reduction in energy usage and would give an EPC rating of an “A”. This is an ambitious target but one that is thought to be achievable by the design team.

Best practice performance criteria were identified for the majority of technology areas. The project proposes the use of heat pump technology and the performance of said technology should match or exceed the best practice performance criteria described in the UK’s Enhanced Capital Allowance (ECA) scheme and its Energy Technology List (ETL).

The control of energy in non-domestic buildings is generally poor and controls are one of the most effective solutions in realising energy savings. As the level of control specified by building regulations is generally very basic, controls should always be considered as part of a refurbishment and EN 15232 used as the methodology for estimating their effect. EN15232 states indicative savings of 62% may be realised by the installation of an advanced Building Energy Management system (BEMs) in this building type - Wholesale and retail trade service buildings.

For a refurbishment best practice case study, it is essential that the methodologies are comparable with those already in use and that technologies match or exceed best practice criteria already published. In addition, producing auditable numbers is essential to showing transparency in how the energy savings claimed are justified.

In addition the energy usage of lifts and escalators should not be ignored; especially in a retail environment, and where new best practice guidance has just been published.

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[20] Renewable Heat Incentive (RHI), https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi
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Appendix 1: Data Collection – Hungary

Country	HUNGARY
Data collected by: ***V0 2013-12-04*** Name Organisation Email Phone ***V0.1 Review 2013-12-05*** Name Organisation Email Phone ***V0.2 Review 2013-12-06*** Name Organisation Email Phone ***V1 20123-12-06*** Name Organisation Email Phone	 **Kinga Horváth** **EnergoSys Inc.** **projekt@energosys.eu** **+36 1 461 0510** **Enrique Grosser** **EnergoSys Inc.** **projekt@energosys.eu** **+36 1 461 0510** **Gábor Németh** **Lagross Kft.** **info@lagross.hu** **Kinga Horváth** **EnergoSys Inc.** **projekt@energosys.eu** **+36 1 461 0510**
Building energy regulations	
Building energy code (s)	 **Building Code of Hungary is:** **Országos Településrendezési– és Építési Követelmények (OTÉK)** **(National Urban Planning and Building Code)** http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=99700253.KOR&celpara=#xcelparam This regulation states that every building shall comply with the requirements of energy-efficiency and thermal protection. Buildings and its parts shall be designed, constructed and products used for these purposes shall be chosen considering that the energy needed for the proper functional and safe use shall be as low as possible. **Requirements are stated in the following building energy codes:** · About Energy Performance of Buildings: 7/2006. (V. 24.) TNM directive, which customized calculation methods (EPBD) http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=A0600007.TNM · About Energy Performance Certification: 176/2008. (VI. 30.) Government directive, which standardized the methods of energy certification http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=A0800176.KOR · About National Building Registry 313/2012. (XI. 8.) Government directive, which regulates storage and use of Energy Performance Certificates http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=A1200313.KOR
Is it mandatory?	**YES.** **EPBD exceptions:** a) buildings with less than 50 m2 efficient floor area b) buildings which are used less than 4 months per year c) buildings designed for maximum 2 years of use d) buildings of religious use e) buildings protected with law and building located within an area protected with law (monumental protection and local architectural value's protection) f) buildings with agricultural use g)[1] buildings which has more than 20 W/m2 inner heat gain form technologies during regular operation time, or air exchange rate is more than 20, or required

	to be h) workshops i) air-blowed or strut tent structures **Energy Performance Certificates are mandatory for:** a) new buildings b) existing buildings or independent functional unit's ba) change of ownership in return for payment bb) renting c) public use government buildings with more than 500 m2 efficient floor area, owned by the State
Chronology **1st version** **Current version** **Next revision**	7/2006. (V. 24.) TNM / 176/2008. (VI. 30.) / 313/2012. (XI. 8.) 2006 / 2008 / 2012 2012 / 2013 / 2013 2013 / 2014 / 2014
Governance **Development** **Implementation** **Verification** **Enforcement**	Hungarian Government Hungarian Government - - -
Compliance software	Use of any software is not mandatory. The governmental order defines the calculation methodology. Several software products had been developed according to this methodology on commercial basis.
Compliance targets	**For demonstrating compliance EPCs with detailed energy performance calculations shall be attached to every request for building permits.** Buildings shall be designed and constructed to meet the building energy regulations. The energy characteristic of building shall be calculated using the simplified or the detailed calculation method, using the values that are set in the directives, or an applicable computer simulation method which is accepted in the international practice, according to the decision of the designer. Calculations shall be done for the whole building, but compliance can be proven by adding results of calculations of parts of a building. Requirements of overall building energy characteristic shall be determined considering the function of the building.
Are there requirements in the building code for the building envelope, especially insulation, thermal bridging, pressure testing and overheating	**Building envelope:** **EPBD:** The requirement system has 3 levels. · Heat transfer coefficient (U values) of building envelope structures: maximum permitted values are set. · Specific heat loss coefficient (q): maximum permitted values are set, in consideration of A/V ratio o Total primary energy: [kWh/(m^2.year)] maximum permitted values are set, in consideration of A/V ratio and function (residential, office, educational, other) of the building. ("A" is the sum of the surfaces (walls + windows + roof + floor) around the heated air volume, and "V" is the heated air volume.) Building has to comply with all 3 requirements. **Thermal bridges:** Thermal bridges are considered in the calculation method. **Overheating:** Risk of overheating of the building in summer and energy need of cooling systems shall be reduced by using building structure, shadowing and natural ventilation solutions. Designers can decide that they calculate overheating of parts of the building separately, because there can be great differences. EPBD: risk of overheating in summer can be accepted, if: Δti, *summer* $\leq$ 3 K (in case of 'heavy' buildings, considering specific heat storage mass of building) Δti, *summer* $\leq$ 2 K (in case of 'light' buildings), and the average inner heat load during operational time is less than 10 W/m2

<table>
<tr>
<td></td>
<td>
Requirements for heat transfer coefficients are related to new buildings, and for existing building, when energy-modernization is being performed.
Requirements for heat transfer coefficient
<table>
<tr><th>Building envelope</th><th>Requirements for heat transfer coefficient
U [W/m²K]</th></tr>
<tr><td>External wall</td><td>0,45</td></tr>
<tr><td>Flat roof</td><td>0,25</td></tr>
<tr><td>Slab under attic</td><td>0,3</td></tr>
<tr><td>Envelope structures of heated attic</td><td>0,25</td></tr>
<tr><td>Bottom slab above arcade</td><td>0,25</td></tr>
<tr><td>Bottom slab above unheated cellar</td><td>0,5</td></tr>
<tr><td>Glazed doors and windows on facade (wood or PVC frame)</td><td>1,6</td></tr>
<tr><td>Glazed doors and windows on facade (metal frame)</td><td>2</td></tr>
<tr><td>Gazed doors and windows on facade, if their nominal area is less than 0,5 m2</td><td>2,5</td></tr>
<tr><td>Glass wall on facade</td><td>1,5</td></tr>
<tr><td>Skylight</td><td>2,5</td></tr>
<tr><td>Skylight window</td><td>1,7</td></tr>
<tr><td>Unglazed front door</td><td>3</td></tr>
<tr><td>Door on facade or between heated and unheated area</td><td>1,8</td></tr>
<tr><td>Wall between heated and unheated area</td><td>0,5</td></tr>
<tr><td>Wall between two heated buildings</td><td>1,5</td></tr>
<tr><td>Wall in contact with ground, between 0 and 1 m</td><td>0,45</td></tr>
<tr><td>Floor slab, on its perimeter 1, 5 m wide</td><td>0,5</td></tr>
</table>
</td>
</tr>
<tr>
<td>Are there requirements in the building code for the Heating, Ventilation and Air Conditioning (HVAC) systems</td>
<td>
Envelope structures and building services systems shall ensure together the required air quality.
In EPBD required operative temperatures, air exchange ratio and CO2 ratio are set.
Heat producers: if energy source is natural gas, condensational boilers are recommended. In case of existing building this is not mandatory, considering technological characteristic.
Control systems: If area heated with one system is bigger than 100 m2, central controlling with weather integration is mandatory.
Heating system:

Separate temperature control in rooms and building parts is recommended.
Balancing of the system is mandatory and shall be documented.
Convenient operation shall be checked and documented during a test operation period.

Ventilation:

At least 70% heat recovery is recommended.
Operating point of ventilators shall be at maximum efficiency. Using EN 13779 standard.
Pressure loss shall be reduced. EN 13779 “normal’ values.
Maximum air loss shall be defined and certified by the constructor. EN 12237
Balancing of the system is mandatory and shall be documented.

Cooling:

Balancing of the system is mandatory and shall be documented.
Convenient operation shall be checked and documented during a test operation period.
Use of a high temperature cooling system is suggested if it is technologically possible.

</td>
</tr>
</table>

	· Free cooling is recommended, when the outdoor temperature is acceptable.
Are there requirements in the building code for Domestic Hot Water (DHW)	· If there is a circulation circle, possibility of time controlled operation shall be ensured. · Balancing of the DHW circulation system is mandatory and shall be documented. · Convenient operation shall be checked and documented during a test operation period.
Are there requirements in the building code for the lighting systems	**Requirements of lighting in general:** · Natural daylighting and lighting shall be ensured in every room according to their function. · Standby lighting shall be ensured if it is required in appropriate directives or standards. **Lighting systems:** · Possibility of artificial lighting shall be ensured in every room and evacuation paths outside of the building. · Fluorescent lamps can be used only as hidden lighting where residents must be positioned towards the lights. **National Standards:** Lighting systems: MSZ EN 1838:2000 Lighting bodies: MSZ EN:60598-2-22:1998/A1:2003
Is day-lighting a requirement of the building code? How is it specified?	**Solar access:** · Solar access shall be ensured in at least one room of a residential unit, except if it is not possible because of the existing structure of the city. Solar access is ensured in a room if there is at least 60 minutes of solar access in 15 February. · Workplaces and educational rooms of children shall be protected from direct sunlight by shadowing structures id the sunlight comes from SW/W. · Summer overheating shall be prevented by architectural tools. **Daylighting:** · Natural lighting of rooms shall ensure enough light for proper and safe use considering function. · Daylighting shall be ensured in every room for permanent residence, except if the function does not require it or forbids: auditoriums, performance areas, congregational areas, catering areas, sales areas. · Floor area and daylighting area ratio shall be: · In educational rooms: 1:6 · Other rooms with permanent residence: 1:8 · With skylights: 1:10 · Indirect daylighting shall not be used between collective spaces and units and between units
Are there requirements in the building code for the use of renewables	Compliance with the basic standards can be proved with implementing the accurate Hungarian national standard or other solutions that ensures compliance with requirements that are equal to these requirements (or higher). Buildings shall be designed and constructed ensuring the possibility of integrating or connecting to renewable energy systems without significant demolition. Possibility of use of renewable energy sources shall be considered in every design project.
Energy Performance of Buildings Directive (EPBD)	
Governance **Development** **Implementation** **Verification** **Enforcement**	**Hungarian Government** **Hungarian Government** **-** **ÉMI- Non-profit Limited Liability Company for Quality Control and Innovation in Building**

	-
Is the Energy Performance Certificate an operational or asset rating?	The governmental order includes both the operational and asset method. The official methodology was only developed for the asset method, so experts use only the asset method.
Is the software compatible with that used for building code compliance?	**Yes.**
Are there any other requirements?	**No.**
Other policy mechanisms and instruments	
Is best practice regulated or encouraged through any other means?	**No, there are no subsidies/grants available at this time.**
Is the uptake of renewables supported by other government initiatives?	**No.**
Related standards	
Which are the allowed electrical connections between renewable energy sources and the electrical grid? (for example: Feed-In Tariffs (FITs), Time Of Use metering (TOU), net metering, etc.)	New electricity meter shall be installed. This device can account consumption and produced energy separately. If the system meets certain requirements there is a possibility for installing an electricity meter which extracts amount of produced energy from consumption and remains have to be paid according to actual tariff. In both cases a new contract has to be signed. Provider ensures the change of the electricity meter and also provides the new meter. Price of energy is determined considering type of energy and period. The system shall have a certified inverter in order to meet the requirements of the grid. Conditions and permit shall be requested in written form in every case. Directives: · 389/2007. (XII. 23.) Korm. rendelet about renewable energy sources or waste generated electricity, mandatory off-take and the final price of electricity generated · 109/2007. (XII. 23.) GKM rendelet about prices
Are there national regulations related to the procedures of authorization, certification and concession of the transportation and distribution of energy?	**Yes.**
Do renewable energy systems have to fulfil any technical specifications, certification (TUV, CE, ISO, MCS, PV CYCLE, SGS, etc)? What are these requirements? Are they related to any European regulation?	It is set in the building code that compliance with the basic standards can be proved with implementing the accurate Hungarian national standard, or other solutions that ensures compliance with requirements that are equal to these requirements (or higher). Every building structures, equipment's, construction works etc., as well as national standards have to comply with CPR regulations. TUV, ÉME (This is a Hungarian certification), ISO, CE certificates are approved. All certificates of EU quality certification institutions are accepted. .
Does the grid have the obligation of buying the generated renewable energy? What are the conditions? Are there limitations?	NOT in all cases. It is obligatory only by "mini" power plants < 50 kWh power potential (PP). By 50< PP < 500 kWh grid decides according to its possibilities and convenience. By PP> 500 kWh the decision will be made by the Energy Authority. If energy suppliers buy the generated renewable energy, they have to pay 50% of the current market fee of energy .
Is there any mandatory regulation about buying the energy from an existing district heating? In the case that a end user connects to the district heating, what are the	No. There are two different tariffs. One is for residential buildings and the other is for the others (commercial buildings, offices, and public buildings). It is cheaper for residential buildings. It is mandatory to contract district heating for 5 or 10 years (depending on the region) after connecting.

obligations that the end user has to fulfill?	
Is there any regulation about the thermal reserves in heating/cooling installations?	

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Session Data Centres

Tapping design and optimisation potentials of information and communication technology equipment and data centres

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Abstract

Information and communication technology (ICT) equipment and data centres (DC) are one of the most rapidly increasing electricity consumers. Next to the electricity used by ICT equipment a substantial amount of energy is consumed by building technology equipment to condition these in DC. Energy consumption of cooling, ventilation, and Uninterruptible Power Supply (UPS) may be in the same order of magnitude as the electricity use of ICT hardware, revealing substantial energy-efficiency potentials. Measures to tap these potentials include modified design of new DC and optimisation of existing ones through, for example, server room temperature regulation, use of variable speed drives, and free cooling systems. This paper reports on the experience and outcome of a promotion program to increase the energy-efficiency of DC through design and operation optimisation along with two recent national studies focused on energy efficiency potentials within DC infrastructure (HVAC, UPS) and energy efficiency within ICT hardware systems. Measurements and modelling showed that the realistic potential to increase energy-efficiency on ICT equipment is about 50% and the same energy demand reduction is possible on the infrastructure side (characterised by the power of usage effectiveness (PUE)), based on two recent studies by the authors. For all DC in Switzerland the PUE could substantially be reduced by about 17% within electrical systems and 40% within HVAC systems, mostly by cost-effective measures. The overall and realistic reduction potential of electrical energy demand resulting from replacing existing DC with state of the art versions in Switzerland is about 64%.

Introduction

Due to increasing trends of business process digitisation, information and communication technology (ICT) equipment and data centres (DC) are one of the most rapidly increasing electricity consumer categories. The need of most companies for constant, uninterrupted access to DC outlines the importance of well designed, reliable data transport infrastructure. Given their importance, the knowledge of DC in Switzerland and other European countries is still very low. For this reason two national studies were commissioned by the Swiss Federal Office of Energy and ASUT. Indeed not only the number and size of the Swiss system of DC's was unclear but also their electricity consumption. The goal of these studies were to define the total energy demand and the potentials for energy efficiency of existing DC in Switzerland. The working hypothesis that Switzerland has an above average DC energy consumption per capita will be verified.

Next to the electricity used by the ICT equipment a substantial amount of energy is consumed by building technology equipment to condition these DC. Electricity consumption of cooling, ventilation (HVAC), and UPS may be in the same order of magnitude as the electricity use of ICT equipment, revealing substantial energy-efficiency potentials. There are various measures to tap these potentials including adequate design of new DC and optimisation of existing ones through temperature regulation within the server rooms, using variable speed drives and adequate controls as well as free cooling, for example. For the purposes of this study, and to aid with the implementation of a promotion program to be discussed below, two broad categories of efficiency increasing measures are identified. First are the changes to the efficiency of the ICT hardware itself, through optimising performance. Second are changes that are applied to the infrastructure used to treat the ICT hardware (cooling, etc.).

This paper reports on two recent studies [1, 2] and on the experience and outcome of the promotion program PUEDA to increase the energy-efficiency of DC. The promotion program aimed to optimise DC design and operation while the national studies focused on energy efficiency potentials within the DC infrastructure (HVAC, UPS etc) as well as energy efficiency within ICT equipment.

Data centres: definition and situation

Definition: what is a data centre?

This study defines a DC according to the definition proposed by Fichter (2007) [3].

"Data centre" refers to a building or premise in which the central computing equipment (servers and additional infrastructure for their operation) of one or more companies or organisations is housed. The minimum requirement is that it be a separate room with safe power supply and air conditioning.

Table 1. Typology of data centres according to Bailey et al. (2006) [4].

Type	Typical size	Typical ICT equipment
Server closet	< 18.6 m2 (< 200 ft2)	1 -2 servers No external storage systems
Server room	< 46.5 m^2 (< 500 ft^2)	< 12 servers No external storage systems
Localised data centre	< 92.9 m^2 (< 1000 ft^2)	12 – 100 servers Extensive use of external storage systems
Mid-tier data centre	< 464.5 m^2 (< 5000 ft^2)	100s of servers Intensive use of external storage systems
Enterprise-class data centre	> 464.5 m^2 (> 5000 ft^2)	100 – 1000 servers Intensive use of external storage systems

Table source: Bailey et al. 2006 [4] and Altenburger et al. 2014 [1]

As per this definition, individual server closets are not considered a DC and so generally this study covers situations where a separate server room is present. Further, because we are concerned with measuring conditions within the DC and its associated energy requirements, we focus on server rooms that are large enough to be interpreted as DC. Still, there is a wide range of different types of DC, from rooms measuring 10m^2 to modern specialised buildings that house redundant infrastructure and multiple access controls. With this in mind and because there is limited knowledge of the number of server rooms currently in use within Switzerland and across Europe, we assumed that, based on expert consultation, any company with more than ten servers in a "server cluster" very likely has a dedicated room that, along with its associated infrastructure, can be considered a DC.

Current stock of data centres

This study aims to better understand the requirements of the entire stock of DC within a country and region. To assist in the assessment of existing DC stock, they are divided into two general categories. The first, classical *internal DC* (also called "in-house" DC) are operated by companies on their respective premises for their own use. The second type, supplied by a growing number of specialised companies whose main business is the operation of these DC, are recognised as commercial "Third party providers", or *third party DC*.

Internal (in-house) data centers

The data for internal DC is based on the Profondia database [5] which collects information on 11,000 Swiss companies and organisations that employ at least 30 people and have more than 10 PCs. This is a reliable sample of the Swiss corporate landscape since the Swiss federal Office of Statistics listed, in 2011, 1,200 large companies (more than 250 full-time equivalent employees) and 10,200 medium-sized ones (between 50-250 full-time equivalents). Table 2 shows the size-categorised distribution of servers in Swiss companies. Overall, there are more than 100,000 physical servers, but 18,271 of these (17.7%) are clustered in groups between 3 and 10, and so are not regarded in the used definition of DC. Between 5.49% (2,001-5,000 servers) and 26.37% (11-50 servers) of these units are located in various company size groupings. The servers are generally distributed over the different size categories while. Once the criteria of DC designation are applied to this database, the number of servers amounts to 84,948 over 1,292 DC with the vast majority of DC (78.56%) located in small companies with 11-50 servers (Table 2).

Table 2. Distribution of physical servers and structure of internal DC in Switzerland in 2013 based on Profundia ICT database.

DC type	11-50 Server	51-100 Server	101-200 Server	201-500 Server	501-2000 Server	2001-5000 Server	5001+ Server	TOTAL
Total installed servers	22400	10887	11402	10730	14865	4662	10002	84948
Share of total servers	26.37%	12.82%	13.42%	12.63%	17.50%	5.49%	11.77%	100%
Number of DC	1015	144	78	36	16	2	1	1292
Percentage of total DC	78.56%	11.15%	6.04%	2.79%	1.24%	0.15%	0.05%	100%

Table source: Altenburger et al. 2014 [1]

What is not known is the development of server numbers in recent years. Through a series of expert interviews conducted by Altenburger et al. (2014) [1] combined with recent data, it is assumed that the number of internal servers has decreased rather than increased, as would be generally expected. This is due to two main reasons. First, server virtualisation has led to enormous savings in hardware as a physical server can be divided so that multiple “virtual servers” can be made available. This process optimises the capacity of individual servers and reduces the number of physical servers required and, accordingly, space and costs. Second, as a result of expanded networking capabilities and speed (through larger bandwidth), companies are increasingly outsourcing their ICT needs to third party providers. Hence in-house servers are losing importance and the number of associated DC is decreasing.

Data centers of third party providers

Third party providers represent a dynamic area of the DC landscape and offer a wide range of DC services, from the “simple” rental of DC floor space to comprehensive managed services solutions (outsourcing of all a company’s ICT needs). In the latter, colocation DC offer infrastructure for the outsourcing of servers by providing physical space in server racks for ICT hardware, power supply, access control, as well as access to telecommunications networks.

The third party market has grown over the last decade, driven by the exponential growth of data produced globally through trends in the mobile use of the Internet, cloud computing, IP-based communication, social media, digitalisation of business models, video streaming and so forth. Increasing numbers of business models, especially of successful startups, require high performance DC, which can be more cost-effective if provided by a third party.

A study by the market research firm Broad Group [6] provides some current information on third party DC in Europe. The total area occupied by this category of DC in Switzerland in 2013 was 149,573 m^2, around three quarters of which is represented by the 13 largest industry suppliers. There are only five

European countries (the UK, Germany, France, the Netherlands and Spain) that have more floor space allocated to third party DC [1], suggesting that Switzerland is an important centre for this service. Within Europe, only Ireland has a higher "DC density" (defined as total area of third party DC per capita). Some comparative results from Germany are available for DC distribution, although the categories are not the same as in the Swiss case (Table 3).

Table 3. Structure of DC in Germany in 2013 based on data from Borderstep. No distinction is made between internal and third party DC.

DC type[a]	11-100 Server	101-500 Server	501-5000 Server	>5000 Server	TOTAL
Number of DC	18,100	2,150	280	70	26,600
Percentage of total DC	87.86%	10.44%	1.36%	0.34%	100%

[a] Original data is given as allocated floor space, so this assumes, for comparison, that each server requires 1 m^2 of floor space. Table source: Hintemann and Clausen 2014 [7]

Estimation of electricity consumption of Data centres in Switzerland and selected European countries

Underlying data and assumptions

Electricity consumption of DC is estimated using three variables; allocated floor area, ICT power use per m^2, and Power Usage Effectiveness (PUE). Through this, estimates for Switzerland were made based on available data.

Allocated floor area

Based on the methodology and definitions of Hintemann and Fichter (2012) [7] and Altenburger et al. (2014) [1], it is assumed that one server requires, on average, 1 m^2 of floor space. It is unclear whether this assumption is equally true for all sizes of DC and if it includes the entire floor space or not.

Installed and used ICT specific power

Due to high uncertainty in ICT power requirements, Altenburger et al. [1] defined eight possible combinations of "assumption sets" for size-specific energy requirements, leading to different consumption scenarios. These are meant to incorporate variable process requirements of different installed hardware.

Internal DC:

- Specific power outputs steadily increasing with DC size from 250 W/m^2 (smallest location) to 500 W/m^2 (largest location) in scenario P1;
- Specific power outputs steadily increasing with DC size from 300 W/m^2 (smallest location) to 800 W/m^2 (largest location) in scenario P8;

Third party DC:

- Specific power outputs steadily increasing with DC size from 400 W/m^2 (smallest location) to 500 W/m^2 (largest location) in scenario P1;
- Specific power outputs steadily increasing with DC size from 450 W/m^2 (smallest location) to 800 W/m^2 (largest location) in scenario P8;

Power Usage Effectiveness

Introduced by the "Green Grid", an association of IT companies, the PUE is an internationally recognised indicator of the energy efficiency of DC [1,8]. It is defined as the ratio of total electric power consumption of the DC (ICT equipment plus infrastructure components) to the electrical consumption of ICT equipment (servers, clusters, data storage, and communication).

$$\boldsymbol{PUE = \frac{Total\ power\ consumption\ of\ DC\ (within\ system\ limits)}{Electricity\ consumption\ of\ the\ ICT}}$$

The PUE can be more than 1.0, and the closer it is to this number, the smaller the proportion of electricity demand by the infrastructure components. A PUE of 1.0 implies 100% efficiency at the level of infrastructure. A value of 2.0 means that only half of the electric power consumption flows into the ICT equipment.

Through consultation with experts, the PUE of various server size classes in Switzerland has been estimated. A conservative estimate of values ranges between 1.40 and 2.10. In this economically advanced country that has a strong financial centre, there are high demands of reliability of many DC which tends to be achieved through redundancy that increases the PUE. Table 4 shows the estimated PUE values for internal and for third party DC in Switzerland.

Table 4. Estimated PUE for internal and third party DC in Switzerland, classified by institution size.

Cluster size	Area covered (m^2)	PUE
Internal DC		
11 - 50 Server	22400	2.10
51 - 100 Server	10887	2.00
101 - 200 Server	11402	1.90
201 - 500 Server	10730	1.80
501 - 2000 Server	14865	1.60
2001 - 5000 Server	4662	1.50
5001 + Server	10002	1.40
Total/Average	**84948**	**1.82**
Third party DC		
< 1500 Server	66627	1.80
1501 - 2000 Server	3716	1.75
2001 - 5000 Server	17187	1.55
5001 + Server	62044	1.40
Total/Average	**149574**	**1.60**

Table source: Altenburger et al. 2014 [1]

Results: electricity consumption of data centers

Switzerland

The electricity consumption of Swiss DC in 2013 was calculated to be between 1,395.85 GWh (P1) and 1,925.57 GWh (P8) (Table 5). The median value of these scenarios is 1,660.71 GWh/yr. Based on a total national electricity consumption of 59.3 TWh (59,300 GWh)[1], DC accounted for between 2.35% and 3.25% (median 2.80%) of the electricity used in Switzerland in 2013. In- house DC used between 461.58 GWh and 652.34 GWh, whereas third party DC used between 934.27 GWh and 1,273.33 GWh. Clearly, third party DC electricity demands are greater than those of the internal DC.

Table 5. Total power consumption of DC calculated across scenarios in Switzerland in 2013.

	P1	P2	P3	P4	P5	P6	P7	P8
Total Swiss DC usage (GWh/yr)	1395.85	1497.26	1538.62	1640.03	1681.39	1782.80	1820.03	1925.57
Portion of Swiss consumption (%)	2.35	2.52	2.59	2.77	2.84	3.01	3.07	3.25
Internal DC electricity usage								
Usage by ICT (GWh/yr)	262.20	284.17	292.66	314.61	323.13	345.10	353.59	375.57
Infrastructure usage (GWh/yr)	199.38	220.49	218.14	239.25	236.90	258.01	255.66	276.77
Combined usage (GWh/yr)	461.58	504.67	510.80	553.86	560.03	603.12	609.25	652.34
Third party DC electricity usage								
Usage by ICT (GWh/yr)	589.59	622.36	655.05	687.83	720.53	753.30	783.18	818.78
Infrastructure usage (GWh/yr)	344.69	370.23	372.77	398.31	400.84	426.38	427.60	454.46
Combined usage (GWh/yr)	934.27	992.59	1027.82	1086.14	1121.37	1179.68	1210.78	1273.23

Table source: Altenburger et al. 2014 [1]

Other European countries

The Swiss case can be analysed in relation to the results from other developed nations, such as Germany and the USA, in order to understand the typical nature of the situation. Hintermann and Fichter [9] determined that DC electricity consumption in Germany amounted to 9.4 TWh in 2012. This value is 5.7 times higher than the Swiss result. However, the IMF estimates that Germany's GDP is also approximately 5.6 times greater than that of Switzerland. If we are to realistically assume that there is a linear relationship between a country's economic performance and the number of DC within its territory, then the results are comparable.

While comparing the Swiss results to Germany, there is, however, a noticeable difference in the proportion of DC electricity consumption over the entire network. German DC only account for 1.8% of total consumption, versus Switzerland's 2.8%. In general, German power demand is 9 times the Swiss average, suggesting that Switzerland's GDP/kWh is higher[2]. This is likely due to Germany's higher proportion of large, energy intensive industries, versus the less energy-demanding Swiss economy which relies much more on the value-added services sector. Additionally, between 2010 and

[1]From BAFU on 10.04.2014 : "Stromverbrauch 2013 um 0,6% gestiegen"; http://www.admin.ch/aktuell/00089/index.html?lang=de&msg-id=52616 (last access: 19.06.2014).

[2] Germany's population is slightly more than ten times that of Switzerland. The power consumption per capita is thus slightly higher in Germany.

2014, 5.8 times more servers were sold in Germany than in Switzerland [1], lending further weight to these results. Further comparison with Germany shows that this larger country has about the same size distribution of DC as Switzerland (Table 4). Commercial third party providers in Switzerland, however, occupy comparatively more floor space than their German counterparts (150,000 m^2 versus 557,000 m^2). This may change, as the trend in Germany is for an increase in large (>5,000 m^2) DC while the number of smaller centres stays relatively constant [7].

Estimates for the USA show that DC consumed 67.1 – 85.6 TWh of electricity in 2010, representing between 1.7% and 2.2% of total electricity demand [10]. When considering that there are likely ICT-intensive areas within the USA where these values are higher, they may in part be more comparable to the Swiss results. Therefore the typical nature of the Swiss case is not clear.

Worldwide, DC were calculated to use between 203.4 TWh and 271.8 TWh of electricity, corresponding to between 1.1% and 1.5% of global consumption [1]. Thus, Switzerland is above average in its DC power needs, but within the range of similar developed countries.

Energy-efficiency potentials in Data Centres

Puntsagdash et al. (2015) [2] and Jakob et al. (2015) [10, 12] examined effective ways in which the efficiency of DC can be increased in order to limit their energy consumption. By combining those listed below as well as by introducing additional measures, a reduction in electricity demand of up to 50% in the field of ICT hardware is realistic. An additional 50% reduction is expected as this lowered hardware power demand in turn diminishes the power requirements of the infrastructure that maintains it. Further energy savings can be achieved through advancements in cooling technology (HVAC) and power conversion. Among the most influential changes are the following: (adapted from Puntsagdash et al. 2015 [2])

- Server virtualisation and consolidation leading to more efficient use of hardware (power savings of up to 96%)
- Increasing storage efficiency through data deduplication, thin provisioning and transfer from hard disk to flash memory technology (savings of up to 94%)
- Switching backup systems from disk based to tape based (savings of up to 94%)
- Direct cooling DC as opposed to air cooling (up to 40% reduction in electricity demand)
- Free cooling, which involves the use of cold air and water from the environment
- High temperature cooling (56˚C in the cooling circuit) (up to 84% energy recovery)
- Allowing a slight increase in DC room temperature

By combining some or all of these measures, a significant overall reduction in electricity demand can be achieved. Figure 1 shows the incremental reduction in energy demand in a model DC with 100 kW input as changes to the ITC hardware are first introduced, followed by the reduction in energy demand of associated infrastructure. The calculated PUE is reduced from 1.8 to 1.35, and the total electricity requirements drop to 65 kW, which is a reduction of 63.9%. This is representative of what can be achieved cost –effectively by updating similar DC in the Swiss power landscape.

Based on practical experience of the authors (who are active planners and managers of the promotion program PUEDA) and from the analysis of PUEDA (discussed below), it is assumed that measures to increase DC efficiency can result in a PUE value of 1.35. By assuming this value over the entire system of DC and across all Swiss scenarios, the associated hypothetical power consumption would be between 1,149.9 GWh (P1) and 1,612.4 GWh (P8) (median: 1,381.13 GWh). The potential for energy savings versus the current estimated condition is therefore between 245.95 GWh (P1) and 313.21 GWh (P8) (median: 279.58 GWh) and corresponds to approximately 17% of today's DC electricity consumption.

A few other studies have found similar large potentials in DC efficiency to reduce energy use. A report by the Natural Resources Defense Council in the USA [13] showed that, by focusing mainly on technical optimisation of DC (i.e. through increasing efficiency of network virtualisation and maximising CPU usage), a conservative estimate of 40% cut in electricity consumption can be achieved, representing 39 TWh.

Although still regarded as an important measure of DC efficiency, PUE has its limitations and there is some debate as to whether other measures should be assessed and compared between systems. Puntsagdash et al. (2015) [2] discuss the future of PUE and potential implications for DC design, management, and monitoring.

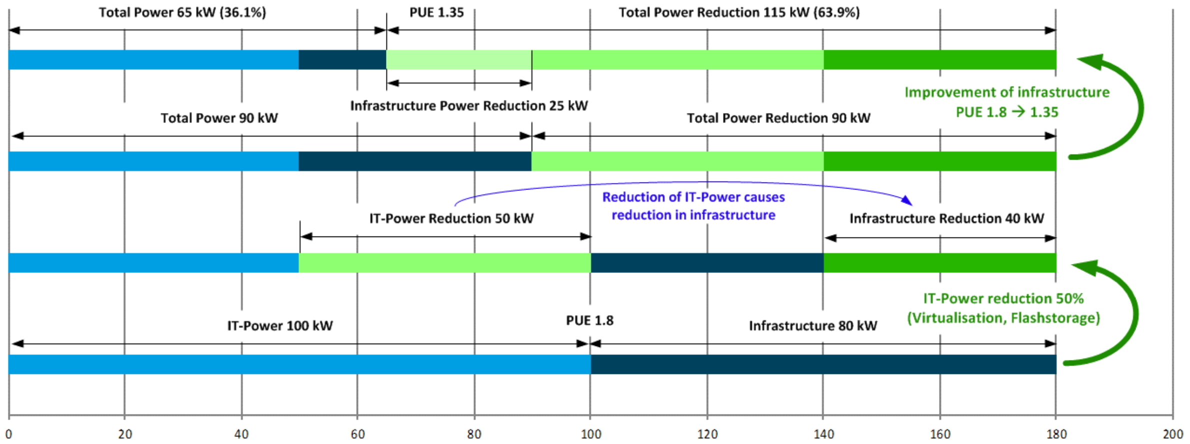

Figure 1. Sample calculation of total electricity saving and PUE reduction in a model DC.

Figure source: Puntsagdash et al. 2015 [2]. Copyright Amstein + Walthert AG.

Mechanisms to implement energy efficiency in DC; Lessons learned from PUEDA

The projects

In order to better understand how to implement some of the energy efficiency measures that are well known to the DC industry, a promotion program was designed in association with the Swiss Federal Office of Energy [11, 12]. PUEDA (Power Usage Effectiveness in Data Centres) was initiated to provide financial incentives for companies that use DC in order to implement some of the energy efficiency increasing measures mentioned above [14]. The aim of the program was to reduce the power consumption of DC without jeopardising the quality of ICT processes [11]. The DC infrastructure was targeted, mainly focusing on the cooling of equipment, heat dissipation, and UPS.

As part of the PUEDA project, two separate programs were implemented; one for existing DC and another for DC in the planning stages. By offering this program to institutions using a self-contained, serviced DC with a power demand larger than 10 KW, PUEDA aimed to reward greater increases in efficiency. In order to be eligible for financial benefits from the program, companies were required to demonstrate a PUE of 1.7 or lower, but consulting services and professional guidance was offered regardless of the existing situation. The maximum benefit was allocated when resultant PUE reached a target of 1.3 in existing DC and 1.5 in new DC. To this end, three broad approaches were used in the program targeting existing DC.

1. Provision of information to reduce the complexity of the issue for participants
2. Consistent execution of energy analysis and tracking of DC. This involved testing the effectiveness of measures in 1 and providing feedback for efficiency measures (package 3)
3. Partial funding of efficiency measures and their planning

Fourteen existing DC in Switzerland were included in the full program representing 2,650 kW of installed power with an average PUE of 1.7 (Figure 2) [11]. The average PUE after the program was 1.28, with all participating DC reducing their power consumption representing potential energy savings of 140 GWh over a 15 year period (Figure 3).

A similar program was introduced to provide these services to new DC [12]. This program consisted of similar approaches.

1. Provision of information to reduce the complexity of the issue for participants
2. Consulting services for creation of efficient DC design, either by the company itself or a third party
3. Funding of new DC after target PUE is calculated and the company adopts energy efficient measures. The financial support is success oriented and represents immediate support in the planning and implementation phase
4. Communication of specialist technical knowledge

Nine new DC representing 8,800 kW of installed ICT participated until the end of the program in 2015. Together, the predicted reductions in energy consumption amount to 460 GWh over the next 15 years. Figure 3 shows the theoretical consumption and the real consumption of the different DC in this second program. The theoretical consumption was calculated on the basis of a standard PUE of 1.6. The savings were calculated based on the difference between the theoretical consumption and the real consumption.

The lessons

The authors involved in the planning, execution, and review of PUEDA outline a few main results from the two programs.

1. Programs to disseminate information about energy efficiency measures in DC design, planning and construction are integral to ensuring these methods are implemented effectively
2. In newly planned DC, the allocation of funding along with proper guidance at these initial stages is critical to measure implementation
3. The potential for energy efficiency improvements in new and existing DC is great, but only when coupled with a comprehensive and analytical model to encourage the acceptance of new measures

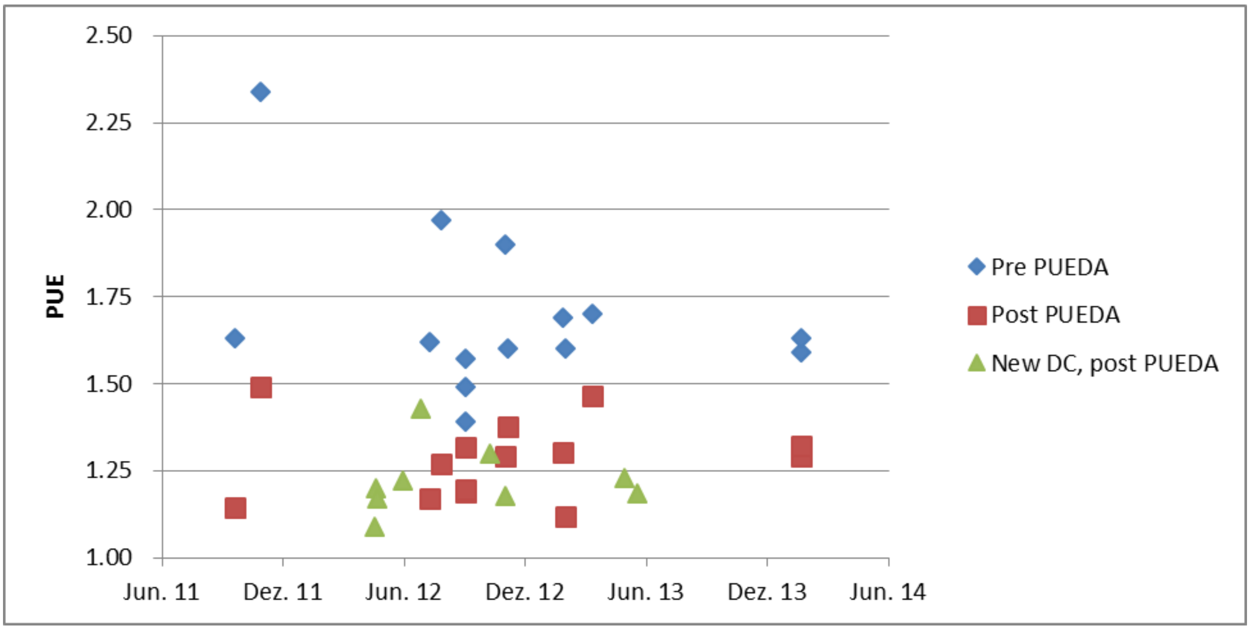

Figure 2. Starting and ending PUE of individual projects listed by date enrolled in the PUEDA program. New projects were all assumed to have a pre-program theoretical PUE of 1.6.

Figure source: Jakob et al. 2015 [10, 12]

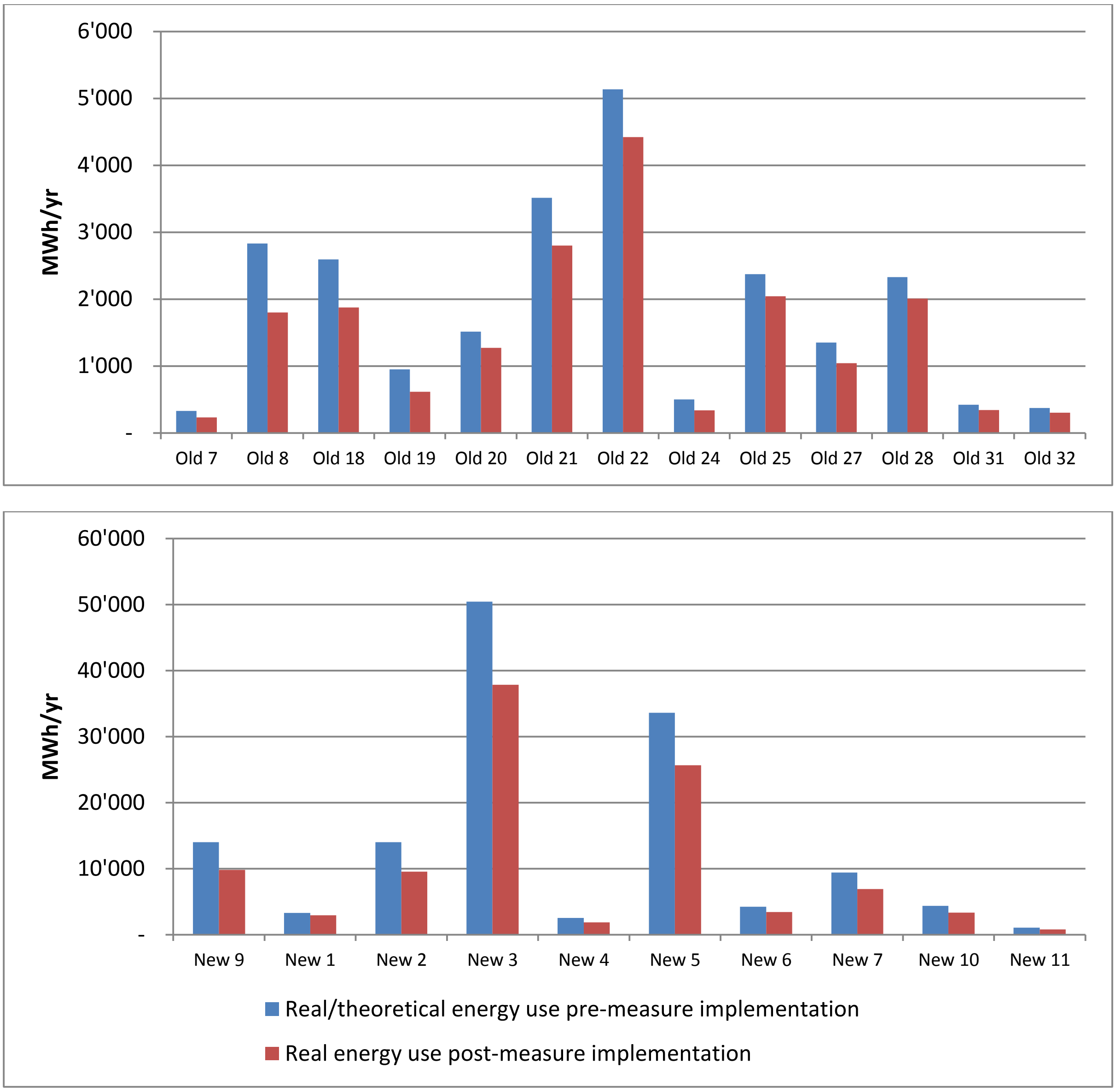

Figure 3. Annual energy consumption of DC involved in the PUEDA program, before and after execution of measures, ordered by project number. 'Old' projects (top) are existing DC that were involved in the PUEDA program while 'New' projects (bottom) are those involved in the program for newly built DC. Note the scale of the horizontal axes is different between the two cases.

Figure source: Jakob et al. 2015 [10, 12]

Conclusion

The importance of increasing the energy efficiency of DC worldwide is clear; since between 2000 and 2015, the energy demand of DC has quadrupled [10]. The technology and techniques to do so are generally widely available in developed countries in Europe and USA, for example, and can be implemented through promotional and incentive programs. With existing technology, a reduction of 50% electricity use can be achieved by addressing the efficiency of hardware and the setup of servers within existing and planned DC. A further 50% reduction in the remaining consumption is possible through associated lowered infrastructure demands with even more savings resulting from alterations to the infrastructure, such as HVAC and UPS. Together, this can make a significant impact on the energy demand of the IT sector in European countries and worldwide.

By using the Swiss case as an example, this paper has shown that increasing efficiency in DC (through changes that affect the PUE) can reduce the energy consumption of electrical systems by 17%. Additionally, 40% can be saved by changes to the HVAC and other infrastructure that support the DC hardware. Overall, up to 64% energy savings can be achieved by simply updating the current system of existing DC in Switzerland.

The implementation of PUEDA, a promotion program to enhance the dissemination of these measures into the design of new DC and conversion of existing DC, has shown the importance of a mechanism for information transfer to the companies involved in installing and managing DC. The successful implementation of energy efficiency measures depends on the appropriate motivation (financial and informative) at the stages of planning new DC and management and upgrading of existing ones.

To encourage energy efficiency in DC, four types of instruments can be used. First are regulatory instruments, second are financial, third are persuasive and educational instruments, and last are structuring instruments based on voluntary agreements. A combination of these can be used in different markets to help implement the changes reviewed in this study.

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Energy Efficiency in Data Centres: Best Practices and Results of the European Code of Conduct

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Abstract

The European Code of Conduct for Data Centres is a voluntary market transformation programme addressing data centre owners and operators. The Data Centres Code of Conduct has been created in response to increasing energy consumption in data centres and the need to reduce the related environmental, economic and energy supply impacts. The aim is to inform and stimulate operators and owners to reduce energy consumption in a cost-effective manner without hampering the critical function of data centres. The Data Centres Code of Conduct has been in operation since 2008 and so far more than 300 data centres of different size and IT service offerings have joined the Code of Conduct. The core of the programme is the commitment by the participant to carry out an initial energy audit to identify the major energy saving opportunities; to prepare an action plan; to implement the action plan; and to monitor energy consumption.

At the heart of the Code of Conduct is the Best Practices document, which indicates the areas for energy efficiency upgrades in data centres, covering day-to-day operations, equipment substitution, major refurbishment and new data centre design. The Best Practices document reflects the principle area of responsibility for each type operators (e.g. managed services providers, co-location, etc.).

The paper reports on the results achieved so far in terms of energy savings and best practices adopted and it includes detailed information about some remarkable examples of highly efficient data centres.

Why Data Centres?

Electricity consumed in data centres, including ICT equipment (servers, storing and networking equipment), cooling equipment and power equipment, is contributing substantially to the electricity consumed in the European Union (EU). Data centre annual energy consumption is estimated to be around 80 TWh or about 3% of total European electricity consumption. It is therefore important that the energy efficiency of data centres is improved to ensure the carbon emissions and other impacts such as strain on infrastructure associated with increases in power demand are mitigated.

Several EU-level programs exist to address energy efficiency in buildings, IT equipment, and appliances. Among policy actions for buildings in the EU is the European Energy Performance of Building Directive (EPBD 2010), which imposes on EU Member States to adopt minimum efficiency requirements for buildings based on cost-optimality in their building codes. For equipment, the Eco-design Directive introduces common minimum efficiency requirements for end-use equipment such as domestic appliances, lighting products, consumer electronics, electric motors, air-conditioners, Uninterruptable Power Supplies (UPS), computers, servers, etc. In addition to the Eco-design directive the EU has an agreement with the US on the shared use of the Energy Star labelling programme. Energy Star equipment is available in Europe and it is promoted by public authorities as well as included in public authority's procurement practices.

It is important to note that data centres either occupy part of existing or new buildings (e.g. one room or one floor), or fill the entire building, but the EPBD does not apply to data centres as such. The Ecodesign Directive introduces efficiency requirements for individual equipment present in data centres such as UPS and servers (both not yet finalized at the time of writing the paper), however the selection of efficient equipment does not guarantee that the system or facility is efficient.

Historically, data centres have been designed with large tolerances for operational and capacity changes, including possible future expansion. Most enterprise data centres today typically run significant quantities of redundant power and cooling systems to provide higher levels of reliability. Additionally IT systems are frequently run at a low average capacity.

Overprovisioning and ensuring availability, along with the associated costs were previously considered a negligible risk to business performance because energy costs were relatively small in comparison to the IT budget, and environmental and energy responsibility was not considered to be under the control of IT departments. Preliminary evidence and the increasing willingness of manufacturers and vendors to compete on the basis of energy efficiency in data centres confirms that there are efficiency gains still to be realised without prohibitive initial costs that can lower the Total Cost of Ownership (TCO).

Many data centre operators are still not fully aware of the financial, environmental and infrastructure benefits to be gained from improving the energy efficiency of their facilities. Still, awareness does not necessarily lead to good decision making, simply because there is no framework in place for the operators to aspire to. Making data centres more energy efficient is a multidimensional challenge that requires a concerted effort to optimise power distribution, cooling infrastructure, IT equipment and IT output.

The European Code of Conduct

In order to improve energy efficiency, policy makers have the choice between a voluntary approach and regulation. For sectors that are hard to reach, or where several decision makers are involved and the potential for split incentives could hamper the decision to invest in energy efficiency, it could be difficult to mandate efficiency requirements through legislation and the voluntary approaches may be adopted instead. Voluntary agreements have proven to be effective in improving energy efficiency in different European sectors (Rezessy 2012), with particular focus on the industrial sector. Voluntary agreements have also been particularly successful as foundation for the US Energy Star programme for buildings and industry.

In Europe some voluntary programmes for the ICT sector have been introduced at the beginning of 2000, including the Codes of Conduct. Today, there are four Codes of Conduct in operation for different categories of ICT products: External Power Supplies, Digital TV Systems, Broadband Equipment and UPS. These Codes of Conduct impose energy consumption limits or minimum efficiency requirements for specific products. Participation by equipment manufacturers is on a voluntary basis, but when they join any of the Codes of Conduct they have to meet the required minimum performance level and report once a year on the energy consumption of the products they place on the market.

It has been decided to follow the same approach for improving energy efficiency in data centres. However it was not possible to set minimum efficiency requirements for data centres given the centres' diversity and the different level of responsibility therein (some companies being only responsible for the infrastructure, while others being responsible for the IT equipment selection and operation). In addition, a good metric to measure data centre efficiency is not yet available.

Therefore it was decided that the key criteria for the data centre Code of Conduct (CoC) was to ask participating companies to monitor their energy consumption and to adopt a set of established best practices.

For the purposes of the CoC, the term "data centres" includes all buildings, facilities and rooms which contain enterprise servers, server communication equipment, cooling equipment and power equipment, and provide some form of data service (e.g. the entire range from large scale mission critical facilities down to small server rooms located in office buildings).

Objective and Aims of the Code of Conduct

The CoC is a "multipurpose" programme, allowing different stakeholders to commit to improve efficiency in their own areas of competence. The primary target of the CoC is the data centre owner / operator, who is encouraged to commit to undertake and implement energy efficient solutions in existing or new data centres, whilst respecting the life cycle cost effectiveness and the performance availability of the system. T

The CoC aims to:

- Develop and promote a set of easily understood metrics to measure current efficiencies and improvement.
- Provide an open process and forum for discussion representing European stakeholder requirements.
- Produce a common set of principles to refer to and work in coordination with other international initiatives.
- Raise awareness among managers, owners, investors, with targeted information and material on the opportunity to improve efficiency.
- Create and provide an enabling tool for industry to implement cost-effective energy saving opportunities.
- Develop practical voluntary commitments which, when implemented, improve the energy efficiency of data centres and in so doing minimise the TCO.
- Determine and accelerate the application of energy efficient technologies.
- Foster the development of tools that promote energy efficient procurement practices, including criteria

for equipment based on the Energy Star Programme specifications, and other Codes of Conduct[1].
- Monitor and assess actions to properly determine both the progress and areas for improvement.
- Provide reference for other companies[2].

The focus of this CoC covers two main areas:
- IT Load – this relates to the consumption efficiency of the IT equipment in the data centre and can be described as the IT work capacity available for a given IT power consumption. It is also important to consider the utilisation of that capacity as part of efficiency in the data centre
- Facilities Load – this relates to the mechanical and electrical systems that support the IT electrical load such as cooling systems (chiller plant, fans, pumps) air conditioning units, UPS, PDU's etc.

- The Code of Conduct has both an equipment and system-level scope. At the equipment level, the Code of Conduct covers typical equipment used within data centres required to provide data, internet and communication services. This includes all energy using equipment within the data centre, such as:
- IT equipment (e.g. rack optimised and non-rack optimised enterprise servers, blade servers, storage and networking equipment);
- cooling equipment (e.g. computer room air-conditioner units);
- power equipment (e.g. UPS and power distributions units); and
- miscellaneous equipment (e.g. lighting).

At system level the CoC proposes actions which optimise equipment interaction and the system design e.g.:

- improved cooling design,
- correct sizing of cooling,
- correct air management and temperature settings,
- correct selection of power distribution, to minimize overall energy consumption.

However the Code of Conduct will consider the data centre as a complete system, trying to optimise the IT system and the infrastructure together to deliver the desired services in the most efficient manner.

Data centre owners and operators can join the CoC as Participants by committing to implement the recommended Best Practices with an indicative timeline and regularly reporting the result achieved. Though not entailing legally binding obligations, Participant status requires strong commitment and a substantial contribution to the objectives of the CoC. Each participant will set the areas of responsibility (defining which parts of the data centre they are responsible for implementing the efficiency improvements), the coverage (defining the data centres / building / sites at which energy efficiency actions will be undertaken) and the nature (specifying the actions that the enterprise proposes to carry out at each location) of its commitment.

Many data centre operators do not control the entire data centre but still may participate in the Code, for example colocation operators or their customers. In order to include these operators as Participants their partial control is recognized and they should implement the practices that fall within their control and endorse the practices outside of their control to their suppliers or customers as appropriate[3].

Participants are grouped into categories according to which parts of each data centre they have control over and responsibility for possible efficiency improvements;
Efforts to improve efficiency differ in the level of commitment and investment ranging from simple energy management practice and low cost solutions, to exploring alternative, energy efficient opportunities before specifying or replacing IT equipment and supporting infrastructure, to designing new highly efficient data centres or upgrading existing ones to a very high level of efficiency. Participants are expected to select, adopt and implement a subset of the recommended best practices.

1 E.g. the Code of Conduct for UPSs

2 The values of the Code of Conduct goes beyond the number of companies that sign and commit themselves, as the principles can also be implemented by other companies, which may not decide to make a public commitment. The existence of the European Code of Conduct introduces targets and guidelines which are open to every data centre.

3 See the Best Practice Guide for further details of the Best Practices, types of operator and areas of responsibility.

For existing data centres participant application starts with an initial energy measurement of at least one month and energy audit or assessment to identify the major energy saving opportunities. The applicant should prepare an action plan and supply a completed reporting form with their application. The reporting form should identify the Best Practices already implemented and those to be adopted within three years of the application date with a description of the action plan to achieve this. From 2010 onwards new data centres (under construction or recently completed) should identify in the reporting form the practices adopted to make the data centre "best in class" for their application.

Role of Best Practices

At the core of the Code of Conduct are the Best Practices, which are the recommended actions, technologies and techniques participants shall adopt in their data centres. The Best Practice Document is provided as an education and reference document as part of the Code of Conduct to assist data centre operators in identifying and implementing measures to improve the energy efficiency of their data centres. A broad group of expert reviewers from operators, vendors, consultants, academics, professional and national bodies have contributed to and reviewed the Best Practices.

Table 1

Type	Description
Operator	Operates the entire data centre from the physical building through to the consumption of the IT services delivered.
Colocation provider	Operates the data centre for the primary purpose of selling space, power and cooling capacity to customers who will install and manage their own IT hardware and services.
Colocation customer	Owns and manages IT equipment located in a data centre in which they purchase managed space, power and cooling capacity.
Managed service provider (MSP)	Owns and manages the data centre space, power, cooling, IT equipment and some level of software for the purpose of delivering IT services to customers. This would include traditional IT outsourcing.
Managed service provider in colocation space	A managed service provider which purchases space, power or cooling in a data centre in order to provide services to third parties.

The Best Practice Document contains a full list of the identified and recognised data centre energy efficiency best practices for implementing the Code of Conduct. The best practice list provides a common terminology and frame of reference for describing an energy efficiency practice, to assist Participants and Endorsers in avoiding doubt or confusion over terminology. Customers or suppliers of IT services may also find it useful to request or provide a list of Code of Conduct Practices implemented in a data centre to assist in procurement of services that meet their environmental or sustainability standards.

The Practices have been classified in different categories according to their applicability and the level of intervention required (ordinary maintenance and management, new IT investment, new infrastructure investment, design and construction of new data centre) as indicated in the table below.[4]

[4] New or replacement IT equipment excludes the direct replacement of failed hardware with like for like as part of normal operations. New software install or upgrade refers to major upgrades of software and not the application of service packs and patches in normal management and use. Retrofit is intended to describe major disruptive works in the data centre which present the opportunity at little incremental cost to implement these additional Practices

Table 2

	Description
Entire Data Centre	Expected to be applied to all existing IT, Mechanical and Electrical equipment within the data centre
New Software	Expected during any new software install or upgrade
New IT Equipment	Expected for new or replacement IT equipment
New build or retrofit	Expected for any data centre built or undergoing a significant refit of the M&E equipment from 2011 onwards
Optional Practices	Practices without a background colour are optional for Participants

Not all operators will be able to implement all of the expected Practices in their facilities due to physical, logistical, planning or other constraints (e.g. data centre soon to be closed). In these instances an explanation of why the expected action is not applicable or practical shall be made by the operator. Alternative best practices from the Code of Conduct or other sources may be identified as direct replacements if they result in similar energy savings. In addition, not all operators are responsible for all aspects of the data centre covered by the Best Practices. This is not a barrier to Participant status but the operator should sign as a Participant for the area they control and act as an Endorser for those Practices outside of their control. An example of Participant responsibility would be a collocation provider who does not control the IT equipment actively endorsing the Practices relating to IT equipment to their customers. This might include the provision of services to assist customers in adopting those Practices. Equally an IT operator using collocation should request their collocation provider to implement the Practices relating to the facility. Operators' areas of responsibility are defined as;

Each operator should determine which of the Practices apply to them based on their areas of responsibility. The table below provides an overview for common types of Participant;

Table 3

	Description
Physical building	The building including security, location and maintenance.
Mechanical and electrical plant	The selection, installation, configuration, maintenance and management of the mechanical and electrical plant.
	The installation, configuration, maintenance and management of the main data floor where IT equipment is installed. This includes the floor (raised in some cases), positioning of CRAC / CRAH units and basic layout of cabling systems (under floor or overhead).
Data floor	The installation, configuration, maintenance and management of the main data floor where IT equipment is installed. This includes the floor (raised in some cases), positioning of CRAC / CRAH units and basic layout of cabling systems (under floor or overhead).
Cabinets	The installation, configuration, maintenance and management of the cabinets into which rack-mount IT equipment is installed.
IT equipment	The selection, installation, configuration, maintenance and management of the physical IT equipment.
Operating System / Virtualisation	The selection, installation, configuration, maintenance and management of the Operating System and virtualisation (both client and hypervisor) software installed on the IT equipment. This includes monitoring clients, hardware management agents etc.
Software	The selection, installation, configuration, maintenance and management of the application software installed on the IT equipment.
Business Practices	The determination and communication of the business requirements for the data centre including the importance of systems, reliability availability and maintainability specifications and data management processes.

Table 4

	Operator	Colo provider	Colo customer	MSP in Colo	MSP
Physical building	Implement	Implement	Endorse	Endorse	Implement
Mechanical & electrical plant	Implement	Implement	Endorse	Endorse	Implement
Data floor and air flow	Implement	Implement & Endorse	Implement & Endorse	Implement	Implement
Cabinets and cabinet air flow	Implement	Implement & Endorse	Implement & Endorse	Implement	Implement
IT equipment	Implement	Endorse	Implement	Implement	Implement
Operating System & Virtualisation	Implement	Endorse	Implement	Implement	Implement
Software	Implement	Endorse	Implement	Implement & Endorse	Implement & Endorse
Business Practices	Implement	Endorse	Implement	Endorse	Endorse

Best Examples

Up until the end of February 2016 there are 116 organisations registered as Participants with 276 approved data centres. Each year since 2011, the best examples among these participants of implementation of the Best Practices, including innovative technologies, holistic approach to energy savings, low PUE, and effective energy reporting practices have been awarded the European Code of Conduct Award. The wining data centres include both refurbished existing data centres as well as newly constructed data centres. Operators awarded this prize include enterprises and data centres (full control of the data centres as operators), telecoms, colocations, managed services, and high performance computing centres. The company type and size range from small companies, to universities, to public authorities (at local and national level), to large multinational companies. The same applies to the data centres size and the data centre age.

Winners of the European Data Centre Annual Award

LCP Oostkamp Data Centre
The DC only uses 11% of the IT energy consumption load to cool and secure the services. The chillers are used for only 2% of the year. The very low PUE (data centre originally built for a PUE of 1,06 after 2 years the cooling was changed from direct free air cooling to an indirect free air cooling with a PUE of 1,11) is achieved by using the local climatic conditions to cool the data centre and using optimal UPS systems to secure the power infrastructure. A 430 kVA solar plant was placed on the roof of the building, generating about 11% of the total energy needs of the data centre.

PGS Weybridge Data Center
One of the most efficient data centres in Europe (with PUE <1.2). These are the best practices adopted: very-efficient cooling system; closed hot aisle containment; sealed hot aisle containment; very uniform air temperature; hot air vents from the rear of the servers to a sealed hot aisle; hot air is drawn into the ceiling plenum by the cooling modules' fans; hot air is filtered and cooled by the heat exchange; cold air blown into the room above the floor; hot water from heat exchange is pumped to the heat exchange in the ambient air; hot water chilled either by the ambient air or by evaporative cooling (supplemented by a chiller for about 40 hours a year); cold water pumped back to heat exchange; dynamic cooling matches IT load; segregation of equipment with legacy temperature and humidity ranges
European Business & Resilience Centre -Data Centre in: Windhof
This data centre adopts many technologies to make it efficient such as the Kyoto wheels, cooling towers providing free cooling, scalable rotary UPS, pumps and fans with frequency converters, heat pumps (connected on chilled water return circuit) to heat offices and to heat up fresh air, cooled water racks for UPS Power above 15-18 KW

Bull Trélazé
This is a genuine refurbishment of an old DC. Besides the introduction of efficient technologies such as: the use of direct liquid cooling, the introduction of multiple zones, air flow containment ("We re-urbanized 80% of our Data Centre using hot/cold aisles including implementation of Cold Corridor the most possible.") and correct humidity and temperature controls, they also engage all customers on energy efficiency ("We run monthly a steering committee with each customer where energy efficiency is discussed as part of the agenda."). This company has also tried to measure software efficiency ("For instance, as certified gold SAP hosting provider we are engaged in partnership with SAP to develop benchmarks of SAP landscape solutions on SAPS/WATT to measure software efficiency").

Telecity with 21 data centres (Corporate Participant category)
TelecityGroup was one of the first colocation companies (and one of the first overall) to join the Code of Conduct and to choose the Participant status for all its data centres. TelecityGroup were awarded group wide certification to ISO14001 in May 2010. With energy consumption being the company's primary environmental impact, TCG's 14001 programme utilises the Code of Conduct best practices and has turned them into an auditable environment management system compliant with ISO 14001.

The Datacenter Group, data centre in Amsterdam, Netherlands This is a large datacentre (4500 m2 data centre with 2700 m2 data floor). The company installed its own developed cooling systems, which uses indirect adiabatic outside air cooling. This means cooling through evaporation and no use of conventional refrigerants. The proof of concept trials with cooling systems started in 2008 with the cooling system being completely replaced in 2010. The company has chosen very efficient UPS with an efficiency of 97%. There is a complete monitoring of the energy consumption; almost every outlet in the building is monitored. Green Electricity is purchased and the latest ISO 14001 certificate was adopted in order to ensure all internal procedures are sustainable. Achieved average PUE was 1.16 in 2011. The ambient temperature is set at 23 degrees Celsius and humidity levels are set at 20 – 80 %. A 100% cold corridor system is in place for all racks where blind plates are supplied by the company to achieve optimal airflow.

Google, data centre in St. Ghislain, Belgium
This was the Google's first chiller-less data centre that is fully "free cooled" using conventional cooling towers; the evaporative cooling uses 100% recycled water, pulled from an industrial canal and treated at a purpose-built plant at the data centre There is an elevated cold aisle temperatures; very efficient on-server batteries replace traditional UPS (with efficiency of 99%). This data centre achieved a trailing twelve month energy weighted PUE of 1.10 for 2010.

Migration Solutions Ltd, data centre Sentry42 in Norwich, United Kingdom
The chillers have integrated free cooling and the water temperature is raised so that cooling is only ever required when the ambient outside temperature is above 20°C. There is metering at every point in the electrical systems (main incomer, primary switchgear, PDU and cabinet power strips). All the cabinets are in a Cold Aisle arrangement, plus there are blanking panels in all cabinets. 100% of lighting throughout the data centre is provided by LEDs. There is equipment to capture and re-use the heat.

R-iX, Intermax, and Hoogendoorn IT Services, data centre Spaanse Kubus in Rotterdam, Netherlands
RiX(R-iX = Rotterdam Internet Exchange) is the commercial data centre, Intermax is a managed services provider and is one of the data centre’s customers, Hoogendoorn is a customer of Intermax renting a number of racks in the Intermax cage and using some shared services (storage, network) from Intermax. The *R-iX* organization has been established as a foundation on a not-for-profit basis. Its (semi) public participants guarantee independence and long-term continuity. The location “Spaanse Kubus” has a 750m2 data centre floor with shared co-location and private cages (260 racks, average 4kW/rack) and incorporates a Kyoto wheel cooling system (2 x 600kW cooling wheel, air temperature cold aisle: 25°C, air temperature in contained hot-aisle: 35°C – 40°C). Based on Kyoto monitoring, the PUE in 2010 was 1.13, while according to EU CoC DC assessment in 2010, the PUE was 1.27.

IBM with 27 data centres in 15 Member States (Corporate Participant category)
All data centres followed a similar route forward. The main pre-requisites were: strong executive support; awareness -training and guidelines; monitoring and Key Performance Indicators. Technical upgrades consisted of: hardware updated (e.g. consolidation and virtualization, software adaptation where needed). The iterative roadmap for all the data centres was as follows: i) equalize the load over the DC and eliminate hot/cold spots; ii) leak elimination blanking plates, brushes, containment; iii) adjust CRAC utilization with VSD or power off; iv) increase room t° to ASHREA 2008 or better; v) Free cooling or free chilling.

ARM Ltd -data centre in Cambridge, United Kingdom
This is a new High-Density data centre (up to 24kW per cabinet) tier-3, lights out facility, with 365 days of free-Cooling with an efficient Flywheel UPS (98% at 100% load and still 96% at 40% load), and Energy Efficient Transformer. The annualised PUE reaches 1.05. The data centre is 100% supplied with renewable energy.

Capgemini UK – data centre Merlin in Swindon,United Kingdom
This new data centre uses fresh air, free cooling, modular sized rooms and the monitoring and management of energy consumption at the rack level. Each module is equipped with a highly efficient dedicated air optimiser climate control cooling unit which cools air in three stages, with primary "fresh air" cooling, second-stage evaporative cooling and backup third-stage cooling through Direct Expansion R410a (DX). The data centre achieves a PUE of 1.2. Low energy losses transformer and flywheel UPS are also used. The Trend Building Management System (BMS) is a sophisticated and energy-efficient System, which fully manages hot and cold air flows to enable constant peak operational efficiency.

Equinix – data centre Amsterdam 3 in Amsterdam, The Netherlands
This new data centre opened in October 2012, a newly-built facility that provides 17,800 m² of gross space in Amsterdam Science Park, one of Europe's most network-dense locations. The data centre deploys Aquifer Thermal Energy Storage (ATES) in the ground instead of mechanical cooling and combines this with hybrid-cooling towers. This allows full use of free-cooling and generates hot water for the neighbouring university throughout the year. This is used in combination with hybrid cooling towers. These and other sustainable technologies generate significant energy savings contributing to a target PUE of 1.2.

eBay Inc – data centre Phoenix 1 in Phoenix, Arizona, US
The refurbished PHX01 data centre is a 4 story, purpose built Tier IV data centre with approximately 6,039 square meters of raised floor technical space. The following Best Practices have been implemented: Airflow Management and Design (5.1) & Cooling Management (5.2) including deployment of rack lineups in a hot aisle/cold aisle arrangement; Site wide use of blanking panels Temperature and Humidity Settings (5.3). This site has implemented setpoint adjustments and control changes to address temperature and humidity. High Efficiency Cooling Plant (5.4) and CRAC (5.6) , including: installation of VFDs on all white space CRAH units and establishing a floor wide temperature sensor network to aid in the control algorithm, installation of ultrasonic humidification systems to replace all steam generation systems.

Unilever, data centre Chester Gates in Chester, United Kingdom
The Chester Gates data centre has been designed and built on a modular basis, leveraging the latest available technologies and, where practical, retro-fitting to older sections of the data centre. In March 2013 average PUE was 1.41, down from 1.68 in March 2012. The data centre uses external ambient air as a free cooling medium together with a cooling system known as 'closed cell– close control' or '4C'. Other solutions implemented are: replacement of legacy non-free cooling chillers, pumps and CRAC units with high capacity components offering improved coefficients of performance; introduction of smart LED lighting and implementation of ultrasonic humidification. Savings in the consumption of energy by IT equipment have been achieved through the adoption of newer server and storage technologies which enable improved IT service consolidation and virtualisation across platforms.

CEA-DAM – data centre TERA in Bruyères-le-Châtel, France
For Tera-100, the first petascale system hosted at CEA, CEA decided in 2009 to work with the vendor of the supercomputer in a joint R&D effort targeting three optimization axes towards higher energy efficiency: reduction of electricity consumption of IT equipment; usage of more efficient cooling system allowing high density racks; and usage of passive devices to reduce the usage of UPS units. A water cooled door was developed. This cold door is composed of an air/water heat exchanger, big fans and a regulation system. It allows a very effective cooling of IT components and it is compatible with the high energy density needed for HPC. Most of the IT configuration, including the computer nodes (85% in terms of electricity consumption) is directly powered by the electricity provider and protected against short term power failures by UltraCapacitor Module (UCM) in each enclosure.

Online SAS -data centre in Vitry sur Seine, France
This new data centre is using outdoor vegetable oil-immersed transformers with only one stage of power transformation (20kV to 410V) in order to optimize efficiency and reliability. The cooling system is using outdoor dry-coolers in closed cooling circuit. The chilled water system uses a specific water temperature 9°C-19°C with 10°C water temperature drop difference. This specific water temperature permits twice the cooling exchange with the same volume of water. High free-chilling capacity using heat exchangers between dry-coolers and chilled water can be used in a 'mixed ' configuration (chillers and free-cooling) between 14,5°C

to 4,5°C outdoor and in ’absolute‘ configuration (free-cooling only) on outside temperatures below 4,5°C. The whole data centre uses cold-aisle containment by default in order to get a return air to CRAC at more than 31°C. The annual measured PUE is of 1.35.

TISSAT SA – data centre Walhalla in Castellon, Spain
This new data centre adopted an advanced structural design (e.g. using the hot aisle containment system) solving the trade-off between the high availability needs of Tier IV DC and the reduction of energy consumption. It also involved the construction of an eco-efficient building. The generation of primary energy and cooling is provided with tri-generation system. Limitation of the power losses is achieved with the use of UPS allowing 99.9% of energy use. The data centre uses the air conditioning condenser for rationalizing energy consumption of air conditioning.

Univerisity of St Andrews – data centre Butts Wynd Data Centre, UK
This refurbished data centre (250kW) adopts: a dual coil free cooling system with EFC and ultimately water-cooled DX; dry air coolers inside the plant room, variable speed pumps and fans; generator installed on the rejection side of the dry air coolers; reuse of waste heat; removed equipment from and turned off old inefficient AC equipment in other areas. The design PUE was 1.2

United Nation Support Base – data centre in Valencia, Spain
This refurbished data centre installed solar PV panel in two phases. In Phase A (February 2012) 700 solar panels of 280 Watt each were installed (196 KW peak, 300 MWh per year), and in Phase B (September 2014), 1080 solar panels of 300 Watt each were added (324 KW peak, 500 MWh per year). Additional installations include: efficient UPS, PVC Curtains in the data centre cold aisle; a free cooling system providing around 3000 hours of free cooling per year; a Data Centre Infrastructure Management Software monitoring the power consumption of the different electrical systems, main electrical panels and all the PDU located in the racks; an automatic light control system in order to switch off unnecessary lights in the data centre.

Zen Internet – data centre DC 1 in Rochdale, UK
Already implemented energy efficiency improvements to this existing data centre: legacy DC space rearranged all cabinets into hot/cold aisle configuration; retrofitted lighting motion sensor control in all DC halls; retrofitted Cold Aisle containment curtains in all DC halls; retrofitted brush strips to raised floor holes in all DC halls; retrofitted gap sealing to all cabinets; fitted blanking panels in all cabinets; retrofitted power sub-metering on all primary switchgear; metered power strips provided to all cabinets. In addition, these measures were currently being implemented: raising air delivery temperatures; raising chiller water temperatures; retrofitting CRAC EC Fans; retrofitting Chiller compressor VSDs

T -Systems International GmbH -10 Data Centres in Germany (Corporate Participant category)
In the 10 data centres the following energy efficient solutions were implemented: equalization of the load over the data centre; elimination of the hot /cold spots; all cabinets were in Cold Aisle arrangement; blanking panels in all cabinets; leak elimination; increased room temperature to ASHRAE 2008 or better; introduction of free cooling or free chilling; using increased t settings; introduction of new technologies such as well water cooling and adiabatic cooling systems.

Kimcell Ltd, UK
The datacentre is a subterranean facility, which considerably reduces the impact of external environmental factors. The facility reuses brownfield space, reducing the impact of new building works. Excess heat is recovered and used to heat office space. Free air cooling system by volume is used. High efficiency UPS system operating in ECO mode. No doors for racks -open front. Installation of blanking plates.

CSC -Sevenoaks Data Centre, UK
The data centre computer rooms are divided into low density kW/sqm and high density 10kW/sqm areas; Room layout is as follows: all data equipment racks are laid out forming hot and cold aisle improving air flow and cooling management. The lighting of the data hall is normally switched off and dark when not occupied. The cooling temperature is controlled to maintain 24°C, 3 degrees higher than traditional data centres. Computer room cooling units will cycle to meet the heat load within the room. All chilled water pumps will vary their speed in order to meet the varying cooling demands of the in-room air handling units. As a direct result of the high chilled water temperature “free cooling” can be used to reduce water temperatures. This uses ambient air whenever below 9°C to cool the water, ensuring the refrigeration compressors only operate for 70% of the year. Data racks – to cater for high heat loads produced by blade technology, cubes have been deployed where hot air is contained and not allowed to mix with cooled air therefore maximizing its cooling ability.

Conclusions

The Code of Conduct is the only independent pan-European scheme in the EU to certify that a data centre has adopted energy efficiency best practices. There is increasing interest in the Code of Conduct among data centre operators, however it is still too early to evaluate the overall impact of the Code of Conduct on energy savings. The implementation of best practices shows that the most cost-effective and short payback period best practices are those that are most commonly implemented. Through the collection of the data centres energy consumption (total facility and IT) we will be able to track efficiency improvement over time. The dataset of over 275 data centres with the energy data (not analysed in the present paper) and the technologies adopted provide a very interesting data set for further analysis in terms of energy consumption per square meter, PUE, temperature and humidity settings. There are already a number of showcase data centres with PUE below 1.2 which have gained the Annual Award for the best implementations (both for new and retrofitted data centres). Winners of the Awards have mainly (and most of them) implemented the following technologies and energy efficiency solutions (all part of the Best Practices): hot/cold aisle containment, blanking panels, raising room temperature, detailed metering and monitoring equipment, efficient UPS, efficient lighting and lighting control. Also most of them have adopted free cooling technologies, some running all year round on free cooling in moderate climates. A number of advanced cooing technologies have also been adopted such as: evaporative cooling, Kyoto wheels, geo-thermal cooling (aquifer), water cooling at rack level, cooling towers. The Code of Conduct has so far received good feedback from participants and industry (with over 230 companies that have endorsed it). With the feedback provided by participants the Code of Conduct will be improved in the communication with market actors and the outreach activities will be further strengthened in 2016 in order to substantially increase the number of participants.

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Monetizing Data Centre Power Flexibility

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Abstract

Data Centres are part of the backbone infrastructure of our always-and-everywhere-online lifestyle. They are also necessary components that smart cities will build on, the more they are processing sensor data in order to offer novel services to their citizens. By fulfilling all these new requirements, data centres are using an increasing amount of electric energy – about 2% of the world-wide energy consumption can be attributed to data centres; and the trend is going upwards.

But how to reduce the CO_2 footprint of those data centres that need to be close to their customers and inside cities, due to latency requirements for instance? The project DC4Cities has developed a software system that enables data centres to communicate with a smart city energy management actor aiming at an optimized use of (intermittent) renewable energy sources in the smart city. In order to achieve this, DC4Cities identifies *IT workload* that can be shifted depending on the volatile supply of renewable energy. Also the *software* running inside the data centre can partially be made adaptive to the availability of renewable energy sources like sun and wind. All this is done without impacting the data centre's core business. The technical feasibility of data centre power flexibility, as defined in DC4Cities, was shown in trials executed in data centres providing public administration services in Barcelona and health care services in the Trentino Region.

The real impact of this approach, however, depends on its penetration in real markets. This paper will show where in Europe a marketing strategy for a DC4Cities based tool has good chances and it will present business models that offer the highest potential to be economically viable for all involved parties. It will also point out to which degree the success of power profile adaptation to renewable supply curves is dependent on exogenous factors.

Introduction and Motivation: Why Data Centres Matter

Data centres are ravenous energy consumers. Most technology users are not aware of the internet's carbon footprint. According to an article published by The Guardian[1] "T*he European data centre consumption will rise to 100TWh by 2020, roughly the same as the electricity consumption of Portugal."*

And prospects are birds of ill omen. Experts claim that data centres' energy consumption is boosted even more in the next few years by Big Data and Internet of Things technologies requiring a tremendous amount of information to be processed. The internet of things alone, which directly results in an increasing data centre service volume, is forecasted to grow three times faster than traditional ICT, and by 2020 will equal nearly all other ICT spending[2] (see figure 1). And data centres are the most inefficient actors in the internet ecosystem.

[1] http://www.guardian.co.uk/sustainable-business/data-centres-energy-efficient

[2] http://www.merrilledge.com/publish/content/application/pdf/gwmol/ThematicInvesting-EnergyEfficiencyPrimer.pdf

Table 89: 50bn connected devices by 2020

	2003	2010	2015E	2020E
World population	6.3bn	6.8bn	7.2bn	7.6bn
Connected devices	500m	12.5bn	25bn	50bn
Connected devices per person	0.08	1.84	3.47	6.58

Source: Cisco IBSG

Figure 1 - Connected devices by 2020, Source Cisco IBSG

How to answer to the increasing hunger for energy and power of data centres resulting in a huge CO^2 emission problem? There are many ways to deal with this – one of them being the traditional focus of reducing energy for cooling. Another strategy is to buy energy with renewable certificates as companies like SAP are doing[3] or looking for storage options like power-to-gas. However, energy storage capacity is still limited and the options to buy certified green energy cannot be stretched without limits. One further suggestion is therefore to adapt data centres' power consumption to the supply of intermittent renewable energy sources. This is the focus of the presented work.

With around 75% of the European population living in urban areas [1] a big part of data traffic originates in cities. And as cities are becoming smarter each year, creating continuously more and bigger data, this trend knows only one direction - upwards. DC4Cities' main motivation is that **Smart Cities need Eco-friendly Data Centres.** However, the impact that urban data centres have on local energy consumption is not yet integrated into Smart City planning. Data centres, until now, have mostly been powered by the global electricity grid or, in Northern regions, settled next to hydro or geothermal sites. Traditionally, this is due to the strict performance orientation of data centre business and thus due to inflexible technical contracts (so-called SLAs); and of course a lack of renewable energy aware work load execution tools and specifically targeted public energy management policies add to this.

The reason for tackling data centres in urban agglomerations is that some **data centres need to be close to users[4]**. This statement is corroborated by a discussion triggered by Greenpeace's open letter to Ballmer, Bezos and Cook inviting them to "go to Iceland" [2] for their data centres, where energy providers use only renewable sources. However, in some use cases, delay is an issue; and this forced Google to serve their New York customers from a local data centre instead of using their Dallas site where power and land are cheap, because of the wasted time in an over 4500km round trip of optical fibres. Also, among others, legal issues around data privacy and ownership are valid concerns that result in locating data centres close by their customers inside urban agglomerations.

In section II, this paper gives a short introduction into how these challenges are tackled through the creation of an energy adaptive workload management tool, not only inside a data centre but also communicating with an energy management authority. In the next section, markets are identified where such a tool has the highest dissemination opportunities. Section IV then deals with business models that are suitable to reach these markets, and the last section gives an outlook for future challenges.

An Approach to Reconciling Data Centre Power Demand with Locally Supplied Renewable Energy

Running data centres at a high level of renewable energy sources is a huge challenge in cases when the energy mix is dominated by highly volatile, intermittent renewables like sun or wind. The problem that must be solved (see e.g. [3]) is how to actively shape the power demand of a data centre in order to match the shape of forecasted renewable-based power supply curves.

3 http://news.sap.com/enter-the-green-cloud/

4 Of course this adaptation approach coud basically also be applied to other industries.

This supply curve generally contains the volatility of two power curves: One is the power supply curve of onsite renewable energy sources like a solar installation or a wind park; the other one is the share or renewable energy sources in the power grid that the data centre is attached to. In some regions and at some times, this share can be high, even close to 75% as in solar dominated southern Germany in summer[5]. And it is real waste not to use this power when it is available and instead turning on brown energy sources some hours later.

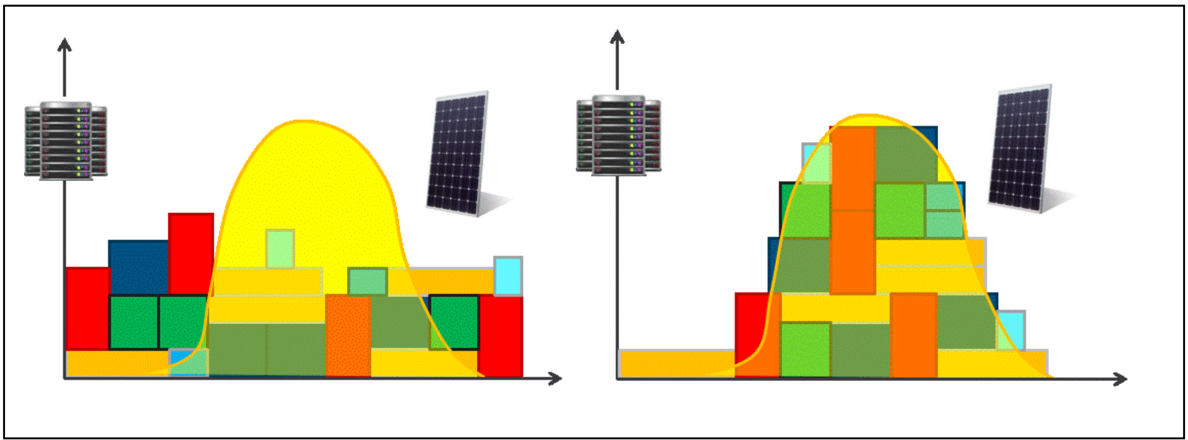

Figure 2 – Workload adaptation to given power profiles (e.g. solar)

To solve this problem, the data centre can be viewed as a building composed of two building blocks: One contains the IT equipment that is used to "produce" the set of IT services that the data centre offers to its final users, and the other is all supporting equipment, like HVAC (heat, ventilation, air condition), lightning or power distribution. The presented approach is based on the fact that the operation of the "IT building block" is not only responsible for the greatest part of the energy consumption of a DC[6] but also influences the energy consumption of the supporting building block to a great degree. Thus it suffices to shape the IT power demand as can be seen in figure 2, which is determined by the workload operated in the data centre. In the image on the left hand side, the workload of the data centre, represented by workload bricks, is operated independently of the supply of renewable energy sources (yellow curve). Through the DC4Cities coordination scheme these two shapes are matched, as shown on the right hand side.

Technical Coordination

In order to solve this optimization problem, a communication and coordination system between the IT workload management, an energy management authority (EMA), e.g. in a smart city, and data from an energy actor was created. When the energy management scheme is set up, the EMA helps at determining goals for an adequate level of renewable energy share in a data centre's energy mix. This is done taking into account both data centre related characteristics and supply side factors like local solar and wind characteristics as well as infrastructure features. The coordination activity between the data centre, EMA and the energy supply side is represented by the basic architecture of the system in figure 3.

In the centre of the logical architecture there is an energy controller that communicates with both, the energy related components and EMA on the *northbound interface*, *and* the data centre operation components where scheduling decisions are implemented on the *southbound interface*. Based on data from the energy actors an ideal power plan (IPP) is calculated. In a next step this power plan is handed over to the data centre operation unit where for each time slot it is split onto several so-called "energy aware software controllers" (EASCs).

[5] http://cleantechnica.com/2014/05/15/germany-reaches-nearly-75-renewable-power-use-sunday/

[6] This share has been continually increasing due to significant savings in HVAC related consumption, represented in the KPI PUE ("power usage effectiveness")

Via these EASCs the envisioned strategies to adapt the workload and thus the power demand of the data centre are enacted: geographical and temporal shifting of workload, but also energy-aware up - and downscaling of the functional range of IT services offered (in alignment with the business strategy of the data centre). Also federation of data centres, as one way to profit from shared resources, is part of the DC4Cities approach[7]. As this paper is aimed at introducing to options where and how such an approach could be economically viable, for details on technical aspects, e.g. related to traditional demand response topics, please refer to [4].

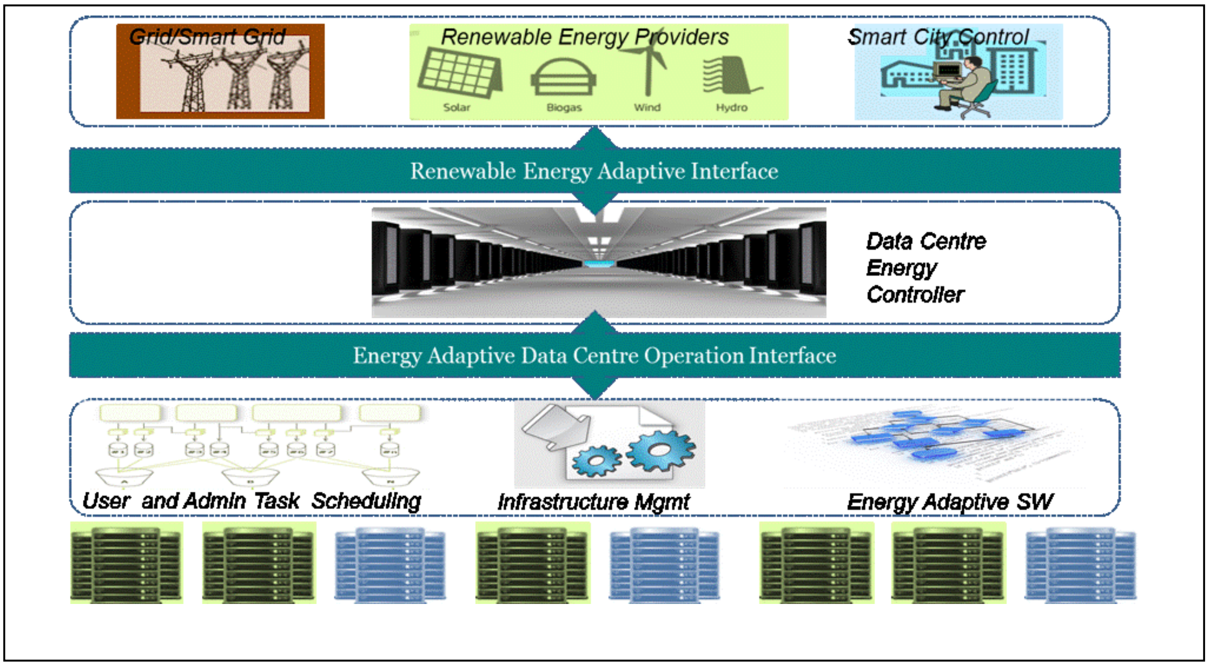

Figure 3 - High-level Architecure of DC4Cities

Incentives

However, why should a data centre take the pains to confine its workload management within a scope "dictated" by external factors? We see basically three reasons for such a decision:

1. *Customers:* If a significant part of a data centre's customer basis wishes to purchase IT services "made with" renewable energy, and if these customers accept consequences like increased latency when renewable energy is scarce – then the data centre will most probably go along with this request.

2. *Legal enforcement:* In case that there are legal requirements to meet a certain renewable energy share goal, the data centre must respect them and modify its IT operation scheme.

3. *Incentives:* If there are incentives e.g. from the smart city or the energy supplier for energy customers to adapt their power demand to the patterns of sun and wind, data centre management will calculate expected losses against expected benefits and decide on an energy-aware workload management whenever it foresees a net benefit. One major motivation for a data centre to take part in such a scheme will for sure be the expected reduction of the energy bill. These incentives might also steer data centre management towards engaging their customers into a collaborative scheme, making them aware of the influence their blind requests for constant performance maximization.

The extent to which the interplay of smart city and energy system can foster renewable adaptive behaviour depends largely on the political framework and other exogenous factors: Even if the framework is generally supportive – like the nuclear phase-out in Germany – there can be side effects

[7] Which can of course be amended by other approaches to share resources like industry parks.

difficult to control like a lack of renewable infrastructure that forces a country to use brown energy sources. Therefore the presented approach focuses on the third item as it seems most likely that legal requirements will at least be flanked by incentives. Incentives are dealt with in depth in the context of demand response approaches which are a predecessor of renewable aware energy management and coordination. The higher the prices of CO^2, of course, the more financial scope there is to reward adaptive behaviour[8]. The selected scheme is based on both energy performance contracting (EPC), which was developed to promote energy efficient investments in buildings, and specific energy provision tariffs like GreenSDAs. A so-called RenEnergy contract between the data centre and its counterpart on the energy supply side, e.g. the EMA, determines the conditions for adaptive activities: To which degree the IPP must be adhered to in order to receive a specific reward, which are the exceptions where the IPP can be over- or undershot without defecting the reward, and the existence and nature of penalties, amongst others. This implicitly rules the sharing of risk. As the requirement on the side of the data centre management will be a zero tolerance to take over any kind of risk regarding availability, the RenEnergy contract must make sure to establish rules that can never counteract this goal[9]. For more information see [4].

Markets for DC4Cities

Both the technical concept of DC4Cities and the incentive approach have been developed to show that it is possible for data centres as big energy customers to follow the patterns of renewable energy generation through adapting their power demand. A market for such a tool or consultancy related to it would be huge, provided that there is a political will – poured into legal guidelines and incentives (e.g. taxes, tariff requirements) – that paves the way for active adaptation to renewable energy supply curves.

There are two separated market segments for a tool optimizing the adaptation of a data centre's workload to the supply or intermittent renewable energy sources: one is the public sector with smart cities that on the one hand have to deal with a mushrooming amount of sensor data to be computed and on the other hand need to adopt political requirements regarding CO^2 emissions and shares of renewable energy sources. These are challenges they will need to deal with in the coming years – Barcelona, for instance, is therefore discussing to install an administrative department that is similar to the suggested "smart city energy management" actor. The other market segment are commercial data centres, either in-house data centres supplying their mother companies with IT services or stand-alone data centres offering IT services to external customers. Both market segments must be taken into account. Even though the public sector is small compared to the commercial sector, it can have an "early adopter" role for DC4Cities, preparing the market take-up in the commercial market segment.

However, the issue has also a natural aspect: The expected adaptive results which influence the marketability of the presented approach are highly dependent on the availability of renewable energy sources and their variability. This means, that in order to find good marketing conditions, several conditions have to meet in suitable geographical areas:

1. A legal framework that fosters the utilization of local renewable energy. With the EU Energy 2020 and 2050 energy strategies[10] a framework is given. The more this is implemented on city level by incentives to use low carbon energy, the higher the prospects for DC4Cities.

2. A high share of intermittent renewable energy sources at the potential local energy mix as DC4Cities focuses on the adaptation to variable energy generation.

3. An advanced technical infrastructure for the required renewable energy sources sun and wind. This is necessary to make use of the natural resources.

8 The currently plummeting oil price is obviously counterproductive.

9 It should be mentioned, however, that in future with an increasing share of renewable energy sources in the grid the reliability of the power grid itself will increase through such kind of collaboration

10 http://ec.europa.eu/energy/en/topics/energy-strategy

4. A high number of potential data centre customers. This means that areas are needed with a high share of data centres at the local industry mix.

5. A high demand for local IT services; one source for this can be the existence of a smart city which is based on the computation of a huge mass of data.

Identifying Suitable Geographical Areas

In order to find areas where these conditions meet, in a first iteration geographically favourable regions were identified regarding weather and climate conditions. To this end, maps with information about the expected yields from wind and sun provided by the EU ESPON program were used[11] and merged with information about highly developed smart cities and agglomerations of data centre activities. Assuming that, where conditions are good, this applies to both commercial and publically managed/commissioned data centres, this approach gave first insights into potential marketing areas for DC4Cities [5] As a result, it was found that there is a huge overlap between the most developed smart cities in Europe and the regional hot spots for commercial data centres. For instance, the major data centre markets London, Paris and Amsterdam, Frankfurt are also among the most advanced smart cities (according to [6]), eligible for DC4Cities. Also, Berlin, Cologne, Ghent, Brussels and most of the top twenty pioneer smart cities [6] are matured data centre markets.

Refined Assessment in 6 Focus Cities

In order to achieve a more refined assessment, however, this approach turned out to be not adequate: the level of information that could be gained from a European perspective was too coarse to allow for more insights, especially with regards to information about areas with a concentration of suitable data centres. Because apart from climate conditions and smart city development, the legal framework for the supply of energy (and subsequently energy pricing) is still highly heterogeneous in the different EU member states, even though the EU follows a harmonization strategy[12]. Therefore additionally to refining the EU-wide research, in a second iteration a hand-full of cities was chosen for a more thorough analysis based on their both being among the data centre industry big five (that is the major cities for data centre industry in Europe) and in the pole positions of becoming real smart cities:

1. *Amsterdam:* A data centre hot spot with aspiring plans both for the smart city development, regarding the use of renewable energy sources and the location policy for data centres.

2. *Paris:* Also a data centre hot spot with ambitious smart city plans that at first sight seems to be well equipped with renewable energy.

3. *London:* THE European data centre market. Rather unprivileged though from the point of view of sun and wind sources. It was put on the list of focus cities as a reference from the data centre market point of view.

4. *Frankfurt:* Together with London the hottest data centre market in Europe; however, regarding the level of renewable energy it was deemed lagging behind cities like Amsterdam or Madrid. It was also added to the list as a reference as part of the Big Five rather than as a candidate for high shares of renewable energy.

5. *Madrid:* At the beginning of 2015, Madrid was still categorized among the European Big Five data centre hotspots; however since then it has lost this attribute. On the other hand, it has a high potential for PV based renewable energy.

6. As a sixth focus city, *Barcelona* was added as trial city of the DC4Cities project, even though not being a big player in data centre industry.

[11]http://www.espon.eu/export/sites/default/Images/Publications/MapsOfTheMonth/MapJanuary2011/PV-Potential-Large.jpg

[12]http://ec.europa.eu/priorities/energy-union-and-climate_en

Core Questions

In order to assess the monetizing potential of a tool that helps adapting the power profile of a data centre to the intermittent and volatile supply of renewable energy, a lot of information needs to be collected. This was done along the following guidelines:

Legal framework: All focus cities are smart cities. Collecting information about smart city policies with regards to both data centres and/or goals for renewable energy generation/infrastructure helped evaluating how the market potential will develop in future: the higher the gap between today's infrastructure and the goals for 2020, the higher is the potential in relation to today's market. The stricter the energy related smart city guidelines, the higher the chances that today's data centres are interested in investing in power adaptability. And the more developed a smart city, the more sensor data need to be computed in data centres inside the city with minimal delay.

Renewable Energy: Information about the renewable local energy infrastructure and/or renewable energy yield, as detailed as possible as well as information about the national power grid energy mix both for today and if available for 2020 and/or 2030. However, in order to assess the power and energy potential of this infrastructure where no information about yields from solar and wind sites was available, also general information about weather and climate data for solar and wind energy harvests was collected.

Local Data Centre Industry: In a first step, information on the number and size of data centres in each focus city was collected, especially regarding power and energy consumption data. This was done as fine grained as possible.

Some data centres are less good canditates to apply the recommended power adaptive strategies due to technical or business restrictions – if the expected extent of load shifting is too small, the effort is not worthwhile. What makes a data centre "suitable" is a high amount of shiftable load. One basic differentiation is according to interactive versus batch load, assuming that interactive load cannot be shifted – if delay tolerant it can be executed using less virtual machines, but the result is in any case lower than if considerable shares of batch jobs can be shifted in time. However, independently of this basic differentiation, the level of control a data centre manager has on workload execution is important as well as the strictness of SLAs (service level agreements).

These facts cannot be researched on the level of an internet based research. Information about business models, however, are partially publically available and point into the right direction: therefore the collected data was sorted into the broad categories colocation vs. cloud computing or application based data centres. The reason is that colocation data centres are mostly housing companies offering space and supporting services to "host" servers of their customers, but they do not have direct control on the workload operated in the data centre.

Results

In parallel to the data collection and analysis of the 6 focus cities a questionnaire aimed at smart city CIOs was conducted in more than 20 European smart cities (for more details see [7]). It raised the topic of how to deal with the expected sharp increase of data volume from an energy perspective and showed that there is a great disparity in interest: all in all, smart cities in Northern, Western and Central Europe responded more actively; Southern smart cities seem to be having a slightly different focus on the issue of smartness. This finding is also corroborated by the analysis of the focus cities, which is summarized in the following:

- *Barcelona: good prospects*. For Barcelona the prospects to create a veritable DC4Cities market are very good. This applies to both smart city policies (the public administration is currently evaluating the creation of an energy management department) and the climate situation of Barcelona with potentially high sun and wind energy yields. 13 data centres of various sizes were identified offering cloud computing services and thus basic flexibility, additionally at least 5 enterprise data centres were found as potential customers. Being a project partner, a detailed analysis of the impact of DC4Cities operations on the energy consumption in Barcelona was possible: it was estimated at around 3 GWh, with the percentage of renewable energy at a sample data centre's energy mix being expected to grow by more than 10 percent points. Also the city's policy to foster and strengthen local energy self-sufficiency can be a driver to market DC4Cities, even more if the city decided to accompany this goal with investment in incentives.

- *Amsterdam: fairly good prospects.* Also for Amsterdam, today's expectations for a DC4Cities market are fairly positive; the outlook is even better. With data centres having a share of 11% at the total commercial electricity consumption, modifications of data centre power profiles can have a considerable effect on the power grid even today. Both an increase of data centre consumption and ambitious targets to reduce CO^2 emissions by 40% until 2025 and 75% until 2050 (against 1990), relying to a great degree on wind energy, create a market for DC4Cities; even though nowadays renewables are responsible for only 4% of overall city consumption. Most data centres offer colocation, but today there are 18 possible candidates (mostly cloud computing or application hosting) for DC4Cities.
- *Paris: bad prospects.* Contrary to Amsterdam, Paris does not offer a huge scope to market DC4Cities. The most important reason for this is that even though also Paris has plans to increase its share of renewable energy sources at the local electricity mix[13] (at the moment 18%) it focuses on geothermal energy which can be scheduled so that the DC4Cities approach seems unnecessary and is not likely to be applied. An additional drawback is that colocation is the prevailing business model.
- *London: bad prospects.* The same applies to London. Unfortunately, even though London is the number one data centre hot spot in Europe, both energy and data centre related factors clearly limit the potential for a DC4Cities market: nearly all data centres offer colocation services, and even though solar irradiation is not as bad as expected, PV plays only a minor role in London's current energy policy. However, plans to cover 25% of London's energy needs by local, low carbon energy sources until 2025 might change the picture.
- *Frankfurt: fairly good/very good prospects.* The big surprise as to the market potential of DC4Cities in European smart cities is Frankfurt. Frankfurt's local energy coverage plans are extremely ambitious: they aim at covering local energy needs at a 100% until 2050 by local energy sources. A feasibility study shows that this goal can be reached relying by more than 2/3 on sun and wind. Together with the information that data centre electricity consumption makes up around 20% (equivalent to 1.3 GWh/year) of electricity demand in Frankfurt, the impact of implementing DC4Cities – and thus its market - can be tremendous. The only drawback is that nearly all data centres offer colocation services.
- *Madrid: bad prospects.* Madrid, finally, is an example for the influence of business and politics on the economic viability of DC4Cities: Even though the irradiation of sun is even better than in Barcelona and wind is about the same, the prospects for marketing DC4Cities in Madrid are by far worse: This is mostly owing to the economic downturn in Madrid, which in the aftermath also reduced the data centre market liquidity up to a point where Madrid has ceased to be assessed as data centre hot spot in Europe. There are simply not enough data centres in Madrid any more to make it a promising market for DC4Cities (however, enterprise data centres were not accounted for). Additionally, Madrid's smart city plans firstly aim at mobility and IT service goals and give less priority to the utilization of abundant renewable energy sources.

Business Models for DC4Cites

Exploiting the market potential must be done via selling the DC4Cities approach. This section contains an analysis of the possible exploitation channels for the project results, in the form of business models (developed using the Business Canvas methodology, see [9]).

Even though the primary markets identified for DC4Cities are focused on smart cities, these business models can be realized in any data centre regardless their location and their usage.

[13] adheres to the factor 4 concept and aims at reducing CO2 emissions by 75% in 2050 compared to 2004

Business models definition work methodology

In order to define these business models, the DC4Cities partners used an iterative approach that started from the definition of the key market drivers and dimensions and from the description of the environments in which trials are performed.

The first step of this methodology consisted of the provision of a common ground for the participants, for which an overview of the intermediate market analysis results and scenarios was given. The second step consisted of the introduction of the Business Model Generation methodology and the Value Proposition (VP) and Business Model Canvas (BMC) concepts, and a few examples were shown. Right after we went through a workshop including a number of brainstorming sessions in which several value proposition and business model ideas were elaborated. The workshop was organized according to the Business Model Generation methodology recommendations: The participants were split into 4 groups that worked in an independent way. Each group was composed by 4 or 5 members with different backgrounds (IT, energy, business, marketing) in order to benefit from a variety of perspectives. Each group worked on several rounds of possible value propositions definitions, each iteration lasting no longer than 5 minutes. Then the value propositions defined by one group were given to a different group in order to create the business model around it. If all the elements of the resulting business model were completed the business model (and therefore its value proposition) was deemed valid.

After the workshop the valid canvases and their components were analysed in detailed in order to be polished and to elaborate more structured reports. In this activity all information collected during the workshops was consolidated and the models were refined. The result of this consolidation (after multiple iterations) was an Excel sheet that contains a structured overview of the Business Model Canvases created during the brainstorming in the workshop.

The final step in the consolidation of the business model canvases is to evaluate if they are viable. For this, the excel file was used to elaborate the final business canvas prototypes and to make a qualitative analysis of a number of potentially viable business models. This needed many iterations in which various combinations of customer segments, revenue streams, customer relationship or channels were evaluated.

DC4Cities Value Propositions and Identified Business Models

In order to successfully sell products or services, it is important to understand what their value can be to existing or new customers. This is the concept of a value proposition. The definition of a value proposition should start identifying the possible products and/or services to be offered and then the potential customer for understanding whether this offer will help to release its current pains. If the gain for the customer is clear, the value proposition is valid and therefore it can serve as the core for a business model definition.

In DC4Cities we identified 15 different value propositions. Based on these, business models were created and shaped into eight different business model “packages”. From these eight possible business models, we finally selected 4 commercial packages to go to the market, taking into account the commercial interests and possibilities of the Consortium partners.

The core solution all business models rely on is the *Capacity Planner*, which describes the core functionality of DC4Cities. This core resulting functionality of DC4Cities (i.e. the adaptation of workload to an IPP) is potentially valuable for data centres in two contexts: a) for a provider having a data centre that is already partially powered up with renewable energies; b) for providers that are willing to make a transition to renewable energy sources. In a scenario where the data centre is already partially powered with renewable energies, the DC4Cities core functionality will increase the renewable energy usage. In case the energy arises from a local production, this scenario will reduce the data centre energy footprint and its Total Cost of Ownership (TCO). In case the provider is also practicing power metering, this proposition might even – depending on tariff conditions - exhibit an additional economic benefit for the provider, as the energy-selling price is usually higher than its buying price. In a scenario where the provider is willing to integrate renewable energies to power his data centre, this proposition would be valuable to assist the provider at sizing the powering. Through the usage of the central system simulator, the provider could evaluate the impact of different kinds of renewable sources (wind farms, photovoltaic arrays) and different powering capacities over his TCO and production workload. Accordingly, the provider might be able to calibrate his investment and pick the most appropriate powering installation with regards to the simulated short-term to long-term ecological and economic benefits.

The graphical representation of this business model is depicted in the canvas below.

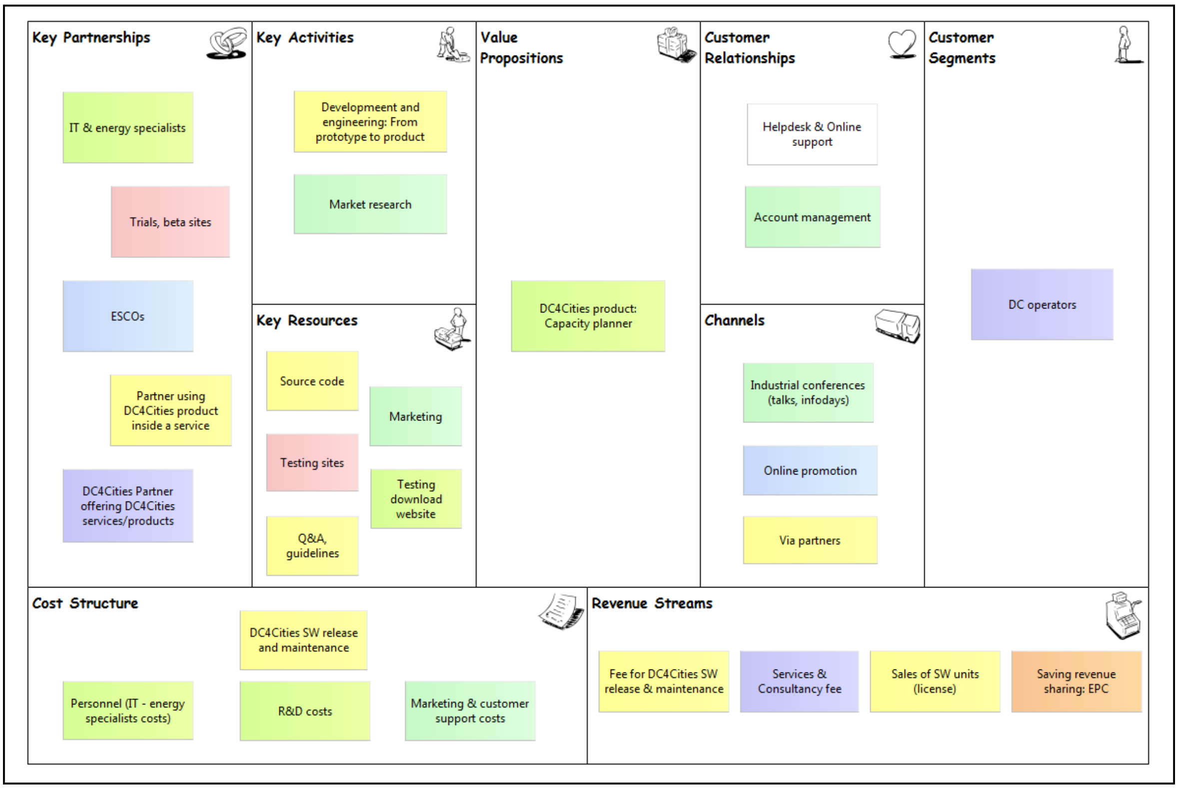

Figure 4 - Canvas representing the core business model of DC4Cities

Based on this DC4Cities core functionality the four commercial packages abovementioned are the following:

1. Consultancy services and use of tools

Taking into account DC4Cities architecture, the product can potentially be offered "as a service" model through a Cloud version to both, public or private DCs. This service can be better positioned as a part of a more global service, which would include energy services considering a general scope. Additional services that could be introduced would be, for example, the optimization of the energy supply, in accordance with the new consumption patterns, design and implementation of energy efficiency or renewable projects, etc. DC4Cities would offer a good opportunity to **ESCO's and datacentres operators** to develop converged solutions around renewals going inside ICT infrastructure and applications energy saving policies as an aggregator.

Moreover, for projects developed in different sites that belong to the same smart city or to the same DC operator, DC4Cities Data Centre Infrastructure Management software (DCIM) ENERGIS [9] could offer an energy monitoring solution aimed at Smart Cities/DC operators to monitor the energy efficiency of the different sites as well as the use of renewable energies thanks to the implantation of DC4Cities and related energy services. This solution would be designed to integrate into Big Data infrastructures.

In order to improve the energetic and environmental behaviour of a DC, the range of actions to perform is broad and DC4Cities SaaS can be considered as a last step, once other efficiency energy measures have been taken. The steps to transform a DC from its current energy situation to an environmental-afriendly DC defined by DC4Cities are the following (the lower part of the diagram shows potential partners capable of supporting the corresponding steps):

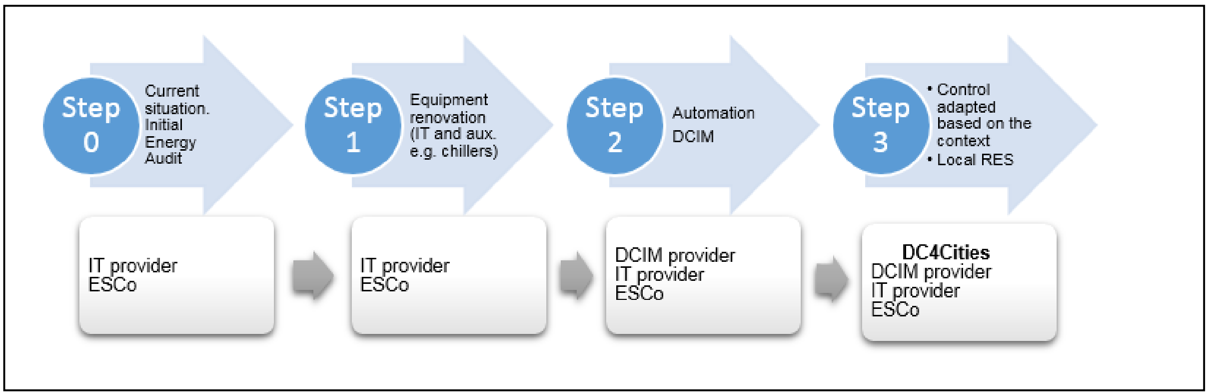

Figure 5 - DC4Cities services roadmap

2. Broker

The core resulting software components of DC4Cities as well as the metrics specified and implemented during the project, are potentially also valuable for brokers. These brokers might publish on their IT web broker portals data centres being ranked according to their energy awareness and ecological footprint. DC4Cities metrics can be used as key performance indicators (KPIs) which will allow data centre clients to benchmark in an objective and neutral way different data centres on their energy awareness and renewable energy utilisation. These brokers can also offer extra services such as audit services to data centres IT departments helping them acquiring the necessary energy expertise. They can give recommendations such as using software components of DC4Cities (EASC, central controller) in their data centres to improve their KPIs or they can help them parameterising these components for their specific applications.

3. Open Source contribution and Training

DC4Cities project contributes to various Open Source communities. These contributions consist in new feature developments and bug fixing in existing platforms such as Cloud Foundry and OpenStack. The DC4Cities project developed a prototype able to schedule the workload of the applications in a data centre so as to increase renewable energy usage. Open Source projects such as OpenStack are extremely complex, and evolving fast. By contributing to OpenStack community, one will first gain a deep understanding of the project. On the other hand, it also gives you a strong visibility and credibility within that community.

4. Public-Private partnership (PPP)

This business package explores the opportunities that can be achieved if the DC4Cities know-how is used in a direct collaboration with a Public Administration.

DC4Cities, in addition to transform Smart City's data centers offering the necessary tools to achieve these objectives (commercial package #1), can also offer a consulting service. These consulting services can be carried out in several different terms:

a) In a first scenario the collaboration comes into force when support and consultancy services are required in order to launch a public procurement for the acquisition of an infrastructure and/or a service.. This collaboration should create a framework with the aim of helping the Smart City administration during the process of acquisition of infrastructure or contracting new services. This framework can guide this process during the preparation of the technical study required for the contracting, as at the time to accept or deny the purchase. To do so the consulting would have to adapt this framework to the legal regulation in each country and the objectives of each Smart City in reference to energy efficiency and the use of renewables. The outcome should include:

- A guide for the evaluation of the received commercial offers.
- A guide to the monitoring regarding the compliance with the objectives defined by the administration in their programs of energy efficiency and use of renewable energy.

- A guide with best practices.

b) In a different scenario, DC4Cities know-how can be used in an activity of consultancy to Public Administrations, required to define and put into action a policy or a general regulatory framework concerning the deployment and operation of Data centres. This consultancy activity can be carried out at National, Regional, or local level, and might originate from a specific role of adviser to the Public Administration using DC4Cities as knowledge base..

Conclusion

We could show that there is an expanding market in Europe for a tool that allows a data centre to adapt its power profile to the volatile renewable energy supply in collaboration with a local energy management unit. The size of this expansion, however, depends on a multitude of factors.

Both regarding data centre business rationales as well as local renewable infrastructure equipment, there is a huge clout of the political framework: The more ambitious political goals exist and the more they are poured into legal guidelines and financial incentives, the higher the direct adaptation scope that pays off for a data centre. On the other hand, the more ambitious the goals for renewable energy utilization, the higher the investment into local renewable energy equipment – the status of the harvesting infrastructure is therefore an indirect effect of policy on the DC4Cities market potential. These goals can be EU, national, but also smart city policies. Only an adequate potential energy harvest creates the opportunity to increase the share of renewable energy in a data centre's energy mix. This is of course also determined by the share of renewable sources in the regional power grid – the higher it is, the higher the potential success of adaptation.

Apart from the political and economic framework, geographical location and climate characteristics influence the market size: Huge potentials of sun and wind foster the adoption of energy adaptation strategies in data centres. Technical characteristics like the share of interactive workload could not be researched in the context of this work; however, they are partially mirrored by the business models of date centre companies. It is a result of this study that colocation data centres need to be targeted by DC4Cities.

Different combinations of these factors lead to a high disparity in opportunities for a DC4Cities based approach in cities with even similar sun and wind energy conditions. So there are for instance good conditions in Barcelona with rather flexible data centre types and a strong commitment to renewable energy compared to Madrid where the data centre industry has been receding and the smart city concept is interpreted from a less environmental perspective. The same applies to Frankfurt versus Paris: Frankfurt has extremely ambitious local energy coverage goals, and Paris relies on geothermal energy which does not need an adaptive approach.

To which degree the identified market potential can be tapped is dependent on the way that the DC4Cities ideas are shaped into viable business models. Several concepts for business models have been presented – they need to be targeted at the right customer segment. Frankfurt, for instance, a basically fairly good potential for marketing the presented approach, could be the forerunner of renewable adaptive data centres provided that the DC4Cities capacity planning business models can be customized for colocation data centres.

Acknowledgment

This work was carried out within the European Project DC4Cities (Grant Nº 609304). Additional contributors to the research about the focus cities and contributors to the work defining the business models were: Thomas Schulze, Torben Möller, Nicole Wesemeyer, Wolfgang Duschl, Florian Niedermeier, Hermann de Meer, Federico Lombart Badal, Francesc Casaus, Eduard Martín, Silvia Sanjoaquin Vives, Elena Alonso Pantoja, Gonzalo Jose Diaz Velez, Mehdi Sheikhalishahi, Frederic Wauters, Marta Chinnici, Gorka Roldán, Fabien Hermenier, Jordi Guijarro, Andrea Quintiliani, Alejandra Sayans Jimenez, Corentin Dupont, Roberto Chiappini, Giovanni Giuliani.

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Session ESCO

Energy Performance Contracting in Europe: Current state and perspectives of EPC in public buildings

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1. Abstract

The European cooperation project EnPC-INTRANS (Capacity Building on Energy Performance Contracting in European Markets in Transition) aims to increase the market uptake of technologies for the improvement of energy efficiency (EE) in public buildings by means of fostering private sector participation in innovative financing schemes for EE investments. This is achieved by means of implementing large-scale capacity building for local public authorities and small- and medium-sized enterprises (SMEs) to jointly set-up and use EPC projects for the improvement of EE in public buildings.

The project participants are the European competence centres on Energy Performance Contracting (EPC) in Croatia, Germany, Greece and Slovenia, a competence centre for e-learning in Slovakia, a competence centre for international cooperation in Germany and key actors for the promotion of EPC at the local level in Latvia, Serbia, Romania and Ukraine.

In the first nine months, the partners investigated best practices of EPC in public buildings in Europe and decided to focus on three complementary EPC business models:

- **EPC light:** Improvements of energy efficiency are mainly achieved by means of energy management measures with little or no investment in technical equipment.
- **EPC basic**: Implementation of investments and services focusing on in technical energy conservation measures (ECM).
- **EPC plus**: Implementation of investments and services providing for a comprehensive deep renovation of public buildings including also ECM with longer pay-back periods.

All models include energy saving guarantees provided to the public building owner by the contracted ESCO. Energy saving guarantees are major references for the verification of due service delivery as well as for the payment of agreed EPC service fees.

The evaluation shows that the specification, the extent, and the contents of single parts of the EPC business models differ across the analysed countries. The applications vary depending on the ESCO market, the availability and engagement of facilitators, as well as the national framework conditions. Nevertheless, the analysis shows that all three business models may be transferred to all partner countries of the project without any major alterations.

A baseline study carried out in summer 2015 was based on the consultation of 446 stakeholders interested in EPC for public buildings from nine European countries. They gave their feedback regarding the current state of the EPC market, specific strengths and weaknesses of EPC business models and the existing needs for capacity development on EPC in the public sector of their countries.

To date, the ESCO markets in the nine countries are representing three different levels of market developments:

- Established ESCO market: Germany
- Emerging ESCO markets: Croatia, Slovakia, Slovenia
- Prospective ESCO markets: Greece, Latvia, Romania, Serbia and Ukraine

In all of these ESCO markets, EPC projects are covering only a minor share in the existing market volume. ESCOs focus on energy supply contracting (ESC) rather than on energy performance contracting, because ESC is closer to the ESCOs' traditional business models. The economic and

technical risk related to the determination and verification of energy performance guarantees is much higher for the ESCOs [1]. Public building owners are often very skeptical regarding EPC despite the large economic energy saving potentials in their buildings. In none of the partner countries, the market for EPC in public buildings has emerged to a level of self-sustaining growth, which would be necessary to attract more actors on both the demand and the supply side of the market, including relevant facilitators like e.g. local energy agencies, engineering companies, and local SMEs which could take this role.

There is a big demand for further capacity development on EPC among public building owners as well as among potential local service providers in all nine countries. Depending on the currently reached level of EPC-related know-how and experience of the involved target groups in the nine countries, different subjects are in the focus of the stakeholders' interest in further information and training on EPC for public buildings.

2. Introduction

Energy performance contracting is an innovative service offered by energy service companies to building owners. EPC aims at facilitating energy efficiency (EE) improvements in buildings and financing necessary investments and service costs from guaranteed future energy savings. The basic idea of EPC is that building owners transfer the economic and technical risk of investments in the improvement of EE and of the potential savings in their buildings to ESCOs which have both the financial means, and the technical capacities and experience to implement the necessary investment and to ensure the achievement and verification of guaranteed energy savings [1].

The main components of an EPC in public buildings are:

- Public private cooperation between the public building owner and the ESCO, which is usually operating as a commercial entity even if owned e.g. by a public utility.
- ESCOs perform as general contractors providing all services and goods from the same source.
- ESCOs and public building owners define the baseline energy consumption in the building(s) under specific conditions, as well as the method of evaluation and verification of achieved energy savings in comparison to the baseline while taking into account variations, e.g. in weather conditions and building use, in a systematic, transparent, and verifiable way.
- ESCOs guarantee the achievement of the agreed energy saving objectives at their own risk and bear responsibility for all investment costs and services related to an EPC project.
- Public building owners guarantee the payment of agreed EPC service fees depending on the achievement of the agreed energy saving guarantee.

The main mechanism of EPC is described in Figure 1:

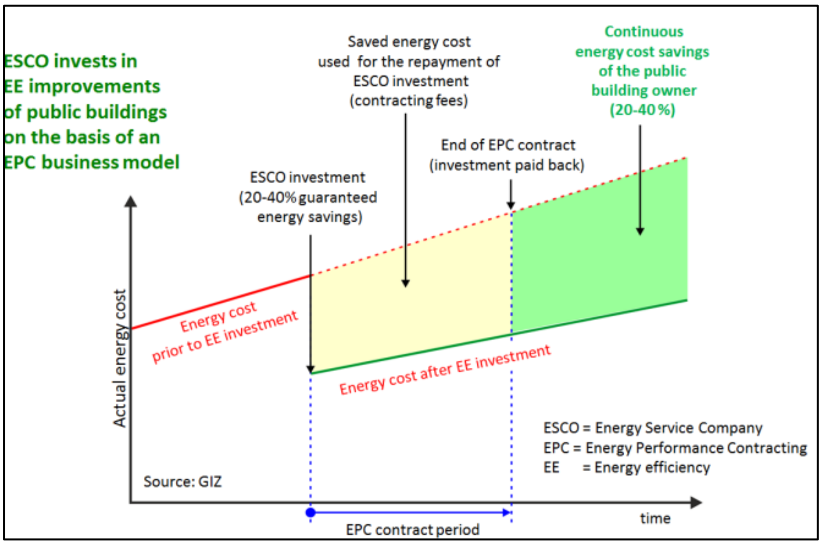

Figure 1: Main concept of EPC [2]

The net present value (NPV) of guaranteed energy savings is the limiting value for the complete costs (planning, investment and services) that may be financed by the ESCO under EPC terms. This is why the potential investment volume and services under an EPC contract are to a large extent depending on the guaranteed energy savings and the agreed contract duration, and vice versa.

In order to facilitate and finance EE improvements in public buildings, the EU promotes the concept energy performance contracting and it´s dissemination in Europe [3].

3. Existing business models and market uptake of EPC

Using a base of existing European market studies, previous and on-going European cooperation projects and a template developed by KEA, project partners investigated and evaluated European EPC practices in the partner countries and abroad [1] [4] [5] [6] [7] [8].

Most of the already existing applications of EPC in public buildings in Europe are based either on general guidelines provided from different sources, or on tailor-made solutions which were developed on a project-by-project basis for individual application cases. This has been a major barrier in the past for the European-wide knowledge sharing on EPC in public buildings as well as for the dissemination and replication of good practices. In order to overcome this barrier, the European Energy Service Initiative identified three complementary EPC business models which may be promoted on the European EPC market [4].

Table 1: Major features of EPC business models [3]

Business models (typical features)	EPC light	EPC basic	EPC plus
State of building and planned investment	All public buildings with energy saving potentials.	The building still serves its purposed, but energy systems installed and used in the building are outdated and inefficient.	Building does no longer serve its (current or future) purpose. Building and installed energy systems are outdated and/or dysfunctional, deep renovation is planned.
Design and planning of the EPC project	Building owners or local facilitators.	Building owners or local facilitators.	Building owners or local facilitators.in cooperation with contracted architects, and engineers.
Installation and operation of equipment and technical facilities	ESCO	ESCO	ESCO
Technical improvements (investments) included in the scope of a project.	Only little investment, e.g. installation of meters and controls.	Rehabilitation, replacement or new installation of technical equipment.	Deep renovation of building structures including technical equipment, building envelope and facilities like fire protection systems, etc.
	Often including the utilization of renewable energies, installation of heat pumps or combined heat and power generation facilities.		
Ownership of installations	All installed devices are property of the building owner.	Ownership of all equipment and facilities installed in a building is usually transferred to the building owner at the date of acceptance as stipulated in the contract.	
Services (operations) included in the scope of a project.	Management services: Energy accounting and management. Verification of energy bills. Measurement of actual energy consumption and verification of achieved energy savings. Grant applications and approval procedures. Operational services: Optimisation of operation and maintenance of installed facilities. Sometimes additional: auditing and certification procedures.		
Energy savings guaranteed compared to	Typically 10-20 %	Typically 20-60 %	Ideally >70%

Table 1: Major features of EPC business models [3]

Business models (typical features)	EPC light	EPC basic	EPC plus
baseline			
Financing	The ESCO bears only the staff cost.	ESCOs own equity, loans, subsidies, financial contributions from the building owner.	
Calculation of necessary EPC service fees on the basis of guaranteed energy savings	Sufficient to provide, within the agreed contract duration, for the amortisation of all cost of the ESCO +ESCO's profit.	Sufficient to provide for amortisation of the planning and investment cost - subsidies+ financing, services, and maintenance cost, + ESCO's profit.	Sufficient to provide for the amortisation of planning and investment cost related to fast-paying ECM - subsidies + financing, services, and maintenance cost + plus ESCO's profit.
Additional financing options that may help reducing EPC service fees.	Usually not necessary.	Down-payments for a part of the public building owner's up-front cost (reduction of the investment cost of the ESCO). Subsidies on interest rates paid by the ESCO (reduced financing cost). Subsidies on specific technical measures (e.g. feed-in tariffs for power generated from renewables or in combined heat and power plants).	
Pay-back of investment	Completely from guaranteed energy savings.		Partially from guaranteed energy savings. The remaining share if investment cost must be paid separately (e.g. up-front by the building owner).
Contract durations accepted on the market place	2-3 years	5-15 years	10-20 years

Research performed during the study and information provided by interviewed stakeholders refers to EPC reference projects in 16 different European countries. Most of these projects are based on the EPC basic or EPC plus model - with many variations. So far, the EPC light business model was found to be promoted and implemented mainly in Germany [3].

EPC for public buildings is still an underdeveloped niche market all over Europe. In none of the partner countries the market for EPC in public buildings has so far emerged to a level of self-sustaining growth, which would be necessary to attract more actors on both the demand and the supply side of the market. The initiation and development of a faster market uptake of EPC business models for EE improvements in public buildings is an important challenge because it allows public authorities to contribute to the EE targets of European and national energy policies.

Table 2: Stakeholder observations regarding main incentives and barriers for EPC projects in the partner countries (shortened version) [3]

	Countries for which these incentives and barriers were emphasized by consulted stakeholders								
	Croatia	Germany	Greece	Latvia	Romania	Serbia	Slovakia	Slovenia	Ukraine
INCENTIVES									
Political and legal incentives									
Political commitment for EE and economical energy savings high at national level	●	●	●	●	●	●	●	●	●
National EE law and supporting laws promote EE in public buildings	●	●	●	●	●	●		●	●
EE objectives and standards for public buildings stipulated in national policies and programs	●	●	●	●	●	●		●	●
Economic incentives									
Expectation of increasing energy prices		●	●		●			●	●
Higher market value and increasing comfort level of renovated buildings	●	●	●	●	●		●		
Financial incentives									
Reduced-interest loans programs offered e.g. by state-owned development banks	●	●	●		●				
Grants available from national or international Energy Efficiency Funds	●					●		●	●
Subsidies for municipal EE programs and projects (planning and implementation)		●	●	●	●				
Other incentives									
EPC guidelines, tools and sample contracts available in the country (or under preparation)	●	●		●				●	
National or regional competence centres promoting EPC	●	●	●					●	
Promotion of inter-municipal cooperation and/or pooling of public buildings in EPC projects		●	●	●	●				
Trade associations of ESCOs promoting EPC as a business model		●	●	●	●				
Regional and local energy agencies and/or associations of local authorities promoting and facilitating EPC		●	●	●	●			●	
BARRIERS									
Political and legal barriers									
Procurement rules and procedures for public authorities (complex tendering procedures)	●	●	●	●	●	●	●	●	●
Budget and accounting rules for local public authorities	●	●	●	●	●	●	●	●	●
Requirements concerning the comparison of EPC and building owners own investment	●	●		●			●		
Administrative barriers									
Lack of understanding of the EPC concept among municipal decision makers and executives	●	●		●	●		●		●
Non-transparent, lengthy, or complex decision making processes in municipalities	●	●	●	●	●		●	●	●
Distributed responsibility for buildings, energy bills, maintenance and operation of facilities in municipal administrations		●	●	●	●		●		●
Lack of finances and/or personal capacities for project preparation, tendering, contract negotiation and monitoring, construction supervision etc. in municipalities		●	●	●	●	●		●	
Economic barriers									
Risk of incorrect calculation of baseline consumption	●	●	●	●	●	●	●	●	●
Financial barriers									
High loan cost of loans			●	●	●	●		●	●

Limited access of ESCOs to bank loans (e.g. high equity to loan ratio required)		●	●	●	●				●
Limited or lacking public funding and limited (or no) access of municipalities to loans	●		●	●	●	●		●	●
Lack of collaterals	●			●	●	●			
Technical barriers									
Lack of experience in the calculation of baseline consumption	●	●	●	●	●	●	●	●	●
Lack of attractive best-practice examples in the country	●		●	●		●			●
Lack of know-how and experience among local public utilities	●	●	●		●	●		●	●
Lack of calculation tools and sample contracts			●	●	●	●		●	●
Lack of know-how and experience in EE technologies among local facilitators and experts	●	●	●	●		●			●
Lack of qualified local facilitators promoting EPC projects		●	●		●	●		●	●
Lack of local ESCOs offering EPC services	●	●	●		●	●		●	●
Other barriers									
Bad reputation of EPC among public administrations and decision makers		●		●	●	●		●	
High barriers for the market entrance of new ESCOs		●	●	●	●	●		●	
Poor image of ESCOs among public administrations and decision makers	●	●	●	●	●	●		●	
Low trust in the EPC concept (savings and calculations)	●	●		●	●	●		●	
Lack of information on EPC in public buildings	●			●	●	●		●	
Lack of standardized EPC models	●			●	●	●		●	
Lack of transparent M&V protocols and rules	●			●	●	●		●	

One of the biggest obstacles for the emerging of a market for EPC in public buildings in the partner countries is the lack of economically attractive EPC projects tendered out on the marketplace by public building owners. Therefore, each new EPC project initiated by participants in EnPC-INTRANS capacity development programs may contribute to the creation of new impulses for the emerging of an EPC market in these countries.

The analysis of the three business models including the analysis of existing framework conditions shows that a successful implementation and dissemination of the EPC business models mainly depends on the legal and administrative regulations, the political commitment as well as financial barriers and incentives. Qualification of stakeholders, standardization and promotion are crucial triggers to support the market rollout of EPC.

4. Stakeholder consultation

The project consortium interviewed a total number of 446 stakeholders from nine partner European countries in order to evaluate training needs for the further implementation of EnPC-INTRANS project. On average 50 stakeholders responded in each of these partner countries [9].

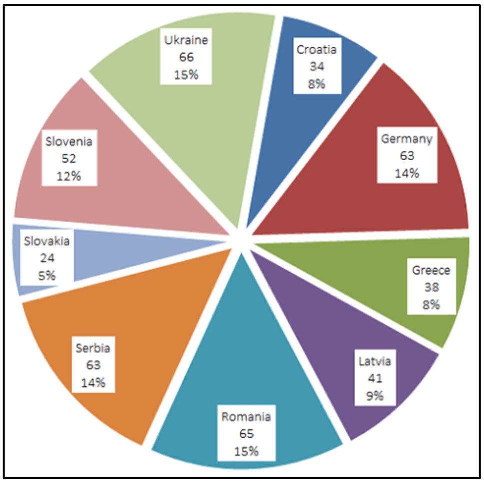

Figure 2: Geographical distribution of consulted stakeholders [10]

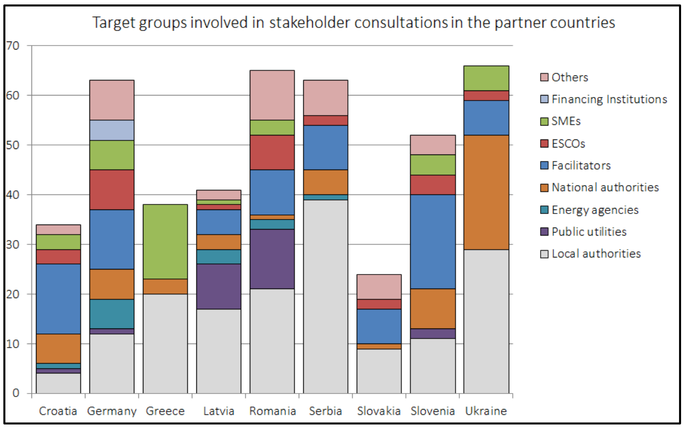

Figure 3: Stakeholder groups consulted in the countries [10]

In all countries, except in Croatia, local authorities are the biggest of the target groups involved in the consultations (see figure 2). In addition, the greatest share of interviewed stakeholders who already have experience with EPC projects is in Croatia and Germany (see figure 3).

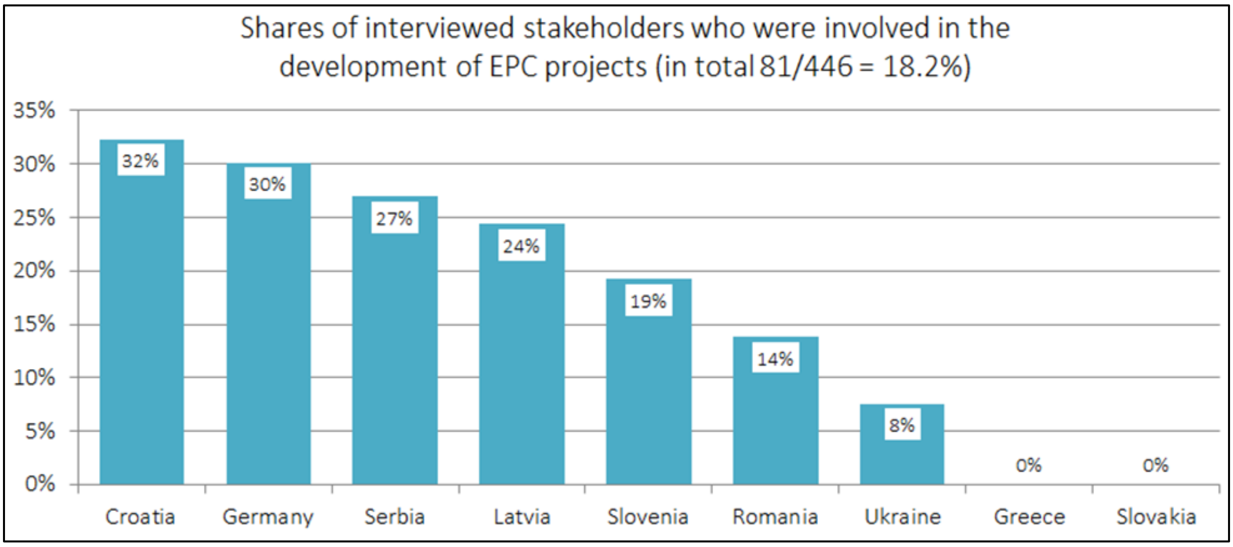

Figure 4: Shares of stakeholders who were already involved in the development of EPC projects [9]

5. Training needs assessments

Only two thirds of consulted stakeholders regarded themselves as “informed” about the basic ideas and concepts of EPC (see Figure 5). At least one third of those commented that their level of knowledge was “very basic” or “limited”. The stakeholders’ uncertainty regarding their level of information and know-how on EPC is also reflected in the fact that 88% of the consulted stakeholders stated that they would be interested to learn more about how to develop and implement EPC projects in public buildings (see Figure 6).

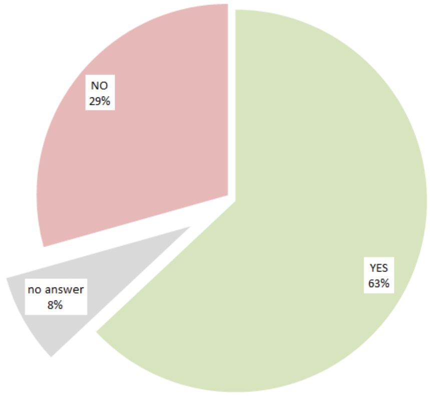	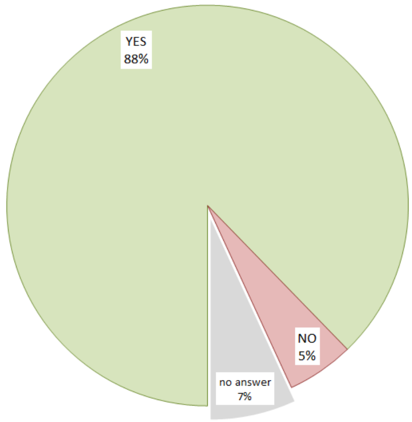
Figure 5: Answers to the questions: "Are you informed about the basic ideas and concepts of EPC?" [10]	**Figure 6: Answers to the questions: "Are you interested to learn more about EPC for public buildings?" [10]**

Those who were interested in learning more about EPC in public buildings were offered a list of potential training subjects and they were invited to select three subjects which they would be the most interested to learn more about.

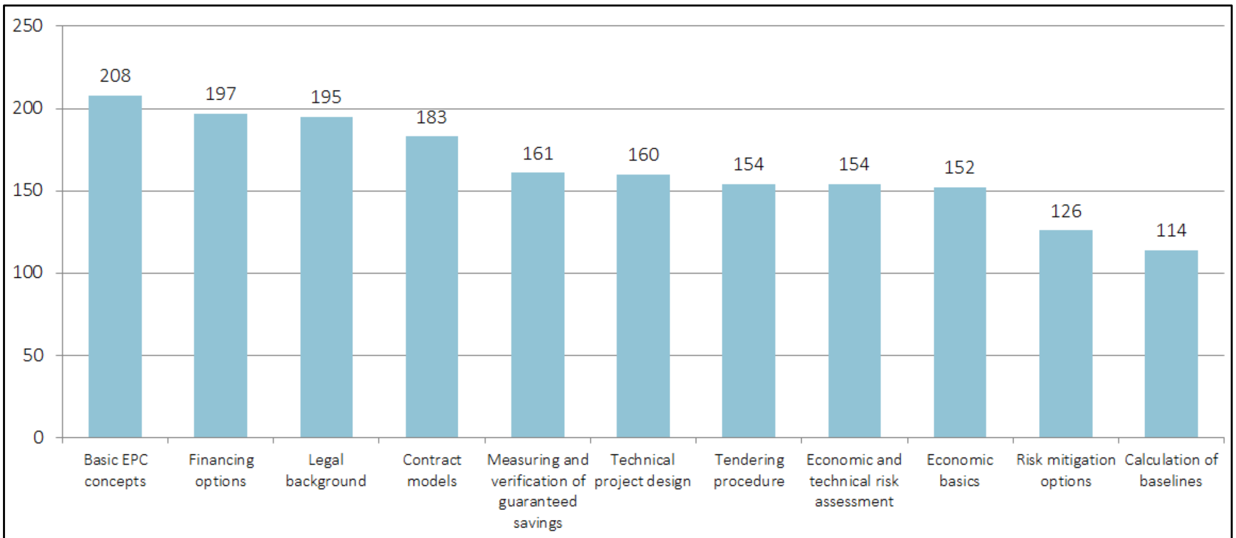

Figure 7: Priority training subjects selected by those stakeholders who are interested to learn more about the development and implementation of EPC projects in public buildings. (Total: 398) [10]

Country-specific differences in the priority training subjects were noted and used to identify the single training needs in every country. Beside the basic EPC mechanisms, the financing and legal parts of EPC business model have a very high priority, whereas risk mitigation and baseline calculation are too specific and received less priority.

Country-specific evaluations of stakeholder comments show that there may be large differences regarding the acceptance of different training methods (see Figure 8). E-learning (self-study) may be of major importance in Croatia, Slovakia, and Ukraine. Webinars may play a bigger role than e-learning in Germany and Slovenia. The strongest focus on traditional forms of seminars will be in Latvia, Romania and Serbia. On average, webinars and e-learning are accepted by 27-28% of the consulted stakeholders.

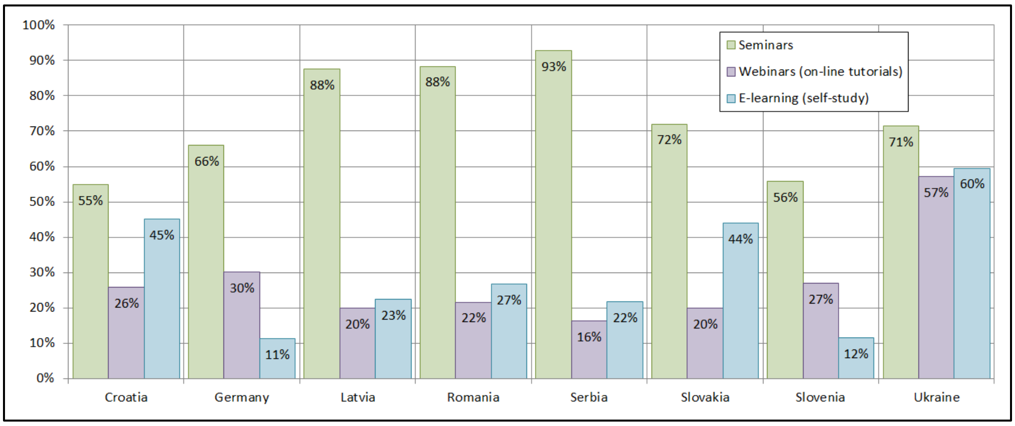

Figure 8: Country-specific differences in the acceptance of proposed training methods[1] (in % of national stakeholders accepting a proposed training method) [10]

On the basis of stakeholder evaluation, the project consortium prepared the agenda of training sessions such as the "train the trainers" seminar taking place in Bratislava at the end of February 2016.

Module I: Selection of EPC projects and appropriate business models
– Basic concept of EPC. – Practical examples of EPC in public buildings – EPC business models. – Economic basics.
Module II: Design of specific business cases
– Technical project design. – Financing options. – Economic and technical risks. – Risk mitigation options.
Module III: Tendering and contracting
– Legal background. – Tendering procedure. – Contract models.
Module IV: Measurement and verification of savings
– Measuring & verification of savings. – Calculation of baselines.

Participants on training sessions will be provided with checklists, templates and guidelines helping them to facilitate the initiation of EPC projects.

6. Conclusions

In order to address the information needs and priorities of the target groups, EnPC-INTRANS will undertake to bring them in contact and direct exchange with each other ,e.g. during road shows, in webinars and e-learning courses, in seminars and in an international conference.

Even if there are some differences between single countries regarding the level of EPC market development as well as regarding the existing barriers and incentives, the planned training and promotion activities will help to overcome the general lack of understanding and reputation of EPC and the lack of

[1] In Greece, stakeholders did not see themselves in the position to answer this question. However, during the interviews stakeholders in Greece expressed a preference for e-learning courses that give them more flexibility in time and effort for their own capacity development.

qualified ESCOs and facilitators. ENPC INTRANS training sessions will contain specific required topics and address the needs of single target groups.

The project consortium has already achieved some of the expected outputs of the project and is heading towards attaining a large promotion of EPC in the nine partner countries and, through consequent dissemination of project outputs at the European level, in all EU28 member states.

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The project receives funding from the Horizon 2020 European Union Research and Innovation Programme under Grant Agreement 649639. It started in March 2015 and will be finished in February 2017.

ENERGY PERFORMANCE CONTRACTING PLUS (EPC+) SME Partnerships for Innovative Energy Services through Standardisation

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Abstract

The main barriers for the implementation of Energy Performance Contracting (EPC) in private-sector SMEs are (1) high transaction costs, (2) small investment and project sizes, (3) difficulty in obtaining financing for such small projects, 4) high costs of the measurement and verification procedures needed to verify the guaranteed savings and (5) the complexity of the contracts,.

The EPC+ project is a HORIZON 2020 Coordinated and Support Action (CSA) running from March 2015 to February 2018 and implemented by the following organizations: Grazer Energie Agentur - Austria, e7 – Austria, Factor 4 - Belgium, Sdruzhene Chernomorski Iszledovatelski Energien Tsentar (BSERC) - Bulgaria, Seven Stradisko Pro Effectivni Vyuzivani Energie (SEVEn) - Czech Republic, Arbeitsgemeinschaft (ASEW) - Germany, Centre for Renewable Energy Sources and Saving - Greece, Helesco – Greece, Tipperary Energy Agency - Ireland, Escoitalia - Italy, Instituto de Sistemas e Robotica - Portugal, Institut Jozef Stefan - Slovenia and Esan - Spain.

The objectives of the EPC+ project are:

- The establishment of pilot SME Partnerships for Innovative Energy Services (SPINs). SPINs are organized clusters of companies, mainly SME's, which jointly supply energy services and have a structured long-term collaboration with commonly agreed objectives. These SPINs consist of market actors along the value-added chain of energy efficiency that offer complementary services to each other. A SPIN maintains the flexibility, customer focus and innovation strength of SME's but with a potentially lower cost structure compared with large ESCOs.
- Capacity building of the pilot SPINs on administrative, technical, legal and financial matters pertaining to operational practices.
- Development of standardized EPC+ packages. These will be based on existing EPC models and other energy service oriented models, so far tailored for large-scale projects. For the identified standardized, technical and service-oriented solutions, simple model contracts will be developed, as well as technical and financial toolboxes.
- Implementation of a total of 33 pilot projects in 11 countries.
- The development of an international EPC+ platform. This will be an international 'market place' where - according to commonly agreed rules - members of different EU member states can efficiently and safely exchange valuable know-how between each other.

In the current paper, the progress of the EPC+ project (until March 2016), its findings and upcoming tasks are described.

Abbreviations (in alphabetical order)

CSA	: Coordinated and Support Action of the HORIZON 2020 programme
EPC+	: Energy Performance Contracting Plus
EES	: Energy Efficiency Service
ESCO	: Energy Service Company
EU	: European Union
SME	: Small-to-Medium Sized Enterprises
SPINS	: SME Partnerships for Innovative Energy Services
SWOT	: Strength, Weaknesses, Opportunities, Threats

1. The EPC+ project

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2. Current situation of the Energy Performance Contracting Market (EPC)

According to Directive 2012/27/EU [8] "*energy performance contracting means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings*".

Since the issue of Directives 2006/32/EC [1] and 2012/27/EC [8], in most of the EU member-states the provision of energy services to the private sector by utilities is still increasing at a very small rate despite the fact that:

(1) Energy services are potentially an excellent customer retention instrument for utilities,
(2) There is a significant demand for the development of new business models for utilities and
(3) Utilities already apply energy supply contracting in some member states and it is thus much easier for them to extend this portfolio to EPC services.

This is mainly due to the hesitancy of the utilities to actively participate in the provision of energy services to its final customers due to the fact that the provision of these services essentially goes against their business logic, which is to sell energy and not save it. Fortunately, there are some noticeable exceptions to the rule (e.g. in Austria, utilities run a wide range of energy efficiency programs for private final consumers, due to the national energy efficiency law). In general, what most utilities favour doing is opting for the "softer" actions such as the provision of energy audits and the dissemination of informative material regarding energy efficiency and renewable energy services. Undoubtedly, these actions have the potential to indirectly trigger energy efficiency improvement initiatives by the final consumer but they do not have the immediate effect of energy services.

This was clearly stated in the Official Opinion of the European Economic and Social Committee regarding the progress of the Energy Services Directive "….Already in its opinion on the Energy Services Directive, the Committee was doubtful about putting energy saving obligations on utilities as this goes against their business logic)" [2].

Energy Service Providers on the other hand, are very keen to pursue the provision of energy services to its potential customers as this is their core business and it is therefore in their interest to pursue such activities. As displayed in Figures 1-4 below, the majority of the stipulated energy performance contracts (EPC) implemented by Energy Service Providers in the European Union concern large project investments (i.e. > 200.000 €), with relatively long payback periods (i.e. > 5 years) in public infrastructure.

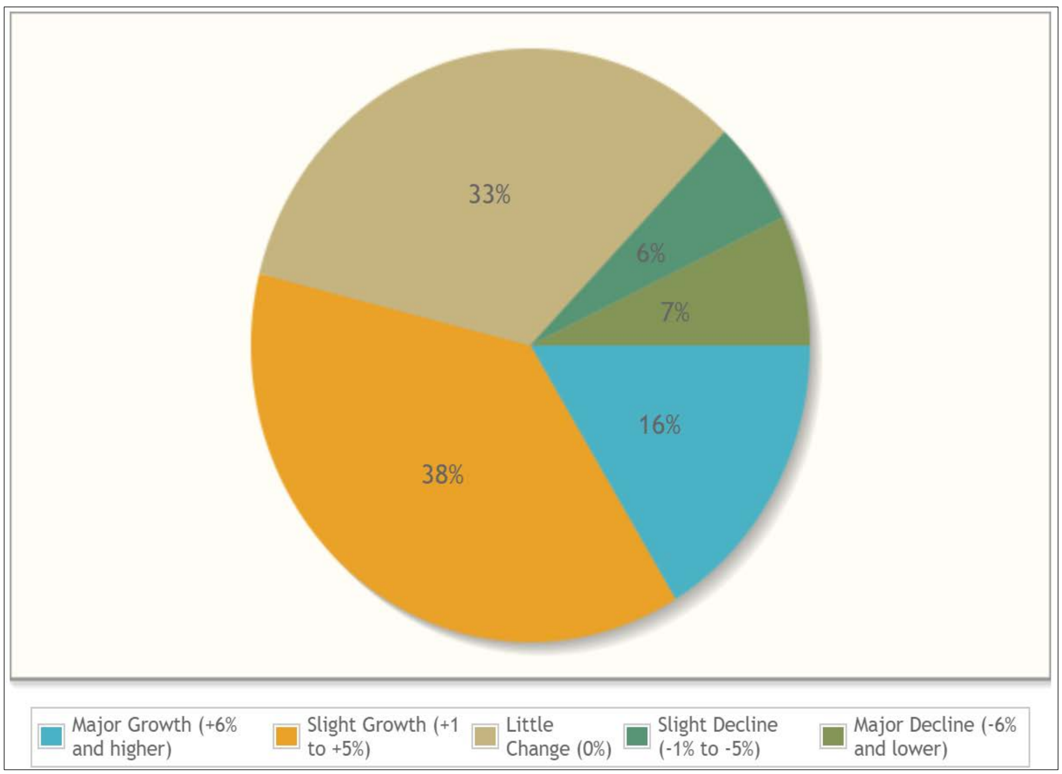

Figure 1 – Status of EPC market in the EU – December 2013 [10]

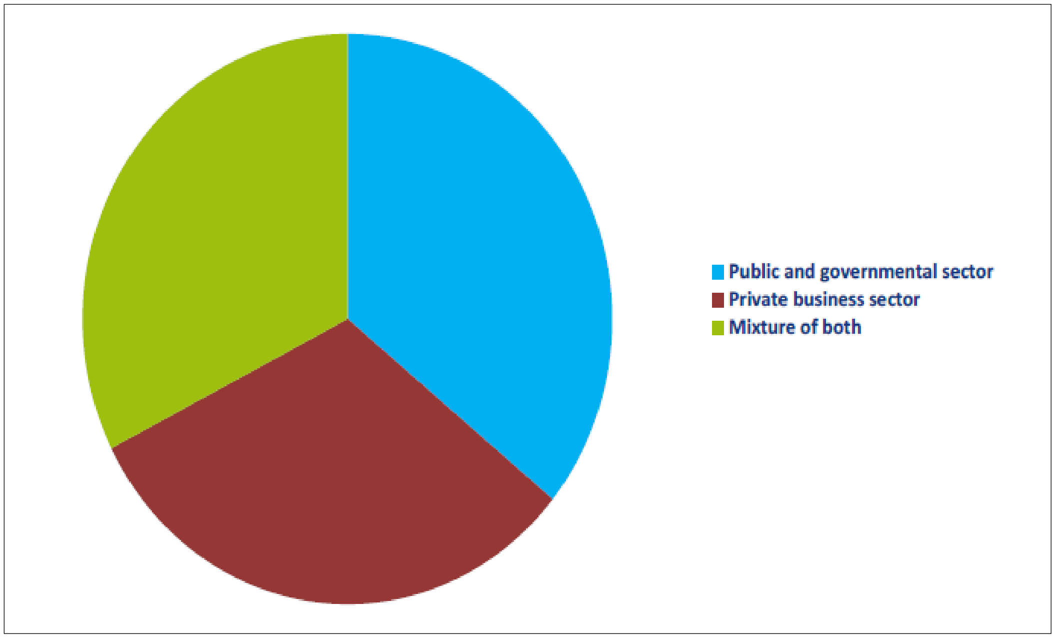

Figure 2 – Final Customer Provenance of implemented EPC projects – December 2013 [10]

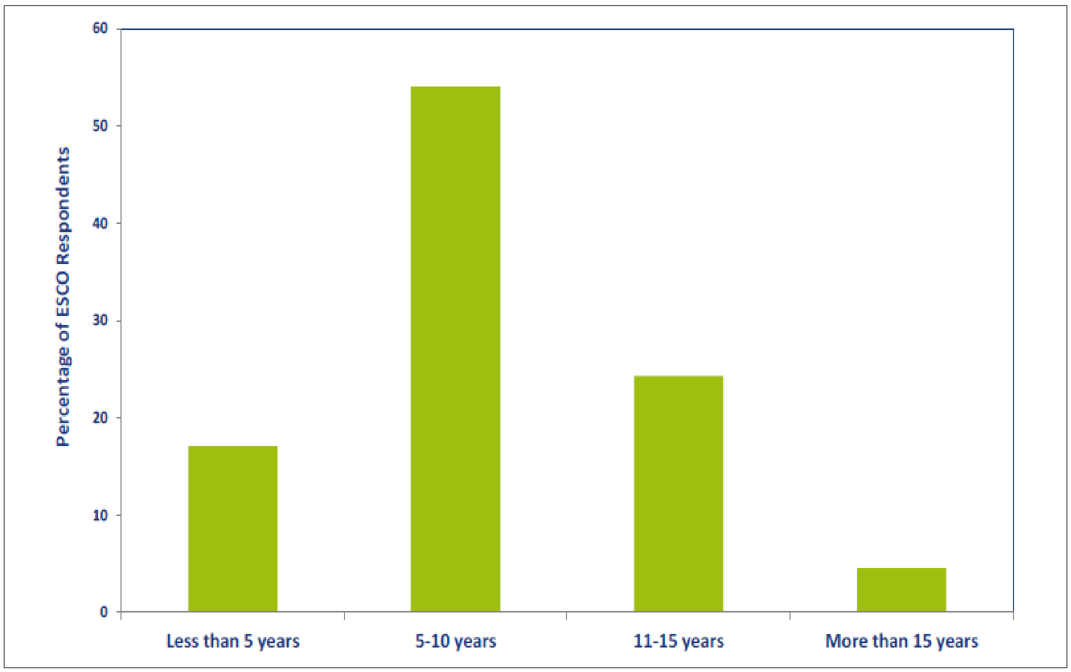

Figure 3 – Typical length of EPC projects – December 2013 [10]

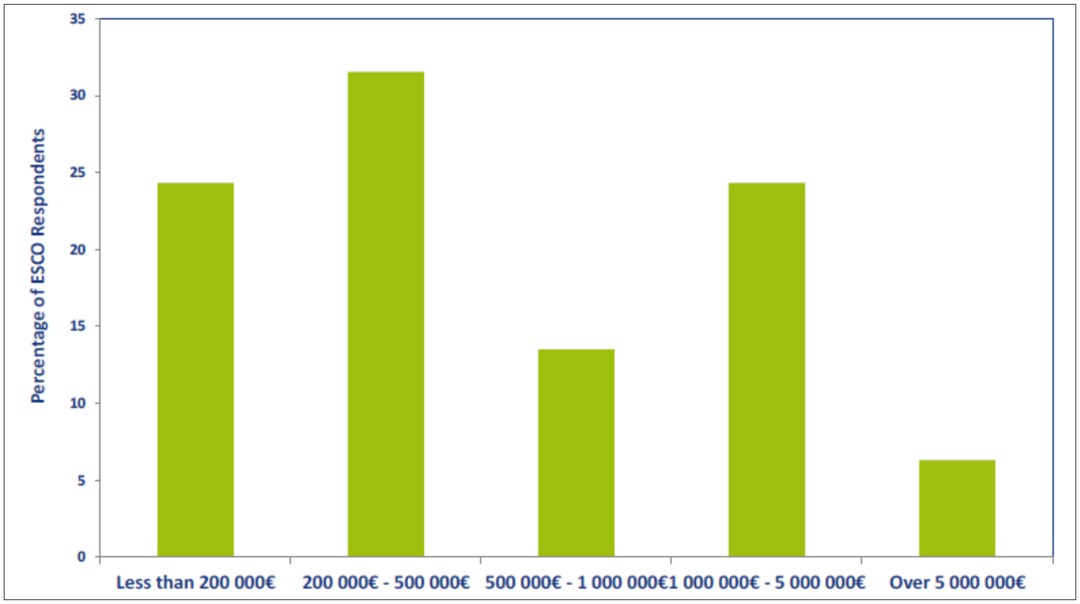

Figure 4 – Most common investment outlay for EPC projects – December 2013 [10]

The penetration of EPC in the private sector has been very limited despite the considerable potential for energy saving [3]. This is even more evident in Small to Medium-sized enterprises (SMEs). The main reason for the limited penetration of EPC and the provision of energy services in the private sector is that although they are generally looked upon favourably, their implementation can often be complicated and lengthy. The main reasons which impede a real breakthrough in the spread of the EPC methodology include:

- High transaction costs for the procurement of the energy services relative to the savings potentials.
- Investments and project sizes are too small to attract bigger ESCOs currently on the market.
- Financing is difficult to obtain for smaller projects, as due diligence costs are relatively high.
- High costs of the measurement and verification procedures needed to verify the guaranteed savings. These are essential in creating confidence for the achievement of the promised savings.
- Risk of bankruptcy of the SMEs.
- Long-term and complex contract

3. Main objectives of the EPC+ project

The main objectives of the EPC+ project, a HORIZON 2020 Coordinated and Support Action (CSA) running from March 2015 to February 2018 are:

(1) The development and establishment of SPINs (SME Partnerships for Innovative Energy Services) in the 11 participant countries (Austria, Belgium, Bulgaria, Czech Republic, Germany, Greece, Ireland, Italy, Portugal, Slovenia and Spain). A SPIN is a nationally organized cluster of independent energy efficiency service providers, mainly SMEs, that jointly supply energy efficiency services and that have a structured long-term collaboration with some commonly agreed objectives.

(2) Capacity building of the SPINs, particularly regarding administrative, technical, legal, financial organizational, communication and business issues and activities.

(3) The simplification of existing EPC models and the creation of standardized solutions. It is planned to simplify existing EPC models and other energy service oriented models, so far tailored for large-scale projects. For the identified standardized, technical and service-oriented solutions, simple model contracts will be developed, as well as technical and financial aids.

(4) Testing, by the SPINs, of the new EPC models through the implementation of pilot projects in the 11 participant countries.
(5) The development and establishment of an international communication platform. The international EPC+ platform is an international 'market place', where - according to commonly agreed rules – its members can safely exchange valuable know-how and develop EPC-models and SPIN-concepts.

4. Definition of an EPC+ service and its business model

An EPC+ service is one that contains all of the following elements [4]:

(1) It must be provided for SMEs by a SPIN, (i.e. a cluster composed of, at least, 3 or more SME's). The inclusion of a non-SME in the consortium may be acceptable if it is not possible to involve only SME's due to market restrictions.
(2) It must be performance-based. Priority should be given to guaranteed or shared savings contracts. However, other innovative alternatives may also be acceptable.
(3) It must be innovative, by implementing either: (1) an existing service in a new sector, (e.g. in the sector of SME's or multifamily buildings), (2) an innovative service in a sector where usual performance-based projects are already realized or (3) a combination of both.

EPC+ services target an uncovered niche at the market. Still, there are various competing offers on the market, that have to be taken into account in promoting the EPC+ service by communicating it's differences and advantages towards those competing offers.

Broadly speaking, the competitor's range starts at pure installation of equipment without performance measurement and ends with standard EPC. In between, there is a lack of available services that reduce the performance risk of the potential customers with affordable transaction costs.

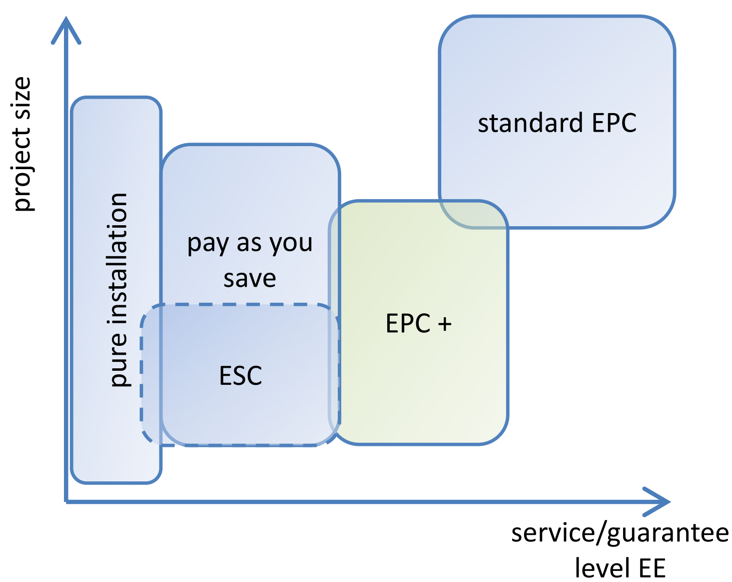

Figure 5 – Positioning of EPC+ services in the energy efficiency market [15]

5. Establishment of SME Partnerships for Innovative Energy Services (SPINs)

Within the frame of the EPC+ project the cooperation of SMEs with the aim to offer joint innovate energy services to the market is described as a SME Partnerships for Innovative Energy Services (SPIN). These SPINs are organized clusters of independent companies that jointly supply novel energy efficiency services to existing or new customers. The partnership sets commonly agreed objectives, valid for a structured and long-term cooperation.

Through the cooperation of independent companies, complementary and innovative energy services can be offered. Cooperation enables SMEs to offer novel and high quality energy services which they could not provide as stand-alone companies. Their common range of services provided can be seen as flexible and highly adaptive ESCOs. Such services are serious alternatives to standard energy efficiency services provided by large ESCOs.

The aim of the project was to establish a minimum of 12 SPINs within the project duration of the project, with at least one SPIN per partner country. Each SPIN should comprise of at least 3 members. The establishment process is considered finished with the signing of a SPIN partnership contract. These organizational SPIN-model partnership contracts were specifically developed by the EPC+ team and are available on the EPC+ webpage. Two types of framework agreements are at hand. One consists of a partnership model contract for a Simple SPIN (see figure 7 for an illustration of a Simple SPIN) and the other consists of a partnership model contract for a Complicated Spin (see figure 8 for an illustration of a Complicated SPIN).

The first round of workshops with potential SPIN members were carried out in all partner countries in 2015 and the second wave of workshops followed in January and February 2016.

As of March 2016, the following number and type (see chapter 5.5) of SPINs have been established. The majority of its members are engineering and energy consultants, energy service providers as well as works contractors and technology suppliers and manufacturers.

Country	Type of SPIN	Number of established SPINs
Austria	Simple	2
Belgium	Simple	1
	Complicated	2
Bulgaria	Simple	1
	Complicated	1
Czech Republic	Simple	1
Germany	Complex	1
Greece	Simple	1
Ireland	Complex	1
Italy	Simple	1
Portugal	Complex	1
Spain	Complicated	2
Slovenia	Simple	2
TOTAL		**17**

Table 1 – Number and type of established SPINs, March 2016 – [12]

5.1 Types of SPINs

The concept of SPINs is an innovative idea but not yet developed in most European countries. As such there is little distributed knowledge about how to initiate, set-up and manage these clusters successfully. An important insight is that SPINs can have different structures and different strengths of interrelations between the parties. This insight is based on the Cynefin framework developed by Cynthia Kurtz and David Snowden [6]. A SPIN could be managed by one partner with a number of subcontractors without interactions between the subcontractors, it could be a dynamic interactive network without much control by one actor or it could be a collaborative network of SMEs with strong connections between all partners. The most appropriate SPIN type in terms of interrelations and connection strengths depends on market circumstances, preferences and characteristics of the partners. As market circumstances change, as well as other factors, it is obvious that the most appropriate organisational structure can also change in the course of time.

To explain the insights more in detail, three SPIN types are described.

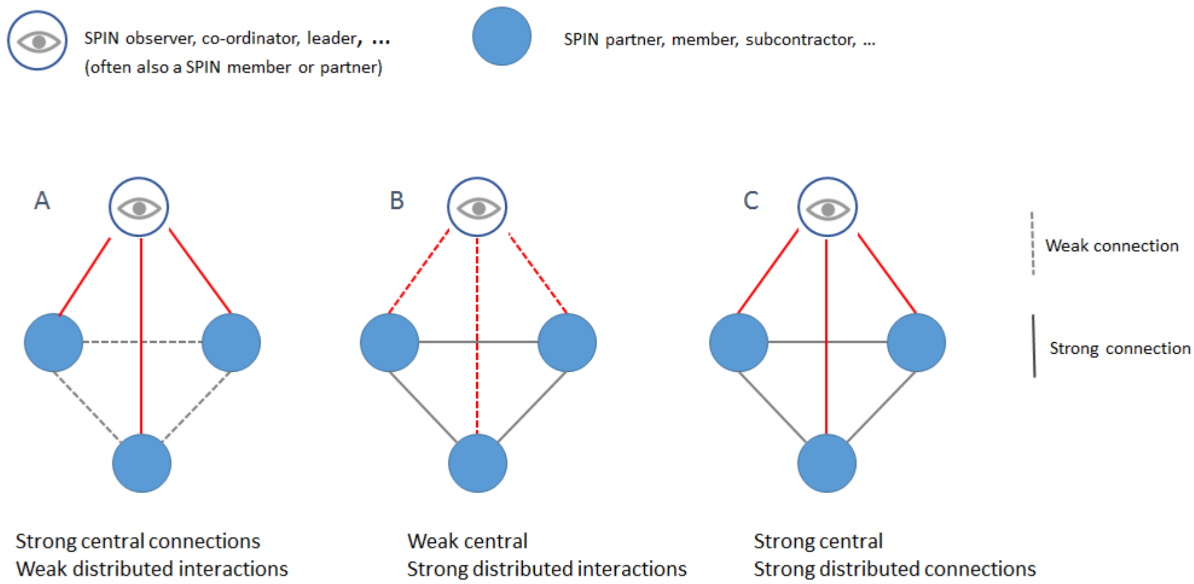

Figure 6 - Different SPIN types in terms of connection strengths [7]

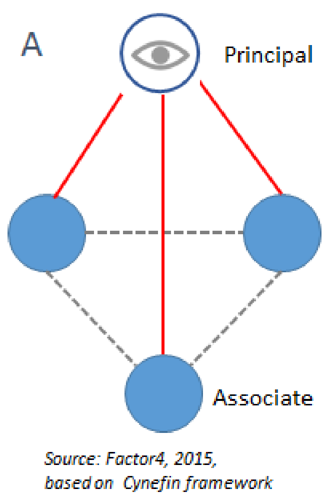

Figure 7 - SIMPLE SPIN [7]

A type 'A' or Simple SPIN is a formal organisation with one leading partner, referred to as the "principal" and partners, referred to as the "associates", but without (much) interactions between these associates. An example is an ESCO working with, often smaller, subcontractors. The number of associates depends on the expertise or domains covered by the SPIN and the total amount of work. Marketing and sales as well as project management are executed by the principal, while associates are experts in different technical fields (e.g. heating, lighting, etc) performing specific contractual agreed tasks on behalf of the leading ESCO. Transactions between the principal and the associates are based on known and widely accepted procedures. The principal is leading and can choose the associates it prefers to work with. The contractual relationship is to a large degree determined by the principal.

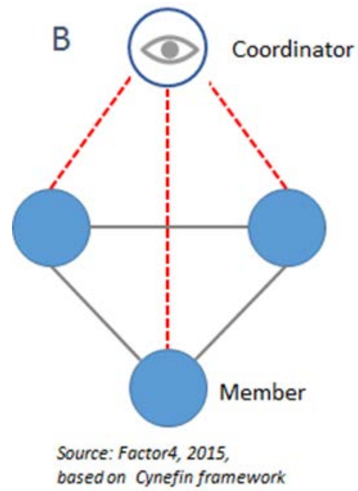

Figure 8 - Complex SPIN [7]

A type 'B' or Complex SPIN is a more informal, self-organising, network of several SMEs, referred to as the "members". One actor, referred to as the "coordinator" in the SPIN takes the initiative to facilitate and strengthen interactions in the network. This kind of organisation is a complex adaptive structure. The coordinator could be an energy service provider and one of the members of the SPIN but also an organisation that only takes the role of coordinator and facilitator. (e.g. a public authority or research institute that support SMEs in the set-up of Simple or Complicated SPINs without being part of these SPINs). Outcomes are the result of dynamic emergent patterns of interaction between all partners willing to exchange knowledge and share (future) business opportunities but the exact outcomes of the interactions are not known beforehand. The contractual relationship is often limited and could be a commonly agreed network contract between the coordinator and the members.

When a market starts to take-up EPC services a Complex SPIN could become one or generate one or more Complicated SPINs or/and Simple SPINsThis could be the outcome of a managed process but also of a more disordered process. The transition phase is a moment that could be used by early adopters to move faster than others. It could be used by participating SMEs to create new partnerships to strengthen their competitive advantage versus other service suppliers (e.g. large ESCOs) or versus previous members in the Complex SPIN.

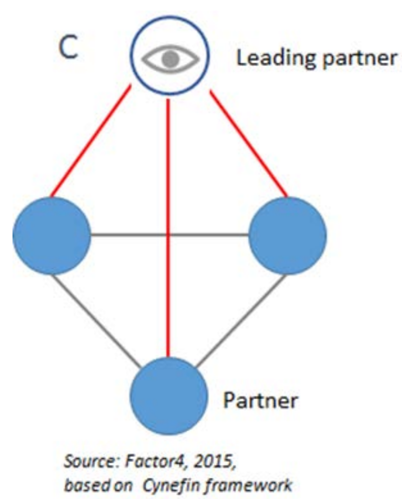

Figure 9 - Complicated SPIN [7]

A type 'C' or Complicated SPIN is a formal collaborative network of SMEs with strong connection strengths between all parties, referred to as "partners", and a collective central control. Responsibilities and tasks are split and allocated to the different partners in the SPIN. A more leading role could be assigned to one partner, referred to as “leading partner”. The decision-making process and how transactions are executed have to be defined before the creation of the SPIN. Complicated SPINs are difficult to create because of the large number of aspects to agree on between all partners. Collaboration can be based on a contract between all partners or integrated in a new legal entity (e.g. a joint venture). Simple SPINs, represented by their principals, can be partners in a Complicated SPIN.

5.2 Choosing the right type of SPIN

Choosing the right type of SPIN will largely define its success. An important factor in the choice of type of SPIN is the level of uptake of EPC in the market on the one hand and the competitive situation of SMEs providing EPC services on the other hand [7].

Simple SPIN

A Simple SPIN organisation is appropriate under the following circumstances:

- A market for EPC services or a market uptake of the EPC concept expected in the short term (6 months to one year).
- The principal (with its associates) should already have a market share or be able to acquire a market in the short term.
- The associates should accept the central role of the principal.
- The associates should not have the ambition and capabilities to become competitors of the principal.

The reason for the appropriateness of a Simple SPIN in a mature market situation is that without business (in the short term) it is obvious that associates will not be interested to join a Simple SPIN or that they will lose their interest after some time.

Complex SPIN

A Complex SPIN organisation is appropriate under the following circumstances:

- Pre-market situation where the EPC concept is not well known or used.
- An expectation that the EPC-concept will be taken up by the market in the medium term (2 to 3 years).
- The expectation that the Complex SPIN can have an impact on the market growth (via lobbying and/or marketing) and/or on the future competitive position of the SPIN partners in this market.

The reason for the appropriateness of a Complex SPIN in a pre-market situation is that members in a Complex SPIN are willing to participate and experiment such a partnership with the ultimate objective of becoming a principal or associate in a Simple SPIN or a leading partner in a Complicated SPIN once the market matures enough.

Complicated SPIN

A Complicated SPIN organisation is appropriate under the following circumstances:

- A market for EPC services or uptake of the EPC concept expected in the short term (6 months to one year).
- Competitors (other SME ESCOs and/or large ESCOs) are present in the market.
- Partners in the Complicated SPIN see a need to strengthen their competitive position by working together.
- Partners are complementary in terms of knowledge, resources or/and market focus.
- Partners in the Complicated SPIN are willing to share costs, risks and benefits.

The reason for the appropriateness of a Complicated SPIN in a market situation where other SME ESCOs and/or large ESCOs are present is mainly due to the strengthening of the competitive position of the SPIN members through their partnership.

5.3 SWOT Analysis

A SWOT analysis was carried out by the project partners based on their personal experience and knowledge, but also on their conversations and dialogue with the SPIN members during the SPIN workshops. From the SWOT analysis, various preconditions for a well-functioning SPIN were derived. On the one hand they are related to the market presence and strategic orientation of the SPIN and on the other hand they refer to the SPIN's internal organization and management.

Market approach and strategy

From the point of view of market approach and strategic answers to market demand, a successful SPIN has to cope with the following challenges:

a. **Joint commitment to strategic alignment of the SPIN**: The SPIN needs to develop a clear strategy, which is shared by all members of the SPIN. This means, that it is not enough to have a good strategy taking into account a specific demand of the market, but it is even more important that all SPIN members are committed to the strategic alignment and move in the same direction.
b. **Selection of suitable customer segments**: Costumer segments where SPIN partners are already represented are predestined for the provision of SPIN services. This means that SPIN partners mutually support the access to customer segments and thus support "cross-selling" of services. Furthermore the customer segments to be addressed need to open to SMEs and innovative forms of collaboration of SMEs.
c. **Common process of strategic product development**: Of course, the service product provided to the market needs to be convincing and beneficial to the customer segments addressed. According to the Change Best Project Guideline [13] on strategic product development of energy efficiency services, the following issues need to be addressed and elaborated:
    - Putting together the elements of the energy efficiency service to be provided to the market (position at the value chain, market segments and customers, technologies and processes);
    - Assessment of needs of the (potential) customers;
    - Definition and strengthening of competitive advantage;
    - Making use of links to other business fields;
    - Comprehensive assessment of economic viability of the EES solution;
    - Financing;
    - Risk Management;
    - Specific marketing and sales for energy efficiency services;
    - Putting together a business case including multi-level calculation of contribution margin.
d. **Longer-term perspective of SPIN collaboration**: The necessity of developing and sharing a joint strategic alignment including the development of joint products underlines the fact that SPIN members need to be willing to resume tasks and duties on a long-term basis. Otherwise ad-hoc collaboration on a case-by-case basis would be easier and more useful.

Internal organization and management

Whereas the necessity of strategic alignment is the same for SPINs as for stand-alone companies there are some significant differences:

a) **Definition of the roles (responsibilities and duties) of each partner in the SPIN:** The definition of roles creates safety among the SPIN members. Roles need to be defined for the tasks related to the provision of EES products as well as to "overhead" functions.

b) **Solid protection of the know-how shared by the SPIN-partners:** Otherwise the motivation to share know-how and experience will be limited, because partners that do not obey the rules might give way to the temptation to make egocentric use of the know-how of others without giving access to own knowledge. Solid protection of the shared know-how is a way to overcome the prisoner's dilemma that is inherent to all kinds of professional partnership.
c) **SPIN management:** The assignment of a SPIN-coordinator or manager that is finally responsible for the well-functioning of the SPIN will be necessary in most cases – mainly for larger SPINs. For smaller SPINs of 3-5 members it seems feasible, to divide up management tasks between partners.
d) **Incentive system stimulating the partners bringing in sales opportunities:** It is important that SPIN partners are motivated to introduce project opportunities into the SPIN instead of trying to implement a smaller project as an independent company. One possibility is to remunerate successful sales by means of commissioning fees for the partner that has initiated the project.
e) **Stimulation of networking and continuous exchange of (informal) information:** Inside companies information can flow more easily. SPINs have to find ways to compensate this disadvantage be using instruments that ensure networking and exchange of informal information across company boundaries. Just to give a few examples: Regular workshops on upcoming tasks; fixed dates for web-based communication etc.
f) **Fair distribution of overhead cost among partners:** Management, marketing, acquisition as well as general administration represent overhead costs which have to be carried by the SPIN partners. The SPIN can only work successfully if these overhead costs are distributed to the SPIN partners in a fair way. In this context, fairness in distribution of cost is closely connected to fairness in distribution of benefits that arise from the SPIN for the participating partners.
g) **Clear and transparent partnership contract:** All relevant rules – most of which refer to the issues mentioned above – need to be summarized in a SPIN framework (contract) which has to be signed by all SPIN partners.

6. EPC+ Platform

The international EPC+ platform is an international 'market place', where - according to commonly agreed rules – its members can safely exchange valuable know-how and develop EPC-models and SPIN-concepts. It can be seen as a conglomeration of the different types of SPINs.

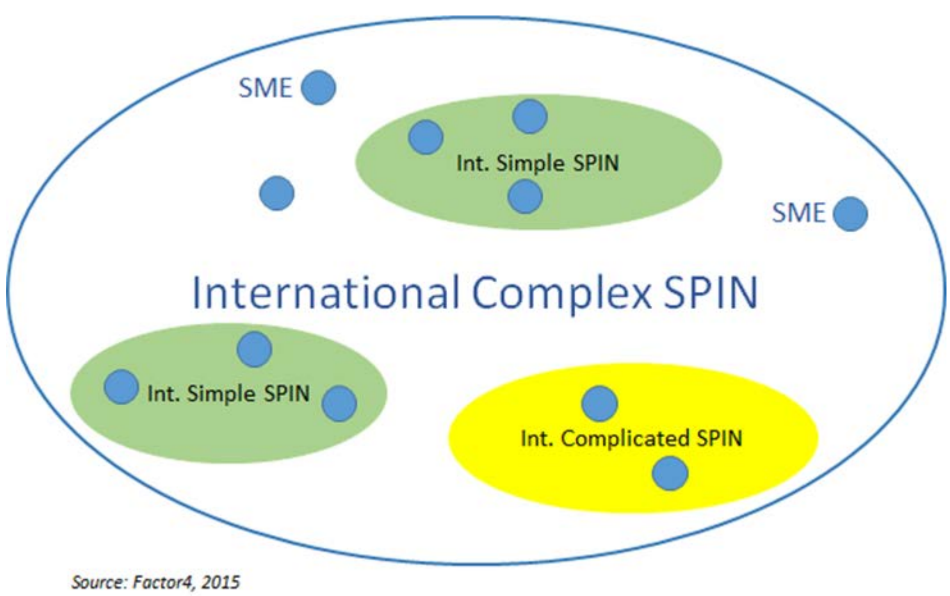

Figure 10 - An International Complex SPIN to generate simple and/or complicated SPINs [7]

A key success factor of the international EPC+ platform is the willingness of companies to join the platform as a member and to participate in interactions and potential business transaction. This willingness depends on the (initially perceived) added value of the platform for members and on the other hand the effort that member will have to spend to participate in the network.

Value for members could come from the other members and from the EPC+ platform itself. The value from other members would strongly increase when each partner would be able to create value for as many as other partners. This value could be generated in following fields:

- Members looking for associates (Simple SPIN) or partners (Complicated SPINs);
- Innovation related to EPC concepts and services;
- Knowledge and expertise in specific fields;
- Management supporting tools;
- Access to financial sources; and
- Access to other networks.

The value from the EPC+ platform itself would come from its ability:

- To unite a number of members creating value to each other;
- To facilitate interactions between members to realise short and medium term business opportunities and innovation;
- To support transactions between members (e.g. standardised transaction rules, contracts); and
- To generate publicity for EPC services and for each member.

'Quick wins' in the form of concrete business opportunities in the short term would strongly increase the added value of the platform and be a good basis to increase the willingness of partners to actively participate in common actions with potential benefits in the medium or long term.

As quick wins related to innovative services such as Energy Performance Contracting (EPC) are less feasible, other concrete business opportunities should be identified and used to generate a willingness of partners to invest in longer term objectives such as EPC.

To create these quick wins it was decided to make use of the mandatory energy audits for large enterprises (Art. 8 of the Energy Efficiency Directive) [8]. Many large enterprises that have to conduct mandatory energy audits are present in several member states while external energy efficiency auditors and SME energy efficiency audit firms, including several EPC+ partners, are mostly only active in one European member state. Several partners in the EPC+ consortium and many energy services providers outside the EPC+ consortium have been supporting public authorities and/or private companies to develop and conduct voluntary energy audits and to support clients with the development of energy action plans and energy management systems (e.g. ISO 50001). Most of these Energy Services Providers started to provide audit services in 2015 in the framework of the mandatory energy audit for large enterprises.

To attract Energy Services Providers to join the international EPC+ platform, the focus of the network in 2015 was on the development of a shared capacity to serve international clients with mandatory energy audits in a large number of EU members' states. As several EU member states have not transposed Art. 8 of the EED or were very late with the practical implementation, many large enterprises still have to comply. This means that the attention of the EPC+ platform for mandatary energy audits in some countries will continue in 2016.

Energy Performance Contracting and related services were added as from the beginning of 2016 and these topics will become the main focus of the EPC+ platform in 2016.

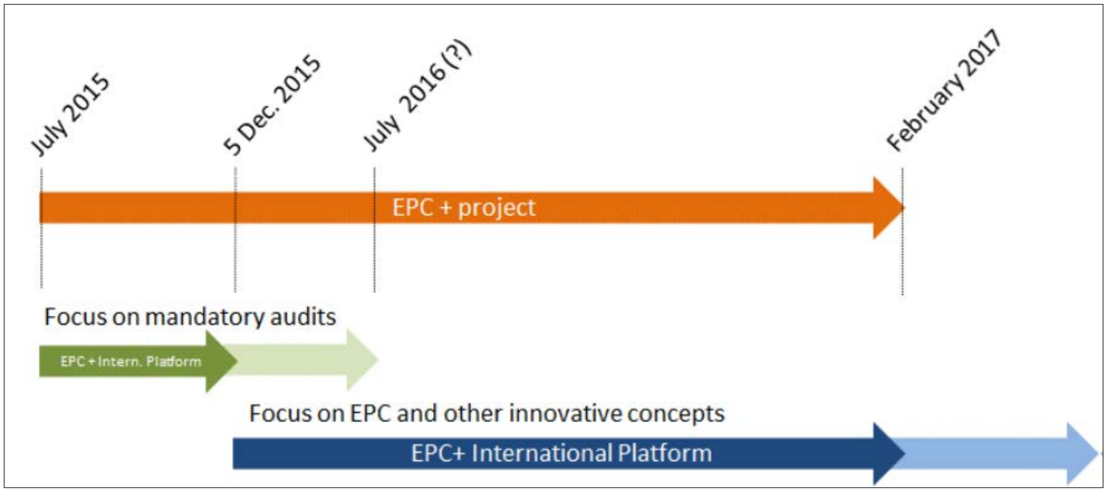

Figure 11 – Development of an EPC+ platform [11]

As depicted in Figure 10, the international EPC+ platform can be seen as an international Complex SPIN to support the development of international Simple SPINs and/or Complicated SPINs. A Complex SPIN is the best type to generate interactions that could lead to innovation and to facilitate the collaboration between Energy Services Providers. Simple and Complicated SPINs are the best types for actors to join forces with the objective to transform new ideas (e.g. generated in the Complex Spin) into business opportunities and to generate revenues by the collaboration of actors in SPINs.

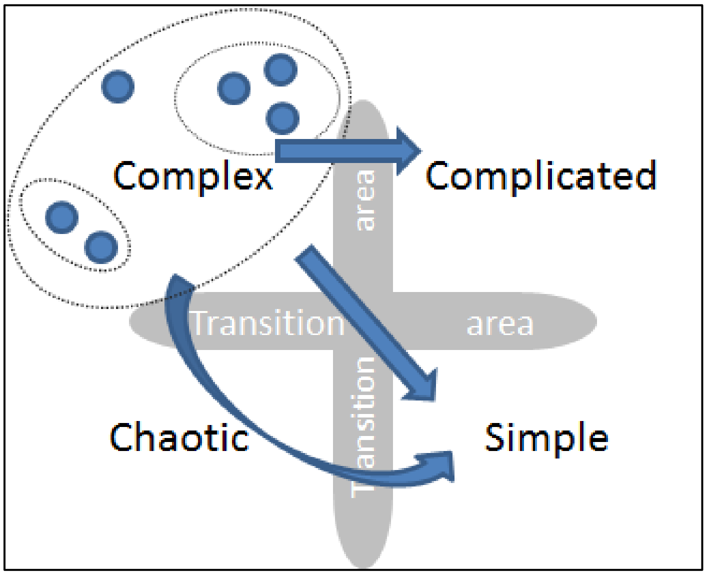

Figure 12 – Moving from a complex SPIN to Simple or Complicated Spins [14]

An initial website www.energyefficiencynetwork.eu with information on the network, its members and the EPC+ project has been developed. Members can refer to this website in their communication to their clients. The website is also used in contacts with potential members. The design of the Website is mobile device friendly. The website will become a multi-lingual website in the first part of 2016 with more specific information per member and per service offered. It will also include additional information on Energy Performance Contracting and related topics.

Potential members are selected based on their ability to act as a partner or principal (generation of income for other partners acting as associates), their ability to act as an associate (e.g. certified energy efficiency auditor) and their expertise and services related to Energy Performance Contracting or/and other more innovative services. Another criterion is the limited geographic presence of the potential member (members should be present in a maximum of two member states, but not in two large member states). This limited geographic presence is important to avoid that a member becomes too dominant or/and would become a competitor of one or more other members.

The initial contact is made by sending an email to potential members with information about the network and an invitation for a web meeting. When a prospect shows an interest a webmeeting is organised to exchange information about the network and about the potential member. The webmeeting is followed by a short period to evaluate whether the prospect fulfils the requirements and for the potential member to confirm its interests.

7. Standardisation of energy services

The overall goal is to develop highly simplified and standardized energy service packages which can be easily implemented by SPINs. These will be based on the existing energy performance contracting models and other energy services oriented models (e.g. RE-CO – re-commissioning models, IEC - integrated energy contracting model), so far tailored for bigger ESCOs and projects. The approach for simple, highly multipliable projects is on the one hand smart energy efficient *technical solutions and on the other hand service-oriented packages with low- or no-cost measures with* simplified measurement and verification procedures. For the identified standardized technical and service-oriented solutions, a technical and financial toolbox will be developed as well as a simple model contract. The high standardization opens the basis for new and broader fields of EPC-projects (multiplying standardized EPC+ solutions in specific market sectors instead of a few big standard EPC-projects).

7.1 Technical toolbox

A technical toolbox will be created and compiled for a specific number of measures with the following content:

1. Technical description of the energy efficiency measure (design parameters and calculation methods)
2. A process flow for the implementation of the measure
3. The measurement & verification options.

This technical “toolbox” is a technical aid for the SPINs. It consists of a holistic, simplified and standardized approach for the design, implementation and monitoring and verification steps of the EPC+ services. Where available, the toolbox will make reference to tools (both technical and financial) that are available on the internet free of charge (i.e. from technology suppliers, national, EU and/or international projects). Some tools will also be developed by the project partners.

Where possible the steps will be concerted in order to achieve the same level of standardization. Above all, a matrix of potential interactions/interferences between the several measures will be developed in order to avoid double-counting effects, technical back coupling or else.

The choice of technical measures is crucial for the whole value proposition, as it has to be customized to the specific needs of the target group(s) of the SPIN. Moreover, to fit into the EPC+ service scheme the measures have to be

- Standardisable, to minimize transaction costs of design, preparation and supervision
- Approvable, to measure the performance with an acceptable effort
- Suitable for the increase of demand side energy efficiency in a facility

The measures in the toolbox include:

<u>Energy efficiency measures</u>

1. Indoor lights: LED lights + control system
2. Hydraulic adjustment of heating system
3. Modernization of pumps

4. Modernization of electrical motors
5. Energy efficient ventilation and/or cooling
6. HVAC control systems
7. Programmers of BMS-systems of different suppliers
8. Renovation/replacement of heating boilers
9. Energy-efficient windows
10. Industrial boiler blow-down heat recovery

Renewable energies (in conjunction with an energy efficiency measure)

1. Solar water heaters
2. Biomass heating systems
3. Micro CHP
4. PV-panels
5. Wind-power
6. Heat pumps

The implementation of the measures always follows a dedicated standardised process, which should be followed to reach the following impacts:

- optimization of effort: for acquisition, communication with the client, administration
- transparency towards the client: at certain milestones the client receives further information about the status of the project and the measures
- one-face-to-the-customer: following this process eases the project-management for the client and thereby reduces his effort

7.2 Modular model contracts

The model contract will be constructed in a modular way, in order to achieve a standardized procedure in the stipulation of the contract between the client and the SPIN. This standardized, modular contract may then be adapted and modified quite easily, depending on the case-specific requirements of the clients. In the contract, the responsibilities and duties in the several phases will be described as well as the regulations for pricing, indexing, causalities, etc.

The modules of this contract will be:

- Implementation phase
- Measurement and verification: responsibilities of the signatories
- Pricing + performance-oriented remuneration
- General terms and conditions

8. First conclusions and outlook

8.1 First conclusions

It can be summarised that the launch of national SPIN development processes led to internal strategic developments in most of the EPC+ partner institutions and also for the potential SPIN members. It can be derived that the existence of long-term objectives and target-setting of a company are prerequisites to start such a SPIN development process, depending on the role of the member in each SPIN. If a member is only interested in facilitating such SPIN development processes only (e.g. this would apply to national energy agencies), no (or to a very little extent) internal strategic process need to be started. But, if member wants to have a leading and/or active role as an innovative energy service supplier, their objectives and targets need be clearly defined and set [9].

The categorisation of SPINs using the CYNEFIN framework helped to understand and to communicate about the different type of relationships between actors in a SPIN and to support the process to the creation of a SPIN. An additional insight is that when a SPIN has characteristics of two or more types it will be more difficult for the actors to understand and agree on their exact relationship.

8.2 Upcoming tasks

The EPC+ project commenced in March 2015 and is due to end in February 2018. The most significant upcoming tasks of the project are the following:

- March – July 2016: Implementation of training courses for SPIN members and other interested companies (1 in each participant country).
- May 2016: Technical toolboxes finalized in each of the participant countries' languages.
- August 2016: Model contracts available to SPINs.
- September 2017: Model contracts available to the wider public.
- September 2016 – February 2018: Implementation of a total of, at least, 33 pilot projects in the participant countries.

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Business and Technical Models for Deep Energy Retrofit - Findings from IEA Annex 61

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Outline:

Recent research works on IEA level show that EU targets for the building stock until 2050 will not be achievable without emphasizing a deep energy retrofit strategy which targets at least 50 up to 80% of energy demand reduction. One of the major hurdles for the implementation of a DER strategy is scarcity of money available for such kind of projects. As the investments in renewable energies in some European countries show, private money is available if framework conditions are transparent and risks seem to be assessable and calculable. Annex 61, conducted under active participation of researchers from BE, DK, DE, EE, IRL, SE, USA is designing technical and business models which allow for the facilitation of DER projects and for the access of private sector money. Meanwhile the first pilot case studies are in the implementation phase. The paper gives a resume of the staged process and describes some of the technical and business models which have been developed and are now in the implementation. The 26 case studies form an interesting collection of Deep Energy Retrofit building projects from around the world. The interested reader will find valuable information about the actually implemented energy renovation technologies – often in terms of both technical parameters and costs.

It may be self-evident, but is nonetheless worth stating, that the overview of technologies that have been implemented clearly shows that, to reach DER, it is necessary to retrofit mechanical systems by implementing technology bundles in concert with a well-planned building envelope renovation. Implementation of extra insulation of the building façade significantly reduced heating energy consumption. The incorporation of a heat recovery ventilation system both reduces the energy consumption and enhances the indoor air quality, resulting in a positive occupant reaction. Moreover, the replacement of artificial lighting with low-energy lighting is often the easiest and most economic retrofit technology.

The investigation of the achieved energy savings shows that Deep energy renovation is quite possible. On average, these 26 case studies achieved 66.4% energy savings.

The analysis of reasons for renovation shows that the non-energy related reasons dominate. Buildings are renovated mainly to meet a need for maintenance. These reasons are often referred to as “anyway renovation.” Anyway renovation is a term characterizing the renovation needed to maintain the building in good condition. It might also come from the fact that use of the building is to change, so the building will have to be renovated/refurbished to some degree to accommodate the changes in use. These anyway measures may very well be the main reason for initiating the renovation process.

The building owners should be aware that costs of the “anyway” renovation must be established and documented to make sure that the energy part of the renovation is not required to “pay back” these elements of the renovation investment costs. The brief cost efficiency analysis carried out show a large variation in achieved NPV of the 12 case studies that could be further analyzed. Four of these have a relatively high NPV and it is assumed that the reason behind is that the energy related costs presented in these case studies are really the net energy related investment costs, when the cost for the anyway renovation has been subtracted.

In this context, it is also worth noting that optimization is not always a straightforward financial optimization of the NPV of the energy saving measures. The optimization calculation depends on the situation of where and when it is carried out. It depends heavily on the parameters/assumptions used — energy prices, interest rates, etc. and might quickly change. Therefore, it is advisable to look also at what is cost-efficient and what uncertainty interval should be considered. The cost-efficient energy renovation may have a less advantageous NPV than the optimized renovation, but as long as the NPV is positive, the financial result will be is better or equal to the outset situation and will result in higher energy savings than the optimized renovation.

Following this line of argument, when identifying the possible energy renovation measures, it is useful to consider the following:

1. In the long run, it may be advantageous to carry out the energy renovation to the fullest possible extent (a deep energy renovation), as each subsequent step will almost always be more costly.
2. The savings resulting from selecting the bundle of energy saving technologies should be calculated in energy and financial terms. As the individual measures influence each other, a separate calculation must be performed for each individual bundle investigated.
3. Co-benefits stemming from each energy saving measure should be noted and to the degree possible given an economical value. For example, improved comfort and indoor air quality have been shown to increase working efficiency and learning performance. Again, for each bundle investigated, the related co-benefits must be documented with the results of the financial analysis for each bundle.

The collection and analysis of the 26 case studies has proven a valuable activity to improve the understanding of the mechanisms behind deep energy renovation building projects and of how to advance the implementation of such projects. This knowledge is now being used to promulgate guidelines under development of the IEA EBC Annex 61 project.

To increase the number and pace of deep energy retrofits the business model also needs to be considered carefully. The assessment of the owner- directed business model, which is mainly in use for the implementation of DER shows significant defaults which make it unlikely that the targets of the EPBD in EU will actually be achieved: the investment cost optimization and the energy and cost reduction are not a major topic in current legal framework for planners and architects. In comparison to that, energy performance contracting EPC offers a remuneration which is related to the life cycle cost performance. EPC has been a proven tool for HVAC measures. Current research projects have initiated research to advance DER EPC business models; here the remuneration is also related to the LCC performance. To mitigate risks resulting from long pay back and contract periods DER EPC has to consider further cost optimization by:

- Least life cycle cost planning to achieve a cost optimized investment/performance ratio

- Involving additional monetized and bankable LCC which have not been considered in DER projects before such as avoided maintenance costs for replaced installations, reduced operational costs, increased savings from better usage of existing floor space etc.

Currently these advanced DER EPC business models are implemented in Belgium, Germany and the USA. First results from Belgium are encouraging as it is likely to increase the savings by considering the thermal building comfort; a first evaluation will be considered by the end of 2016.

1.1 Introduction: Barriers and Solutions for DER strategies

Many governments worldwide are setting more stringent targets for reduction of energy use in government/public buildings, to take the lead and show the right direction for a sustainable future. However, the funding and “know-how” (applied knowledge/experience) available for owner-directed energy retrofit projects have not kept pace with the new requirements. This is clearly shown by the fact that the reduction of energy use in typical retrofit projects varies between 10 and 20%, while experiences from executed projects around the globe show that reductions can exceed 50%[1] of the energy baseline[2] and that renovated buildings can cost-effectively achieve the Passive House standard or even approach net zero energy status; however not many projects have been evaluated

[1] IEA Annex 61 has defined the minimum requirements for DER to save at least 50% of the energy consumption baseline including electricity with plug- loads and heating

[2] Energy baseline includes climate and usage adjustments according to German industry standard VDI 3807, ASHRAE Work Statement 1561-WS

so far. With regard to scarcity of public funding private sector money will have to be integrated; the EEFIG[3] working group however has identified lack of evaluated data which would allow private capital to assess the risks and opportunities of their engagement.

The major barriers to scaling up EE projects in buildings **Error! Reference source not found.** include barriers on the market level that are mainly related to the market structure. One major barrier that prevents the allocation of funds to EE projects is the lack of information about the performance of energy efficiency measures and projects. Wind energy and PV which have been a success story in many EU countries and the US have been in a comparable situation 10- 15 years ago: no performance and durability data, no experience record for different technologies created major barriers to the implementation of a renewable energy policy and to the financing of projects. This changed as soon as framework conditions have been developed more comfortably for investors: information on the performance, reliability secured the return of investment from the technological part; correctives in pricing provided the same effect from the perspective of business.

Now these lessons learnt from renewables need to be transformed to the energy efficiency and DER market. From the technical point of view the technical part is covered by the experience record of accomplished DER projects, also results of modelling of cost effective DER measure bundles have to be taken into account. Towards business and technology the process of calculation, planning, construction, quality assurance, operation, maintenance, monitoring and verification have to be taken into account. Currently such a process related tool based on protocols to steer the major efforts in each stage of a DER/EE project is transferred from the US to EU[4].

In the changed and lack of information creates uncertainty, undermines confidence, and ultimately drives decision makers to hesitate to invest private or public funds in DER projects. As yet, there is little valuable information on DER projects; in recent research projects carried out in IEA EBC Annex 61 [5] six participating countries in EU, Canada and the USA were only able to collect less than 30 evaluated DER projects in the non- residential building sector. After years of publicly funded energy retrofit projects, the amount of evaluated data on the effectiveness of retrofits is still insufficiently small. There is a need for more and better information to effectively assess and communicate the multiple benefits of DER in the building sector, essentially to build the investor's confidence required to channel finances into DER projects.

This paper reflects two activities of IEA Annex 61 which were the assessment of accomplished DER projects and the assessment of business and financial models for DER project. The results of cost optimized DER measure bundles will also been summarized in a separate paper.

Table 1: Major Barriers to DER in building (IEA 2010, KEA 2014)

[3] https://ec.europa.eu/energy/en/news/new-report-boosting-finance-energy-efficiency-investments-buildings-industry-and-smes

[4] ICP EUROPE www.eeperformance.org

[5] www.iea-annex61.org

Level	Barriers to EE
Market	▪ **Market organization-price distortions** prevent building owners from **appraising value of EE measures** ▪ Split incentives: investors cannot capture the benefits of EE investments ▪ Labile framework conditions do not allow for long term investment decisions
Financing	▪ **Upfront costs** and **dispersed benefits** ▪ EE = shelf warmer: **complicated** and **risky** with **high transaction** costs ▪ Lack of **awareness** of potential financing entities
Information	▪ Lack of **sufficient information** to prepare rational investment decisions
Regulatory/ institutional	▪ **Discouraging energy prizes** (declining block prices) ▪ **Institutional bias towards supply-side** instead demand-side investments ▪ **Lack of sufficient business models** with incentives for EE and life-cycle costs ▪ Lack of **sufficient long term strategies** to deploy EE in building stock ▪ EE investment programs are mainly **perceived to be risky due to the uncertainty of predicted energy cost savings**: lack of evaluated projects and default analysis ▪ **Standardized protocols for de-risking** is not much in practice in the EU ▪ **Standardized evaluation methods for measuring and verification** is still lacking
Technical	▪ Insufficient capacity to develop, implement, maintain high efficient ECM bundles

Under the umbrella of the International Energy Agency, IEA ECB Annex 61[6] conducts research on technical and business models for DER in public buildings. In consecutive subtasks DER includes the collection and analyses of DER case studies, modeling of DER (ST A), the development of business models (ST B) and the implementation in case studies (ST C) and the dissemination of results (ST D). This paper refers to first findings from the analyses of DER case studies and the development of business models.

1. Assessment of accomplished DER case studies

Over the past 2 years, this effort used a standardized template to collect and analyze information on 26 DER case studies from Austria, Denmark, Estonia, Germany, Ireland, Latvia, Montenegro, The Netherlands, the United Kingdom and the United States. After these data were collected, the case studies were analyzed with respect to energy use (before and after renovation), reasons for undertaking the renovation, co-benefits achieved, resulting cost effectiveness, and the business models followed. Finally the lessons learned were compiled and compared. The objectives of this work were:

[6] www.iea-annex61.org

- To show successful renovation projects as inspirations to motivate decision makers and stimulate the market.
- To support decision makers and experts with relevant information to support their future decisions.
- To learn from the experience and to create lessons learned from these early cutting-edge projects.

To achieve these objectives, the case studies were analyzed to and extract all relevant information. The analyses focused on:

- Energy saving strategies
- Energy savings/reduction levels
- Plotted comparison of energy use before and after renovation
- Reasons for renovation
- Co-benefits
- Business models and funding sources
- Cost effectiveness

DER Core Bundle of Technology in accomplished DER projects

The implemented energy saving strategies were grouped into 16 categories Table **2**1 lists the core bundles of technologies used to achieve deep energy retrofit. In Table **2**1, those renovations that apply to more than half of the case studies are outlined as core DER technologies in red.

- Building envelope including measures with roof top, wall insulation and new double or triple glazed windows.
- Lighting systems,
- HVAC, and
- to some extend also the integration of renewable energy systems.

All technologies are available on the market. However the measures did not improve the “plug- loads” and common infrastructure. While in Europe the majority of evaluated buildings in the pre- DER phase have not been equipped with air ventilation systems, and the airtightness has been increased in the DER the majority of buildings is now equipped with ventilation systems with heat recovery.

Most of the buildings were from ASHRAE climate zones 4,5 and 6 and heating consumption is taking a large part of the energy baseline. To achieve DER energy savings of > 50% it is necessary to integrate the thermal envelope; without major measures at the thermal envelope the savings target of 50% can hardly not been achieved in these buildings. Those projects which considered the thermal envelope did obviously implement more measures than required in the national building codes. In 8 projects building owners stated that measures at the thermal envelope of a building would have to be always carried out in the combination of roof, façade and windows to avoid issues with the building physics.

Table 2. Core bundles of technologies implemented in DER [7]

CORE BUNDLES OF TECHNOLOGIES IMPLEMENTED IN DER																
	Building Envelope					Lighting & Electrical systems			HVAC					Renewable energy systems		
Case study	Wall insulation	Roof insulation	Floor insulation	New window/ door	Roof lights	Daylight Strategy/external shading	Efficiency lighting/control	BEMS	MVHR	New ventilation system	New heat–cooling supplier/distribution system	New heat supply: radiators, floor heating	Air source heat pump	Ground coupled heat pump	Solar thermal system	Photovoltaic panels
1. Social house Kapfenberg. AT	√	√	√	√					√		√				√	√
2. School Egedal. DK	√						√	√	√	√	√					√
3. OfficeVester Voldgade. DK	√			√		√	√		√		√			√	√	
4. Kindergarten Valga. EE	√	√	√			√	√		√		√				√	
5. Passivehaus LudMun. GE	√	√	√	√						√		√				√
6. Apartments Nûrnberg. GE	√	√	√	√					√		√				√	
7. Gym Ostildern. GE	√	√		√	√		√		√							
8. School BaWû. GE	√	√		√			√			√	√					√
9. School Osnabrueck. GE	√	√	√	√			√		√	√	√			√		
10. School Olbersdorf. GE	√	√	√	√	√	√	√			√				√		
11. Passivehaus Office Darmstadt. GE	√	√	√	√			√		√	√						
12. Town Hall- Baviera. GE	√	√	√	√	√		√		√		√					
13. Passivehaus High school NordWest. GE	√	√	√	√		√	√		√					√		√
14. Social housing Dún Laoghaire. IE	√	√	√	√					√		√					
15. Apartments.Riga. LV	√	√	√	√			√		√		√	√				
16. Primary school Plevlja. MON	√			√			√	√			√					
17. Student Dormitory Kontor. MON	√	√		√			√				√	√			√	
18. Shelter home. Leeuwarden. NL	√	√	√	√		√	√		√	√	√				√	
19. Mildmay Center London. UK		√	√	√		√	√		√	√				√	√	√
20. Federal building Grand Junction. USA	√	√			√		√			√	√	√		√		√
21. Office/Federal building		√		√			√	√	√	√	√	√	√	√	√	√

[7] Source: IEA Annex 61, Preliminary ST A Report, Zhivov, Moerck et al

Maryland. USA																
22. Intelligence Community Maryland. USA	√	√	√	√		√	√		√	√					√	
23. Office.Seattle WA. USA				√		√	√		√				√			√
24. Beardmore Priest River. USA	√	√		√	√		√			√			√			
25. Office/Warehouse Indio. USA	√	√		√	√	√	√		√	√	√		√			√
26. Federal building Denver-Colorado. USA	√	√	√	√			√				√		√		√	

1.1. Accomplished DER projects: Energy demand Before and after

The obtained energy savings were plotted to show the total energy consumption before and after renovation, the solar energy contribution to that energy consumption, and the net energy consumption. In a first assessment two plots were generated, one for public buildings (offices and schools), and another for dwellings or family housing (see Figures 1 and 2). Both plots exhibit the same tendency; generally, the energy efficiency renovation or Rational Use of Energy (RUE) reduces energy consumption considerably. For those of the case studies where a Renewable Energy System (RES) is installed, site energy consumption from grids is further reduced, but not the total energy demand itself. In the working phase of the Annex 61 the definition on savings was intensively discussed. With regard to the business and financing models the total energy demand (net energy consumption in figure 2), including the partition which was provided by renewables and not by the electricity grid was considered in the first place.

The assessment of the DER cases shows the following results:

- The initial pre- DER situation had an energy consumption of in average 238 kWh/m²yr in non-residential and 328 kWh/m²yr in residential buildings.
- All buildings (except two) were able to achieve energy savings of more than 50% related to the energy baseline.
- Energy savings with more than 70% were in most of the cases with the implementation of photovoltaics or other renewable sources. Buildings Nr. 4, 13 and 23 are exemptions, here a passive- house or a close to passive house concept allowed to reduce the energy demand > 70% without renewables.

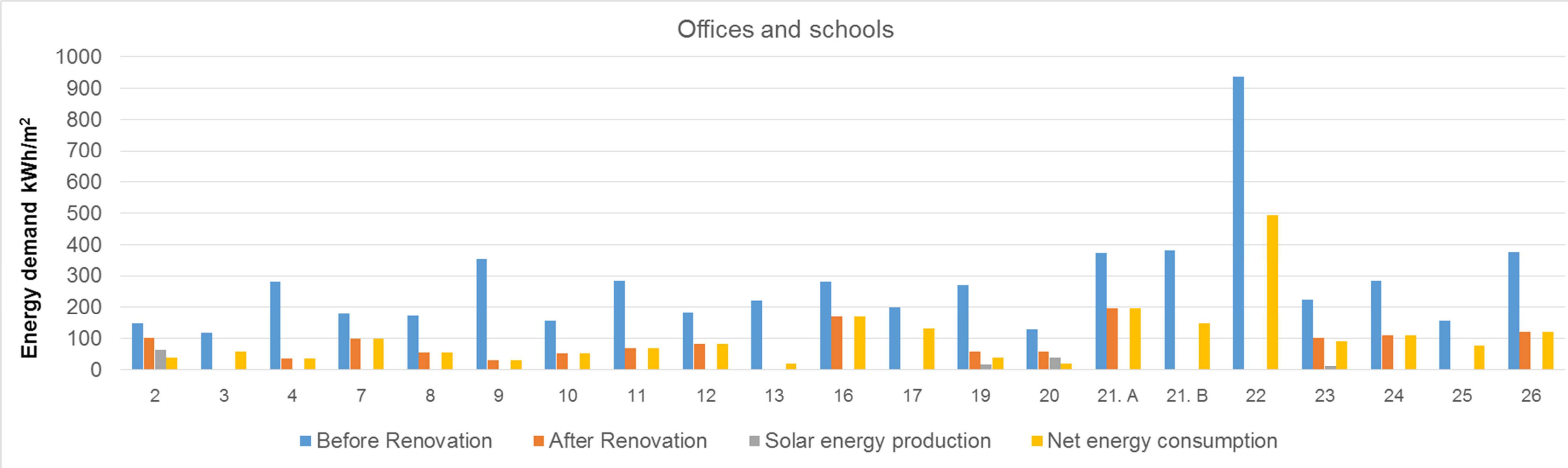

Figure 1. Comparison of energy use before and after retrofit for Public buildings.

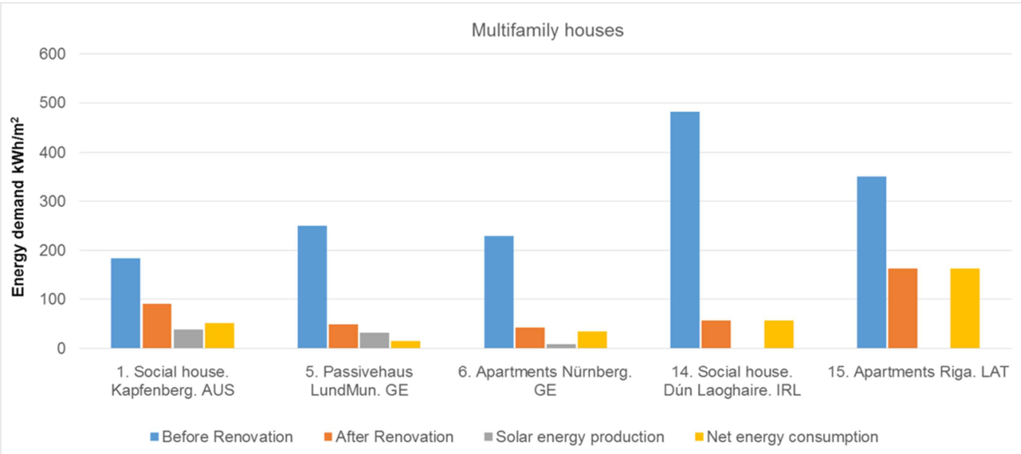

Figure 2. Comparison of energy use before and after retrofit for family housing.[8]

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[8] Source of both figures: IEA Annex 61, Preliminary ST A Report, Zhivov, Moerck et al

1.2. Decision making criteria for DER

The observed reasons for undertaking a renovation were categorized in two main groups: energy related and non-energy related (Figure 3). In Figure 3, the number to the right of each horizontal bar indicates the percentage of the case studies that performed retrofits for the listed reason.

Obviously, general maintenance ranks the highest of the non-energy related reasons for performing retrofits (88%). Most of the case studies were not renovated to save energy; the DER has been a side effect which was carried out in the context of a repurposing project (" general refurbishment" of the buildings. This means that DER has to be considered in the context of the decision making process of a general refurbishment. The main criteria to be considered are:

- The add- on is relatively small in comparison to the costs of a general refurbishment

- The general refurbishment targets many building components anyway such as walls, roofs and windows which are also part of the DER core bundle of technologies

- The general refurbishment offers a once in 20- 40 years- lifetime opportunity

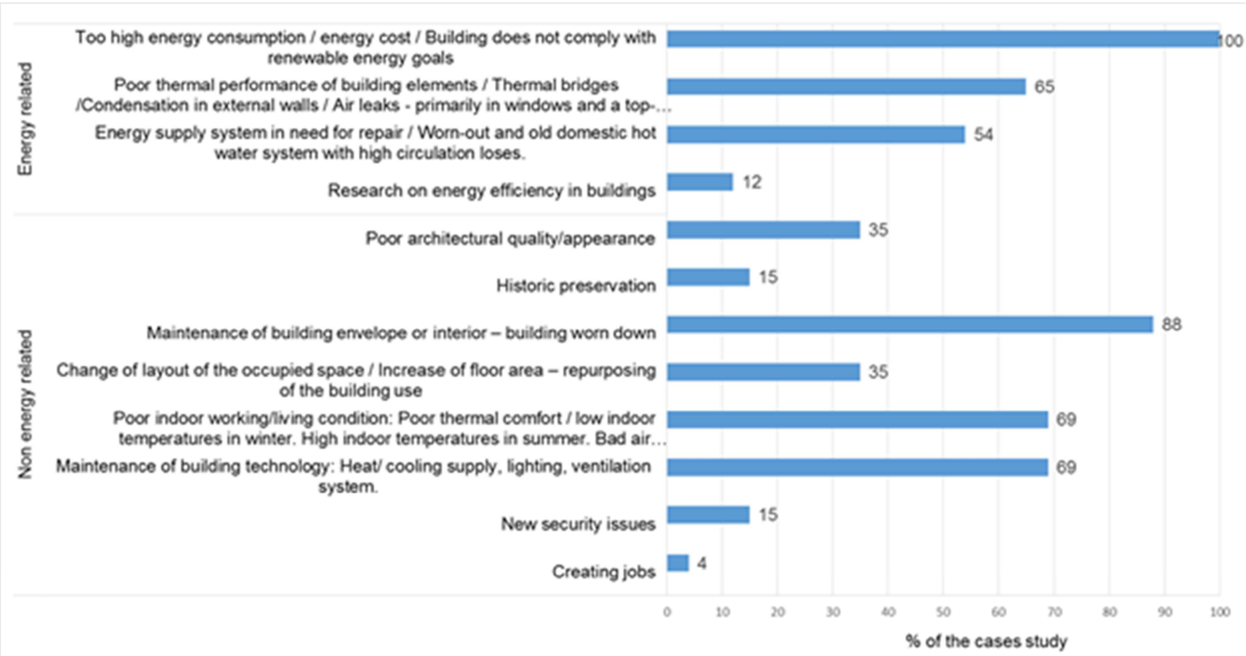

Figure 3. Anyway measure/ reason for renovation. Percentage of the cases studies

1.3.Co-Benefits of accomplished DER projects

The co-benefits can also be categorized into energy and non-energy related groups. The histogram in Figure 4 shows that three of the energy related co-benefits (improvement of thermal comfort, improved green building image, and reduced dependency of fuel price fluctuations) were identified in all case studies. In 85% of the cases, an improved operational comfort was observed, which was in most of the cases related to the refurbishment of the building control systems. Of the non-energy related co-benefits, upgrade of worn out equipment was found in all case studies. This increases the asset value of the building and its installations and also contributes to the reduction of maintenance costs for the worn down installations; however most of the building owners were not able to evaluate the exact increase of the asset value. As in most of the cases public buildings were assessed, it has to be considered that in many European countries the evaluation of asset values of public buildings is not common practice.

Next is the improved air quality due to an improved ventilation system; this however is surprising as most of the buildings had no ventilation systems before DER. More than half of the case studies also cited better weather protection of the building and improved use of space.

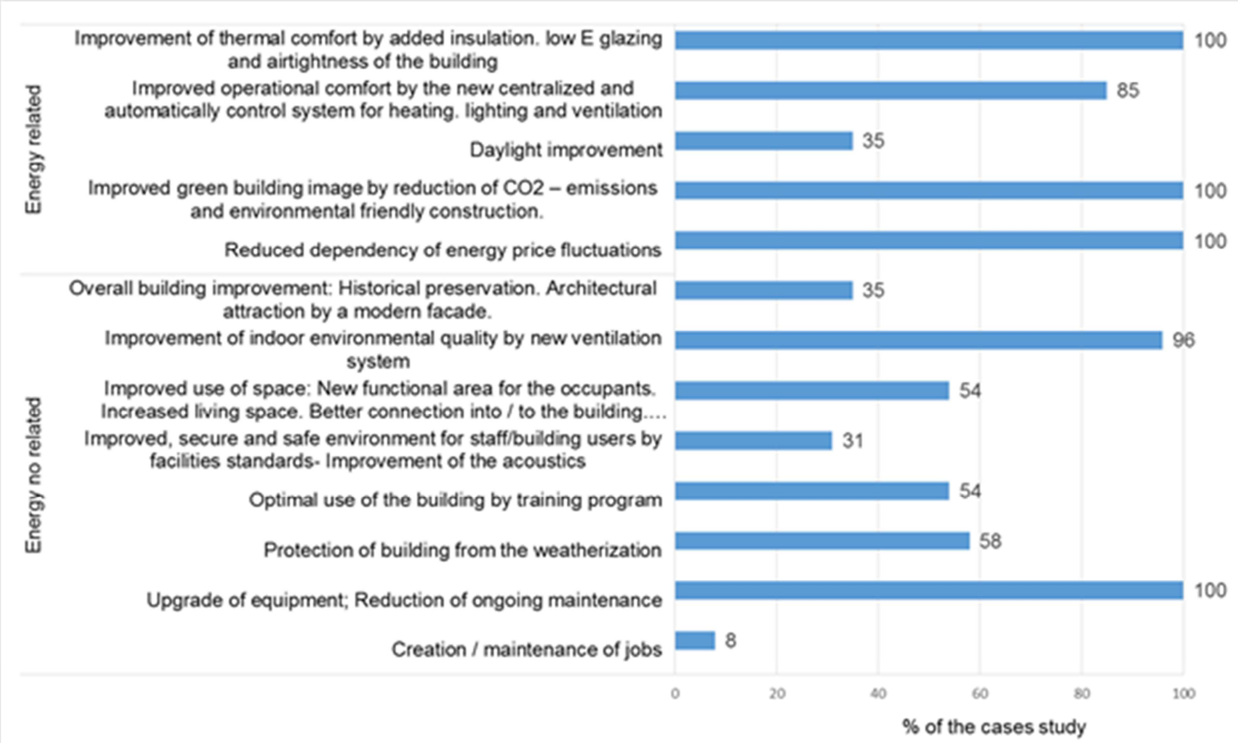

Figure 4. Energy related and non-energy related Co- benefits. Percentage of the cases studies9.

1.4.Cost Effectiveness

Figures **Error! Reference source not found.** and 6 show total, non-energy and energy related renovation costs. For those case studies where both the non-energy and energy related costs were available, it can be seen that the non-energy costs are generally considerably higher than the energy-related costs. This shows the importance to combine high- cost repurposing projects of buildings with the additional measures towards a DER approach. The cost assessment shows a broad variety of results due to the following reasons:

- different assumptions which part of the measures was energy- related in which part not

- different approaches to combine measure bundles of less costly roof attic floor insulation with high costly window or basement perimeter measures

- different price levels for measures in different countries

[9] Source: IEA Annex 61, Preliminary ST A Report, Zhivov, Moerck et al

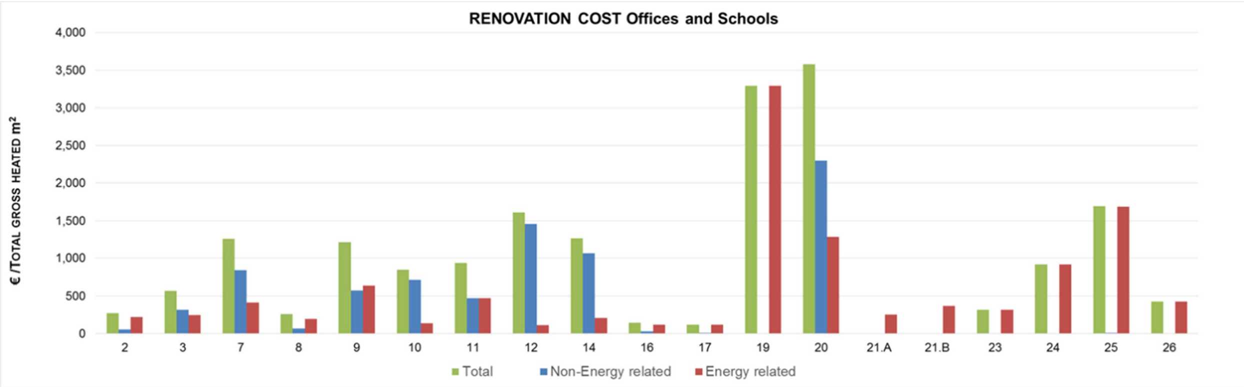

Figure 5. Renovation cost for public buildings

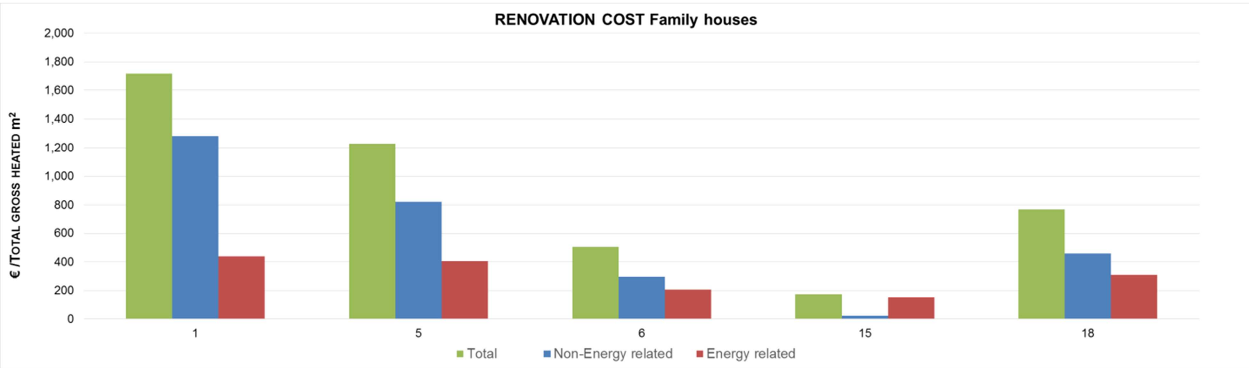

Figure 6.Renovation cost for residential buildings

Because the case studies are located in different countries, there was considerable variation in the way calculations of cost effectiveness were done. Some focus on Net Present Value (NPV) and some on Simple Payback (SPB). Also, financial parameters such as interest rate and inflation vary from country to country. To generate an overall picture, it was decided to calculate the NPV using the same parameters for discount rate and inflation for all the cases (2%), but to use the investments costs and energy savings values provided in each case study. The expected economic lifetime and expected lifetime was set to 30 years. Twelve of the 26 case studies presented sufficient information for this calculation (Figure 3).

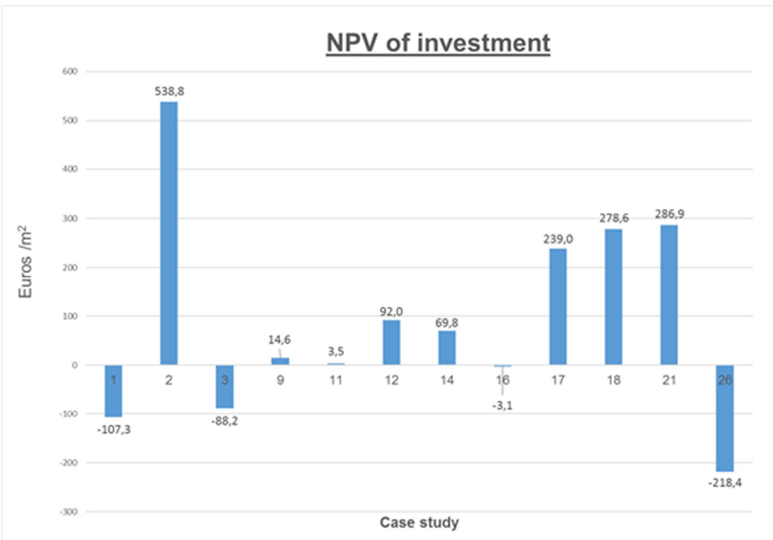

Figure 3. Net present value of 12 case studies calculated with rates for discount and inflation of 2%.

Figure 3 shows that eight of the 12 case studies represented here have a positive NPV of the energy investment costs. For four of them, the NPV was negative; however for one of them (Case Study No. 16), it was only slightly negative. Simply put, the financial result is acceptable for three-fourths of the case studies. Figure 3 also shows that there is a large variation between these 12 case studies.

For Case Study No. 2, the NPV was as high as 538.80 Euro/m² (which were the global investment costs) and for Case Study No. 26, it is 218.40 Euro/m² which is apparently not even the energy related costs. This probably mostly reflects the fact that the investments costs vary widely, depending mostly on which measures have been carried out (for example no thermal wall insulation in No.2), and in which way global and energy related costs have been considered. It may also reflect an issue already mentioned above, that for those case studies that exhibit high, positive NPV (Case Studies No. 2, 17, 18, and 21), a high fraction of the renovation costs has been assigned to non-energy measures, thereby leaving a smaller fraction to the energy-related measures.

The assumptions on the payback period from the relation of global or energy related investment costs and the energy cost savings may be acceptable from the perspective of the building life- time period which, in most of the assessed buildings already has achieved 40 and more years. From the perspective of commercial building owners however these pay back periods would hardly be considered as “cost- effective”. Discussions with public building owners indicated that such pay back periods would at least reduce the priority of DER. These results show that the cost attractiveness of DER needs to become more attractive.

1.5. Business Models and Financing Models currently in use

Business models consider all major relationship (services, remuneration and communication) between parties involved in the DER process (building owner, contractor, planner, funding source). The financing models describe the part of the financial streams and the monetary value of the DER investment and benefits. From the perspective of the building owners financing deep energy retrofit is recognized as a major barrier for the implementation of DER projects; in the design of a general refurbishment the incremental costs for a DER project are often considered to increase the investment costs. In spite of the above observations concerning the reasons for renovation and the resulting co-benefits, it is still most often a requirement that DER has to “pay itself off” in a reasonable amount of time. This requirement has a close relationship to the business models and financing models used for the implementation of the case studies; these were identified, and subsequently grouped in the main categories listed in Table .

- DER projects in Europe are in the majority carried out in the “owner- directed” business model; this model considers the building owner in the responsibility to conduct, finance and take over the risks for the investment cost and energy saving performance.

- The financing models of these models usually use appropriate funding or bank loans. Subsidies may also be integrated into the financing model. Only in one German case and in two US cases energy performance contracting was considered as business and financing model.

Table 3. Business models and financing models.

BUSINESS MODELS AND FUNDING SOURCES	CASE STUDY
Self-financing Standard monthly "Maintenance and improvement contribution" by the tenants- funding model. Loan at low interest rates for Danish municipalities. Other loans – i.e., bank loans. Private funding.	All cases except 4, 5, 10, 13, 14, 16, 17, 19, 20, 21, 25 (58%)
EU or internationally supported Project	2, 4, 6, 15 (15%)
National research program: American Recovery and Reinvestment Act of 2009; Agency provided funds (RWA); ARRA funding time-frame for completion;	20, 22, 26 (12%)
National/Regional/local funding program	1, 3, 4, 6, 8, 9, 10, 13, 14, 15, 16 (46%)
Subsidies: For implementation of ecological and sustainable measures; Subsidized feed-in tariff for electricity generated by PV; Subsidy loans for social housing companies – 0.5 % - 25 years	1, 23, 24 (12%)
EPC Energy Performance Contracting- business model.	8, 25, 26 (12%)

2.0 Comparison of Business models for DER

Investors' lack of confidence in energy efficiency measures and DER projects is closely related to the way these projects are carried out and to the way the projects' performance documentation is maintained and communicated. The strong demand for evaluated project performance data cannot be satisfied because the method and implementation tool (the business model) used to carry out DER projects does not account for project performance. Many indicators show that our currently used business models to implement DER projects are not providing useful structures.

The business models are assessed with regard to how the demands of the building owner and/or financiers are considered in terms of reliability of the energy and costs savings and the investment costs. How does the design of the responsibilities, services and financial streams between these parties support the reliability of these outcomes in common regulatory structures currently in use in Austria and Germany such as standard contracts between architects, planners and building owners [10] and ESCOs[11]?

One of the crucial criteria for building owners to invest their own or borrowed money and for private or institutional financiers to invest in the DER in buildings is the reliability of outcomes[12]; these are summarized under the following sub- criteria; the rating (Tab. 2) of these criteria has been carried out in a telephone interview questionnaire among 19 commercial and private building owners and funding

[10] Honorarordnung Architekten und Ingenieure HOAI 2013, Bundesministerium für Justiz, Berlin, Deutschland, HOA AU Austria, BIK Verlag, Wien, 2002;

[11] Standard Contract for EPC , EESI European Energy Service Initiative

[12] EEFIG Final report, Feb. 2015, Brussels

entities with experience in both business models in Germany and Austria.

a) Reliability of investment and planning costs: For the preparation of an investment decision and any financing decision the reliability of the investment cost calculation is a mandatory requirement. The investment and planning costs are usually collected by the architects and planners; the precision of this estimation is related to commercial and scientific databases; as in DER projects not many evaluated projects[13] are available the experience of the planners and architects involved is the major criterion. To which degree incentives exist which motivate parties involved to keep existing investment and planning cost limitations or to agree on flat rate or turn- key cost agreements.

b) Reliability and impact of energy and Life Cycle Cost (LCC) performance: The pay back from DER investments has an impact on the cash- flow of the building owner. Appropriate funding requires an internal return on investment, external funding requires annuity costs; to achieve a "cost- neutral" cash- flow it is necessary that the energy and LCC performance balance the cash- flow within a predicted time period. The common regulatory framework of the business model is assessed in which way it is supporting the achievement of this criteria.

c) Bankability of cost benefits: the criteria collected under a) and b) are assessed with regard to their bankability. With the requirements for appropriate capital ratios a "debt neutral" approach creates certain requirements for commercial and (in some EU countries also for) public building owners: one example is the legal note of Eurostat which demands for a debt neutral approach that the savings are guaranteed and that the investment costs equate to at least 50% of the current asset value of the building. To assess the bankability it is also considered to which extend the cost benefits could be forfeited[14] and traded among financing institutions. The regulatory framework of the business models are assessed with regard to the bankability of the cost benefits created in a DER project.

d) Cost- effectiveness: the cost- effectiveness is defined by the savings per € investment; the business models are assessed with regard to the support it provides to improve this ratio. In the cost side investment and interest rate costs are considered; these are compared on the side of the savings with average values for avoided energy, maintenance and other LCC.

Tab. 4. Rating criteria for the evaluation of reliability sub- criteria

	0- 3	4- 7	8- 10
Contracts between building owner and "apcs" (architects, planners and contractors) provide incentives in which level to optimize the criterion	Regulations do not support directly or indirectly the building owner to hand over the responsibility for the criterion	Regulation support indirectly the building owner in handing owner in handing over the responsibility for the criterion	Strong support to hand over the responsibility for the criterion
Remuneration model between	Payment is not related to the	Payment regulation is only	Payment regulation is

[13] Report on the analysis of DER projects accomplished, IEA Annex 61, 2016

[14] EEEF Program, 2013, Brussels

building owner and "apcs" are creating incentives to follow the criterion	achievement of the criterion	indirectly related to the degree the criterion is achieved	directly taking into account to which degree the criterion is achieved
Services are provided to support the criterion	Services are not provided to support	Services are provided but only to a certain degree supporting the criterion	Services are provided targeting to support the criterion

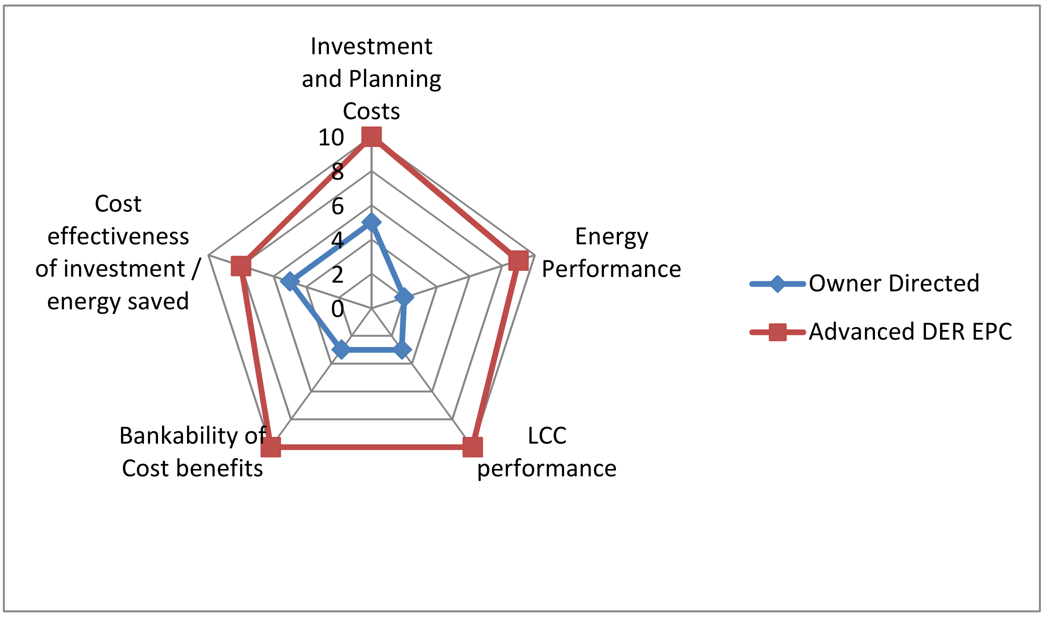

Figure 8. Comparison of Reliability Sub- Criteria of two DER business models

The results of the evaluation show clearly that EPC business models for DER were perceived as more reliable and consistent:

- The sample is particularly small as not many experience exists with DER in EPC and not many owner directed DER projects have been evaluated so far
- The reliability of predictions and the bankability is significantly better in EPC business models
- The cost- effectiveness is better in EPC business models

2.2. Advanced DER EPC business models

In consequence the result of recent research projects[15] is an advanced EPC business model for DER that is able to provide technical solutions for the holistic refurbishment of buildings and to steer larger

[15] Iea-annex61.org

amounts of private sector money into DER projects. The advanced DER EPC devises a financing scheme that avoids inflating the debt level of the public sector by guaranteed and bankable DER benefits. Since Basel III and the austerity policies the debt level has become an important factor to both commercial and public sector. In the past few years, a number of new and innovative contract types have been developed. However the technical scope has to be extended: in the recently carried out DER EPC projects the measures have provided the refurbishment of a single rooftop or windows but not yet included significant parts of the building envelope; the integration of the thermal envelope however will be necessary to establish DER EPC projects.

The key competence of major ESCOs is apparently still in the building automation. In some countries, the scope of EPC has already been extended to Renewable Energy and some infrastructural measures. The development of a DER EPC considers the following criteria:

- DER EPC project must be designed in a way that risks stay considerable and can be calculated; this is mostly the case when technical risks (maintenance and operability), organizational risks (change of usage) and performance risks (energy and other cost savings can be verified) are clearly described and approvable for both sides.
- EPC usually see the ESCO in the responsibility to maintain and refurbish their energy efficiency measures implemented in the building over the pay back /contract period. If thermal envelope is integrated into the technical scope the pay back will, even in countries with high energy prices move towards 20 years and more.
- This time period typically sees parts of the HVAC such as building control systems and hot water pumps at the end of their technical life time period; on the other hand the maintenance of a thermal envelope and windows needs also be described. A full coverage of the ESCO for the maintenance and refurbishment of these components with a shorter technical life time period needs to be defined to calculate the future costs.
- The organizational risks will increase over time: a building in use for public school may be closed down or may serve a new purpose. These risks should be covered by a stipulation describing how these risks are outweighed between ESCO and the building owner.
- Performance risks: Over 20 and more years' time, the monitoring and verification needs to consider simplified approaches which do not keep the ESCO in risk for future building usages. One way to approach this is to relate the remuneration of the ESCO only for a limited time to the monitored and verified energy savings.

1.2. Life Cycle Costs in advanced DER EPC

In the commercial and public sector decision making is prepared on the basis of a life cycle cost analysis which considers energetic and non- energetic benefits. As most of the risks for the ESCO are related to the contract time period one major topic is to minimize the time period of the EPC contract. This can be provided by two means:

- Integrating non- energy related benefits into the account (➔LCC for DER)

- Optimizing cost- effectiveness by least LCC planning

1.2.1. Life Cycle Costs in advanced DER EPC

To reduce the pay- back period different LCC need to be considered. Operating costs included into the LCCA shall account for increase or decrease of maintenance costs before and after refurbishment. In maintenance costs are between 5 and 10% of the LCC and depend on the complexity of the building systems. For example, additional building control system allows for a centralized monitoring and reduction in time for fault detection and troubleshooting; installation of high efficient heat recovery system increases maintenance load for changing filters and cleaning heat exchangers; installation of biomass boilers increase maintenance costs compared to using gas boilers .[16]

Tab 5. DER Life Cycle Cost benefit evaluation

	Life Cycle Cost	Calculation	Variations and Values
1	Energy savings: effects from improving the e-performance of equipment by maintenance or replacement	kWh savings x energy price	Fixed or flexible energy price; in DER it is expected to at least reduce by 50% Values: Germany office building stock 7-14€/m²yr
2	Energy savings II	kWh *RE replacing fossile* x energy price *(RE-fossile)*	kWh replaced by RE; fixed or flexible energy prices;
3	Reduced maintenance I	Maintenance costs for replaced, worn down equipment at the end of its life cycle as a percentage of the new investment value	Average percentage value or end of life cycle value (➔ graph LCC maintenance) Values applied at the market: -0,25$/ft² in US; EU: - 2 to -4 €/m²
4	Reduced maintenance II	Downsizing of investment in a DER bundle means reduction of investment cost related maintenance	A component downsized by 30% reduces maintenance costs by 30%
5	Reduced operation costs I	Building automation reduce operation workloads	Consider workplans and operation schedules individually
6	Insurance costs I	Building compontents replaced achieve lower premiums and improved protection against loss	EU: compared to pre- refurbished status: -2 up -4€/m²

[16] Building space 5.000 <x<20.000 m²

7	Rental Costs for floor space	m²savings x rental rate	DER may contribute to more flexible room concepts and certainly downsize space needs for mechanical systems
8	Reduced absence costs	Relationship between indoor climate,lighting and absenteeism	Few case studies assessed the relationship: 30- 40% less absenteeism

1.2.2.Least Life- Cycle- Cost Planning for DER

For the LCC analysis (LCCA), it is important to consider synergy of different EEMs (energy efficiency measures), rather than their individual impacts and costs. In comparison with the "base case" several EEM will be carried out to achieve DER. Synergy effects will be result from a combination of a better insulation of the building envelope and reduced heating and electricity loads. When the project life is low (e.g. 15 years) the life of some EEM can be significantly longer (e.g., wall and roof insulation, selling the building envelope), a residual value of this EEM will be left. Depending on accounting method used, this residual value can be either subtracted from the first cost or it can be ignored (and considered as an added value) by adjusting the write- off period to the life of the project.

Least- LCC- planning (LLCCP) is to be used to define a cost- optimum between different measures and their impact on annual costs. For the LLCCP the following needs to be prepared:

- Definition of an energetic target value for the heating and electricity consumption
- Investment costs for the implementation of different energy conservation measures: in the case of the wall, roof, and basement insulation this will be a more or less constant cost function over the thickness / average U- value. Other cost functions for double and triple glazing, ventilation system with different heat recovery factors need also be collected.
- Impact: for the impact of different energy conservation measures a relation between different energetic standards and the affected energy and other cost savings needs to be set up: in the case of the thermal building insulation this can be a constant function of energy savings over U- value; for different quality levels of ventilation/heat recovery and triple or double glazing respective figures can be calculated.
- The LLCCP is accounting the LLC resulting from the investment (capital costs, maintenance, operations) and impacts (energy and other LCC savings) and looks for a cost optimum of different measures (Fig.5).

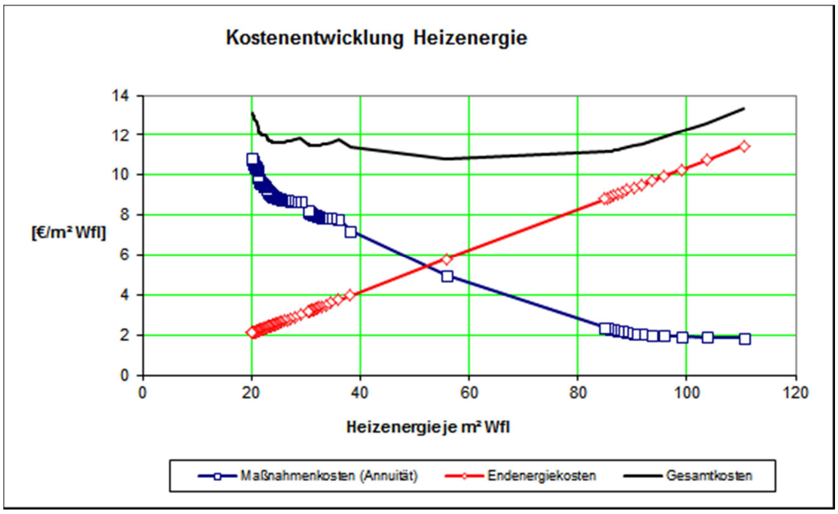

Fig.9. Least-Cost-Path for an office building in Darmstadt, ASHRAE climate zone 5, heating energy price of 85 €/MWh Hu and 130 kWh/m²yr heating energy and 12.7 €/m²yr heating costs before refurbishment. Different insulation thickness, ventilation with heat recovery and triple or double glazing have been considered (source Reinhard Jank, VROM modeling, 2015[17]).

1.2.3. Bankability of advanced LCC approaches:

This means that the LCC are described in a way that measuring, monitoring and verifying of the costs is allowed according to defined and mostly standardized methodologies which are understood and agreed by the DER provider, the building owner and the financier.

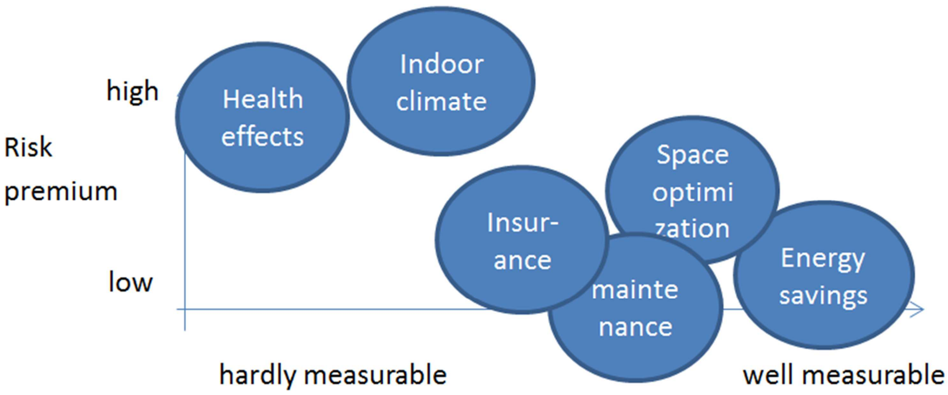

Fig. 9: Measurable impacts in relation to the risk premium. When M&V parameters are more subjective the risk of disputes between parties is higher and bankability lower

17 More Information on the methodology: R. Jank, R. Kuklinsiki, Integrales Energie- Quartierskonzept Karlsruhe, 2015, IRB Verlag

1.3. First experience in DER EPC business models DER EPC:

1.3.1. Experiences from the US: GSA NDER Program

In the USA EPC has a longer tradition and is used by the Federal government to implement energy efficiency targets in the public building sector despite scarce public funding. Apparently US legislation has more flexibility to account those EPC in which the payments of the building owner are strictly related to the cost saving performances not relevant for the debt balance. Energy savings of US EPCs have been in average 20- 25% in the last years; the Federal building agency GSA has in 2013 started the NDER program in which also EPC business models targeted energy savings of 40% and more. ORNL´s analysis of the GSA NDER[18] projects showed that the key criteria to target DER is to encourage ESCOs to propose longer-payback ECMs. To achieve this it is necessary to have an integrated design approach considering the building, its occupants, and energy consuming equipment as a system, and considering investment costs different from conventional projects.

1.3.2. SmartEPC in Belgium

The Belgian facilitator Factor4 enhanced the EPC (energy performance contracting) business model into "SmartEPC". The "SmartEPC" model Integrates non-energetic measures and benefits in EPC and mirrors the building owners' needs. The owners' investment decisions are often not driven by the aspiration for more energy efficiency. The mechanisms of "business as usual" EPC are exclusively related to the energy savings. The integration of non-energetic measures into the scope of EPC projects means to increase investment costs for these measures.

To keep the balance between investment costs and savings, "SmartEPC" adds non-energy related savings into the cost balance, to include: (1) increased value of the building, and (2) a higher level of indoor climate and user comfort. "SmartEPC" provides calculation methods to make the non-energy related savings accountable and gives guidance on how to assess and to verify their performance.

The net financial advantage of a the energy cost saving in a conventional EPC/ESCO/EE-project in a Belgian office is 1,5 €/m² [19]. By integrating employee comfort satisfaction and overall maintenance in an EPC-contract via SmartEPC the net financial advantage becomes – related to office buildings 2 up to 6 times higher compared with a standard EPC-project. In the currently ongoing SmartEPC project the following results were achieved:

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[18] Energy Savings from GSA´s National Deep Energy Retrofit Program, John Shonder, Oak Ridge National Lab, 2014

[19] The **energy cost** of an average Belgian office is 10.000 m² office is 18 €/m², taking into account:

- Fuel: 158 kWh/m² x 0,05 €/m²
- Electricity: 67 kWh/m² x 0,15 €/m²

An EPC-project with 25% energy saving realizes an energy cost saving of 4,5 €/m². Assuming that 2/3 of this energy cost saving is needed for compensating the investment and other costs of the ESCO, the net profit of a conventional EPC/ESCO/EE project amounts to 1,5 €/m²

- By integrating the overall maintenance of the building in the EPC-contract and organising it on a performance based way, the maintenance cost can be reduced with 30 up to 35%, or about 1,35 €/m²[20]

- The salary cost of the employees working in an office building is typically 100 times higher than the energy cost of this same building. By increasing the comfort, a significant and measurable productivity increase can be realised that creates a financial advantage of 7,8 €/m² [21].

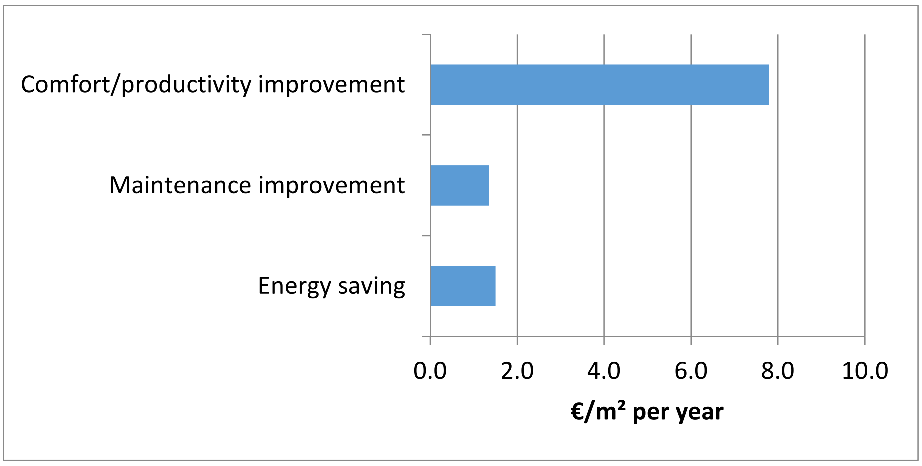

Fig. 10. Financial impact of comfort on the total cost savings of a DER project (source: Factor4, Johan Coolen, 2015, Antwerp)

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20 Source: Facility Management Magazine (Aug 2014), Sustainable maintenance via performance contracts ('Duurzaam beheer en onderhoud met prestatiecontracten'). The maintenance costs, regular maintenance and replacement investments - of an office building is typically one fourth of the overall energy cost.

21 The **salary cost** of an average Belgian office is 1820 €/m², If we assume that the non-salary cost (building, ICT, facilities, external service providers,…) and normal profit amounts to 50% of the salary cost, than the **turn-over** is about 2.730 €/m². By applying smartEPC-project, the production/turn-over of a company could increase 7,8 €/m² (1,5% x 0,19%/% x 2730 €/m²).

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Acknowledgements

The work presented in this paper is the result of a joint effort by participants in the IEA EBC Annex 61. Each of these has received national funding to participate in this IEA cooperative R&D work. Cenergia Energy Consultants has received financial support from the Danish EUDP program administered by the Danish Energy Agency.

Energy Services Market in the EU

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Abstract

The need to improve energy efficiency in buildings due to carbon and energy security goals, increased sustainability and reduction of energy costs has created a demand for energy efficiency and energy service providers. Over the years the concept of energy service and energy service company (ESCO) has evolved and matured in several markets in the EU. Energy services and ESCOs are particular active in commercial buildings. There is a large variety of energy services offered under different contractual arrangements and different financing schemes, both for the public and private sector. The papers summarize recent developments in energy services markets in EU countries with particular focus on non-residential buildings, and analyses the existing barriers and future expectations. The paper highlights that ESCOs are important actors to improve energy efficiency in commercial buildings, however they cannot be expected to be the only players to deliver energy efficiency. The paper offers also some recommendation on how to expand the ESCO market for non-resiential buildings in coordination with other policy instruments.

Introduction

Governments have designed policies and measures to help overcome the energy efficiency gap. In addition to governmental policies and measures, the private sector, including energy service companies (ESCOs) can play a critical role in promoting energy efficiency at the market level. ESCOs have the necessary know-how to provide turnkey services and solutions to achieve significant energy cost reductions through addressing various market related barriers on the ground. ESCOs can handle projects, manage or mobilize financial resources, undertake installation and maintenance work as well as collaborate with other market players. Most importantly, they can often assume performance risks by linking their compensation to the performance of their implemented projects, thus incentivising them to deliver savings-oriented solutions.

The value of energy services companies in unlocking the energy saving potential in the market is recognized by various EU directives and initiatives in the European context, as well as including the promotion of the ESCO market with national and local policies. The Directive 2006/32/EC on energy end-use efficiency and energy services (ESD) stressed the importance of managing end-user demand for energy with cost-effective measures, in particular relying on the energy services markets, and by setting improvement targets. The provisions of the ESD were later strengthened with the introduction of the Energy Efficiency Directive (EED) in 2012, which set explicit requirements to promote the market of energy services through its Article 18. The EED provides definitions for energy performance contracting, energy services and energy service providers and calls for Member States to take concrete actions:

- disseminate information on available energy service contracts and clauses as well as financial measures supporting energy efficiency service projects;
- publish EPC model contracts and list of available energy service providers;
- encourage the development of quality labels;
- disseminate information on best practices for EPCs;
- provide a qualitative review of the current and future development of the market;
- identify and publicise contact points for final customers;
- consider putting in place an independent mechanism for handling complaints and disputes;
- enable independent market intermediaries.

The EED provides additional opportunities to further support the energy services market. Article 5, calling for renovation of 3% of the national central government building stocks, can, inter-alia, promote the use of energy services in the public sector, while the energy efficiency obligations (Article 7) enables additional actors such as ESCOs to contribute towards meeting the end-use target imposed on the energy companies. The obligation for large companies to do mandatory energy audits (Article 8) offers a boost for the uptake of energy consultations, a key segment of the energy services market. The call for Member States to evaluate and, if necessary, take appropriate measures to remove regulatory and non-regulatory barriers to energy efficiency (Article 19) shall take into account barriers to the uptake of energy performance contracting in the public sector with regards to public purchasing, annual budgeting and accounting. Finally, the establishment or use of existing financial facilities including the set up an Energy Efficiency National Fund may also include dedicated streams of financing to support the uptake energy services projects.

Despite the theoretical appeal of low-capital energy saving opportunities and current policy framework, the energy service market in the European Union is far from utilizing its full potential, even in countries with a particularly developed energy services market. While the provision of energy services, is often associated with a well-established track record of delivering substantial energy and economic savings, successes in one sector or national market do not transfer to the other client sectors even within one jurisdiction.

Building on its previous reports investigating the status of the ESCO market in the EU, the current paper reviews the efforts made by Member States to stimulate the market of energy services in the market in the past few years, and in particular, analyses the information[1] provided by the Member States in compliance with Article 18 of Directive 2012/27/EU. Together with the information provided in the National Energy Efficiency Action Plans, the JRC reviews existing literature sources and gathers national expert views to evaluate:

- ESCO market overview
- Status of the energy performance and supply contracting
- Energy services in the public sector
- Energy services in other sectors
- Remaining energy services potential and barriers
- Policies to stimulate market growth including information and awareness raising measures.

Terms and definitions

Despite a rather long history, *energy services* are still characterised by definitional confusion, which is mainly attributed to the complexity of the offerings, to the traditional use of terms in certain countries, and to the diversity of players in the market.

Differences in the interpretation of what is entailed by Energy Services Company (ESCO) still exist among experts in the field. The Energy Services Directive (2006/32/EC) describes an ESCO as natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. It stresses that the payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria. The Energy Efficiency Directive (2012/27/EU), on the other hand, does not provide a definition of ESCOs but instead refers to the general term of energy service providers, which includes any natural or legal persons delivering energy services and/or other energy efficiency improvement measures in a final customer's facility or premises (see **Error! Reference source not found.**).

Definitional varieties also exist at national level. Most of these are found to converge with EU-level definitions:

[1] This information has been outlined in the third National Energy Efficiency Action Plans

Energy Service Company (ESCO) (Directive 2006/32/EC): A natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria.

Energy Service Provider (Directive 2012/27/EU): A natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a final customer's facility or premises .

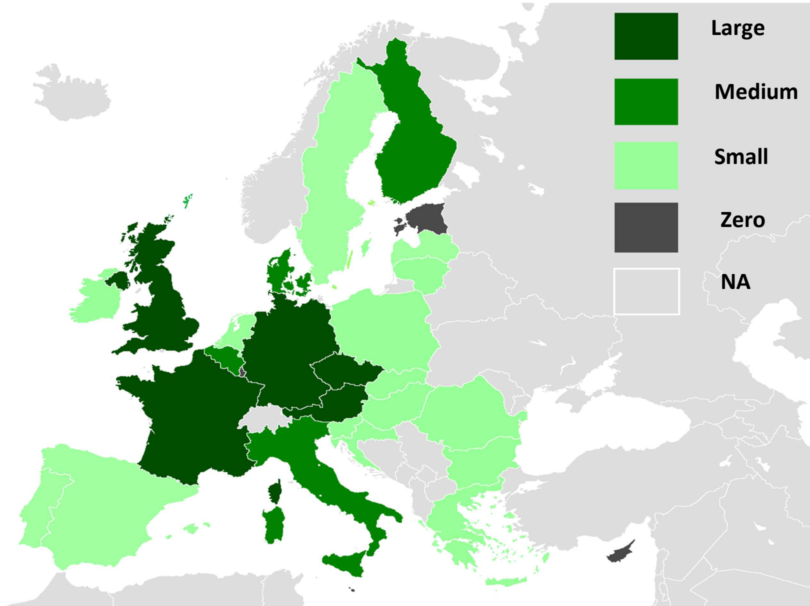
Energy Services (ES) (Directives 2006/32/EC, 2012/27/EU): The physical benefit, utility or good derived from a combination of energy with energy efficient technology and/or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to lead to verifiable and measurable or estimable energy efficiency improvement and/or primary energy savings.

Energy Performance Contracting (EPC) (Directive 2006/32/EC): A contractual arrangement between the beneficiary and the provider (normally an ESCO) of an energy efficiency improvement measure, where investments in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement. (Directive 2012/27/EU): A contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings

Market size and maturity

The size of the EU energy services market is not known. The Economist Special Report Energy and Technology 2015 stated that the European ESCOs were a €41 billion industry in 2014, a figure which is much higher than the corresponding figures of America and China at $6.5 billion and $12 billion, respectively (The Economist, 2015). In their latest review of the European ESCO market Bertoldi, et al. (2014) reviewed the sizes of the national ESCO markets in qualitative terms across Europe and found that Germany, France, Austria, the Czech Republic and the UK currently have the most active markets (see Figure). Germany is regarded as the champion amongst the European ESCO markets in terms of maturity and a frontrunner during the period 2010-2013. Italy, Belgium and Denmark were found to have medium-size markets, while the ESCO markets of Estonia, Malta, Cyprus, and Luxembourg were found as non-existent. All other European markets were identified as small.

Figure 1 – The size of the ESCO market across the EU (Source: Bertoldi, Boza-Kiss, Panev, & Labanca (2014))



A picture of the extent to which energy contracting is currently used can be drawn through investment volume data and number of undertaken EPC- and ESC-based projects provided in the NEEAPs 2014. The collated data are summarised in Table 1. While data are not available for all countries, the available information confirms the picture drawn above. Spain and Germany have the largest volume of investments realised, attributed naturally to the size of the country and hence large potential for energy services. The remaining countries have a relatively small market size, indicating a very large unexploited potential across most Member States, while the embryotic state of the energy services market is evident in Cyprus, Malta and Slovenia.

Information on the current and expected trends with regards to the energy contracting market can also be drawn for some countries through information outlined in the NEEAPs. In Germany, a rapid growth of the energy contracting market has been observed in recent years (with corresponding annual rates of 8-14%) and positive future expectations stress the importance of energy service contracting an a means of tapping into the energy efficiency potential through market mechanisms. While the extent to which ESCO services are used in the Netherlands is not currently known, a rise in the use of these services is expected in the coming years, albeit at a slow rate. The Belgian market is at a growing stage, mainly due to increasing public sector awareness and activity. In the Czech Republic, future expectations outline the provision of 30-50 EPC-based projects based on guaranteed savings (currently at 10-15 projects per year), while Cyprus expects the market to become more mature in the years to come. In Spain, an analysis based on a sample of 36 energy service companies showed that the business volume in this activity grew by just over 10% in 2012, a rate that has been maintained in 2013 despite the economic crisis. Energy performance contracting has experienced a surge over the last few years in France, with upward energy cost forecasts and national regulations creating favourable conditions.

Table 1 - Size of energy contracting market reported in Member States' National Energy Efficiency Action Plans 2014 (missing data are indicated as grey areas)

	Investment volume	Number of projects		Investment volume	Number of projects
AT		15-20 EPCs in 2014 (370 in 2014-2020); 30-35 ESCs in 2014 (505 in 2014-2020)	IE		
BE	€1.5 million for EPCs (currently)		IT	€3.5-4 billion per annum is the total turnover of ESCOs (members of ASSISTAL)	
BG			LT		
CY		2 EPCs in 2014	LU		
CZ	€10 million yearly	10-15 EPCs yearly (200 projects over 20 year span)	LV		
DE	€1.6-2 billion market volume for entire contracting market (2010)	Around 200 (mostly ESCs)	MT	No investments	Energy contracting is not currently practiced
DK			NL		
EE			PL	PLN 40-100 million turnover (2011)	
EL			PT		
ES	Around €1 billion yearly		RO		
FI			SE	SEK 40 million (underestimate) yearly	10 EPCs in recent years
FR	€189 million (2013)	143 EPCs	SI	Poorly developed market	
HR			SK		
HU			UK	GBP 180 million	

On the other hand, Austria has reported a slight decline in the energy contracting sector (especially with respect to performance contracting) but the potential of energy contracting remains significant. In Poland, the volume of ESCO projects in the public administration sectors has decreased in recent years, despite the sector being one of the most important segments of the ESCO market in the country. A growing interest in the ESCO models is however overall observed. Sweden has reported a significant increase in the volume of energy services procured in the public sector in the period 2006-2011 with an average SEK 40 million procured every year. However, less than 10 EPCs have been noted in recent years, despite the total number being in the order of hundred since 2000. Slovenia considers energy performance contracting as a measure that can lead to a quick exit from the current financial crisis as well as the means to comply with a number of EU obligations (especially of the obligatory renovation rates of the public sector), however the future of the ESCO market is unsure, in spite of the fact that recently it has been growing steadily. Finally the UK considers that its current market is only at emerging stage, the nation-wide implementation of the Greater London Authority RE:FIT programme has been a driving force for the development of the market. Through this programme, contracts totalling GBP 27 million have been completed, with an estimated GBP 51 million in the pipeline and a further GBP 25 million by the end of 2014/2015.

Actors, contracts and sectors

An overview of energy service providers across the EU is given in Table 3. Only 11 Member States (Austria, Cyprus, the Czech Republic, Denmark, Finland, Greece, Luxembourg, Netherlands, Poland, Spain and the UK) have provided information about lists of energy service providers, while Croatia, Sweden and Slovakia stated that they have plans to do so.

In terms of active ESCOs, Germany is the leader with 500 contractors. At the same time, there are large differences between these contractors in terms of offered services, company size and scale of undertaken projects, with only a quarter of the German ESCOs having energy service contracting as their main business activity. Spain has reported a large number of energy service providers. There are in total 968 registered ESCOs in Spain, a number which has been on the rise since 2010, mainly due to the active promotion and support of this business model in the Spanish market. It should be noted that these are likely to fall under the more generic nature offering any energy efficiency services (i.e. energy service providers) rather the strict definition of ESCOs (specialising in energy performance contracts). Their profile is essentially that of engineering, installation and assembly companies, some of which are associated with building heating system maintenance or with subsidiaries of building companies and electricity suppliers. The profile of the 41 active contractors in Austria can be categorised as general firms focusing on energy services (13), energy supply companies (9), technical building system firms (10), engineering offices/planners (5) and consultancy firms (2). In Belgium the number of ESCOs has remained stable (at around 10-15) over the last few years. A distinct feature of the Belgian market is that four ESCOs are public. In Bulgaria, 5 ESCOs are registered with the Sustainable Energy Development Agency (SEDA, 2015), while in Cyprus there are now 8 ESCO companies[2] officially registered on the responsible ministry's website. In addition to Bulgaria and Cyprus, Estonia, countries such as Greece, Lithuania, Luxembourg have only a few ESCOs currently on the market as ESCOs and EPC-based projects are a relatively new concept.

About two thirds of the German contractors are SMEs with fewer than 250 employees. The vast majority of Spanish ESCOs fall under the SME profile (93%), while only 7% of them are considered large enterprises. In Italy, 95% of the enterprises are SMEs (60% with less than 10 workers) and only 5% are large ESCOs forming part of large multi-national groups (with more than 250 workers). A large share of SMEs is also observed in the registries of ESCOs in Greece and Cyprus. Only In Belgium there is a more balanced share with 6 large companies (sister companies of large international companies) and 5-7 SMEs.

The extent to which energy performance contracting is used as opposed to energy supplying contracting varies from country to country. In Germany 86% of all contracting agreements in 2012 were for energy supply contracting, 9% for energy saving contracting, 2% for financing contracting

[2] Based on the ministerial registry of energy service companies dated 08 April 2015

and 3% for management contracting (VfW, 2013)[3]. In Austria, both forms of energy contracting have been popular, with both types of contracts gaining significant momentum in the early 2000s. This was followed by a slight decline, which began later in the case of energy supply contracts. In Lithuania and several other Central-Eastern European countries, "chauffage" contracts are more popular.

Table 2 – Energy service providers across the EU (various sources)

	ESCOs	Energy advisors*	Other ES suppliers		ESCOs	Energy advisors	Other ES suppliers
AT	41	388	71	IE			
BE	10-15			IT	390		
BG	5			LT	"A few"		
CY	8	47		LU	"A dozen"		
CZ	15			LV			
DE	500	14000		MT	0		
DK			512	NL	41		
EE	"A few"			PL	28/88		
EL	28			PT			
ES	968 ESPs			RO	20	100	
FI	6			SE			
FR				SI	4-6		
HR	10			SK			
HU	7	10		UK	13 under RE:FIT scheme		

ESCOs have been the most active in the buildings sector, and in particular in commercial and the public buildings. Nearly all ESCOs target energy contracting offerings to large customers, partly explained by the large transaction costs of energy performance contracts. As a result, very few ESCOs work in the residential market, with those that do targeting large multi-family and social housing facilities. Among non-residential customers, ESCOs have had most success in public and institutional sector such as federal, state and local government facilities, schools, universities/colleges and hospitals. Street lighting is also common. Table 3. shows how ESCO activity, i.e. ESCO projects are divided amongst the different sectors in a given Member State. Commercial buildings are not amongst the most preferred clients, however in more developed markets these are also on the palette. There are only a few countries where there is a significant ESCO market for commercial buildings, including Italy, Netherlands, Germany, Spain; UK while in a few underdeveloped ESCO markets, it happens that among the few projects, offices and other commercial buildings receive a small share, too, i.e. in Hungary, Ireland, Estonia

Table 3. - Sectors targeted by ESCOs in the Member States as of 2013-2014. * - means a few projects, *** - a lot of (most/all of) the projects (comparison only within the MS, not amongst them). Source: Bertoldi et al. 2014.

	Industry	Public sector	Non-residential buildings	Resid. buildings		Industry	Public sector	Non-residential buildings	Resid. buildings
AT		***	*		IE		*	*	
BE	**	**			IT	***	**	**	*
BG		***			LT		*	*	**
CY		*			LU				
CZ		***	*		LV				
DE	**	***	**	*	MT				
DK	*	***	*	*	NL		***	***	
EE	*		*		PL		***		
EL					PT	***	***	**	
ES	**	***	*		RO	*	**	*	

[3] For definitions see Annex **Error! Reference source not found. Error! Reference source not found.**

FI	*	***	*		SE		**		
FR		***	*	*	SI	*	**		
HR	*	**			SK	*	*		
HU	**	**	**	*	UK	***	***	***	*

Policies and measures supporting the energy services market

An overview of policies and measures focusing on the energy services market is presented in Table 5. Several countries have specific legislations for facilitating the development of the energy services market and other policy measures. This is important as legal barriers (see Section **Error! Reference source not found.**) can severely hinder the market development. In Bulgaria, the Energy Efficiency Act and Regulation No RD-16-347 of 2 April 2009 form the main legislative measures addressing issues related to energy services. In Greece, the main legislative measures are the Law 3855/2010 on the institutional framework for the provision of energy services and Ministerial Decision D6/13280/07.06.2011 on Operation, Register, Code of Conduct and related provisions for energy service providers. To address legal obstacles to contracting in Germany, the Tenancy Law was revised in 2013 in order to allow the tenant to bear the costs of het supply as operating costs when heat supply is switched to contracting.

A few countries have in place financial instruments promoting energy services in various sectors. In Austria, the Federal Property Contracting programme has seen substantial success in facilitating the renovation of more than 200 federal buildings since 2001. Within the state of Upper Austria, subsidies for energy saving measures (energy performance contracting) or construction/operation of energy equipment (energy supply contracting) have been made available, giving rise to €45 million of project investments. In Bulgaria, co-financing and guarantees for ESCO service contracts are made available through the Energy Efficiency and Renewable Sources Fund. In Spain, the Jessica Holding Fund/FIDAE[4], established in 2010, financed sustainable urban development projects implemented by energy service companies and other companies through a budget of €122 million. The possibility of ESCOs to participate in comprehensive renovations of existing residential buildings has also been given through the Aid Programme for the Energy Renovation of Existing Buildings in the residential sector (PAREER). In Finland the development of the energy services market is promoted by two programmes coordinated by the Finnish Funding Agency for Innovation, namely the programme "Green Growth-Road to Sustainable economy" (2011-2015, €80 million) and "Built environment" (2009-2014, €75 million). In the Czech Republic, support to energy service providers in the form of subsidies for the installation of energy saving measures have been made available since 1999 through the State Programme on the Promotion of Energy Savings and Utilisation of Renewable Energy Sources.

Many countries have in place information, knowledge & advice measures to raise awareness on the benefits of the use of energy services. These include the development of contracting portal (e.g. Austria), various dissemination activities (e.g. Spain, Finland, Croatia, the UK) and stakeholder consultations with the banking sector (e.g. Latvia). Ireland has set up the comprehensive National Energy Services Framework, providing guidance on project development, etc. Pilot projects are also planned by some countries. These include Ireland through its Better Energy Financing scheme and Cyprus with two ongoing pilot ESCO projects in the public sector.

To support the uptake of energy contracting in the public sector, the EED calls Member States to provide model contracts for energy performance contracting which include at least the items listed in the EED Annex XIII. Only 10 Member States have so far made available EPC models (see Table 5).

Table 4 - Policy measures related to the energy service market mentioned in the NEEAPs 2014 (p: planned)

	Registry of ESPs	Legislative measures	Financial Instruments	Information, knowledge & advice	Other measures (e.g. pilot schemes)

[4] Energy Diversification and Saving Investment Fund

AT	✓		✓	✓	✓
BE					
BG		✓	✓		
CY	✓	✓			✓
CZ	✓	✓	✓	✓	
DE		✓			
DK	✓			✓	
EE		✓			
EL	✓	✓		✓	
ES	✓	✓	✓	✓	
FI	✓		✓	✓	
FR					
HR	p	✓	✓	✓	
HU					
IE				✓	✓
IT		✓	✓		✓
LT		✓			
LU	✓				
LV		✓		✓	
MT					
NL	✓			✓	
PL	✓	✓			
PT					
RO		✓		✓	✓
SE	p				
SI			p		
SK	p				
UK	✓			✓	

Table 5 - EU Member States with published Energy Performance Contract models

Published EPC models	AT, CY, CZ, EL, ES, FR, LU, PL, NL, UK
Plans to publish EPC model	SK, IT, HU
No plans/no information	BG, DE, DK, EE, MT, SE, SI

Remaining barriers and future expectations

Despite considerable efforts to promote the energy services market development, persistent obstacles inhibit many cost-effective energy efficiency projects and prevent the full development of the energy services industry. This section addresses the barriers limiting market penetration of ESCOs and EPC-related projects. Some of the barriers are interrelated and act together to inhibit the deployment of energy efficiency investments, while many of the barriers are hereditary to the general nature of energy efficiency. A summary of the barriers identified is shown in **Error! Reference source not found.**. These are divided into: information & awareness, institutional & legislative, financial, market & external, technical & administrative and behavioural. With more projects taken off the ground, it is expected that several entry-level barriers will be overcome in certain countries. In addition to these general barriers, specific sectors and countries have unique constraints that must be addressed if the energy services market is to reach its full potential.

Information & awareness

The absence of positive examples and success stories is often an obstacle in markets with little experience in these new concepts. Latvia has cited the lack of positive examples as a barrier and many other countries with emerging energy services market are expected to face similar issues as there is low customer awareness about ESCO possibilities. The lack of knowledge among end-consumers of the economic potential for energy savings continues to impede the uptake of energy contracting projects on the market even in more advanced markets such as Germany. Partly as a result of the lack of trusted information, the energy efficiency benefits are often regarded as less certain and energy efficiency is undervalued relative to other investment options. Despite various efforts at different levels, many enterprises find it difficult to recognise opportunities for energy savings, procedures, various options and available products etc. and are thus not able to fully assess the benefits of an energy efficiency investment. Concrete advice (e.g. through targeted, tailor-made information on potential measures and their benefits), cost-effective measuring and metering systems and qualified providers of energy efficiency measures can all help alleviate knowledge-related barriers.

Legislative

The legal aspects related to off-balance sheet investments may affect the ability of the public sector. This is the case in Estonia, but also in other countries. The ambiguity of legal aspects pertaining to service contracts such as title to the installed equipment has been mentioned by Latvia. In a survey carried out in Sweden, procurement procedure rules and legislation relating to the activities of municipal energy companies have been cited as a major barrier. Alongside these challenges, legal issues with tenancy laws may also inhibit the use of energy services in the rented sector. In Germany, there have been issues with the tenancy regulation of energy-related modernisation projects in balancing financial incentives for landlords against protection of social housing tenants, planning laws and energy management conditions affecting the generation and distribution of energy. This is expected to be addressed with the new amendment act put in place.

Behavioural

Users, clients and investors are faced with the complexity of certain markets and contracts. For example, energy performance contracting is a relatively risky business for energy suppliers and service and requires clear framework conditions and well-defined user behaviour in order to provide sufficient confidence that the investment will be recouped. While this is generally the case with commercial and public service customers, residential end-users represent a higher risk associated with an unpredictable element of user behaviour. This barrier has been included in the assessment made by France but is applicable across all Member States. Client distrust of energy services has been cited by Estonia, which may be connected to general client risk aversion about EPC models or future uncertainty. Limited confidence in ESCO services (a feature of markets at development phase) or preferences for in-house solutions are also additional behavioural factors that can act as barriers to market maturation. The latter could be the case for major energy consumers have long since established internal structures and responsibilities to ensure a cost-effective supply of energy (e.g. Austria, Malta). In such cases, energy management systems are already in place and the potential for optimisation is regularly examined.

Market & external

Energy prices have a significant impact on what is cost-effective. Low energy prices mean that short-term returns on investment, in particular for extensive investments and associated services, are difficult to demonstrate. In addition, energy price volatility may have a major impact on the deployment of energy efficiency measures. This barrier has been included in the German analysis. When it comes to SMEs (e.g. in the case of Austria), the cost factor of energy is often less significant (due to lower energy intensity) and the potential to achieve cost-effective percentage improvements is not taken into consideration. In addition, small scale projects are not compatible with energy performance contracting. For example, the reluctance by municipalities to engage in EPCs, which can be in part explained by the small structure of many municipalities, is an impending factor for the uptake of energy performance contracting by the public sector in Luxembourg. In addition, split incentives can severely limit market penetration of ESCOs and EPC-related projects in the rental and multi-family sectors. Misaligned financial incentives exist in both residential and non-residential (e.g. offices) sectors. All countries with a large share of rented commercial or residential space (e.g. UK and Germany) face this market barrier.

Financial

Energy-efficiency projects compete for scarce capital with more traditional investments such as small power plants and industrial expansion. Investors might not have sufficient capital and would be forced to draw on their lines of credit in order to invest in energy efficiency measures. Moreover, companies generally add energy costs under overhead costs, and energy consumption is considered as secondary issue with regards to investment decisions. Overall awareness in the area of energy efficiency is generally low among the banking sector (e.g. Estonia). For many banks and financial institutions, the concept of energy services is new. In certain countries (e.g. Latvia), there is a lack of clarity on financial aspects related to ESCOs.

Technical & administrative

The lack of technical knowledge, handling of technical risks as well as lack of experience in procurement are issues faced by many countries in which the concepts of EPCs and ESCOs are new (e.g. Estonia). Despite its long experience, Germany also refers to technical risks, particularly with complex technical solutions, and operational risks such as adverse effects of processes of changes in product attributes. Hidden costs, such an unexpected maintenance or training needs, may also arise, reducing the savings from efficiency measures.

Energy contracting, and in particular energy performance contracting, entails relatively high transaction costs associated with compiling information and identifying technically, financially and contractually attractive solutions. Transaction costs are also incurred in preparing projects, from arranging the financing, issuing the request for tender and implementing the measure, and from drawing up the contract. For this reason, contracting is often seen as an option for relatively large projects only. Reducing the transaction costs could help to exploit further market potential.

Public procurement, annual budgeting and accounting

As energy savings are a central focus of an EPC, it is important that obstacles related to public procurement and accounting are removed to allow the public sector to engage in energy performance contracting and promote the use of ESCOs to other sectors by showcasing the benefits through real examples in their own premises. To support this, the EED has called Member States to take measures, regarding public purchasing and annual budgeting and accounting, with a view to ensure that individual public bodies are facilitated to make investments in improving energy efficiency and use long-term energy performance contracting.

Only Austria, Spain, Sweden and the UK provided information, while Germany, Finland and the UK stated that no legislative barriers preventing the public sector from accessing ESCO services exist. In the UK, a working group, established in 2012 to analyse the specific accounting rules governing energy efficiency improvements and look at available financing and structuring options, concluded that there are no specific barriers, it was decided that guidance on the precise accounting treatment of energy efficiency projects may be helpful and a toolkit to assist public sector organisations develop business cases for energy efficiency investments is to be now considered.

In Austria, it is stated that a legal provision relating to the measures required by Article 19(1b) EED is standardised in Article 19(5) of the Federal Procurement Act, which stipulates that environmental compatibility must be taken into account in the public procurement process. This may be achieved, in particular, by including environmental aspects (such as final energy efficiency) in the performance or technical specifications or by defining concrete environmental criteria for awarding contracts. In its NEEAP, Spain has pointed out the lack of a specific and binding interpretation by Eurostat on the consideration that must be given in national accounting to investments made by an energy service company in publicly-owned buildings or installations. It has therefore urged for Eurostat to make a decision regarding the national accounting of public-private collaboration agreements on integral measures for restoring buildings owned by public administrations (or others which affect publicly-owned installations), since applying the current general interpretation in relation to part VI.5 of the manual on government deficit and debt (ESA 95) leads to the application of the 50% criterion to the calculation of such investments as public debt, which under the current budgetary and fiscal restrictions acts as a deterrent from energy service procurement in the public sector.

In Sweden, a study commissioned by the Swedish Government to audit the public sector identified various barriers to energy efficiency upgrades in public bodies. One of the most significant barriers included organisational issues, such as failure to engage in collaboration between administrative bodies, failure to produce steering documents for energy requirements in connection with procurement procedures and failure to give sufficient priority to such work in terms of time. Lack of skills, for example in relation to how energy requirements may be imposed in the context of procurement and financial management were also stressed, where budgeting methods may constitute a barrier. With regard to public procurement, one in four local authorities have said that they do not have steering documents for energy requirements in procurement procedures, and more than three in four local authorities and county councils said that they do not have the skills for imposing energy requirements in the context of procurement procedures. Approximately, half of the local authorities and county councils rarely or never follow up the energy requirements that are imposed in the context of procurement and purchasing and nearly half of the local authorities felt that their budgeting methods were a barrier to energy-efficient measures, with a primary focus on short-term rather than long-term measures. Similar barriers also exist for housing companies. Various existing instruments and initiatives aim to tackle the identified barriers to improving energy efficiency at public bodies. For example, the Swedish Environmental Management Council is working on a broad portfolio of information initiatives aimed at energy-efficient procurement, and the Swedish Environmental Protection Agency has support in the form of various networks for national authorities. In addition, the authorities are working on a benchmarking network for authorities with a focus on measures to reduce their own energy consumption. The Swedish Government’s assessment concluded that no additional measures need to be adopted with regards to legislation and practices in the areas of public procurement, annual budgets and annual accounts but provides a valuable basis for establishing how the Swedish Competition Authority’s support for national authorities, local authorities and county councils for the procurement of energy-efficient goods and services could be developed.

Conclusions and recommendations

The ESCO market in Europe has seen an impressive development in the last 5-10 years. The number of ESCOs and ESCO projects has been on a growth path, and a large array of policy instruments have been designed to further promote this solution. Policy instruments are partially based on the requirements from EU Directives, but the EU itself has also contributed by specific projects, on awareness raising, project financing, piloting, and providing financial support or guarantees.

As a result, ESCOs have become an acknowledged and applied alternative for construction project financing, management, quality assurance and risk management in several countries. At the same time, they are considered as part of the energy efficiency policy system, and can be related to EEOs, public sector obligations, energy management requirements, and so on. However, the ESCO concept remains almost unknown and/or unutilized in other Member States, as a result of poor policy implementation, fear of the “new” concept, legal barriers, lack of construction projects in general.

In the countries with a strong ESCO sector, such as Germany, Austria, the Czech Republic, Italy, it used to be common to focus on large-scale, long-term projects where the owner is expected to be fix for several decades providing a certain level of security of investment, therefore reducing the transaction costs. By 2015, these ESCO markets have matured significantly, and they are backed with a stable policy system, and it is possible to carry out projects in smaller scale investments, longer pay-back, or bundle buildings into a larger set. It gives an opportunity to do ESCO projects in the commercial buildings sector, and refurbish office-buildings, hotels, shopping malls, etc. ESCOs have a significant market in the non-residential private buildings sectors in Germany, Italy, the Netherlands, Portugal and the UK. There are still only a few countries where ESCos act extensively in the commercial buildings sector, and generally, industrial and public sector projects are more preferred.

There is another tendency, in countries with less developed ESCO markets, that non-residential private buildings receive an equal or higher interest from ESCOs than the public sector. A reason for this lies with the fewer legal barriers the partners (ESCO and the client) have to overcome outside public procurement and public management. It is applaudable that ESCOs can work on a market basis across Europe, and ESCO projects – even if a few – can be carried out in countries with less developed markets.

As can be seen from comparing Table 3 and Table 4, policy instruments for improved information dissemination, awareness raising and demonstration are linked to the possibility to transfer earlier successful projects into the commercial buildings sector. Furthermore, a registry of ESCOs is also typical in the countries with ESCO projects in commercial buildings, probably by supporting a more transparent ESCO market, and an ease in choosing the contractor.

While ESCOs could provide a crucial share of energy renovation of public buildings and sites, as soon as the market value of this solution is apparent, they can become an important player for commercial buildings. EU and national policies should work towards moving ESCO projects to a market basis as much as possible. This can be further aided with more awareness raising, partnership development (e.g. at market fairs, registries, associations, advertisements, demonstrations). VAT and tax regimes should be fair, and the booking of ESCO projects should be made simple and fair. Energy performance requirements and obligations for energy management can also contribute to a need to improve energy efficiency performance of commercial buildings, and thus opening a niche area for ESCOs. Availability of monitoring and verification, and a transparent market will also popularize ESCOs for this segment. Finally, regular policy adjustment, acknowledgment of energy performance, or the promotion of intermediators, such as ESCO facilitators can also be helpful.

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Session HVAC

Features of Air Conditioning Energy Consumption in UK Commercial buildings

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Abstract

This paper summarises the analysis of information relating to energy use for cooling in UK commercial buildings collected from a number of sources. The primary purpose of the study was to expand the evidence base for policy analysis relating to the future air conditioning energy of buildings in the UK, but the results will be of wider interest.

In particular, the data sources included:

- The recommendations made in a sample of 500 air conditioning inspection reports
- Technical characteristics of the 500 inspected air conditioning systems as defined in the Energy Performance Certificates (EPCs) for the buildings in which the inspected systems were situated.
- Standardised annual, monthly and peak electricity consumption for cooling measured in a sample of 32 offices. These data were analysed using an algorithm that was developed to expand the scope of an existing product policy model that is used to estimate aggregate air conditioning electricity consumption for purposes of policy analysis and development.

This paper does not address policy issues or future ownership levels of air conditioning as these were outside the scope of the study. A full report of the work will be available from DECC during 2016 [1].

Introduction

The ownership of air conditioning in UK buildings is increasing as the result of its continued market penetration. Despite policies that require minimum system and equipment efficiencies and constrain cooling loads in buildings, energy use for air conditioning continues to increase. The impact of existing and possible new policies has been studied by the Market Transformation Programme [2] but the evidence base which underlies these analyses is, in some respects, incomplete. The information in this paper is a summary of work carried out for the UK Department of Energy and Climate Change (DECC) to (partially) fill these gaps.

In particular the study included the following activities relating to electricity used by air-conditioning in UK Commercial and public buildings:

- A literature review of the trends in air conditioning usage patterns in the UK and the possible future impacts of new technology
- Assessment of the most common problems noted in 500 anonymised air-conditioning inspection certificates and reports. These were selected at random by the UK Department of Communities and Local Government (DCLG) and covered a wide range of types of premises (retail, offices, hotels/restaurants etc.) and a range of sizes.
- Analysis of the Energy Performance Certificate (EPC) data relating to the reported cooling system characteristics and the calculated cooling demands and energy consumptions of the systems
- Reanalysis of existing measured electricity use for cooling (and, in some cases for other elements of the air conditioning systems) in 32 offices.
- Development of an algorithm to allow the estimation of peak and monthly electricity demand due to air-conditioning in the UK.

This paper provides an overview of the results. More information will be found in the final report, which will be published by DECC during 2016. The results are presented under the following headings:

- Overview of the algorithm methodology
- Energy consumption
- System and product efficiency

- Operation and maintenance
- Characteristics of the UK stock of air conditioning systems
- Conclusions

The different elements of the study have overlapping scopes and do not map one-to-one onto these themes but are related as shown in table 1. (Relative importance of the contribution is represented by more Xs, where XXX is of the highest importance)

	Study Element			
Topic	**Algorithm**	**Measured Data (including algorithm outputs)**	**Analysis of Air Conditioning Inspection Reports and Energy Performance Certificates**	**Literature Search**
Algorithm methodology	XXX	X		
Energy consumption	XX	XX	XX	X
System efficiency		X	X	XXX
Operational practice		X	X	X
Stock characteristics			XX	XX

Table 1 Mapping of topics and study elements

Methodology and Results

General

The study contained several, sometimes overlapping tasks required to fill knowledge gaps rather than forming as an integrated comprehensive study. This is reflected in the structure of the paper which is, to a degree, a narrative rather than a formal framework. . In particular, key results sometimes reflect information from several different tasks and issues of methodology are dealt with as they arise, rather than as a separate “methodologies” section.

Overview of the algorithm methodology

An important objective of the study was to develop an algorithm to extend the scope of DECC’s existing air conditioning energy model [2] to allow it to estimate the distribution of electricity consumption by month and to provide a standardised estimate of peak half-hourly electricity demand. The methodology employed is also used to analyse measured air conditioning electricity consumptions and it is this application that is particularly relevant to this paper. Full details can be found in the DECC report [1]. The algorithm can also, in principle, be used to examine how consumption varies with climate, including location, urban heat island and estimates of future climate change. Within this study, the impact of location in the UK was examined.

The general principle of the algorithm is the well-known concept of an energy signature, in this case applied to daily electricity consumption (specifically, but not exclusively, of the cooling generator of an air conditioning system). For a number of reasons, the shape of the energy signature for the electricity consumption of an air conditioning system can be expected to be non-linear [3] and a simple linear relationship (as is implicit in degree-day analysis) is not always appropriate. The energy signature is therefore expressed in the form of average consumptions for 1 degree K wide outdoor air temperature bins. Monthly electricity consumptions are calculated by applying frequency distributions of daily mean temperature to energy signatures. The energy signatures are ideally based on measurements – as in this study - but simulation results may also be used. In this study, outdoor temperatures were taken from CIBSE Test Reference Years.

Energy signatures only reflect the effect of variations of external mean temperature, so an additional process, which requires information with a finer time resolution is necessary to produce a standardised peak (half-hourly) power demand. This part of the algorithm uses the frequency distribution of differences between power at half-hourly intervals within a day and the mean 24-hour power requirement for that day predicted by the energy signature. This variable reflects all the factors that affect consumption but which are not correlated with mean daily temperature, for example within-day variations of external temperature or ventilation rate, and internal heat and solar heat gains (any correlation with temperature will have been captured by the energy signature). In this study, the value corresponding to the upper 5% of the observed residuals was used initially but was revised to 1% as this gave better agreement with observed peak power demands.

Energy consumption

General Considerations

The energy consumption of air conditioning systems comprises several elements: cooling generation, fans and pumps, heating (including preheating and reheating, humidification, dehumidification and controls. These can be expected to differ between system types, buildings, locations and users. The literature search revealed estimates for annual consumptions for some of these elements, usually for specific buildings, but very few measurements.

The analysis focussed on electricity consumption by cooling generators of systems in offices, reflecting the relatively large quantity of available data. However, the rather sparse information on other sectors suggests that energy use in the retail sector is of similar magnitude to that in offices, has rather different characteristics and would justify further examination. The relatively limited information on energy use by the rest of the system is given in the full report.

Annual energy consumption can be described in two main ways: as kWh per square metre of treated space, or as equivalent full load hours (EFLH, in effect, an annual load factor). A floor area basis is usual for energy benchmarks, while EFLH is used when peak cooling demand (or installed cooling capacity) is known. The current DECC model is based on estimates of total installed capacity

.

Literature search

The literature search focussed on publications within the last decade that are relevant to the UK – though in some areas only older information was identified. It identified well-known (but 20-year old) UK benchmarks for office air conditioning consumption [4] and a number of public domain and "grey literature" reports of simulated annual consumption [5, 6] for specific buildings but only one set of measured consumptions [7].

The "typical" benchmark consumptions for cooling in offices are between 31 to 36 kWh/m^2 pa depending on office type, and 14 to 21 kWh/m^2 pa for "good practice. (Whole-system benchmarks, including fan energy, are 44 to 103 kWh/m^2 pa). Reported simulation results for cooling cover a somewhat similar range of 10 to 45 kWh/m^2 pa and usually assume good operational practice. The calculated electricity consumptions in the EPCs were also mostly within this range, although there were values as high as 175 kWh/m^2 pa. A recent analysis of electricity consumptions reported in Display Energy Certificates for UK public sector offices [8] found that the median values for air conditioned and heated and naturally ventilated buildings differed by 72 kWh/m^2 pa, while mechanically ventilated but not air conditioned buildings lay half way between these values. The measured consumptions for were between 14 and 270 kWh/m^2 pa with differences between buildings and, to varying degrees between system types. This data was reanalysed for the present project – results are summarised in later sections.

EPC analysis.

The sample of EPCs contained different types of air conditioning systems and a range of building types. It therefore provides some insight into the variability of energy cooling demand and energy consumption between types of buildings and systems, albeit based on the (CEN-based) monthly calculation methodologies employed in most cases (16 EPCs which used dynamic simulation models)

The average calculated electricity consumption for cooling in offices was 37 kWh/m^2 pa when weighted by number of installations; when weighted by floor area the figure increased to 51 kWh/m^2 pa. There were large variations in annual energy consumption (and also in cooling demand) per m^2 between office buildings. These figures relate to standardised weather conditions (for a given location), occupation patterns and levels of heat gains from equipment (and for cooling demand ignore system efficiency). The variations must therefore result from difference between buildings, heat gains from lighting or location. Table 2 shows summary figures for other types of building (but note the very small sample sizes in some cases!).

Building Type (and planning class)	Number of Buildings	Floor Area (m^2)	Average (sensible) cooling demand kWh/m^2	Average Cooling electricity consumption kWh/m^2
A1/A2 Retail	319	391,313	87	55
A3/A4/A5 Restaurants & Cafes	32	20,522	126	99
B1 Offices	99	376,660	74	37
B2/B7 Industrial	5	53,432	70	46
B8 Storage and Distribution	6	22,980	46	33
C1 Hotels	16	132,255	47	29
C2 Hospitals and Care Homes	1	8,221	353	238
C2 Universities and Colleges	1	558	159	39
D1 Libraries Museums and Art Galleries	1	2,351	62	27
D1 Primary Health Care	4	4,424	89	43
D2 General Assembly and Leisure	6	13,827	54	47

Table 2 Overview of EPC data (averaged by number of systems)

Table 3 shows calculated consumption figures from the UK cost-optimality report [9] calculated using the same tools. This shows what is (theoretically) cost-effective and, in principle, can be compared to the values from EPCs. The cooling energy is considerably less than that observed in the EPCs. As the cost-optimality report showed that current building regulations are already close to being cost-optimal, cooling consumption in optimised new buildings is (theoretically) much lower than in existing ones. There is no cost-optimality data for existing air conditioned offices, but there appears to be significant potential for savings in new and existing hotels.

	Calculated annual consumption (kWh/m^2 pa)							
Building type	**New Buildings**				**Existing**			
	England, Wales, N Ireland		Scotland		England, Wales, N Ireland		Scotland	
	Cooling	Auxiliary	Cooling	Auxiliary	Cooling	Auxiliary	Cooling	Auxiliary
AC Office	9	14						
Hospital	15	15	15	15	36	26	29	19
Hotel	7	39	4	29	17	73	13	63
Distribution centre	0	1	1	3				
Retail warehouse	13	21	18	29	40	47	39	47

Table 3 Calculated cost-optimal consumptions

2.2.4 Measured data

The measured data were originally collected as part of a collaborative project between BRECSU, Cardiff University and National Grid as an input to a planned Good Practice Guide. The buildings were all offices, of varying sizes, located across Southern and South Western England and Wales and were monitored for at least a year, but not for identical periods. The “as measured” results showing the variability of measured annual consumption between buildings and differences between types of system have previously been published [7] and focus on the combined energy use by each air conditioning system for cooling, heating (if the system is reversible) and air handling. This data was reanalysed to separate cooling, heating and – where it was measured - “rest of system” energy consumption. The data were also temperature-corrected using the energy signature procedure outlined in section 2.1 to produce comparable annualised consumptions. Average electricity consumption for cooling for London (CIBSE Test Reference Year) weather was at the upper end of the ECON 19 “typical” at 50 kWh/m^2 when weighted by system numbers, and 43 kWh/m^2 when weighted by cooled area.

Several systems showed changes of consumption pattern during the period (typically two years) of monitoring. In some cases these appeared to reflect users learning how to operate the system effectively. In other instances there appeared to be changes to time control settings, perhaps reflecting changes of occupancy, Where there were different patterns of consumption, data from the most consistent period were used (these generally also covered the longest period of time.)

Some systems were reversible, in which case the electricity consumption for heating was also determined – this is reported on the full report [1]. Two systems provided heating but never operated in cooling mode (the zero consumption figures are excluded from the averages above).

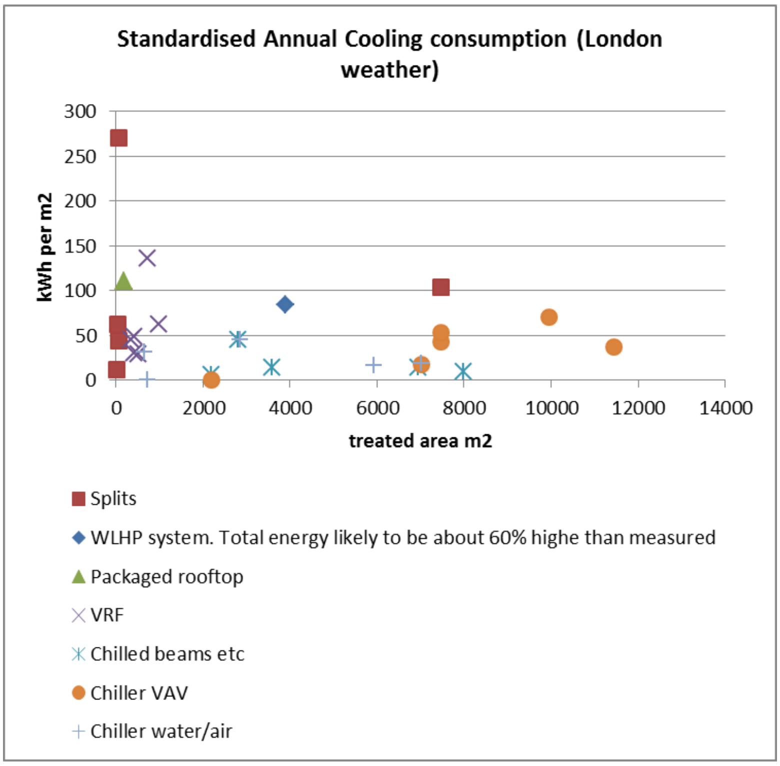


Figure 1 Standardised cooling consumptions from measured data by floor area

Figure 1 summarises the annual electricity consumption per unit of floor area for cooling for London weather. It is clear that the average value hides considerable variation between individual systems. The sample size is too small to make definitive statements but several features are apparent:

- There is slightly more variability between buildings with small floor areas, though this appears to be dominated by one system (which, unusually, serves a small office area within a larger industrial space).
- There is more variability for split and variable refrigerant flow (VRF) systems, which may be due to them being more commonly used in smaller spaces or to the greater degree of local control that they provide.
- Chilled ceiling and beam systems (all except one were passive) generally have lower consumption than the average – but they are presumably less likely to be specified for high-load situations.

Standardised peak half-hourly power consumption was also determined for each system using the procedure described in section 2.1 above. The initial use of a 5% exceedance value resulted in standardised peak values that were significantly below those that were actually observed. Reducing the exceedance level to 1% increased the average peak power by 16%, with the value for some systems virtually unchanged but others increasing substantially. Clearly the frequency distribution of high power demands differs significantly between buildings. By inspection, systems with relatively infrequent high values, tended to exhibit periods during which they were relatively common. This may have resulted from changes of building use, or possibly from shadowing patterns from nearby buildings. (In two cases, there were consistent high power levels for isolated periods of one or two warm but not especially hot days – including, in one case, a weekend day. It is speculated that these might have resulted from window opening). Peak electric power values for London with the 1% exceedance level varied between 5 W/m² and 40 W/m² (the split system in an unusual space is off-scale, with a peak demand of 200 W/m²). At an Energy Efficiency Ratio (EER) of, say 2.5, they would correspond to peak cooling demands between 12.5 and 100 W/m², which are lower than the indicative figures in guidance for system inspectors [10]. In the majority of cases they are significantly below the installed system power. (Sizing figures may, of course, need to consider the possibility of above-design loads and are unlikely to reflect load diversity between different spaces served by the same system.) Comparable measured peak power levels (median day-time peak across a large number of systems of 19 W/m²) have been reported from a large European study [11].

The 1% value also reduced the variability of the EFLH values determined from the ratio of peak to annual consumption compared to the use of a 5% value..

Figure 2 plots the standardised peak power against the standardised annual consumption for London weather. The ratio of the two values is the EFLH value. As can be seen, there is a generally consistent trend.

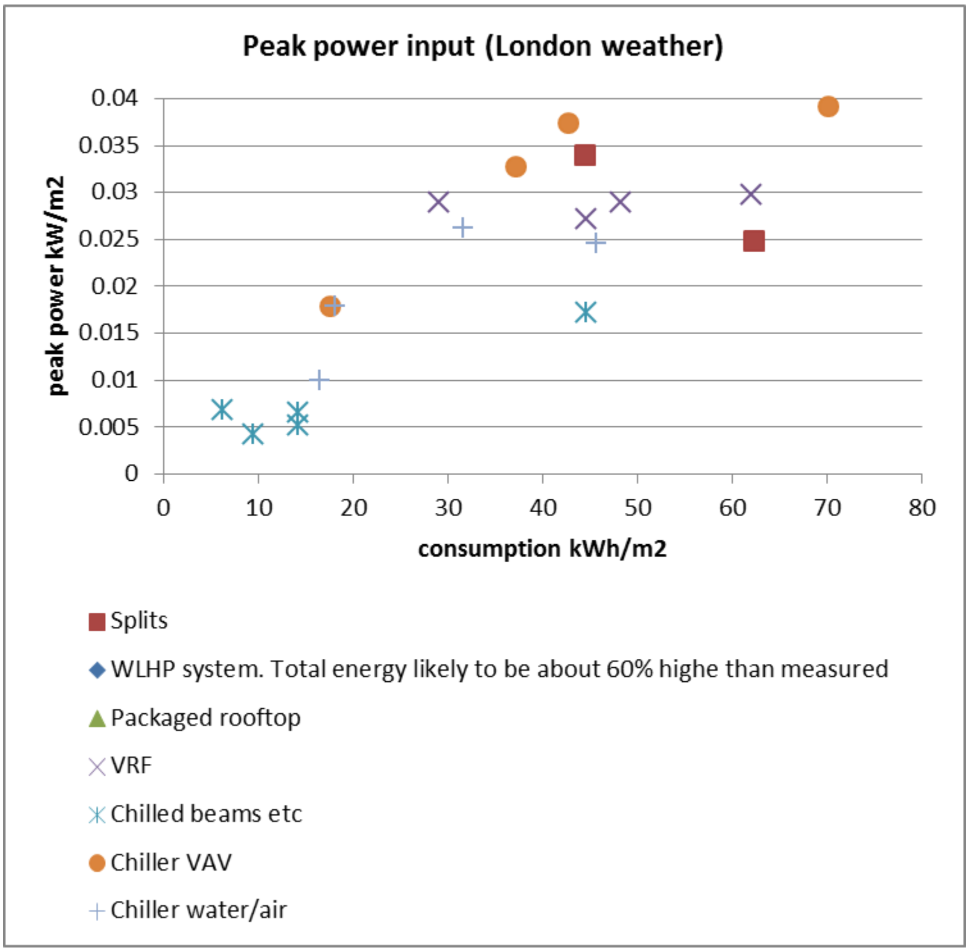


Figure 2 Standardised peak power input versus standardised consumption

Figure 3 shows the variation of standardised peak power per square metre of treated floor area with system type and floor area. It is noticeable that the chilled ceiling systems have low peak demands. This may reflect the fact that such systems are unlikely to be used in spaces with high heat gains. Apart from this, there is no apparent systematic variation with system type of treated floor area.
The coefficient of variation for EFLHs was 40% of that for consumption based on floor area, implying that peak power demand is a more reliable indicator of annual consumption than is floor area.

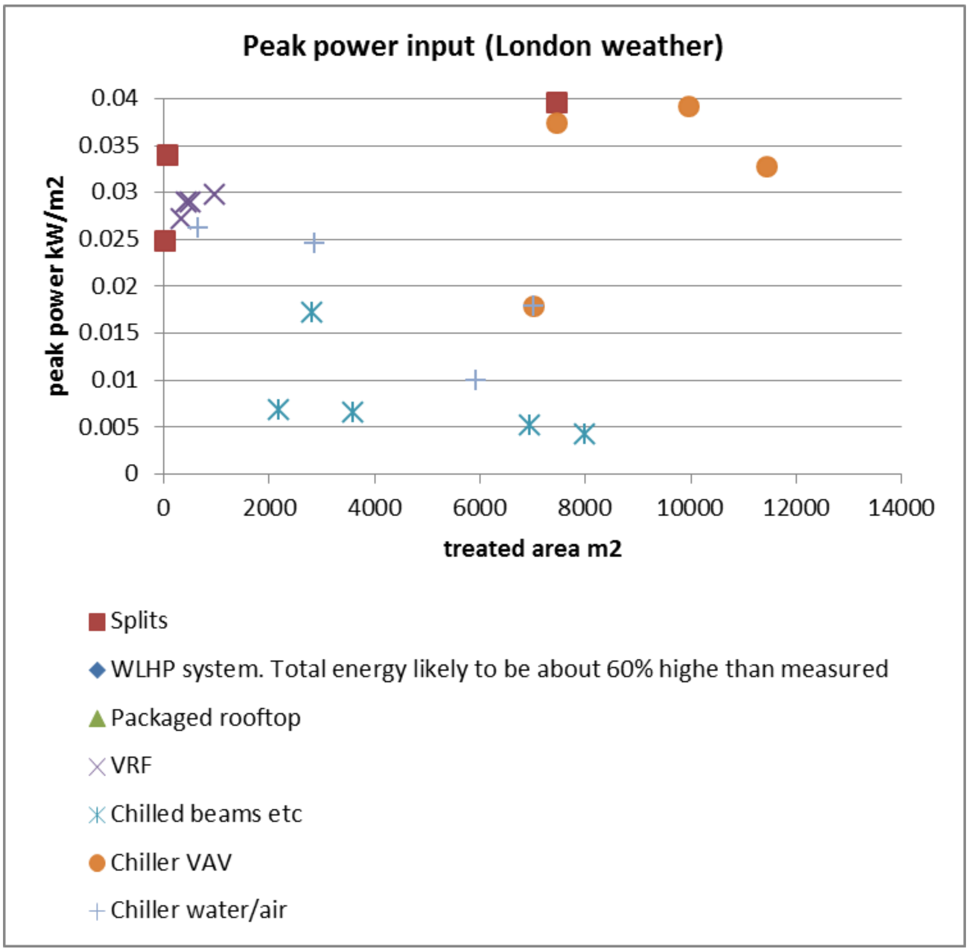


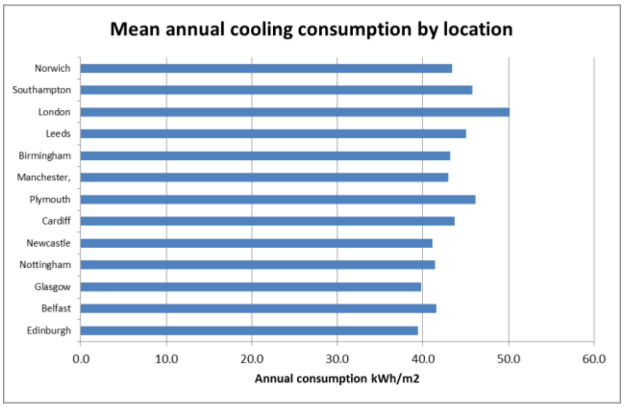
Figure 3 Standardised EFLH versus floor area

The EFLH figures are high compared to the results of simulations (which typically are 100 to 700 hours). In part this might be due to weekend and overnight energy consumption (including base consumption not related to cooling load) in the measured data. Another possible contributor is that the efficiency (EER) of cooling generators varies with load and (for air-cooled products) with external temperature. This effect is not always included in simulations but is integral to the measured data. It is also possible that the probabilistic basis for the standardised peak power demands in this study is less demanding than that produced by simulations using summer design years. For 14 of the monitored systems we know the connected electrical power of the cooling generator.

Models of national electricity use for cooling [2, 12, 13] that are based on estimates of total installed cooling capacity (obtained from sales data), need to take this discrepancy into account. The current DECC product policy model uses a default value of 1000 hours in conjunction with estimated installed cooling capacity rather than peak demand. This combination will yield estimates of annual electricity cooling demand that are broadly consistent with the observed values of energy consumption.

Standardised consumptions, EFLH values and peak power levels were also calculated for each of the locations for which CIBSE TRY data were available. These are summarised in figures 4 and 5. In both figures, the average value (weighted by number) is shown for each of the locations.

The variations of average values between locations are less marked than the variations between individual buildings. Broadly speaking, there is a south to north tendency for the annual consumptions and perhaps an inland – coastal difference for EFLH. London (Heathrow) weather produces the highest consumption figures (which presumably would be higher if weather data for central London was used).



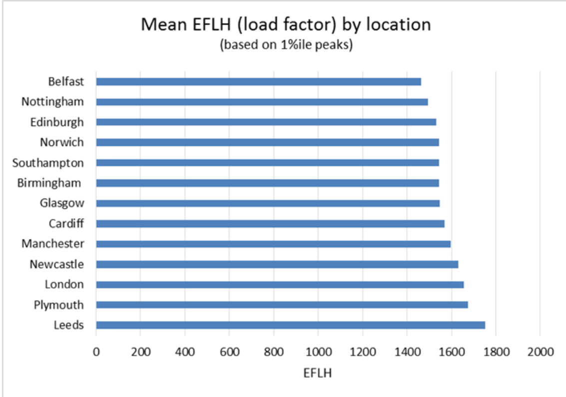


Figure 4 Cooling consumption by location

Figure 5 EFLH by location

System and Product Efficiency

There is a considerable literature on product efficiency, not least from the Preparatory Studies for the Energy-related Products Directive [14, 15]. There is very little information on the distribution of products of different efficiencies in the stock, with the principal source [16] being based on the Eurovent-Certification product database [17].This database provides information on products that are on the market and were tested for the database. Estimates of the distribution of efficiencies within the existing stock are therefore somewhat speculative. The data from EPCs, shown in table 4 provides an empirical (if incomplete) comparison.

	Number of reported SEERs in range				
System type	**< 2**	**2 to 3**	**3 to 4**	**4 to 5**	**>5**
Active chilled beams		1			
Chilled ceilings or passive chilled beams		2		2	
Constant volume system (fixed fresh air rate)	1	26	3	1	
Constant volume system (variable fresh air rate)		12	1		
Dual duct (constant volume)		1	1		
Dual-duct VAV		4	3		1
Fan coil systems		39	13	5	1
Indoor packaged cabinet (VAV)		4	2		
Induction system		3			
Single room cooling system		15	3	1	
Single-duct VAV	1	7		1	
Terminal reheat (constant volume)		1			
Water loop heat pump		1			
Split or multi-split system	3	401	146	23	12

Table 4 Cooling generator Seasonal EER (SEER) by system type

Table 4 summarises the average SEER values reported by EPC assessors for cooling generators associated with different types of system (with a small number of technically implausible values removed). About 60% of the reported values were (conservative) NCM default values which vary between 2 and 2.7, depending on product type and whether or not products are on the Energy Technology List. This presumably reflects a lack of evidence available to assessors, probably for older products.

These values can be compared to the existing and forthcoming requirements of the Energy-related Products Directive. These are currently between 3.87 and 4.3 for products of 6 to 12 kW cooling capacity and 4.14 to 4.6 for products of less than 6 kW cooling capacity depending on the GWP of the refrigerant used. Requirements for products of more than 12 kW cooling capacity are expected shortly and, for air-cooled chillers, are expected to be initially in the range 3.5 to 4.5 (but expressed in terms of primary energy). Replacement of the less efficient cooling generators would clearly reduce energy consumption, but is unlikely to be cost-effective until they reach the end of their lives and this was rarely recommended in the inspection reports. Default and lower values of SEER automatically trigger an EPC recommendation to consider replacement.

Energy consumption for cooling depends is not simply dependent on the efficiency of the cooling generator but also depends on heat gained from fans – and hence on specific fan power – and the leakage of and heat pick up by ductwork and air handling units. Although assessors are required to input Specific Fan Power (SFP) and duct and air handling unit leakage values, this information is not recorded in the EPC database and so cannot be analysed. Calculated overall system cooling efficiencies can be deduced and are reported in the full report [1].

Operation and Maintenance

Published studies [18] have estimated that the amount of air conditioning energy wasted by inefficient operation and maintenance is similar to the potential savings from load reduction or use of more efficient equipment. This wastage is, however, less amenable to reduction by regulatory policies, the main current policy instruments being the current requirement for system inspections and the (somewhat elderly) energy consumption benchmarks for office air conditioning.

Within this study, 457 Air Conditioning Inspection Certificates (ACICs) and 500 Air Conditioning Inspection Reports (ACIRs) were inspected (a number of ACIRs did not have corresponding ACICs). These were the same buildings whose EPCs were analysed, although in some cases a single building contained several systems.

The majority of certificates relate to the retail sector which has the most buildings but not the largest total cooled area. The other categories include a hospital, medical centres, bingo halls, laboratories and gyms. The breakdown by system type is shown in Table 2 in section 2.3 which illustrates the predominance of split systems. In the sample, almost all retail outlets and bank branches are air-conditioned by splits, multi-splits, or VRFs. The central systems (chillers) are mainly to be found in office buildings with a very small number of examples (<5) of chiller installations in retail buildings and hotels.

Over 80% of installations are reported as being well-maintained. However, 25% of these “well-maintained” systems are noted as having dirty or blocked filters, missing or damaged insulation, or faulty or out of order units. In some of these cases it appears that the decision to classify the systems as “well-maintained” is based on the presence of a maintenance agreement with a reputable firm rather than the observed condition of the system.

Of the 442 systems which fell within the f-gas parameters stipulated for leakage checking, the inspector reported an F-gas inspection report in 89 (19.5%). 22 buildings (4.8%) had sub-metering of the HVAC systems, whilst another 16 buildings (3.5%) had partial sub-metering.

On average there were in excess of nine recommendations per inspection report but the majority of these were generic and not linked to specific measures. Table 5 shows the specific recommendations classified into subject areas, ignoring repeated recommendations in the same report. As in published studies [18], the most frequent recommendations relate to operation and maintenance issues, followed in this study by the related issues of documentation and staff training.

Description	Frequency
Controls	27%
Maintenance	16%
Documentation	10%
Staff training	10%
Metering and Monitoring	8%
Refrigerants	7%
Equipment	7%
Internal heat gains	4%
System sizing	4%
External heat gains	3%
Renewable energy	2%
Others	2%

Table 5 Frequency of recommendations

Inspectors reported that 56% of systems were incorrectly sized, based on comparison against benchmarks for different building uses [10], varying slightly with building use. Some of the apparent mismatches could result from specific building characteristics which are not reflected in the generic benchmarks. Systems which were highlighted as incorrectly sized were equally distributed between being undersized and oversized. In the case of oversizing a number of inspection reports highlighted the fact that the systems installed had capacity control which made oversizing less of an issue.

From the literature search, a European study [18] found that although two-thirds of the savings identified by inspections related to operational and maintenance issues, these only represented 23% of the potential savings of this type were identified by more detailed Case Studies. The inspections were even less effective at identifying other potential savings: only identifying 9% of the load reduction and 6% of the system efficiency potential improvements.

In 19 of the monitored systems the intended hours of occupation were known. Actual weekend patterns of cooling were inferred from the daily load profiles and the form of the daily energy signatures. They can be categorised into four classes shown in table 6.

Weekend system operation	Weekend occupancy	No Weekend occupancy
Operating (generally for weekday hours)	4	4
Not operating	4	7

Table 6 Weekend system operation and reported occupancy

In 11 of the 19 buildings the weekend system operation appeared to be consistent with reported occupancy: either system operating and occupants present or no occupants and no system operation. In the other 8 buildings the system operation was not in line with reported occupancy.

On average 14% of annual consumption in the monitored buildings was at weekends, ranging from less than 1% to 35%. The highest value was associated with a system that was intentional use at weekends, apparently with a significant load. Some of the weekend consumption by cooling generators was a base level of consumption not related to outdoor temperature, presumably for ancillary purposes, but many systems appeared to be in normal operating mode at weekends. Overnight operation of cooling generators is difficult to assess since night-time cooling loads will often be low. Judged by the occurrence of energy consumption early in the morning (before reported cleaning times) during the summer, a number of system appeared to be “live” at night

Stock characteristics and related issues

The most comprehensive data for air-conditioned floor space that was located by the literature search [19] relates to 1994 and is summarised in table 7. Estimates for the overall increase in installed cooling capacity derived from market research studies of sales for new and replacement equipment have been published in connection with the Energy-related Product Directive [14, 15]. These suggest that the installed cooling capacity in the UK in 2009 was about 250% of that in 1994. However, the operational life of chillers that gave the best-fit to the data was significantly higher than the usual assumptions, at over 30 years, so the overall increase in installed stock may be lower than this estimate. On the basis of a less detailed analysis of sales by building type, most growth appears to have been was in offices and the retail sector. The analysis said nothing about the geographical location of the increase and growth. The 1994 data originated from a database of rateable values of buildings - it is planned to update the study with the most recent current data, but this is not yet available.

Region (E&W)	Percentage of floor area with full or partial air conditioning in 1994		
	Office	**Retail**	**Warehouse**
East Anglia	22%	15%	1%
East Midlands	14%	11%	4%
Northern	11%	14%	1%
North West	19%	16%	2%
South East	40%	19%	4%
South West	24%	15%	3%
Wales	15%	11%	1%
West Midlands	22%	14%	3%
Yorks and Humberside	15%	13%	1%

Table 7 Estimated percentage of floor space air conditioned in 1994

The EPC and ACIR data provides an insight into the prevalence of different types of air conditioning systems in different types of building (in this sample) and is summarised in table 7. The regional geographical location of the sample is also known and is reported in the full report [1]

	Total cooled floor area (m^2) and number of buildings per system type														
Building type	**Active chilled beams**	**Chilled ceilings or passive chilled beams**	**Constant volume (fixed fresh air rate)**	**Constant volume (variable fresh air rate)**	**Dual duct (constant volume)**	**Dual-duct Variable Air Volume (VAV)**	**Fan coil systems**	**Indoor packaged cabinet (VAV)**	**Induction system**	**Single room cooling system**	**Single -duct VAV**	**Split or multi-split system**	**Terminal reheat (constant volume)**	**Water loop heat pump**	**Total**
A1/A2 Retail and Financial/Professional services	5171		50421	45378	1895	5694	38191			1712	8251	136058		3089	295861
	1		*19*	*10*	*2*	*4*	*12*			*10*	*5*	*379*		*1*	*443*
A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways			1315	1342			1594	433	384	540	373	5974			11956
			4	*3*			*2*	*1*	*1*	*3*	*1*	*23*			*38*
B1 Offices and Workshop businesses		44368	14603			10628	98343	2206	7936	413	51639	86923	69		317126
		4	*4*			*1*	*37*	*2*	*2*	*5*	*16*	*127*	*1*		*199*
B2 to B7 General Industrial and Special Industrial Groups			16138				12435			33	147	3510			32263
			1				*3*			*1*	*1*	*9*			*15*
B8 Storage or Distribution			3380								1088	7054			11522
			1								*1*	*7*			*9*
C1 Hotels			1869			9976	7606	865		3755		71641			95712
			1			*2*	*2*	*3*		*1*		*28*			*37*
C2 Residential Institutions - Hospitals and Care Homes											1175	2553			3727
											1	*2*			*3*
C2 Residential Institutions - Universities etc												404			404
												2			*2*
D1 Non-residential Institutions - Libraries Museums and Galleries												1616			1616
												1			*1*
							14					1256			1269

D1 Non-residential Institutions - Primary Health Care Building							*1*					*10*			*11*
D2 General Assembly and Leisure plus Night Clubs and Theatres			719				4568			215		5485			10987
			2				*2*			*1*		*6*			*11*
Total	5171	44368	88444	46721	1895	26298	162752	3505	8320	6668	62673	322473	69	3089	782443
	1	4	32	13	2	7	59	6	3	21	25	594	1	1	769

Table 8 Overview of EPC information

Discussion and Conclusions

The main objectives of this project were to review existing data, provide new information and to make improvements to DECC's existing modelling procedures for estimating aggregate UK air conditioning electricity consumption. Results and issues of particular interest are summarised below.

Annual consumption

Calculated annual cooling demands from EPCs for offices showed considerable variation, despite using standardised occupation patterns, weather and values of heat gains from equipment. The variability in offices was only slightly increased when system characteristics were included. (For retail, hotel and restaurant buildings system characteristics were more important). Most of the calculated cooling consumptions were broadly in line with ECON 19, though there were a few systems with much higher calculated consumptions. For offices therefore, the sources of this variability seem likely to be building design, heat from lighting or location.

Measured electricity consumption for the provision of cooling (excluding that used by fans, pumps and controls) was normalised for external temperature and was also variable between different office buildings, especially for relatively small areas cooled by VRF or split systems. Average measured consumptions covered a wider range than that of the ECON 19 benchmarks (or from simulation estimates for well-controlled systems). In this case the variability is likely to reflect different occupancy patterns and densities and any imperfect operational practices. Rather few of the measured (or calculated) consumptions fell within the ECON 19 "good practice" range.

Peak power and load factor

Standardised half-hourly peak power demands were determined for the measured systems and were often substantially lower than the connected power. In some, but not all systems, standardised peak power is sensitive to the value of frequency of exceedance chosen.

The relatively low peak power levels and high annual consumptions resulted in higher load factor values (equivalent full load hours) than are commonly assumed or result from simulations, presumably from differences between the assumed loads or operating patterns. Nevertheless EFLH appears to be more consistent between systems and buildings than is consumption per m^2 of cooled area. It is therefore arguably a better basis for estimating aggregate electricity consumption – though this conclusion is contingent on the availability and reliability of data.

Cooling generator efficiency

The EPC data showed that the seasonal energy efficiency of cooling generators reported by assessors was generally low compared to the range of products currently on the market – and the current and imminent Ecodesign minimum requirements. 60% of the values reported were the default values built into assessment procedure. These presumably relate to products where efficiency information is difficult to obtain – probably older products which may well have low efficiency. As older products are replaced by new ones, significant reductions in consumption can be expected.

Operation and Maintenance

Other studies have indicated that imperfect operation and maintenance is a common cause of high energy consumption in buildings. Several elements of this study confirmed this. The most common recommendations from inspection reports related to controls, maintenance, documentation and staff training. Intended and actual operating patterns were known for some of the monitored buildings and showed that a significant proportion of systems were operating at weekends and at night when the building was reportedly unoccupied.

While the EPC and inspection report data provided some insight into the relative prevalence of different types of system in different building classes, there was little information on the total cooling capacity or location of air conditioning in the UK. The most recent floor area breakdown dated from 1994. Estimates of the subsequent increase of total installed stock of cooling products, based on sales figures can be used to estimate the current total cooling capacity, but not its location. A source of more recent information was identified but the data could not be accessed within the time frame of this project.

Information gaps

While the study has improved the evidence base in several areas, significant gaps remain. In particular there is very little accessible detailed measured consumption data, especially for building other than offices (of which the retail sector stands out) and for "rest of system" consumption. Up to date statistics on the size and location of air conditioned buildings are needed. The analysis of the sample of EPCs provided insight into the structure of the installed stock: a more detailed analysis of a larger and more structured sample would be valuable. In principle, successive changes to Building Regulations should have encouraged load reduction and more efficient systems in new and refurbished buildings: a breakdown of calculated consumption by new (or recent) systems and older ones would show the extent to which this has taken place.

Caveat
Some of the results confirmed existing but generally unquantified beliefs, while others were more surprising. Nevertheless, the relatively small and somewhat unstructured samples from which information was extracted mean that the results should not be seen as definitive.

Disclaimer
The work described was carried out by BRE under a contract funded by the UK Department of Energy and Climate Change. The measured consumptions were originally made by Gavin Dunn, then at the University of Cardiff. Thanks to the UK Department of Communities and Local Government for the EPCs and Air Conditioning inspection reports. Opinions, interpretations and any errors are the authors'.

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About actual management of large HVAC systems and about most attractive retrofit opportunities

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JCJ Energetics

Abstract

This paper is an attempt of valorization of the experience gained in the audit of several large air conditioned office buildings.

The selected examples of problems and solutions presented make appear the following facts:

- Specific fuel and electricity signatures can be used to detect important wastes ;
- Actual information and control provided by Building energy management systems (BEMS) disserve to be carefully checked;
- Buildings are very often over-ventilated and the actual air renewal disserves to be checked by CO2 concentration measurements;
- CO2 and water mass balances can be combined in order to detect any non-efficient control of air humidity inside the occupancy zones;
- Fans characteristics and similarity laws, combined with a few local measurements, are easy to use in order to check and to re-tune the ventilation flow rates;
- It may occur that "condensing" boiler are not condensing at all and such default disserves to be corrected…

1. Introduction

This paper is based on experience gained in the audit of various air-conditioned office buildings. Some examples of results were already presented in a previous paper [1], which was mostly devoted to the different ways of analyzing the building energy consumption through global and local recordings. The present paper is going further in the diagnostic and in the identification of possible retrofits.

2. About energy signatures

Typical examples of energy consumption trends are presented in **Figures 1 and 2**. The minimal powers observed for gas and electricity, respectively, could not justified by a satisfactory management:

- The "signature" of **Figure 1** consists in a correlation between the monthly gas consumption and the corresponding monthly average of outdoor air temperature. In the office building considered, the gas is only used for HVAC; except for some (very marginal) post-heating in air handling units, its consumption is expected to disappear when the average outdoor temperature is overpassing 18 or 20 C. Around that "no-heating" temperature, there remain, in the case considered, a very significant "residual" consumption.
- Another type of information is provided in **Figure 2**: the electrical consumption remains very important during no-occupation time periods (nights and weekends).

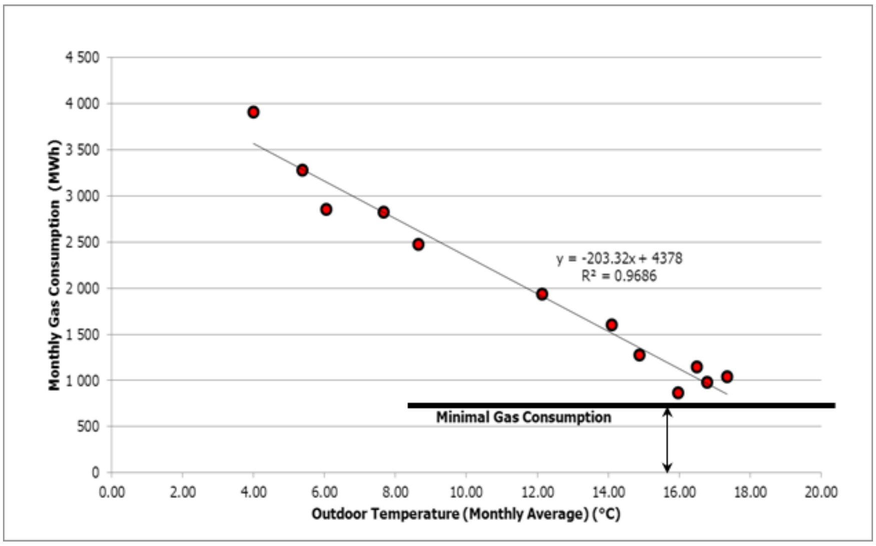

Figure 1: Trend of the measured monthly gas consumption vs. outdoor temperature on one year

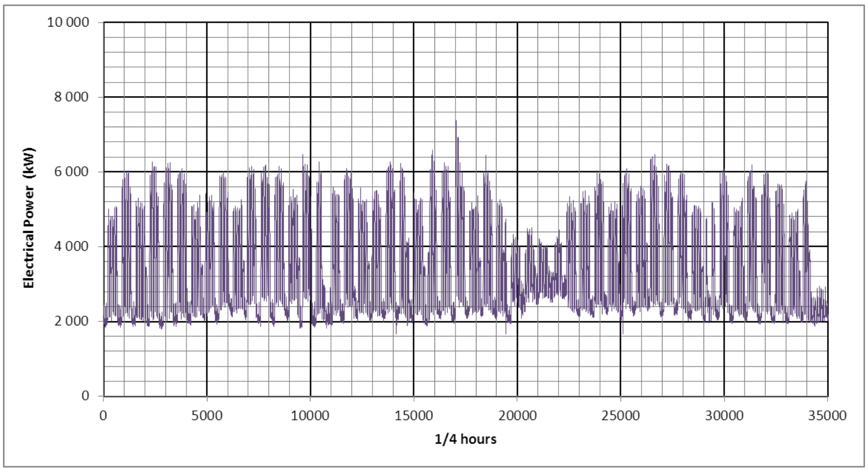

Figure 2: Quarterly electrical power vs. time on one year

Verifications made on the schedules contained in the management system of that building make appear unjustified long time periods of both HVAC and lighting uses. The actual occupancy rate is not taken in consideration; even the fair information collected at the level of safety services about total occupancy rate is not transmitted to HVAC and lighting management.

It also appeared that the water temperatures of too many distribution subsystems are grouped into common control strategies. This generates useless circulations of hot and cold waters in large networks and, therefore, too high distribution losses…

3. BEMS inspection

The main objective of BEMS records analysis, onsite inspections (with direct readings of existing counters) and complementary measurements is to identify the actual behaviour of the system considered with special attention to all inefficiencies and losses.

An example of air temperature recordings inside an AHU is presented in **Figure 3.**
It appears that, even in cold weather conditions (outdoor temperature floating around 0 °C), the cooling coil is supplied with chilled water and that, after having been pre-heated, the air is cooled across this coil, before being re-heated through the post-heating coil!

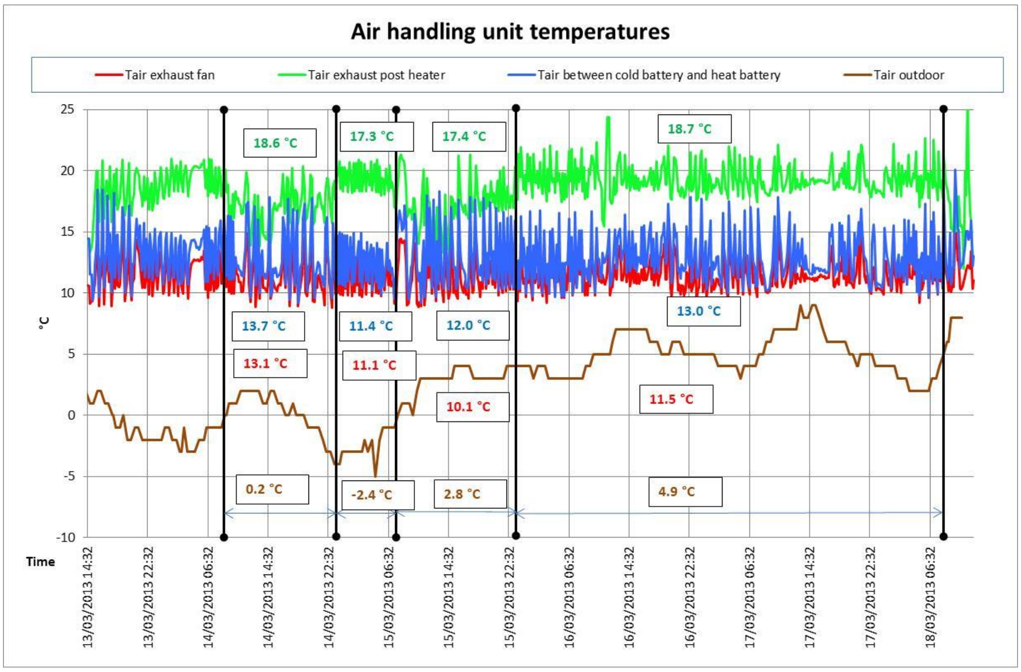

Figure 3: Example of air temperatures recorded inside a AHU

Examples of pictures taken on the control panel of energy management system are presented in **Figures 4** and **5**. Each picture is supposed to describe the status of one AHU at given time.

In the example of **Figure 4**, some of the temperature measurements are obviously not satisfactory.

The sensor located between the adiabatic humidifier and the post-heating coil is suggesting a temperature increase which has no meaning at all.

This is not the whole of it: on that time, the “plenum” temperature is 13.7 °C (the actual outdoor temperature), which means that the fresh air shouldn’t need any treatment (its temperature and water content should be almost satisfactory). But this picture indicates the occurrence of useless heat recovery, useless humidification and useless post-heating!

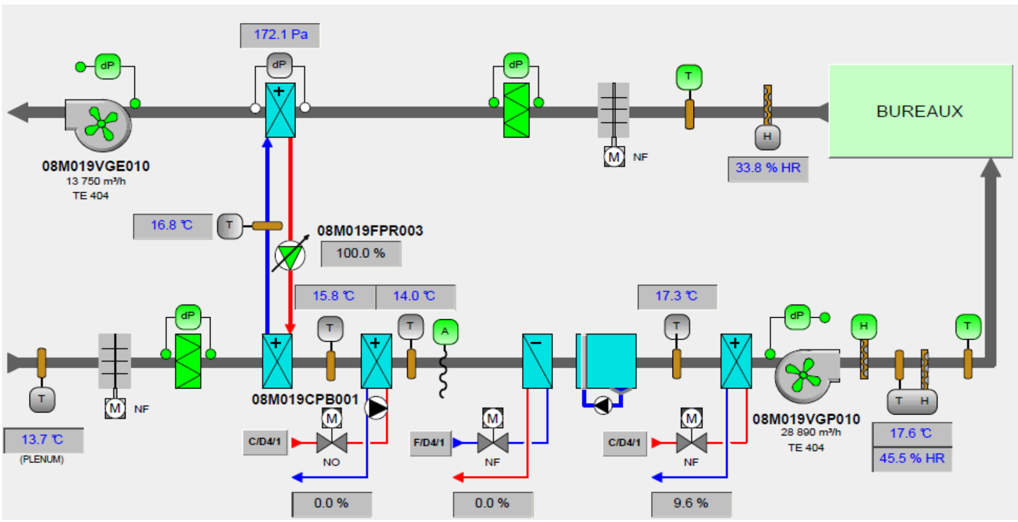

Figure 4: Status of one AHU in the morning of a working day (outdoor temperature: 14 °C)

The picture of **Figure 5** is taken in another AHU, but at same time.

Again here some (if not all) the temperature measurements are questionable. From other part, the valve of the cooling coil appears as largely open (at 75.9 %); this, associated to an outdoor temperature of 14 °C (Figure 4) corresponds to a fully useless cooling…

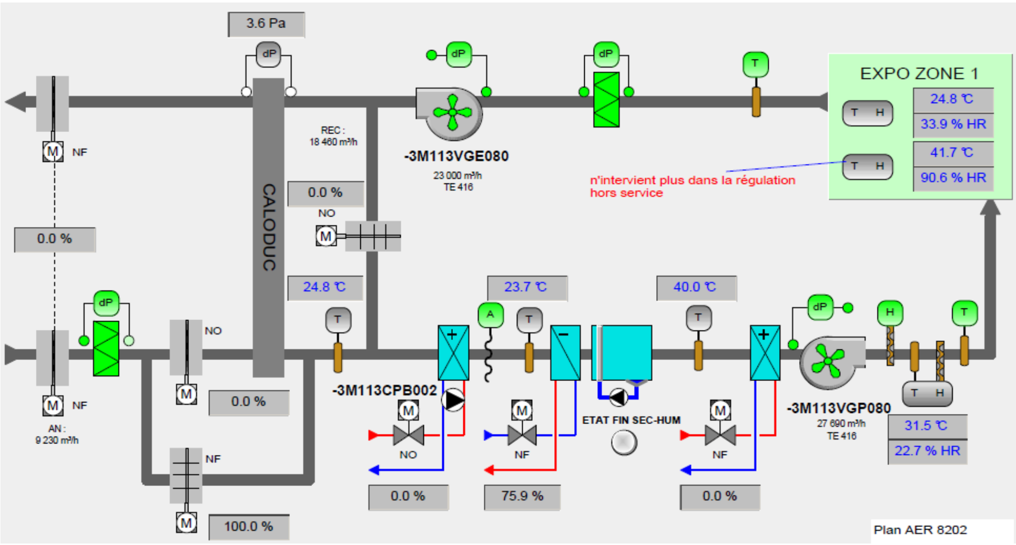

Figure 5: Status of another AHU at same time as in Figure 4

A more detailed analysis of such pictures and of all recordings available would also tell that, very often, an unjustified humidification demand (and therefore an unjustified use of both pre-heating and post-heating coils) is occurring, because of a too “rigid” control law: the relative humidity of the air returning to the AHU may go down below its set point, not because the air is to dry, but because it is too warm (or, in other terms, because of a lack of cooling power). Such response is, of course, very irrational.

The main conclusion of such enquiry is that the very high BEMS potentialities are still very poorly used…

4. Excessive air renewal in relationship with actual occupancy rate

Records of temperature, humidity and CO2 concentration at AHU return may also tell us a lot. An example of such record is presented in **Figure 6**. The values indicated in this graph are only meaningful during occupancy periods (i.e. when the fans are running): the air must circulate along the return duct.

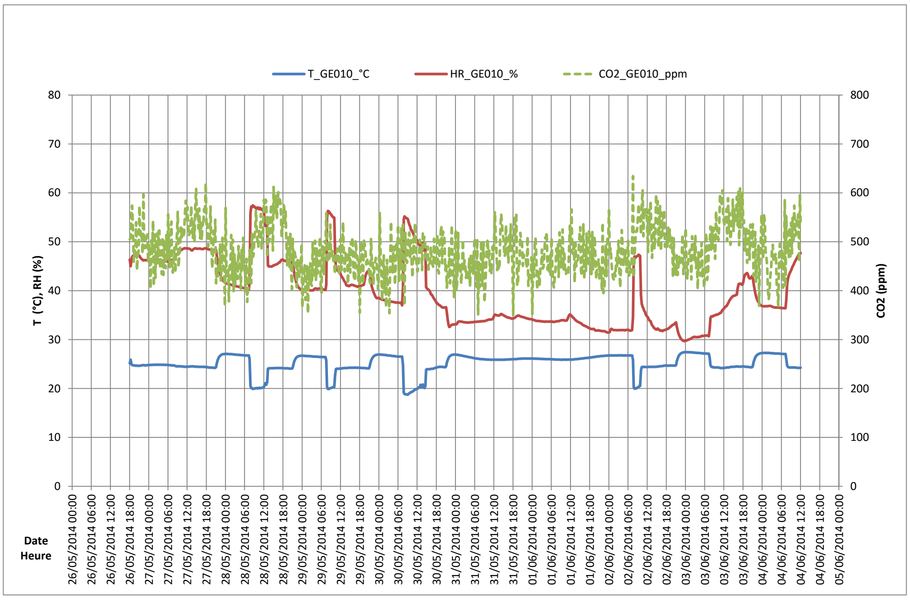

Figure 6: Temperature, relative humidity and CO2 concentration at return to AHU

It appears in this (much more typical than exceptional) example that the CO2 concentration stays far below the “comfortable” level of 1000 ppm, which means that the zone considered is very much over-ventilated.

It also appear that, in the May-June period considered, the return air is, time to time, cooled until and even below 20 [C]. This also represents a waste of energy in this period of cooling demand.

5. Too much rigid and/or unappropriated control laws and schedules

As seen hereafter, the actual ventilation flow rates can be identified from fans characteristics and from some other local verifications. This information, combined with records of CO2 concentration at AHU return can be introduced into a simple mass balance to identify the global CO2 flow rate emitted inside the zone considered and, at the end, the actual occupancy rate, thanks to a fair estimate of CO2 emission of each occupant in relation with its activity.

Also in relation of their activity (and in the hypothesis of comfort conditions) the global water flow rate emitted by these occupants inside the zone can be identified. At the end, a water mass balance can be used to track any (justified or not) humidification or dehumidification of the air supplied to the zone.

The humidity ratios plotted in **Figure 7** correspond to the return to two AHU’s (one of them is the same as in Figure 6) and to the outdoor air.

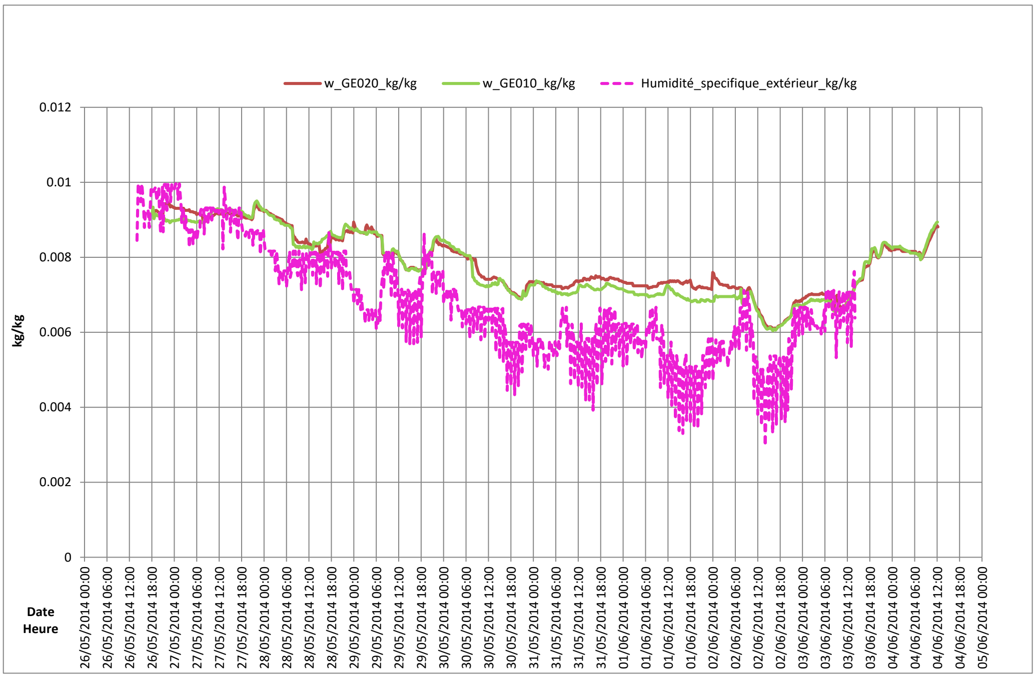

Figure 7: **Humidity ratios at two AHUs supplies and in outdoor environment**

Examples of calculation results obtained with diurnal averages of the records of Figures 4 and 5, combined with actual air flow rates, are presented in **Table 1**.

Each row of this Table corresponds to one diurnal period; from left to right, the different columns correspond to the day considered, the fresh air flow rate, the outdoor and indoor CO2 concentrations, the outdoor and indoor humidity ratios, the number of occupants, the ratio between actual and required fresh air flow rate and the latent power consumed for air humidification.

Both wastes, related to overventilation and useless humidification respectively, are very spectacular.

This confirms the previous conclusion: the BEMS potentialities could be much better used…

jour	$\dot{V}_{air,m3\backslash h}$ [m3/h]	$X_{CO2,out}$ [-]	$X_{CO2,in}$ [-]	ω_{out} [-]	ω_{in} [-]	n_{occ} [-]	Surventilation [-]	$\dot{Q}_{latent}$ [W]
27	28525	0.0004	0.000523	0.00901	0.0092	163.8	4.878	-2061
28	28525	0.0004	0.000524	0.00787	0.00841	165.1	4.839	6205
29	28525	0.0004	0.000466	0.00722	0.00791	87.89	9.091	12872
30	28525	0.0004	0.000478	0.00601	0.0072	103.9	7.692	24116
2	28525	0.0004	0.000521	0.00505	0.00643	161.1	4.959	26333
3	28525	0.0004	0.000535	0.00666	0.00731	179.8	4.444	8232

Tableau 1: **Main results provided by CO2 and water balances associated to actual air flow rates**

6. Unappropriated rotation speeds of fans

Two of the three following variables can be used to identify the actual flow rate provided by each fan:

- Its actual rotation speed, fairly well estimated from synchronism speed of the motor, corrected by some small slip and multiplied by the pulleys diameters ratio;
- Its "head" (or total pressure increase), determined from static pressure measurements and estimate of diffuser effectiveness;
- Its electrical consumption also measured onsite.

These variables are combined with the help of similarity laws and characteristic curves provided by the manufacturer.

The similarity variables are defined as follows:

Flow rate calculation:

$$\dot{V} = \phi \cdot A \cdot U$$

with

$$A = \pi \cdot \frac{D^2}{4}$$

(reference area)

$$\dot{M} = \frac{\dot{V}}{v}$$

(specific air flow rate)

With v= air specific volume

$$U = \pi \cdot D \cdot N$$

(peripheral speed)

$$N = \frac{rpm}{s\backslash min}$$

(rotation speed)

With rpm=rounds per minute

Pressure factor calculation:

$$\psi = \frac{\Delta p_{total}}{P_{dynam,periph}}$$

with

$$P_{dynam,periph} = \frac{U^2}{2 \cdot v}$$

(peripheral dynamic pressure)

Power calculation:

$$\dot{W} = \frac{\dot{W}_s}{\varepsilon_s}$$

with

$$\dot{W}_s = \dot{V} \cdot \Delta p_{total}$$

(isentropic power)

and

$$\varepsilon_s = \phi \cdot \frac{\psi}{\lambda}$$

(isentropic effectiveness)

Pressures:

$$p_{ex} = p_{tot,ex} - p_{dynam,ex}$$

with

$$p_{tot,ex} = p_{su} + \Delta p_{total}$$

and

$$p_{dynam,ex} = \frac{C_{ex}^{2}}{2 \cdot v}$$

(exhaust dynamic pressure)

With ptot=total pressure

$$C_{ex} = \frac{\dot{V}}{A_{ex}}$$

(exhaust velocity)

An example of such analysis is presented in **Figure 6**. It concerns two fans of the same type located in two different AHU's; both "nominal" and "actual" running points are indicated in each case. It appears that the "flow" and the "pressure" factors are, respectively, bigger and smaller than foreseen in the design.

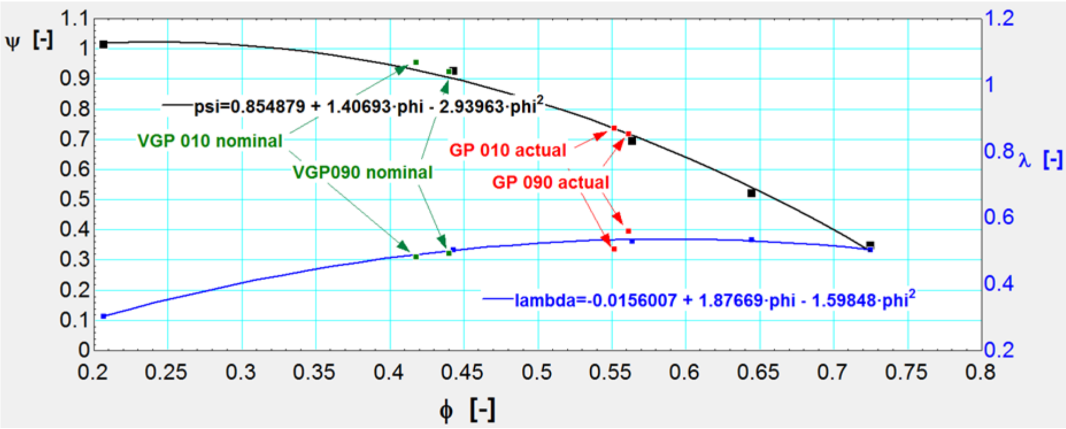

Figure 8: Fans VGP010 and VGP090 (of same type)

The same similarity curves can be used in order to identify the new rotation speeds required in order to get the design flow rates. The results expected from such tuning applied to the first fan are shown in **Figure 9**:

- The "nominal" flow was supposed to be of *24640 m3/h* at *1520 rpm* and under a static pressure difference of 1419 Pa;
- The "actual" flow rate is reaching *32110 m3/h* at *1500 rpm* and under a pressure difference of 999 Pa;
- The easiest way to restore the "nominal" flow rate of *24640 m3/h* is to reduce the rotation speed to *1151 rpm*.

In the case considered, such adjustment is easy to realize by tuning the frequency of the inverter. In other case (without inverter), it would be easy to change the pulleys ratio.

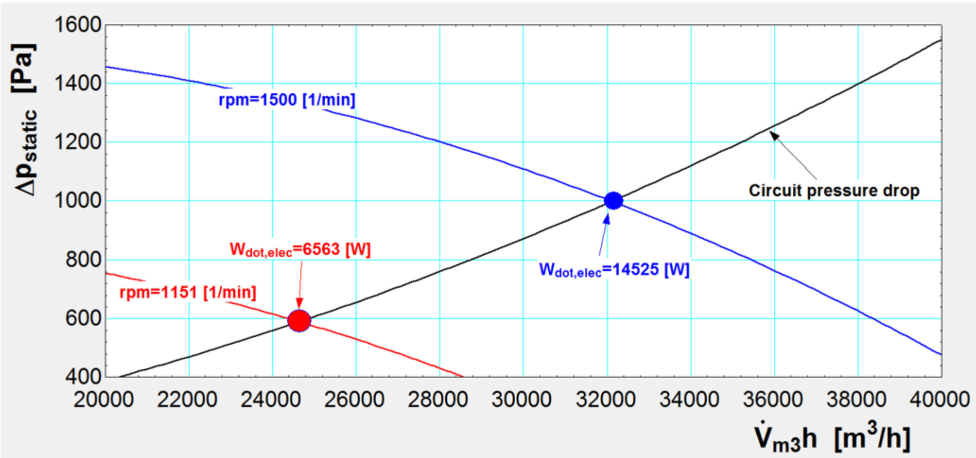

Figure 9: Adjustment of fan rotation speed

Two important benefits can be expected from such retrofit:

- A reduction of fresh air flow rate and of corresponding conditioning (heating and/or cooling) energy consumptions;
- A spectacular reduction of electrical power (from 14.5 to 6.6 kW, i.e. by more than 50 % in the case considered).

7. Inefficient heat production

Too often, the audit of a heating plant makes appear that boiler designed for condensing regime are actually not condensing at all.

7.1 Boiler with heat recovery unit

In the example presented hereafter, heat recovery exchanger were added to two classical (non-condensing) gas boilers of 1.65 MW; each recovery unit was sized in such a way to recover 66 kW at 90/70 C regime, i.e. *without* condensation.

As to be expected and as shown in **Figure 10** and **11** (manufacturer data), the actual benefit produced by each recovery unit depends mainly from return water temperature and also from the boiler load ratio.

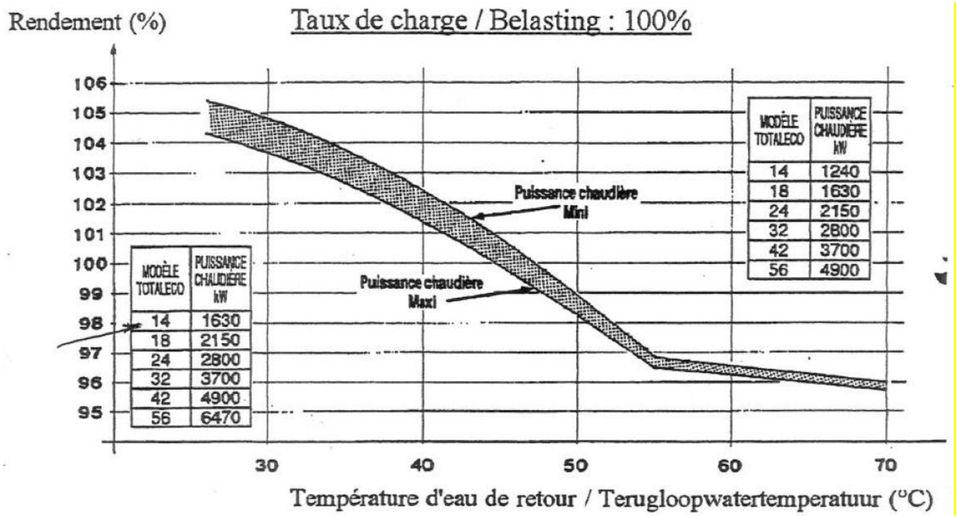

Figure 10: Global efficiency of the system (boiler+recovery) at 100 % of load ratio (according to manufacturer's catalog)

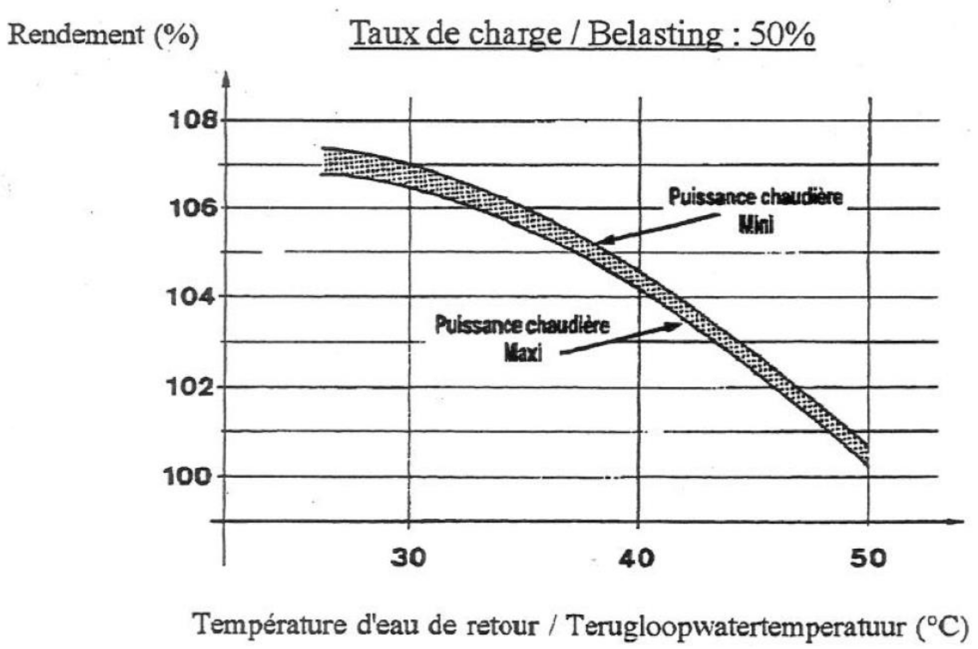

Figure 11: Global efficiency of the system (boiler+recovery) at 50 % of load ratio (also according to manufacturer's catalog)

Below 55 °C and thanks to condensation, the global efficiency of each such system (boiler +recovery) is quickly increasing. Around 40 °C of return temperature, one could get about 8 % of « free » heating power. Such expected benefit is confirmed hereafter by simulation…

7.2 Actual heating demands and simulation of potential recovery

Four groups of heat « emitters » are distinguished in this example:

Pre-heating coils, post-heating coils, fan coils and other (static) terminal units (radiators and convectors).

The hourly heating demands of these different emitters are identified by whole building simulation on a reference year with the help of a reference software [2].

The global signature of **Figure 12** is obtained by addition of all heating demands.

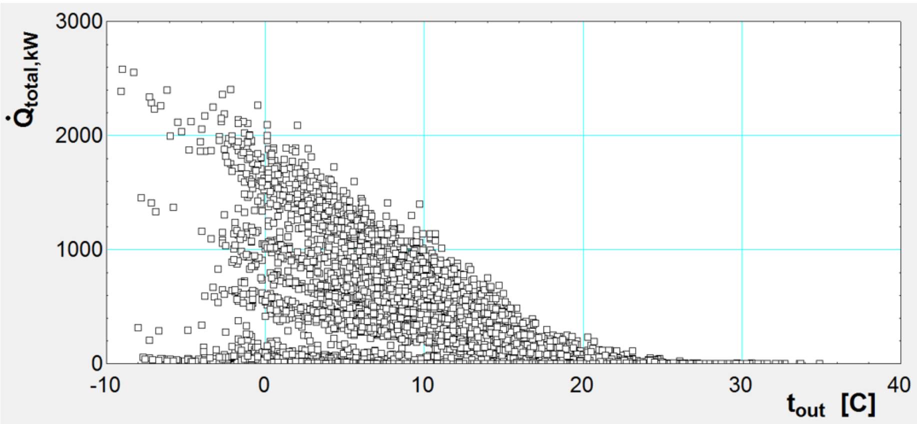

Figure 12: Hourly global heating demand as function of the outdoor air temperature

In the system considered, the fan coils and other terminal units are working at 60/40 C regime and the water circuit is designed in such a way to get the heat recovery units supplied in priority by the water at lowest temperature.

The global heating demand affected to this part of the water circuit and the maximal heating power which could be recovered (if getting water at 40 C) are plotted in **Figure 13**.

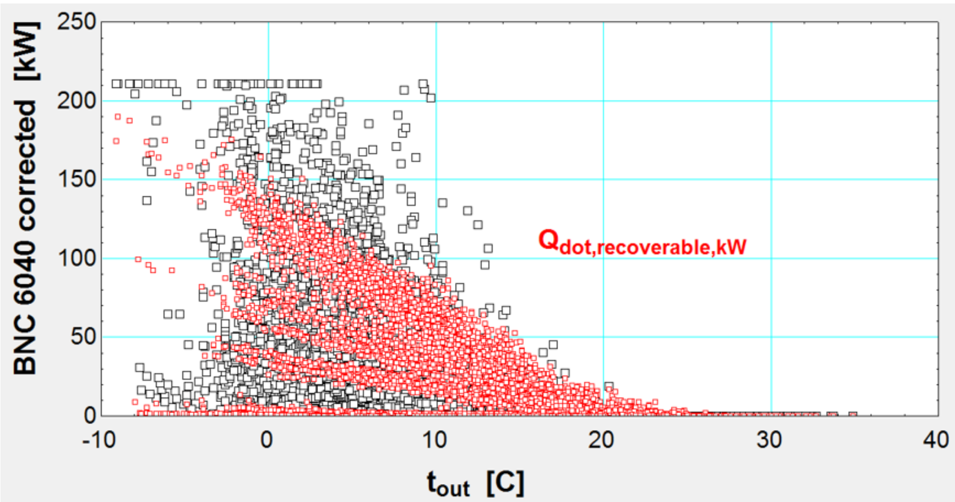

Figure 13: Heating demand affected to heat recovery circuit (in black) and maximal heating power actually recoverable (in red)

In such ideal conditions (i.e. if the return water temperature could be lowered until 40 °C), this recovery would correspond to 8 % of the heating power supplied by the boilers.

Unfortunately, the audit of *this* system shows that the actual return temperature is almost always much higher than 40 °C, because of a topology defect which produce an unexpected mixing between water returning from the terminal units and the (warmer) water returning from the (pre-heating and post-cooling coils of the AHU's. Such, apparently trivial, "plumbing" deserves to be corrected…

7.3 Modelling of the subsystem considered (boiler + recovery)

The simulation model, developed and used with the help an engineering equation solver [3], includes the following fictitious components:

- For the boiler: an adiabatic combustion chamber, a dry gas-water heat exchanger and a water-environment heat exchanger (to represent the surrounding loss);
- For the recovery unit: a *dry or wet* gas-water heat exchanger.

The models of both parts of this systems are tuned in such a way to fit the best with all manufacturer data: boiler efficiencies, boiler gas exhaust temperatures and heating powers provided by each recovery unit at various regimes.

An example of final verification is presented in **Figure 14**: the two global efficiency curves generated by simulation can be compared to manufacturer curves already shown in Figures 10 and 11: shapes and levels of both curves corresponding to 100 and 50 % of load ratios are in fair agreement.

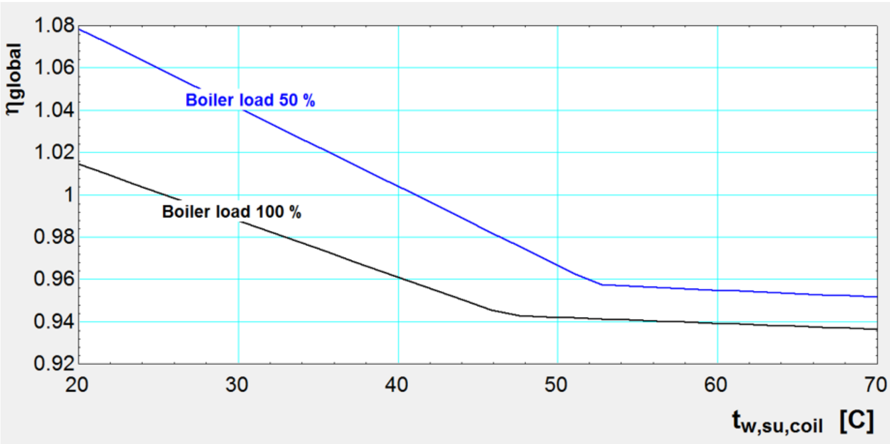

Figure 14: Simulated efficiency of the [boiler + recovery] subsystem

7.4 Global simulation

In order to simulate the responses of both [boiler + recovery] subsystems to the heating demands, the linear regressions of **Figure 15** can be grouped into one simple polynomial law.

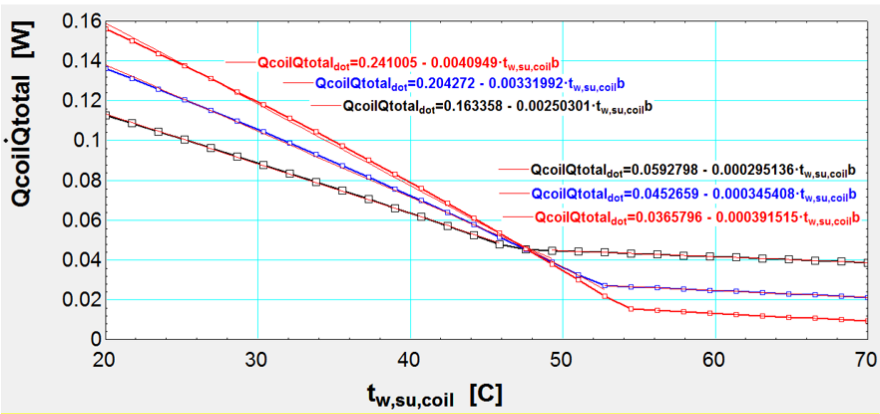

Figure 15: Ratio between the heating power recovered and the total heating power as function of the return water temperature and of the load ratio (black : 100 %, blue : 50 % and red : 25 %)

The accuracy of such simplification is very satisfactory as shown in **Figure 16**.

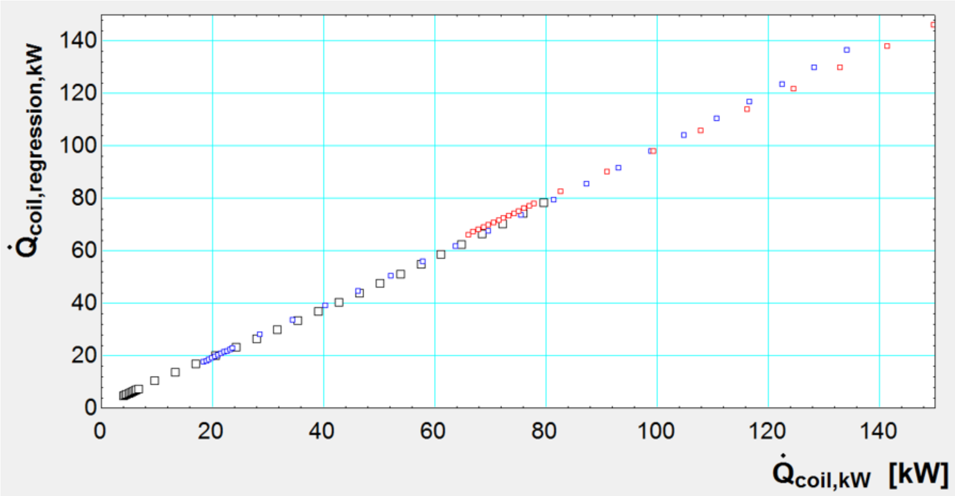

Figure 16: Validation of the regression

By running this simplified model in connection to hourly heating demands, one can see (**Figure 17**) the heat recovery degradation with rising return temperature.

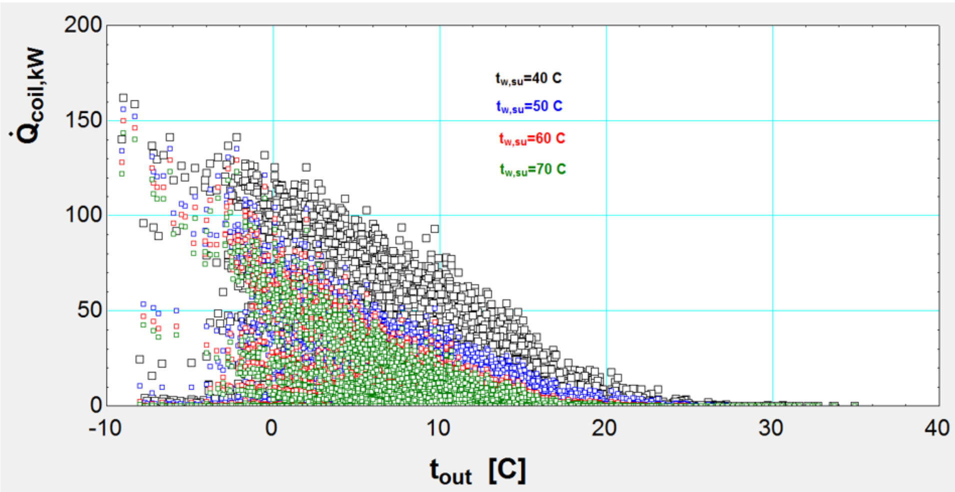

Figure 17: Heating power recovery as function of return temperature

Such simulations indicate what could be the recovery after having corrected the topology defect already identified. They also indicate that the best results would only be obtained if *varying the water flow rate* (in such a way to get the lowest return temperature)…

8. Conclusion

A very few examples only, extracted from some case studies, were presented in this paper. Hopefully, these examples might give some ideas on how to further develop the different approaches already experimented. The following facts are here observed:

- Specific fuel and electricity signatures can help in identifying the dominant energy losses;
- Building energy management systems disserve to be carefully commissioned in order to guaranty the information reliability and the control effectiveness;
- CO_2 concentration measurements can help a lot in identifying a possible excess of air renewal;
- Combined CO_2 and H_2O balances can also help in identifying wastes associated to humidity control;

- Fans are very reliable flow meters and ventilation flow rates deserve to be checked and tuned by adjusting the rotation speeds;
- It's often worthwhile to ensure that the (supposed-to-be) "condensing" boilers are actually condensing!

9. References

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[2] Design Builder Software Ltd. UK *v 3.0. 2013*.

[3] Klein S., *Engineering Equation Solver* F-Chart Sofware 2009

Efficiency and intelligence in new and existing offices

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Abstract

Distributed generation indicates a high technology in the new development plan of renewable realizing energy efficiency both in new construction processes, for existing buildings, new construction in view of environmental sustainability. The administrative offices and commercial buildings, increase the demand over supply of new housing market, for reasons of efficiency and energy savings, applying new technologies from RES, in view of the Directive 2012/27/EU.Low cost, high performance with distributed intelligence and control energy environmental best practices, creation of efficient operating models building with smart grid and energy islands indicate quantitative and qualitative targets for the end use of renewable energy.
So cogeneration, fuel cells, smart metering, solar cooling, solar photovoltaic, energy storage systems, communication technologies with techno economic self-sufficiency and integration between production and consumption. Intelligence from synergy of new business models of the design processes with the *office building* and distributed generation. Efficiency of tenant offices with sustainable relationship and principle of *Lake Interior Life*. Use of environmentally friendly, natural, resilient and durable materials, emerging and innovative technologies represent the excellence in environmental energy regeneration, for new construction in the practice building and the new design. In fact, from pre-production to their disposal, improve environmental performance with platform of eco productive and sustainable indicators. So new management models of urban redevelopment / territorial improvement of sprawl, and offices existing or new public / private and tertiary hospitals, shopping malls, etc. pouches, with low impact integrated in the context and environment.
Performance requirements of building technologies and energy efficiency of BA, with ventilated facade, cladding systems, new challenges of energy strategy including UN-Mission Innovation COP-21 in Paris. Investment in research and development of clean technologies worldwide with Breakthrough Energy Coalition, Alliance Solar International, etc.

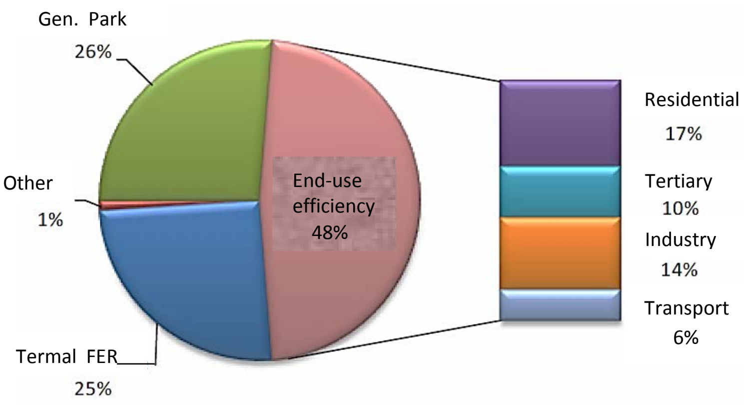
1. Introduction

The new themes aimed use of renewable resources follow a trend of regulations and innovative actions co-investments of citizens, technicians, governors and businesses in order to improve environmental performance, but also to reduce carbon neutral with the construction of the buildings and all human and industrial production.
The thesis is to create **new models** of the design process in the construction sector that affects the environment by 33% of CO_2, the EU with 40% of energy consumption with 10% of GDP compared with 11% in Europe. For energy efficiency, the European Council points to 27% in 2030 to 30% in the EU.
So technological innovation and **energy efficiency** with growth and socio-economic development in line with climate change, such issues at the center of the global debate and Action Plans for Sustainable Energy (PAES) with the Covenant of Mayors for the use of renewable energy sources (RES).
Policy strategies supplemented by regulations for the management of clean energy are aimed at sustainability and zero impact, both for new and existing buildings with the use of innovative technologies and intelligent that improve the environmental quality of the individual and for new jobs.
In fact, large companies or energy-including government offices, commercial and service, according to Directive 2012/27 / EU, implemented in Italy with Decree 4 July 2014, n.102, aimed at savings of 20% with the development of energy efficiency (Fig. 1) [1] and reduction of CO_2.

So complex issue of adoption by RES (Renewable Energy Sources) and the depletion of energy resources from fossil designating high consumption of natural gas, with coal and oil objective in the strategies of space management and performance of the building. In particular, the sustainability of *facility management* for the security, safety in building low environmental impact with energy saving design CIB and towards sustainable development.

In this area decreases consumption of coal both in the EU than in the States, with the oil for the increase of renewable energy, and according to estimates of the Worldwatch Institute [2] and IEA[1] is expected that coal will replace oil as a primary resource in 2017. Furthermore it suggests a saving of 7.3 Mtoe in 2016 and pointing to the revaluation of LNG strategic perspective to standardize the price of natural gas in an infrastructure network to access market to extraction points.

Increasing demand for clean technologies and improvement of market economies affected by the



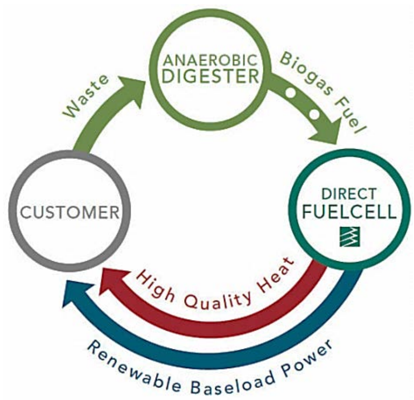


Fig. 1: Reduction $C0_2$, in 2020, depending on the energy efficiency, source [1]

Fig. 2: **Fuel Cell energy**, source [5]

Emissions by 84% of CO_2, use of distributed generation, smart grid, smart metering and **smart cloud technologies of control for business buildings** energy consumption of heating, cooling, ventilation and air-conditioning systems (HVACs)

For sales offices in the US, according to research at the Pacific Northwest National Laboratory (PNNL) can reach up to 67% savings on your heating bills and cooling with at least four control points with rooftop heating, ventilation and air-conditioning systems (HVACs) [3]. Another target for energy efficiency with effectiveness of the results, especially for the timing and for the regulation of the absorbed power compared to that of the draft installations, is the Building Automation (BA) with control systems-BACS- to artificial intelligence, in the management and application of innovative technologies.

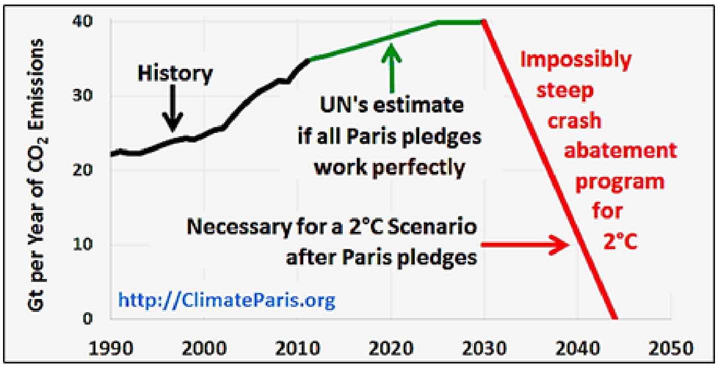
They are connected to control systems BMS (Building Management System), Building Energy Management System (BEMS) and focus on sustainability and energy savings in energy consuming buildings for commercial, business and public administration. For this purpose the architectural envelope, together with the installations of a building in an integrated design building / plant are the cornerstones of energy efficiency, with the effectiveness of installation in function of the time. And 'connected to the system they TBM (Technical Building Management) management and maintenance. This practice is the methodology of the European standard DIN EN 15232 (Table 2) [4], in collaboration with the European Directive EPBD 2002/91 / EC.

In them it is thrown cogeneration, clean technology par excellence with fuel cell (Figure 2) [5] etc. **Robotics is an objective** the creation of innovative technology for energy-saving and cost of high-rise offices with prefabrication systems with application of plant intelligent, automated BA integrated BMS system. So upgrading urban/ territorial and new construction with energy islands [6] with distributed generation applied best practices such as Rome's Sapienza University campus.

[1] IEA (International Energy Agency)

The same subsidy support to consumption of fossil fuels (Green Growth Studies: Energy - OECD) with estimated price gap method of the IEA (International Energy Agency) promote policies to encourage the use of new technologies in the design capture and storage, with reduction of about 1/6 of emissions and more independence from third countries for the supply of energy.
The WEO (World Energy Outlook) in the 2015 IEA report confirmed the increase of such initiatives by presenting the COP 21 summit in Paris (Table1) [7], the climate, according to the IPPC (Integrated Pollution Prevention and Control). Directive which has been replaced by IED-2010/75/EU on industrial emissions.

Table 1: COP 21- Reduction CO_2 , source [7]



In fact, the directive EU-IED promotes BAT- Best Available Technologies for the reduction of emissions of pollutants from industry, focusing processes than purifications, and whose management is monitored by control plans of the various competent authorities and managers.

For industrial processes and subject to the AIA, in Italy are concerned, respectively, the Minister for the Environment and the ISPRA and ARPA / APPA express opinions of both monitoring and control of polluting emissions that plant with release of authorization and its assessment of compliance with the requirements.
So initiatives that protect the environment from the extraction, processing and end use of the product for the realization of human activities with reduction targets to below 2% the percentage of CO_2 (below the level of 1,000 gigatonnes) avoiding the risk of passing this limit in 2030.
Therefore ETP 2015 [8] with incentive strategies of **Clean Energy Progress**, that control carbon emissions along with the principles of the mission of Breakthrough Energy Coalition for the climate challenge shared funding of technological research on energy and its supply at affordable prices.

Table 2: DIN EN 15232, source [4]

Building Automation and Control (BAC) **Efficiency classes EN 15232**		**Efficiency factor for thermal energy**			**Efficiency factor for electrical energy**		
		Office	School	Hotel	Office	School	Hotel
A	Highly efficient Building Automation and Control System (BACS) and Technical Building Management (TBM)	0.70	0.80	0.68	0.87	0.86	0.90
B	Advanced BACS and TBM	0.80	0.88	0.85	0.93	0.93	0.95
C	Standard BACS	1.00	1.00	1.00	1.00	1.00	1.00
D	Non-efficient BACS	1.51	1.20	1.31	1.10	1.07	1.07

At the same COP21 agreement of 195 countries including Italy, the Alliance Solar International, between India and France, has also, among the primary objectives, investment and use of clean technologies from solar sources, also aimed at improving in low income countries, global environmental protection. In fact, all countries of the world is essential to know the amount of energy that can be achieved through renewable energy resources and establish a methodology for the working with reduced operating costs and elimination of environmental degradation. This increase in construction sector research and training with the **application of solar technologies** of solar panels (HIT), concentrating solar collectors (TECCSP), systems Photovoltaic Panels (PV) for new buildings in the renovation. Application of sustainable construction technologies with ventilated roofs, ventilated façade double or triple glazing with natural ventilation with terminals for air conditioning in the ceilings with chilled beams [9], external insulation systems, cool roof and cool materials, NBIC technologies emerging, the Information and Communications Technology (ICT), the Intelligent Building, smart building, smart materials environmentally innovative and resilient, etc.

Table 3: From HORIZON 2020, source [10]

Excellence Science	Industrial Leadership	Societal Challenges
• Consiglio Europeo della Ricerca • Azioni Marie Curie • Tecnologie future ed emergenti • Research Infrastructure	• Leadership in tecnologie abilitanti e industriali • Accesso al risk finance • Innovazione per le PMI	• Salute e benessere • Sicurezza alimentare, agricoltura sostenibile, bioeconomia • Energia sicura, pulita, efficiente
Istituto Europeo di Innovazione e Tecnologia		
Joint Research Centre (JRC)		

2. Strategies in new buildings and redevelopment: sustainable energy technologies and distributed generation

The environmental quality and context are essential from the architectural quality of the integrated building / facility and connected to the technological quality that involves the efficient building envelope. It integrates innovative and resilient materials that interact with need and performance parameters of the technological system.

In Italy both the Dl.gs no.102 / 2014 on energy efficiency, as the transposition of Directive 2012/27 / EU on the National Action Plan for Energy Efficiency 2014 (PAEE 2014), in line with the SEN (National Energy Strategy), seeking primarily to the development of clean technologies and efficient with positive effects on the markets and jobs, as well as environmental restoration.

Reinforced by the objective of reducing the energy of 15.5 Mtoe and about 60% energy savings on White Certificates system coherent European program Horizon 2020 (Table 3) [10] mainly for the development of **clean technologies**, **the ICT** and the trend of the Industrial Leadership, nanotechnology. Similarly to printing processes, they are produced in rolls for flexible realization of *prototype solar panels* whose **cells nanostructured** [11] are easy and quick application, resulting in more economical and low environmental impact. They are distinguished quality products and comply with EU (RoHS, REACH and TSCA) with application of Nanosys Quantum Dot, the DSSC, the carbon nanotube (CNT), etc. Power engineering and ICT areas to encourage the installation of district heating networks and encourage companies and businesses that exceed 20 MW of thermal energy with the promotion of RES.

It also promotes the increase of NZEB (nearly Zero Energy Building) on the principles of passive house and launched by EPBD2 (Energy Performance Building Directive 2) supplemented by Directive 2010/31 / EU on the energy performance of buildings and the obligation for the public administration, to achieve nearly zero energy buildings, since 2008.

Just under the new decrees of L.90 / 2013 innovations we are to provide on-site power for NZEB establishing minimum standards for energy performance, both for new construction as well as redevelopment, calculation methods to the type of 'building, environment and climate UNI TS 11300 and Recommendation 14 of the Italian Thermotechnical Committee (CTI). For energy-intensive buildings and large enterprises it is required to perform the Obligatory Energy Audit [2] (DEO), every four years, with the aim to match the certificate of Energy Performance, increase energy efficiency and reduce its consumption.

In particular, the practice is related to buildings with useful floor area of less than 250 m² at the end of the calculation of floor space conditioning (heating and cooling), production of domestic hot water (DHW), consumption and transport, and optimization of costs / benefits of the redevelopment work and new intervention. They are supported by the ESCO and managers of energy services also indicate that the opportunity to apply the distributed generation, the district-heating, district cooling, and **high efficiency cogeneration**.

As part of these assessments apply energy simulations to check the power consumption, and to optimize the performance of systems of renewable energy sources, in distinct models of centralized and decentralized generation. The latter applies in particular to the practice of re-qualification, on the wrappers of existing buildings and near the point of dispensing with control of local communities. In fact are the property of the local wind energy ½ and ¾ of solar panels, throughout Germany.

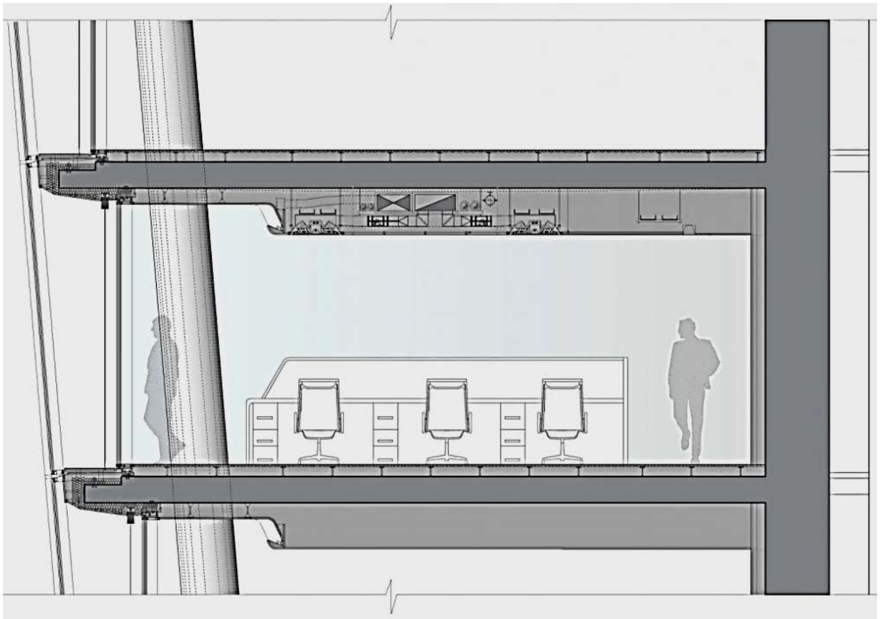


Fig.3: Z.Hadid building. (In redevelopment project CityLife-Milan, Italy) Air conditioning: installation of chilled beams in the ceiling, source [9]

In Italy there was a system of tax deductions as enshrined in the Stability Law 2015 (190/2014). In particular clean technologies, in the renewable energy program, they are also a response to those needs, and the opportunity to intensify them occurs in this particular time when you are down more oil prices and gas and be in line with technological development of Europe.

This will **improve energy efficiency**, especially in buildings with high energy consumption, with demand reduction and decarbonization of the economy [3] and security for the supply and delivery of energy services.

Presidential Decree 75/2013 sets out standards on building energy certification performed by qualified, ESCo, inspections with ACCREDIA (Italian National Accreditation Body) and private or with other European and public bodies.

[2] Energy audits and energy performance certificate

[3] COM 2015 European Commission 201

2.1. Intelligence- efficiency and smart grid, smart city

The framework of legislation and strategies on energy efficiency policies is that redevelopment of the built environment involve **the development of technological systems** that improve the performance and construction of buildings **for new business models** and the adoption of distributed power generation. The latter is based mainly on the production of electricity using renewable sources of **RES** which cogeneration, wind, solar photovoltaic, biomass, bioliquids, biogas, and in smaller percentages from hydro. The Distributed generation (GD) but is applicable to fossil fuel resources and is distributed with relocation, the central main territory.

In fact, distribution is accomplished through a series of medium and small networks placed at the centers of consumption energy end-to generating installations national or different storage systems with the advantage of recovering about 10% of the energy dispersal, over networks traditional large, for the less distance in the transport of supply to the end user.

The energy efficiency of the distribution network to medium size is almost 80%, compared with 35% of the production plant, and is distributed with affordable costs, greater resilience, flexibility and adaptation. Among the critical issues is highlighted that the economies of scale for reducing the size of the installations.

For optimal management of GD, the smart grid or smart grids for electricity or information, represent the best contribution to their tree configuration that controls reverse energy flow from the power of distributed generation to the central electricity. In fact the ends of the network are self-produced energy from renewable sources distributed as sets, the core network, the dispatching. Additionally renewable resources not being programmable, and intermittent, may cause surplus energy that with adoption of smart grids [12] is adjusted and redistributed in neighboring networks where there is a deficit of energy supply.

Their benefits are to be able to intervene **dynamically and in real time**, on loads or accumulation systems, in cases of surplus energy flow at low voltage on the network device, compared to the high voltage of the electricity network central. So that there is the control of management, delivery and maintenance is critical automation with specialization and exchange of information with the IP (Internet Protocol Address) for timely interventions by the donor, in case of interruption, alerted by intelligent sensors- smart metering- Wireless, RS485, Plc.

As part of the infrastructure networks, local area networks (Wide Area Network) and MANs (Metropolitan Area Network) allow the exchange of information with the LAN networks of smart buildings and BA (Building Automation) in an urban integration with buildings intelligent and office building that emphasize the service sector with distributed intelligence-functionality of decentralized control units in data transmission.

So **peer to peer** (P2P) networks architectures client / server networks for data communication building and smart city with cloud computing for energy efficiency and public Wi-Fi, the municipal waste management, smart & virtual government, smart lighting and SOA (Service Oriented Architecture) and Business Process Management (BPM) (Figure 5) [13] .The **Cloud ecosystems** represents a standard to encourage enterprises and companies that cooperate in order to meet social.

The cloud software based, which is fitted to the lighting network, has ability to control and balance the energy consumption, in real time, and to rework data transmissions by all the light points Illuminant provided mobile chip and connected to the network. These neighborhoods also highlights the smart metering technology, aimed at improving energy efficiency in the evaluation of consumption, savings or energy losses, with the calculation of indices in remote management and monitoring, before and after a redevelopment of the building or facility.

So for energy efficiency, among the measures to be taken, there are also the transformers, switches, storage technologies and integration of devices of control and monitoring to prevent the black out with reduction of costs. In particular smart grids are also connected to the remote control of ICT infrastructures which play further protective action, dispatching that energy monitoring and interface with XML data such/IP. However, for the security of smart grid you will always consider a vulnerability of communications networks, by creating a parallel world to the Internet, according to the National

Institute of Standards and Technology (NIST) is highlighting the **risk management**, while applying control systems including Supervisor Control and Data Acquisition (SCADA) that refer to the needs of security and encryption.
Even for the 66% of citizens who will move to cities, they call for smart city (Fig. 4) [14], the objective of sustainability by 2050 and where more details and information on the costs and consumption of energy, on energy bills which now are still high, and for greater user participation in the processes of service management urban / territorial.
So **more transparency and participation of consumers** in the **European strategies** in which the New Deal aims adoption of new technologies, including smart metering reduction of greenhouse gas emissions by using renewable resources with encouragement and facilitation of consumer demand for energy and open date.

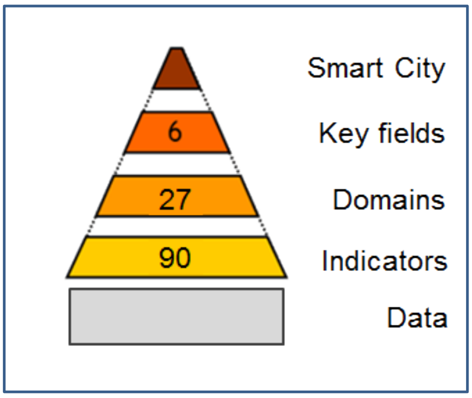


Fig. 4: Smart City, source [14]

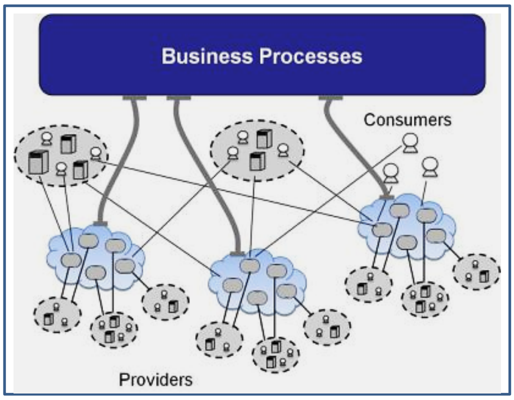


Fig. 5: BPM- Cloud Ecosystem, source [13]

Born within these initiatives **also smart community** [15] in which the share becomes the input of agreement among experts, architects, specialists, engineers, planners, researchers and so on. For the efficient management of the city and benefits for general utilities-electricity, gas, water, telecommunications, security and privacy.
Also in creating new services according to city requirements, improve the flow of traffic, interchanges, road traffic and sustainable mobility. Vehicles with power-ups are widespread although the question might require increased electricity supply, while energy storage surplus would become a reserve and could become an incentive for renewable sources.
Therefore increased awareness on the part of citizens, administrators, in smart cities with distributed generation and actions co-investments, benchmarking and indicators architectural, environmental and contextual, with distribution networks of Internet The Things Network (TTN) type Iot. So radio access technology for smart building, smart lighting and smart mobility.
To this end, the **urban audit** is the analysis tool indispensable in the sustainable development of the smart city, smart building, based on criteria for the collection of information and data on the efficiency and urban renewal with reduction of sprawl and low density.
Smart city means a city that manages to communicate and establish relationships metropolitan, with social responsibility and political awareness of the citizens, in view of social and sustainable development, cultural and environmental.
The **challenge** is not to limit the habitat and the quality of urban rhythms to only eco environmental standards, but **project them into the smart planning** of interventions conversion of brownfield sites in the industrial, commercial and relocation decarbonization of service industries and manufacturing.

3. Clean technologies-*smart office*

The efficiency of the ***office building*** understanding of this twofold aspect environmental and energy when it reaches *space planning* outcomes of efficiency of work spaces, it identifies a number of performance based on organizational needs and in which converge estate management expertise and businesses, in addition to the design and use of space standards.
The trend is to open office in which there will be greater communication between work groups, etc. as well as individual offices which are distinguished by the highest concentration, acoustic comfort, etc.
The project is coordinated systems to the architectural objectives for efficiency, low environmental impact and quality in **open plan** with **wireless technologies** that improve the performance of distributed workstations in interior design in the *bullpen* and *cubicle space*.
Also they articulate efficient spaces of ***brainstorming lounge*** **areas** in which to focus and reflect, after lunch, in a new trend of location-free working with Hot-desking, desk sharing, Hoteling, Telecommuting, Virtual office, etc.
In these workplaces office activity it is distributed throughout the common space pointing to the flexibility, mobility and co-working with voice recognition technologies to geo-sensing transmission with smart phones, etc. objective is Ahmed Datoo, VP Mobile Citrix XenMobile, then efficiency and productivity with IT and working on multiple device platforms to bring productivity to high levels.
The automation is mainly related to lighting, air conditioning, water and security. Offices plant design BA maximizes comfort with a distribution of workstation (WKS) in **open space** or individual offices with intelligent systems and energy-saving.
Usually in the office setting energy levels vary on the use of the occupants: pre-comfort (to start work activities), comfort (for many employees are in the office), economy (for the night and on weekends), protection (for long closure of the offices) and the settings are derived from the function room climate.
Automation example of an office class A with BA (Building Automation) with reduction of energy consumption (Figure 6) [16]:

• Lighting of the corridor and window (activation and control DALI light according to the natural light);
• In the whole office sensors are installed presence of occupants for the management and control, other sensors for the light is in the ceiling.
• Electrically operated blinds and control keys.
• Cooling with actuator on the radiator in the ceiling.
• Radio Technology EnOcean for adjustment and maintenance of the temperature.
• Ventilation with system with variable volume flow
• Sensors Opening and closing windows with digital inputs and sensors for dew point on the ceiling.
• Adjustable hot / cold with schedulerdependent for energy
• radiator for heating

For this purpose, in Italy the Ministry for economic development, for the non-residential construction sector, recorded an evolution in the electric charge of the 50% increase, from 2000 to 2013, reinforcing the development of clean technologies that improve energy efficiency.
It is also **evidenced by indicators of unit consumption**, according to the index ODEX EU, which is found in **various types of energy systems** of the building and weighted for their impact on final consumption. **Application of clean technologies**, as an alternative to conventional plants (use of fossil fuels), with micro-generation and district heating, photovoltaic, solar thermal, wind, hydroelectric, geothermal, biomass, inverters, lamps and high-efficiency motors, condensing boilers, etc. Then the energy saving technologies through **intelligent technological systems** that control the levels of internal temperature, domestic hot water systems, lighting in order to reduce energy consumption of buildings. In the EU, the energy consumption of buildings accounts for 40% of total energy consumption and exceeds the 32% transport and 28% of the industry.
From data CRESME 2013, they indicate that, in Italy, the buildings destined for public offices are 13,675, out of a total of 65,000 of buildings to public and private use. The consumption is about 38% of the energy requirements related to commercial and residential buildings, the report ENEA CRESME 2012 in which 35% of offices can sometimes be about 18% energy savings.

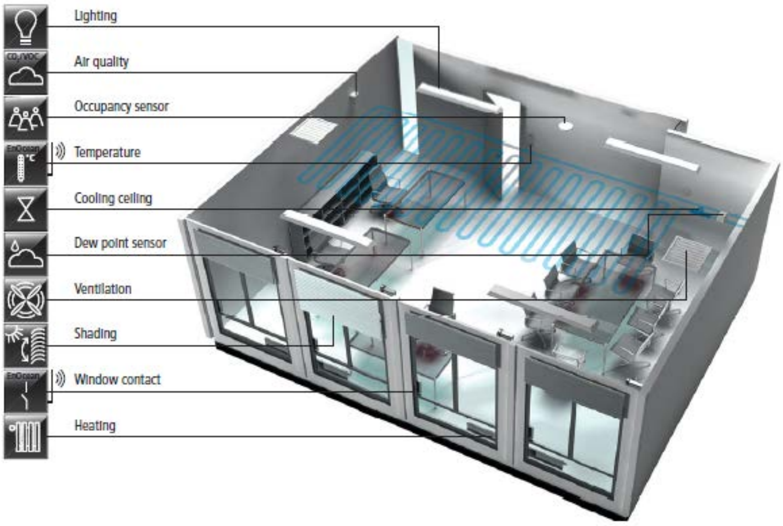


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Fig. 6: BA- Application Standards utilities, source [16]

Then the retraining environmental energy, is essential if they were overcome those critical of the process, to achieve efficiency and improving the lives of every person who spends most of the day, work spaces, as an index of productivity and sustainability.
The methodology shows us above all to know the context data, meteorological and environmental, with indices of density, as well as project data which indicate existing installations.
So achieve objectives redevelopment supplemented by an **energy audit** and green energy audit, of the plant up to the design, implementation and management with, in times of ROI investment. The certification establishes the parameters of quality which are established during the design phase to the implementation of interventions.
The *better place to work* is one of the guidelines that promote the design of users, designers, contractors, technicians, etc., full-blown in Italy through co-participated actions for sustainable redevelopment and low environmental impact. So new organizational models for the approach of the new operating model of the design process. Basic parameters related to the redevelopment of work spaces for offices are related to pedestrian mobility, driveway, outdoor areas, etc.
Integrated contextual those that create diversity. Also for **new designs of offices** stand these design features depending, on the performance characteristics, of the body building and organizational work in a synthesis of people and work activities related to confined spaces and context. So for a facility management aimed at the application of the performance of the building. The Audit plan for the management defines the amounts, distribution characteristics, efficiency of used space and management costs and ultimately more spaces.
The ***office building*** is usually divided into categories of activity with Office Space (OFC) in Net Usable Area (NUA) obtained from net minus the area of utilities (UTIL) depending on the characteristics of distribution. Also Pipes, Ducts, and Vertical Shaft Penetration (PDSV) Net Rentable Area (NRA), Net Productive Area (NPA), Gross External Area (GEA), Gross Internal Area (GIA).
The space efficiency is obtained if the ratio NUA / NRA is equal to 80% or 85% with indicators 80% NRA / GIA to obtain the **Owner efficiency** and instead the **Tenant efficiency** is obtained with a value of 85% of the relationship NUA / NRA.
In order to use a common standard and shared to facilitate the work in tertiary buildings it has developed a proposal of 56 professional associations worldwide in the International Property Measurement Standards (IPMS) IPMS 1 IPMS2-Office, IPMS3-Offices.
In general sources renewable energy are launched across the construction sector in order to lower impact on the environment, cost reduction and energy savings with indoor air quality (IAQ) and outdoor and growth of new jobs.

For the safety of basic energy, from distributed generation, energy supply, for the majority of the offices, to large in size, is carried out on-site electrical power generation with fuel cells.
They convert hydrogen and oxygen into electricity ultra-clean with advantages of high efficiency, reliability, flexibility and cost reduction and are located in proximity of the buildings.
The technology of internal reforming is characterized by the production of hydrogen obtained from gas or biogas that is reformed within the same fuel cell.
The fuel cells are also applied for the supply of energy in shopping centers, accommodation and entire residential neighborhoods.
They combine with the heat power (CHP) with results of low emissivity and cost reduction. Their application may eliminate or reduce the installation of boilers for the production of domestic hot because the heat produced within the fuel cells can be spread in the different types of installations of air conditioners.
In the German city of Mainz, Siemens, in a nearby wind farm, it built the largest plant in the world, with peak power of 6 MW, powered by wind energy and where it employs *technology electrolysis*. It is formed by proton exchange membranes (PEM) in which in passing the electric current, the water molecules and oxygen break down under the effect of electrolysis. It was conducted by the University of Rhein-Main with the local electric utility using clean technology from renewable resources, which reduces maintenance costs of operating temperatures not requiring a warm them up.
The target energy distribution is for industrial use, for release into the gas grid or for e-mobility.

3.1. Best Practices

A major redevelopment energy/environment has been created in the university city of Rome Sapienza, which shows the application of **distributed generation** for the production of electricity and heat.
Part of the "smart grid Sapienza" were designed 11 energy islands, of which 8 are currently in operation, connected to the network power company ACEA Rome and district heating of the Sapienza University campus.
The building units are the offices of the Rector, the different Law Faculty, Mineralogy, Physics, Mathematics, Humanities, Chemistry, Physiology, Pharmacology, Botany and Genetics, Hygiene and Bacteriology, Orthopedics, General Services, Theatre, Nursery, Clinic Regina Elena, etc.
The plant management is carried out by RTI to private companies, according to a framework agreement between Sapienza University and companies in the Energy Performance Contract (EPC).
The result is a pre-existing annual requirement of 20,000 MWh of electricity, and more than 12,000 MWh of thermal energy.
The electricity is supplied to the islands, 22 MV-BT 12990 kWt, while thermal energy is supplied by 24 substations Exchange 1567 kWt, buckling of the hot water through the steam generators, powered by methane gas , near the Umberto I ° Policlinic.
In the islands from 1 to 8 is the installation of photovoltaic systems, and are equipped with fuel cells powered by hydrogen, cogeneration, heat powered by gas, oil plant.
While the island 9 adopts the cogeneration engine hydro, and is called Micro-Grid in the Smart Grid as they apply ICT. On this island there is the University Sports Centre (CUS) (Figure 7) [17] which is divided into two buildings, built at different times, on stilts plans are for offices for the administration, management, in gyms (Fig. 8) [18], pools, with tennis courts, soccer, rugby, etc.
The CUS is a building distributed intelligence with a system of intelligent management of services, monitoring the pollution level, with system interface for control, data processing, with digital telecommunications, presenting for electricity, cogeneration technologies while for the thermal power from hydro and hydrogen production on site and from renewable sources.

Fig. 7: CUS- Facade integrated PV glass, source [17] **Fig. 8: CUS- Gym-Interior**, source [18]

In it has been realized the first micro-hybrid system, with a mixture of hydro produced just in time, in Italy in which converge **cogeneration technologies**, along with photovoltaic systems, solar thermal, fuel cell, hydrogen at low pressure and subsequent storage.
This project was implemented software Intelligent Operations Center (IOC) IBM for data collection and management throughout the system, both environmental and energy building system, from the town, the environmental characteristics that are provided to you.
This system is used in many offices and administrations and can provide information to the business interface with access to the domain, arrange in a synergistic way, data sets, through management models of business enters the domain, etc.
Energy management is entrusted to the Energy Manager must for public institutions according to Italian law. These energy-saving strategies are highlighted throughout the EU with growth for public and private investment and focusing on technological innovation also second-SET Plan with growth industries. For the smart energy (Figure 9) [19] BA in systems based on PC technology and integrated data-logger, ensure monitoring of energy consumption with outcomes of efficiency, flexibility and security. These systems interface in the network of smart grid, interacting with the grid but are independent from it and only through smart metering control, you can detect the consumption in specific configurations.

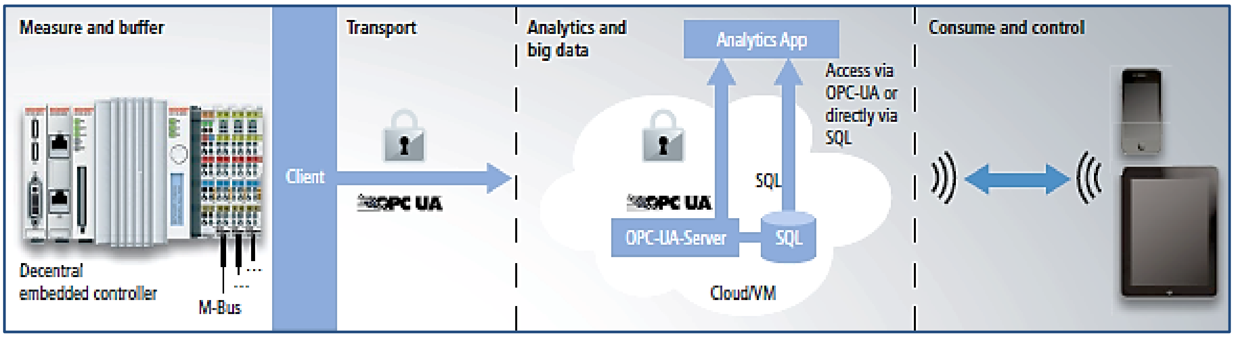


Fig. 9: Cloud connectivity scheme such as 2 watch. Smart Energy in buildings, source: [19]

They allow the user to adjust the degree of warming, while at times of peak energy, whose data can be transmitted in automation systems for the management of the network, even during fluctuations in energy and thus being able to set and adjust prices. According to Bloomberg New Energy Finance, in Europe in the decade, it should install about 180 million smart metering, from the current 55 million, while in China there is the installation of almost 250 mln.

The category of Intelligent Building (IB) and integrated automation, line up also NZEB concerning infrastructure supervision and control of the IB. Among the building automation of the new building is the **office tower of 185 Frankfurt** (Figure 10) [20], building quality certified LEED gold, which rises in the context and in the surrounding environment by a complaint that the architectural configuration 'innovation and development of environmental energy. The low building is clad with sandstone, while the facade of the tower, is made of steel and glass, forming the entrance to the Europaviertel, new business district established between the banks and the fair.
The massive structure with type tower was designed and built in 2011 by prof. arch. Christoph Mäckler and highlights from a base platform horseshoe, a six-storey building and stands at the top for more than 200 m and is used mostly in offices across 50 floors with office space of 100,000 m^2.

b) Internal offices

Fig. 10: The office tower 185, Frankfurt, Germany, source [20]: a) , b)

a) Perspective

The structure is made of concrete a.c. with over 76000 square meters of floor, Cofrastra 40 (ArcelorMittal)-slab of high quality composite steel and concrete, with service facilities and self-supporting facades.
The layout of the tower, with a grid of 1.25 m, distributes 35% of individual offices on each floor, with 54 desks and eight corner offices.
It 'a green building and sustainable low impact with flexible facade curtain wall, glass, full-height that allows transparency and natural light, and aluminum with prefabricated panels of 4m x 4m mounted with the help of a robot.
This has installed 20 panels per side per day in the wind conditions and precarious climate and weather.
It shows intelligence and energy efficiency with 50% glass facade that save heating and cooling energy with natural exposure to the north by reducing energy for air conditioning.
The principles of sustainability are apparent in rainwater recycling reused for 2.3 million liters, of water for irrigation plants, drains, green roofs of the building base, and vegetation by about 25% of the site. 90% of construction waste was recycled.
Materials in the site that maximize transport and **reduce the rate of pollution** of C_2.
Its automation, XXL Hermos which includes heating, ventilating, and air conditioning (HVAC) is connected to the BMS system management and is equipped with control sensors 700 of the PC from Beckhoff and 60.000 points date, interface via Ethernet.al, with the communication system ADS TwinCAT for the control and management of the services.

In Turin was made the new high-rise green and intelligent building for Intesa Sanpaolo Bank, (Figure 11) [21], getting the energy certification LEED Platinum by the GBC Council, in 2015.
The construction technologies reveal structures concrete and iron, coordinates with BIM modeling. Megacolumns steel filled with concrete floors and precast concrete alternating jets, at work are the backbone main, similar to shelf steel and concrete, which integrate both bracing with steel cables and columns, in the south, which the core. In coverage, a reticular beam system- transfer-reports the load on the columns, and on the core in reinforced concrete.
166 m high with 44 floors (38 floors above ground) and a basement (46 m x161 m) 6-storey underground, the building presents, west and east, with casing of double skin façade in glass with low reflectance (Figure 12) [22], but with a interspace of 2.5 natural ventilation, equipped with intelligent sensors for the automation system of brise soleil connected to BMS. Are highlighted in the west, the bioclimatic greenhouse, with coverage in the distribution of offices is open space and comfort, energy / environmental, insulation flooring with jets of expanded clay, conservatories vertical south rainwater recycling on principles of sustainability.

Fig.11: Building by Renzo Piano for Intesa Sanpaolo Bank, Turin, Italy.
Perspective, source [21]

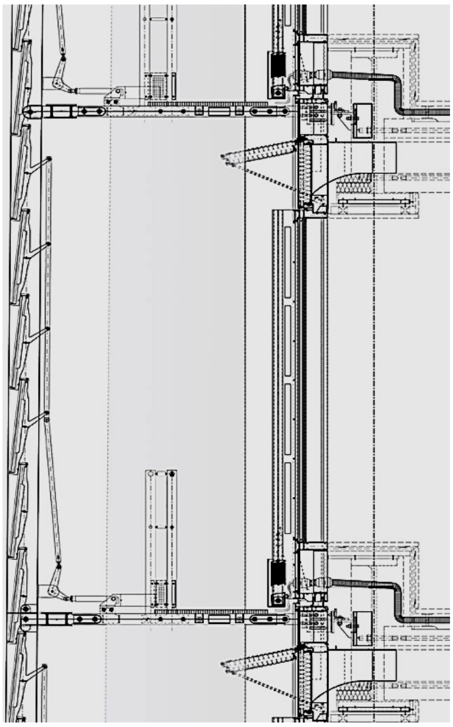


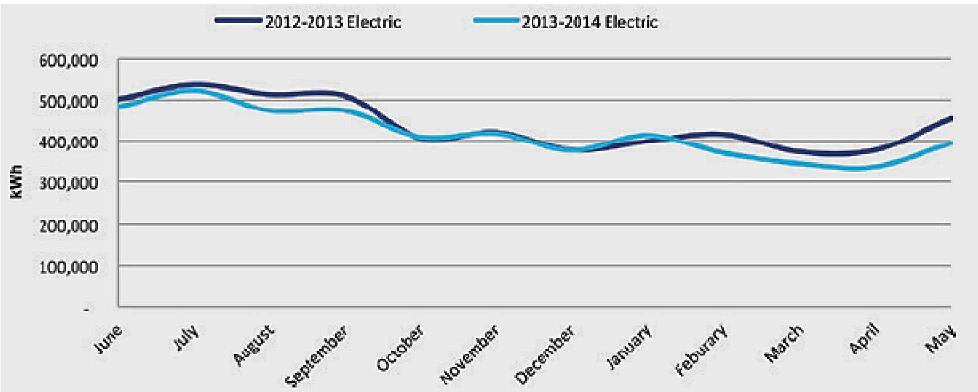
Fig.12: Building by Renzo Piano, Intesa Bank, Turin, Italy.
Section, source [22]

The building in energy class A, has 1,500 m² of PV panels (about 120,000 kWh / year), on south façade exploits energy from geothermal sources, inverter heat pump with variable flow for heating and DHW.
The cooling chillers TECS2W - HC, High Condensing, and a FOCSW HS 1902, with indicator greater than 5 - EER (Energy Efficiency Ratio) with internal distribution of radiant island suspended.
Offices (h 3.20 m) have an indirect natural lighting with an overall saving of energy by 45% less. In terms of comfort and well-being of individual stands in central innovation of the 31st, the construction on the ***home feeling*** based on the principle **Lake Interior Life.**

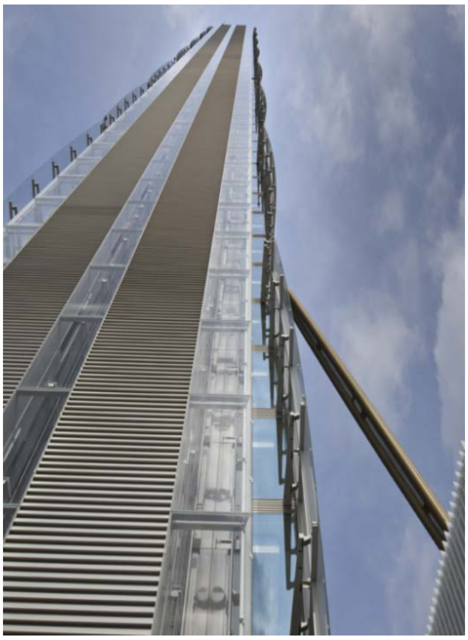
4. The smart redevelopment of *office building*

In the global debate of climate change the real estate industry is the turning point of some problematic issues both energy and environmental pointing also to the **redevelopment and recovery of buildings**. So many are the intervention strategies based primarily on standards and EU directives that stimulate research and training with incentives to support interventions, including in Italy, the Decree 102/2014 implementing Directive 2012/27 / EU, etc.
The offices, in Italy, there are about 65,000 of the total area of 56.7 million m² and a volume of 200 million m³, while shopping centers are 1,114 and occupy an area of 16,07 mln m² GLA (Gross Leasable Area).
In reference to certain indicators recording a power consumption greater than 50% for which intervenes with an integrated design building / plant on 'insulation of the casings, especially for a low thermal transmittance, and power plants**. Offices indicate major energy** issues for both air conditioning systems, lighting, cooling and heating-about 60% of energy from sources such as IEA [23], of safety and security. In them it is working with alternative systems from renewable energy resources, smart technologies and innovative construction technologies with natural materials of excellence and environmentally sustainable, given the cost of investment ROI (Return on investment) and Payback Time. For greater efficiency of the interventions, around the world, it modifies skyscrapers converting them into smart buildings, as in the United States in New York, the island of Manhattan.
In fact, in high technology companies Italian Finmeccanica and SELEX Ex (Selex Electronic Systems), the American Society of Real estate Rudin Management Company in collaboration with Columbia University in New York, working in the conversion efficiency of skyscrapers.
It plans to redevelop 16 existing buildings offices in Intelligent Building, applying smart technology and the **Di-Boss** (Digital Building Operating System Solution). OS data acquisition systems building (thermal, electrical, security, air conditioning, access, etc.) That converge a single trading platform and in energy efficiency by reducing energy consumption and related savings for the 'elimination of CO_2, Supervisory Control and Data Acquisition (SCADA). Some of these are already in office building, and service are two recent cases pilot efficiency and distributed intelligence system implementation with Di-Boss: 560 Lexington Avenue in the skyscraper of 22 floors, two centrifugal chillers are installed, two twin-tube and UTA 125 points of BMS (Table 3) [24] programmed into the system Di-Boss; 345 Park Avenue South in the skyscraper of 44 floors and designed by architect Emery Roth & Sons in 1969. The result of the two buildings was to reduce costs and save energy, 33% of the temperature.

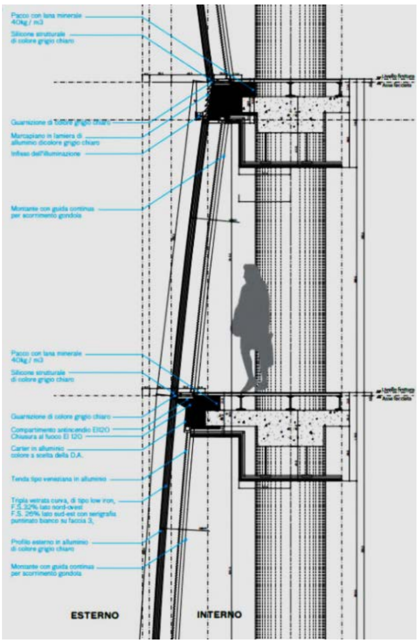
Table 3. Electrical Normalized curve for Weather -345 Park Avenue, NYC-Manhattan, USA



"Using building's turnstiles the occupancy is integrated into platform and is implemented lunchtime ramp-down and modulating the frequency variable by fit to the occupancy curve", source [24]



a) Perspective, source: [25]



b) section, source: [26]

Fig.12: Allianz tower Isozaki, Milan, Italy, architects Isozaki, Maffei: a), b)

The redevelopment project Citylife, the former district of Milan Fair (2015), has made the tower Alliaz Isozaki, high 202 m (Fig. 12) [25] [26], points to another theme of efficiency is the space that planning of plants with bio-climatic with optimization of "water efficienty" etc., for energy saving and natural ventilation. In Italy is the first building with the facade, curtain wall (26,000 m²), triple glass (4500) structural cells, bent with cold bending technology. Facades double glass on the short sides. The offices are open spaces with surfaces of 24m x 36 m are distinguished by the tenant efficiency. Especially energy from the PV panels (PV) and district heating. The building has been certified LEED Gold.

In England, in London city, it is part of the district Islington, London, the redevelopment energy / environment of the Angel Building by AHMM (Allford Hall Monaghan Morris) architects. (Fig.13) [27]. Gross internal area (GIA): 33.224 m². Building sustainable, low environmental impact with energy efficiency and intelligence services, elevators that use 50% less energy than conventional ones. Intelligent Digitally Addressable Lighting Interface (DALI) for sensors that regulate the levels of natural light, the BA-saving. RES with biomass boilers provide 100% of the heating, ash pellet biodegradable and recyclable. The existing vegetation creates a microclimate between the building and the context in which are favored by public transport.
Following the occupation levels: Ventilation / Servicing Strategy, Toilet Provision, Travel Plan, for 1 person / 10 m²mentre for Means of Escape, Lifts, respectively for 1 person / 7.5 m², and 1 persons / 12 sqm with 15% absenteeism.
The building has got a rating of excellent quality Breem.

Fig.13: Angel Building by AHMM, London, UK, hall reception, source [27]

5. Conclusions

Energy strategies for energy efficiency and environmental restoration in the building sector denounce a series of reversals indicate that, above all, research and the use of RES resources, alternative sources to fossil fuels. RES representing the platform of action on which to apply all the utilities of different organizational and operational systems for new approaches to constructive policy and in view of social and environmental benefits, focusing on the **distributed generation**-centralized and the decentralized to the built [28] .

In fact we see the improvement of new design processes and product with application clean and smart technologies, on renewable resources, with the field of components and materials in the different political strategies. These include the Directive 2012/27/EU, with support for European Funds Investment, Fund (EIF), the EIB (European Investment Bank), etc., improve, in the construction sector, the rehabilitation of existing buildings with ROI (Return on investment) and Payback Time.

So it points to the **intelligence distributed architectures** with efficient smart building, with EN 15232, in thesis multidisciplinary actions co-investments, in line with changing needs and climatic changes that lead to energy saving solutions with operations worldwide. The criticality of the smart building is the lack of knowledge of different applications, especially depending on the use of renewable energy sources, because they are intermittent and mainly depend on climate and weather.

So we need to promote scientific research with training for one coordinated and sustainable development of distributed, both for new buildings and for existing ones.

The intelligence of the *office building* and *distributed generation* are in synergy with the **new business models of the design processes** [29] for tertiary buildings, where offices represent places with the highest percentage of jobs. They are performance requirements of new generations of the tablet, iPhone, iPhad, intelligent and efficient by creating new spaces and *lounge* areas *brainstorming* in which communicate and think. Distributed intelligence with the *tenant office* space with efficiency and sustainable relationship, location-free working with hot-desking, desk sharing, hoteling, telecommuting, virtual office, etc., feeling on the home based on the principle *Lake Interior Life*.

Sustainable buildings in contexts where new political strategies, including COP21, encourage the reduction of 2% of CO_2 with use of renewable resources due to climate change and related environmental degradation. The analysis of the amount of resources of each country along with the establishment of a **methodology** of exploitation become important benchmarks for the reduction of the management costs for the exploitation, and to raise the quality of management in the building sector. Already the first signs of increased production of distributed generation with solar thermal and photovoltaic, cogeneration, trigeneration, micro hybrid from hydro, proton exchange membrane (PEM) electrolysis technology, the BA and BMS systems with innovative platforms such as Di- Boss.

The measures of *quantitative easing* from the ECB with the collapse of oil prices and the fall in the value of the euro, could work together to the recovery in the construction industry, as indicated by Cresme for the next biennium. In Italy the percentage of 35% of the offices with the redevelopment would reach an average energy savings of 18%, for which you require, for both the existing built that for new construction, the adoption of new business models for design processes and the application of innovative technologies and risk management.

With global adoption of BA *system spanning* based on synergies, it reduces the consumption of a building by about 30% by controlling software transmit data across systems in flexible workspaces, with mobility and **co-working** by applying **smart technology,** geo-sensing transmission with smart phones, etc. So efficiency and productivity with IT (Information Technology).

In Europe we feel the improvement of the buildings, which in Italy is entrusted mainly to public works with growth forecast of 4% to the total of 36.4% in 2020. The **smart grids** in the **smart cities**, the **smart buildings** and **net_zero**, between emerging technologies with **innovative energy technologies** and construction, technology BIM software platforms that interface designers, manufacturers and suppliers to an open date of the building, from the creation to the management and final disposal of its useful life. They represent **challenges to the achievement** of operating and management models in the construction sector where technological innovation marks the sea change

aimed especially to the welfare of the citizen, with the advantage of greater awareness of the political management, the increase in employment, the adjustment of businesses and the new approach of building.
So **clean technologies** in the **smart community** and sharing among industry experts including architects, engineers, planners, energy managers, researchers, etc. All aimed at efficient management in the construction industry for the security and **resilience of cities**, with services lot of ***crowdsourcing,*** smart buildings and improving the quality of life.

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Experimental validation of different air flow correlations for natural single sided ventilation

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Abstract

Humans in the developed countries spend most of their time indoors. Therefore, the importance of good indoor air quality is evident. Natural ventilation is common for the air supply in many private residential buildings as well as in offices around the world. It grants the hygienic minimum or even more air exchange, protects from moisture damages and can provide good thermal comfort by intensive night ventilation in summer. The window opening process can be automated to compete with the air quality resulting from mechanical cooling and ventilation. Considering energy efficient buildings with controlled natural ventilation, the air exchange rate provided by window openings is a crucial design variable. Multiple correlations from literature allow the determination of air change rates for various window opening configurations and types under static conditions.

This work compares calculations from these equations with field measurement data. Most accurate correlations are identified. Limitations and challenges for technical planners are pointed out.

Traces-gas (TG) measurements with the Constant Concentration Method (CCM) were carried out, collecting five minute mean values of air change rates. Temperature differences ranging from 0K to 21 K and wind velocities between 0m/s to 1.5m/s were monitored. The window types examined are bottom-hung and side-hung windows. This work focuses on single sided ventilation.

Nomenclature

Q	total volume flow	[m³/s]	g	gravitational acceleration	[m/s²]
v_L	local wind velocity	[m/s]	C_p	wind pressure coefficient	[-]
v_R	reference wind velocity	[m/s]	C_d	discharge coefficient	[-]
T_{in}	room air temperature	[K]	A_{eff}	effective window cross sectional area	[m²]
T_{ex}	air temperature in front of the façade	[K]	β	wind incident angle	[°]
T_{Av}	mean temperature = $(T_{in}+T_{ex})/2$	[K]		0° wind directly into window, anticlockwise	
ΔT	temperature difference $(T_{in}-T_{ex})$	[K]	H	window opening height	[m]

Introduction

Humans in the developed countries spend most of their time indoors. So the importance of good indoor air quality is evident. Natural ventilation occurs in many private residential buildings as in existing offices around the world. It realizes the air exchange for the hygienic minimum or even more, protects from moisture damages and can provide good thermal comfort by intensive night ventilation in summer. The window opening process can be automated to compete with mechanical cooling and ventilation. Considering energy efficient buildings with this controlled natural ventilation the air exchange rate provided by window openings is a crucial design variable. Multiple equations from literature allow the determination of Air CHange rates (ACH) for various window opening configurations and types under static conditions.

Literature Equations

We cite three ways to calculate the volume flow through window openings from Warren [1], De Gids [2] and Larsen [3]. The following correlations (1) and (2) by Warren consider the influence of thermal and wind driven ACH separately. The case differentiation, if the temperature or wind result is true, is simple: The valid value is the greater one of both correlations. The British Standard 5925 [4] also utilizes this approach.

$$Q_{Warren,Temp.} = \frac{1}{3} \cdot A_{eff} \cdot c_d \cdot \sqrt{\frac{|\Delta T| \cdot H \cdot g}{T_{av}}} \quad (1)$$

$$Q_{Warren,Wind} = 0{,}1 \cdot A_{eff} \cdot v_L \quad (2)$$

De Gids combines not only both driving forces in the same equation (3), but also includes a turbulent part represented with the parameter C_3. The parameters C_i are empirical coefficients obtained from measurement data. The reference wind velocity v_R is the free stream velocity at window height. Although in the present study the local wind speed v_L is used instead. It was measured 1 m in front of the facade at window height 5 m besides the opening

$$Q_{\text{de Gids}} = \frac{1}{2} \cdot A_{\text{eff}} \cdot \sqrt{C_1 \cdot {v_R}^2 + C_2 \cdot H \cdot |\Delta T| + C_3} \tag{3}$$

Larsen's correlation (4) involves the wind direction in addition. Again, the parameters C_i are empirical coefficients obtained from measurement data too. The values of C_p and f(ß) were directly taken from literature [3].

$$Q_{\text{Larsen}} = A_{\text{eff}} \cdot \sqrt{C_1 \cdot f(ß)^2 \cdot |c_p| \cdot {v_R}^2 + C_2 \cdot H \cdot |\Delta T| + C_3 \cdot \frac{\triangle c_{p,\text{opening}(\beta)} \cdot |\Delta T|}{{v_R}^2}} \tag{4}$$

Method

Tracer gas measurements of ACH under real conditions were carried out similar to DIN EN ISO 12569. Over 100 hours measurement data of a test room were collected. The test room serves as a meeting room during normal use. Five minute values of all necessary physical quantities are averaged during that time. The raw recording interval was 45 seconds. The wind velocity sensor is located 5 m aside the window opening on the same facade. A more detailed description can be found in the paper of Erhart et al. [5]. The measured ACH was compared with calculations from equation (1) - (4).

The quality of the agreement between experiment and calculation is assessed with three indicators:

- The Pearson product-moment correlation coefficient
- The percentage shift between measured and calculated values via linear regression
- The mean absolute percentage error (MAPE)

Test room and experimental procedure

The test building (geographic coordinates 48.779561 N, 9.172081 E) is an historical office building, built in 1850. It has been re-erected after World War Two. Closely adjacent buildings cover it from influence of free stream wind. The southern facade is situated in an urban canyon situation. Its facade consists of a massive limestone and brick construction with wall thicknesses between 35 and 65 cm. Fig. 1 depicts a bird's-eye view of the building (blue circle); the test room for this case study is located on the first storey (red square). This corner meeting room (Fig. 2) has been equipped with monitoring hardware for the measurement of various ventilation scenarios. The test room is almost square with a net space area of 30.2 m² and a ceiling height of 3.5 m and a free room volume of 106 m³. The southern and western window configurations are identical.

Fig. 1. Birds eye view of the building (blue dot). The test room is located at the red square. [source: Bing]

Fig. 2. Test room: Numbered window openings and the sample point of the TG on the table.

In order to obtain a wide range of data, several test cases have been investigated to assess most relevant ventilation configurations for single rooms. Other flow-paths than through windows have been sealed (gaps, cracks, window gaskets). Tab. 1 gives an overview on the test cases including the geometric parameters. The effective areas of each configuration were calculated according to Van Paassen [6].

Tab. 1. Test scenarios and calculated flow relevant effective opening area used as inputs for analytical flow rate calculation.

configuration	level	Window type	Opened windows 1	2	3	4	A_{eff} [m²]	H_2 [m]
1	top	bottom-hung		x			0.43	0.44
2	bottom	side-hung			x		0.43	1.22
3	two level	bottom- & side-hung	x		x		0.96	1.66
4	bottom	2x side-hung			x	x	1.07	1.22

Detailed information on window geometry can be found in [5]. The discharge coefficient C_d of an orifice is defined as ratio of the actual flow to the ideal flow without effects of friction and flow contraction. In this work the reasonable value 0.61 is used according to BS 5925 [4].

The concentration measurement of the TG system (Lumasence INNOVA 1412i and Lumasence INNOVA 1303i) was carried out using the CCM according to DIN EN ISO 12569. Deviating, the air change calculation was done with software algorithms integrated in the software “Lumasence 7620”. Two fans, underneath the window facades and orientated 20° upwards, ensure a homogenous mixing of TG and incoming air (see Fig. 3). This is necessary to guarantee a representative concentration measurement. TG dosing occurred via a third fan in the opposite corner. The only sampling point is located in the center of the room (see Fig. 2). The sampling period was between 35 - 50 seconds. Preliminary to the start of each campaign, the concentration has been increased until the set point (10 ppm) was reached. Then, the windows were opened in the specific configuration (Tab. 1). Each measurement in one window configuration was performed for one hour (with fans running).

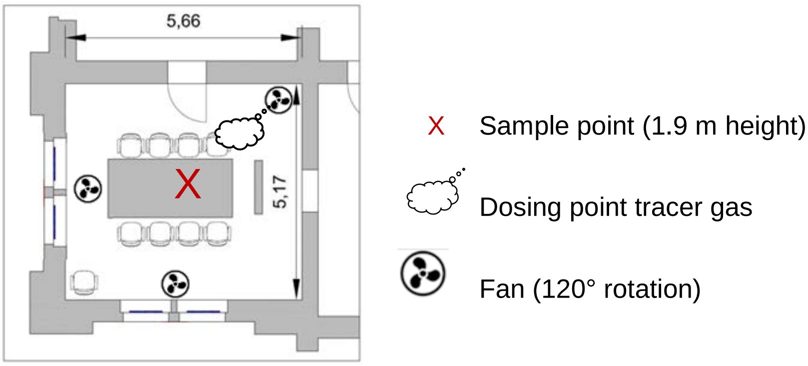

Fig. 3: Tracer Gas configuration

These campaigns were repeated on different days and different configuration. Five-minute mean values were used for all further calculations and evaluations.

To give a good understanding of the experimental procedure we show the data of one campaign in Fig. 4. The indoor air temperature decreases slowly over time since the external temperature is lower. The TG concentration stays remains constant at around 10 ppm when using the constant concentration method. The amount of dosing TG is not shown here. Every 45 s a TG injection occurs with which the ACH value is calculated. The steps in calculated ACH can be seen as the different window configurations are changed over time. With an increasing A_{eff} also the ACH rises.

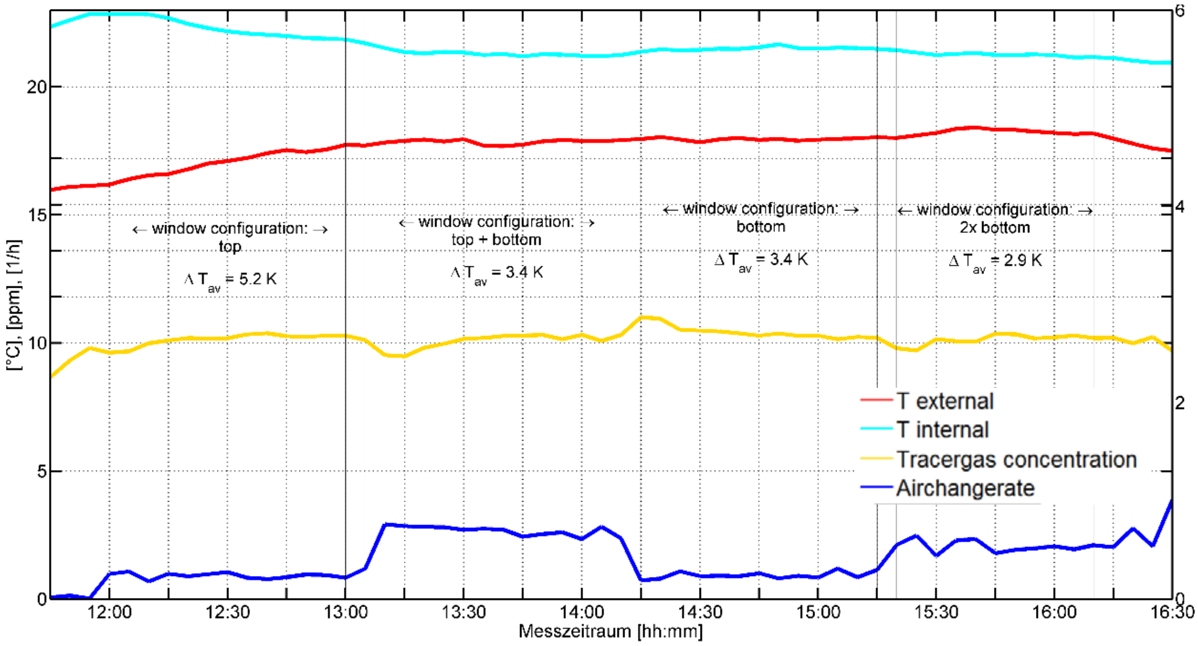

Fig. 4. Example of a measuring day with 4 different campaigns. The date is 5.11.2015

Validation Quality

For all measured values four corresponding theoretical values were calculated using equations (1) - (4). These values are plotted in Fig. 6 exemplarily for one window configuration. The correlation between experiment x and calculation y should ideally be f(x) = y. The parameter which rates the quality of a linear correlation is the Pearson product-moment correlation coefficient. But it does not detect a different slope for that correlation related to f(x) = y or axis intercept. Therefore, the factor difference of the slope of a linear regression on the data points through the origin related to that f(x) = y line is a measure for the relative shift between measurement and calculation. In addition the mean absolute percentage error (MAPE) is taken into analyses as a measure for the accuracy of the scattering [7].

$$MAPE = \frac{100\%}{\mathrm{n}} \cdot \sum_{i=1}^{n} \left| \frac{x_i - y_i}{x_i} \right| \tag{5}$$

The shift factor in combination with the correlation coefficient and the MAPE indicates the quality of the match between calculation and measurement.

Results

For all four investigated window configurations air exchange rates were measured over a temperature difference from about 1 °C to 20 K. The wind velocities were within 0 m/s to 1.5 m/s.

Volume Flow

Typical results for the volume flow are shown in Fig. 5. For window configuration 1 the measured ACH is drawn over the temperature difference. The wind influence is insignificant at the monitored velocities lower than 1.5 m/s. The part with square root dependency from temperature difference in all correlations for the volume flow is prominent. All other configurations behave similar to this figure.

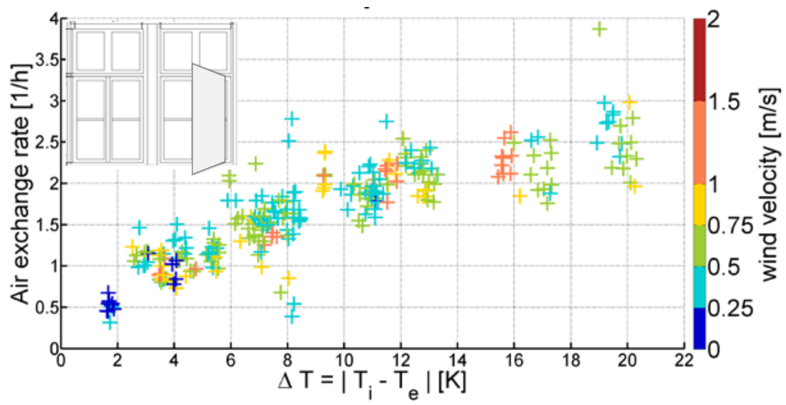

Fig. 5. Measuring results of configuration 1 (one bottom window side hung)**.**

Validation Quality

The calculated values corresponding to the measurement values are plotted for one configuration in Fig. 6. As a guideline for the eye f(x)=y is drawn into the plot and the deviation lines with ±25%. Similar plots exist for every correlation and window configuration (not shown).

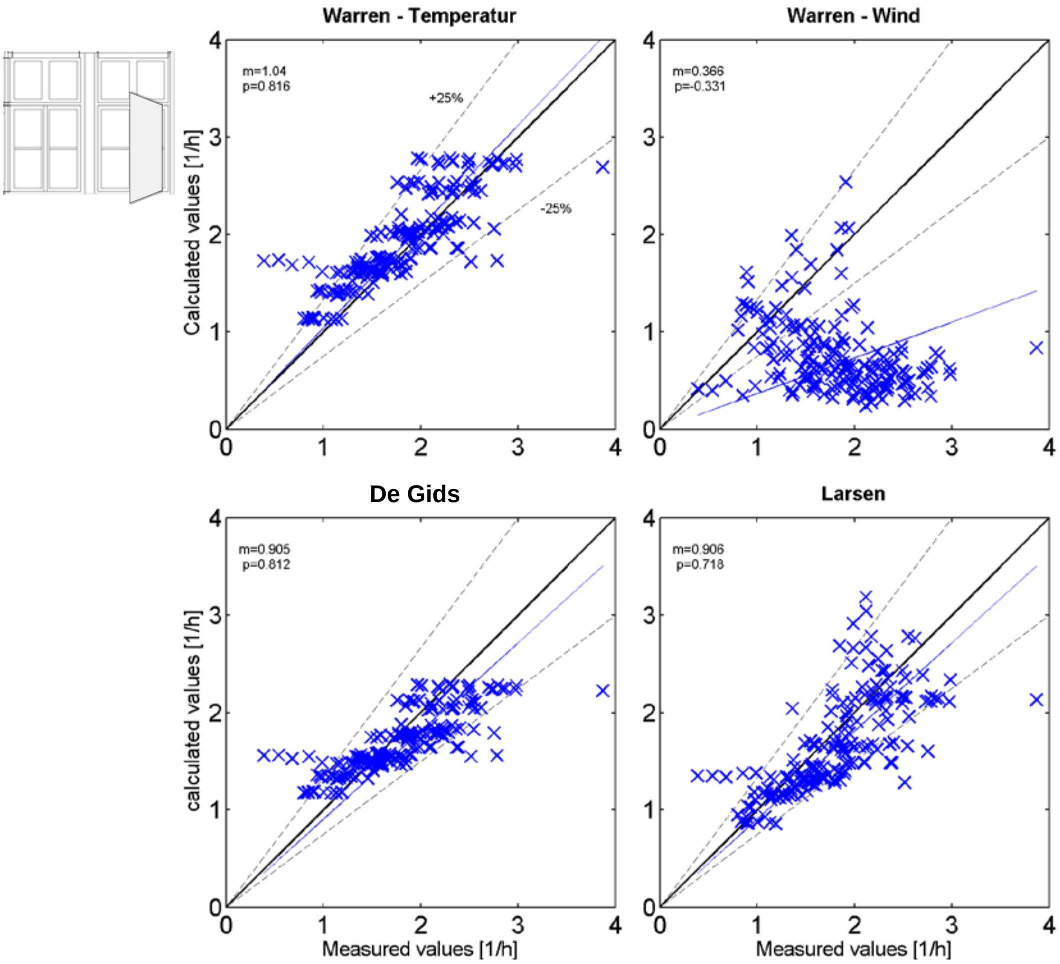

Fig. 6. Calculated over measured values for equations (1) to (4) in configuration 1.

For every case a linear regression is calculated for the data points with a fix point at the origin (blue line in Fig. 6). The difference factors in the slope are identical with the slope value itself. Meaning a slope of 1.21 has a 21% difference to the ideal slope which equals one. In Tab. 2 these shift factors for every evaluated case are presented as percentage value.

Tab. 2. Quality of shift: Shift factors between measurement and calculation.

	Warren Temp.	Warren Wind	de Gids	Larsen
bottom	4%	-61%	-9%	-11%
top	8%	-12%	17%	12%
top+ bot	-2%	-57%	-12%	-17%
2x bot	-5%	-58%	-15%	-14%
total	-2%	-57%	-12%	-14%

The parameter which indicates the quality of a linear correlation is the Pearson product-moment correlation coefficient. The correlation coefficients for the different campaigns can be found in Tab. 3.

Tab. 3. Quality of correlation: Pearson correlation coefficients.

	Warren Temp.	Warren Wind	de Gids	Larsen
bottom	0.86	-0.12	0.86	0.69
top	0.60	-0.02	0.63	0.49
top+ bot	0.69	-0.17	0.69	0.63
2x bot	0.71	-0.19	0.71	0.56
total	0.89	0.35	0.88	0.81

As third statistical indicator the MAPE is presented in Tab. 4. The detailed analysis of the different window configurations are not in the focus of the present work and hence not evaluated further.

Tab. 4. Quality of accuracy: Mean absolute percentage errors (MAPE).

	Warren Temp.	Warren Wind	de Gids	Larsen
bottom	19%	54%	20%	24%
top	28%	44%	34%	34%
top+ bot	37%	50%	34%	34%
2x bot	18%	51%	18%	24%
total	24%	50%	25%	28%

The Warren Wind correlation is highly shifted, completely out of correlation and connected to the highest deviation of 50%. The slow wind velocities are the reason for being in the thermal regime of the case differentiation of Warren's equation (1) and (2). Hence the wind correlation (2) is highly inaccurate.

The Larsen correlation shows a modest total shift factor with -14%. The small linear correlation with a mean Pearson coefficient of 0.81 together with a MAPE of 28% indicates a high variation around the average fit line. Correlation (4) was measured in a wind tunnel under stationary wind directions. In contrast the present work's data were measured under outside weather conditions. It can be assumed that the dynamics of the outdoor wind cannot be fully covered with the correlation from stationary laboratory measurements.

The correlations of de Gids and Warren (temperature case) show good agreement with the in-situ measurements. Warren performs best with slight advantage in every category of the total measurements. The shift factor of -2% gives a very good mean agreement of equation and measurement. The best correlation coefficient of 0.89 supports that statement. The MAPE of 24% though expresses the existing variance and is consistent with the correlation coefficient being still away from 1.

Conclusions

In the present study air change field measurements were carried out for single sided natural ventilation. The building was situated in a wind covered urban situation. The measurement results contain data for a large temperature difference range of up to 20 K, wind speeds varying between 0.1 m/s and 1.5 m/s and wind directions often parallel to the building facade.

The experimental results were compared to available literature correlations for single sided ventilation and the correlation quality and deviations were determined. Warren's correlation separates cases for wind or thermal regime. Its results fit to the measurements of this work with a shift of -2% and a MAPE of 24% and a maximum Pearson coefficient of 0.89. De Gibs combines wind and thermal influence in one equation and delivers almost equal precise results. For the wind covered building investigated the simplified Warren equation is sufficient for determining the volume flow. In more exposed building situations Luv and Lee directions could play a more dominant role and should be taken into account.

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Session Monitoring I

Monitoring occupancy practices and comfort in commercial buildings

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Abstract

Improving energy efficiency in commercial buildings is of great importance, given the large percentage of energy consumed in the sector. Energy consumption in commercial buildings account for 30-40% of the primary energy consumption in developed countries. The implementation of low carbon technologies in buildings can potentially decrease energy consumption, however many small and medium companies lease buildings and therefore investments in building technology are not a viable option. In addition, energy consumption is only a very small part of the financial burden of companies, and thus, economic incentives have a low impact in these environments. Furthermore, occupancy behaviour is greatly affected by the type of building and installations. Very environmentally friendly occupancy patterns in an energy inefficient building will not show up in the energy bill, and so, the efforts of the occupants would not be visible or rewarded. On the other hand, very wasteful occupancy patterns in a very energy efficient building might hinder the buildings' performance, but might not be discovered looking only at energy figures.

The Building Occupancy Certification System (BOCS) aims at developing an evaluation system focused on the building's occupancy instead of its technical characteristics. The objective of BOCS is the reduction of energy consumption in offices while improving indoor conditions. In this regard, the improvement of indoor conditions and thus, productivity is the incentive for company managers and staff to implement the BOCS system. This paper reports on the system infrastructure and evaluation of the BOCS methodology.

1. Introduction

The implementation of low carbon technologies in new and in the existing building stock promise not only a reduction in energy consumption and carbon emissions, but also a good indoor environment for the building's occupants. However, the penetration of new technologies in the market is not easy because of the uncertainties related to payback periods and usability constraints. Past and current research has shown differences between the expected and the actual performance of buildings [1-5] both in terms of energy consumption and indoor comfort, which are partially caused by the influence of occupant's behaviour in the operation of the building [6-8].

In the Netherlands, 25.1% of the non-residential buildings are offices. There are 60,000 office buildings from which 77% are owned by corporate investors, 20% are privately owns and 3% are governmental [9]. The yearly specific energy use in office buildings is 220 kWh/m2 from which 132 kWh/m2 are gas and 88 kWh/m2 are electricity [9]. Classified according to the final use, office buildings in the Netherlands use 39% on space heating (85.8 kWh/m2), 1% on hot tap water (2.2 kWh/m2), 22% on lighting (48.4 kWh/m2), 4% on cooling (8.8 kWh/m2) and 35% on others uses (77 kWh/m2), including electronics and other office equipment [9].

According to the literature, energy savings based on occupancy patterns and better management of office equipment can lead from 25% to 60% [10-12] on energy savings without extra costs. Other studies show that only addressing behavioural change can reduce up to 6% energy consumption [13]. This can be compared to the 23-33% on energy savings achieved with the refurbishment of a typical office building [14].

However, the effect of occupant behaviour is difficult to identify and to correct, because of the large variety of occupant typologies, comfort preferences and user-technology interaction [15]. Therefore, to reduce energy consumption and carbon emissions in the built environment, it is necessary to take into account the role of the occupant in the performance of buildings.

There are several ways to assess building performance, from national building regulations and energy requirements to well-known energy performance certifications such as LEED, BREEAM, and CASBEE [16]. Most of these assessment tools are based on the ‘expected’ performance of a building. The expected performance is the calculated or predicted energy consumption in a building, and in some cases the expected indoor environment. This performance is often based on building modelling (either static or dynamic) [17-20], in which building characteristics and average occupant behaviour (building operation) are used to calculate the energy consumption. The expected energy consumption is then compared with a benchmark, defined as the average energy consumption in a sample of buildings or in a reference building.

In some certification systems, such as BREEAM in-use, a checklist is employed to determine the efficiency of the management of the building in relation to energy conservation and other environmental aspects such as water usage and waste management [16]. These certifications use quantitative data on energy consumption or energy costs, and qualitative data on building operation. However, there is a lack of integration between qualitative and quantitative data, and therefore, a lack of understanding on the influence of occupants on the energy performance of the building.

Current energy labels and regulations focus only on building-related, or regulated, energy consumption. The impact of occupancy in user-related energy consumption is not only difficult to decrease through low carbon technologies, but it is also difficult to quantify. The Building Occupancy Certification System (BOCS) aims at quantifying, understanding and evaluating the influence of occupancy on the performance of buildings. More importantly, BOCS makes use of real-time actual energy consumption and occupancy information, providing a more reliable and accurate assessment in comparison to checklist-based evaluation systems.

The purpose of BOCS is twofold. Firstly, it will provide a more accurate building occupancy performance assessment, which will be useful for building owners and financial institutions to make decisions regarding the implementation of renovation schemes and low carbon technologies. Secondly, it will provide feedback to building managers and occupants regarding building operation practices to reduce energy consumption while increasing or maintaining occupants’ comfort.

2. BOCS methodology

The BOCS project aims at combining research with development of market-ready solutions that support reduction of energy consumption through behavioural change [21-23]. Monitoring building performance is necessary to understand and to influence occupancy practices [24-25]. Therefore, BOCS provides a platform to monitor pragmatically building performance [26]. The data collected during monitoring activities in the buildings will be stored and processed within the BOCS database, which will be the basis for the assessment system. The data will provide the information needed to define the efficiency of diverse building operating practices and behaviours.

A number of projects [26-28] were studied to determine the type of data collection needed to assess the performance of office buildings. The preliminary study showed the need for subjective and objective data, as well as qualitative and quantitative analysis. In the context of our study, objective data refers to data measured in the building. In such measurements, the perceptions of the occupants have no influence. On the other hand, subjective data is provided by the users, and therefore it is influenced by their own perception. For matters such as energy use or building operation (opening windows, thermostat settings) the least influence we have from the occupant, the better. To determine the thermal comfort performance of the building, BOCS aims at understanding the subjective comfort of the occupants.

Qualitative data will be used for the analysis of occupancy practices and their relationship with building operation and comfort. Qualitative analysis will be used to explain phenomenological experience (experience from the point of view of the occupants). Qualitative data collection and analysis is intended to be applied to fewer subjects, decreasing the statistical significance of the data but leading to a deeper understanding on the subject of study. Co-creation sessions with building occupants [29] are intended to provide the information needed for the qualitative analysis.

With quantitative research methods, BOCS aims to find relationships between indoor parameters, building operation and occupants’ preferences and satisfaction. The data analysis on these relationships will provide the basis for the occupancy evaluation. Further sections contain more information about quantitative analysis of BOCS for building occupancy evaluation, and building performance. The qualitative methodology is out of the scope of this paper.

2.1 BOCS data collection techniques for building performance monitoring

The BOCS approach has been developed to facilitate the development of solutions for energy savings. The approach developed provides a new way for organising research, and for innovating and implementing solutions in a living lab context. This approach allows parallel execution of research and innovation, providing new opportunities for addressing the challenges of social practice change. The approach is organised around the BOCS platform, which consists of software and hardware components supporting the measurement of objective and subjective data on-site, and providing real-time feedback to users (occupants and facilities managers). The platform employs a modular system architecture, allowing easy modifications and addition of features.

The BOCS platform consists of sensor nodes and self-reporting devices, online feedback interfaces, and a back-end for collecting and processing data. The platform has been designed to support fast and flexible adaptations regarding types of collected data (e.g. qualitative or quantitative), sensors used (e.g. temperature, relative humidity, movement), and self-reporting and feedback interfaces (e.g. screen-based or physical devices).

The BOCS platform employs state of the art monitoring systems to gather information about indoor parameters, indoor comfort and occupant behaviour. All the measured data has a direct or indirect effect on energy consumption and indoor environmental quality [30-32]. Table 1 shows the type of data collection (parameters) supported by the BOCS system through the Sensor Boxes and Self-reporting devices, which are described below.

Occupancy evaluation within the BOCS platform is classified in three aspects: energy consumption, occupants' comfort and building operation. To carry out the building assessment on the three aspects, the data collected through different methods (shown in Table 1) is integrated for the analysis. For an overview on the relationship between diverse types of data and performance evaluation, see [27].

1. Energy consumption. Energy metering can be used to measure the delivered energy while energy sub-metering can be used to determine the usage distribution within the building. The data collection from energy meters and sub-meters can be done in different ways: energy readings, high frequency energy monitoring and Building Management Systems (BMS). The BOCS platform will allow the integration of externally collected data.

2. Occupants' comfort. Within BOCS, there are two methods to collect data for the evaluation of thermal comfort: measurements of indoor parameters, and application of thermal comfort surveys. The first method involves physical monitoring of the building (thus, objective data), while the surveys gather subjective data from the occupants, for example preferences for thermal comfort and indoor air quality. This two methods aim to be complementary of each other.

3. Building operation / occupancy practices. There are several techniques to investigate building operation, they can be classified into two main types: physical monitoring and occupants' investigation. Although physical monitoring could be more objective than occupant investigation, measuring building conditions is expensive and it is not free of errors (for example devices can be unplugged or broken). In some instances, physical monitoring is not possible because of restrictions on resources or accessibility to the building. Therefore, in some cases, occupants input will be used instead of measuring devices. Occupants can report on their practices and activities related to energy consumption, for example they can report on window opening, air conditioning system operation or on the use of radiators.

It is important to notice that not all types of data can be obtained in each monitored building due to technical or corporate restrictions. The BOCS system aims for flexibility in order to evaluate performance based on the available data.

For data collection, two devices have been prototyped: the Sensor Box and the Self-reporting device. The devices were originally intended for the SuslabNWE project [28] and they have been extensively modified for the BOCS project.

Table 1 Data collection methods in BOCS

Type of data	Parameters	Equipment
Measurement of indoor environment conditions	indoor temperature (^{o}C) relative humidity (%) CO2 level (PPM) noise level (dB) illumination level (LUX)	**BOCS sensor boxes**
Measurement of outdoor environment conditions	outdoor temperature (^{o}C) relative humidity (%) solar radiation (W) wind speed (m/s) wind direction (-)	Local weather station
Measurement of occupant behaviour (occupancy practices)	windows opening (binary) use of radiators (binary/^{O}C/setting) use of blinds (binary) use of air conditioning system (binary/^{O}C) use of thermostat (^{O}C per heating period) use of artificial light (LUX) use of small power (kWh) location (-)	**BOCS Sensor Box** and other sensors
Self reported occupant behaviour parameters	windows opening (binary) use if radiators (binary/setting) use of blinds (binary) use of air conditioning system (binary/^{O}C) use of thermostat (^{O}C per period) use of artificial light (binary) use of small power (binary) location (-)	**Self-reporting app or device** (only when deployment of sensors is not possible)
Measurement of energy consumption per final use	artificial lighting (kWh) small power (kWh) space heating (kWh/m3 gas) water heating (kWh/m3 gas) space cooling (kWh) mechanical ventilation (kWh) auxiliary energy (kWh)	Energy sub-meter on site (building EMS) Data from energy companies
Self-reported comfort and satisfaction	thermal comfort (1-7 scale) perceived air quality (1-7 scale) noisy environment (1-7 scale/binary) illumination quality for work (1-7 scale) reflection/glare bother (binary) privacy (binary)	**Self-reporting app or device**
Self-reported data on occupants actions to achieve comfort	clothing level (CLO/categories) adjusting clothing (categories) activity rate (MET/categories) changing space (-) others	**Self-reporting app or device**

The Sensor Boxes and Self-reporting device have been developed using modular electronic components. These components, in combination with a system of rapid-prototyped enclosures, permit fast production of small batches of fully customised devices. A similar approach has been taken for the online feedback interface in which input components have been developed as modular interface elements, which can be assembled into a custom dashboard for each specific user, based on requirements determined in co-creation sessions.

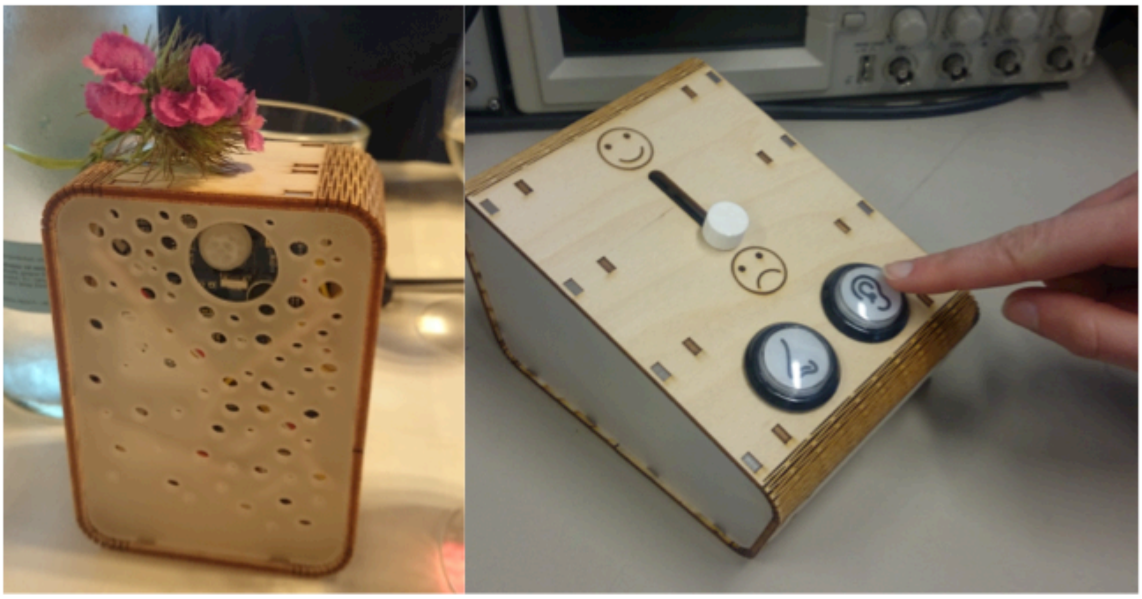
In the first version of the BOCS Sensor Box, sensors measuring CO2 concentration, humidity, sound level, temperature, light intensity and movement were used. Figure 1 (left) shows the first version of the BOCS Sensor Box.

The first version of the Self-reporting device was developed based on co-creation sessions with the participants of the first BOCS pilot in the Netherlands (summer 2015). The device was prototyped based on the indoor conditions that the occupants considered of greater importance for their productivity and work satisfaction: satisfaction, noise and air quality. The co-creation participants specifically asked to only give input when feeling discomfort.

Figure 1 (right) shows the first version of the BOCS Self-reporting device.

The frequency and length of data gathering of self-reporting data is currently being tested in the pilots. The frequency consists on the times per day that the user is required to fill in the data (in the device); and the length could be from a couple of weeks to permanent data collection. It is likely that a single solution will not work for all buildings, since it would depend on the company house-rules, type of work environment and characteristics of the building (size, installations, building control, etc.). For example in centrally controlled buildings, in which the manager is the only person responsible (and able) to make changes in the indoor temperature, permanent occupants' self-reporting on thermal comfort could help facilities managers to provide a comfortable indoor environment. On the other hand, in a building where users are able to control their environment, seasonal self-reporting could suffice. Therefore, the BOCS system would be flexible enough to accommodate for different types of office cultures.

Figure 1. BOCS Sensor Box and Self-reporting device version 0.1



2.2 BOCS data analysis: assessment system

As mentioned in the previous section, BOCS aims to assess building occupancy based on three aspects: 1) occupants' behaviour/occupancy practices (the core feature of BOCS), 2) measured and self-reported indoor environmental quality, and 3) relative energy performance. These are described in the following sections. The assessment of each of the three aspects can be seen in Figure 2 in relation to the indicators used for the assessment and the data collection method.

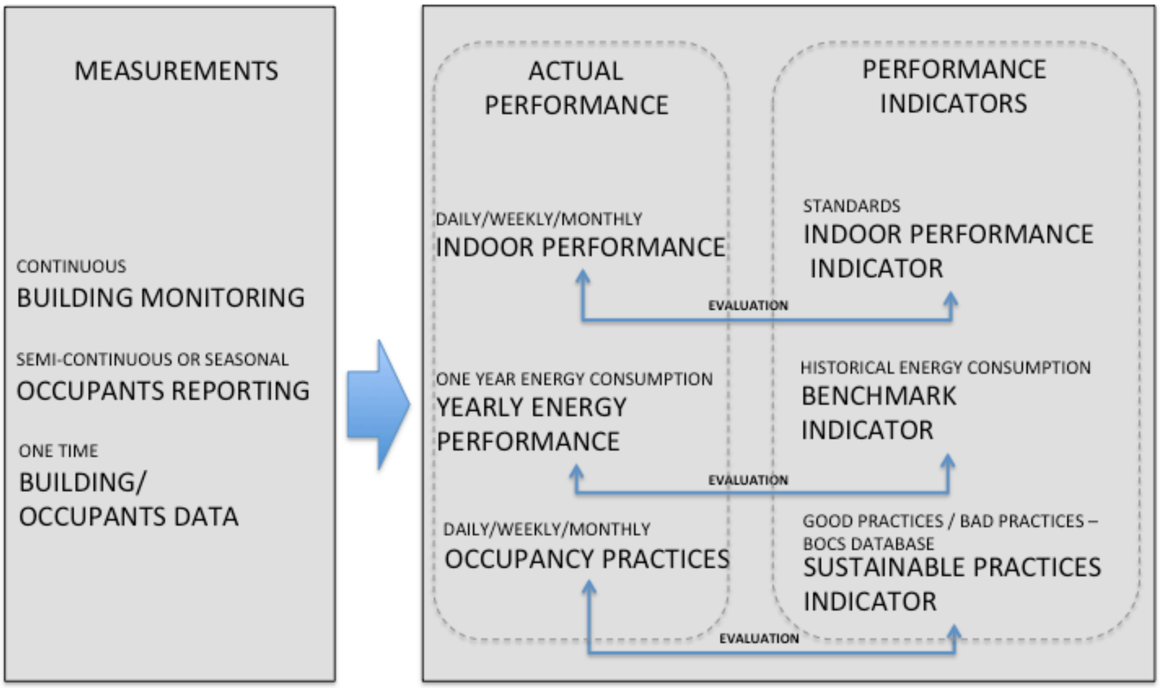
2.2.1 Occupant behaviour/occupancy practices

Occupant behaviour is considered, within the context of BOCS, as the actions of the occupants that have a direct impact on energy consumption and indoor environmental quality. The occupant behaviour makes up the occupancy practices followed in the building. The relation between specific occupants' behaviour (actions) and occupancy practices will be further investigated through the co-creation sessions in the monitoring pilots.

Data on occupant behaviour can be measured with diverse sensors or can be reported by the users. The data will be used to quantify, with data mining methods, the number of sustainable and unsustainable behaviours directly or indirectly related to energy consumption and indoor environmental quality. The definition of sustainable and unsustainable behaviours will be defined per building, since the type of building systems, level of building control and building characteristics will have an effect on the behaviour. For example, a good ventilation behaviour will be different for a building in which air conditioning is controlled by the occupants, and a building in which the air conditioning system is controlled by the facilities manager.

Occupant behaviour will be assessed against the occupancy practices BOCS database, which will be developed with the results from the pilot projects carried out in the Netherlands and the UK. Each seasonal pilot will provide with insights into how to establish relationships between building characteristics, occupants' characteristics, the occupants' behaviour. The occupancy practices generated from the pilots and incorporated into the BOCS dataset will be also the basis to categorise practices in relation to suitable behavioural change interventions.

Figure 2. Performance indicators to assess the occupancy of the building



2.2.2 Measured and self-reported indoor environmental quality

Indoor parameters can be measured with sensors (temperature, relative humidity, CO2 level, sound, light) and assessed in relation to available national or international standards to obtain an objective and average (for all users) assessment of the indoor environmental quality. The main advantage of measured indoor parameters is that data can be obtained with no interference on work activities, and can be permanently collected and fed back to the relevant party.

Using Self-reporting devices, the occupants of the building can give their ratings on the same indoor environmental factors, thus taking into account the diversity in preferences and needs among the occupants. The self-reporting data is subjective but can be quantitatively assessed in terms of percentage of time or percentage of people showing discomfort. The main disadvantage of self-reported data collection is the need for the occupants participation. To overcome disruption on work activities, the self-reported data collection could be limited to a two week period in the winter, summer and shoulder seasons.

2.2.3 Relative energy performance

We define the relative energy performance as the improved energy performance (after a number of weeks/months using BOCS) in relation to a previous period. The goal of this indicator is to assess the occupancy effect on energy performance. Although not primordial for the BOCS system, energy performance comparison between buildings is possible based on the percentage of energy savings in comparison to a previously established benchmark, for example the weather-normalised yearly energy consumption of a previous period. Therefore, the indicator (and the comparison) would be evaluating the efforts made by managers and occupants to decrease the energy consumption of the building by using the BOCS platform.

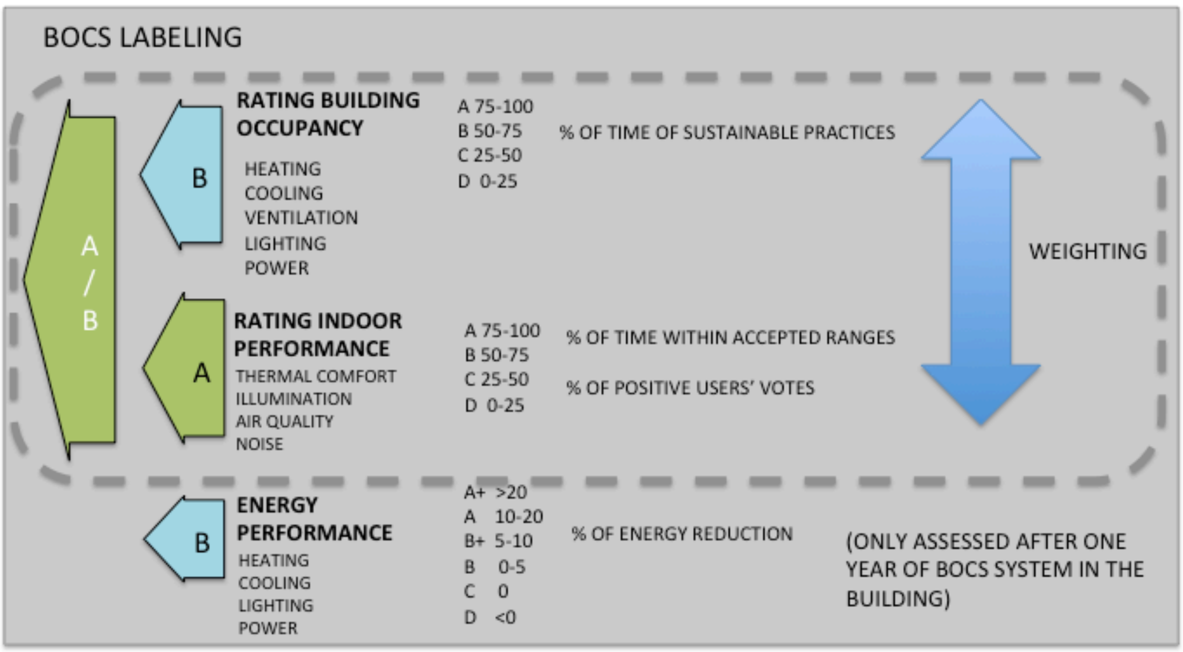
3. Preliminary BOCS assessment

As previously mentioned, the BOCS systems is able to provide building occupancy evaluation based on measured real-time parameters, and to provide real-time feedback to building occupants to improve the performance of the building. In this section, we explore the possible integration between the three aspects in the occupancy performance evaluation: energy, behaviour and occupants' comfort.

Figure 3 shows graphically the integration of the different components of the analysis. The 'RATING BUILDING OCCUPANCY' (occupant behaviour) is made up of five components: heating, cooling, ventilation, lighting and power. Each of these aspects consists on a number of sustainable and unsustainable behaviours that have a direct or indirect effect on the aspect. For example, the heating aspect could refer to both the thermostat setting (direct effect on energy consumption for heating) and to opening windows (indirect effect on energy consumption for heating). The 'RATING INDOOR PERFORMANCE' (occupants' comfort) is based both on measured/objective/standardised indicators, and on self-reported/subjective/personal indicators. These are integrated into the same rating, but with the possibility of disaggregation to provide more useful information to facilities managers and occupants. The 'ENERGY PERFORMANCE' is only assessed after one year (or full season) using BOCS in the building, given that the energy performance is the reflection of energy reductions based on the application of BOCS to the management and use of the building.

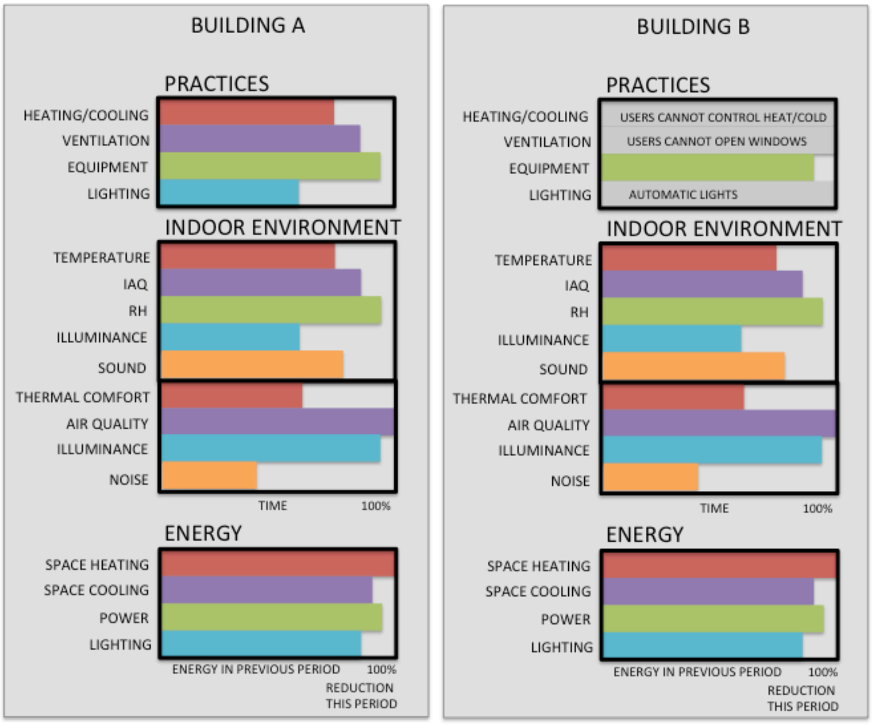
In the centre of the figure, we can see the possible ratings that each component can score. For example for *building occupancy* the scoring goes from A (sustainable practices are followed from 75 to 100% of the time) to D (sustainable practices are followed less than 25% of the time). Based on the rating scores, for each aspect (behaviour, comfort and energy) we can assign a total score from A to D, which would be the average of all the components in each aspect (e.g. heating, cooling, ventilation, lighting, power). A final total score could be produced in order to allow comparison with other buildings (far left of figure).

Figure 3. Integration of three aspects of assessment system



The disaggregated occupancy certification, where the scoring for different aspects can be seen, depends on the building type and building characteristics. For example, Figure 4 shows how the certification would look for: A) a building in which the occupants have total control on their environment (e.g. can open windows, turn on heating systems, air conditioning and lights); and B) a fully automatized building (e.g. occupants do not have access to controls).

Figure 4. Disaggregated configuration of occupancy evaluation



4. Further work

The next stage of the BOCS project aims at testing the data collection tools (Self-reporting device and Sensor Box) before further prototyping. The tools will be evaluated in respect to the reliability of the data collection, the usefulness of the self-reported data, and the devices interaction with the back-end for processing the gathered data. The evaluation will be performed based on the data collection and data analysis, as well as on questionnaire surveys applied to the participants of the pilots.

Further work will be aimed at a second prototyping iteration of the Self-reporting device and Sensor Boxes as part of the second round of BOCS pilots in the Netherlands and UK.

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Supporting Building Portfolio Investment and Policy Decision Making through an Integrated Building Utility Data Platform

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Abstract

The American Recovery and Reinvestment Act stimulus funding of 2009 for smart grid projects resulted in the tripling of smart meters deployment. In 2012, the Green Button initiative provided utility customers with access to their real-time[1] energy usage. The availability of finely granular data provides an enormous potential for energy data analytics and energy benchmarking. The sheer volume of time-series utility data from a large number of buildings also poses challenges in data collection, quality control, and database management for rigorous and meaningful analyses.

In this paper, we will describe a building portfolio-level data analytics tool for operational optimization, business investment and policy assessment using 15-minute to monthly intervals utility data. The analytics tool is developed on top of the U.S. Department of Energy's Standard Energy Efficiency Data (SEED) platform, an open source software application that manages energy performance data of large groups of buildings. To support the significantly large volume of granular interval data, we integrated a parallel time-series database to the existing relational database. The time-series database improves on the current utility data input, focusing on real-time data collection, storage, analytics and data quality control. The fully integrated data platform supports APIs for utility apps development by third party software developers. These apps will provide actionable intelligence for building owners and facilities managers. Unlike a commercial system, this platform is an open source platform funded by the U.S. Government, accessible to the public, researchers and other developers, to support initiatives in reducing building energy consumption.

Introduction

The American Recovery and Reinvestment Act stimulus funding of 2009 for smart grid projects resulted in more than 60 million smart meters being deployed in the U.S [1]. In 2012, the White House introduced the Green Button initiative to give utility customers secure access to their real-time energy usage and consumption [2]. However, the sheer volume of time-series utility data from a large number of buildings poses challenges in data collection, storage quality control, and database management. With the spread of "Internet of Things (IoT)" and better network capabilities, streaming data from various IP addressable devices and sensors within buildings with various communication protocols and systems provide further challenge for data collection and management. The management of large datasets is time consuming, potentially costly and often challenging for rigorous and meaningful analyses for energy conservation and improved building occupant comfort.

The U.S. Department of Energy developed the Standard Energy Efficiency Data (SEED) Platform, an open source software application to support "data-driven energy efficiency program design and implementation". The software application provides a "flexible and cost-effective method to improve the quality and availability of data to help demonstrate the economic and environmental benefits of energy efficiency, track program activities and target investments." The SEED platform is part of a suite of projects that the U.S Federal Government is developing to help "standardize, systematize and link data so that building owners, contractors, researchers, financiers, and other experts can aggregate and share information about building energy performance." These public tools, and a

[1] Currently, electric utilities provide the interval data on a daily basis e.g. an XML file will be provided at the end of the day with 96 values from a meter that is capable of capturing 15-minute interval data.

growing number of private tools, utilize a common set of data definitions, called the Building Energy Data Exchange Specification (BEDES) [3]. DOE intends for SEED to remain a fully interoperable piece of this system [4].

Data Collection and Storage

Existing SEED Platform

The main features within the current platform include data upload from tax assessor data and Energy Star Portfolio Manager (PM) data. Users import tax assessor or PM data into the platform, map the terms into BEDES format and define relationships between buildings and tax lots. If the upload contains new utility data, SEED automatically updates the records without having to repeat the manual matching process. To reconcile different data sources (e.g. tax assessor and PM), SEED simplifies and automates the data matching process by displaying likely matches to the user. With user approvals, SEED stores this information for future data matching. SEED also supports the manual upload of XML, csv and Excel-based utility data files [4]. ***Figure 1*** below illustrates the SEED user interface.

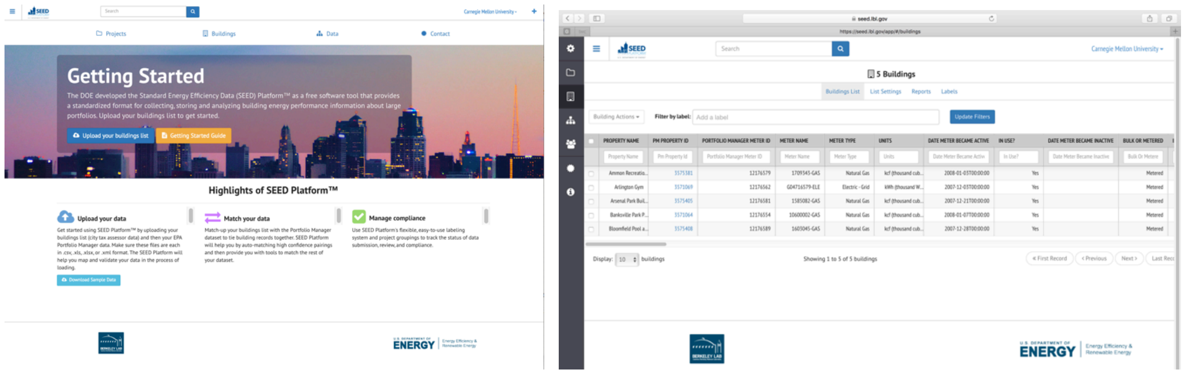

Figure 1: SEED platform user interface

Currently, the existing platform does not support automatic data import and does not display the imported Green Button data on the user interface. The platform utilizes PostgreSQL database to store all the various collected data types. PostgreSQL, a general purpose relational database, is very mature and able to handle massive amounts of data. However, its performance will downgrade with the rapid increase of finely granular meter data (e.g. import of real time Green Button 15 min interval data). In addition, the complexity of creating multiple tables to facilitate queries from different applications, as the database expands to accommodate new building portfolios, would require extensive knowledge of all the underlying table layouts and relationships.

Enhanced SEED Platform

To increase the functionality of the SEED platform, we developed a utility data upload, storage and retrieval feature to overcome the platform's current limitations, as mentioned above. This feature will enhance the manual utility data upload from Excel-based files and support automatic data upload of XML Green Button files from utility providers. In general, the structure of the framework is as follows: A driver periodically requests interval usage data from utility company (service provider) or the user uploads the Excel-based fie manually. Once the XML or Excel-based file is obtained, it will go through a parser that formats the data to a SEED time-series data. The data will then be stored in databases to be accessed by third-party apps. This framework is designed for scalability and to minimize modifications to the existing platform. ***Figure 2*** illustrates the overall framework with the various modules to integrate an additional database to manage the time-series utility data. The five modules and associated tasks are listed below:

1. "Data Driver and Parser" modules import the XML and Excel-based files into the SEED.
2. "Time Series (TS) Data Analyzer" module determines where and how to store the imported data.

3. A secondary time series database (TSDB) manages interval data of higher granularity (15 min to daily).
4. “Monthly Scheduler” module aggregates and pushes monthly data to the existing PostgreSQL database.
5. Application program interface (API) Management Platform enables queries from third-party app developers

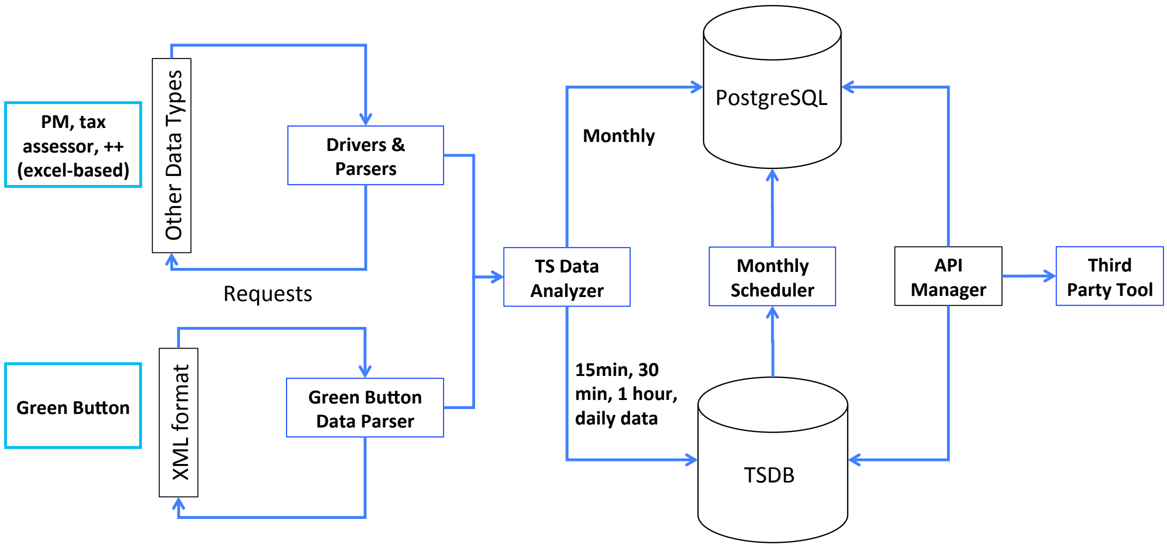

Figure 2: Overall SEED platform architecture diagram

The following sections describe in detail the various modules in the database.

Green Button Data Parser

Green Button data is obtained via Connect My Data (CMD) or Download My Data (DMD) method. Data from either method is in the standard Green Button XML format. Green Button CMD can be accessed automatically through RESTful web services while DMD is a manual operation. The standardized Green Button format simplifies the task of the Green Button data parser. To enhance it's the SEED data upload interface, we added a display of the imported data for monthly and daily intervals, if higher granularity data is available.

Time Series (TS) Data Analyzer

The TS Data Analyzer detects the data time interval and utility type (electricity, gas, water, etc.), provides the meter_ID and other pertinent information (unit, utility type, etc.) from the PostgreSQL database, and inserts the utility data into the a time-series database TSDB or PostgreSQL based on their time interval. The TS Data Analyzer module will directly push utility data from buildings with monthly interval into the existing PostgreSQL. For other time intervals (15min, 30min, hourly and daily), the TS Data Analyzer will direct the data to the TSDB.

Monthly Scheduler

The Monthly Scheduler module retrieves and aggregates data from the TSDB and saves the monthly aggregated data into the existing PostgreSQL. The Scheduler runs on the first day of every month, queries data from the TSDB through RESTful web services (provided by the TSDB), aggregates the interval data into one month, and pushes the aggregated data into the time series table in PostgreSQL.

Time Series Database

In addition to the PostgreSQL relational database, we are implementing the use of a secondary time-series database. The TSDB is a specialized database optimized for time-series data storage and processing, highly optimized for time range query and aggregation calculation. The TSDB is the centerpiece of the whole system, potentially hosting billions of data points per day. Database performance, scalability, aggregation functions and community support are crucial aspects when choosing a TSDB. We opted for the use of the open source KairosDB TSDB based on the aspects mentioned above, in addition to supporting RESTful API, which makes it compatible with our system design. Due to the modularity of the systems design, the platform should also be able to accommodate other time series databases.

Application Programming Interface (API) Manager

In addition to a set of APIs for internal use to enable the multiple modules to interact, the enhanced platform will have an API program manager to enable interaction with third-party systems and applications outside of the SEED platform. We are currently considering an API platform with our collaborators at Lawrence Berkeley National Lab (LBNL) as a hub to connect with multiple third-party applications, services and systems.

Apps and Tools for Actionable Intelligence

The following section describes the development and types of user interfaces to support actionable intelligence towards better investment decisions, policy evaluations and optimum building operations and maintenance. These interfaces were developed based on findings from a usability study with participants from stakeholders of large portfolio owners. During the survey, the participants were presented with different types of data graphics containing various information on utility usage and cost at the portfolio level all the way to building level information (Energy Use Intensity (EUI), monthly/yearly usage and spending, ranking of buildings based on usage and cost, etc.) and general overview information about the portfolio (building area and number, distribution of buildings of different typology, building geographical data, etc.). Questions regarding the attractiveness of the graphic (attractiveness), understandability of the data representation (clarity), and usefulness of the analytics (usefulness) were posed for each of the data graphics. The participants were also given questions to gauge their ability to interpret the data graphics accurately to assess the usefulness of the data representation (accuracy). The question groupings from the usability study are illustrated in **Table 1**.

Table 1: List of questions at the portfolio, building type and building level for the various data graphics

Group	Questions	Portfolio	Building Type	Building
Overview	1. Background Information: Portfolio, Building Type	•	•	
	2. Chart Preference: Pie, Square, Bar		•	
	3. Cost vs. Usage, Total vs. Normalization		•	
Yearly Trend	4. Year-to-Year Cost/Usage and Monthly Comparison	•		
	5. Year-to-Year Monthly Breakdown	•		
EUI Comparison	6. EUI Comparison: City vs. National		•	
	7. EUI Comparison by Building Type		•	
	8. EUI Comparison by Building (Smaller Sample Set)			•
	9. EUI Comparison by Building (Larger Sample Set)		•	•
	10. EUI Comparison: GIS Mapping			•
Building Performance	11. Five Buildings to Be Improved: Table			•
	12. Five Worst Buildings: LEAN Analysis			•
	13. Best / Worst Buildings: Heat Map Comparison			•

The participants rated detailed building level data analyses (graphic 13: “Heat Map,” graphic 11: “Potential Savings”, and graphic 12: “LEAN Analysis”) with the highest average scores in all categories of attractiveness, clarity, usefulness, and accuracy of the graphics. It shows that even policy makers and executives need detailed and specific building level data to make actionable decision-making.

The “heat map” graphic (***Figure 3***) scored highest in attractiveness. This graphic utilizes interval data (15min, 30min or hourly) to represent energy usage intensities, color coded, by the hour (x-axis) for every day (y-axis). We chose to represent higher intensities in the red color family and lower intensities are represented in green. This data graphic assists the users to understand building operation schedule and identify unnecessary usage during unoccupied hours (weekends and nights). For a building portfolio, users can compare buildings that are operated well and ones that are not optimized. Users can use this information to lower energy usage by changing operation schedules, adding more building controls, and developing strategies to engage building occupants to reduce energy consumption.

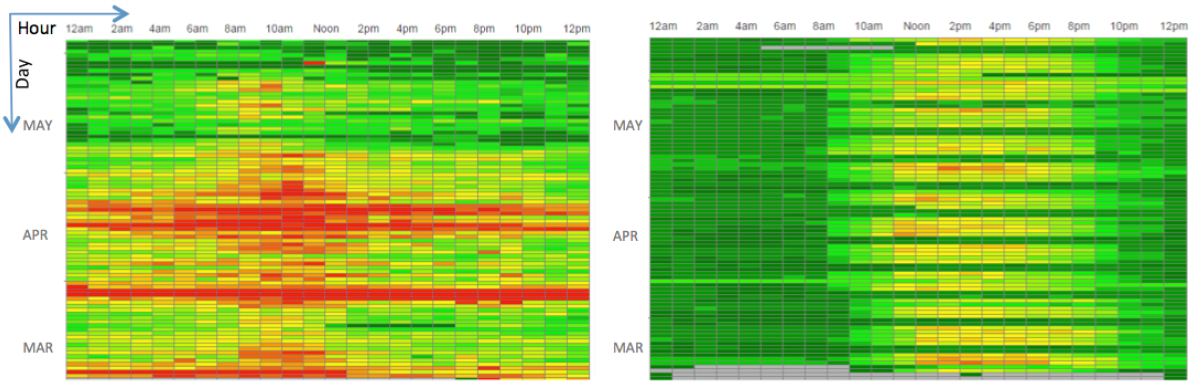

Figure 3: Heat Map data graphic

Rated second, the “potential savings” graphic (***Figure 4***), rank-ordered buildings based on their potential savings. The potential savings are calculated based on the difference of the building’s EUI against the median EUI within that category. A building with bigger EUI differential potentially has bigger savings. This information allows building owners to plan their budget allocations for capital improvements/retrofits, building audits and commissioning and leasing terms.

The 25 buildings are selected from the **highest average energy consumption (kBTU) for 2011-2013 per sq. ft.**

	Building Name	**Energy Use Intensity (kBTU/sf)**	**Avg. Yearly Expenditure**
1	East Brunswick - 710 Turnpike, NJ	214	$110,583
2	Naperville South Office, IL	194	$112,822
3	Dupont - DC, DC	174	$100,082
4	Cincinnati - 925 Annex, OH	162	$72,155
5	Greensburg South Main Street, PA	142	$41,338

Figure 4: “Potential Savings” table

Finally, the “LEAN analysis” graphic (***Figure 5***) provides information on a building’s heating, cooling and base (lighting, plug-load and domestic hot water) loads. The graphic enables the users to identify buildings that consumes significant amount of energy during heating and/or cooling periods and high base loads year-round. This information allows building owners and facility managers to identify building inefficiencies (poor building enclosure, inefficient equipment, non-optimized building schedules) and target retrofits, such as boiler or furnace replacements or re-commissioning based on the load curves. The “LEAN analysis” graphic is a powerful data analytics tool to enable entire portfolio level analyses as a pre-cursor to site inspections for the worst performing facilities.

Variables used to conduct the LEAN analysis include monthly electricity and gas consumption data, building size, cooling degree days (CDD) and heating degree days (HDD) [6]. Basically, heating load is decided based on the linear relationship between gas consumption and degree days, and cooling load is decided based on the linear relationship between electricity consumption and degree days. Lighting and plug-load base load is estimated by the average value of the electricity consumption during the lowest CDD months. Similarly, domestic hot water base load is estimated by the average value of the gas consumption during the lowest HDD months [7]. This method needs to be varied to accommodate for the specific energy sources used for heating or cooling a building (e.g. an all electric building uses electricity to cool *and* heat the spaces).

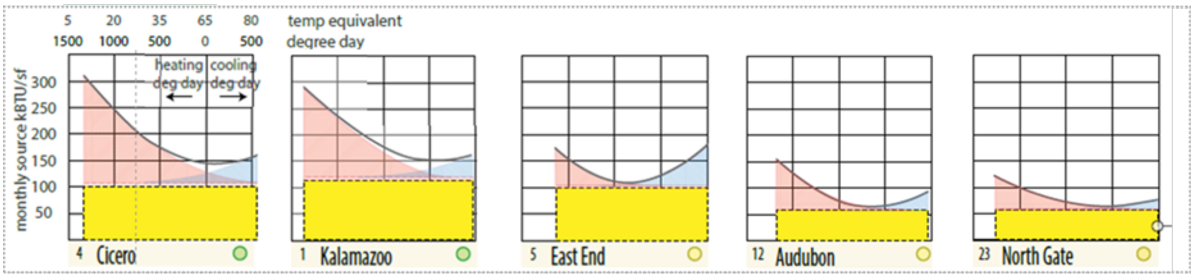

Figure 5: "LEAN Analysis" data graphic

Based on the findings from the usability study, we developed new graphical interfaces and refined the top three data graphics for prototype development. The interfaces will help inform building owners, executives and policy makers in decision making for investments and operations using a visually oriented and data driven narrative. Three major sections have been identified from the user testing to create this narrative: utility consumption, facility efficiency and energy saving solutions. The "consumption" section presents the utility cost, usage and greenhouse gas emissions to highlight the total impact of energy consumption on the portfolio. The "efficiency" section identifies specific buildings and the potential savings by evaluating the energy usage of each building compared to national medians for the same building typology. Lastly, the "solutions" section recommends potential retrofits or operational adjustments for the target buildings

Consumption

As a general overview, the graphs in this section describe the total utility cost, usage and greenhouse gas emissions of the entire portfolio over a period of time (***Figure 6***). The user can sort the data by building type to help identify the highest consumers. Consumption trends over a 12-month period may also show the results of retrofits and operational changes or areas of improvement for future consideration. With this knowledge, the user can evaluate the effectiveness of their decisions on the overall portfolio

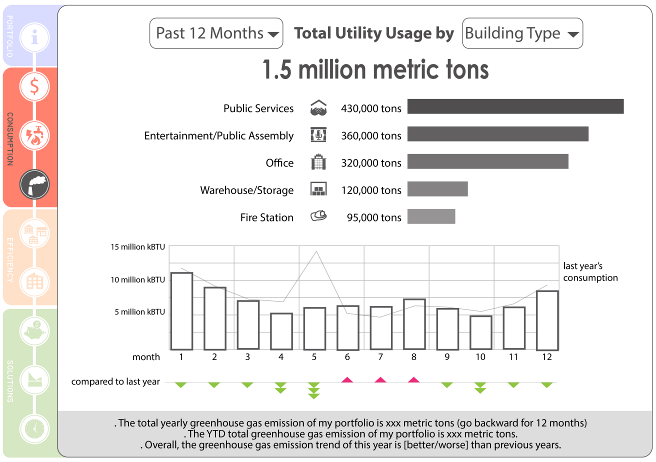

Figure 6: This data graphic provides an overview of the portfolio's CO_2 emission breakdown by building type, monthly emission profiles at selected 12-month period and analysis of emission above or below previous period.

Efficiency

The efficiency section helps executives select buildings to retrofit or operate in a more efficient manner. By comparing the building's energy consumption per square foot to the U.S. national median of the equivalent building type (**Figure 7**, left), the executive can identify the building types and specific buildings to improve. A second graph shows the comparison in terms of savings (**Figure 7**, right); if the building performed at the national median, the building owner could save a certain amount of money.

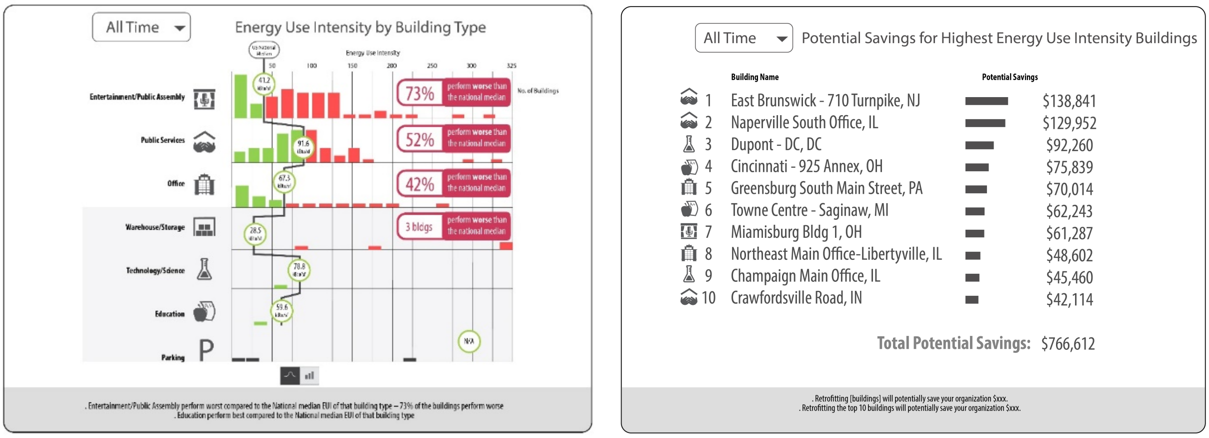

Figure 7: This efficiency data graphics analyze energy usage of each building typology compared to national medians (right) and identify specific buildings and their potential savings (left).

Solutions

The solutions section helps the executive make decisions about the type of retrofits to invest in as well as identify waste in building operations. A heat map shows the usage per hour of a certain building (**Figure 8**, left). High consumption is shown in red and low consumption is shown in green. The owner can immediately recognize and eliminate the extra utility usage during unoccupied hours. Using LEAN regression analysis, the buildings' plug loads, heating loads, cooling loads and hot water loads can be expressed. The executive can use this data to identify the type of retrofits that are needed (**Figure 8**, right).

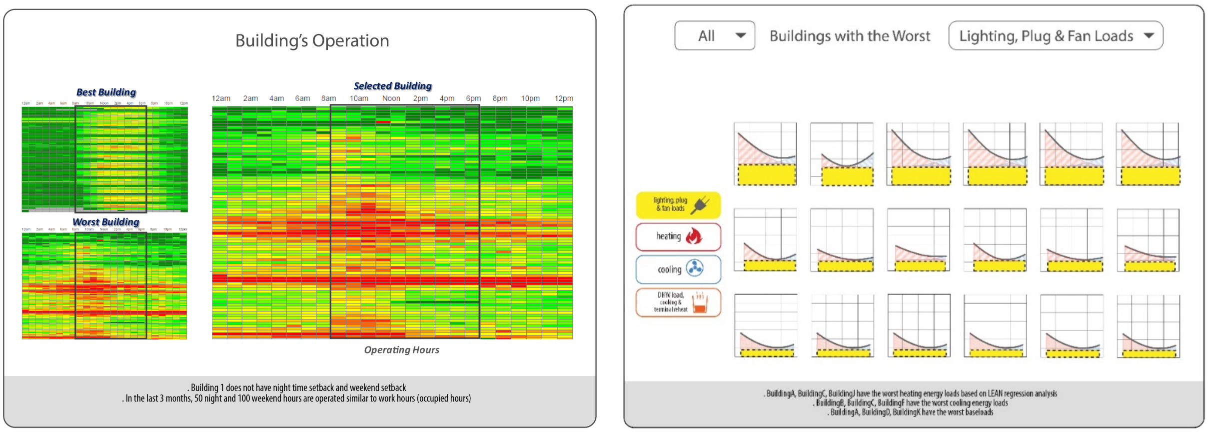

Figure 8: This "heat map" graphic on the left provides an hourly overview of the building energy usage and the LEAN regression data graphic on the right isolates heating, cooling and baseload energy consumptions.

Conclusion

The new features in SEED will enable data-driven investment decisions for strategic energy conservation measures and building operation optimization. Building owners can potentially compare their portfolios against other building portfolio, facilitating sharing and collaboration among organizations with similar building typologies e.g. cities/municipalities, states, board of educations, military base installations, etc. The enhanced platform can facilitate energy benchmarking and disclosure law initiatives, by streamlining and automating utility data upload and performing data quality checks. The next step of enhancement is to expand this open source platform by integrating building automation systems and indoor/outdoor environmental quality data. These datasets will be necessary to correlate the impact of energy consumption on indoor environmental quality and occupant comfort and satisfaction. Currently, there are no robust and fully integrated data acquisition, monitoring and analysis platforms that are being used in the building industry. Middleware technologies for building industry data acquisition are in nascent stages and have very limited capability. Often, they are not robust enough to support the various communication protocols, multiple data types and sources, and shear data volume [8]. However, any energy conservation measures, without accounting their impact on occupant comfort and satisfaction, will not be very successful in the long run. Building stakeholders' engagement is key to energy conservation. In addition to providing tools for building owners and facility managers to make better investment decisions and operate facilities more efficiently, apps developed with data from this platform can engage building occupants and the general public towards building energy conservation and environmental sustainability [9]. Finally, other organizations, such as the International Sustainability Alliance (ISA), GRESB, and District 2030, are working on similar benchmarking initiatives to support energy conservation in building portfolios. Some initiatives go beyond simple resource use benchmarking to include real estate's social and governance performance. It would be natural for these various entities, including the federal government, academia and NGOs, to learn from each other and collaborate in the development of better tools as we push forward towards a better and more sustainable built environment that is healthy and comfortable for the occupants and at the same time occupies a small environmental footprint.

Acknowledgement

The work is funded by the U.S. Department of Energy through the Consortium for Building Energy Innovation (CBEI).

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Study on Database for Energy Consumption of Commercial Buildings (DECC)

Part 3: Change of Energy Consumption after the Great East Japan Earthquake in Commercial buildings

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Abstract

Great East Japan Earthquake occurred on March 11, 2011. Energy consumption for commercial buildings has been changing dynamically after the Great East Japan Earthquake in Japan. We have been collecting the energy consumption data from 2008 as a national database, DECC. DECC has 38,000 samples in 22 building types, but has not reflected the Influence of the Great East Japan Earthquake. So we have continued to collect energy consumption data in 2013 and 2014 to observe a change after the Great East Japan Earthquake.

In 2013, we surveyed the monthly energy consumption data of 2011 and 2012 by energy sources and the measures adopted for energy saving in the building types of office, public office, commercial building, hotel, hospital, welfare and school. In 2014, we added nursery and kindergarten, research office, theater, exhibition, sport and restaurant. So now we have five years' data on changes of energy consumption from 2008 to 2012.

The national average energy use in office in 2011 was reduced by 6.5% from 2010, and 11.6% in 2012 from the same base. The national average in public office in 2011 was reduced in 10.2% from 2010, and by 16.3% was in 2012. So increase use of energy was not observed in these two building types. But increase use of energy was observed in school, hospital and some other building types.

1. Introduction

Currently, in Japan, CO^2 emissions from buildings extend to about one third of total CO^2 emissions. With the realization of a low-carbon society a worldwide goal, energy saving of buildings in Japan is an important issue. To this, the "Environment-related Database Review Committee of Non-Residential Buildings" was founded in 2006. Under this committee, with support from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and from industry, government and academia is a survey of environment-related data on non-residential buildings from 2007 to 2009 together, which has started to publish the energy data of 38,000 responses in 22 building types as environment-related database of non-residential buildings [1]. We also conducted an emergency survey immediately after the Great East Japan Earthquake in order to understand the power-saving and energy-saving reality due to the earthquake, and announced the research results at the Architectural Institute of Japan [2] [4]. In 2013, these data were published as environment-related database. After that, in order to continuously observe the recovery condition from the state of shock immediately after the earthquake, in 2013 and 2014 re-survey was conducted of the building that cooperated in the previous survey. The surveyed years were 2010-2012, the responses numbered about 4,500. This study is based on data collected over six years, with the purpose of understanding the changes in energy consumption before and after the earthquake, to analyze further and effectiveness of energy conservation measures.

2. Overview of DECC

DECC is the abbreviation of the Database for Energy Consumption of Commercial Buildings. It holds data on energy and water use of buildings. DECC has two levels, the basic database and the detailed database. The basic database holds monthly energy consumption by energy types and also water consumption, while the detailed database holds information of energy usage equipment, and energy consumption over time [3]. DECC is divided into eight regions throughout Japan, combining industry, government and academic efforts in data collection. It is the largest database covering non-residential buildings across Japan.

It is the fundamental database used in this study. From the 38,000 DECC entries in the basic database. Figure 1 shows the number of each use categories. Table 1 and Table 2 show the information that is published as a database.

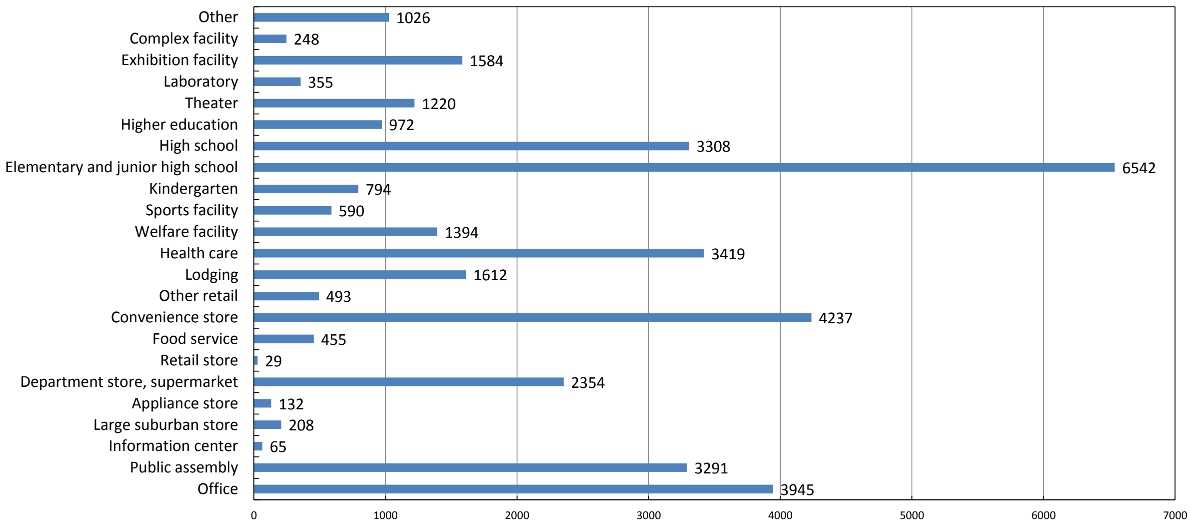

Figure 1 Number of data in each building type in DECC

Table 1 Building information

Data type	Detail
ID	Region(alphabet)+Building use(2 digits)+serial number(6 digits)
Region	Hokkaido, Tohoku, Hokushinetsu, kanto, Chubu, Kansai, Chugoku and Shikoku, Kyusyu
Ownership form	Own building or rented building
Floor area category	Under 300 m^2
	More than 300 m^2 and under 2,000 m^2
	More than 2,000 m^2 and under 10,000 m^2
	More than 10,000 m^2 and under 30,000 m^2
	More than 30,000m^2
Completion year	Year
Number of floors	Number of ground floors and underground floors
Business hours	Weekday, Saturday and Sunday [hours/day]
Air conditioning period	Cooling starting and ending day
	heating starting and ending day
Contract demand	[W/m^2] or [VA/m^2]

Table 2 Energy consumption

Energy consumption data	unit
Electricity consumption	$kWh/m^2 \cdot year$
City gas consumption	$m^3 \times 10^{-3}/m^2 \cdot year$
LPG consumption	$m^3 \times 10^{-3}/m^2 \cdot year$ or $g/m^2 \cdot year$
Oil consumption	Type of oil, little/$m^2 \cdot year$
District heating accepted amount	$MJ/m^2 \cdot year$
Clean water consumption	$m^3 \times 0.001/m^2 \cdot year$

3. Methodology

a) We introduce an overview of the survey conducted in 2013 and 2014. Between the 2013 survey and the 2014 survey, the survey content is the same, but the target architectural applications are different. The 2013 survey targets 7 applications (office, public office, commercial facility, hotel, hospital, school, welfare facility). The 2014 survey targets 5 applications (nursery school, kindergarten, research institution, theater, exhibition facility, sports facility). The survey method is a questionnaire addressed to building owners, and the survey content is building information, information on energy consumption and energy conservation measures. Table 3 shows the survey items that are listed in the questionnaire. The number of responses to the questionnaire and the number of distribution in both researches are shown in Table 4.

Table 3 Items of the investigation in 2013 and 2014

Building infomation	· Building use · Floor area · Year constructed · Office hours · Office days · Demand contract (2010, 2011, 2012) · Indoor parking area · Air-conditioning period · Setting temperatures · Large-scale repair · Introduction of the flextime and so on…
Energy / Water consumption	· Monthly energy consumption (Electricity, City gus, Propane, Oil, District heat, Clean water) from April 2010 to March 2013 (3years) · Monthly maximum electric power (3years)
Condition power-saving	· Organizational structure and target value of power-saving measures in 2010, 2011, 2012 · Performing rate and future policies of power-saving measures (44 items) · Having energy-saving device or not (19 items) · The measures that people felt effective (top 3 measures)

Table 4 The number of questionnaire distributed and collected

year	building type	Distribution	Collection	Percentage of response
2013	Office	1,458	369	25.3%
	Public office	964	443	46.0%
	Commercial building	747	160	21.4%
	Hotel	402	108	26.9%
	Hospital	934	306	32.8%
	School	1,944	456	23.5%
	Welfare	473	158	33.4%
2014	Nursery and Kindergarten	1,068	213	19.9%
	Research institutions	461	123	26.7%
	Theater	1,329	295	22.2%
	Exhibition facility	1,628	352	21.6%
	Sports facility	671	112	16.7%

b) We introduce the analysis contents of this study. Energy consumption data collected in 2013 and 2014 surveys the four major applications (office, government offices, hospitals, hotels), together with their energy consumption data collected in the previous survey, allow analyzing the trends of energy consumption of the six-year period. The analysis considers the Tohoku, Kanto, and Kansai region for each application, to observe transitions of annual energy consumption per unit. We extract one region among them, to analyze the change in the monthly energy consumption per unit. Finally, based on the answers of the questionnaire, it assesses the actual condition of the efforts for energy conservation measures. Table 5 shows the questions about power-saving and energy-saving measures that are listed in the questionnaire.

Table 5 power-saving and energy-saving measures that are listed in the questionnaire

division	No.	Countermeasure	division	No.	Countermeasure
Advance preparation to grasp the actual situation	1	Grasp of the power peak value and the generation time	Lighting	23	Turned off at the time of absence
	2	To the power peak value, grasp equipment the large degree of influence		24	Frequently turned off to rest time and night
	3	Grasp of the power-saving effect of the lighting equipment of time cooling and heating demand is low		25	Use the spot lighting
	4	Set the power-saving targets such as peak power suppression	Outlet power	26	Refrain from the use of the elevator and escalator
	5	Refer the energy consumption data of other buildings		27	Use PC with the appropriate power management and power saving mode
Air conditioning	6	Confirmation the operation of the equipment has been carried out properly		28	Suppression of the copy machine running number
	7	Optimization of cooling and heating temperature		29	Suppress the use of the water heater
	8	Check whether the air conditioning setting temperature is not too low		30	Suppression of running the number of vending machines
	9	Adjust the start time and end time of heating and cooling		31	Extension of the cooling stop time of vending machine
	10	Stop the air conditioning of the room that is not used		32	Suppress the use of hot water heating toilet seat and hand dryer
	11	Periodically clean the filter		33	Suppress the use of electric water heater
	12	Preferentially use the air-conditioning heat source other than electricity	Other	34	Promote Cool Biz and Warm Biz
	13	Suppression of the start-up peak power		35	The power-saving request to residents
	14	By continuous operation, reducing power peak		36	Provides power usage information to residents
	15	Optimization of the outside air introduction amount		37	Use of blind and eaves
	16	Devise so that direct sunlight does not strike		38	If having a cogeneration facility, operated at a power generation priority
	17	Take advantage of power-saving service of the package air conditioner		39	Readjustment of the refrigerator temperature
	18	Set the outlet temperature of the refrigerator a little higher		40	Use a plastic curtain as refrigerator of cold air does not leak
	19	Increase the reliance on thermal storage tank		41	Readjustment of the refrigerator of the set temperature
Lighting	20	Thinned the lighting of the lobby and hallways		42	Household appliances will be powered off as much as possible for the demonstration
	21	During the day, turn off the lighting in the range does not interfere with business		43	In order to avoid the peak time, to reduce the operating hours
	22	Suppress the output of lighting		44	In the case of group companies, closed in alternation with a plurality of office

4. Result of analysis

4.1 Office

4.1.1 Annual energy consumption

We analyzed the change of annual energy consumption per unit over six years. Figure 2 shows the changes in annual energy consumption per unit in the Tohoku, Kanto, and Kansai regions, as well as the national average. Energy consumption per unit of Tohoku region is below the national average every year. Looking at the change in energy consumption per unit, every year except 2010 was reduced from the previous year. In the year of the earthquake, the reduction rate is the highest, 12% less than the previous year. There were also external factors, such as a cool summer, but still it is the fact that Tohoku was a major disaster area of the Great East Japan Earthquake that was the major factor that led to cutting energy consumption. In addition, further reductions in 2012 have been made, It can be seen that the consciousness of power-saving and energy saving is maintained. Energy consumption per unit in the Kanto region shows a high transition when compared with the national average. As with office in Tohoku, every year except 2010 has seen a reduction in energy consumption. The cut in 2011 is not as large. Reduction of energy consumption continued in 2011 and 2012. The Kansai region also maintained high reductions compared with the national average. Although about 10 percent reduction has been calculated immediately after the earthquake, a 4.3% rebound in the next year has been confirmed. Looking at the national average of energy consumption per unit it can be seen that it is being continuously reduced each year. The highest reduction rate is 6.5% in 2011, immediately after the earthquake. The Next year's reduction was also about 5%, indicating that the consciousness of power-saving and energy conservation is widespread.

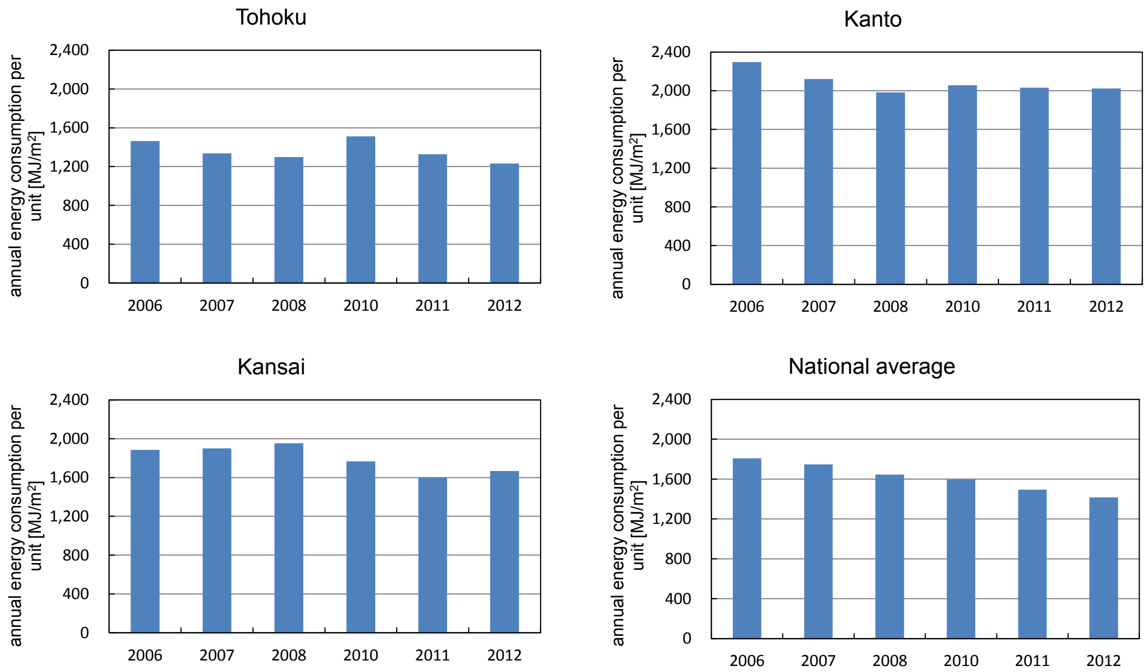

Figure 2 Annual energy consumption per unit (Tohoku, Kanto, Kansai and National average)

4.1.2 Monthly energy consumption

We examined the change in the 6-year monthly energy consumption per unit. Figure 3 shows the monthly energy consumption per unit of each year in the office of Tohoku region. As you can also see from the figures, it can generally be said that the energy consumption per unit was low in the summer of 2011. Energy consumption per unit in August was about 40MJ/m^2 lower than the highest year, 2006, whereas February 2012 showed the highest value as compared to other years. Although energy consumption per unit of 2012 shows a transition of a low value compared with before the earthquake, it appears that consciousness of power-saving and energy-saving has faced away from immediately after the earthquake. (The sample for the Kanto region is insufficient for analysis since 2010.)

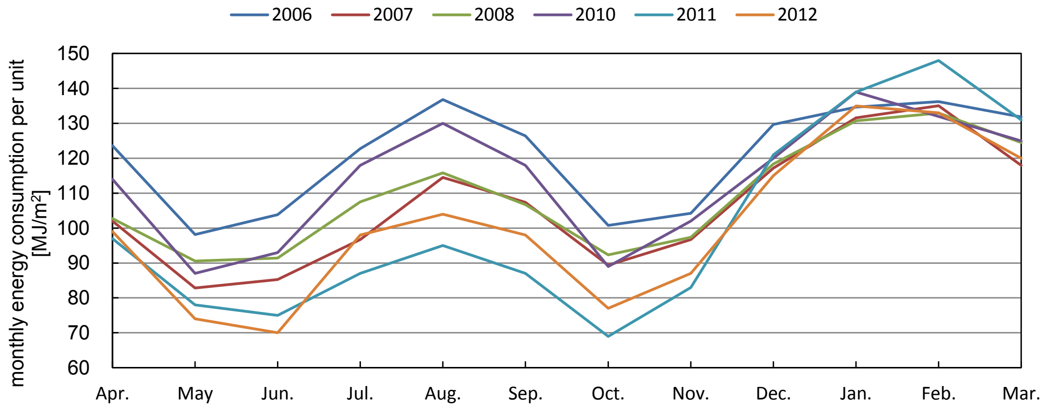

Figure 3 Monthly energy consumption per unit (Tohoku)

4.1.3 Power-saving and energy-saving measures

Among the power-saving and energy-saving measures that have been carried out immediately after the earthquake, we investigated the top five items that its implementation is lowered to the following year. The results it is shown in Figure 4. Furthermore, the results of examining the future policies for the five items in Figure 5. The item which resulted in the biggest fall from one year to the next is "Refrain from the use of the elevator and escalator". Implementation degree from 2011 through 2012, fell 7.4%. However, the same item was also the most expensive item that is wanted to continue in the forthcoming policy. Use suppression is a little inconvenient, but it can be said to be that not even as much as a burden on to continue. Even implementation of other items is declining, because it is not even so high future continuation will, it can be said that the power-saving and energy-saving consciousness with the passage of time is small.

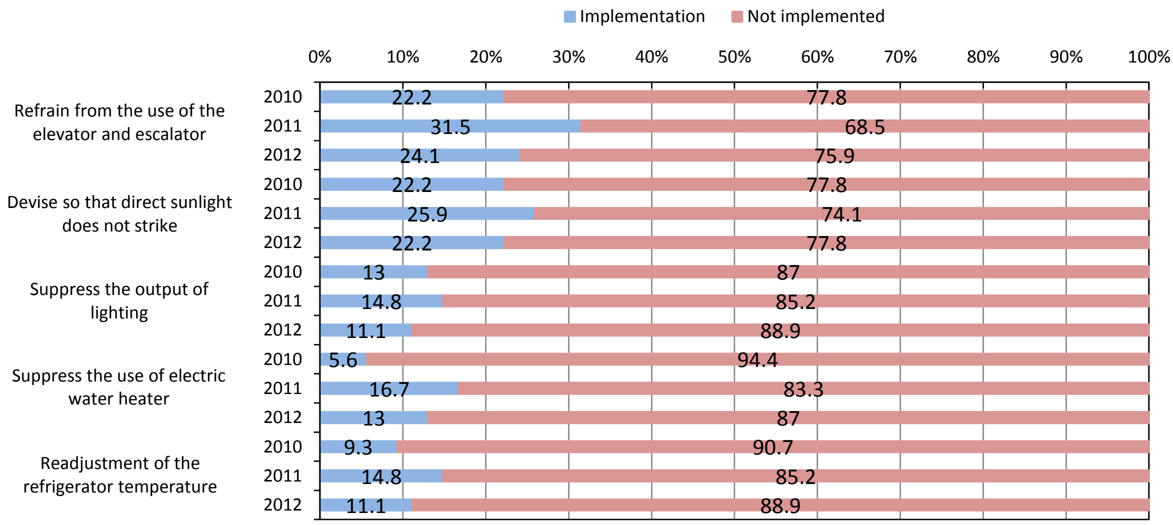

Figure 4 Implementation of the power-saving and energy-saving measures (office)

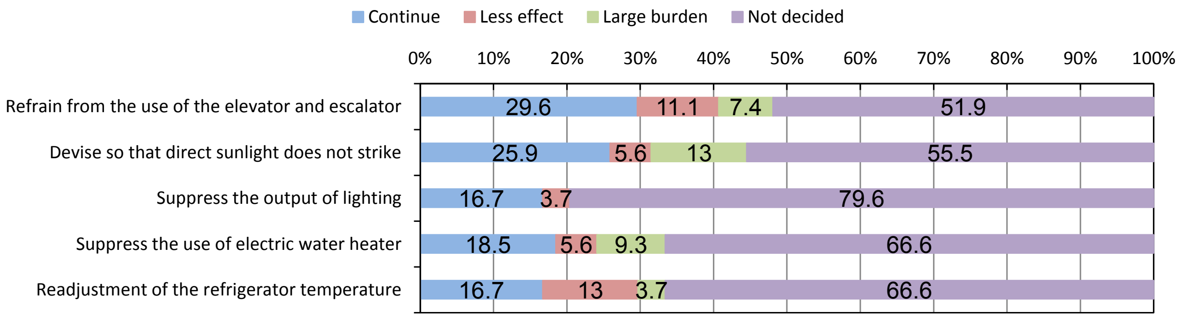

Figure 5 Future policy of power-saving and energy-saving measures

4.2 Public office

4.2.1 Annual energy consumption

We analyzed the change of the annual energy consumption per unit of six-year. Figure 6 shows the changes in the annual energy consumption per unit in Tohoku region, Kanto region, Kansai region and national average. Tohoku region is a significant reduction in energy consumption per unit in 2008 was observed, even in comparison with the transition of the national average, the possibility that the value of 2008 is one that is calculated from a little biased data which is building data of small energy consumption. About 11% reduction was observed immediately after the earthquake, even reducing it albeit slightly year is continued. Kanto region also shows a transition similar to the Tohoku region, there is a reduction of 16% in 2011, and continued the following year. Kansai region also, two years after the earthquake have been made both reduction of energy consumption per unit, the reduction rate of 2012 showed a higher value than other regions.

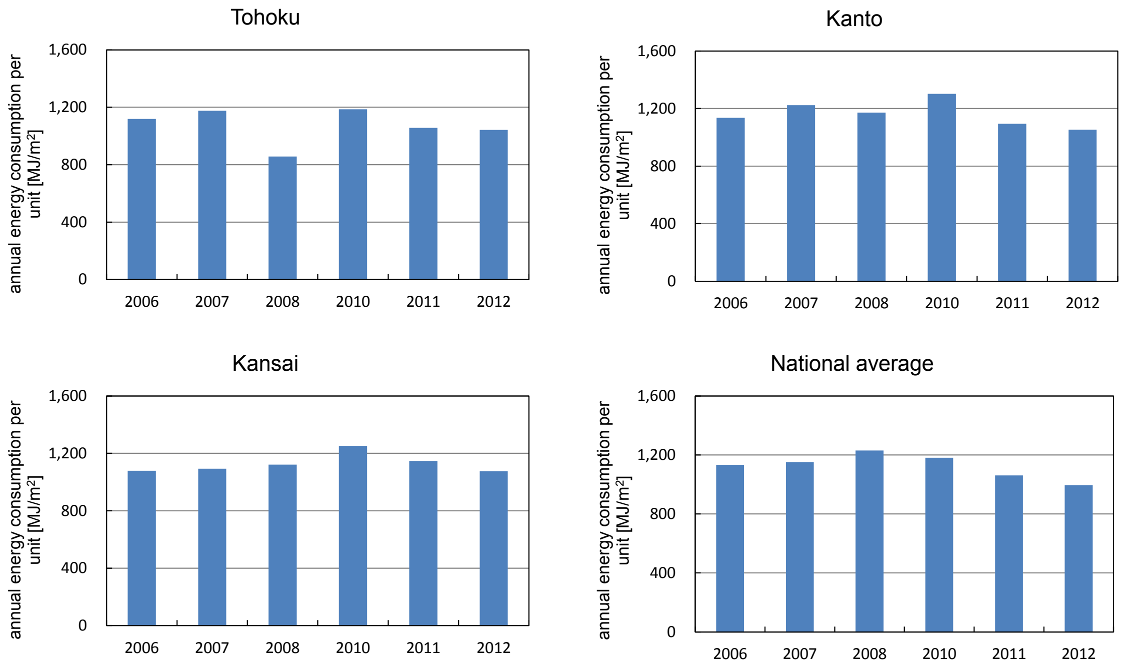

Figure 6 Annual energy consumption per unit (Tohoku, Kanto, Kansai and National average)

4.2.2 Monthly energy consumption

We examined the change in the 6-year monthly energy consumption per unit. It shows the monthly energy consumption per unit of each year in the public office of Kanto region in Figure 7. Because has been made many power-saving measures immediately after the earthquake, it showed low values of energy consumption per unit compared to other years. In winter, it became a mean value relatively, the following year also, monthly energy consumption per unit is kept low transition, the growing power-saving and energy-saving consciousness can be confirmed.

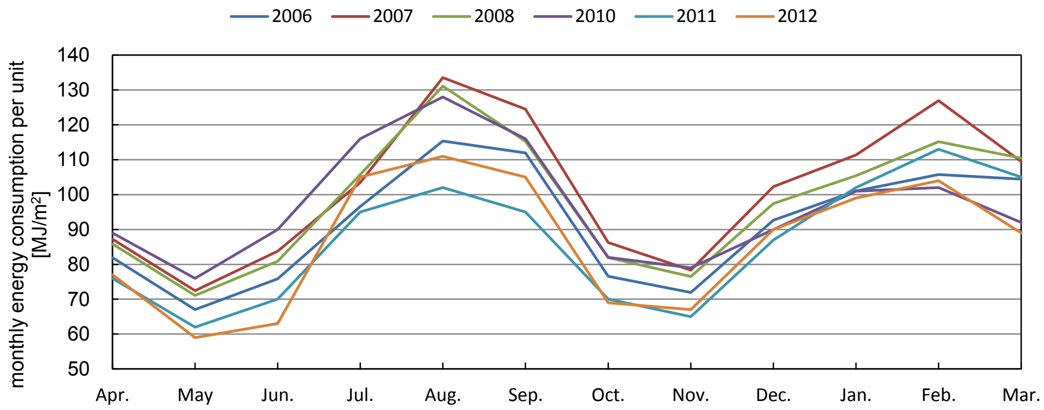

Figure 7 Monthly energy consumption per unit (Kanto)

4.2.3 Power-saving and energy-saving measures

Among the power-saving and energy-saving measures that have been carried out immediately after the earthquake, we investigated the top five items that its implementation is lowered to the following year. The results it is shown in Figure 8. Furthermore, the results of examining the future policies for the five items in Figure 9. The item which resulted in the biggest fall from one year to the next is "Refer the energy consumption data of other buildings". Implementation degree from 2011 through 2012, fell 8.0%. One possible the cause is that a large burden in implementation. It is seen that burden in other items that is large is preventing the continuation. Public office seems like have a feature similar to the office, a little bit of difference comes in the power-saving and energy-saving measures.

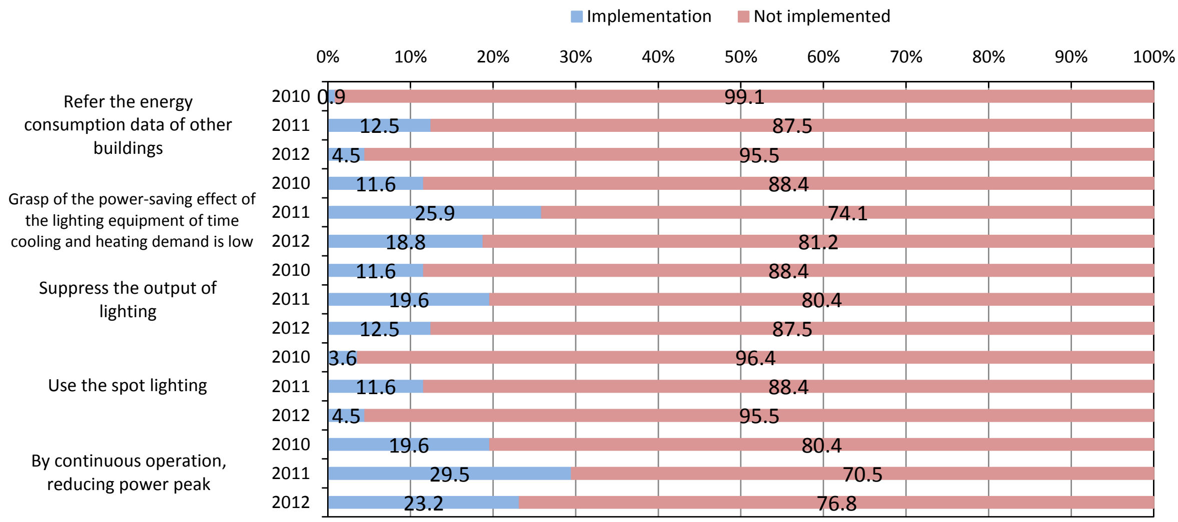

Figure 8 Implementation of the power-saving and energy-saving measures

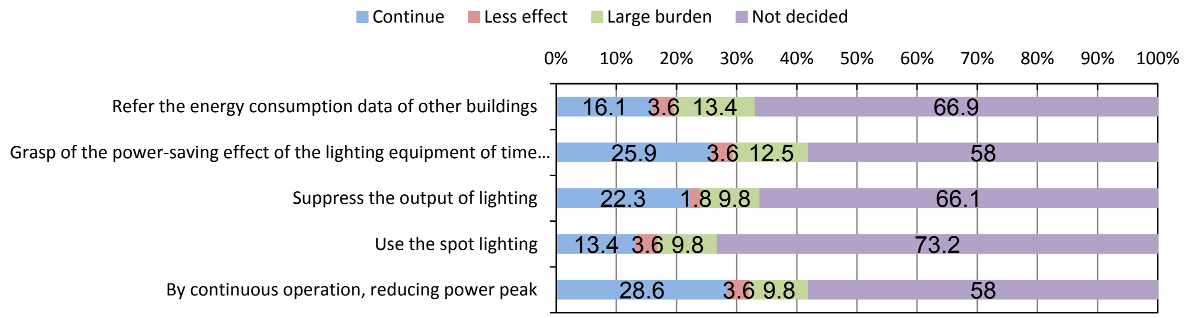

Figure 9 Future policy of power-saving and energy-saving measures

4.3 Hospital

4.3.1 Annual energy consumption

We analyzed the change of the annual energy consumption per unit of six-year. Figure 10 shows the changes in the annual energy consumption per unit in Tohoku region, Kanto region, Kansai region and national average. As can be seen from the national average of energy consumption per unit, energy consumption per unit of the hospital it can be said that the multi-consumption buildings more than a year 2,500MJ/m^2. In the Tohoku region, but has been about 8% of the reduction in after the earthquake, the rebound of about 6% in the next year has been confirmed. With the building characteristics of the hospital, impossible can be said to be due to it is difficult to respond to the power-saving. On the other hand, the Kanto region showed the following year is higher reduction rate than immediately after the earthquake. Kansai region shows a two-year reduction rate of the same degree of after the earthquake, continued was seen efforts to save power and energy conservation. For the national average, there is a reduction of about 4% immediately after the disaster, followed by a slight rebound in the following year.

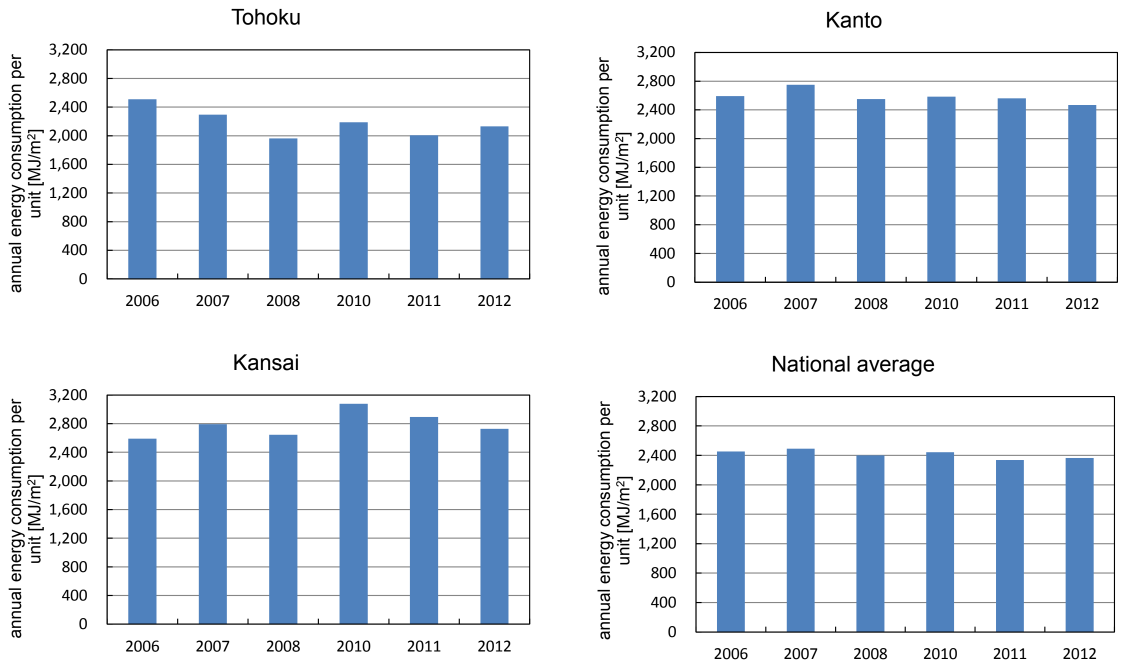

Figure 10 Annual energy consumption per unit (Tohoku, Kanto, Kansai and National average)

4.3.2 Monthly energy consumption

We examined the change in the 6-year monthly energy consumption per unit. It shows the monthly energy consumption per unit of each year in the public office of Kanto region in Figure 11. 2010 is a low level, and in 2007 the high level has been confirmed. Whether there is bias in the data that was used in order to calculate the monthly energy consumption per unit, it is necessary to check again. Two years after the earthquake it can be said that the transition at a relatively low value is continued. Hospitals there is a limit to the power saving by the building characteristics of, but also seen the month it can be said that the reduction of energy consumption is made slightly.

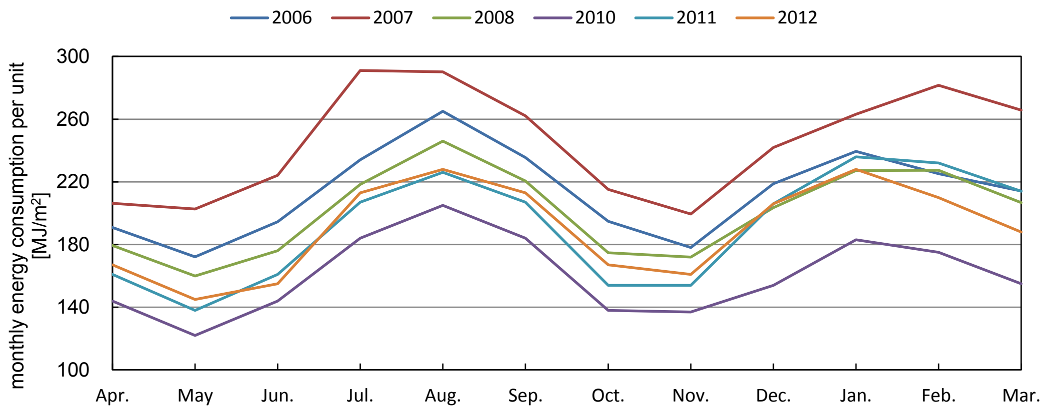

Figure 11 Monthly energy consumption per unit (Kanto)

4.3.3 Power-saving and energy-saving measures

Among the power-saving and energy-saving measures that have been carried out immediately after the earthquake, we investigated the top five items that its implementation is lowered to the following year. The results it is shown in Figure 12. Furthermore, the results of examining the future policies for the five items in Figure 13. The item which resulted in the biggest fall from one year to the next is "Preferentially use the air-conditioning heat source other than electricity". Implementation degree from 2011 through 2012, fell 3.4%. Reduction in implementation of the Hospital of the power-saving and energy-saving measures compared to other applications was less. "During the day, turn off the lighting in the range does not interfere with business" is despite implementation degree has fallen a little, was the very high level both of continuity will and implementation rate.

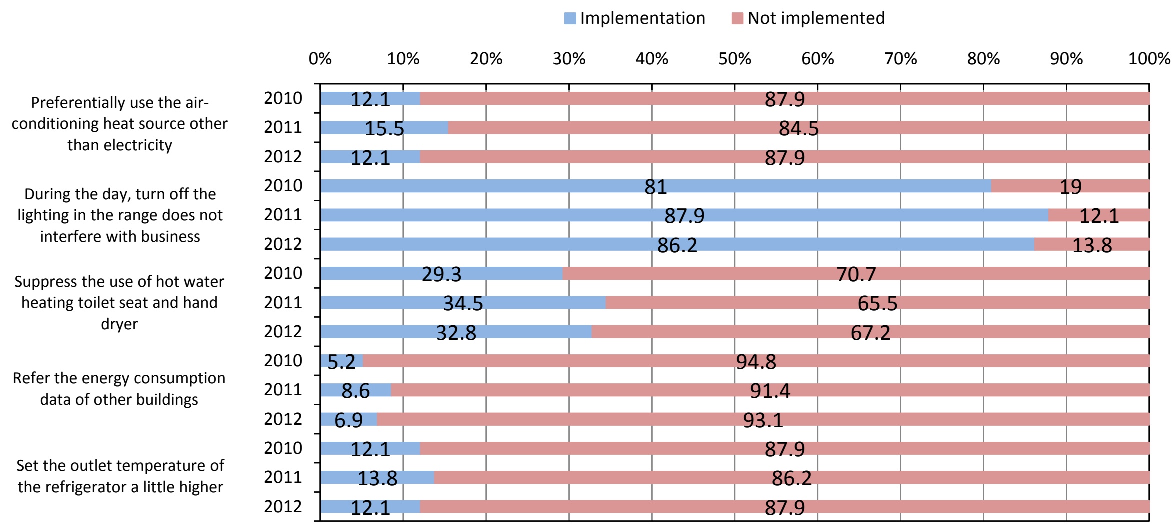

Figure 12 Implementation of the power-saving and energy-saving measures

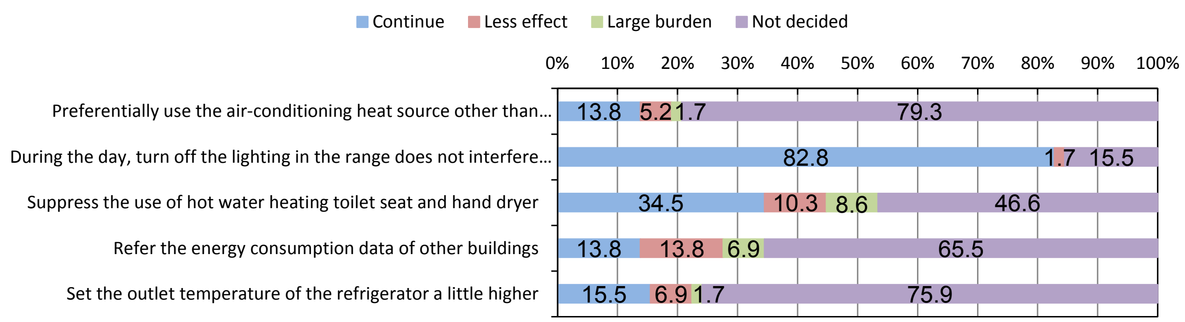

Figure 13 Future policy of power-saving and energy-saving measures

4.4 Hotel

4.4.1 Annual energy consumption

We analyzed the change of the annual energy consumption per unit of six-year. Figure 14 shows the changes in the annual energy consumption per unit in Tohoku region, Kanto region, Kansai region and national average. Hotel is an energy-intensive buildings that energy consumption per unit of the year except for the Tohoku region of the immediately after the earthquake more than a year 2,400MJ/m^2. Tohoku region, the reduction rate of energy consumption per unit of 2011 is remarkable. Because in this that such as a decrease of the turnover may be mentioned as a cause, hotel unlike the other three applications, it can be said that the influence of the power-saving of the earthquake was large. Although recovery from the immediately after the earthquake was observed in the following year, since it is not returned to the energy consumption per unit of before the earthquake, although it is slightly, and energy consumption per unit in after the earthquake compared to before the earthquake it can be said that the reduction of has been made. Kanto region, after the earthquake is a gradual reduction was seen. In the Kansai region, compared to the immediately after the earthquake, the following year, but to a significant reduction rate has been calculated, the cause is also considered the possibility that had been biased sample of the 2010 and 2011 years. Here, the term "bias" is in the sense that the building data of the large energy consumption has gathered a lot. In terms of the national average, two years after the earthquake ongoing reduction of energy consumption per unit is seen.

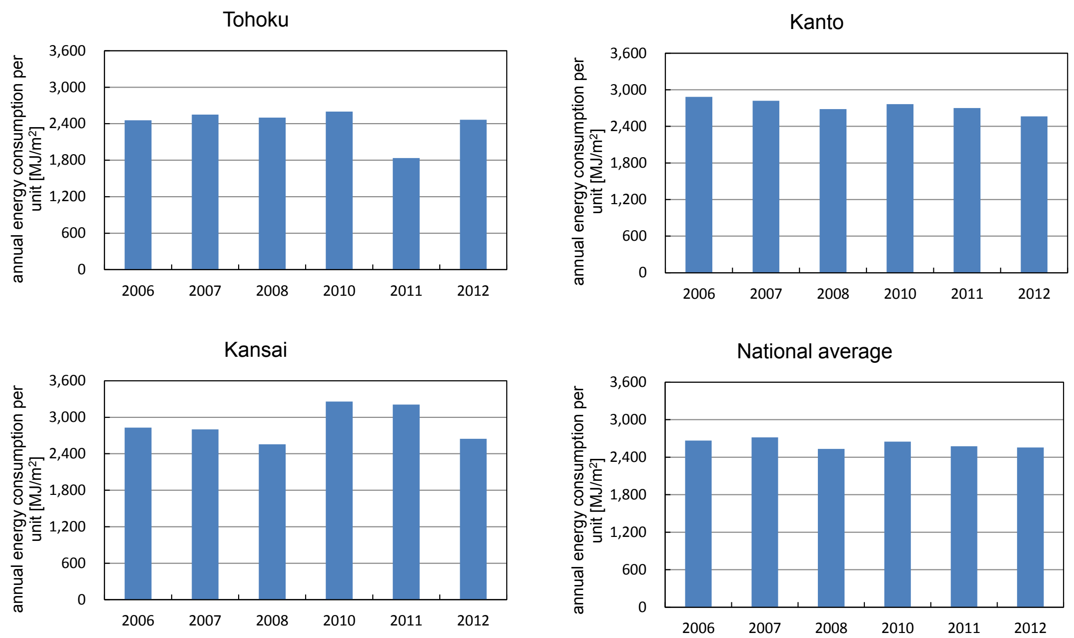

Figure 14 Annual energy consumption per unit (Tohoku, Kanto, Kansai and National average)

4.4.2 Monthly energy consumption

We examined the change in the 6-year monthly energy consumption per unit. It shows the monthly energy consumption per unit of each year in the public office of Kanto region in Figure 15. As with hospitals in the Kanto region, monthly energy consumption per unit of 2010 has been calculated low. The value immediately after the earthquake since a large change is not observed so much, even when compared to other years, is considered possible that could not be secured enough samples to calculate monthly energy consumption per unit. The analysis of the monthly energy consumption per unit is needed expansion of further sample.

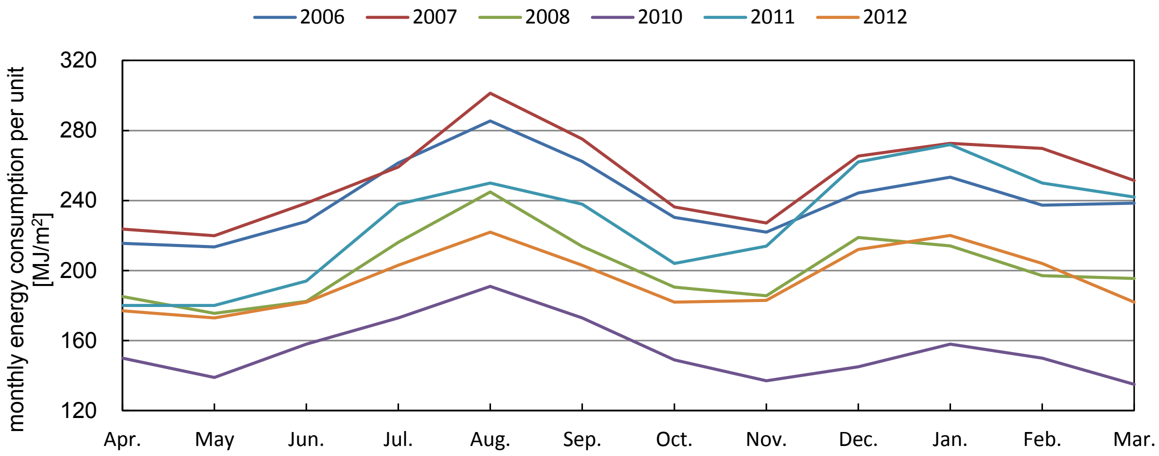

Figure 15 Monthly energy consumption per unit (Kanto)

4.4.3 Power-saving and energy-saving measures

Actual conditions of implementation of the hotels of power-saving and energy-saving measures, could not be calculated because of the lack of the number of samples. Understanding of the implementation of the effect of measures it is that necessary, is required to collect samples by further research in the future.

5. Conclusion

It shows the findings obtained by this study below.

(1) The variation of annual energy consumption per unit of office before and after the earthquake is different depending on the region, in Tohoku and Kanto there is continued reduction trend, but in Kansai a 4.3% rebound in 2012 has been confirmed.

(2) Monthly energy consumption per unit of office of the Tohoku region showed a significant power-saving trend the summer immediately after the earthquake. However, it has found that the energy consumption per unit of production is approaching the previous value with the passage of time.

(3) After the earthquake, in annual energy consumption per unit of public office in all regions analyzed there had been ongoing reductions. However, as compared with immediately after the earthquake, the following year the reduction rate was less. It is necessary to continue the observations.

(4) In the monthly energy consumption per unit of public office in Kanto region, the value of summer in 2011 was low, since a lot of power-saving measures were taken immediately after the earthquake due to the operation stop of the nuclear power plant. Also in 2012 monthly values were kept low, so it can be seen that power-saving and energy-saving consciousness is continuing.

(5) In annual energy consumption per unit of hospital, in Tohoku, about 8% reduction after the earthquake was followed by a confirmed rebound of about 6% in the next year. With the building characteristics of the hospital, it is difficult to forcibly respond to a power-saving.

(6) In monthly energy consumption per unit of hospitals in Kanto, two years after the earthquake it can be said that the transition at a relatively low value is continued. There is a limit to the power saving in hospitals because of their building characteristics, but also seen the month it can be said that the reduction of energy consumption is made slightly.

(7) In annual energy consumption per unit of hotels, the reduction rate of energy consumption per unit of 2011 was remarkable especially in the Tohoku region. Although rebound was confirmed the following year, from the fact that it was not back to the level of before the earthquake, it is believed that a slight power-saving consciousness has become fixed.

(8) In this analysis of any application, there is a case that the analysis result is extreme because of bias of the sample and lack of sample. Further, it is difficult to say that a precise analysis is performed due to the lack of the number of responses in the implementation of the power-saving and energy-saving measures. There is a need to promote the expansion of the number of samples in the future.

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SWIVT as a case-study on energy management platforms supporting design, planning and operation of smart districts.

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Abstract

On the way to carbon-neutral energy supply, the construction industry faces big shifts: digitalization, the merging of power and heat networks, and a larger, more specialized set of actors taking part in integrated building projects. These shifts are introduced and made possible by a wide array of innovative products and services, such as energy potential mapping, energy supply management and storage systems, as well as information and communication technologies.

The integration of components within the planning process of interdisciplinary systems is the key to confidence in implementing innovation. Next to the technologies, the main challenge is in the effective coordination of shared information between data models for three-dimensional building and component design, dynamic energy flows, and contextual parameters from markets and regulations. Research is needed for the communication and visualization of multi-criterial outputs based on shared key performance indicators (KPIs).

Based on a parametric integration and through a graphic driven interface, results of structural and analytic models can be shared within a strategic management platform displaying complex mutual correlations between data sets. This way, specialized expertise can be made immediately available and intuitively understandable to all involved actors at all times.

Such platform should be built modularly in order to enable a wide range of applications, empower fast identification of synergies and implement creative solutions. Monitoring and evaluating the entire building life-cycle together with its energy flows offers a huge potential not only during the planning phase, but also throughout the operation, renovation and disassembling phases, thus unlocking circular-economies potentials.

1 Introduction

In 2010, the German Government issued a revised concept for its energy transition ("Energiewende"), which envisions an extensive conversion of the national energy supply system until the year 2050. Essential goals of this concept are a 50% reduction in primary energy need, as well as the increase in the share of renewable energy to 80% of power demand and 60% of gross final energy consumption [1]. This last parameter was recorded at 24% in 2012 [2]. The 6.Energy research program ("Energieforschungsprogramm“) of the Federal Ministry for Economic Affairs and Energy (BMWi) came into effect in 2011 and orients itself to the guidelines of the energy transition. The highest priority lies in increased energy efficiency and in the development of renewable energy technologies, while the relevance of storage and distribution technologies is expected to grow strongly due to increased input of fluctuating energy from renewable sources [1].

Buildings alone are responsible for more than 40% of total final energy consumption in Germany. About two thirds of this energy is used for room heating. A study of the Institute for Living and the Environment (IWU) commissioned by the German Federal Ministry of Traffic, Building and Urban Affairs (BMVBS), states that a renovation with standard EnEv2012 can sink energy demand for heating by about 60%, while offering a very detailed analysis of the costs involved [3]. This intervention alone would cut final energy consumption on a national level by about 16%. With about 2 millions square meters of buildings in Germany built before the first Heat Insulation Ordinance in 1978, the renovation quote needs to remain at a stable 2% rate in order to contribute the calculated reduction in energy consumption by 2050. In recent years, however, the renovation rate has been closer to 1% [4].

2 Background research

2.1 The potentials of architecture within the goals of the energy transition

In order to fulfil its potential for the contribution to the goals of the energy transition, the building industry has to find means to cut its final energy consumption at a faster pace. By means of technical improvements, this can be achieved through faster façade renovation rates, which mostly impact heat demand, or by integrating innovative technologies for an efficient use of energy. Both methods present implementation challenges. The façade renovation of historical buildings is complicated by cultural preservation legislations. Buildings from the 1950's to 1970's are often rented, so that the interests of the stakeholders involved are not aligned. Buildings from the 1980's on often do not see enough incentives, especially in the form of return of investment (ROI) within a useful timeframe in order to undergo renovation works.

2.1.1 Obstacles to technological upgrade of building systems

Higher energy efficiency in buildings can also be achieved through existing or innovative energy technologies, such as high efficient boilers, heat pumps and floor heating in combination with solar thermal energy and different types of heat storages. These components work better through synergies, for example, surface heating works at low temperatures, which are only efficient if the building envelope provides enough thermal quality. Market availability of more affordable energy technologies also helped research in systemic approaches. As a result, it was possible to aim at exploiting combined strategies between diverse components in order to drastically cut waste of resources. Examples of this approach are Net Zero Energy Buildings (NZEB), which are based on three principles: reduce demand, reuse waste energy, and avoid fossil fuels [8]. To classify as NZEB, total energy demand needs to be balanced to CO_2 neutrality within a defined timeframe, usually a year. International regulations require European countries to build only Near Zero Energy buildings by 2019/2020 [9].

In an interview with one of Germany´s leading energy companies, low client´s acceptance and unwillingness to invest upfront were cited as the main obstacles towards the implementation of innovative technologies, such as storage systems, even when economic benefits were extensively conveyed. Clients were reportedly skeptical about having to change systems they did not see as immediately needing replacement. Here again, personal commitment on the client´s side to sustainability and innovation, rather than monetary savings, was seen as the main driver for willingness to adopt innovative technologies such as heat exchangers and solar thermal collectors. On the provider's side, investment in innovation is seen as an inherent/intrinsic necessity, without which the company would simply "fall out of the market", overtaken by more innovative competitors. The only question left to debate is what technologies to invest in. Uncertainty on this point is understandable because the energy transition is now recognized as a radical systemic change that will involve a very large and diversified set of actors, and which will have long-lasting consequences on the whole of the building industry.

2.2 The integrated system approach

As opposed to the autarkic home-unit approach, influential works such as [10] presented nationwide plans for exclusively renewable energy generation and distribution. One of MacKay´s most stressed points is the relevance of decentralized storage systems, for which he recognized electro-mobility as presenting by far the most potential. The same goal was set by the project "Kombikraftwerk", which developed the following energy-mix for a 100% renewably powered Germany: 60% wind power, 20% photovoltaics, 10% biofuels and 10% hydropower and geothermal sources. Here, one of the main outcomes was the necessity for careful planning of restructuration of the current energy transmission network [11].

These works have highlighted the essential role of an integrated system approach as underlying the success of the energy transition. They also exposed some of the effects of extreme volatility of weather-dependent energy sources, the consequences that this volatility will have on system design and regulations are the object of upcoming research. Prof. Dr. C. J. Brabec, Chairman of the Board of the research institute ZAE Bayern, calls this the "decade of flexible power generation and consumption" and describes a subsequent constant growth of the role of intelligent grids, consumers, and producers [12], or "prosumers", a definition given to entities that use and eventually market own locally generated energy. After the decade of flexibility, Prof. Brabec envisions a decade of progressive merging of the power and heat networks, aided by the widespread implementation of electro-mobility, which will be followed by the development of big seasonal storage systems. Regulatory frameworks as well as social acceptance and adapting infrastructure are expected to occur in parallel, or rather in an iterative feedback loop, as they are responsible for unlocking potential and hence economic feasibility.

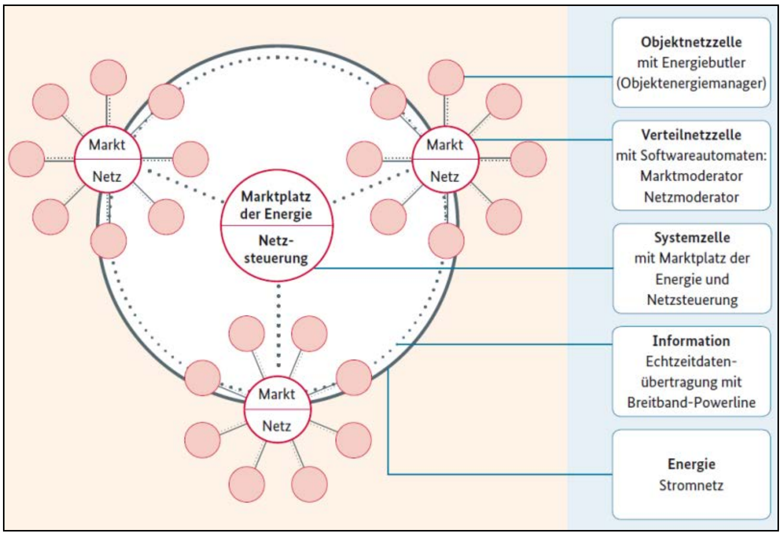
2.2.1 Meeting volatility through the Internet of Energy

Analyses and expert assessments, i.e. [14], have made increasingly clear that more progress in energy efficiency will not be possible without fully exploiting the potential of computational intelligence and digital networks. This potential, as well as the challenges that will have to be met in order to fulfill it, were addressed in the recently concluded five-years technological research program "E-Energy – Smart Energy made in Germany" sponsored by the BMWi, which supported the development of six selected model-regions. The projects committed to contribute findings to key aspects of intelligent energy: service security, environmental sustainability and cost-effectiveness.

One of the main successes of the model-regions was to turn volatility, the defining characteristic of renewable energies, from a drawback into an opportunity. Through information and communication technology (ICT) smart energy systems were found to be contributing positively to the stability of the power network as well as managing peak demand times more effectively than the current grid, especially on the distribution level. This was also found to postpone the need for expansion or upgrading of existing networks. In 2007, the term “Internet of Energy” was first introduced to describe this interdisciplinary development [15].

2.2.2 *Smart District, technological system framework*

Independently from the scale of decentralized energy systems, also called “virtual power plants” (“virtuelles Kraftwerk”), multiple research projects identify roughly the same constellation of elements. It is worth noting the cellular architecture of the pilot project “moma”, in Mannheim, as an exemplary solution. The system is described as an organism of self-optimizing hierarchically organized energy loops, or cycles. Each connected building is called an object-cell, about 200 object-cells are aggregated in a distribution-network cell. About 300 distribution-network cells build a system-cell, which are then directly plugged into the transmission network. A core platform integrates and manages system-cell interactions between each other and with the transmission network, automated network controls take over coordination within distribution-cells, while an “energy butler” interfaces and steers energy flows within each single object-cell. Local energy markets are established within and between distribution-network cells, while system-cells operate in energy markets on the transmission level. Through market integration and thanks to the “energy butler”, the client is able to define its own parameters in order to adapt to energy price changes in real time. On the other side, the “energy butler” receives network signals aimed at influencing the components it controls when system stability requires balancing power [13].



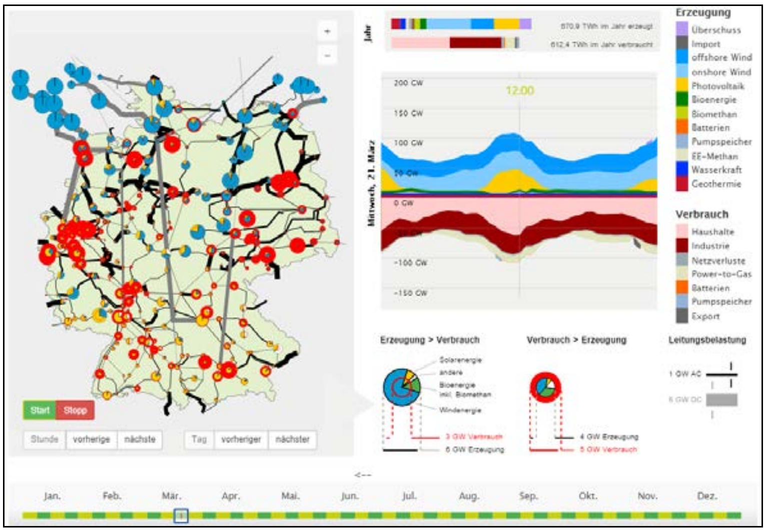
The cellular structure of “moma”

Figure source: [15] p.55

2.2.3 *Power storage systems and DSM*

The stabilizing effects of smart power on the grid are thus achieved through more effective Demand Side Management (DSM), thanks to better forecast and feedback on transmission and distribution networks as well as for individual customers. A combination of diversified decentralized, interconnected storage systems plays a central role, as it is the measure of available energy load shift capacity, as well as its flexibility. For example, DSM can be optimized on district level through a combination of electro mobility, heat pumps, power storage through big heating and/or refrigerating units, as well as so called “white goods” such as dishwashers, driers and washing machines, each one responding to a specific energy-balancing need.

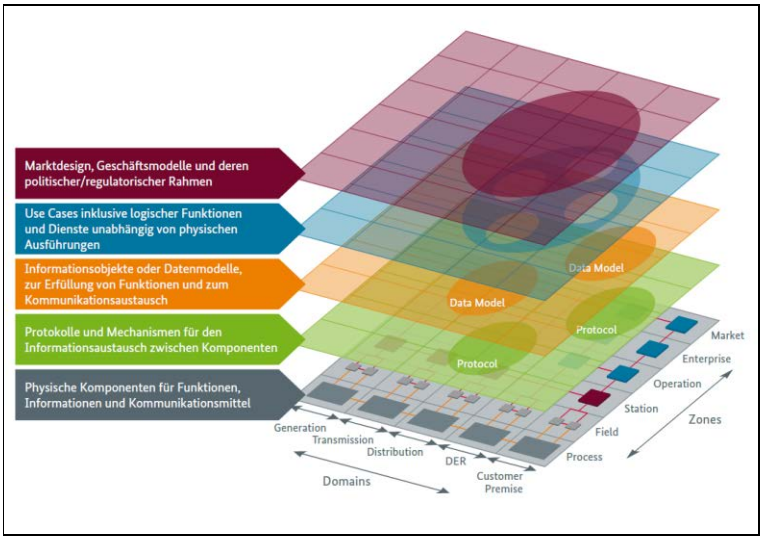
Individual users as small as single households can be prompted to increase or decrease their consumption, either manually or, in the case of smart electric appliances, through an automated process. Shifting loads at peak times helps to quickly resolve bottlenecks in the distribution grid. It has been recognized that big industrial and commercial consumers in Germany can potentially shift their power usage by more than 20%, thus opening up 5% of total power demand as balancing reserve on a national scale [15], which could upscale DSM to the transmission network. Management and automated control of a national smart grid was modelled in [11], and proved that thanks to the role of ICT control the whole demand of energy in Germany could achieve yearly CO_2 neutrality with the technology of today [11].



Electricity production, consumption and transport through 100 %renewable energy.

Figure source: http://www.kombikraftwerk.de/100-prozent-szenario/leistungsflussanimation.html

When fluctuations can be predicted with close approximation, flexibilities can be integrated in the smart district through different components. Multiple use-case scenarios are a central aspect of future grids. They are used to design market and business models as well as to shape future regulatory and political frameworks, two mutually influencing systems. The Smart Grid Architecture Model (SGAM) is a technical reference architecture developed within the EU-Smart-Grid Mandate M/490, aimed at representing functional information data flows and integrating several systems and subsystems architectures [16].

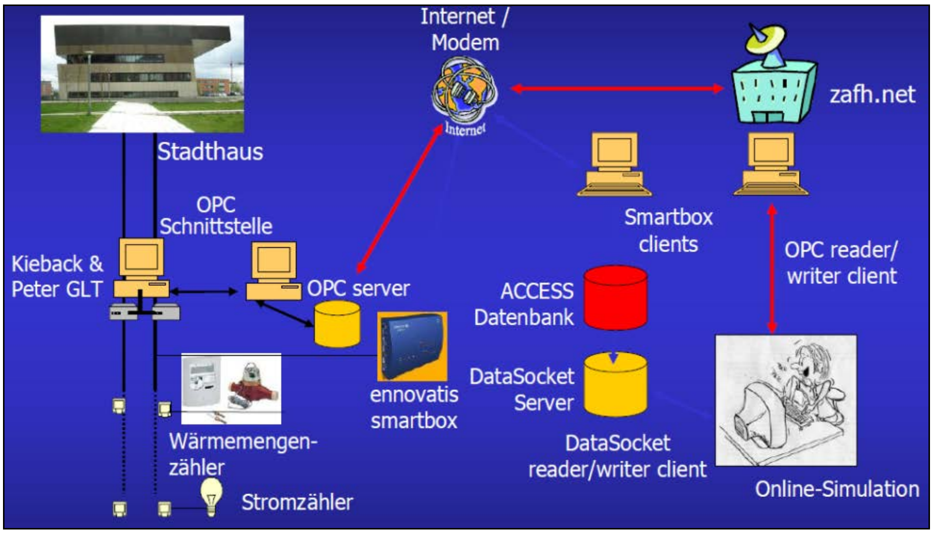


The Smart Grid Architecture Model (SGAM)

Figure source: [15] p.55

2.2.4 Smart District, ICT system framework

ICT solutions for smart districts or regions consist of hardware and software components. Technical components are usually a client interface, either online-based such as an app or dedicated such as a monitor, smart meters and sensors, servers, computers and their accessories. Respectively, information components are: programming languages for visual interfaces, communication standards for gateways, steering algorithms for control automation, data models for databases and communication protocols. In the same order, their target entities are client/user, building-integrated smart technologies and storage units, local network operations and markets, weather stations, and transmission system operator (TSO), or new “aggregators”, and energy markets.



Optimized management through simulation.

Figure source: Courtesy of Prof. Dr. Ursula Eicker, HFT Stuttgart

2.3 Current areas of research

Field tests and simulations within [11] brought to reconsider the main obstacles preventing constructive participation of renewable energy supply within the current network. These have been identified not in technical challenges regarding energy components, but in lack of communication technology and certification procedures, missing regulatory framework in balancing power markets, and social acceptance. More research is surely needed to increase efficiency of single technologies, especially power storages such as batteries, flywheels and phase changing materials. At the same time, high priority needs to be directed to improved communications. Information technology needs development in highly detailed forecast systems, genetic/self-learning control algorithms and operational technologies for data transfer. In the field of communication protocols, research is necessary in semantic data models, language and certification standards, as well as in cyber security. As for regulations, energy markets are still focused on conventional power stations with regards to the size and time limits for the tenders, while social acceptance is mostly necessary in order to shift the current ownership and business models to changing stakeholder's relationships within building projects. These relationships will be more complex due to new contracting typologies between higher numbers of actors, as well as between entirely new functions, such as system "aggregators" and new operational platforms.

2.3.1 Communication technologies

In order to allow for interoperability on component level, a number of standardized data models have been developed. Already in 1995 an International Electrotechnical Commission's (IEC) project group of about 60 members from different countries worked to create the IEC 61850 communication standard for electrical substation automation systems. Among the objectives set for the standard were to make mapping to the communication protocol entirely future proof, to promote information exchange among two or more Intelligent Electronic Devices (IED) from different vendors, and to set a common format for storing complete data [17]. The OPC Foundation, a task force for interoperability for industrial automation, mapped the IEC 61850 on the OPC Unified Architecture, a core standard specifying a server-client-architecture, connecting the industrial world and the power domain [18]. In the German area, the EEBus Initiative e.V. is set to standardize data modelling in order to "open up a new market of smart connectivity" for the areas of energy, building, connected home devices, and electro-mobility [15].

End-use specific information about electrical demand can be sent through powerline communications (PLC), a technique that uses existing cables, therefore offering fast and accessible implementation. Thanks to an adaptor placed directly on the plug, data is sent to a receiver through IP-based broadband. Data of this type has to be "disassembled" in order to identify end uses. At the receiver it is eventually decrypted, sorted out and made readable for further applications. A problem of PLC is its narrow range of reach and its vulnerability to interference. PLC is also commonly used for sensors, which usually monitor temperature, humidity, air quality, lighting levels and movement.

2.3.2 Forecasting methods

The energy system works because it is kept in balance, that is to say, the energy inflow has to be equal to the energy demand at all times. In order to program interrelations between components, therefore, forecast systems are of central importance. Current systems are kept in balance by the Transmission System Operator (TSO), which uses sophisticated energy modelling, weather forecasts and historical data to plan the daily schedules received by power plants. The smart grid will rely much more on weather and real-time user behaviour forecasts. Weather forecasts will have to become geographically and timely more precise, as current techniques are reliable on the hour, but not within the hour [11]. This makes operational use-cases and economic feasibility for storage systems such as flywheels, which operate in time-spans of minutes or seconds, difficult to assess.

User behaviour can be forecasted through genetic algorithms, which can learn to map a user's defining parameters and patterns by repeatedly modifying a population of individual solutions. The algorithm "learns" by comparing given data with newly acquired one until the right kind of parametrical response in order to reproduce the desired outcome values are found, i.e. the right temperature or the right time interval. Data can be transmitted from smart meters and sensors, but the possibility to override the program and manually insert specifications should always be guaranteed.

On the other hand, consumption profiles will have to be split into single end uses in order to identify potentials for DSM, as well as for energy savings. Algorithms can do this by mapping typical power usage profiles and comparing their stacked outlines with a given "energy landscape". This is necessary in order to automate detailed feedback commands. Feedback can also be sent to the user, but manual self-regulation through messages or other types of notifications is not a durable solution, as reported by the accompanying research of the E-Energy program. In all pilot projects, users whose smart technologies required active participation in order to provide benefits, mostly in form of monetary savings, showed signs of "fatigue" after a few months, and slowed or even stopped to respond altogether [15].

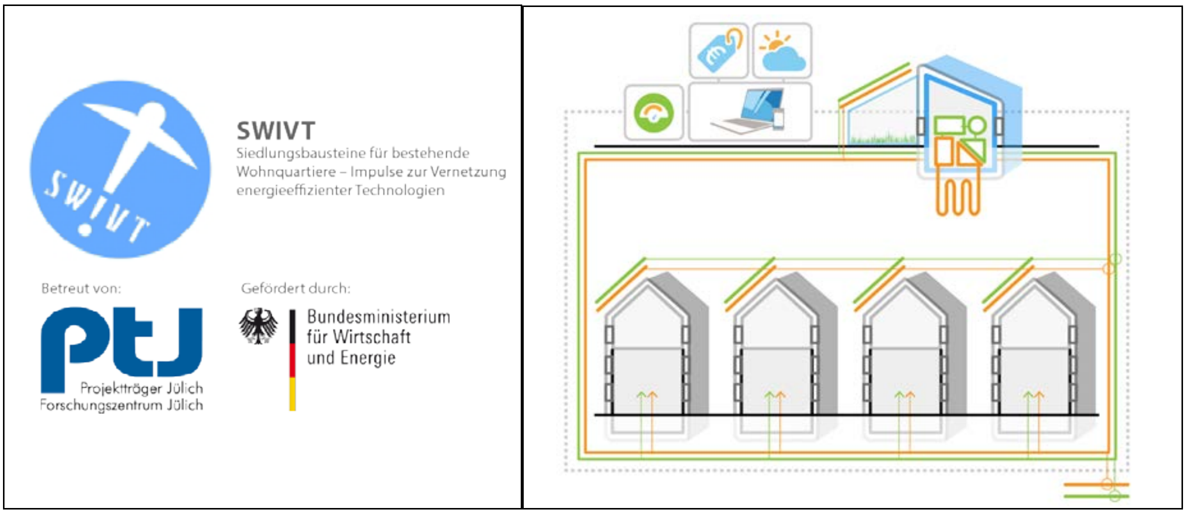
2.3.3 Market regulations

Smart local networks can exchange energy according to different optimization strategies, usually based on price parameters. When prices go over or under a pre-set threshold energy is exported or imported, otherwise it is moved to the next available temporary sink (storage component) for later use. According to planned schedules, energy can also be imported in excess when this results to be more profitable. Some use cases can bring to times where energy generated within the system is entirely sold, and energy consumed by the system is entirely imported. Because of transmission losses, the actual kilowatts flowing to households may still come from locally installed photovoltaics, but are acquired at a cheaper price thanks to the participation in market mechanisms. Override mechanisms and certifications should regulate the export of energy for balancing power, at times when reserves are needed to stabilize the network. The supply of electricity from photovoltaics and other renewable sources in Germany is regulated by the "Erneuerbare-Energien-Gesetz" (EEG 2014), committing grid operators to connect and market them. The EEG also regulates payment rates in form of sliding market premiums.

3 Pilot project SWIVT

3.1 Problem statement

Which are the parameters of Smart Districts operation, how are functions allocated within the system, which entity would ideally be responsible for each subsystem (component, communication, information)? These questions are asked within the interdisciplinary project SWIVT, „Siedlungsbausteine für bestehende Wohnquartiere – Impulse zur Vernetzung energieeffizienter Technologien" (District energy modules for existing residential areas - Impulses for linking energy efficient technologies), under development from December 2014 to January 2017 at TU Darmstadt, promoted by the Federal Ministry for Economic Affairs and Energy and supervised by Projektträger Jülich.



Left, Logos of the project SWIVT, the supervisor Projektträger Jülich, and the promoter Federal Ministry for Economic Affairs and Energy. Right, Schematic concept for the layout of the smart district SWIVT.

Figure source: SWIVT, 2015.

3.2 Project description and goals

In the research project SWIVT multiple disciplines come together to develop a smart district concept for existing housing developments. Researchers from architecture, building physics, electrical and mechanical engineering, informatics, sustainable design and finance are collaborating on an integrated solution that aims to improve the energy balance/footprint achieved through a standard renovation by at least by 30%, through a much less invasive measure. The central idea is to densify the district with a new “energy module”, a building block that contains all necessary technical components to operate a local smart grid, such as energy storage solutions for power and heat, as well as ICT equipment. The module can also host high-quality living space as well as public space for exhibitions and displays of informative materials, aimed at improving social awareness and acceptance. The SWIVT module, in combination with a basic building renovation and decentralized power generation, will not only drastically improve the energy balance of the district in one simple step, but also introduce the concept of energy transition to the public as a new, more comfortable and sustainable living standard.

3.2.1 Coordination tools, the SWIVT Platform

One of the reasons why small energy systems are still not implemented may be simple lack of experience with similar projects. Actors involved in the planning process share very different areas of expertise, and need to possess good interdisciplinary background knowledge in order to effectively contribute to the success of the project. Bridging this gap can be helped through innovative project coordination tools and techniques, such as structured shared databases, platforms for real-time parameter exchange and dynamic visualisation of results. The application of these approaches is investigated in SWIVT trough the creation of a project platform.

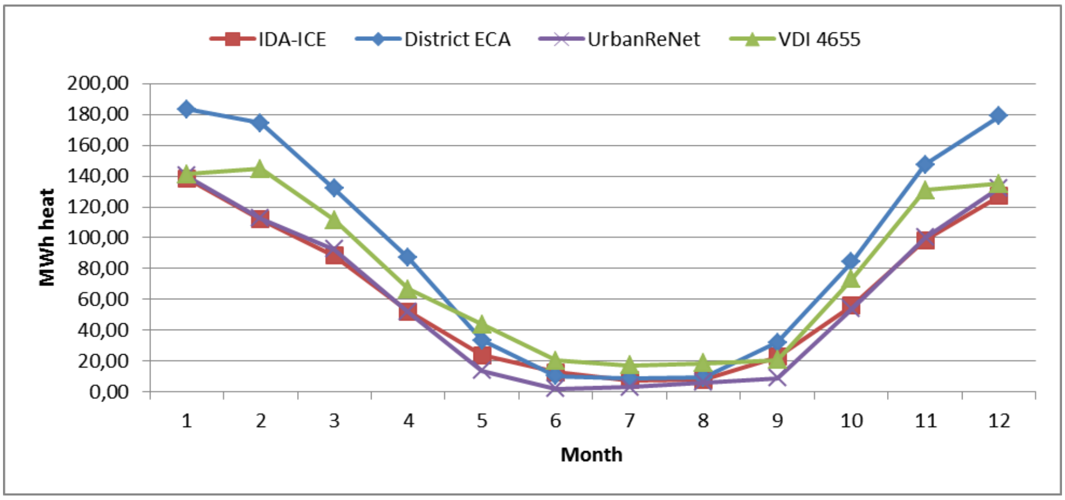
3.2.2 Materials Database

Within SWIVT, the first step consisted in documentation on the existing structure in order to create a reference context. This set the base framework for the different disciplines to start designing concepts for new scenarios. The small district in Darmstadt, consisting of five buildings from 1952, has an averaged final energy consumption of 270kWh/m^2 for about 4000m^2 of living space. External facades of plastered structural concrete have never been renovated, apart from a replacement of the original wooden windows for early double glazed, plastic framed ones in the 1980s. Insulation has been placed between the wooden beams of the roofs. The heating supply is partially centralized and partially located on each separate floor. Central boilers have actual efficiencies well under 60%, due to the fact that there are no thermostats to provide feedback. In the buildings where gas floor heating is used, radiators have been found lacking even a simple manual control knob. Nevertheless, the physical structure of the small district is in good conditions, is evaluated to last another 50 years, and would generate unnecessary waste of time, material and embodied energy if demolished.

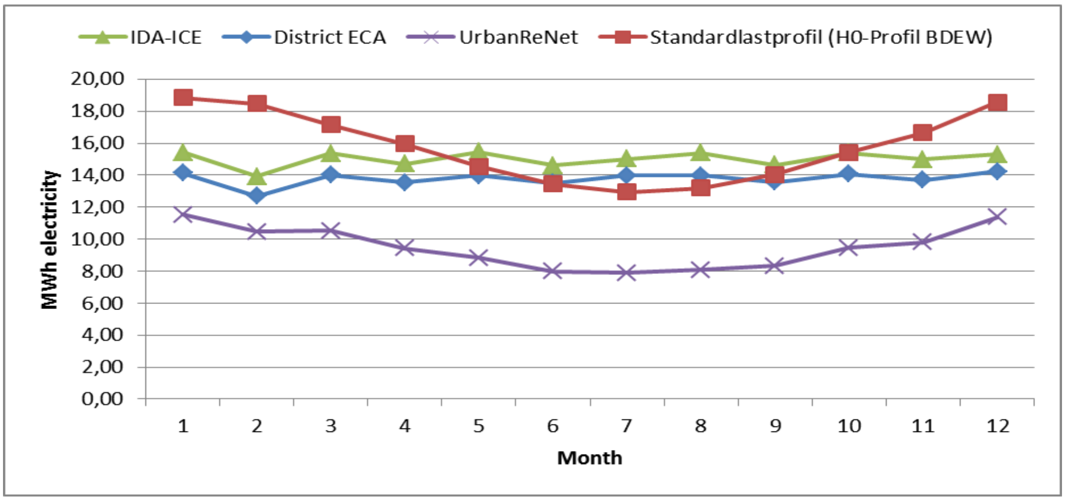
Building Information Modeling (BIM) was chosen for architectural building documentation. BIM is a widespread standard for integrated architectural projects in the United States as well as in Australia and parts of Asia, but is only starting to be implemented in the German speaking area. Among other advantages, it allows the automatic generation of schedules following specifically defined parameters for the whole project and facilitating their exchange among multiple users. BIM virtually enables updated project progresses for all partners in real-time. This feature greatly improves communication between disciplines and thus enables faster and better informed decision making processes. All schedules are exported to the Materials Database. The Materials Database also contains specifications for physical components which are part of the energy system but not (yet) modelled in the project's BIM. Both are described by the same parameters defined in cooperation with all disciplines, consisting of Key Performance Indicators (KPI) for dimensions, capacities, prices and schedules, and embodied energy where possible.

3.2.3 Energy Database

In order to map the reference context, data on final gas and electricity consumption from different sources has been compared. Measured data came from the energy utility company, which provided yearly consumption values, and measurements on site, which provided two-weeks highly detailed consumption values. Both data sets were useful for validation and as a benchmark, but they did not provide enough information for the integral planning. A first estimation of the monthly hourly consumption of the site was generated using reference profiles from VDI 4655 from the Association of German Engineers (VDI) for heat, and standard H0 profiles from the German Association of Energy and Water Industries (BDEW) for electricity. Furthermore, two planning tools developed within the framework of the EnEff:Stadt research group, District ECA from Fraunhofer Institute and UrbanReNet from TU Darmstadt, were tested and evaluated for consistency. For detailed daily hourly simulation the BIM-compatible software IDA Indoor Climate and Energy (IDA ICE) was used. IDA ICE accurately models the physical building as well as technical HVAC components and occupancy data. The normalized results can be seen in the table below.



a)



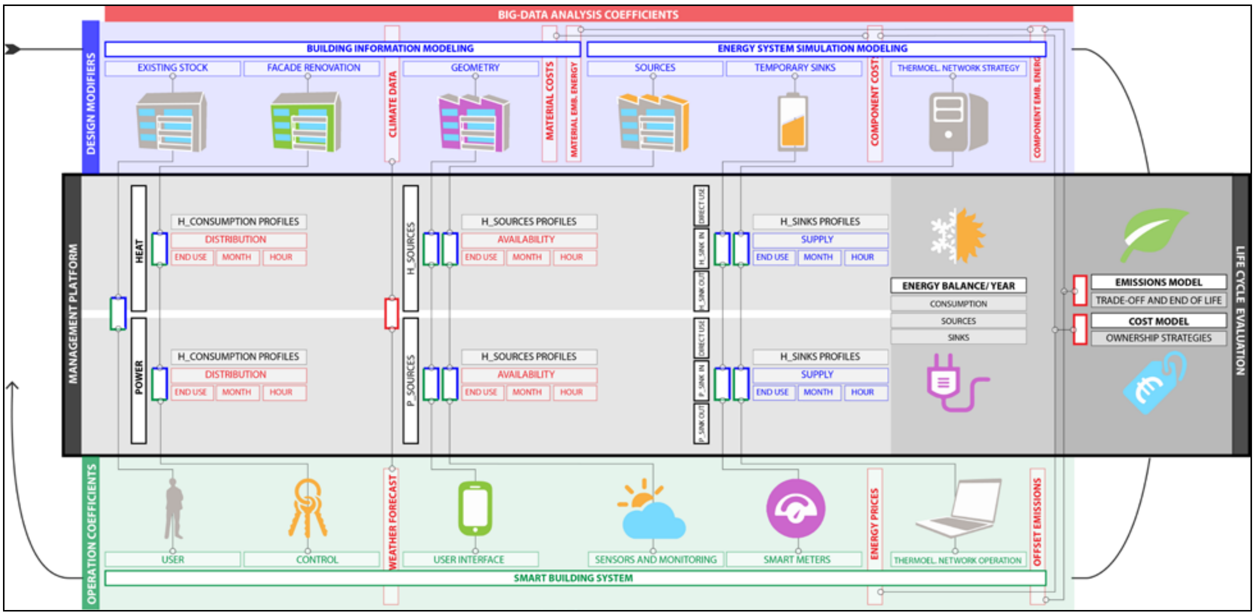
b)

a) Monthly hourly heat consumption for the existing buildings on project site. b) Monthly hourly electricity consumption for the existing buildings on project site.

Figure source: SWIVT, 2015.

Energy profiles for demand will be combined with generation profiles to create residual energy profiles. Parameters describing these three profiles on an hourly basis comprise the Energy Database. Component schedules can roughly be modeled within the Database, but are going to be simulated in detail using the software MatLab and/or Simulink, so that evolutionary optimization and linear programming approaches can be implemented to study market interactions. According to use-cases developed by the accompanying evaluating research, algorithms will be programmed to steer the system in order to maximize profits for the user or for other actors, such as the energy provider. Optimization of the system from the side of the ecological assessment can also be implemented, in which case a combined parameter or fitness function for costs and climatic impact will have to be designed. A fitness function is a particular type of objective function that is used to summarize, as a single figure of merit, how close a given design solution is to achieving the set aims.

Both Materials and Energy Databases are built as XML files in order to maximize interoperability, and are integrated within a project-specific designed SWIVT Platform. The role of the platform is to graphically visualize results in order to facilitate reading and sharing of information. Ideally, the platform with its databases and BIM model could be delivered to the management and operation spheres of responsibilities of the district after the planning phase is concluded. Such cooperation would open up very interesting possibilities for new contracting models within the system. In combination with Geographic Information System (GIS), it would have a tremendous potential for the development of smart grids on a regulatory scale as well. District energy platforms could contain all relevant data on a 100 to 300 living units-scale, and could be linked as a reference within communal and national GIS models. Combining the two inherent scales of detail of BIM and GIS, it would be possible to identify potential synergies for the integral planning of smart grids.



Schematic concept for the layout of the SWIVT Platform.

Figure source: Conci, 2015.

4 Conclusions

4.1 Use-cases scenarios …

Use-cases and final statements about evaluating parameters of costs and climate impact are only relevant when assessed within pre-agreed time frames. These will be addressed from the point of view of different stakeholders, some of which are known, such as the user/community, the housing company, the energy supplier, and the component vendor. Other new actors, whose responsibilities are not defined yet, are the smart system operator and the ITC developer/system designer. Scenarios will be designed in order to investigate different relationship structures.

4.1.1 … for energy management platforms

The responsibility for the smart home network operation may rely with the energy provider or with the DSO with similar benefits, such as optimized planning for new investments in infrastructure and capacities. However, suppliers of smart appliances will wish to provide own interfaces, not least because of the value of information on households' personal data that can be derived from them. The interfaces could be apps, which could be compatible with a central home service platform within the sphere of responsibility of the energy provider or of the DSO. Component suppliers may then have to pay a fee in order to reach the consumer, as well as to comply to specified standards for encoding, privacy, protocols, and so on.

This could offer a further level of protection for users' data, while benefitting from competition between industries to offer the best "app", or operating mode, for their appliances. Component suppliers' apps could come with optimized setups for entire home systems, for example a complete lighting design or an integrated kitchen equipment, with software offering predefined scenarios ("comfort", "active", "economy", "vacation", "working day", and so on), thus encouraging clients to buy more appliances from the same brand in order to benefit from the programmed synergies.

If the home energy platform is within the sphere of responsibility of the energy supplier, it might result in a more straightforward way to display the total energy bill, read through a smart meter which integrates data from all transactions. Another consequence is that the user would download a new energy platform when switching to a new energy supplier, and reinstall its components-apps. Through the home energy platform, the energy supplier could offer own sets of scenarios for personalized tariffs or price rates depending on the type of service, similar to current "Revenue through use" internet bundles ("pay-as-you-go", "flat-rate", "1MW/month"). In this scenario, competition between energy providers to offer the best service would reach the PR sphere, with benefits for the user. This scenario is also in line with recent development discussed within the extended project group, whose partner believe energy providers are investing in a more "local" public image, reaching out to the small costumer through their advertising [20], a strategy perceived as a measure of sustainability, both social and environmental.

4.1.2 … for physical energy components

In an overview of positive influences allocated to assigning the sphere of responsibility for decentralized power storage to different actors within the energy system, modeled after a VDE study [21], the Distribution System Operator emerges as the most favorable solution. The benefits are aligned with those listed in 2.2.3 of this paper. The positive influences described measures of quality of service, most of which regarding supply security measures. The Transmission System Operator followed the DSO for number of fulfilled measures. Structured communication between the TSO and the DSO should guarantee that the benefits provided by both solutions are met at the same time.

Energy collecting components are currently in the sphere of responsibility of the landlord or of the tenant, as described by the EEG and in 2.3.4 of this paper, while smart meters from energy suppliers monitor the monetary benefit the owner of the components will receive from feeding renewable energy into the grid. There are many disadvantages to this model, for example, privileges coming with access to a roof, soil or collecting surface, wasted potential from the fact that many large roof surfaces are owned by housing associations or by industrial entities, which do not have incentives to generate power since their energy bills may be relatively small (industrial clients pay different rates or directly feed from the transmission network). This market gap has already been filled by new companies, such as SolarCity, which designs, finances, and installs solar power systems in order to profit from active participation in energy spot markets. In order to gain access to collecting surfaces, these companies need to find an agreement with landlords and other groups of property owners and managers. A similar use-case could be implemented with storage technologies, installed not in private homes but in "hubs", new "energy blocks" such as the SWIVT-module.

4.1.3 … for architecture

Smart districts could be developed in cases where the landlord owns a number of buildings in the same area, or when different building owners come together to discuss the opportunity. This could be initiated by the municipality through awareness campaigns, by the energy supplier through advertising or personal consultancy, or independently by one of the owners.

5 Further research

Will smart districts and smart houses present a challenge for the construction industry? New spheres of responsibility for energy suppliers and system operators could free architects from having to integrate the role of energy consultants, since the district system would regulate itself thanks to ICT and the Internet of Energy. On the other hand, developers of virtual power plants might be called to invest in building facades already from the planning stage of new or renovation projects. The architect would then design volume and geometry, while energy companies would develop the building skin. Contracts would need to adapt to a completely new scenario, in which a building has two or more owners, one for the structure and the living space, and one or more for the building envelope and its components [22]. In this scenario, the energy company might even become the active developer of new projects, or become the main stakeholder for an increase in the renovation quota for existing buildings.

Services provided and enabled by smart districts and their system architecture call for use-cases for new spheres of responsibilities. This is expected to require new typologies of project management and delivery of projects, to which regulations will need to comply, for example, by revising the schedule of services and fees for architects and engineers (“Honorarordnung für Architekten und Ingenieure“ or HOAI), which already presents a difficult integration of services offered through BIM.

The energy transition opens new markets to architecture, energy providers, network and markets operators, but especially informatics, programmers and software developers. End users and customers are also expected to profit, while a new figure managing smart district on distribution level is surely necessary. Thus, multiple actors and new stakeholders represent rising complexity but also an entirely new field of opportunity.

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Session Monitoring II

Supporting Energy Efficiency Decisions with Energy Consumption Data Analysis

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Abstract

Traditionally, building owners had to make significant investments to ensure that their buildings were energy efficient. In the past, building owners relied on their experiences instead of historical and predicted building energy data. However, leveraging information by linking multiple datasets such as Energy Star Portfolio Manager ®, municipality benchmarking data, utility rebate data and building attributes can change this approach and result in providing criteria to assist in energy efficiency retrofit decision-making.

This collaborative research is a partnership between industry and academia and utilizes a dataset of over 250 buildings in Washington, DC and Philadelphia, PA. The research findings provide building owners and managers with a rule-set to guide them in their energy efficiency decisions through statistically significant correlations between buildings attributes and energy consumption in existing buildings.

This document describes the unique methodology and findings through different level of statistical analysis of energy data and building attributes. The research highlight how linking multiple data sources, can provide a smart means to make energy efficiency investment decisions and take advantage of rebates. Additionally this cross-sectional analysis can be used to refine the design guidelines, and ultimately improve buildings energy performance and EnergyStar scores.

Introduction

In the United States and in Europe, buildings account for more than 40 percent of total energy use [1]. In both cases, governments provide energy tracking and benchmarking tools to help building owners assess their energy performance. In the US, ENERGY STAR Portfolio Manager, was developed by the U.S. Environmental Protection Agency (EPA) as an online tool for building owners to voluntary manage energy use in buildings. This tool is quickly becoming the reference standard across the U.S. for building benchmarking, with now 14 cities using ENERGY STAR Portfolio Manager to implement their benchmarking policy. Buildings can receive an ENERGY STAR score ranging from 1 to 100, which compares the building to other buildings nationwide that have the same property type [2]. A score of 50 points represents median energy performance while a score of 75 points indicates that the building perform better than 75% of its peer group. Those buildings scoring more than 75 points are eligible for ENERGY STAR certification. Since the launch of Portfolio Manager in 1992, more than 27,000 buildings and plants have been ENERGY STAR certified [3].

With the increased availability of benchmarking data as well as the deployment of smart meters in the United States, more and more energy data is available publicly and to the building owners allowing the government, energy utilities and building owners to be informed on energy profile of buildings, individually or at a city scale. By adding buildings attributes data to this newly available energy dataset, this research investigates how certain building attributes could be indicators of high energy consumption.

In the past 15 years, researchers investigated whether various building characteristics could be linked to energy use with sometimes contradictory findings as described in this section. The results of the 2003 Commercial Building Energy Consumption Survey (CBECS) shows that era built does affect the Energy Use Intensity (EUI), with buildings constructed between 1960 and 1989 having the highest EUI [4]. CBECS data also indicates that the later the building was constructed, the lower heating EUI and higher cooling EUI, which may indicate the increased presence of insulation in newer buildings [4]. However, an analysis of annual data in New York, San Francisco and Seattle, David Hsu found no relationship between year built and EUI [5]. A 2013 analysis of NYC buildings found that site EUI correlated directly with a building's gross square footage of floor area [6].

A 2012 study by Choi et al. found that building shape significantly affected energy use. The study classified new high-rise multifamily apartment complexes in Korea into two categories: "plate type" broad, flat buildings and "tower type" buildings with multiple branches in their floorplan, and found that tower type buildings used 48% more energy in total, but that plate type buildings use 10% more heating energy [7]. Another study found that a 30% window-to-wall ratio (WWR) resulted in a 500 lux condition at the work plane for 76% of the year, and that the addition of on/off daylighting control systems given 30% WWR could reduce lighting energy by 77% and cooling energy by 16% [8]. Many recent studies have suggested that energy performance decreases linearly with WWR. As documented, the research is still nascent and additional research is need to collect more data on the relationship between EUI and Bbjlding attributes.

Through an interdisciplinary collaboration between multiple Universities and Industries, tis research investigates new data mining and analysis techniques to identify statistically significant correlations between buildings attributes and energy consumption in existing buildings. Such techniques can lead towards refining design guidelines for energy efficient retrofits and new construction. Additionally, the findings can also be used to identify facility management recommendations that can reduce a building’s energy consumption.

Building attribute data (including information on building envelope, building systems, shading devices, hours of exposure to sunlight etc) were collected using virtual and in person site visits, while the corresponding energy data of the same buildings was assimilated through Portfolio Manager and authorized data provided by the utility. The data thus collected was analyzed on three levels of concentration against weather data i.e. yearly data, monthly data and interval data broken down into 15minute intervals. Each level of analysis presented their own challenges and required a unique methodology, thus each energy interval provides different lessons learned and energy efficient opportunities.
To quantify the energy impact of building attributes, twenty-three sub-hypotheses were formulated and statistical regression were performed for each sub hypothesis. Buildings of similar classifications based on usage, built area, patterns of occupancy and period of construction were thus compared to extract specific valuable (physical attribute or building system) results which can potentially lead to identifying energy efficient retrofit projects. These results relate to building characteristics such as heating and cooling equipment, window wall ratio, façade area to floor area ratio etc. Because not all levels of energy data are easily available in all regions of the country, this research seeks to provide a replicable method for analyzing whatever type of data is available within a particular benchmarking region. This paper will focus on annual and monthly data findings, additional information can be found in upcoming publications.

Methodology

Data Collection

In order to gather data on physical building attributes this research explored a variety of methods. After an initial list of sub-hypotheses was created, a list of data points necessary to test each hypothesis was written. Each of these points was categorized into one of four groups: information available from publicly available geodatabases such as Google Maps and municipal GIS catalogues, information available by driving by the building, information available by an up-close inspection of the building, and information that would only be available by contacting building managers or owners. Ease of information gathering was prioritized, and it was found that a large number of data points needed for each building were able to be obtained through Google Maps alone. A cross-section of these data points is shown in table 1.

Following this step, building visits were made to gather information such as the number of glazing layers which was not available using online tools. Two sets of building visits were done – one visit during the day when the building was in operation, and one during the night in order to find whether or not lighting was left on during the night or turned off, and what percentage of lighting. Buildings which turn off as much lighting as possible during the night may indicate a larger effort to conserve energy. Annual energy use and Energy Star score were publicly available while monthly energy consumption were obtained from the partner utilities. Annual building energy data for Philadelphia gathered through the city benchmarking portfolio and annual energy data for Washington, D.C. gathered through the BuildSmart DC website provide the annual-related dependent variables of Energy Star Score, site EUI, source EUI, and energy use by fuel type [9].

Table 1 - Building attribute data availability by data source

Data points available		Portfolio Manager	Google Maps	Building exterior visit	Building exterior inspection	Interval Data	Asset Scoring Tool	Occupant Input	Metric	Evaluation Input	Time Required per Building
Potential Retrofit Measures											
HVAC											
1	Rooftop Packaged AC Units	○	●	○	○	○	●	○	Total Number of units and fans	Number	2 min
2	Rooftop Chillers	○	●	○	○	○	●	○	Total Number of units and fans	Number	
3	Rooftop Cooling Towers	○	●	○	○	○	●	○	Total Number of units and fans	Number	
4	Rooftop Condenser AC Units	○	●	○	○	○	●	○	Total Number of units and fans	Number	
5	Window AC units	○	●	○	○	○	●	●	Total Number of units	Number	
6	Shading of AC units	○	●	○	○	○	○	○	Nearby shading	# shaded chillers or RTUs	
Glazing											
7	# Glazing layers	○	○	○	●	○	●	●	Number of glazing layers	Number	30 sec
8	Tinted Glass	○	●	●	○	○	○	●	Shade of glass	No tint, Slight tint, Dark Tint, Reflective/Mirror	30 sec
9	Window frame material	○	○	○	●	○	●	●	Material	Metal, Wood, Vinyl	30 sec
10	Operable windows	○	●	○	○	○	○	●	Percentage of windows that are operable, rounded to 5%	percent	1 min
Shading											
11	External shading (on each orientation)	○	●	○	○	○	●	●	Estimated depth of external shading from the glazing surface	Feet	1 min
12	External shading device type	○	●	●	○	○	●	●	Type of external shading device used, if any	Horizontal, Vertical fin, Eggcrate	30 sec
13	Internal shading	○	●	○	○	○	○	●	Type of internal shading used, if any	Horizontal blind, Vertical blind, Curtain, Roller shade, None	1 min
Other											
14	Roof reflectivity	○	●	○	○	○	●	○	Color of the roof surface	Black, White, Gray, Brown, Glass	30 sec
15	Lighting fixture design	○	○	●	●	○	●	●	Type of ceiling mounted lighting fixtures	Pendant, Recessed, Parabolic louver	30 sec
16	All electric building	●	○	○	○	●	●	○	Gas bills less than 500 CCF/yr or steep electric heating curve	Yes/No	2 min

	Data points available	Portfolio Manager	Google Maps	Building exterior visit	Building exterior inspection	Interval Data	Asset Scoring Tool	Occupant Input	Metric	Evaluation Input	Time Required per Building
New Building Design											
Building Plan											
1	Gross Floor Area	●	○	○	○	○	●	○	Reported Square footage	square feet	0 min
2	Floor Plate Size	●	●	○	○	○	●	○	(Gross floor area)/(number of floors)	square feet	calculated
3	Orientation	○	●	○	○	○	●	○	Facades with greatest surface area	N/S, E/W, NE/SW, NW/SE, Equal faces	30 sec
4	Number of floors	○	●	○	○	○	●	●	Number of floors in building	number	1 min
5	Building Depth	○	●	○	○	○	●	○	Depth of building, in feet	feet	1 min
6	Building Shape	○	●	○	○	○	●	○	Categories of building layouts such as "L shaped" or "E shaped" (Cochran, 2014).	B1, B2, D, O1, X2, A1, A2, C1, C2, E, F, H1, H2, T1, T2, L	30 sec
7	Façade area/floor area ratio	○	●	○	○	○	●	○	Calculated wall area/reported floor area	square feet per square foot	2 min
8	Proximity to other buildings at each orientation	○	●	○	○	○	○	○	Measured distance to nearby buildings	feet	2 min
Glazing											
9	Overall WWR	○	●	●	○	○	●	○	Weighted average WWR of all facades	percent	calculated
10	WWR by facade	○	●	●	○	○	●	●	WWR at each façade estimated to 10%	percent	5 min
Other											
11	Envelope materials	○	○	●	●	○	●	●	Primary façade materials	Brick, Stone, Concrete, Steel, Spandrel panel cladding, Metal cladding, Glass	30 sec
12	Roof pitch and orientation	○	●	○	○	○	●	○	Cardinal direction and degree of roof tilt	N, S, E, W; Degrees	1 min

	Data points available	Portfolio Manager	Google Maps	Building exterior visit	Building exterior inspection	Interval Data	Asset Scoring Tool	Occupant Input	Metric	Evaluation Input	Time Required per Building
Building Management											
Lighting											
1	Lighting use at night	○	○	●	○	○	○	○	Percentage of lights on at night, rounded to 25%	percent	1 min
HVAC											
2	Thermostat Heating Setbacks	○	○	○	○	●	●	○	Setbacks visible in interval electrical data	Yes/No	5 min
3	Thermostat Cooling Setbacks	○	○	○	○	●	●	○	Setbacks visible in interval electrical data	Yes/No	

Building Level Analysis

Analysis of how building attributes affect annual and monthly energy use was performed using the sample data sets described previously. A summary of the available metrics for each level of data presented in this paper is detailed below in table 2.

Table 2: Metrics available at various level of details

Level of Energy Data	Annual	Monthly
Useful Metrics Available	Energy Star Score Site EUI Source EUI Electricity EUI Fuels EUI	Energy Star Score Site EUI Source EUI Electricity EUI Fuels EUI Peak heating load Peak cooling load Overall inflection point Heating inflection point Cooling inflection point Base energy use Heating seasonal energy use Cooling seasonal energy use

Additionally, different analysis methods can be used depending on the time interval of energy data at hand. Annual data analysis employs ANOVA statistical analysis of energy use as a function of the building attribute. Monthly data analysis uses this and a version of LEAN regression analysis (described below) to understand weather-related and seasonal energy use.

Energy Star Score

Energy Star Score is the most frequently significant dependent variable in annual data analysis. For several reasons Energy Star Score may be a better metric of building energy use than EUI. Although Energy Star Score is calculated using EUI, it also controls for many factors input into Portfolio Manager that are not retrievable in benchmarking data. Although EUI, as used here, could be controlled for building age, use type, and location, Energy Star Score additionally controls for occupancy, number of desktop computers, fuel mix, weather, and operational attributes like schedules and setbacks - a major confounding factor found in CBECS. Portfolio Manager does not release the information about number of occupants or number of computers for privacy reasons. Since factors like occupancy and plug loads can mask the impact of specific building attributes on energy consumption, therefore comparison of two buildings based solely on EUI becomes impossible. This makes Energy Star Score a better metric for determining the influence on energy use of specific building attributes.

Monthly Data Analysis

For this part of the analysis, monthly energy data was disaggregated into discrete energy end uses. From the large pool of data sets available, only those buildings were selected for analysis, which were either all electric, or for which both monthly electrical and monthly gas usage data was available. Moreover, buildings with anomalous energy data, or occupancy patterns were also removed, leaving a total of 38 buildings in the first phase of analysis after the data cleansing process. Next, each month's energy use was normalized for the number of days in the month, by dividing it by the number of days, yielding a dependent variable of energy use per day, which was then divided by the floor area to become EUI per day, or energy use per day per square foot.

Because monthly energy data is normalized by the number of days in the given month, heating and cooling degree days in the month must also be divided by the same number of days. Once this is accomplished, two independent variables exist for each dependent variable of energy use: heating degree days/day and cooling degree days/day. For this analysis, months with at least thrice as many heating degree-days than cooling degree-days, use the heating degree-days as the independent variable, and vice versa. For months whose heating and cooling degree days were almost equal, the month's data was removed from the analysis. This enabled a continuous degree-day x-axis and hence LEAN-Monthly regressions and load disaggregation could be performed.

To disaggregate particular loads, LEAN analysis as demonstrated by Kissock & Seryak was used with some modifications [10]. LEAN is most commonly used with a portfolio of buildings to distinguish between energy use patterns across the limited number of buildings in the portfolio, pointing to buildings that need the most attention and areas in which each building can improve, as done for Johnson Controls' building portfolio [11]. For this analysis, an inflection point between heating-dominated and cooling-dominated seasonal loads was used instead of separate breakeven temperatures to acknowledge residual heating and cooling that occur in reality, often simultaneously, as illustrated in figure 1 a &b. Another difference is that regression curves, rather than linear change point regression models, were used because individual heating and cooling season data points aligned best with quadratic equations rather than linear equations. For an easier visual comparison, all site energy was plotted on the same axis rather than separating heating and cooling regressions for mixed-fuel buildings based on the fuel type used. Henceforth this type of analysis will be called "LEAN Monthly" and will reference monthly analysis.

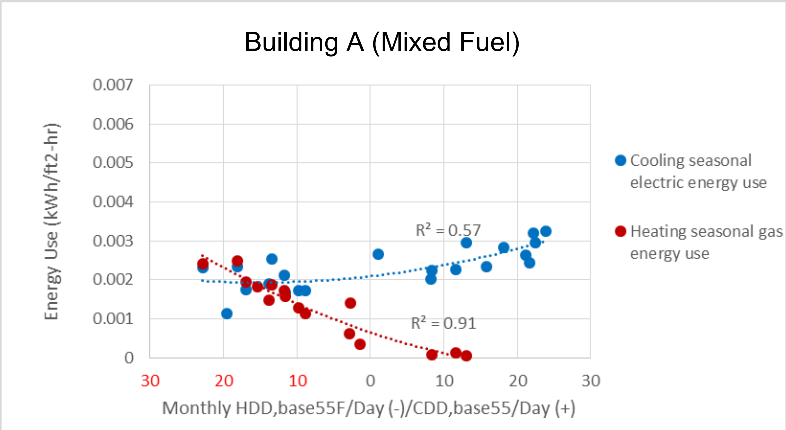
Metrics developed for monthly analysos

Metrics common to both annual and monthly data i.e. Energy Star Score, site, source and electricity EUI, and gas EUI and can be easily discerned. Others however, must be calculated based on the LEAN-Monthly regressions, such as heating and cooling inflection points, LEAN-Monthly-derived baseload, LEAN-Monthly-derived heating load, LEAN-Monthly-derived cooling load, peak heating energy, and peak cooling energy. A significantly small sample size of buildings with monthly and interval data however, limited the ability to control for confounding factors where ANOVA analysis is performed.

Heating and cooling inflection points denote the temperature corresponding with the degree-day value at which the heating or cooling curve has a minimum.

Baseload is considered to be all energy use below the lowest point on the combined gas and electricity curve, the area of which is considered to be baseload electric use. This baseload also contains some HVAC energy baseload, but this cannot be separated from other baseload end uses in monthly data, and is not weather-dependent. Finally, heating season energy use area is calculated as the area between the heating season curve and the baseload curve, while cooling season energy use area is calculated as the area between the cooling season curve and the baseload curve.

Peak heating load is calculated as the y-value for the monthly energy use curve at the lowest temperature represented in the LEAN-Monthly graph. Peak cooling load is the y-value of the cooling curve at the highest temperature represented. These highest and lowest degree-days/day are constant for all buildings and are representative of the highest and lowest common temperatures occurring within the regions represented. In this case, 25^{0}F is the lowest temperature, so -30degree-days (base 55^{0}F)/day is the lowest value on the LEAN-Monthly x-axis. 85^{0}F is the highest temperature, so 30 degree-days (base 55^{0}F)/day is the highest value on the LEAN-Monthly x-axes.



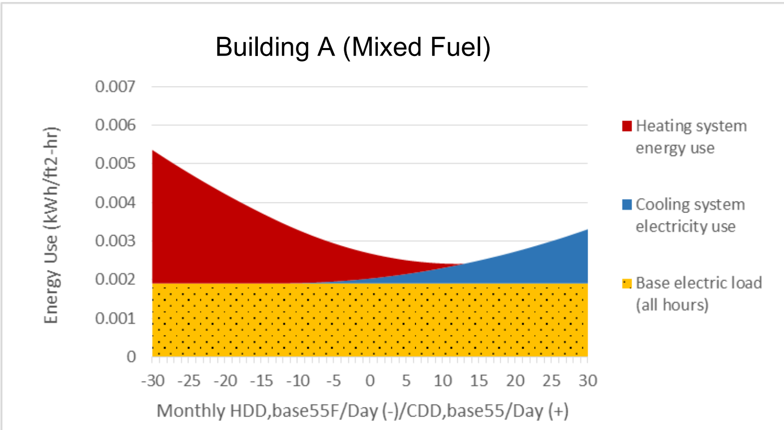


Figure 1-a&b: regression curves and LEAN monthly graph for 1 mixed-fuel building

Portfolio level analysis

Statistical analysis was thus performed as described for annual statistical analysis, but with the additional metrics of heating seasonal energy use, cooling seasonal energy use, baseload energy use, inflection point, highest heating load, and highest cooling load.

After completing the data gathering process, analysis of each building attribute and its effects on the six metrics of energy consumption was performed. For preliminary analysis, some variables expected to affect energy use were tested against the six metrics using one-way ANOVA statistical analysis with 95% confidence interval in Minitab 17. After establishing several important relationships between building characteristics and energy use, post-hoc multivariate tests for each hypothesis were performed using SPSS. Given the sample data set, buildings were able to be separated into sub-groups by up to 3 characteristics, meaning that up to 2 controls could be used depending on the resulting sample sizes. To represent findings from these tests, the data was visualized using box-and-whisker plots in Minitab 17. Often, it was necessary for individual building attributes to be grouped into categories encompassing a percentage of the data points found; for example, wall area-to-floor area ratio was grouped into 3 groups: “0-0.25,” “0.26-0.50,” and “0.50+”. To create controls, building characteristics were treated as binary values for controls—for example, buildings constructed before 1970 and buildings constructed from 1970 onwards.

Particular controls were used for each analysis depending on the attribute at hand. Some controls represent common potential confounding factors such as building age, which were checked initially on the data set at large to determine whether they had a significant impact on the six metrics and should thus always be controlled for when testing a particular metric. Other controls are attribute-specific; for example, if one is checking for the impact of roof color/material on any metric, one must also control for the number of floors in the building to narrow down impact of roof attributes on only those buildings with high relative roof area whose energy use would be expected to be impacted by the roof. This was done by using sub-groupings determined by the binary controls mentioned above. This methodology may be modified in future work to inclue factor analysis. In each instance of analysis, it is noted which factors were tested for confounding influence and which were accounted for in the particular analysis.

The trends found in annual analysis are supplemented by monthly metric tests, following the same analysis procedure with their applicable metric variables.

Findings

Replacing glazing on buildings with dark glass (T-Vis<0.5) will lower electric consumption.

The sub-hypothesis tested was that darker glass will lead to higher heating energy use and may slightly decrease cooling energy use. Dark glass will also lead to increased lighting loads. The statistically significant preliminary finding confirmed that buildings with Dark glass (T-Vis <0.5) have a Higher Electric consumption than other buildings.

During preliminary analysis, it was found that the presence of dark glass is so closely linked with the era in which the building was built that no metric could be reliably tested without first controlling for era built. However, there were too few buildings in the LEAN data set that were built before 1970, meaning that heating-, cooling-, and base-energy-specific hypotheses could not be tested. The Work Plan for Future Research includes testing this hypothesis when more buildings, especially older buildings, are added to the LEAN data set.

Despite being unable to test glass tint against LEAN metrics, metrics affiliated with annual data were still available. Although dark glass is found most commonly in post-1969 buildings, enough buildings built pre-1970 were available to test annual metrics with both dark glass and non-tinted or slightly tinted glass. Statistical analysis showed that in mixed-fuel buildings built pre-1970, electric EUI was 50% higher in those with dark glass, which could be due to higher lighting loads(figure 2). If this finding holds true, older mixed-fuel buildings with dark glass may reduce their electricity use by 33% by applying windows without a dark tint. However, this relationship should be explored further in upcoming research with larger sample sizes in post-1960 buildings or with the control of lighting characteristics and/or WWR.

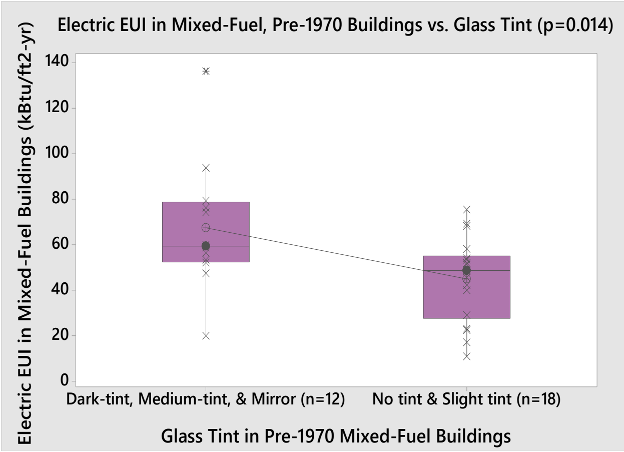


Figure 2- Pre-1970 mixed-fuel buildings with dark glass have 50% greater electric EUI's than do buildings without dark glass (p=0.014).

Surprisingly, when testing only buildings built after 1969, the presence of dark glass (including dark-tint, medium-tint, and mirror glass) also correlates with higher Energy Star Scores (***Figure 3***). It is possible that this is due to lower solar heat gain in these newer buildings, assuming that most tinted glass has a lower solar heat gain coefficient than non-tinted or slightly tinted glass. Given the previous finding about electric EUI, however, it is also possible that dark glass is not the major contributing factor, since other variables not considered here could also be linked with the presence of dark glass. It is hypothesized here that lighting loads are negatively affected with the implementation of dark glass, and since older buildings may use less efficient ballasts and bulbs, lighting loads—the largest office building load—could be amplified here. Preliminary analysis showed that higher south WWR was associated with higher Energy Star Scores, so an attempt was made to control for both era built and south WWR, but this left only 7 buildings without dark glass that were also built post-1969 and had south WWR's of 30-90% because WWR is collinear with year built, in figure 4. When the analysis was performed, the same trend was observed, but a significance of only p=0.195 was achieved. Again, larger sample sizes will enable further testing of this hypothesis and will shed light on whether lighting energy use and cooling energy use specifically are affected by window glass tint.

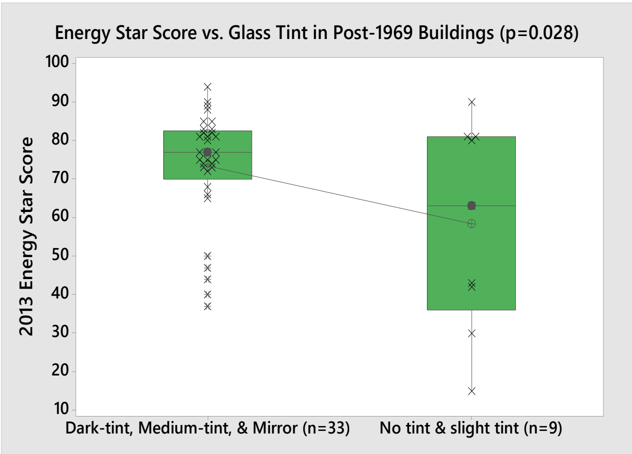


Figure 3 – Buildings with tinted glass tend to have higher Energy Star Scores than those without tinted glass, even when controlled for the era in which the building was constructed (p=0.028).

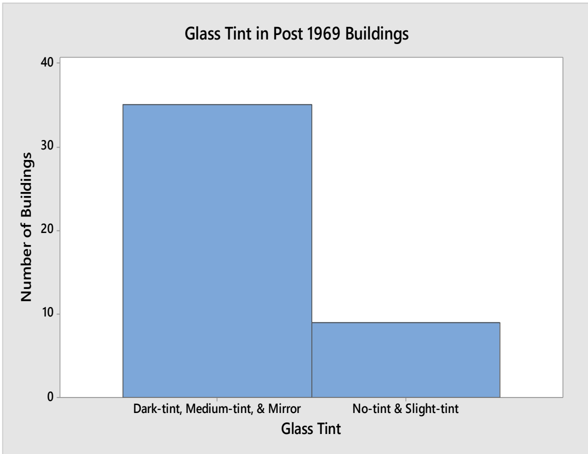


Figure 4 - Number of buildings in glass-tint test categories

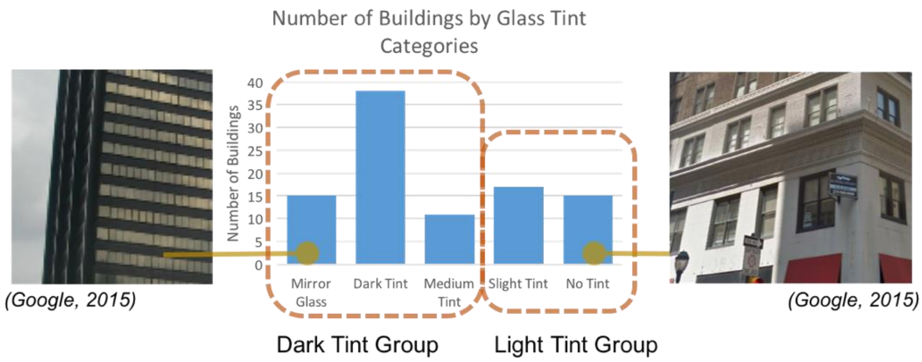


Figure 5 - Frequency of glass tint categories (Google, 2015)(photos)

Installing new BAS and includes nighttime setback will lower the Building Site EUI.

The sub-hypothesis tested was that buildings with thermostat setbacks will reduce space conditioning loads in lengthy unoccupied periods, leading to less heating and cooling energy use. The statistically significant preliminary finding confirmed that Buildings with lights ON at night have a higher source EUI than others.

When thermostat setbacks are implemented, they are likely implemented for both heating and cooling. This was found to be true when analyzing the data through ECAM, where it was discovered that nearly all buildings with heating setbacks had cooling setbacks, and nearly all buildings without heating setbacks did not have cooling setbacks either as illustrated in figure 6. This means that testing for heating setbacks is equivalent to testing for cooling setbacks, since attempting to control for the other would leave nearly no buildings in the data set. If observing all-electric buildings and testing electric EUI or base electric use for the effects of either heating or cooling setbacks, it would be unclear which setback was a greater contributor to the results found.

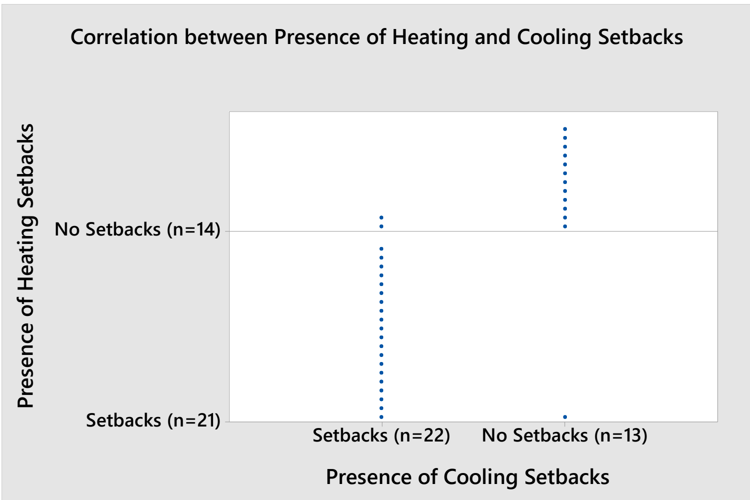


Figure 6 - Buildings with heating setbacks have cooling setbacks, and vice versa

Although heating and cooling setbacks are correlated, neither heating nor cooling setbacks correlate with the percentage of lighting left on at night, which allows one to control for this when necessary.

Thermostat setbacks work by reducing the temperature difference across the building envelope, leading to less unwanted heat loss in the winter or heat gain in the summer. Heating setbacks, but not cooling setbacks, prove to be significantly correlated with heating energy use found in the LEAN Monthly load disaggregation.

From the “Preliminary Analysis” section, one should recall that heating and cooling setbacks are so tightly linked that it is impossible to test for only one of these things. In reality, the test is between all setbacks and no setbacks (either heating or cooling), but certain loads can be assumed to rely only on one of these variables; heating energy use will likely have more to do with heating setbacks than with cooling setbacks, and cooling energy will likely have more to do with cooling setbacks than with heating setbacks. Therefore, separate heating and cooling metrics from LEAN analyses were the focus of this study. When heating setbacks were tested against LEAN Monthly seasonal heating energy use, it was found that buildings with heating setbacks use 60% less seasonal heating energy across all temperatures than do buildings lacking setbacks (p=0.009).

When heating setbacks were tested against LEAN Monthly seasonal heating energy use, it was found that buildings with heating setbacks use 60% less seasonal heating energy across all temperatures than do buildings lacking setbacks (p=0.009) as indicated in figure 7. Heating setbacks were also tested against LEAN Monthly seasonal heating energy while controlling for lights on at night. Lighting had the slight potential to influence LEAN Monthly base energy use considering that nighttime lighting may be used at the same times as peak heating times. The same trend was found as for without the control, demonstrating that the finding is truly dependent on heating setbacks alone as illustrated in figure 4.

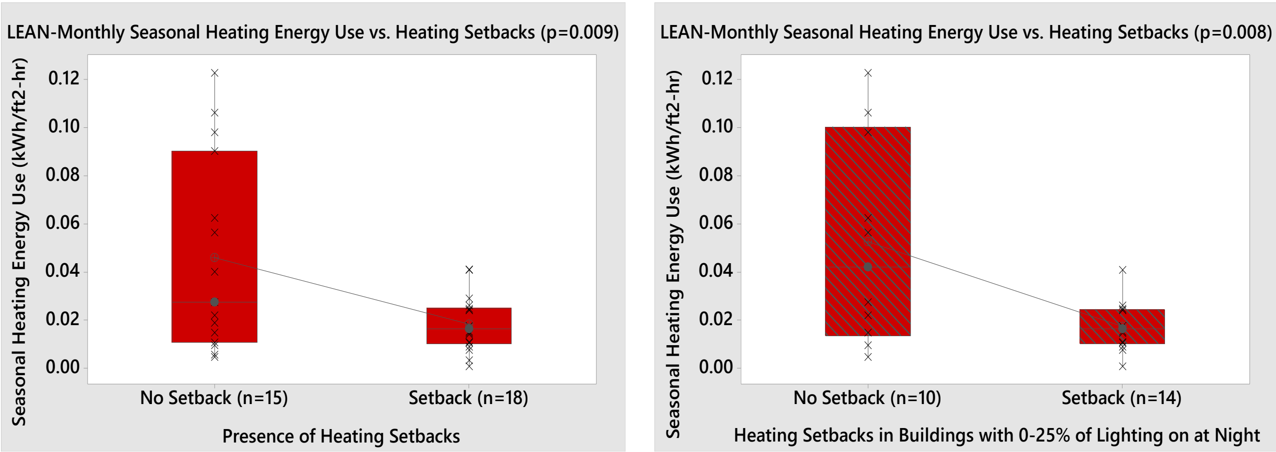


Figure 7 **Buildings with heating setbacks use less overall heating energy including when controlled for lighting use at night (p0.008).**

Utilize PECO Custom Lighting Rebates to install a lighting schedule controller and program a night schedule for lighting systems.

Additional statistical findings relevant to retrofit:

Providing new cooling tower to building owners will significantly reduce energy use especially for smaller buildings.

Buildings with cooling tower use more electricity than others (p-value=0.022). Utility should provide a utility custom incentive for process equipment and chiller to make sure the building use an efficient system and reduce their wasted electrical energy.

Install shading device on south and west façade to increase Energy Star Score

External shading on both the south and west facades is correlated with higher Energy Star Score (p-value =0.084). Installing External Shading on the South and West façade through a utility Custom Whole-Building System program can help building get better Energy Star Score.

Provide new lighting schedule controller to turn light OFF at night to reduce the building EUI.

Buildings with lights ON at night have a higher source EUI than others (p-value=0.081). Utility should promote a Custom Lighting Rebates to install a lighting schedule controller and program a night schedule for lighting systems.

Conclusion

In this research paper, we detailed 2 findings and shared 3 additional ones of the 238 analyses of statistically significant relationships between building attributes and energy use that were investigated. Those findings are currently being used to help identify buildings that would benefits the most for rebate programs from their local electric utilities. The findings highlighted here indicated that utilities should target buildings without thermostat setbacks and assist them in implementing them in order to reduce energy and therefore develop application processes that collect this information to help them identify the right candidate buildings.

Two main limitations exist in the statistical analysis used in this research, one being the sample size and the other being the statistical methods themselves. Often, the sample size was large enough to test a hypothesis, but limitations existed in controlling for more than one factor in the analysis, as the sub-groups tested simply became too small to achieve significance.

The complexity of the analysis used here is preventative for most benchmarking programs. If the goal of this research effort is to create a replicable model and promote the adoption of analyzing benchmarking data in combination with building attributes, it will ultimately be necessary to automate data analysis with some form of scripting. Developing tools specifically for this type of energy data analysis is an ojective as a long term goal of this research effort.

Acknowledgement

The work is funded by the U.S. Department of Energy through the Consortium for Building Energy Innovation (CBEI).

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Energy Profiling Analysis Based on Energy Assessments for Small Rural Businesses in West Virginia

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Abstract

The efficient use of energy plays a vital role in a nation's development. It is important to increase energy efficiency in various sectors in order to conserve fossil fuels and reduce carbon emissions. Small and medium sized rural businesses play a large role in the US economy and they often have less assistance in terms of knowledge related to energy efficiency. The United States Department of Agriculture (USDA) conducts the Rural Energy Development Program, funds and supports energy audits and feasibility studies and provides assistance for energy efficiency improvements. The Industrial Assessment Center of West Virginia University (WVU-IAC) obtained a grant from the USDA to conduct energy audits for small rural businesses in the State of West Virginia. This report summarizes the energy audit work done through the grant. The collected data is analyzed using the graphical method. Results generated through the research have led to conclusions that the size and type of the businesses as well as the type of energy efficiency recommendations have a significant effect on the annual energy savings, cost savings, and payback on investment. Other conclusions relate energy efficiency for electricity and natural gas with respect to the type of businesses. The results from the research as presented in this paper can be of significant assistance to decision makers in government, industry, and technical entrepreneurs.

1. Energy profiling amongst sectors

The Department of Energy has designated four sectors of the economy that consume energy: residential, commercial, industrial, and transportation [1]. The industry and transportation sectors consume more than half of the energy produced, followed by the residential and commercial sectors. Together, homes and commercial buildings consume more than a third of the energy in the world. The main energy consumers in these sectors are heating and cooling, lighting, and appliances [1]. This sector also includes the service industries. The small rural businesses targeted by the USDA energy audit grant address the commercial buildings sector mostly. Figure 1 summarizes energy consumption in each sector in terms of the world and US energy consumption and with specific regard to the energy used by buildings.

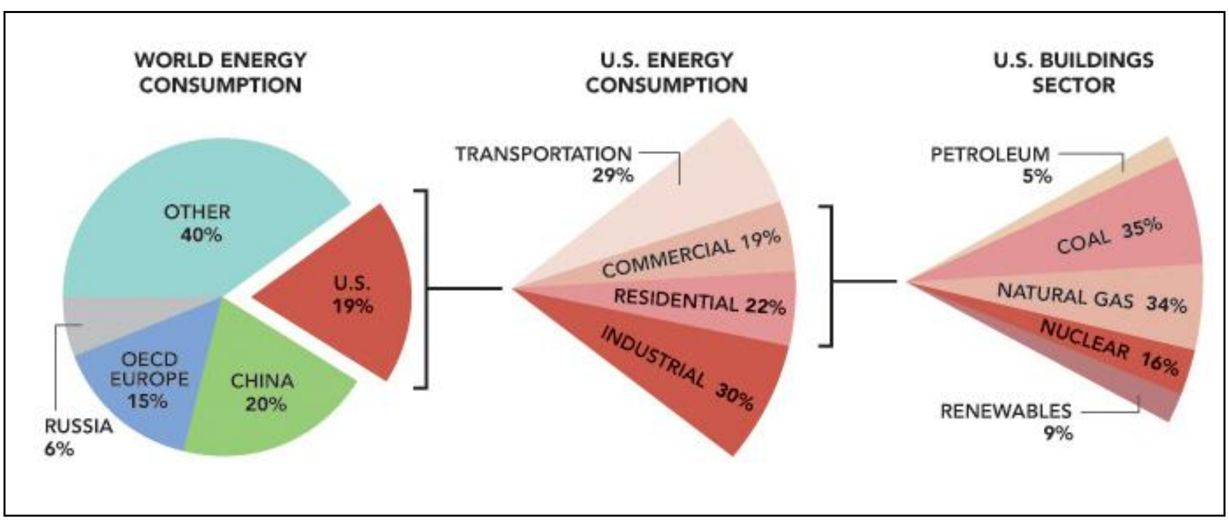

Figure 1. Energy consumption profile with specific reference to the buildings sector

Energy consumption in the commercial sector depends on the services demanded by the buildings, such as lighting, heating in the winter, cooling in the summer, water heating, electronic entertainment, computing, refrigeration, and cooking. It accounts for 40 quadrillion BTU (quads) per year, and this number has been increasing over years. In 2008, nearly 40% of U.S. energy is created for residential and commercial buildings, where the former includes up to 114 million buildings and the latter includes 4.7 million. Requirements for energy are driven by:

- Population that leads to the increase in the number of buildings
- Economic growth, which is a major driver of new offices and commercial buildings
- Service demands like lighting and air conditioning, increasing the human comforts
- The cost of energy
- The efficiency with which energy service demands are met

Lighting takes up a quarter of energy consumption in commercial buildings. Heating and cooling comes next, each of which is one-seventh. Figure 2 further shows the commercial primary end-use splits [2].

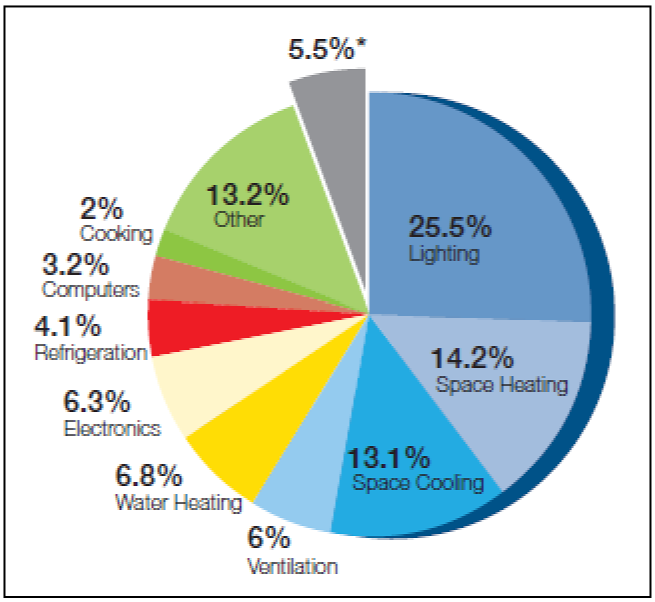

Fig 2. Commercial Primary Energy End-Use Splits, 2005 [2].

Considerable amount of the energy consumed by the commercial sector is used by small rural businesses in the USA. All of the non-metropolitan counties in the United States constitute rural America [3]. The use of energy is for heating, ventilation, air conditioning, and lighting predominantly, with some process oriented use in specific types of businesses such as bakeries and florists.

The United States Department of Agriculture (USDA) is a United States Federal office responsible for developing and executing federal policies on farming, agriculture, and food. The USDA was formed on May 15, 1862 by President Abraham Lincoln to safe-guard the nation's agricultural resources [4]. "This agency works for the needs of the farmers and ranchers to promote agricultural trade and production, assure food safety, protect natural resources, foster rural communities, and end hunger in the United States [5]."

The programs and services associated with USDA are:

- **Assisting Rural Communities**: grants loans, disaster assistance, and insurance programs.
- **Conservations:** deals with restoration and conservation, environmental markets, water resources, and wildfire prevention.

- **Food and Nutrition:** SNAP, WIC, food security, child nutrition programs, and national organic programs.
- **Marketing and Trade:** importing and exporting of goods.
- **Education and Research:** economic research, agricultural research, and agricultural statistics.

The objective of the USDA energy audit program is, "to develop and implement a state-wide energy audit program that delivers cost-effective audits to assist agricultural producers and rural small businesses reduce energy cost" [6]. The definition of a small business is one that has less than 500 employees and does not qualify for the WVU-IAC assessments and which is a part of USDA associated rural area of West Virginia. Except for a relatively small amount of area associated with the cities of Charleston and Huntington and a small stretch of I-64 interstate corridor, the all other areas of West Virginia can be considered as rural. The energy audit grant obtained by the WVU-IAC form the USDA was supported in funds by the West Virginia Division of Energy and administratively by the Industries of the Future WV program.

The audits were provided free of cost to rural, small businesses, thanks to the cost share provided on their behalf by the West Virginia Division of Energy. The objective of this research was to collect and analyze energy assessment data based on audits conducted at 98 small and rural businesses and agricultural producers in West Virginia.

2. Literature Survey

Energy monitoring is one way to get information for making efficiency plans and comparisons between factories. Such bench marking activities may be important to identify investment opportunities and promote knowledge transfer. Energy audits are also a way to identify opportunities for energy related investment [7]. The efficacy of energy efficiency opportunities vary with respect to the process of the energy auditing, ranging from results obtained pre-assessment to post-assessment, in terms of implementation of energy efficiency measures [8]. When energy audits are done, it should be understood as to how energy is used by the facility to make sure that the energy efficiency recommendations are accurate and appropriate. One must know what equipment uses energy, how much energy it uses and how much energy it consumes in proportion to the total energy use of the facility [9]. Simulating research and development (R & D) of innovation energy-efficient technologies for industry is an attractive option for reducing greenhouse gas emissions [10]. Each of this are analyzed and appropriate recommendations are implemented to help small scale industries to reduce energy consumption. The usage of an energy stored in an industrial system may minimize the system cost primarily by keeping the level of power demand for the whole system equal to or less than the maximum value of the level of the power demand for the whole system according to electricity or natural gas contact [11].

3. Methodology

The data collected from the energy audits was organized using key fields as Name of the Business, State, County, Address, Size of Business, NAICS Code, Type of Business, Energy Savings(Natural Gas) MMBtu, Energy Savings (Electricity) Kwh, Total Energy Savings (Natural Gas) MMBtu, Total Energy Savings (Electricity) Kwh, Suggested Recommendations, Implementation Cost (Individually) ($), Total Implementation Cost ($), Cost Savings/year (individually), Total Cost Savings/year, and Pay Back Period. Here are additional utilized information concerning to type of industry, size of industry, and type of recommendation.

Type of industry: The type of industry classification is as below.

1. Service Type: Accommodation & Food Service, Health Care & Social Assistance, Art, Entertainment & Recreation and Other Service (except public administration).
2. Trade Type: Retail Trade, Wholesale Trade, Agriculture, Forestry, Fishing & Hunting and Manufacturing.
3. Finance Type: Finance & Insurance, Professional, Scientific & Technical and Real Estate Rental & Leasing.

Size of industry: Determined based on the extent of the annual energy usage as well as the depth and potential for energy efficiency.

Types of Recommendation: There are twelve different kinds of recommendations. The recommendations have been grouped together to enhance the integrated energy efficiency determination structure pertinent to the specific energy audits.

1. Lighting System: Lighting System and Replace the existing T12 fluorescent bulbs with magnetic ballast with T8 fluorescent bulbs.
2. Comfort System: Add economizer on the rooftop air conditioning system units, Install setbacks for HVAC, Replace the existing heating system with infrared space heaters, and Recommendations according to the operation.
3. Efficiency Improvement System: Adjust air to fuel ratio for boilers, Reduce heating load due to infiltration in the doors, Insulation System, and System enhancement recommendation.
4. Replacement Process Improvement System: Replace single paned glass with double paned glass and Replacement Process Improvements and System Enhancement Recommendations.

4. Results from analysis

Figure 3 shows the distribution of the types of businesses in terms of energy audits conducted. The buildings associated with supermarket, real estate, auto parts, and hair stylist industries were found to have a larger share of energy audits mainly on account of business interest and relatively larger energy usage. Supermarkets consumed the most energy due to lighting systems and air conditioning needs. Real estate consumes the second highest amount of energy mainly on account of space conditioning needs. In the auto parts industry, most of the energy was used for running air compressors, hydraulic presses, and other mechanical equipment that consume energy.

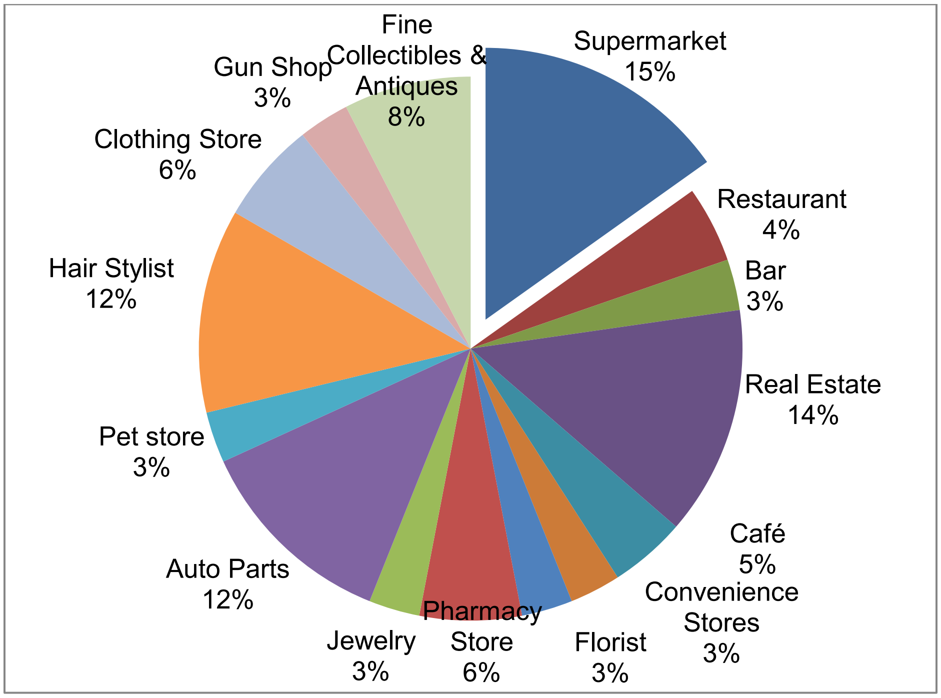

Figure 3. Percentage No. of Assessments Based on Type of Industry

The energy savings in terms of electricity far exceeded the energy savings with respect to natural gas as fuels. The reason was that most of the commercial buildings audited for energy were electrically intensive in terms of energy use mostly used for lighting and space conditioning. The use of natural gas mostly occurred in bakeries, where it is used for oven heating, and in some buildings for space heating.

4.1 Percentage Number of Suggested Recommendations

Figure 4 shows the distribution of energy efficiency recommendations. Replacing T12 with T8 fluorescent lamps was most highly recommended. Recommendations related to other lighting systems were close to 12%. Combined, adjustments to lighting systems make up 46% of the total recommendations. This proves that most industries use older lighting systems that consume a lot of energy. The next highest recommendations are to install setbacks for HVAC systems, accounting for 18% of the total recommendations. This recommendation helps in adjusting the room temperature according to working and non-working hours. The setback helps control any unnecessary heating or cooling of the building, thereby saving energy. Adding an economizer and replacing the existing heating systems with infrared space heaters will increase the energy efficiency of a system. Insulation was the next most recommended, accounting for 23%. Insulation helps avoid heat exchange with surroundings, retaining the set temperatures of the room. Infiltration and replacing single paned window with double paned window falls under the insulation system, of which replacing the windows has the most with 14%.

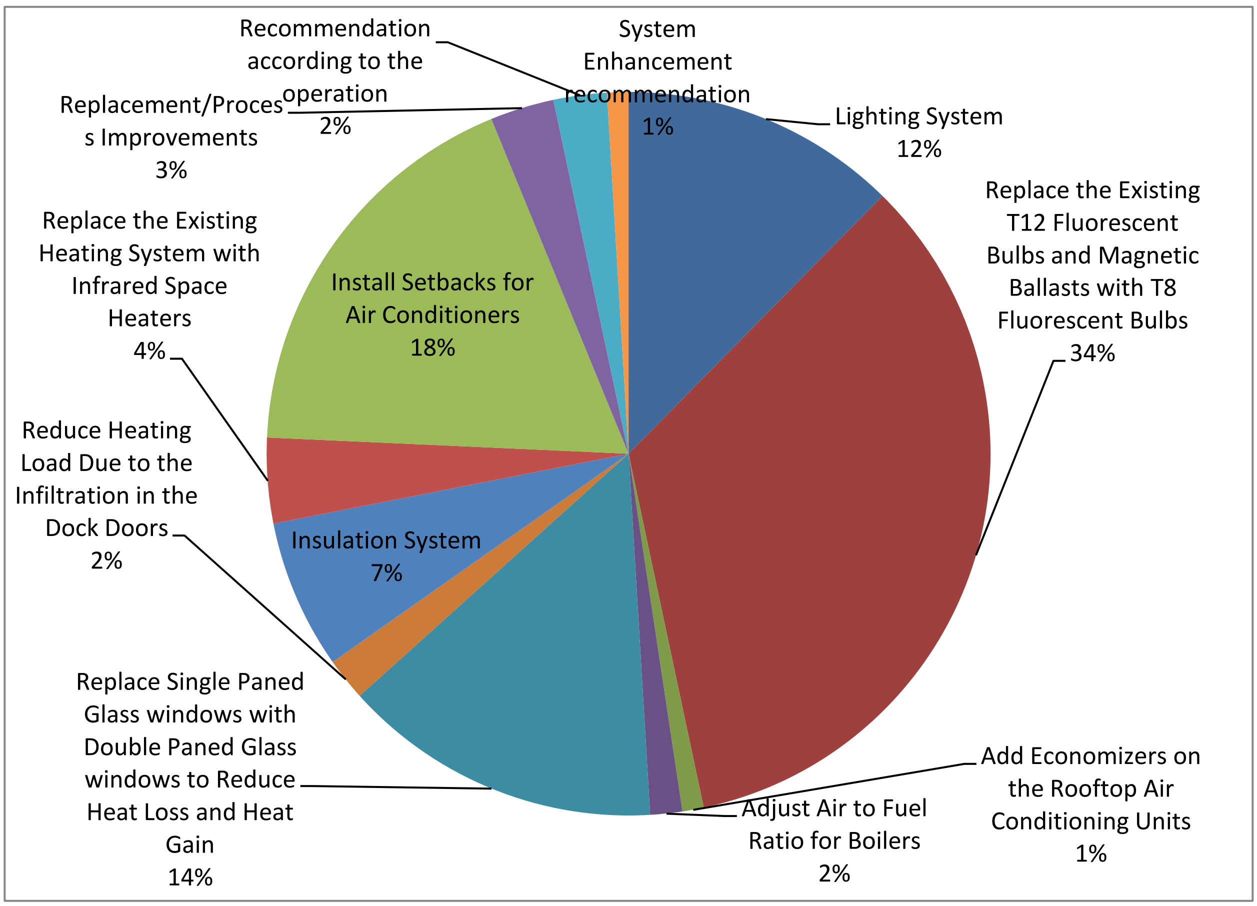

Figure 4. Energy efficiency recommendations

4.2 Estimated Cost Savings According to the County

Figure 5 shows information about the annual energy cost savings in each of the counties if the suggested recommendations are followed. Berkeley and Braxton County had maximum annual energy savings close to $40,000, though the number of assessments performed in the two counties only made up 8% of all assessments done. The reason behind this is that, the industries are large-scale retail industries, and also a large number of recommendations were suggested. Cabell County had the least cost savings because there were only a few assessments done, where the firms were small and medium sized with less energy savings.

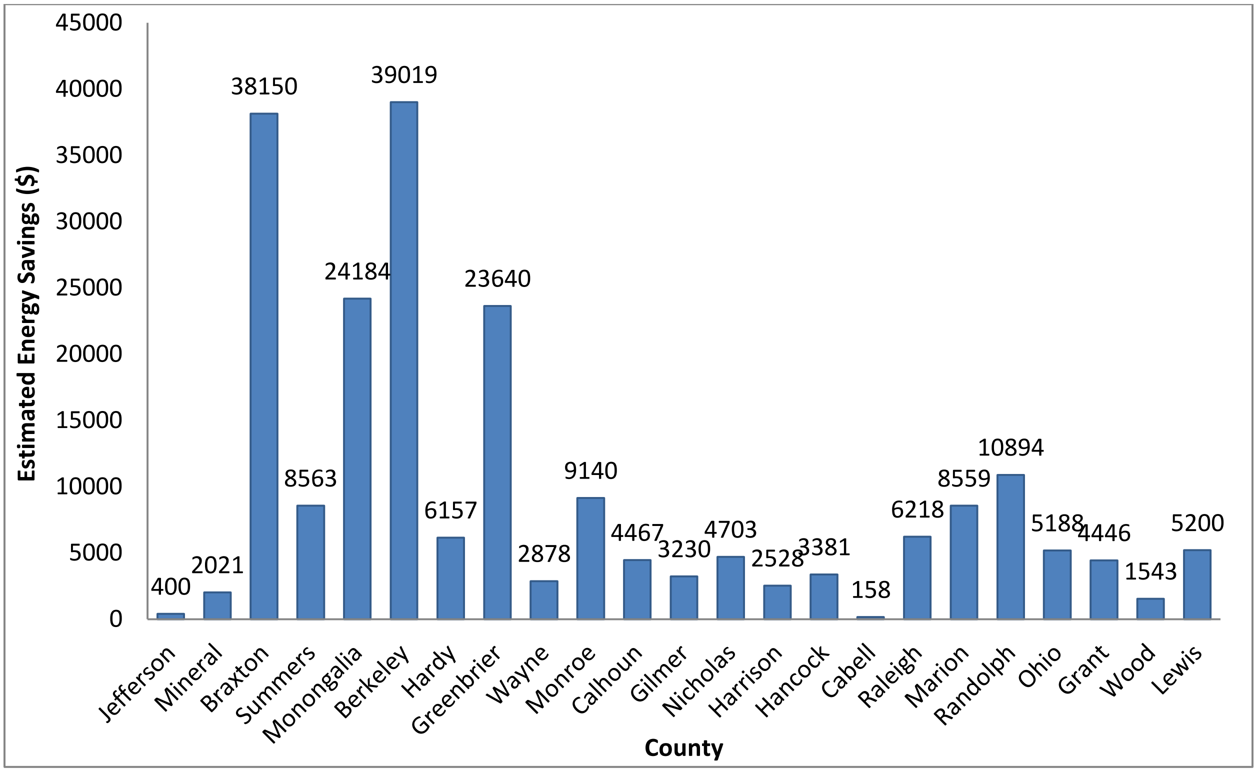

Figure 5. Estimated Energy Savings in Each County

Greenbrier and Monongalia County saved the most in natural gas. This is because natural gas was predominantly used for the heating of buildings. There are few restaurants where natural gas is used for heating the grill and ovens. Mineral County saved the most in electric energy followed by Monongalia County. The reason was the large number of businesses that used more electrically intensive manufacturing processes and the use of electricity for space heating.

4.3 Estimated Implementation Cost for Suggested Recommendations

Figure 6 shows the implementation cost for the various recommendations. Here, both graphs represent the same title, but with a difference in scale. The graph on the left shows the recommendations that cost above $50,000, whereas the graph on the right shows recommendations that have implementation costs less than $50,000. Table 1 provides information about the various recommendations. Replacing a single-paned glass window with a double-paned glass window (i.e. Recommendation Code 9) costs the most, followed by replacing T12 bulbs with T8 fluorescent bulbs (Recommendation Code 4). Recommendation Code 10 has the lowest implementation cost. This type of recommendation, which is to avoid infiltration, was suggested mostly in supermarkets and poultry farms. There is not much cost associated with this type of recommendation mainly due to the ease in procedures for preventing air infiltration. The Table 1 does not have recommendation codes 7 and 13 as they were eliminated due to effectiveness analysis.

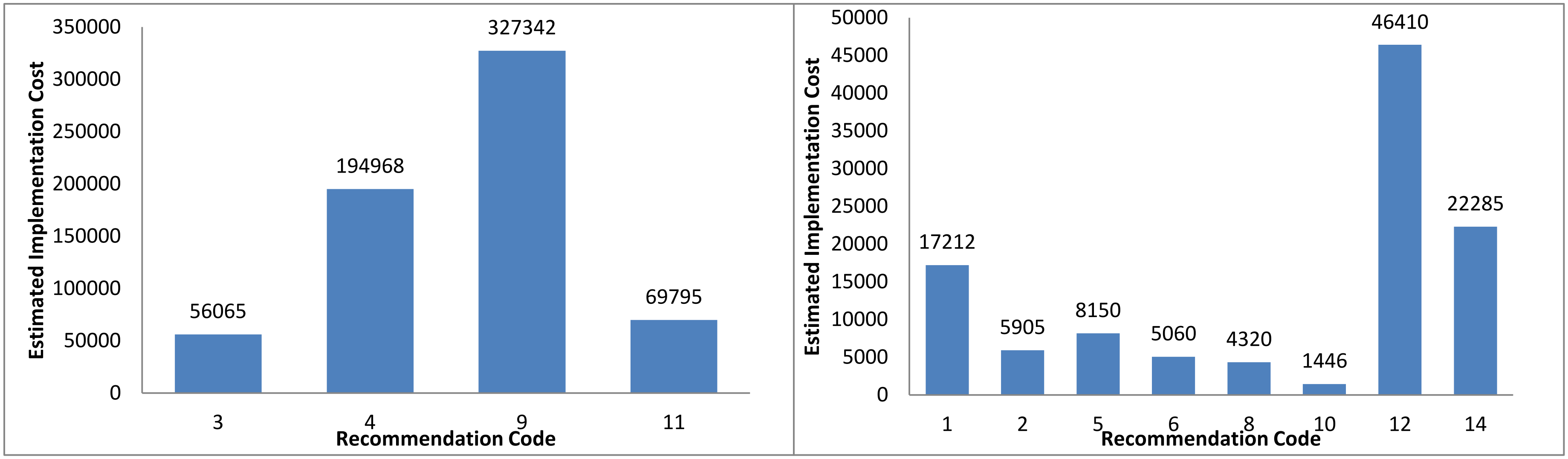

Figure 6. Estimated Implementation Cost for Various Suggested Recommendations

Table 1. Recommendation Table

Code	Recommendations
1	Replacement/process improvements
2	Recommendation to modify operational procedures
3	Lighting Systems
4	Replace existing T12 fluorescent lamps with magnetic ballasts to T8 with electronic ballasts and specular reflectors
5	Add economizers on the roof top air conditioning units
6	Energy system enhancement recommendations
8	Adjust air to fuel ratio for boilers
9	Replace single pane glass windows with double pane
10	Reduce heating load due to infiltration from dock doors
11	Insulation system
12	Replace the existing heating system with infrared space heaters
14	Install setback controls

4.4 Estimated Average Payback Period for the Suggested Recommendations

Figure 7 shows the average payback period for the suggested recommendations. Except for replacing the single paned glass window with double paned glass window the average payback period for the remaining recommendations is less than 5 years. The reason behind high payback period for the windows recommendation is the high implementation cost and low annual energy savings.

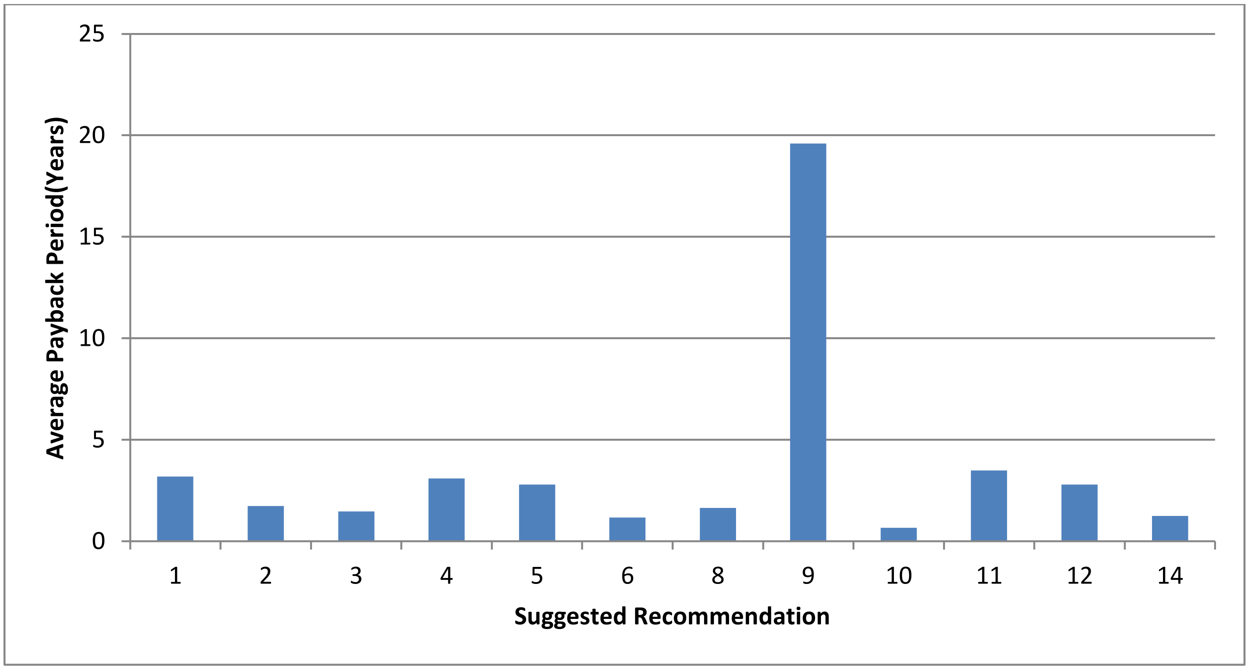

Figure 7. Estimated Average Payback Period for the Suggested Recommendations

4.5 Top 10 Natural Gas Saving (MMBtu) Industries

There were 98 energy audits done in the state of West Virginia, of which the top 10 energy savings (MMBtu) businesses in terms of natural gas are shown in Table 2.

Table 2. Top 10 Natural Gas Saving Industry Details

No.	Size	Type
1	Medium	Retail Trade
2	Large	Manufacturing
3	Medium	Real Estate Rental and Leasing
4	Large	Accommodation and Food service
5	Large	Agriculture, Forestry, Fishing and Hunting
6	Medium	Accommodation and Food service
7	Large	Manufacturing
8	Medium	Food service
9	Large	Retail Trade
10	Small	Retail Trade

Figure 8 depicts the best opportunities in various types of businesses to save natural gas. Table 2 shows the size and type of each business. Most businesses in the top 10 are the large-scale industries, mostly retail and accommodation. For example, a hosiery manufacturing company that uses natural gas to heat materials and utilizes excess heat to warm the building. Hence, when a recommendation was suggested, the energy savings associated with natural gas was higher.

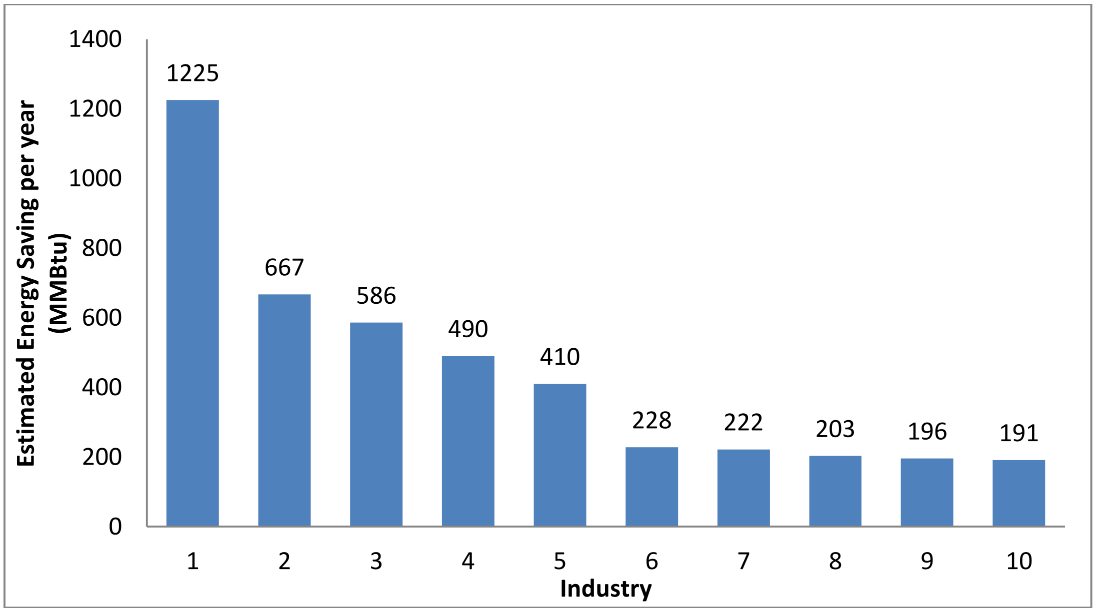

Figure 8. Top 10 Natural Gas Saving Businesses

4.6 Estimated Implementation Cost of the Top 10 Natural Gas Saving Industries

From Figure 9, one can observe that business #2 had to spend more to implement the suggested recommendations, as it is a manufacturing industry and the heating system associated with it is energy consuming. That heating system had to be replaced by infrared heating, which saves energy but has a high initial setup cost.

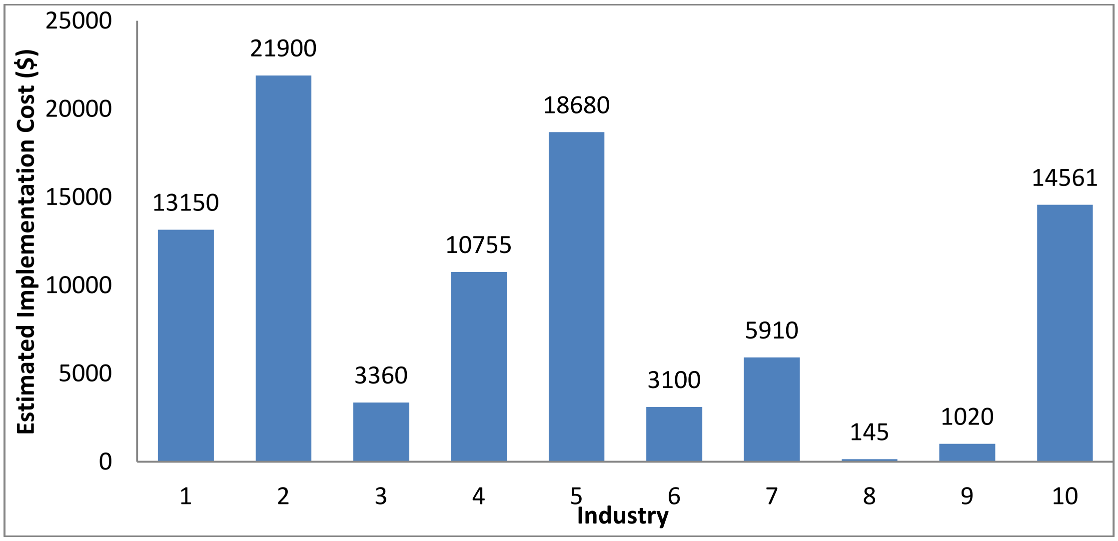

Figure 9. Estimated Implementation Cost for the Top 10 Businesses in terms of natural gas

4.7 Estimated Cost Savings for the Top 10 Natural Gas Saving Industries

Figure 10 shows the annual energy savings in terms of natural gas for each type of business. Business #1 had the highest energy saving because it is has a relatively lower natural gas cost rate. Therefore, business #1 saves more on cost savings ($) if the recommendations suggested are implemented. The remaining businesses saved an average of $4,000 per year.

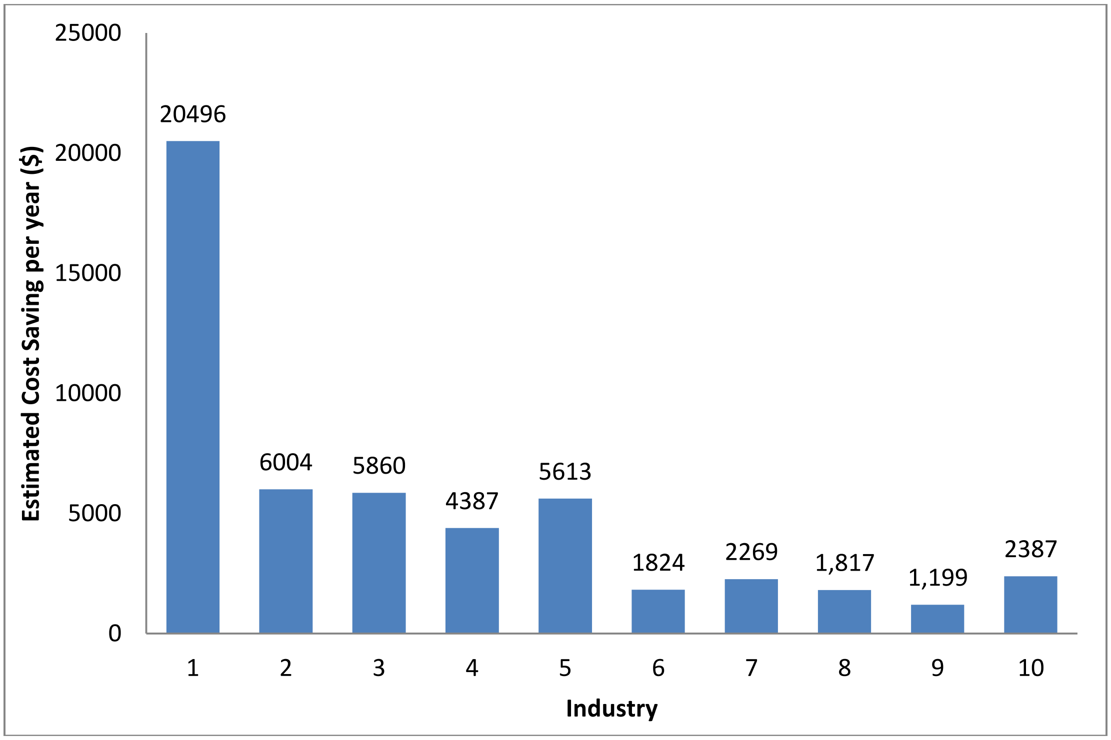

Figure 10. Estimated Cost Savings for the Top 10 Natural Gas Savings businesses

4.8 Top 10 Electricity Saving (Kwh) Industries

The top 10 businesses that save the most in terms of energy efficiency recommendations associated with electricity have been shown in Table 3. The implementation cost and the cost savings are varied with respect to the top 10 energy saving industries.

Table 1. Top 10 Electricity Saving Industry Details

No.	Size	Type
1	Large	Accommodation and Food service
2	Medium	Retail Trade
3	Large	Retail Trade
4	Large	Manufacturing
5	Large	Retail Trade with process
6	Small	Retail Trade
7	Medium	Manufacturing
8	Small	Retail Trade with process
9	Medium	Accommodation and Food service
10	Medium	Retail Trade with process

The information given by Figure 11 states that the Business #1 would save around 407,227 Kwh of electrical energy every year if the suggested recommendations were followed. Since the business was large in size, and belonged to the accommodation sector, there were more recommendations to be applied to a large scale of energy intensive equipment. Energy saving were higher when compared to the remaining set of businesses in the list. The remaining businesses incurred energy saving 72,891 Kwh per year.

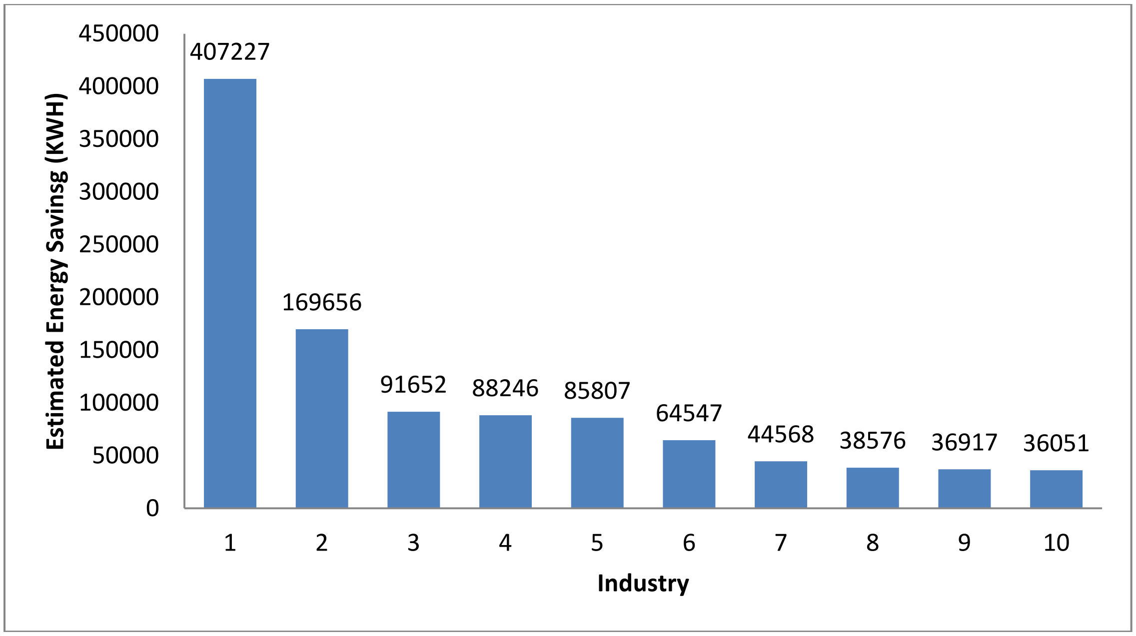

Figure 11. Top 10 Electricity Saving Businesses

4.9 Estimated Implementation Cost for the Top 10 Electricity Saving Industries

Figure 12 gives us information about the implementation cost as related to electricity energy efficiency recommendations. In general, the implementation cost for electrical appliances and equipment are high due to presence of computer controlled electronics.

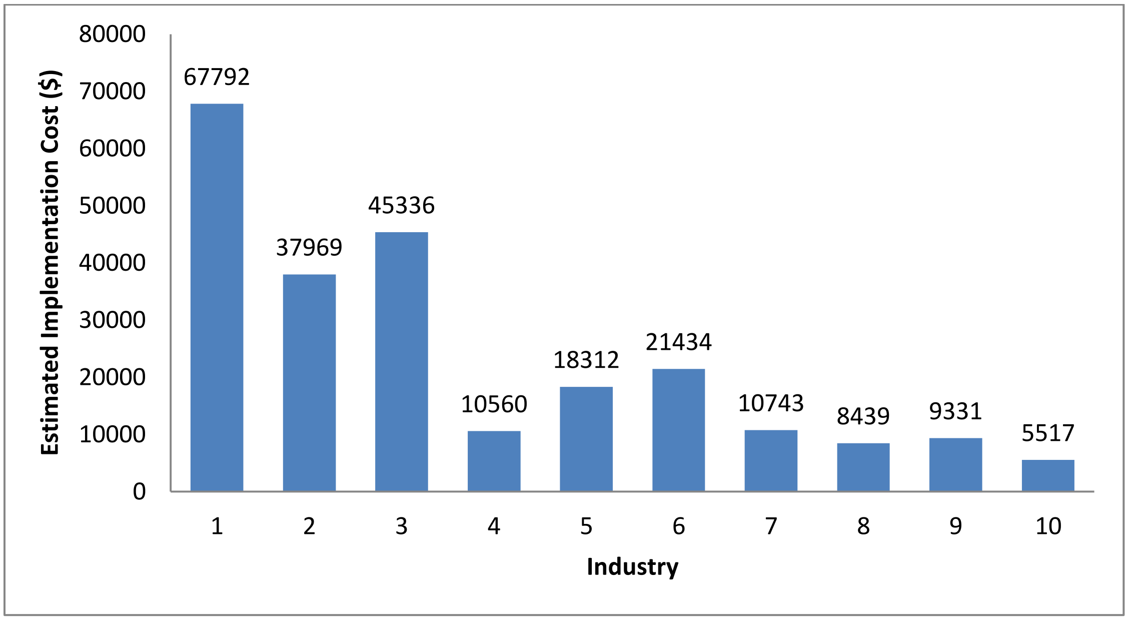

Figure 12. Estimated Implementation Cost for the Top 10 Electricity Saving Industry

4.10 Estimated Cost Savings for the Top 10 Electricity Saving Industries

Business #1 would save $24,307 per year followed by Business #2, which would save around $16,123 per year. The remaining businesses would save around $4,500 per year. From Figure 13 one can conclude that the electricity rates vary considerably across various counties in which the businesses are located, because similar recommendations produced varied cost savings.

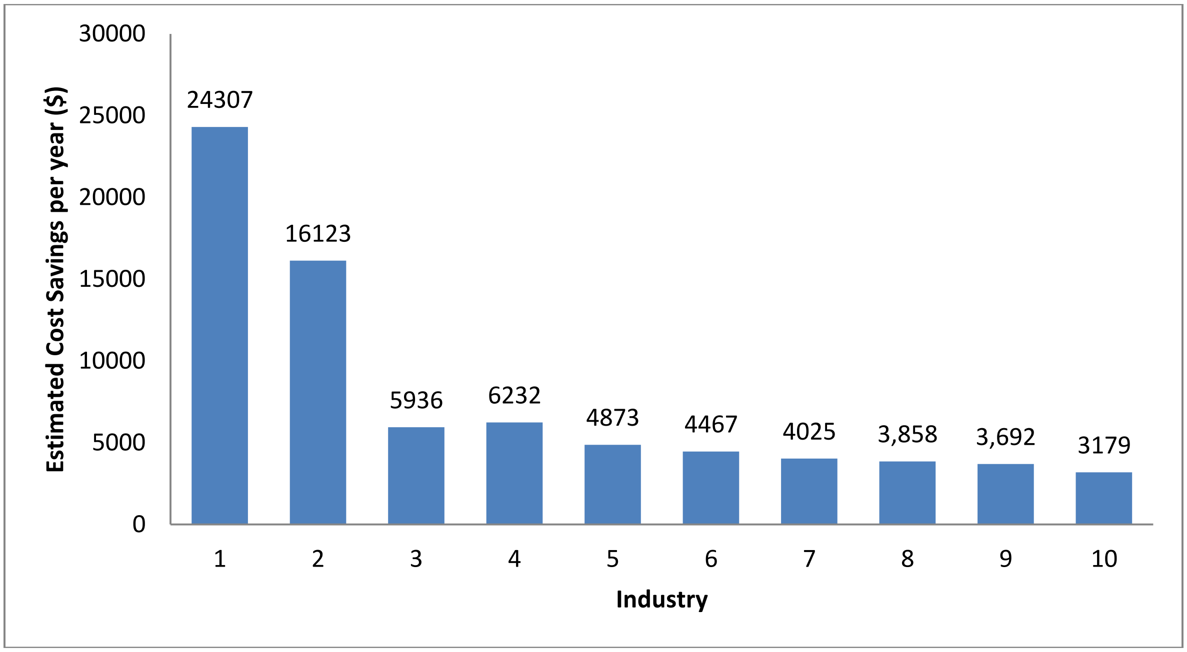

Figure 13. Estimated Cost Savings for the Top 10 Electricity Savings business

5. Conclusion

The energy audits conducted for small rural businesses in West Virginia, USA revealed interesting results regarding the variance of the efficacy of the energy saving recommendations as well as the influence of energy costs in the overall energy efficiency implementation scenario. Some businesses are more energy intensive than others while offering varying opportunities to save energy with a good payback on investment. Although the energy audit program did not mandate the need for follow up on obtaining implementation results, informal follow up that was conducted revealed an implementation rate across businesses ranging from 25 to 50% of the recommendations. The program was a success in terms of acquiring stakeholder interest and impetus for continued improvement in the energy efficiency sector.

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Study on hypermarket energy consumption with a Key Performance Indicator evaluation system

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Abstract:

Hypermarket, a retail store that combines a department store and a grocery supermarket, offers various kinds of products such as appliances, clothes and groceries. There are more and more hypermarkets with the improvement of life quality in China. However the energy consumption of one hypermarket can be 5~10 million kWh/year. This paper gives a KPI evaluation system to analyze the energy use and compare the energy consumption between different hypermarkets. To achieve this objective the paper begins with an investigation of 40 hypermarkets in China including area, electric equipment, the breakdown of energy used by end demand for activities and so on. Then present an evaluation system to probe into the question of how to evaluate the level of energy consumption among different places. At last a tentative evaluation is given.

Keywords:

Hypermarket, Energy Consumption, Evaluate System, Benchmarking

1. Background

With the rapid development of the Chinese economy, the industry of retailing also gets great progress. Since 2004, China canceled the restrictions on foreign retailers in China, so Chinese retail industry especially chain retailing has entered a stage of rapid development. Hypermarket plays an important role in the chain retailing, such as American Walmart, French Carrefour, Chinese CR Vanguard and so on.

For example, the number of chain hypermarkets in China was 7332 in 2007, which rose to 9481 in 2014, with an increase of 29 percent. Compared to the number, the total area and sales amount of chain hypermarkets accounted for more in the chain retailing, because they are bigger. The total area of chain hypermarkets in China was 11.25 million square meters in 2007, which rose to 31.09 million square meters in 2014, with an increase of 176 percent. The total sales amount was 24.6 billion dollars in 2007, which rose to 75.7 billion dollars in 2014, with an increase of 208 percent. From 2007 to 2010, both area and sales of each hypermarket have increased.

According to investigation, the electricity consumption can be more than 300 kWh/m^2/year. If estimate the total energy consumption of all chain hypermarkets in China with 300 kWh/m^2/year, it is more than 9.32 billion kWh. In 2013, the total power consumption of gas production and supply industry was13.12 billion kWh, only 40 percent more than all chain hypermarkets.

So energy evaluation and energy saving of hypermarket should be paid more attention.

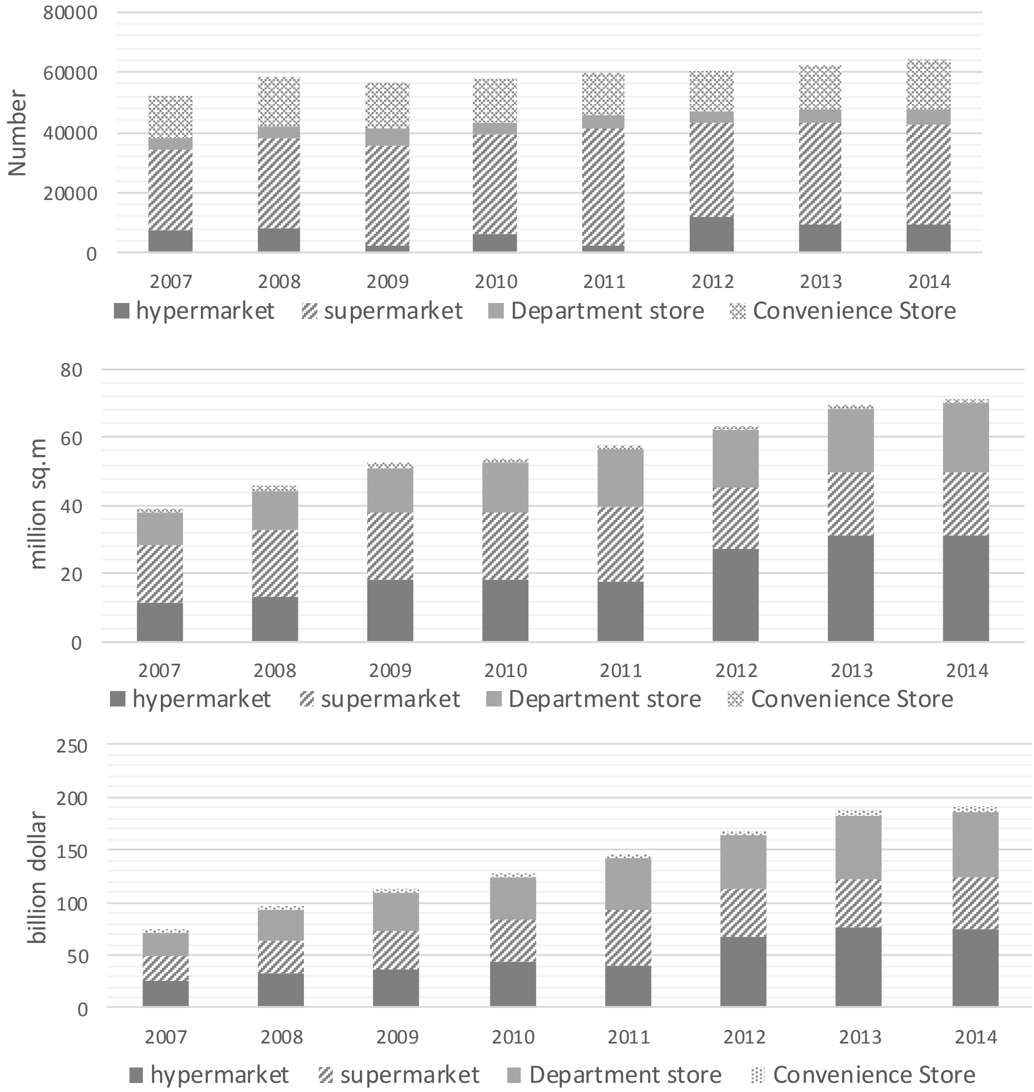


Figure 1 the number, area and sales of hypermarket, supermarket, department store and convenience store in China

2. Research method

In this study, we investigated 41 hypermarkets of 3 companies. Among them, 12 hypermarkets are in Guangdong Province, 2 in Guangxi Province, 2 in Hunan Province, 1 in Hainan Province, 1 in Fujian Province, 4 in Beijing, 3 in Chengdu, 9 in Shanghai, 7 in Jiangsu Province and 1 in Zhejiang Province. Guangdong, Guangxi, Hunan, Hainan and Fujian are in Southern China. Beijing is in the north of China. Chengdu is in western China. Shanghai, Jiangsu and Zhejiang are in the east of China.

The smallest hypermarket is 7463 square meters, while the largest one is 45266 square meters, and most of them are between 9000 to 15000 square meters.

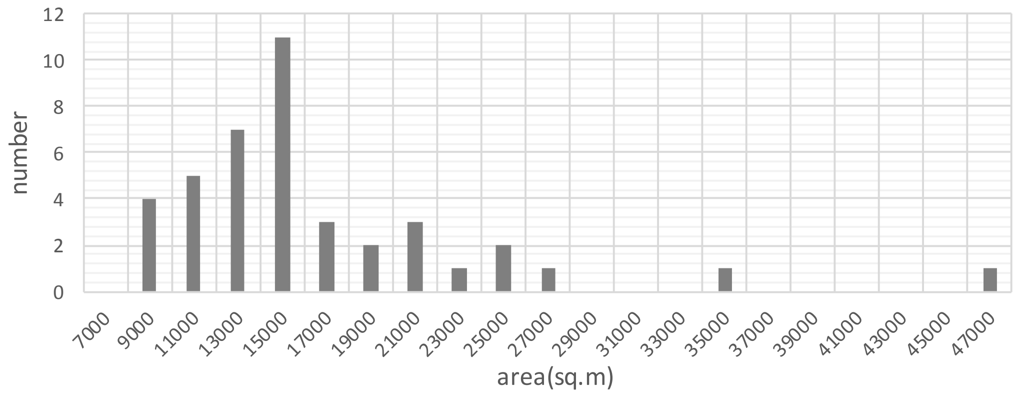


Figure 2 the distribution of the investigated 41 hypermarkets' area

In this study, the author got the energy consumption by questionnaire survey and actual visiting. Questionnaires generally include the following points:

1. Basic information: branch name, company name, address, area, business time, cooling days and heating days, construction time, enclosure structure and so on.
2. Equipment information (including the number of each type of electrical equipment and its rated power): Air conditioning equipment include chillers, cooling water pumps, chilled water pumps, cooling towers, air-handing units, fan coil and so on. Heating equipment include boilers, hot water pumps, heat exchangers. Refrigeration equipment include compressors, condenser, low-temperature freezers and high-temperature freezers. Cooking equipment include steamers, roast chicken furnaces, toasters, eggbeaters and so on. Lamps include LED, downlight, spotlight and so on. Other electrical equipment include elevators, escalators, computers, printers and so on.
3. Energy consumption each month including electricity, gas, water, oil and so on.
4. Annual energy consumption of tenant, market, refrigeration, cooking, air-conditioning, lighting and others.

The major conclusion of the actual visiting are:

1. Most of the hypermarkets have 3 stories. A typical hypermarket is like this: the first floor is for tenants including restaurants and clothes shops. The second floor is mainly for food especially fresh food such as vegetables, milk, bread, roast chicken and so on. The third floor is mainly for daily products such as TV, towel, books, clothes and so on.
2. Some of the buildings are leased and some of the buildings are their own. This affects the boundary of energy consumption. For example, if the building is leased, the hypermarket doesn't pay for the electricity of the chilled-water plants.
3. Most hypermarkets have large internal area, which decreases the effect of weather on cooling load and heating load. Because of the large internal area and great internal heat, no ne of the investigated hypermarkets needs heating in winter even in cold region such as Beijing. So we don't include energy consumption for heating in this paper.
4. Different hypermarkets have different product. For example some hypermarkets mainly sell vegetables, while some hypermarkets mainly sell bread. So they show very different structure of electricity consumption.

On the basis of the above investigation, we analyze the energy data for benchmarking and present an evaluate system to probe into the question of how to evaluate the level of energy consumption among different places, and give a tentative evaluation.

3. KPI evaluation system

3.1 Energy consumption model

On the foundation of the investigation, the following model is proposed to describe the energy consumption structure and area structure for all hypermarkets. The energy consumption model consists of two sections: energy consumption status and service status.

Energy consumption status contains of two parts. The one is the total energy consumption, including monthly consumption of 12 months and moving average of 12 months which could reflect whether the consumption decreases or not. The other one is the breakdown of energy consumption, including landlord and tenant. Landlord's consists of electricity for cooling and heating, electricity of public equipment and electricity of market including lighting, refrigeration, cooking, air-handing units and so on. Electricity of public equipment is often too small to evaluate so we don't consider it in this paper.

Service status contains sales volume and area. Sales data is hard to gain, so in this paper area is adopted to evaluate the service. Three types of area are most commonly used: total area excluding parking lot, area of market and area of fresh food.

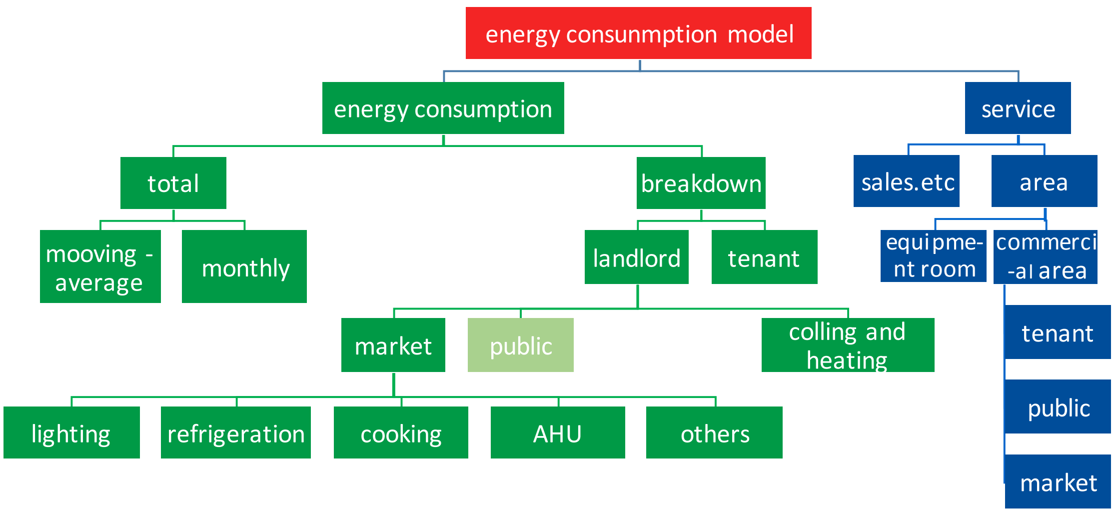


Figure 3 energy consumption model of hypermarkets

3.2 KPI evaluation system

Based on the energy consumption model, the following KPI evaluation system is proposed. The indexes include 1 overall index, 3 classified indexes, 4 item indexes and some efficiency indexes.

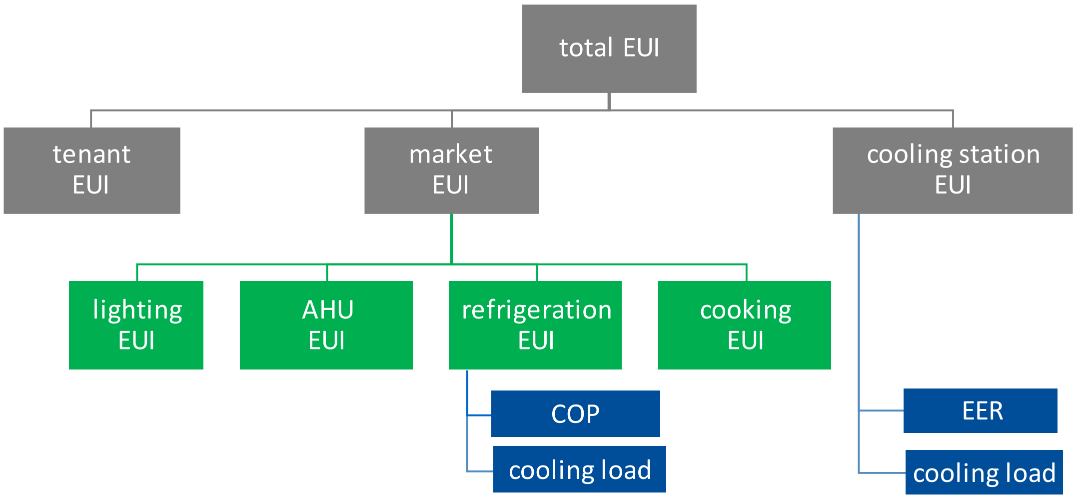


Figure 4 KPI evaluation system

The overall index is total EUI, which equals the total energy consumption divided by the area excluding parking garage. This index gives an outlook of the energy level, however because of different retail format it couldn't estimate whether the energy usage is reasonable. So if we have more detailed data, we do not use the total EUI to evaluate.

The three classified indexes are tenant EUI, market EUI and cooling station EUI. The tenant EUI equals the tenant energy consumption divided by the tenant area, which stands for the level of the tenant energy. Tenant EUI relates to format and tenant's behavior. Because tenant's energy usage is neither an important part nor the focus of energy savings, there's no need to do much research on it. Market EUI equals the market energy consumption divided by the area of market, which could be broken down into 4 item indicators. Cooling station EUI equals the energy consumption for cooling divided by the total area excluding parking garage. Because of the large internal area and great internal heat, none of the investigated hypermarkets needs heating in winter even in cold region such as Beijing. So energy for heating is not considered in this system.

The four item indexes are lighting EUI, AHU EUI, refrigeration EUI and cooking EUI. Because lighting and air-handing units mainly serve for the market, lighting and AHU EUI equal power consumption for lighting and air-handing units divided by market area. Different from lighting and air-handing units, refrigeration and cooking energy consumption are mainly related to fresh foods rather than all goods in the market, but sales data lacks, so fresh area is adopted to calculate these two indexes.

The refrigeration and cooling station indexes could be disassembled into cooling load and efficiency. Power consumption equals cooling load divided by efficiency. The efficiency of chiller-plant evaluates both chillers, pumps and cooling towers.

The following form summarizes the calculation method of those indexes.

Table 1 the calculation method of all indexes

i.d.	index	formula
1	Total EUI	$\frac{E_{total}}{S_{total} - S_{parking}}$

2.1	Tenant EUI	$\frac{E_{tenant}}{S_{tenant}}$
2.2	Cooling station EUI	$\frac{E_{cooling\ station}}{S_{total} - S_{parking}}$
2.3	Market EUI	$\frac{E_{market}}{S_{market}}$
3.1	Lighting EUI	$\frac{E_{lighting}}{S_{market}}$
3.2	AHU EUI	$\frac{E_{ait-handing\,unit}}{S_{market}}$
3.3	Refrigeration EUI	$\frac{E_{refrigeration}}{S_{fresh}}$
3.4	Cooking EUI	$\frac{E_{cooking}}{S_{fresh}}$
4.1	Cooling load for refrigeration	$\frac{Q_{refrigeration}}{S_{fresh}}$
4.2	COP of compressor	$\frac{Q_{refrigeration}}{E_{refrigeration}}$
4.3	Cooling load for air-conditioning system	$\frac{Q_{HVAC}}{S_{total} - S_{parking}}$
4.4	EER of chiller-plant	$\frac{Q_{HVAC}}{E_{cooling\ station}}$

3.3 Energy consumption evaluating index (ECEI) of hypermarket

For managers who do not understand energy consumption structure, efficiency or cooling load, an obvious indicator is needed. Energy consumption evaluating index of hypermarket, which consists of the 1 overall index, 3 classified indexes, 4 item indexes and some efficiency indexes is proposed. ECEI is from 0 to 100, and the closer to 100, the better. The calculation method will be introduced in chapter5.

4. Study of rational value

In this chapter, rational value of each index is researched. Because of the lack of cooling load and efficiency data, the rational values of efficiency are default in this paper.

4.1 Total EUI

The following two figures show total EUI including gas and electricity of the 41 investigated hypermarkets, and give a simple distribution. Electricity is the main energy for hypermarkets. Total EUI between hypermarkets of the same company can vary significantly according to the first figure, and the difference between hypermarkets of different companies is bigger. So energy breakdown is needed.

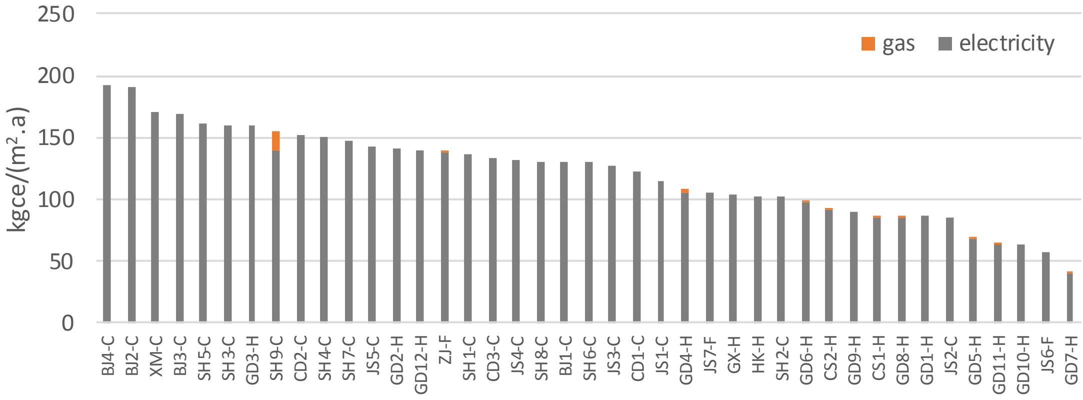


Figure 5 total EUI of the 41 investigated hypermarkets

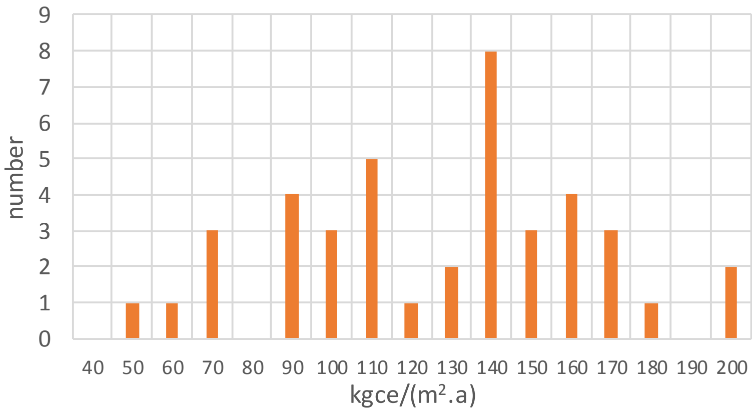


Figure 6 the distribution of the 41 investigated hypermarkets' total EUI

4.2 3 classified indexes

4.2.1 Tenant EUI

The following two figures show tenant EUI of the 41 investigated hypermarkets, and give a simple distribution. By calculating the median of tenant EUI is 280 kWh/(m^2.a), and the lower quartile of tenant EUI is 197 kWh/(m^2.a).

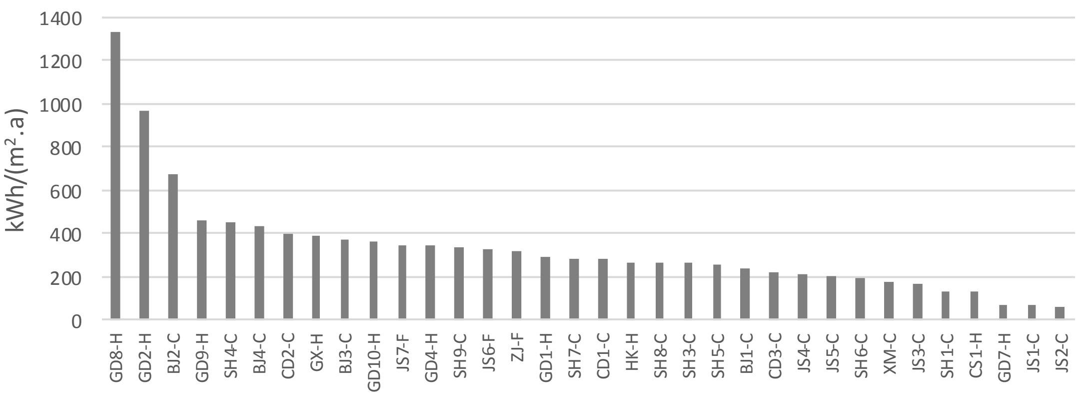


Figure 7 tenant EUI of the 41 investigated hypermarkets

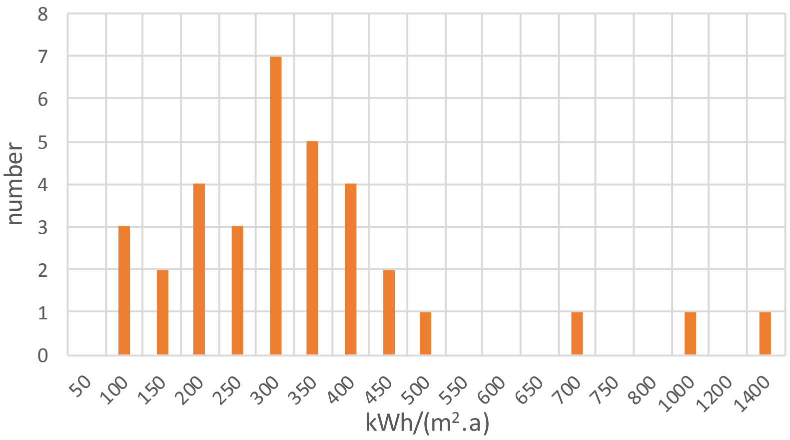


Figure 8 the distribution of the 41 investigated hypermarkets' tenant EUI

4.2.2 Cooling station EUI

The following figure shows cooling station EUI. Data of southern hypermarkets tends to be bigger than that of northern hypermarkets, mainly because of more cooling hours.

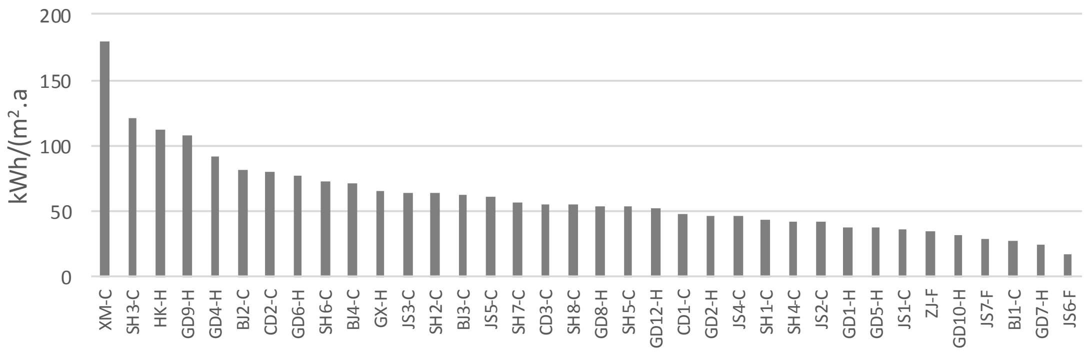


Figure 9 cooling station EUI of the 41 investigated hypermarkets

Correct the cooling station EUI with cooling days, the following figure could be obtained. Difference between regions becomes smaller.

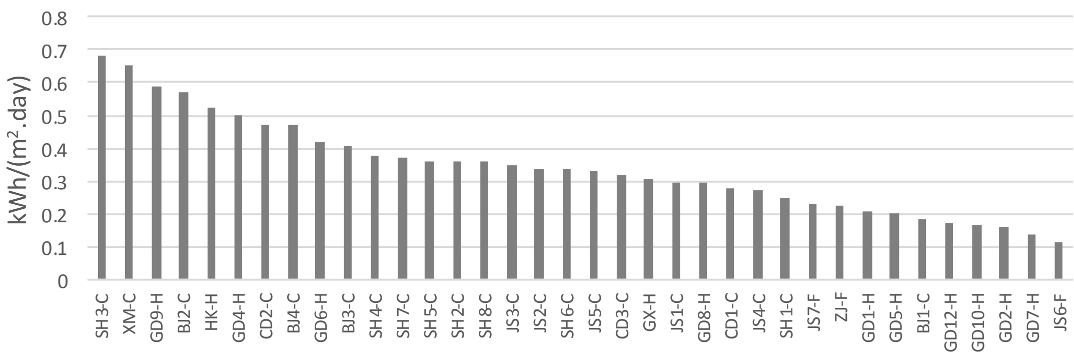


Figure 10 modified cooling station EUI of the 41 investigated hypermarkets

By calculating the median of cooling station energy consumption is 0.33 kWh/(m^2.cooling day), and the lower quartile is 0.22 kWh/(m^2.coolingday).

If 184 days from May to October are used as standard cooling days, the calculating formula of cooling station EUI should be

$$\frac{E_{\text{cooling station}} \times 184}{(S_{\text{total}} - S_{\text{parkng}} \times \text{coolingdays}}$$

Then the median of cooling station EUI is 60 kWh/(m2.a), and the lower quartile is 40 kWh/(m^2.a).

4.2.3 Market EUI

The following two figures show market EUI of the 41 investigated hypermarkets, and give a simple distribution. Data of C company tends to be larger than H company, maybe because of more fresh foods or more lambs. The market power consumption plays the most prominent role in the total energy consumption, so a more detailed analysis would be needed.

According to the calculation, the median of tenant EUI is 352 kWh/(m^2.a), and the lower quartile is 292 kWh/(m^2.a).

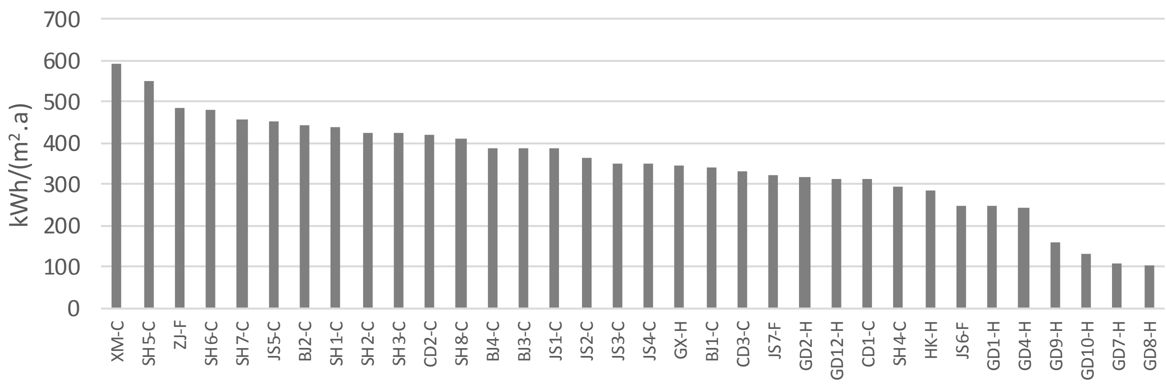


Figure 11 market EUI of the 41 investigated hypermarkets

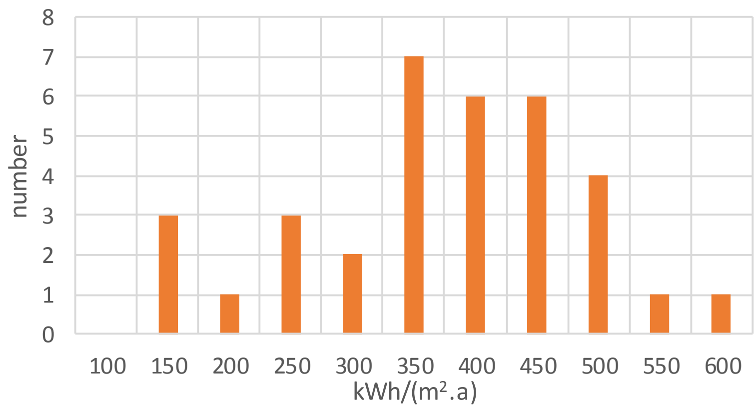


Figure 12 the distribution of the 41 investigated hypermarkets' market EUI

4.3 4 item indexes

4.3.1 Lighting EUI

The following two figures show lighting EUI, and give a simple distribution. Data of C company tends to be larger than H company, because H company uses more energy saving lamps. If C could replace energy saving lamps, the EUI of C company will be lower, just like H company.

The median of lighting EUI is 144 kWh/(m2.a), and the lower quartile of lighting EUI is 111 kWh/(m2.a).

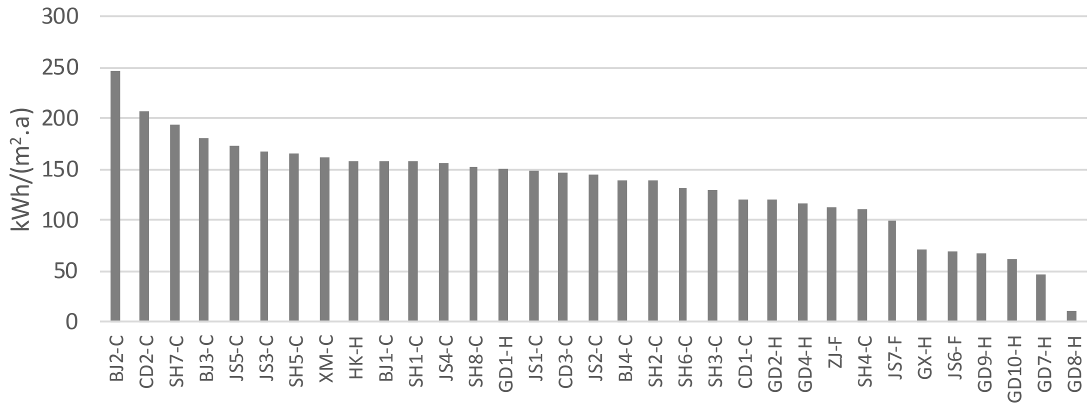


Figure 13 lighting EUI of the 41 investigated hypermarkets

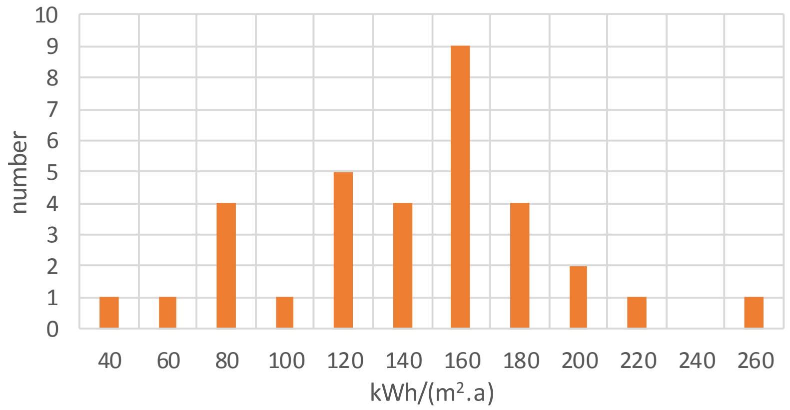


Figure 14 the distribution of the 41 investigated hypermarkets' lighting EUI

4.3.2 AHU EUI

The following figure shows AHU EUI of the 41 hypermarkets. Data of southern hypermarkets tend to be larger than northern company, mainly because of more cooling hours.

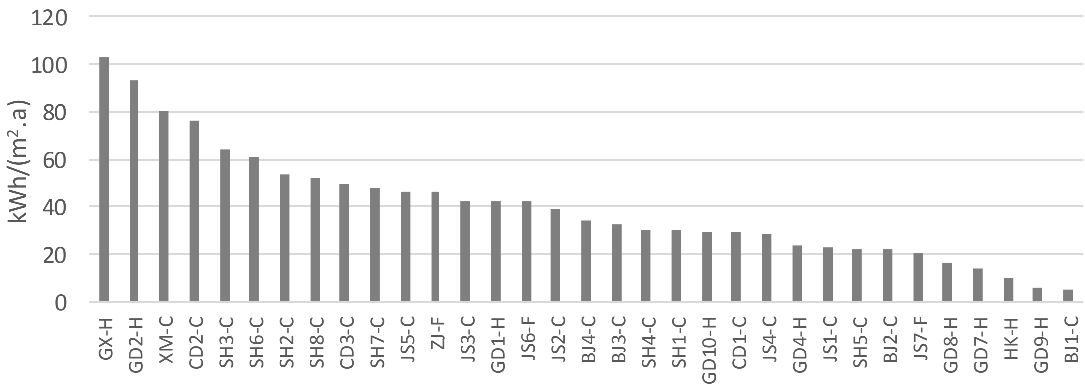


Figure 15 AHU EUI of the 41 investigated hypermarkets

If correct the AHU EUI with cooling days, the following figure could be obtained. Difference between regions becomes smaller.

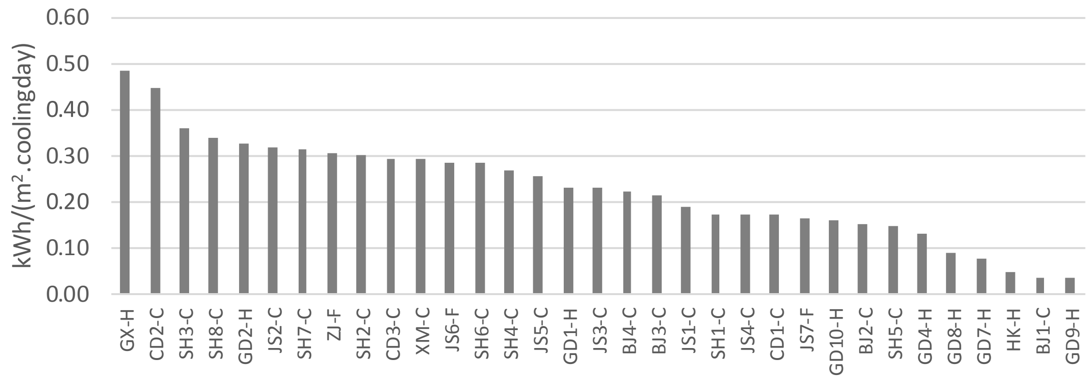


Figure 16 modified AHU EUI of the 41 investigated hypermarkets

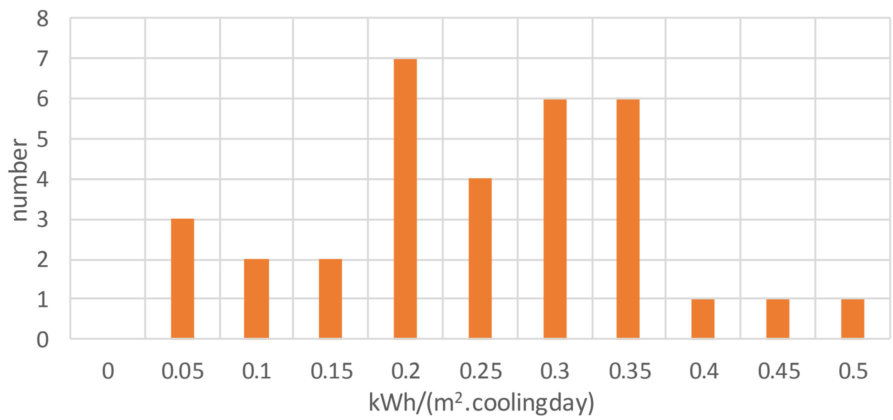


Figure 17 the distribution of the 41 investigated hypermarkets' AHU EUI

According to the calculation, the median of AHU energy consumption is 0.23 kWh/(m².cooling day), and the lower quartile is 0.16 kWh/(m².cooling day).

If 184 days from May to October are used as standard cooling days, the same as to cooling station, the calculating formula of AHU EUI should be

$$\frac{E_{air-handing\,unit} \times 184}{S_{market} \times cooling\,days}$$

Then the median of AHU EUI is 42.3 kWh/(m².a), and the lower quartile of AHU EUI is 29.4 kWh/(m².a).

4.3.3 Refrigeration EUI

The following two figures show refrigeration EUI of the 41 investigated hypermarkets, and give an analysis of power consumption and area. Refrigeration EUI between hypermarkets of the same company varies significantly according to the first figure, and hypermarkets of different companies varies even more.

The electricity consumption is related to area of fresh in one company according to the second figure, so the difference comes from companies' sale decision and the performance of refrigeration equipment.

So if assume that space and energy consumption data are correct, sales, sales volume or freezer volume are better evaluation unit rather than area, because area can only reflects part information of the sales or freezer volume .But because of the lack of data, we have to use area in this paper.

From calculating the median of refrigeration EUI is 1136 kWh/(m2.a), and the lower quartile of refrigeration EUI is 380 kWh/(m2.a).

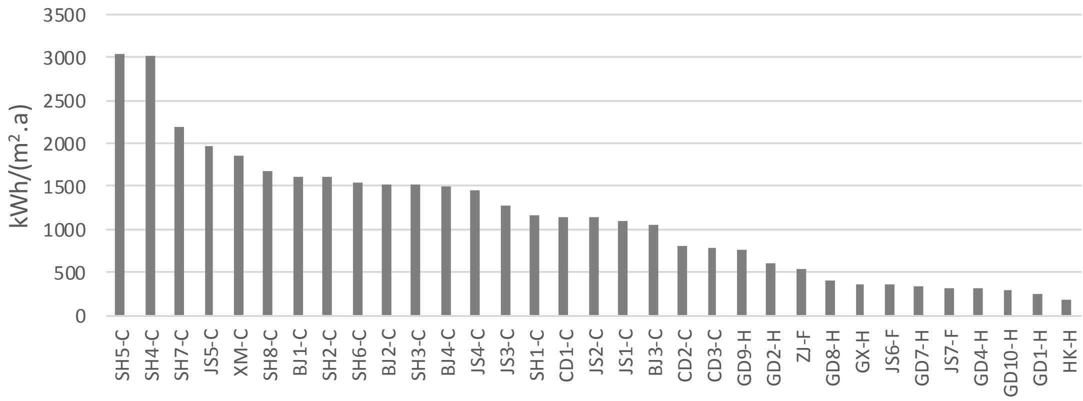


Figure 18 refrigeration EUI of the 41 investigated hypermarkets

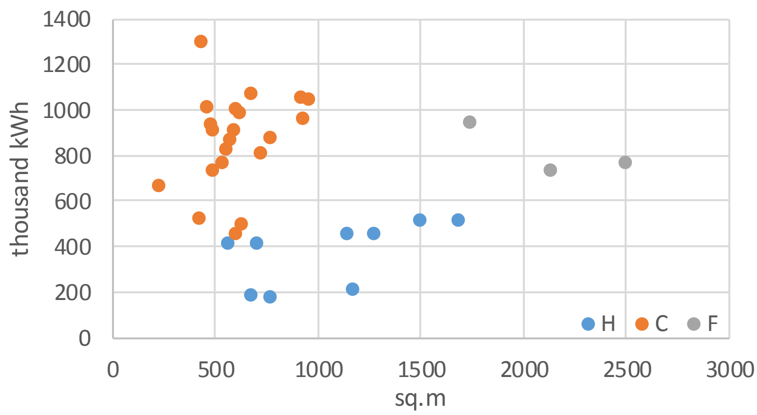


Figure 19 the relationship of refrigeration annual energy consumption and refrigeration area

4.3.4 Cooking EUI

The following figure shows cooking EUI. Cooking EUI is more dispersed compared to lighting, AHU and refrigeration. Some correction methods are adopted.

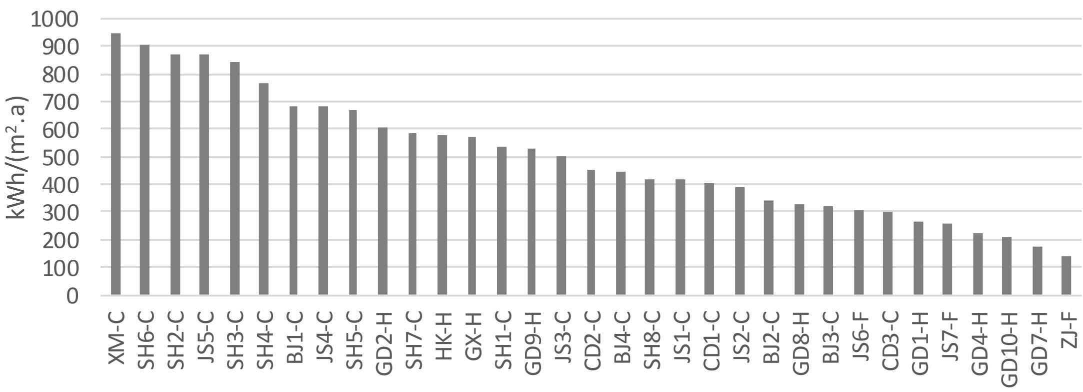


Figure 20 cooking EUI of the 41 investigated hypermarkets

If divide the electricity consumption of cooking by area of fresh and total power of cooking equipment, we could get the following figure. Compared to the not optimized cooking EUI, this index is more concentrated. Though calculating the median of this index is 1.74, and the lower quartile is 1.17.

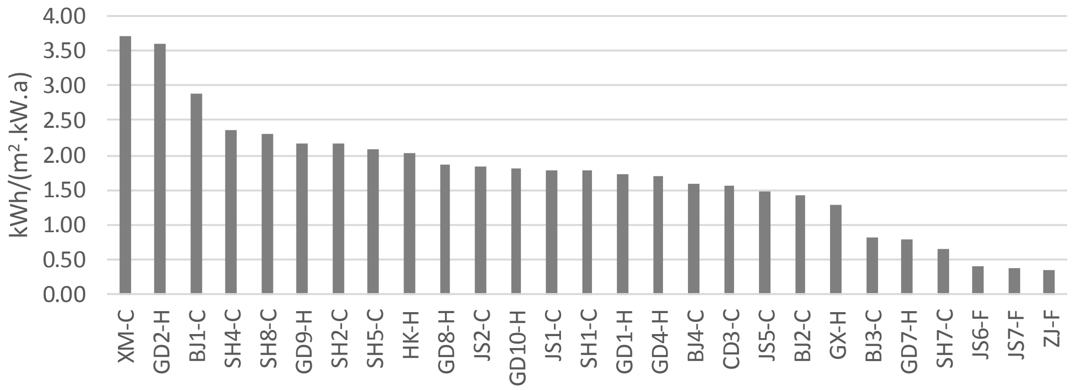


Figure 21 modified cooking EUI of the 41 investigated hypermarkets

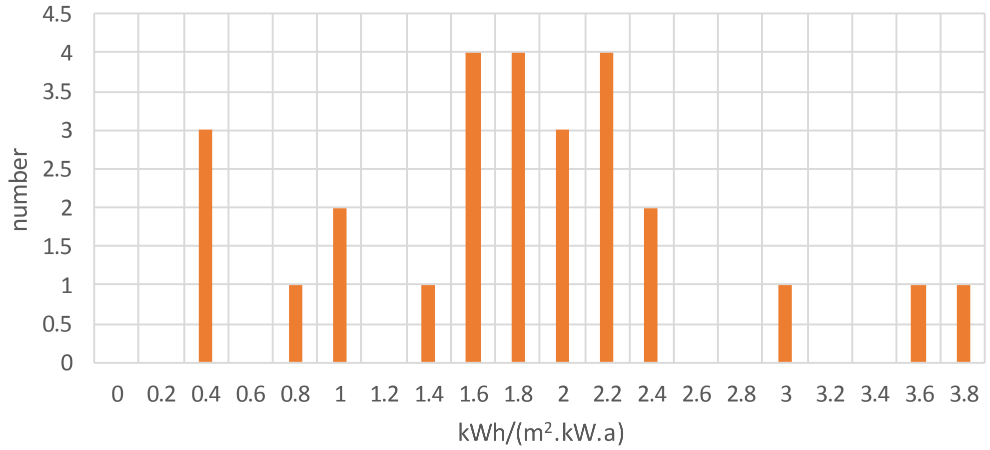


Figure 22 the distribution of the 41 investigated hypermarkets' modified cooking EUI

If the average power of cooking equipment 300kW is used as standard, the calculating formula of cooking EUI should be

$$\frac{E_{cooking} \times 300}{S_{fresh} \times power\ of\ cooking\ equipment}$$

Then the median of cooking EUI is 523 kWh/(m2.a), and the lower quartile is 350 kWh/(m2.a).

4.4 Summary

Use median to be constraint value and lower quartile to be advanced value, the following chart could be obtained:

Table 2 the constraint and advanced value for each index

i.d.	index	constraint value	advanced value	remark
1	Total EUI	130	92	$\frac{E_{total}}{S_{total} - S_{parking}}$

2.1	Tenant EUI	280	197	$\frac{E_{tenant}}{S_{tenant}}$
2.2	Cooling station EUI	60	40	$\frac{E_{cooling\,station} \times 184}{(S_{total} - S_{parkng} \times coolingdays}$
2.3	Market EUI	352	292	$\frac{E_{market}}{S_{market}}$
3.1	Lighting EUI	144	111	$\frac{E_{lighting}}{S_{market}}$
3.2	AHU EUI	42	29	$\frac{E_{air-handing\ unit} \times 184}{S_{market} \times coolingdays}$
3.3	Refrigeration EUI	1136	380	$\frac{E_{refrigeration}}{S_{fresh}}$
3.4	Cooking EUI	523	350	$\frac{E_{cooking} \times 300}{S_{fresh} \times power\ of\ cooking\ equipment}$

5. Energy consumption evaluating index (ECEI) of hypermarket

5.1 calculation method

Considering the overall nature of the system, the availability of basic data, ECEI should consist of tenant, cooling station, lighting, air-handing unit, refrigeration and cooking.

$$\mathrm{ECEI} = \sum_{i=1}^{6} S_i \times w_i$$

i: KPIs: tenant, cooling station, lighting, air-handing unit, refrigeration and cooking EUI
S: score of each KPI
w: weight of each KPI

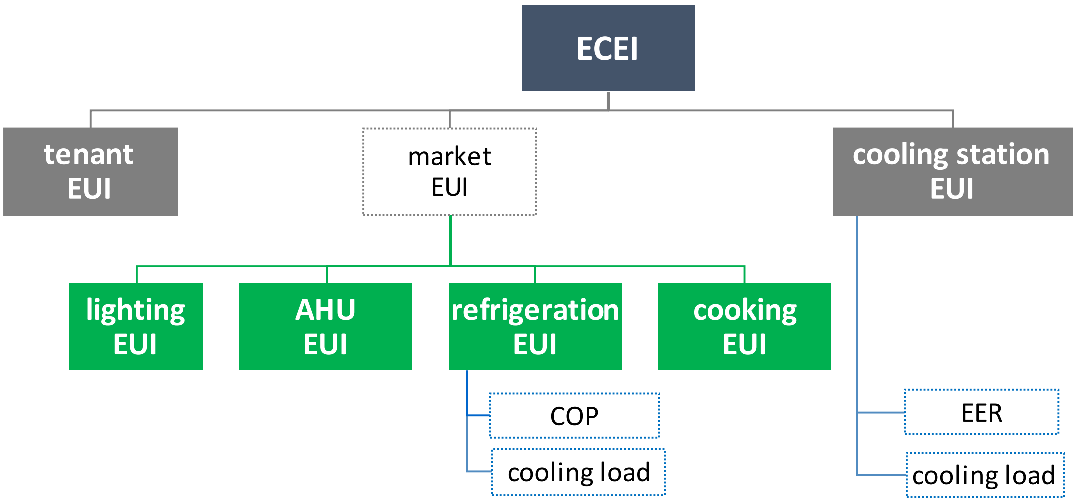


Figure 23 ECEI system

At first calculate the score of each KPI. Define median value to be 60 points, lower quartile to be 80 points and upper quartile to be 40 points.

If EUI is higher than median, its score equals： $40 + \frac{upper\ quartile - EUI}{upper\ quartile - median} \times 20$, if it is lower than zero, it equals zero.If EUI is lower than median, its score equals： $60 + \frac{median - EUI}{median - lower\ quartile} \times 20$, if it is higher than one hundred, it equals one hundred.

Secondly determine weights for each KPI.

According to investigation, typical structure of hypermarket energy consumption is: market energy consumption takes up 63 percent, tenant takes up 22%, cooling station takes up 15%. Typical structure of market energy consumption is: lighting takes up 43%, AHU takes up 13%, refrigeration takes up 30% and cooking takes up 14%.

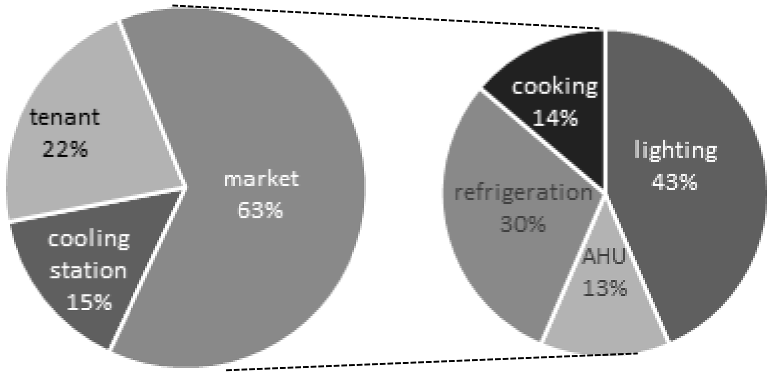


Figure 24 typical structure of hypermarket energy consumption

Take both the proportion of energy consumption and property of energy management into consideration to assign the weight.

The following chat present all data for ECEI:

Table 3 the median, lower quartile, upper quartile and weight of each index

i.d.	index	median	Lower quartile	Upper quartile	weight
2.1	Tenant EUI	280	197	374	0.05
2.2	Cooling station EUI	60	40	75	0.15
3.1	Lighting EUI	144	111	160	0.35
3.2	AHU EUI	42	29	56	0.10
3.3	Refrigeration EUI	1136	380	1574	0.24
3.4	Cooking EUI	523	350	628	0.11

5.2 trial evaluation

Calculate the ECEI for all investigated hypermarkets to verify the feasibility of the index system.

Here is the distribution of ECEIs, it is near the normal distribution:

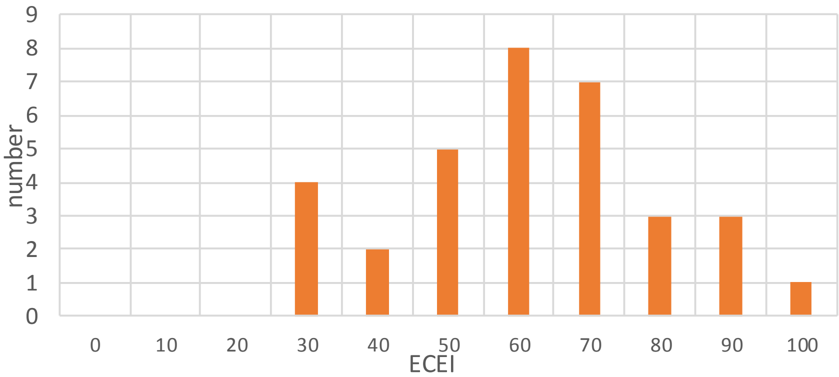
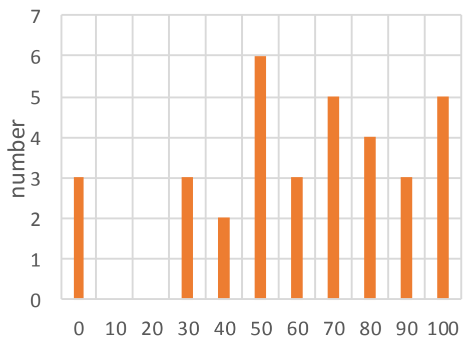


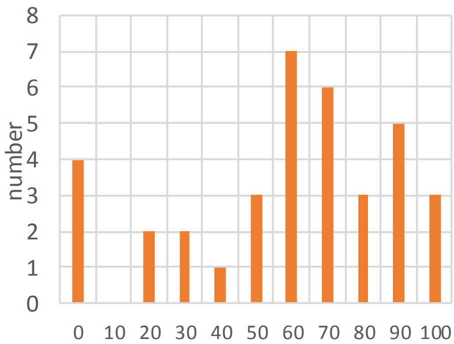
Figure 25 the distribution of ECEI

These following six figures are the distribution of each KPI's scores:

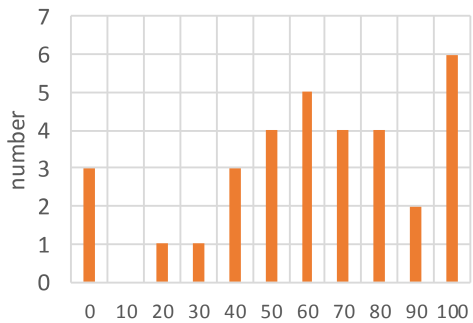
tenant：



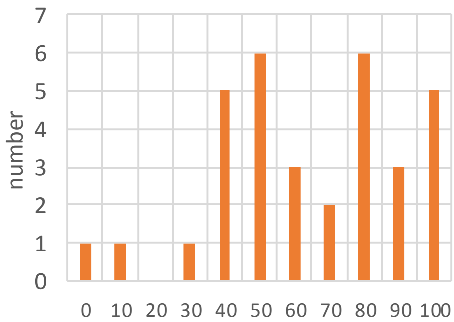
Cooling station:



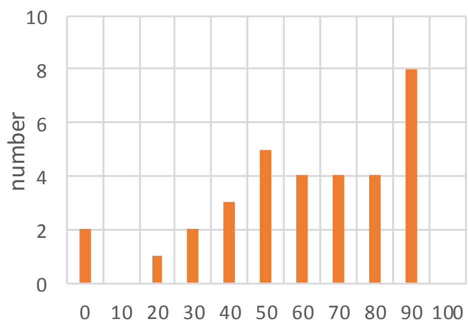
Lighting



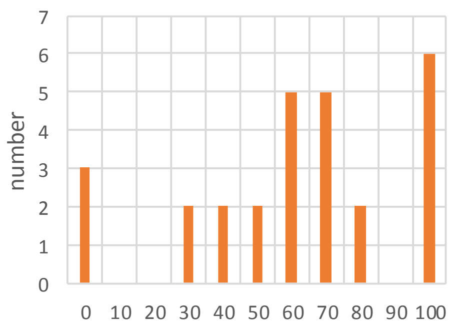
AHU



Refrigeration：



Cooking



5.3 One case

A wind rose map which could express the strengths and weaknesses obviously can be provided to each hypermarket. Here is the wind rose map of one investigated hypermarket whose ECEI is 67. From the map, we could find that the lighting, cooking, tenant especially cooling station are the focus of attention.

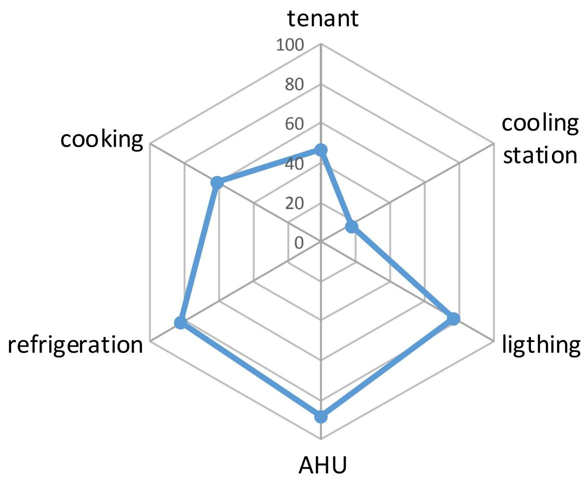


Figure 26 the wind rose map of one investigated hypermarket

6. Conclusions

This paper gives a KPI evaluation system to analyze and compare energy consumption of hypermarkets. Through analyzing the data of the investigated 41 hypermarkets in China, rational value and modified calculation method for each index are proposed. Then present the energy consumption evaluating index (ECEI) and the wind rose map to make energy consumption more manageable.

By using the KPI evaluation system, the company can identify which hypermarket need energy saving reconstruction, so as to balance of the company's resources. And Chain Store &Franchise Association, and industry association, can set up a demonstration for reference to make hypermarket more green and energy-efficient.

7. Acknowledgements

This research was funded by Innovative Research Groups of the National Nature Science Foundation of China. And thanks to China Chain Store &Franchise Association and Department of Building Science of Tsinghua University.

Session Monitoring III

Analysis of detailed building energy consumptions Using Database and Simulation tool

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Abstract

The reduction of building energy is effective for the various thermal environmental problems on the earth scale that have been actualized recently. It is important to understand a detailed characteristics for the building energy consumption and to establish the detail building database. In this study, the building database and the estimation tool are focused to achieve these objectives. DECC (Database for Energy Consumption of Commercial buildings) is a database for energy consumption and estimation tool is original tool based on another formal simulation tool. Using these, the building energy simulation is conducted simply. As a result, the detail energy consumption are estimated and the building database is expanded.

Introduction

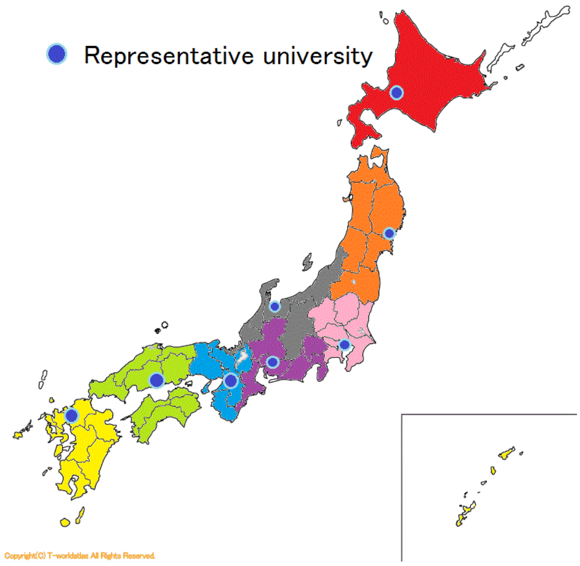
Recently, various thermal environmental problems on the earth scale are actualized. According to the 4th IPCC report, the reduction potential in the field of buildings is bigger than other fields, and the measures in this field are effective for reduction of the greenhouse gas [1]. For the drawing up the suitable reduction plan of the building energy considered building use, scale, location and time, it is important to understand a detailed characteristics for the building energy consumption. However, it is very difficult to obtain such hourly detailed data. In this study, a database and a simulation tool about the building energy are focused to solve this problem.

Outline of Study

This study attempt to estimate the detail energy consumption from monthly and annual total energy consumption, and to establish the database for detail characteristics of the building energy consumption. DECC database is used for a building energy database. And estimation tool is used for a simulation tool. This database has more than 40,000 buildings data. Estimation tool is original tool based on energy consumption models calculated by BEST tool. Inputting the energy consumption data, this tool is able to calculate the detail energy consumption. Along this method, DECC database is expanded.

Outline of DECC database

DECC is a shorted form of “Database for Energy Consumption of Commercial buildings”. This database is a first national building energy database. It is established by support of Ministry of Land, Infrastructure and Transport (MLIT), Ministry of Environment and Ministry of Economy, Trade and Industry (METI). This database is expected to contribute to the promotion of the energy saving. That is the method to collect data in DECC. The whole country is divided into eight arias. And the representative universities are set. As these universities are main, universities in each areas collect building energy consumption data. Each areas are shown Figure.1 [2]. The collection and analysis of its data is conducted as a part of their studies, therefore DECC is established low costs. The contents of collected building data is location, building use, floor space, annual or monthly energy and water consumption and etc. That database has more than 40,000 samples in 2012 and it has increased. Table.1 shows the number of samples. It has a statistical significant in most areas and building uses [3], [4], [5]. So the database has a great number of samples. But the energy consumption data in this database is not detail.



on

Figure.1 Measures area and representative university

Table.1 Number of samples about DECC database (2012)

	Hokkaido	Tohoku	Hokushinetu	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu	Total
Office	96	640	208	981	273	591	581	533	3903
Computer/Information	0	0	3	44	1	56	0	6	110
Government office	107	412	669	1148	81	421	485	650	3973
Mercantile	222	2514	403	4115	918	970	702	1022	10866
Hotel	52	247	117	514	136	265	210	230	1771
Hospital	545	707	564	957	566	653	589	390	4971
Education	1783	2623	1656	3125	1475	765	801	1172	13400
Culture	527	264	214	871	316	508	358	586	3644
Complex	0	0	5	52	86	50	6	61	260
Other	0	3	7	290	16	133	174	283	906
Total	3332	7410	3846	12097	3868	4412	3906	4933	43804

Outline of BEST tool

BEST is a shorted form of “Building Energy Simulation tool”. This tool is based upon the energy saving calculation standard settled by Ministry of Land, Infrastructure and Transport. [6], [7]. BEST tool is used in various studies and building management. This tool is useful to understand a building energy consumption and to submit the energy reduction plan, which is duty in Japan. This tool is able to calculate various detailed energy consumption of building, inputted the detail building information about structures, facilities and etc. BEST tool has many input items. And we have heavy loads when we simulate a building energy consumption by using BEST tool. So BEST tool is unsuitable to expand the database. It is necessary to develop a tool that is capable of calculating detail energy consumption by a simple method

Method of Estimation

The estimation tool is developed. And we estimate the detail energy consumption of buildings in database, using this tool. The flow of the estimation is shown Figure.2. And the detail method is shown the following.

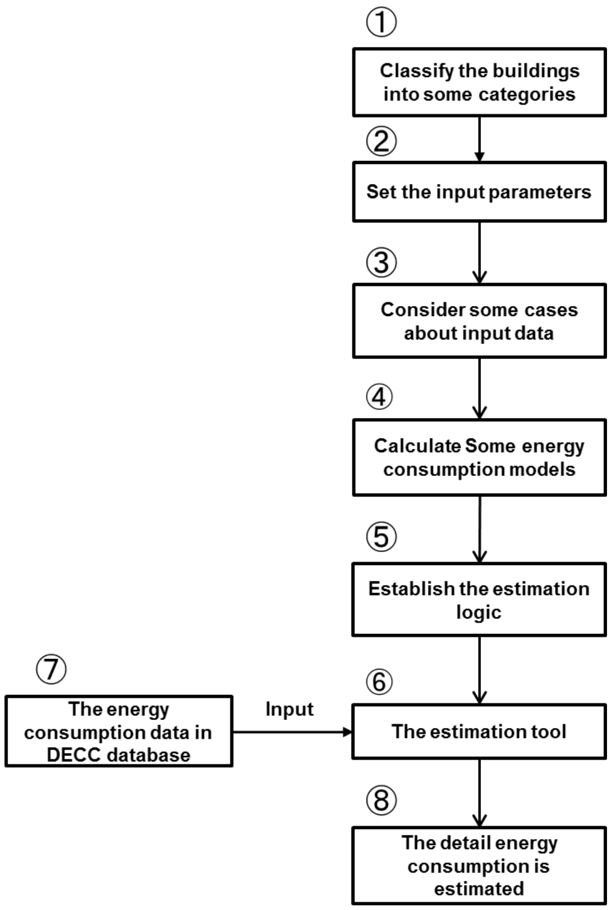


Figure.2 Flow of the estimation about detail building energy consumption

1. Classification of the buildings into some categories

The buildings in DECC database are classified into some categories by four conditions that is seemed its influence for the energy consumption is great. The conditions are this.

・Location area

・Building use

・Building scale

・Heat source equipment

Location areas are classified into two categories, a standard area and a cold area. A standard area is the gray zone, a cold area is the blue zone in Figure.3 [2]. The building scale is classified into a small scale (The total floor space less than 2000 m^2), a middle scale (2000m^2 ~ 10000m^2) and a large scale (more than 2000m^2). In this paper, it's just focused on small buildings for office which placed in the standard area and have EHP system for heart. This category is called Category A.

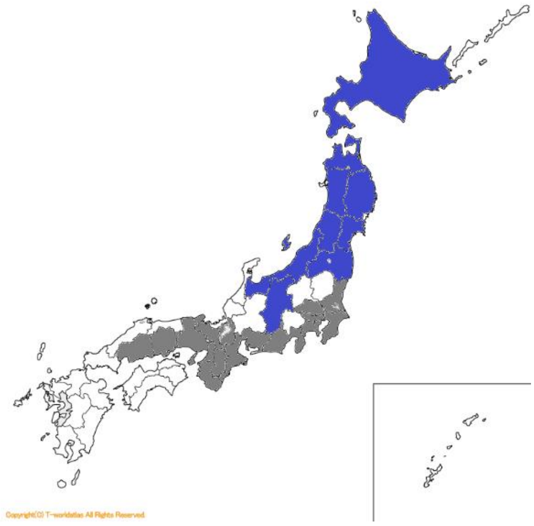


Figure.3 Standard area and the cold area

2. Setting the input parameters

The input parameters for three levels are set. These are the energy saving type (level 1), the standard energy type (level 2) and the energy wasting type (level 3). These parameters are based on practical measures, actual instruments or previous studies [8], [9], [10]. Table. 2 shows the input parameters. The weather data is Tokyo. The five-story building is assumed. Total floor space of the model building is 2000m^2 (one floor space is 400m^2). The aspect rate of the floor is referred to the previous study [8].The floor plane is shown in Figure.4. The floors from second to fifth are the same interior. The running schedules of humans and instruments by day were set, based on the assumption that the business time of this building is 9:00 ~ 18:00. And the overtime work of each level is set zero hour (level 1), one hour (level 2) and two hours (level 3). Figure. 5-1, 5-2, 5-3, 5-4, 5-5, 5-6 show these schedule. The running rate at noon is 60% in the schedule about the number of humans because of lunchtime (Figure.5-1). The running rate at only 8:00~9:00 in outlets is 100% (Figure5-3). It is based on practical measures. It is set a low rate at noon in the same as the schedule of humans. The indoor temperature is set to 25°C in level 2. And level 1 is set 28°C / 22°C (summer / winter), level 3 is set 22°C / 28°C (summer / winter). The level 2 parameter of structures is set, based on the actual data and the previous studies [8], [9]. About the outdoor unit of air conditioners, these parameters are set based on the actual instruments and previous studies. The period of air conditioning is set, based on the practical measurement and the actual weather data. About lightings, the three types of lightings are assumed, LED (level 1), Hf (level 2), and FLR (level 3). The level 1 parameter of outlets is 7.5 W/m^2, based on the practical measurement. And others were set 12 W/m^2 and 20W/m^2 based on the previous studies [9], [10].

Table. 2 Input parameters

Building information					level 1		level 2		level 3	
Structure	Location (=Weather data)				Tokyo					
	Building use				Officce					
	Total floor space				2000m² or less					
		Running schedule by day			schedule.1		schedule.2		schedule.3	
		Indoor temperature(℃)		Summer	28		25		22	
				Winter	22		25		28	
	Wall	Wall	Structure		Steel frame					
			Insulation	Material	Polyurethane Spray Foam		Extruded Polystyrene Form		Extruded Polystyrene Form	
				Thichness(mm)	35		25		15	
				Performance(W/m²K)	0.5		0.63		0.74	
		Indoor wall			Light iron partitioning					
		Roof	Insulation		Polyurethane Spray Foam		Extruded Polystyrene Form		Glass Wool Insulation	
			Thichness(mm)		50		35		20	
			Performance(W/m²K)		0.38		0.49		0.64	
		Windows	Tipe		Double glazing 6mm		Double glazing 6mm		Single Glazing	
			Kind of glass		Low-e/Float Glass		Float /Float		Float Glass	
			Windows area (%)		20		30		40	
Air conditioner	Outdoor unit	Type			EHP					
					Cooling	Heating	Cooling	Heating	Cooling	Heating
		Capacity (kW/m²)			50.01	56.01	50.01	56.01	50.01	56.01
		Electric power consumption (kW/m²)			15.19	15.91	21.70	22.73	30.38	31.82
		COP			3.3	3.5	2.3	2.5	1.6	1.8
		Number of units			10					
		Refrigerant pipe		Length (m)	21m+4m×floors					
				Height (m)	4m×floors					
		Air conditioning period		Cooling	16.Jun ～15.Sep		16.May ～15.Oct		01.May ～31.Oct	
				Heating	01.Dec ～31.Mar		16.Nov ～15.Apr		01.Nov ～30.Apr	
	Indoor unit	Capacity (kW/m²)		Cooling	0.2832					
				Heating	0.3136					
		Electric power consumption (kW/m²)		Cooling	0.003043					
				Heating	0.002256					
		Blast volume (m3/m²)			46.67					
		Number of units (number/m²)			0.02479					
	Ventilation	Heat Exchangers		Exchanger rate (%)	60					
				Electric power consumption (kW)	0.042					
				Capacity (m3/h)	400					
		Number of units (number/m²)			0.018					
Lighting	Type				LED		Hf		FLR	
	Air conditioned room	Electric power consumption (W)			28		64		88	
		Illumination (lm/W)			127		110		62	
		Number of units (number/m²)			0.243728		0.334055		0.424383	
	Non Air conditioned room	Electric power consumption (W)			14		32		44	
		Illumination (lm/W)			122.7		110		62	
		Number of units (number/m²)			0.177778					
Outlets	Electric power consumption (W/m²)				7.5		12		20	
Ventilation	Non Air conditioned room	Kind of fan			Sirocco fan					
		Blast volume (m3/h)			160					
		Static pressure(Pa)			100					
		Number of units (unit number/room number)			1					
Elevator	Speed control method				The variable voltage and frequency control system					
	Load (kg)				600					
	Rating speed				60m/min					
	Number of units				1					
Hot water supply	Kind of hot water supply device				Gas hot water supply device					
	Capacity for heating (kW)				8.72					
	Fuel consumption (kW)				10.5					
	Number of units (number/hot water supply room)				1					

- level.1 : the energy saving type, level 2 : the standard energy type, level 3 : the energy wasting type
- These parameters are based on practical measures, actual instruments or previous studies.

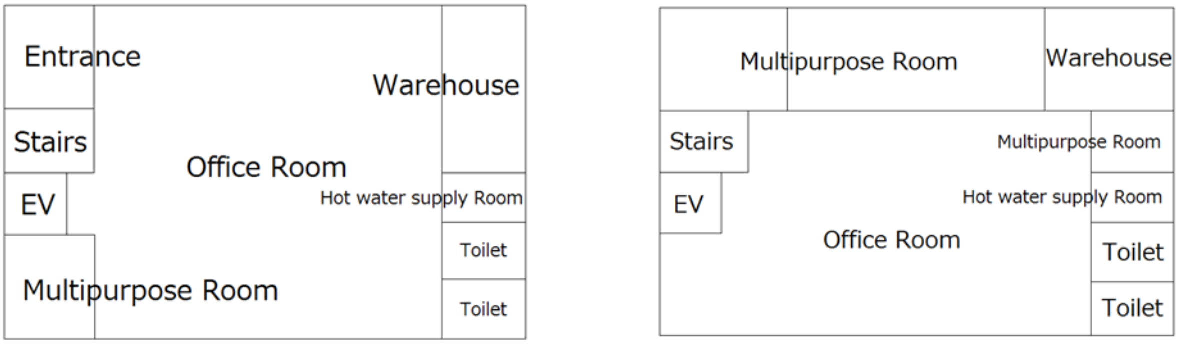


Figure.4 Floor plane of the first floor

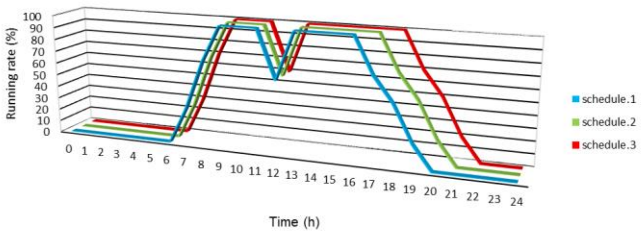


Figure.5-1 Running schedule of number of humans

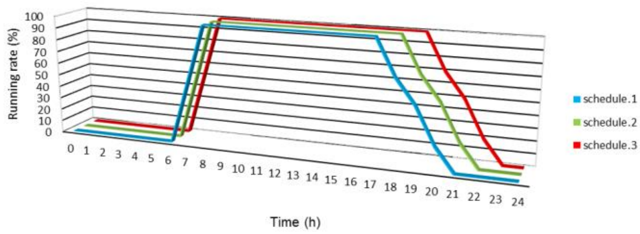


Figure.5-2 Running schedule of lightings

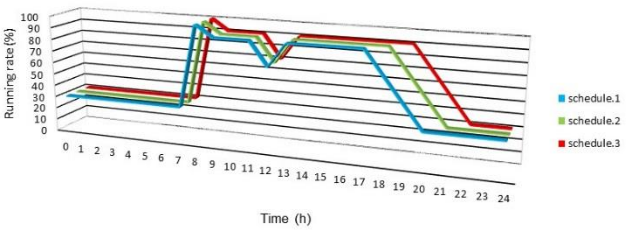
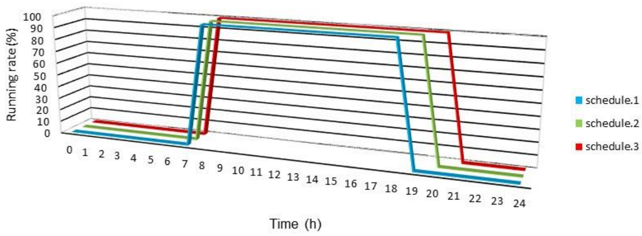


Figure.5-3 Running schedule of outlets



Figuer.5-4 Running schedule of air conditioners

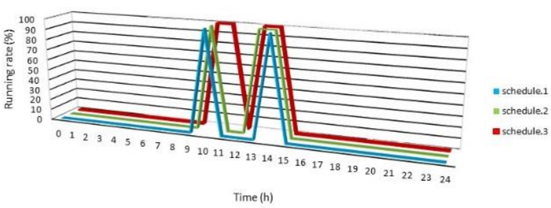


Figure.5-5 Running schedule of multipurpose room

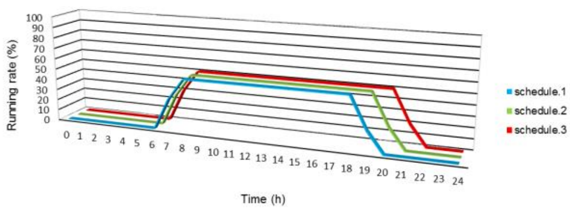


Figure.5-6 Running schedule of non-air conditioning room

3. Some cases about combinations of parameters

We guessed this. If we make some detail energy models, all of samples in the database are able to apply for the energy models. Therefore we considered some cases about combinations of input parameters to make some energy models. Table. 3 shows these cases. The numbers in Table. 3 show the input level of each parameter. Then, the case whose all parameters are level 2 is the Base-Model.

Table. 3 Considered cases and Input parameter levels

	Level of the input parameter									
case	Electric power consumption of lightings	Electric power consumption of outlets	Electric power consumption of outdoor units	Running schedule by day	Indoor temparature (summer)	Indoor temparature (winter)	Indoor temparature (Annual)	Parameter about the wall and the roof	Parameter about the windows	Air conditioning period
Base	2	2	2	2	2	2		2	2	2
case.1	1	1	1	2	2	2	2	2	2	2
case.2	1	1	2	2	2	2	2	2	2	2
case.3	1	1	3	2	2	2	2	2	2	2
case.4	1	2	1	2	2	2	2	2	2	2
case.5	1	2	2	2	2	2	2	2	2	2
case.6	1	2	3	2	2	2	2	2	2	2
case.7	1	3	1	2	2	2	2	2	2	2
case.8	1	3	2	2	2	2	2	2	2	2
case.9	1	3	3	2	2	2	2	2	2	2
case.10	2	1	1	2	2	2	2	2	2	2
case.11	2	1	2	2	2	2	2	2	2	2
case.12	2	1	3	2	2	2	2	2	2	2
case.13	2	2	1	2	2	2	2	2	2	2
case.14	2	2	2	2	2	2	2	2	2	2
case.15	2	2	3	2	2	2	2	2	2	2
case.16	2	3	1	2	2	2	2	2	2	2
case.17	2	3	2	2	2	2	2	2	2	2
case.18	2	3	3	2	2	2	2	2	2	2
case.19	3	1	1	2	2	2	2	2	2	2
case.20	3	1	2	2	2	2	2	2	2	2
case.21	3	1	3	2	2	2	2	2	2	2
case.22	3	2	1	2	2	2	2	2	2	2
case.23	3	2	2	2	2	2	2	2	2	2
case.24	3	2	3	2	2	2	2	2	2	2
case.25	3	3	1	2	2	2	2	2	2	2
case.26	3	3	2	2	2	2	2	2	2	2
case.27	3	3	3	2	2	2	2	2	2	2
case.28	2	2	2	1	2	2	2	2	2	2
case.29	2	2	2	3	2	2	2	2	2	2
case.30	2	2	2	2	1	2	2	2	2	2
case.31	2	2	2	2	3	2	2	2	2	2
case.32	2	2	2	2	2	1	2	2	2	2
case.33	2	2	2	2	2	3	2	2	2	2
case.34	2	2	2	2	2	2	1	2	2	2
case.35	2	2	2	2	2	2	3	2	2	2
case.36	2	2	2	2	2	2	2	1	2	2
case.37	2	2	2	2	2	2	2	3	2	2
case.38	2	2	2	2	2	2	2	2	1	2
case.39	2	2	2	2	2	2	2	2	3	2
case.40	2	2	2	2	2	2	2	2	2	1
case.41	2	2	2	2	2	2	2	2	2	3
case.42	1	1	1	1	2	2	2	2	2	2
case.43	1	1	1	3	2	2	2	2	2	2
case.44	1	1	1	2	1	2	2	2	2	2
case.45	1	1	1	2	3	2	2	2	2	2
case.46	1	1	1	2	2	1	2	2	2	2
case.47	1	1	1	2	2	3	2	2	2	2
case.48	1	1	1	2	2	2	1	2	2	2
case.49	1	1	1	2	2	2	3	2	2	2
case.50	1	1	1	2	2	2	2	1	2	2
case.51	1	1	1	2	2	2	2	3	2	2
case.52	1	1	1	2	2	2	2	2	1	2
case.53	1	1	1	2	2	2	2	2	3	2
case.54	1	1	1	2	2	2	2	2	2	1
case.55	1	1	1	2	2	2	2	2	2	3
case.56	3	3	3	1	2	2	2	2	2	2
case.57	3	3	3	3	2	2	2	2	2	2
case.58	3	3	3	2	1	2	2	2	2	2
case.59	3	3	3	2	3	2	2	2	2	2
case.60	3	3	3	2	2	1	2	2	2	2
case.61	3	3	3	2	2	3	2	2	2	2
case.62	3	3	3	2	2	2	1	2	2	2
case.63	3	3	3	2	2	2	3	2	2	2
case.64	3	3	3	2	2	2	2	1	2	2
case.65	3	3	3	2	2	2	2	3	2	2
case.66	3	3	3	2	2	2	2	2	1	2
case.67	3	3	3	2	2	2	2	2	3	2
case.68	3	3	3	2	2	2	2	2	2	1
case.69	3	3	3	2	2	2	2	2	2	3
case.70	1	1	1	1	1	1	1	1	1	1
case.71	3	3	3	3	3	3	3	3	3	3

4. Development of the estimation tool

Inputting the parameter combinations into BEST tool, the detail energy consumption models are calculated. Table.4 shows the annual energy consumption and the standard deviation of monthly energy consumption. Table.5 shows the calculation result of Base-model. And Figure. 6 shows the energy characteristics of each model about the annual energy and the standard deviation. Then, as the unit is different between each item, these are converted into Standard value. Standard value is defined by equation (1).

$$\text{Standard value} = \frac{X_n - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Table. 4 Calculated annual energy consumption and the standard deviation

case	Annual Energy	Standard deviation	case	Annual Energy	Standard deviation	case	Annual Energy	Standard deviation
Case1	730.00	11.62	Case26	1,507.90	21.82	Case51	757.60	12.44
Case2	853.70	16.75	Case27	1,670.60	30.51	Case52	748.70	12.73
Case3	1,018.30	23.62	Case28	1,076.70	15.44	Case53	776.60	13.07
Case4	834.30	11.39	Case29	1,262.10	18.72	Case54	802.00	24.72
Case5	957.70	16.36	Case30	1,255.70	23.40	Case55	921.20	13.83
Case6	1,121.90	23.05	Case31	1,123.30	14.45	Case56	1,582.90	28.36
Case7	1,018.90	11.62	Case32	1,135.30	19.78	Case57	1,858.90	34.86
Case8	1,140.70	16.67	Case33	1,245.20	17.99	Case58	1,626.10	23.69
Case9	1,303.00	23.42	Case34	1,070.70	14.59	Case59	1,826.30	40.34
Case10	945.60	11.48	Case35	1,313.50	21.78	Case60	1,658.20	34.65
Case11	1,067.30	16.47	Case36	1,182.50	18.41	Case61	1,801.90	29.42
Case12	1,229.60	23.20	Case37	1,194.70	18.44	Case62	1,561.10	25.70
Case13	1,049.60	11.99	Case38	1,179.20	16.74	Case63	1,904.90	37.06
Case14	1,170.60	17.12	Case39	1,224.90	19.95	Case64	1,716.60	31.77
Case15	1,332.00	24.06	Case40	1,097.50	23.24	Case65	1,729.80	31.53
Case16	1,237.00	13.46	Case41	1,226.50	15.19	Case66	1,706.20	28.21
Case17	1,357.80	19.16	Case42	692.50	10.98	Case67	1,778.90	33.86
Case18	1,519.00	26.83	Case43	812.10	13.40	Case68	1,447.20	25.62
Case19	1,090.10	12.67	Case44	704.30	12.56	Case69	1,591.00	20.56
Case20	1,210.90	18.06	Case45	802.20	13.48	Case70	606.40	9.92
Case21	1,371.90	25.34	Case46	708.30	11.32	Case71	2,150.20	43.02
Case22	1,196.00	13.55	Case47	795.40	14.24	AVE	1,211.08	20.07
Case23	1,317.10	19.28	Case48	659.40	10.16	STV	356.82	7.79
Case24	1,478.20	27.00	Case49	844.20	14.23	MAX	2,150.20	43.02
Case25	1,385.90	15.40	Case50	749.30	12.07	MIN	606.40	9.92

Table. 5 Detail energy consumption of Base-model

	Energy Comsumption (MJ · m^{-2})							
	Air conditioner	Lighting	Outlet	Hot water	Ventilation	Elevator	Others	Total
Jan.	42.72	29.41	22.79	0.05	0.16	1.43	1.83	98.40
Feb.	44.02	32.68	22.31	0.05	0.18	1.43	1.65	102.32
Mar.	38.84	35.94	24.63	0.05	0.20	1.57	1.83	103.08
Apr.	13.46	32.68	23.24	0.04	0.18	1.43	1.77	72.80
May	23.53	32.68	23.71	0.04	0.18	1.43	1.83	83.39
Jun.	41.40	35.94	24.17	0.03	0.20	1.57	1.77	105.08
Jul.	63.30	32.68	23.71	0.02	0.18	1.43	1.83	123.15
Aug.	66.82	29.41	22.79	0.03	0.16	1.64	1.83	122.68
Sep.	51.02	32.68	23.24	0.03	0.18	1.43	1.77	110.35
Oct.	16.99	34.31	24.17	0.04	0.19	1.50	1.83	79.03
Nov.	15.29	32.68	23.24	0.05	0.18	1.43	1.77	74.64
Dec.	37.83	32.68	23.71	0.05	0.18	1.50	1.83	97.78
Annual	455.22	393.75	281.73	0.4743	2.200	17.80	21.53	1172.70

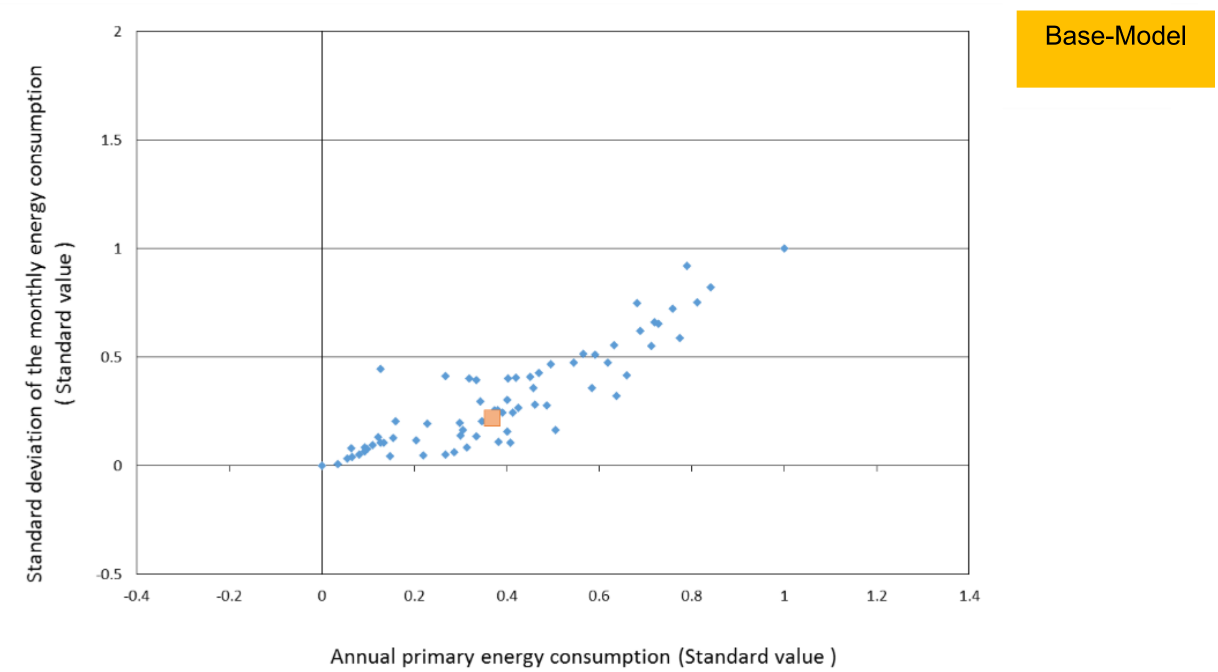


Figure.6 Energy characteristics of each model

5. The logic of Estimation tool

First, the sample data is imputed into the scatter diagram, Figure.6. And the nearest model to a sample is identified. This model is called case X. Next, line BX is drawn. This line is through point B and point X. And next, Point A is calculated. Point A is the intersection with BX and the perpendicular line drawn from a sample to BX. We regard Point A as a sample building. These are shown in Figure.7. The detail energy consumption on Point A is calculated by equation (2) and (3). Furthermore this result is modified by equation (4) to adjust the estimated total energy consumption in a sample.

$$R_A = \frac{BA}{BX} \tag{2}$$

$$E_1 = E_x + R_A \times (E_x - E_B) \tag{3}$$

$$E_2 = ET_0 \times \frac{E_1}{ET_1} \tag{4}$$

R_A	Coefficient to calculate the E.C at Point A from Base-Model and Case X
E_B	Detail energy consumption of Base-Model
E_x	Detail energy consumption of Case X
E_1	Detail energy consumption at Point A
E_2	Estimated detail energy consumption (Result of estimation)
ET_1	Monthly total energy consumption at Point A
ET_0	Monthly total energy consumption of a sample building

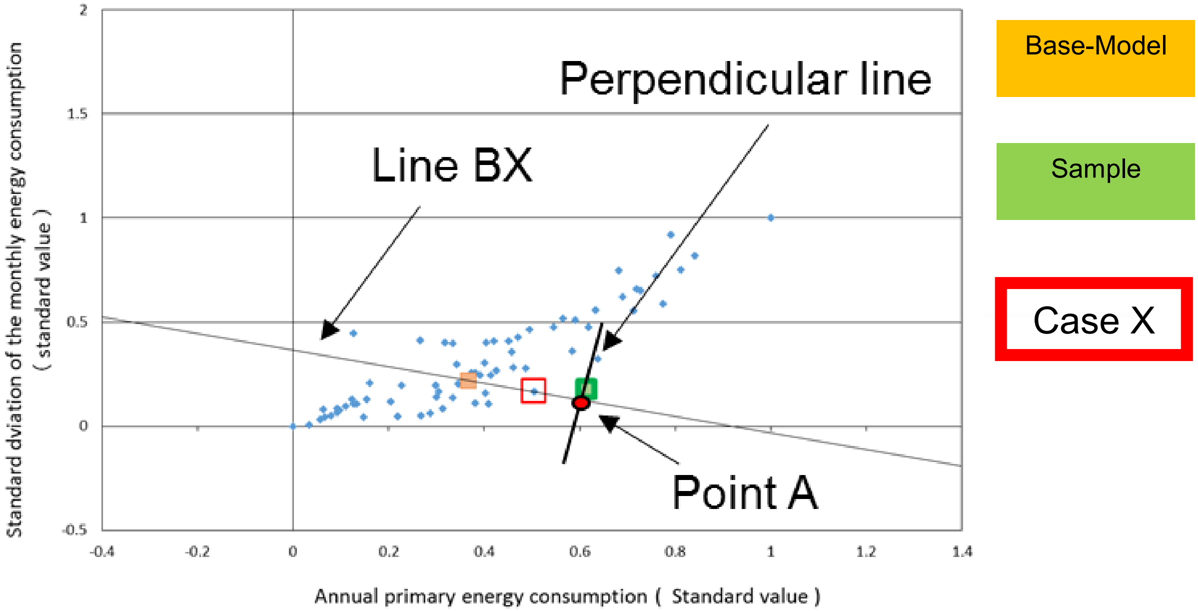


Figure.7 Logic of Estimation

Verification of precision

The verification of the precision is conducted, using the actual energy consumption data whose detail is obvious. The building measured this data belongs to the category A. This data is composed of the energy consumption about air conditioner and lighting and outlets. The data about lighting and outlets is unified. Therefore each corresponding data is compared. Table.6 shows the actual data. Table. 7 shows the relative error of the monthly detail energy consumption between the actual data and the estimated data. Table. 8 shows the result of the estimation.

The result of the verification shows in Table. 7. The biggest error is 42.4%. However, in absolute error, these are not big, less than 10 MJ. And almost relative errors don't show big value, less than 20%. Under the existing circumstances, the detail energy consumption is estimated in this precision.

Table. 6 Actual data of building energy consumption

	Air conditioner	Lighting & Outlet	Total
	MJ/m^2	MJ/m^2	MJ/m^2
Jan.	-4.4	0.6	-3.8
Feb.	-6.0	3.1	-2.9
Mar.	-4.6	1.4	-3.2
Apr.	-2.5	-0.1	-2.6
May	4.8	-6.9	-2.1
Jun.	2.0	-4.7	-2.7
Jul.	-0.4	-3.0	-3.3
Aug.	7.4	-10.3	-2.9
Sep.	9.6	-11.9	-2.3
Oct.	3.2	-5.8	-2.6
Nov.	-6.1	3.2	-2.9
Dec.	-3.1	-0.1	-3.2
Annual	-0.1	-34.4	-34.5

Table. 7 Relative error between the actual data and the estimated data

	Air conditioner	Lighting & Outlet	Total
	%	%	%
Jan.	-7.6	1.0	-3.3
Feb.	-10.5	5.7	-2.6
Mar.	-10.3	2.6	-3.2
Apr.	-16.5	-0.2	-4.2
May	42.4	-15.7	-3.8
Jun.	6.3	-9.1	-3.2
Jul.	-0.6	-5.4	-2.8
Aug.	15.3	-20.0	-2.9
Sep.	37.8	-24.6	-3.1
Oct.	31.9	-11.8	-4.5
Nov.	-28.7	6.9	-4.4
Dec.	-7.1	-0.2	-3.3
Annual	-0.02	-5.6	-3.3

Table. 8 Estimated detail energy consumption

	Energy Comsumption ($MJ \cdot m^{-2}$)							
	Air conditioner	Lighting	Outlet	Hot water	Ventilation	Elevator	Others	Total
Jan.	53.41	32.83	25.92	0.12	0.24	1.65	2.12	116.27
Feb.	51.18	33.81	23.48	0.10	0.22	1.52	1.85	112.17
Mar.	40.38	33.01	23.03	0.10	0.19	1.55	1.74	100.01
Apr.	12.41	26.72	19.30	0.08	0.17	1.21	1.55	61.42
May	16.11	21.29	15.71	0.06	0.14	0.96	1.23	55.50
Jun.	33.56	27.69	19.00	0.07	0.16	1.30	1.46	83.25
Jul.	61.94	30.01	22.14	0.09	0.19	1.35	1.74	117.47
Aug.	56.17	23.11	18.25	0.08	0.17	1.33	1.49	100.59
Sep.	35.04	21.18	15.29	0.06	0.14	0.96	1.23	73.89
Oct.	13.03	25.16	18.07	0.07	0.15	1.16	1.39	59.04
Nov.	15.18	28.44	20.54	0.08	0.18	1.28	1.65	67.36
Dec.	40.82	31.25	23.06	0.09	0.20	1.51	1.81	98.74
Annual	429.24	334.49	243.78	1.00	2.15	15.77	19.27	1045.70

Result of estimation

Using this tool, the estimation of a detail energy consumption is actually conducted. All of buildings in Category A are estimated the detail energy consumption. The number of estimated data is 49. Representatively, one sample is picked out from 49 buildings. Table.9 shows a part of data about in DECC database. And the estimated detail energy consumption of Building A is shown in Table. 10, Figure. 8, and Figure. 9. From monthly energy consumption, their energy uses for examle air conditioners, lightings and outles are calculated.

Table. 9 Samples picked out from DECC database

	Building	Building A	Building B	Building C	Building D	Building E	Building F	Building G	Building H	Building I	Building J
	Location	Tokyo	Tokyo	Tokyo	Tokyo	Tokyo	Tokyo	Kyoto	Kyoto	Osaka	Aichi
	Total Floor Space	1844.0	1999.3	1764.0	1405.9	1405.9	1234.8	1391.0	468.5	654.0	525.1
Energy Comsumption (MJ $\cdot$ m^{-2})	*Jan.*	129.0	103.7	44.3	170.3	153.6	141.8	251.4	69.2	219.0	116.3
	Feb.	155.8	144.2	62.5	207.7	163.0	144.7	196.6	90.6	197.4	133.5
	Mar.	140.7	107.2	54.6	150.4	130.4	157.9	167.5	85.1	179.3	104.8
	Apr.	132.2	100.3	49.8	113.7	144.5	141.6	134.4	78.9	178.0	66.1
	May	106.9	98.8	39.8	109.3	124.2	134.7	148.8	54.3	176.1	65.2
	Jun.	118.2	95.0	50.8	139.2	155.7	128.6	158.0	61.9	178.4	55.9
	Jul.	122.9	129.7	57.1	137.1	170.0	157.4	233.6	70.5	200.7	107.7
	Aug.	148.7	155.1	73.6	189.1	204.4	181.9	280.2	80.5	277.6	166.3
	Sep.	143.3	126.5	62.2	148.6	173.1	224.9	209.5	87.1	254.2	138.8
	Oct.	111.9	90.3	49.6	114.0	132.5	195.1	154.3	74.0	174.4	84.5
	Nov.	109.6	97.5	41.5	116.5	117.6	169.1	178.6	62.1	176.8	69.3
	Dec.	132.2	107.2	53.7	158.7	151.5	144.5	229.2	75.4	213.5	112.1
	Annual	1551.3	1355.6	639.4	1754.6	1820.5	1922.1	2342.1	889.6	2425.5	1220.5

Table. 10 Estimated detail energy consumption of Building A

	Energy Comsumption (MJ $\cdot$ m^{-2})								
	Air conditioner	Lighting	Outlet	Hot water	Ventilation	Elevator	Others	Total	Actual
Jan.	75.07	30.86	18.00	0.14	0.27	1.92	2.46	128.73	128.95
Feb.	90.02	39.96	20.40	0.16	0.32	2.23	2.70	155.63	155.78
Mar.	73.27	40.65	20.95	0.15	0.30	2.36	2.66	140.33	140.72
Apr.	36.82	56.94	30.25	0.23	0.45	3.17	4.08	131.70	132.16
May	39.64	39.93	21.70	0.16	0.32	2.22	2.86	106.68	106.89
Jun.	58.27	36.33	18.45	0.13	0.26	2.11	2.38	117.81	118.15
Jul.	76.42	27.53	14.97	0.11	0.22	1.53	1.97	122.64	122.90
Aug.	97.08	29.48	17.19	0.13	0.26	2.09	2.35	148.46	148.72
Sep.	81.47	36.86	19.58	0.15	0.29	2.05	2.64	142.89	143.33
Oct.	32.12	47.73	25.36	0.18	0.36	2.72	3.27	111.57	111.87
Nov.	33.73	45.43	24.13	0.18	0.36	2.53	3.25	109.43	109.61
Dec.	70.55	36.59	19.89	0.15	0.29	2.18	2.62	132.12	132.18
Annual	764.46	468.29	250.87	1.86	3.71	27.13	33.24	1547.98	1,551.27

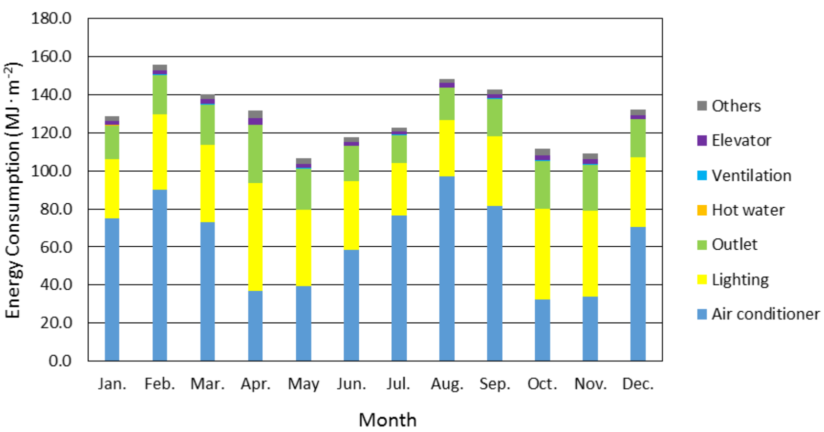


Figure.8 Estimated detail energy consumption of Building A

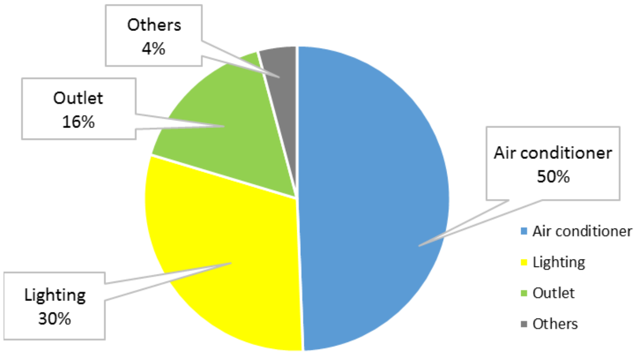


Figure.9 Rate about the use of the estimated annual energy of Building A

These detail energy consumption data will be useful to draw up policies of the energy reduction plan. In Building A, the energy consumption of air conditioner is large. In Category A, the average of the estimated energy consumption for air conditioners in sample buildings is 463.8 W/m^2. Therefore it is guessed that this building had better improve the use of air conditioner.

Conclusion

The conclusion and acknowledge are as follows.

1) In this study, it was developed the simple tool to estimate the detail energy consumption.

2) As a result, it is enabled to conduct the estimation and to expand the database easily.

3) The detail energy consumption will be useful to draw up policies of the energy reduction plan

4) However there is still room for improvement in this tool.

5) It is very significant mission to modify this tool and to improve the precision.

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Advances in Data Science for Building Energy Management

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Abstract

The increasing computational capabilities for information acquisition and storage have led to a massive increase of available data in different areas of interest to Energy Management; e.g. smart grid monitoring, equipment consumption measurement, user activity identification, supply and demand estimation, and building operation logging. Exploiting such *big data* offers a great opportunity to gain insights into many aspects of buildings energy performance, and therefore, to support the implementation of solid data-based policies for improving energy efficiency. Data Science comprises a set of techniques and technologies for building system models from large data volumes, with the aim of discovering and predicting trends, groups, parameter correlations, anomalies, exceptions, and other relevant patterns. Data Science has been identified as essential to address several energy efficiency challenges, such as demand prediction, operation optimization and network maintenance, to name some of them. This paper provides an introduction to the fundamentals of Data Science methods and their application to these problems. To illustrate the role Data Science in Building Energy Management, we present an illustrative example in the context of efficient building operation and maintenance.

Introduction

The building sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally, and an equally important source of CO_2 emissions, according to the International Energy Agency [1]. Around 90% of the building emissions are produced during the operational stage, primarily through the use of fossil fuels to operate the HVAC (heat, ventilation and air-conditioning) and lighting systems [2]. These figures have soared in the last decades, and they are expected to steadily increase in the near future because of the inefficiency of aging infrastructures. Therefore, the implementation of building energy saving measures has a major impact on the reduction of the contaminant emissions, as well as the most potential for delivering significant economic savings. This is the objective of the Directive 2012/27/UE of the European Parliament and of the Council [3], which establishes energy efficiency as one of the headline targets of the EU policies.

There are several complementary strategies to reduce buildings energy consumption, particularly in non-residential buildings. Sustainable architectural designs and affordable energy sources are essential in that regard, but they must be accompanied by suitable protocols to optimize energy management in order to be effective. A critical task is to adapt HVAC and lighting operation to users' needs, minimizing the equipment utilization while maintaining the occupants comfort. Usually, the actuations to reduce the energy consumption are based solely on the manager experience and informal estimations of the expected energy requirements, thus leading to inefficiencies. Nevertheless, the development and the decrease of the cost of sensor technologies in the last decade have changed this scenario. Operators have increased their awareness on their own buildings, since they are capable of monitoring them in real time and remotely applying control commands.

Now, it is time for shifting more human-based control to computer-assisted control. The large amount of data generated by the Building Management System (BMS) can be collected and exploited to obtain much more insights about the building energy behavior. Data Science –a set of techniques to discover knowledge, detect patterns, and generate predictions from large-scale data– has emerged as a suitable toolkit to this end. It offers a unique opportunity to the actors in the energy efficiency industry (including constructors, building operators and consultants) to strengthen their competitiveness and industrial leadership. So far, Data Science has been applied to address problems such as the following: (i) the prediction of energy demand in order to adapt production and distribution; (ii) the analysis of building operations as well as of equipment status and failures to optimize operation and maintenance costs; (iii) the detection of energy consumption patterns to create customized commercial offers and to detect fraud.

This paper presents an overview of different Data Science techniques, and explains how they have been employed to address these issues. Thus, in Section 2 we provide an introduction to the typical Data Science process and the most relevant techniques. In Section 3, we summarize some recent advances in the areas mentioned before. Section 4 describes an application of Data Science to a real problem in building management. Specifically, we use association rules to detect frequent situations in a test building not well solved by the current practices that may help to increase energy efficiency, both at the local and the global level. This work has been carried out in the context of the FP7 project Energy IN TIME, which aims at the development of simulation-based techniques for implementing better building automatic operation procedures. Last but not least, we finish the paper with a summary of the conclusions obtained in our research work, and some reflections about the new approaches that are expected to be predominant in the field in the next years.

Data Science

Data Science comprises different numerical techniques aimed to automatically identify non-trivial, new, valid, potentially useful and understandable knowledge from raw data. It mostly involves mathematical and statistical data analysis supported by information technology tools. Despite this fact, the role of the human user is very important in Data Science: she is who provides expert and common-sense knowledge to guide the analysis, sets the parameter of the algorithms, and interprets the obtained results to make them actionable.

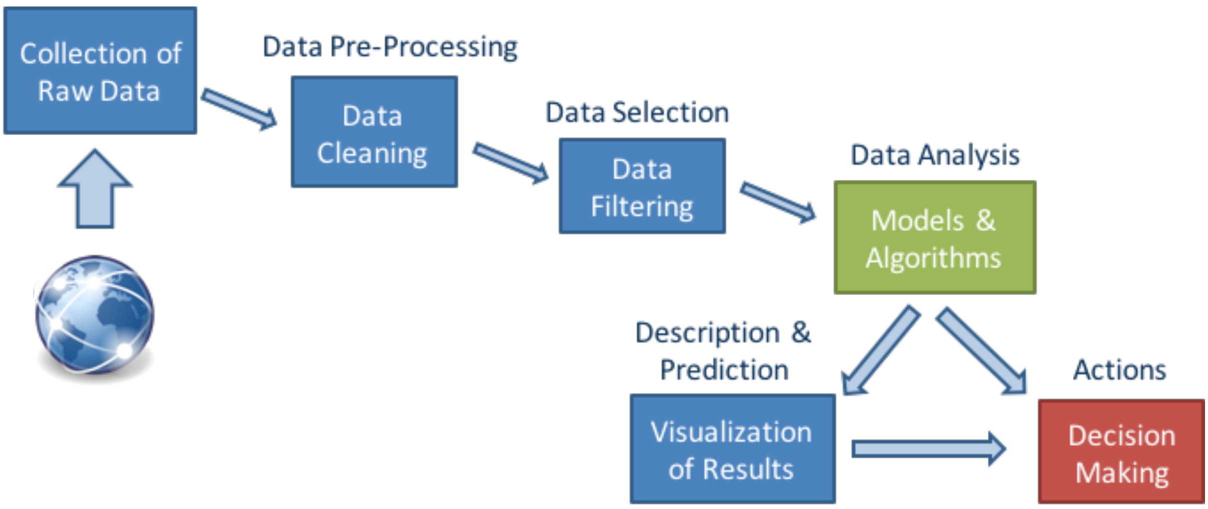

Figure 1: Data Science process

The typical Data Science process encompasses four steps (Figure 1): data collection and cleaning (pre-processing), filtering (selection), exploration and model building (analysis), and visualization (for data description and prediction). Here we focus on the analysis stage; for more information on pre-processing and visualization, references [4] and [5] provide, respectively, comprehensive reviews on these topics. Among the most commonly used techniques, we can find the following:

Classification

In classification, we start from a set of objects, each defined by a collection of attributes. Attributes are represented with computable values, typically numbers. Classifying an object consists in calculating the class to which it belongs on the basis of its attributes [6]. Decision trees are a common way of performing classification: they define a kind of flowchart based on attribute values that leads us to a class. Decision trees can be automatically built (i.e. *learnt*) from a set of already classified samples according to the amount of information conveyed by an attribute; e.g. how effective is to create object partitions based on the attribute values. In general, building a data model (particularly, a decision tree) from an already classified dataset is called *supervised learning.* Other widely used classification technique is Support Vector Machines (SVM) [7], which consider objects as points in a multi-dimensional space, and calculates an optimal set of hyper-planes to separate them.

Clustering

Clustering is the separation of objects into groups (clusters) based on an estimation of their similarity [9]. It is an unsupervised method, since there is no previous knowledge of the classes to which the objects can be assigned, or even how many of them we have. The simplest clustering methods are those based on assigning an object to the nearest cluster. The proximity is calculated by using a distance measure; e.g., the Euclidean distance of the values of their attributes. An example of distance-based clustering algorithms is k-means, which forms clusters by minimizing the mean distance between the objects inside them. A more sophisticated technique is hierarchical clustering, where clusters do not have a plain organization but rather they are arranged in cluster groups at different degrees of granularity. Clustering is often used as a first step in a classification problem when there is no training dataset with information about the classes.

Regression

Regression analysis is the estimation of the relationship between variables [10]. Firstly, regression methods calculate if the variables are statistically correlated by means of the standard deviation, Pearson correlation, and other correlation coefficients. Secondly, a numerical model of the dependency, if any, is created. This model can be used to predict how the values of the dependent variables would change when the others do. Regression methods can be linear, which assume that a variable can be modeled as a linear combination of other variables, or non-linear, which use more complex aggregation operators. Regression is particularly useful to predict the behavior of dynamic systems that evolve in time, since it can be applied to forecast the values of a time series based on past values. Neural Networks (NN) are also capable of building regression models. In contrast to numerical regression methods, they create black box models that are not directly interpretable, but can estimate the values of an output variable from input values. The NN models are tuned by using a backpropagation algorithm [8], which reconfigures the network links to minimize the error produced to interpolate the points of the training dataset.

Association

The concept of association is similar to that of regression, because it also aims at discovering relationships between variables. However, association methods do not rely on strong numerical models, but in quantifying value co-occurrences: the more co-occurrences appear, the stronger the association between the variables is. One of the most used tools for modeling and estimating associations are association rules. Association rules have the form $A \rightarrow B$, which means that A and B appear frequently and with high reliability together. The Apriori algorithm is the most widely used technique for extracting association rules [11]. It is based on the computation of two statistical measures: the support, which measures how many times A and B appear together in the database; and the confidence, which measures how probable is having B provided a transaction that includes A.

Most of the previously mentioned techniques have a fuzzy extension that allows them to manage imprecise and uncertain data [12]. Fuzzy logic allows a non-strict representation of object membership to a set, thus avoiding the problem of hard boundaries that are often present in basic techniques. For example, fuzzy k-means can assign an object to one or more clusters with a strength degree. Fuzzy approaches also produce more user-friendly representations of the extracted knowledge, since it can be expressed in linguistic terms closer to human understanding.

Applications

Building operation

Data Science techniques can be applied to exploit the tremendous amount of data generated by BMS. One evident problem is to support the building operators to make optimal decisions in their daily work. In this regard, decision trees have been used to generate IF-THEN rules from datasets of recorded successful strategies [16]. Association rules can be also employed to extract hidden correlations in control variables [17]. Building operators can interpret this not so evident knowledge to improve their management practices. The influences of equipment operation variables energy into consumption measures can be as well studied by using NN. Specifically, a prediction model can be built to forecast the functioning of the system under different hypothesis [18].

A second aspect of building operation is medium-term planning in relation to the architectural elements of the building and the equipment. Detecting and correcting energy loss imply considerable savings, but the reasons are not always easy to identify. Clustering techniques have shown effective in that aim, helping managers to find outliers and overall malfunctioning [19]. Similarly, decision trees have been used for classifying basic architectural elements, such as walls and ceilings, according to their energy performance in order to provide support to building designers [20].

Prediction of building energy loads

Energy load, or energy demand, is the amount of energy needed by the building in a certain period of time to operate. One important challenge in building management is to predict the energy load due to the HVAC sub-system. The energy required to operate the HVAC strongly depends on two factors: the internal loads, which refer to the heat produced by the building elements (equipment, people, lightning), and the external loads, which are influenced by external factors such as sun radiation and air temperature. Demand may not be uniform, and peak demands may happen when the building requires to be supplied with more electrical power than the average. These events are difficult to forecast, and produce several inconveniences, from inhabitant dissatisfaction to power outages.

Clustering and classification methods have been applied in the literature to characterize and group buildings according to their load profiles [13]. They have proved useful to make an initial estimation of the building behavior. Regression methods, in turn, have been commonly used to predict peak demands, usually in combination with other methods due to the high number of variables involved and the difficulty to build a regression model [14]. Recently, the role of the occupants' activities has been acknowledged as an important factor impacting the energy demand. This suggests that activity recognition methods could be exploited to incorporate this information into the energy load prediction methods [15].

Analysis of electricity consumption

A pillar of any energy saving initiative is to understand how and when people use energy in the building. Therefore, there have been several proposals aimed at analyzing energy consumption data to characterize energy user profiles, and to distinguish behaviors with the highest potential for implementing new energy saving policies. Not surprisingly, classification and clustering methods have been applied in this regard, in particular to identify consumption patterns in domestic setups [22, 23].

It is particularly interesting to find among electricity consumption patterns those that correspond to non-technical losses (NTL), i.e. failures in the measurement equipment, either accidental or product of fraudulent manipulation. Traditionally, classification, regression and association discovery methods have been used to identify these scenarios [24]. In several approaches, the focus is not particularly centered on modeling frequent behaviors, but on detecting anomalous inconsistent consumption patterns [25].

Use case: extracting association rules from buildings' big data

In the introduction, we have mentioned that energy management systems generate nowadays large datasets. The Data Science techniques presented in Section 2 need sufficient data to be effective, yet small enough to be manageable –being 'sufficient and 'small enough' quite imprecise and problem-specific terms. Big Data technologies have recently emerged to address the issues that appear when analyzing large datasets: volume, variety and velocity [26]. They allow us to reliably run Data Science algorithms in a distributed computing platform, which may even be virtual and transparent to the developers (in *the* cloud).

In a previous work, we proposed an algorithm that extracts association rules from very big datasets [21]. For illustration purposes, we have applied this algorithm to a database of sensor data collected from an intelligent building located in the center of Spain. The database contains more than 160.000 measurements (transactions) of more than 1.000 variables. The set of variables include temperature, humidity, power supplied by different electrical systems, status of cooling and heating systems, and energy consumption logs. Our objective with this analysis is to study the dependencies between the variables, and their impact to the overall energy consumption of the building.

Generally speaking, in data mining processes it is very important to engage the participation of the expert in order to elicit the most interesting relations, and particularly which of them were previously unknown, in order to implement new building operation policies. In this example we have followed a quite straightforward approach, but it is worth to mention that the expert building manager would have a more active participation in the process to provide support for tuning the algorithm, and more importantly, to interpret the discovered associations.

Before applying the rule extraction algorithm, the dataset was conveniently cleaned and pre-processed, following the workflow depicted in Figure 1. In this way, we prevent the problems that may arise in the first steps of the process, such as the management of missing values (time periods for which we do not have sensor data), or the configuration of the filtering process (to avoid losing information). Afterwards, the association rule mining algorithm was executed in a computing cluster with several combinations of parameters, thus obtaining in some cases thousands of rules.

Many of the extracted association rules corresponded to the expected correlations among variables, such as the intensity and the tension of an appliance. Even though these associations do not typically entail new information, they are useful to verify the normal functioning of the system, and to make explicit common-sense knowledge. Other correlations found between variables worth to notice are those corresponding to (sometimes unintentionally) redundant sensors.

Moreover, we found correlations between different equipment actuators; i.e., the configuration setpoints of a machine are directly dependent of those applied to another one. These dependencies helped us to identify fixed operation procedures. They can be helpful to identify inefficient routines, or conversely, to simplify the operation protocols by learning undocumented usual procedures. Other potentially relevant associations that appeared in the rule set may imply equipment faults; for example, we identified a relation between a specific smoke detector and the amperage demanded in one room. Cross-data analysis, enriched with information from the building information model (BIM), can be also very relevant to improve the whole data mining process. For example, location data can be used to know which devices are close, and therefore to study in more detail the interactions between them. Furthermore, incorporating architectural and materials data would remarkably extend the scope of our initial approach.

Conclusions

This paper has reviewed the field of Data Science and how Data Science techniques can be applied to building energy management. Specifically, we have focused on building operation, energy load prediction, and identification of consumption patterns. Our experiments show that Big Data technologies can solve the computational problems that appear when processing of large amounts of data, which are likely to have an increasing relevance with the advent of the Internet of Things –with smart meters and appliances fully connected to the Internet. However, the applications to real-world scenarios are still scarce. In our experience, one of the most important aspects to improve is achieving a greater involvement of the building managers in the data analysis process. To do this, future research work should explore two complementary directions, namely, showing the potential of Data Science to building managers, and developing more user-friendly algorithms and tools. In this way, we expect that new approaches will be less opaque, easier to use, more customizable, and above all other features, more engaging.

Acknowledgements

This work is partly funded by the Spanish Government (TIN2012-30939 project), the European Commission (FP7 Energy IN TIME project, grant agreement no. 608981), and the University of Granada (Programa de Proyectos para la incorporación de jóvenes doctores a nuevas líneas de investigación).

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Data gathering and architecture aspects of a major EU wide energy efficiency project for SMEs

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Abstract

"Support and Training for an Excellent Energy Efficiency Performance" is a 3-year European project helping over 600 European cross-sector small and medium sized enterprises (SMEs) to reduce their energy use and become more energy-efficient. Companies participating in STEEEP benefit from tailored training and guidance on effective energy management tools and best practices provided by an established network of energy advisors from Chambers of Commerce and Industry (CCIs) in 10 different countries. SMEs in many EU countries employ over 90% of the workforce, so improving the energy efficiency of EU SMEs is therefore compelling, with clear advantages for the European economy. Energy efficiency in SMEs previously received less attention than in larger companies, the public sector and dwellings. Previously, policymakers had little energy (and related) data for SMEs, making prioritising ways to support energy conservation difficult. In addition staffing resources and knowledge levels with in SMEs frequently determine the level of commitment to energy efficiency and implementing EU energy and climate policy. , with a dedicated or even part time energy manager for many SMEs a rarity. The STEEEP project aims to help this by introducing training to SMEs via CCIs, and monitoring savings and providing feedback to SMEs. Crucial to this is the benchmarking of energy use: Basic data about the SMEs, the SME's energy consumption, and information about the SME policies and procedures relating to energy were gathered form each of the over 600 participants. Managing these data is a considerable task, notably in several languages, using combinations of numeric, free text and other data, gathered through questionnaires. It is not merely fiscal metering data, and supporting information that are gathered, we ask for from occupancy, to building types, and to complete the energy management matrix. We describe how this is done; the data processing . survey design, initial data gathering, benchmarking, and database architecture. Energy use is gathered as the project progresses , with interventions and changes captured. This paper describes the methods used and presents lessons learnt. This include the process of collecting , storing and analyzing the data from over 600 SMEs in 10 different countries. It identifies how barriers were overcome and how information from the data collection is being used by Chambers of Commerce and Industry to help reduce energy use of SMEs

Introduction

Within the context of EU Energy and climate policies, the case for energy efficiency is compelling. The STEEEP (Support and Training for an Excellent Energy Efficiency Performance) project began in March 2014, involving EUROCHAMBRES, 35 Chambers of Commerce and Industry (CCIs) from 10 different European countries and the Institute of Energy and Sustainable Development, De Montfort University (DMU) [1]. These would provide 630 cross-sector SMEs with tailored training and guidance on effective energy management practices and tools, taking into account specific regional needs, enabling SMEs to approach energy management in the way that traditionally larger organisations have been able to [2]. A key part of the project is to be able to measure progress of SMEs, of different sizes, in different sectors in different countries. Our approach to this is to produce a series of benchmarks from the data that we collect.

Crucial to the process of producing a European benchmark for SMEs, is to receive a representative sample of each with respect to industrial classification. While utility datasets are large, information for energy efficiency improvements is rarely gathered, data being restricted in the main to fiscal billing. Published data for benchmarking for nondomestic buildings has tended in the past in most countries to concentrate on the public sector, so buildings such as council offices, government buildings, schools, are usually well represented [3]. However, the manufacturing sector has been frequently under represented with often insufficient samples in national nondomestic stock databases to produce sensible figures for benchmarking [4]. This a major contribution of the STEEEP project. The number of SMEs involved means that this may be regarded as significant - from this it should be possible to pursue various levels of disaggregation with industrial classification codes to compare companies against their peers, as long as we have sufficiently representative sample numbers.

The approach described here in terms of data gathering is aimed at partner countries, this is due to the project structure since CCIs in partner countries receive project data, and while data will then be fed back to partners the same way, the benchmarking process itself may disregard countries and concentrate on industrial classifications. This builds enough sample numbers within the dataset for each classification type to perform useful benchmark calculations. The NACE descriptors [5] for industrial classification represent an extensible system of taxonomy for business types of SMEs. The codes can be used to describe the general area of activity, for example manufacturing, or finance, and subsequent extensions to the code may be used to describe company activities in more detail. Therefore, should a low sample number exist for a particular kind of disaggregation of company activity, we can achieve a broadly sensible result for benchmarking, albeit with slightly reduced precision, by moving up to the next level of aggregation for benchmarking purposes. For example, from mining organisation we may move from the mining of a specific mineral as described in the classifications, to, for example, general opencast mining. A reduced version of the codes was applied to improve the functionality of the long questionnaire, to reduce the load on translation for each country's version, and to remove unnecessary activity types which would not apply to the companies recruited for the project.

Qualitative Benchmarking

The Energy Management Matrix (EMM) came into existence in the mid-1990s as a means of assessing the state of organisation of businesses with regard to certain key areas for responding to energy issues [6]. A major advantage of EMMs, is that they can quickly identify areas of excellence, and likewise, areas that needs improvement. By continually reassessing and using an EMM, performance can be tracked over time. EMMs can also be used to benchmark a business's organisation against that of other businesses. Despite the functionality of this tool, there is precious little literature relating specifically to EMMs, evenoutside the context of the EU. There are some case studies that highlight the importance of EMMs, Zastava, a Serbian car manufacturer was able to achieve a remarkable 25% reduction of total energy use in the factory. The EMM was credited as a very effective way of quickly identifying areas in most need of attention [7]. A study conducted on the work of Envirowise notes the utility of EMMs. They noted that when EMMs were incorporated into a survey of UK businesses, 30% of companies had a strong energy management policy, yet only 10% were taking effective action [8] [9]. A sample EMM is shown below in figure 8.

LEVEL	POLICY AND SYSTEMS	ORGANIZATION	MOTIVATION	INFORMATION SYSTEMS	TRAINING AND AWARENESS	INVESTMENT
4 Multi-national	Formal energy / environmental policy and management system, action plan and regular review with commitment of senior management or part of corporate strategy.	Energy / environmental management fully integrated into management structure. Clear delegation of responsibility for energy use.	Formal and informal channels of communication regularly exploited by energy / environmental manager and staff at all levels	Comprehensive system sets targets, monitors materials and energy consumption and wastes and emissions, identifies faults, quantifies costs and savings and provides budget tracking	Marketing the value of material and energy efficiency and the performance of energy / environmental management both within the organisation and outside it.	Positive discrimination in favour of energy / environmental saving schemes with detailed investment appraisal of all new build and plant improvement opportunities
3	Formal energy / environmental policy, but no formal management system, and with no active commitment from top management	Energy / environmental manager accountable to energy committee, chaired by a member of the management board	Energy / environmental committee used as main channel together with direct contact with major users	Monitoring and targeting reports for individual premises based on sub-metering / monitoring, but savings not reported effectively to users	Programme of staff training, awareness and regular publicity campaigns	Same pay back criteria as for all other investments. Cursory appraisal of new build and plant improvement opportunities.
2 Family owned	Unadopted / informal energy / environmental policy set by energy / environmental manager or senior departmental manager	Energy / environmental manager in post, reporting to ad-hoc committee but line management and authority are unclear	Contact with major users through ad-hoc committee chaired by senior departmental manager	Monitoring and targeting reports based on supply meter /measurement data and invoices. Env. / energy staff have ad-hoc involvement in budget setting	Some ad hoc staff awareness and training	Investment using short term pay back criteria mostly
1	An unwritten set of guidelines	Energy / environmental management the part-time responsibility of someone with only limited influence or authority	Informal contacts between engineer and a few users	Cost reporting based on invoice data. Engineer compiles reports for internal use within technical department	Informal contacts used to promote energy efficiency and resource conservation	Only low cost measures taken
0	No explicit policy	No energy / environmental manager or any formal delegation of responsibility for env / energy use.	No contact with users	No information system. No accounting for materials and energy consumption and waste	No awareness raising of energy efficiency and resource conservation	No investment in increasing environmental performance / energy efficiency in premises

Figure 1 - Energy Management matrix [8]

Data Gathering

The project consortium or Eurochambres, the CCIs and DMU agreed on a common methodology to collect relevant data from SMEs, using two questionnaires - data were collected via the submission of an initial online questionnaire, with updates on energy use and any changes made, via a shorter online form, every two months.

(Initial) Long Questionnaire

Energy benchmarking methodologies and data are relatively scarce for industry, and even more so for SMEs, with some areas of industry represented little in non-domestic energy datasets [3]. The first in a set of two questionnaires focuses on the nature of the SME and its energy and building use. Specifically, it asks for information on the participating company (e.g. sector of activity, level of activity), descriptions and readings of its energy meters, information on past energy use, basic energy use and relevant production data, or any other quantifiable data that energy use may be measured against [10]. To make accurate energy saving recommendations, it is necessary to understand existing demands on energy, notably if they vary from one year to the next [11], so questions are included on local climate, building occupancy and building use, indeed, all data needed to produce an energy benchmark from a potentially disparate set of data [4]. Technical building services, such as ventilation and compressed air, can use more energy as a constant load than production in some cases , so the questionnaire asks about these, also the presence of any heavy machinery or plant [12], and building characteristics [13]. The second part of the questionnaire gathered qualitative data on the organisational culture of supported SMEs with a view to reducing energy use. Mere technical interventions only take us part of the way towards serious energy use reduction, and taking human factors into account allows us to give better advice on energy efficiency, including maintaining it . Questions relating to the Energy Management include presence and type of energy policy, organisation, the level of staff training that may or may not have been given, types of performance measurement, level of communication and type of investment.

Further questions would analyse motivations, attitudes and perceptions of control of participating SMEs. Questions will show if SMEs are motivated to change their energy use, have a positive attitude towards saving energy, and their level of knowledge on energy efficiency. Comparing attitudinal behaviour with actual energy data will support the related evaluation and recommendations for effective energy strategies.

The questionnaires provide 490 columns of data, some which may be empty, since it allows for up to 10 streams (from different meters) of energy (building) data, the same for energy (production) data, and multiple buildings, with subsets of data for each, such as fuel type - in general, most SMEs tend to have a maximum of two energy meters (gas and electricity), with many having electricity only. The main question groupings are summarised below in table 1.

Table 1: Long Questionnaire (up to 490 data entries in total)

Question Group	Question types
Operational	Company name, contact information, location (address)
Benchmark	Building details, square meterage, company type, location (lat, long)
Building Physics	Building construction, height, plant, treatments (e.g. air conditioningg)
Energy (Building)	Main meters, meter reference numbers, meter types, previous data, fuel type, connected buildings or areas
Energy (Production)	Main meters, meter reference numbers, meter types, previous data, fuel type, connected buildings or areas
Qualitative	Energy Management Matrix and supporting data
Supporting data	Multi use buildings, seasonal occupancy or use

Short questionnaire

This short questionnaire was designed to be much quicker to fill in, asking seven questions on energy use, production or similar performance indicators and weather (Table 2). Also, SMEs report relevant information on any energy conservation intervention or investment, and any events which may have affected the pattern of energy use. Operational details, such as change of the main contact on site, will also be gathered. The form is integrated on the STEEEP website. All companies have a personal account and password to access the short questionnaire. After the first submission, businesses may see the history of their entries and, consequently keep track of their own energy use. Both questionnaires have been translated by partners in 10 different languages to facilitate SMEs to report the requested data. Apart from English, translations were made into Croatian, Dutch, Estonian, French, German, Hungarian, Italian, Latvian, Romanian and Spanish.

Table 2: Short Questionnaire

Question group	Question types
Operational	Company name, company ID number
Energy (Building)	Main meters, meter reference numbers, meter data
Energy (Production)	Main meters, meter reference numbers, meter data
Supporting data	Any changes to be made to Long Questionnaire data, details of any energy savings

Data handling

A spreadsheet was used as the main 'terminal' to the software, such that hand-cleaning of all data is straightforward. However, it must be remembered that no calculations are to be carried out within spreadsheets, which are then useful to the flat file database. The spreadsheet therefore is simply used as a visualisation and editing too, with GNU Octave used for the detailed analysisThe following physical data flow diagram (figure 2) shows how software fits together for processing of long questionnaire data.

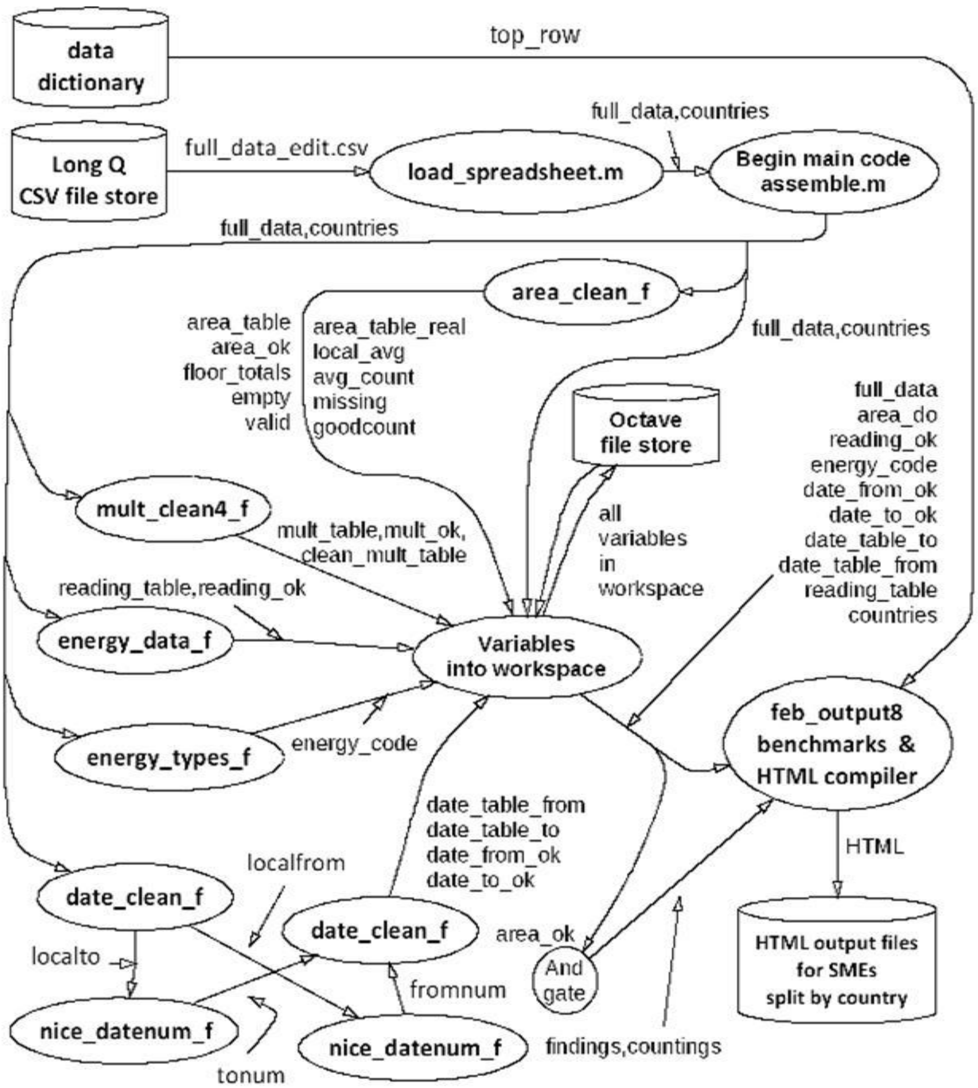


Figure 2 - Benchmarking dataflows

Floor areas are extracted from the data using a custom algorithm (area_clean_f in figure 2). These data need cleaning since many errors arise, for example sometimes text is mixed in with data, and a reference to be appendix will show parts of software which are used to remove frequently occurring words in all languages. Sometimes an SME may have indicated, for example if a floor area is approximate, e.g. "3453 SQ.M APPROXIMATIV", although the position of numbers within text descriptors is not a given. However, while such details are preserved in a copy of the full_data array (because it is good practice to preserve raw data), text cannot be processed by machine of course to input to the equation which calculates benchmarks. So floor areas are checked by hand just in case any text data is given which could hamper data processing.

The ISO format for presentation of numbers is not adhered to routinely across Europe, What is certain is that the variation in presentation of numbers between countries can be significant, for example a "." or ",", may be used as the decimal separator in some countries, and a corresponding "," or "." may be used as 1000 separator in these same countries. Conversely, most software for processing numbers available from the UK and the USA uses a "." as a decimal separator, and sometimes a "," as 1000 separator by default. Conversion between these systems is easy to manage. However, to compound this, sometimes a space is used as 1000 separator, anathema to processing of text to numbers, and in some participating countries, symbols such as "" may be used with 1000 separator too. To this end, floor areas, energy usage and other key variables are machine cleaned, but subsequently checked by hand as part of the project's quality control strategy.

Cleaning of data for meter reading dates is rather more complicated. Date data have been provided whereby it is usable, but sometimes a string of numbers or text were entered by some SMEs - a text to date function (nice_datenum_f in figure 2) runs in an error trap wrapper, which has a fairly high processing overhead and runs slowly, but only needs to run once, the whole dataset processed in around 10 minutes - the function exports dates from and to the meter reading purposes, so that we can count the number of days between meter readings and use this to calculate benchmarks or so tables are produced to let us know whether or not the entered dates are usable.
Variables are then placed in the Octave workspace, whereby they can be viewed, and saved/backed up. The full data set exported to HTML compilation includes the full data itself, cleaned data tables, and all arrays which indicate whether or not the data from a company is usable. This is so that benchmarks are not generated from missing data, with simply an error message sent back to the SME.

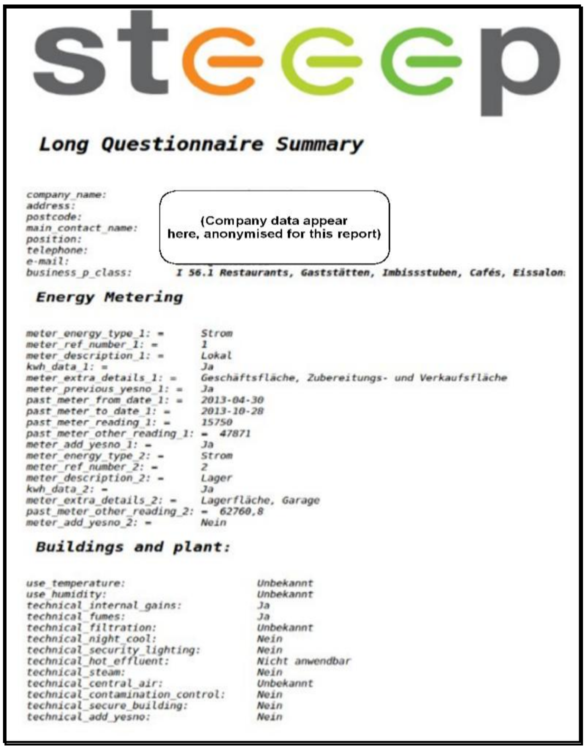
The main data types which are captured are for electricity, gas, oil, liquefied petroleum gas, biofuels/ biomass, none, or to query the energy type. We noticed that some SMEs are still using coal so this will need updating. A mixture of upper and lowercase characters appear in the survey data here, which cannot be processed normally, so all data cells must be extracted and made into lowercase before processing. The software then translates fuel types from every language in the project (energy_types_f shown in figure 2), which is relatively straightforward since many similar letters appear in each country's word for electricity or gas, so we can run searches on abbreviated versions. An output log file is also generated which is available to read for anybody who may find it useful showing a detailed description of all meters and meter data types for every company.
The function energy_data_f (figure 2) is used to check whether meter readings can be used for benchmarking, and to check where the units are in kilowatts, cubic metres, and so forth. When an empty cell is encountered, should further metering data be added in the short questionnaire, a message is generated that this needs to be done. Where text appears in the multiplier type, then this is logged. So, as the software is running, it reports on finding empty cells, whether a cell contains text, if there is a validated meter reading for benchmarking, or if something else appears in the meter reading cell. This function also generates a log file which is available for SMEs, or CCIs.
Company names cannot be used as the primary key to search for their details, since companies may type names in differently between the long and short questionnaires. Assigning a number, while errors may still take place, reduces ambiguity [Some Aspects of a Framework for Energy Data., Brown et al, 2012].

New companies are best grouped by country, and physically grouped in data tables with their counterparts. Sequential numbering would mean that companies could only be added at the end of the main data block, making any visualisation or direct printing difficult. The solution to this therefore

is to leave a gap between ID numbers, such as was done in the early days of programming where line numbers would increase by multiples of 10, so that spare lines could be inserted. Should any particular line need to be ignored this is not deleted from the main data table, or rather is represented by a signal in a separate array which lets the software know whether it should process or ignore the entry for a particular company. This also is used to remove duplicate or test entries, but at the time of final processing only. It follows that grouping by country may be allowed for each identifier as an extra data quality check. The quickest way to do this is simply to add the international dialling code for each company.
Thus the identification structure is:
Incremental ID, country dialling code.

Output

Benchmarking software produces summary files in HTML (Figures 3 and 4) - this enables connection between any further glue code, databases, and word processors with formatted printed output for SMEs - also it means that automated import of graphics such as plots of energy use are possible. Once all data were cleaned, it was possible to load these processed results into a PostGreSQL database, with a skeleton copy of the Octave processing code used to continue to produce HTML containing long questionnaire data (and processed data / information) for SMEs, including energy use, energy benchmarks, where available, and this is also where any energy-saving recommendations may appear. To extend this process to handle short questionnaire data is a relatively simple process requiring an extra import, and an extra processing module. This will then be used to produce a series of benchmarks for each company, whereby it will be possible to track any increase or decrease in normalised energy use.



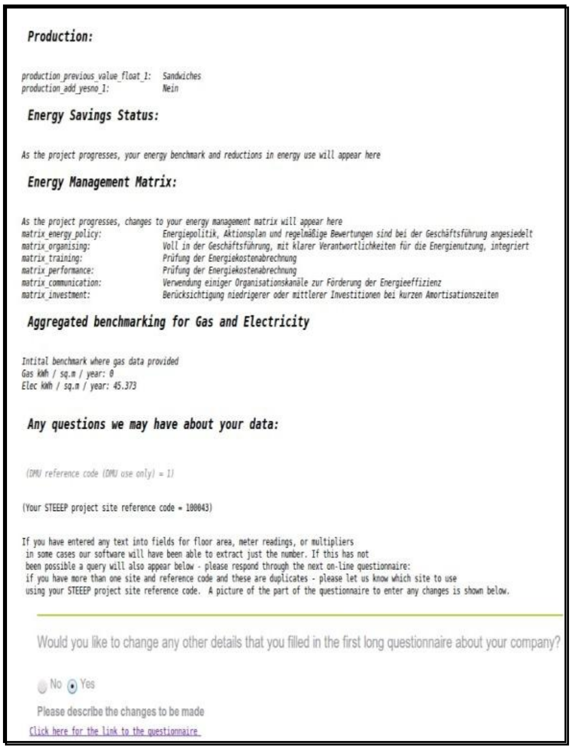


Figure 3 (left) Sample Page 1 of HTML, Figure 4 (right) Sample Page 2 of HTML

Data snapshots

This is a method paper but nevertheless it is still interesting to present results at this stage, notwithstanding of course final results from interventions remain to be seen. Figure 5 shows the distribution cohort wide of SME types by NACE descriptors, and shows a healthy sample size for manufacturing, which has been previously under represented in many datasets.

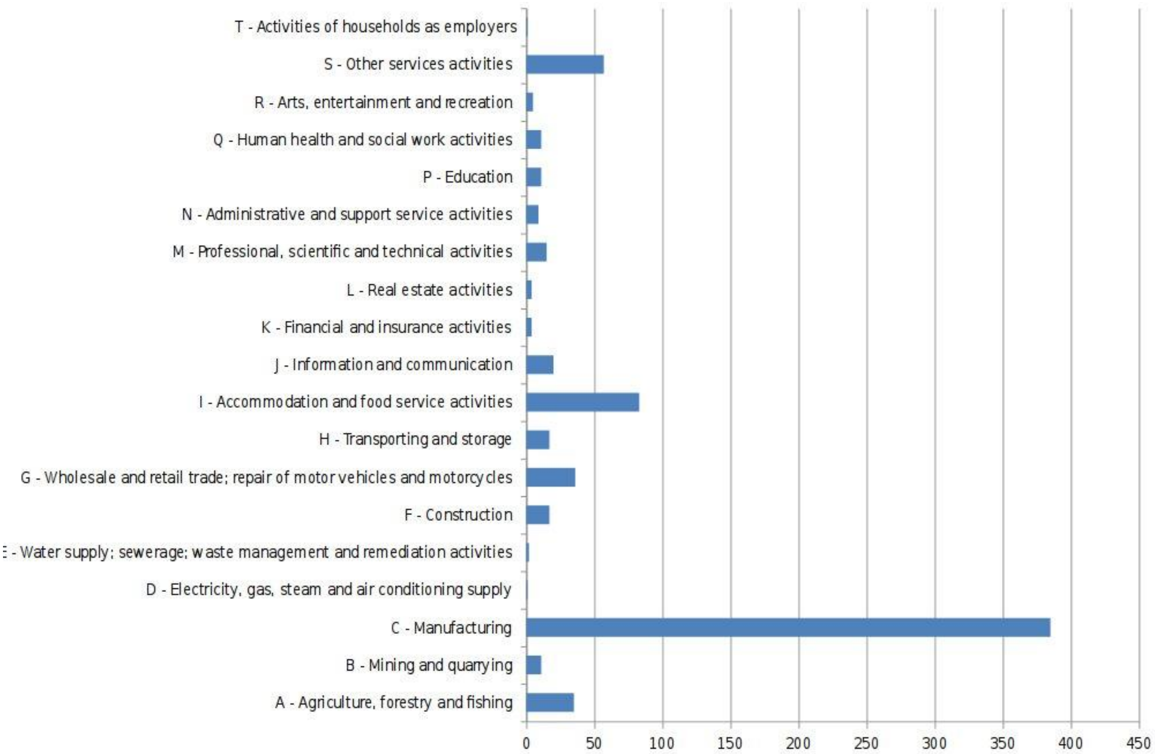


Figure 5 – Cohort by NACE grouping

Quantitative Benchmarking

Sample benchmarking results are shown below in figures 6 and 7 for gas and electricity use across the whole cohort by count. These data refer to 2014 and before.

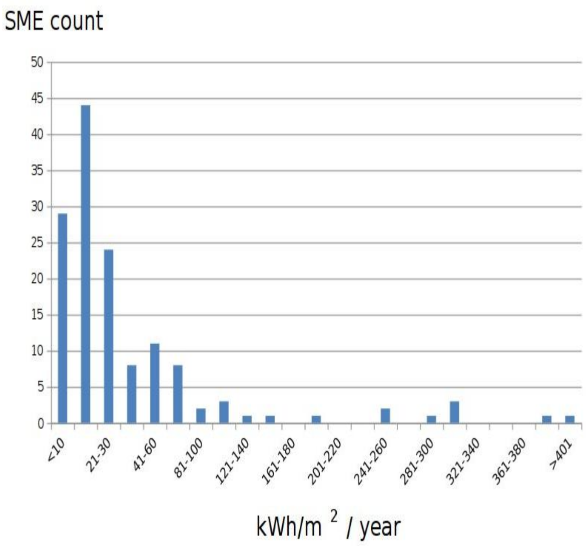


Figure 6. Benchmarking for electricity

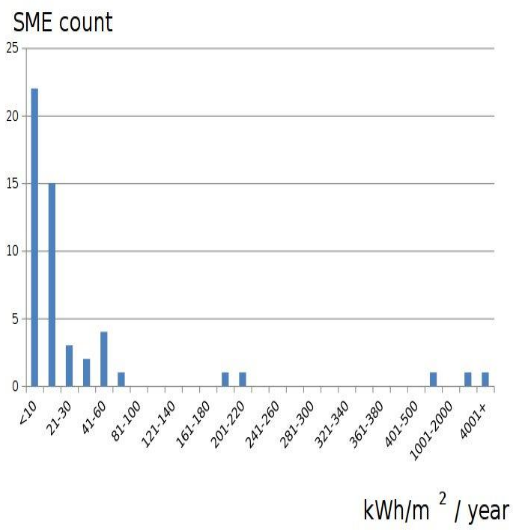


Figure 7. Benchmarking for gas

Qualitative benchmarking

Figure 8 shows the results of an EMM survey of the whole cohort, on first viewing, confidence in investment appears to stand out as higher than other factors, but the overall picture is not especially clear - what becomes fascinating is when grouping all data by country and averaged EMM, as shown in figure 9, which shows clear needs for training and communication. This suggests strongly that these data validate the ethos of increasing training in energy efficiency in SMEs.

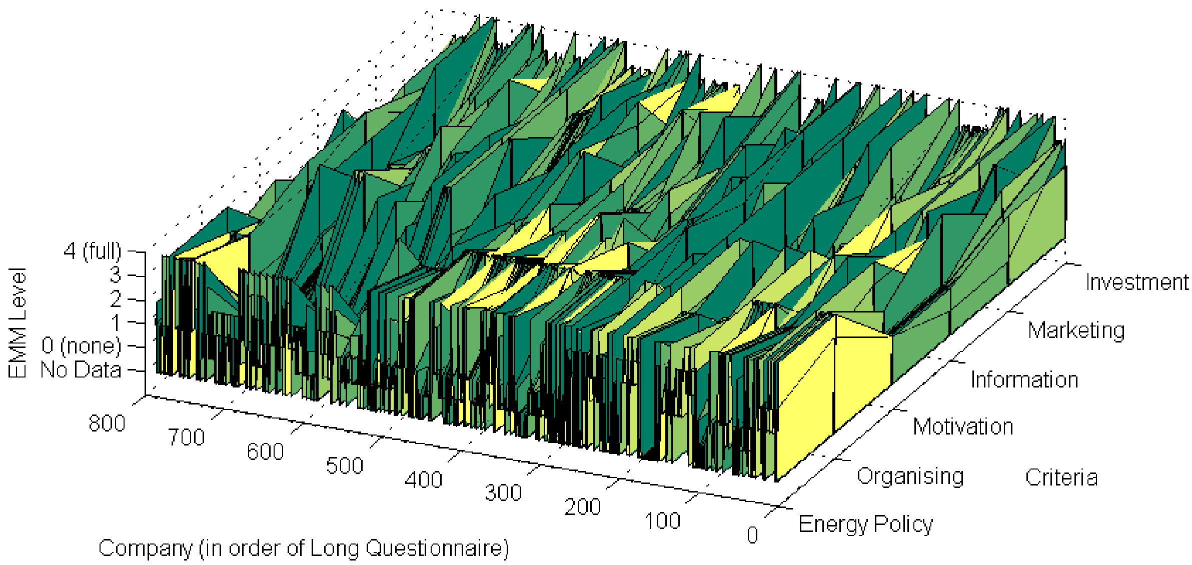


Figure 8 - EMM values for whole cohort

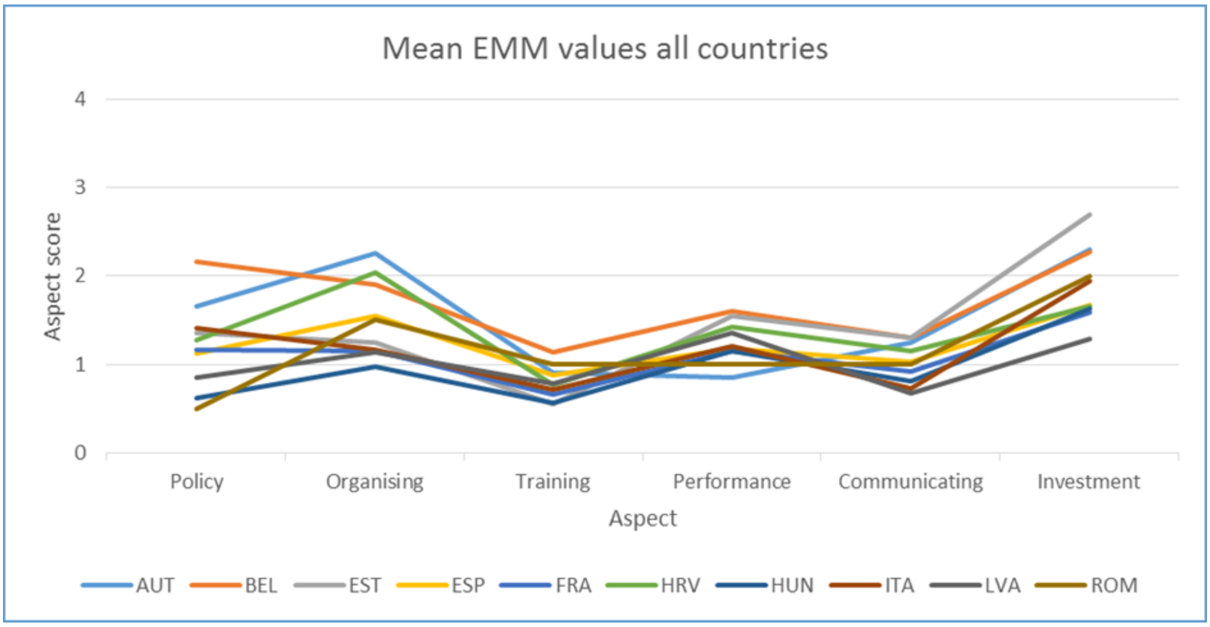


Figure 9 - EMM values averaged by country

Analysis by country and by NACE sector has shown that in general, EMM data are too noisy to draw firm conclusions geographically or by sector, which makes the mean values particularly interesting. Future work will involve looking for correlations between qualitative and quantitative benchmarking, as well as benchmarking on production.

Conclusions

We have presented an effective methodology for initial data gathering and energy benchmarking for over 600 EU wide SMEs. Crucial to any project of this scale is to budget effectively for data preparation and cleaning, notably when data are collected in many languages. A hybrid approach to this may automate much data preparation using scripting languages (such as Octave) before data are loaded into a relational database. The usefulness of a joint approach combining quantitative and qualitative benchmarking is to be explored as benchmarking progresses.
The effectiveness of gathering data by questionnaire for the project has been proven, and engagement from SMEs is very encouraging, with participants continuing to regularly submit data.

Enthusiasm for energy efficiency amongst SMEs strongly suggests that this area of energy efficiency, arguably overlooked in some cases in the past, is an area where resources for saving energy whilst maximising productivity may be well spent. As the effects of training and interventions become known, the next step for data analysis is a longditudinal study to analyse energy savings.

Acknowledgements

The work described in this paper was undertaken as part of the project STEEEP : Support and Training for an Excellent Energy Efficiency Performance, project leaders are EUROCHAMBRES, Avenue des Arts, 19 A/D , B1000 Brussels, Belgium, Duration: 01/03/2014 to 28/02/2017, EU funding Contract number: IEE/13/844/SI2.675838. The project website is www.steeep.eu
The authors would like to thank all project partners, CCIs and SMES for their cooperation.

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Increase of efficiency impacts by goal-orientation-based user segmentation

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Abstract

Urban areas are a key destination to reduce CO_2 emissions in a cost-effective manner. To enhance building energy performances at district and urban level the EU-funded project iURBAN tests an ICT tool which addresses increasing market demands for cheaper, cleaner energy services by targeting on behavioral change. While previous interventions report challenges to motivate users to engage actively, this paper presents research on the psychological factors to address users according to their prevalent goals. As goals are considered an important predictor and thus motivator of behaviour, this research identifies specific goals for two consumer segments. Empirical evidence draws on six lead user focus group discussions in the two European cities, Rijeka (Croatia) and Plovdiv (Bulgaria). We conclude that the two segments carry a set of multiple and different goals towards smart energy tool usage. The energy citizen persona which is highly motivated and interested to save energy can be engaged by approaching the goals: learning, mastery, energy savings, financial savings and control. In contrast, the energy consumer, who lacks general interest and responsibility, will participate if financial rewards, guidance and user-friendly tools are provided. The paper discusses the empirical data with strategies to integrate the social scientific findings with technological solutions to provide personalised approaches for behavioural change.

Introduction

Presently, approximately two-thirds of total primary energy is consumed by the half of the world's population which lives in urban areas. Globally, this consumption causes over 70% of energy-related carbon dioxide (CO2) emissions. The global energy consumption of buildings, both residential and commercial, has progressively increased reaching figures between 20% and 40% in developed countries, and has together exceeded the other major sectors such as industry and transportation [1]. This shows that urban areas are key areas to reduce CO_2 emissions in a cost effective manner whereby energy-efficiency in buildings is nowadays a major target for policy at national and EU levels [2]. In addition, the integration of district heating and cooling and renewable energy sources (RES), demand response and smart grids would enable CO_2 and energy savings [3].

With the installation of smart meters and information & communication technologies (ICT), consumption and production data on heating and electricity can offer new services to energy consumers, thereby potentially influencing occupant behavior, improving the technical operation of the energy distribution system, and generating new business models for utilities and system operators. To enhance building energy performances at district and urban level the EU-funded project iURBAN tests a tool which addresses increasing market demands for cheaper, cleaner energy services. iURBAN integrates a smart Decision Support System (smartDSS) that collects real-time or near real-time data, aggregates, analyses and suggests actions of energy consumption and production from different buildings, renewable energy production resources, combined heat and power plants (CHP), electric vehicles (EV) charge stations, storage systems, sensors and actuators. The consumption and production data is collected via heterogeneous data communication protocols and networks. The iURBAN smartDSS through a Local Decision Support System (LDSS) allows citizens to analyze the consumptions and productions that they are generating as they receive information about CO_2 savings and advices in demand response with the intention to change their consumption behavior. In addition, utilities, ESCOs, municipalities or other unauthorized third parties receive a Centralized Decision Support System (CDSS) which allows them to continuously get energy snapshots of the city, manage energy supply and demand, forecast energy consumption and thus plan new services or infrastructure. In iURBAN, the smart system includes smart energy services, such as feedback [4], peer comparison [5] and demand response [6], being designed with the direct involvement of end users - local residents, energy companies and public administration.

The imperative of consumers should take more efforts in energy efficiency

Our research presented here particularly addresses residential consumers and their behavior, recognizing that they are now being allocated a more active role in energy management in their homes and that behavioral change is as much required as technological systems to achieve the high energy efficiency targets set by the EU [7]. In particular, we are investigating how to best approach users and identify what actually their motivation is to use smart ICT tools for changing consumption behavior. Why is this important? Because research has found that many energy-efficiency projects still fail in approaching the complexities of social practices [8]–[10]. There is evidence that not all consumers are actively engaged, despite even having pro-environmental values or attitudes [11]. Despite some knowledge and research into the psychology of energy consumption behavior and user engagement, many energy-related projects are still challenged to motivate users to participate [9]. Recognizing that most consumers still remain passive participants, there are increasing efforts to finding functional ways to motivate users to engage in energy-efficiency, for example by offering increased information through offering energy feedback systems in web-portals or in-home displays as well as by offering monetary rewards [12], [13].

We argue that there is actually a stigma of existing projects and services that actually aim at active consumer engagement but design their systems in a way that do not support or satisfy consumer intentions. Almost all studies about feedback and behaviour or practices related to electricity consumption, carry - almost unreflected – the notion that energy consumption feedback is something, consumers absorb passively. The recipients of the energy feedback were seen as a globally reactive individual "doing something" with the feedback which would turn out the end product electricity saving [14]. There is often a used imperative when consumers are asked to change – being considered as passive receivers and accepters of new technologies. However, efforts of researchers, industry and policy makers can get misdirected, if consumers do not act according to the pre-made assumptions.

Theoretical framework of changing the imperative to goal-orientation approaches

This asks to change the perspective from anticipating what the user should do towards designing systems which support users in their own intentions and what they want to achieve with such tools. In order to develop a solution that becomes successful and useful, it is thus indispensable to understand the motivations of people that make them use energy feedback systems (or ICT services) and to change behaviors. Energy feedback in this paper is defined as any information related to energy consumption that a consumer can use to learn about his performance and improve it accordingly. It may include real-time data, historic consumption overviews, peer comparisons, demand response or serious games provided through ICT. Using feedback systems shall enable consumers to take decisions in an environmentally-friendly manner based on a chain of actions where a stimulation of frequent and persistent usage of feedback systems enables household members to change their behavioral patterns [15].

What does affect users to seek feedback and to become an energy co-manager? Recent research has increasingly investigated the reasons for user engagement by investigating individual goal orientations as well characterising consumer in a consumer segmentation approach. There already exists mainly qualitative research on identifying individual motivations of users [15], [16] recognising that there does not exist *the* one user [17].

Through previous research various goals could be already identified why people would be willing to seek feedback from an ICT tool. Some relate directly to energy consumption – whereas other goals do not. For example, [16], [18] found that goals can be of financial nature (e.g. saving money by reducing energy consumption), but also related to saving electricity for environmental reasons, discovering technologies, or to have fun. Another, quantitative study has identified the goals of having fun, controlling and reducing costs, learning to save energy, and avoiding inconvenience, which showed that people pursue multiple goals at once which differ across different user groups [19]. In psychological research and practices, it is a central assumption that planned behaviour is strongly affected by a person's intentions and goals to perform the specific behaviour [20]–[22]. Therefore, we focus on individuals' goals towards energy feedback usage to examine the anticipated manifold antecedents of feedback usage behaviour. Goals are considered to be internal and subjective processes and states [23], initiating cognitive and behavioural actions [24], [25]. We expect these goals to be essential antecedents of subsequent feedback usage behaviour leading to energy efficiency practices.

Other research approaches shed light on differentiating users to characterise different kind of users. On the one hand, people show interest and passion about saving energy in buildings whereas other people are not interested. The distinction of the two user groups *energy citizen* and *energy consumer* offers a practical approach to separate differently motivated users [17]. Like so, the energy consumer can be described having a low intrinsic motivation to engage in energy issues. In contrast, the energy citizen has already a high intrinsic motivation. Intrinsic motivation can be described as undertaking actions that are rewarding in and of themselves [26]. Based on this segementatin, they suggest to apprach both personas according to their characteristics. Whereas Goulden et al presented findings about the general characteristics of the two groups, this investigation aims to additionally provide details about their internal goals and thus motivations for using any type of energy feedback.

This paper aims to extent the existing investigations by analysing: Which goals drive the behaviours of the two consumer segments? As goals and consumer segments have ben analysed seperately previously, little is yet known about which goals are pursued by which types of users. Therefore, this research connects goal orientations with customer segmentation to offer a practically relevant framework for developing ICT tools targeting on individual motivations. This more differentiated approach shall provide support in designing energy-efficiency programs or systems tailored to consumers in order to increase the effectiveness of future interventions.

In the following, a qualitative analysis of focus group discussions will offer an insight into the different goals users have when addressing the issue of energy management in their homes. This will be discussed with existing research and implications for practical intervention will be highlighted. Finally, the conclusion will summarize the findings and provide an outlook.

Study: Goal-orientation frameworks for energy citizens and energy consumers

This chapter deals with the empirical research exploring people's goals of energy citizens and energy consumers. Empirical evidence draws on the analysis of six focus group discussions using the Grounded Theory approach [27]–[29]. The focus group discussions formed part of the co-development process of designing ICT-related energy feedback systems in iURBAN. They took place before the actual pilot implementation so as to facilitate the inclusion of end-users' needs and feedback in the development of smart energy services and to consider consumer goals prior to an energy-efficiency intervention. The aim of the empirical investigation was to identify goals specific for the two types of users in order to better approach consumers for ICT related feedback systems.

Data collection and analysis

Data were gathered through moderated focus group discussions from March 2014 to April 2015 in the iURBAN pilot cities Rijeka, Croatia and Plovdiv, Bulgaria. They all took place during the first year of the 3-year project. As regards this study, five focus group discussions were held in Rijeka and one discussion in Plovdiv. We have included the Bulgarian example because the opinions of those users were also considered relevant for the scope of this analysis. This complies with the GT approach as data collection ends only when the study has achieved theoretical saturation. [29]. Generally, the GT method is an inductive approach where findings found in practice, i.e. the empirical material, are translated and generated into a theory [27].

Given the complexity of the field, it was important to recruit people who are knowledgeable about energy and technology, since the needs for smart energy services have yet to fully emerge in these countries and represent largely-futuristic concepts to most consumers throughout Europe [30], [31]. The lead-user methodology, first introduced by von Hippel in 1986 [32], [33], assumes that, for a given scenario, there exists a sub-group within the larger target group of all users, the so-called "lead-users". They seem to be especially adept at identifying problems and innovating appropriate solutions, especially involving technical issues. Involving lead users has the advantage that they are usually at the forefront of adapting to improved behaviors, adopting new trends and knowing how to use cutting-edge technology. They can furthermore be described as users who exhibit relevant real-world experience, would strongly benefit by enacting change and can provide accurate data about the matters at hand [32], [33]. In this research, we have recruited individuals who fulfil the following screening criteria: they are open to technological and behavioral change, can provide constructive criticism, are willing to participate and discuss, and either live or work in the pilot buildings of the project, ideally also having some understanding or experience in the scenarios we discuss. The participants were recruited by phone and email with the help of the local energy provider, municipality and energy agency in each city. In total, 42 citizens participated, among which 33 were men and 9 were women.

The focus group discussions took place in the evening hours and had a duration of approximately 2.5 hours each. A question-manual was prepared in advance to serve as a rough script in facilitating the discussions, starting with an introductory round, ice-breaker games to develop a sense of community, summary presentations about project plans, initial discussions of people's heating needs and habits to serve as an orientation on subsequent discussions, evaluations of the specific energy services and their benefits, and a final round of discussions to close the workshop. Creative working sessions (e.g. users fashioning their own product via collages and drawings) also served to stimulate a deeper exploration of the technological functionalities and helped to make energy consumption more visible and vivid to all. The discussions were conducted bilingually (English and Croatian, as well as English and Bulgarian, respectively), recorded and afterwards transcribed into English.

From the transcripts that represented the discussions word for word in a written document, we have classified the relevant sequences that are subject to this analysis. This was followed by the coding procedure, starting with open coding (exploration of phenomena and formulating categories to identify key terms), axial coding (relating the codes to each other in a combination of inductive and deductive reasoning) and selective coding (to choose a core category or identify the central theme) [34]. In the following we present the findings and interpretations from the different coding procedures for addressing the research question: which goals pursue users to engage in thermal energy services and activities? Our intention was to derive a classification of goals linked to the energy citizen and energy consumer to assist research and policy makers in addressing consumers effectively. The categorization of goals was carried out without considering the identified goal frameworks of previous studies in order to approach the investigation without pre-conceptions to be open for new discoveries. Given that the GT theory in practice involves sometimes a mix between inductive and deductive thinking, the following section will present the results sometimes with additional reference to literature findings. This is due to the nature of qualitative investigation which forms an iterative process of working with the empirical evidence and linking it to existing theories in order to establish new propositions.

Results

This chapter enfolds an overview of the analysis of data that was available in form of written texts. For qualitative analeyses it is not important to count frequencies and derive conclusions, but to detect findings that explore a topic in detail [34]. That is why in the following we are reporting the results exploratively restraining from counting any frequencies or percentages.

The energy citizen persona

Based on the characteristics that the energy citizen considers energy as an important factor in life and has carried out already specific energy-saving actions or can think of potential actions, which is consistent with the literature [17], we have identified five goals that stimulate them to seek energy consumption feedback and perform energy-efficiency actions in general (table 1).

The first relates to their *learning goal* orientation, which means that they approach a new task in order to understand something new or to enhance their level of competence. They usually look for challenging tasks that provide an opportunity to enhance their existing knowledge and competencies [35]. They simply enjoy analyzing data and are willing to commit to new challenges as they want to improve themselves: “For me the favorite [ICT service] is the first one, Consumption information [real-time and historic data on energy consumption]. You put the statistics, up and down.”/[154 (3)]. This means that the person is interested to learn and improve which has an effect on protecting the environment. This is related to the second goal *mastery*, where a user has already achieved expertise and is extremely skilled: “I have optimized everything I can.”/[47 (2)]. This shows that they are already very knowledgeable about energy management in their homes.

The third goal *energy saving* states that people directly intend to save energy. They will seek feedback to compare consumptions before versus after, indicating that they will check either energy consumption data per se or screening their translation into economic terms (financial savings). *Financial savings* is the fourth goal as some people clearly stated the need for financial savings: “All such services are interesting, since they bring the decrease of expenses.”/[73 (4)]. This means that they will screen the data for financial savings, comparing different periods. However, financial savings seem to be rather an additional bonus and are not considered as a major motivator. For example the statement “We all should be interested to decrease the costs/[161 (4)]” could be interpreted in a way that it questions if people are actually motivated by reducing costs, or if money has a rather marginal impact. It was included as it nevertheless is related to their attitude towards resource savings of any kind (energy and financial). Another goal relates to being in *control* of their energy management, stating that they get the ability to manage technology and course of events. This is not only restricted to their own homes but towards being responsible to influence and direct other people’s behaviors as well. For example, they feel responsible in supervising other residents: “Each month I monitor the consumption of each apartment and I display it on the bulletin board.”/[116 (4)].

Table 1 Goals to engage with energy efficiency feedback for the energy citizen persona

Identified goals	Empirical proof
Learning goal	For me, as a user, it is interesting to know how much I spent per each energy source – gas and electricity, in kWh on daily basis, and the other chart which transforms it, in real time, into weeks, months, into the price. Namely, current consumption status, with history review and on daily basis to know how much of gas and electricity I spent, in monetary terms. Here I can also see how much each apartment spent and how much was spent for the whole building/[118 (3)] When you go to details here, you would have another page and on that page I

	would like to see everything separate, very detailed one"/[123 (5)] For me the favourite is the first one, Consumption information, you put the statistics, up and down./[154 (3)]
Mastery	I have optimised everything I can./[47 (2)] During the day it is switched off, we are not in. It was and is a pretty good saving method, after we installed the allocator, because we use less impulses...there is a financial effect, and there was no effect, until we did not install the allocator/[48 (1)] In our building, we already started to manage energy from our home/[15 (4)]
Energy savings	Because you either have to change your lifestyle, or because, if you look at it, you can convert from an incandescent light bulb to an energy saving one and you can see the effect. Or buy yourself a more energy-saving home appliance. But this is just if you have an interest in doing this./[247 (6)] I see it in continuity of heating and cooling, day – night regime. There are possibilities for big savings./[39 (4)] If we replace the window panes with energy saving ones, the following year we'll be able to see if there is some effect./[248 (6)]
Financial savings	Since I am unemployed, any saving would be welcome to me/[73 (6)] I get dressed a little bit warmer and I do not pay/[77 (4)] We all should be interested to decrease the costs/[161 (4)] All such services are interesting, since they bring the decrease of expenses./[73 (4)]
Control and Supervising others	I have data for the apartment building where I live./[82 (4)] We receive annual report on consumption, per each apartment and we can compare them, not anonymously but concretely. Each month I monitor the consumption of each apartment and I display it on the bulletin board./[116 (4)] I tried to explain that to one of my neighbours, who used to smoke in the cellar –I told him not to leave the window open when he finishes smoking. He asked, why? I explained to him that we all are paying for that. Since then he closes the window./[76 (1)] We have a team who will monitor it and issue periodical bulletins, on monthly basis, depending on our decision. Particularly, after the end of season there will be a short analysis in order to set up the next goal, as well as which measures need to be undertaken to achieve such goals./[124 (4)]

The energy consumer persona

The energy consumer persona can be generally described having a low intrinsic motivation to engage with energy efficiency and would only carry out actions that are convenient [17] or that are being incentivized. An example is external incentives such as *monetary rewards* to engage people: "You should enable them to get something, like in lottery"/[142 (4)]. So in comparison to the energy citizen who is motivated by performing the task itself that generates financial savings, this group desires an additional financial benefit for spending time and efforts on top of the possibly gained financial savings. Their low initial motivation also explains why they are not motivated to learn and take on challenging tasks, but request advice or *guidance*: Could you show us some brochures, leaflets with possible technological solutions in order to save energy?/[100 (1)]. They prefer activities that minimize efforts at the expense of getting new skills. Also, the third goal *simplicity* depicts that they seem likely be driven by the perceived enjoyment and ease of use of the technology. Frankly speaking, the topic of environmental protection is not considered as an interesting issue to engage, with the assistance of easy-to-use tools, including color codes or a simple representation of information, energy feedback systems could nevertheless stimulate their participation.

Table 2 Goals to engage with energy efficiency feedback for the energy consumer persona

Identified goals	Empirical proof
(Financial) reward	In order that people wish to visit this web page, you should enable them to gain something, like in lottery./142(4) There must be motivation to invest in energy saving/248 (6) What will be the impact of my savings and how much I will profit from financial point of view./140 (4) You spend a lot and you will save in 20 years. It does not “pass” with us/173 (3) People should see fast what is their benefit. Should there be an benefit, than it is OK./72 (3)
Simplicity	User friendly interface. If we are talking about software, average users nowadays are not experienced in programs which use too many parameters./168 (4) What you just described means that I and other tenants are supposed to stand next to the screen and wait for the arrow to change. Believe me, I have better things to do, than standing next to a tablet waiting for a sign to show cheap tariff. And then we are supposed to inform each other. /97 (2) For me it is interesting to be as simple as possible/118 (3) Maybe the screen should be equipped with an electronic regulator and LED diodes – depending on what tariff is on, the light above it goes on and shows to you which tariff you at the moment are charged for/105 (2) You are going to pay that much if you continue heating with that amount or speed, people would automatically turn their thermostat down./98 (1)
Guidance	Could you show us some brochures, leaflets with possible technological solutions in order to save energy?/100 (1) This means that we should include advices as of how to save energy,/140 (4) I do not know what are the measures available though/58 (5) It [the software] doesn’t tell you what to do. /263 (6) it would be nice to have some positive messages as well./180 (6) Also there is a calculation how much I saved compared to preceding period, how much it could impact/122 (3)

Discussion

The findings clearly indicate that different types of users possess different goal orientations, which challenge the existing manner of offering a one-size-fits-all approach. In addition it extends the narrative from the rigid adherence of the statement that consumers should engage to protect the environment by shedding light on the particular motivations consumers actually have to participate. The dimensions of the users when it comes to seeking energy related feedback systems is multi-dimensional in scope which offers a more grounded basis to reach consumers in ICT or energy-efficiency projects. Identifying several goals for two consumer groups proves that in terms of energy feedback usage, individuals are not solely guided by a single goal but multiple goals interact in influencing behavior, which was also shown in the quantitative study by Gölz and Hahnel [19]. In particular the goals differ for the energy citizen and the energy consumer persona.

On the one hand, the energy citizen has a high intrinsic motivation which is also reflected in the prevalent goals. While it could be argued that it is a beneficial basis to work with people being highly motivated intrinsically, this assumption must be treated with caution as this motivation will only flourish if the circumstances, and thus the technology or project, permit. This means, maintenance and enhancement of the intrinsic motivation is strongly dependent on supportive conditions [36], necessitating to discuss which conditions and mechanisms elicit or sustain such tendencies. We have found that goals of this persona include *mastery*, *learning* and *supervising/being in control of* others as well as *savings in terms of energy and money* as a result of the interesting activities. The *learning goal* has been investigated before [19] stating that people will use feedback to reduce their actual energy consumption. It was shown that they target *savings* of both kinds, *energy* and *money* – the two goals that have been identified in other qualitative assessments as well [15], [16]. In addition users will be driven by the achievement (i.e. *mastery*) of the technology and the resulting actions which require skills and knowledge. Widely unrecognized in feedback literature, this has been also approached in the field of user experience where hedonism (i.e. pleasure of non-task oriented aspects) is considered importantly for the usage of ICT tools [37] so it can be related to the fun aspect of having a new technology or implementing it. In addition, the energy citizens do not only consider their personal savings important but also feel responsible for the other apartments in the building and can be thus considered as a community energy ambassador (i.e. goal of *control/supervising others*). This reflects the attempts to consider energy-saving in a community approach [38], [39] to transform the energy market including the needs and ideas of local citizens, which would also require soft instruments besides technological approaches.

Principally, this persona must be considered and treated as an energy expert. In practical terms this implies that the person needs feedback instruments that provide a monitoring tool to compare values before versus after an action (period) or actual versus target values. Like so, energy-efficiency technology must assist the person's personal need to continue learning and acquiring more knowledge by showing differentiated consumption data per sector and appliance, possibly even for various buildings/apartments to supervise other citizens. It is important to understand that the improvement of the building and the self is most important – so in order to motivate the user one has to communicate it in a way how this person can learn and improve him/herself rather than by overly emphasizing the target of environmental protection (which indeed is nevertheless be included if they change their behaviors). They do not need monetary or other tangible rewards but the investments must pay off financially. This can be confirmed by other findings where extrinsic, tangible rewards undermined intrinsic motivation [40] as well as threats, deadlines, directives or imposed goals [36]. For example, if a financial reward is offered, the persistency and efforts of the consumer get diminished, indicating that financial rewards could even harm intrinsic motivation and thus the strength of will and engagement. Generally, beneficial conditions for energy citizens give the person a choice what to do, acknowledge feelings and opportunities for self-direction and allows a certain level of autonomy (rather than being controlled) [36]. This means that the learning goal orientation and the initially high intrinsic motivation must be nourished by offering autonomy as this person wants to master and control everything (rather than being controlled by project stakeholders or technology). Generally, this persona must be offered very detailed and even complex information to keep engaged with behaviour change through ICT and any project should take his/her comments and activities seriously. To all professionals designing such tools or programmes it can be summarised by: Do what the energy citizen tells you to provide rather then telling the person what to do. Given their need of improving and learn, the aim of the project could be focussing on change per se rather than describing particular goals or even asking the citizen which goals the project should target.

The energy consumer is extrinsically motivated and will be doing something because it leads to a separable outcome. Engagement may be induced through monetary rewards. Given the low commitment towards energy efficiency, as well as sustainability concepts just not being very tangible to many people, extrinsic *rewards*, related to money or otherwise, could motivate people to act in a pro-environmental manner without doing it out of pure environmental concern [41]. Thereby the tasks must be easy to perform and users have to be provided with tailored advice and *guidance* on how to achieve the desired outcome. They are likely to withdraw from tasks that are challenging or make negative attributions of their ability, as the latter is something they want to prevent [42]. For practice, this means that marketing tailored to this segment needs to address concerns such as perceived (or anticipated) inconvenience by providing examples on how measures to save energy could be integrated into daily life without negative impacts [19].

While the former persona asked for detailed information, the energy consumer is better approached by simple, accessible and enjoyable feedback tools and information. Therefore, the usability or user experience with the ICT is a crucial factor to attract feedback usage [37]. Given their low commitment, it can be also argued that automation can be beneficial to support the user in energy efficiency by offering a tool that acts on his/her behalf [30]. Another beneficial condition could also be that performance goals are set. This complies with the goal-setting theory, which states that an externally set goal can motivate people immediately [43]. In practice, realistic goals can be set including the skills and local knowledge of the energy citizen persona. To summarize practical implications that can be withdrawn are to incentivize them through rewards, fun or by providing them automatized control, goal-setting and offering guidance on possible actions that demand least efforts.

Conclusion

The present research challenges the assumption that people's motivation to use energy feedback is merely based on the goal of saving energy. Policy or technological interventions aiming to increase energy efficiency by means of energy feedback should take the findings into account that different types of users pursue various goals when engaging in energy-feedback usage. The results clearly offer a differentiated approach to motivating consumers based on customer segmentation and identification of inherent goals when seeking for energy feedback to lower energy consumption in their homes. It was shown that the energy citizen and the energy consumer pursue several different goals to seek energy feedback. The findings shall support designers, engineers or other stakeholders to develop new ICT services or plan energy projects that aim for user engagement and behavioral change.

The energy citizen persona will likely engage in energy efficiency being intrinsically motivated. It nevertheless becomes clear that energy projects targeting on behavioral change cannot only rely on intrinsic motivations to trigger energy efficiency but that the real difficulty is to keep the people who are highly motivated engaged by offering them detailed and even complex information. They also require autonomy enabling them to control and supervise actions locally. This can be done when addressing the goals learning, mastery, energy and financial savings as well as control and supervising others. Simultaneously, the energy consumer group – possibly the majority of people – must be incentivized or can be attracted by enjoyable technologies that are easy-to-use and attract users with rewards and guidance. This is because the energy consumer has initially no desire to learn more about energy consumption and means to save. The persona can nevertheless be motivated when goals such as financial rewards, simplicity and guidance are approached.

Overall, recognizing the underlying goals that can explain people's motivations has important implications on the successfulness of projects. Although goals are considered as an important predictor of behavior, people can fail to attain their goals. This makes it necessary to develop interventions and technologies that support the attainment of consumer goals in the long-run. This means that users must be able to pursue their own goals and motivations as they contribute to project or macro-level objectives. The goals orientations we offer here, shall serve as a framework for approaching consumers in the field more effectively and to consider the dynamics of how different types of users can shape an intervention. Future research should target on developing feedback interfaces and functionalities as adoptable and interactive tools that identify the different personas. This could be realized through analyzing human-machine interaction whereby the type of persona gets identified. This can then allow presenting the corresponding information and motivational features. ICT can then become a valuable tool in changing energy consumption behaviors of people.

As a limitation of this research it has to be stated that the goals are based on people's opinions about features expected to be important. Thus, the goals relate to the anticipated preferred actions for change, which necessitates future work on surveying goals during the field phase as well.

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Session Polygeneration

Assessing Capital Investment on Energy Improvement Projects from a Global Energy Management Perspective: A Tri-generation Case Study

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Abstract

For multi-national companies, assessment of energy improvement projects across a global site-base requires a thorough understanding of the driving factors affecting energy consumption on each site. Traditionally, assessment is performed on the basis of single site-level audits. These audits provide quantitative metrics for the implementation of energy improvement projects such as economics (capital cost, operating costs, return on investment, net present value) and energy/greenhouse gas reductions. However, audits do not typically assess, holistically for all sites, metrics concerning the three levels of abstraction namely system, facility and global. In order to improve effectiveness of capital spending in terms of corporate social responsibility (CSR), sustainability, business continuity and return on investment, it is necessary to develop standardised approaches for auditing sites across a global site-base. Within this context, Boston Scientific, a leading multinational medical device company with a diverse global presence, is currently in the process of implementing a global energy management system (GEMS) in order to improve corporate decision-making on capital energy efficiency spending. The paper will illustrate, from a site's perspective, the interactions between a typical energy project life cycle and the GEMS corporate energy management system.

Introduction

Over the last decades, the energy demand worldwide has almost doubled in a trend that is set to continue in the near future [1]. This has led to a significant rise in energy costs and increased awareness of the impact energy efficiency has not only on the world's climate but also in the sustainable competitiveness of the industrial sector. In fact, the industrial production and processing sector consumes around 25% of the EU-27 energy requirements [2]. Within the industrial sector, approximately 10 million m^2 floor space are used for energy intensive clean room activities, of which the medical device industry accounts for 6% [3].

Managing energy and carbon footprint in large organisations presents significant challenge due to the lack of appropriate methods to address energy efficiency in a way that is both practical and comprehensive, thus inherently leading to effective implementations [4]. In particular, such challenge is increased when aiming at maximising the effectiveness of capital spending on energy improvement projects in organisations with manufacturing facilities across geographically diverse locations. In such cases, it is often the case that the identification of improvement opportunities - and the request for funding to implement them - originates at site level but will ultimately require corporate level approval, particularly when significant capital investment is required. The challenge then lies in matching the corporate and site views, and integrating all the information necessary for informed decision-making. From a corporate perspective, this can include diverse variables such as climate, economics, politics, infrastructure, building type, technology availability and maturity, culture and product mix, to name a few. From a site point of view, it is important to understand the criteria upon which global investment decisions are based in order to maximise the potential for project approval, and minimise time spent analysing projects which are ultimately not viable.

In order to address this challenge, this paper proposes a novel methodology that supports a global energy manager in decision making within a 'Global Energy Management System' (GEMS) [5], complementing the local site's energy improvement project life cycle within the corporate network. GEMS is divided into foundations, pillars and decision support framework (DSF) as shown in Figure 1.

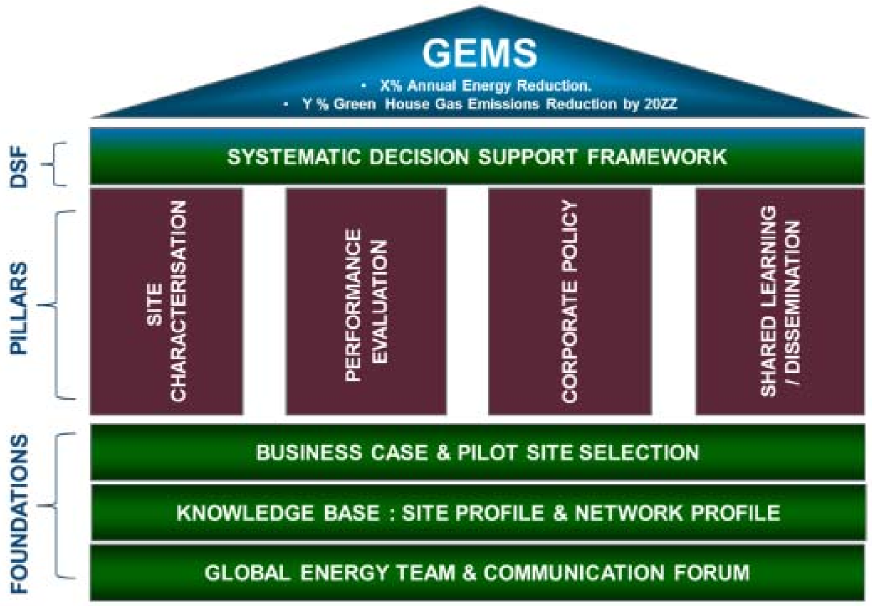

Figure 1. GEMS methodology overview.

Key infrastructural or organizational enablers represent the foundations of GEMS including:

- **Global Energy Team & Communication Forum:** This is a global energy management team with representatives from each individual site. A discussion forum (both physical and virtual) supports by information sharing between members, thus allowing for knowledge sharing and collaboration regardless of the geographical location;
- **Knowledge Base (Site and Network)**: A central platform for data collection, aggregation and analysis which enables a unified cross-site comparison of benchmarks (e.g. electricity, water, gas) as well as general network performance profiling;
- **Business Case and Pilot Site Selection**: Initial pilot case that is used to secure management buy-in and funding for the development of GEMS;

Four pillars are built upon these foundations to deliver the necessary information to the decision support framework such as:

- **Site Characterisation**: Understanding the characteristics of each site in the network, in particular establish the drivers for energy consumption, the baseline of energy consumption and the best energy efficiency technological possibilities for each geographical location;
- **Performance Evaluation**: Evaluate the performance of each site against its network peers via normalised key performance indicators
- **Corporate Policy**: Ensure awareness and alignment between corporate and individual sites management on the organisation policy towards energy improvement investments;
- **Shared Learning & Dissemination**: Create a dissemination network to share the learnings and ensure the success stories are properly communicated across the network, to the decision makers and to the general public.

Finally, the information is aggregated, analysed and processed within a decision support framework (DSF). This facility incorporates current and proposed project performance parameters (technical, economic, sustainability etc.), the corporate capital application model (own capital investment, per purchase agreement) and the outputs from a multi-criteria decision making model (MCDM) developed by GEMS (Figure 2). The methodology accounts for the combined positive impact of operational savings, improved sustainability and a more resilient site infrastructure and outputs a ranking on proposed projects.

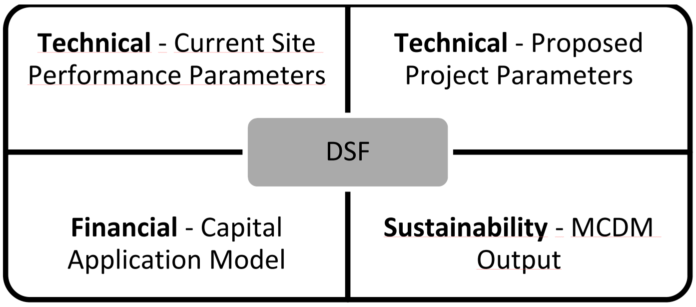

Figure 2. Decision support framework.

This paper presents the development of an energy improvement project – installation of a tri-generation plant – at one of Boston Scientific's sites. We provide a brief summary of the key stages of the tri-generation project, with particular emphasis on the interactions with GEMS. as shown in Figure 3.

Case Study

Boston Scientific Corporation (BSC) is a worldwide developer, manufacturer and marketer of medical devices, with annual revenue of approx. $8.2 billion, and global workforce of approx. 23,000. The corporation has a presence in more 40 countries, with 16 manufacturing site located in the US, Ireland, Costa Rica and Puerto Rico.

The case study will present the approval process of a tri-generation project in BSC Galway site, its interaction with GEMS and its ranking against other two projects in other BSC sites in Cork and Coyol.

- **BSC Galway** is the largest site in the global network with approximately 3,000 employees. The BSC Galway site was established in 1994 and is situated on a 24 acre site. As well as 14,800 m^2 of manufacturing space, the site accommodates an R&D facility, warehousing, laboratories and 1,900m^2 of office accommodation.
- **BSC Cork** is in existence since 1998, and has a total floor area of 19,500m^2, of which 7,200 m^2 is production space. The Cork site has approximately 900 employees and manufactures products for the Interventional Cardiology, Peripheral Intervention, Endoscopy & Urology divisions.
- **BSC Coyol,** the larger of the two BSC manufacturing sites in Costa Rica, extends to 35,000 m^2, with 12,300 m^2 of production floor area and 16,700 m^2 of office and common area. There are more than 2,000 people and the site manufactures products for the Endoscopy, Urology & Pelvic Health, Peripheral Intervention and Cardiology divisions. The site was established in 2009.

Tri-generation Project Proposal at the Galway Site

For the purposes of this paper tri-generation, refers to the simultaneous extraction of electricity, heating, and cooling from the on-site combustion of natural gas from the grid. The system, as illustrated in Figure 3, consists of the following key components:

- An **internal combustion engine** producing power via an alternator,
- A **heat recovery system** for extracting heating from the engine jacket cooling system and the exhaust gas
- An **absorption chiller** driven by the low quality heat that would otherwise be exhausted, providing the cold water required to meet the building cooling loads, principally for air conditioning.

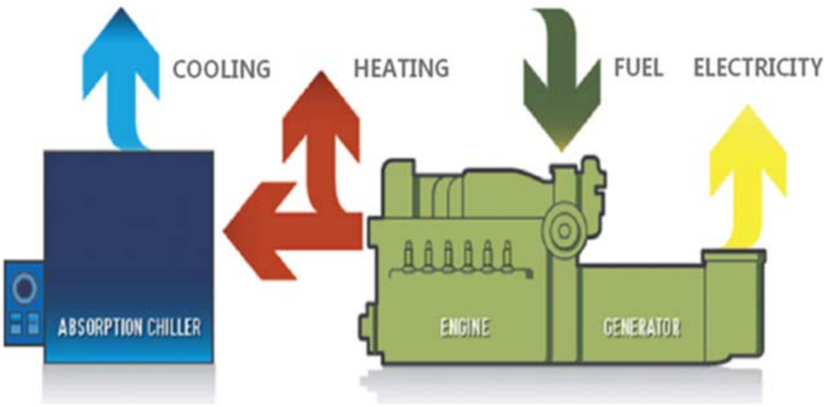

Figure 3. Tri-generation schematic.

The recovery of heat energy results in high thermodynamic efficiencies and reduced environmental impacts per unit of energy consumed. The remaining building requirements for electricity, heating, and cooling are provided by a combination of gas-fired boilers and grid power.

Technical suitability of this solution for any given building is dependent on electricity, heating and cooling load profiles, while financial feasibility will depend on the cost of installation and the thermal and electrical utility costs.

The overall timeline for the tri-generation project includes the following steps and interactions with GEMS as shown in Figure 4:

- Opportunity identification and interaction with the global energy team and communications forum;
- Opportunity assessment extracting and providing data for site characterisation and performance evaluation;
- Project approval integrating the details from the opportunity assessment with the corporate policy into the decision support framework;
- Design, planning and construction which enforces the business case and pilot site selection for GEMS being this among the first projects to use the methodology;
- Commissioning and operation which will provide details and a success story for the shared learning and broad dissemination of GEMS.

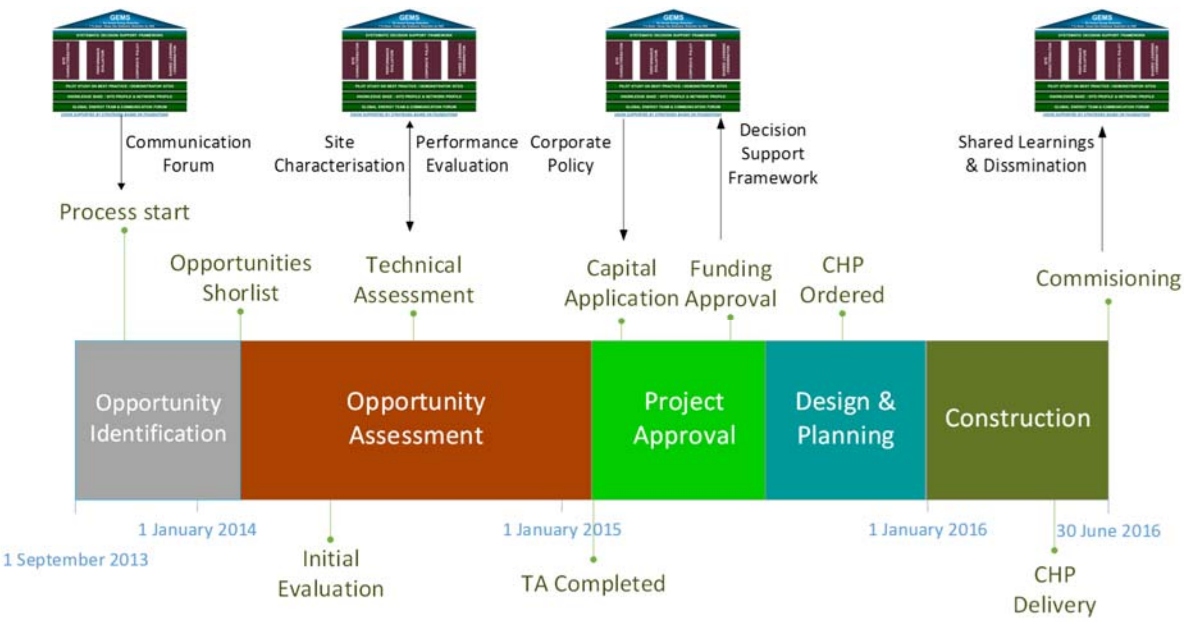

Figure 4. Tri-generation project timeline with GEMS interactions and information flows

This paper presents the work to date which represents the first three phases and a future work will detail the later ones.

Opportunity Identification

A competitive marketplace drives downward pressure on plant operating costs, including energy expenditure. In addition, a continuous improvement philosophy requires all departments to consistently review the significant areas of spend, and look for reduction opportunities. A robust plan for cost reduction, based on actual projects, is a key deliverable of the budget cycle of each year for all departments.

The BSC Galway Facilities group, supported by the outcomes from previous meetings of the global energy team and communications forum, ran an opportunity identification process in late 2013 in order to develop a comprehensive list of cost reduction or improvement opportunities. Key information for this process included a breakdown of the annual facilities overhead budget into key categories including energy, maintenance, consumables, etc. The annual energy cost and consumption had been further analysed to quantify areas of significant energy use and spend.

Through information sharing during the global energy team and communications forum, it was possible to see what utility cost reduction ideas were planned, or had already been implemented at other sites across the BSC network. This produced new ideas for possible implementations in BSC Galway. In total, approx. 312 "brainstorming" ideas were collected, and these were later consolidated into 113 cost reduction opportunities with a total value of $4 million, one of which was Tri-generation which was included in a 3 year implementation plan. Figure 5 summarises this process.

Figure 5.: Site opportunity identification process – Summary by numbers

Opportunity Assessment

Once the realistic improvement opportunities have been identified, the next step is to perform an assessment of the impact such improvement would have in the site and across the network. This assessment required two steps: an initial evaluation and a technical assessment as explained below.

Initial Evaluation

A high-level evaluation was carried out on all opportunities identified during the opportunity identification process, including gross estimations of project cost, potential savings and additional benefits and risks. In the case of the Tri-generation project, the initial assessment indicated a potential payback of approximately 6 years, with additional environmental benefits through CO_2 reduction. Crucially, the assessment also highlighted a potential source of funding for detailed technical assessment: National Energy Services Framework via Sustainable Energy Authority of Ireland. Although initial indications were that the payback criteria did not meet the BSC guidance of 2 years, the potential environmental benefits and the availability of funding for detailed technical analysis led to a decision to proceed to the next stage as it would potentially align this project with the corporate policy on sustainability.

Detailed Assessment

Technical assessment of the tri-generation proposal examined in detail the technical and economic feasibility of installing this technology solution at the BSC Galway site, and specifically addressed the key electrical, mechanical, economic and environmental issues. Thermal and electrical load profiles were assessed in detail to establish the optimum tri-generation plant capacity for the site. Several system integration options and system configurations were assessed prior arriving at a recommended solution. A financial analysis was also carried out for each of the potential system solutions considered. The optimum solution was found to be a 1,169 kW (electrical) combined heat and power (CHP) plant, with a 580 $kW_{thermal}$ absorption chiller. Figure 6 shows a 12-month profile of heating and cooling loads for the BSC Galway site and the loads that could be offset by the tri-generation plant. As can be seen from Figure 6, all the heating demand will be met by the tri-generation plant while the cooling demand will be partially met by the tri-generation plant and partially by chillers in situ. In addition the new CHP will provide a 36% of the yearly electrical energy demand. When combined with the existing CHP (2009), this will bring the total electricity demand that will be generated on-site to 72%.

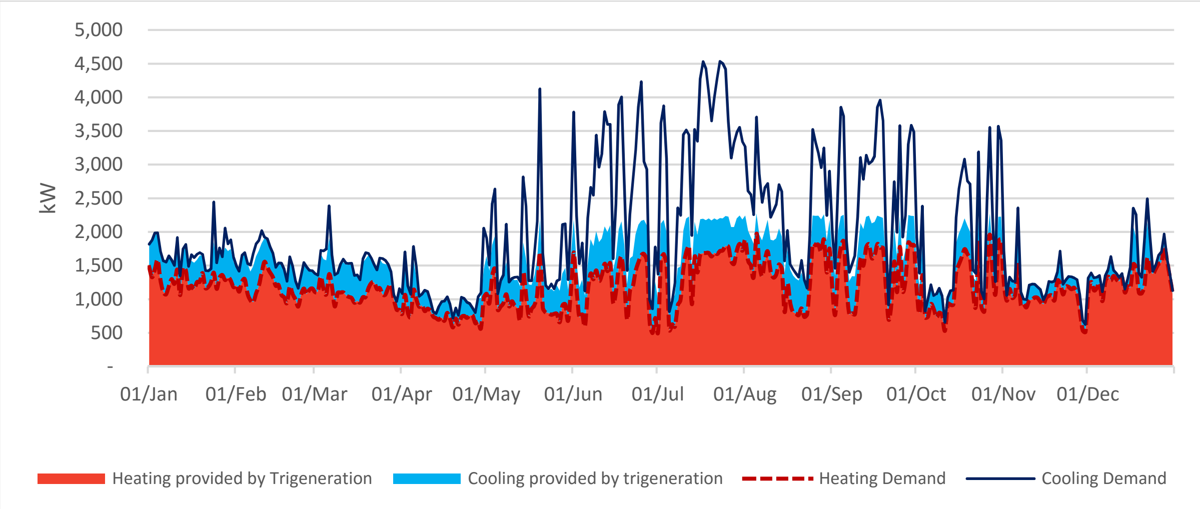

Figure 6. Tri Gen thermal utilisation analysis

Project Approval

The level of capital investment for the tri-generation project required approval beyond the BSC Galway site since corporate finance approval is required for all projects above a pre-determined value. For capital requests for large utility projects, BSC corporate facilities – Global Real Estate Facilities – are required to evaluate the proposed site-level investment and make recommendations regarding funding approval. Here the decision support framework of GEMS is utilised as follows.

Investment model

The detailed assessment formed the primary supporting documentation of the application for internal BSC project funding. As well as a calculation of primary energy savings, the technical assessment also identified some additional potential project supports and revenue streams which will constitute the investment model of the decision support framework. For the purposes of this work, the investment model investigated is that of BSC directly expending capital on the project supported by local State funding and other revenue streams. Following a process to validate the estimated energy savings, revenue streams, supports, and develop high level project cost estimates, a financial evaluation was carried to examine key cost-benefit analysis criteria, including return on investment (ROI), internal rate of return (IRR), net present value (NPV) and simple payback period (Figure 7).

Financial Valuation Results	
IRR	19.0%
Net Present Value	$ 841,053
Payback Period	3.90
Average ROIC	*26.2%*

Figure 7. Financial evaluation summary

Multi-criteria decision-making outputs

Besides the fulfilment of the technical selection criteria of BSC, any selected project must contribute to generate positive impacts in terms of economic, environmental and social criteria. For BSC it also implies that energy improvement projects must be executed where they are the most needed and can deliver their maximum contribution to achieve corporate sustainability goals. BSC uses a Multiple-criteria decision-making (MCDM) method based on fuzzy - Analytical Hierarchical Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [6]–[8] to facilitate a rational selection of energy improvement projects manufacturing sites globally. Each alternative can be evaluated using this fuzzy-AHP-TOPSIS method and ranked out of a discrete number of initiatives based on the quantitative and qualitative criteria presented in Figure 8.

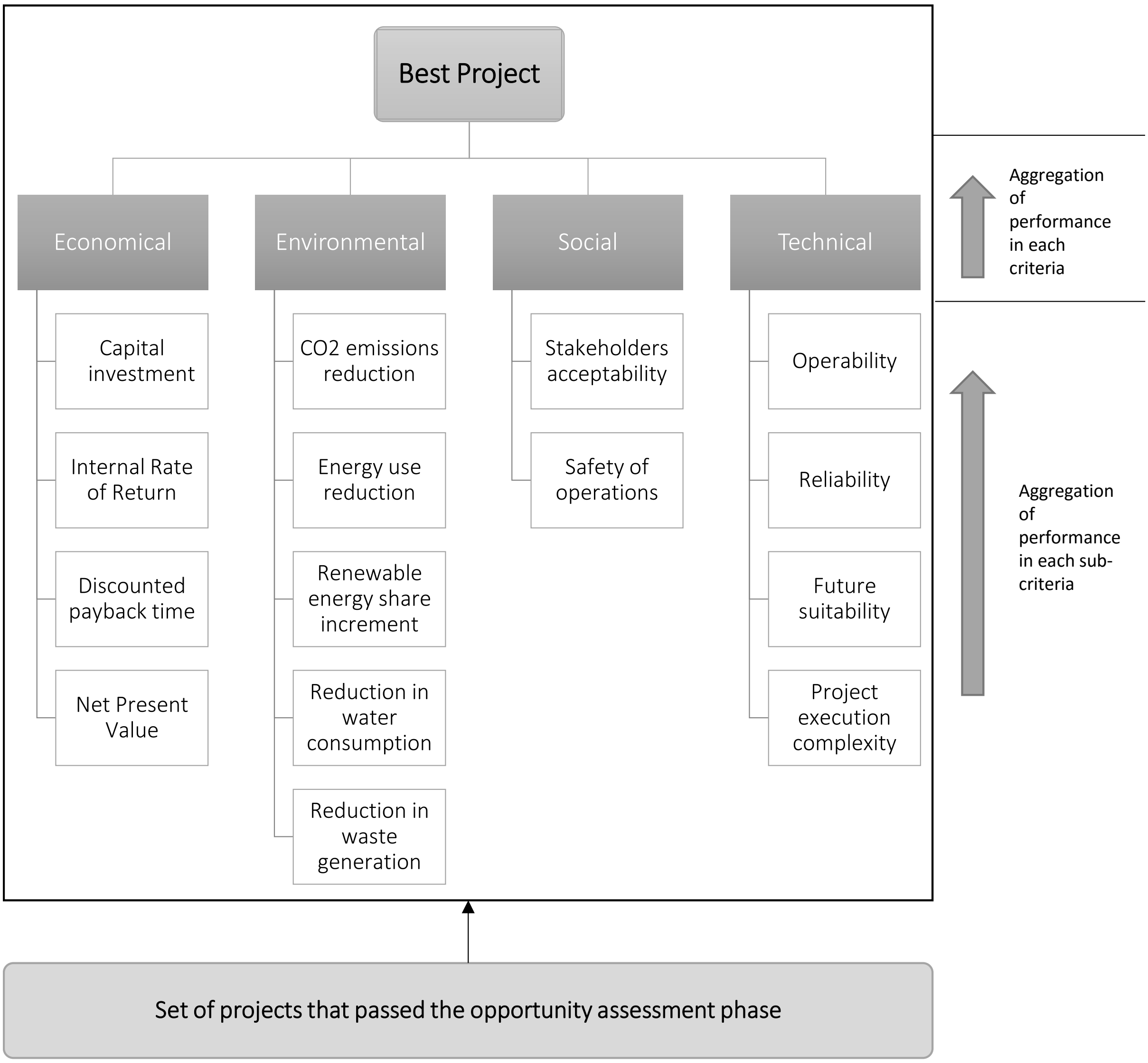

Figure 8. AHP structure and set of criteria for sustainability assessment of alternatives for BSC

For this case of study, BSC's MCDM method (under development) is applied to rank the best energy improvement project between those of Galway, Cork and Coyol using, as a first approach, the same weights for each criteria and sub-criteria from Figure 8. Figure 9 shows the performance of each project in each sub-criteria, which are divided into four main criteria groups: Financial, Environmental, Social and Technical. Information to fill these criteria was obtained through the technical assessment and capital application.

Financial criteria comes directly from the capital application as explained before. Environmental criteria information is obtained mainly through the technical assessment and represents the impact of each project, in environmental terms, for the whole corporation and thus allows to align each project with corporate goals in this regard. Performance in social and technical criteria is given in linguistic terms, which are integrated into the model using fuzzy logic.

				A1	A2	A3
Criteria	**Weight**	**Sub criteria**	**Weight**	**Galway**	**Cork**	**Coyol**
Name	**%**	**Description**	**%**	**Tri-generation**	**CHP**	**Ice Storage**
Financial	25	Capex ($)	25	$2,575,000	$1,346,000	$1,250,000
		Net present value ($)	25	$841,000	$1,900,000	$609,627
		Opex savings ($)	25	$588,000	$648,000	$347,000
		Payback time (yr.)	25	3.9	2.1	3.6
Environmental	25	CO_2 emissions reduction global (%)	34	1.9	1.5	0.0
		CO_2 emissions reduction site (%)	34	14.7	25.0	0.0
		Energy savings site (%)	33	15.0	49.0	14.0
Social	25	Safety of operations	50	High	High	High
		Stakeholders acceptability	50	High	High	Medium
Technical	25	Operability	25	High	High	High
		Reliability	25	High	High	High
		Future suitability	25	Medium	Medium	High
		Project complexity	25	Very High	Very High	Medium

Figure 9. BSC's MCDM method ranking for Galway, Cork and Coyol energy improvement projects.

The results in Table 1 show that in this case the best investment opportunity is the project for the Cork site, followed by the one for Galway, while the least attractive opportunity is given by Coyol. Between Cork and Galway, the former performs almost 40% above the later given its better contributions in terms of financial and environmental criteria. At the end of the study at corporate level, both projects were funded.

Table 1. MCDM results.

Rank	Alternative	Closeness to best %
1	Cork – CHP	0
2	Galway – Tri-generation	-60
3	Coyol – Ice Storage	-70

Conclusions

It is in the interest of every company to reduce their energy consumption and cost base. For multi-national companies, with a global production and manufacturing base, this requires the assessment of multiple variables across diverse countries, sites and individual segments of a product value-chain and life-cycle. This is currently a complex task, requiring integration and analysis of diverse data-sets. The GEMS framework provides a structured methodology for integrating these diverse data sources and support in the process of deciding the best approach for capital expenditure in energy improvement projects for a global corporation.

From the site's point of view, the key conclusions that can be drawn to date are:

- A consistent and robust approach to ranking of energy improvement projects across a global network is a critical input to a corporate-level decision support framework;
- Standardised performance improvement measures provide clarity on project outcomes for both the site and the corporation, thus simplifying and improving the project evaluation process;
- Clarity on key corporate-level project evaluation criteria enables an improved project assessment process at site-level;
- GEMS provides a critical role at site level for early opportunity identification, through network shared learning. In turn, dissemination of the tri-generation project outcomes via GEMS will enhance the network knowledge base and provide the basis of opportunity evaluation for other sites in the network;
- Of the three projects evaluated, both the Galway and Cork proposals received approval in 2015. The Coyol Ice Storage project has not been approved;
- Under the GEMS framework, sites are required to not only evaluate the financial benefits of their proposed project, but also the sustainability impacts for the site and ultimately the corporation. This not only serves the green and sustainable image of the site, but can also help increase site resilience in the case of energy supply interruptions or global price volatility;
- The GEMS system enables a corporate link at a site level which boosts the chances of project approval at the site level.

Acknowledgements

This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number SFI/12/RC/2289 through a TP agreement between the SFI Centre for Ireland's Big Data and Analytics Research, ZuTec Inc. Ltd and Boston Scientific Corporation

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Development of Performance Evaluation Method for Cogeneration Systems

-Measurement Data Analysis and Development of Simulation Program -

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Abstract

Cogeneration system=Combined Heat and Power (CHP) is introduced in a variety of capacities and combinations by the needs of electric- and heat-demand. Considering future dissemination, establishment of an appropriate evaluation method of CHP is necessary.

Although the performance evaluation method of CHP has been developed domestically in Japan, targeting the household[1] and district heating[2]. The conventional performance evaluation methods for commercial buildings were unsuitable for current practical energy-saving performance evaluation.

In this study, we aim to construct an energy-saving performance evaluation method for CHP and take into consideration the use of optimal CHP models and operation methods. So, we developed a CHP simulation program for evaluation based on an analysis of the measurement data and existing programs [3]. The program reads the configuration conditions, electric- and heat-demand data, and calculates the amount of generation, exhaust heat, and gas consumption. There is a number control for CHP for both the electric- and heat-demand in this program.

For accuracy verification, we compared the actual data and the calculation results of the program. The program results had small errors, but it was able to capture actual values. Accuracy verification of the program confirmed that the calculation result generally captured a transition of actual values. In addition, we studied the influence factors to CHP energy-saving performance using the program.

Finally, we studied the effects of the CHP generation capacity and each demand of the building to the CHP energy-saving performance. The calculation results showed that CHP energy-saving performance is susceptible to heat-demand than electric demand. Also, it was found that energy consumption is lower in buildings with CHP compared to buildings with no CHP, but is increased in buildings with CHP systems of higher capacity than the building demand.

Keywords

Cogeneration system; Measurement data analysis; Simulation; Energy-saving performance evaluation method; Number control

Introduction

Japan relies on fossil fuel imports from overseas, and the situation change at home and abroad has a significant impact on energy supply to the country. After The Great East Japan Earthquake of March 2011, the fundamental weakness of Japan's energy supply system became clear again.

For such economic activity in the event of a disaster or prevention of global warming, equipping cogeneration system (hereinafter, CHP) in commercial buildings may become an issue in the future. Because CHP is introduced in various capacities and combinations to suit the needs of electric and heat-demand, the study of a suitable evaluation method is essential in order to promote CHP use. This paper studies the construction of an energy-saving performance evaluation method for CHP, and a CHP simulation program is developed. The use of optimal CHP models and operation methods using the developed simulator is also considered.

CHP Data analysis of some buildings

Measured Overview

In the measurement data analysis, measurement data was collected from six buildings. The list of buildings is shown in Table 1, and Table 2 shows a summary of the collection result of the measurement buildings data. The study analyzed three office buildings and three hospitals. In each building, all CHP was a gas engine. Power generation capacity ranges between 25 kW and 930 kW, and the installed number varies from one to three. Although more than one year of data was obtained from three buildings in the collection result, a mix of measurement and estimated data was used for some of the buildings while others used measurement data. The hot water and air conditioning load value of some buildings were hard to distinguish from one another in the measurement buildings.

Table 1. Overview list of the measurement buildings

Building Name	Office 1	Office 2	Office 3	Hospital 1	Hospital 2	Hospital 3
Location	Tokyo	Shizuoka	Kyoto	Sapporo	Niigata	Kitakyushu
Area[m²]	7477	7516	36200	26679	50034	48200
CHP Type	GE	GE	GE	GE	GE	GE
CHP Units[U]	1	3	2	2	2	2
CHP Generation Capacity[kW]	25	75(25×3)	1040(520×2)	1860(930×2)	-	800(400×2)
Data period	2012/11/1 ～ 2015/2/28	2013/7/21 ～ 2014/8/1	2012/1/1 ～ 2012/12/28	2012/10/1 ～ 2012/12/31	2012/8/1 ～ 2013/2/28	2011/4/1 ～ 2012/3/31
Days[Day]	849	376	362	91	211	365
Interval	1 Hour					

Table 2. Summary of the collection result of the measurement buildings data

Building Name	CHP Measurement Data			Load Measurement Data		
	Generation	Exhaust Heat	Gas Consumption	Electricity	Hot Water	Air-Conditioning
Office 1	○	○	○	○	○	○
Office 2	○	○	○	○	△	△
Office 3	△	△	△	○	○	○
Hospital 1	○	○	○	○	○	○
Hospital 2	×	○	○	×	○	○
Hospital 3	△	△	△	×	△	△

○ means the exact value.

△ means the estimated value or the mixing value of the other items.

× means loss of data.

Measurement result

In this paper, we show the measured result in Office 1 and Office 2, along with the data period. The transition of the daily average of the outside temperature of the nearest weather station of the building location and daily power generation amount integrated value are respectively shown in Fig. 1 and Fig. 2. Since the CHP generation capacity of each building was smaller than the electric demand of the building, almost all CHP works were rated during operation time. In moderate seasons (such as May and November in Japan), CHP operations were stopped because the heat-demand of the building was small. Office 1 and Office 2's hourly CHP generation in the sample period is shown in Figure 3. It shows that both Office 1 and Office 2’s CHP generation were stable near the rated capacity (Office 1=25kW, Office 2=25×3 = 75kW). Both office CHP was operated to a fixed time period. In Office 2, the same load factor was assigned to all CHP units.

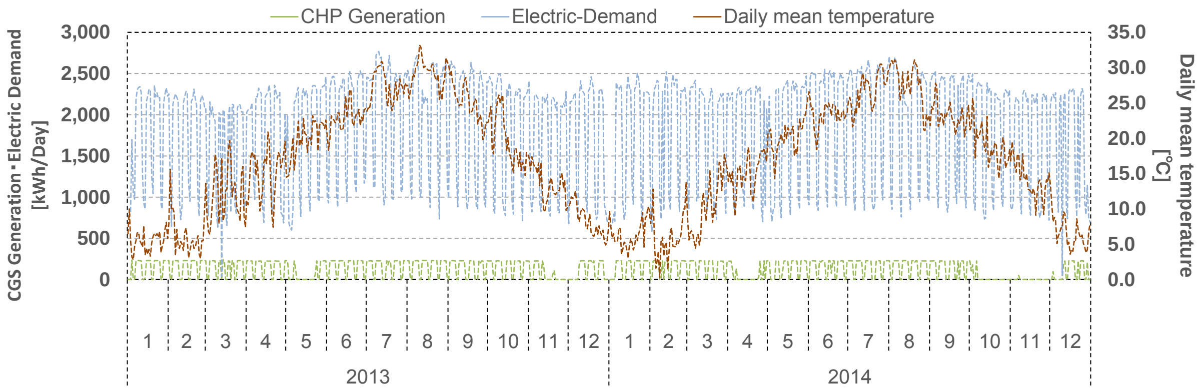

Figure 1. The measured result in Office 1

10 11 12

Figure 2. The measured result in Office 2

12 12 12 12 12 12 12 12 12 12 12 12 12 12

Figure 3. Office 1 and Office 2's hourly CHP generation in the sample period

Development of Simulation Program

In reference to the measured value analysis and existing programs, we developed a CHP simulation program. This program can calculate the amount of generation and exhaust heat in 1-hour intervals and can have different operating settings for each day. The simulation program is able to assess the energy performance of CHP of business buildings. It can make the operational methods and CHP model characteristics, build instruments to reflect energy performance, and the user can consider and improve each item.

The calculation flow of the simulation is shown in Figure 4. At first, the program reads the configuration conditions, and the electric- and heat-demand data in 1-hour intervals. Then, the power generation amount and operating number are determined according to both the electric- and heat-demand. Generating efficiency and exhaust heating efficiency are determined according to the load rate and the characteristics of the curve. From the two kinds of efficiency, the simulator calculates the exhaust heat and gas consumption. Calculated Exhaust heat is supplied to hot water, heating, and cooling in set order. After the calculation of the exhaust heating supply, the excess exhaust heat is added to the hot water storage tank to use when the exhaust heat of CHP cannot supply the hot water demand.

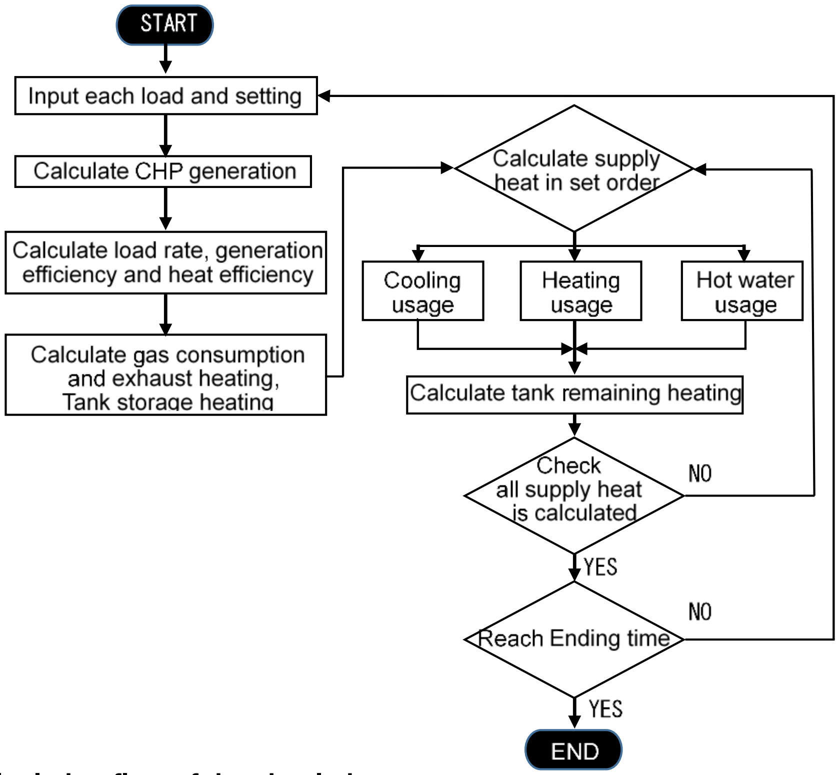

Figure 4. The calculation flow of the simulation

Accuracy verification

For the accuracy verification, we used the simulator and measurement data and compared the actual data and the calculation results of the program. To better clarify the program accuracy, we chose multiple buildings for a comparative verification. In this paper, the accuracy verification result about Office 1 from January 15 to January 28, 2013, Office 2 from August 15 to August 14, 2013, and Hospital 1 from November 1 to November 14, 2012 is shown. Table 3 shows each building setting value. Each building's CHP generation efficiency and exhaust heat efficiency (lower heating standards) is shown in Figure 5. The setting of each of the buildings and CHP performance curve were referenced from information of joint research destination and product catalog value [4], measurement data. We used the same setting value of exhaust heat efficiency and generation efficiency in Office 1 and Office 2 because both buildings installed the same CHP. Although Hospital 1's CHP exhaust heat was utilized for steam and hot water, the calculation target in this paper is decided for the heat supply amount of hot water. Hospital 1's performance curve of exhaust heat efficiency is smaller than the other building's because it was set in reference to the CHP hot water exhaust heat efficiency of hot water and steam-combined heat recovery from the product catalog value.

Table 3. Each building's setting value

	Office 1	Office 2	Hospital 1
CHP type[-]	GE	GE	GE
Generation capacity[kW]	25	25	930
Number[-]	1	3	2
Generator maximum load rate[-]	1	1	1
Generator minimum load rate[-]	0.3	0.3	0.3
Operation start time[O'clock]	9	9	6
Operation end time[O'clock]	19	22	20
Minimum purchase electricity[kW]	6	5	1100
Hot water storage tank[-]	Absence	Absence	Absence
Operation of Saturday, Sunday and public holidays[-]	No	No	Yes
Rated generation efficiency[-]	0.335	0.335	0.4
Rated exhaust heating efficiency[-]	0.515	0.515	0.183

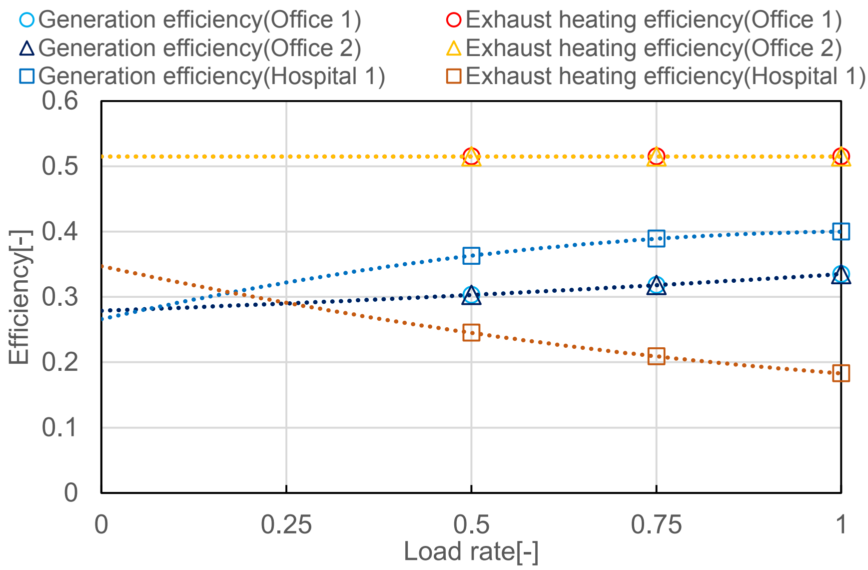

Figure 5. Each building' CHP generation efficiency and exhaust heat efficiency (lower heating standards)

Comparisons of the calculated results and the measured values of Office 1, Office 2, and Hospital 2 are shown in Figures 6 to 8. Operation controls of the CHP in the electric-load following an operation, electric-load, and heat-load were input in the measured data.

Figure 6 shows that the program results were able to capture actual values. In Figure 7, there are some calculation values bigger than the measured value of gas consumption and exhaust heat in the calculated results of Office 2. Since the CHP generation calculation value is almost equal to the measured values, it is considered that the amount of gas consumption used for CHP generation is computed greater than the actual values. Figure 8 shows that calculation results of Hospital 2's gas consumption is slightly larger than the actual measured value, although it captures the measured value for the most part.

The results of the accuracy verification confirmed that the program results had small errors but were able to capture actual values.

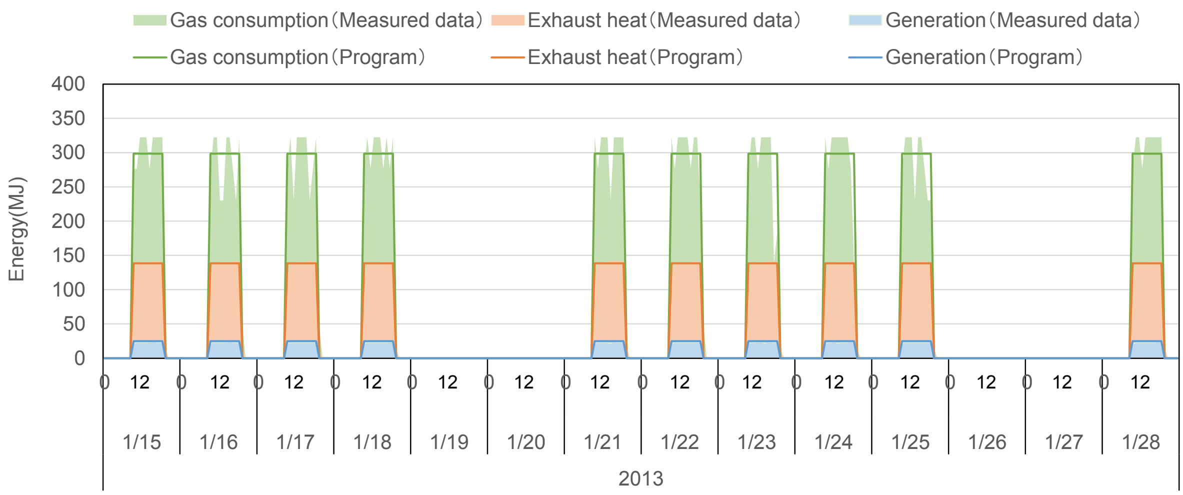

Figure 6. Comparison of the calculated results and the measured values (Office 1)

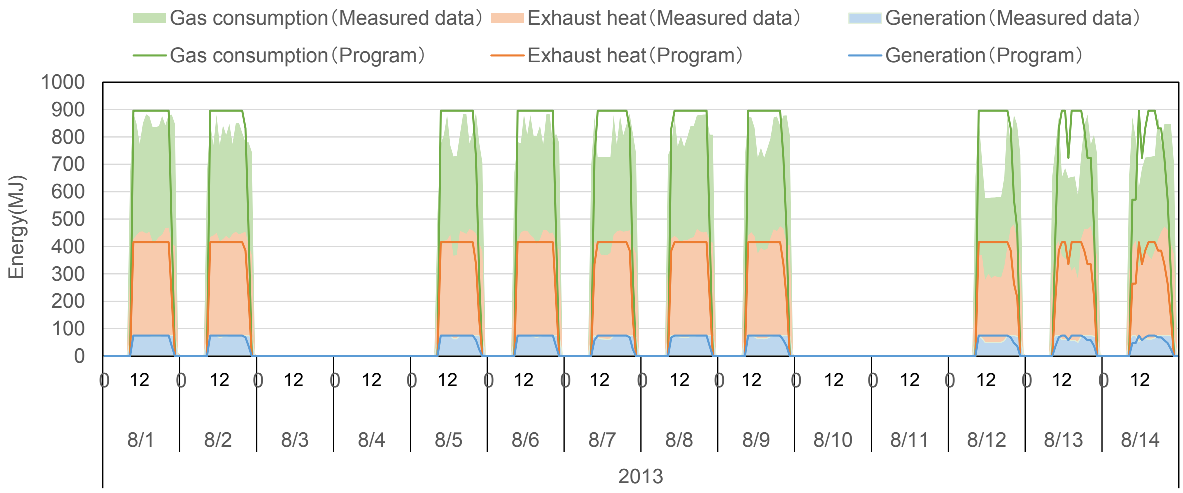

Figure 7. Comparison of the calculated results and the measured values (Office 2)

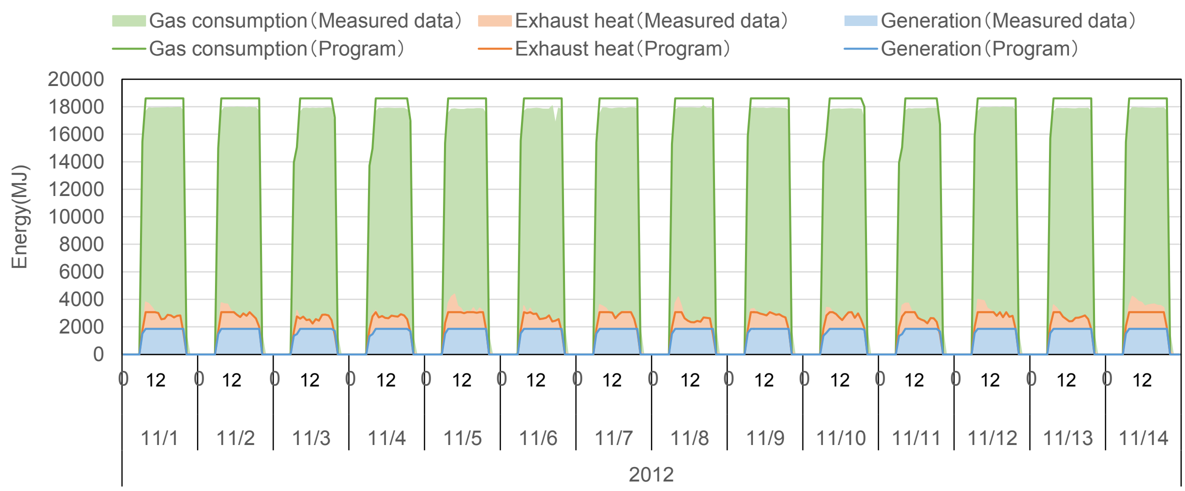

Figure 8. Comparison of the calculated results and the measured values (Hospital 2)

Case Study

We carried out a case study using the simulation program and measurement data of Office 1. We calculated the energy-saving amount in different cases of the number of operating units or electric- and heat-load amount, and CHP capacity. The energy-saving amount is calculated from purchased electricity amount and the gas consumption. From comparing the energy-saving amount in both case, while CHP is introduced and not introduced, the CHP energy-saving performance in the case is studied. Two case studies are shown in this paper.

Study 1

Study 1 examined that the building load and CHP generation capacity impact on the CHP operation energy-saving performance. This case simulation is based on the load data and operation setting of Office 1, is calculated with the changing the value of the CHP generation capacity and each load.

The case of Study 1 is shown in Table 4. CHP generation capacity has three types, each of them electric-, and heat-load had four types. The simulation is calculated by using the case of 48 kinds in a total of 3×4×4. CHP generation capacity standard is the same 25kW in reference to the CHP installed in Office 1. We simulated two virtual CHP which had the same characteristic curve at standard and generation capacity two and four times the standard. The electric-load and heat-load standard used in Office 1 measured the data from 2014. Operation control of the CHP is the electric-load following an operation, which was the same as Office 1.

Table 4. The case of Study 1

CHP Generation capacity	Electricity-load	Heat-load
①Standard(25kW)	①Standard×1/4	①Standard×1/4
②Standard×2(50kW)	②Standard×1/2	②Standard×1/2
	③Standard(Office 1)	③Standard(Office 1)
②Standard×4(100kW)	④Standard×2	④Standard×2

The results of Study 1 are shown in Table 5. The table shows that the energy-saving amount is more affected by the heat-load than the electric-load, and the energy-saving amount to the same generation capacity is more affected by the increase in heat-load rather than in the electric-load. The increase in electric-load only slightly affected the energy-saving amount when same capacity CHP was introduced and the heat-load was the same. When the heat-load is not large enough, the energy-saving amount falls because the high CHP exhaust heat, which increased by CHP high operation for electric-load, is not used. The energy consumption amount increased in all cases when CHP 100 kW was introduced and the heat-load 1/4.

Table 5. The results of Study 1

Energy saving amount[GJ] (Energy reduction rate[%])					
Generation capacity[kW]	Electricity load	Heat load			
		Standard×1/4	Standard×1/2	Standard	Standard×2
25	Standard×1/4	89.1 (4.22)	129.4 (5.05)	147.0 (4.25)	165.9 (3.15)
	Standard×1/2	95.6 (2.52)	125.3 (2.97)	145.4 (2.84)	165.6 (2.39)
	Standard	80.6 (1.13)	123.1 (1.63)	144.2 (1.71)	165.3 (1.61)
	Standard×2	80.8 (0.59)	123.3 (0.87)	144.5 (0.96)	165.6 (0.98)
50	Standard×1/4	30.1 (1.43)	122.9 (4.79)	158.5 (4.58)	180.5 (3.43)
	Standard×1/2	31.1 (0.82)	175.2 (4.15)	257.5 (5.02)	293.8 (4.24)
	Standard	6.2 (0.09)	163.6 (2.17)	248.6 (2.94)	289.7 (2.83)
	Standard×2	3.6 (0.03)	161.0 (1.13)	246.1 (1.63)	288.3 (1.71)
100	Standard×1/4	-18.9 (-0.89)	77.1 (3.01)	113.8 (3.29)	135.4 (2.57)
	Standard×1/2	-203.8 (-5.38)	53.9 (1.27)	269.2 (5.25)	355.7 (5.14)
	Standard	-283.2 (-3.99)	32.7 (0.43)	346.6 (4.10)	512.7 (5.00)
	Standard×2	-305.9 (-2.22)	10.8 (0.08)	325.7 (2.16)	495.7 (2.93)

Study 2

From Study 1, it is found that both electric-load and heat-load are important for CHP energy-saving amount, and they are more affected by heat-load than electric-load. Therefore, we added the heat-demand conditions to the conventional electric-load following operation, and simulated and examined the energy-savings amount of it in Study 2.

The type of case Study 2 is shown in Table 6. Four types of CHP generation capacity were included, and the heat-demand condition for CHP operation number control also had four types. Two models were chosen from the actual CHP. The condition of the heat demand condition was whether the percentages of heat demand to CHP-rated exhaust heat exceeds the set values (0.3, 0.5, and 0.7). CHP operation number is also determined according to the conditions of heat demand in addition to the electric-load following operation. For example, when a set value of heat demand condition is 0.3, and the heat demand is 1.3 times that of CHP-rated exhaust heat, the operating unit number by heat demand condition is determined to be two units. The simulation is calculated by using 16 cases in total 4×4.

Table 6. The type of case Study 2

CHP Generation capacity × CHP units	Heat demand conditions for CHP operation number control
①25kW×1	①Without heat-demand condition
②25kW×2	②heat-demand is More than 0.3 × Rated exhaust heat
③25kW×4	③heat-demand is More than 0.5 × Rated exhaust heat
④230kW×1	④heat-demand is More than 0.7 × Rated exhaust heat

The results of Study 2 are shown in Table 7. It is shown that heat-demand condition for CHP operation number control increase the energy-saving amount. In every case of adding heat demand conditions to the control, the energy-saving amount increased. Regarding the heat demand conditions for CHP operation number control, the energy-saving amount in the case of the set value 0.5 was the largest.

Table 7. The results of Study 2

Energy-saving amount[GJ] (Energy reduction rate[%])					
Generation capacity[kW]	CHP units	Heat demand conditions for CHP operation number control			
		No condition	0.3	0.5	0.7
25	1	127.6 (1.51)	134.5 (1.59)	134.5 (1.59)	133.6 (1.58)
	2	240.4 (2.84)	258.4 (3.06)	258.7 (3.06)	256.5 (3.04)
	4	343.9 (4.07)	442.2 (5.24)	443.1 (5.25)	437.2 (5.18)
230	1	-168.6 (-1.9)	82.7 (0.97)	135.9 (1.61)	74.4 (0.88)

Conclusion

We developed a CHP simulation program and considered CHP models and operation methods. As a result, it became clear that the size and balance of electric- and heat-load is greatly related to the energy-saving amount of CHP. When CHP generation capacity was too high for the building heat-load, CHP could not increase the energy-saving amount. Thus, the change of heat-load was affected by the saving amount more than the change of electric-load. Also, both the electricity and heat demand operation could increase the CHP energy-saving amount. Adding a heat demand condition to the electric-load following operation increased the energy-saving amount.

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BIOMASS TRIGENERATION SYSTEM FOR RETAIL STORES

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Abstract

Retail stores are heavy energy consumers, using 3-5% of the electricity swallowed by developed countries. The fight against global warming must address new alternatives adapted to the renovation of supermarkets.

This study analyzes the technological solutions planned for the energy refurbishment of a 1600 sqm retail store in Vitoria (north of Spain) in the frame of the LIFE12 ENV/ES/000787 project. The electricity consumption has been monitored during 2014 and 2015, and, based on the results, a number of action packages have been designed.

One of the core actions within this project consist on a trigeneration prototype based on biomass. A 250kWt boiler will supply heat to an ORC, that willl produce electricity (27,5kWe) and residual heat regulated at two levels. High temperature heat will power a Li-Br absorption chiller, while the lower temperature heat will be used for air heating or rejected when no necessary. The absorption chiller (17,6 kWf) will be integrated with an indirect refrigeration cascade compression system in order to feed medium and low temperature cooling cabinets. Cascade system will be composed of a N13 compressor (a new refrigerant with low GWP) and a CO_2 compressor. The integration with the absorption chiller is made by subcooling N13 after condensation. This way, the refrigeration will be guaranteed even if the prototype stops working.

This paper will describe this energy solution, analysing the energy perfomance simulated with TRNSYS 17.0 based on real demand data. This study validates this novel 100% RES trigeneration prototype.

1.Introduction.

The electricity consumption of the retail store sector is 4% of the overall electricity consumption in the United States and France [1], about 3% in Sweden [2] ,3% in the UK [3] and 3,39% in Spain according to our own calculations based on two previous studies on this sector [4&5]. It may be said that developed countries spend an average of 3-5% of their total electricity consumption in Supermarkets [6].

The agreement of Paris (COP21) to fight global warming and the European H2020 objectives show clearly the need to reduce the energy consumption.

In this context, the project LIFE12 ENV/ES/000787 was approved in order to demonstrate the feasibility of innovative integral reliable solutions for supermarket retrofitting in order to reduce the energy needs and produce part of this energy out of RES.

The selected supermarket for the demonstration activities is a 1.600 sqm sales room store in Vitoria, capital city of the Basque Country in the north of Spain.

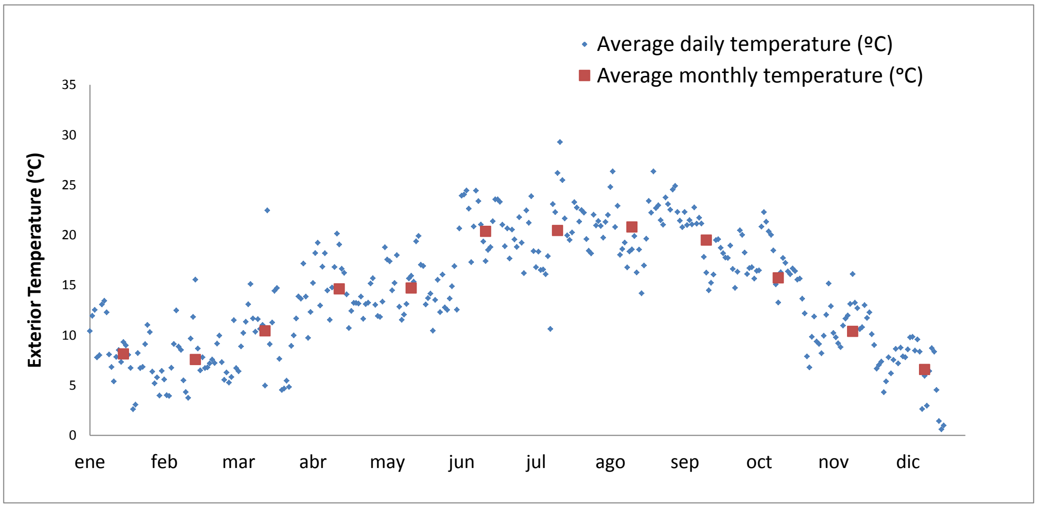

Fig. 1. Measured daily and monthly average temperature in Vitoria (2014).

Electricity consumption has been monitored in detail during 2014 and 2015. This paper will analyze the actual energy consumption in the supermarket, calculating the thermal energy needs. Based on this data, it will be possible to assess the performance of a novel prototype of trigeneration system based on biomass.

2. Energy Consumption Distribution in the Retail Store.

Currently the pilot Supermarket is heated by two rooftops and has two condensing cooling R404-A units for refrigeration. The specific electricity consumption was 460 kWh/m^2 in 2014. This is in line with previous studies in UK like [22] or [3], where it shows that specific consumption is highly dependent on the supermarket size.

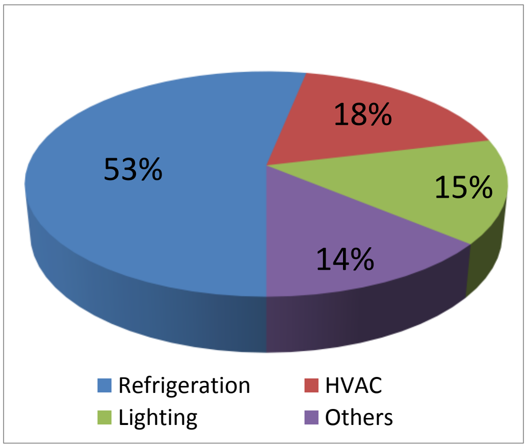

Fig. 2. Measured distribution of the electricity consumed by the pilot store in 2014.

Many references [1], [2], [3], [6], [7], [8], [9], [10] y [11] show that the refrigeration means the major energy consumption in a supermarket, ranging from 30 to 60% of the overall electricity consumption, depending mainly on the exterior temperature, the share of refrigerated products and the cooling technology.

In the case of the pilot supermarket, 53% of electricity was used for refrigeration in 2014, while 18% for HVAC, 15% for lighting and 14% for other uses (office…).

3. Trigeneration possibilities

Trigeneration or CCHP is the combined production of cooling, heat and power in one process. Retail stores traditionally use electricity from the grid to get heat and cooling, mainly through heat pumps. Trigeneration may be a good way to produce in site the required energy out of local resources. Several attempts have been made to integrate different technologies with this aim:

3.1. ICE. Internal Combustion Engine.

ICEs burn a gas or liquid fuel in order to obtain mechanical energy, latter transformed into electricity while waste heat (exhaust gases & jacket cooling water) is used both for activating an absorption/adsorption chiller and for heating/ DHW. It is a mature low cost technology, well adapted to the power needs in a supermarket. One study made for a 5.000 sqm store in UK[3] showed that the integration of a gas ICE with a single effect Li-Br absorption chiller optimized the economic results compared with other thermally activated chillers (NH3, Silica Gel, Double Effect).

3.2. Gas Turbine.

Gas turbines follow the Brayton Power Cycle, where the air is first compressed and mixed with gas. The combustion rises the temperature and the gas flow at high temperature and pressure is turbined to obtain electricity. They are more quite and efficient engines, but more expensive and only available for a greater range of power needs. Studies like [6] showed that microturbines may save up to 49 Tn of CO_2 with paybacks under 4 years when the relative cost of gas to electricity is below 0.3.

3.3. Biomass trigeneration.

There are no references of CCHP systems based on biomass applied to supermarkets. However, it is possible to find diverse experiences of trigeneration with biomass.

One study (Huang et al. [13]) uses a simulation package 'ECLIPSE' to analyze the behavior of a trigeneration system applied to buildings varying the type of biomass and combining this heat with an ICE. It concludes it is more efficient than conventional systems, but the ratio of power/heat needs must be between 0.5 and 0.75. Better results may be achieved if the building maintains a more constant cooling demand throughout the year.

In 2012 different biomass trigeneration systems were studied (Maraver et al. [14]) with the intention of determining the environmental impact of six CCHP biomass configurations, varying the cogeneration unit (ORC or Stirling) and the cooling machine (absorption or adsorption). The study shows the environmental benefits of trigeneration with respect to conventional systems are very high, being still higher when the heat demand exceeds the cooling demand.

Reference [15] shows that the ORC is a good alternative for small-scale use for biomass trigeneration power. One particular experience (Jradi and Riffat. 2013 [16]) put this in practice and built a small CCHP system with a pellet boiler, an ORC and a dehumidifying unit based on cooling. The overall system efficiency was 84.4%.

Several studies (Al-Sulaiman et al.)[17]&[18] have analyzed trigeneration systems based on the combination of biomass boilers and Rankine cycle (ORC) to generate electricity. Cooling is obtained by thermally activated chillers, generally connected to the boiler. A comparison among four systems: conventional, heat cogeneration, cooling cogeneration and trigeneration, showed that trigeneration is the most efficient system in terms of CO2 emissions and exergetic efficiency, rising from 14% to 89% the energy efficiency with respect to conventional system, and from 13% to 28% the exergetic efficiency.

Same authors presented a thermoeconomic study of a trigeneration system [19] and [20] varying the heat source for the ORC and a single-effect absorption chiller: solid oxide cells (SOFC), biomass and solar collectors. The SOFC system provides the highest energy efficiency and exergy; but is rather expensive. Lowest exergetic cost were reached by the solar pannels with $ 24 / GJ, closely followed by the biomass $ 26 / GJ, and the SOFT with $ 38 / GJ.

In the industrial sector, the multinational company L'Oreal located in Villalonquéjar (Burgos, Spain) set a trigeneration system in September of 2014, based on biomass and solar photovoltaics with aim of becoming carbon neutral. This plant of 3.800 sqm will produce 20.000 MWh of thermal energy every year, consuming 70% of the production and selling the other 30% [21].

4. Trigeneration prototype

In the frame of LIFE12 ENV/ES/000787 a trigeneration prototype was designed to fit with the energy demands of the pilot supermarket (heat, cold and power), taking into account several security and regulation restrictions. EROSKI decided to go beyond already proven CCPH systems based on fossil fuels, and check the biomass as renewable energy source for a trigeneration system.

Initially a NH_3 absorption chiller was planned to directly distribute glycol water to the medium temperature cabinets. For security reasons, this idea was rejected changing the technology to a simple effect Li-Br chiller, dependent on the ORC and indirectly connected to the vapour compression refrigeration units.

As a result, a wood chips boiler of 250kWt was designed, integrating a thermal oil circuit to provide heat at 205ºC. The ORC produces 27,5 kWe and has the ability to reject the waste heat at two temperature levels: 88ºC and 50ºC. Heat at 88ºC will power a Li-Br absorption chiller, while 50ºC heat will be used for the supermarket heating and DHW needs, or rejected when no necessary.

The absorption chiller (17,6 kWf) will be integrated with a refrigeration cascade compression system in order to feed medium and low temperature cabinets. Cascade system will be composed of a N13 compressor (a new refrigerant close to the R134a with low GWP) and a CO_2 compressor. The integration with the absorption chiller is made by subcooling N13 after condensation.

This indirect connection was designed to ensure the refrigeration even if the absorption system fails or just cannot reach the required power do to regulation problems. Current rooftops will remain in place, so that the whole supermarket will still be operative in case the trigeneration prototype goes wrong.

In addition, the new facilities will avoid the use of the current R404A refrigerant, with high GWP, which is currently heavily taxed by the Spanish Government according to the RD 1042/2013.

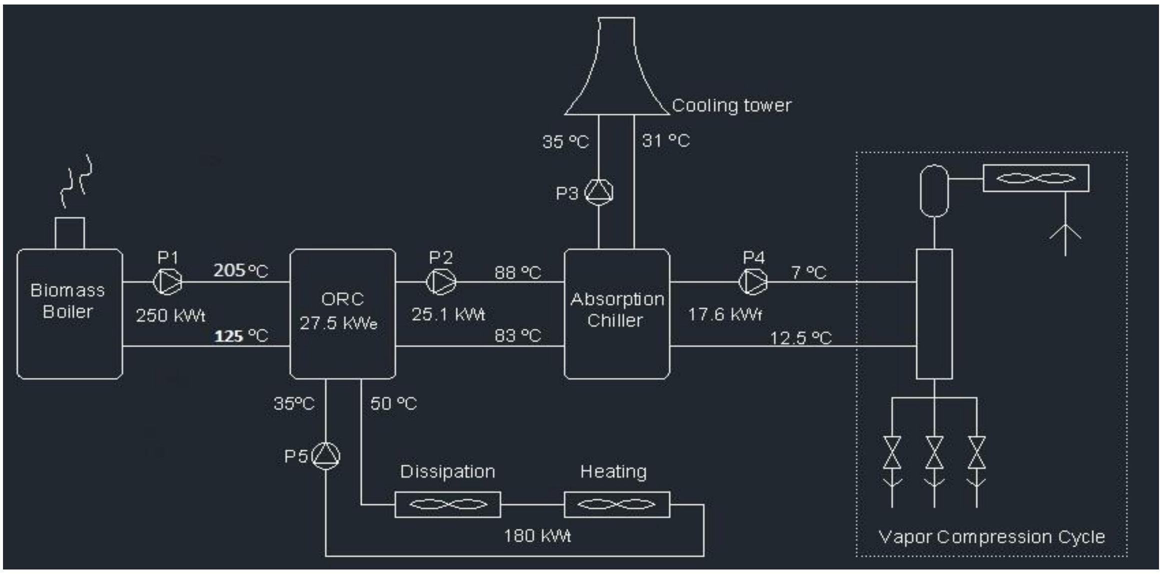

Fig. 3. Trigeneration scheme proposed within LIFE12 ENV/ES/000787 project.

5. Methodology of study

In parallel with the design of the different components of the trigeneration unit, several simulations were carried out in order to analyze the energy performance in the supermarket, taking as a reference the electric consumptions in 2014.

5.1. Energy demands registration & calculation.

27 power analyzers were installed in the pilot supermarket by the end of 2013. Thanks to these devices it is possible to know the electrical consumption of each application during the years 2014 and 2015. Moreover, two temperature and humidity meters are located in the shop. One for the external conditions and another for the indoor conditions.

One of the main goals of this project is to estimate the electricity savings of the trigeneration system compared with the real measured electrical consumption of the conventional equipment. Hence, the first step in the study was to estimate the energy demand of the supermarket from the recorded data. Electric energy consumption needs then to be translated into thermal energy demand in order to carry out the simulations.

Therefore, the energy needs of the HVAC and Refrigeration units were estimated based on the electrical consumption and the external and internal conditions (Temperature, Humidity) for a week of the year 2015. Note that the selected week (14/12/2015 – 20/12/2015) (in black the exterior temperature below) was not the coldest week in Vitoria (in green), but the selection was done considering the most representative week for Vitoria's cold climate in the second half of 2015, reflecting the current status of the supermarket before any other modification is done.

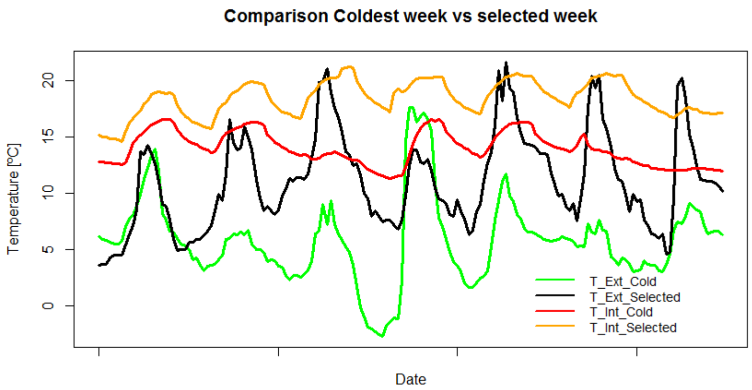

Fig. 4. Comparison between coldest and selected week.

After that, the thermal estimated demand is used to simulate the behavior of the trigeneration as it is explained forward. In the two figures that are shown below, it can be seen the electrical consumption of each different use (Total, HVAC, and refrigeration) – left figure- and HVAC and refrigeration with interior and exterior temperature –right figure - during the week under study.

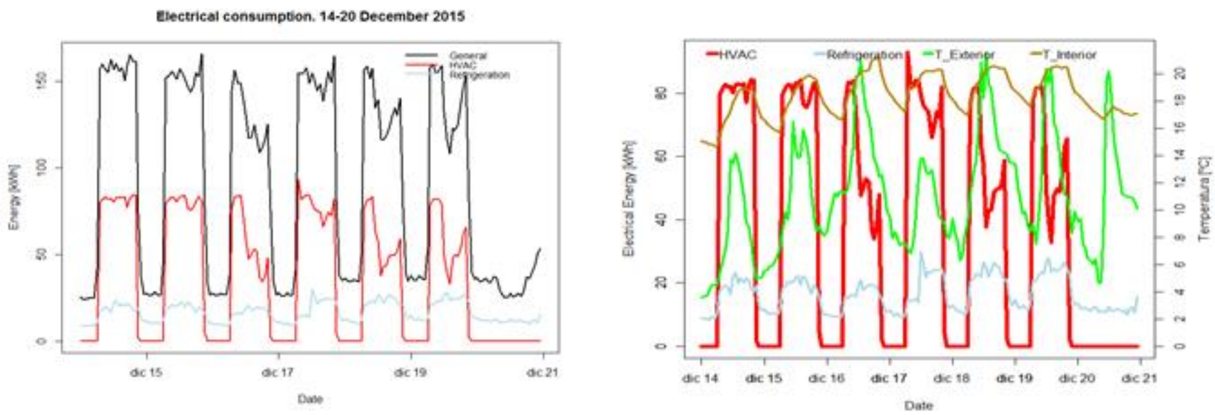

Fig. 5. Electric consumption and temperature evolution from 14th to 20th of December 2014.

A power meter measures the electrical consumption of condensers and compressors to refrigerate freezers and another measures electrical consumption to refrigerate the low temperature cabinets. Furthermore, the pressure and temperature in different points of the Refrigeration installation has been registered.

There are also power meters to measure the electrical consumption of the rooftops that satisfy HVAC demands.

5.2. Trigeneration Calculation model.

The energy performance of the trigeneration system has been evaluated using TRNSYS , a worldwide reference software for energy systems [23]. TRNSYS solves complex equation problems dividing them in several simpler problems. In this sense, the trigeneration system is modelled by means of various “types”, which are the visual representation of every component of the thermal installation to simplify the introduction of data, and they include several equations that define the thermal behavior of the component under several circumstances. The equations of all the types are solved by the kernel of the software. The following figure shows the energy model defined in TRNSYS.

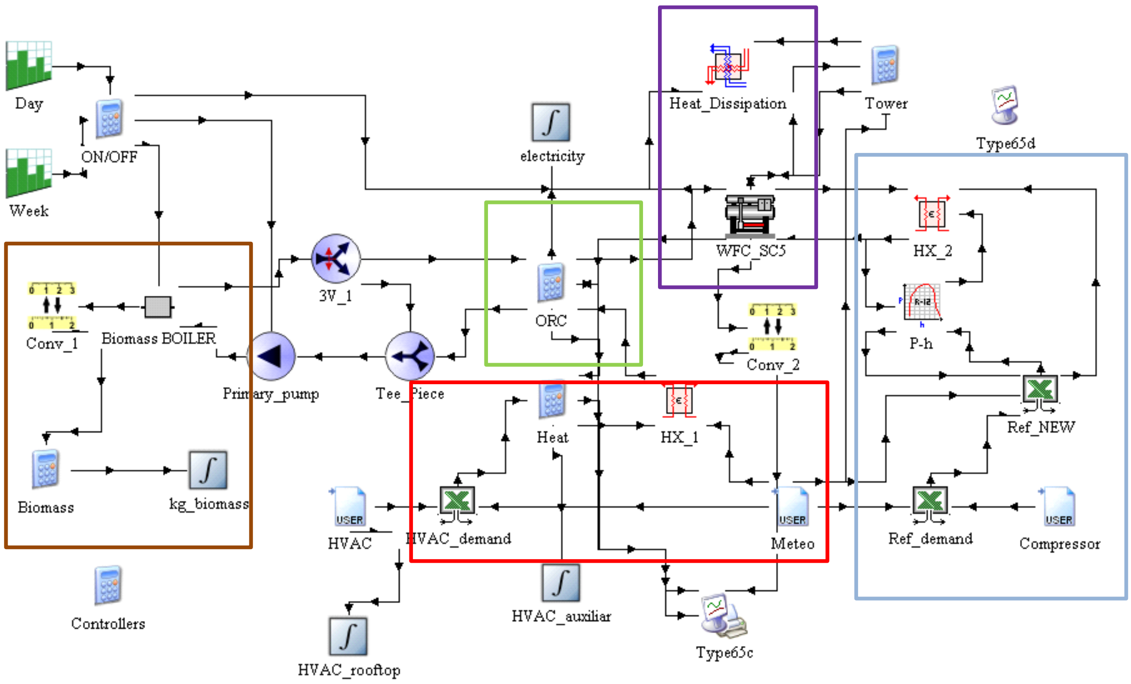

Fig. 6. TRNSYS model of the trigeneration system.

According to the scheme in TRNSYS, the installation has been divided in 5 main blocks, (i) the biomass system (in the brown square on the left), (ii) the ORC (in green, in the middle), (iii) the heat dissipation system (in red, below the ORC), (iv) the absorption machine (topright, in purple) and (v) th compression refrigeration compression system (in lightblue, bottom right).

(i) The biomass boiler has a nominal thermal power of 250 kWth ,and a 83.3% nominal efficiency. The TRNSYS type allows the introduction of the energy performance ratio under different working conditions, like the part load ratio or the setpoint temperature of the fluid. The combustion afficiency and boiler efficiency are defined in a file that is read in every simulation. Since the thermal difference between the inlet and outlet of the thermal fluid is 40ºC, a three way-valve is placed to guarantee this requirement. The fluid, which is a specific thermal oil used for this purpose, enters the ORC.

(ii) The setpoint temperature of the fluid that enters the ORC is 205ºC, The ORC produces electricity and thermal energy at two energy levels, 88ºC and 50ºC.

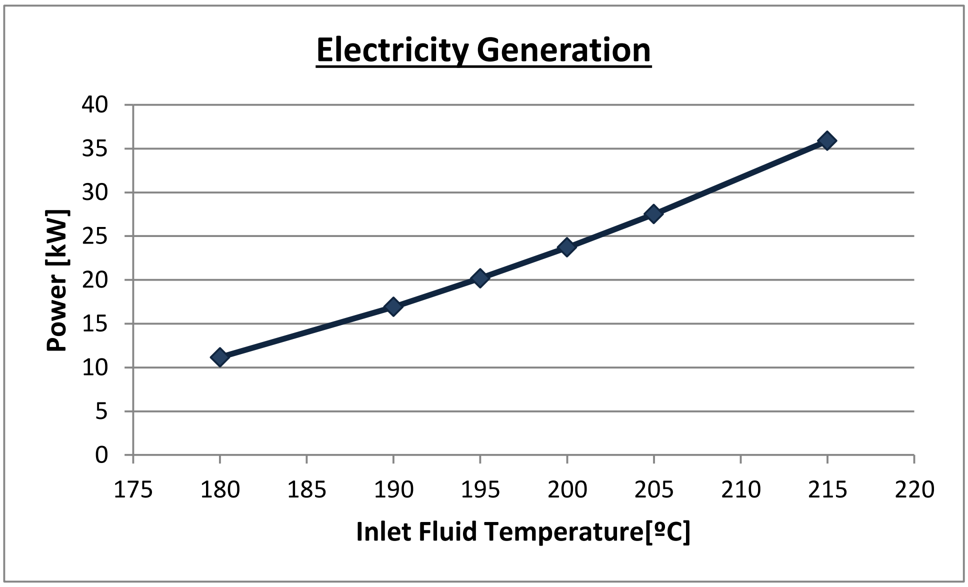

Fig. 7. Power generation of ORC depending on inlet fluid temperature. Source: RANK.

(iii) The low temperature circuit feeds two additional heat exchangers placed in the two rooftops that are providing heat to the supermarket to guarantee adequate thermal comfort to clients and workers. The rooftops maintain their working conditions, but the heat pump will only work when the low temperature circuit is not capable to fulfill the heating demand of the supermarket. To calculate the heating demand, the hourly electrical energy consumption of the two rooftops is converted into thermal energy. An excel routine has been defined, and a connection between TRNSYS and excel provides the COP of the rooftop every hour. The excel routine calculates the COP of the rooftop when working under different circumstances. The inlets of this routine are the exterior temperature and the part load ratio, and since the COP of the rooftops has been introduced in the excel file for several operating conditions, by interpolations, the COP is calculated. The water should return the ORC at 35ºC, so a heat dissipation system is included.

(iv) The high temperature circuit will provide hot water to a single effect LiBr absorption machine that has a cooling capacity of 17,6 kWf with a COP of 0,7. This absorption machine subcools the refrigerant N13 after the condenser, increasing the global efficiency of the refrigeration system. A heat dissipation system is required in an absorption machine. In this case, to simplify the maintenance, a dry cooling tower has been selected, and it has the goal to maintain the cooling water that enters the absorption machine between 28ºC and 32ºC.

(v) The actual refrigeration system includes two groups of compressors, depending on the working conditions, because one works at an evaporation pressure of 1.5 bar and 15 bars of condensation pressure providing cooling to the freezers maintaining the products at -30ºC approximately, and the other works at an evaporation pressure of 4 bar and 16 bars of condensation pressure, maintaining the products in the range of 0ºC - 2ºC. Both of them use R404A as a refrigerant.

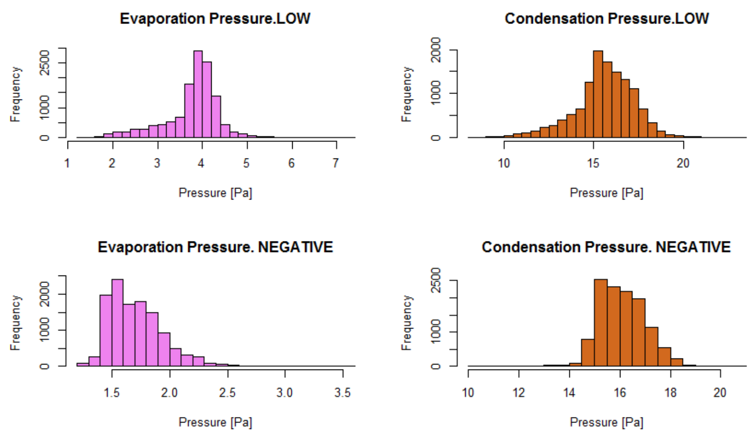

Fig. 8. Evaporation and Condensation pressures in LOW and NEGATIVE refrigeration

To model the refrigeration demand (negative temperature and low temperature) a database of the compressors installed was defined. These compressors are BITZER 4H252Y for the low temperature and BITZER 4H152Y. BITZER [24] gives access to a software that modifying the operational conditions (condensation temperature, subcooling of the fluid, evaporation temperature, and reheat of the fluid) useful data for every compressor is provided, incluiding cooling power, electrical consumption, COP…etc. A database containing these data was created. An excel routine is called from TRNSYS, and the inlets are exterior temperature and electrical consumption. The subcooling temperature is calculated from the exterior temperature, since data form the refrigeration system has shown a relationship between both temperatures. It can be seen, that the lowest the exterior temperature, the highest the temperature reduction.

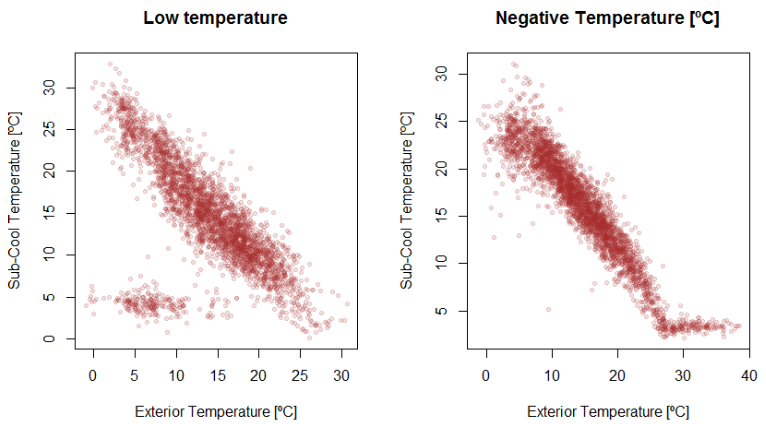

Fig. 9. Subcooling effect temperature.

The excel routine does a two level interpolation to calculate the COP and refrigeration demand of the cabinets and freezers.

The opposite is done to calculate the new/future refrigeration system, because another database was created, and a new excel routine was defined to provide electrical consumption from exterior temperature and refrigeration demand. In this new refrigeration system the CO2 circuit (negative temperature) condensates into the N13 circuit, working in cascade, and the fluid that exits the N13 condenser is subcooled thanks to the absorption machine.

6. Results.

As mentioned in point 5.1, the analysis is done for a representative winter week to evaluate the energy behavior of the system in heating mode. To provide high quality results from the simulation, a timestep of 0.1 was defined.

The following figure shows the comparison between the real hourly electricity consumption measured in the supermarket (in black) and the expected energy consumption with the new trigeneration system (in yellow). The difference between both areas is the slashed area and shows the energy savings.

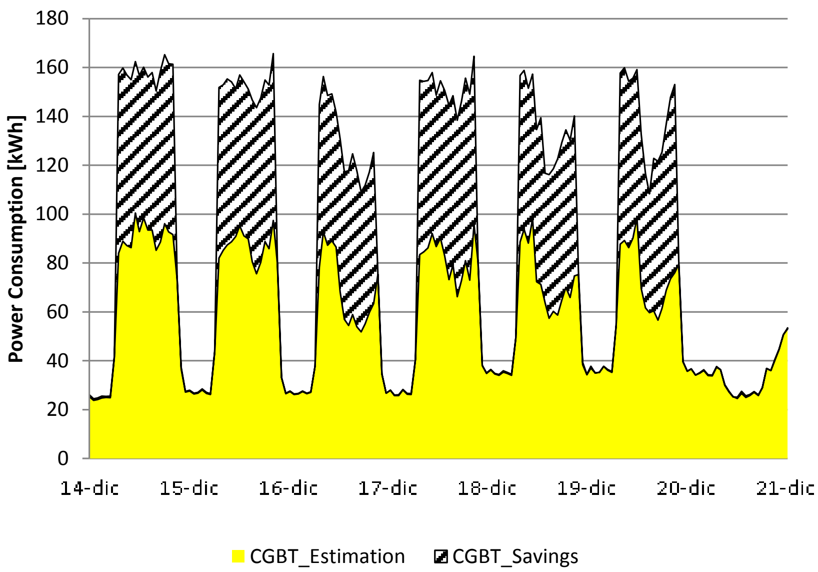

Fig. 10. Power consumption with and without the trigeneration system.

Firstly, it has to be noted that the peak power consumption has been lowered from 165 kWe to 100 kWe, and the electricity bill could be reduce lowering the electrical power contracted. The previous figure shows that although there is a high reduction, other equipment of the supermarket like lighting is not affected by the trigeneration system. In fact, only the 57% of the electricity consumption in that week was consumed for heating and refrigeration purposes.

The next figure only considers power consumption for refrigeration (blue line) and HVAC (red line) and also electricity production of the ORC (red line). The black shows the net electricity consumption considering the three aspects, adding HVAC and refrigeration consumption and subtracting the power production of the ORC.

$$NEC = HVAC + REF - POWER$$

NEC: Net electricity consumption

HVAC: Electricity consumption of the HVAC system

REF: Electricity consumption of the refrigeration system

POWER: Power production of the system

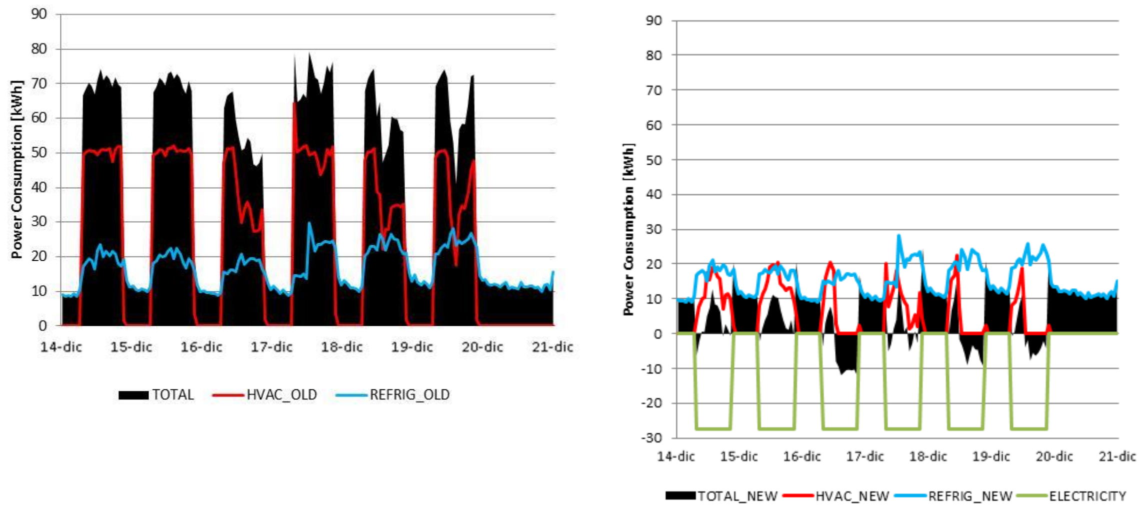

Fig. 11. Power consumption with and without the trigeneration system.

It can be seen in the previous figure that the energy consumption is highly reduced, being the net energy consumption of the actual system (left figure) around 70 kWe, and 12 kWe (right figure) after the implementation of the trigeneration system.

It is also shown that the trigeneration system only works from 8:00 to 20:00 hours from Monday to Saturday, and although Sunday was also included in the calculation.

The energy saving results are shown in the following table

	Electricity consumption [kWh]		
	ACTUAL	TRIGENERATION	SAVINGS
NET	6499,46	1030,36	84,1%
HVAC	3750,98	748,06	80,1%
REFRIGERATION	2748,48	2592,98	5,7%
POWER		2310,68	

Fig. 12. Power consumption with and without the trigeneration system.

The Net electricity consumption is reduced a 84% which is very significant. In can be noted that the highest energy savings come from the heating system. In fact, the energy consumption reduction achieved in the HVAC system is higher than 80%. This is supported by the electricity production.

However, the energy savings in the refrigeration system are not so significant because for the week considered the subcooling effect was not very high because the fluid temperature that exits the condenser is low, and in the week considered the actual refrigeration system shows a good performance.

Future investigations will be focused on the refrigeration system, considering the whole year.

7. Conclusions

Being responsible of 3-5% of the electricity consumed by developed countries, retail stores are considered as heavy energy consumers. The energy saving measures implemented in retail stores will imply a high energy reduction, and a high CO_2 emissions reduction.

This paper evaluates a trigeneration system in a supermarket providing heating, electricity and cooling using biomass as a fuel. The comparison has been done in a supermarket whose electricity consumption is being monitored in detail.

An in-depth energy model has been developed in TRNSYS, to evaluate the energy behavior of the trigeneration system.

For the week considered, the potential of energy reduction is high, mainly in heating, where 80% electricity consumption reduction is achieved.

The net electricity consumption, considering HVAC, refrigeration and power production, is reduced a 84%, which shows good perspectives. The week considered was not the most appropriate to evaluate the electricity consumption of the refrigeration system.

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Optimal cooling load sharing in trigeneration plants for a District Heating and Cooling network

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Universitat Rovira i Virgili

Abstract

Trigeneration plants can use different types of chillers in the same plant, typically single effect and double effect absorption chillers, vapour compression chillers and also cooling storage systems. The distribution of the variable cooling load demand of the buildings connected by a District Heating and Cooling (DHC) network has to be distributed among these chillers to achieve lower operating costs and higher energy efficiencies. This problem is even more difficult to solve taking into account the different partial load behaviour of each chiller and the high number of possible unit combinations that can cover a given cooling demand specially with the appropriate dimensioning of the cooling storage.

In this paper is presented a MILP (Mixed Integer Linear Programming) model of a trigeneration plant based on cogeneration engines. Real data from a trigeneration plant connected to a DHC close to Barcelona (Spain) is used for the development of this model. This model is used to optimize the daily plant operation and to study the optimal cooling load sharing between the different absorption chillers. This distribution is heavily influenced by the price of the electricity sold to the grid which rules the duration of the operation time of the engines. The main parameter to compare load distribution configurations is the primary energy saving indicator. Cooling load distribution among the different chillers changes also with the load of the whole plant because of the chiller performance change with load.

Introduction and objectives

In many cases the deployment of District Heating and Cooling (DHC) networks is not as fast as initially planned at the design stage of the project because the number of consumers connected to the DHC increases at a lower path than expected. Thus, in spite of the modularity nature of these plants to handle this type of problems is not enough to avoid a low partial load of the trigeneration plant serving the DHC during the first stages of the implementation of the project [1].

Additionally trigeneration plants can use different types of chillers, typically single effect and double effect absorption chillers and vapour compression chillers and cooling storage systems. The distribution of the variable cooling load demand of the buildings connected to the DHC has to be distributed among these chillers to achieve lower operating costs and higher energy efficiencies. This problem is even more difficult to solve taking into account the different partial load ehavior of each chiller and the high number of possible unit combinations that can cover a given demand specially with the appropriate dimensioning of the cooling storage.

The distribution of the load or “load sharing” should not be confused with the load sharing concept also used in the literature [2] that refers to a trigeneration system with a thermal or cooling load from a diversified type of end users (residential and commercial users). The overlapping of the load is interesting to increase the efficiency due to a higher annual operation hours. Another concept is the internal load sharing inside of the trigeneration plant between the units providing the same type of utility, electricity, heating or cooling. This last concept is of special interest to develop the load-sharing strategy to maximize the aggregate performance [3].

Usually, the multiple-chillers systems are controlled using a sequential approach to provide the building load demand [4]. Since the flow of chilled water in each chiller is constant, they have to operate at the same part load ratio. Instead of this it could be interesting to study other sharing load strategies. Abou-Ziyan et al. [3] analyzed the load sharing effect in multiple compression chillers achieving performance improvements between 22-33% with respect to the same part load ratio. So far the load sharing optimization has not been studied for a combination of different types of chillers (thermally driven and compression chillers) and connected to a cooling storage. In this paper is presented a MILP (Mixed Integer Linear Programming) model of a trigeneration plant based on cogeneration engines. This model is used to optimize the daily plant operation and to study the optimal cooling load sharing between the different types of chillers and the cooling storage. The main parameter to compare load distribution configurations will be the primary energy saving. The heat of the exhaust gases is recovered to produce cooling in a double effect chiller and the engine cooling waste heat is used to drive a single effect absorption chiller. A high efficiency compression chiller is used as a back-up system. The system uses also a chilled water storage tank. Real data from a trigeneration plant connected to a DHC close to Barcelona (Spain) is used for the development of the model.

Description of the trigeneration plant

The studied trigeneration plant provides energy services to Science and Technology Park in Cerdanyola del Valles (Barcelona). The main facility of this Science and Technology Park is a Synchrotron Light Facility but also includes office buildings among other public and private buildings. This trigeneration plant known as ST4 plant was already described in detail and analyzed by Ortiga et al [5]. Therefore only the main needed characteristics to understand the present analysis will be given here.

ST-4 plant is composed of three high efficiency (>44%) gas cogeneration engines of 3.3 MW each one, a direct fired exhaust gas absorption chiller of 5 MW and a COP=1.3 using directly the engine exhausts gases, a single-effect absorption chiller of 3 MW and a COP=0.75 recovering heat from the engine jacket cooling, a compression chiller of 5 MW and a COP of 5.8, a natural gas boiler of 5 MW and a chilled water storage tank of 4000 m^3. The waste heat recovered from the jacket water circuit of the engines is used to produce hot water for the district heating network and to drive a simple effect (SE) water/LiBr absorption chiller of 3 MW of cooling. As a function of the chilled water demand and the operation conditions of the ST-4 plant, some of the exhausts gases pass through the double effect (DE) water/LiBr absorption chiller of 5 MW of cooling to produce more chilled water.

Currently, the three engines always work at full capacity 16 hours a day to provide all the electricity to the grid but the chillers always have to work at low capacity due to the low cooling demand of the users. The partial load ratio of both absorption chillers is always below 60% but offer a quite good COP at these adverse conditions.

The compression chiller works when the absorption chillers are not in service: during the night and at the weekends when the price of the generated electricity is too low to keep the engines running. The cooling storage is mainly used to reduce the load of the compression chiller.

Modelling

The mathematical programming optimization model was developed using GAMS (General Algebraic Modelling System). The model is able to optimize the operational strategy for a typical day using a MILP approach. The binary variables are used to indicate when a given unit is in operation or not, o when the storage tank change its operation mode. The objective function is the difference between the income to the plant and the operational and maintenance costs.

$$Objective = Income - Cost_{operational} - Cost_{maintenance} \tag{1}$$

$$Income = \sum_{j=1}^{24} (El_{to\ grid}(j) \cdot El_{export\ price} + Demand_{cooling}(j) \cdot Price_{cooling} + Demand_{HW}(j) \cdot Price_{HW}) \tag{2}$$

$$Cost_{operational} = \sum_{j=1}^{24} \sum_{i=1}^{3} ICE_{fuel}(i,j) \cdot NG_{price} + \sum_{j=1}^{24} Boiler_{fuel}(j) \cdot NG_{price} + \sum_{j=1}^{24} El_{from\ grid}(j) \cdot El_{import\ price} + \sum_{j=1}^{24} MakeUp_{water\ price} \tag{3}$$

The days selected for the analysis include weekdays and weekend days. The required inputs are the hourly demand for each day and some parameters such as the price of electricity, heating and cooling sold to the end users, nominal capacity of each unit, maintenance costs, etc. The considered cost of natural gas is 30,2 €/MWh. The price of the electricity fluctuates along the day and has two contributions, a fixed and a variable cost. Some restrictions are added to the model to avoid continuous on-off of the same unit. The partial load performance of each unit has been modelled using the plant operational data and the nominal performance provided by the manufacturer.

The trigeneration Primary Energy Savings (PES) indicator is used to compare the different operational configurations. A crucial point in the numerical assessment of the primary energy saving is the merit of assigning suitable values to the reference efficiencies, which, in general, will depend on the technologies replaced. There are no official guidelines for this kind of reference efficiencies. In the following analysis intermediate efficiency values have been assumed, in particular: electrical efficiency was set equal to 0,45, thermal efficiency to 0,95 and the COP of the compression chiller equal to 5.

$$PES(j) = 1 - \frac{\sum_{i=1}^{3} ICE_{fuel}(i,j)}{\frac{\sum_{i=1}^{3} ICE_{el_{capacity}}}{0{,}45} + \frac{HW_{to\ users}}{0{,}95} + \frac{Q_{eva_{SE}} + Q_{eva_{DE}}}{0{,}45 \cdot 5}} \tag{4}$$

Results

Daily optimal plant operation

The developed model can be used to evaluate the optimal operational strategy and to analyze the differences with the real schedule of the plant. Of course, because of the simplicity of the model, it is not possible to take into account the transitional periods of the units, especially for the thermal chillers, but the simulations can offer important information about the amount of working hours of each component and its capacity level. The model is used for evaluating alternative strategies to those adopted by the plant, in typical days. Each day is subdivided in 24 time steps. Then, with the aid of a spreadsheet created on Microsoft Excel, it was possible to evaluate the production for each component, the income to the plant and the operational and maintenance costs in the same day analyzed with the model.

The day taken into account is a day of June when the plant works with all the internal combustion engines simultaneously. The engines are switched ON at 8 and switched OFF at 24, their transitional time is very low and it is almost 20 minutes. The trends of the cooling demand and of the import and export electricity price are shown in Figures 1 and 2. The peak cooling demand is around 42% of the total capacity of both thermal chillers.

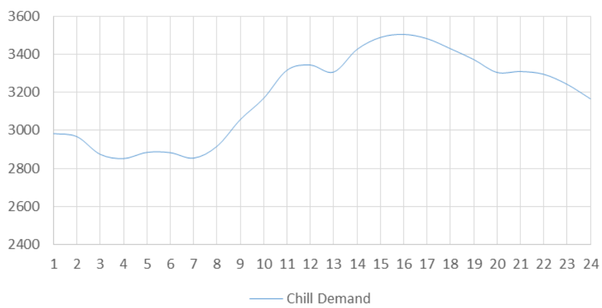

Figure 1. Chilled water demand in kWh.

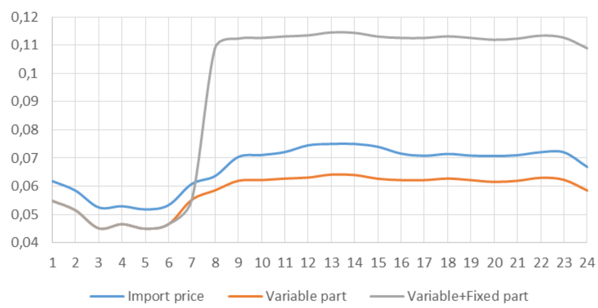

Figure 2. Electricity price in €/kWh

In the actual operational mode, the thermal chillers run during the same period as the engines. In the morning, they produce, more or less, a stable power, with the double effect that reaches an output of more than 3 MW, while in the afternoon there is a decrease (Figure 4). The trend of the single effect and of the double effect is very similar. During the night the use of the compression chiller is necessary, with two peaks, at the beginning and at the end, and a constant production in the middle of the night. Instead from the optimized solution (figure 3), the DE chiller works during the same hours of the engine at the maximum limit imposed while the single effect works from 8 to 12 h and from 17 to 22 h. Certainly, taking into account the transitional time of the machine, it could not be convenient stop it in the middle of the day from a practical point of view but the energy storage tank is better used in this case, as will be shown later.

Figures 5 and 6 show how the demand is covered in both cases. In the actual schedule the storage is used only during the night, from 2 to 8 h, with a peak of discharge power of almost 2000 kW while, in the suggested schedule of the optimization the storage is used during the night and also from 13 to 16, when the single effect absorption chiller is switched OFF. The maximum energy stored is about 15000 kWh (Figure 7) and is completely empty when the engines start.

The economic revenue with the optimized solution and the actual plant operation are compared in Table 1. The operation cost is higher with the proposed solution but the economic benefit is slightly higher because of a better use of the cooling storage system that saves electricity.

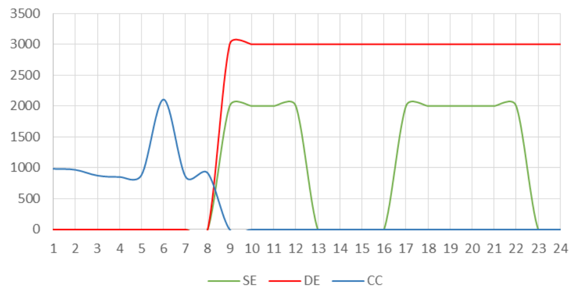

Figure 3. Optimized chiller water production (kWh).

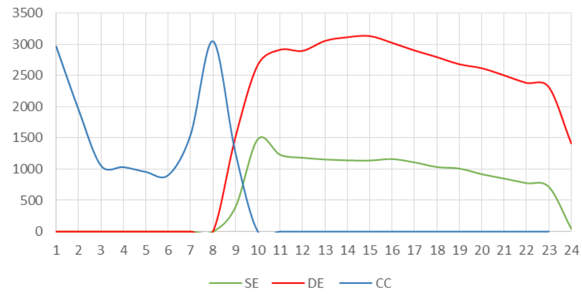

Figure 4. Actual chilled water production (kWh).

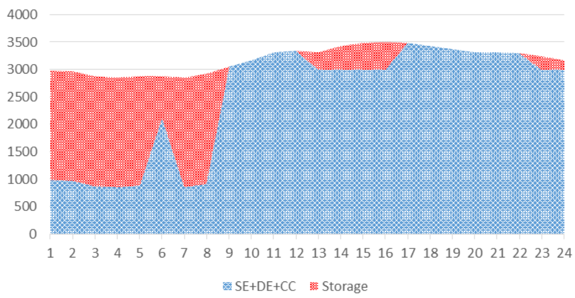

Figure 5. Optimized coverage of the demand (kWh)

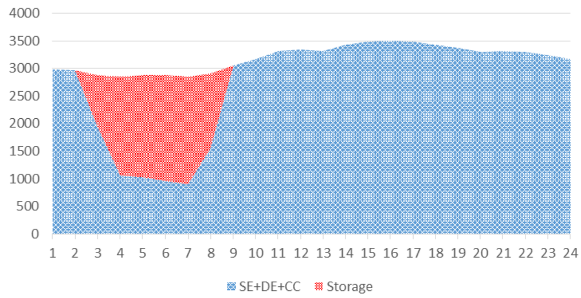

Figure 6. Actual coverage of the demand (kWh).

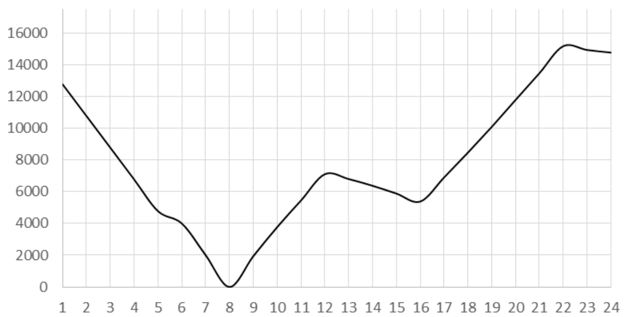

Figure 7. Hourly energy level of the storage (kWh).

Table 1. Comparison of the optimized and actual operation of the plant.

	Model	*Actual*

Maintenance costs (€)	1292	1253
Operational costs (€)	11246	10938
Income (€)	19825	19410
Economic revenue (€)	7287	7219

Optimal sharing of the cooling load between absorption chillers

Figure 8 shows the typical cooling load demand representative of the current operation of plant. The peak load is about the 40% of the total installed capacity of the absorption chillers.

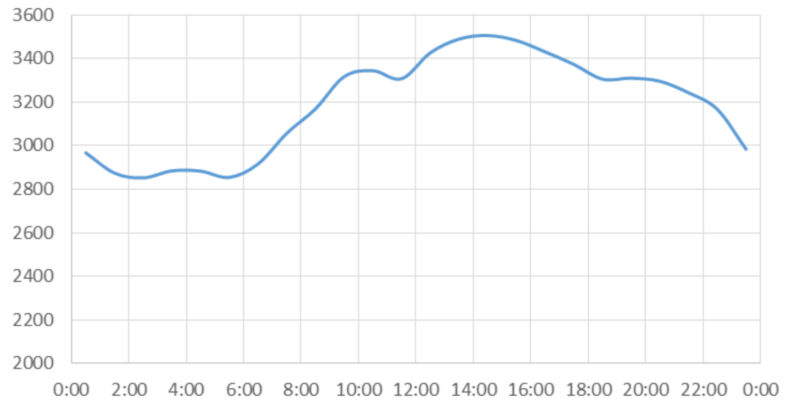

Figure 8. Typical cooling load demand (about 40% of the nominal capacity of both chillers).

To distribute the load among both chillers, capacity limits have been imposed to the model to check the effect on the PES and the optimal load for each chiller. Figure 9 shows the maximum daily PES for this plant using these limits. The dashed lines represent configurations that are not acceptable since the use of the compression chiller is necessary to charge the storage during the night in order to cover the demand during the day; the solid lines therefore represent acceptable solutions. As shown in this figure, the best PES values are obtained when the capacity limits are set higher than 50% for both chillers. This means that the best efficiencies correspond to the case when both chillers work at high capacity but not too high to reduce the load of the other chiller excessively. The load sharing for all cases is presented in figure 10. Each column represents the total production of both units, in particular the dark blue column is the portion produced by the single effect absorption chiller while the light blue color is the portion produced by the double effect absorption chiller. Solutions that require a massive use of the compressor are not taken into account. The best configurations are underlined with the use of orange columns for the production relative to the SE. The best allocation of the cooling load between both chillers has to be chosen between the configurations that produce the highest daily cooling production. Also it is convenient to choose the configurations were the contribution of the Single effect is relevant to get a high PES as shown in figure 9. In this way the amount of hot water to dissipate generated by the engines decreases. So the load of the SE chiller has to be selected between 70%-80% and between 50%-60% for the DE chiller.

The evolution of the objective function that corresponds to the plant economic revenue increases continuously with the increase in the limit capacity of the chillers as shown in Figure 11. Thus the highest value corresponds to the highest capacity limits. In this case the optimization procedure decides to work preferably with the more efficient chiller, the double effect chiller as seen in the last columns of figure 10. However, to get a balanced plant operation and a similar PES it is more convenient to work with an important contribution of the SE chiller around 70% or higher.

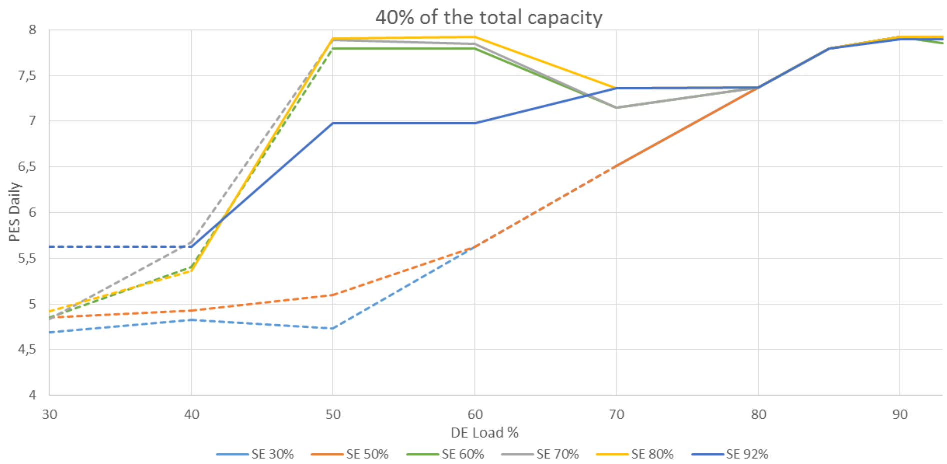

Figure 9. Daily PES for different maximum capacities for each chiller.

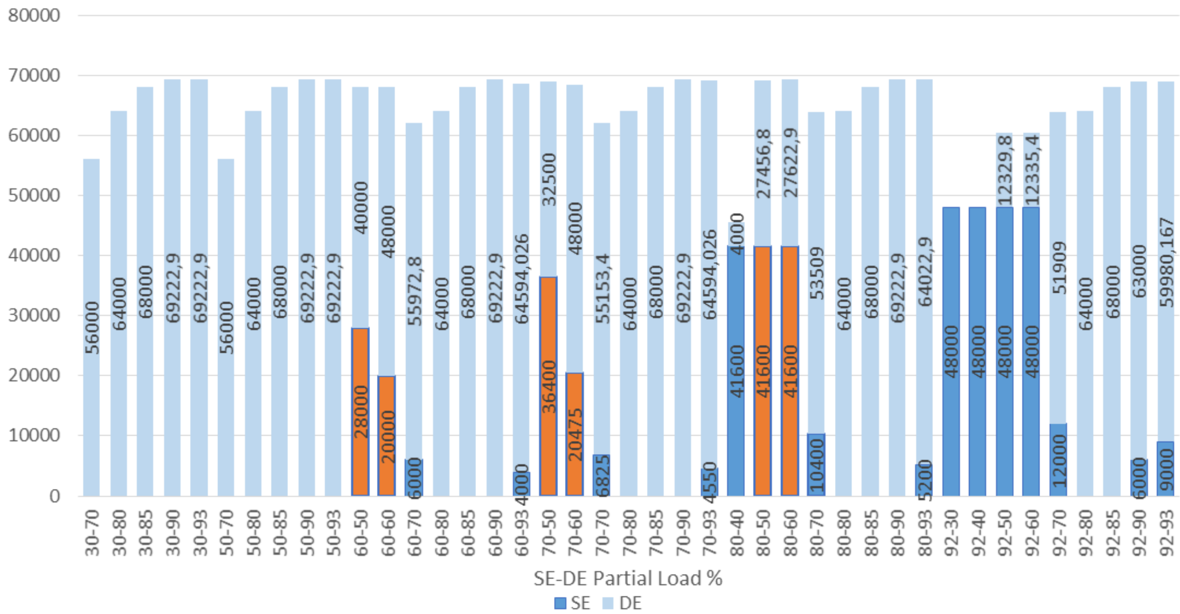

Figure 10. Sharing of the load between the Single and Double-effect chiller.

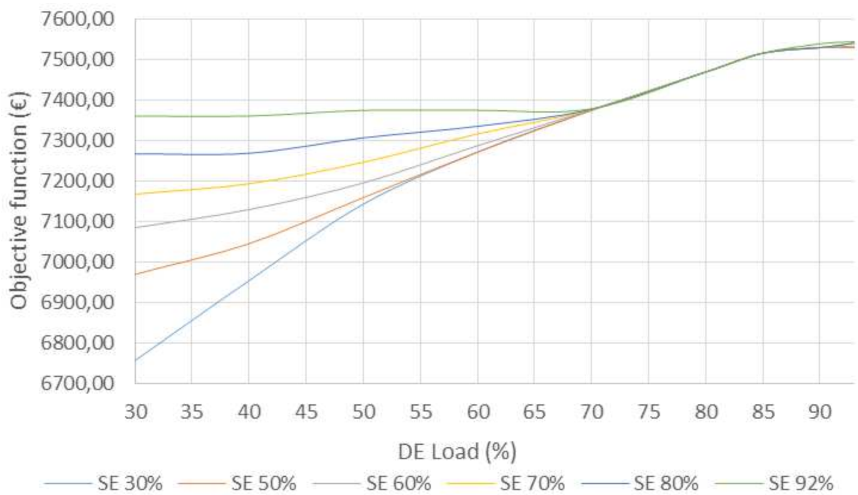

Figure 11. Objective function as a function of the capacity limits for each chiller.

Conclusions

The model developed was used to study the optimal cooling load sharing between the different types of chillers and a cooling storage system using the primary energy saving indicator as the main parameter to compare the different load distribution configurations for a given cooling demand. This distribution is heavily influenced by the price of the electricity sold to the grid which rules the duration of the operation time of the engines. The load sharing strategy was also studied for a typical day. Cooling load distribution among the different chillers changes also with the cooling load of the whole trigeneration plant because of the characteristic chiller performance change with the load. The efficiency of the single effect chiller is the lowest one but its operation is important to increase the heat recovery of the cogeneration engines and reduce the cost of engines cooling heat rejection.

From the economic point of view the optimization approach prefers to use the Double effect chiller as much as possible because it is more efficient but to get an acceptable saving in primary energy it is interesting to work also with the single effect chiller at around 70-80% of its maximum capacity to avoid excessive dissipation of heat to the ambient and obtain good primary energy savings.

The developed model is very useful to study different plant operation strategies and allocate the different energy loads among the chillers.

Acknowledgements

The authors acknowledge the collaboration of the company *Poligeneració Parc de l'Alba ST4 S.A.* in this study.

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Session NZEBs I

Balancing energy efficiency and renewable energies: An assessment concept for nearly zero-energy buildings

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Abstract

This paper explores and highlight the correlations between energy efficiency and renewable energy in the context of enabling sustainable solutions for buildings and districts.

Over a third of the total energy consumed in developed countries is required for operating buildings, especially to heat them. Energy efficiency measures are available, tried and tested, that contribute to significantly reducing this consumption. It then becomes possible to cover the comparatively low remaining energy demand sustainably with renewable energy resources. In the light of the Nearly Zero-Energy Building standard stipulated in the European Buildings Directive, which will come into effect in 2021, it is important to provide guidance for an appropriate balance of energy efficiency levels and renewable energy supply in the context of buildings.

A new assessment methodology was developed, which specifically does not promote the simple annual offset of on-site energy demand and energy production in the context of individual buildings. The achieved level of energy efficiency and renewable energy supply need to be assessed independently of one another. Direct offsetting disregards important aspects, such as energy losses due to storage and space availability for RE production. The new methodology uses a contextualised approach, in which the energy demand of buildings is analysed in an environment of a solely renewable energy supply network. Depending on the type of energy application, as well as on the locally available RE resources, the amount of required storage varies, and thus the associated losses. Based on these interrelationships, weighting factors, the so-called PER factors (Primary Energy Renewable) are used as indicator as to which energy applications are the most resource intensive.

Introduction

Over a third of the total energy consumed in the European Union is required for operating buildings, especially to heat them. The significance of this sector with respect to its impact on climate change has been recognised and regulations are being put in place to address the issue. The European Union's Directive 2010/31/EU on the Energy Performance of Buildings (EPBD recast) stipulates the "nearly zero-energy building" (NZEB) as minimum energy standard for all new buildings in the member states after 31 December 2020 (or 2018 for public buildings) [1]. As the name "nearly zero-energy" suggests, this standard implies a high level of efficiency. The actual definition of this standard, however, varies for the individual member states, with significant differences in terms of the pursued reduction in demand by means of energy efficiency (EE) versus the allowance to offset a building's energy demand with the use of renewable energy (RE).

The intended purpose of NZEBs is to reduce greenhouse gas emissions in the building sector and thus to mitigate the impact of buildings on climate change [1]. Energy efficiency and renewable energy: Neither technology will work alone as means to the end; it is a combination of both that provides a feasible path to the sought after sustainable (in a broader sense) energy performance of buildings. The question arises how to find an appropriate balance between the two contributions, in order to reliably reach the overall goals at low costs and preferably soon. Whilst the recommended technical solutions will vary on an individual basis, clear tendencies become apparent when analysing the energy supply of buildings in the context of available renewable energy resources. Efficiency measures for buildings are available and they have been tried and tested for reliable long-term performance [2]. These measures successfully lead to substantial reductions of the consumed energy, especially with respect to space heating. Only then does it become realistically feasible to cover the comparatively low remaining energy demand sustainably with renewable energy resources.

Sustainable energy performance of buildings: Assessment methods

Different approaches currently exist to assess the sustainability of the energy performance of buildings. In most cases, the final energy demand of the building gets weighted with different factors for the various energy carriers in use (electricity, gas, etc.) in order to obtain an indicator for the overall environmental impact. Two common methodologies are: Primary energy (PE) (non-renewable) and the greenhouse gas impact indicated by the emissions of units of CO_2-equivalent, the so called Global Warming Potential (GWP). For both these weighting methods renewable energy resources are essentially regarded as “freebie” i.e. with no negative environmental impact and available in unlimited quantities. All inefficient solutions can simply be offset with renewable energy generation – not taking into account the implied need for energy storage and associated energy losses. It must, however, be recognised that renewable resources are in fact also a limited resource – mainly due to space constraints and for economic reasons. A timely and reliable transition to a fully renewable energy supply infrastructure, which is a non-negotiable aspect of mitigating climate change, is only possible if this fact is recognised and acted upon. In other words, the available renewable resources need to be put to use responsibly rather than being wasted. The more renewable energy gets wasted, the more non-renewable energy will be needed in the long run to compensate for this.

The energy supply is already transitioning from the previously dominant fossil fuels to a substantial increase of renewable energy resources. Hitherto existing sustainability assessment methods are thus no longer reliable indicators of a building’s energy impact. In the light of this lack of a reliable energy sustainability indicator for buildings, a new methodology based on so-called “Primary Energy Renewable” (PER) was developed. The intention of this approach is to reflect the required renewable energy resources to cover a building’s final energy demand.

Primary Energy Renewable

Renewable primary energy (PER) is the unit of energy generated from renewable resources, e.g. electricity produced by a photovoltaic system / wind turbine or heat generated with a solar thermal system. PER-factors reflect the primary renewable resources needed to cover the final energy demand of a building, including distribution and storage losses. In the case of a PER-factor of e.g. 1.5, a surplus of 50% renewable primary energy is needed in order to be able to meet the final energy demand at the building. The higher the PER-factor, the higher the required resources and therefore the more important the implementation of efficiency measures in order to avoid compensation from non-renewable sources.

Renewable Electricity

The PER assessment method anticipates the energy transition to 100 % primary energy supply from renewable resources – a scenario that has been recognised to play a fundamental role in global climate change mitigation actions and that is already being implemented step by step. In this scenario, electricity plays a major role, generated mainly by wind turbines, photovoltaic systems and hydropower plants. The prevailing weather conditions drive all of these resources, which implies an imbalance between the times of electricity availability and electricity demand. Only a certain proportion of the generated electricity can be distributed via the mains grid used directly, i.e. when energy demand and supply occur at the same time. A certain capacity of energy storage is inevitably required to buffer energy supply during times of surplus production to times of deficiency in RE supply. Various technologies are available with a comparatively high efficiency around 70-80 % as short-term storage to overcome several hours or even days of energy shortcomings (e.g. pumped or other mechanical storage, batteries, thermal storage etc.). A highly promising technology for longer term seasonal storage is power to gas (PtG) [3], where the RE electricity is converted into methane with an efficiency of typically 57 %.

During times of energy demand, the gas can then either be used directly as energy carrier in the building or it can be re-converted into electricity in a CCTG plant at an efficiency of approximately 50 %. Electricity consumed at the building, which has had to undergo seasonal storage, therefore can be supplied with an overall efficiency of approx. 30 % (see Figure 1).

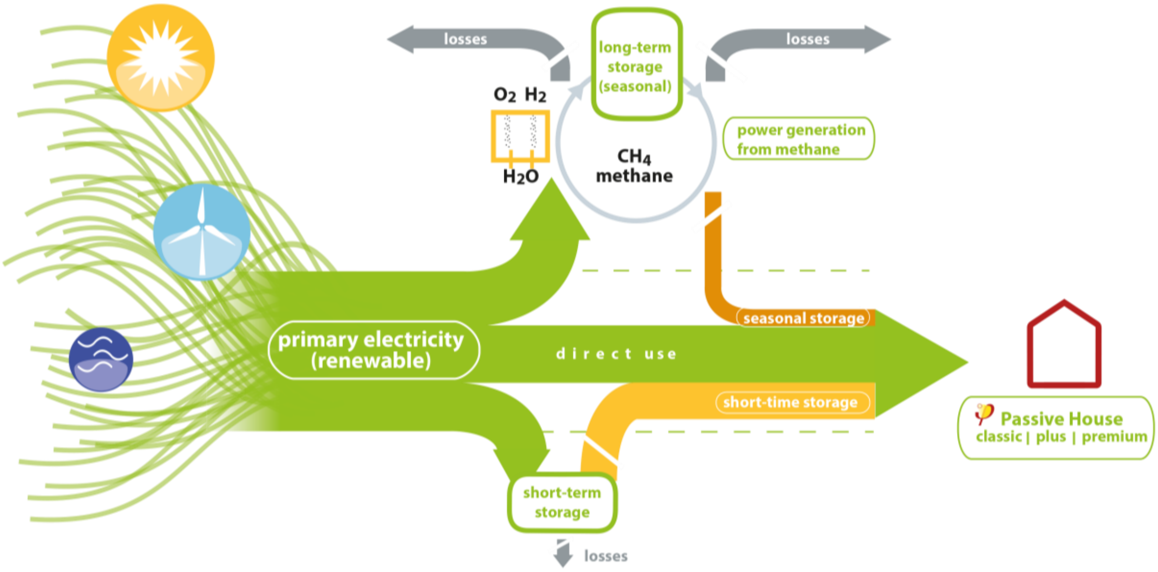

Figure 1: The electricity used to meet the final energy demand at the building is composed of three different components: (1.) direct low-loss consumption when there are sufficient resources to meet the demand (center), (2.) via short-term storage with an efficiency of approx. 80 % (bottom) and (3.) via seasonal P2G storage with an efficiency of approx. 30 % (top).

The PER factors are driven by the timely concurrence of energy supply and demand and thus the need for storage and associated losses [3], [4]. Consequently, the factors vary for:

a) different locations, due to the different climatic conditions and thus available RE resources
b) different load profiles (heating, cooling, hot water, electricity).

PER weighting factors were determined for locations worldwide by means of hourly dynamic simulations that model the energy supply and energy demand under given weather conditions and for different regionally expected load profiles [5]. The heating demand for domestic hot water and for electricity feature fairly constant demand profiles over the course of the year, which results in PER factors of about 1.3. The demand can be covered to a large extent directly from the primary source, without the need for storage, or via efficient short-term storage technologies. The energy demand for heating, on the contrary, only occurs during winter with low solar energy resources. A large part of the energy demand must therefore undergo seasonal storage, which implies high losses. As an example: For Central Europe the PER-factors for electric heating (e.g. via a heat pump) are around 1.8. This higher factor clearly indicates the increased importance of employing efficiency measures to reduce the heating demand.

Application of PER-weighting factors

The PER assessment methodology can be applied with the Passive House Planning Package Version 9 (PHPP) [6]. The PHPP calculates the building's total final energy demand and then automatically determines the total PER-demand by weighing the final energy demand with the PER factor corresponding to the type of energy consumer and the energy carrier used. In parallel, the PHPP carries out an assessment based on non-renewable primary energy and on CO_2 equivalent emissions.

The PER factors for electricity-use for different consumer profiles, as described above, have been integrated into the PHPP for locations worldwide. The following paragraph briefly describes how energy carriers other than electricity are treated in the PER methodology.

Each building is assigned an annual **biomass** budget of 20 kWh_{PER}/m^2_{TFA} [1] with a PER factor of 1.1. This budget reflects the maximum contingent of biomass that can sustainably be used in the building sector for energy purposes, caused by limited availability of biomass worldwide and its competitiveness for other uses (food, transport sector, raw material use) [4] [7] [8]. This same biomass budget is credited for all buildings and all energy uses, assuming that if the biomass is not being used locally (e.g. in a wood burner or pellet furnace) it is being put to use in a centralised plant (e.g. in a CHP to provide electricity and heat for a district heating network). If the biomass used in a building exceeds the admissible budget, the respective final energy demand is rated as RE gas (RE electricity converted into methane). Applying this approach restricts the use of biomass in buildings to a certain extent, rather than enabling its use as means for carbon offsetting with inefficient solutions. The PER approach encourages solutions where the highly valuable energy carrier, biomass, is used in buildings only in the winter period but not during summer when there are plenty of other renewable sources readily available.

For the PER assessment of heat generated with on-site **solar thermal**, the system's yield is compared with the potential yield of a photovoltaic system under the same boundary conditions (size, location, orientation, shading etc.) [8]. This approach encourages small and medium sized systems, whilst penalizing large systems over-dimensioned for the on-site energy demand.

Any **gas** used in a building is considered RE gas. The comparatively high PER factor of 1.75 (beyond the biomass budget) reflects the efficiency of the energy intensive conversion process from RE electricity into methane.

Future-oriented energy concepts for buildings

The following aspects are general tendencies when assessing the energy supply of a building based on the PER methodology:

- Efficiency measures for space heating have the biggest impact compared to other energy applications in the building.
- The use of biomass in buildings is only encouraged to a certain extent.
- Moderate use of gas and other fossil fuels becomes important.
- The PER-factors for electricity for heating turn out to be quite favourable, especially in combination with heat pump systems.

The last point mentioned above is worth exploring in some more detail, i.e. the fact that the assessment based on PER rates the use of electricity for heating in buildings quite favourably. The reasoning behind this is coherent: In the future scenario the electricity produced from renewable sources and thus entirely "clean" and free of greenhouse gas emissions. There is no doubt that the proportion of renewables is increasing, which is cause a decarbonisation of the electricity generation. Figure 2 shows the historical development of emissions and predictions for the electricity generation in Germany according to different sources. The question arises, however, whether it is indeed appropriate to encourage electric supply systems already today, or whether solutions based on gas or oil would currently actually have lower emissions. A comprehensive analysis of this question in [9] verifies that the PER recommendations are reliable and suitable also today.

[1] TFA = Treated Floor Area, reference area for the energy demand of Passive Houses. Similar to the living area, defined in (6).

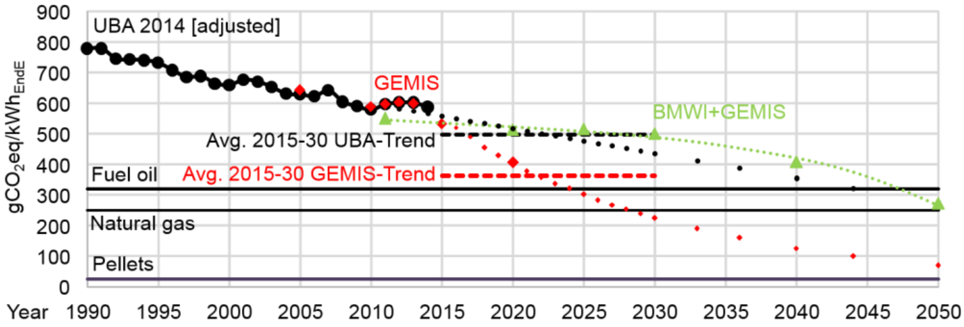

Figure 2: Equivalent CO2 emission factors for the electricity generation in Germany. Historical values and predictions according to different sources. Data derived from: [10] [11] [12].

Offsetting energy demand with on-site renewable energy

Offsetting the energy demand with on-site renewable energy production is often set as a goal, leading to “net-zero” or even “plus energy” buildings. The objective is to generate at least as much energy, as is being consumed – in absolute terms, i.e. MWh per year. Whilst this at a first instance appears a noble approach in terms of minimising climate impact, this approach is problematic for the following reasons:

- The effects of energy storage and distribution are neglected entirely. As indicated by the PER factors, however, the timely misbalance between demand and supply can lead to significantly higher amounts of required energy supply in order to be able to compensate for the losses and still meet the on-site final energy demand.
- It is much easier to offset the absolute energy demand in the case of a single family home than it is for a multi-storey building. Multi-story buildings, however, have a much lower impact in terms of space and material use and are therefore significantly advantageous in terms of sustainable housing developments.

Absolute off-setting is therefore misguiding in many cases and does not lead to sustainable solutions as an automatism. It is therefore important to assess the energy efficiency of a building and the associated renewable energy production independently of one another. Whilst the first is an inherent property of a building – energy is needed to provide healthy and comfortable living and working conditions – the latter is an “add-on” in the sense that energy need not generally be generated on-site but can also be provided from elsewhere. Developing and expanding renewable energies is an indispensable aspect of mitigating climate change and it does make sense to make use of buildings as hosts for energy production. Every building occupies a certain amount of space, which is no longer available for other uses. Harvesting the renewable energies available on this occupied area creates an additional benefit and means that the energy need not be generated elsewhere with additional space requirements. It makes sense, therefore, to assess the energy being produced on-site to the occupied area, e.g. the building’s projected footprint.

The suggested approach of independent assessment of the efficiency level (with respect to the living area) and the energy generation (with respect to the projected footprint area) encourages the best possible solutions for both parameters. Regardless of whether the building is a bungalow or an office tower, it is ensured that the energy input needed for health and comfort is low and the energy output with respect to the locally available renewable resources is high. Bungalows will automatically become “plus-energy” houses in many cases, whilst high-rises will not be misguidingly downgraded for not achieving “net-zero”.

Passive House Classes

Simultaneously with the introduction of the PER assessment methodology in the PHPP, the Passive House Classes were introduced that classify the building in terms of their overall efficiency level and the renewable energy production: Passive House Classic, Plus and Premium [13].

The underlying functional definition of the Passive House standard remains unchanged and is the same for all three Passive House classes (relating to useful energy demand for heating and cooling, as well as airtightness and comfort criteria). The hitherto existing criteria for the overall efficiency was based on PE and has now been replaced with a PER demand of three different thresholds. This includes all energy applications in a building i.e. the heating and cooling energy, as well as hot water, the complete electricity and any auxiliary electricity to provide the energy services.

Up-to-date, energy generation was not at all a requirement for the Passive House standard (though it was often added voluntarily). In order to encourage the expansion of RE and recognise its important contribution of renewable energy supply in the context of buildings, all energy supplied by a newly constructed RE systems are now accounted for as renewable primary energy input (PER-factor =1).

The higher the achieved level of overall efficiency and of renewable energy generation, the higher the Passive House class according to the thresholds as listed in **Table 1**. This makes the Passive House an ideal blueprint for the NZEB standard [14].

Table 1: Threshold values for the Passive House classes with respect to the overall energy efficiency and renewable energy generation.

Passive House Class	Efficiency requirement **PER demand**	Renewable energy harvest **PER supply**
Classic	**≤ 60** kWh / (m^2_{TFA}·yr)	no requirement
Plus	**≤ 45** kWh / (m^2_{TFA}·yr)	**≥ 60** kWh / ($m^2_{footprint}$·yr)
Premium	**≤ 30** kWh / (m^2_{TFA}·yr)	**≥ 120** kWh / ($m^2_{footprint}$·yr)

Because the defined threshold for the overall efficiency is not based on a functional requirement, a certain flexibility is permissible. Up to ± 15 kWh / (m^2TFA·yr) PER demand can be compensated with higher/lower RE supply. For example: No renewable energy generation is required per se for the Passive House Classic standard. If the PER efficiency threshold of ≤ 60 kWh / (m^2_{TFA}·yr) cannot be met in an individual case, it is permissible to offset the exceeded demand with energy production (in absolute terms, i.e. the same MWh), e.g. by a photovoltaic system or solar thermal unit on the roof. Similarly, if in the case of the higher Passive House classes it is difficult for a specific project to reach the required RE generation (e.g. due to strong shading at the site), this deficit can be compensated for with higher overall PER efficiency. **Figure 3** shows the criteria for all Passive House classes.

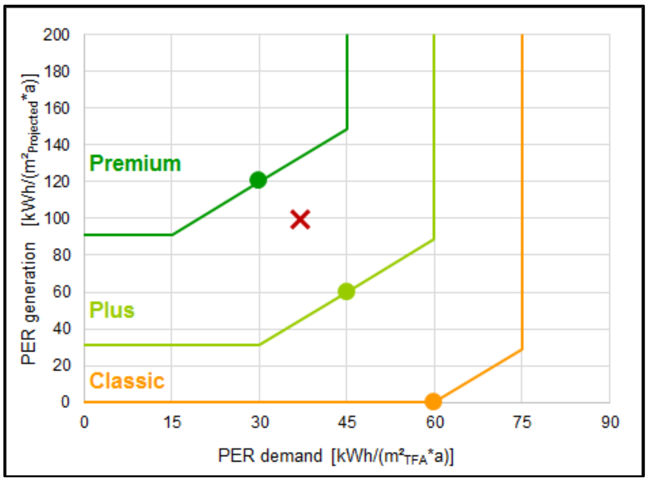

Figure 3:

Screenshot taken from the PHPP [6] that shows the requirements for the overall efficiency (PER demand, y-axis) and the RE generation (x-axis) for the three Passive House classes Classic, Plus and Premium. The red cross indicates the performance of the building currently modelled in the PHPP, in this case a single family home as Passive House Plus.

Some example projects

Renewable energy supply of Passive House projects

Supplying the energy demand of a highly energy efficient building is a complementing decision and logical choice. Many Passive House projects thus include some form of renewable energy supply, may it be on-site or nearby. One early, very successful and extensively documented example is the Passive House development of row houses in Hannover Kronsberg [15], built in 1998 for the EXPO 2000. One single 1.5 MW wind turbine close to the site of the housing development was used to offset and even exceed the primary energy demand of all houses. This project demonstrated for the first time in Europe that a fully renewable energy supply (in the "net-zero" sense) was not only technically feasible but also economically attractive, made possible due to the high level of energy efficiency of the Passive House settlement. Hannover is continuing their success story that began with the 1998 Kronsberg district with the currently emerging "zero:e park am Hirtenbach", a housing development with some 300 Passive House residential units, complemented with solar thermal energy and a reactivated hydroelectric power plant.

There are also examples of larger and non-residential projects that demonstrate the exemplary combination of energy efficiency and renewable energy supply. One such example is the so-called "House of Energy" in Kaufbeuren [16], which was the very first project to be certified to the Passive House Premium standard. The building has a total area of 900 m² with mainly office space, some residential units and an exhibition area. As in every Passive House building in Central Europe, maximum energy efficiency is ensured through triple-glazed windows, an excellent level of thermal protection, an airtight building envelope, largely thermal bridge-free construction and a ventilation system with heat recovery – as for the ventilation, devices from different manufacturers were installed for comparative measurements. A ground-source heat pump is used for the remaining small heating demand and hot water provision. The necessary auxiliary energy and domestic electricity are provided by the photovoltaic system. Any surplus energy that is generated is fed into the grid.

Passive House districts / regions

Municipalities around the globe have recognised the importance role of high efficiency standards as a pre-requisite for reaching climate goals and are targeting their policies and legislations, as well as their incentive and support programmes accordingly.

The PassREg project [17], supported by the Intelligent Energy Europe Programme of the European Union, aimed at showcasing successful example regions and providing guidance and support for others to follow suit. Hannover, with their previously mentioned zero:e park, is one of the highlighted municipalities. Another is Heidelberg, with their new "Bahnstadt" district of 116 hectares that will eventually provide housing for over 5 000 people and office space for approximately 7 000. By making the Passive House standard mandatory for all buildings on-site early on during the development process and by ensuring high quality assurance throughout, the buildings now in use in the Bahnstadt are performing very successfully with a measured low energy consumption [18]. The remaining low heating demand of the entire development is supplied by a district heating network, which in the medium term is to be run fully from renewable sources. Other examples from the PassReg project are Brussels, the city of Frankfurt am Main, as well as the regions of Tyrol in Austria and Antwerp in Belgium.

Not only the targeted energy standard for new-builds is of importance, the potential that lies in retrofitting existing buildings accounts for the larger share of energy savings. EuroPHit [19], another project funded by the EU's Intelligent Energy Europe Programme, focuses on advancing and facilitating step-by-step deep energy retrofit solutions. SINFONIA [20], a project supported under the European Union's 7th Framework Programme, takes the questions surrounding retrofit solutions to a larger scale. Two cities, Bolzano and Innsbruck, are cooperating as pioneering partners with a focus on developing district solutions that are transferable and scalable with respect to retrofitting practices, optimisation of the electricity grid and improving the heating and cooling concepts.

Summary and conclusion

Within less than a decade, the building standards in all member states of the European Union must fulfil the requirements of the Nearly Zero-Energy Building. This standard stipulates a very low energy demand as well as renewable energy generation – the exact handling of both is to be defined by the individual member states. The question addressed in this paper is how to find a suitable balance of energy efficiency measures for buildings versus offsetting their energy footprint with renewable energy supply. The aspects presented hold true equally for small and large buildings, for residential and non-residential uses, for new-builds and for retrofits, for individual projects as well as for districts.

The overall goal is to minimise the greenhouse gas emissions, in order to mitigate the impact on climate change. The individual boundary conditions are of course decisive for the most suitable strategy but one fact generally holds true: Efficiency must come first for a successful transition to an entirely “clean” energy supply of buildings. As the selected examples demonstrate, energy efficiency to the level of the Passive House standard is “tried and tested”, both in terms of their economic feasibility and in terms of their reliability in performance. Implementing this level of efficiency is a prerequisite for being able to cover the entire energy demand, including losses, from renewable sources.

In order to enable a transparent and honest assessment methodology for the performance of buildings fit for purpose, a new approach was developed of dealing with buildings in the context of renewable energy supply. The newly introduced assessment methodology, which is based on PER (renewable primary energy), enables future-oriented design choices with a focus on treating available resources responsibly. Rather than encouraging offsetting of the absolute energy demand in context of individual projects (and thus neglecting storage and distribution losses), the proposed method takes into account the timely correlation of demand and supply. Efficiency measures become most relevant in the energy-scarce winter period i.e. for the space heating demand. The demand and supply are assessed independently of one another, in order to enable both aspects to be exploited to their full potential. Projects optimised with this approach are not only future-ready and fully in line with the climate protection objectives, they furthermore play an extremely important role in facilitating and accelerating the necessary transition in the energy supply structure towards 100 % renewable energy supply.

Acknowledgements

Part of the presented work was developed with the SINFONIA project (www.sinfonia-smartcities.eu). The SINFONIA project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under the grant agreement 609019.

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Demonstrating Nearly Zero Energy Hotels in Europe

Examples and experiences from the European initiative neZEH

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Abstract

According to the EPBD recast, all new public buildings should be Nearly Zero Energy Buildings (nZEBs) after the end of 2018 and all new buildings from the 1st of January 2021. However, only a few successful demonstrations of nZEBs exist in Europe to inspire replications in the private sector. Hotels in specific represent a large challenge, as accommodation accounts for about 21% of global tourism sector CO_2 emissions.

In this frame, the "nearly Zero Energy Hotels" (neZEH) initiative, co-funded by the European Commission through the IEE Programme, has been working to accelerate the rate of refurbishments of existing hotels into nZEBs. The work plan included: technical advice to committed hoteliers, demonstration of the feasibility of investments towards nearly Zero Energy through lighthouse examples, training and capacity building activities, promotion of front-runner hotels at national, regional and EU level.

This paper presents key results from the neZEH project: a) 16 demonstration pilot hotel projects in 7 countries (Croatia, France, Greece, Italy, Romania, Spain and Sweden) acting as lighthouse examples, b) a practical e-toolkit for hotel owners to assess their energy profile, c) policy recommendations to help this kind of refurbishment projects.

The overall average primary energy reduction for the hosting functions of neZEH hotels reaches to 62% whereas RES share reaches to 53%. The preliminary estimation of the positive impacts triggered from the neZEH activities in the accommodation sector assumes cumulative primary energy savings up to 47,000 toe/year, renewable energy production of 6,900 toe/year, 93.000 tCO_2eq/yr GHG emissions avoided by the end of 2020.

Abbreviations

DHW = Domestic Hot Water

EED = Energy Efficiency Directive

EPBD = Energy Performance of Buildings Directive

GHG = Green House Gas

MS = Member States

nZE = nearly Zero Energy

nZEB = nearly Zero Energy Buildings

RES = Renewable Energy Sources

1. Introduction

Buildings are held responsible for 40% of total energy consumption and 36% of CO_2 (GHG) emissions in Europe [1], thus have important energy efficiency potential. Hotels and other accommodation buildings are responsible for 21% of total GHG emissions of the tourism sector [2]. The European Directive on the Energy Performance of Buildings (2010/31/EU, recast), commonly known as EPBD, stipulates that Member States (MS) shall ensure that: (i) by 31 December 2020, all new buildings are nearly Zero Energy Buildings (nZEBs) and (ii) after 31 December 2018, new public buildings are nZEBs [3]. It also mandates that MS, following the leading example of the public sector, should develop policies and take measures to stimulate the transformation of buildings into nZEBs. According to the EPBD, an nZEB is a building that has a very high energy performance; the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources (RES), including energy from renewable sources produced on-site or nearby.

Table 1 nZEB numerical definitions for refurbished buildings in Member States

Country	Primary energy use indicator for new buildings (kWh/m^2/y)		Primary energy use indicator for refurbished buildings (kWh/m^2/y)	
	Residential	Non-residential	Residential	Non-residential
Austria	160	170	200	250
Belgium-Brussels	45	~90 [a]	54	~108 [a]
Cyprus	100	125	As for new buildings	
Czech Republic	75-80% [a,c]	90% [c]	As for new buildings	
Denmark	20	25	As for new buildings	
France	40-65 [a,b]	70-110 [a,b]	80 [b]	60% PE [a]
Latvia	95	95	As for new buildings	
Lithuania	comply with class A++		As for new buildings	

[a] Depending on the reference building; [b] Depending on the location; [c] Maximum primary energy consumption defined as a percentage of the primary energy consumption (PE) of a reference building. In the Czech Republic, the non-renewable primary energy is considered instead of the primary energy.

Additionally, the Energy Efficiency Directive (2012/27/EU, EED) establishes a set of binding measures to support the EU in meeting the 20% energy efficiency target by 2020 [4].

National legislation should answer to questions such as "what is the nearly zero amount of energy" or "how much should be the RES share", as well as other technical issues and include numerical indicators. According to recent reports [5], 16 MS have already legally set nZEB numerical definitions for some building types, out of which 9 have also numerical definitions for refurbished buildings.

The energy performance of a building is determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and reflects the heating and cooling energy needs to maintain the envisaged temperature conditions of the building, and domestic hot water (DHW) needs.

Hotel buildings, however, feature some special characteristics that inevitably are taken account when planning an energy renovation:

a) Seasonal operation in many occasions. Many hotels, especially coastal, operate only during spring/summer months whereas the hotels that stay open all year round have high and low seasons, causing a fluctuation in their energy demand.

b) A large share of their energy demand is consumed for functions that are not associated with the building's typical use, but have to do with additional services provided to their guests, such as spa, pools, gym, etc. These functions are tightly connected with their guests' comfort and expectations, thus critical for their business competitiveness and sustainability. Data from Spanish hotels indicate that energy consumption for additional services, such as that, can reach up to 35% of the total consumed energy [6].

2. Demonstration pilot projects

In the frame of the European initiative "Nearly Zero Energy Hotels" (neZEH), 16 pilot hotels in 7 EU countries (Croatia, France, Greece, Italy, Romania, Spain and Sweden) spread out to 5 European climate zones [7], follow a refurbishment plan in order to become nearly Zero Energy Hotels. Due to the limited successful nZEB demonstrations in the accommodation sector at EU level [8], these pilot hotels are considered to be frontrunners that will inspire and drive replications.

Pilot hotel selection began in 2014 when public calls were launched in each country. This was followed by a number of awareness raising activities, such as launch events and workshops. The project reached out to over 4,000 European hotels resulting in 85 applications from hoteliers wishing to be part of the neZEH initiative. A rigorous selection process was applied to create a shortlist of 40 candidates. To establish whether candidate hotels had the potential to become nZEBs, energy pre-audits took place in the buildings by experienced auditors. Out of this process, 16 pilot hotels were chosen based on the pre-audit results, their commitment and potential to achieve nZE.

Following the selection of the pilot hotels, a robust work plan was applied; the steps being: i) an energy audit ii) a feasibility study and rollout plan, iii) tendering, contracting and financing alternatives and iv) training of management and staff.

The energy audits benchmarked the initial status of the hotels, outlined recommendations specific to each of them in terms of suitable energy efficiency measures/RES solutions in order to reach the neZEH status and provided a rough estimate of the financial implications involved. An initial hurdle in this process was the lack of legally set nZEB numerical definitions in the target countries and thus a difficulty in establishing primary energy use and RES targets for the pilot hotels. This was countered by introducing benchmarks for nZE hotels, based on already existing indicators in other countries [9]. The benchmarks concerned only the hosting functions of hotels i.e. the standard zones of a hotel where standard indoor environmental conditions need to be met, including the reception hall, guests' rooms, all common areas (restaurant, bar, siting rooms, meeting rooms) and offices. Non-hosting functions are additional facilities which may be provided by the hotel, including kitchen, laundry, swimming pool, spa, sauna, gym. In any of the cases, technical rooms, garages or similar places not heated, cooled or ventilated are not included. For this reason, the energy consumption and RES share of both hosting and non-hosting functions were calculated separately, where possible. In Table 2 we can see that the primary energy use for the whole building will be decreased from an average of 325 kWh/m^2/y to an average of 142 kWh/m^2/year by applying the measures identified by the energy audits; that is an average decrease of 56%. At the same time, RES share will go up from an average of 15% to an average of 40%.

Table 2 Primary energy use and RES share before and after refurbishment for the whole building for the 16 pilot hotels, as resulted from the energy audits

				BEFORE		AFTER		
Hotel	**Country/Region**	**EU climate zone**	**Hotel category**	**Primary energy use (kWh/m^2/y)**	**RES share (%)**	**Primary energy use (kWh/m^2/y)**	**RES share (%)**	**Investment (€)**
Hotel 1	Croatia/Dalmatia	2	Coastal	142	32	80	33	104,800
Hotel 2	Croatia/Dalmatia	2	Coastal	126	48	110	52	76,650
Hotel 3	France/Corse du Sud	2	Coastal	244	1	100	22	803,003
Hotel 4	France/Provence-Alpes-Côte d'Azur	2	Rural	303	9	257	11	236,100
Hotel 5	Greece/Crete	1	Urban	293	30	112	50	536,000
Hotel 6	Greece/Crete	1	Coastal	281	26	91	50	1,095,000
Hotel 7	Greece/Crete	1	Urban	287	20	100	40	155,000
Hotel 8	Italy/Piemonte	3	Mountain	166	63	114	69	30,100
Hotel 9	Italy/Piemonte	3	Urban	290	0	167	35	111,050
Hotel 10	Romania/Brasov	3	Urban	470	0	115	28	414,389
Hotel 11	Romania/Brasov	3	Urban	285	4	113	25	112,079
Hotel 12	Romania/Covasna	3	Mountain	360	0	69	35	488,435
Hotel 13	Spain/Vizcaya	4	Rural	202	3	127	65	305,900
Hotel 14	Spain/ Alicante	1	Coastal	609	6	397	20	579,841
Hotel 15	Sweden/Gotland	5	Urban	760	0	195	58	86,084
Hotel 16	Sweden/Uppland	5	Urban	378	0	117	46	1,490,821
AVERAGES				**325**	**15**	**142**	**40**	

Table 3 shows the primary energy use and RES share for hosting and non-hosting functions, where available. As it can be seen, non-hosting functions are particular energy intensive in the majority of hotels, especially in the resort type. The primary energy use for the hosting functions (the functions included in the benchmarks set initially), can be decreased dramatically – from an average of 259 to an average of 99 kWh/m^2/y, that is an average reduction percentage of 62%. At the same time, RES share for the hosting functions can be increased from an average of 18% to an average of 53%.

Table 3 Primary energy use and RES share before and after refurbishment for (a) hosting functions and (b) non-hosting functions for the 16 pilot hotels, as resulted from the energy audits

		BEFORE				AFTER			
Hotel	Facilities	Primary energy use (kWh/m^2/y)		RES share (%)		Primary energy use (kWh/m^2/y)		RES share (%)	
		Hosting	Non-hosting	Hosting	Non-hosting	Hosting	Non-hosting	Hosting	Non-hosting
Hotel 1	Spa/wellness	126	16	36	0	64	16	37	0
Hotel 2	spa, sauna, pool, gym	66	60	64	0	57	53	68	0
Hotel 3	lounge bar, pool, spa	244	0	1	0	100	0	22	0
Hotel 5	kitchen, restaurant, pools	200	450	30	0	92	250	50	50
Hotel 6	pools, bars, restaurants, conference room	250	293	26	20	88	110	60	50
Hotel 7	Bar	287	0	20	0	100	0	40	0
Hotel 8	Spa/ wellness	100	66	74	0	48	66	83	0
Hotel 9	kitchen, gym	266	24	0	0	143	24	41	0
Hotel 10	restaurant, conference room	379	1,258	0	0	99	470	37	0
Hotel 11	restaurant, conference room	202	459	4	0	108	182	45	0
Hotel 12	spa, pool, adventure park, conference rooms, restaurant, disco, tennis	341	520	0	0	68	81	56	0
Hotel 13	spa, pool, shrine room	181	226	0	8	96	162	85	50
Hotel 14	spa, restaurant, gym, sauna	363	2,272	9	4	200	1,726	61	5
Hotel 15	kitchen, restaurant, sauna	722	38	0	0	186	10	58	58
Hotel 16	kitchen, restaurant, sauna, gym	151	227	0	0	38	79	46	46
AVERAGES		**259**	**394**	**18**	**2**	**99**	**215**	**53**	**17**

Indicative energy efficiency measures proposed for the pilot hotels are presented in Table 4.

Table 4 Indicative energy efficiency measures proposed in the pilot hotels per energy use

Energy use	Energy efficiency measures
HVAC	Building envelope insulation Installation of sun shades Double-glazed windows Heat recovery in chillers Balancing of heating system Installation of BEMS Installation of ceiling fans Outdoor redesign for better microclimate Installation of thermostatic valves Improvement of air-tightness Optimization of air handing units
DHW	Water saving aerators Insulation of hot water pipes
Equipment	Laundry schedule operation during the night hours Replacement of electric appliances with more efficient ones
Lighting	Replacement of conventional lamps with LED Lighting controls (occupancy sensors)
Increase of RES	Installation of solar collectors Installation of photovoltaics Installation of heat pumps Installation of small wind turbines

Projections for 2020 for nZEB investments in the accommodation sector, expected to be triggered by the neZEH activities assume cumulative primary energy savings up to 47,000 toe/year, renewable energy production of 6,900 toe/year, 93.000 tCO_2eq/yr GHG emissions avoided by the end of 2020 while the cumulative investment could reach 162 M€. These projections are based on an optimistic, base scenario of 90 nZEB hotels by the end of 2020.

3. Tools for hoteliers

A neZEH online e-tool to support decision-making and motivate hoteliers wanting to refurbish their hotels to nZEB is being developed. The e-tool benchmarks the hotel's current energy performance and provides suggestions for energy efficiency measures. The tool is based on the previously developed HES e-toolkit [10] and it is being upgraded to include the neZEH project approach and findings. At the back-end of the upgraded e-tool lies an Excel Ranking Tool, facilitating the ranking of energy efficiency measures for different types of hotels aiming to reach nZEB status at the country level, taking into account local parameters, such as prices and climate.

The ranking is based mainly on four parameters (size of the financial investment, profitability, potential energy saving, European climate zones). It includes a list of energy efficiency measures which are modelled independently and with the help of a typical energy savings database. Climatic data are incorporated (heating and cooling degree days for the 28 EU members, heating and cooling needs, etc.), as well as correction factors to slightly change potential energy savings percentage (%) depending on the climate zone a country lies in.

These data are put together in 4 reference (and real) buildings which give the output, a ranking of energy efficiency measures regarding three different aspects:

1. Profitability of the financial investment (incorporating a European Climate Zones parameter). This ranking is done based on the € invested per kWh saved ratio. The "€/kWh saved" ratio is dependent on the size of the financial investment in each country and the potential energy saving, which in its turn is affected by the correction factor for the climate zone.

2. Size of the financial investment. The ranking is done based on the cost of each technology (€), which in turn is affected by the selected country.

3. Potential Energy Saving (incorporating the European Climate Zones parameter). The ranking is done based on the energy saved per year (kWh/y) by installing each technology. The kWh/y saved is also affected by the correction factor for the climate zone.

In Figure 1 the detailed flux diagram of the Ranking Tool is presented. The tool needs 5 inputs (A1a-e), distributed among 3 topics: Energy, Buildings and Economics. In order to get the rankings, it is needed to feed both kWh saved and €/measure, which are shown as red squares in the flux diagram. The energy saved per measure is achieved mainly by three inputs: a typical energy saving percentage per measure (A1a), climate severity per country (A1b) and energy balances (A1c). The first two are subordinated to several specific parameters which work as correction factors. Those corrections factors are based on different modelling for every measure. The latter is achieved by a database of energy balances extracted from real energy audits. A correction factor for the energy saved has been developed to adjust it to some climates. As the last step, there is a need for the model to establish some reference buildings (A1d) in order to have fixed energy consumption (A6). The estimation of €/measure is based on a partner-contributed prices database (A1e) where they establish: €/unit (i.e. €/LED lamp, €/Boiler etc.) and the labour cost per country.

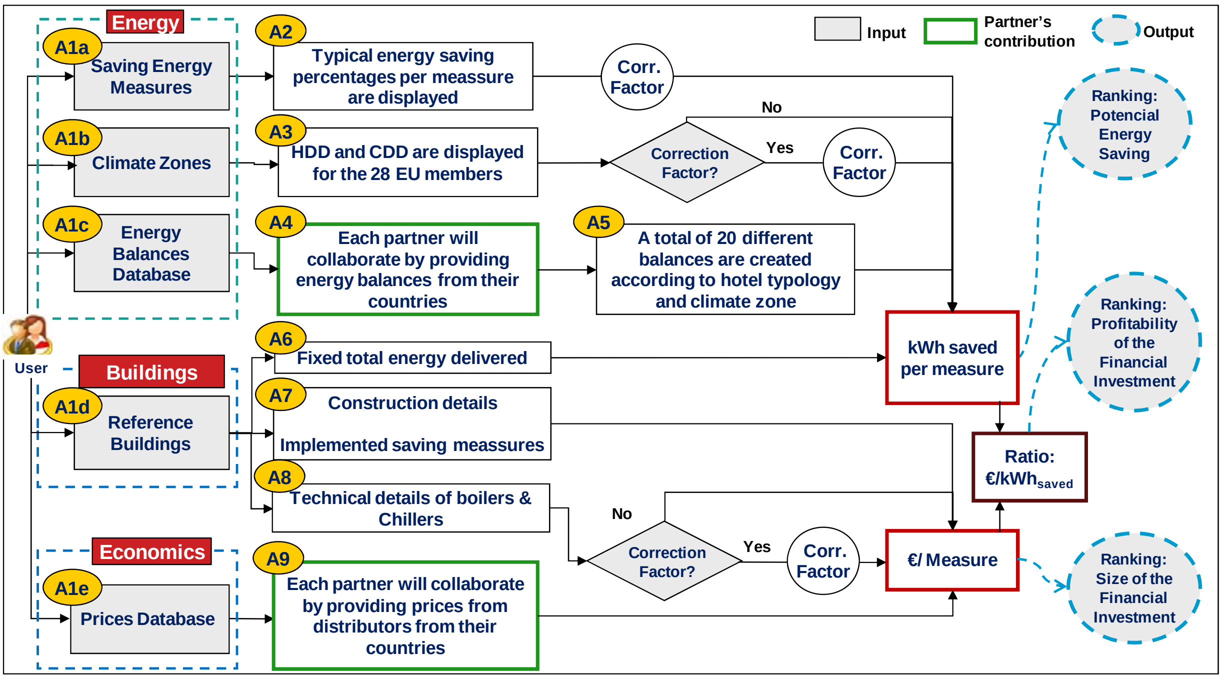

Figure 1 Flux diagram of the back-end Excel Ranking Tool

4. Recommendations

The experience of the neZEH project helped to identify common features of the SME hotel sector from the perspective of building energy renovation in the involved countries, summarized in the following:

- Lack of technical awareness and capacity in energy efficiency issues.
- Little capacity to get acquainted with and use available support schemes.
- Being certified as a green hotel is perceived as a holistic approach of how to operate a hotel in a sustainable way, as well as an effective marketing measure, which brings competitive advantage for the certified hotels while re-branding them with a green concept.
- The uptake of energy efficiency and renewable energy measures reduces the operational and maintenance costs; increases the independence from energy suppliers and reduces the hotel and guests' carbon footprint.

- Endorsing green initiatives also leads to meeting the hotel's corporate social responsibility targets while increasing the living comfort and enriches the guests' experience and therefore, loyalty.

- Policies supporting the tourism sector and building energy renovation in the neZEH countries and at EU level are not very well coordinated.

The above helped to highlight the challenges and barriers and suggest policy solutions and measures.

Improved European, national and regional policies: In most MS, numerical nZEB definitions concern only new buildings, whereas in some cases the indicators for both new and refurbished buildings are the same. Refurbished buildings cannot easily comply with these values; there is a need for realistic nZEB criteria for them. Hotels represent a specific building type due to their business operation; a high ratio of the delivered energy is used for non-hosting functions. The nZEB calculation methodology is usually based on the standard use of non-residential buildings in general, which does not include hotel specific uses.

Tailored financial support schemes and incentives could be provided in order to help SME hotels to overcome the problem of high initial investment costs of ambitious nZEB renovations. For example, these policies could group the needs and capabilities of different market segments of the accommodation industry to reach also SME hotels more effectively.

Coordination between support policies targeting to the tourism sector development and the ones focusing to buildings energy efficiency could be enforced. Policies should also facilitate the development of regional/local financial schemes (e.g. revolving funds, guaranteed or supported loan programmes, EPC schemes) which are able to mobilize private financing. The ongoing programming of the European Structural and Investment Funds (ESIF, 2014-2020) [11] is a huge opportunity to mainstream buildings energy efficiency policies and achieve large scale improvements in the MS.

Credible and independent technical assistance: A common barrier faced in energy refurbishments is the complexity of the renovation decision-making process, requiring insights and decisions not only of financial but also of technical, organisational and legal nature [12]. The set-up of "one-stop-shop" consultancy services or energy help-desks for the non-residential building sector (similar to the examples in France available for the residential sector) could be an answer, in order to guide hotel owners through the whole renovation process.

Awareness raising, capacity building and certification schemes: Hotel owners have to gain a general understanding about sustainable buildings and the available support schemes for them. Training sources on basic technical knowledge related to energy efficiency/nZEB as well as on the potential of investing in ambitious refurbishment projects [13] and public support schemes for capacity building can contribute to that direction. At the same time, building professionals need to be ready to respond to the new era of nZEB; there should be requirements for training leading to qualified professionals and companies in high energy efficiency, and especially to energy retrofits towards nZEB.

Tailored awareness raising activities targeting the accommodation industry can help to convince hotel owners about the feasibility of becoming a neZEH. It is easier to engage hotel owners that are already committed to sustainability in the discussion about investing in deep energy retrofit. Synergies with the existing engagement of hotels in different eco/green hotel certification schemes can be exploited.

Conclusions

Today it is technically and economically feasible to retrofit existing hotels into becoming nZEBs. The economic benefits of such investments become more apparent for hotel owners once the indirect benefits are realized: branding as a green hotel, added value in reducing carbon footprint and meeting corporate and social responsibility targets as well as increasing living comfort for guests and customers' loyalty. The 16 pilot hotels of the European initiative neZEH pave the way towards such investments, by implementing ambitious refurbishment plans that will lead them to becoming nZEBs and reducing their primary energy use for hosting functions from an average of 259 to an average of 99 kWh/m^2/y -an average reduction percentage of 62%- and increasing their RES share from an average of 18% to an average of 53%. Based on the experience and lessons gained, an online e-tool for hotel owners to assess their current energy performance and get suggestions of energy measures and interventions that can bring them closer to nZEB is being developed. Policy support is required, though, in order to remove barriers that hinder deep energy refurbishments in the accommodation sector: inclusion of hotel building type in national nZEB policies, specially defined nZEB criteria for refurbished buildings, better coordination between relevant authorities for energy and tourism, technical assistance, awareness, capacity building and training.

Acknowledgments

This publication is supported by the European Commission under the Intelligent Energy Europe Programme, within the framework of the project neZEH (Nearly Energy Zero Hotels, www.nezeh.eu). The sole responsibility for the content of this paper lies with the authors. It does not necessarily reflect the opinion of the European Union. It does not necessarily reflect the opinion of the European Union. Neither the EASME nor European Commission are responsible for any use that may be made of the information contained therein.

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Economic strategies for Low-Energy Industrial Buildings

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Abstract

After 2020 all new buildings in Europe will have to meet the so called Nearly Zero-Energy Standard required by the recast of the European directive on the energy performance of buildings. This standard will already be ambitious for the residential building sector but will even more challenge the industrial building sector, tending just to meet the statutory provisions. Hence, new strategies for low-energy production buildings, logistic centers and warehouses are required. Crucial is not only to find technical solutions but cost-effective ways for such future hall buildings.

In this research cost-optimal future building standards were defined for the industrial building sector. Therefore extensive parametric studies were undertaken, using transient building energy simulation coupled with an air-flow network and a 3D ground model. Additionally air-tightness measurements helped defining required input data for the air-infiltration model.

To determine economic solutions and to place them in a reasonable order, costs for all energy saving measures were determined. The calculation of marginal payback times for all measures finally allowed defining a cost-optimal energy standard. The results are decision tools for a rough and first determination of a reasonable energy standard for industrial buildings. This applied research shows that there are still economic energy saving potentials to tap in industrial facilities.

Introduction

According to the European directive on the energy performance of buildings, after 2020 all new buildings within the Union will have to meet a so called nearly zero-energy building standard. The aim is to reduce the carbon emissions, but also to reduce the dependency on energy imports. [1]

Such nearly zero-energy buildings (NZEBs) will have to be very energy efficient and will have to be supplied to a significant extent by renewable energy. In addition it shall be ensured that NZEB standards are cost-optimal. This means that the expenses for energy saving measures have to be paid back whilst the life-time of the building or the specific building component. [1] Hence, all member states regularly have to report to the European Commission to ensure that their national plans facilitate to increase the number of NZEBs and to ensure cost-efficiency. [2]

However, such reports unfortunately just cover residential buildings and commercial buildings other than industrial facilities. E.g. in the German report [3] warehouses or production buildings are not even mentioned. Thus, the cost-efficient level is just defined based on analyses for other buildings. Though, due to the completely different building components, building shapes, indoor temperatures, leakage distribution, internal gains (machine and process gains) and usage times it can be assumed that for industrial buildings the cost-efficient standard will be on a different level.

In general research for low-energy buildings was mainly carried out for residential and office buildings. Here many low-energy standards, such as the “Passive House Standard” or the German “KfW-Effizienzhausstandards” exist. Unfortunately they are not directly applicable to the industrial building sector and also the demand by the industry was very low. Mostly in this sector just the statutory building regulations are met, but advanced standards are rarely aspired. Hence, research results from dwellings were often the only basis for the development of energy balance calculation methods. Such methods were later on adopted for assessing the energy performance of industrial buildings. This can lead to significant imprecisions as claimed in [4], [5], [6], [7].

Therefore also for an economic building design of industrial buildings it is required to undertake specific analyses considering the parameters of warehouses and production buildings. In the here presented research, strategies for economic low-energy buildings were developed.

Methods

To develop economic energy standards and energy saving measures for industrial buildings different simulation and measurement methods were used and combined. The main assessment was carried out with the building energy simulation software TRNSYS 17. Here the transient building model type 56 was linked to a transient 3D finite difference model of the ground (see Figure 1).

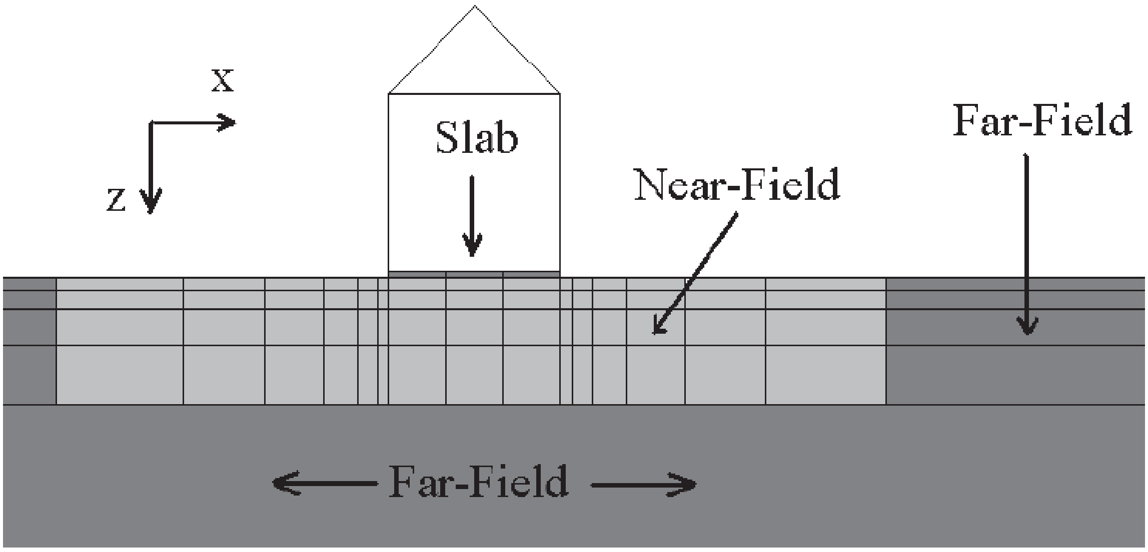

Figure 1: Discretized 3D soil model linked to the transient building energy simulation [8]

This finite difference simulation model allows a detailed and transient assessment of the energy losses via ground. As industrial buildings have large floor slabs, a precise evaluation of these losses is very important and should not be undertaken with standard steady-state approaches like for small dwellings.

Thermal bridges were assessed using 2D and 3D simulation software. The gained results were used as input data for the building energy simulations. U-values and solar heat gain coefficients (SHGC) were determined by the external software WINDOW [9]. The detailed analysis of window parameters also allowed to carry out parameter studies to find the optimal glazing strategy for industrial buildings. This means to determine optimal glazing qualities and optimal glazing orientation.

The air-infiltration and thereby caused energy losses were determined by an advanced air-flow network model integrated into the TRNSYS environment. Input data for C_p-values was provided by the software C_p-generator by TNO [10]. This allowed a precise determination of the infiltration rates during the year, dependent on the dynamic wind pressure and the stack influenced pressure on the building envelope. To gain leakage data of relevant leakages in industrial buildings an air-tightness test stand was built. With this test stand extensive measurements of typical joints between building components, such as between wall and roof, slab and wall, wall and wall or at various accessories were measured. The results (leakage coefficients and flow exponents) were used as input data for the simulations. A detailed description of the test stand is provided in [4]. In addition pressurization tests of industrial halls were undertaken to define typical levels for the permeability of whole buildings.

By using the described simulation tools, a large parameter study was carried out. There typical parameters of industrial buildings, such as building height, floor area, inside temperature, usage times and internal gains were varied. To define these typical parameters, a large database with data of already erected industrial hall buildings was used. The database [11] contained more than 4000 different warehouses and production buildings and therefore allowed a representative modelling of typical sample buildings.

To determine economic measures and cost-effective levels for the thermal insulation of buildings it was required to calculate the cost-differences for all single energy efficiency measures. For this purpose the cost calculation software Cyprion [12] was used. In addition tenders were solicited.

Results

Solar optimization of industrial buildings

The reference-building method, which is preferably used in Europe, does not reward heat energy savings by an optimization of the glazing orientation in buildings. Hence, it was first tested, how the energy demand in industrial facilities can be reduced by an optimized orientation of glazed surfaces. In industrial buildings the potential by such measure is considerable, as most glazed surfaces are still oriented to the sky (sky lights and dome lights in the flat roofs).

Figure 2 shows, how the heat energy demand of a low-heated warehouse building can be reduced by increasing the glazing in the south façade. By increasing the façade glazing in south orientation to the whole façade area (25 %) and eliminating the complete horizontal glazing at the same time, the heat energy demand can be reduced by up to 30 %. This will of course not be possible for all industrial buildings, as a complete elimination of the roof glazing is always dependent on the depth of the building in order to avoid missing natural lighting in some areas of the building. But the study demonstrates that increasing the south oriented glazed surfaces is a reasonable measure, especially for low-heated warehouses. Expensive glazing is not required for such optimization. Low-cost multi-cell polycarbonate sheets are sufficient, which do not have higher costs than a wall. Hence, no extra costs are expected for such measures.

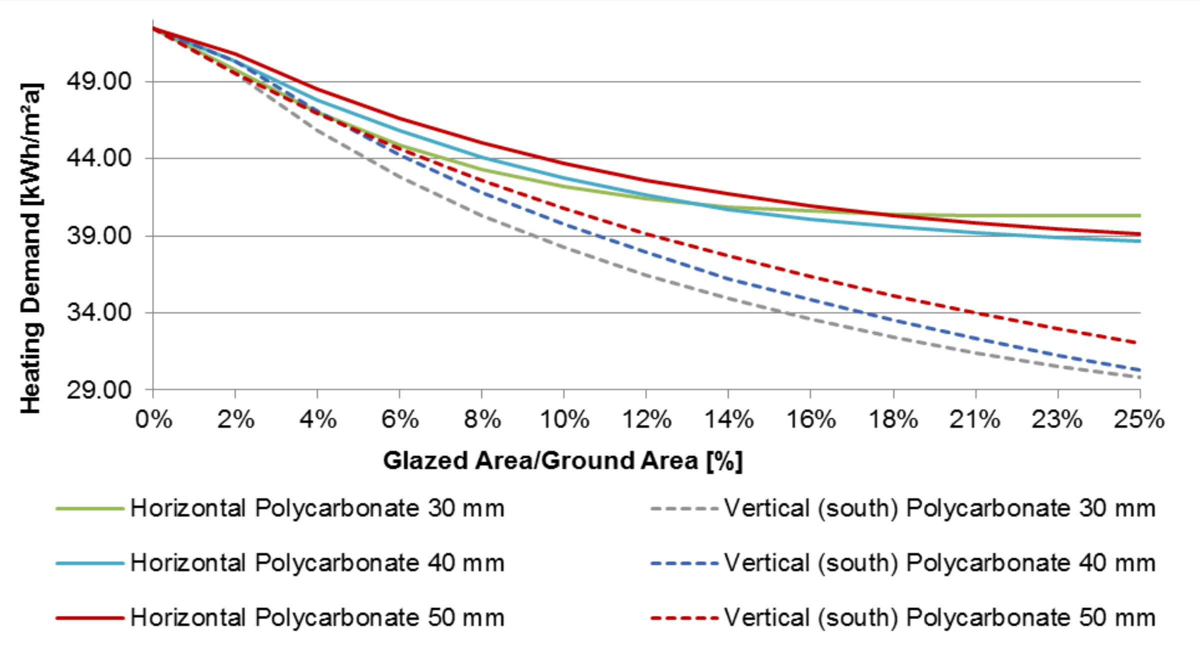

Figure 2: Heat energy demand dependent on the area of glazed surfaces θ_i = 12 °C [13]

Determination of reasonable U-values for the opaque building envelope

In recent years the building regulations in most European countries such as Germany [14], UK [15] and France [16] mainly focused on reducing the thermal transmission via the opaque building envelope by increasing the insulation thickness. Such measures were reasonable and caused good improvements in the energy performance of buildings in the residential and the commercial building stock. However, due to the already made achievements such measures get less and less effective as the reduction of the U-value is not linear to the increase of the insulation thickness. Hence, decreasing the heat energy demand of a building by increasing the insulation thickness of the opaque building envelope increases the marginal costs for energy saving measures extremely. In Figure 3 the marginal costs for reducing the U-value of the opaque building envelope are shown for three sample buildings. This graph is based on simulations for light steel buildings. For such steel constructions the effect is even stronger than for solid constructions as significant thermal bridges exist, which can hardly be reduced by increased insulation thickness.

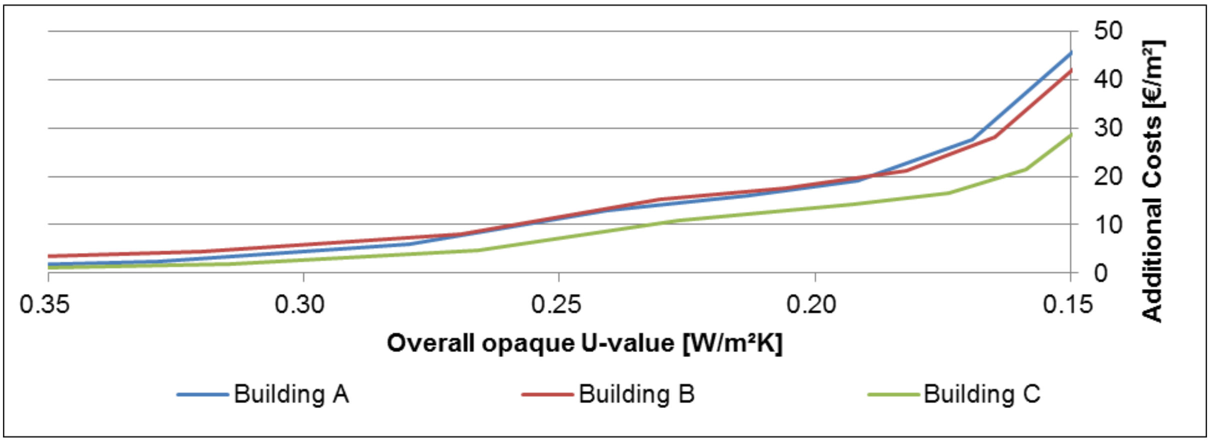

Figure 3: Cost development for improving the U-values of the opaque building envelope

Definition of economic U-values for opaque building envelopes

Due to the increasing marginal costs for reducing the U-values of the opaque building envelopes extensive economic calculations were carried out. For all variants of the parameter studies the costs were determined. Based on the marginal costs for every energy saving improvement the marginal payback times were calculated. Figure 4 shows how the marginal payback times develop for different levels of U-values. Here buildings without significant internal gains were analyzed. The glazing of this building is mainly oriented to the south façade as advised before. The simulated building could represent a warehouse.

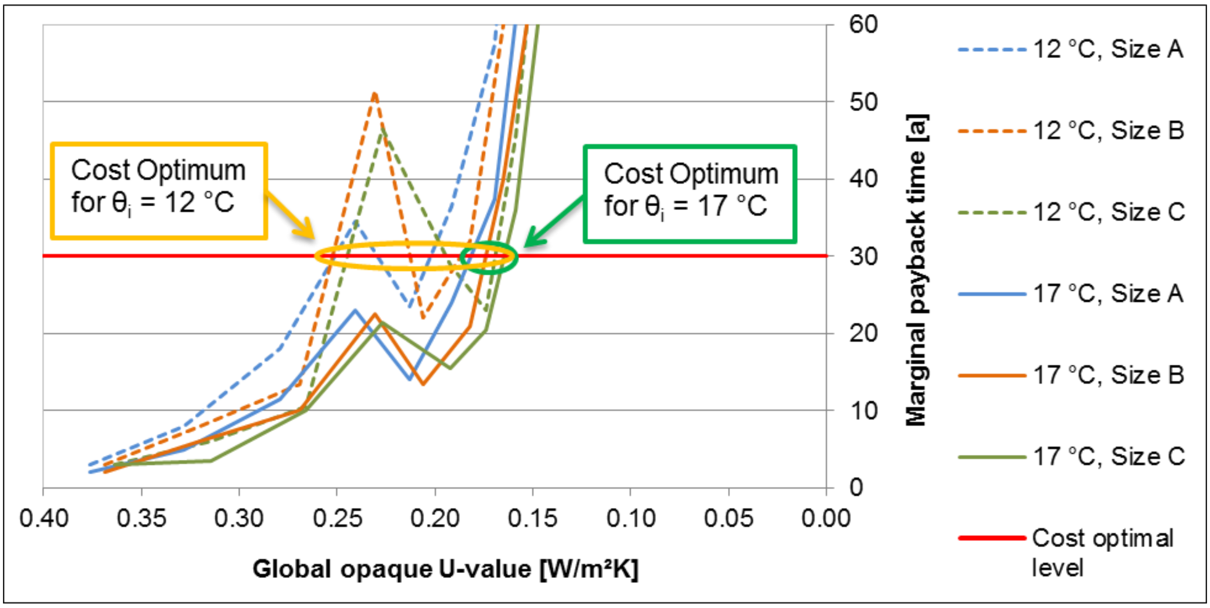

Figure 4: Marginal payback times dependent on the global opaque U-value of the building

Due to the increasing marginal costs for reducing the U-values of the opaque building envelope, also the payback times for these measures increase significantly. The European directive on the energy performance of buildings [1] declares that the cost-optimum for nearly zero-energy buildings is met, when the additional costs for energy saving measures are paid back whilst the life time of the specific building components or the whole building. For walls and roofs a life-time of 30 years was assumed here, based on [17]. This means a marginal payback time of 30 years complies with the cost optimal level according to the EU directive.

In general the graph shows considerable variations for the cost-optimal level. For the lower heated building (θ_i = 12 °C) the cost-optimum for the U-value varies between 0.17 and 0.26 W/m²K. For the building with higher inside temperatures (θ_i = 17 °C) the cost-optimal U-value varies between 0.16 and 0.19 W/m²K. The building size has a lower impact on the cost optimum. The sample building size A has 1000 m², size B 1950 m² and size C 5000 m² floor area. The energy price was determined for wood pellets based on [18] with a price increase of 2.6 % based on [19]. For the calculation interest 1.7 % was used as suggested by the German Ministry of Finance [20].

Figure 5 shows, which marginal payback time corresponds to which heat energy demand. The graph corresponds to the same building variations as the graph below.

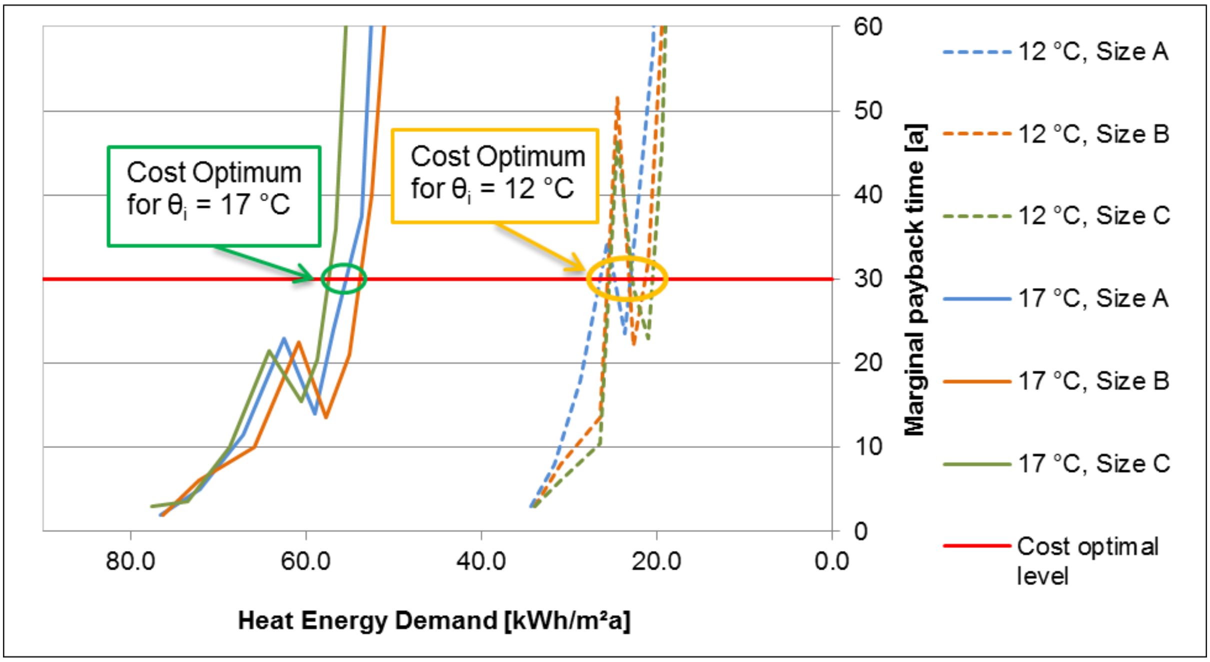

Figure 5: Marginal payback times dependent on the heat energy demand

Here the cost-optimal level depends a lot on the required minimum inside temperature in the building. For lower heated buildings also lower heat energy demands can be realized at a cost-effective level. For the low heated building (θ_i = 12 °C) the economically achievable heat energy demand varied between 20 and 27 kWh/m²a. For the other sample buildings with a higher inside temperature (θ_i = 17 °C) the cost-optimal heat energy demand is between 53 and 59 kWh/m²a. The impact of the building size is also low.

Most cost-effective energy saving measures

The described calculations have shown, that energy savings by reducing the U-values of opaque building components, lead to quite long payback times after reaching a certain level of insulation. Therefore, it is important to tap also other sources that can help reducing the heat energy demand at lower costs. Examples are the heat losses via ground, air-infiltration losses via leakages and open doors and the reduction of thermal bridges.

In [7] the potential of optimizing the floor slab insulation was described in detail. In simulations it was shown that vertical footer insulation is more reasonable than horizontal insulation under the floor slab of large low-heated buildings. If only a perimeter insulation is used, solar energy that heats up the building in summer can be stored in the ground under the slab. This cost-free energy can be used in the first months of the heating period to heat the building. This is of course only possible if the floor slabs are large enough, as often the case for industrial buildings. Moreover, low required inside temperatures such as 12 – 15 °C increase that effect.

To replace a horizontal slab insulation by a vertical perimeter insulation saves costs, which can be invested into more effective energy saving measures. Thick horizontal floor slab insulation is only reasonable under small high heated buildings (e.g. residential buildings).

The reduction of air-infiltration is another cost-effective potential to save heat energy in industrial facilities. Increasing the air-tightness in hall buildings is usually possible on very low costs. It mainly requires a detailed design of the air-tightness and few additional material, as described in [6]. In practice q_{50}-values of 0.5 m³/m²h can be met by such measures, which means heat energy savings of up to 20 % compared to just meeting the current requirements in Germany. In the here carried out calculations, payback times for air-tightness improvements were mostly below 5 years.

Another economic saving potential is the optimization of thermal bridges. In the analyses, thermal bridges in light steel industrial buildings accounted for about 10 % of the total heat energy losses in the energy balance. By design improvements such losses can be almost eliminated. Many of these design changes do not even cause extra costs. Sample details are given in [6].

Conclusion

The study has shown, that energy savings in industrial buildings can mainly be achieved economically by design changes. Thermal bridge optimization, air-tightness improvements and optimization of floor slab insulation are energy saving measures with much shorter payback times than the simple increase of insulation thicknesses. However, for industrial buildings with low internal gains, such as warehouses, it is still cost-effective to increase the insulation thickness in walls and roof. Though, the other mentioned measures should be carried out first, as their payback time is usually shorter. Another important and recommended design change is the solar optimization of industrial buildings. Passive strategies, as already standardized in residential buildings (e.g. Passive Houses), should be used to increase the solar gains. Large glazing in the south façade is more reasonable than large sky lights or dome lights.

For all mentioned improvements simulation methods are advised to use, as steady-state methods often do not consider the specifics of industrial buildings. This is mainly because many steady-state methods were developed based on findings for residential buildings only. More information about this topic is provided in [4], [5], [6] and [7].

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Session NZEBs II

Towards sustainable and smart communities: integrating energy efficient technologies into buildings through a holistic approach

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Abstract

As the EU energy industry is clearly moving towards a new era of reliability, availability, and efficiency that will contribute to the improvement of Europe's economic and environmental sustainability, smart technologies provide the opportunity for new applications with far-reaching interdisciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart grids and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities in order to achieve zero energy targets. The integration of smart technologies requires a holistic approach that takes into account all aspects of sustainability.

The methodological approach is based on a cycle expansion of three phases: 1. the users/consumers aspects, focusing on smart and zero energy buildings analysis, 2. the smart grids penetration at community and city level, offering the technological platform for fast moving towards sustainable communities by exploiting the ICT and energy systems development in the maximum degree 3. development of smart applications and smart grids optimised operation.

This paper analyses the three-phase approach addressing issues of providing optimal operation and adaptation to ICT technologies. It also highlights the principles of integrated design procedure and links the process with smart building technologies. Energy efficiency methodologies and innovative techniques applied at building level are also presented.

Keywords

smart communities, smart buildings, smart grids, integrated energy design, zero energy communities

Introduction

The effects of global warming and climate change are evident in every societal level to such a degree that immediate actions for reducing greenhouse gas (GHG) emissions is no longer an option but rather an imperative. Buildings are responsible for 40% of energy consumption and 36% of EU CO2 emissions. To help address climate change, in March 2007, the European Council set clear goals for 2020, known as the 20/20 targets: a) reduction of 20% of energy used (below 2005 levels), b) 20% contribution of Renewable Energies to total energy use and c) 20% reduction of GHG below 1990 emissions. Therefore a number of further research and development activities need to be initiated now, in order to deliver applications and solutions for the long term perspective of 2050 and beyond.

To move towards an increasing low-carbon economy, European electricity networks will need to evolve to provide support for possible future energy vectors, for effective introduction of carbon credits, taxes and trading, for generating buildings integrated with energy distribution and finally for massive combination of renewable generation in the built environment. In this context, the SMART GEMS EU funded project contributes towards this perspective by providing the necessary knowledge and state of the art uptake to move towards smart grids integration in a large scale. It also raises awareness and improves understanding of the public with respect to the social value and the potential of smart grids towards a safer and healthier environment. The project intends to show that smart grids and smart communities are technologically feasible, environment friendly and economically sustainable.

Smart grids are electrical power grids that are more efficient and more resilient — therefore, "smarter" — than the existing conventional power grids. The smartness is focused not only on elimination of black-outs, but also on making the grid greener, more efficient, adaptable to customers' needs, and

therefore less costly [1], [2]. Smart grids incorporate the innovative IT technology that allows for two-way communication between the utility and its customers/users. As a result, the sensing along the transmission lines and the sensing from the customer's side is what makes the grid "smart". Like the Internet, the Smart Grid will consist of controls, computers, automation, new technologies, smart buildings and equipment working together, but in this case these technologies will work with the electrical grid to respond digitally to the users' quickly changing energy demands.
Smart Grids open the door to new applications with far-reaching inter-disciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart buildings and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; using automatic grid reconfiguration to prevent or restore outages (self-healing capabilities); enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market.
In order to implement these technologies in building and city scale a methodological and holistic approach is required ensuring effectiveness and sustainability.
A three-phase approach addressing issues of providing optimal operation and adaptation to ICT technologies through integrated design procedures is analysed in the present work.

The principles and benefits of Integrated Design

Integrated Design is an approach that considers the design process as well as the physical solutions, and the overall goal is to optimize buildings as whole systems throughout the lifecycle. For the purpose of reaching high sustainability performance, the alternative building and technical solutions should be developed and discussed by an integrated, multidisciplinary team [3].
ID emphasizes a decision process rooted in informed choices with regard to the project goals, and on systematic evaluation of design proposals. This approach for building design is paralleling the principles of environmental management referred in the international ISO 14001 standards. Here, identifying and prioritizing goals, and developing an evaluation plan with milestones for follow-up, are central issues. A shift of approach emphasizes that the very early phases need more attention because well informed decisions here will pay off in the rest of the design process as well as in the lifecycle of the building. Well informed planning from the start can allow buildings to reach very low energy use and reduced operating costs at very little extra capital cost, if any. Experience from building projects applying ID shows that the investment costs may be about 5 % higher, but the annual running costs will be reduced by as much as 40-90 % [4], [5]. The process of ID emphasizes that the performance of buildings should be assessed in a lifecycle perspective, both regarding costs (LCC) and environmental performance (LCA). Figure 1 indicates the importance of the Integrated Design process at the early phases (www.integratedesign.eu)

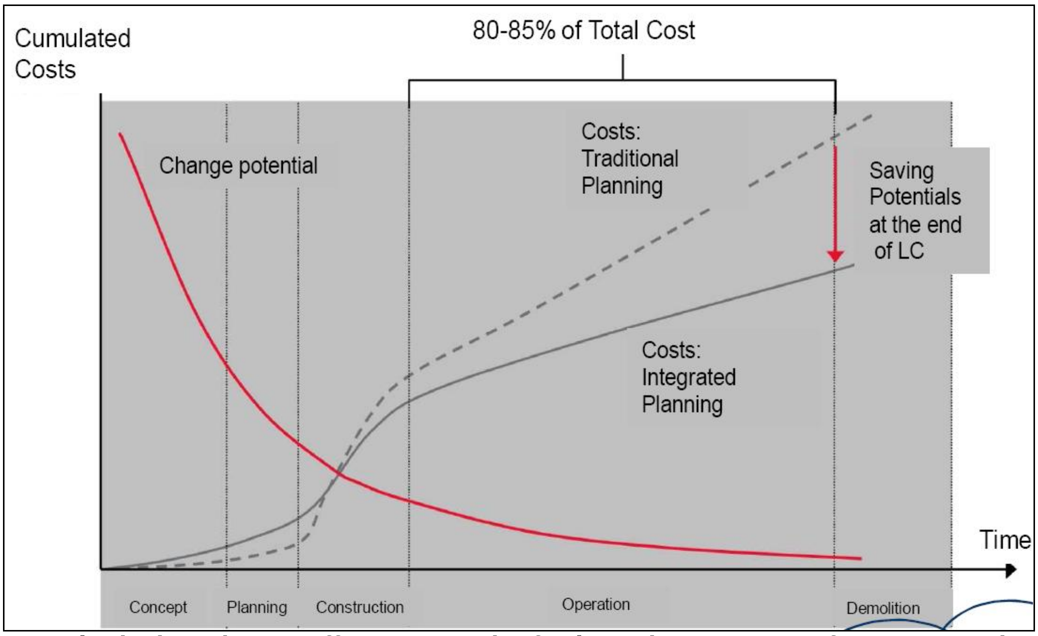

Figure 1. Early design phases offer opportunity for large impact on performance to the lowest costs and disruption. Therefore, a shift of work load and enhancement to the early phases will probably pay off in the lifecycle of the building.

An Integrated Design approach that combines smart, passive design, thermally efficient building skins and effective space planning to reduce energy demands as a first step, combined with highly efficient systems, provides a cost-effective alternative to bolt-on systems installed on an otherwise under-performing building.

Six steps can be identified for a successful Integrated Design implementation:

1. *Project development:* discussion of the project ambitions and challenge initial client presumptions, initiating ID process and preferably make partnering contracts.
2. *Design basis:* selection of a multi-disciplinary design team, including an ID facilitator, motivated for close operation, analysis of the boundary conditions. Also refine the brief and specify the project ambitions, preferably as functional goals.
3. *Iterative problem solving:* facilitate close operation between the architect, engineers and relevant experts through workshops etc. Use of both creative and analytical techniques in the design process. Discussion and evaluation of the multiple concepts and finalise optimised design.
4. *On track monitoring:* Use goals/ targets as means of measuring success of design proposals, make a Quality Control Plan, evaluate the design and document the achievements at critical points/milestones.
5. *Delivery*: Ensure that the goals are properly defined and communicated in the tender documents and building contracts, motivate and educate construction workers and apply appropriate quality tests, facilitate soft landing. Make a user manual for operation and maintenance of the building.
6. *In use:* Facilitate commissioning and check that the technical systems etc. are working as assumed, monitor the building performance over time regarding e.g. energy consumption, user satisfaction etc.

Integrated Design processes result in higher energy performance: optimization of building form, orientation and facades is reached through open multidisciplinary discussions and design decisions in early project phases, where knowledge about important conditions is exchanged to inform the design of the building. It also contributes to the reduction of embodied carbon as optimized design is given priority before advanced technical systems and control mechanisms. Indoor climate is significantly improved: the building and technical systems work together in a logical symbiosis in order to achieve sufficient indoor air quality, temperature control and daylight access/ solar protection. Running costs of the building are reduced: simplified technical systems are more cost efficient, both in terms of investment costs for manufacturing and installation and in terms of running costs and maintenance. Another aspect is the reduction of risks and construction defects as improved planning leads to less building faults. Thus; less claiming and money saved. Early involvement of users and inclusion of user needs in the design process may improve the following performance of the building in the operation phase, as well as increase user satisfaction. A high performance building can yield higher rental costs which can be compensated for by a lower energy bill thus the sales value of the building will increase. A green image can also benefit the building owner or tenant organization.

Methodological approach of ICT integration

In order to ensure the that Integrated Design takes into account recent trends and developments in Information and Computer Technology a methodological approach is designed by taking into account the potential role of smart grids.

Smart Grids can create a revolution in the building sector. The accumulated experience of the last decades has shown that the hierarchical, centrally controlled grid of the 20th Century is ill-suited to the needs of the 21st Century. The smart grid can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability. The role of buildings in this framework is very crucial. A since the vast majority of smart grids' potential customers are buildings (residential, commercial, retail and industrial) and communities the smart grids' challenges on building and community level is of major importance.

The methodological approach's phases are (see Figure 2):

1. Phase 1: Zero energy buildings and integrated design: How to design buildings that can be easily integrated with smart grids.
2. Phase 2: Zero energy communities' components: Energy production and Energy demand.

3. Phase 3: Successful integration of zero energy buildings and communities with smart grids.

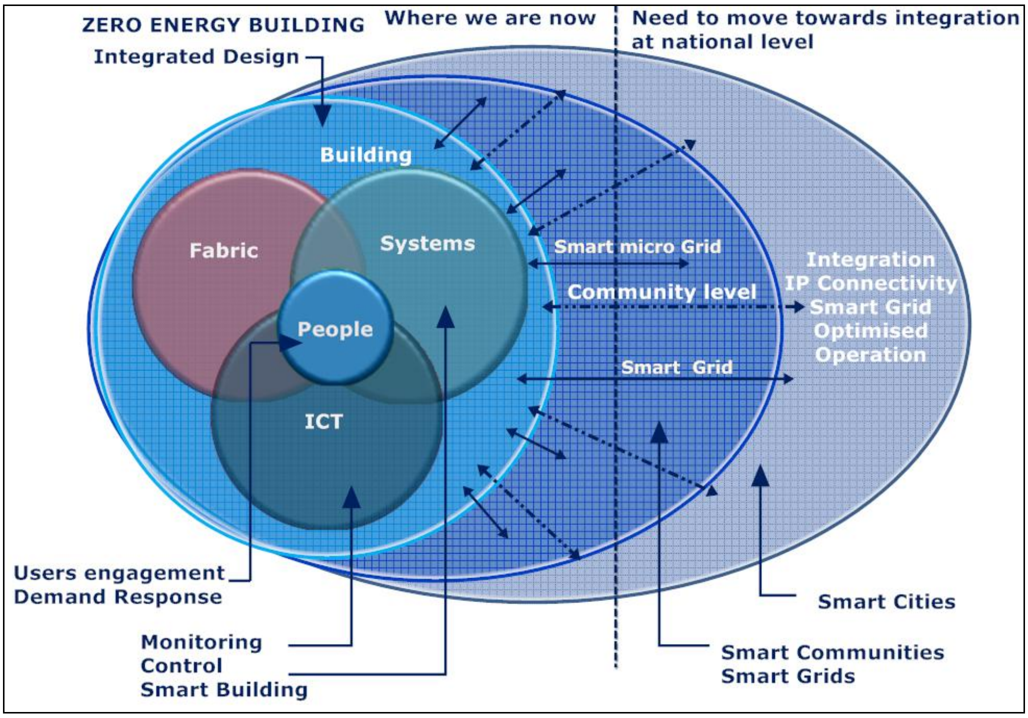

Figure 2 The methodological approach of smart technologies

Phase 1: Zero Energy Buildings

Phase 1 starts from the users'/consumers' aspects by focusing on smart and zero energy buildings' analysis [6]. This is a mandatory requirement based on the fact that by 31 December 2020, all new buildings shall be nearly zero-energy consumption buildings. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018[7], [8]. This is the core of the cycle approach.

ZEBs are buildings that work in synergy with the grid, avoiding putting additional stress on the power infrastructure [9]. Achieving a ZEB includes apart from minimizing the required energy through efficient measures and covering the minimized energy needs by adopting renewable sources, a series of optimised and well balanced operations between consumption and production coupled with successful grid integration [10].

In the framework of Phase 1 the following topics are investigated:

- *Integrated design (ID) and low energy buildings*

Since buildings are major consumers in smart grids, the integrated design task will assist to develop a collaborative method for designing buildings for smart grids. The integrated design process requires multidisciplinary collaboration, including key stakeholders and design professionals, from conception to completion. Decision-making protocols and complementary design principles must be established early in the process in order to satisfy the goals of multiple stakeholders while achieving the overall integration design objectives.

- *Smart buildings and smart technologies*

Smart buildings' operation is essential in order to assist the promotion of smart technologies. For example, smart controls and advanced monitoring for buildings' operational phase are analysed. Energy storage based control strategy development and implementation in the ZEB are implemented.

- *Zero energy buildings and integration in smart grids*

This includes the implementation of energy load predictions and outdoor conditions' predictions in order to evaluate load shaving applicability in conjunction with ID. The role of smart meters is emphasised.

Phase 2: Smart Grids Components and Zero Energy Communities

Moving from the building to the community level, the requests of the future communities are very demanding. They should be places of advanced social progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account [11].
In Phase 2 research is focused on the various smart grids' [1], [2], [12], [13] components to expand the cycle by the smart grids' penetration at community and if possible at city level. EU has a long tradition of being active in the field of urban development and regeneration and has taken on a major role in supporting cities and regions in their quest for competitiveness and cohesion. European cities should be places of advanced progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account. In this context smart grids offer the technological platform for fast moving towards sustainable communities by exploiting the ICT and energy systems' development in the maximum degree. Figure 3 depicts the smart grid components and their application to smart communities. More specifically the following points are investigated:

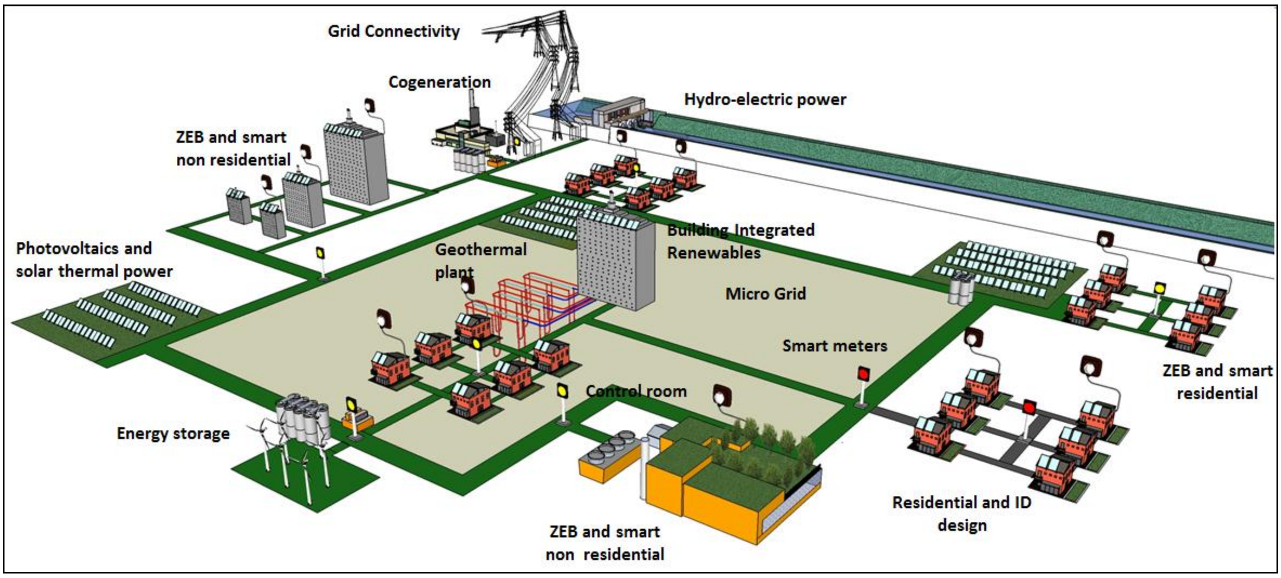

Figure 3 The smart grids components and the application to smart communities

- *The role of renewables for smart grids*

The aim of this research is to understand the sizing and positioning as well as the effective operation of renewables for smart grids. Existing renewables installations are analysed. Effective communication of the renewables operation with the smart grids is examined. Improvements via advanced control and monitoring protocols are established.

- *Cogeneration and district heating/cooling*

In this research existing knowledge concerning the cogeneration technologies and the applications of district heating and cooling for smart grids is analysed. The role of multi agents [14], [15] in smart grids and IT technology are exploited.

- *Study of existing smart grids*

The aim of the task is to analyse and monitor benefits and drawbacks of existing smart grids. Algorithms for energy management and asset management, successful exploitation of smart meters in smart grids, via mobile connectivity, as well as data mining techniques and energy predictions are developed and tested. Advanced modelling methodologies for district and community levels will be shared among the participants.

Phase 3: Integration of components

The integration of all components is performed in Phase 3 targeting to the development of smart applications and IP connectivity as well as smart grids' optimized operation. Moreover, since the smart

grids provide an excellent field for career development, funds' raising opportunities as well as development of spinoffs in collaboration with the academic institutions are exploited via the industrial partners' competences.
In this phase the following research is performed:

- *Integration of smart grids.*

This research gives the opportunity of a merging collaboration, brainstorming sessions allowing the transfer of concluding knowledge via interaction between industry and academia. Optimisation mechanisms, conflicts' management and major criteria for smart grids optimal operation will be put under the microscope for analysis and evaluation. This aims to significantly contribute to the Smart Cities concept.

- *Innovation management skills and future collaborations*

This work will become the leverage for future collaborations. The innovation management skills acquired during the previous phases will have assisted the establishment of a common language among the participants and strategic decision making for career development, investments in time and resources and further promotion of smart grids. Existing research products outlined in previous works will be followed up by innovation and entrepreneurship competence building.

Case Study at Technical University of Crete

Camp IT microgrid consists of 18 smart energy meters and an extensive network of sensors (temperature, relative humidity, CO2, presence, illuminance, etc.) and control equipment integrated with the aid of a web based platform. A Demand Response (DR) optimisation and control approach is being developed to highlight the potential benefits of energy and power management in terms of energy cost savings at microgrid level. Validated building models based on indoor and outdoor measurements are used and minimization of the annual total cost of energy is exploited as the major criterion of the optimization and control. Modelling the cost of energy involves an analysis of the various cost domains:

- Energy tariffs (€/kWh)
- Maximum Power demand (kW)
- Power quality
- Transmission of energy (€/kW)
- Distribution of energy (€/kWh)
- CO_2 rights (€/kWh)
- Taxes and other costs

The cost of energy profile is modelled according to the actual energy pricing profile and validated based on utility accounted cost data. Integrating renewable energy sources, storage and the importance of load shifting and peak shaving is exploited. The Camp IT infrastructure (www.campit.gr, fig.4) at Technical University of Crete will be used for pilot implementation purposes.

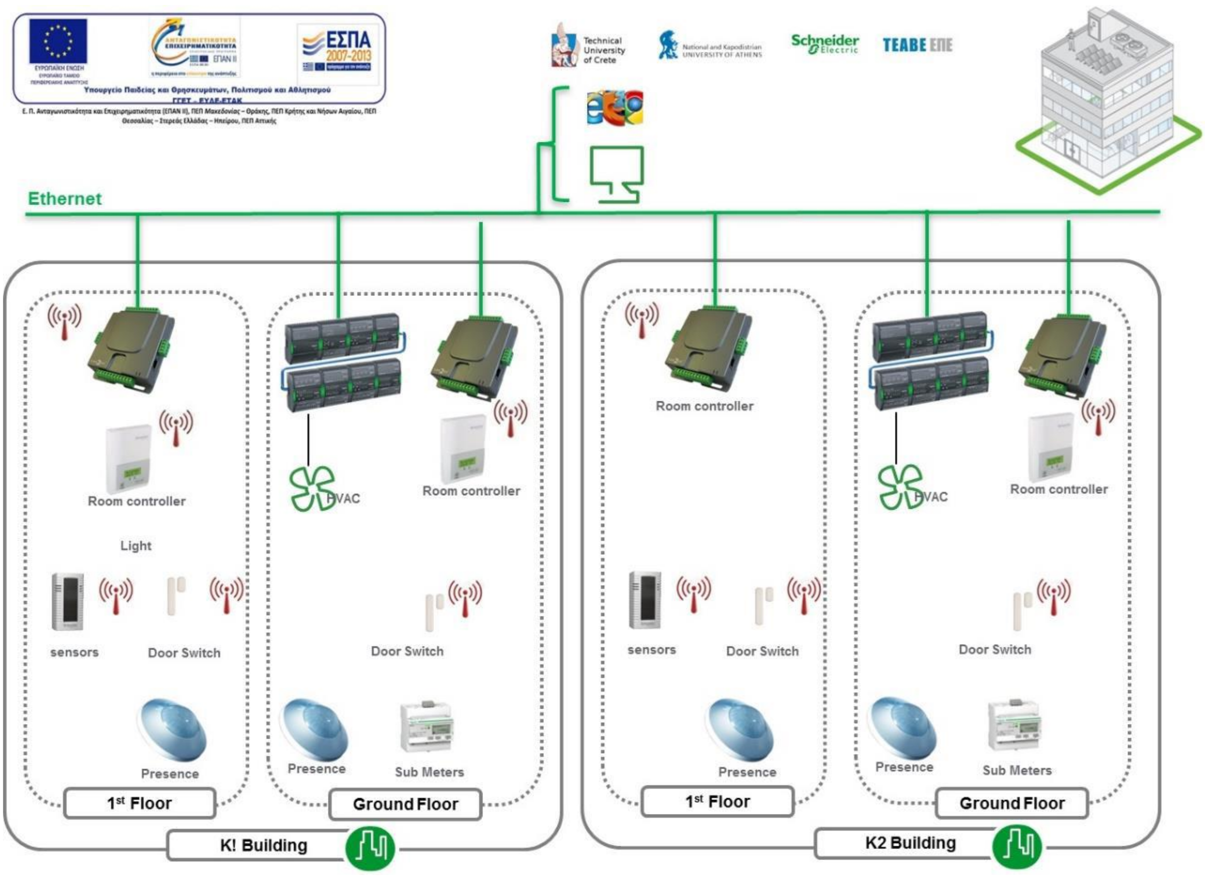

Figure 4: The Camp IT infrastructure at Technical University of Crete

Conclusions

Measures and changes in the building modus operandi can yield substantial energy savings minimizing the buildings' carbon footprint. Moreover buildings in the near future should be able to produce the amount of energy they consume, i.e. become zero or nearly zero energy buildings (ZEB). This is a mandatory requirement based on the fact that by 31 December 2020, all new buildings shall be nearly zero-energy consumption buildings. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018.
Smart Grids and Integrated Design can be considered very promising for the energy and built environment industry among others due to the physical proximity between consumers and micro energy sources which can help in increasing consumer awareness towards a more rational use of energy. Smart grids offer new opportunities for gas emissions reduction due to the creation of technical conditions that increase the connection of devices and renewable energy resources at the low voltage level.
The proposed 3-phase methodological approach provides a coherent framework for the implementation of smart grids at building and community level. The various levels of analysis allow for adequate consideration of important concepts such as the integrated design, users' engagement, exploitation of ICT capabilities, demand response optimized control and integration in smart grids at community and city level. In parallel a holistic perspective on major components of smart grids such as alternative renewable energy technologies, smart metering and the technological platform for overall concerted operation through IP connectivity is addressed. The research activities in the Smart GEMS project comprise multidisciplinary efforts in establishing generalized principles and effective integrative techniques through modelling and testing of a wide framework of applications to drive the future design and implementation of Smart Grids.
In this direction conflicts' management and major criteria for Smart Cities is put under the microscope for analysis and evaluation. This work will become the leverage for future collaborations, innovation and entrepreneurship. Vital prerequisites for the wide scale implementation of the proposed framework relate to the removal of energy market barriers and to the creation of a transparent investment and

operational framework allowing a balance in sharing costs, benefits and risks, addressing smart consumer and consumer protection policies, fostering international collaboration etc.

Acknowledgement

The research is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement SMART GEMS: SMART GRIDS ENERGY MANAGEMENT STAFF (Contract No 645677).

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Evaluating the Benefits of Exposing the Thermal Mass in Future Climate Scenarios to Reduce Overheating

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Anglia Ruskin University (United Kingdom)

Abstract

Thermal mass has the benefit of regulating energy in buildings and generates potential savings in energy and CO_2 emissions. The result of the effect of climate change will be more intense and longer periods of summer heat waves. Use of the building thermal mass can reduce overheating in summer and minimize the need for cooling energy, reducing energy consumption and CO_2 emissions. In many buildings, the thermal mass is hidden behind a suspended ceiling, avoiding the loading and unloading of the thermal mass.

The aim of this study was to investigate the impact of future climate scenarios in overheating and to evaluate the benefits of using thermal mass to reduce the overheating in those conditions.

This study was based on dynamic thermal modeling to analyse the overheating performance of a test room with suspended ceiling and with the thermal mass exposed. The testing room was simulated for two emissions scenarios, high and medium, using weather files from the Prometheus project produced on the outputs of UKCP09 data for London Islington in the United Kingdom.

The simulation results show that making use of the room thermal mass can reduce the number of occupied hours above 28ºC reduced by at least 35% for the baseline (1970s). Small reductions of overheating are shown for high and medium emission scenarios for 2080s projections. This study shows that the use thermal mass and night ventilation can provide a reduction in overheating in the short term. In the long term, 2080s, the use of the thermal mass has a minimal effect on the high number of overheating hours and a different strategy must be in place if overheating wants to be avoided due to higher outdoor temperatures.

Introduction

Thermal mass has the benefit of regulating energy in buildings and generates potential savings in energy and CO_2 emissions. The benefits of coupling thermal mass and ventilation in housing to avoid overheating have been already presented in the literature [1, 2]. According to the Zero Carbon Hub [3], thermal mass and purge ventilation have a beneficial effect on reducing overheating. This study focus on non-domestic buildings, where normally the thermal mass is hidden behind a compressed mineral wool suspended ceiling. This suspended ceiling produces a blocking effect for the use of the thermal mass to regulate the indoor conditions, avoiding the loading and unloading process of the thermal mass to be used as a regulatory mechanism for comfort indoor temperature. Exposure and use of the building thermal mass can reduce overheating in summer and minimize the need for cooling energy, reducing energy consumption and CO_2 emissions [4].

As a result of the effect of climate change, temperatures in summer will be higher and longer periods of summer heat waves will be expected [5]. Previous work has presented the issue of overheating in future weather conditions for non-domestic buildings [6]. Exposure of the building thermal mass combined with a night ventilation strategy can reduce overheating in current weather conditions [4], whether the same effect and reduction in overheating can be achieved in future climate change scenarios is currently unknown.

The aim of this study was to investigate the impact of future climate scenarios in overheating and to evaluate the benefits of using thermal mass to reduce the overheating in those conditions.

Method

A test room, as shown in Figure 1, was modeled with dimensions 7.5m x 7.5m x 3.5m. The test room was dynamically simulated using energyplus in DesignBuilder software. U-values for internal floors hidden (with suspended ceiling) and exposing (without suspended ceiling) the thermal are presented in Figure 2. The test room was naturally ventilated and a night cooling ventilation strategy was used to cool down the thermal mass. No cooling was used in the simulations to be able to isolate and quantify the benefits provided by the thermal mass to reduce overheating on its own. The simulated test room results were audit to confirm corroboration of results with building physics principles.

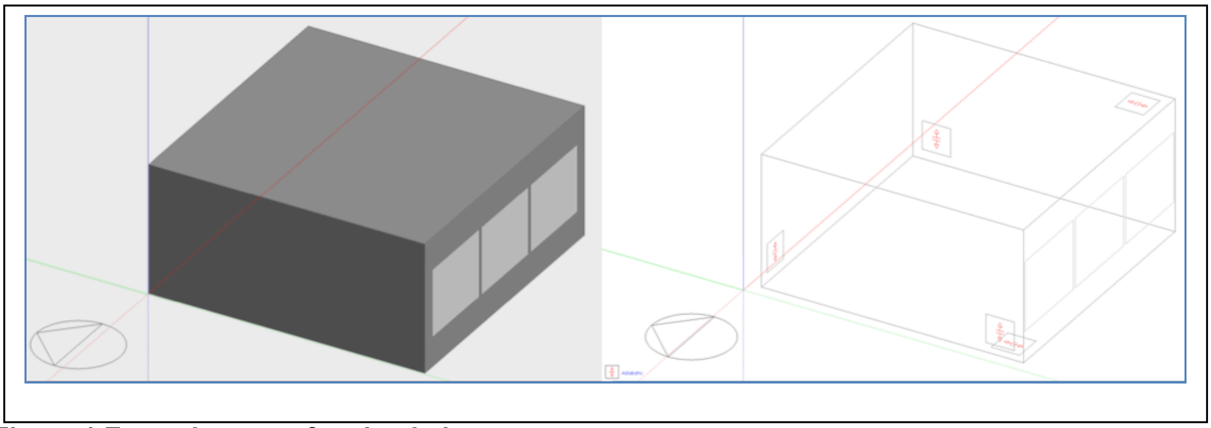

Figure 1 Exemplar room for simulation

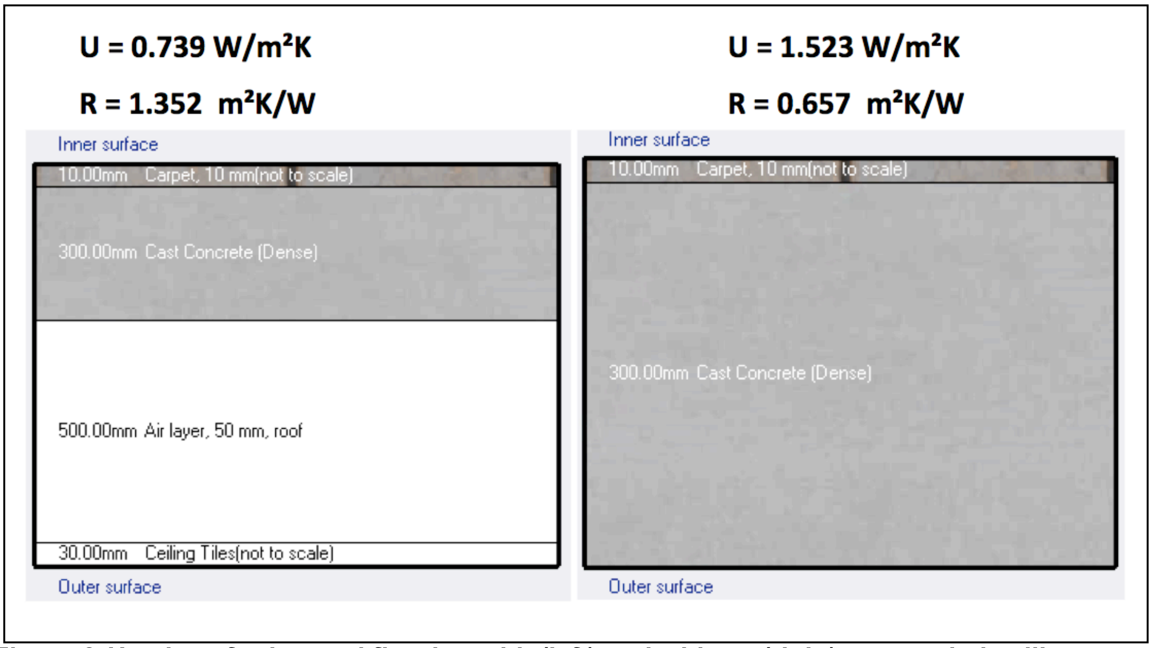

Figure 2 ***U-values for internal flooring with (left) and without (right) suspended ceiling***

The dynamic computational simulation in DesignBuilder had the following parameters:

- Simulated location in London (Islington).
- Medium weight construction according to Part L2 2010 (UK).
- All surfaces adiabatic apart from south wall being external with a U-value of 0.26 W/m^{2}K.
- 50% glazing in south wall with a U-value of 1.978 W/m^{2}K and g-value of 0.687.
- Office equipment load of 10 W/m^2.
- Lighting load of 0 W/m^2.
- People density of 0.111 people/m^2, following an occupancy schedule from 9:00 to 17:00
- Constant infiltration of 0.5 air changes per hour (acph).
- Natural ventilation rate of 1.5 acph, following a schedule from 8:00 to 19:00
- Night ventilation rate of 6 acph, following a schedule from 24:00 to 6:00
- Simulations run for a full year.

The test room was dynamically simulated using the weather files produced as part of the Prometheus project, which are based on UK Climate Projections 2009 (UKCP09) data to provide weather projections in future climate [7]. This study used Design Summer Year (DSY) weather files with a probabilistic prediction for the 50th percentile reflecting climate change for a medium and high emission scenarios. The test room was simulated with and without suspended ceiling for the baseline (1970s), 2030s, 2050s and 2080s weather files to compare the effect on overheating hours.

The overheating limit was set to 28ºC in accordance with CIBSE definitions [8, 9].

Results

In terms of assessing the overheating performance with and without the suspended ceiling, fourteen simulations were solved using the dynamic Energyplus engine in DesignBuilder without the use of (simulated) cooling preventing overheating. Two simulations were performed for each weather file and each emission scenario, medium emissions (ME) and high emissions (HE), for London (Islington), simulating the test room with suspended ceiling and non-suspended ceiling.

Figure 3 shows the temperature distribution results for London (Islington) with the use of suspended ceiling for the baseline (1970s) weather file as an example. Similar results were collected and analysed for the other fourteen computational simulations, the final results for overheating hours above 28ºC are summarised in Figure 4.

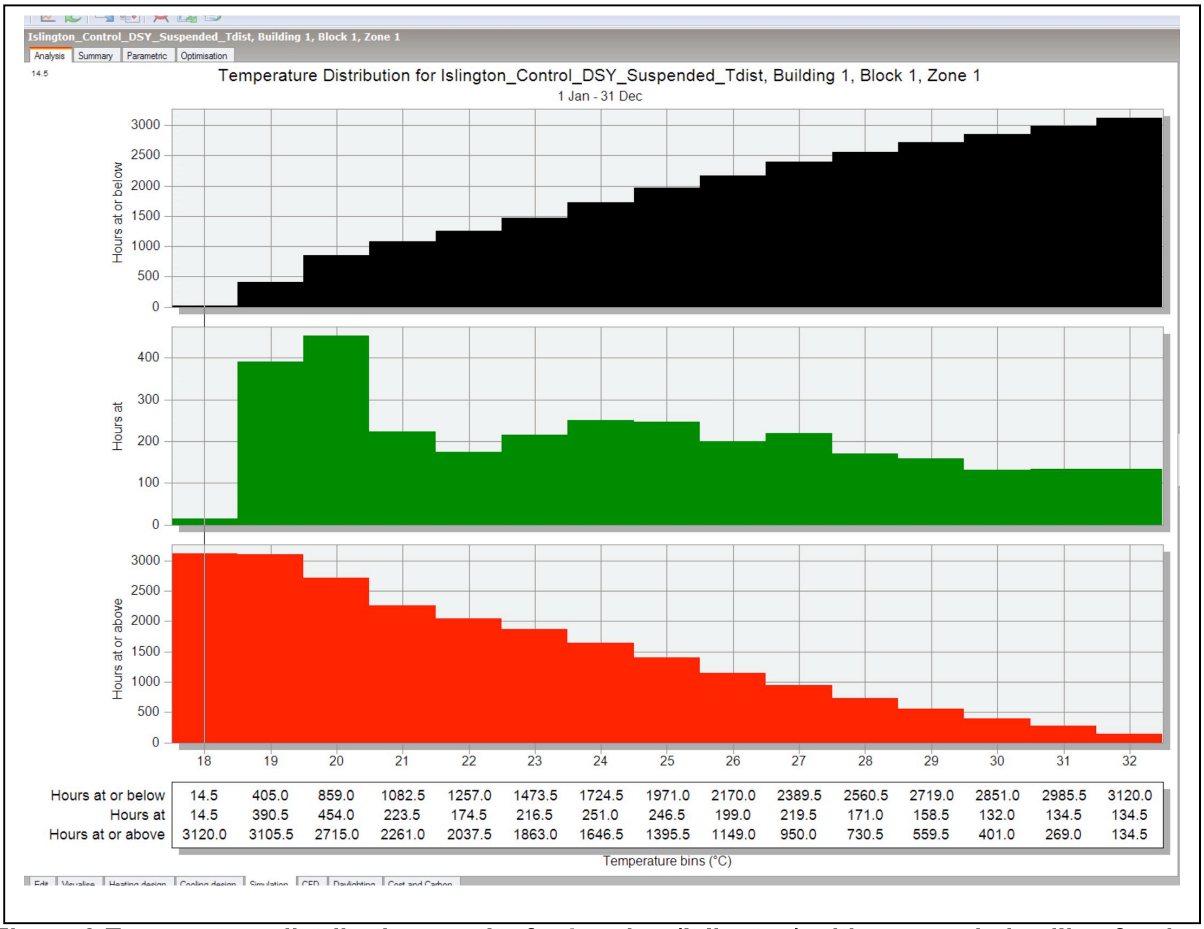

Figure 3 Temperature distribution results for London (Islington) with suspended ceiling for the baseline (1970s) weather file

Exposing the thermal mass by elimination of the suspended ceiling reduces the overheating hours above 28ºC by about 35% for the baseline (1970s) simulation compared to the same room featuring a suspended ceiling with accompanying isolation of the thermal mass from ambient temperatures.

As expected, overheating hours above 28^{0}C are higher for the high emissions scenario than for the medium emissions scenario, as higher emissions will accelerate the global warming effect of climate change, producing warmer and longer summers.

Overheating hours above 28^{0}C by 2080s will be roughly four times the baseline levels in 1970s for both, medium and high, emissions scenario.

The reduction in overheating hours became smaller and smaller as the weather files simulates the latest years of the emission scenario. To the point of having small percentage reduction in overheating of 5% for the high emission scenario and 7% for the medium emission scenario due to the benefits of using thermal mass. This effect is due to the outdoor temperature being much higher in 2080s than in the reference simulations of 1970s, reducing the night cooling effect on the thermal mass and limiting the saving in overheatign hours and previously presented in the literature [10].

The number of overheating hours correlates with the need for cooling in a building and subsequently with the energy use and carbon emissions that cooling would incur. The higher the number of overheating hours, the more energy and carbon emission will be driven by cooling to alleviate the overheating.

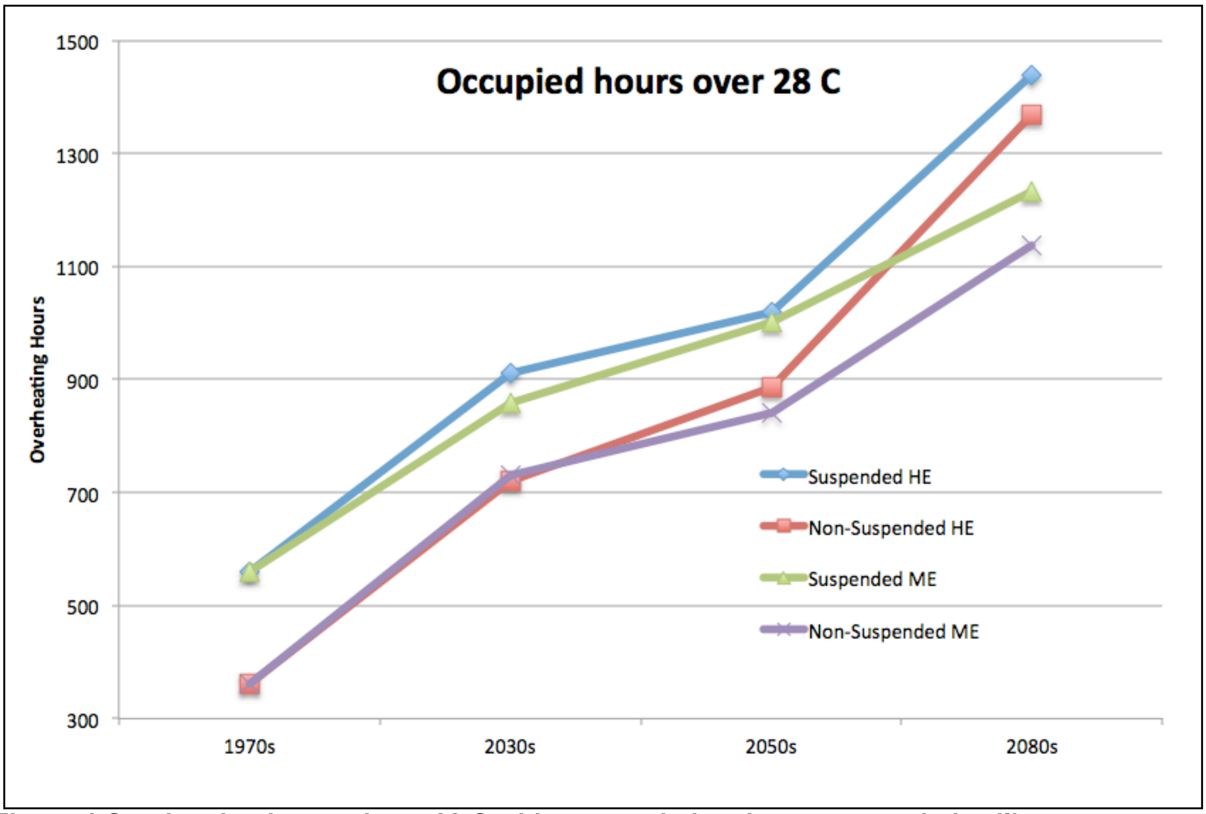

Figure 4 Overheating hours above 28 C with suspended and non-suspended ceiling

Discussion

Exposing the thermal mass by removal of the suspended ceiling in non domestic buildings can reduce the overheating hours above 28ºC by up to 35% for the baseline (1970s) simulation in London (Islington) compared to the same room featuring a suspended ceiling with accompanying (simulated) isolation of the thermal mass from ambient temperatures. These results agree with previous research highlighting the benefits of exposing the thermal mass and the use of night ventilation [1,2,11]

The number of overheating hours correlates with the need for cooling in a building and subsequently with the energy use and carbon emissions that cooling would incur. The use of cooling is driven by the number of overheating hours in the building, which will affect the thermal comfort of the occupants, so the higher the number of overheating hours, the more energy and carbon emission will be generated and the more probable the high emission scenario will be.

The simulation results show that by exposing and making use of the room thermal mass, the number of hours above 28ºC can be reduce by at least 35% for the baseline (1970s) simulation but the beneficial effect of the thermal mass is very much reduced in subsequent simulations for 2030s, 2050s and 2080s with a bigger reduction for the high emission scenario, due to an increase in outdoor temperatures [10].

While this study support the use of thermal mass and purge ventilation as a mechanism to avoid overheating [1, 2, 3] in the short term, a different strategy must be applied to reduce overheating in the long term (2050s and 2080s) as the achieved overheating reduction is just 5% for the high emission scenario and 7% for the medium emission scenario. Under these scenarios, the reduction of overheating hours will be minimal to achieve thermal comfort to the occupants and futher measures must be put in places to reduce the use of cooling if a reduction in energy and CO_2 emissions must be achieved.

These results should be taking into account in the design of new buildings and refurbishment work to avoid overheating in the future due to climate change due to the long life of buildings.This study highlights the need of further understanding on the effect of future climate on quantifying the benefit of energy efficient measures in the long term to avoid the need to refurbish in the short term due to the higher temperatures in future climates.

Conclusion

This study shows that the use thermal mass and night ventilation can provide a reduction in overheating in the short term. In the long term, 2080s, the use of the thermal mass has a minimal effect on the high number of overheating hours and a different strategy must be in place if overheating wants to be avoided due to the outdoor temperatures.

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Energy consumption – A comparison between predicted and measured performance

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Abstract

The basis for the nearly zero energy building (NZEB) is a highly energy efficient building. In public discussions, the expression of a "performance gap" often arises in the context of energy efficiency. This expression implies that the actual energy consumption of buildings in use is significantly higher than the calculated and predicted energy demand during the planning phase. This paper presents and discusses a statistically significant comparison between measured energy performance and calculations for a large number of buildings built to the Passive House Standard. In general, a good correlation with the previously calculated energy demands with the Passive House Planning Package (PHPP) is observed – leading to the result that Passive Houses planned with the PHPP did not show a "performance gap". The general data agreement by far does not mean that each individual building's energy consumption is equal to the predicted demand. Deviations of ±50 % (minimum/maximum) from the average value constitute the expected normal distribution due to factors such as user behavior and, in the case of commercial buildings, control settings. Finally, it can be stated that the Passive House Standard is proven to reliably reach extremely high heating energy savings in a practically verifiable and reproducible manner. These savings amount to 90 % compared to the old building standard and about 80 % on average when compared with the legally stipulated requirements for new buildings in Germany.

Introduction

The Energy Performance of Buildings Directive (EPBD) requires all new buildings to be nearly zero energy buildings (NZEB) by the end of 2020. New public buildings must be NZEBs already by 2018. The prerequisite for reaching this ambitious target is a very energy efficient building as the basis and a combination with renewables. A special focus has to be set on low heating energy demands since in the European climate the harvest of renewable energy sources during winter is much worse than in summer. So to avoid inefficient and expensive seasonal energy storage here, a special focus has to be set on the efficiency. The Passive House Standard as functional criterion for buildings is a very good basis for the NZEB development. This will be boosted by the new Passive House Classes introduced by the Passive House Institute, which include the consideration of renewables (s. contribution by Jessica Grove-Smith [1]).

When deciding the energy standard of a new building or a refurbishment, the question often arises if this standard will really be met afterwards. Systematic evaluations showed that there was a tendency for the measured energy consumption (e.g. for heating) to be higher than the expected demand calculations. The difference was called the "performance gap". One example is the work by Johnston et al. [2] from the UK. Performance tests of the building envelope were carried out for 25 different buildings. The heat loss per Kelvin temperature difference was determined for the entire buildings (co-heating test). The measurements included 22 low-energy projects and three Passive House buildings (s. [2]). Deviations of more than 50 % between measurement and predictions could be observed. The question therefore arises if this is a general problem for all building energy standards and what a demand calculation is worth, since in the end, economic and ecologic aspects that can determine how to build are made on the basis of the demand prediction. Looking at the three last examples from Figure 1, which are Passive House buildings, the opposite can be seen: measured quality is really close to the planned one and additionally the quality is more than 50 % better than that of the best low-energy building (compared with the measured data). This paper starts with the discussion of an example for a heat loss coefficient measurement of a Passive House building, where only the thermal building quality is measured. Afterwards a huge number of measured consumptions are compared with according calculated demands and discussed.

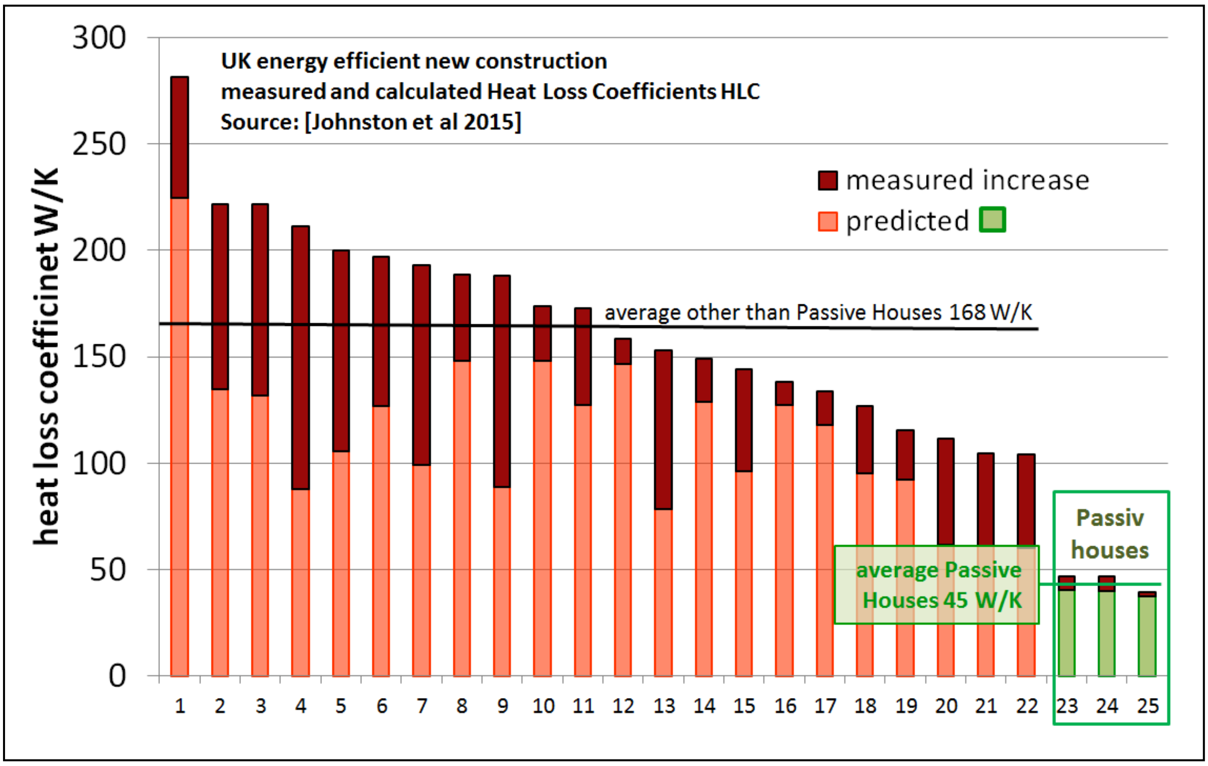

Figure 1: The results of the performance tests carried out for 25 highly efficient new builds in England [Johnston 2014]. The three Passive House projects scored best by far and in every respect: there was almost no difference between the predicted and the measured specific heat loss, they exhibited a heat loss coefficient lower by a factor of two compared with the next best projects and they saved almost 75% of the heating losses compared with the average losses.

Heat loss coefficient of a passive house

In many discussions about the performance gap the strong influence of users is discussed. In order to see if the thermal envelope itself correspondents to the planned quality, a co-heating test for a Passive House building was performed. During the experiment, the building was held to a constant elevated indoor temperature of 25 °C and the energy for electrical heating was measured. Solar gains were minimized by closing external shadings. The heat loss coefficient (HLC, [W/K]) is defined as the heat loss in [W] per temperature difference between inside and outside temperature. For the experiment, a round, one story certified Passive House (Figure 2) with a floor area of 142 m² was chosen. Because of its form, the house which was built in 2000, is also called the “Passive House Disc”. It is a wooden construction with a highly insulated envelope (38 cm walls, 30 cm floor slab, 48 cm roof insulation with a thermal conductivity of 0,04 W/mK). The measured airtightness with a value of n_{50} = 0,4 h^{-1} was very good, so infiltration heat losses are small. A detailed PHPP [3] with all thermally relevant planning details was available and used to calculate the expected HLC. The resulting total theoretical HLC of the building consisting of transmission and ventilation is 60.0 W/K. The error for this value was estimated to be 2 W/K assuming that the planning details are correctly implemented into the PHPP. The measurement conditions were nearly perfect with constant low outdoor temperatures and only very little solar radiation. The HLC resulting from the co-heating experiment was 59.9 ± 2 W/K hitting nearly exactly the calculated value [4]. From this, it can be stated that for this building the thermal quality of the planning phase was implemented very well. Other examples for HLC determinations of Passive Houses are published by Johnston et al. [5]. Since the co-heating method is very time- and in consequence cost-consuming it cannot be applied broadly. To investigate if there is a performance gap for very high performing buildings, it seems much easier to use the easy-to-measure annual heating demand. This is done in the following, starting with a short introduction to the necessary statistical basics.

Figure 2: Passive house disc, a one story Passive House with a floor area of 142 m² being located in Austria.

Statistical basics

The energy consumptions of single buildings have often been monitored. When the result, for instance the measured heating energy consumption, is compared with a calculated demand and especially when a general statement should be derived, it is important to be aware of the achievable accuracy and associated error margins of such numbers. It can be said with certainty that every consumption and demand value has a considerable associated error. If such a demand and consumption are being compared the error becomes important because a statement becomes meaningless if the errors are large compared with the difference.

Origin of errors

In general, the sources of errors can be separated into statistical and systematic errors. The first mentioned can be reduced if the measurement period is prolonged (e.g. several years instead of one) or the number of measurements (e.g. different measurement instruments, lots of values instead of one). A systematic error cannot be reduced if the reason is unknown. An example for a systematic error would be measuring the sum of heating energy and energy for domestic hot water (DHW) and comparing this with the heating demand without DHW. This example shows that the measurement and the definition of which values are to be compared have to be done very carefully. A guideline for monitoring the energy consumption of buildings was published in the framework of the European FP7 project SINFONIA by Peper et al. [6]. It forms the basis for the development of a monitoring concept of approximately 500 living units in the cities of Bolzano and Innsbruck. There, the success of a refurbishment process will be investigated on a large scale.

For generalized statements about energy standards, for the reasons given, it is very important to consider not only one single building. Even when the error of the measurement is small because it was done very carefully there is also a considerable user influence on the buildings energy consumption. It is quite obvious that the heating consumption cannot be the same if a student with limited finances lives in an apartment who, is often not at home and another apartment that is occupied by an elderly person who needs elevated room temperatures (for reasons of health and comfort). From this example it becomes clear that the energy consumption of buildings should be strongly influenced by the user behavior – this was tested in a field project and proven as early as 1986 by Lundström et al. [7]. In the next paragraph the resulting distribution will be briefly discussed.

Distributions and mean value

The probability density *f* of a normal (Gaussian) distribution is

$$f(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}.$$

The parameters are the mean value μ and the standard deviation σ. This has the form of the famous bell curve. The integral over the distribution function gives the probability that a value lies below a certain limit x

$$F(x) = N(\mu, \sigma, x) = \int_{-\infty}^{x} \frac{1}{\sigma \sqrt{2\pi}} \cdot e^{-\frac{(x'-\mu)^2}{2\sigma^2}} dx'.$$

The corresponding graphs of the normal distribution and the normal distribution function are depicted in Figure 3. The normal distribution function is discussed here because it is of great importance for understanding and analysis of the measured performance of buildings. As shown in the following examples, the energy consumption of similar buildings follows such a Gaussian distribution. This fact facilitates the statistical analysis of measured energy performances.

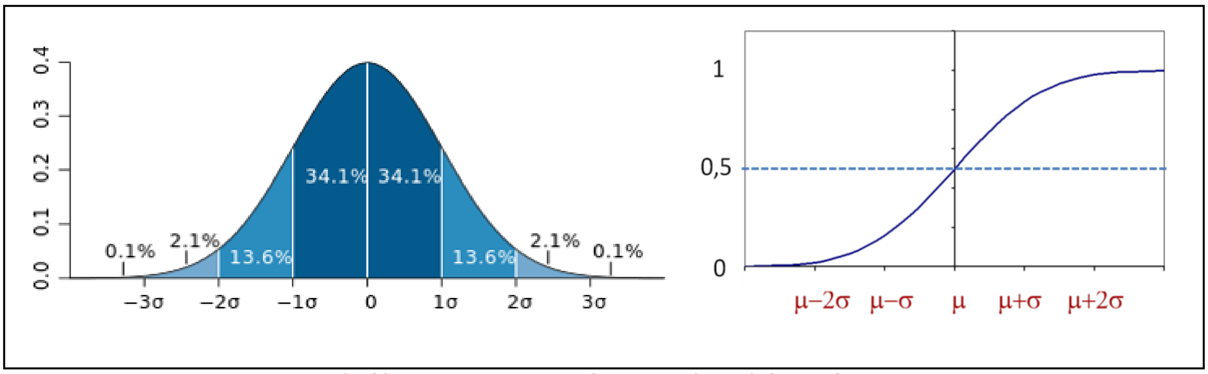

Figure 3: Probability density (left) and distribution function (right) for a Gaussian normal distribution with a mean value μ and a standard deviation σ.

For the comparison of building standards or between consumption and demand the mean value of a series of buildings as shown in the following has to be taken. It is important that the error of this mean value is not mixed up with the standard deviation. The standard deviation is a measure for the broadness of the distribution whereas the error of the mean value depends on the number of considered objects. It is defined as $\Delta\mu = \sigma/n^{0.5}$ (for the 1- σ interval).

Statistical evaluation of measured data

Energy consumption of existing buildings

To show the difference in building standards and to investigate the savings of the Passive House Standard, an example for the distribution of measured heating demands in the building stock is first shown in Figure 4. The graph shows the ordered specific heating consumption of 98 terraced houses built in 1955 and measured during the heating period 1987/88 in Kassel in the Belgiersiedlung. The blue horizontal line indicates the mean value of 158.5 kWh/(m²a). This, as well as the standard deviation of 39.2 kWh/(m²a) being 25 % of the mean value result from a fit of the Gaussian distribution function (s. Figure 3, right). The error of the mean value here is about 4 kWh/(m²a), being below 3 % only. The mean value lies very close to the German mean heating energy consumption from 2007 of 161 kWh/(m²a) [8]. On the other hand, the difference between the highest and lowest consumption is nearly a factor of 4. This clearly shows that if only one of these houses had been measured, the conclusion drawn when comparing the energy consumption to the predicted performance would be misleading – and very different depending on the choice of the individual building. That the energy consumption of buildings has a large spread and is dominated by the user behavior, was already recognized by Lundström in 1986 [7]. Besides other things like times and frequencies of opening windows, internal heat gains (electrical appliances), the most important factor determining the heating energy consumption due to user influence is the indoor temperature. For the discussion about performance gaps this is very important, because it influences the result of calculation tools for energy demands in the same way. If the operation temperature is set too low in the calculation a “performance gap” will be the consequence – independently from the building’s quality.

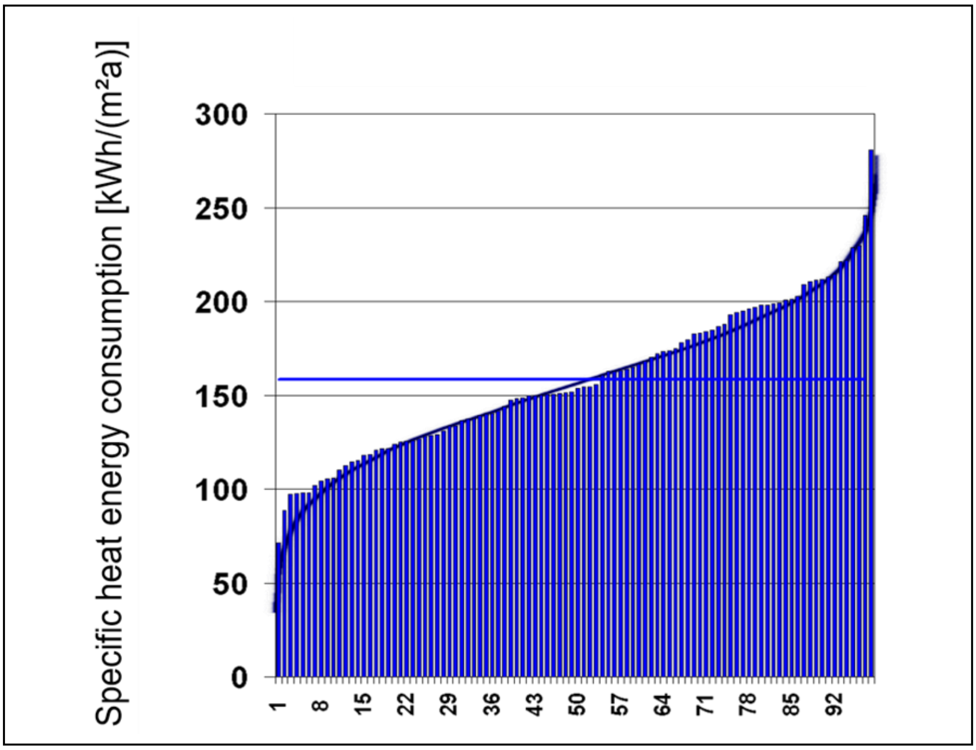

Figure 4: Ordered specific heating demands of 98 terraced houses built in 1955 measured in 1987 in Kassel in the Belgiersiedlung. The horizontal blue line indicates the mean value of 158 kWh/(m²a) and the black line is the fitted normal distribution curve.

Measurements results for the Passive House Standard

Long-term experiences and statistically verified measurement results for actual consumption values are also available for Passive House buildings. With all building standards there are significant differences in consumption due to user behaviour, even in the case of identically constructed buildings. Figure 5 provides an overview of measurement results from 41 low-energy houses and a total of 106 Passive House buildings from three different projects in Germany. Although the highest consumption for a Passive House building and the lowest of the low-energy buildings are almost equal, comparing the mean values (horizontal blue lines) a clear difference between the Passive House Standard and the low-energy standard is visible. The projects are described in some detail in the following. In addition to the measured consumptions the calculated heating demands are shown. All heating demands were calculated using the Passive House Planning Package (PHPP) [3]. It was introduced for the first time in 1998 and has been continually further developed ever since. It allows the detailed calculation of space heating demands (annual and monthly methods) as well as for the electricity and primary energy demand of buildings and is the basis for Passive House certification.

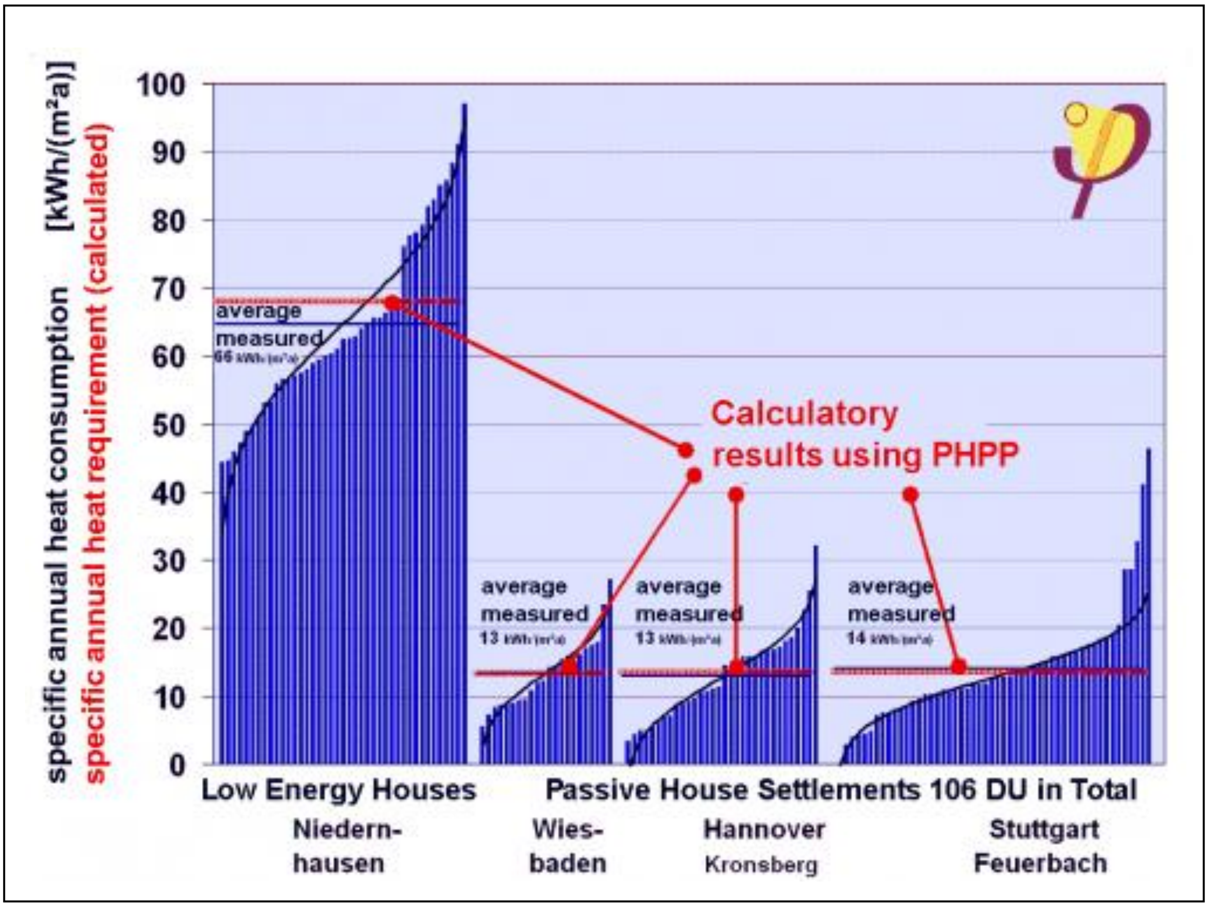

Figure 5: Overview of consumption measurements. This diagram summarises the measured heat consumptions from four housing estates, a low-energy settlement (left) and three Passive House settlements.

The low-energy settlement in Niedernhausen with 41 terraced houses is used as a reference for comparison purposes. The individual values of the heat meter readings for the year 1994 are shown in Figure 5 (measurement: [9]). The average value for all homes measured is 65.6 kWh/(m²a). (Here and subsequently, the living area is used as the reference value for the consumption, as is usually done for heating cost invoices).

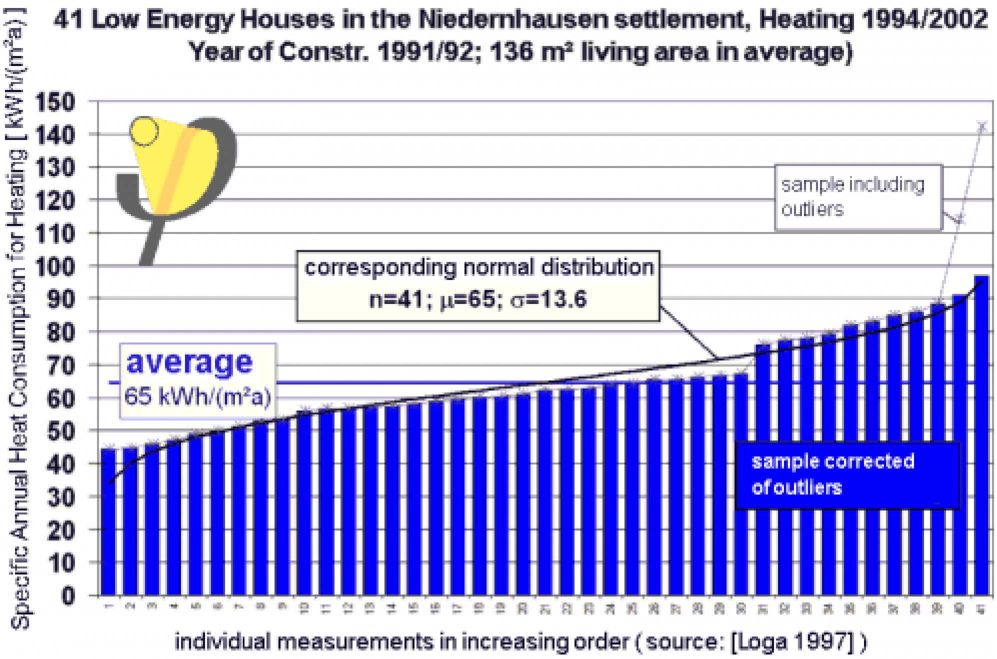

Figure 6: Consumption statistics for a low-energy settlement with 41 houses in Niedernhausen (Germany) which was first inhabited in 1992. The average consumption of 65.6 kWh/(m²a) correlates with the calculated demand of 68 kWh/(m²a) (PHPP) within the achievable accuracy. The curve added in the diagram is the respective normal distribution. The consumption measurements were carried out by T. Loga and M. Großklos [9].

This average value is considerably lower than the average heat consumption in existing housing stock in Germany. If the space heating value of 112 kWh/(m²a) is used as the current (2013) reference value for Germany, corresponding to the average heating consumption in apartment buildings that are invoiced according to consumption [10], then the consumption in 1997 in the low-energy settlement was at least 41.5 % less than today's average consumption. Incidentally, although built in 1991, the construction standard of this settlement is still better than the requirements of the currently applicable German energy standard (EnEV) [11].

The measurement (s. Figure 6) shows that the individual values are scattered around the average value depending on user behaviour. The influence of the user on the consumption is even quite high (about a factor of 2). The standard deviation for this settlement is 13.6 kWh/(m²a) or 21% of the average consumption value.

The deviations due to individual user behaviour average out to a great extent if an average value is used, even more so for a large number of identically constructed units. The average consumption value for this housing development is statistically accurate to ±2 kWh/(m²a). It is therefore statistically secured that the low-energy standard leads to significant energy savings (41.5% ± 1.8%) compared with the current building stock.

Passive House settlement in Wiesbaden/Dotzheim

This was the first Passive House settlement project in Germany (built in 1997, by Rasch & Partner) and consists of 22 houses. In figure 6 the heat meter readings of the 1998/99 winter season are documented. The average value was determined as 13.4 kWh/(m²a). This means that the average consumption of the Passive House settlement is 80% lower than that of the low-energy settlement in Niedernhausen.

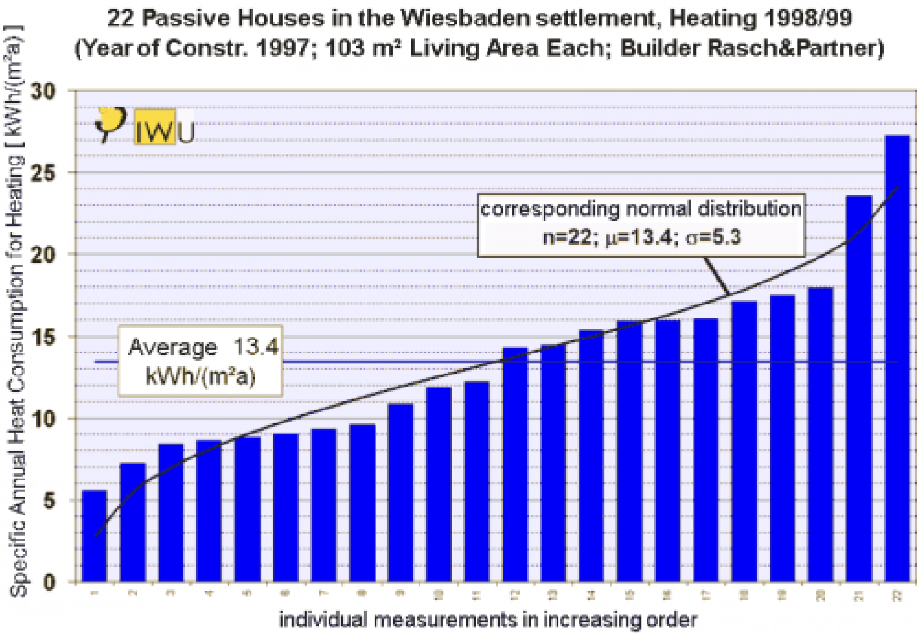

Figure 7: Consumption statistics for the Passive House settlement in Wiesbaden (Germany). The settlement with 22 Passive Houses was built in 1997. The average consumption of 13.4 kWh/(m²a) correlates extremely well with the previously calculated demand of 13 kWh/(m²a) (PHPP). Measurements Wiesbaden-Dotzheim: [12,13].

The standard deviation of the individual values of the Wiesbaden settlement is ±5.3 kWh/(m²a) and in absolute terms is much lower than that of the low-energy settlement. However, relative to the much smaller average consumption, the effect of user behaviour is more noticeable. Given this, there is nearly a factor of 5 between the lowest and highest consumptions. The determined average value is statistically accurate to ±1.1 kWh/(m²a). The energy savings due to the Passive House Standard are therefore statistically reliable for this project.

Passive House settlement in Hanover/Kronsberg

The Passive House settlement in Hannover/Kronsberg consists of 32 essentially identical terraced houses built as mixed constructions according to the Passive House Standard. The settlement was built in 1998/99; all units were designed individually. These were part of the Europe-wide CEPHEUS project. Figure 7 documents the heat meter readings in the heating season of 2001/2002. The average value is 12.8 kWh/(m²a). The average consumption values of all occupied Passive Houses in the housing development as measured by means of heat meters in all studied periods were as follows:

1. Heating period 1999/2000: **14.9 kWh/(m²a)**
2. Heating period 2000/2001: **13.3 kWh/(m²a)**
3. Heating period 2001/2002: **12.8 kWh/(m²a)**

The extremely low heat consumption values for the Passive House housing development in Hannover/Kronsberg are therefore also statistically secured and this for several years - the standard deviation of the individual values is 6.6 kWh/(m²a), the average value is accurately determined to ±1.2 kWh/(m²a).

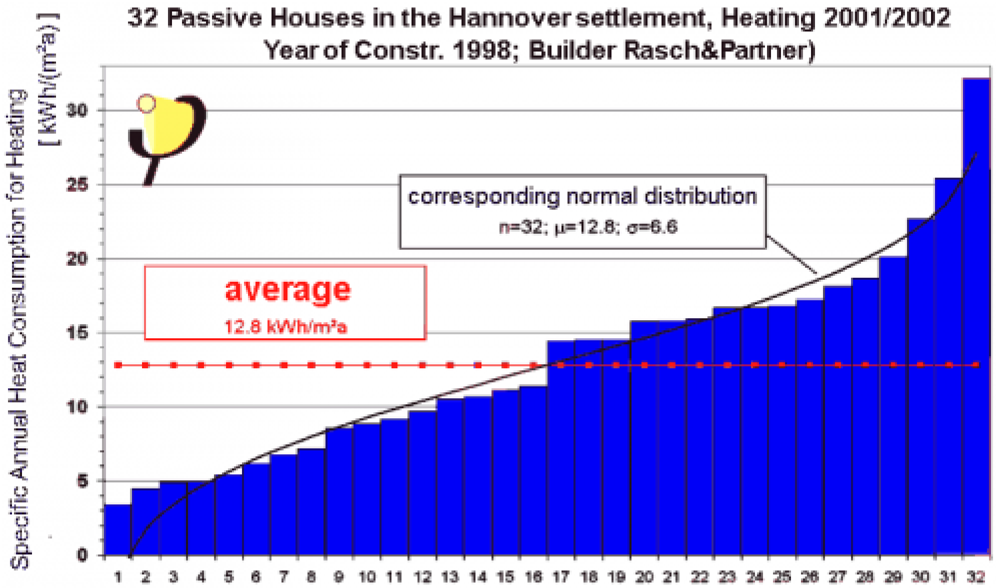

Figure 8: Consumption statistics for the Passive House settlement in Hanover/Kronsberg (Germany): the settlement with 32 Passive Houses was first inhabited in 1999. The average consumption in the third year of operation (2001/2002) was 12.8 kWh/(m²a). The calculated demand according to (PHPP) was 13.5 kWh/(m²a).

Passive House settlement in Stuttgart/Feuerbach

The Passive House development in Stuttgart/ Feuerbach with a total of 52 terraced and detached houses was finished in the year 2000 by the architectural practice Rudolf. Figure 8 documents the consumption values of the 2001/2002 heating season. The average consumption value is 12.8 kWh/(m²a) [14]. In this housing development there are a few outliers that are clearly identifiable as such (we now know, that these were due to failure in the heat pump control systems of these houses). Those were not considered in the Gaussian fit.

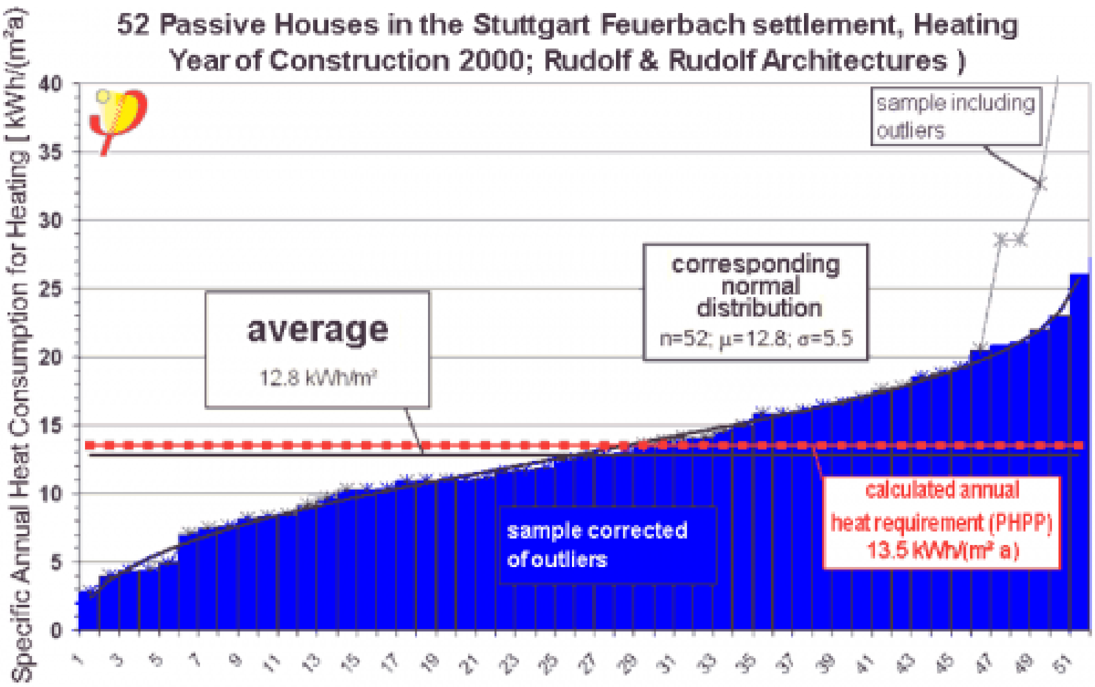

Figure 9: Consumption statistics for the Passive House development in Stuttgart/Feuerbach (Germany). The settlement with 52 Passive Houses was completed in 2000 (architectural practice Rudolf). The average consumption was 12.8 kWh/(m²a). The calculated demand according to (PHPP) was 13.5 kWh/(m²a)

The extremely low heat consumption values for the Passive House housing development in Stuttgart/Feuerbach show a standard deviation of the individual values of 5.5 kWh/(m²a), the average value is accurately determined to ±0.8 kWh/(m²a).

Conclusion regarding Passive House settlements

All shown measurements of annual heating energy consumptions followed a Gaussian distribution so standard deviations could be derived. The comparison of the mean values of the measured results for the four housing settlements clearly shows the huge difference in the heating consumption values of the low-energy houses and the Passive Houses. The heating consumptions of the three Passive House projects are very close to each other and completely fulfil the requirement for Passive House buildings. Compared to the low-energy buildings a saving of 80 % has been realized. What is very important here is that because of the statistically relevant number of houses per settlement the errors of the mean values are very small compared to the differences (0.8 – 1.5 kWh/(m²a) for the Passive House and 2 kWh/(m²a) for the low-energy buildings in Niedernhausen.

Comparison of measured consumptions with PHPP calculations

The measured heating energy consumptions for a huge number of more than 2000 new built Passive House building units and of more than 130 retrofitted building units using Passive House components were collected by Peper et al. [15]. Those include the aforementioned projects but also the world's largest passive house settlement in Heidelberg - "Bahnstadt". Also included are large projects from Vienna and Innsbruck (Austria) with more than 600 dwelling units. For most of the large projects, the quality of measured data is not the same as for the projects discussed in detail so the detailed analysis as done before is not possible. However, a mean value for the about 2000 new built Passive Houses can be derived to be 14.6 kWh/(m²a). This is very close to the requirement for Passive House buildings: a heating demand below 15 kWh/(m²a). For comparison, the mean heating energy consumption in Germany (2007) being 161 kWh/(m²a) [8] (this is very similar to the mean value of the Belgiersiedlung present before) and the mean value for the low-energy house settlement Niedernhausen (comparable to the actual German national standard (EnEV) are depicted, too. The

Passive House Standard proves to reach extremely high heating energy savings in a verifiable and reproducible manner. These savings amount to 90 % compared to the old building standard and approximately 80 % on average when compared with the legally stipulated requirements for new buildings in Germany (which is comparable to the shown low-energy buildings).

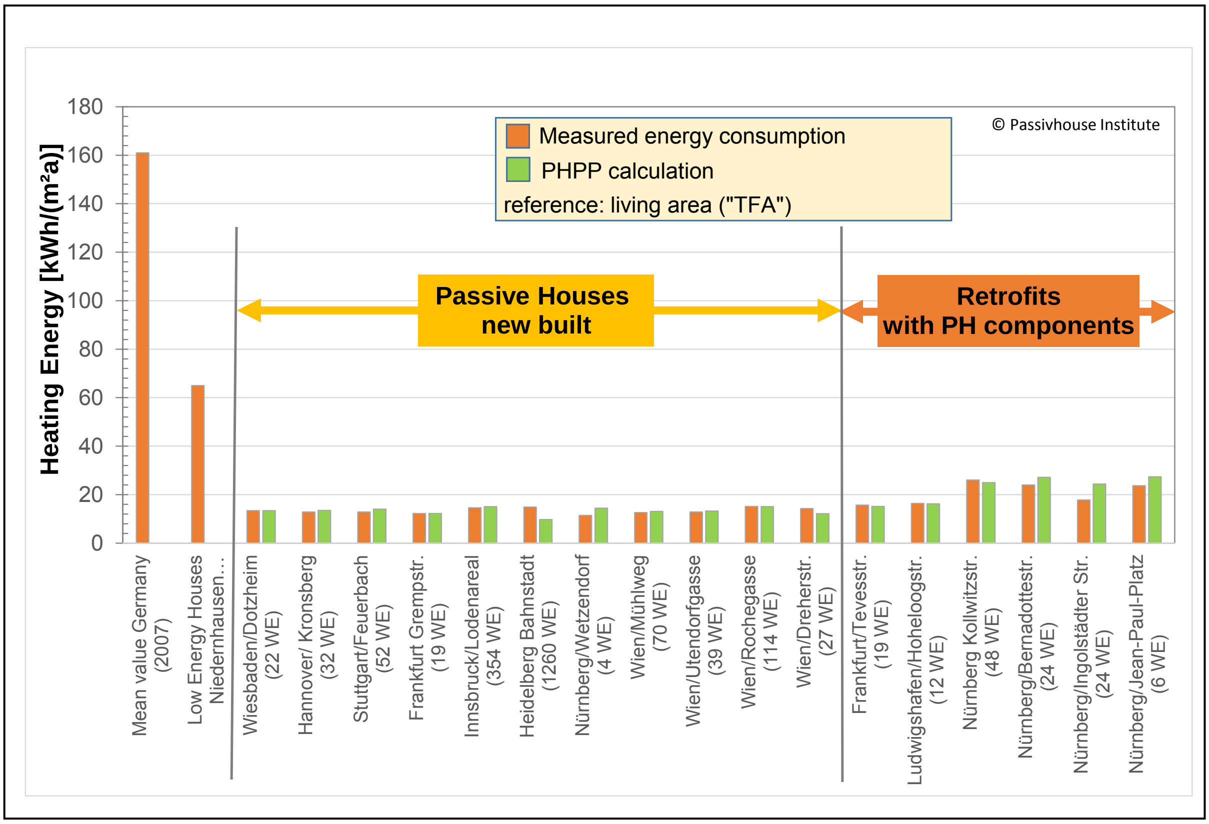

Figure 10: Collection of measured specific annual heating energy consumptions for several new built and retrofitted Passive House building projects, a low-energy project and the mean value for Germany. For the Passive House projects the PHPP demand calculations are shown as green columns.

Comparing the measured consumptions with the PHPP demand calculations there is no systematic deviation that could give a hint for the existence of a performance gap. As expected, for statistical errors in some cases the demand exceeds the consumptions and in some cases it is the other way around. A performance gap would mean that there is a systematic error leading to higher consumptions than expected.

Discussion

In contrast to findings for old buildings, for the large number of analysed Passive House projects no significant deviations (higher than expected statistical error) between demand and consumptions could be seen. So the question arises, what are the reasons for the deviations in other cases and how could this deviation be decreased in general. The first answer after looking at the discussed data seems to be that the solution is to build according to the well-defined and quality assured Passive House Standard even though there are variations in the consumptions as for all building standards, but those are smaller than for others.

Having a closer look at the definition of the performance gap as the difference between measured and predicted heating energy consumption (Figure 11) and the factors determining demand and consumption, reasons can be separated in influencing the consumption and the demand. Concerning the consumption, a bad built quality could be a cause. This is improvable by improving the quality assurance at the building site and for the components used. A very important process at the beginning of the operation of a building is the adjustment of the regulation of the HVAC systems. Often this is not done properly during commissioning but done in the first years. The consequence is a reduction of the consumption in the first years in many cases – but at least the first year shows unexpected high consumption. The measurement itself also has to be done carefully, since if, for example, the domestic hot water (DHW) production is included in the measurement but the consumption is compared with the heating energy (without DHW) this leads to a large systematic error which has nothing to do with the building quality. Concerning the user influence, the biggest factor is indoor temperature. If this rises, the consumption rises in turn, but in general a statistical deviation around a mean indoor air temperature can be expected. Another point that noticeably influences the consumption is the actual climate. So for comparisons, always climatically adjusted consumptions should be used or the actual climate has to be used for the demand calculation.

Deviations can also be caused by imperfections in the demand calculation. A good demand prediction is very important because this is the basis for many decisions concerning energetic and economic optimization of buildings in the planning phase. It is obvious that detailed and updated plans of the building have to be used for the calculations. According to the author's experience, one of the most important aspects for projects without quality assurance is the fact that characteristic values for components and technical systems are often introduced at an early stage in the calculation, are chosen much too optimistically and never corrected during the planning and construction process. Calculation approaches may also be incomplete (e.g. approaches for shading are inadequate or internal heat gains are set too high), or commissioning of construction work deviates from the original planning (e.g. because lack of thermal separation in the case of windows is still accepted as being "equivalent"; in such a case, the result is not a "performance gap" but anything between sloppiness and fraud). Especially for non-residential buildings, the usage (occupancy, internal heat gains e.g. by electrical appliances etc.) plays a big role and should be estimated well. In the end there will always be uncertainties in the range of 3 kWh/(m²a) for demand calculations (caused by deviation in material quality, deviations in indoor temperatures, variations in climates etc.) for Passive Houses. Those should be seen as normal considering a single object. Only if statistical relevant numbers are considered the expected deviations decrease.

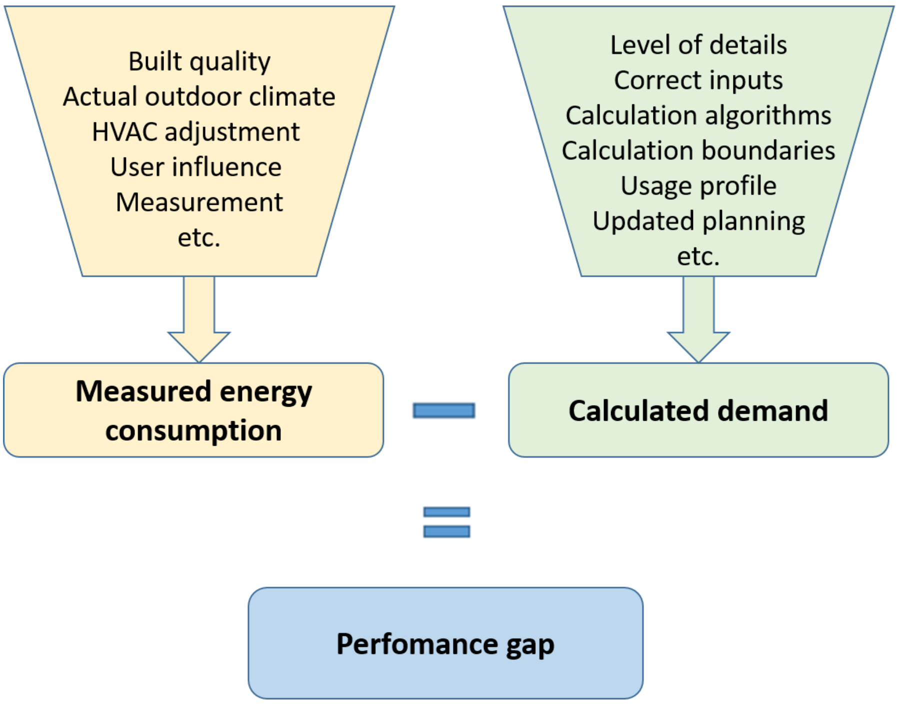

Figure 11: Calculation of performance gap as difference between measured consumptions and calculated demands and some influence factors on it.

Summary

The measured values from more than 2000 dwelling units built to the Passive House Standard and around 130 apartments which were refurbished with Passive House components prove that the Passive House concept works reliably and leads to extremely high heating energy savings in a practically verifiable and reproducible manner; these savings amount to 90 % compared to the old building standard and about 80 % on average when compared with the legally stipulated requirements for new buildings in Germany. These savings have been proved through statistically significant empirical studies and have been confirmed in a large number of projects. The highest use-related individual consumption values of Passive House buildings are still lower than the lowest consumption values in conventional new buildings.

Different users often have different consumption values even if they live in identically constructed homes. Deviations of ±50% from the average value are no exception, rather they constitute the expected normal distribution. This applies for all energy standards (existing buildings, low-energy houses, Passive Houses etc.) The most significant cause for this distribution is with simultaneous measurements at different set temperature settings during the heating period. For these reasons, an average value from a sufficiently large selection of identically constructed buildings is always necessary for assessing an energy efficient building standard.

The measurement results for the Passive House projects correlate very well with the previously calculated demand values (PHPP). The balancing tool proves to be excellent for reliably predicting the average heating demand during the planning phase. This applies equally for new constructions and refurbishments. With the Passive House Standard, no significant difference can be detected between the demand value and the reality (so-called "performance gap").

Acknowledgements

Thanks to the German Federal Ministry of Economics and Technology represented by the PTJ for financial support within the framework of the IEA EBC Annex 58 (Förderkennzeichen 03ET1144C). And Thanks to the European Union for supporting the work from the SINFONIA project (FP7 initiative, Grant agreement no 609019).

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Implementation of nearly zero energy buildings (NZEBs) retrofit in Europe: a focus on the non-residential building sector

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Abstract

Buildings are the core of EU policies to achieving a sustainable and competitive low-carbon economy by 2020. Reducing energy consumption of the existing building stock and implement Nearly Zero Energy Buildings (NZEBs) are key points of the Energy Efficiency Directive (EED) and the recast of the Energy Performance of Building Directive (EPBD). In the view of the EU requirements, Member States are required to adopt specific actions to exploit the potential energy savings deriving from the building sector.

This paper contextualizes the theme of deep and NZEB renovation and it provides an overview of policies to target building retrofit and investment in renovation, with a special focus on non-residential buildings.

The paper shows how the attention given to NZEB refurbishment increased over the last years, but this topic and the achievement of a widespread implementation of retrofit measures remains one of main challenges that Member States are facing.

1. Introduction

Buildings are a strategic focus of European policies aiming to achieve a sustainable and competitive low-carbon economy by 2020. The European Commission encourages Member States to decrease energy consumption in buildings and convert national building stocks from energy consumers to energy producers through retrofit measures and renewable energy sources (RES).

The key policy instrument towards this goal is the Energy Efficiency Directive (EED), which includes provisions to increase energy efficiency at the European level [1]. In accordance with Article 24(2) of the EED, Member States are required from 2014 (and then every three years) to submit National Energy Efficiency Action Plans (NEEAPs) and Article 4 requires Member States to establish (by 30 April 2014 and update every three years) a long-term strategy beyond 2020 for mobilising investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. The exemplary engagement of public authorities is required to satisfy the Article 5 of EED, asking Member States for ensuring that, as from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year.

Another central policy action is represented by the recast of the Energy Performance of Building Directive (EPBD)[2], which officially introduces the Nearly Zero Energy Building (NZEB) concept and establishes that all new buildings have to be NZEBs by December 31, 2020 (Article 9). Moreover its Articles 4 and 5 require to define new minimum energy performance requirements (for new buildings and major renovations) applying a cost-optimal calculation (with the first report due by 30 June 2012).

Besides efforts to design new buildings having low energy demand and available RES (e.g. [3][4][5]), it is essential to tackle the high energy consumption in existing buildings, characterised by an average age of about 55 years. The contribution of buildings to the total final energy consumption in the EU was 40% in 2012, making the building stock responsible for 36% of the EU's total CO_2 emissions. While more stringent building codes and policies made this value decrease slightly in residential buildings since 2007, the final energy consumption in non-residential buildings remained quite stable in the last decade. This mainly because of the increasing cooling energy needs, leading to a 6% rise of primary energy use per m^2 in the period 2002-2013.

It is undeniable that also the economic crisis has significantly influenced the energy trends of recent years. On one hand it led to a reduction in energy consumption due to the increase of the households' poverty[1], and on the other hand it contributed to curb building renovation activity. This is quite evident looking the evolution of building permits (Figure 1) and the sale trends of material and equipment related to low-energy buildings (Figure 2).

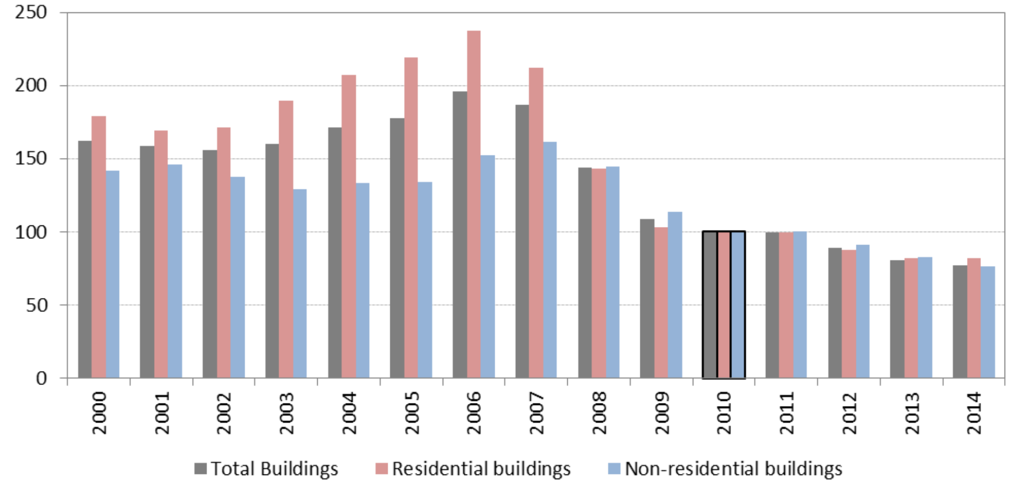

Figure 1 - Trend of building permits in EU28 referred to 2010 (2010 = 100). Source: EUROSTAT [sts_cobp_a]

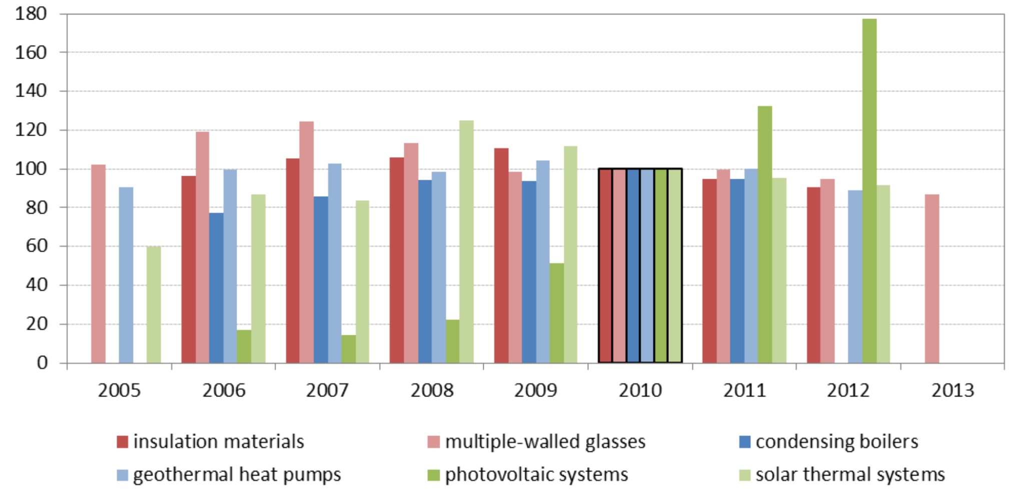

Figure 2 - Sales trend of equipment related to low-energy buildings in EU28 (2010 = 100). Source: elaboration from ZEBRA2020 database.

On the other hand the stimulus resulting from the growth of the building sector on the entire economy (in terms of GDP and employment) add motivations for investing public funds in the energy renovation of the European building stock. Other important positive effects are the reduction of gas import (as buildings are currently responsible for 35% of these imports) and the improvement of the indoor comfort and living conditions.

[1] The recent evaluation of the Europe 2020 strategy [6] reveals that, due to the economic crisis, the number of people at risk of poverty increased from 80 million prior to the crisis to 124 million in 2012.

2. Deep, major and NZEB renovations

In this context it is necessary to stimulate the building market in order to increase the actual renovation rates, of which, moreover, it is difficult to have a clear picture: few data are available on their numbers, their depth, or indeed trends in renovation rates.
In 2011, BPIE [7] noted that most estimates of renovation rates (other than those relating to single energy saving measures) are mainly between around 0.5% and 2.5% of the building stock per year. The authors have assumed a European renovation rate of 1%, considering that higher rates had reflected the activity of the previous few years which in some cases had linked to special circumstances (e.g. the existence of a renovation programme). This value was in line with the study carried out for the European Commission led by Fraunhofer Institute [8], where refurbishment rates of 1.2%, 0.9% and 0.5% per year were assumed for North-Western Europe, Southern Europe and New Member States respectively.
However, the main expectations are focused on the “deep” and “NZEB” renovations. Firstly it is interesting to observe that the term “renovation” has been used by different experts to describe a wide variety of improvements to an existing building or group of buildings. Qualitatively, it can be seen that the refurbishment of the building façade (i.e. walls and windows) will provide a different level of energy saving than one addressing all of the building envelope and its energy systems (HVAC, lighting, etc.) as well as the installation of renewable technologies.
The EED Directive defines it as: “deep renovations which lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance”. In its report (Amendment 28, Article 2, paragraph 1, point 27.a) of July 2012 [9] the European Parliament proposed this definition: "‘deep renovation’ means a refurbishment that reduces both the delivered and the final energy consumption of a building by at least 80% compared with the pre-renovation levels”. In the SWD (2013)143 final, the Commission services have indicated that Member States should aim to encourage deep renovations of buildings leading to significant (typically more than 60%) efficiency improvements.
Adopting the BPIE setting [7], the energy performance of a building can be improved by the implementation of a single measure, such as a new heating generator or the insulation of the roof. Normally, these types of measures might be called “small retrofit” or “minor renovation”. Typically, energy savings of up to 30% might be expected by the application of 1-3 low cost/easy to implement measures. At the other end of the scale, renovation might involve the wholesale replacement or upgrade of all elements which have a bearing on energy use, as well as the installation of renewable energy technologies in order to reduce energy consumption and to close to zero (or to less than zero). The reduction of the primary energy demand towards very low levels (also including RES systems) can lead to the avoidance of a traditional heating/cooling system. This level can be termed nearly Zero Energy renovation, because in line with the EPBD recast definition[2]. In between these two examples are renovations involving a number of upgrades. These can be subdivided into: “moderate”, involving improvements (typically more than 3) resulting in energy reductions in the range 30-60%; “deep”, related to the integration of high-grade improvements, able to reach energy savings of 60-90%.
The term “deep renovation” has also been used by other references with similar, but not identical meanings:

- The Global Buildings Performance Network (GBPN) [10] equates a deep renovation to a reduction in energy consumption for heating, cooling, ventilation and hot water of 75% or more.
- The ENTRANZE Consortium selected as "deep" the renovation level implementing high-grade refurbishment packages (e.g. 30, 20 and 15 cm of insulation on roof, walls and basement; very efficient heating/cooling generators; heat recovery strategies).
- The ZEBRA2020 project[3] defines it as deep thermal renovation with more than 2 thermal solutions (e.g. heating + insulation of wall/roof, etc.).

ZEBRA2020 is also collecting data and evidence for policy evaluation and optimisation (providing a strategy to boost the market uptake of NZEBs). As shown in Figure 3 - Evolution of deep renovation rates in some European Member States (in terms of % of the whole building stock renovated every year). Here "deep renovation" means deep thermal renovation with more than 2 thermal solutions (e.g. heating + insulation of wall/roof, etc.). Source: ZEBRA2020

2 *"‘Nearly zero-energy building’ means a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [2].*
3 http://www.zebra2020.eu/

, at the moment deep renovation rates are available only for few Countries and, despite the efforts of EU Member States, they are significantly lower than 1% of the whole building stock renovated each year.

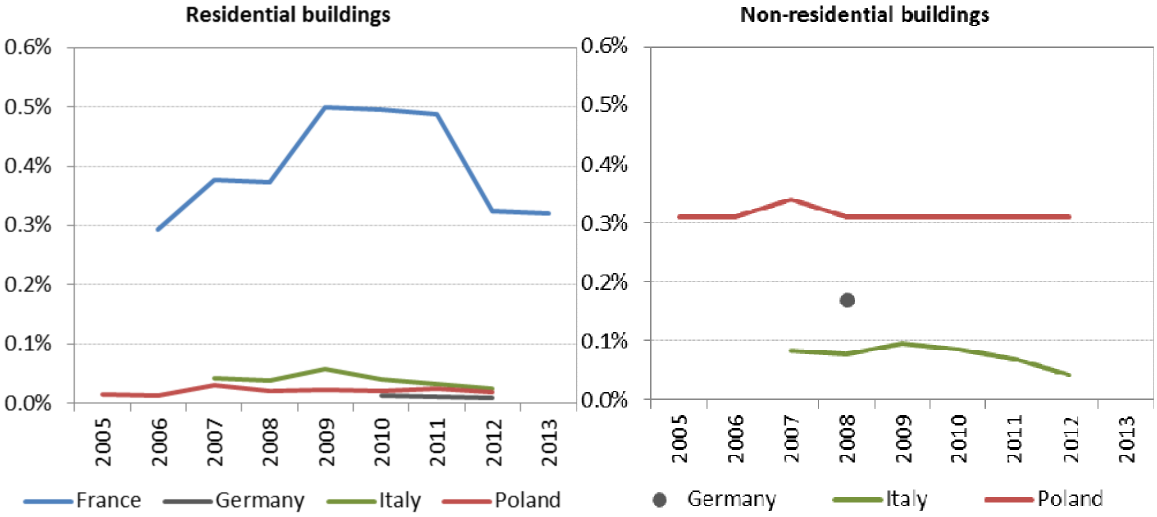

Figure 3 - Evolution of deep renovation rates in some European Member States (in terms of % of the whole building stock renovated every year). Here "deep renovation" means deep thermal renovation with more than 2 thermal solutions (e.g. heating + insulation of wall/roof, etc.). Source: ZEBRA2020

Another term used in the reference bibliography (sometimes as synonymous of "deep") is "major renovation". In 2010 it has been officially defined by the EPBD-r Directive (where there are no mentions of the term “deep renovation”) as: "the renovation of a building where: (a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated; or (b) more than 25% of the surface of the building envelope undergoes renovation; Member States may choose to apply option (a) or (b)".

As suggested by Shnapp et Al. [11] this definition identifies a window of possibility for a “deep renovation”, but probably it is erroneous to associate these two terms. In the spirit of the EPBD recast Directive it was necessary a reference to harmonize a certain level of renovation to the minimum energy requirement of new buildings. In this context an ex-ante reference (economical or geometrical) was considered functional to the administrative management (i.e. building permit, inspections, etc.). The EPBD asked for effective renovations[4] but the message has been emphasized with the EED Directive. The run to establish a long-term strategy (for mobilizing investment in the renovation of buildings with a view to improving their energy performances) introduced the need for an ex-post reference: we have to stimulate the renovations able to reach significant energy savings; we need for "deep renovations".

Notwithstanding the above, we should avoid to overlap the meaning of "deep renovation" and "major renovation"[5], and to start to talk about "deep or NZEB renovations". Even if the meaning of term "NZEB renovation" is not already consolidated, and it will be better characterized in the coming years. At the moment the main references are the NZEB definitions provided by the Member States, to implement the EPBD requirements. In accordance with the last information available (often collected with the templates provided by the Commission, or included in specific national plans), we can refer to the target energy performances shown in Table 1.

4 *"Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance. For reasons of cost-effectiveness, it should be possible to limit the minimum energy performance requirements to the renovated parts that are most relevant for the energy performance of the building" [2].*

5 In application of EPBD-r, a "major renovation" has a legal implication in terms of building codes. On the other hand a "deep renovation" does not carry these legal requirements.

Table 1 - Energy requirements defined by EU Member States for NZEB levels.

Country	Residential buildings [kWh/m2/y or Energy Class]		Non-Residential buildings [kWh/m^2/y or Energy Class]	
	New	Existing	New	Existing
AT	160	200	170	250
BE	45 (Brussels region) 30 (Flemish region) 60 (Walloon region)	~ 54	95-2.5*C (Brussels region) 40 (Flemish region) 60 (Walloon region)	~ 108
BG	~30-50	~40-60	~30-50	~40-60
CY	100	100	125	125
CZ	75-80% PE	75-80% PE	90% PE	90% PE
DE	40 % PE	55% PE	n/a	n/a
DK	20	20	25	25
EE	50 (detached housse)	n/a	100 (office buildings)	n/a
			130 (hotels, restaurants)	
		n/a	120 (public buildings)	n/a
		n/a	130 (shopping malls)	n/a
	100 (apartment blocks)	n/a	90 (schools)	n/a
		n/a	100 (day care centres)	n/a
		n/a	270 (hospitals)	n/a
FR	40-65	80	70 (offices without AC)	60% PE
		n/a	110 (offices with AC)	n/a
HR	33-41	n/a	n/a	n/a
HU	50-72	n/a	60-115	n/a
IE	45 (Energy load)	75-150	~ 60% PE	n/a
IT	Class A1	Class A1	Class A1	Class A1
LV	95	95	95	95
LT	Class A++	Class A++	Class A++	Class A++
LU	Class AAA	n/a	Class AAA	n/a
MT	40	n/a	60	n/a
NL	0	n/a	0	n/a
PL	60-75	n/a	45-70-190	n/a
RO	93-217	n/a	50-192	n/a
ES	Class A	n/a	Class A	n/a
SE	30-75	n/a	30-105	n/a
SI	45-50	70-90	70	100
SK	32 (apartment buildings)	n/a	60-96 (offices)	n/a
	54 (family houses)	n/a	34 (schools)	n/a
UK	~ 44	n/a	n/a	n/a

Looking this summary, it is quite evident that the Member States mainly focused on the requirements for new buildings and rarely introduced different limits for the existing ones. As discussed above, the EPBD

requires conforming the major renovations to the new constructions[6], but some Member States decided to introduce less stringent (and probably realistic) requirements. This is the case of Bulgaria, Germany, France, Ireland and Slovenia.
Moreover the majority of EU Governments decided also to consider higher energy requirements for the non-residential buildings (which typically consume more energy for cooling and lighting), but in few cases different energy limits for different non-residential categories have been defined. Considering the great variety of the non-residential building stock, this approach (applied by Estonia, France and Slovakia) should be recommended to all Member States.
About the framework of the energy calculation, the analysis [12] of the national NZEB definitions reveals that:

– The main included energy uses are heating, DHW, ventilation, and cooling. Auxiliary energy and lighting are taken into account in almost all EU Member States. Several Member States also include appliances and central services.
– The most common choice regarding the energy balance calculation is the difference between the primary energy demand and the energy generated, over a period one year, and considering annual constant weightings/factors (e.g. primary energy factors);
– Single building or building unit are the most frequent indicated physical boundary for the calculation, but the overall impression is that the differences among building unit/site/zone/part need to be better addressed.
– As regards the normalization factors, conditioned area is the most agreed upon choice in EU Member States. Although other options, such as net floor area and treated floor are selected.
– The most common considered RES option is the on-site generation, but many countries also consider external generation and nearby generation (but probably not always with the same meaning).
– Almost all Member States prefer the application of low energy building technologies and available RES. The most used technologies are PV, solar thermal, air- and ground-source heat pumps, geothermal, passive solar, passive cooling, wind power, biomass, biofuel, micro CHP, and heat recovery.
– In general a NZEB can be achieved by combining high efficient technologies with RES.

3. Policies designed to target building renovations

In accordance with the scenario analysis carried out by the ENTRANZE Consortium[7], the policy measures already in place (BAU scenario) should result in the Deep Renovation of approximately 2.5% of the EU-28 building stock by 2020 and of around 5-5.5% by 2030. As shown in **Error! Reference source not found.** 3, a moderate additional effort[8] could increase these shares to 3.7% (by 2020) and 8.7% (by 2030) and an ambitious improvement[9] to 5.4% and 14.4%.

[6] *"Member States shall take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set in accordance with Article 4 in so far as this is technically, functionally and economically feasible" [2].*
[7] http://www.entranze-scenario.enerdata.eu/site/
[8] Some effort in more innovative and consistent policy packages, however with a moderate ambition. Information, qualification and training are intensified. Regulatory instruments (RES-H obligation) and enforcement of building renovation are implemented. A moderate energy tax is introduced. Budgets for subsidies for building renovation and RES-H are increased moderately.
[9] Strong effort in more innovative and consistent policy packages, with a high policy ambition. Information, qualification and training are intensified, leading to a comprehensive coaching and support of building owners. Split incentive is addressed in the legal framework leading to a reduction of this barrier. Regulatory instruments (RES-H obligation) and enforcement of building renovation are implemented. A high energy tax is introduced and accompanied with social measures to support in particular low-income households. Budgets for subsidies for building renovation and RES-H are increased.

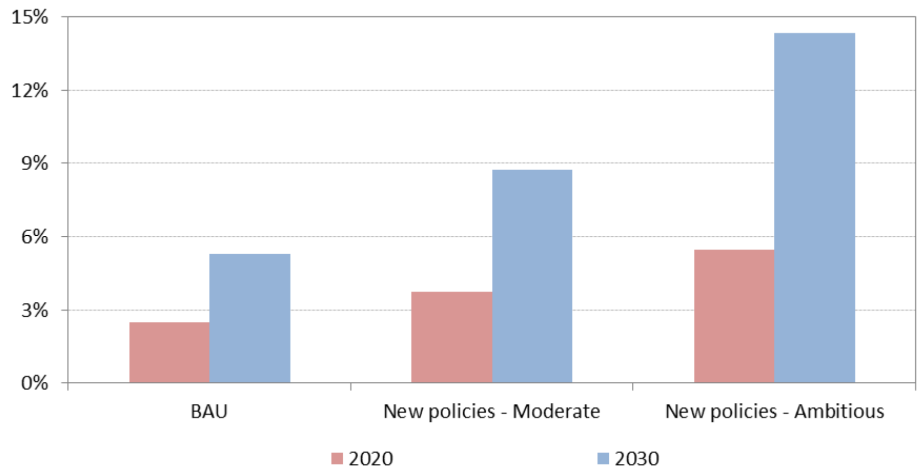

Figure 4 - Share of EU28 building stock renovated deeply (or to an NZEB level) by 2020 and 2030, varying the policy scenario. Source: ENTRANZE.

A key issue will be therefore the development and the adoption of new national policies, but no less important will be the guidance role of the European Commission. For example the stakeholders are asking for a clear guidance for NZEB renovation, to be possibly followed up in the context of the EPBD review. Moreover several experts point out that the net yearly primary energy indicator is insufficient to characterize NZEBs: for instance Hermelink et Al. [13] proposed to implement several indices for a more complete and correct description and ranking of NZEBs.

Most EU Member States did not describe in a detailed way the policies and measures that would lead to the NZEB level in refurbishments. Reported policies appear in line with the EPBD requirements, but rarely these legislative and normative measures explicitly refer to a clear definition of an NZEB renovation.

Moreover, the Governments' efforts are mainly aimed at reducing the residential consumption. This makes sense, considering the great energy saving potential of European homes, but also actions on the non-residential (public and private) stock should be taken. The general impression is that this intervention area is often neglected by the national energy policies not because it represents a small source of energy savings, but because it is complicate to define a general picture of the issue. Often the available data on the non-residential stocks are fragmentary and the heterogeneity of these buildings implies the necessity to develop very specific and targeted policy measures.

In order to summarise recent improvements towards the effective support of deep and NZEB renovation with a special focus on non-residential buildings, several data sources have to be considered. For the present analysis we refer to: i) the ODYSSEE-MURE database[10] includes around 2000 energy efficiency policy measures (including their impact); ii) the third NEEAPs provided by EU Member States in mid-2014 which include descriptions of the new measures adopted; iii) the first renovation strategies in line with Article 4 of the Energy Efficiency Directive which Member States were due to provide by 30th April 2014.

Successful policy measures can be selected from ODYSSEE-MURE, which includes about 225 measures explicitly related to the renovation of all existing buildings. Selecting the most recent ones (those adopted in the last 10 years), excluding the legislative-normative ones and focusing on those with a medium or high impact, many interesting ongoing or proposed measures can be recognised. An overview of those explicitly referred to the non-residential stock (i.e. tertiary) is shown in Table 2.

[10] http://www.measures-odyssee-mure.eu/

Table 2 - Ongoing and proposed policy measures on non-residential building renovation with medium or high impact, extracted from the ODYSSEE-MURE database.

Country	Sector	Measure title	Status	Type	Starting Year
BE	Residential and Tertiary	Brussels - Develop and promote exemplary buildings - BATEX (with virtually zero consumption and of high environmental quality)	Ongoing	Financial	2007
BG	Tertiary	National Strategy for financing the building insulation for energy efficiency 2006-2020 - services	Ongoing	Financial, Legislative, Informative	2006
EE	Tertiary	A programme for reconstruction of public sector buildings	Ongoing	Financial	2009
ES	Residential and Tertiary	State Plan 2013-2016 for Rental Housing, Housing Rehabilitation, and Urban Regeneration and Renewal	Ongoing	Financial	2013
	Tertiary	Action Plan 2008-2012:Energy Saving and Efficiency Plans in Public Administrations	Ongoing	Information-Education-Training, Legislative-Informative	2008
FI	Tertiary	Renovation of State Property Stock	Ongoing	Information-Education-Training	2009
FR	Residential and Tertiary	Energy Savings Certificates (ESC)	Ongoing	Financial	2006
	Tertiary	"Moderning building and cities" programme	Ongoing	Financial, Legislative-Informative	2008
HR	Tertiary	Energy reconstruction of commercial non-residential buildings	Ongoing	Financial	2011
	Tertiary	Energy renovation of commercial non-residential buildings	Ongoing	Financial	2012
LT	Tertiary	EU Structural Funds 2007–2013	Ongoing	Financial	2007
	Tertiary	Renovation of State institutions	Unknown	Financial	2014
LV	Tertiary	Increasing Energy Efficiency in State (Central Government) Public Buildings: EU Programming Period of 2014-2020	Proposed	Financial	2015
	Tertiary	Increasing Energy Efficiency in Municipal Buildings: EU Programming Period of 2014-2020	Proposed	Financial	2015
SI	Tertiary	Financial incentives for energy-efficient renovation and sustainable construction of buildings in the public sector	Ongoing	Financial	2008

According to the EED, Member States were requested to provide within their renovation strategies an overview of the policies measures to stimulate cost effective deep renovations of buildings, in particular to: a) give an appraisal of existing measures/policies in the Member States; b) provide an analysis of existing barriers to deep building renovation; c) give an appraisal of relevance of policies used in other territories; d) provide a design of new policy landscape that addresses barriers and enables the delivery of the required ramp up in deep renovation activity, with a particular focus on those measures which need to be introduced within the next 3 years.

Overall, Member States addressed quite exhaustively Article 4(c) requirements, providing a comprehensive set of policy designed to address the identified barriers. As shown in Figure 5 there is a great heterogeneity of policy packages in different Member States, both in terms of absolute number and in terms of policy type, with a predominance of financial/fiscal and regulatory measures.

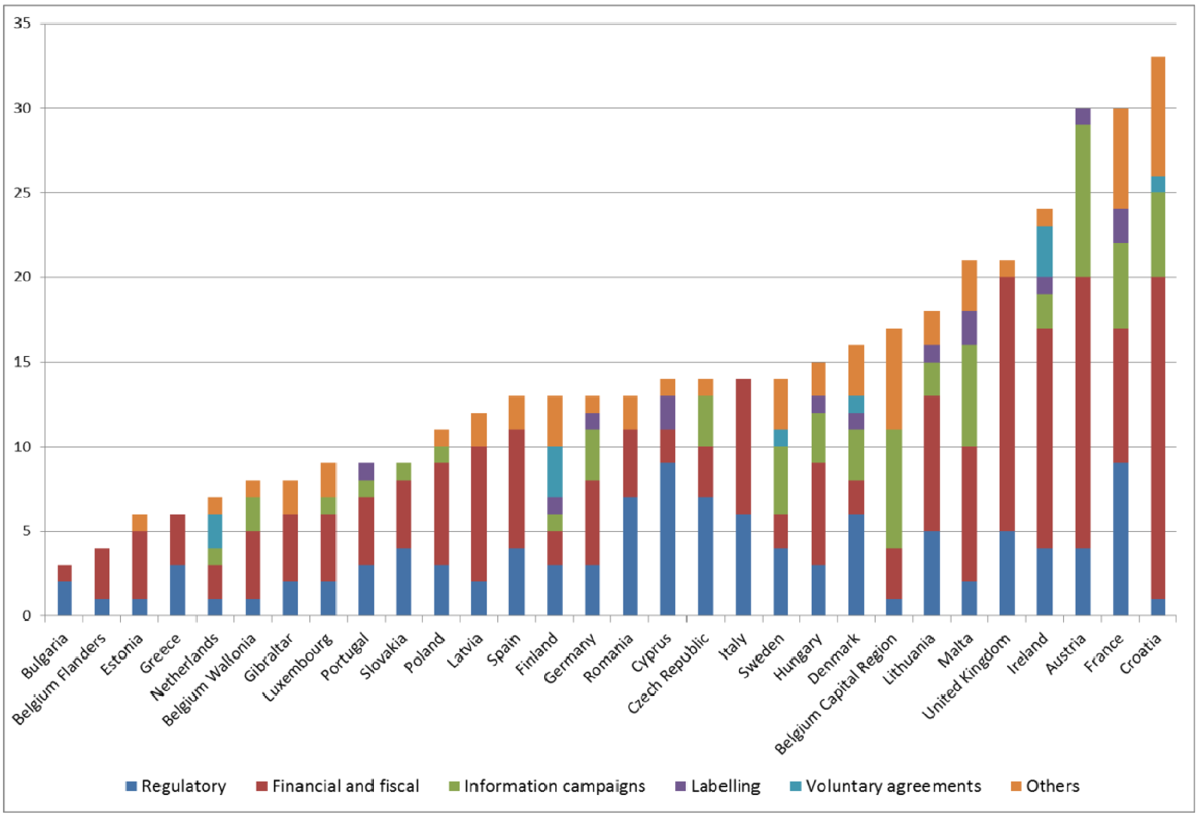

Figure 5 - Number of all the measures in the building sector (implemented and planned) by country and type.

Regulatory measures were mostly composed of requirements related to the EPBD and more specifically on minimum energy performance requirements for new and existing buildings. Nearly all Member states included information on the last building regulations and few of them referred to further improvements in their building codes, strengthening the energy standards to be met during building construction and renovation. Examples include Denmark reporting various upgrades in the energy requirements for new buildings and specific requirements for building envelope, windows and installations, and Austria which stated that on-going adjustments are made in building regulations. Other examples of countries with measures tightening of energy performance standards include Ireland and the Netherlands. Other building regulations mentioned in the strategies include inspections of water boilers and air conditioning systems (e.g. Bulgaria, Cyprus, Italy, Croatia and France).

Specific regulatory measures for the services sector include the Luxembourgish scheme on improvement of lighting in non-residential buildings, which introduces specific energy efficiency requirements for lighting in new non-residential buildings. The Netherlands has an Environmental Management Act for non-residential buildings which places a legal obligation to take energy-saving measures with a payback time of less than 5 years. The obligation applies for large or medium-sized companies with an energy consumption of more than 50 000 kWh and 25 000 m^3 gas per year and also for non-residential buildings including offices, healthcare institutions and schools.

All Member States have reported financial and fiscal measures supporting energy efficiency improvements in the residential and non-residential sectors. Specific measures for services include the Greek financial incentive scheme for energy upgrading of commercial buildings. Ireland ran a grant scheme for exemplar projects in the public and business sectors, offering support for sustainable energy upgrades to buildings, services, facilities and processes. Ireland also provides on-going advice, mentoring and training in energy management to participating SMEs in the commercial sector since 2008. The Energy Investment Allowance enables companies to deduct energy efficiency investments from their taxable profit. In Sweden, aid is provided to small and medium-sized enterprises in the form of

energy audit checks. This aid may be granted to enterprises with energy consumption in excess of 500 MWh per annum.
Market-based instruments in the residential and non-residential sectors are mainly in the form of Energy Efficiency Obligation Schemes. Austria, Flanders region of Belgium, Bulgaria, Denmark, France, Italy, Ireland, Latvia, Luxembourg, Malta and the United Kingdom have energy efficiency obligation schemes which target these sectors.

About the new policy measures that the EU Member States are implementing (or aim to implement) to reduce the energy consumption of the existing building sector, information can be found in the third NEEAPs, that Member States provided by April 2014.
The great majority of Governments Table 4 lists the main news, referred to non-residential buildings and distinguished by Member States and typology.

Table 3 - New measures on the building renovation of non-residential buildings included in the 3rd NEEAPs.

Country	Measure Type	Description
DE	Financial	Additional funding for energy-related building renovation is secured from 2013 onwards with extra KfW grants of €300 million. To promote not only the energy-efficiency of residential buildings, but also of commercial and municipal buildings, the state-owned promotional bank KfW will increase support for energy-efficient renovations of commercial and municipal buildings.
EL	Financial	Greece plans to carry out Energy performance improvements of services buildings through ESCOs in the period 2015-2020 where 3000 buildings should be renovated through ESCOs.
ES	Financial	The Aid Programme for the Energy Renovation of Existing Buildings (PAREER) approved in September 2013, aimed at buildings used for housing and in the hotel industry. With a budget of €125 million, it promotes integrated energy efficiency improvement and renewable energy measure in the stock of existing buildings by awarding grants and repayable loans to projects.
IE	Financial	A National Energy Efficiency Funds (NEEF) has been established in March 2014 (€35 million committed by government) with the objective of directly assisting energy efficiency upgrades in the commercial and public sectors.
IT	Financial	An incentive scheme for the promotion of renewable thermal energy and energy efficient heating (also known as "Conto Termico") started in 2012. This measure partly overlaps with the existing tax credits scheme, meaning that a large series of measures implemented by private actors can be eligible both for tax credits and incentives available under the "Conto Termico".
LV	Financial	An existing public building renovation scheme will be refinanced for a new period (2014-2020). Specifically, a grant scheme, financed through EU structural funds will target renovations of central government buildings and improvements in the energy performance of municipal buildings.

3. Conclusions

In the framework of the EPBD and EED Directives, the European Commission requested that Member States develop and adopt more concrete actions with a view to achieving the great unrealized potential for energy saving in the building sector, to which other key benefits are related. Among these there are the improvement in energy security, job creation, fuel poverty alleviation, and improved indoor comfort.

According to the EPBD, by the end of 2020 all new buildings should be Nearly Zero Energy Buildings (NZEBs). As a consequence, the attention given to NZEBs increased consistently over the last decade. It is widely recognized that NZEBs have great potential to decrease energy consumption and at the same time to increase the use of renewables, alleviating depletion of energy resources and deterioration of the environment.

In past years most Member States introduced measures addressed to the existing building stock and new strategies have been recently defined, in accordance with Article 4 of EED. As results the Member States are more aware of the huge impact of the existing building stock, but they need to further strengthen the adopted measures in order to successfully stimulate cost-effective deep and NZEB renovations. Only few Member States are developing NZEB definitions specifically addressed to the renovation of the existing buildings, and on the other hand it is not clear how the existing measures will be adapted to the new NZEB requirements.

The analysis of the national renovation strategies reveals that only a few Member States reported planned measures for energy efficiency in buildings, while the vast majority reported only existing policies. In view of the coming challenges, i.e. wide refurbishment to the NZEB target, EU Member States should effectively develop detailed strategies both to overcome the existing barriers and to guide investment decisions in a forward-looking perspective. The effectiveness of existing policies, as well as the need of new ones, should be better evaluated in many countries. Furthermore, as a suggestion for the preparation of the next round of the plan, EU Member States could be explicitly asked to provide more information and measures specifically designed for the non-residential stock.

Member States need to design consistent mixtures of policy instruments (policy packages), depending only partially on public budgets, in order to provide the required long-term stability to investors in efficient buildings, including deep and NZEB renovations. Well-defined monitor systems are required to obtain reliable data on the policy impacts, and roadmaps shared with key stakeholders should be formally adopted.

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Poster Session

Innovative approaches for retail planning. The design of territorial retail scenarios in Trentino (Italy).

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Abstract

The paper presents the recent evolution and development of Trentino retail planning policies and discusses an experimentation of a meta-evaluation methodology, namely Territorial Integrated Evaluation (TIE), for designing retail development scenarios. A research team from the Interuniversity Department of Regional and Urban Studies and Planning of the Politecnico di Torino applied this methodology experimentally to the practices of spatial planning in order to integrate *territory* and *retail* in the Trentino development policies.
The application of TIE set out to design territorial retail scenarios that integrated various topics –retail, tourism, infrastructure, nature and landscape. On the base of TIE principles and criteria, each Valley Community (VC) is now implementing to design its territorial retail scenarios assuming different approaches and visions in accord to its retail opportunities and risks. Starting from the presentation of some best practises, the paper focuses on the innovative perspective for retail planning and for retail sites designed in Trentino. The emerging regional policy is aimed at linking quality of territorial retail development with environmental sustainability, respecting attractiveness and balance among different retail sites.

1. Retail and territory

Retail is an element that characterises identity of cites beyond the simple economic dimension. Effectively, retail supply has historically added attractiveness and influence to neighbourhood stores located in urban centres in addition to economic impacts.

The recent important changes occurred in urban retail dynamics leads to a *retail revolution* essentially associated with the growing of large-scale stores mostly located outside the city centres [1]. These recent transformations changed both the retail settlement phenomena in cities and the consumers' everyday habits. In this perspective, retail is conceived as an open system operated by several actors who, in last decades, have gone through periods of intense innovation and change followed by periods of reaction and adaptation [2].

In light of this situation, European planning agendas have been generally moved towards place-based approaches, target to developing attractiveness of urban areas on a global scale through increasing leisure and retail activities [3]. According to the place-based approach, Italy has been one of the first European countries that, during 2000s, adopted region-targeted policies [4]. The first National Reform Decree in 1998 characterised the Italian retail policies by a strong territorial approach and by the decentralisation to regional governments of the construction of strategies and collaborative partnerships between public authorities, private firms and civil society. Basically, the Italian retail reform takes on two main components. The first is the modernisation of retail sector, which allowed the growth of new large-scale stores and an increasing trend of innovation among retailing groups [5], while the second is a strong territorial-based argument that entails the integration of retail development with environment, respecting attractiveness and the balance among different retail sites [6]. In this perspective, the effort of this approach to retail development is not a simple competitive relationship between retail stores, but rather a complementary relationship among retail territorial systems [7]. Briefly, retail is understood as an economic activity that can network with regional other functions which territorial dimension is the fulcrum [8].

From a regulatory point of view, the Italian decentralisation of retail competence to regions created an extremely varied situation. Regions addressed retail planning in very different ways, establishing barriers and quantitative constraints more or less strict for the control of large-scale stores development. In most Italian Regions, despite the institutional innovation introduced by the national retail policy, the integration among *retail*, *territory* and *landscape* has been weakly pursued or even complete disregarded. In this panorama, the Autonomous Province of Trento (APT) is one of the few Italian regions that have been able to grasp fully this mutual relationship adopting innovative solutions for retail sector, strongly anchored to territorial identity and oriented to a spatial scheme of organisation and economic development.

2. Retail planning in Trentino

The Autonomous Province of Trento (APT) is going through a deep renewal in its spatial planning. The reasons for this on-going evolutionary process can be traced back to two basic institutional conditions:

1. The reform of APT planning legislation, initiated by the approval of the Provincial Territorial Plan (PTP) – that is the strategic framework for territorial planning within the inter-municipal policies of Valley Communities (VCs);

2. The reform of APT retail planning legislation, conducted with the enactment of the European reform regulations and national decrees on the programming of services.

In this context, the provincial government has had to face a formidable challenge, namely to orient the new direction of territorial retail development policies to fit the aims of the reform, which establish the abolition of quantitative parameters, without giving up the territorial planning and the conservation of the landscape values introduced by the PTP. Thus the provincial government has had to radically rethink its planning approach to designing the processes of retail development keeping in mind that accepting the logic of the reform decrees (liberalization of services) does not mean giving up the territorial planning. Hence the APT administration found it necessary to refer to new knowledge paradigms and instruments of governance to renew technical competences in support of public action.

It is within this concrete perspective of planning action that the APT requested the Interuniversity Department of Regional and Urban Studies and Planning of Politecnico di Torino research group to apply the Territorial Integrated Evaluation (TIE) methodology, which had already been experimented in other Italian planning contexts[1]. The goal was designing a new direction of provincial policies while harmonizing the needs of territorial development with those of conservation of landscape values. Trentino is a cross-border area characterized by a lively tourist and a retail demand that needs to be harmonized with the exceptional and internationally renowned value of its landscape, such as the Dolomite Mountains, a UNESCO World Heritage Site. This context means that TIE's approach to designing territorial retail scenarios needs to look simultaneously at different themes, such as retail, tourism, territorial infrastructures, environment and landscape. The example of Trentino has allowed us to apply and redesign the TIE methodology with the aim of setting up territorial retail scenarios which meet both the need for economic growth (in the retail and tourist sector) and the need for landscape conservation values, which are very much being fostered at the international level.

The application of TIE led to design territorial retail scenarios. In these, several of the leading economic factors in the provincial development – especially tourism and retail – are able to work together as factors for regeneration, enhancement and development, under certain circumstances, in synergy with the conservation of environmental and landscape values. The assumption underlying this experimentation is the idea that retail planning cannot go on without a territorial perspective and that this perspective includes shared qualitative criteria of urban and landscape renewal in harmony with specific local characteristics.

TIE results are the design of territorial retail scenarios in which local economy, in synergy with the conservation of landscape values, could become factors contributing to urban renewal and territorial development. The proposed operating processes have to do with two specific aspects of territorial planning:

1. The definition of principles and criteria to bring out elements of territorial opportunities within the regional development framework;

1 TIE methodology is the result of a research programme coordinated by Grazia Brunetta and conducted from 2004 to 2008 for Piedmont Region. The research had to do with the designing and preliminary experimentation of this methodology to support the planning of the retail territorial development, in particular large retail areas [9]..

2. The definition of proactive territorial partnerships for integrating sector-focused policies (retail / tourism/ landscape) in territorial retail scenario design.The territorial retail scenarios were projected as multi-level and multi-sector systems of governance, or clusters of guiding visions, that could activate the implementation of integrated policies for the development and enhancement of local resources and local potentialities to be articulated in the institutional design of Trentino [10].

The TIE territorial retail scenarios are not forecasts of horizons to reach but potential routes to be charted by local action, routes towards territorial enhancement. Hence the process of evaluation leads to visions, updated periodically, of the development dynamics and perspectives in each territorial context. These visions would then be supports for the territorial planning choices that the VCs must make when they are designing the Community Territorial Plans (CTPs). The TIE principles and criteria at the basis of the construction of territorial retail scenarios have become the language of each local discussion, in every VC, finalized at working out its own territorial development strategy. This process is oriented to a decentralized approach to regional planning, where local administrations enjoy full responsibility in making decisions about the design of future territorial retail development strategies.

3. The TIE territorial retail scenarios

TIE methodology comes to an operational proposal for three types of territorial retail scenario (Figure 1) characterised by the different role played by retail in accord to opportunities and capacities of local rehabilitation:

1. Scenario 1 Retail – designing the territorial retail system;
2. Scenario 2 Marketing – designing the integration of retail / tourism/ territory;
3. Scenario 3 Landscape – enhancing the landscape identity of territorial system.

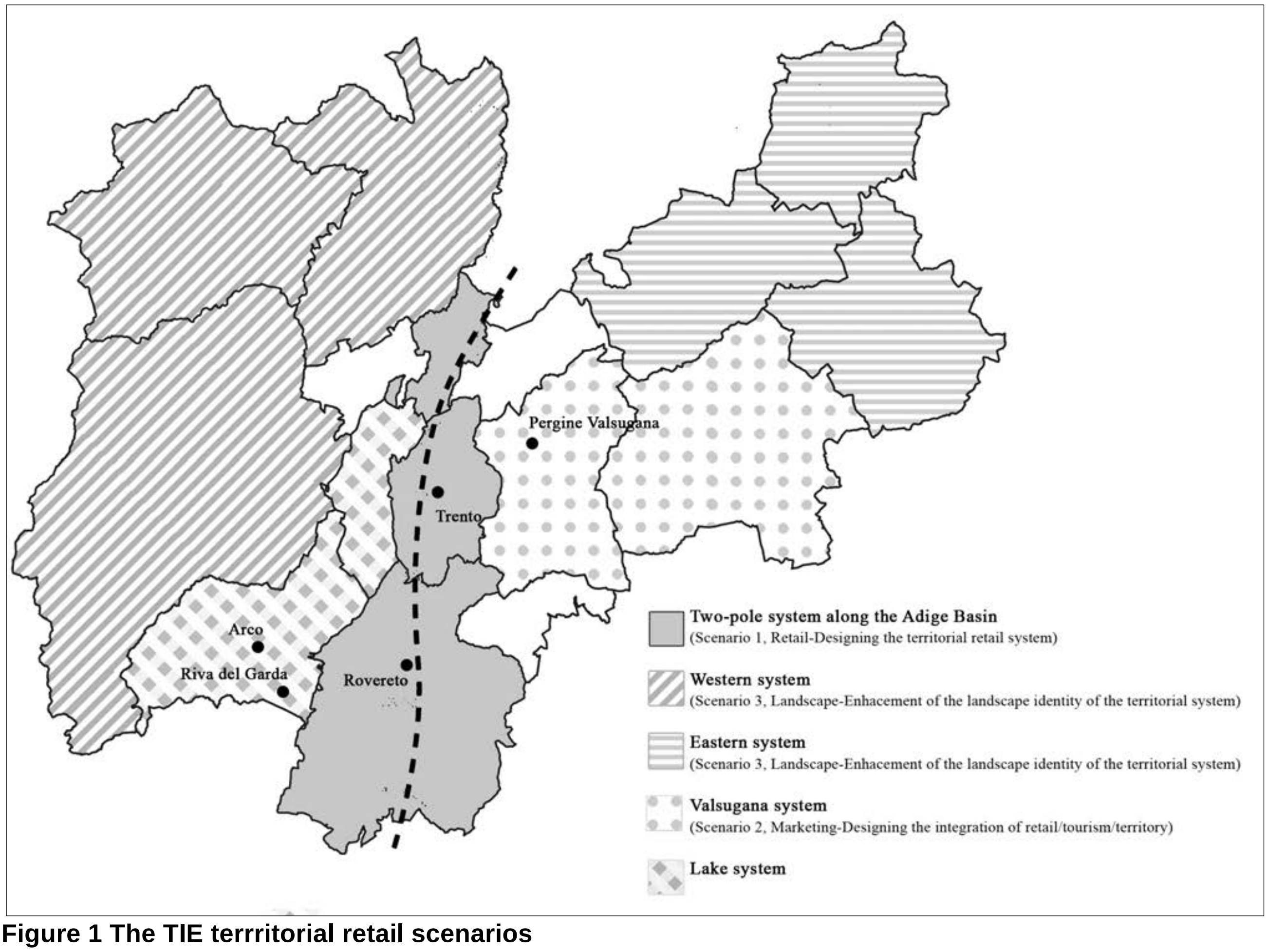

Figure 1 The TIE terrritorial retail scenarios

These scenarios are potential pathways for the valorisation of VCs that are anchored in a set of shared principles and criteria. This is a process that is primarily based on proactive local territorial policies. In other words, this process is sensitive to respect of ethical choices in relation to economy, environment and landscape. These are proposals that are addressed to the VCs, who are assigned the project of their CTP. Any proposal for strategic actions is made to design the territorial retail scenarios and hence it is a proposal that is very far from the standard model that the placement of retail large-scale stores has followed.

The emerging territorial retail scenarios are based on the following features:

1. The relationship with the infrastructure system - networks of primary accessibility, pedestrian and bicycle paths, and public transportation network in order to reduce the growth of traffic and production of pollution from emissions;

2. The relationship with the urban context – historical city /rural areas/ high-quality areas – that implies the return to cities and the search for new models and formats marked by logic of re-use and recycling rather than by of consumption of territorial resources;

3. The relationship with the territorial and the local-landscape system leads planners to define an unified project for a diversified mix of retail and other functions – diversification / integration / short supply chain.

4. Principles and criteria for designing territorial retail scenarios in Trentino

The principles and criteria of TIE methodology helped the APT to reorganize its regional retail policy. The reform is based on two principal elements of innovation that pursued harmonisation between retail development and the conservation of landscape values. In particular, TIE used:

1. Three principles for designing territorial retail scenarios that intend to promote the integration between the regional retail policies with the landscape-related policies (APT Resolution 1339/2013, section 4.3.4).

2. Five criteria for designing retail areas no longer founded on quantitative parameters but addressed to promoting the quality of territorial development processes (APT Resolution 1339/2013, section 5).

Firstly, the three principles for designing territorial retail scenarios are pathways to follow for the retail territorial development in which land use, landscape and retail are combined. The three different types of scenarios are characterised by the different role that retail is called to play in relation to the specific potentialities of development of every VC (Figure 2).

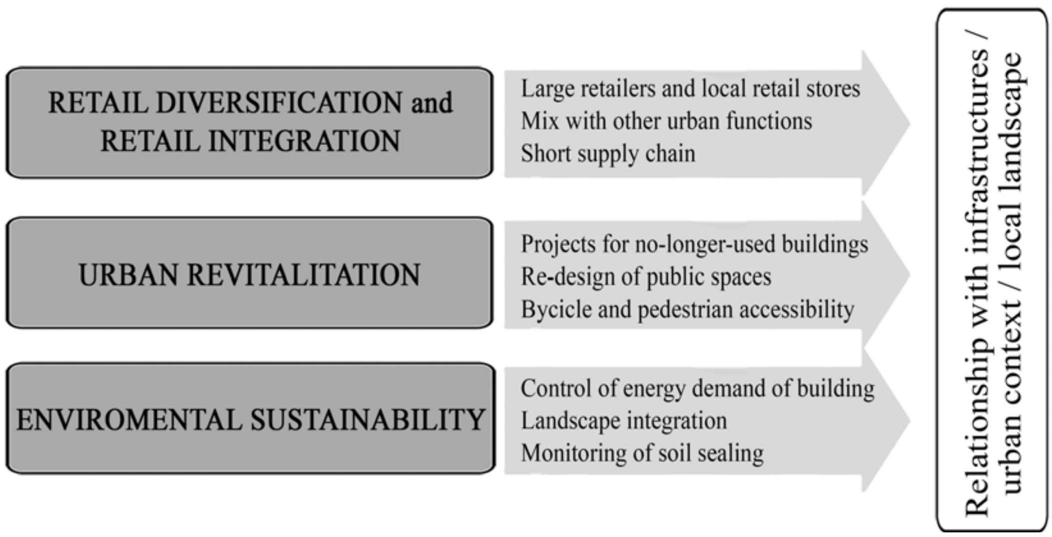

Figure 2 Three principles for designing territorial retail scenarios

The first principle - *Retail diversification and retail integration* - is generally defined as the interrelation between retail development and local framework. Here, retail diversification is intended not as the entry of a business unit into new lines of activity [11], but as the mutual relationship between large-scale stores and neighbourhood stores. Traditionally, these are in opposition because of, historically, superstores in decentralised locations are replaced the shops located in city centres. This new perspective entails that, under certain conditions, large-scale stores and neighbourhood stores can create mutual advantage for the local economy development. In some situation, therefore, this interaction can trigger a virtuous circle of improvement of local competitiveness growing the quality of the retail system. On the contrary, retail integration is conceived as a unified retail project in which retail is mixed with other urban functions related to territorial characters, as tourism, leisure, local production and landscape resources. Finally, this principle arises a new innovative logic in which retail is not interpreted as a sectorial element but as one component of a joint and diversified urban functions project. In this perspective, territorial dimension is the fulcrum in which retail, understood not only as an economic activity, works with other territorial functions for the VCs development.

The second principle - *Urban revitalisation* - concerns the role of retail in urban regeneration. Traditionally retail, along with infrastructures to which it is intrinsically linked, contributes to delineate spatial planning defining the perception of historical centres and suburban areas creating, in some cases, new amenities, shopping and amusements. In this perspective, the role of retail development is recognised as substantial in supporting urban regeneration [12]. Retail, then, turns out to be an element that can support the project of urban regeneration in the VCs, not only from a purely economic point of view, but also from a social and territorial standpoint by providing jobs, services, investment and a focal point for community activities. Practically, retail-led regeneration [3] entails the development of new retail areas located in no-longer-used buildings avoiding soil sealing and re-designing public spaces and local accessibility.

The third principle - *Environmental sustainably* - is primarily links to landscape integration, here intended as the preservation of the high naturalist, ecological and scenic values of each VC, and the monitoring of soil sealing avoiding the dangerous propensity towards the use of natural, semi-natural and agricultural land. In addition, this principle is related to retail buildings high-performance achieving a better balance between occupants' requirements and energy demand. As other types of new generation buildings, also retail stores should be designed following a mix of environmentally-friendly materials and technologies ensuring that all energy-consuming equipment is efficient as possible. In this perspective, new retail areas should be designed according to some basic principles as the use of natural light or the use of highly efficient artificial lights, where needed, and the use of natural ventilation to flow in and out in order to reduce the air-conditioning.

In addition to these principles, the APT retail planning introduced five criteria for designing retail sites that are no longer based on quantitative parameters but on the quality of territorial development processes of each VC. In particular, the principles are the following:

1. Enhance the relationship with the urban context, and in particular with the city centre, improving the attractiveness and the quality of retail system in a logic of retail diversification and retail integration, as allowed above[2];

2. Guarantee a good level of accessibility and a rapid connection with the primary roads infrastructure system along with pedestrian, bicycle and public transportation network in order to reduce any growth in traffic or pollution emissions;

3. Rethink the traditional supply models integrating retail with other urban function as tourism, leisure and local production[3];

4. Reduce the dynamic of soil sealing and support the reuse and the renewal of no-longer-used buildings in a perspective of retail-led regeneration[4];

5. Use an environmentally-friendly approach for design, materials and technologies[5].

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2 The *Plaza Shopping Mall* (Pasadena – USA) is a new retail area that aims to developed synergetic and shared actions by the shops in city centres and large-scale stores, by non-material actions, such as the promotion of coordinated events, and material actions, such as sharing parking lots.

3 The *Decathlon Village Oxilane* in Bouc Bel Air (Marseille/Aix - France) is a new retail area where the purchase is combined with a *shopping experience* in which consumers can buy a product, perform their favourite sport and spend their free time.

4 The *Gazometer City* (Wien – Austria) is a new retail area in which four-abandoned gasometer are re-design. Each gasometer was divided into several zones for living (apartments in the top), working (offices in the middle floors) and entertainment and shopping (shopping malls in the ground floors). Shopping mall levels in each gasometer are connected to the others by sky bridges.

In respect to local potentialities, the new APT retail approach was meant to link the quality of the territorial retail development of each VC with the environmental sustainability. Such sustainability can be articulated in terms of enhancing territorial resources, containing environmental pollution, and integrating other sectors with the landscape-related context of accessibility.

Starting from this theoretical framework, some best practices that implemented this new retail approach directly on the VCs retail development are been identified.

5. Best practices

The Trentino territorial retail supply system is characterised by a complex and varied structure [13]. On the one hand, the five most populous VCs in Trentino, located along the main roads, are characterised by a solid retail system. On the other hand, the rest of the Trentino VCs are marked by low retail consistency. Yet, they have a higher number of neighbourhood stores than large-scale stores. So, in the first case retail is a factor of opportunity for the development of VCs, while in the second one retail systems are weak. At the same time, Trentino is generally characterised by a lively tourism, both in the mountain VCs and in marginal territories where tourism of eno-gastronomy and excursions are promoted, and by a high variety of landscape values alternating between mountain - protected areas, the resources of the Dolomites, forests and glaciers - and valley areas.

On the basis of the provincial retail approach, each VC is starting to rethink its retail system according to its main local characters in order to orient retail development to the three principles and the five criteria introduced by the APT Resolution 1339/2013. In this perspective, each VC must analyse its retail ambition and design a territorial retail scenarios helped and supported by the TIE results. To date, the sixteen VCs are definitely implementing, in their territorial plans, territorial retail scenarios assuming different approaches and visions in relation to their specific retail potentialities.

In order to reinforce its territorial retail system, *Val di Sole VC* prefers to activate a retail strategy principally based on two aims. First, the territorial strategy tries to guarantee the permanence of retail stores in urban areas avoiding retail desertification. Second, the territorial strategy tries to integrate the retail system inside or near urban areas in view of enhancing the historical city centres. Therefore, the *Val di Sole VC* strategy is oriented to the conservation of present landscape values which are exceptionally high ecologically and scenically – thanks to the Adamello Brenta Park and the Stelvio Park - through monitoring the potential spread of urbanized areas and therefore of soil sealing. The VC is established policies for the development of new retail stores – both small and large – that follow the principles and the criteria of new provincial retail approach. In this perspective, it is interested to analyse the development of a new shopping area, with a sales area of 1,800 sm^2, located near the centre of the city of Malè (Figure 3).

Figure 3 The new retail area in Malè

5 *Tesco zero-carbon stores* is a long-term retail programme. Tesco – a British multinational grocery and general merchandise retailer the third largest retailer in the world measured by profits and second-largest retailer in the world measured by revenues - has a goal to become a zero carbon retailer by 2050. Tesco stores use 66% less energy than a typical store of a similar size and employ renewable energy on-site using sources including photovoltaic (PV) roof panels and cladding, solar hot water generation, alternative fuel combined heat and power (CHP) and ground-source heat pumps. Actually, Tesco have seven zero-carbon stores across the Group – four in the UK and one in Ireland, Thailand and the Czech Republic. The stores are all operating at a zero-carbon level, and some are generating excess energy. In 2012/2013, the four zero-carbon stores in the UK generated nearly 7% more renewable energy than they required. In addition, Tesco exported this excess electricity to the national grid where it reduced the need to produce electricity from fossil fuels.

This retail area, recently opened on December 2015, is based on two main innovation elements that are able to fully grasp the new provincial approach to the design of retail sites:

1. The shopping area is characterised by a high-specialized offering that is correlated with local products – in particular agricultural – and with sports activities and events organized in the VC, in order to avoid competition between the new large-scale store and the existing shops [14]. In particular, the promotion of a specialized supply of products correlated to the local ones is be made through special forms of promotion and distribution in the large store, such as corners and temporary stands of farmer producers;

2. The retail building uses an environmentally-friendly approach for design, materials and technologies using natural ventilation - by wind catchers on the roof that let air flow in and out - efficient artificial lighting, and fridges and freezers with natural refrigerants, as carbon dioxide, that avoid energetic losses.

Following a similar logic, the *Alta Valsugana-Bersntol VC* aims to activate a retail strategy in its territorial plan that primarily works on avoiding the risk of retail desertification in scarcely populated areas and the enhancement of the short supply chain specialising retail offerings, such as sales of local agricultural and dairy products. In this direction, the territorial plan recognises territorial vocations of each area of the VC (Figure 4) and the main local peculiarities as fruit farms and rural farmhouses, where forest-wild fruits were produced, viticulture and beekeeping.

Figure 4 Territorial vocations of Alta Valsugana-Bersntol VC

On the contrary, *Trento* and *Rovereto* – the two poles and the most populous cities in Trentino – have to orient their retail development directly in the local plans. The two cities demonstrate a high index of attractiveness because it is endowed with excellent conditions of inter and intra-provincial accessibility - motorway and railway - and with good conditions of functional integration.

Trento pursued the creation of new retail areas, even for large-scale stores, through the reuse of no-longer used urban areas and buildings. In particular, the new retail areas must address themselves to new formats appropriate for the integration of various urban functions, for example, entertainment and free time. Moreover, they must be characterized by a retail offer diversified and complementary to the offer already existing. In particular, the local plan is focused on retail-led regeneration of Trento Nord, a commercial strip that is leading to the suburb in which underperforming large-scale stores are located (Figure 5). In this strip, vacancies are high, sales per square meters are low and money to reinvest in aging structures is scarce. Following the revitalisation of this commercial strip, the local plan aims to reinforce retail activities encouraging street life by:

1. Creating an active street life designing shops, cafes, restaurants and community services at the house ground-level inviting pedestrian-oriented streets, squares and public spaces;

2. Providing a central focus as a public space such as a town square;

3. Designing pedestrian streets;

4. Locating parking for support walking. For visitors who drive to the centre, a park-once-and-walk experience should be the most appealing and practical way to visit.

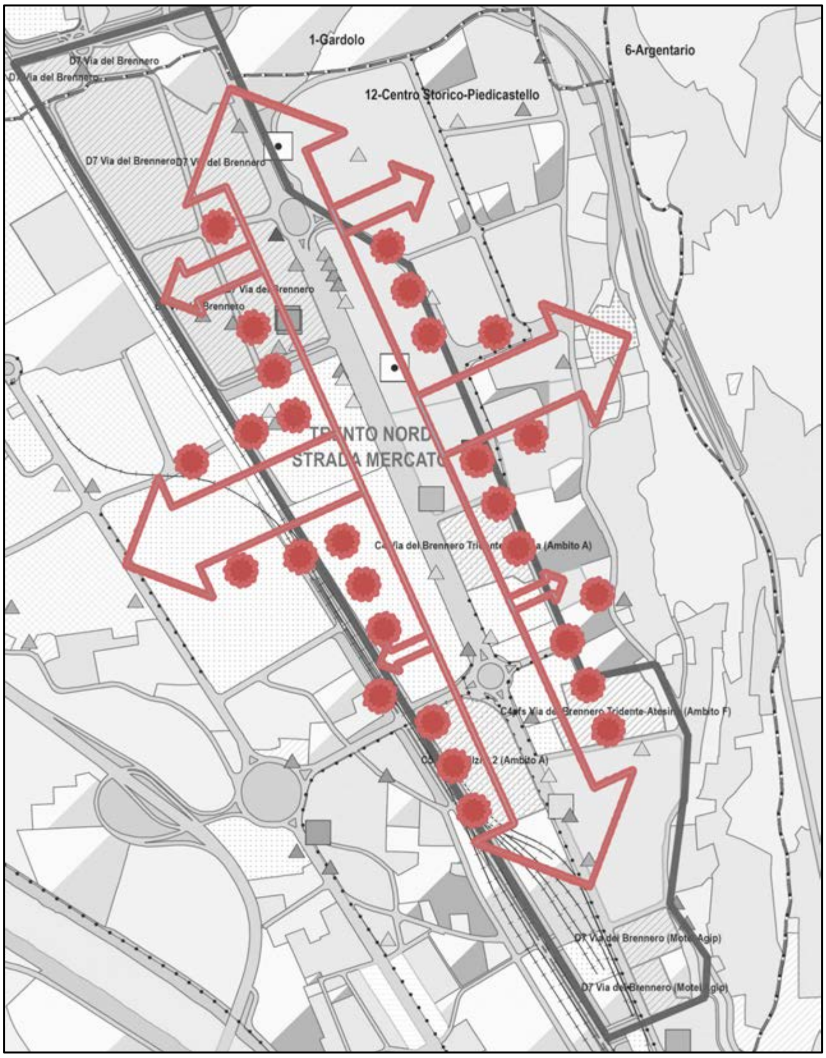

Figure 5 Commercial strip in Trento Nord

In according to the territorial plan of *Vallagarina VC*, the primary need for the city of *Rovereto* is to activate a strategy that aims to integrate the existing retail supply, maintaining today's level of quality in terms of retail varied typology and specialization, and to regenerate the urban periphery. In this direction, Rovereto decided to improve its retail system opening a new large-scale store in urban periphery as one of the element of urban revitalisation in a comprehensive vision. In particular, the project of this new retail area is focused on three main points:

1. Guarantee a good level of accessibility, in particular by pedestrian, bicycle and public transportation network (Figure 6);

2. Integrate the large-scale store offer with local products, in particular viticulture;

3. Design the relationship with the urban context, in particular with high quality agricultural areas located near the large-scale store and the cultural offer located in the city centre.

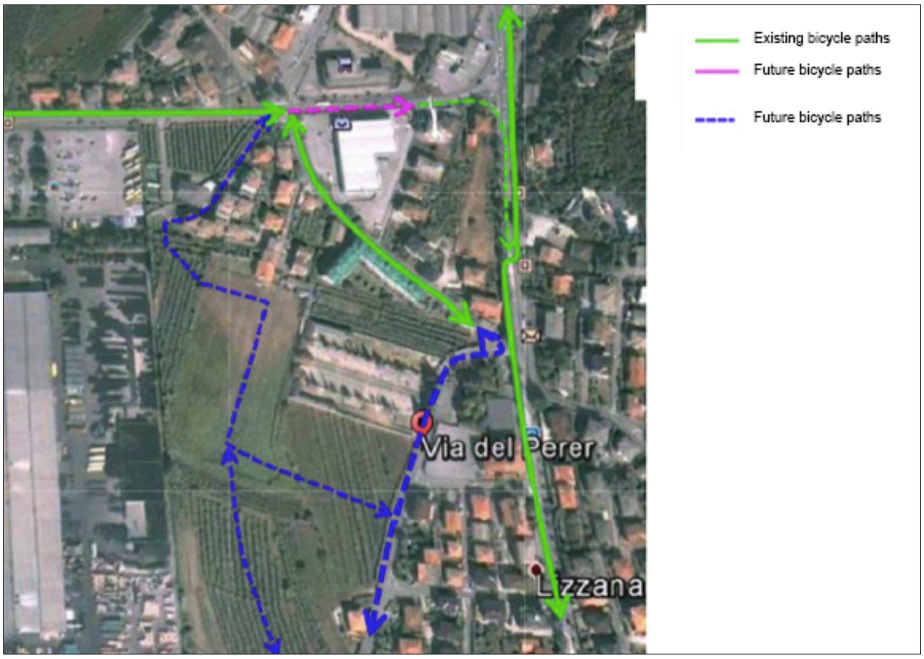

Figure 6 Existing and future bicycle paths between the new large-scale store and the city centre

6. Some final remarks

This paper has presented the recent evolution and development of Trentino retail policy. This exceptionally institutional dynamic context has allowed us to experiment with some emerging concepts in retail planning, such as integration, regional development paradigms and institutional capability. In addition, TIE methodology, based on the harmonisation of retail development with the conservation of landscape values through territorial retail scenarios, allows us to underline basically two themes of work.

The first element is focused on the perspective for planning that the Trentino retail policy presented. In particular, APT Resolution 1339/2013, adopting TIE principles and criteria, introduced in the Province a new rational paradigm for territorial retail planning, that was no longer founded on quantitative parameters of retail development. Instead, it was addressed to promoting the quality of territorial development processes [10]. In respect to potentialities and special features of each VC, Trentino retail policy was meant to link the quality of territorial retail development with environmental sustainability – as the enhance of territorial resources, the containment of environmental pollution and the integration of other sectors with the landscape - respecting attractiveness and balance among different retail sites. More generally, Trentino retail legislation introduced a new paradigm for sectorial policies in which territorial opportunities could emerge when forms of integration among policies of different sectors are implemented, making the competitive characteristics of areas emerge. More generally, TIE methodology has introduced in the regional retail planning a flexible approach in which territorial retail scenarios are anchored to shared criteria that every VC have to perform in according to the formulation of the CTP. In this perspective, TIE territorial retail scenarios are not closed vision but the starting point for VCs retail strategy. Since almost three years from this retail planning reform, to date the sixteen VCs are completing the discussion and the sharing of TIE results and they are implementing them in their CTPs in relation to their potentialities and special features.

The second element is focused on the implication for designing retail sites. In Trentino retail policy, urban areas assumed a leading role as actors fundamental for effective activation of regional strategies. In particular, the city is becoming a great attractor of new retail projects that overtake conventional retail formats characterised by low-quality offer and localised outside the city centres. Instead, these proposals envisage the reuse of city areas and buildings, distinguishing retail as engine of urban revitalisation and an attractor for initiatives of enhancement and requalification. As opposed to what happened in the preceding decade, in Trentino retail policy new retail activities are more and more oriented towards seeking out the highest level of spatial, formal, typological, and functional integration with their urban contexts. In this perspective, retail becomes a strategy to build urban resilience, here intended as the overall goals of an effective retail policy to attain the economic, social, and environmental goals of urban sustainability and to diminish the negative impacts of suburban retail development [15]. More generally, retail urban resilience is essential to understand retail system's evolution, after threats or shocks, helping local authorities and other stakeholders to maintain and improve the urban commercial areas. Therefore, adopting a resilience perspective means a focus on retail change, trying to understand the performance and the capacity of different retail areas to transform both in city and regional dimension considering that retail might contribute to a community's image, identity, satisfaction and cohesion [2].

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Integration of user perspective when selecting sustainability measures

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Abstract

When making major investments to improve energy efficiency of organisations, a cost and benefit analysis is crucial to identify useful measures. Usually the potential of measures to increase energy efficiency is based on hard factors like time of amortization or reduction of carbon dioxide emissions. In this paper it is argued that in addition to effectiveness and feasibility, the subjective user perspective is a third aspect that should be considered when evaluating the suitability of energy efficiency investments. The integration of the user perspective is important because users are affected by any changes in the buildings and often have to adapt to these changes. The personal evaluation of these changes during the planning process will further influence their attitudes towards the perceived usefulness and acceptance of sustainability measures. As multipliers they will carry their attitudes into their private life and may thus affect (in a positive or negative way) family/ friends close to them. Adding the user perspective before making a decision will, thus, gain insights into the acceptance of potential measures and into the positive/negative influence on users' attitudes and behaviour. In addition, unaccepted measures will hinder the implementation and success, since users may either ignore them or even work against these measures in a destructive way. This paper presents different approaches on how to identify factors which are important for occupant acceptance and how to implement these results when it comes to major investments of bigger buildings with heterogenic user groups.

Introduction – relevance of sustainability for organisations

Organisations gain increasing interest in Corporate Social Responsibility (CSR) as it is expected to be relevant for a company's success. The European Commission believes that organisations, which take responsibility for their impact on society by integrating CSR, benefit in regard to their risk management, cost savings, access to capital, customer relationships, and human resource management (European Commission)[1]. Companies of public interest with more than 500 employees even will be obliged to publish detailed non-financial reports on their environmental performance i.a., beginning in 2017 (European Parliament 25.10.2012)[2]. Pursuing organisational sustainability goals (e.g. energy savings or reduction of carbon dioxide emissions) can be beneficial to companies. Thus, they have to decide which measures will be best suited to attain these goals.

A major driver for investments into energy efficiency is the great potential for reducing energy costs. New regulations as well as funding programmes regarding investments and organisational improvements were established laying out the basis to exploit energy efficiency gains. Since December 2015, companies with more than 250 employees in Germany are by law obliged to undergo an "Energy–Audit" (Deutscher Bundestag 04.11.2010)[3]. Small and medium-sized enterprises are believed to achieve a profitability of 20% to 25% when investing in energy efficiency. However, research has shown that most corporations often cannot quantify their energy consumption, while only 14% operate an energy management system (Federal Ministry for Economic Affairs and Energy 2014)[4].

If embedded in a strategic concept, organisations should be able to realize various synergies by combining energy-audits and sustainability reporting (Baumgärtler und Popovic 2015)[5]. In this context several instruments are applicable to support the process of pursuing strategic targets: The ISO 26000, ISO 50001, EMAS and EMASplus, established by national and international bodies, are sustainability standards that build the framework for an organisation's sustainability management. Instruments promoting measuring and reporting on the organisations' social and environmental matters, are the Global Reporting Initiative (GRI) and Deutscher Nachhaltigkeitskodex (DNK). These standards find increasing attention since their application enables organisations to comply with current regulations and supports reaching sustainability targets.

However, when organisations strive to become more sustainable by applying management instruments, not all members within an organisation might share this enthusiasm and approve the company's sustainability goals. Measures implemented in order to reach sustainability goals can have a negative impact on staff working within organisations. It may then negatively influence the attitudes of individual employees and in the long run their support when it comes to reaching the set goals. In addition, individual attitudes and corresponding behaviours may influence other co-workers and a negative social norm may evolve from this.

In this article it is argued that the subjective user perspective is an important aspect that should be considered in addition to other more objective aspects when evaluating the suitability of sustainability measures. Adding the user perspective into existing planning concepts will bring insights into the acceptance of potential measures and into the positive influence on users' attitudes and behaviour. In the following an ideal measuring and evaluation process is outlined, integrating not only objective hard facts but also the subjective user perspective. In the first part, a standard process is described in order to identify and evaluate suitable sustainability measures – solely based on objective criteria. In the second part an outline is given, how the user perspective can be integrated into this standard process. We will make our ideas more tangible by describing an exemplary process implemented at our university. The ideas of this article are highly relevant not just for the refurbishment of public real estate (such as universities, schools, ministries, further public authorities) but also for a large number of companies.

Normal Process of evaluating sustainability measures

Effectiveness/ performance perspective

A number of sustainability management and reporting standards were already presented above. For the following examples an environmental management systems according to the European Eco-Management and Audit Scheme (EMAS) is exemplified. Within the context of EMAS[6] organisations intend to improve their performance by reducing their environmental impact: With EMAS organisations take a proactive approach to improve their environmental performance (c.f. European Commission 2015a)[7]. Therefore environmentally relevant aspects within operational processes are evaluated to identify an organisation's current state and areas for improvement (German EMAS Advisory Board at the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB))[8]. In a second step, derived environmental measures contribute to the organisation's overall performance. Thus, the effectiveness of an improvement measure can be assessed by its contribution in improving the organisation's overall environmental performance. Since the last update of the European Regulation six areas (Energy Efficiency, Material Efficiency, Biodiversity, Water, Waste and Emissions) have been determined to present the environmental performance (European Parliament 25.11.2009)[9].

Feasibility/ technical and economical perspective

Within the framework of EMAS, environmental aspects are part of an input-output-analysis including all environmental relevant areas listed above. The evaluation of operational processes and subsequently the identification of areas for improvement and possible improvement measures are based on data that are collected during frequent review processes covering all environmental aspects. In a first step, an organisation's improvement potential is assessed focusing primarily on the effectiveness of measures.

When reviewing proposed improvement measures in a second step to discover improvement potentials, technical and economic feasibility tend to be the main criteria besides the effectiveness of the measure. On the one hand, the ease of implementation, implying a simple technological integration into the current system without major changes, indicates the preferability of a measure. On the other hand, a low investment combined with high effectiveness such as significant energy or (raw) material savings, leading to tangible cost savings over time, also indicates the preferability. The projected outcome aims at the dimension of economical sustainability and is a main driver for organisations to invest in energy efficiency measures to reduce operating costs.

According to the evaluation of an organisation regarding the environmental impact and potential for improvement in the six fields, these two dimensions can be both considered to prioritize measures. As such high potential areas can be identified to significantly improve the performance (effectiveness) while showing a high level of (financial and technical) feasibility. As an example, a use case is presented in the following part, describing the implementation of such an evaluation process.

Use Case at the Hochschule für Technik Stuttgart (HFT Stuttgart)

The presented use case is part of an ambitious project at the HFT Stuttgart called "EnSign - field laboratory for climate-neutral city campus". The project has been established to pursue the state government of Baden-Württemberg's goal to build a largely carbon-neutral state administration by 2040 (Landesregierung Baden-Württemberg 2012)[10].

With a mix of protected historic buildings, post-war constructions as well as innovative new buildings, the building stock of the HFT Stuttgart is highly heterogeneous. The campus contains numerous classrooms, work and service rooms, computer centres, a cafeteria, laboratories and external firms. With more than 4000 students, technical and office employees, academic staff and professors, the user group of the campus is also very heterogeneous. When it comes to sustainable measures that will lead the goals of a "campus energy master plan", the different building requirements must be taken into account as well as the users who will have to live with it.

The presented use case had the aim to identify measures with the highest potential to reach set sustainability goals. The described approach can be separated into two steps: The first step had the aim to identify general areas in the organisation with high potential to reach sustainability goals. The second step tried to identify potential measures in the selected area based on the dimensions effectiveness and (financial/ technical) feasibility.

STEP 1: Identification of the relevant areas for sustainability goals

Environmental Impact

The overall target is to improve the organisation's performance by setting sustainability goals. As such the effectiveness is measured within EMAS core areas and provides information on the organisation's inputs or environmental impacts that can be analysed by correlating the results to the organisation's size. The greater the observed improvement within the key areas, the more effective the preceding measure. Once the performance has been evaluated, areas for improvement need to be identified that indicate the field of action and build the basis for deriving measures in the respective field.

Potential for Improvement

When identifying areas for improvement, the environmental management process starts with a primary environmental review which includes the visit of all of the organisation's building areas and the collection of environmental relevant data. In the case of the HFT Stuttgart, the EMAS EASY concept (European Commission 2015)[11] was applied that consists of an eco-mapping process. The mapping of the organisation, in terms of location and internal processes in order to identify its environmental aspects, resulted in 1,100 findings (see Figure 1). For subsequent reviews, the HFT Stuttgart developed an EMAS-smartphone app showing the findings on electronic floor plans and to be used by personnel to include more individual information (Fridrihsone und Kettemann 2015)[12].

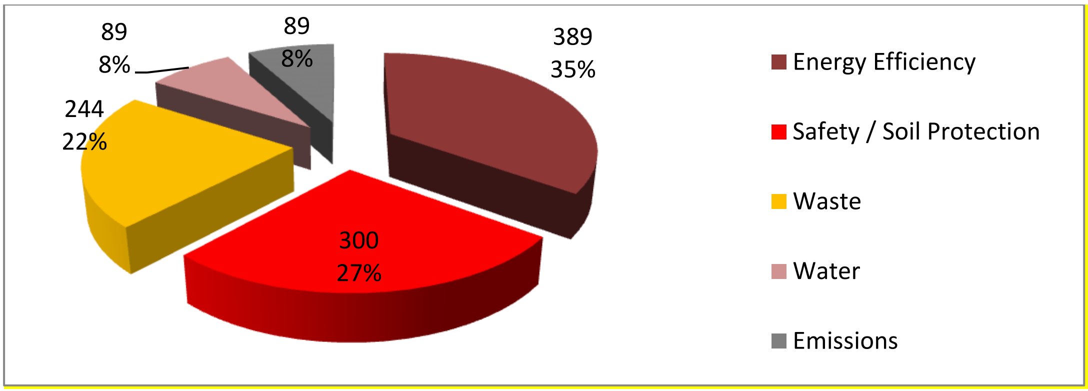

Figure 1: Summary of the results of the eco-mapping

As part of the evaluation process within EMAS EASY, the common method "FLIPO" (Flow, Legislation, Impact, Practices, and Opinions) was applied. During this part of the process the collected data supported evaluating the organisation's operational processes. Most weighted assessment criteria of the FLIPO concept are the legal aspects regarding a work process and the processes' environmental impact. These evaluation criteria are followed by the frequency of energy/material flows as well as the evaluation of the applied technical practices. A further criterion was the opinion of experts of the corresponding operational process that was integrated as well.

Results Step 1

After the evaluation of the university's environmental impacts from its operations and measuring the potential for improvements within the environmental fields, the HFT Stuttgart identified the field of "energy efficiency" to be further investigated in the second step, given its high potential for improvements and the significant environmental impact expected. Thus, different energy efficiency measures were analysed in step two.

STEP 2: Identification of potential measures to reduce energy consumption

Two representative buildings (out of 9) were chosen to be investigated in the second step. They were chosen given both will undergo major renovations in the near future. As such, there was a realistic opportunity to implement some of the suggested measures, which would also increase the willingness of the staff to participate as interview partners.

As part of the implementation of the environmental management system at the HFT Stuttgart, a variety of measures had already been assessed regarding effectiveness and (technical/ economical) feasibility (see Table 1 for selected examples). The retrofitting of the lighting systems showed for example technical barriers (limitation to make architectural adjustments) regarding effective measures to improve it. Although overall electricity consumption could be significantly reduced, these measures were given medium priority since they also required more individual and local solutions. Hand dryers on the contrary are simple to replace. However, investments relative to the outcome concluded an unfavourable improvement measure. Programmable digital thermostats were rated with a good technical and economic feasibility and reduced the energy consumption significantly, thus indicating the preferability of this measure.

Results Step 2 (selection of planned measures)

Installing efficient hand dryers requires comparably high financial investments (low feasibility) while the overall reduction of the energy consumption will be very low. Despite the technical feasibility being considered high, the result is still a measure of low priority (C). A medium range investment on lighting retrofits in lecture rooms, with a medium ease of implementation, a medium level of improving the energy efficiency performance of the university results overall in a measure of medium priority (B). A low investment on programmable digital thermostats in offices with the ease of implementation being very high together with the expected significant improvement of the energy efficiency performance of the university, results in a measure of high priority (A).

Table 1: Standards evaluation and priorities of improvement measures

	Effectiveness	Feasibility	Priority
Hand dryer	Low	Medium (High technical, Low financially)	C
Lighting retrofit	Medium	Medium	B
Thermostat office	High	High technical High financially	A

Relevance of user perspective

Despite the revealing evaluation results of the examples described above, we can learn that sustainability measures that are evaluated as effective still can be found ineffective during frequent reviews and environmental audits. Furthermore they can even result in an increased resource use and costs. Simultaneously, users may be dissatisfied with sustainability initiatives and perceive it as a loss of comfort and autonomy.

In one case at our university thermostats were installed in lecture rooms. Afterwards, unexpected problems with this measure appeared. Users of lecture rooms individually attempted to adjust room temperatures depending on sunlight level, number of occupants or sitting location that affected the perceived temperature. The only adjustment room users could make was opening windows for fresh and cold air, which caused the thermostats to provide more heat to keep the room temperature level. The Audits had shown that the interference by users resulted in windows that stayed open until the next user group arrived later in the day or even the next day while thermostats attempted to maintain the intended room temperature. In contrast, in the case of office space, tests have shown that by introducing thermostats to users correctly, they will find personally programmed room temperatures as a gain in comfort.

In organisations, decisions are usually made based on the hard facts described above and the user perspective, i.e. acceptance of measures and expected behaviour of users are not taken into account. When disregarding the user perspective, actions may remain ineffective or the potential for improvements is not exhausted due to prevailing consideration of hard facts during the decision making process. Thus, we recommend integrating this perspective as a final evaluative step.

User behaviour

In order to make sure that sustainability measures are selected that have got the highest likelihood to be implemented successfully in the organisation, one must take the potential users' behaviour into account. This means that one has to predict how users will react towards certain measures. A theoretical framework often used in psychology to predict (pro-environmental) behaviour is the Theory of Planned Behavior (Ajzen 1991)[13]. The core of this model is the idea that (planned) behaviour is best explained by behavioural intentions, which in turn are best explained by three variables: attitudes, social norms, and (perceived) behaviour control (see Armitage und Conner 2001)[14]. The PLABE-model construes humans as rather rational beings who behave in a way which will aid them in reaching their goals (corresponding to their personal attitudes). However, humans are also "social animals" in a sense as they take into account how significant others may perceive their behaviour (i.e. social norms). The third predictor in the PLABE-model is perceived behavioural control, meaning that humans will only show certain behaviour, if they feel that reaching the desired goal lies within their area of control and is a possible consequence of the behaviour. If a certain action has no chance of resulting in a desired outcome, a person is not likely wasting time and energy by showing this behaviour. The PLABE-model has received an impressive range of empirical support from different domains of human behaviour and has also shown its prowess in the prediction of pro-environmental behaviour, e.g. in a study investigating behavioural intentions at the workplace (Greaves et al. 2013)[15]. In this study, the three predictors mentioned above accounted for 46%-61% of the variance in behavioural intention regarding various pro-environmental behaviours (e.g., switching the computer off when leaving the desk). Thus, assessing individual attitudes and social norms can help to understand and predict pro-environmental behaviour. Likewise, negative attitudes (or norms) towards certain sustainability measures can be seen as critical indicators of how potential users might react towards the measure when implemented. Since the behaviour of users can seriously harm the effectiveness (and feasibility) of a sustainability measure, it is in our view of utmost importance to asses this perspective in the pre-decision-making-phase. Moreover, the user perspective should be included as a separate evaluation dimension into the decision-making process when selecting which sustainability measures to implement.

Predicting potential future behaviour regarding a certain measure, however, is not the only reason to integrate the user perspective. The implementation of sustainability measures can be seen as a social resource allocation process (i.e. a limited resource, money, is spent on one or more measures). Such processes have long been known to be strongly influenced by the perceived fairness of such allocations (i.e. distributive fairness) and the perceived fairness of the process of this allocation (i.e. procedural fairness). The perception of an individual that a certain process is fair triggers many favourable attitudes and behaviours toward the organisation implementing this process, independent of the outcome of the process. This well-researched phenomenon is called the "fair-process-effect" (Folger 1977)[16] and has been shown in many domains of social life (c.f. Colquitt et al. 2013)[17]. Effects of favourable perceptions of procedural fairness include a more positive attitude toward the organisation implementing the process, higher compliance to the rules and regulations in the organisation, more corporate citizenship behaviour, stronger endorsement of organisational goals and higher productivity (Colquitt et al. 2013)[17]. All these effects occur regardless of the person's impressions about the actual outcome of the process. This means that in the case of the selection of a sustainability measure, users who perceive the process by which the measure was chosen as fair show more favourable attitudes and behaviour towards the organisation and endorse its goals to a higher degree. All this should be beneficial with regard to the overall cost-benefit-structure of the selected sustainability measure. So, how can we render a process fair? Previous research has identified different aspects that make processes fairer, such as transparency and consistency. However, the single most influential aspect seems to be the opportunity to state ones' own opinion (Folger 1977)[16]. Voicing ones' own ideas and attitudes, regardless whether this leads to the desired outcome or not, makes people see a process as more fair. Combining this with the above-mentioned fact that asking people about their attitudes and social norms helps to predict their future behaviour, the mere act of asking people should have a positive side effect on their perceptions of the measures resulting from the process of identifying suitable sustainability measures.

Possibilities for user integration

So far we have stressed the relevance to integrate the user perspective into the planning and implementation process of sustainability measures. But what are viable options to assess the user perspective in an organisation and give users a "voice" as described before? Different approaches are described in the next section.

From our point of view the most obvious approach would be to simply ask users (e.g. employees) directly via a survey or interview. Apart from more general questions about attitudes and behaviours regarding sustainability, different suggested sustainability measures should be directly evaluated by users. It is important that the concepts of these measures are described prior to evaluating them in a way that is understandable by the respective target group. Otherwise evaluations may be distorted. Evaluation dimensions could be the perceived effectivity and costs of these measures as well as the personal liking of the measures.

Online Surveys

Online surveys have probably become the most common form in order to assess opinions in a comparatively efficiently way. The main reasons for this are the low costs. Compared to classic paper and pencil questionnaires, there are only some costs for programming and hosting the survey (assuming that a survey software is already available), but not for printing, distributing and collecting the questionnaires and entering the data. Online surveys are also a very fast way to assess opinions and have some additional specific advantages: perceived anonymity is very high and the risk for social desirable answers is, thus, reduced. They are very convenient for respondents and may be filled out on any computer or handheld device available. Answers are stored on a server immediately making loss of data unlikely. Online surveys have the option to integrate pictures and videos, e.g. in order to better explain or display certain sustainability measures to users. There are no problems with missing questions and filters can be easily integrated, making this instrument very flexible and adaptive. However, there are also some relevant disadvantages concerning online surveys one should keep in mind. The scope of questions is reduced, since an online survey should not take longer than 5-10 minutes in order to maximize motivation to participate and to minimize drop-out rates. If open-ended questions are used, users will only give short answers to these, limiting the possibility to get a deeper understanding of users' judgements. Since there is no interviewer available, no questions can be asked if e.g. a concept or a question has not been understood. Last but not least, since the invitation to the survey is usually distributed via email, the response rates may be quite low, because there is little commitment from users' side to answer the survey (compared to a personal approach). Thus, online surveys are only useful for surveys with a limited scope and will not generate understanding of underlying motives and attitudes that easily. Since we believe that a deeper understanding of reasons for evaluations is necessary in order to draw valid conclusions, we suggest using qualitative interviews as an alternative approach, especially if this kind of survey is conducted for the first time with the selected target group.

Qualitative Interviews

The main goal of the qualitative approach is to truly understand the interviewed person, i.e. to see the world through his/her eyes. Qualitative interviews often have a semi-structured format. Structure is given by an interview guide that combines all relevant topics and questions to be addressed, thus ensuring comparability of interviews. However, the interviewer is free to change the order and re-phrase the wording of topics and questions and even integrate new questions if relevant topics arise during the interview. This way, e.g. new suggestions for sustainability measures can come up during the interview. The whole setting is closer to a "normal" conversation than to a "question-response game" as in quantitative interviews. The interviewer tries to build rapport to the interviewed person. The interviewee is, thus, more likely to open up to the interviewer. This makes it possible to get a deeper understanding of the underlying reasons of a person's behaviours and judgements. Based on these evaluations and underlying reasons it is possible to select preferred measures to be implemented. In addition to the effect on sustainability goals, this will positively influence users' attitudes towards the set goals and will increase commitment to support these goals in the future. Furthermore, even if some measures are negatively evaluated in the beginning, it may be possible to adjust the suggested measures to better meet users' demands. Misunderstandings of sustainability measures can be identified and addressed accordingly as well. This way they may be seen in a more positive light if described differently. Another advantage of qualitative interviews is that users' opinions are truly appreciated. They express that the interviewer (as a representative of the organisation) cares and values their opinion. By giving users a “voice”, it is more likely that they will evaluate the process of choosing and implementing measures as more fair and are more likely to accept and even support it. However, qualitative interviews also have some disadvantages. Most of all, they are costly and time consuming. A skilled interviewer is needed, interviews might take up to one hour and transcribing and analysing the data is demanding as well as time consuming. Because of this, only a small number of interviews are usually conducted, thus challenging the quantitative representativeness of the collected answers. However, from our experience, the richness and quality of the collected data often makes up for this. And, sample size is not necessarily lower compared to online surveys due to the low response rates of the latter. Finally, the two approaches may be combined, e.g. by running an online survey after conducting qualitative interviews first.

Collecting employee suggestions

An additional approach could be to implement a system to collect employee suggestions regarding sustainability measures. At our university we developed e.g. a service app that gives all students and staff members the possibility to hand in suggestions in the specific room or area of the building they suggest to implement it (Fridrihsone und Kettemann 2015)[12]. I.e. the app offers a three-dimensional building layout and suggestions can be directly linked to certain rooms or areas within the buildings. A menu based categorization system is also offered in order to specify each suggestion, which makes it easier to quantify suggestions. All suggestions are collected and presented via a web interface making them accessible to all users of the buildings right away. Apart from the automatized data analysis this app has some specific advantages when it comes to user integration. Firstly, suggestions can be handed in whenever an idea comes to mind. This is especially useful, because many ideas are triggered by problems in a certain room or building (e.g. the heater in a lecture room is running although the windows are open – the suggestions might be to implement an automatized system for opening and closing the windows and/or adjusting the heater) and these ideas can then directly be connected to that room. Secondly, since suggestions are immediately accessible to all users, this makes this system especially transparent and will positively influence perceived fairness of the process. Third, users can actively participate as “eco scouts” in the process to reach set sustainability goals. Users see themselves as self-efficient agents that are responsible for changing the environment they live and work in.

Of course, the choice for any approach depends on the specific surrounding conditions within a given organisation. The expertise for choosing an approach may already be available in an organisation, e.g. in the human resources department or alternatively in the market research department. We suggest consulting the experts within an organisation in order to choose an approach. For making the suggested approaches more tangible, in the following an example is presented, describing the user integration at our university.

Example for user integration

The HFT Stuttgart (University for Applied Sciences) has recently started a process to become a more sustainable organisation. As described above, one of the first steps was to describe relevant areas for reaching this goal. Becoming more energy efficient was seen as an approach with big environmental impact as well as potential for improvement. Concrete measures to improve energy efficiency were suggested and evaluated regarding their effectiveness and (technical as well financial) feasibility (e.g. hand dryer, lighting retrofit, and thermostat in offices). But how would users (here: staff members) evaluate these measures?

It was decided to use qualitative interviews in order to assess the evaluation of the selected measures. We employed a set of questions as an interviews guide, thus following a semi-structured approach described above and making the interviews comparable but also open to individual input. The qualitative approach was chosen because there was little knowledge concerning the environmental attitudes and behaviour of staff within the organisation. It was also employed in order to allow participants to give a more detailed evaluation of their attitudes compared to an alternative quantitative approach (e.g. online survey as described above).

In order to prepare participants for the interview, they were asked to fill out a diary three days prior to the actual interview. In this diary they had to document some of their energy consumption (e.g. “Where did you use energy today?”) and energy saving behaviour (e.g. “Do you try to save energy, e.g. by switching off the light when leaving the room?"). The reason for this diary was to make people become aware of the topics that were to be addressed during the interview.

The interviews took place in the respective offices of the participants given the main topic was "energy use at the office" and it was also convenient for participants. The interviews, lasting from 30 to 60 minutes, were all conducted by the same interviewer. The interviews started with questions regarding the position and working routine of the respective participant, followed by the subjective evaluation of the atmospheric environment in the respective office and how it could be improved. The main part of the interview concerned questions about energy usage, waste of energy and possibilities do decrease energy consumption. Participants were asked to evaluate different methods promising to decrease energy usage, including the measures introduced above. The interviews closed with questions about the attitudes towards environmental consciousness.

The interviews were conducted in two different buildings of the campus. In one building (Building 3) 43 people have their offices, while in the other (Building 4) 50 people do. It was planned to draw a sample of 10 participants for each of the two buildings, thus reaching 20-25% of total staff. In order to gather as many different views as possible regarding the topic of energy consumption, different target groups were included in the sample design: Professors as well as other employees, men and women, and – most importantly – participants from each floor within each building. Within each sample group, participants were selected randomly from a list of all employees and then contacted by phone/ email in order to set a date for the interview. Due to some not being able to participate, the final sample consisted of N=7 interviews (building 3) and N=6 interviews (building 4), respectively. In the end, the total sample consisted of N=13 interviews, which is about 15% of all staff in these two buildings. Gender was equally distributed, but only few of participants were professors (N=4). There were participants for each of the four floors of the two buildings, with the exception of the ground floor in building 3.

The next section presents the evaluation of the three exemplary measures from the users' point of view. Acceptance widely differed between these measures (see Table 2 for an overview).

Table 2: Evaluation of improvement measures including the user perspective

	Effectiveness	Feasibility	Priority	Acceptance
Hand dryer	Low	Medium (High technical, Low financially)	C	High
Lighting retrofit	Medium	Medium	B	Medium
Thermostat office	High	High technical High financially	A	Low

According to objective evaluations (effectiveness and feasibility), hand dryers were not a very effective and also comparably expensive measure. However, staff members would highly appreciate this measure, since it would not only reduce energy consumption (at least to some amount), but also increase comfort. It might, thus, be an effective measure to be implemented, because it would positively affect the attitudes of staff members, especially when it comes to the whole process of making the organisation more sustainable in the future. If the whole project and its outcomes were seen in a positive light, staff members were more likely to support it, even if less pleasant measures were to be implemented in the following. The overall acceptance would rise. This measure could, thus, be used as an "admission ticket" for the overall process.

To install programmable thermostats in offices seemed to be an effective measure based on objective evaluation, especially due to relatively low costs. Staff members would have the opportunity to program the heating system according to their individual demands. Some staff members were also already used to these thermostats from their private homes. Surprisingly, there was little support for this idea for their offices. Staff members feared that programming would be a hassle (reducing comfort) and would reduce their flexibility, e.g. when they wanted to work late some days and start early on others. Even though acceptance was low for this measure, it does not mean that it is unacceptable per se, but, before implementing it, concerns of staff members have to be heard and addressed. In addition, individual training sessions should considered accompanying the installation.

When evaluating lighting retrofit as a third measure, there was some doubt regarding the possibility to find acceptable lighting settings for all staff members. An additional problem arose due to the demand for dimmable lighting. This would cause additional costs, thus decreasing the economic feasibility of this measure.

To conclude, by taking the view of staff members into account, evaluation of measures became more differentiated, but also somewhat more diverse. Using qualitative interviews proved to be a viable way to reach staff members and to gain a differentiated and deep understanding of their individual perspective. Generally, this underlines the necessity to include voice of staff members before implementing any of the suggested measures. This could be done, as suggested in the presented case study, by using qualitative interviews as a viable way to reach staff members and to gain a differentiated and deep understanding of their perspective. Qualitative interviews are though also time-consuming. One might think about other ways to assess user evaluations in an organisation in addition to or as an alternative to qualitative interviews. As described in this article, quantitative online interviews for example are a rather efficient alternative method and could prove to be successful if kept to an answer time of 5-10 minutes.

Conclusions

Improving energy efficiency or implementing other measures designed to increase the sustainability of an organisation's operations often requires significant investments. Decision-making processes designed to ensure the optimal allocation of organisational resources usually focus on objective dimensions such as the effectiveness of a measure and the technical and financial feasibility. This paper proposed that the subjective user perspective is a valuable third evaluation dimension in such decision-making processes. The user perspective is important since low acceptance by the users and subsequent behaviour inconsistent with the measure's intention might significantly decrease the positive effects of an otherwise effective and feasible measure. At the same time, the assessment of the user perspective gives the users voice in the decision-making process and therefore heightens the chance that the result of the decision-making process is perceived as desirable and is supported. Both effects not only help organisations to choose more successful measures but transform users into multipliers who will carry their attitudes and behaviours into their private life and may thus positively affect family and/or friends. This can give the organisations' investments in sustainability measures even bigger leverage. Thus, considering the user perspective as an additional dimension on which to evaluate potential sustainability measures should greatly enhance the likelihood of a successful implementation of such measures and maximise the outcome for environment and society.

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HumbleBee is not a bug, but an innovative lighting system

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Abstract

HumbleBee is an innovative lighting system combining LED with remote phosphors technology for luminaires together with a customized smart lighting control system (for dimming and switching) that uses a wireless network based on ZigBee protocol. The system was designed and realized and installed at the ENEA Laboratory in Ispra (Varese) . Before the installation and the commissioning phase, the evaluation of thermal, electric and photometric aspects, of the luminaire was provided to characterize HumbleBee as a whole. This operative phase included a monitoring campaign in the laboratory towards thermal and electric response of the appliance during operation and the characterization of the solid photometric of the light engine. The following phase of installation and commissioning aims to quantify physical environmental and energy performances (energy consumption, illuminance, state, users presence, malfunctioning, etc.). And finally the monitoring campaign will also calculate the actual energy savings.

The goal of the HumbleBee project is to realize an innovative prototype of lighting system, useful for tertiary sector, able to reduce energy consumption and improve the lighting quality and the visual comfort in working places, through the use of innovative technologies.

The paper will show the results of the thermal, electric and photometric evaluations and the preliminary data of the real use in terms of energy savings.

This experimentation has been developed in the graduation thesis with the University of Insubria in (Varese).

The HumbleBee system

The HumbleBee lighting system has been designed combining two innovative technologies: luminaires with remote phosphors LED and a smart control system.

The case study is at the technology-hall in ENEA laboratories located in Ispra: everyday people spend many hours in these workplaces. Therefore it is important to evolve from the “stereotyped” workplace to the “anthropyzed” workplace. The true challenge is to obtain the correct equilibrium among different key elements, as shown in the following figure.

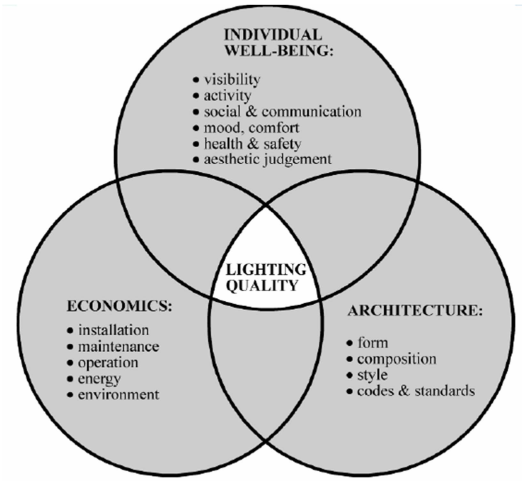


Figure 1 – Elements of light quality

The case study concerns two laboratories where we test household cold appliances(ICELAB) and electric ovens (FIRELAB) by sharing several infrastructures (e.g. climatic chambers). The hall, an industrial-like room, 8.00 x 9.40 m, with a height of 7.00 m high, hosts task zones for researchers and technicians. These zones consist of 3 climatic chambers and 2 workstations (desks at 1 m high) where part of the experimental setup is executed.

The luminaires are designed and realized ad hoc, by incorporating electronic devices for wireless communication and antenna.

The dedicated smart control system is used for the whole management of the individual luminaires. Wireless ZigBee protocol is used for communication between all the devices: luminaires, photo sensors, actuators, presence sensors, manual control devices, automatic control devices. Tablets have been selected for the case study, among other possibilities including smartphones. A central controller collects data from the mesh net and overlooks all the manual and automatic controls. Presence sensors, originally thought to be inside the luminaires themselves, have been realized as standalone devices, allowing more investigations on habits while the user moves in the the room.

In the following Figure 2 the planimetry of the hall and some views of the Installed HumbleBee system is given.

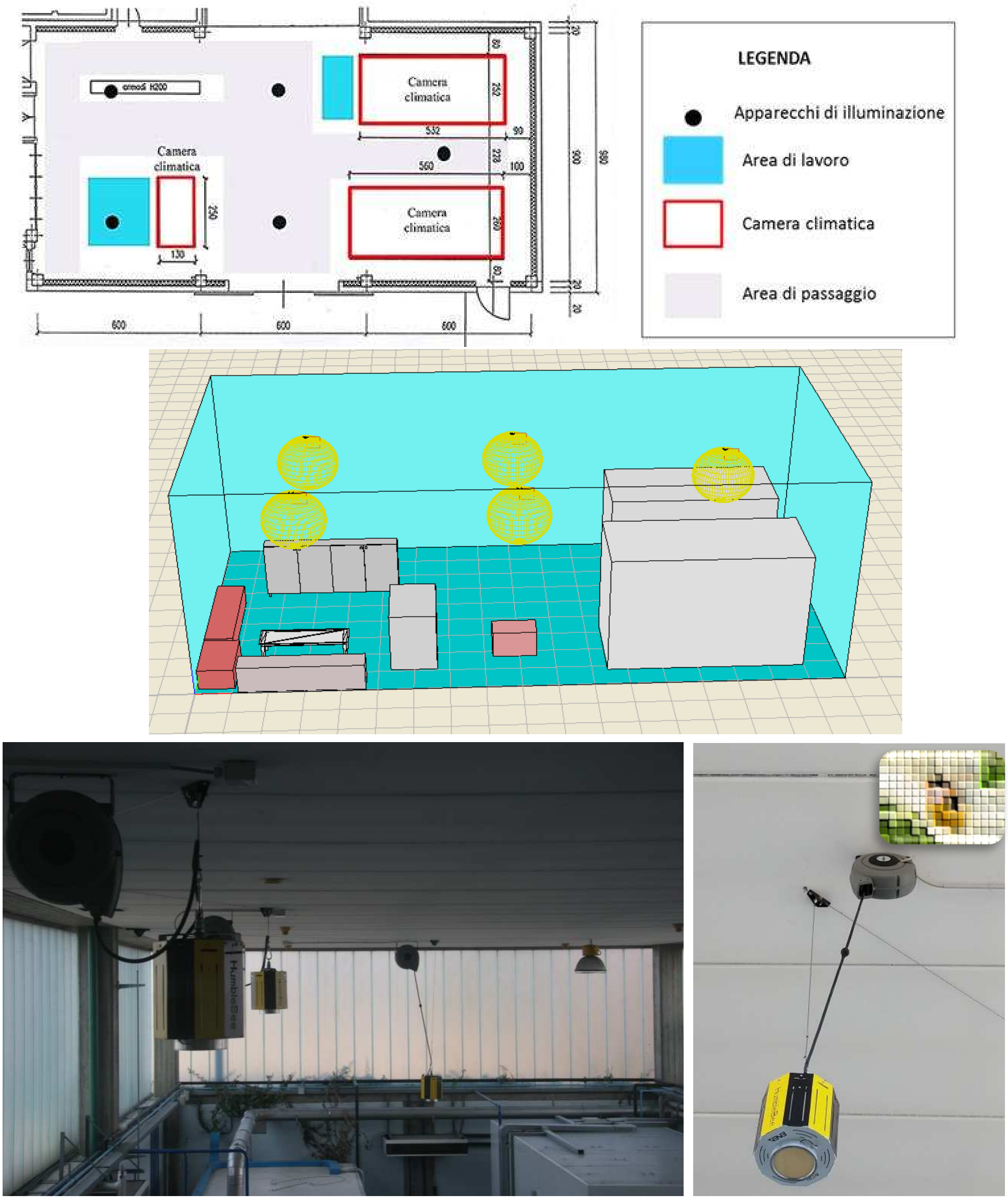


Figure 2 – Case study with installed HumbleBee system

The performed tests and evaluations

Thermal tests

In order to assess the maximum temperatures potentially dangerous for the correct operation of the luminaire, critical thermal zones have been selected,. They include the remote phosphor area, the case, the DALI driver, the heat sink and the zone with the blue LEDs. PT100 thermo-resistances have been placed on the surface of the selected critical zones. The test has been performed in a climatic chamber, at an environmental temperature 20°C and 50°C.

At the same time, during a test at 20°C, an infrared camera has been used to make a qualitative / quantitative analysis of the luminaire surface, as shown in Figure 3. Special care has been taken in order to detect data from high reflectance surfaces (e.g. metal surfaces). For this purpose high emittance target have been applied to the surface.

Figure 3 – Thermal images

Tests show that the temperatures in the different zones depend on the environmental conditions. The remote phosphor glass is one of the most critical zones, followed by the flange.

Figure 4, shows a comparison between the temperature measured with PT100 and the same one calculated by infrared measures (i.e. with infrared camera).

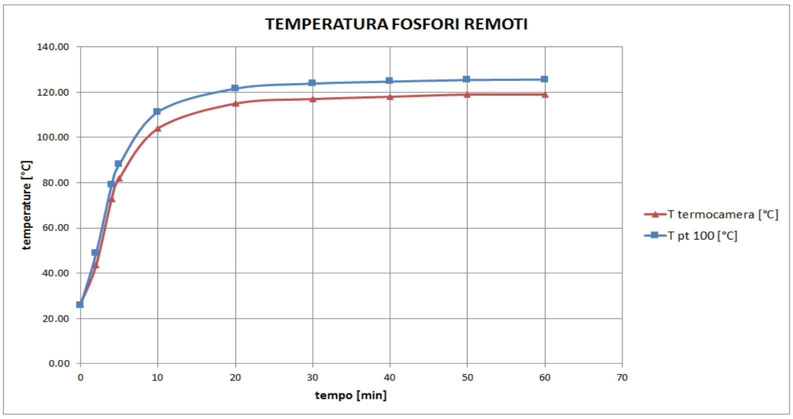


Figure 4 – Comparison of temperatures measured with termoresistance and infrared camera

Electric tests

Electric parameters have been measured an assessed: electric power, voltage, current at LED level and whole luminaire level (i.e. including driver), at different current levels, i.e. at different dimming levels (range 0% - 100% dimming, step 5%). In Figure 5 the trend of the measured electric parameters (at LED level) depending on the dimming level is plotted.

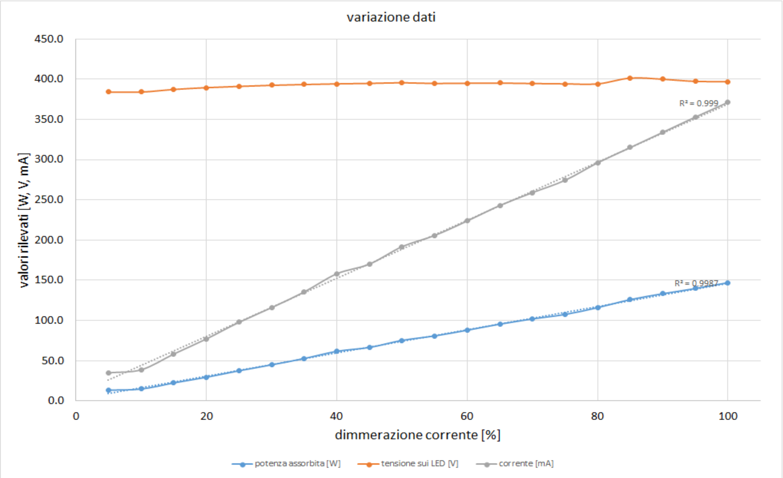


Figure 5 – Electric parameters measured during dimming

Photometric tests

A number of photometric tests have been performed:

1. In the Ulbricht sphere, luminous flux and spectral distribution depending on dimming level
2. By a goniophotometer (in an external laboratory), the spectral distribution, the luminous flux and the distribution of intensities (photometric solid).
3. The variation of luminous flux with dimming levels is almost linear. has been measured (see figure 6)
4. CCT, calculated from the spectral distribution, results independent from the dimming.

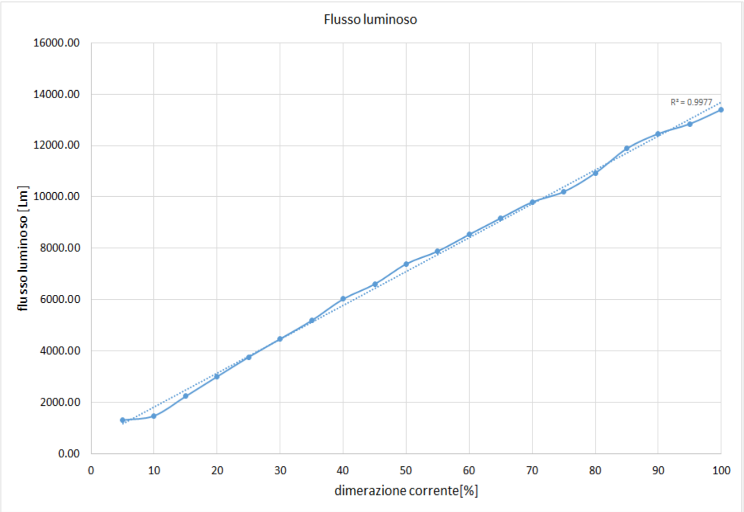
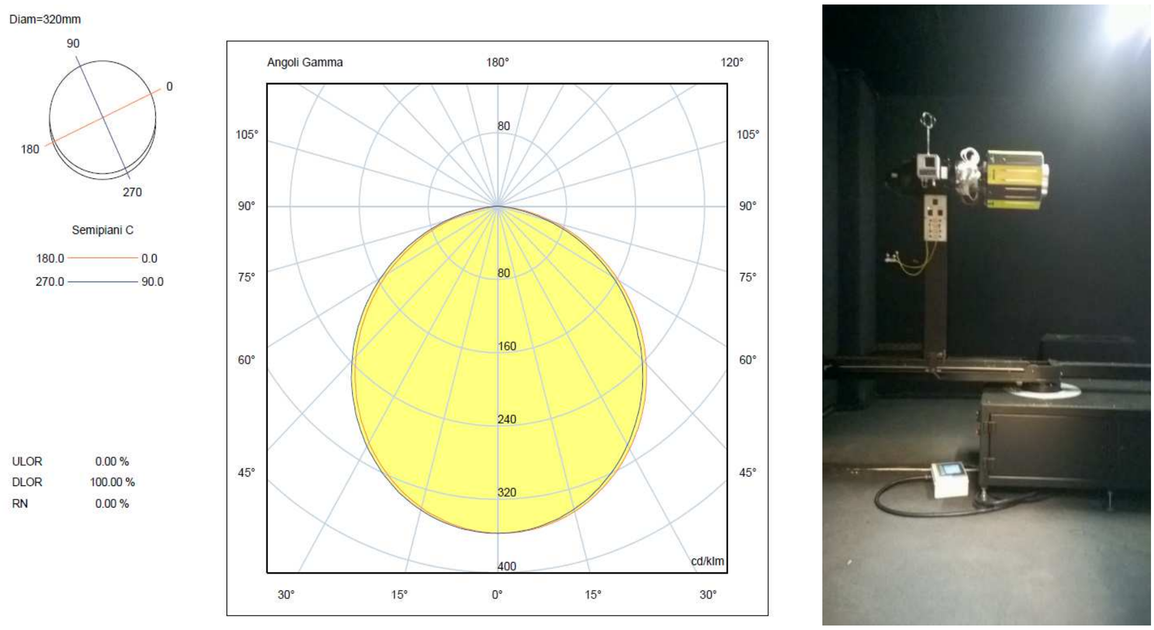
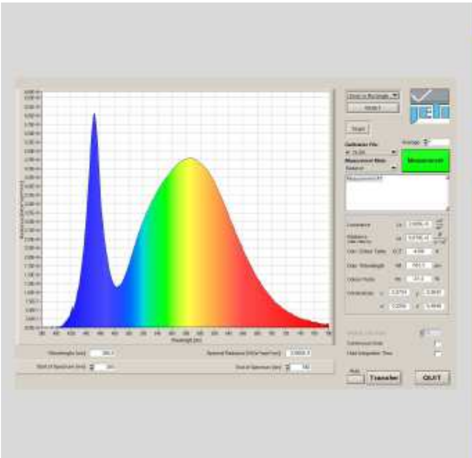


Figure 6 – Luminous flux = f(dimming)

The photometric solid of the luminaire is shown in Figure 7.





CIE Chromatic Coordinates				
1931 (x,y)	x	0,3734	y	0,3643
1976 (u',v')	u'	0,2255	v'	0,4949
Corr. C.Temp.	CCT	4109 K		
Color Rendering Index (CRI)				
Ra	80,49	R8		67,1
R1	79,3	R9		12,9
R2	86,1	R10		65,0
R3	89,1	R11		75,3
R4	79,0	R12		54,7
R5	78,6	R13		80,6
R6	78,7	R14		93,6
R7	86,0	R15		76,3

Figure 7 – Photometric and spectrometric results and the sample inside the goniophotometer

Another test has been performed in a dedicated "dark room" (i.e. a room, dull black painted, 4.00m x 4.00m x 3.00m). The luminaire has been suspended at 2.5 m heigth on the working plane. Figure 8 shows illuminance levels on the working plane with different dimming levels. Also in this case, illuminance is almost linear depending on power.

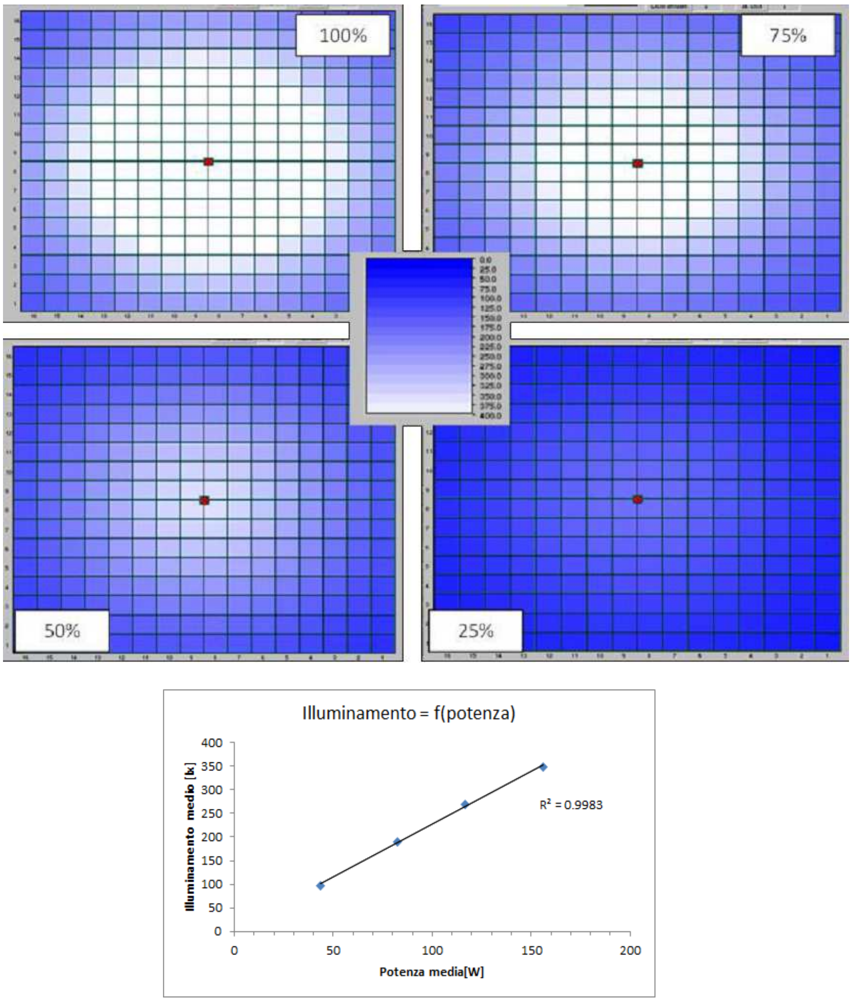


Figure 8 – Measured illuminance at different dimming levels in the dark room

Photometric simulation of the case study has been performed using measured photometry of the luminaires (see Figure 9). The results validate the project hypothesis, i.e. standard requirements are fulfilled with the luminaires installed at 4 m height.

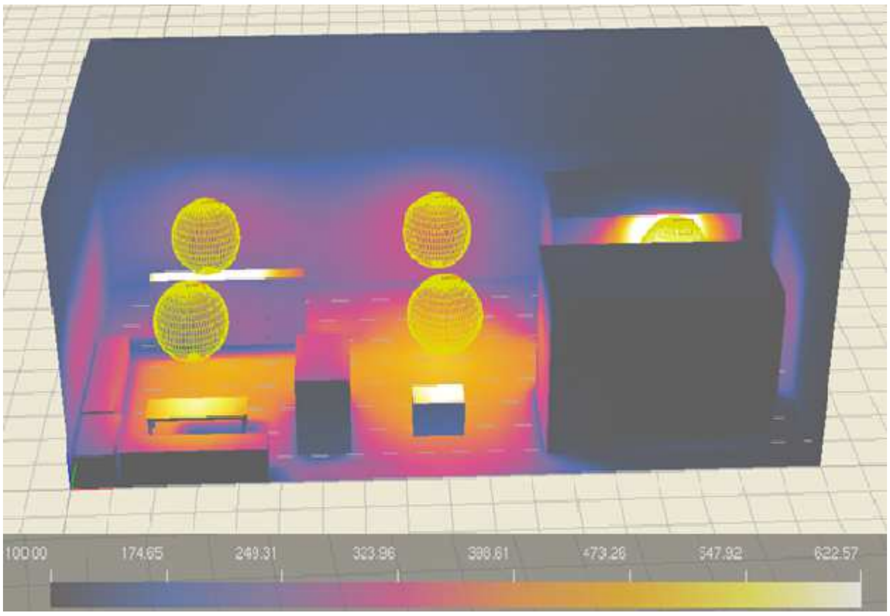


Figure 9 – Photometric simulation with HumbleBee luminaires installed at 4 m height

Preliminary data of the real use in terms of energy savings

A preliminary campaign has been started with the aim to assess the energy performance of the installed system.

Results of typical working day are shown in Figure 10. Data have been collected and recorded by using laboratory instruments. At the same time, automatic data have been collected by the smart control system. Preliminary analysis show a very good agreement between the two different acquisitions.

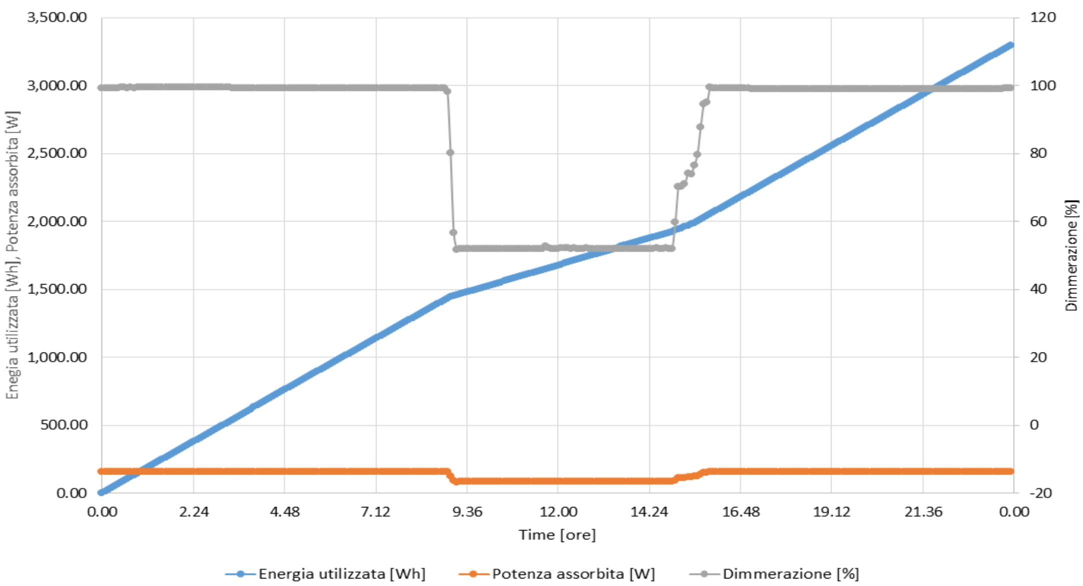


Figure 10 – Energy consumption, power and dimming level during a typical working day

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Case study of deep retrofitting of a residential building towards plus energy level

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SINTEF Building and Infrastructure

Abstract

A typical residential building from 1937 located near Wuerzburg in Germany, was deep retrofitted in 2013. Roof, façade and ceiling in the basement were highly insulated and thermal bridges were minimized. Windows were replaced with three-layered glazed windows with wood-aluminium windows. A compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed together with an 8 KW PV system with a south-west orientation and 50 degrees angle (roof-integrated). The ventilation ducts were integrated into the existing chimneys. Residential appliances/white goods (Refrigeration, Laundry, Dishwashing) were installed/replaced by A+++ equipment. Cooking equipment was replaced by induction device. Lighting fittings were replaced with LED in the whole building.

This represents a very comprehensive retrofitting towards plus energy level. Energy consumption and production as well as usage patterns and load profiles were monitored over a period of one year. The simulations of energy balance and load profiles match well with measurements. Self-consumption and export of electricity to the grid was monitored. The results show variations in self-consumption. Monthly self-consumption varied between 6% and 25.5%. Energy and load profiles represent a new type of grid load that needs further recognition.

Introduction

Residential use of energy is responsible for 28% of EU energy consumption [1]. The barriers to consumer energy saving have been known for more than 30 years but are still present, in particular split incentives (e.g. tenants vs. landlords), lack of information, high initial investment in energy-efficient equipment and habits of energy users [2].

Likewise, while awareness of the existence of renewable energies has improved considerably in the last years, there is still a lack of understanding of how to use and optimize them in practice.

The EPBD requires nearly zero energy buildings from 2021. There are many approaches to this goal and several pilot buildings have been built and extensively measured [3]. The theoretical approach is normally based on two pillows; first, energy saving measures have to be applied that ensure a massive reduction of heating energy. The second pillow is the production of renewable energy on-site. Both measures have been applied in this case.

A residential building from 1937 located near Wuerzburg in Germany, was deep retrofitted in 2013. The project received funding from the German Bank for Rebuilding (KfW) in the class kfW50 which uses 50% of the energy budget defined in the existing German building code (EneV) [4;5]. More ambitious levels (e.g. KfW40 or any type of zero energy buildings) do not exist for refurbishments (only new constructions). There are however, additional funding schemes for heating systems and FIT for photovoltaics (PV) [6;7]

History

The building is part of a community built between 1937 and 1960ies with identical footprint. An almost rectangular plan (9 x 11 m) paired with a steep roof (52degrees) starting from the basement level ensured a compact building form. The heated floor area in ground and first floor was 125 m2. It was increased by adding heated floor area in the second floor (formerly unheated attic) and by insulating the roof to 160 m2. In order to increase functionality, the old bathroom without WC was converted into a bedroom and a new space formed a new bathroom (with WC and shower) and new space for an additional stair to the second floor.

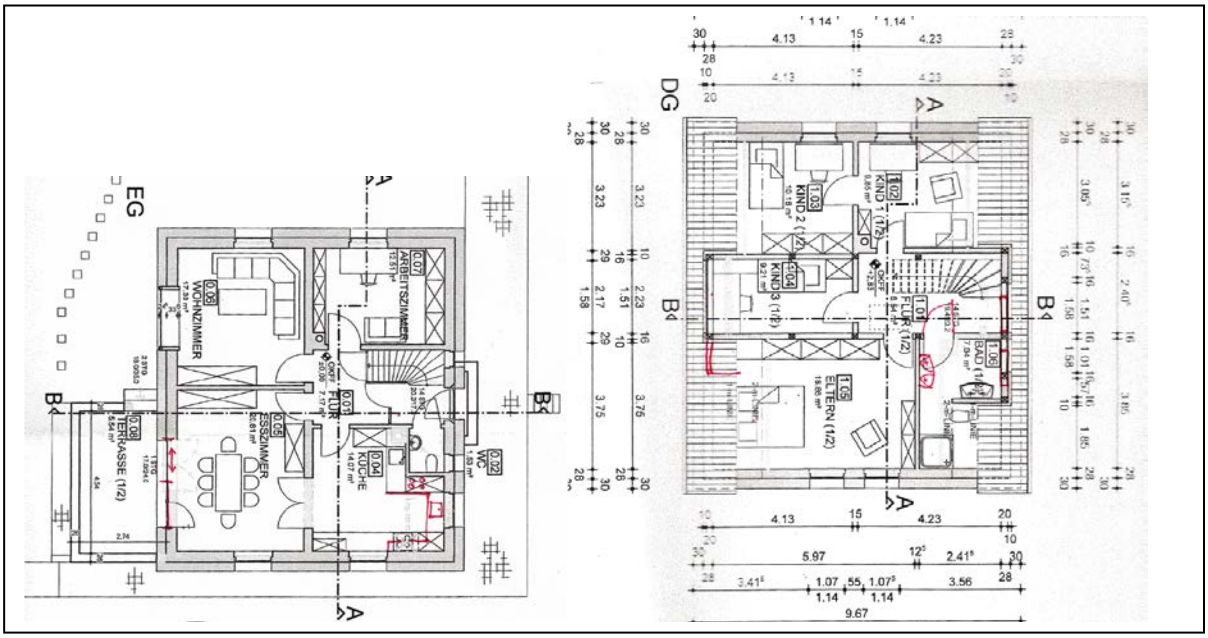

Figure 1 floor plans of ground floor (EG) and 1. floor (DG)

The area in the building is distributed over 4 floors (including basement). While the basement is not heated, the ground floor, 1. and 2. floor are heated. The building is inhabited by a family with 4 children, i.e. 6 persons household which equals 26.5 m2 heated floor area per person (Figure 2).

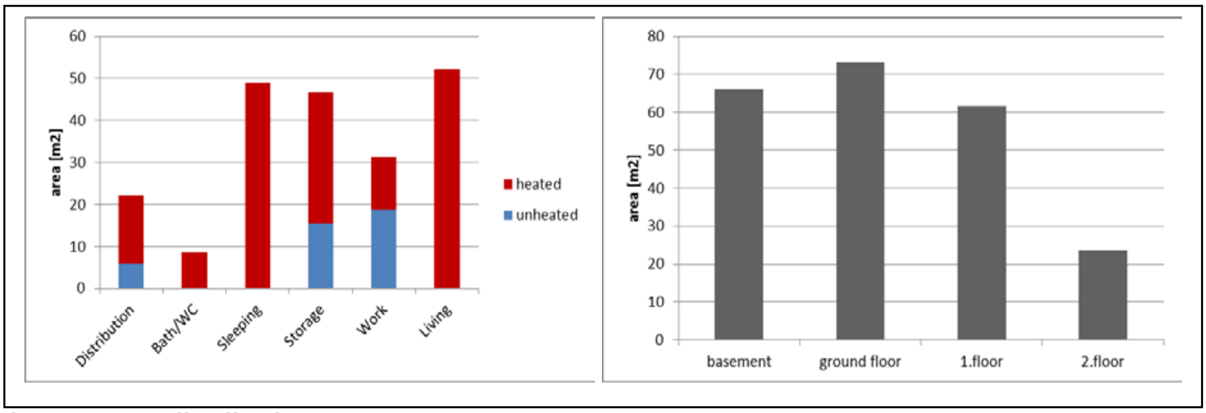

Figure 2 area distribution

Objectives

This represents a very comprehensive retrofitting towards plus energy level. Energy consumption and production as well as usage patterns and load profiles were monitored over a period of one year. The simulations of energy balance and load profiles match well with measurements. Self-consumption and export of electricity to the grid was monitored. This provides valuable insight into the concept of zero energy buildings (ZEB) [8;9].

Method

A typical residential building from 1937 located near Wuerzburg in Germany, was deep retrofitted in 2013. Roof, façade and ceiling in the basement were highly insulated and thermal bridges were minimized. Windows were replaced with three-layered glazed windows with wood-aluminium windows. A compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed together with an 8 KW PV system with a south-west orientation and 50 degrees angle (roof-integrated). The ventilation ducts were integrated into the existing chimneys. Residential appliances/white goods (Refrigeration, Laundry, Dishwashing) were installed/replaced by A+++ equipment. Cooking equipment was replaced by induction device. Lighting fittings were replaced with LED in the whole building.

Usage patterns and load profiles were monitored over a period of one year. Load profiles were simulated and measured. Electricity generation from PV system was monitored for one year. Self-consumption and export of electricity to the grid was monitored over the period of one year.

Results

The old building had an energy use of 479 kWh/(m2 a) including 279 kWh/(m2 a) for heating after the German standard (EnEff) [5]. During the deep retrofitting process the whole building envelope was insulated and thermal bridges minimized. The heating system as well as water supply and plumbing system were upgraded/renewed. In addition, a compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed together with a 7.95 KW PV system with a south-west orientation and 50 degrees angle (roof-integrated). The total renovation project resulted in 1350 € / m2 costs for energetic upgrading measures and 1150 € / m2 costs for maintenance and increase in user quality. The intentions of the project were highly ambitious and the catalogue of measures can be divided into the following sections.

Building envelope

The roof beams were doubled with 12cm wooden beams and the gaps between were filled with isofloc, a loose filling material based on recycled paper fabric and 2 x 3 cm insulating wind break plates. The façade was insulated with silicate blocks of 24cm thickness. The construction process focused on reducing thermal bridges to a minimum.

The ceiling in the basement was insulated with 12cm insulation mats.

Windows were replaced (not directly replaced since the position of the window frame moved from the center of the brick wall to the outside of the brick wall) with three-layered glazed windows with wood-aluminium windows. The position was on the outside of the original wall (see Figure 3, left for construction details) and it was made airtight by gluing a foil around the frame (Figure 3, right)

Figure 3 Left photo: construction detail of fixing the frame on to the wall; right photo: airtightness foil glued to the wall

Some of the south and south-west facing windows were enlarged (vertically and horizontally) and in addition equipped with a shading system (manual venetian blinds) covered with an additional glass layer. The U-value of the window (including frame) is 0.75 W/(m2 K).

Air tightness was improved to a measured infiltration rate of 1.0 h-1 (n50). Infiltration was not measured before the retrofitting. But the visual inspections showed large holes around window frames in the 1. Floor (bathroom) and ground floor (terrace door in 2. Living room).

Plug loads

The old building was equipped with fridge, washing machine, toaster and microwave in the kitchen. A TV and a telephone were used in the living room. All appliances were replaced by A+++ equipment. Cooking equipment was replaced by induction device.

Dishwashing was installed with A+++ equipment. Cooking equipment was replaced by induction device.

Two computers (laptops; each 60W) were installed in the office room, together with a printer, a rooter and a telephone (with 2 hand-helds, one was installed in the office room, one in the sleeping room on the 1. Floor).

Lighting fittings were replaced with LED in the whole building.

Table 1 Number of LED fittings distributed in the building (with living, kitchen and office in ground floor, sleeping rooms in 1. and 2. floor)

	Ground floor (EG)	**1. floor**	**2. floor**	**sum**
Area [m2]	73,28	61,68	23,57	158,53
Number of fittings	13	11	5	29
Installed power [W]	93	63	15	171
Installed power per area [W/m2]	1,269	1,021	0,636	1,079

In addition, 4 LED task lights with solar cells and battery were put in 1. (3 pieces) and 2. (1 piece) floor. They are not connected to the grid.

All electric cables were replaced by new. This was necessary because the old cables were not complying with the existing standards.

Figure 4 shows annual electricity consumption for household and heat pump compared with average values (BMWi) [10]. It can be seen that household electricity use was 1806kWh while heat pump (compact unit) electricity use was 4643kWh.

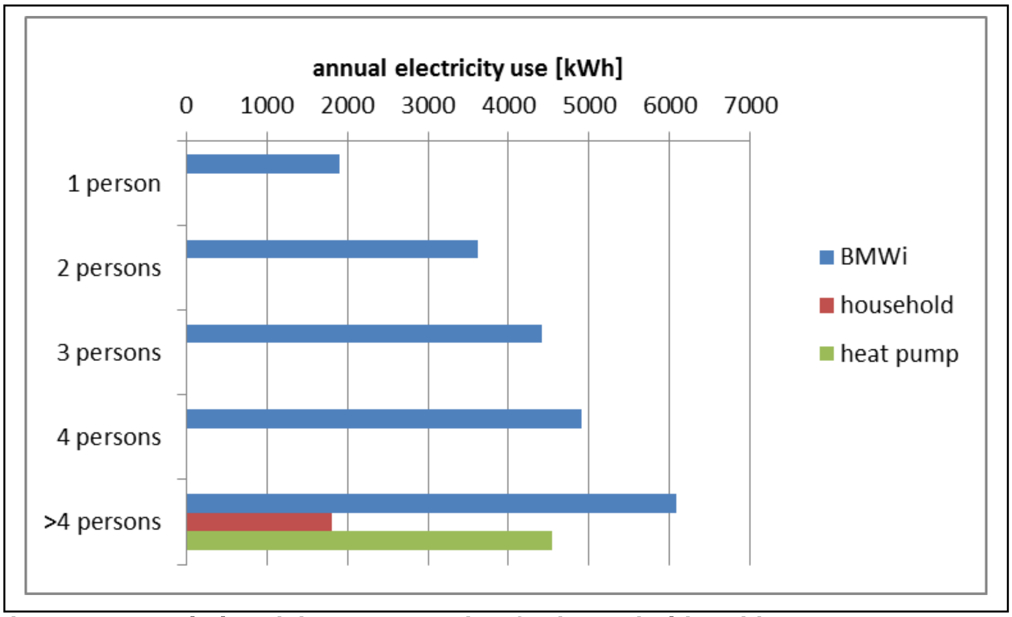

Figure 4 Annual electricity consumption for household and heat pump compared with average values [10]

Building services

A central heating cycle with 1-2 radiators in each room has been installed in the 1970ies. Several water pipe breaks have been detected and have been repaired. The central heating system was reused and extended for the 2 additional rooms (additional bedroom in 2. floor, new bathroom and 1 bedroom which was converted from the bathroom in the 1. floor). An underfloor heating system was installed in the kitchen (and 2. Living room extension).

Water supply and drainage system was old. The whole water supply system was renewed with a grey water system.

Ventilation

A 6 kW compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed. This delivers 220m3/h to all the rooms (except storage room in 2. floor; 35m2) with a supply and extract fan (with dampers). A cross-plate heat exchanger with 85% thermal efficiency is included in the compact unit.

Energy supply

The old building used a 6kW oil boiler equipped with a 5200l heating oil storage tank. A 6 kW compact unit (balanced ventilation system with integrated air-to-water heat pump) was installed. The COP of this unit varies with outdoor temperature. Since exhaust air is used as heat source, the heat pump is able to run without activating the electric heater until outdoor temperature of -6.8 °C. For the electricity supply a special 'heat-pump' tariff was chosen (HT: 28 € cent/kWh; LT: 20 € cent/kWh) which does not allow connecting the PV system directly.

Figure 6 shows the monthly monitored electricity consumption of compact unit (HP with ventilation system)). Here, the results show high and low tariff operation hours (HT: form 06:00 am until 22:00 pm and NT: from 22:00 pm until 06:00 am). The heat pump is equipped with a 400l DHW storage tank and operation optimization seems possible (shifting more operation time from HT to NT). But the figures include fan power for the balanced ventilation system (220m3/h supply and exhaust airflow rates).It can be seen that electricity use was higher in the winter months (as expected). In the summer months the electricity was used for ventilation and DHW. A more detailed analysis (including COPs) is expected for later this year.

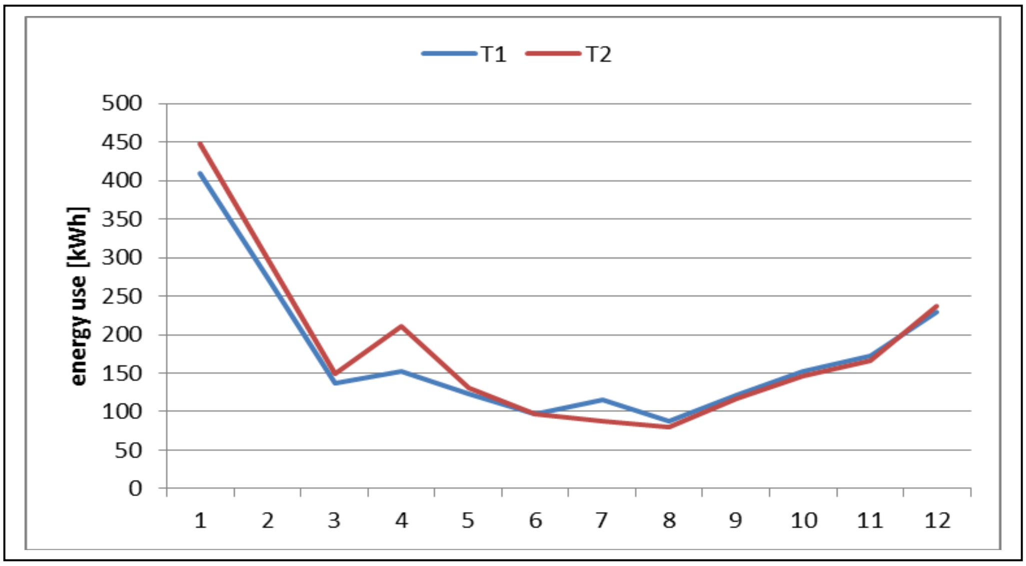

Figure 6 Monthly monitored electricity consumption of compact unit (HP with ventilation system) for two tariffs (T1 and T2, day and night time tariff respectively)

Renewable energy sources

A 7.95 KW PV system with a south-west orientation and 50 degrees angle was installed. It was chosen to use a roof-integrated system consisting of 32 modules with 165 W each (see Figure 7). The inverter controls each module separately, ensuring minimized shading effects from the 'Gaube'. The PV system provided appr. 6383 kWh p.a. The electricity was first used in the building (1010kWh) and secondly sold to the grid (5373kWh). Since FIT was fixed in October 2013, a rate of 0.1454 €/kWh was given by the local energy provider ('Stadtwerke') for buying while providing electricity costs 32 € cent/kWh (including fix costs). The potential for saving energy costs should encourage self-consumption.

Figure 7 PV system and layout, south-west orientation (left photo of the south-west facade; right module layout with monitoring figures for each module)

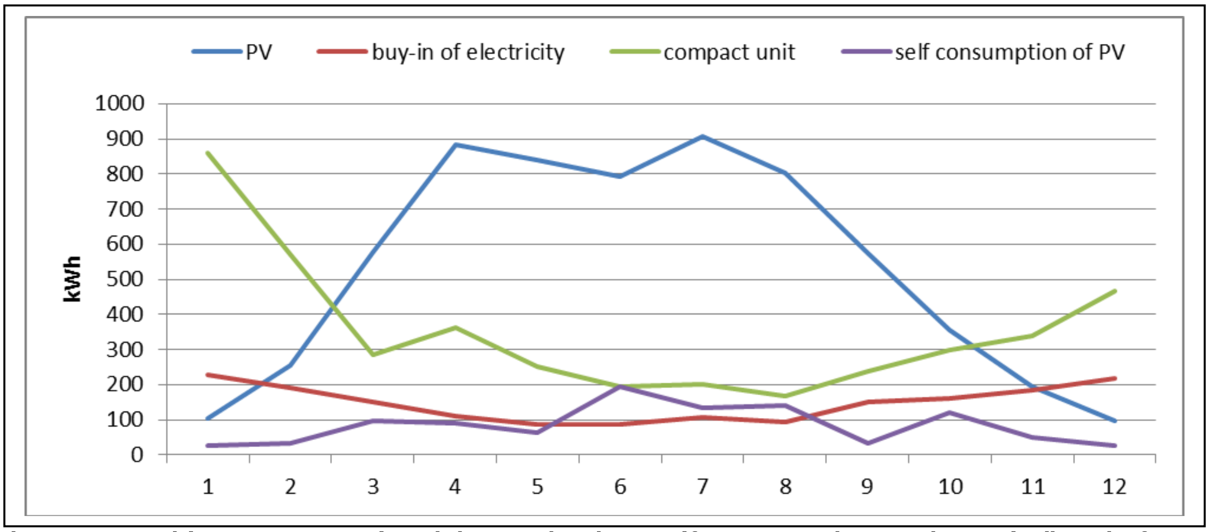

Figure 8 Monthly PV system electricity production, self-consumption, and supply (buy-in from grid)

Figure 8 shows It also illustrates electricity production from PV, the amount of electricity that had to be bought from the grid and the amount of electricity that is self-consumed.

Self-consumption

The results show variations in self-consumption. While self-consumption was larger during summer months in absolute figures, it dropped during the winter months (see Figure 6 and Table 2). The highest self-consumption was monitored for June (194kWh), while PV production was relatively low (with only 792kWh compared to 840kWh in May and 907kWh in August). Self-consumption was also visualized in Figure 9. Here, energy use and energy production are plotted in x- and y-direction. The red line illustrates when zero energy is reached (ZEB). It can be seen that in 5 months of the year (Jan, Feb, Oct, Nov, and Dec) the energy used in the building is larger than energy produced. In the other seven months (Mar, Apr, May, Jun, Jul, Aug, Sep) energy production is larger than energy demand.

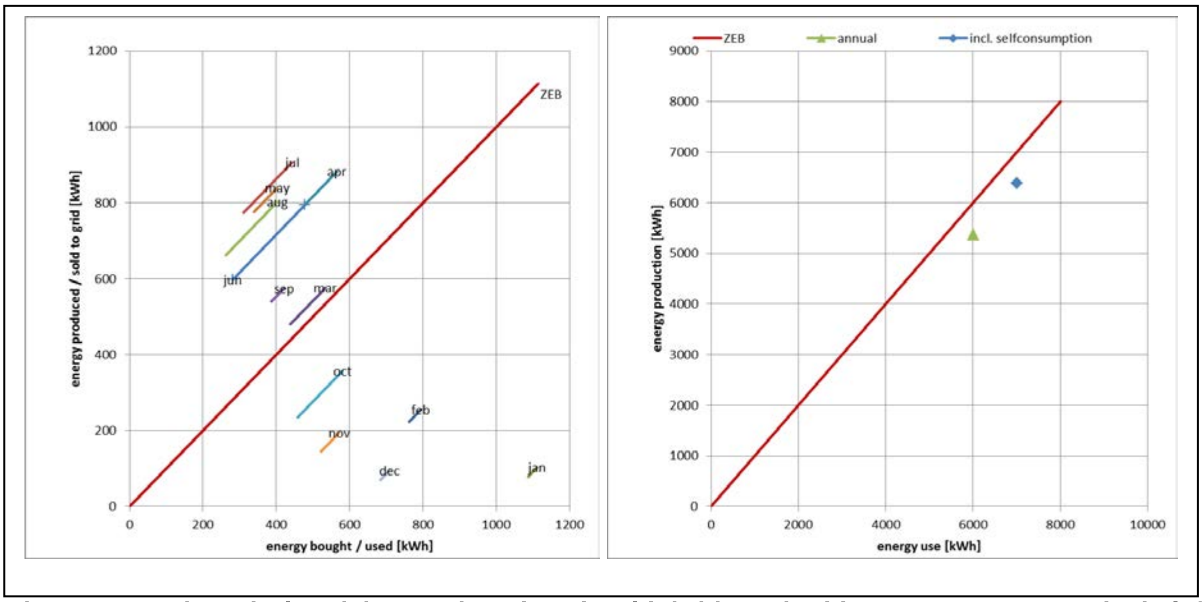

Figure 9 Monitored electricity produced and sold (with and without own consumption), left with monthly values, right annual values

Table 2 Monthly PV production, self-consumption and excess sold to the grid

period	PV electricity sold to grid [kWh]	PV electricity produced [kWh]	Self- consumption (C-B) [kWh]	Self-consumption (D/C) [%]
January	78	104	25.85	24.9 %
February	223.3	256	32.71	12.8 %
March	480	576	95.94	16.7 %
April	792	883.2	91.70	10.4 %
May	776	840	64.00	7.6 %
June	598	792	194.00	24.5 %
July	774	907	133.05	14.7 %
August	662	803	140.50	17.5 %
September	540	575	34.62	6.0 %
October	235	356	121.44	34.1 %
November	145	194	49.00	25.3 %
December	70	95.3	25.30	25.5%

Discussion

The results show variations in self-consumption. There is considerable potential for increasing self-consumption by using energy storage to shift PV electricity production to demand. However, an increase in self-consumption will not improve the building towards ZEB. But additional PV power could increase the balance towards ZEB. At the moment (with data for 2015) the building is missing 632kWh. However, PV production was slightly lower than projected (and simulated). Also, the heat pump (compact unit) used almost 700kWh more than 2014. The reason for this is still under evaluation.

Conclusions

This paper reports a case study of deep retrofitting of a residential building towards plus energy level. Energy consumption and production as well as usage patterns and load profiles were monitored over a period of one year. The simulations of energy balance and load profiles match well with measurements. Self-consumption and export of electricity to the grid was monitored. The results show variations in self-consumption. Monthly self-consumption varied between 6% and 25.5%. Energy and load profiles represent a new type of grid load that needs further recognition. An optimization of the operation of the building should be done based on the following needs:

- Optimization of operation of the heat pump
- Careful check of heating demand, demand for DHW and saving potential
- Monitoring of PV system over a longer period (several years) and analysis with weather data
- Analysis of user pattern (dryer operation, lighting, other appliances)
- Increase of PV area, e.g. south facade or east roof, or carport
- Analysis of battery for electricity storage for operation optimization of building (but also additional electric vehicle (EV)

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doi:10.2790/290244

ISBN 978-92-79-59779-4