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Building Energy Performance and Location – from building to urban area

Bloem, J.J., F. Pignatelli, G. Martirano, M. T. Borzacchiello, C. Lodi, G. Mor and G. Hernandez

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Contact information
Name: Bloem J.J.
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 450, 21027 Ispra (VA), Italy
Email: hans.bloem@ec.europa.eu
Tel.: +39 033278-9842

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Chapter 3 by authors: J.J. Bloem, G. Martirano

Chapter 8 by authors: G.Mor, J.Bloem, G.Martirano, M.T.Borzacchiello, C.Lodi, C.Rassmussen, A.Tureczek

Chapter 9 by authors: G.Mor, G.Martirano, J.Bloem. M.T. Borzacchiello

Collaborating authors:

Hans Bloem

Joint Research Center (Ispra, Italy) e-mail: hans.bloem@ec.europa.eu

Francesco Pignatelli

Joint Research Center (Ispra, Italy) e-mail: Francesco.PIGNATELLI@ec.europa.eu

Giacomo Martirano

Joint Research Center (Ispra, Italy) e-mail: Giacomo.MARTIRANO@ext.ec.europa.eu

Maria Teresa Borzacchiello

Joint Research Center (Ispra, Italy) e-mail: maria-teresa.borzacchiello@ec.europa.eu

Chiara Lodi

Joint Research Center (Ispra, Italy) e-mail: Chiara.LODI@ec.europa.eu

Gerard Mor

CIMNE BEE Group (Barcelona, Spain) e-mail: gmor@cimne.upc.edu

Gema Hernandez Moral

CARTIF, Energy Division (Valadolid, Spain) e-mail: gemher@cartif.es

Christoffer Rassmussen

Technical University of Denmark (Lyngby, Denmark) e-mail: chrras@dtu.dk

Alexander Tureczek

Technical University of Denmark (Lyngby, Denmark) e-mail: atur@dtu.dk

Foreword

This report on the ELISE Energy & Location project gives an overview of the activities during the reporting year 2017 and the progress made for the development of methodologies for the assessment of energy performance of buildings based on geo-location and big data handling.

The joint project by two JRC Units B6 and C2, started based on mutual interest on building energy performance and geo-location. Now, after several years of working on the development of practical methods and approaches, the network of international experts is extending as well as the projects that run in several Member States.

This report is relevant to the use case dealing with the identification, analysis and application of certain selected methodologies to assess energy performance of buildings based on dynamic data of measured energy consumption, measured on-site and coming from smart meters.

An analysis of existing methodologies to identify climate dependent energy and end-user energy with dynamic measured data will be presented, together with different methodologies to scale up the energy performance assessment of buildings to district level and beyond.

So far, the potential role of INSPIRE has been identified as a possible source of input data for some of the methodologies, primarily data related to buildings and/or addresses, but other INSPIRE data themes (e.g. Atmospheric Conditions/Meteorological Features, Utilities and Governmental Services, Statistical Units/Population Distribution), as well as INSPIRE data access and sharing mechanisms, can be exploited.

J.J. Bloem

Abstract

This report has been produced by the Joint Research Centre (JRC) as a joint activity of several JRC Units. The purpose of this report is to provide insight in the development of methods for the assessment of energy performance of buildings based on geo-location data. The JRC has studied internal documents, project reports together with relevant information available in the public domain.

The presented information is organised in several chapters dealing with different aspects in the study to appropriate methodologies for the assessment. Close collaboration between JRC Units as well as with international projects like the IEA-EBC Annex 71 is presented to clarify the dimension of the undertaken activity. In addition expertise has been brought into the project by contracting an external expert to study a particular part.

An introduction is given to the ELISE Action and the importance of the INSPIRE Directive in relation to the energy performance of buildings. A short introduction is given to the EU Energy Policy programmes and instruments directly related to this project: The energy related EPB and EE Directives and initiatives like CoM and the ELISE programme.

A chapter is devoted to the conclusions of the Energy Pilot project 2016 and presents a classification of approaches to which methodologies can be addressed as well as defined Use Cases to demonstrate selected methodologies. In the context of present EU Energy Policy, the requirements are identified for the development of methodologies.

Support was also given to the development of standards (CEN and ISO) for *in-situ* measurement methods during several European research projects. Presently the expertise is made available to support the development of energy performance assessment methods based on location data under the ELISE Energy Pilot project.

As an example of the development of a methodology, the Spanish case, taking into account the specific administration data and construction regulation, is presented in a separate chapter.

1 Introduction

The Energy Pilot is a pilot project[1] [2]in the frame of the ELISE Action[3] - European Location Interoperability Solutions for e-Government - led by JRC, of the ISA[2] Programme[4]- Interoperability solutions for public administrations, businesses and citizens – funded by DIGIT. The Energy Pilot aims at showing the benefits of using geospatial information and related technologies in the energy efficiency and energy saving EU policies lifecycle, with implementation and testing in a series of use cases.

Assessment of energy use in the built environment by using geo-located data to improve the quality of input data:

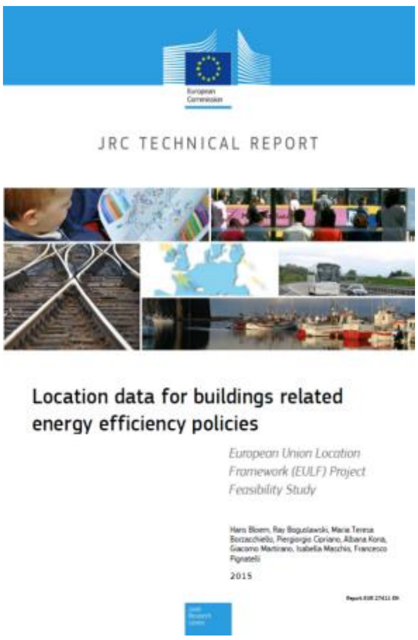
to support policy-makers in reporting and monitoring of energy policies and initiatives and

to harmonize the monitoring and reporting of energy efficiency policies at different scales.

The developed methodologies may support the whole policy life-cycle e.g. urban planning, implementation of measures for efficient renovation of buildings, etc.

The JRC concluded a Feasibility Study "Location Data for Buildings related Energy Efficiency Policies" in 2015.

http://publications.jrc.ec.europa.eu/repository/handle/JRC96946.

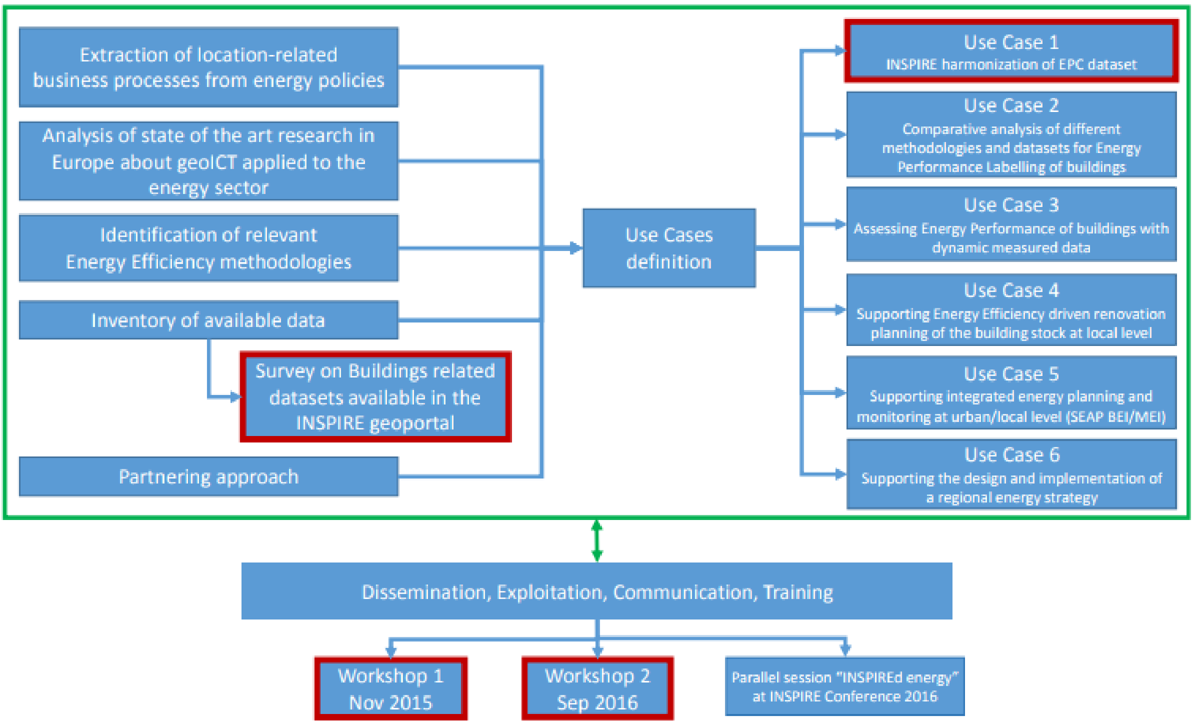


The report:

- identified an approach to compare different methodologies to support EPBD, EED and CoM policy instruments, based on the re-use of INSPIRE components
- made an initial analysis of the data flows relevant to EPBD, EED and CoM, has identified the relevant INSPIRE data themes best fitting for purpose and has made an initial mapping exercise
- outlined scope and content of a full pilot project that started in 2016

[1] https://joinup.ec.europa.eu/community/eulf/og_page/eulf-energy-pilot
[2] https://inspire.ec.europa.eu/pilot-projects/inspire-energy-pilot/440
[3] https://ec.europa.eu/isa2/actions/elise_en
[4] https://ec.europa.eu/isa2/home_en

Figure 1. Schematic overview of the Energy Pilot project.



Approaches and Use Cases were identified at an expert meeting that took place in 2016. Details can be in the appropriate chapters. Three main methodologies have been categorised, e.g. based on a holistic approach, by measurements and calculation methods. In Chapter 4 more details are given.

The importance of the INSPIRE Directive is highlighted. Summarised:

- INSPIRE offers the feature of scalability; from building to district or urban area up to Member State level
- INSPIRE offers also the development of new applications, such as:
  - Static building maps
  - Creation of real time service
  - Energy markets for electricity and gas
- INSPIRE offers big data handling in manageable and protected way
- INSPIRE offers usage of multiple databases (building stock, climate data, EPC data, utility data, etc.)

The ELISE Energy Pilot project involves a series of cities and regions to demonstrate how an integrated data approach can be established for planning, implementing, monitoring and reporting for policies and initiatives. The pilot will be implemented and tested through a series of use cases:

Use Case 1 - INSPIRE harmonisation of existing Energy Performance Certificate (EPC) datasets and creation of a web application for accessing them

Use Case 2 - Benchmark of different Energy Performance Labelling of buildings

Use Case 3 - Assessing the Energy Performance of buildings with dynamic measured data

Use Case 4 - Supporting Energy Efficiency driven renovation planning of the building stock at local level

Use Case 5 - Supporting integrated energy planning and monitoring at urban/local level (SEAP BEI/MEI)

Use Case 6 - Supporting the design and implementation of a regional energy strategy

So far a short introduction, the following chapters will discuss more details of the project, its policy context, the philosophy that supports the development of different methodologies and exemplary Use Cases that bring to the front the specific aspects of application of methods using the available data both from administrative sources as well as real measurements.

2 Policy Context

The EU is giving more and more emphasis to its energy policy, whose strategy and actions are included in the Energy Union Package and the 2030 Framework for Climate and Energy [1]. Buildings in which people live and work are responsible for an important portion of the energy consumption in Europe (40%). Several policies and initiatives aim at improving the energy performance of buildings and to collect data of sufficient quality on the effect of energy efficiency policies on building stock across Europe. So, the focus is on buildings.

According to studies conducted by BPIE (Buildings Performance Institute Europe) [2], buildings are responsible for the 40% of final energy consumption:

- Over 75% of building stock is older than 25 years;
- Averaged final energy consumption data is 185 kWh/m^2 for residential buildings and 280 kWh/m^2 for non-residential buildings;
- Whereas deep renovation of buildings could cut 36% of their energy consumption by 2030

In several Member States stringent requirements are imposed by energy performance legislation and an increased awareness for environmental issues in building codes can be observed. At present, requirements and labelling of the energy performances of buildings is mostly done in the design phase by calculating the theoretical energy consumption.

Regarding normative measures, this interest has been materialized in different European Directives and the progressive enactment of related regulations. Instruments of the European Energy Policy are Directives, Standards and other initiatives. In the framework of the Energy and Location project the most relevant are:

- Directive 2010/31/EU - Energy Performance of Buildings – EPBD [3]; efficient use of energy in buildings
- Directive 2012/27/EU- Energy Efficiency Directive – EED [4]; efficient energy systems
- European energy policy initiative Covenant of Mayors (CoM), involving local and regional authorities
- European Location Interoperability Solutions for e-Government (ELISE) [5]; INSPIRE Directive [6]

The Directives could be considered as a framework for the Energy and Location project when the following aspects are considered:

- The aim of scaling up from a typical building (EPBD) up to national level (EED) by using location data to support stakeholders engaged in energy policies' lifecycle. The CoM is supportive in the sense that it considers urban areas and energy flows in cities.
- To leverage location-based data at building level as enabling factor to scale-up the methodologies to assess energy consumption and performance from local to urban to district to regional to MS level as required by the European Directives in the field of energy efficiency.

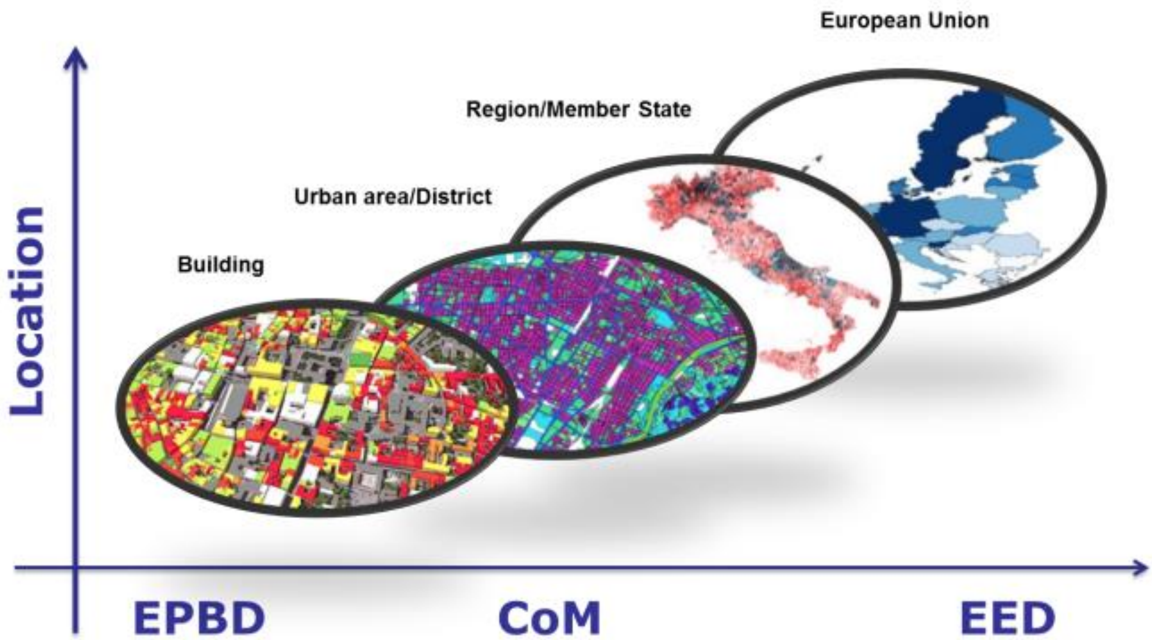
When it concerns buildings there are important legislative instruments to mention. Construction products are subject to the rules on the free movement of goods in the European Union (EU) and the rules relating to the safety of buildings, health, durability, energy economy and the protection of the environment. The Construction Products Regulation[5] (CPR) lays down harmonized conditions for the marketing of construction

[5] Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EC

products. Reliable information on construction products in relation to their performance is achieved by providing a common technical language and standardized assessment methods. The CPR – which was adopted on 9 March 2011 – repeals the Construction Products Directive[6] (CPD). The CPR entered into force in April 2011.

In particular the Energy Performance of Buildings Directive (EPBD) 2010/31/EU [3] adopted by the EU Council and the European Parliament in 2010, requires that from the year 2020 onwards all new buildings will have to be *'nearly zero energy buildings'*, comply with high energy-performance standards and supply a significant share of their energy requirements from renewable sources. To achieve the objectives of the EPBD, it is necessary to consider renewable energy technologies, the dynamic nature of the building energy flows and occupancy behaviour. It is also necessary to establish a robust energy performance assessment for new and renovated buildings.

Figure 2. Relation between EU energy policies and location



Apart from the CPR, there are a number of European policy directives in place that aim to exploit the potential offered by energy saving technologies, principally the Energy Performance of Buildings Directive (EPBD- 2010/31/EU), which require Member States to apply minimum energy performance requirements for new and existing buildings and which makes high energy performance design and the use of renewable sources of energy obligatory for new constructions after 2020.

The EPB Directive 2010/31/EU mentions in article 2:

> *The 'energy performance of a building' means the **calculated** or **measured** amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting;*

The European Committee for Standardisation (CEN) is currently working on bringing the present EPBD related energy standards in-line with these requirements. The CEN/TC 371 Energy Performance of Buildings Project Group, has been mandated to coordinate the

[6] Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (89/106/EEC)

development and maintenance of a coherent set of standards for the determination of the energy performance of buildings.

Working Group 13 of the Technical Committee 89 of CEN (CEN/TC 89 /WG 13) [7] has received the mandate (since 2009) to develop a standard for the in-situ thermal performance of materials, products and structures. However, to date, no standard has been agreed and no standard is available that adequately deals with the in-situ measurement methods associated with construction products, building elements or building structures for the energy performance assessment.

Further work is necessary to support the development of reliable procedures that are needed to implement new standards and regulations in this field. This development will facilitate the application of the EPBD contributing towards saving energy in buildings. Associated tools should be made available to practitioners.

European Location Interoperability Solutions for e-Government (ELISE) - Enabling Digital Government through Geospatial and Location Intelligence

Enabling Digital Government through Geospatial and Location Intelligence

European Location Interoperability Solutions for e-Government (ELISE)

When is this action of interest to you?
This action targets those working in public administrations or private companies that deal with information, data, services and processes using the power of location.

Relevant text in this chapter is taken from the ELISE web-site [5] and presented here to make the report more complete.

The ELISE action.

Location-related information underpins an increasingly high proportion of EU and national governmental policies, digital services and applications used by public administrations, companies and citizens dealing with information, data, services and processes using the power of location.

The European Location Interoperability Solutions for e-Government (ELISE) Action is a package of legal/policy, organizational, semantic and technical interoperability solutions to facilitate more efficient and effective digital cross-border or cross-sector interaction and data re-use. These digital interactions involving location information connect European public administrations with each other and with citizens and businesses they serve. This Action supports the goals of the Digital Single Market Strategy, including specific actions of the e-Government Action Plan and the European Interoperability Framework.

The ELISE action builds on the principles of the INSPIRE Directive which establishes an infrastructure for environmental spatial information in Europe, while continuing the work from two ISA Actions:

- The European Union Location Framework (EULF), which developed and promoted a best practice policy and guidance framework, underpinned by INSPIRE, with pilots in different countries and thematic domains, and
- A Reusable INSPIRE Reference Platform (ARe3NA), which facilitated INSPIRE implementation in Member States through the development of a structured implementation approach and body of reusable interoperability solutions.

ELISE continues this work by fostering the adoption of best practice interoperable solutions across the European Union in the context of 'location interoperability'.

Objectives

The ELISE objective is to break down barriers and promote a coherent and consistent approach to the sharing and reuse of location data across borders and sectors, supporting Better Regulation goals in terms of EU policy and the Digital Single Market strategy in the context of digital transformation of public services.

To achieve this ELISE will:

- Carry out studies to assess enablers and barriers of geospatial interoperability, examining the role of location information in the data economy and new digital platforms, including the Government as a Platform (GaaP) concept, and how these developments may be turned into value-add services, such as Application Programming Interfaces (APIs), developments in the Internet of Things (IoT), next generation statistics etc.
- Develop a framework of guidelines, recommendations and reusable tools for implementing and enabling geospatial interoperability, building on the initial work of EULF and ARe3NA, to expand into new business models for re-use of privately-held data and information for tasks in the public interest (reverse-PSI).
- Investigate disruptive technological developments for data exchange, licensing, privacy, trust and new ways of finding and using location data.
- Develop pilots and applications to test principles in practice, offer lessons and resources for others to build upon, provide the basis for a widespread rollout, and show the benefits of geospatial interoperability. These pilots will both support crosscutting applications or provide in-depth impetus in specific thematic areas, such as Energy Efficiency of Buildings and the Intelligent Transport Systems.
- Provide a "Geospatial Knowledge Base Service", including landscape analysis, capacity building and stakeholder support to help improve and implement geospatial interoperability.

Among many benefits of the ELISE Action, it is worthwhile to mention in the context of the Energy and Location project the benefits for citizens

- Better location-based services and access to public sector information for e-Government purposes as both consumers and co-creators of data.
- Public data (in particular geospatial data) are an engine for job creation and growth.

And for policymakers

- More effective policy development in domains featuring location information and services.
- Improved connections between public authorities across the EU in the field of location information.
- Improved geospatial data sharing and re-use between public authorities.

The ELISE Energy and Location Pilot project fulfils all requirements of the aforementioned achievements.

In 2016 ELISE started several activities, which are being followed up in 2017. Among these activities are to be mentioned:

- Establishment of an ISA2 Working Group on Geospatial Solutions, gathering Member States representatives from the geospatial and e-Government domain.
- Study on assessing the role of location information and services in building the EU data economy.
- Further development of the INSPIRE in Practice platform and Re3gistry software.
- Location extension to ICT assessment of new legislation.
- Definition and provision of a Geo Knowledge Base Service.
- Design and piloting a Location interoperability observatory in Member States.
- **Energy and Location Pilot related to the assessment of Energy Performance of Buildings.** This report contributes to the activity.
- Integration of EULF and ARe3NA solutions.

3 The role of INSPIRE

INSPIRE is the acronym of the Directive 2007/2/EC [6] of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community[7], to support European Union environmental policies, and policies or activities which may have an impact on the environment.

Energy policies well fit into the scope of INSPIRE and therefore they can benefit from a set of common data models and common data sharing mechanisms provided by INSPIRE and adopted by all EU MS to ensure the interoperability of their national SDIs (spatial data infrastructures) by 2020, according to the deadlines set by the INSPIRE roadmap[8].

This chapter aims at assessing at which extent INSPIRE can support the methodologies described so far in this report.

In both the dwelling energy footprint estimation (presented in chapter 8) and the benchmarking workflows (illustrated in chapter 9) INSPIRE has been envisaged as a potential source of input data.

In order to further explore this potential, a fit for purpose analysis has to be carried out on some candidate INSPIRE data themes. Among the thirty-four spatial data themes addressed by the Directive[9], the following six are relevant to the methodologies described in this report:

- Buildings
- Addresses
- Atmospheric conditions and meteorological features
- Statistical Units
- Population Distribution
- Utility and governmental services

Each of the above listed themes is analysed in more details in the following sub-sections.

Figure 3. Make INSPIRE work for you: https://inspire.ec.europa.eu

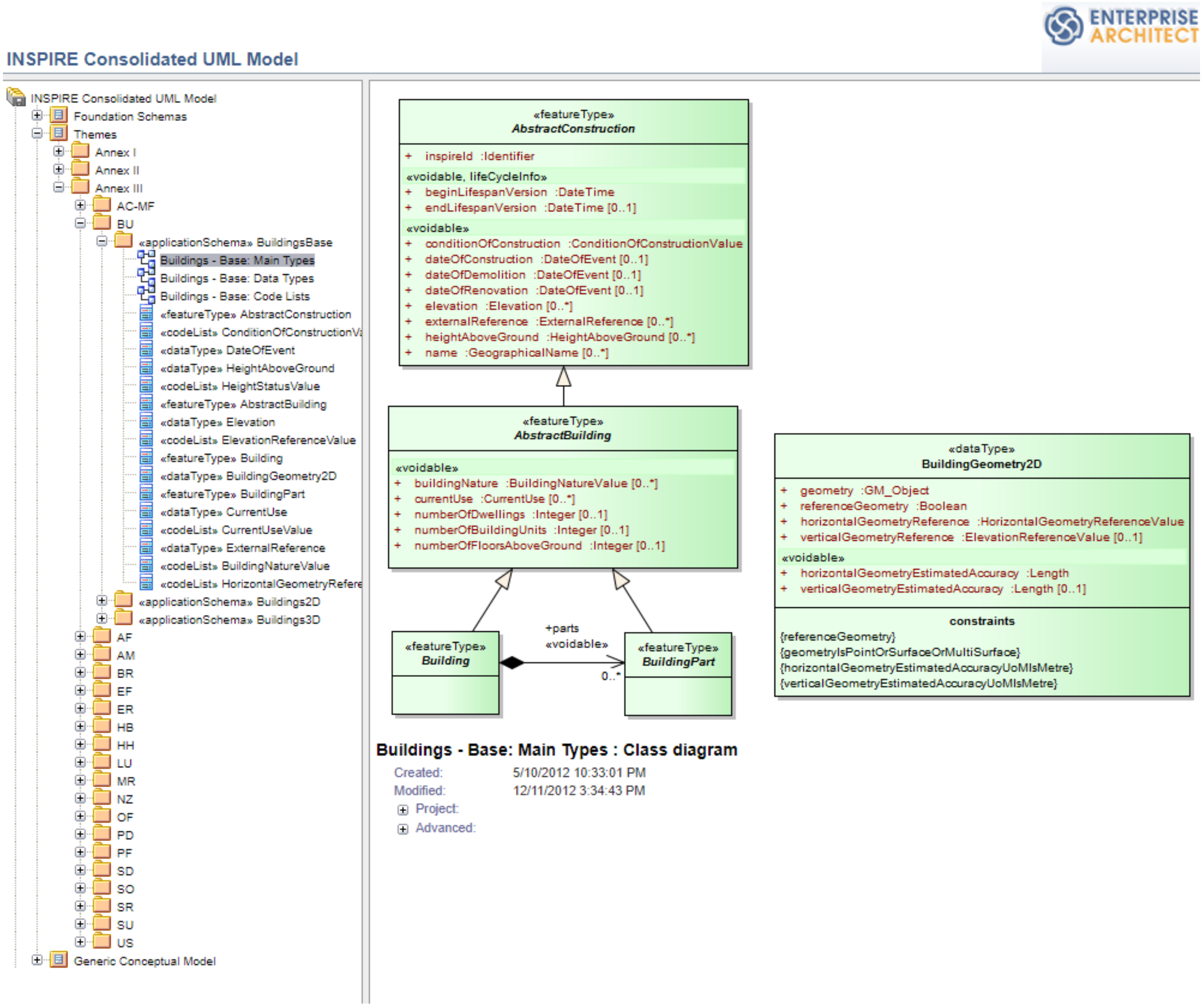
[7] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:EN:PDF
[8] https://inspire.ec.europa.eu/road-map-graphic/32443
[9] http://inspire.ec.europa.eu/data-specifications/2892

Buildings

The INSPIRE Data Specification on Buildings[10] contains a set of attributes relevant to energy simulations, such as dateOfConstruction, currentUse, numberOfDwellings, numberOfBuildingUnits, heightAboveGround. In particular, the currentUse attribute value has to be selected among a list of predefined values, set in the CurrentUse codelist[11]. It is important to highlight that the fixed parent values of the code list (residential, agriculture, industrial, commerceAndServices, ancillary) can be extended with new child values. As an example, new child values can be added to the current child values of the residential parent value (individualResidence, collectiveResidence (two or more than two dwellings), residenceForCommunities), in order to better match the energy simulations needs.

A UML representation of the application schema BuildingsBase provided by INSPIRE for the Buildings data theme is shown in Figure 4, in which are also visible some of the above mentioned attributes and some of their properties.

Figure 4 – Attributes of INSPIRE data model for Buildings

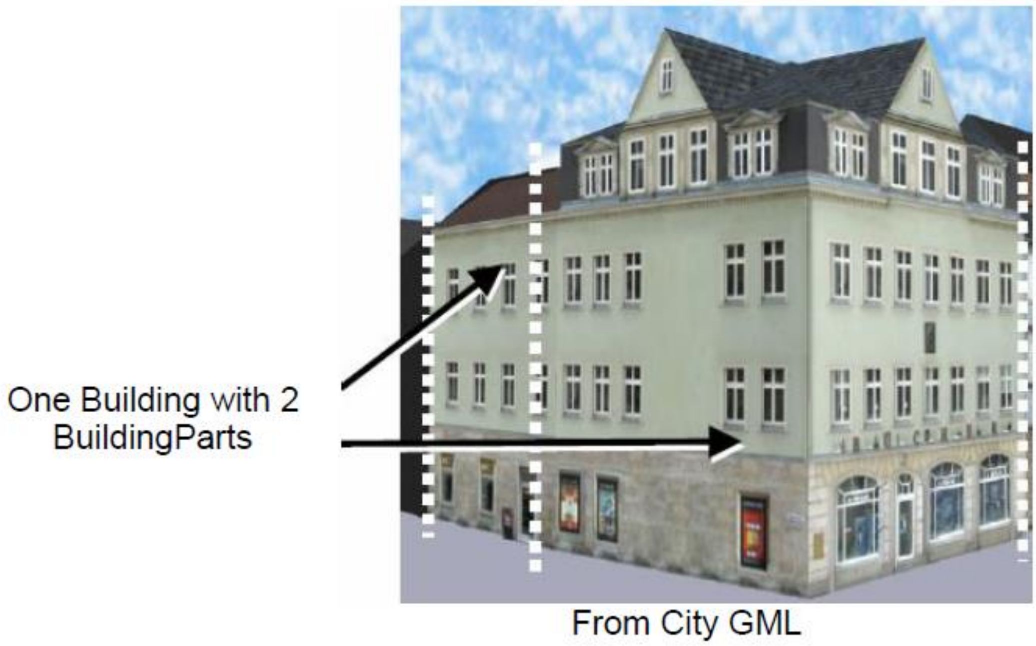


With reference to the Figure 4, it is to be highlighted that a Building can be composed by many "Building Parts". The definition of Building Part provided by the INSPIRE Data

[10] https://inspire.ec.europa.eu/Themes/126/2892
[11] http://inspire.ec.europa.eu/codelist/CurrentUseValue

Specification on Buildings is the following: "*A BuildingPart is a sub-division of a Building that might be considered itself as a building. NOTE 1: A BuildingPart is homogeneous related to its physical, functional or temporal aspects. NOTE 2: Building and BuildingPart share the same set of properties. EXAMPLE: A building may be composed of two building parts having different heights above ground.*" Figure 2 shows an example of relationship between Building and BuildingPart.

Figure 5 – Relationship between Building and BuildingPart



In order to provide a more detailed representation of the elements constituting a Building or a Building Part, INSPIRE introduced also the concept of Building Unit, defined as follows: "*a BuildingUnit is a subdivision of Building with its own lockable access from the outside or from a common area (i.e. not from another BuildingUnit), which is atomic, functionally independent, and may be separately sold, rented out, inherited, etc. Building units are spatial objects aimed at subdividing buildings and/or building parts into smaller parts that are treated as separate entities in daily life. A building unit is homogeneous, regarding management aspects. EXAMPLES: It may be e.g. an apartment in a condominium, a terraced house, or a shop inside a shopping arcade. NOTE 1: According to national regulations, a building unit may be a flat, a cellar, a garage or set of a flat, a cellar and a garage. NOTE 2: According to national regulation, a building that is one entity for daily life (typically, a single family house) may be considered as a Building composed of one BuildingUnit or as a Building composed of zero BuildingUnit.*"

But, despite the information related to Building Units could be very useful for the energy-related methodologies applied at dwelling level, unfortunately this spatial object has been defined only in a draft extended INSPIRE data model for Buildings. Therefore, before to expect that information related to Building Units will become available through INSPIRE, the endorsement of the INSPIRE extended models will be needed. This endorsement, which is part of a process handled within the INSPIRE Maintenance and Implementation Framework/Group[12], is not likely to happen in the very next future.

Moreover, it is to be highlighted that most of the attributes shown in figure 1 are optional and not mandatory (their multiplicity is indicated as [0..1] or [0..*]).

[12] http://inspire.ec.europa.eu/inspire-maintenance-and-implementation/46

Therefore, within the time frame set by the INSPIRE roadmap, harmonized information related only to mandatory attributes of Buildings and Building Parts spatial objects is expected to be available by the end of 2020.

Addresses

Most buildings can be identified (geocoded) by one or more addresses. An address is an identification of the fixed location of a property. The full address is a hierarchy consisting of components such as geographic names, with an increasing level of detail, e.g. town, then street name, then house number or name. It may also include a post code or other postal descriptors. More details can be found in the INSPIRE Data Specifications on Addresses[13]. The main concept of this data specification which can be relevant for the methodologies described in this report is that an address has a geographic position, which enables an application to locate the address spatially.

Atmospheric conditions and Meteorological geographical features

The INSPIRE "Atmospheric Conditions" and "Meteorological Features" themes are covered together in one Data Specification. These themes provide basic concepts and data models for environmental protection related activities requiring information on atmospheric conditions like weather, climate and air quality. The two themes are defined as follows:

- **Atmospheric conditions**: physical conditions in the atmosphere. Includes spatial data based on measurements, on models or on a combination thereof and includes measurements locations;
- **Meteorological geographical features**: weather conditions and their measurements: precipitation, temperature, evapotranspiration, wind speed and direction.

Regarding the temporal coverage aspects, the INSPIRE Data Specification on Atmospheric Conditions and Meteorological Geographical Features[14], state that "*for climate projections, only long-term time-means are considered to be in scope; data at a high temporal resolution is excluded*". Past data including climatological information, e.g. monthly means, as well as forecast data including climate information from numerical simulations can be considered within the scope of the INSPIRE theme Atmospheric Conditions and Meteorological Features.

Statistical Units and Population Distribution

The combined use of the data models of these two themes will facilitate harmonisation of datasets consisting of indicators. The Population Distribution theme deals with datasets of statistical information describing how some phenomena regarding human population are spread within some part of the 2D space. The theme has no direct spatial features, and only contains attributes supporting the description of population phenomena related to statistical units. Population data is linked to spatial objects (statistical units) through their common identifier, e.g. NUTS codes, administrative units or grid identifiers. However, the absence of direct spatial features is currently hindering the exploitation of harmonized statistical data in a GIS context and the use of alternative technological solutions (e.g. TJS – Table Join Service - of OGC – Open Geospatial Consortium) is under investigations.

Regarding the genericity of its range of applications, the Executive Summary of the Data Specification on Population Distribution[15] states that: "*There are many different kinds of statistical data about human population: about people, dwellings, people at their work place, etc. This document does not intend to provide specifications for all these. Common characteristics have been extracted and represented into a generic data model. Using the data model described in this specification, all statistical data regularly organized in tables or data cubes can be provided in the INSPIRE framework.*"

[13] https://inspire.ec.europa.eu/Themes/79/2892
[14] https://inspire.ec.europa.eu/Themes/141/2892
[15] https://inspire.ec.europa.eu/Themes/138/2892

Utility and governmental services

According to the INSPIRE Directive, the Utility and Governmental Services theme "*Includes utility facilities such as sewage, waste management, energy supply and water supply, administrative and social governmental services such as public administrations, civil protection sites, schools and hospitals*"[16]. This theme has been divided into three sub-themes, one of which deals with "Utility networks".

Utility services and networks include the physical constructions for transport of defined utility products (namely pipelines for transport of oil, gas, chemicals, water, sewage and thermal products), transmission lines and cables (included those for transmission of electricity, phone and cable-TV signals) and other network elements for encasing pipes and cases (e.g. ducts, poles and towers). All kinds of transmission utility systems have nodes (e.g. pump stations), and they are linked to facilities for production and treatment of different kinds of utility products. These major production and treatment sites are described in the "Production and industrial facilities" theme, which is considered out of scope of this report.

Six important types of utility networks are distinguished, namely Electricity Network, Oil, Gas & Chemicals Network, Sewer Network, Telecommunications Network, Thermal Network and Water Network. They have been designed to describe data in a structured model with only the most basic characteristics, but adhering to the node-arc-node concept (taken from the "Network" concept in the INSPIRE Generic Conceptual Model[17]), respectively for the six types of utility networks (electricity, oil-gas-chemicals, water, sewer, thermal and telecommunications).

In the current data model there is not any semantic link between the utility networks and the buildings connected to the networks. At present, the only way to extract information about the connections between utility networks and buildings is by means of proximity GIS-based analyses, using the point coordinates of the nodes of the network classified as deliveryPoints (according to the Appurtenance Type values of the related code lists available for the six type of utility networks) and the geometries of the possible connected spatial objects, e.g. buildings or addresses. The introduction of a deliveryPoint attribute in future extended versions of INSPIRE data models for buildings, to be associated to the corresponding nodes of the utility networks, would create a stronger semantic link, which would be more beneficial for the application of some of the methodologies described in this report.

INSPIRE network services[18]

Besides the considerations above made, related to the fitness for purpose of some of the INSPIRE data themes, the main advantage of INSPIRE consists in the discoverability of and the accessibility to the harmonized data, by means of mechanisms and protocols commonly agreed and implemented by INSPIRE data providers. In particular:

- Discovery services allow users to find the data available for their needs, searching information e.g. about data content, data quality and conditions to access and use the data, which is contained in metadata published in catalogues;
- View services allow users to view the data matching the search criteria and to make some operations, such as overlaying thematic data on the maps served by the view services;
- Download services allow user to download the data matching the search criteria and to make any further data processing.

[16] https://inspire.ec.europa.eu/Themes/136/2892
[17] https://inspire.ec.europa.eu/documents/inspire-generic-conceptual-model
[18] http://inspire.ec.europa.eu/network-services/41

INSPIRE data models extension[19]

For the thirty-four spatial data themes INSPIRE has defined several core data models, which are legally binding for the Member States, with the ultimate goal to achieve cross-border and cross-domain data interoperability across Europe. In order to achieve this goal, a set of use cases have been analysed and have driven the definition of a minimum set of attributes and properties for each core data model.

However, the semantic content of these core data models is sometimes not sufficient to serve national as well as domain specific needs. Therefore, the core data models should be properly extended, following the relevant rules defined in the INSPIRE Generic Conceptual Model [20] and benefitting from the outcomes of the project recently concluded "INSPIRE data specification extensions"[21].

But, as previously mentioned, whilst the INSPIRE core data models are legally binding for Member States, the extended ones are draft and their endorsement process on behalf of the INSPIRE MIG has still to be defined.

In conclusion, the role of INSPIRE can be potentially very beneficial for the application of the methodologies described in this report, in terms of provision of harmonized input and/or output data. However, the potential benefits can be really achieved only if the INSPIRE implementers will adopt the legal prescriptions pursuing the data usability beyond formal conformance, e.g. providing also the information related to the optional attributes and following all the requirements and recommendations contained in technical guidelines (which are not legally binding).

[19] http://inspire.ec.europa.eu/portfolio/inspire-extensions
[20] https://inspire.ec.europa.eu/documents/inspire-generic-conceptual-model
[21] http://inspire-extensions.wetransform.to/index.html

4 Methodological approaches to assess building energy performance

Several approaches can be applied to assess the energy performance of a building, each of them having different requirements on input data and different methodological complexity, determining different levels of accuracy of the results obtained.

Six different approaches have been identified and classified into three categories named "holistic", "measured data" and "calculation", according to their main characteristics [8 and 9]. A definition of the six approaches is provided below:

- Holistic
    - Approach 1: Simplified method based on administrative data
    - Approach 2: Approach 1 + climate data and user behavior information
- Measured data
    - Approach 3: Energy consumption and energy performance data, including metering data
    - Approach 4: Energy performance assessment based on measured data
- Calculation
    - Approach 5: Simplified calculation method
    - Approach 6: Detailed calculation method, according to standardized calculations.

A brief introduction to each of these approaches is given below.

<u>Approach 1: Simplified method based on administrative data</u>

It consists in a holistic assessment, based on building administrative data, such as year of construction and/or renovation, type of building, size (surface area or floor area), geo-location. Some of these data can be retrieved by authoritative data sources such as the cadaster. The building energy performance is often assessed by means of a comparison with reference buildings for which a performance assessment is available. No climate or energy data is considered.

<u>Approach 2: Climate and user behavior information included</u>

It is an extension of approach 1, including additional data coming from climate and end-user feedback. This may give further insight into and a more accurate assessment of the energy needs of the building, as well as of the energy systems and resources in the building. End-user information may be linked to annual energy billing for a correlation indicator of indoor and outdoor climate. Geo-location data may be used for selection of energy resources, in particular from environmental sources (renewables) or energy infrastructure and providers.

<u>Approach 3: Energy consumption and performance data, including metering data</u>

It represents a further extension of approach 2, which is possible when metering data is available at daily or even hourly interval. A combined statistical and analytical method might be applied to distinguish building energy needs (related to real climate and building fabric) from end-user energy consumption (behavioural aspect). The assessment techniques are more dynamic than static and offer the possibility to optimise the energy demand to climate as well as to user behavior. Integration of renewable energy related technologies could be considered as well.

Approach 4: Building performance assessment based on in-situ measured data

It is based on in-situ measurements of the energy performance. The main energy flows, e.g. thermal transfer through envelop and by an air tightness measurement, are measured by so-called co-heating experiments. These measurements are often accompanied by infrared camera observations or other specific measurements. The information obtained is correlated to site and local weather conditions and requires proper conversion to a generalized energy performance value.

Approach 5: Not standardised calculation

It consists in a simplified calculation, for which two versions can be identified: the first one is based on annual climate data, the physical building structure is simplified and represented by its volume and by the envelop area exposed to climate. Climate data can be simplified and represented by HDD (Heating Degree Days). In the second one, a more detailed assessment can be made based on monthly climate data and details of the envelope, such as window area, orientation to include impact of solar radiation and ventilation for air quality requirements. The impact of thermal mass may be also taken into account.

Approach 6: Detailed calculation based on standards

It is based on detailed calculation rules and requires hourly or monthly data for the assessment. These calculation rules are described in standards, such as those provided by CEN, ISO or by national standards related to energy in buildings, e.g. the overarching standard EN 15603 and the corresponding technical report EN 15615 of CEN. The dynamic calculation assessment takes into account variable climate data as well as thermal mass of the building.

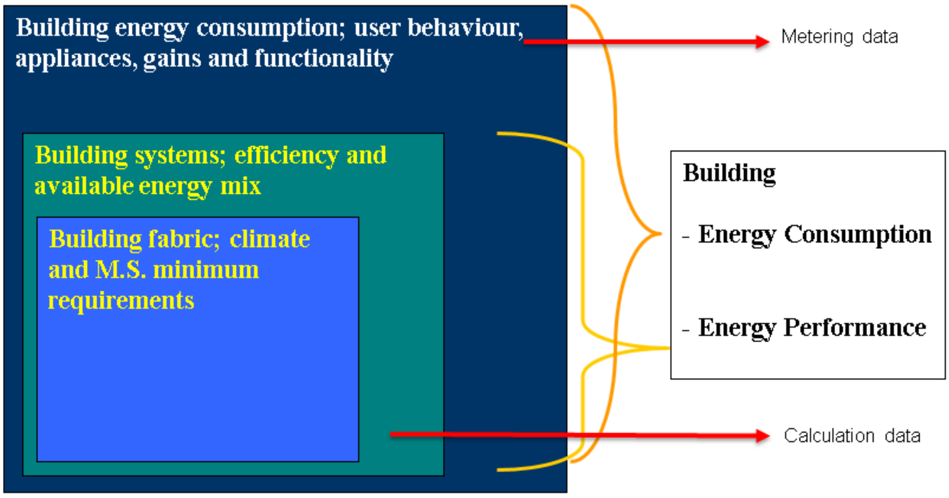
An example of the different level of accuracy of the assessments made using different approaches can be made comparing approach 5 and 6, focusing on the limitations implied by the use of HDD. HDD is used in approach 5 to take into account the relation between indoor and outdoor climate, for an annual assessment, not providing information for shorter calculation intervals. Moreover, HDD do not consider impact of solar radiation nor wind. Another consideration to be made when using simplified calculations is that HDD do not consider the building insulation characteristics, which are becoming more important for new constructions. Indeed, newer buildings (as from 2010) are built with more severe requirements for insulation levels and energy system technologies. Member States review the national building codes and define more strict requirements in relation to energy consumption and quality of the indoor environment. This may lead to so-called nearly-zero energy buildings (nZEB), as requested by the EPBD. As a result, the importance of the energy needs for exchanging the air volume contributes more significantly to the total energy needs of the building. A simplified method based on only annual data (based on HDD) does not take sufficiently into account this aspect. It should be also noted that passive solar buildings and nearly-zero energy buildings should be treated as high performance buildings in which specific building energy system techniques are applied to optimize the energy balance. These and other methodological limitations can be removed using the detailed approach based on standards.

Another important aspect to be considered is related to the terminology used in the energy related methodologies. In particular, the three main expressions widely used, and illustrated in *Figure* xyz, are energy performance, energy efficiency and energy consumption, which have different definitions, meanings and units of measurement:

- Energy performance "means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting", as defined by EPBD [3]; Unit of measurement: CO_2/m^3 or kWh/m^2.
- Energy efficiency is the ratio between output and input energy from/to a building energy system and it is a unit-less expression: %, 0 … 1, COP (Coefficient of Performance).

- Energy consumption is the amount of energy actually used and depends also on factors such as user behaviour, gains, appliances, in additions to factors determining energy performance (e.g. building fabric and climate conditions) and energy efficiency (e.g. building energy systems); Unit of measurement: MWh.

Figure 6 – The relation between energy performance and end-user energy consumption



A clear distinction has to be made between building energy needs, building energy systems that are needed to fulfill the requirements of the building energy needs and energy consumption, corresponding to the end-user demand for working and living in the building in a comfortable way. Note that the EPBD defines energy usage for: Heating, Cooling, Ventilation, Hot Water and Light and therefore the user energy consumption part that covers energy use of appliances and user behavior (user-profile) is excluded from the Energy Performance Value or Certificate. Energy consumed for appliances, communication (TV, computer, internet) is not considered under the EPBD.

Moreover, it is worth also to recall the Trias Energetica model[22] developed by the Delft University of Technology (NL) that supports the reduction of energy consumption in building sector, presenting three priority steps in relation to "minimize", "maximize" and "optimize" concepts:

Minimise energy needs of a building, improving insulation of the building envelop and therefore energy saving related to indoor (comfort level of temperature, air quality and light) and outdoor environment conditions (temperature, solar radiation and wind) for comfortable working and living in buildings.

Maximise energy efficiency of building energy installations and systems, combining efficiency of the installations for heating, cooling, ventilation, hot water and electricity in relation to available energy mix, which are the relevant factors in the end-use energy consumption.

Optimize the use of renewable energy resources (solar energy, bio-energy, etc.), as well as the energy consumption due to behavior of the occupants, including control and gains.

All approaches can be also considered as consisting of four components, input requirements, method, tools (software) and output, as schematised in the tables below.

[22] http://www.eurima.org/energy-efficiency-in-buildings/trias-energetica

Holistic - Approach 1: Simplified method based on administrative data	
Input requirements	Minimum information is building location, age, size and type.
Method	Cross reference list of buildings.
Tools	Software for linking databases and filtering required input.
Output	Energy label for each dwelling.

Holistic - Approach 2: Climate and user behaviour information included	
Input requirements	Minimum information is building location, age, size and type. Extended input: climate, resources, renovation, qualitative insulation levels and building systems. If possible annual energy consumption data, family composition, etc.
Method	Cross reference list of buildings; cross reference list for building energy systems, resources and usage profiles. Feedback from consumer.
Tools	Software for linking databases and filtering required input. Parameter adjustment.
Output	Energy performance indicator for each dwelling.

Measured data - Approach 3: Energy consumption and performance data, including metering data	
Input requirements	Regular readings from gas, electricity, water, heat and other resources. Time frequency can be hourly, daily or other frequent meter readings. Climate data.
Method	Distinguish building performance data and user consumption by means of correlation techniques (statistical or mathematical).
Tools	Dedicated software environments to deal with dynamic calculation rules and statistics, including conversion to reference climate conditions.
Output	High quality data (values) on energy performance and consumption for the specific dwelling.

Measured data - Approach 4: Building performance assessment based on in-situ measured data	
Input requirements	Measurement data from co-heating experimental set-up from ventilation (infiltration) and heat transfer based on an agreed measurement method. Measurements may include tracer gas measurements as well as infrared measurements to assess details about thermal losses through the building envelop.
Method	An agreed/ harmonized measurement set-up based on envelop thermal transfer.
Tools	Data treatment software and energy performance assessment including conversion to reference climate conditions.
Output	Energy performance indicator for the specific dwelling.

Calculation - Approach 5: Not standardised calculation	
Input requirements	Minimum information is volume, floor area, exposed envelope area, air change per hour (ACH) and reference climate for the location. Approach 5a could be based on annual climate data (HDD) whereas approach 5b could be dealing with monthly climate data and incorporate a seasonal calculation method. See ASIEPI tool [Ref 10].
Method	Assessment of thermal transfer through envelop by means of thermal conductance and by ventilation as well as solar gains. Impact of wind could be included.
Tools	Software for calculating thermal transfer through building envelop.
Output	Energy performance indicator for each dwelling in kW/m^2

<table>
<tr><th colspan="2">Calculation - Approach 6: Detailed calculation based on standards</th></tr>
<tr><td>Input requirements</td><td rowspan="4">See CEN standard EN15603 and related EPBD energy standards. ISO EPB standards numbering from ISO 52000.
Hourly and monthly calculation methods are provided, for example the calculation of energy needs for heating and cooling: ISO 52016-1 (a) (hourly method) and ISO 52016-1 (b) monthly method with correlation factors. Reference climate data is required for the calculation.</td></tr>
<tr><td>Method</td></tr>
<tr><td>Tools</td></tr>
<tr><td>Output</td></tr>
</table>

The ELISE Energy Pilot project involves a series of cities and regions to demonstrate how an integrated data approach can be established for planning, implementing, monitoring and reporting for policies and initiatives. These approaches can be considered being part of three overall classifications e.g. holistic, measured data and calculation. The pilot will be implemented and tested through a series of use cases that are based on defined approaches. The report [11] presents selected Use Cases that will address specific topics of energy and location for buildings.

- Use Case 1 - INSPIRE harmonisation of existing energy performance certificate (EPC) datasets and creation of a web application for accessing them
- Use Case 2 - Benchmark of different Energy Performance Labelling of buildings
- Use Case 3 **-** Assessing the Energy Performance of buildings with dynamic measured data
- Use Case 4 - Supporting Energy Efficiency driven renovation planning of the building stock at local level
- Use Case 5 - Supporting integrated energy planning and monitoring at urban/local level (SEAP BEI/MEI)
- Use Case 6 - Supporting the design and implementation of a regional energy strategy

In particular Use Cases 2 and 3 will deal with on-site measurements for validation of the applied method.

Why is a holistic approach important for the assessment of the energy performance of buildings?

In the past, energy performance requirements were set at component level – minimum thermal insulation levels and minimum efficiencies of products. This, however, leads to sub-optimal solutions and creates a barrier to the necessary technology transitions. Use Case 2 is based on this.

The holistic approach to assessing the overall energy performance of buildings and the built environment, provided by the set of EPB standards, is a key tool to overcome these

barriers. The set of EPB standards enables to assess the overall energy performance of a building. This means that any combination of technologies can be used to reach the intended energy performance level, at the lowest cost. Due to this 'competition' between different technologies, the holistic approach is a key driver for technological innovation and change. It requires validation by measurements on site and Use Case 3 is dealing with it aiming to develop a methodology to assess the energy performance of buildings identifying climate dependent energy and end-user energy. The results obtained from the application of the methodology will support decision-making process for refurbishment, renovation and management of building energy flows. The Use Case is aiming to the up-scaling of the energy use in buildings to district level and beyond, by proper implementation of geolocation data. In the perspective of in-situ measurements the objectives are:

- To analyse/compare existing methods to assess the energy performance of buildings with *dynamic measured data* from metering and in-situ measurements
- To *define requirements* for input data, including interval of observations
- *Validation* of the selected methods with measured data from field experimental work or from metering readings (e.g. electricity, heat, gas and water) and link the different data sources to an *uncertainty assessment*
- To up-scale with a proper implementation on the *INSPIRE Directive*

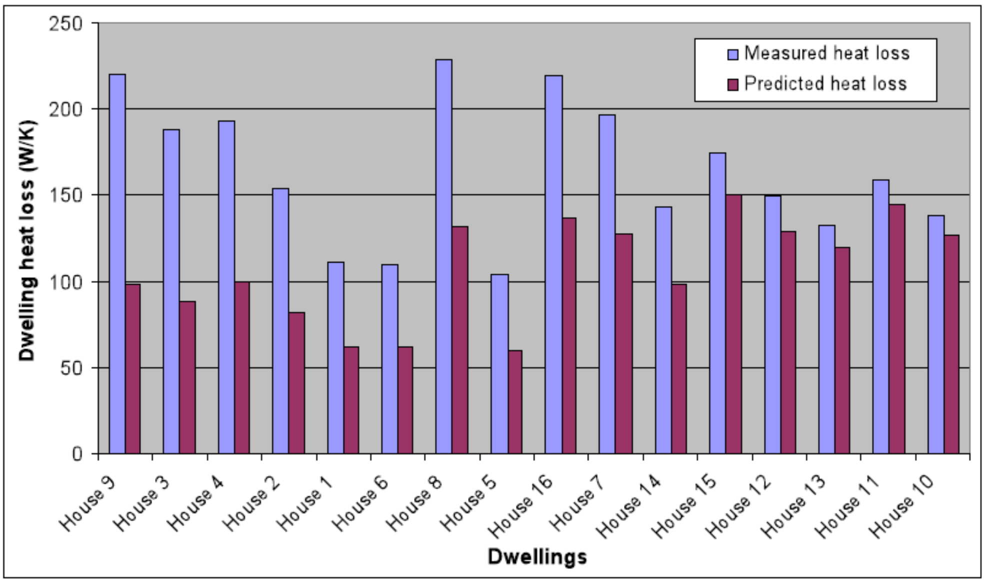
A mathematical model represents reality however it is, by definition, always a simplification of the true physical system. The user is responsible for choosing a method and defining the model based on available data and knowledge and hence the simplification of it.

5 Building Energy Performance Assessment

In order to quantify the energy requirements of a building, an appropriate assessment is needed that takes into account the various areas of energy consumption and energy production that contribute to a building's overall performance. Energy performance assessment by calculation (for the purpose of building design) or measurement (dealing with renovation of existing buildings) should be based on a concise methodology, especially when it concerns specific construction products and the integration of variable renewable energy technologies in the building envelope.

Several reports ([12, 13 and 14]) circulate about the gap that exists between energy performance design figures and real energy performance. The picture below (figure 7) shows those gaps for several residential building types, e.g. the under-estimation of the performance by designers.

Figure 7. The gap between design figures (by calculation) and real energy performance figures (by measurement) [13].



In general one may conclude that energy performance of a building importantly depends on:

- Fabric, structure, geometrics, orientation, quality of workmanship and the location of the building in a climate zone
- Type of building energy systems for heating, cooling and ventilation and available energy resources.

The assessment of real energy performance of buildings is an important aspect when it concerns renovation issues and related financial investments. A proper evaluation of the energy performance of any building starts from on-site measurement and monitoring. Intelligent metering environments may facilitate an optimised energy performance assessment.

A final consideration about methodologies is related to the different implications that energy policies have on energy consumption of buildings.

The assessment of the energy performance of a building, as required by the EPBD, is related to a single building (or building unit) and requires an energy performance certificate, expressed in primary energy (that requests for a controversial conversion). EPBD links directly to standards for calculation as well as measurements when it

concerns performance assessment. EPBD does not cover energy consumed by appliances, but restricts the expression EPC to the energy consumption for Heating, Cooling, Ventilation, DHW (Domestic Hot Water) and Light. EPBD addresses new as well as renovated buildings. Energy providers and industry products consuming energy are not directly affected by the EPBD. Energy providers, such as producers of electricity, gas and district heat, as well as energy distributors, use in fact physical networks that serve many buildings (end-users).

The Energy Efficiency Directive [4] defines energy savings requirements on buildings, but at Member State level. This includes making central government buildings more energy efficient and requiring EU countries to establish national plans for renovating their overall building stock. EU countries have also drawn up national building renovation strategies, to show how they plan to foster investments into the renovation of residential and commercial buildings. These strategies are part of their National Energy Efficiency Action Plans, and provide an overview of the national building stock, identify key policies that the country intends to use to stimulate renovations, provide an estimate of the expected energy savings that will result from renovations. EED links to energy savings, e.g. reduction of energy consuming appliances and other products, refers to EPBD for renovation and role of public bodies' buildings and requires annual reports of the progress towards 2020 targets.

6 In-situ Measurements and Standardization (CEN, ISO)

CEN/TC 371 is responsible for the overall consistency and horizontal harmonization of the set of EPB standards. This includes the preparation and maintenance of overarching EPB standards and other EPB framework documents and the management of the overall consistency as well as other common quality and usability aspects of the subseries of EPB standards that are developed and maintained by the other CEN Technical Committees, in particular:

- TC 89 Thermal performance of buildings and building components;
- TC 156 Ventilation for buildings;
- TC 169 Light and lighting systems;
- TC 228 Heating systems and water based cooling systems in buildings;
- TC 247 Building automation, control and building management.

CEN/TC 371 closely collaborates with ISO: an increasing part of the set of EPB standards is developed and maintained under the Vienna Agreement in collaboration with ISO, in particular with ISO/TC163/WG4, *Energy performance of buildings using holistic* approach, the Joint Working group of ISO/TC 163 *Thermal performance and energy use in the built environment* and ISO/TC 205 *Building environment design*. The collaboration aims at a coherent and complete set of EPB standards as the (EN) ISO 52000 series of standards. The first standards and technical reports under the ISO 52000 series have been published May/June 2017. Standards for performing in situ measurements are still under development.

Discussions on a potential standard for *in situ* measurements of building insulation products have been centred in the Working Group 13 [7], under Technical Committee 89 of the European Committee for Standardization (CEN). Two distinct groups with different viewpoints emerged in TC89 WG13.

An initial analysis of the data flows relevant to the Energy Performance of Buildings Directive (EPBD) has been made. A clear distinction (see also figure 6) has to be made between building energy needs, building energy systems that are needed to fulfill the requirements of the building energy needs and energy consumption, corresponding to the end-user demand for working and living in the building in a comfortable way. Note that the EPBD defines energy usage for: Heating, Cooling, Ventilation, Hot Water and Light and therefore the user energy consumption part that covers energy use of appliances and user behavior (user-profile) is excluded from the Energy Performance Value or Certificate EPV or EPC. Energy consumed for appliances, communication (TV, computer, internet) is not (yet) considered under the EPBD.

The assessment of the energy performance of a building, as required by the EPBD, is related to a single building (or building unit) and requires an energy performance certificate, expressed in primary energy. The EPBD links directly to standards for calculation as well as measurements when it concerns performance assessment. The EPBD addresses new as well as renovated buildings.

Since *in situ* measurements are in most cases performed under real climatic conditions, the variability has to deal with application of dynamic methods, including the experimental design and the analysis of the collected data. The information obtained from *in situ* measurements in the form of electronic data should contain the necessary (dynamic) information for an evaluation (analysis) that suits the experimental set-up and execution.

7 Assessing the Energy Performance of Buildings with dynamic measured data

Increase energy efficiency in the residential sector has become a priority for the European Countries. It is clear that an immense energy efficiency potential lies in buildings and it is mainly untapped. Nowadays, dynamic measured data coming from consumption smart metering, in-situ monitoring systems or Internet of Things (IoT) home devices provides valuable information to characterize the energy performance of buildings and the behaviour of the occupants. For this reason, the data analysis with this kind of data plays a key role in the energy assessment of dwellings.

This report describes the implementation of a methodology to support decision making processes for refurbishment, renovation and management. Furthermore, this methodology is able to be scaled up to district levels and beyond, in order to give better information to municipalities, regional or national governments about their building stock.

All the activities undertaken and the results achieved in the frame of the Use Case 3 of the ELISE Energy and Location pilot project are explained in this report.

Introduction

Several approaches can be applied to assess the energy performance of a building, each of them having different requirements on input data and different methodological complexity, determining different levels of accuracy of the results obtained. As explained in [15], there are six approaches identified to assess building energy performance, classified into three categories named 'Holistic', 'Measured data' and 'Calculation'.

> In the 'Holistic' assessment, the building energy performance is often assessed by means of a comparison with reference buildings for which a performance assessment is available. The reference buildings are based on building administrative data similarity, such as year of construction and/or renovation, type of building, size (surface area or floor area), geo-location. In this category, reference climate data could be used.
>
> The 'Measured data' category uses real measured time series from the building to obtain the building energy characterization by statistical analysis of this data. In this category real climate data is used.
>
> The 'Calculated' category consists on simplified or detailed simulations of building energy models based on building characteristics, reference or real climate data and real consumption data to calibrate those simulations.

This technical report is focused on the assessment of dwelling energy performance based on approaches related in 'Measured data' category. The first approach applies multiple analytic techniques to metering devices and real climate data related to the geo-location. The second one applies similar analysis techniques, but in this case to data coming from in-situ monitoring systems, which gathers lots of information such as high frequency consumption measurements, heat transfer coefficients through envelope, air tightness coefficients or indoor temperatures. This second approach requires highly monitored buildings, which may hinder the massive application of these methodologies.

Taking advantage of the intelligent meter infrastructure being developed at European level, the methodology that discovers the energy characterization of building performance must use the high frequency time series provided by this infrastructure, as well as location-related information, such as weather, administrative, social or economic data. Due to the advanced metering time series are presented normally in an aggregated

way, some methodology has to be used to split the energy between climate dependent and end-user consumption.

The following report shows the state of the art of existing methodologies to split electricity and thermal consumption, the two most important energy sources in dwellings.

State of the art of methodologies for building energy characterization with dynamic measured data

The algorithms most commonly used in data mining for the purpose of characterizing dwelling energy consumption are prediction models. The two main classes are: black box models and grey box models. The class of predictive models that are difficult to interpret in terms of the drivers of energy use can be labelled as black box models. Their unique objective is prediction accuracy, and the mechanism responsible for their predictions contains little information about the system being modelled. Thus, these techniques, which include neural networks, are only suitable for prediction models designed for forecasting proposes. The coefficients of the models lack of physical significance.

Models based on both insight into the system and experimental data are called grey box models. Those whose primary purpose is to deliver meaningful parameter fits are called inverse models because they work backward from observations to reconstruct system parameters. They are useful to recover and interpret semi-physical information from residential smart meter data. Grey box models can also be built based on physical heat transfer equations, similar to those used to model the dynamics of RC electrical circuits. Other data mining techniques useful to infer hidden information from consumption time series would be clustering and machine learning algorithms.

A closer look to the models will be given for both electricity as well as thermal energy consumption

Electricity consumption

Electricity is used for a wide-range of applications in dwellings, such as domestic appliances, lighting, Space Heating (SH), Space Cooling (SC) or Domestic Hot Water (DHW). The described methods are useful to breakdown the electricity usage and/or to characterize the energy performance of buildings from low to high accuracy. Data requirements will be described for each of the methods.

Linear steady state models

This technique determines the linear relationship between the consumption data and climate during a defined period. Nowadays, this low fine-grained model is already used in order to make a first estimation of weather dependence in consumption. Reference [16] uses linear regression models to fit monthly heating fuel consumption, assuming a baseline of consumption not climate dependent a, and a slope b which represents the response of the building to outside temperatures.

The data requirements are:

- Monthly consumption data.
- Daily outdoor temperature data or monthly HDD/CDD.

Piecewise linear models

Changepoint temperature models are based on this technique, a piecewise linear model between daily consumption and temperature response, with one or two breakpoints, corresponding to heating and cooling thresholds. The response to outside temperature therefore has up to three segments. For two segment cases, one of the segments can be fixed to zero thermal response to capture temperatures below the cooling threshold or above the heating threshold without conditioning. Alternately, the temperature response of both segments can be fit by the model to capture both heating and cooling. The three-segment model consists of heating and cooling segments separated by a zero-slope segment for temperatures without conditioning. Reference [17] describes a set of standardized regression tools for fitting interval-meter data.

The data requirements are:

- Daily consumption data.
- Daily outdoor temperature data.

Locally Weighted models

This method, described in [18], gives local estimates in time of the model coefficients by only considering observations within a limited time window. This makes it possible to see if they are constant over time, e.g. to look for variations during the heating season and how they change during the summer period. And hence it will be able to estimate the energy performance of buildings based on daily consumption measurements and nearby climate measurements.

The data requirements are:

- Daily consumption data.
- Daily weather data.

Autoregressive models

This techniques can be used for linear and stationary, not time-varying dynamical systems. Consequently, if it has been concluded that the system is either non-linear or non-stationary, then typically the concept of RC models, must be used. However, in some cases a non-linear transformation of the input signals might be sufficient for the usage of autoregressive models. Depending on the application and the properties of the building/dwelling an appropriate sampling time range from, five minutes to an hour should be considered. This class of models provides HTC and gA-values, and the time constants of the system. Multiple implementations of this technique are described in [19]

The data requirements are:

- Hourly/Sub-hourly consumption data.
- Hourly/Sub-hourly weather data.

RC models

The thermal characteristics of buildings and building components are frequently approximated by a simple network with resistors and capacitances. This, so-called RC network model, is an example of a linear and stationary (time-invariant) grey box model. In [19], RC models were used in some examples to characterize and predict energy consumption from multiple dwellings. This technique also useful for characterize building components, because physical parameters could be estimated. Other literature which uses RC models applicate to characterization and identification of physical building parameters are [20, 21 and 22].

The data requirements are:

- Sub-hourly consumption data.
- Sub-hourly weather data.
- Sub-hourly indoor temperature data

Hidden Markov models

Hidden Markov models have been well-studied in the Non-Intrusive Load Monitoring (NILM) literature. It is a common technique used for energy disaggregation. In [23] hidden states of the Hidden Markov chain are defined as the states of the domestic appliances and building systems, and the power demand is used as the observation of the model. In this case, a transition matrix to describe the probability of the devices transitioning between states was trained. Hidden Markov was also used for the estimation of user occupancy of dwellings in real use. In this case, occupancy and activity status of the users are the hidden states of the model.

The data requirements are:

- Sub-hourly/Secondly consumption data.

Deep Learning networks

Recently, deep neural networks have driven remarkable improvements in classification performance in machine learning fields such as image classification and automatic speech recognition. One of the main benefits of deep neural networks is that they can automatically learn a hierarchy of feature extractors from raw input data (provided that enough training data is available). In some deep learning networks are tested in NILM datasets in order to make energy disaggregation.

The data requirements are:

- 10 Hz consumption data.

Thermal consumption

In the case of thermal consumption, the energy needs to be split by domestic hot water usage, which depends highly with the end-user usage on occupation of his dwelling, and space heating/cooling, which depends either on building fabric and systems, and the user behaviour. Reference [24] develops an effective methodology, based on a non-parametric model, which relies on the fact that the domestic hot water consumption is a process generating short-lived spikes in the time series, while the space heating changes in slower patterns during the day.

The data requirements are:

- Hourly/Sub-hourly consumption data
- Maximum thermal power of the heating/cooling device.

Conclusion on State of the Art

Most of the existing methodologies require the availability of several high frequency data (e.g. consumption data, indoor comfort sensors), in order to provide information about the energy performance of the building by energy disaggregation. To tackle this issue the methodology developed in this study requires only data from electricity smart metering devices and the related climate data to provide information on the energy performance of buildings by an estimation of the consumption due to the user behaviour (lighting, water

and domestic appliances) and due to the climate conditions (space heating/cooling systems).

Case scenarios

Two different case scenarios have been selected for this study. The scenarios have different characteristics, ranging from an end-terraced dwelling to an electricity smart-metered neighbourhood. In the former case, data comes from an in-situ monitoring system and in the other data comes from an electricity utility.

Case 1 - General characteristics of an end-terraced dwelling

This first case scenario was adopted from a common exercise of IEA-EBC Annex 71 [25] and in the frame of this technical report; it represents the assessment of energy performance of buildings when dynamic measures data are available from in-situ monitoring systems.

The dwelling is located in a semi-detached building built in Gainsborough, UK (53.4N, 0.77 W) which contains 4 social houses. Figure 8 gives an overall view of the house. The dwelling has been monitored for 3 years, starting October 2012 until November 2015. The building is used by two adults and one child up to January 2013. In March 2013, new tenants (1 adult and 2 children) have moved in. Due to tenancy change, the house was vacant and unheated in January and February 2013.

Energy data

Electricity and gas consumption is available at 5 minutes frequency data between October 2012 and November 2015. This dwelling has a gas-fired space heating and domestic hot water system. However, there is no monitored data about the disaggregated usages. Considering the user's manual and the characteristics of the boiler, the estimated performance is a 90%. In this case, electricity is only used for domestic appliances and lighting.

Figure 8. Semi-detached building in Gainsborough (UK)

Additional data

Furthermore, other data and characteristics of the house was given. For example, weather conditions (outdoor temperature, solar radiation and wind speed), CO_2 levels and interior temperatures inside the dwelling, and also water consumption (cold and hot) data in 5-minutes frequency.

Case 2 - Electricity smart-metered neighbourhood

General characteristics

Nowadays, traditional electricity meters are being changed to more advanced electronic devices called smart meters, which can record consumption in intervals of an hour or less and communicate this information, at least, daily back to the utility for monitoring and billing.

The overall successful roll-out of smart meters across the EU is dependent on criteria largely decided by Member States however. 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 [26]. For the analysis made in the framework of this technical report, an electricity smart-metered neighbourhood is considered in the north-east of Spain.

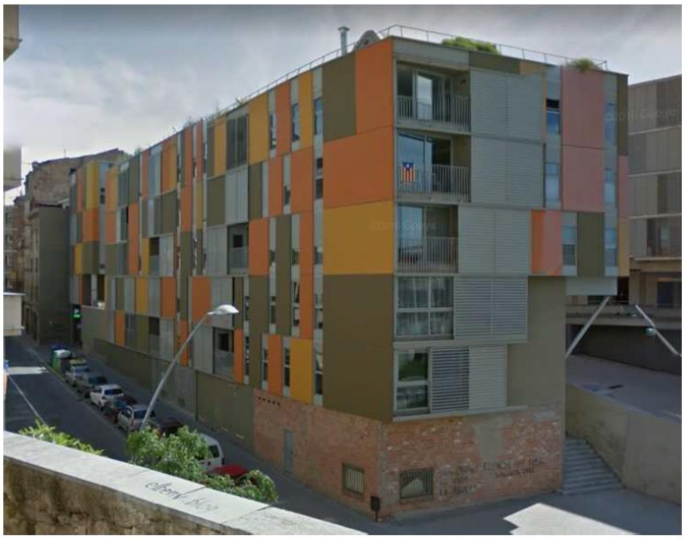
Energy data

The only energy data available in this case scenario is electricity at hourly frequency. This dataset is composed by electricity time series of 6500 customers between, in the majority of the cases, May 2012 to mid-February 2014. The biggest issue with this kind of data is that the end uses made for each customer is highly singular and adapted to each user. For example, in the case of electricity consumption, household appliances or electronic devices, light, hot water, space cooling and space heating could be considered as frequent end uses for this type of energy.

Location-based data

In this case scenario, the exact location of the dwellings is not available, so there is no possibility to infer building or dwelling information about the constructed area, volume or orientation. Only approximate location based on the Spanish postal code, which is enough in order to retrieve the historical weather conditions of each of the customers.

Figure 9. Apartment building in Manresa (Spain)



Determination of the energy footprint of dwellings

The methodology used for assessing the energy performance of buildings (EPB) highly depends on the input available and the data format of the desired output. Commonly, those methodologies are based on modelling techniques which use the input data to fit a statistical model to infer the physical features from the coefficient of those models. The characteristics of the input variables must be known beforehand, since this information is needed for the selection of the most suitable technique and the hypotheses to be used in the case under consideration.

Thus, the principal characteristics to take into consideration are the following:

Data variables

Data gathered in buildings can contemplate from energy consumption (water, gas, electricity or thermal consumption) to comfort features (indoor temperatures, relative humidity, CO_2 concentration). However, for an EPB assessment, an input considering the energy consumption due to space heating or cooling is mandatory. Sometimes, especially in the case of in-situ monitoring systems, a combination of energy consumption inputs and comfort variables are available.

Data granularity

Energy consumption data is gathered in many different frequencies, from monthly to minutely data. In the case of in-situ monitoring systems, even higher frequencies could be available (10 Hz or higher). Normally, the higher the frequency, the more advanced techniques could be used to infer characteristics of the building and the energy consumption.

Data quality

Methodologies for EPB assessment usually consist on fitting a statistical model considering real data from the building (also known as inverse modelling), so models trained with non-quality data obtain fitted coefficients which do not have any reliability. Therefore, to work with the finest data set possible, multiple data cleaning techniques are used to detect and filter outliers in raw time series. The setting for this data cleaning techniques depends on the data variable being processed. For instance, temperature variables are easier to manage due to the continuity in the signal. Regarding instantaneous energy consumption (Hourly and higher frequencies) is harder to clean due to the strong stochastic component of consumption peaks.

Energy resources

Being aware of the energy resources for Domestic Hot Water (DHW), Space Heating (SH) and Space Cooling (SC) is really significant, since it allows to simplify the EPB assessment to those energy consumption variables that are weather-influenced. Other information that could refine the output of the methodology are those related with the characteristics of the heating and cooling system. Especially important when dealing with electricity consumption, due to the enormous ranges of Seasonal Factor Performance (SFP) between different types of heat pumps and electricity boilers.

Data units

The unit of measurement used for each variable should be analysed in terms of representativeness, taking also into account the granularity of the time series. Especially in the case of energy meters, the unit must represent with sufficient definition the

consumption carried out in the determined time interval. For example, it is not appropriate to define a 15-minute consumption of domestic hot water in integers of kilowatt hours.

Sometimes, especially when in-situ monitoring, the representativeness of high-frequency energy meters has not been taken into account because the initial objective was to summarize these values on a daily or monthly basis.

Weather data

Historical weather datasets contains crucial inputs for EPB assessment, such as outdoor temperature or solar radiation. If no weather input is given by the input dataset, it should be obtained through third-parties considering the building location.

Another important factor in selecting the most appropriate methodology is to consider the characteristics of the algorithm outputs. The estimation of energy performance indicators of a building with the purpose to benchmark similar buildings does not require the same precision as estimating them to simulate the energy savings of a retrofitting intervention.

Two levels of accuracy have been considered in the cases presented in this report. In the first case scenario, considering that more detailed inputs are available, the Heat Transfer Coefficient (HTC) and the solar gains (gA value) of an end-terraced dwelling has been obtained with the aim at commissioning its energy consumption. In the second, the accuracy of the outputs is lower due to the fact that the input data is smart-metered electricity consumption with multiple uses. In this case, the obtained energy footprints aim at benchmarking among comparable dwellings.

On the first case scenario a filtering based technique combined with an AutoRegressive model with eXhogeneous inputs (ARX) has been used. On the second case, as the hourly electricity consumption time series is harder to split between climate dependent and user dependent share, a hybrid methodology based on clustering algorithms and Generalized Additive Models (GAM) is used to characterize the energy performance of each dwelling.

Definition of energy footprint of dwellings

The dwelling energy footprint represents a simplified characterization of the energy performance of a single dwelling, which is considered as a part of a building. This energy footprint is composed of indicators estimated from statistical models which are fitted with dynamic measured data. Figure 10 depicts a set of indicators which can be inferred from a set of data gathered in a single dwelling.

The method used for the estimation clearly depends on the characteristics of the input data, but basically is always composed by the following steps:

- Detection of the energy source used for heating/cooling purposes.
- Split the time series of the energy consumption used for heating/cooling purposes, between energy consumption due to the end-user behaviour and due to the building. In the frame of this technical report, as it only concerns the assessment of the building energy performance, only the energy consumption due to the building is analysed.
- Once obtained this weather dependent energy consumption, use modelling algorithms to estimate the indicators that will compose the energy footprint of the dwelling.

These indicators represent consumption response factors to exogenous variables like outdoor temperature, wind speed and direction or solar radiation. The accuracy of those indicators will depend on the quality and characteristics of the input data. For instance, if comfort variables, such as indoor temperature of the dwelling, would be available, the Heat Transfer Coefficient (HTC) could be much better estimated than in the case when a fixed indoor temperature is considered.

The data mining techniques used for the purpose of characterizing the energy performance are, in most of the cases, prediction models (see explanation before). The two main classes of statistical prediction models are black box models and grey box models.

Black box models are difficult to interpret in terms of the drivers of energy use. Their unique objective is prediction accuracy, and the mechanism responsible for these predictions contains little information about the system being modelled. Thus, these techniques, which include neural networks, are only suitable for prediction models designed for forecasting purposes.

The coefficients of these models lack of physical significance because there is not any kind of representative heat transfer equation which relates the measured data and the building physics.

Grey box models fit parameters which yield meaningful information about the systems they model. Those models whose primary purpose is to deliver meaningful parameter fits are called inverse models because they work backward from observations to reconstruct system parameters. They are useful to recover and interpret semi-physical information from residential smart meter data. Grey box models can be built based on physical heat transfer equations, similar to those used to model the dynamics of RC electrical circuits.

Other data mining techniques useful to infer hidden information from consumption time series would be clustering algorithms, which could be used to detect similar usage profiles. Subsequently, a subset of indicators broadly used in building physics is:

Heat Transfer Coefficient (HTC)

In thermodynamics and in mechanics is the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat. In this technical report, this is a measure which include both the transmission heat transfer and ventilation heat transfer, hence a sum of the UA-value and ventilation losses. The unit in International System (SI) is WK^{-1}.

Solar Heat Gains Coefficient (gA value)

The solar gains are determined by the prevailing solar radiation intensity, the total solar energy transmittance (g value) and the area of the aperture. The ’g value’ is the total fraction of the incident solar energy that is transferred through a building component at normal incidence irradiation. The ’gA value’ of a building as one variable is composed by the product of: ’g’ total solar energy transmittance of the opaque parts (windows) of the building and ’A’ the effective area of the opaque parts. The unit in SI is m^2.

Wind speed response

The relevant weather data for air infiltration is: wind speed, wind direction, difference of temperature (indoor and outdoor) and barometric pressure. In this report, the objective does not aim at calculate the air infiltration rate. However, as one of the main factors of air infiltration is the wind speed, its signal response against energy consumption or indoor temperature is interesting to analyse. The unit in SI is Wsm^{-1}.

Time constant

Thermal inertia of a building can be quantified by thermal time constant which describes how long it takes, where the heating/cooling of a building is discontinuous for building temperature to change. Thermal time constant is defined as the ratio of a building's thermal mass and overall heat loss. Time constant of the building area is characterized by internal thermal inertia conditioned area during the heating period. The unit in SI is s.

Uncertainty evaluation depending the input data

Assess the energy performance of dwellings using energy footprints and scale-up the method to district level and beyond As seen in Chapter 4, dynamic measured data coming from consumption smart metering and in-situ monitoring systems provides valuable information to assess the energy performance of buildings and characterize the energy behaviour of the occupants at a dwelling level.

Geo-location data of dwellings

Here we need to explain the necessity to establish the relation between the energy consumption meters and their location, the issues about obtaining the detailed address of a dwelling due to actual data protection laws and the possibility to use an administrative division, such as postal code, zip code, district, town or city, to represent the location.

8 Methodology to scale up the energy performance assessment in buildings to district level and beyond

Introduction

Dynamic measured data coming from consumption smart metering and in-situ monitoring systems provides valuable information to assess the energy performance of buildings and characterise the energy behaviour of the occupants at a dwelling level.

The analysis of this data allows to obtain a set of indicators which relates the energy consumption of a dwelling with multiple exogenous variables related to the location of the dwelling and the comfort of its users. This set of indicators conforms a unique energy footprint, which could be used as the numerical energy characterization of each dwelling. It describes the performance of the building envelope, the building systems and the user behaviour of the occupants.

Afterwards, an interpretation of this numerical characterization should be done in terms of energy efficiency, which is made in order to determine the weak and strong points of each dwelling and give an energy performance assessment much more personalized. Furthermore, the same method could be used on district levels and beyond. In these cases, the energy performance is evaluated considering an aggregation of the energy footprint of all, or a significant part, of the dwellings which constitute that district or administrative area. For this comparative purpose, benchmarking techniques are useful because the individual energy characterization is contextualized against similar buildings.

One of the most common benchmarking techniques used in the energy field is to compare indicators against fixed reference values. These techniques are mainly used in energy labelling calculations, which it is already an initial holistic approach to assess the building performance of a building. However, considering the type of methodology developed in this technical report, which is essentially based on data analytics, a far more intelligent benchmarking technique would be to generate groups of similar entities based on building characteristics and socioeconomic information. For instance, at the dwelling level, a clustering algorithm could calculate groups of similar dwellings based on building administrative data such as year of construction, number of occupants, dwelling area, building type, weather severity or occupancy profiles. In higher administrative levels, such as districts or cities, socioeconomic information also based on location like economic level, population distribution or social statistics could be used to detect similar items. It would provide the power to understand better the differences in energy performance of a single or several number of dwellings and to work on multiple administrative levels.

Additionally, it could be used as a building stock model, or to complement them, in order to estimate the energy-saving potential in groups of buildings. Regarding building stock models, [27] made a methodology review which condenses all the existing literature in a review. In the following paragraph, a brief summary of this paper is made, considering the advantages and drawbacks of each model typology.

8.1 Models for building stock energy assessment

Engineering models

These models aims to account for the end-user energy consumption based on power ratings, use of equipment and systems and heat transfer relation-ships. To reduce the amount of buildings to model, it requires the consideration of a representative building

for each archetype. Article [28] describes the work developed in the European Project TABULA (Typology Approach for Building Stock Energy Assessment), the aim of which was to define building typologies archetypes for 15 European Countries. These models offer the possibility to simulate the effect of different energy saving measures for future scenarios proposed [29] [30], life-cycle considerations [31] and multiple housing parameters. However, there is not a common validation method to generate the archetypes representation of the buildings [32] [33], and this is a consequence of the heterogeneity of the models represented. Another problem is the trade-off between simplicity and complexity: the more aspects introduced in the model, the more archetypes are needed for representativeness in a given building stock. Moreover, these models usually do not take into account the user behaviour [34] and this often causes the gap of performance between simulations against reality.

This concept gets more importance when the models are applied to energy-low consumption buildings, mainly because the traditional building physics factors does not affect in the same manner the energy consumption.

Statistical models

As explained in [35], statistical models rely on historical information and data analytics which are used to attribute dwelling energy consumption to particular end-uses. The methodology developed in this report corresponds to these type of models. On one hand, this method is usually based on the energy consumption analysis, so user behaviour, building envelope and systems performance is considered inherently to the characterization. On the other hand, the major drawback is that it requires a collection of the historical data which is time consuming to obtain and limited in many European countries [36]. However, some authors use a statistical hybrid model which is based on monitoring data and building-physics knowledge. This prior knowledge is used to make assumptions in case of lack of real data. Reference [37] describes the creation of a building stock model of the Piedmont region (Italia) based on statistical data and the building typology approach developed in [28].

Energy-economic models

A rather new approach to building stock models are the energy-economic models, also known as energy epidemiology models, which adopts an inter-disciplinary approach that could allow to account for complex relationships between different energy uses and economics or sociological factors. These models are also combined with the traditional engineering approach to describe the drivers of the demand for energy in terms of sources and fuels, services and uses, practices and norms, across the interacting sectors and actors within the built environment [38]. At the moment, there is no much literature about this topic, but the concept is being developed in the IEA Annex 70 [39].

To sum up, the methodology to scale up the building energy performance assessment from the dwelling to the district level and beyond could be considered as a building stock model because the distribution of the dwelling energy footprints in the district, describes precisely the energy characterization of the building stock, so then this information could be used to generate energy-efficiency scenarios. Additionally, as a consequence of the usage of real end-use energy consumption (Dynamic measured data) from the consumers to generate the energy performance assessment, accounts for the user energy behaviour and the supply-side systems installed on the dwellings. This fact will contribute to the development of more accurate building stock models.

8.2 Dwelling energy footprint

The dwelling energy footprint represents the characterization of the energy performance of a single dwelling. This footprint is composed of indicators calculated using the dynamic

measured data gathered in the dwelling and the real climate data of the location. This technical report will not focus on the explanation of how to calculate these indicators, which is already presented in another JRC technical report [8 and 9]. However, a brief introduction to this topic is made in order to get the general perspective of the energy performance assessment. Figure 10 depicts a set of indicators which can be inferred from a set of data gathered in a single dwelling.

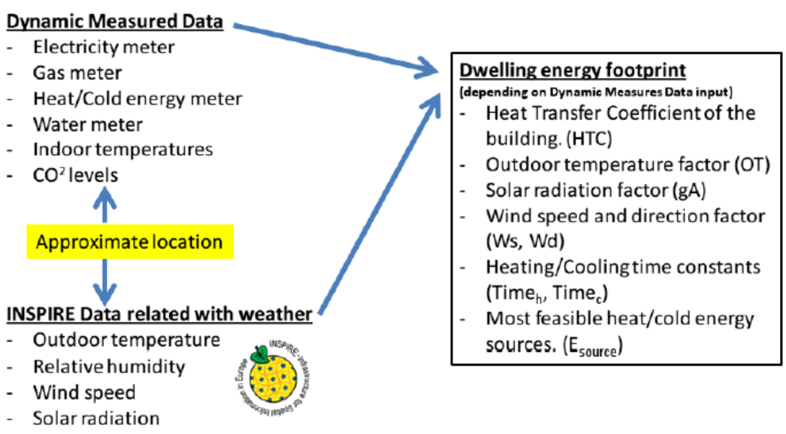
The algorithms and the data to use clearly depend on the characteristics of the gathered data and the dwelling. The steps proposed to detect a set of indicators to compose the energy footprint are the following:

Detection of the energy source used for heating/cooling purposes

Split the time series of the energy consumption used for heating/cooling purposes, between energy consumption due to the end-user behaviour and due to the building. In the frame of this technical report, as it only concerns the assessment of the building energy performance, only the energy consumption due to the building is analysed.

Once obtained the heating/cooling energy consumption due to the building, modelling algorithms are used to detect the consumption response factors to exogenous variables like outdoor temperature, wind speed and direction or solar radiation. If comfort variables, such as indoor temperature of the dwelling, are available and the heat transfer coefficient could be calculated, which is an important indicator to characterize the building envelope.

Figure 10. Inference at the dwelling level



The data mining techniques used for the purpose of characterizing the energy performance are, in most of the cases, prediction models. The two main classes of statistical prediction models are black box models and grey box models.

Black box models are difficult to interpret in terms of the drivers of energy use. Their unique objective is prediction accuracy, and the mechanism responsible for these predictions contains little information about the system being modelled. Thus, these techniques, which include neural networks, are only suitable for prediction models designed for forecasting purposes. The coefficients of these models lack of physical significance.

Grey box models fit parameters which yield meaningful information about the systems they model. Those models whose primary purpose is to deliver meaningful parameter fits are called inverse models because they work backward from observations to reconstruct system parameters. They are useful to recover and interpret semi-physical information

from residential smart meter data. Grey box models can also be built based on physical heat transfer equations, similar to those used to model the dynamics of RC electrical circuits. Other data mining techniques useful to infer hidden information from consumption time series would be clustering and machine learning algorithms.

8.3 Definition of the geographic levels

The geographic levels considered in the scaling up process define the stratification from the dwelling level to the city or regional level. Subsequently, in this section, a clear definition of each level is provided.

Dwelling. The formal definition of dwelling is a place where someone lives. Regarding the EPBD (Directive 2010/31/EU), the closer definition to dwelling is referred to building unit, which means a section, floor or apartment within a building which is designed or altered to be used separately.

Building. The formal definition of building is a structure that has a roof and walls, for example a house or a factory. According to the EPBD (Directive 2010/31/EU), building means a roofed construction having walls, for which energy is used to condition the indoor climate. A building could be constituted by a single or multiple dwellings, depending the building typology and the specific characteristics of that building.

District. The formal definition of district is an area of a town or country which has been given official boundaries for the purpose of administration. Regarding the energy context, the definition of district is described in [14], which refers to a geographical zone with a particular characteristic or condition. For instance, in case of district heating installations, the whole group of buildings supplied by the system, forms a district, because the heating system is the particular characteristic among them.

City. The formal definition of city is a large or important town, which is a place with many streets and buildings, where people live and work. Towns are larger than villages and smaller than cities. In the context of this technical report, a city or town is an administrative level composed by multiple districts.

Region. The formal definition of region is an area of a country, especially one that has a particular characteristic or is known for something. In the context of this technical report, in rural situations, a region is considered an administrative level composed by multiple rural districts or villages, and would be considered at the same level than cities, which are also composed by districts.

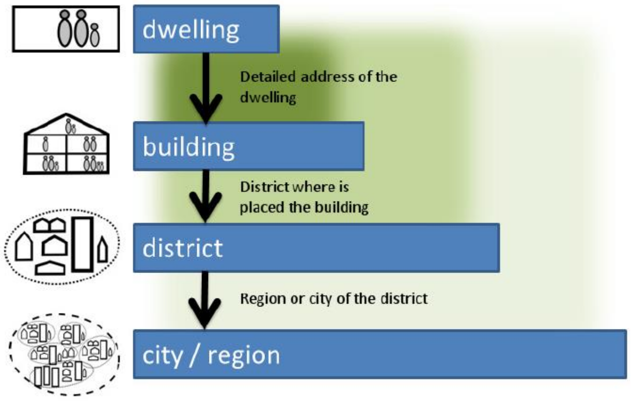
Interrelation between geographical scaling up levels

The interrelations between the levels are based on location information from the dwellings. Basically, the energy footprint of each dwelling relates to the energy consumption made on that dwelling to the geographical location where it belongs, ideally, the precise location of the dwelling (Detailed address). Then, to scale up the assessment of the building energy performance to district level and beyond, this location is considered to relate groups of dwellings to higher geographical zones, such as districts, cities or regions.

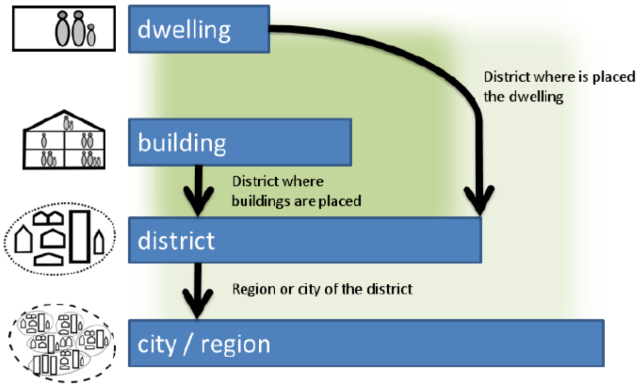
The detailed address of dwellings is available to utility companies, with whom the end-users have a direct contract and an explicit permission of data transfer. Nevertheless, and due to European laws on data privacy, sometimes consumption metering data could not be related with detailed location of dwellings or consumers. For instance, in the case of third-party data analysis companies treating data coming from DSO's or energy utility companies, this information must be anonymized. As a consequence, this technical report will take into account these two different situations. Figure 11 depicts them: the first one (Situation 1) which considers the availability of the detailed location of the dwellings and

a second approach (Situation 2) which only considers an approximate geographical location, such as postal code, zip code or district to represent the location of the dwelling.

Figure 11. Geographic scaling up levels and the interrelations between them



(a) Detailed location of the dwelling (Situation 1)



(b) Approximate location of the dwelling (Situation 2)

8.4 Scaling up the energy performance assessment

The methodology to assess the building energy performance in multiple geographic levels is based on benchmarking single or multiple dwelling energy footprints against comparable dwellings. As explained above, the method considers two situations of availability information about the location of the dwelling: Situation 1 considers detailed location of the dwelling and situation 2 considers approximate location of the dwellings.

Benchmarking of dwellings

As shown before, the first level of assessment concerns the dwelling level which requires information obtained from the dwelling and the building. It requires the detailed location of the dwelling to relate its energy footprint with its building administrative data. Thus, this case only concerns situation 1. The steps to benchmark dwellings are:

Obtain the energy footprint. Analyse the dynamic measured data and the weather data to obtain the energy footprint of each dwelling, obtain the building administrative

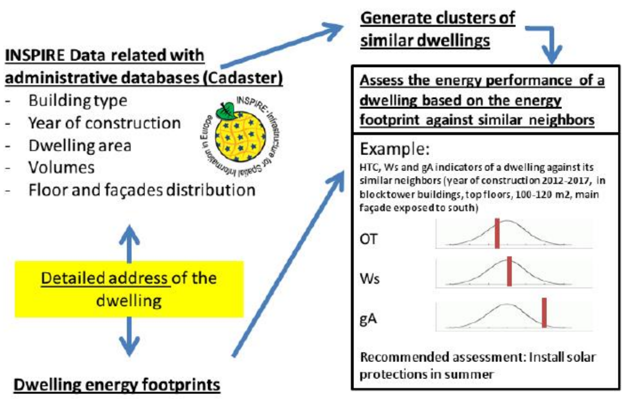
data, get the building typology, the year of construction and the floor area of the each dwelling through the cadastral service.

Detect similar groups of dwellings. Cluster the dwellings using the building administrative data and a clustering algorithm to detect different groups of similar dwellings. Multiple clustering techniques could be used, like k-means or self-organizing maps. Additionally, other factors could be considered in this phase. For instance, it is broadly known that the building envelope characteristics can differ a lot between hot and cold climatic zones. Thus, the climate zone of the dwelling should be also considered in the clustering, to avoid detection of similar dwellings with completely different energy demand due to weather conditions.

Benchmark the dwelling energy footprint against its comparable dwellings. Once the comparable groups are defined, compare the energy footprint of each dwelling against its equivalents, which will be represented as a distribution of each indicator composing the energy footprint of the group of dwellings. The assessment should provide managing or retrofitting actions as a consequence of the interpretation of the comparison.

Figure 12 depicts the workflow and an example of the result of the benchmarking technique considering one dwelling against comparable dwellings. This example shows the OT (Outdoor temperature factor), Ws (Wind speed factor) and gA (solar radiation aperture) indicators characterising the distribution of similar buildings. In this case, the assessment should recommend the installation of solar protection devices during the summer period, because the gA value is considerably much higher.

Figure 12. Workflow of the similar dwellings benchmarking (Situation 1)



Benchmarking of districts

The benchmarking of districts would be useful for local or regional governments to compare the building stock of a certain district of their region or city among other similar districts in Europe. The steps to benchmark districts are:

Define the geolocation of the district. Define the districts as certain geographical zones with known location, shape and dimensions, where a set of dwellings have a

common characteristic between them. In cities, districts could be considered as neighbourhoods or zones with common district heating/cooling systems. In rural regions, could be considered as villages or groups of small municipalities.

Obtain the dwelling energy footprints. Analyse the dynamic measured data and the weather data of each of the dwellings to obtain the energy footprint of the district. In this phase, the main difference between situation 1 and 2 would be that, with the detailed location of the dwelling the situation of the dwelling within the district is known. Moreover, the relation between the building administrative data and the dwellings are known. Thus, in situation 2, there is no possibility to filter outlier dwellings or building which could add noise to the district characterization.

Obtain the building administrative data. Get the building typology, the year of construction and the floor area of all the dwellings through the cadastral service.

Obtain the demography and society characteristics of the district. Get the statistical data about migration, evolution on demography and society referred to the district through the national statistics centres, local authorities or Eurostat.

Detect the similar groups of districts Cluster the building stock administrative data, the climate zone, the demographic and the society macro statistics of each district using a clustering algorithm to detect different groups of similar districts. Multiple clustering techniques could be used, like k-means or self-organising maps. In this case, the clustering is quite more complicated since some of the considered factors are represented by distributions, such as the building stock characteristics.

Benchmark the dwelling energy footprints of the district against similar districts. Once the similar districts groups are defined, compare the dwelling energy footprint distribution against the distribution of comparable districts. The assessment should provide general managing, user awareness campaigns or to create focus programs for buildings retrofitting at a district level.

On one hand, figure 13 depicts the workflow when situation 1 is considered, complementing the results from the benchmarking at the dwelling level. On the other hand, figure 14 shows the workflow when the situation 2 is considered. In this case, the general statistics from the dwellings level and the buildings level are accounted for. An example of the result of the benchmarking technique is shown and explained in figure 15 and 16.

Figure 13. Workflow of the similar districts benchmarking (Situation 1)

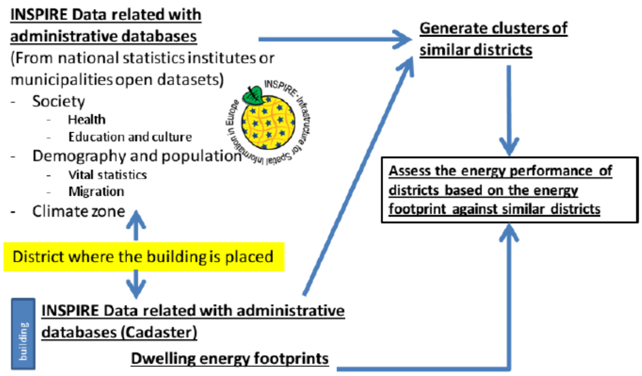
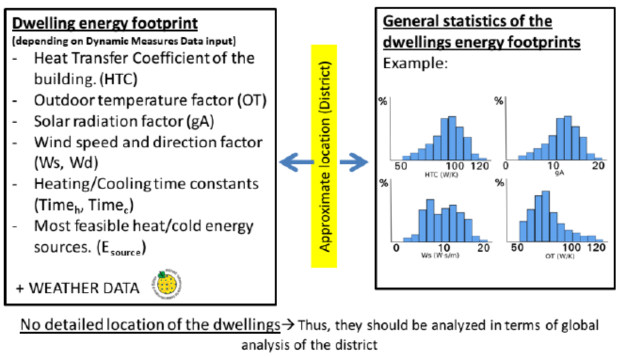
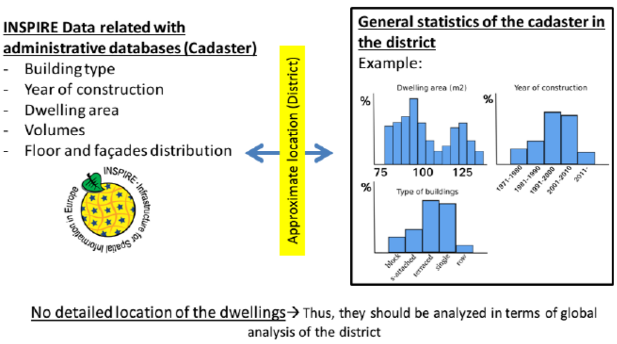


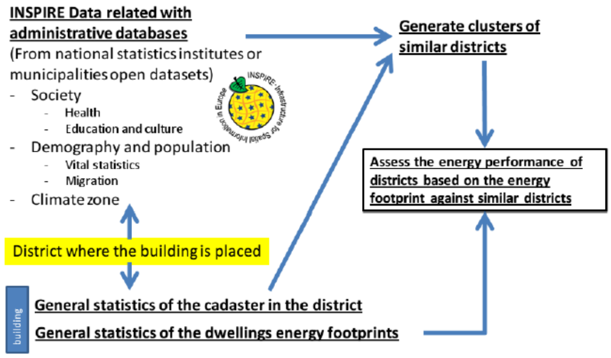
Figure 14. Workflow of the similar districts benchmarking (Situation 2)



(a) Data coming from dwellings dynamic measures



(b) Data coming from buildings databases



(c) Proposed workflow

Figure 15. Example of the similar districts benchmarking (Situation 1)

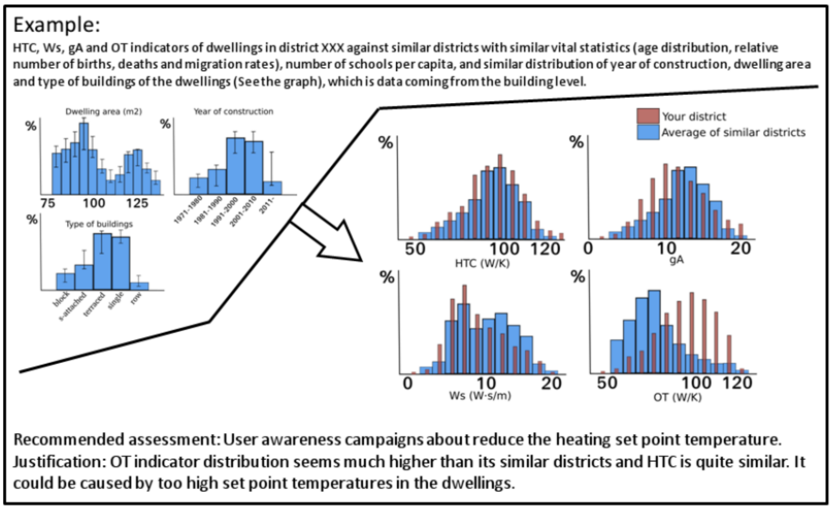
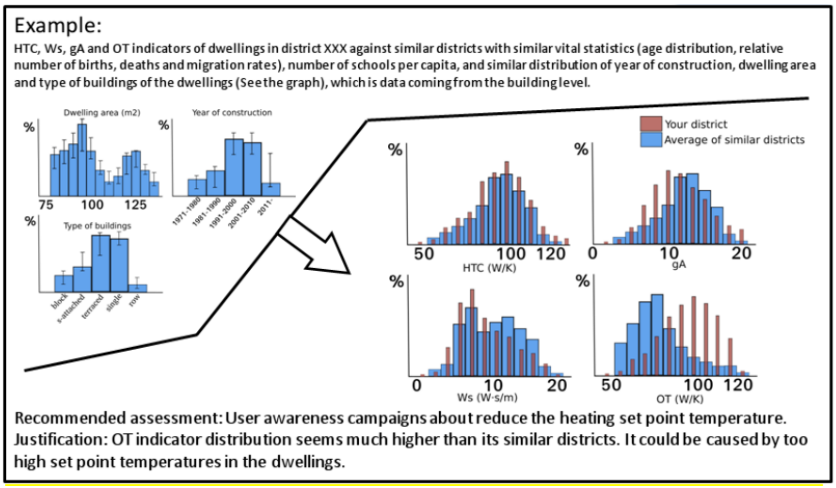


Figure 16. Example of the similar districts benchmarking (Situation 2)



8.5 Conclusions and future work

To sum up, this technical report offers a conceptual vision of a methodology to assess the energy performance of buildings from the dwelling to the district level and beyond, based on dynamic measured data from the dwellings and administrative data which could be obtained through the INSPIRE framework.

The methodology considers two common situations when handling real data, the first one considering there is no problem about dealing with real consumer names, location and private consumer information, and the other when the data must be anonymous in terms of detailed location and user information. Essentially, the main difference within these two situations is that the assessment at the dwelling level could not be provided in situation 2, as a consequence of the impossibility to merge the dynamic measured data to the building administrative data. However, from district level to beyond, very close assessments could be done.

Finally, a short list of really interesting future work that could be deeper investigated, are:

- The validation of the methodology in a real use case, in order detect the usefulness and understand better the advantages and drawbacks that could provide this methodology.
- The analysis of the available administrative data in each Member State considering the framework developed by INSPIRE.
- The extended revision of the factors used to detect similarity within geographical levels with the scope of getting a better characterization of the geographic level, especially regarding the districts level.

9 Ongoing International Research Projects

As stipulated in the Energy Performance of Buildings Directive (EPBD), the requirement of nearly-zero energy buildings from 2018 to 2020 will necessitate the development of a new design approach, based more on energy flows in buildings. The observed trend for energy consumption in buildings is towards a decrease in thermal energy for space conditioning and an increase in electricity consumption for installations and appliances.

It is also noted that the more dynamic nature of energy demand and supply requires an updated and more flexible approach for energy performance assessment. Field measurements and experiments on-site are required to give evidence of the dynamic energetic characteristics of the building and building envelope. ICT is seen as indispensable part of future energy management in the building sector.

Research is also focussing on bridging the gap between building energy performance design figures and real energy performance of the building. This gap is partially due to the presently limitation of standardised calculation methods (legal compliance issues) but also due to quality of workmanship and usage of the building. Field measurements and dedicated research is needed to clarify the gap and to give feedback to building simulation software makers.

The recently started IEA-EBC Annex 71 project [25] focusses on Building Energy Performance Assessment Based on In-situ Measurements (follow-up of Annex 58) Several groupings are studying the in-situ measurements in practise. Better prediction, characterization and quality assurance of actual building energy performance is essential to realise the anticipated worldwide energy reductions in buildings and community systems. Quantifying the actual performance of buildings can only be effectively realised by optimized in-situ measurements combined with dynamic data analysis techniques. This project is advancing the development of in-use monitoring for buildings to obtain reliable quality checks of routine building construction practice to guarantee that designed performance is obtained on site.

The project focuses on residential buildings, both at the level of individual dwellings, as well as at the community level. At the building level, methodologies to assess and characterise occupied buildings, controlled with the buildings' own services and metering data, will be explored. Compared to the current assessment methods, this means that the intrusive, dedicated tests are left behind in favour of assessment methods based on monitoring systems. At the aggregated level (to be interpreted as a cluster of individual dwellings, be it an apartment building, a small neighbourhood or a district) the aim is to develop procedures to assess large – but often rather crude – data sets that allow the identification of opportunities at the building stock level. At both levels the development of characterisation methods will be explored, as well as of quality assurance methods. This project collaborates closely with DYNASTEE [40], the Network of Excellence on full scale testing and dynamic data analysis.

Two approaches may be distinguished

1. Co-Heating measurements on site

   CEN TC89 WG13 is developing a standard

1. Metering data

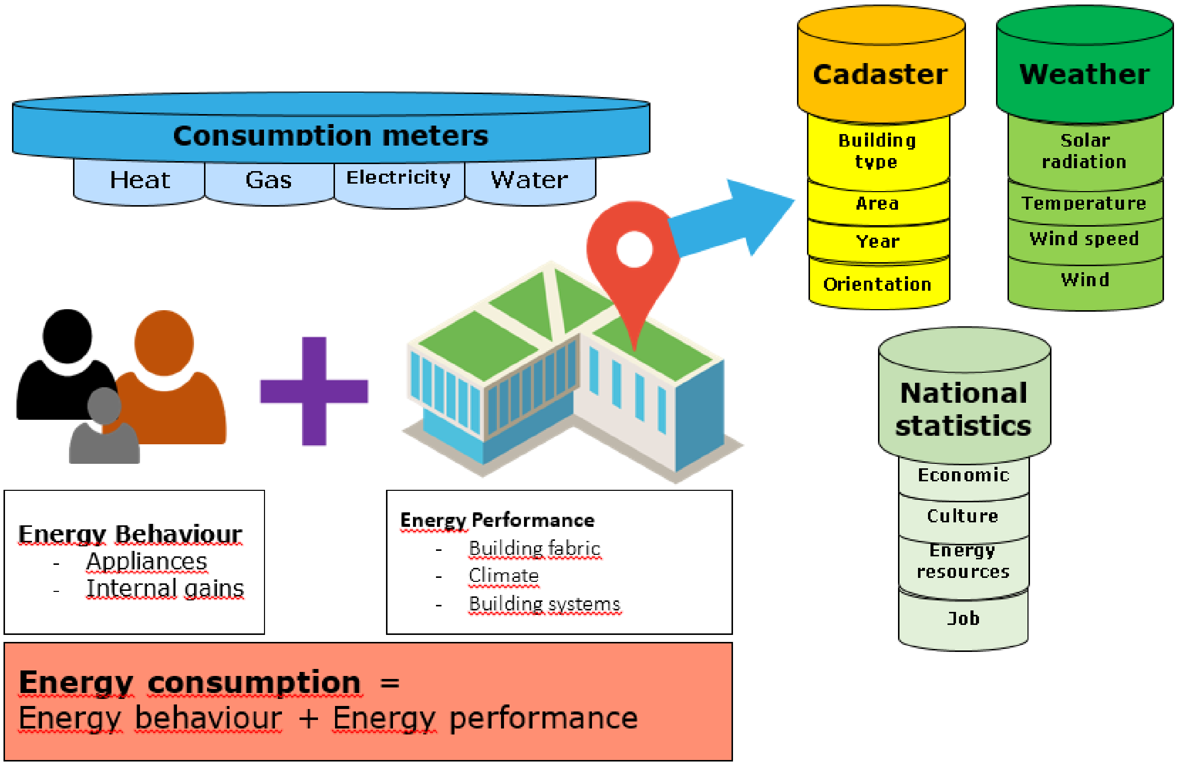
   - Electricity, gas, heat, water…

   - Regular readings with intervals ranging from a few minutes up to daily values

Note that both approaches require climate data from the site or a nearby weather station as well as a proper conversion to reference climate data. Figure 17 gives a schematic view on the required input data. The advantage of metering data is that a growing amount of data is coming available and hence an improved accuracy is feasible. In order to split building related energy use from occupant energy consumption a combined

statistical and dynamic method is investigated for the analysis of collected time series [41].

Figure 17. Schematic view on input requirements



DYNASTEE [40] is an informal grouping of organisations involved in research and application of tools and methodologies for DYNAmic Simulation, Testing and Analysis of Energy and Environmental performances of buildings. DYNASTEE provides a multidisciplinary environment for a cohesive approach to the research work related to the energy performance assessment of buildings in relation to the Energy Performance for Buildings Directive (EPBD). DYNASTEE, being a network of competence in the field of outdoor testing, dynamic analysis and simulation, has over 30 years of experience through a series of EU research projects.

As an informal grouping of outdoor test facilities is an open platform for sharing knowledge with industry, decision makers and researchers. It provides training for application of dynamic analysis techniques and makes software tools available, developed in international projects. DYNASTEE has the expertise needed to support the developments and design of nearly-Zero Energy Buildings as required by the EPBD. Specific outdoor experimental work needs knowledge of the analysis process in order to optimise the dynamic information in the measurement data. Simulation requires results from analysis in order to be able to scale and replicate the results from analysis and testing to real buildings in different climates.

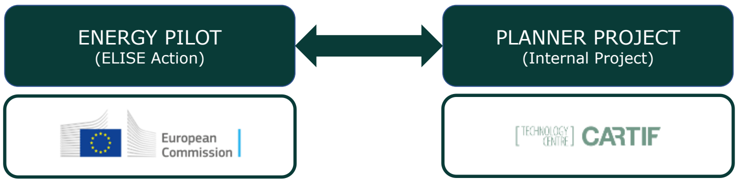
The JRC ELISE Energy Pilot project [5] and [42] has developed close collaboration with the aforementioned projects.

10 Harmonisation of EPC datasets according to INSPIRE – Replication of Use Case 1 results in the Spanish context

This chapter is devoted to the explanation of the process carried out to study the replication of results obtained in one of the Use Cases of the Energy Pilot project, in particular Use Case 1: "Harmonisation of existing Energy Performance Certificate datasets and creation of a web application for accessing them". To obtain more information on this subject, please refer to [8 and 9].

This study has been carried out under a collaboration framework between the JRC and Fundación CARTIF[23] during a three month stay of a visiting scientist (Gema Hernández Moral) in the centre from mid-September 2017 to mid-December. The interest of this collaboration has been the mutual growth of both entities with respect to two projects that share many common aspects: the Energy Pilot (JRC) and PLANNER (CARTIF), which will be referred to in the following sections.

Figure 18. – Energy Pilot (JRC) and PLANNER project (CARTIF)



Energy Pilot (ELISE action) / PLANNER project

The energy directives (Energy Performance of Buildings Directive, Energy Efficiency Directive, and Covenant of Mayors) pose several challenges when trying to implement them in different contexts and scales. To aid the stakeholders involved in this process, the Energy Pilot and the PLANNER project aim at providing insight in the energy policy lifecycle implementation. Coming from different backgrounds (the Energy Pilot stems from the ELISE action mentioned before and the PLANNER project is an internal project in CARTIF), both projects cover similar topics and tackle the different scales in energy planning and monitoring of results.

In the figure 19, the use cases or steps can be observed in both projects. The shaded fields correspond to the matching aspects covered in both cases and marked in yellow, the scope of this chapter. As it can be observed, the PLANNER project has a wider scope delving into the analysis of highly detailed BIM models.

Use Case 1: Harmonization of existing Energy Performance Certificate datasets and creation of a web application for accessing them

The first step of the Energy Pilot was successfully finalised and reported in the "INSPIRE harmonisation of existing Energy Performance Datasets"[24]. The main objective, which was "*to establish and accessible and interoperable common knowledge base for EPC datasets to support local government and private sector involved in energy efficiency policies*", was reflected in the following achievements:

[23] http://cartif.es
[24] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104587/jrc104587_d7.1-usecase1_final_report_v2.0_pubsy%20pf.pdf

Study of Trento's EPC datasets and structure (based on real public building EPCs): at the moment of the study, the Energy Performance Certificates in Italy were managed at regional level; that is the reason why a region was selected for the study and for data privacy issues, only EPCs of public buildings had been analysed.

Target data model proposal following INSPIRE: following INSPIRE specifications a data model (target data model) was conceived to hold the datasets that correspond to Energy Performance Certificates. The new attribute set was built upon the core of the "Buildings"[25] theme, as depicted below and explained in section 5 (The role of INSPIRE). This target data model in UML version[26] has been the basis for the study.

Figure 19. – Energy Pilot Use Cases and PLANNER steps comparison

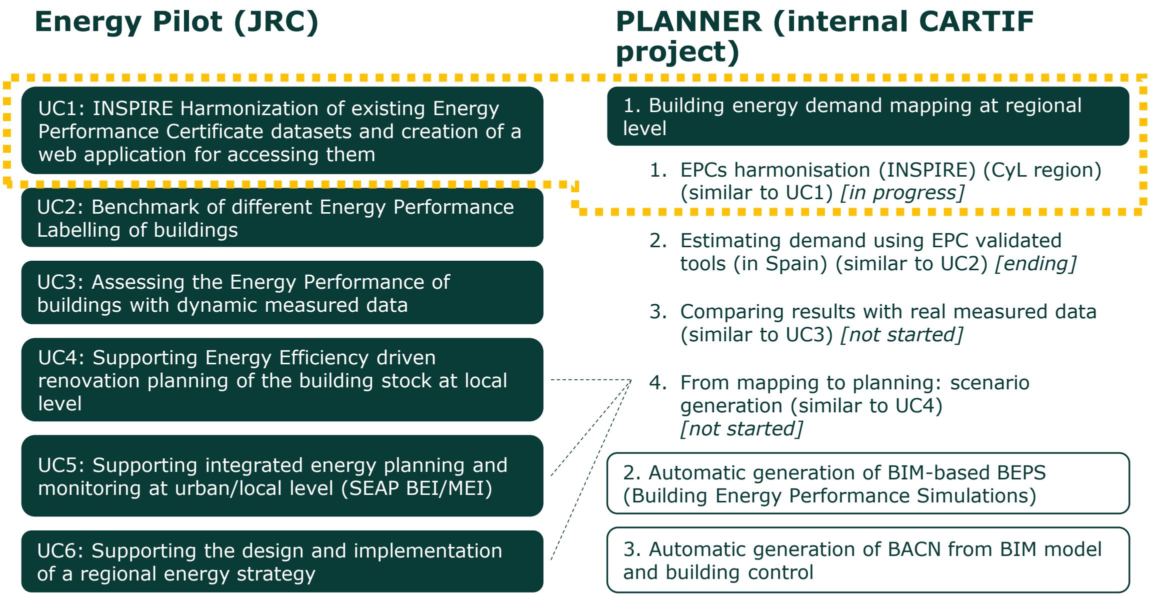
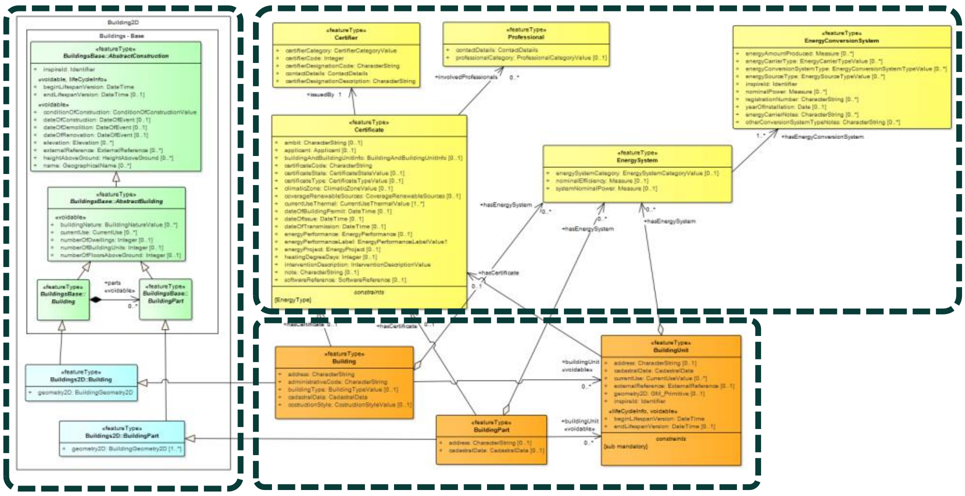


Figure 20. – Target data model (UML version)



[25] https://inspire.ec.europa.eu/Themes/126/2892

[26] http://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/use-case-1/data-models/uml-html-viewer/

Creation of a web app to access EPCs following INSPIRE specifications[27]: the EPCs analysed in the Trento region were made available through a website according to INSPIRE specifications.

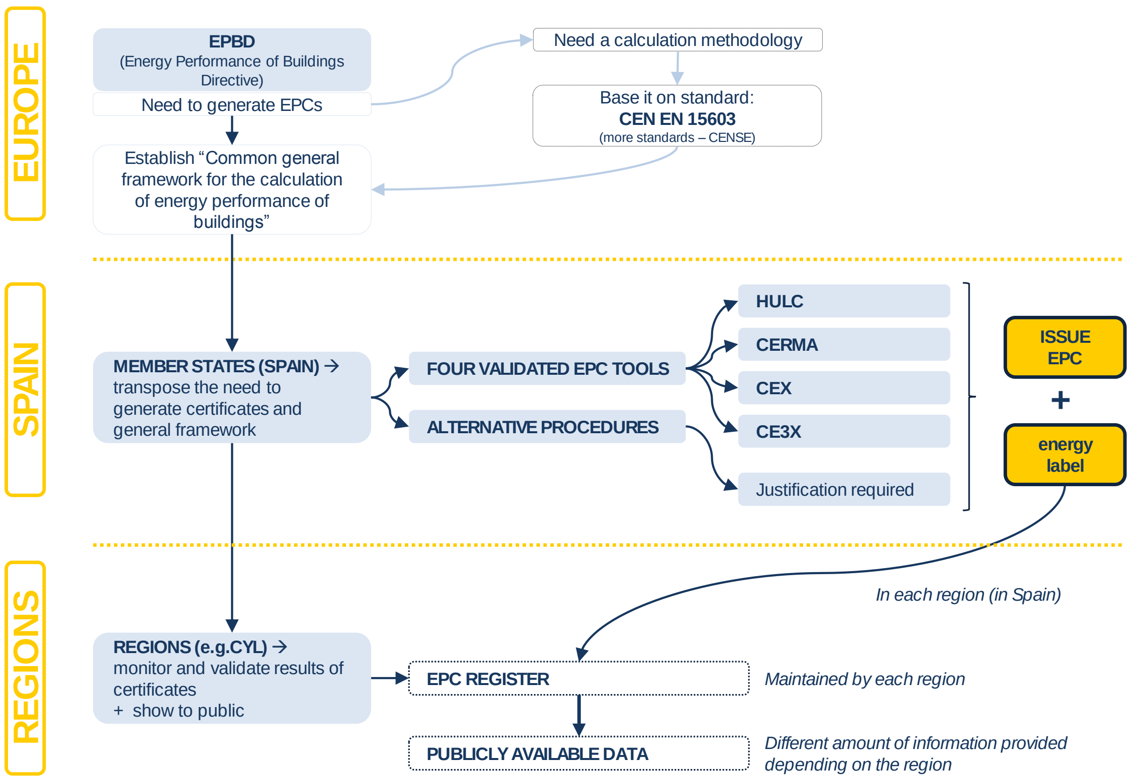
Analysis of Spanish EPC datasets

Based on the target data model structure, the Spanish EPC data model was analysed. To understand the process followed it is necessary to set the context (EPC issuing process in Spain) and provide a general overview on what are the datasets contained in an Energy Performance Certificate.

EPC submission context in Spain

There are three main steps in the issuing and submission process in Spain, which are reflected in the image below.

Figure 21. –EPC submission process in Spain



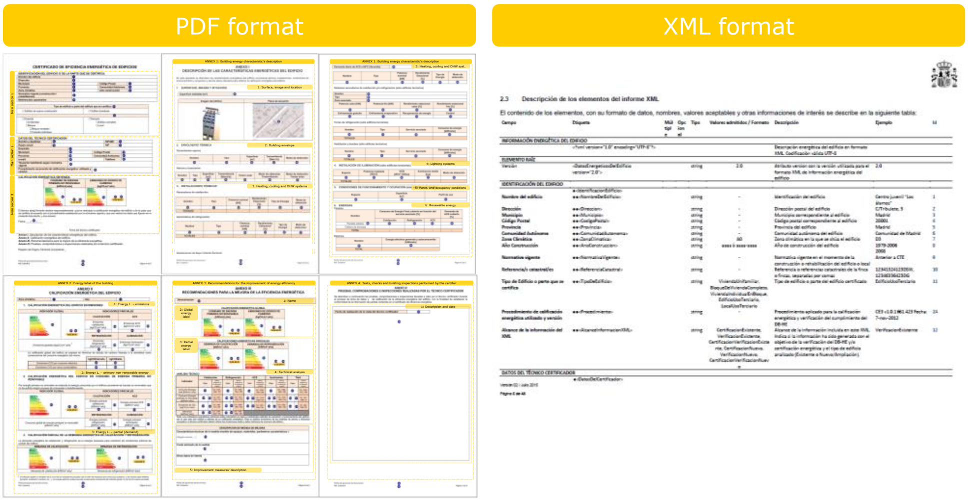
At **European level**, the Energy Performance Directive of Buildings is set, which is the main responsible for the necessity to issue Energy Performance Certificates. To this aim a calculation methodology is required, which should be based on European standards (CEN EN 15603); however, it is only in Annex 1 of this Directive where some kind of framework and recommendations are expressed.

It is at the **Member State level** where this framework should be interpreted. In this case, in Spain this has resulted in the creation of four validated EPC tools at national level (HULC, CERMA, CEX and CE3X) to be deployed by certifiers and obtain the EPC and the energy label. It is also possible to use alternative procedures, but they should be well justified.

[27] http://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/use-case-1/webapp/

The outcomes of this process are an EPC in PDF format and an XML format file, where all the relevant data are contained. Below an image can be seen where the six-page long PDF format and an example of XML EPC structure are shown.

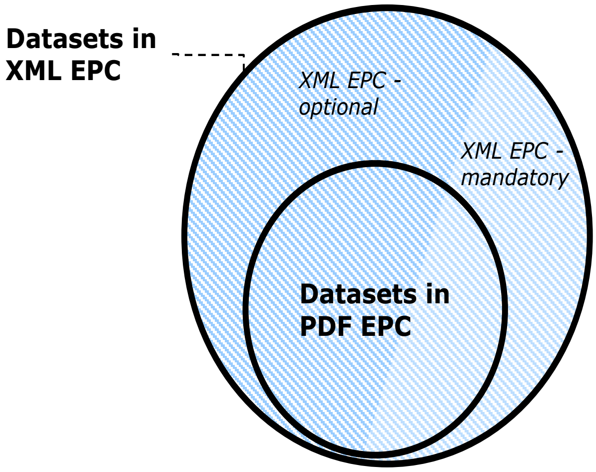
Figure 22. –Contents of PDF and XML EPC formats in Spain



EPC PDF format - Spain

Sample of document – XML EPC content

Figure 23. – Semantic richness comparison among the PDF format and the XML format in Spanish EPCs



The contents of these two formats vary significantly, in the same proportion as in the image to the right. It should be noted also that many of the attributes contained in the two data models (two thirds approximately in both cases) are optional. In addition, it can be observed that the XML format is much semantically richer as the PDF EPC format.

This is the reason why the XML structure to contain the datasets established at national level in Spain has been analysed.

Finally, both types of files are handled at **regional level** in the corresponding registers. They are managed by each region, which decide which sets of information should be available to the users or not.

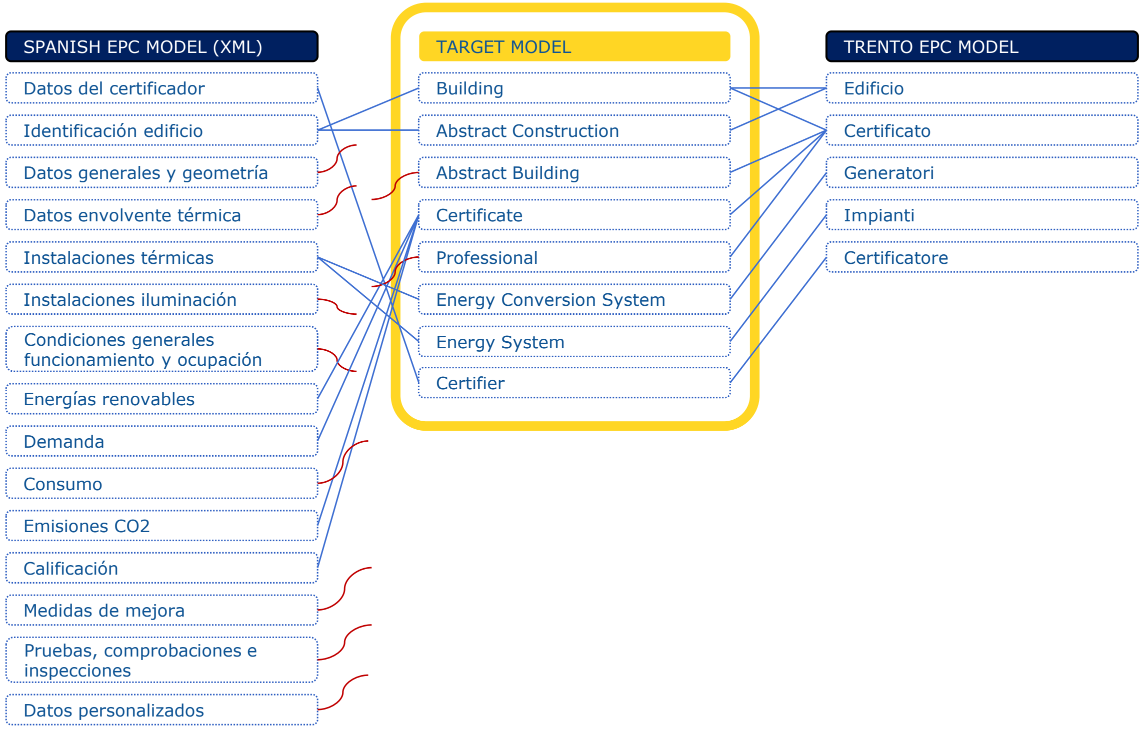
The practical use at the regional level of the XML scheme set at national level is out of the scope of this first analysis, where only the XML structure proposed by the Ministry

has been studied. Delving into the problematic of the implementation of the XML structure at regional level will be tackled in the future with the involvement in the project of the Ente Regional de la Energía (EREN), the regional authority in charge of the Castilla y León (Spain) EPC register.

Comparison of the XML EPC format with the target data model

The comparison with the target data model (Use Case 1 result) has followed two main steps: main category comparison and an attribute per attribute comparison. The first is reflected in the following figure, where the three data models considered are showcased. Since the target model was based on the Trento EPC datasets, all of the categories have found a perfect match, whereas in the case of the Spanish EPC model in XML some mismatches are found, which have been studied in more depth in an attribute per attribute comparison.

Figure 24. –Comparison of the main categories in the three data models



Several sets of tables were deployed for the attribute per attribute comparison. Special attention was paid to the multiplicity of each attribute (if the attribute should appear one or more times, one time, cero, or cero or more times – if they are optional or not). As a result the following outcomes can be observed:

Table 1 –General quantification of the data models compared

Concept	Number of elements (Target model)	Number of elements (Spanish XML model)
Total number of attributes	**113**	**254**
Main categories (feature types)	10	17
Sub-categories (data types)	14	50
Mandatory attributes	24 (21.23%)	67 (26.38%)
Optional attributes	89 (78.76%)	187 (73.62%)
Code-lists[28]	24	42

From the quantification of both sets of attributes it can be observed that the Spanish XML model is semantically richer; however, the proportion of mandatory and optional attributes is comparable in both cases. The same situation can be observed in the main categories, sub-categories and code-lists, where the quantity of attributes is in relationship to the number of attributes existing in the data model.

Performing an attribute per attribute comparison, the results depicted in the following table were observed.

Table 2 –Attribute per attribute comparison results

Concept	Number of elements (Target model)	Number of elements (Spanish XML model)
Matching attributes	13	
One to more relationships	21	33 (+7)[3]
Similar attributes	9	
Other sources	43	-
Non-matching attributes	27	199
Total number of attributes	**113**	**254**

From the table 2, the following conclusions can be derived:

- A low number of attributes (13) matched perfectly with the definition of the opposite data model.
- Situations where one to more relationships were observed, that is, when an attribute in a data model corresponds to several attributes in the opposite data model.

[28] Code-lists are lists of possible values that a determined attribute could have. For instance, the attribute "Energy label" can have the possible values "A", "B", "C", "D", "E", "F" or "G".

- A certain degree of similarity was found in 9 attributes, where aspects such as the unit of measure did not correspond, or the concept behind the attribute was not reflected in the same way.
- Some of the attributes in the target model (other sources, 43) are assumed to be contained in other sources, such as the register (EPC identification) or the cadastre (building identification).

Special attention should be paid to the non-matching attributes, which in the case of the Spanish XML model the value is quite high. The reason behind this is that this model covers more concepts as the target model does, including information on improvement measures and detailed information on the building envelope among others.

Next steps

Having these aspects in mind, it is possible to align both data models by extending the target data model and including more classes to hold the attributes that have not been considered in the target data model. These transformations will be explored in the future and the specific difficulties found in the process registered. The main aim of this exercise is to test the replication possibilities in other Member States of this process and what type of obstacles can be found. To do so, the next tasks will be explored:

— **Real Castilla y León EPCs**. This exercise will be much more grounded if it is based on real EPCs contained in registers. Therefore, the example used in Use Case 1 (Trento's EPCs) will be complemented by the set of EPCs hosted in the Castilla y León region register. This will enable to observe as well how the XML structure proposed at national level is put in practice. To this end, the collaboration of the Ente Regional de la Energía (EREN) will be highly valuable.

— **Italian EPC data model**: from the time of the analysis performed in the Trento region, Italy has changed how the EPCs are managed moving from regional level to national level.

As an outcome of this process, a better understanding and more accurate approach towards the harmonisation of EPC datasets based on several real cases will be obtained. Moreover, the difficulties encountered in this replication process will be reported in order to provide more examples for other Member States to follow.

Conclusions

Working on the data harmonisation of Energy Performance Certificates is a highly relevant task. Firstly because providing the same information in every country would enable to easily perform comparisons and derive conclusions to implement different retrofitting actions. Secondly, it should be highlighted that EPCs are one of the most relevant communication tools with citizens, where the energy performance of a building can be conveyed and understood in a simple way. However, they should be considered reliable and this fact is not granted if every country offers to the citizen different data.

In this sense, INSPIRE role is highly relevant in harmonising, providing the attributes across all Member States and making them accessible through catalogues. In addition, the location information provided allows analysing patterns by location, to in the end be able to implement action plans or policies.

As it has been explained in this section, while the replication of the target data model is possible, there are many differences related to the way EPCs are defined or conceived in each Member State and how the EPCs are managed (registers etc.). These differences have their origin in how the calculation framework of the Energy Performance of Buildings Directive has been interpreted and which has been the final calculation adopted.

Having a common calculation methodology in Member States and establishing registers at national level following the same data model would be highly beneficial to support energy action plans and monitor their results. Assuring that the same input data (harmonised across Europe and terminology) is deployed combined with the same calculation methodology will ensure reliable and comparable results across Member States.

Moreover, assuring an adequate methodology and making these data available to the public will also contribute to their reliability and as a consequence will result in a better uptake of Energy Performance Certificates.

11 Presentations

At several conferences and workshops, the progress of the ELISE Energy and Location project has been presented during 2017. Below follows a list of selected oral presentations by C2.

"Building Energy Use –assessment methods based on location data" GeoSmartCity Final Conference *Genova, 15th February 2017*. Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

"In–situ Measurements and Building Energy Use – requirements for measured data". Annex71 *Loughborough, 26 April 2017.* Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

"**Methodologies for energy performance assessment of buildings based on location data – Use Cases**" Participation to the CITIES workshop *30-31 May 2017; Aarhus, Denmark*. Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

Presentations to the INSPIREd Energy workshop *5 October, Kehl (DE).* The workshop took place during the INSPIRE Conference in Kehl and Strassbourg, 4 – 8 September

"**Use Case on Assessing the Energy Performance of Buildings using dynamic measured data**"

Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

Chiara Lodi. European Commission, DG JRC, Unit C.4 – Sustainable Transport Unit

Gerard Mor, CIMNE - UPC, Polytechnic University of Catalonia, Barcelona, Spain

"Assessment Methods based on Location data for Building Energy Use",

Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

"First Common Exercise: From holistic to calculation approaches" Annex 71 *Chambery, 24 October 2017.*

Gerard Mor, CIMNE - UPC, Polytechnic University of Catalonia, Barcelona, Spain

Hans Bloem, European Commission, DG JRC, Unit C.2 - Energy Efficiency & Renewables

Chiara Lodi. European Commission, DG JRC, Unit C.4 – Sustainable Transport Unit

12 Conclusion

This approach will include modelling based on simulation as well as modelling based on system identification in a unified framework for performance assessment and modelling. It will work towards reducing the gap between the actual and theoretical performances considering both approaches in parallel: simulation and system identification. Harmonisation criteria established by the INSPIRE Directive [6] will have a positive impact.

When it concerns the reliability of measurements in the built environment, it is noted that ICT technologies have shown a spectacular advancement in recent years, with modern developments and on-going projects very much focussed on communications and data management. This area has a high potential for innovation considering the issue of high quality measurement in the context of reducing the performance gap combined with application of the advancement ICT technologies. In the Dossier "Clean Energy for all Europeans" [26], the importance of digitisation is highlighted, enabling the citizen with digital monitoring and control of energy use.

This area has a high potential of innovation regarding extending and generalising the scope of application of these techniques to energy performance assessment from building components to full size buildings, considering new features of modern buildings, production of renewable energy and in occupancy conditions.

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List of abbreviations and definitions

BPIE	Building Performance Institute for Europe
BEI	Baseline Emission Inventory
CDD	Cooling Degree Days
CEN	European Committee for Standardization
CTSM	Continuous Time Stochastic Modelling
CoM	Covenant of Mayors
COP	Coefficient of Performance
CPD	Construction Product Directive
CPR	Construction Product Regulation
DG	Directorate-General
EBC	Energy in Buildings and Communities
EED	Energy Efficiency Directive
ELISE	European Location Interoperability Solutions for e-Government
EN	European Norm
ENTR	DG for Enterprise and Industry (now DG GROW)
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
ETA	European Technical Assessment
EOTA	European Organization for Technical Assessment
EPC, EPV	Energy Performance Certificate or Value
EU	Europe
EULF	European Union Location Framework
gA	Solar Aperture
GHG	Green House Gas emission
GIS	Geographical Information System
GROW	DG Internal Market, Industry, Entrepreneurship and SMEs
HDD	Heating Degree Days
HTC	Heat transfer Coefficient
ICT	Information and Communication Technology
IoT	Internet of Things
IEA	International Energy Agency
ISO	International Organization for Standardization
ISA	Interoperability Solutions for public Administrations, businesses and citizens

JRC	(Directorate-General) Joint Research Centre
MEI	Monitoring Emission Inventory
MS	Member State
NUTS	Nomenclature of Territorial Units for Statistics
nZEB	nearly-Zero Energy Building
RC	RC model; Resistance and Capacitance model
SEAP	Sustainable Energy Action Plans
TAB	Technical Assessment Body
TC	Technical Committee
PEF	Primary Energy Factor
WG	Working Group

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JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.