ENHANCING ENERGY PERFORMANCE CERTIFICATES WITH ENERGY RELATED DATA TO SUPPORT DECISION MAKING FOR BUILDING RETROFITTING

by

Leandro MADRAZO*[*], Alvaro SICILIA, Marco MASSETTI, Fabian L. PLAZAS, and Eric ORTET

ARC Engineering and Architecture La Salle, Ramon Llull University, Barcelona, Spain

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The increasing availability of large-scale repositories of energy performance certificates offers the opportunity to interlink them with other data sources (cadastre, geographical data, weather data, building regulations, catalogues of refurbishment measures) and to derive innovative services that use the integrated data in conjunction with various tools (energy performance simulation, environmental impact). In the ENERSI project, two applications have been developed to make it easier for building owners and planners to take informed decisions to improve building energy performance in their properties and in their municipalities. These applications, named ENERHAT and ENERPAT, are based on the integration of building data from multiple sources and domains (energy performance certificates, cadastre, geographic information, and census), building refurbishment policies and assessment tools. Data integration has been performed using Semantic Web technologies. A user-friendly interface enables end-users of these on-line applications to obtain information about the current building status of properties, the measures which could be undertaken to improve them, the energy savings achieved and their respective costs.

Key words: *energy performance certificates, building retrofitting, energy information systems, data integration, semantic technologies*

Introduction

Buildings are responsible for 40% of energy consumption and 36% of carbon emissions in the EU [1]. In order to reduce this economic and environmental impact, it is fundamental to improve the performance of the existing building stock. However, it is estimated that only 1% of the overall floor area of residential and non-residential buildings is renewed each year in Europe and other regions. A preliminary comprehensive understanding of the state of preservation and the energy performance of the building stock is essential for the success of any type of building retrofitting programme. This knowledge can only be obtained by gathering and analysing information from multiple sources: energy performance certificates (EPC), socioeconomic data, planning and building regulations and energy consumption, among other.

The application of measures to improve buildings' energy efficiency involves multiple agents (owners, city planners, and architecture and engineering offices, among other) operating in different decision realms. The various actors involved need to have access to information

* Corresponding author, e-mail: leandro.madrazo@salle.url.edu

about the building stock which is often distributed in different data sources (open and proprietary), and available in multiple formats (web sites, data repositories, reports). These actors need to have information which suits their knowledge and expertise, in order to take well-informed decisions in their respective decision making realms. For example, building owners typically make decisions considering the costs that the renovation will represent for them and the return on the investment they will achieve. Municipalities, in particular, need to have information to develop energy models to know the energy and environmental costs at the city level [2], as well as to help them to implement sustainable energy actions plans [3]. In order to take these decisions, they might need data about building characteristics, residents' income, energy consumption and available budgets, which is presented to them in a way that they can evaluate the impact –in terms of energy savings and costs, for example of different renovation scenarios.

In recent years, different kinds of initiatives have been undertaken to facilitate access to building information with the purpose of improving their energy performance. The EU Building Stock Observatory collects data about buildings' energy performance in European countries in order to assess their real energy consumption [4]. The information which is gathered in a database includes the energy efficiency levels in buildings in EU countries and the EU as a whole, the certification schemes and their implementation, funding for building renovation and energy poverty levels. However, the information provided by this observatory focuses on countries, rather than on urban or building scales.

Unlike the EU Building Observatory, there are other tools that operate with building data. INSMART collects data at the building level which has been compiled via door-to-door surveys, smart meters, and statistics. The data is gathered and displayed in a GIS-based energy information system [5]. The collected data can serve as inputs for simulation tools and the outputs used to support decision making by city planners. However, this process to collect data building by building, door by door, is not feasible when it comes to analysing large number of buildings in urban areas. To simplify this process, building typologies can be used. SimStadt uses third party tools, such as CitySim, as well as building typologies and energy system libraries to estimate the energy demand of the buildings and to propose retrofitting measures, using CityGML models based on LiDAR surveys [6]. SUNSHINE integrates the geometric data of buildings with their thermophysical properties and climate data. A building typology database is used to estimate thermophysical properties. The combined building's energy performance information is shown in a 3-D interface for the use of citizens, public administrations and government agencies [7]. However, this tool does not support the calculation of retrofitting scenarios to increase the energy efficiency of the building stock within an urban area. The UMI is an urban simulation tool that enables urban planners and architects to analyse operational energy, daylighting, outdoor comfort and walkability in urban areas [8]. Neither does this tool help to determine improvement measures. Furthermore, users need to manually introduce the data for each building in an urban area, one by one using a graphical user interface, something which requires a lot of time and effort. The abovementioned energy information systems combine existing GIS data, building data, surveys, and building classifications to assess building energy performance.

The EPC contain information about individual buildings and dwellings, for example, energy demand, carbon emissions, building equipment, and characteristics of the construction. In accordance with the guidelines of the European Directive 2002/91/EC and the recast 2010/31/EU [9, 10], public agencies in Europe are collecting EPC in countries and regions. In recent years, some applications have been developed to take advantage of the increased availability of the data derived from derived from energy certificates. For example, the Energie Label Atlas is a web-based tool that provides visual information about the energy labels for buildings in The Netherlands [11]. The energy information is displayed in a map in which the buildings have the colour of their energy label (*e. g*., green for A class, red for G class). In this tool, the label can be determined from building typologies or it can be provided by a certified consultant. The main limitation of this tool is that the building data, even though is readable, cannot be re-used by the public. Furthermore, the tool does not provide recommendations about refurbishment measures which could be applied to improve the building stock. Finally, there are other works, such as the one from Gupta & Gregg, which enrich EPC with socio-economic data and ordnance survey data (*e. g*., maps, addresses) to plan large-scale retrofitting programmes at a city scale [12].

Table 1 summarizes the main features of the tools listed above as compared to the applications developed in the ENERSI research project –ENERHAT and ENERPAT– which are described in the next sections. As the tab. 1 shows, ENERSI applications share some features with previously developed tools, to a lesser or greater degree. Their main contribution is to encapsulate all of the features in user-friendly on-line applications for different user profiles to determine building refurbishment measures for buildings, which may refer to either individual buildings (ENERHAT) or groups of buildings in municipalities (ENERPAT).

Table 1. Main features of the tools related to the ENERSI applications

Features	INSMART [5]	SimStadt [6]	Sunshine [7]	UMI [8]	Energie Atlas [11]	Gupta and Gregg [12]	ENERSI
Integrating data from multiple domains	Yes	No	Yes	No	No	Yes	**Yes**
Extracting building geometry from public administration databases	Yes	Yes	Yes	No	Yes	No	**Yes**
Calculating measures for each single building (without resourcing to building typologies)	No	No	Yes	No	No	Yes	**Yes**
Proposing retrofitting scenarios	No	Yes	No	No	No	No	**Yes**
Visualizing the integrated data	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**
End-user applications available on-line	No	Yes	Yes	No	Yes	No	**Yes**
Adapted to diverse user profiles	No	No	Yes	No	No	No	**Yes**

In addition, a major contribution of the ENERSI applications is the use of Semantic Web technologies (RDF, OWL, and SPARQL) to integrate data from multiple sources and domains. The use of these technologies helps to overcome the structural and semantic heterogeneity of the data sources. Their application is based on a shared understanding (*i. e*. ontology) of the meanings associated to the heterogeneous data, whose terms are derived from international standards in the field of energy efficiency. The ENERSI ontology can be expanded and re-used by third parties to develop new applications.

Methodology: integrating data, policies and building refurbishment assessment tools

The ENERHAT and ENERPAT are two on-line applications created by the research group ARC Engineering and Architecture La Salle within the research project ENERSI, *Energy services platform based on the integration and analysis data from multiple sources*, co-funded by the Spanish National Plan for Scientific and Technological Research and Innovation and carried out from 2013 to 2017. These applications integrate building data from different sources to support decision making in building refurbishment: ENERHAT, for building owners to assess the energy performance of their property and take measures to improve it; and ENERPAT, for urban planners to identify the buildings in their municipality with the highest renovation potential in order to develop large scale building renovation programmes.

The development of the two applications, ENERHAT and ENERPAT, has conveyed bringing together these four components through an ad hoc methodology created through the project, fig. 1:

(1) Integration of building data obtained from the EPC public register (facilitated by the Catalan Institute for Energy, ICAEN), technical building inspection reports (provided by the Catalan Housing Agency, AHC), cadastre, census and land registry (the three of them available on Internet) by means of a shared vocabulary (ontology). The contents of the multiple data sources have become unified in a semantic data model using Semantic Web technologies.

(2) Identifying refurbishment policies and guidelines which can be applied to buildings and applying them according to the available data.

(3) Interlinking an on-line building retrofitting assessment tool provided by ICAEN, which suggests refurbishment measures and facilitates their costs, with the integrated data.

(4) Defining the users' profiles and requirements for the front-end applications, with meetings and interviews with representatives of the two public agencies involved, ICAEN and AHC.

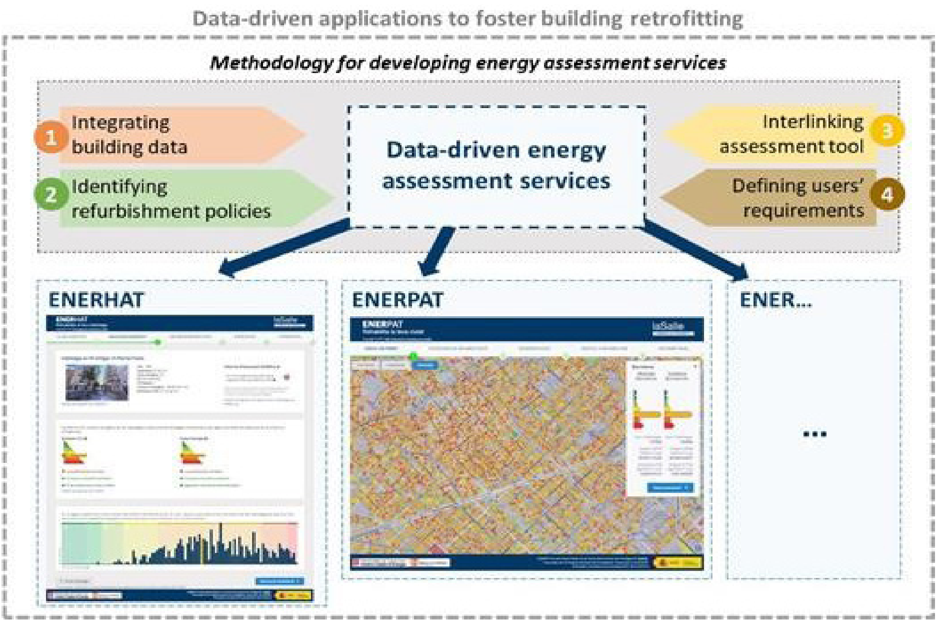

Figure 1. Methodology used in the development of data-driven energy assessment services for building refurbishment included in the applications ENERHAT and ENERPAT

These four components became intertwined in the two applications, ENERHAT and ENERPAT. The value of these applications lies in the seamless integration of the contents of the EPC database provided by ICAEN in .xml format; the building technical reports, facilitated by AHC in Excel tables; the refurbishment policies which were extracted from a .pdf document available to the public, and an on-line building retrofitting assessment tool from ICAEN which is automatically invoked within the applications.

Bringing together these four components was the result of a development process carried out in successive iterations, not always following the same order, fig. 2. This was so because of the interconnections between them. For instance, as more data from the EPC database became available to the ENERSI team during the realization of the project, new services could be devised which had not been foreseen at the start of the project. Conversely, as the user requirements specifications became increasingly defined as a result of the meetings with the two public agencies, it was necessary to search for additional data to fulfil the needs that emerged during the discussions. The specificities of the work to interlink each of the components integrated in the applications are described next.

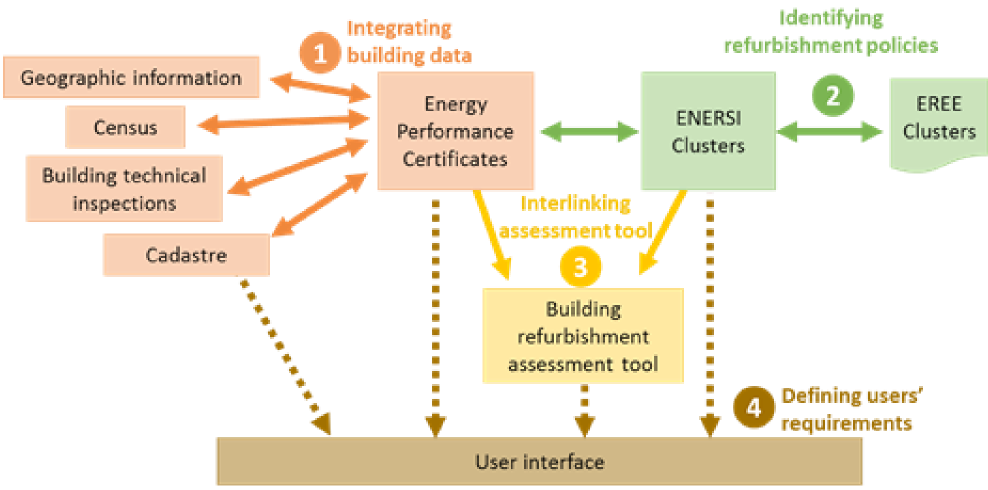

Figure 2. Process to develop the applications: (1) Integrating energy-related data, (2) Identifying refurbishment policies, (3) Interlinking building refurbishment assessment tool, and (4) Defining user's requirements

Integration of building data with semantic web technologies

The ENERHAT and ENERPAT applications have been developed by integrating data from multiple sources, formats, and domains. So far, 600,000 EPC records facilitated by the Catalan Institute for Energy (ICAEN) have been integrated with 8,000 records from the Geographical Information National Institute, data from Spanish cadastre available on-line, 25,000 building technical inspection records from the Catalan Housing Agency, and census sections data from National Institute of Statistics. All of these data have been harmonized with the EPC data adhering to the methodology and using the indicators recommended in the European Directive 2002/91/EC and the recast 2010/31/EU.

To integrate the data from different sources and with different formats (*e. g.* relational database tables, spreadsheets, text files, web pages), we have used standard languages of the Semantic Web such as RDF, OWL, and SPARQL. The semantic data integration process has encompassed three steps:

(1) *Vocabulary agreement.* Development of an ontology that formalizes a shared understanding of the meaning associated to the data. It includes concepts like *certificate*, *performance*, and energy consumption among others. The ontology has been created with the Click-On editor [13].
(2) *Data modelling.* Generation of mappings between the ontology and the data sources. Each data source has been mapped to the ontology using the R2RML standard mapping language. The mappings have been created with Map-On tool [14]. Transformation of the data sources into RDF. The mappings are executed to transform the data source into RDF according to the ontology developed in Step 1. The mappings have been executed by Morph-RDB [15].
(3) *Data linking and curation.* The data – in RDF format – is curated to eliminate errors such as misspellings and invalid values. Moreover, the energy certificates have been enriched with data obtained from the cadastre and census sections. Tailored scripts have been developed to clean and enrich the data. Specifically, during the data linking and curation process, it became necessary to tackle the following issues:
   - *Data format.* Some text-free fields such as the year of construction, the cadastral reference or the address of the building, had been introduced with diverse inconsistent formats in the EPC database. Therefore, it became necessary to harmonize all of them to a common format.
   - *Data unique identifiers.* To unequivocally identify a building, each public agency – ICAEN and AHC– uses their own identifier. In these cases, the building identifier of the cadastre was used as a shared reference.
   - *Data inconsistency and reliability.* Some data, such as the year of construction, was different in the cadastre and in the EPC. In such cases, a decision had to be made on which source to trust. It was decided to follow the cadastre since it is an official source (in the EPC the construction year is introduced by the expert who issues the certificate).
   - *Lack of data.* When there were no records of a building in any of the databases of the public agencies, then the building was assimilated to other buildings with similar characteristics which already had an EPC record. This way, it was possible to determine the refurbishment measures that would be applicable to the building with no registers.

Identifying and applying refurbishment policies

In Spain, the reference policy for building refurbishment is the *Long-Term Strategy for Energy Renovation in the Building Sector in Spain Pursuant to Article 4 of Directive 2012/27/EU* (EREE) which provides a comprehensive and detailed technical appraisal of the building stock and energy saving opportunities in a document which is available on-line [16]. The following information has been extracted from the EREE:

Clusters. Categories used to segment the Spanish residential building stock in ten clusters (A, B, C and D, for single family housing; E, F, G, H and I, for housing in multifamily buildings). Clusters are the result of crossing the following information: province (from which climate zone is derived), size of the municipality (which indicates if this is located in an urban or rural area and, from this, the energy sources); construction year (<1940, 1941-1960, 1961-1980, 1981-2007, 2008-2011); building type (single-family, multi-family), state of preservation of the building; heating system (central, individual), and type of dwelling (main, secondary or empty).

Intervention menus. The EREE considers packages of standard refurbishment solutions – so called, intervention menus – which are assigned to buildings which are part of a cluster. To assign the packages of measures to a building, a cluster is assimilated to a building type. For instance, buildings from cluster A (single-family housing built before 1940, with 1 to 3 floors), are represented by a building with a traditional construction system having thick bearing walls, a pitched roof with a ventilated chamber, and a ground floor slab in contact with the terrain. Considering these building characteristics, the EREE recommends the addition of isolation to the inner face of the walls and the roof chamber, the instalment of a layer of heavy pavement on the ground floor as well as sealed windows. With these package of measures, a decrease of 60% to 90% in heating energy consumption is expected and a 50% solar energy supply for the domestic hot water demand [16].

Interlinking an on-line building retrofitting assessment tool

In order to apply the packages of refurbishment measures proposed by the EREE to each of the buildings for which there is an EPC register, ENERSI uses an on-line building refurbishment assessment tool provided by ICAEN [17]. This tool segments the building stock in terms of year of construction, building use, and climates zones, a segmentation which is different from the one used by the EREE [18]. However, the EREE clusters only embrace 85% of the overall building stock. To overcome these two limitations, and in order to create an automatic link between integrated data, EREE policies and on-line assessment tool, it has been necessary to define new clusters within the ENERSI applications. These ENERSI clusters (nine in total, taking into account construction year, building type and climate zone) represent 100% of the building stock and act as nexus between the assessment tool and the EREE clusters.

The interlinking of all the components for each of the two applications is shown in fig. 3. In both applications, the inputs for the assessment tool (building use, construction year and climate zone) are obtained from the integrated building data (1). In the case of ENERHAT, the refurbishment measures (2) proposed by the assessment tool are summarized and organized to deliver a concise report to the end-user, including suggestions and recommendations for the most appropriate measures in terms of efficiency and costs. In the case of ENERPAT, the refurbishment measures proposed by the assessment tool (2) must be applied to the group of buildings selected by the user. To do so, the measures are mapped to the ENERSI clusters (3). This mapping is needed because the outputs of the on-line assessment tool do not always match the intervention menus of the EREE. As a result, the user gets the refurbishment measures assigned to each one of the nine ENERSI clusters.

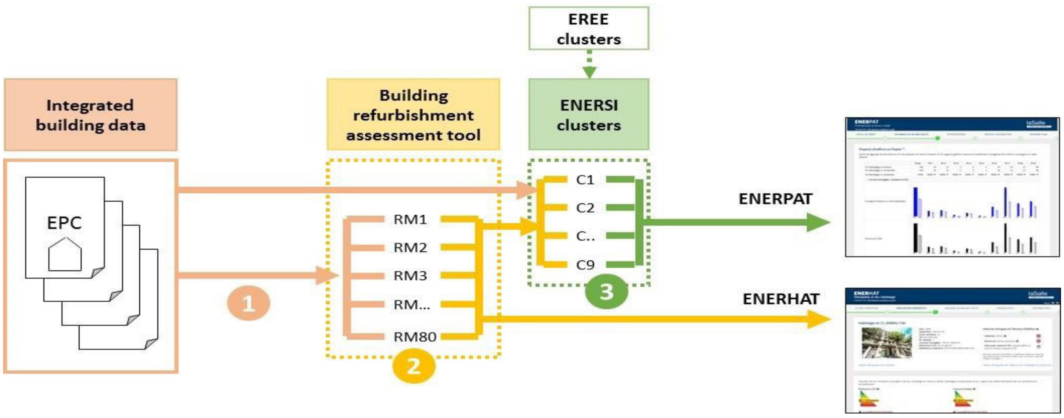

Figure 3. Interlinking of integrated data, assessment tool and clusterization

Defining users' profiles and requirements

One of the recurrent obstacles in the development of energy services based on data integration is the difficulty for end-users to envision the new possibilities that this integration offers them. Knowing the new information which could be obtained by integrating and analysing data from multiple domains and sources, and for what and for who it will be useful, is by no means straightforward. These questions cannot be answered exclusively by a multidisciplinary team of experts who design and implement the services (in our case, architects, energy consultants and ontology engineers). Rather, the participation of end-users in the design of the services is fundamental in the definition of the users' profiles and requirements. Therefore, it is necessary to discuss with them which data is available and what it can be used for, the policies and guidelines to be applied, and the tools to be interfaced.

The user requirements capture has been done in close collaboration with representatives of the two public agencies involved, ICAEN and AHC. In the development process, and through the various meetings held in separate and joint meetings with members of both organizations, the need to have an overall view of the building stage by gathering the data managed by the two agencies separately emerged. This need was grounded on several reasons: both agencies were concerned with the improvement of the building stock, but while ICAEN focused more on energy performance, AHC was concerned with the overall physical structure of the building; each agency held their registers in separate databases, whose contents were not public; and both agencies were interested in facilitating the general public access to data with the purpose of fostering the adoption of building retrofitting measures.

As a result of the meetings with the two agencies, it was decided to create two applications for two basic users: a building owner, with little knowledge about energy performance certification who needs to know the status if the dwelling (also of the building technical report) to decide if it is worth undertaking a refurbishment project, and planners and politicians in municipalities, who need to assign funds to carry out refurbishment projects to improve the city's building stock. In order to find out the needs of the two types of users, working samples of the interfaces were discussed and subsequently refined with the participation of members of the two public agencies. Furthermore, questionnaires to identify the information which would be useful to endusers to help them to take well-informed decisions were completed by participants from both agencies.

Results: ENERHAT and ENERPAT applications

The complexities behind the integration data from diverse sources, policies and tools remain hidden for the end-users of the two applications, ENERHAT and ENERPAT. The users of these applications follow a sequence of simple steps to arrive to the information which can help them to take decisions concerning the refurbishment of a single building or dwelling (ENERHAT) or about the application of large-scale renovation programmes in an urban area (ENERPAT). The data sources, and the procedures and tools used to process the data, are provided in the user interfaces.

ENERHAT: Renew your property

Through a sequence of five steps, ENERHAT (www.enersi.es/enerhat) enables owners to assess the energy performance of their building or dwelling, to compare it with similar buildings, to find out which refurbishment measures would suit the building and their respective costs. At the start, the user searches the property by introducing the address (Step 1– My Dwelling), fig. 4. After introducing an address (2), the user is provided with the information about the corresponding building (cadastre, EPC and building technical report) (3) and a list of the dwellings contained in it, indicating those which have an EPC (4).

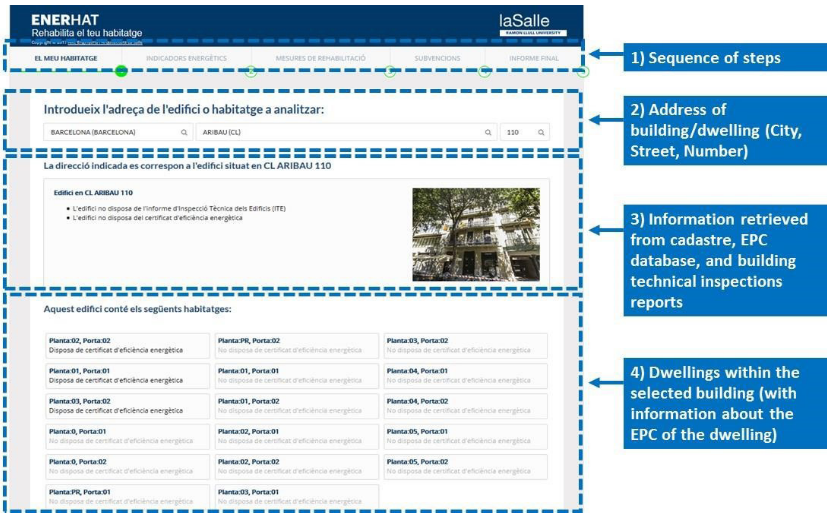

Figure 4. The ENERHAT. Step 1 – My Dwelling

Then, the user obtains information about the performance of the dwelling in comparison with similar buildings (this means, buildings with the same construction year, climate zone, use, and built surface) (Step 2 – Energy Indicators), fig. 5. The integrated data is shown thein a way which suits the user's knowledge (5), in this case, someone who does not know much about building energy performance, including a standard coloured energy label diagram (6) and a chart showing the performance of building as compared to similar ones (7).

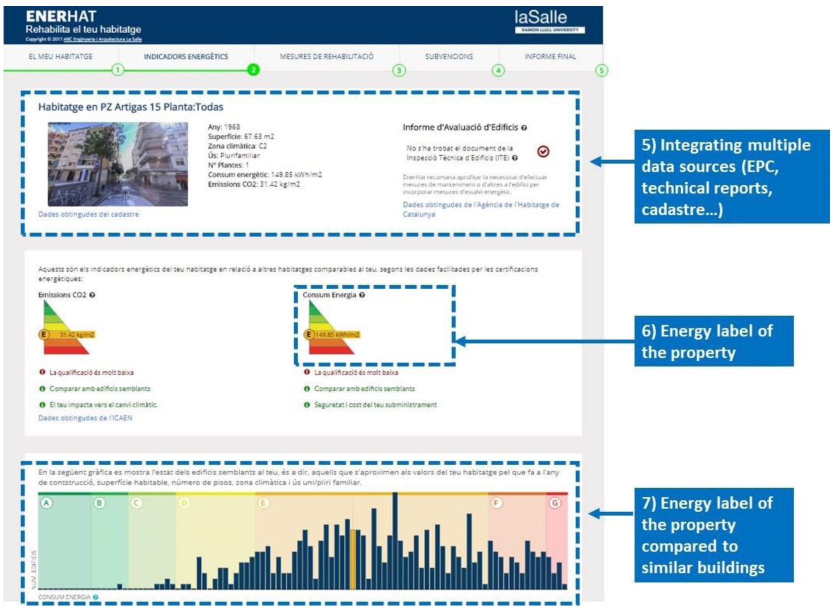

Figure 5. The ENERHAT. Step 2 – Energy Indicators

In the next step, recommendations about the refurbishment measures and their costs are provided (Step 3 – Refurbishment Measures) and the user can access information about government aid to finance the renovation costs (Step 4 – Subsidies). Finally, a report in .pdf format containing the information provided in the previous steps can be downloaded (Step 5 – Final report).

The ENERPAT: Renew your city

The ENERPAT (www.enersi.es/enerpat) helps users in city planning departments to know how the building stock in their municipality is performing – in terms of energy consumption and carbon emissions –, the renewal potential of the buildings, which buildings are more adequate to carry out refurbishment projects and their cost following a sequence of five steps. In a first step (Step 1- Search an Area), fig. 6, the user finds an area of interest, typically a province, county or town (2). A map shows the integrated building data from multiple sources (EPC, cadastre, census sections) (3). Once an area is located, a table shows the number of EPC, the consumption of non-renewable primary energy and the carbon emissions of all buildings for which there is information on the selected geographic scale, and also at the scale immediately higher (4).

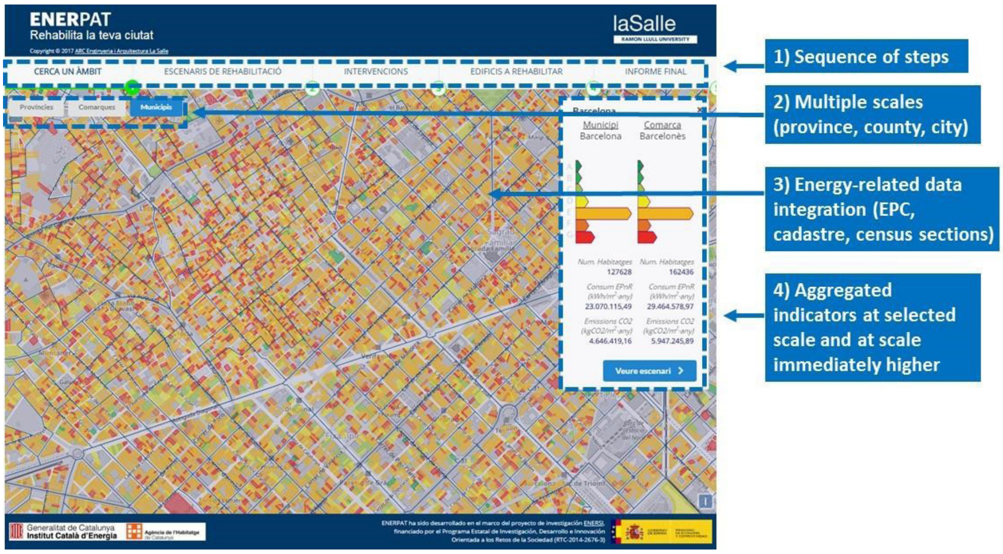

Figure 6. The ENERPAT. Step 1 – Search an Area

In the next step (Step 2 – Refurbishment Scenarios), fig. 7, it is possible to assess the impact and costs of the refurbishment scenarios for the buildings included in the selected area. In this interface, the user can explore multiple alternatives, identifying the building clusters where to intervene, and specifying the buildings to renovate in each cluster. By interacting with the interface, the impact on energy savings and costs for the multiple scenarios can be analysed. The buildings of a city are categorized in clusters based on the EREE policy (4). The current performance of the buildings in the selected area is shown in dark colour, and the performance modified as a result of the application of the refurbishment measures is displayed in a lighter colour (5). These values are calculated using ICAEN's assessment tool. The economic indicators – costs and return on investment – are also provided by the tool (6). After selecting a scenario, the measures proposed for the selected clusters are calculated (Step 3 – Interventions). The buildings to be renovated are displayed in the next step, in the map and in tables (Step 4 – Buildings to Refurbish). At the end of the process, a report with the information facilitated in the previous steps can be downloaded (Step 5 – Final report).

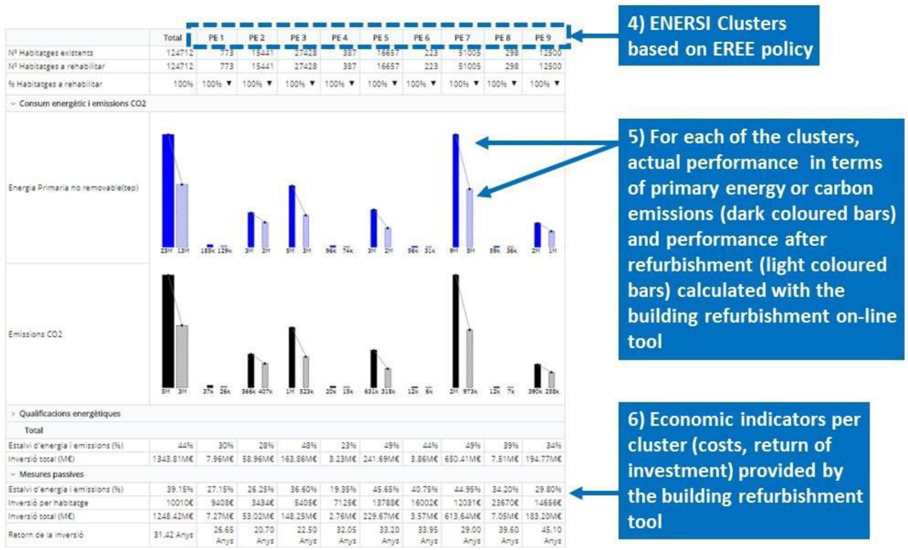

Figure 7. The ENERPAT. Step 2 – Refurbishment Scenarios

Scalability and replicabilitty

Other applications could be developed to support new services in the domain of building energy efficiency applying the techniques and methods for data integration developed by ENERSI. The scalability of the ENERSI applications can occur at three levels:

(1) Providing additional services based on the data already integrated. For instance, it would be possible to provide a specific service to visualize certain kind of information in way that suits the needs of a new user of the ENERHAT application, for instance, a real estate agent.
(2) Adding additional data which in turn will open up the possibility of creating new services. This would be the case of an application to identify fuel poverty which could be developed if socioeconomic data were available.
(3) Developing new services and applications to other domains, not necessarily related to building's energy efficiency. In this case it would be necessary to expand the existing ontology (in the case of applications related to energy efficiency) or creating a new ontology (for other domains). In both cases, the ontology engineering methods and tools used to develop ENERHAT and ENERPAT would still be applicable.

Conclusions

The applications developed in the ENERSI project, ENERHAT and ENERPAT, integrate building data, an on-line building refurbishment assessment tool, and refurbishment policies to make it easier for building owners and city planners to take informed decisions to improve buildings' energy performance. The interlinking of the different components integrated in these applications was the collaborative work of ontology engineers, data providers, and energy experts. In addition, and in order to develop data-driven services which are useful for specific end-users, it was necessary to assess the available data (repositories, documents), to select the information that is required to perform specific analyses and to determine the criteria for the data selection and their processing. The collaboration of representatives of two public agencies for which the energy assessment services were developed, ICAEN and AHC, was fundamental to achieve this.

In fact, a major difficulty in the development of the applications was the alignment between the users' requirements and the available data sources. It is difficult for those involved in the design and implementation of data-driven services to envision the potential derived from the integration of data from multiple domains. This requires from users to think differently as they do in their regular practice, opening up possibilities to include other factors in their decision-making which they might not be considering. Therefore, the development of applications such as ENERHAT and ENERPAT is becoming an opportunity to reconsider existing working practices, and to foster interdisciplinary, multidimensional approaches to building energy assessment which cut across domains and administrative structures. This is particularly challenging when public agencies are involved, since each one tends to operate within the limits established by their administrative duties, often overlooking the work done in other departments. In the field of building energy performance, however, it is fundamental to gain a holistic view of the building which can only be acquired by having access to information obtained by different agencies.

In the process of integrating the data from the various sources, some inconsistencies and errors arose. Although some of the problems were solved within the ENERSI applications, in other cases the solutions had to be found at the data sources level, for example, by introducing standardized procedures to name a building address, to name and classify building components and systems, or to assess the building performance using standard indicators and values. Therefore, one of the consequences of the data integration was to issue recommendations to improve the data collection and management in order to harmonize the data contents and structure.

In order to integrate heterogeneous components – such as data from various sources, refurbishment guidelines and policies and on-line assessment tools – in a seamless process within the on-line applications we have created, it was necessary to obtain a deep understanding of their contents and principles. Based on this understanding, it was possible to create our own mechanisms to interlink them in a way that they could be part of a unified information flow. The underlying complexities of this integration are hidden to the end-users of the applications. However, the procedures we have followed to interconnect the various components need to be transparent to experts and professionals, who should be able to trace the data transformation processes which are carried out within the applications.

The two applications – ENERHAT and ENERPAT – are publicly available in the ENERSI web portal and in the websites of the public institutions which have provided their energy data to the project. At the time of writing this paper, the applications are in the process of being available to the public. Following the feedback received by the future users, the interfaces will be further developed and refined.

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