Energy Planning Support with Geomapping Tool and Energy Demand Estimation: The Energis Platform

Gema Hernández Moral, Víctor Iván Serna, Giulia Massa and César Valmaseda
Energy Department
Fundación CARTIF
Boecillo, Valladolid, Spain
Email - gemher@cartif.es, vicser@cartif.es, giumas@cartif.es, cesval@cartif.es

***Abstract*—Energy directives aim at decreasing energy consumption and assuring a low carbon environment, in line with climate change mitigation strategies. Their implementation gives rise to the need of energy plans to improve actual energy tendencies. However, making informed decisions in energy planning is not always immediate, nor it is based on contrasted criteria, since normally the current conditions are unknown. There is a lack of tools that can aid planners in this decision-making process by showing the energy status of a determined area. In order to provide an adequate diagnosis and propose energy actions to cope with those needs, the baseline conditions should be based on validated calculation methodologies that make use of accurate and reliable data and are displayed in an easy and understandable manner. To deal with these problems, the ENERGIS platform is proposed where the energy demand of the residential sector is estimated with validated Energy Performance Certificate (EPC) software tool in Spain making use of public available data of buildings from official sources. The results are then reflected on a map, making use of geo-visualisation capabilities, which sets the basis for informed energy planning.**

Keywords- Energy planning; demand estimation; Energy Performance Certificates (EPCs); maps; geo-visualisation; Geographic Information System (GIS).

I. INTRODUCTION: ENERGY PLANNING CONTEXT IN EUROPE AND PLATFORM NEED

Growing CO_2 emissions have increased the concerns with respect to Climate Change, which has been especially acknowledged by the United Nations with the signature of the Paris agreement [1]. In this ambitious, universal agreement some guidelines and objectives were set to provide a way forward to fight against climate change and to stop the current temperature rise below 2 degrees.

The main source of these emissions is the deployment of fossil fuels for heating and cooling purposes, which in the end can be translated to the energy consumption produced by this type of fuels. In Europe, one of the main sectors contributing to the increase of CO_2 emissions is the built environment, and in particular the residential sector accounting for 25,4% of the share according to Eurostat figures.

These facts describe a reality where it is necessary to act upon, to implement regulations that enable to control the energy consumption and thus be able to secure a low carbon environment, which in the end will contribute to the fight against climate change.

Reacting upon this necessity, the European Commission has proposed a package of Energy Directives [2], which aims for three main goals: putting energy efficiency first, achieving global leadership in renewable energies and providing a fair deal for consumers. It includes as well eight different legislative proposals that tackle, among other Energy Efficiency, Energy Performance in Buildings, Renewable Energy and Governance.

These directives set certain objectives to Member States and should be transposed by each nation in order to comply with them by establishing plans and strategies. Depending on the administrative structure existing in each country, the plans can either be established at national level, or some high level guidelines at national level can be set and then specific objectives or actions at regional level implemented. After each Member State has carried out his strategies, the results should be reported at European level.

These steps in energy policy implementation require the establishment of mechanisms to be able to propose adequate strategies according to the current energy status of the residential sector in each country at regional and national level. It is paramount to base the energy actions on a precise diagnostic of the situation to avoid off-target actions that result in a non-compliance of the objectives set and an inadequate allocation of resources.

However, when a national or a regional authority intends to perform any kind of energy planning there is a lack of information and tools related to energy that aid in the diagnosis of the current situation at a global level (district, city or regional level), which in the end hinders the possibility to propose any contrasted energy action plan.

Nevertheless, there are many elements that are not fully exploited and that can be deployed in this field. Firstly, there is public information regarding the built environment and climatic conditions, such as the cadastre or climate data from weather stations. Secondly, from the need imposed at European level to submit EPCs, several validated methodologies or tools have emerged at national level in order to obtain Energy Labels and basic energy information.

Thirdly, the existing Geographic Information Systems (GIS) can provide the spatial component, which is intrinsic to any kind of planning that involves considering cities, regions or nations.

Based on these existing elements and combining their potential, the ENERGIS platform offers support in the energy planning process by enabling the visualization through GIS of the energy demand of the residential sector, which has been calculated deploying validated methodologies (Energy Performance Certificate tools in Spain) using public information. This platform will set the basis to have an adequate view of the current status and be able to make informed decisions.

In Section II a review of similar approaches to ENERGIS has been performed. Then, in Section III, the approach followed in the project is presented. The specific modules integrating the platform are described in Sections IV, V and VI. Finally, some conclusions are extracted in Section VII.

II. SOME APPROACHES IN THE ENERGY PLANNING FIELD

The need to represent the energy current status has been explored in some studies in this field and they should be highlighted since some of the main elements introduced in the ENERGIS platform are addressed, even though lacking some of the features of the latter. These major differences will be explained in Section II-B.

A. Examples of energy mapping tools

The following represent examples that integrate simplified estimations to obtain energy indicators and are combined with GIS, which enables an immediate visualization, as it will be observed in the examples.

1) Estimated total annual building energy consumption at the Block and Lot level for NYC

Developed by the Sustainable Engineering Lab, this project aims at analysing the dynamics of final energy consumption in the city of New York [7]. To this aim, the final heating, cooling, DHW and electricity energy consumption in the built environment is estimated. The results are then displayed following a colour code through a web map, providing two levels of aggregation: at block and at lot level. The information is complemented with a pop-up that appears when clicking on a block or lot.

The calculation methodology deployed was based on data at district level on the energy use, natural gas, diesel and vapour consumption of 2009 and it was combined with information coming from MapPLUTO, a geographical database of the Urban Planning Department in NYC. The estimation was based on the functions contained in the buildings (residential 1-4 people, residential multi-family, educational, health, storage, offices, commercial), making some special considerations regarding the location of the building. It is also based on the hypothesis that all ground floors have a commercial use and the upper floors are dedicated either to offices or residential use.

With respect to visualization, it was developed with Mapbox tool, where with a colour code the different energy intensities are represented. However, this map only covers the city of New York, where the calculations have been estimated, without offering the capability to replicate this methodology in other cities.

2) Energie label atlas

The objective of the Energie Label Atlas is to represent the estimated Energy Labels of buildings in Holland [9]. This project was carried out with the aim of covering almost all residential buildings in the country and of offering citizens the possibility to obtain an accurate EPC of their dwelling. This would require performing additional calculations over the estimated value proposed in the map, but at a lower cost than usual.

The origins of this project are to be found in the ‘Block by Block – Brooklyn’s Past and Present’ project that showed this area in New York with a colour code representing the age of the building. This idea was replicated in the Netherlands within the project Smart CitySDK, where all the buildings in the Netherlands are assigned a colour according to their age [8]. Building upon it, the Energie Label Atlas emerged, assigning to each building or dwelling an estimated Energy Label.

To make these estimations reference buildings were calculated and a label was assigned to each of them. That implied the study of a number of building typologies that was representative enough of the residential sector in the Netherlands. Afterwards, all of the reference buildings were simulated, assigned to their corresponding typologies and mapped. In addition, the real Energy Labels coming from real EPCs were also mapped and the comparison among both results enabled. This results in some cases in high discrepancies between both results.

The visualization capabilities are similar to those of the NYC case (Section II-A-1); however, the whole country was covered providing the estimated results at block level, regardless of the visualization scale. The information is also complemented by a widget, which serves to detail information at dwelling level, if real EPC information is available.

B. Main differences with the ENERGIS tool

The projects described above represent interesting approaches to the energy planning problem, by providing basic information on the energy status of a city (in the case of NYC) or of a country (in the case of the Netherlands). However, it is worth highlighting the main differences to the ENERGIS platform.

The **calculation methodology** is considered highly relevant in order to provide accurate results. Therefore, instead of deploying estimated approaches in order to calculate consumption (as in the NYC case) the ENERGIS project is constrained to the **estimation of the energy demand**. This is due to the fact that there is no source of public information that can provide data on the energy systems, rendering it inaccurate to assume the existence of a determined energy system. The approach used in NYC to calculate consumption, that is, assigning an energy system according to the typology of the building would be highly beneficial if applied within ENERGIS and would improve the quality of the platform. However, since there is no available database where these systems are described in Spain, no reliability can be assumed from this process. Moreover, the calculation is focused on the **automation of validated tools** to generate EPCs in Spain. This fact ensures a determined level of precision to the results obtained, opposed to the abovementioned approaches. With respect to the **scale** considered, aggregation possibilities are granted as in the case of the NYC map, but the unit of measure used to estimate the demand is the block, as in both showcased projects. Nevertheless, the scope to which the ENERGIS platform can be applied is the same as in the Netherlands case: at country level, since the main source of data is the Spanish Cadastre which covers the whole country [10].

C. The approach followed in the ENERGIS project – Main objectives

As it has been observed, the ENERGIS key objectives can be summarized in three main points: (1) exploiting the potential of available public data sources, (2) automatizing a process of demand estimation based on validated methodologies, thus granting trust and precision and (3) exploiting visualization capabilities making use of GIS in the web.

In order to fulfil these objectives, the ENERGIS platform is divided into three main modules:

- Module 1: Information processing and treatment: which will be in charge of collecting the required information and processing it for its later use by Module 2.
- Module 2: Estimation of the energy demand: based on Energy Performance Certificates tools in Spain, this module will be in charge of automatizing the calculations and providing the results of the energy demand of the buildings at block level.
- Module 3: Geo-referencing and visualization: the results obtained by Module 2 are then displayed in a web map, following a colour code that corresponds to the Energy Label scale and providing different data to be shown and a range of filtering capabilities.

III. MODULE 1: INFORMATION PROCESSING AND TREATMENT

In order to design and develop this module, two main processes were carried out: identifying the main data sources to fulfil the needs of the second module (estimation of the energy demand) and the methods to process and transform the data.

A. Identification of main sources of data

Public data sources were examined in order to determine the most valuable among them according to the identified needs of Module 2. Information regarding the building is required (geometrical aspects, orientation, neighbouring blocks, thermal properties of the elements it is composed of and identification data) as well as climate data according to its location.

For this purpose the Spanish Cadastre was analysed. It contains relevant data on buildings which is accessible for download through standardized mechanisms, following directives on spatial data, as it is the INSPIRE Directive. From this data source, relevant information on geometrical aspects, orientation, identification data and neighbouring blocks can be derived.

To cope with the climate requirements, the National Code for Building Construction in Spain was queried, since it establishes reference climate data according to the province or town (static).

For the building thermal properties assignation the National Building Code was also consulted. Based on several studies a Catalogue of building elements and materials has been generated. Based on it the different EPC tools are able to assign thermal property values to walls (external and internal), roofs, floors, windows, etc. The ENERGIS project based different building characteristics on the values used in the EPC tools, where according to the type of element, the year of construction and the climatic zone, some thermal characteristics and other parameter were assigned.

B. Processing of data

The processing of the data was needed mainly to derive geometrical characteristics of the data contained in the cadastre. For instance, the calculation of the number of pillars to calculate thermal bridges and estimate the number of windows; shadow calculation based on neighbouring building blocks, to determine the orientation of a wall or if it is interior or exterior, etc.

All of these calculations were performed by deploying two scripts developed by VOXEL3D, one devoted to the extraction and pre-processing of raw data coming from the cadastre and the other devoted to the detection of neighbouring buildings and generation of shadow patterns that will be assigned to each individual wall and opening.

As a result of the processing of this data a JSON file is generated containing all the required categories of information, which is then sent to Module 2 to estimate the energy demand.

IV. MODULE 2: ESTIMATION OF THE ENERGY DEMAND

The second module can be considered the core of the platform. If inadequate calculation methodologies are deployed, then the complete platform loses veracity and thus cannot be deployed with the expected results. For visualization purposes, it should also be able to perform quick estimations. Therefore, the steps followed in the design and development of this module were: the definition of the requirements, definition of the module, its development and its validation.

A. Status of EPC tools in Spain

Having an understanding of the validated calculation methodologies deployed in Spain is paramount prior to the selection of one of them. Therefore, the first step was to perform an analysis of the tools used at national level.

Based on the requirements imposed by the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) [3], Member States of the EU are required to make mandatory the submission of EPCs for every dwelling, building block, or commercial premise to be leased or sold, as well as for every new construction and public buildings.

In order to assure coherence among the results obtained in each Member State a methodological framework is described in the annex of the aforementioned Directive, which does not exactly set the formulas to be deployed, but instead presents the type of calculations to perform or which aspects to consider (for instance, thermal bridges).

Afterwards, each Member State has the obligation to transpose this framework in their country and develop either a concrete methodology or develop specific tools to serve this purpose. In the case of Spain four validated tools were developed and made available to the public free of charge: *Herramienta Unificada Líder-Calener* (HULC), CE3, CE3X and CERMA. The main differences among them are the following:

- **HULC**: tool developed based on public initiative, it presents the general energy certification method for buildings in the design phase, built buildings and existing ones (single family houses, building blocks, individual dwellings in a block and tertiary buildings). Through a relatively complex graphical user interface, the data insertion through this platform requires modelling in 3D and inserting precise data of the components integrating an element in the building (for instance the layers in a wall). The order followed when inserting the data should not be modified and the evaluation of different energy conservation measures proposed as an improvement to the baseline scenario cannot be evaluated.
- **CE3**: tool developed based on public initiative, presents a simplified method for the energy certification for existing buildings (single family houses, building blocks, individual dwellings in a block and tertiary buildings). The insertion of data at different levels of detail is allowed and if some data is unknown a library of reference data is provided. In addition, it automatically offers three energy conservation measures as a suggestion for its improvement.
- **CE3X**: similarly to CE3, this tool was developed based on public initiative, presents a simplified method for the energy certification for existing buildings (single family houses, building blocks, individual dwellings in a block and tertiary buildings). Through user-friendly graphical user interfaces the insertion of different levels of detail is allowed and also the evaluation of energy conservation measures. It offers interoperability capabilities with more advanced programs and the possibility to export an XML file with the results of the calculations.
- **CERMA**: the only recognized tool developed based on private initiative, which offers a simplified energy certification method for building blocks. It allows certifying single family houses, building blocks or individual dwellings in a block, for existing and new buildings. The evaluation of different energy conservation measures is allowed. Data requirements of this tool are high in comparison to the rest.

B. Definition of requirements

Based on the objectives defined for the platform, the requirements of the estimation of the demand module were quite straightforward: the tool should enable the introduction of an adequate amount of data that can be fed by the public data sources identified.

For this aim the study of the tools was performed, choosing in the end CE3X because of being the reference in terms of data model at national level (the data model proposed at national level to represent information related to EPCs follows the same structure as the output of CE3X). Moreover, it is easy to use and has data requirements that can be easily covered with information coming from public sources. Additionally, the accuracy behind the results provided in the calculations of the tools was also tested, which is explained in the validations named “prior to the selection of the EPC calculation tool” shown in Section E-1.

C. Definition and design of the module

The definition of the module was performed following the next steps:

- **Identification of the data required to perform simplified calculations**: based on the analysis performed on the data required by the estimation tool and the available data in public data sources, as well as the performance validations carried out, the exact datasets required were identified. Among these, data from the cadastre, three climatic zones maps and data on building elements contained in a catalogue were identified (walls, roofs, windows, floors, internal walls, thermal bridges, etc.).The data introduced into the platform is considered to be slowly evolving or almost static. For instance, in the case of the climate data, reference data is assumed at this stage of the project. Given a determined location, and the zone where it is located, certain climatic characteristics are deployed, which are tabulated according to the Building Code in Spain. Other data deployed in the platform, such as the geometrical data, is considered to be invariable; however, the datasets contained in the platform should be updated regularly according to the updates followed in the main source of data deployed: the Spanish Cadastre (approximately six months).

- **Simplified approaches for geometric definition of data**: from the data coming from the cadastre some could be directly applicable, while other geometric characteristics had to be estimated, since they were not directly available in the cadastre. For instance, the information on openings, thermal bridges or the shadow calculation.
- **Establishing a workflow diagram**: once the method to process the data had been established, a workflow depicting the functioning of the module was devised. In it the normal input data process and certification steps of the tool were taken into account.

D. Development

The development of the module was divided into two sub-modules. The first one is in charge of extracting the information contained in the JSON file coming from module 1 and generating one file per building block compliant with CE3X (.cex). Afterwards, the second sub-module will gather all of the compliant files and will automatize the CE3X process by introducing the information contained in the files and generating the Energy Performance Certificates. As a result, an XML is derived per building block where the heating, cooling and global demands are contained.

E. Validation of the module

Several types of validations have been performed during the design, development and validation process of the ENERGIS platform. Firstly, the appropriate EPC tool to use as a basis for the calculation module was chosen according to their data insertion processes, the capabilities they offer, and the accuracy obtained. Secondly, once the tool had been selected, hypothesis and simplifications with respect to geometry issues such as thermal bridges, windows, etc. have been tested. These hypotheses were based on a set of tests performed on a model by model comparison, where the objective was to test how much do the definition of thermal bridges, windows and other elements of the envelope affect the results. Finally, once the platform had been developed, the final results obtained with it when automatically retrieving the data from the public data sources, processing it and automatizing the process were analysed.

1) Prior to the selection of the EPC calculation tool

The objective of these validations was to test the functioning of the different tools and the results obtained among each other. From this analysis the main output was that even though the process followed in the data insertion process and the tools were different, the results were similar among each other. This allowed selecting the tool based on other type of criteria than only on accuracy aspects. The outcome of this process was the selection of CE3X as the main calculation tool to be deployed, as previously justified.

2) Testing the capabilities and how the program works

After having selected the calculation tool and having analyzed both the data required and the available data in public data sources it became apparent that some of the geometric data was not directly available in public data sources. Therefore, an estimation to calculate openings, thermal bridges and shadows was required.

To test if these hypotheses were reasonable in terms of precision deviation (i.e. their Energy Label did not vary) from a real Energy Performance Certificate, real cases were tested. These real cases were selected buildings in Valladolid (Spain), of which detailed data to perform energy simulations, was available. The EPC of real buildings was calculated based on information coming from detailed CAD plans, as if they had been performed by a certifier. The numbers of elements, their surfaces, as well as the final EPC results were contrasted and the result was satisfactory in terms of accuracy. As a consequence, and without delving into the hypotheses were calibrated and developed into the platform.

3) Testing the results obtained

Finally, once the hypothesis had been validated from an accuracy point of view, it was necessary to test that the process designed was responding as expected. To this end, the real calculations previously performed were compared to the results that would have been obtained manually by performing the geometric estimations proposed and also with the results obtained from Module 1. Several issues were detected during the process and errors were solved in a wide range of cases were different typologies of buildings and configurations were considered.

V. MODULE 3: GEO-REFERENCING AND VISUALISATION

The last module is devoted to the geo-referencing and visualization of data, which is highly relevant since it is the point where the information is communicated to the planner. A web-based platform has been developed taking into account the following aspects: the data to be stored and shown, how to store these data and the GIS web viewer.

A. Visualization data

The information that has to be shown in the visualizer and stored in the database is:

- Information of the buildings from the cadastre without processing: year of construction, address, use of the building, location, etc.
- Geometrical information of the building post-processed from the original geographical information: surface of the building, information about the façades and other elements, etc.
- Energy demand information calculated in the module 2: cooling, heating and global demand.

In order to be able to represent the data in a map using a GIS system it was necessary to populate a geodatabase

 ISBN: 978-1-61208-635-4

which stores the aforementioned data with their location information.

B. *ENERGIS web mapping platform*

The ENERGIS web mapping platform is a map service platform that offers the geospatial information stored in the geodatabase by a set advanced tools for the access and management of this information, which is supported by vector cartography of the zones of interest or by orto-photographs coming from the *Plan National de Ortofotografía Aérea* (PNOA).

The backbone of the geographical web viewer is its functioning as an API that allows for flexibility, and easiness in the integration. This API allows consuming directly vector layers with energy information of urban settings. The capabilities offered can be summarized in the following: precise visualization tools at different scales; intelligent real-time filtering tools of the visualized contents, interactive querying the contents relative to each element of the map, showing different type of data, visualization with different base maps: PNOA, Open Street Maps, Mapzen or Stamen; and integration of other data of interest, such as the cadastre information or other post-processed information.

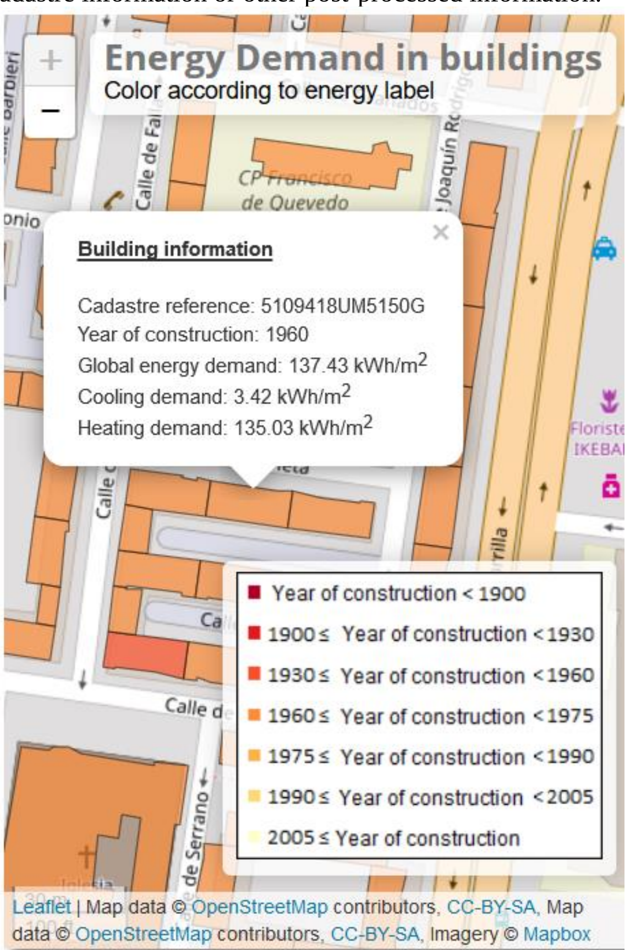

Figure 1. GIS web-viewer example

The values displayed through the viewer are represented through a colour code that corresponds to the EPC scale. This enables a quick understanding of the status of a city, identifying which areas are most in need of retrofitting. An example of the viewer can be seen in Figure 1. In it, some of the capabilities listed above can be observed.

As it can be seen, complementary information of each building can be displayed on the screen, such as: cadastre reference, year of construction, global energy demand, cooling demand and heating demand. In addition to this, more in depth information related to each building is available for download by the user. In it, data on the envelope used for its calculations, as well as additional identification data, thermal data and shadow information. Additionally, it should be mentioned that depending on the scale there are aggregation mechanisms where values of energy demand at region, district or at group of buildings' level can be displayed.

VI. LESSONS LEARNED

The development of an energy platform to support energy planning has offered a number of lessons learned, which have arisen from trying to implement the objective of working with public data as a basis for energy planning based on existing validated energy tools.

The first difficulty encountered was related to **the lack of relevant geometric that has an impact on the energy results** in public databases. Estimations on the dimensions of openings, lengths of thermal bridges, etc. had to be applied according to the types of buildings so as to consider these aspects in the energy simulations.

Also the work with **building typologies was necessary in order to apply thermal characteristics** to the building elements considered. This assignation was based on the climatic zone where the building is located as well as its year of construction.

Moreover, even when these assumptions were implemented in the platform, issues arose with respect to the **geometric definition of the buildings encountered in the Spanish Cadastre**, where not all the information was homogeneously defined.

With respect to the **calculation methodologies** implemented, several stumbling blocks were encountered. Firstly, the analysis of the Energy Performance Certificate tools showed great differences among each other, mainly in the input data process. Once CE3X was chosen, the file formats used in this tool presented a complex structure, which was difficult to work with since the elements (walls, openings, or other type of data) reflected in the files were not easily identifiable.

Furthermore, working with the tool when considering a restricted area (limited number of buildings) was manageable, but **when applying the approach at a bigger scale (for instance, citywide), problems emerged at all steps of the process**: public sources did not allow querying such amount of data at the same time and the simulation

 ISBN: 978-1-61208-635-4

time increased drastically, sometimes leading to the interruption of the process.

Thus, in addition of the validation of the results mentioned before, a closer look to the improvement of the working process was necessary.

However, regardless of the difficulties described above, having analysed citywide data, it was shown that this platform can have a high potential in the support of energy planning activities within local authorities.

VII. CONCLUSIONS AND FUTURE WORK

The ENERGIS platform combines existing public data, validated calculated methodologies and GIS capabilities to offer a complete and powerful product to support energy planning.

The process to define, design and develop the platform has followed several stages, which involved the analysis of data coming from public sources, working with EPC tools, the validation of results at all stages and working with GIS in order to explore its full potential. Difficulties in this process involved mainly the work with public sources of data, in particular the Spanish Cadastre. The main problem was the lack of a standardised approach in the definition of geometric data. This fact would be solved with an adequate implementation of the INSPIRE Directive, which would guarantee homogeneous information of the buildings.

The platform provides users energy planning capabilities which will aid in the decision-making process when generating energy plans, by providing with maps showing the energy demand of cities and urban settings. It will reduce uncertainties and provide a knowledge base upon which to ground decisions.

Future work related with this platform includes: (1) enhancing the displayed data (providing consumption estimation), (2) performing calculations at dwelling level, or (3) offering new functionalities, such as capacity to introduce improvement measures.

All in all, by supporting energy planning, the adequate allocation of resources will be fostered to comply with energy directives' objectives and thus, energy retrofitting interventions will be boosted. As a consequence, the energy consumption of buildings will be reduced, resulting in lower emission rates, which will finally contribute in the fight against climate change, advocated by the United Nations with the signature of the Paris agreement.

ACKNOWLEDGMENT

This platform was developed in the framework of the collaborative project 'ENERGIS' in a consortium formed by Fundación CARTIF, VOXEL 3D and SYLTEC and cofounded by the *Agencia de Innovación, Financiación e Internacionalización Empresarial* and FEDER funds.

REFERENCES

[1] Paris agreement (2015) (COP 21): http://unfccc.int/paris_agreement/items/9485.php [retrieved: April, 2018]

[2] Communication COM/2016/0860 final. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment – Bank. Clean Energy for all Europeans". Brussels, 30.11.2016: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0860 [retrieved: April, 2018]

[3] Directive 2010/31/EU (2010). European Parliament and the Council of 19 May 2010 "On the Energy Performance of Buildings": http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32010L0031 [retrieved: April, 2018]

[4] INSPIRE Knowledge Base: Infrastructure for spatial information in Europe: https://inspire.ec.europa.eu/ [retrieved: April, 2018]

[5] INSPIRE Roadmap: https://inspire.ec.europa.eu/road-map-graphic/32443 [retrieved: April 2018]

[6] New York City Map – City-Wide GIS.: http://maps.nyc.gov/doitt/nycitymap/ [retrieved: April 2018]

[7] Estimated Total Annual Building Energy Consumption at the Block and Lot Level for NYC: http://qsel.columbia.edu/nycenergy/ [retrieved: April, 2018]

[8] All buildings in the Netherlands: http://code.waag.org/buildings/#52.3884,4.9438,11 [retrieved: April, 2018]

[9] Energie Label Atlas (Netherlands): http://energielabelatlas.nl/# [retrieved: April, 2018]

[10] Spanish Cadastre Official Website : https://www.sedecatastro.gob.es/ [retrieved: April, 2018]

[11] B. Howard, L. Parshall, J. Thompson, S. Hammer, J. Dickinson, V. Modi. "Spatial distribution of urban building energy consumption by end use". ELSEVIER Energy and Buildings 45. (2012) pp. 141- 151.

[12] M. Kavgic; A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, M. Djurovic-Petrovic. "A review of bottom-up building stock models for energy consumption in the residential sector". ELSEVIER. Building and Environment 45 (2010) pp 1683 – 1697.

[13] I. Miranda Pereira, E. Sad de Assis. "Urban energy consumption mapping for energy management". ELSEVIER Energy Policy 59. (2013) pp. 257- 269.

[14] R. Nouvel, M. Zirak, H. Dastageeri, V. Coors, U. Eicker. "Urban energy analysis based on 3d city model for national scale applications". IBPSA BAUSIM 2014 - Fifth German-Austrian IBPSA Conference RWTH Aachen University. 2014

[15] Spanish Cadastre Official Website. https://www.sedecatastro.gob.es/. [retrieved: April 2018]

[16] Spanish National Building Code (Código Tenico de la Edificación). Documento Básico HE: Ahorro de la Energía (Document on Energy Savings) : https://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/DBHE.pdf [retrieved: April 2018]

[17] Energy Perfomance Labelling Technical Basis Manual of existing buildings CE3X. (Manual de Fundamentos Técnicos de calificación energética de edificios existentes CE3X), IDAE, 2012. http://www.minetad.gob.es/energia/desarrollo/EficienciaEnergetica/CertificacionEnergetica/DocumentosReconocidos/Documents/Manual_fundamentos_tecnicos_CE3X_05.pdf [retrieved: April 2018]

[18] E. Olivero, E. Onillon, P. Beguery, R. Brunet, S. Marat, M. Azar. "On key parameters influencing building energy performance". Proceedings of BS2015: 14th Conference of International Building Performance Simulation Association, Hyderabad, India, Dec 7-9., 2015