Benchmarking of energy demand of domestic and small business buildings

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Abstract: Rapid expansion of solar thermal energy for increasing energy efficiency of buildings has been adopted in short/medium and long-term energy strategies of EU countries. This enhancement of energy efficiency in buildings is in line with regional actions with the European climate energy objectives as defined in the European Union's "20-20-20" targets and in the European Commission's Energy Roadmap 2050.

Within this context, the overall objective of this work is to develop an innovative high performance and cost effective hybrid solar heat and power system, which consist in a novel flat Fresnel mirror solar concentrating collector and micro organic Rankine cycle plant combined with advanced phase change materials as thermal storage, all system managed by smart control units. The initial application is to be implemented in individual dwellings and small business residential buildings for on-site electricity and heat generation using solar thermal energy. It is estimated that the proposed technology will deliver 60% of domestic energy requirements and provide 20% reduction in energy costs and greenhouse gas emissions compared to the best existing low carbon energy technologies.

To reach the main objectives, the first step consist in providing information on features of architecture of domestic and small business residential buildings and their annual energy demands for different countries such as: Spain, France Germany, Italy, and United Kingdom. This will include detailed building information of envelopes (walls, roof, lofts, etc.), structure, fabric, and results of energy demands (domestic hot water, space heating and electricity) for the abovementioned countries. This information will be used as input data during the development of this technology as it will point out the potential benefits of the system in different countries, climates, and building typologies.

Keywords: Solar thermal energy; Micro organic Rankine cycle; Thermal energy storage; Phase change materials; Energy savings; Building integration

1. Introduction

In Europe the building sector represents 41% of the final energy consumption and the 40% of the total GHG emissions of end-use sectors (Directive 2010/31/EU). Within the target to reduce the energy demand of buildings and preserve the environment, innovative technical solutions have to be proposed and adopted.

The Renewable Heat Incentive (RHI) and similar schemes, which are deployed across a number of EU countries (e.g. UK, Germany, France, Italy, Spain), encourage uptake of renewable heat technologies to support the ambition of 12% of heating coming from renewable sources by 2020. Solar energy is one of the forms of renewable energy that has the greatest potential to enable EU to meet this goal. Therefore, a fast implementation of solar thermal energy in housing is being used as an interesting energy strategy for many EU countries which aim to meet the upcoming climate and energy targets for the year 2020 (Horizon 2020) and the European Commission's Energy Roadmap by 2050.

To develop a new technology and promote the renewable energy sources, the project Innovative Micro Solar Heat and Power System for Domestic and Small Business Residential Buildings (Innova MicroSolar) was started in September 2016. The project is funded within the framework research and innovation programme Horizon 2020.

The overall objective of Innova MicroSolar is to develop an innovative high performance and cost effective solar heat and power system for application in individual dwellings and small business residential buildings for on-site electricity and heat generation using solar thermal energy at temperatures levels of 250-280 ºC. The proposed technology will be built around a small scale solar concentrating collectors based on linear Fresnel mirrors in which the specific dimensions (area/kW) have reduced on 25-30% in comparison to existing concentrating solar collectors. These collectors supply thermal energy to power the small high performance ORC turbine with 2-kWel output.

To control the energy input and output of the system, a thermal energy storage unit with PCM will be designed. The novelties of this unit are the eutectic salt PCM compound with the tuned melting temperature for heat storage, and the reversible heat pipes capable of transferring heat at the required high rate in both directions, from the solar circuit to the thermal storage tank with PCM and from the tank to ORC plant circuit or DHW tank and spacing heating circuit.

The system objective is to integrate all the components into a high performance, cost effective and high durability 2-kW$_{el}$/18-kW$_{th}$ solar system for heat and power supply to individual dwellings and small business residential buildings, which will provide 60% of the required building energy and reduce 20% the energy costs and Green House Gas (GHG) emissions compared to the best existing low carbon energy technologies.

The main objective of this paper consists on providing information on types of domestic residential buildings in such countries as Spain, Italy, UK, France, and Germany. This will include specification of details on their architecture, building envelope, range of dimensions of living space, their insulation properties, hydronic domestic hot water (DHW), and space heating boiler systems, seasonal and annual demands for DHW, heating and electricity.

2. Continuous benchmark of building and energy demand and market analysis

To overcome the objectives of this project the first step consisted of providing information on building construction characteristics and their energy demands of domestic and small business residential buildings for the aforementioned European countries.

After a literature review, three consecutive projects co-funded by the Intelligent Energy Europe Programme (IEE) were found to deal with the main requirements of the continuous benchmark of building and energy demand and market analysis:

- **IEE Project DATAMINE (2006 - 2008)**

  This project aimed to improve the knowledge about the energy performance of building stocks forming a data structure for exchanging information. It intended to stimulate large-scale monitoring activities using energy performance certificates as a data source. All in all the DATAMINE data structure has proved to be a suitable approach for EPBD related data comparison and monitoring activities in the building sector on regional, national and European level, thus was successfully applied in 12 model projects in 12 European countries.

- **IEE Project TABULA (2009 - 2012)**

  The idea was to make an agreed systematic approach to classify building stocks according to their energy related properties. Residential building typologies have been developed for 13 European countries. Each national typology consists of a classification scheme grouping buildings according to their size, age and further parameters and a set of exemplary buildings representing the building types.

- **IEE Project EPISCOPE (2013 - 2016)**

  It takes building typologies defined according to the TABULA approach as a basis for building stock monitoring activities. The main project activity was to track the energy refurbishment progress of certain housing stock entireties. Some of these typology based "pilot actions" were focused on distinct housing portfolios on local level, others on entire regional or national housing stocks. The implementation rate of different refurbishment measures was determined and compared with those activities which are necessary to attain the relevant climate protection targets.

The main outcome of these three consecutive projects is an interactive database named TABULA Web tool (Figure 1) created to share valuable information with the scientific community and building experts from European countries.

The objective is to disseminate the general idea of national residential building typologies and to give an understanding of the concrete implementation according to the TABULA concept, which is defined as:

- The division of the EU residential building stocks in size and age classes.
- Data of exemplary buildings: visual appearance, commonly found construction elements and corresponding U-values.
- Data of exemplary heat supply systems: commonly found system types and their energy performance indicators.
- Typical values for the energy consumption by energy carriers.
- For old buildings: energy saving measures on two quality levels and their impact on the energy consumption.
- For new buildings: examples based on three energy performance levels: minimum requirements, improved and ambitious or NZEB standard (assumed or announced level of Nearly Zero-Energy Buildings).
- Standard reference calculation procedure based on an agreed data format, user conditions and national climatic data.
- Calibration of the standard calculation procedure to the typical level of measured consumption.

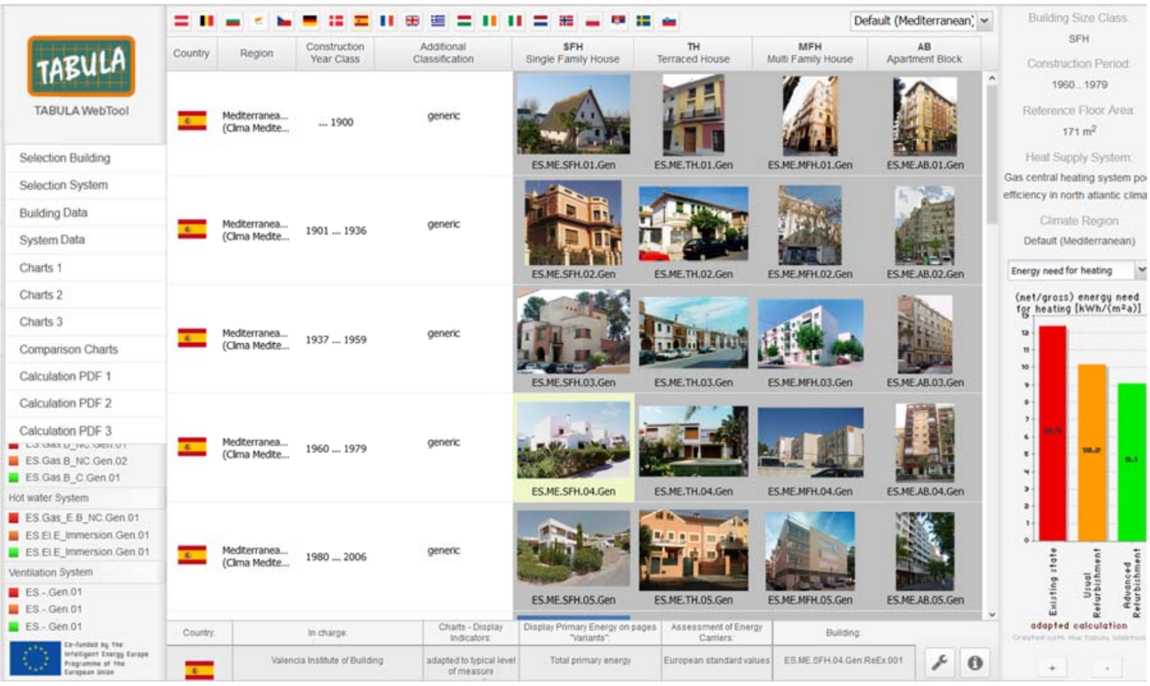


Figure 1. TABULA Web tool database interface

From this powerful database, based on three consecutive European projects, valuable technical information was obtained. On one hand, a standardized building classification divided in four typologies: single family house (SFH), terraced house (TH), multifamily house (MFH) and apartment block (AB) (Figure 2) and organized by age and climate conditions from 20 different European countries. To analyse and treat all the information, the age of buildings were divided into three different age classes, from 1970 to 1985, from 1986 to 2000 and from 2001 to 2016. Also, the climatic conditions inside a country were divided into three different classes, hot, temperate and cold, representing the hottest, the average and the coldest climatic conditions of a country, respectively.

Figure 2. Standardized building classification for Spain from 2001 to 2016 divided in four typologies by TABULA

On the other hand, the main technical parameters that fit with the aim of Innova MicroSolar project were: building envelope and their insulation properties, range of dimensions of living space, energy demand for heating and domestic hot water (DHW), CO_2 emissions sorted by typology, age classes, and different climatic conditions.

Besides providing the actual calculated energy consumption for the residential building stock, TABULA database provides an approximation of the energy consumed based on two different levels of refurbishment, usual and advanced levels.

3. Results

The results are organized according to the main outcomes from the aforementioned findings divided in building construction characteristics, energy demand for heating and DHW and CO_2 emissions.

3.1. Construction characteristics

Since reference floor area [m^2] is the conditioned floor area based on internal dimensions (measured from edges at the inside surface of external walls), its dimensions are directly related with the construction period, the typology of the building and the country. As it can be seen in Figure 3, single family and terraced houses were bigger in

70s when compared with those from 2001-16 in Spain, Germany and France. However, the opposite trend is detected for multifamily houses and apartment blocks that are becoming more popular due to the limitations of space in cities, the high prices of land and the rapid growing of urban environments. Figure 3 highlights that multifamily houses and apartment blocks have higher values of reference floor area in comparison to single family and terraced houses, especially in a new apartment blocks in Spain that have 43 times more floor area in comparison to single family houses and 53 times more compared to terraced houses.

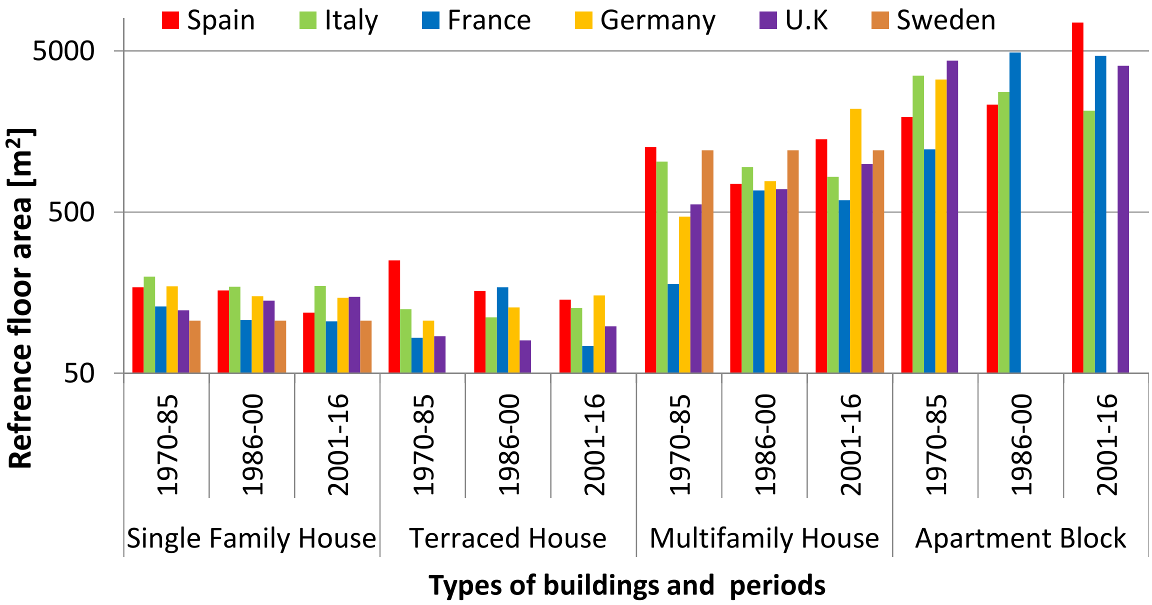
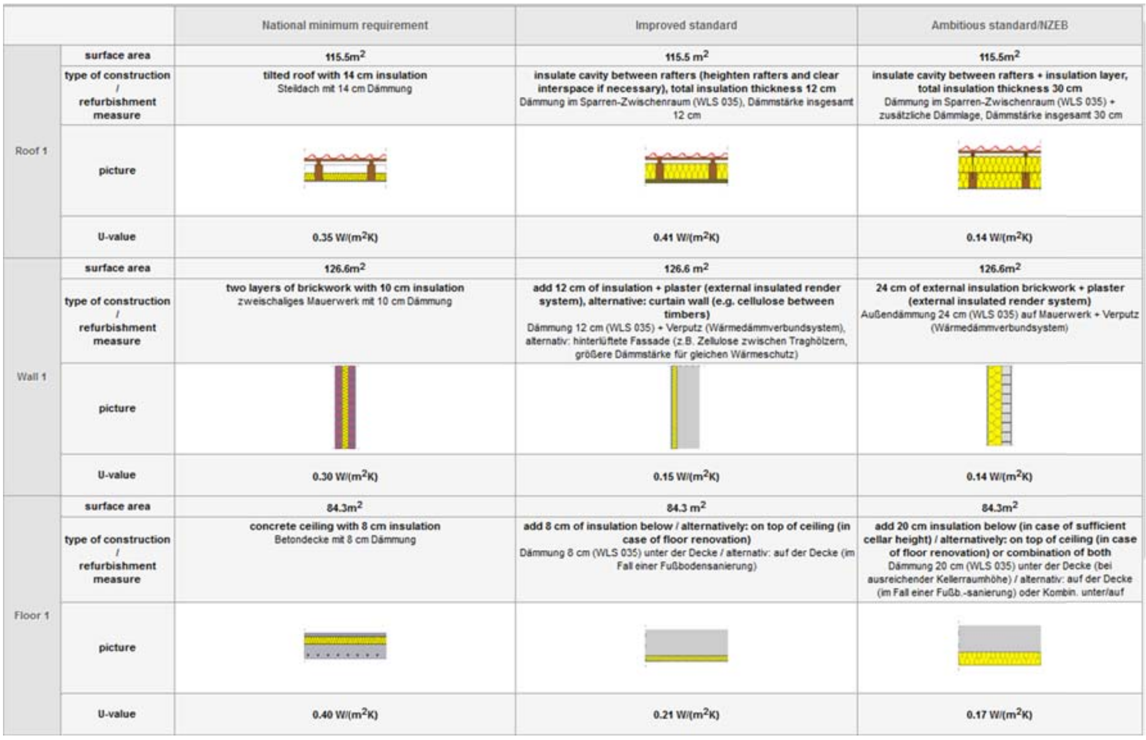


Figure 3. Range of dimensions of living space by countries

An example of detailed information for a German single family house (roofs, walls, floors and windows and doors) from 1986-00 and their insulations properties (U_{Value}) in the current state can be seen in Figure 4. In addition to this technical information, energy saving measures on two quality refurbishment levels (improved standard and ambitious NZEB) and their impact on the energy consumption were also provided. As it can be seen in Figure 4, the improvements due to the refurbishment levels are considerable when the national minimum requirements are compared with the ambitious standards. Reductions up to 50 % of the thermal transmittance can be obtained in this scenario, 0.35 to 0.14 $W/m^2·K$ in roofs, 0.30 to 0.14 $W/m^2·K$ in walls and even in floors, 0.40 to 0.17 $W/m^2·K$.

The same information for all case scenarios (all building typologies and construction period) is available for 20 different European counties including Spain, Italy, France, Germany, and U.K.



		National minimum requirement	Improved standard	Ambitious standard/NZEB
Roof 1	surface area	115.5m^2	115.5 m^2	115.5m^2
	type of construction / refurbishment measure	**tilted roof with 14 cm insulation** Steildach mit 14 cm Dämmung	**insulate cavity between rafters (heighten rafters and clear interspace if necessary), total insulation thickness 12 cm** Dämmung im Sparren-Zwischenraum (WLS 035), Dämmstärke insgesamt 12 cm	**insulate cavity between rafters + insulation layer, total insulation thickness 30 cm** Dämmung im Sparren-Zwischenraum (WLS 035) + zusätzliche Dämmlage, Dämmstärke insgesamt 30 cm
	picture			
	U-value	0.35 W/(m^{2}K)	0.41 W/(m^{2}K)	0.14 W/(m^{2}K)
Wall 1	surface area	126.6m^2	126.6 m^2	126.6m^2
	type of construction / refurbishment measure	**two layers of brickwork with 10 cm insulation** zweischaliges Mauerwerk mit 10 cm Dämmung	**add 12 cm of insulation + plaster (external insulated render system), alternative: curtain wall (e.g. cellulose between timbers)** Dämmung 12 cm (WLS 035) + Verputz (Wärmedämmverbundsystem), alternativ: hinterlüftete Fassade (z.B. Zellulose zwischen Traghölzern, größere Dämmstärke für gleichen Wärmeschutz)	**24 cm of external insulation brickwork + plaster (external insulated render system)** Außendämmung 24 cm (WLS 035) auf Mauerwerk + Verputz (Wärmedämmverbundsystem)
	picture			
	U-value	0.30 W/(m^{2}K)	0.15 W/(m^{2}K)	0.14 W/(m^{2}K)
Floor 1	surface area	84.3m^2	84.3 m^2	84.3m^2
	type of construction / refurbishment measure	**concrete ceiling with 8 cm insulation** Betondecke mit 8 cm Dämmung	**add 8 cm of insulation below / alternatively: on top of ceiling (in case of floor renovation)** Dämmung 8 cm (WLS 035) unter der Decke / alternativ: auf der Decke (im Fall einer Fußbodensanierung)	**add 20 cm insulation below (in case of sufficient cellar height) / alternatively: on top of ceiling (in case of floor renovation) or combination of both** Dämmung 20 cm (WLS 035) unter der Decke (bei ausreichender Kellerraumhöhe) / alternativ: auf der Decke (im Fall einer Fußb.-sanierung) oder Kombin. unter/auf
	picture			
	U-value	0.40 W/(m^{2}K)	0.21 W/(m^{2}K)	0.17 W/(m^{2}K)

Figure 4. Technical characteristics of building envelope

3.2. Energy demand for heating

Near to 30 different climatic conditions have been analysed and treated for the different analysed countries (Spain, France, Italy, UK, Germany and Sweden). However, due to the huge variation on climatic conditions across Europe, the following section only shows the representative temperate conditions of the above-mentioned countries (Table 1).

Table 1. Temperate climates of the analysed countries

Country	Spain	Italy	France	Germany	U.K	Sweden
Climate	Atlantic	Middle	H2	Kassel	England	Zone 2

As it can be seen in Figure 5, the energy need for heating is lower in apartment blocks in comparison to single family houses for all the EU countries analysed. Moreover, many variations in terms of energy consumptions were observed for the same building typology when countries and building construction periods are compared. These results highlight the wide application potential of the Micro Solar Heat and Power System in different countries and different building typologies.

Additionally, as it is expected, northern countries such as Sweden and Germany consume more energy for heating purposes than southern countries such as Spain and Italy, even being better insulated. As an example, it can be referred to standard U-value for walls of a single family house in Germany (1986-2000) that is 0.35 W/m^2·K while in Spain for the same building characteristics and period is the double (0.60 $W/m^2 \cdot K$). However, for the specific period of 1986-00 a German single family house need 117 [$kWh/(m^2 \cdot year)$] for heating while in Spain the same building typology requires only 45 [$kWh/(m^2 \cdot year)$].

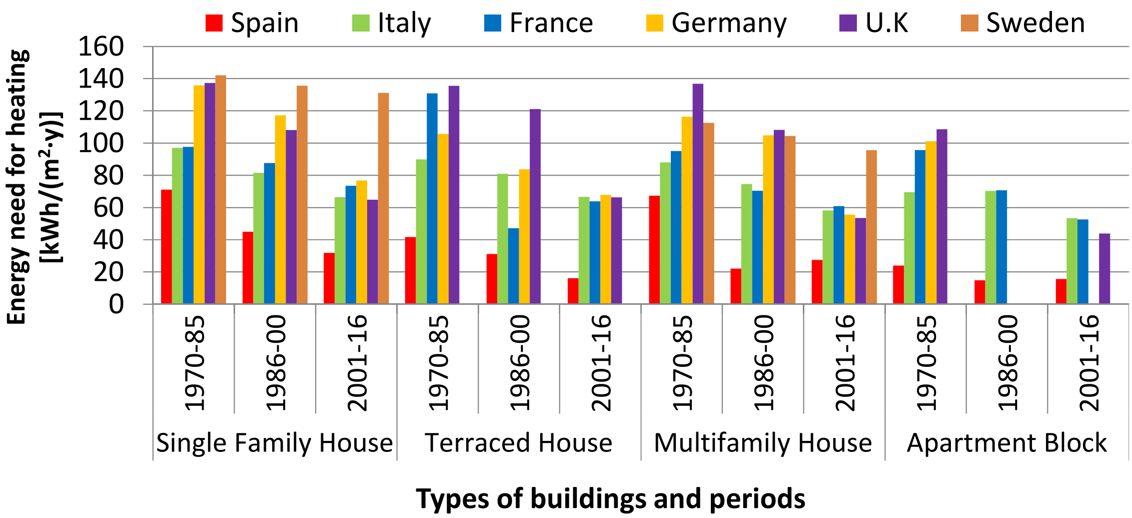


Figure 5. Energy need for heating in temperate climatic conditions for four types of buildings divided in three building construction periods in different EU countries

3.3. CO_2 emissions

The expected trend in reducing the CO_2 emissions in all studied countries can be seen in Figure 6. All the building typologies show a reduction of the CO_2 emissions throughout the years, being the newest period (2001-16) the lowest emissions. These results could be directly related with the increment of floor area of multifamily houses and apartment blocks that have the lowest ratio of kg $CO_2/(m^2 \cdot y)$.

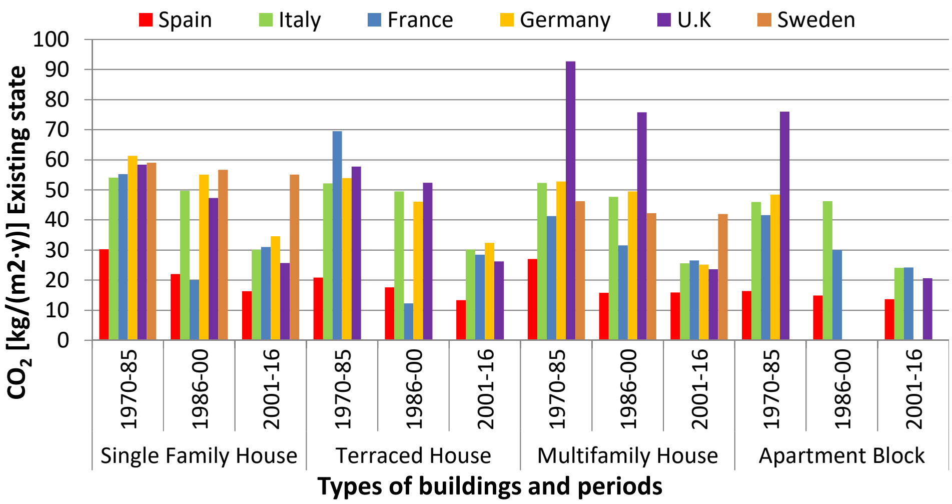


Figure 6. Energy need for heating for four types of buildings divided in three building construction periods in different EU countries

4. Conclusions

Valuable technical information for domestic residential buildings was collected, analysed, and organized to provide a continuous benchmark of building and energy demand and market analysis. It will be used as input data during the development of this project to evaluate the potential benefits of the proposed solar domestic heat and power system in different countries and building typologies.

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References

Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings. Available from: http://www.epbd-ca.eu (February 2016).

Horizon 2020, The EU Framework Programme for Research and Innovation. Available from: http://ec.europa.eu/programmes/horizon2020/en/ (February 2016).

European Commission's Energy Roadmap 2050. Available from: http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm (December 2016).

Final Report from DATA MINE project 2009. Monitoring by use of Energy Performance Certificates. Available on: http://www.meteo.noa.gr/datamine/DATAMINE_SR3.pdf (December 2016)

Main results of the EPISCOPE project 2016. Monitor progress towards climate targets in European housing stocks. Available on: http://episcope.eu/welcome/ (December 2016)

Visscher H, Sartori I, Dascalaki E. Towards an energy efficient European housing stock: Monitoring, mapping and modelling retrofitting processes Special issue of Energy and Buildings. Energy and Buildings 2016;132:1–3.