CODE 430

REVIEW OF THE EUROPEAN DWELLING STOCK AND ITS POTENTIAL FOR RETROFIT INTERVENTIONS USING SOLAR-ASSISTED HEATING AND COOLING

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ABSTRACT

This study provides a characterization of the existing European stock of residential buildings, with a specific focus on their energy performance. Eight countries with different characteristics and climates have been selected as a representative sample. After identifying relevant parameters, data has been compiled from several sources, including national statistical bodies and European datasets from official and unofficial bodies, as well as previous research projects. Based on those projects as initial source of information, the study is complemented with energy efficiency related regulations as well as with external climate data. The collected information has been subject to a critical review and analysed to identify insights and trends related to the energy performance of European dwellings. The information gathered is intended to provide a general view about the current status for each of the assessed countries and by extension a global picture of the European stock. The outcomes of this study will constitute a realistic baseline scenario for identifying needs, potentials and constraints for renewable energy technologies, and will assist the development of a novel software tool for planning energy-efficient retrofits of residential buildings.

1. INTRODUCTION

The substantial impact of buildings on the environment due to their energy consumption is an accepted statement. Around 40% of the global energy demand and 60% of the world's electricity consumption are required to cover residential and commercial buildings needs [1]. In Europe the share of energy designated for buildings is approximately the same with a 40% of the Union's total energy consumption generating as a consequence a 30% of the greenhouse gas emissions [2]. The effort of the European Commission to redress the balance of this negative scenario has being intensive in the last years resulting in two remarkable legislative documents; the Energy Performance of Buildings Directive (EPDB) [3] and the Energy Efficiency Directive (EED) [4], aiming to set the main strategy and paths towards more energy efficient buildings. Three major lines for improvement are considered in these documents; to reduce the energy as main objective, secondly to increase the share of Renewable Energy Sources (RES) and thereby to reduce the dependency on fossil fuels and, lastly, to consume the energy efficiently to avoid unnecessary waste. The Nearly Zero Energy Building (NZEB) is the way that the EPDB has adopted to specifically represent that target for buildings, looking to establish a threshold of the primary energy consumed expressed in kWh / m^2 per year. The specific definition and adoption of the NZEB concept has generated some controversy and its application has had different considerations about how it should be determined, as well as its maximum admissible [5]. However, the aim to define a global reference pattern seems to be of strong interest, as it would allow direct comparison and general overview of current and future ideal scenarios at continental level, in order to consider specific strategies and initiatives to overcome the current situation.

Despite the importance of building new, modern and efficient buildings, the relevance of renovating the existing ones and updating them accordingly is a crucial task. Indeed, the current building stock is responsible for the aforementioned consumption and even relying on very low energy buildings in the next years, the replacement rate would not be sufficient [6] to turn the situation around until some decades in the future. Different approaches have been considered up to now for renovating the buildings, implementing measures to improve the performance in the envelope, HVAC and controls, lighting and appliances in order of relevance according to the investment required [7]. Depending on the specific case, the cost effectiveness of these interventions varies, but individually or collectively the three measures described are intended to significantly reduce the energy consumption.

Despite the necessity of developing novel systems, current technologies that are commercially available are quite mature right now, having a high potential to improve the situation [1], and are able to significantly reduce energy consumption of buildings. Thus the necessity of improving efficiency, reducing costs and in general making these technologies more accessible is critical for moving forward towards a more sustainable built environment.

However, the return on the investment and the benefits of each retrofitting activity depends strongly on the initial situation. Thus, a careful diagnosis of the current building stock is required to consider different alternatives and to provide a baseline for the quantification of the energy reduction. A poorly performing building has a high potential of improvement while a well performing one has a more limited set of alternatives. But on the other hand the investment required to get a bad and good building performing to an equivalent level is going to be much higher for the bad one. Information to describe the building's situation is required in this case referred to the constructive components, thermal energy producing services and the environment of building.

In this study and within the scope of the EU funded Heat4Cool project [8], an assessment of the current dwelling stock performed with a focus on residential buildings, as one of the big energy consumer sectors in Europe [9]. This assessment aims to provide a realistic picture of current situation that will be later used to evaluate different alternatives for the improvement of the services, to foster activities to increase the penetration of solar energy and heat pumps in the current buildings.

2. OVERALL APROACH FOR THE STUDY

2.1. Scope

The present analysis of the dwelling stock is the starting point for the development of a Retrofitting Design Planner Tool (RDPT) as one of the main objectives of the Heat4Cool project. The aim of the RDPT is to provide a reliable design tool to simulate the effect of different retrofitting measures combining various systems and to support the retrofitting decision process.

Thus the scope of the study is derived from the overall approach of this project. The geographical coverage adopted and the special focus on the residential sector provides a useful tool to generate realistic scenarios for considering a wide application of various technologies as the developed in the project.

In such line, the limits of the following study are defined by the available general information to get an approximate image of the stock and the fact that, the consideration of eight different countries accounts to up 73% of the total energy consumed in Europe's residential sector. The countries considered in this case are: France, Germany, Greece, Italy, Poland, Spain, Switzerland and United Kingdom.

2.2. Methodology

The methodology adopted for the study consists in three main steps:

- Identification of relevant parameters. The identification of relevant parameters to correctly understand the energy performance of the buildings is essential. These are grouped in parameters for buildings, parameters for systems and parameters related with the external environment.
- Quantification of parameters. Once identified the next step is to gather statistical values for these parameters under the global approach of this study. The information is collected from to the available data bases and accessible sources as described in the following section.
- Results review and discussion: As a last step, an assessment of the information is carried out evaluating the quality and consistency, looking for patterns that offer useful information for the research under progress.

2.3. Sources of Information

The availability and reliability of the available information is the key aspect of the present study. Previous research projects in Europe have already studied the existing building (TABULA/EPISCOPE [10], ENTRANZE [11], INSPIRE [12] and ODYSSEE [13]). The outputs of these studies complemented by information from other available databases have been referenced as relevant sources for other general studies at European level [14]. As a result, the European Commission published the Building Stock Observatory [9] in the beginning of 2017 as a reference database representing the stock and its energy performance.

To complement and check the information for buildings, some statistical offices have been consulted as well for Europe [15], Switzerland [16] and EU Member States [17].
For those parameters related to energy consumption, the data in the Building Stock Observatory provide also useful information that has also been complemented with information about the regulation and the requirements in terms of maximum energy consumption of buildings and NZEB definition [18-26].

Finally information related to the external environmental conditions [27-29] as well as the available solar irradiation [30]has been collected.

3. Identification of parameters

The identification of a parameter is directly linked with the available information as it is necessary to properly set the scope of the study in order to define the stock characterization for buildings, their energy consumption and the environment where they are located.

The set of parameters considered to describe the buildings are related to the size, age, occupants and constructive components of the envelope. Specifically, the number of dwellings and total surface distinguishing single-family and multi-family houses, the average floor area, age distribution, envelope insulation levels per dwelling and age and the ownership of dwellings is evaluated.

For defining a set of parameters that enables the quantification of the energy consumption in buildings, initially, the source of energy consumed in buildings by country is described. In a second step the energy consumption of residential buildings is split in the contribution of space heating, water heating and space cooling uses. Eventually, the technologies for heating and cooling as well as the implementation of the EPDB in the country-specific regulations are analysed.

Finally for the case of external climate and potential for renewable energy based technologies a relation between heating degree-days (HDD) and cooling degree-days (CDD) is referenced in relation to the incidence of solar radiation.

4. Quantification of parameters and discussion

4.1. Building Parameters

Regarding either the total number of dwellings or total floor area, five countries concentrate the majority of the EU dwelling stock: Germany, France, UK, Italy and Spain. The rest of the countries in this study have a relatively modest dwelling stock (below 500 million m^2, except for the case of Poland, which poses as an intermediate case).

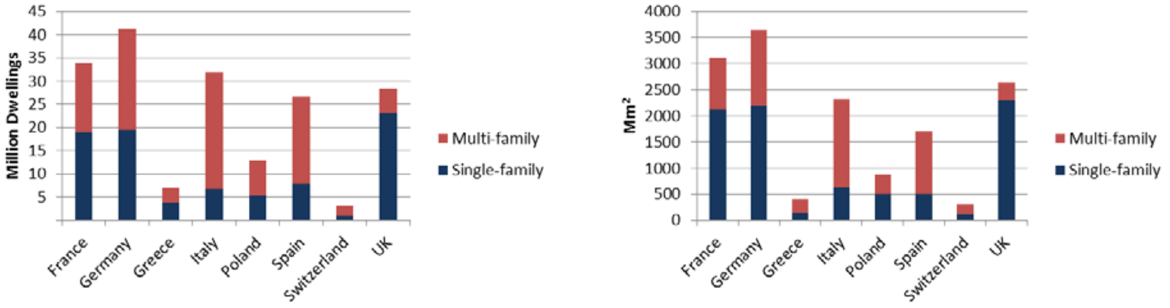

Figure 1: Building Stock quantification for the countries selected. Number of dwellings (left) and available floor area (right)

Regarding building type (single-family vs. multi-family), there are important differences among the countries assessed. Single-family houses are especially predominant in the UK (81%), while multi-family houses are prevalent in Italy (79%), Spain (71%) and Switzerland (71%). The rest of the countries have a closer balance, with multi-family houses taking the lead in Poland (59%) and Germany (53%) and single-family houses in the rest of countries assessed.

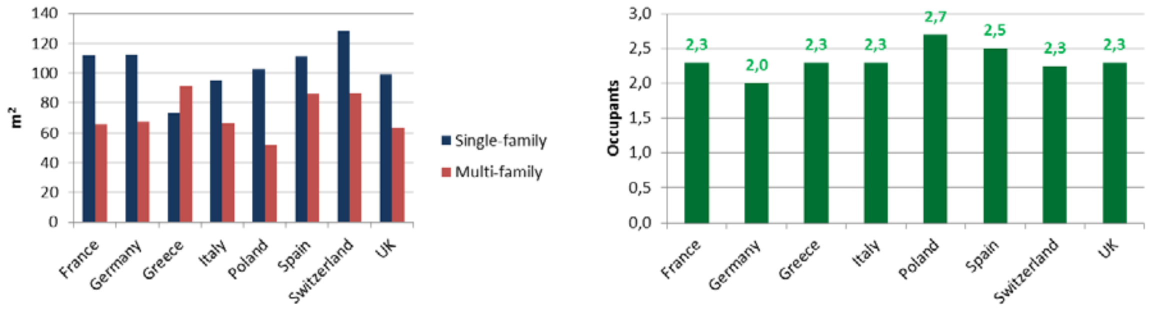

Figure 2. Average floor area (left) and average occupants per household (right)

When looking at the average size of dwellings, for most countries single-family houses tend to have a larger floor area per dwelling than multi-family houses. Poland has the greatest disparity, with single-family houses being roughly double the size of flats in multi-family houses. The largest average size for single-family dwellings is found in Switzerland, France, Germany and Spain, while Greece has the smallest single-family dwellings. The largest average size of multi-family dwellings is found on Greece, Switzerland and Spain.

In terms of average population of households, there is a slight variation among the European countries assessed, averaging about 2.3 occupants. Germany has the lowest average household size (2 occupants), while the largest average household population is found in Poland (2.7 occupants).

The age distribution of the dwelling stock (Figure 3), also highlights interesting differences among the studied countries. Generally, Spain and Greece have the largest share of new buildings, and the lowest presence of historic dwellings. In contrast, the presence of pre-1945 building stock is highest in the UK. Germany and Italy experienced a large amount of post-war building, and the post-1980 dwelling stock is small in comparison.

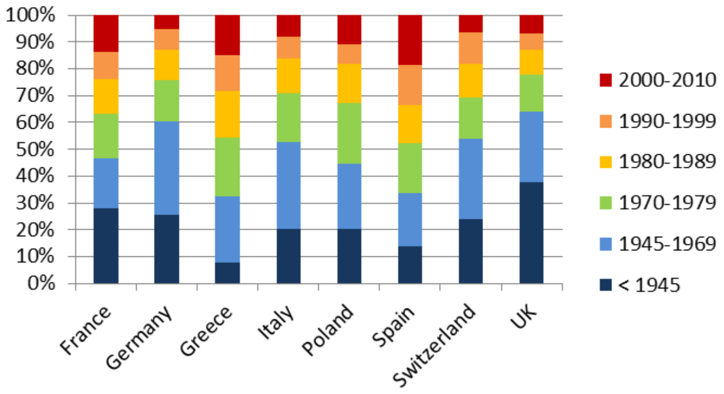

Figure 3. Period of construction of dwellings for those built before 2010

The thermal performance of building envelopes clearly shows an improvement over time, for all countries assessed, driven by the oil crisis, the availability of thermal insulation and, more recently, EU-driven requirements for energy efficiency in national regulations. However, the speed and extent of this improvement differs across countries. Generally, colder countries (Switzerland, Germany & Poland) have historically built with better U-values, while the poorest thermal performances are found in the warmer Mediterranean region (Greece, Italy, Spain).

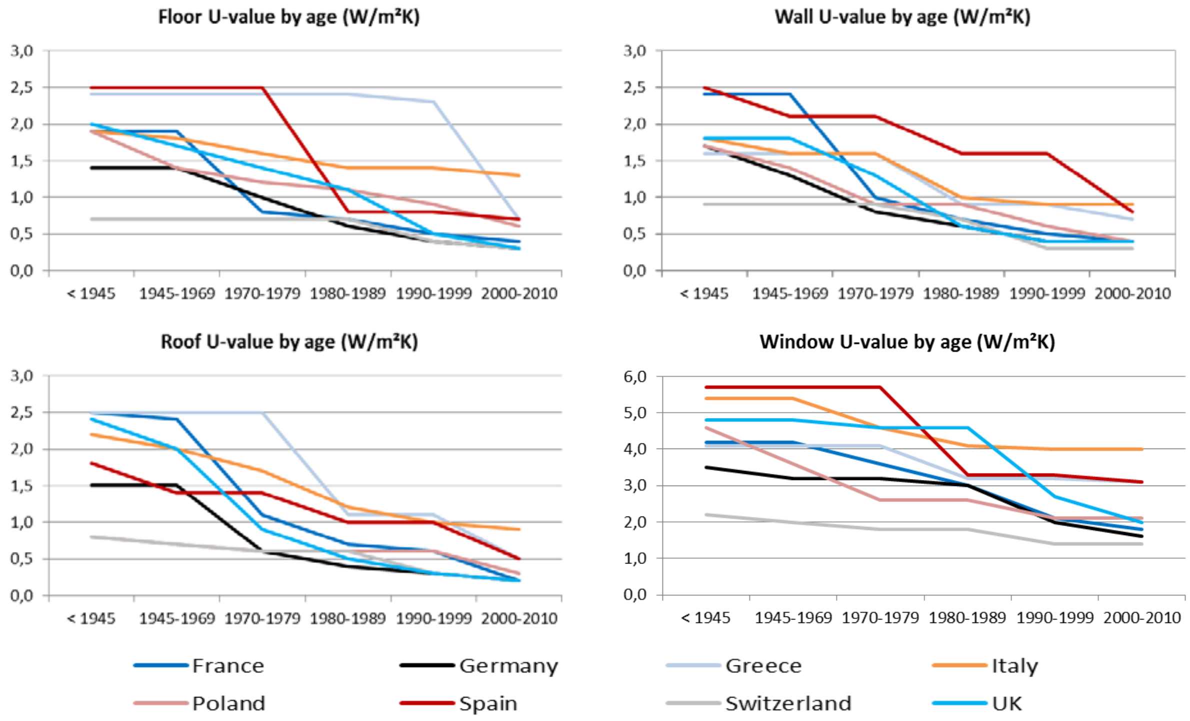

Figure 4. Average U-Values for different building components by age and country

The data has been checked against several sources and corrected when appropriate. The values appear to be consistent, with the only exceptions of post-1990 window U-values for Italy (which seem too high). Due to differences in the data collection methodology, the U-values relate to the original assemblies for EU countries, while the Swiss values include also assemblies that have been retrofitted.

4.2. Energy consumption

The source of the energy consumed in buildings is also quite different among the countries assessed. Natural gas is clearly predominant in UK (59%) and Italy (51%), while electricity is clearly predominant in Greece (53%) and Spain (51%). The share of oil is significant in Germany (23%), Greece (21%) and Spain (17%). Poland poses a particular case with a high proportion of coal-sourced energy (27%). Derivated heat has the highest presence in Poland (19%) followed by Germany (6%). Finally, the share of energy from renewable sources is highest in Greece (19%), followed by Italy (14%), France (12%) and Spain (12%), and smallest in the UK (2%).

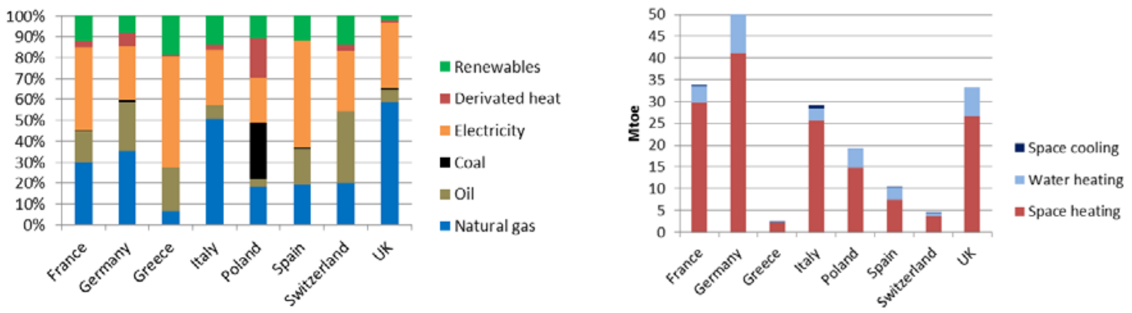

Figure 5. Source of energy consumed in buildings (left). Energy consumption of residential buildings for space heating, water heating and space cooling use (right)

Regarding HVAC systems, the available information is much more limited. Generally, the majority of energy consumed in dwellings is directed to space heating use. Therefore, when aiming for improvements in energy efficiency, this should be considered a priority area to be targeted. Data on space cooling is only available for certain countries, and the associated energy consumption is much smaller than for space heating. Among the countries studied, the share of space cooling is largest in the Mediterranean countries (Italy, Greece and Spain) accounting around 1–2%.

Table 1. Share of HVAC systems within dwellings

	Condens. boiler (2012)	Convent. boiler (2012)	Stove (2012)	Fireplace (2012)	Heat pump (2012)	Solar heating (2014)	Solar PV (2013)	District heating (2013)
France	6.00	34.65	8.10	n/a	5.00	2.40	0.60	n/a
Germany	10.83	35.14	7.10	n/a	1.20	5.10	2.08	n/a
Greece	0.27	26.59	n/a	n/a	n/a	31.00	4.71	0.15
Italy	6.81	47.45	67.50	18.90	61.80	3.80	3.87	n/a
Poland	3.32	13.04	n/a	7.00	0.20	2.10	0.00	40.00
Spain	1.56	29.34	3.70	n/a	1.10	4.70	4.91	n/a
UK	48.62	37.81	n/a	n/a	0.30	0.60	0.30	n/a

Complementary data has been gathered on the existing stock of HVAC systems within the countries assessed (Table 1). Some figures show a good correlation with the source of energy consumed in buildings (e.g. large share of gas boilers in Italy and UK), but the data is not complete and some figures appear inconsistent (e.g. share of heat pumps attributed to Italy).

Finally the application and transposition of main EU Directives to each of the countries assessed has been done under different scopes and tools, resulting in a quite heterogeneous situation that does not permit a fully equivalent comparison between the cases considered.

As main remarkable results of the documents and regulations studied, the following key outcomes can be highlighted:

- Different approaches to evaluate the energy performance of buildings and the difficulty to establish general threshold values. Especially for the case of reference buildings, where the quantification of the final results needs a specific assessment suited to each case and thus difficult to extrapolate to other situations.
- The different way for defining how the adoption of renewables is carried out at country level, or in some other cases explicating the adoption of a minimum at building scale.
- Finally the development of NZEB definition by each country is still ongoing and as in the case of maximum consumption not expected to be provided as absolute values but as a relative values compared to reference buildings.

Despite the limitations highlighted above, an exercise of bringing all the different requirements to a common framework has been done with the aim of providing a rough comparison of the situation in each country. Table 2 summarizes the main information highlighting those parameters related to energy retrofitting of buildings and thermal equipment. It has to be highlighted that in many cases the results presented are not explicit values extracted from legislative documents, but interpretations of the current situation aiming to provide a reference of how these regulations are being developed.

Table 2. Summary table of key parameters related to regulations for each country

		Maximum energy	Minimum contribution of RES	NZEB definition
Germany	New	75% of reference building demand (40 – 60 kWh/m^2·year)	15 – 50%	Under Development (40 kWh/m^{2}year)
	Retrofit	140% of reference building demand	Not defined	
United Kingdom	New	Reference building (32 – 60 kWh/m^2·year)	Not defined	Under Development
	Retrofit	Not defined for whole building		
France	New	50 kWh/m^2.year	> 50%	< 50 kWh/m2year
	Retrofit	80 – 150 kWh/m^2.year	> 50%	
Italy	New	Reference building (7,7 – 94 kWh/m^2.year)*	New & Deep Retrofit: 50% for DHW (after 2018, 50% for DHW, heating and cooling)	Ref. Building.
	Retrofit	Reference building		
Spain	New	40 – 70 kWh/m^2·year	30 – 70%	Planned for 2018.
	Retrofit	Reference building		
Poland	New	65 – 120 kWh/m^2·year	Not defined	Under Development (ranged in 65 – 70 kWh/m^2 year)
	Retrofit	NA		
	Retrofit	70 – 100 kWh/m^2.year		
Greece	New	40 – 75 kWh/m^2·year	20% as a national plan for RES installation	Under Development
	Retrofit	90 – 145 kWh /m^2.year		
Switzerland	New	35 kWh/m^2.year**	Not defined	Under Development
	Retrofit	Approx. 30 – 46 kWh/m^{2}year for space heating	10% (of heating demand, for replacement of heating systems)	

* Maximum Primary Energy for Italy is extracted from previous regulation, and is not in force since 2015 (Just provided as reference)

** Space heating, DHW, ventilation, air conditioning weighted by energy source

*** Once NZEB comes into force

4.3. External climate impact and potential

External climate has a crucial impact on energy consumption, as well as on the energy saving potential for renewable sources. However, the incident solar irradiation and the period when this is available is key when considering possible solutions based on renewables to be implemented. Figure 6 represents the total horizontal irradiation in 12 European cities, distinguishing three periods of the year, based on data obtained from Meteonorm [27].

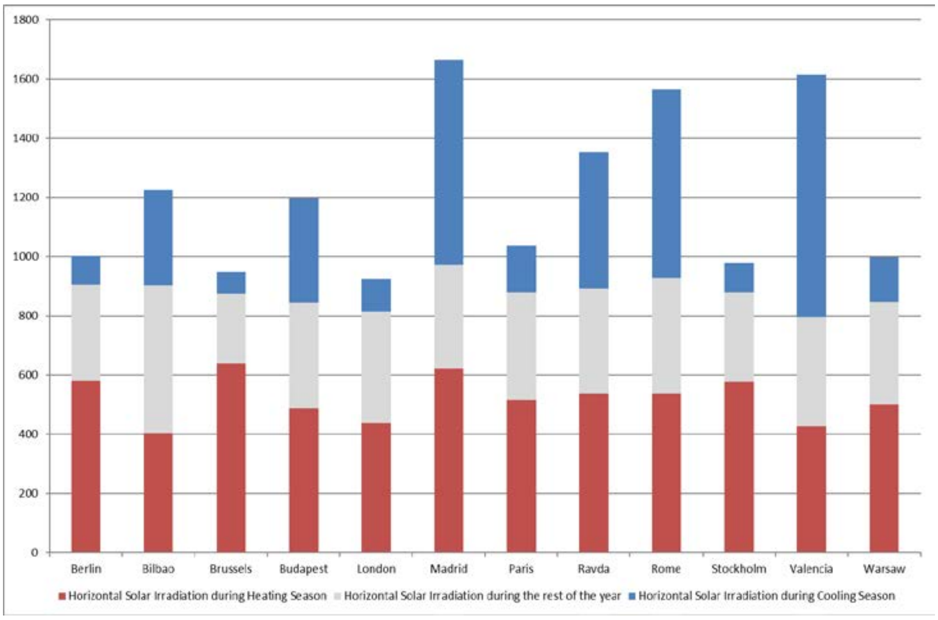

Figure 6. Graphic assessment of demand and potential for solar heating and cooling in different European cities.

The relevance of different demands during the year, the intensity of those demands as well as the available irradiation to cover those needs varies depending on the location. In such line Figure 7 compares the potential of solar heating and cooling for the considered European cities.

The horizontal axis indicates the energy required for space heating (to the left) and space cooling (to the right). These are based on the number of heating degree days (HDD, with base temperature of 15 °C) and cooling degree days (CDD, with base temperature of 20 °C). Locations further from the vertical axis to the left (Stockholm, Warsaw, Berlin) have higher heating requirements, while locations further from the vertical axis to the right (Valencia, Madrid, Rome) have higher cooling requirements.

The vertical axis indicates the availability of solar irradiation during the heating or cooling season. A higher position indicates a higher potential for solar heating or solar cooling.

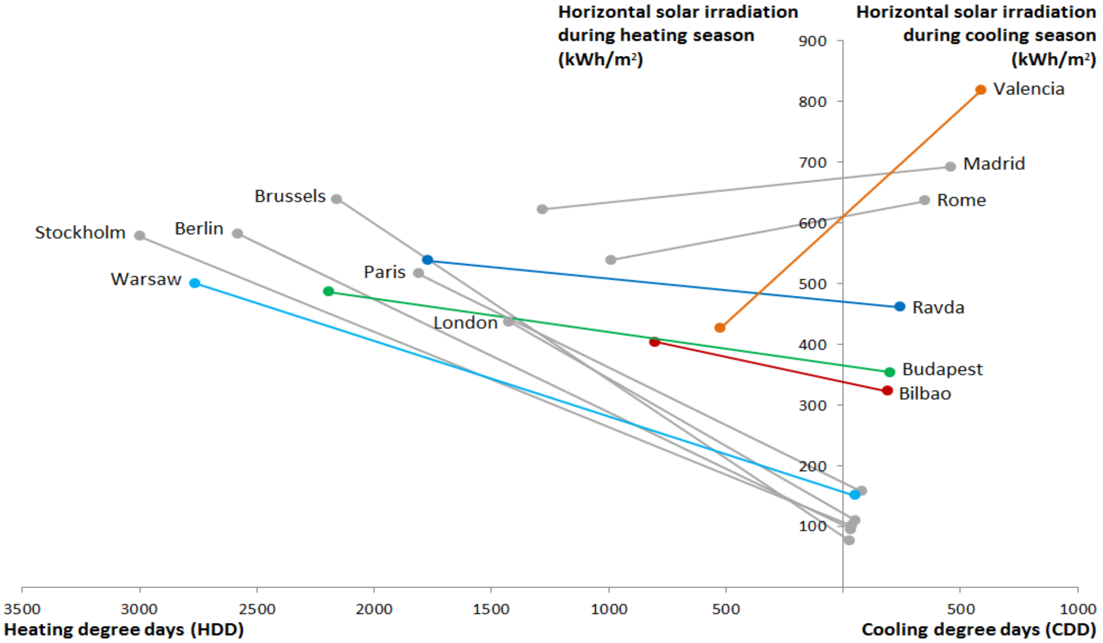

Figure 7. Graphic assessment of demand and potential for solar heating and cooling in different European cities.

It's worth noticing that this graph, is only representing the part of solar energy that is potentially usable for solar heating and cooling production depending on the climate of the site. Brussels would have a high potential for solar heating, but not for solar cooling, while Madrid would have a high potential for both solar heating and solar cooling. Both cases, Madrid and Brussels are very representative examples of locations where a high share of solar energy can be harnessed even if they have different demand profiles.

The four demonstration sites of the Heat4Cool projects are indicated with colours in Figure 6. They cover a variety of situations, both in terms of heating/cooling requirements and solar irradiation potential.

5. CONCLUSIONS

The information collected will be included in future research of the Heat4Cool project and is the basis for the development of the Retrofitting Design Planner Tool which is still ongoing. As a result, the data and information collected has been in all the cases oriented to such application.

The main outcome of the information resulting from the present study is a general overview of the current European building stock. This has been obtained to provide an overall picture of the current status in eight different countries representing major countries at continental level and as well as those of special interest within this project.

A set of parameters for determining interesting aspects about buildings, energy efficiency and external climate have been first defined to later be quantified and reviewed. As a progress over previous research projects in the building stock characterization field, the external climate and the regulations related to energy performance and retrofitting have been identified and interpreted within the scope of present study. The complexity of each case poses a challenge to understand each country's approach to comply with requirements stated in EU Directives. Nevertheless and even if it is not fully comprehensive, an exercise of bringing all the different requirements to a common framework has been done, with the aim of providing a rough comparison of the situation in each country.

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7. ACKNOWLEDGMENT

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