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Benchmarking of energy demand of residential buildings

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Abstract

Solar thermal energy has been adopted in medium and long-term energy strategies within EU countries for increasing the energy efficiency of buildings. In this context, the overall objective of this project consists in developing an innovative high performance and cost effective hybrid system (solar heat and electrical power). The initial application is to be implemented in residential buildings for on-site electricity and heat generation using solar thermal energy. The proposed technology is expected to deliver 60% of domestic energy requirements (heating and domestic hot water) and provide 20% reduction in energy costs and greenhouse gas emissions compared to the best existing low carbon energy technologies. A benchmark on the energy demand for the different types of residential buildings in Europe serves as reference scenario to evaluate the potential applicability of the different existing renewable technologies and to establish a comparative framework in terms of quantitative values. Thus, the specific aim of this study consists in performing a state-of-the-art on the different building typologies, which can host this technology, and their energy demands for heating and domestic hot water, as well as their associated CO_2 emissions.

Keywords: Residential building typology; building energy demand; European building stock; solar thermal energy; micro organic Rankine cycle; energy savings.

1. Introduction

The building sub-sector is responsible of about 41% of the final energy consumption and the one-third of total direct and indirect CO_2 emissions of end-use sectors in Europe (Directive 2010/31/EU). The domestic Renewable Heat Incentive and similar schemes, which are deployed across a number of EU countries (e.g. Spain, Germany, UK, France, Italy) encourage uptake of renewable heat technologies to support the ambition of 12% of heating coming from renewable sources in domestic residential sector by 2020.

This study is part of the project Innova MicroSolar, which is funded within the framework research and innovation program Horizon 2020. The core of this project is based on solar thermal energy and aims to develop an innovative high performance, cost effective and solar high durability 2-kW_{el}/18-kW_{th} heat and power system for on-site heat and power supply for residential buildings (single family and multifamily houses). The technology will consist of a small scale solar concentrating collectors which supply thermal energy to power the small high performance organic Rankine cycle (ORC) turbine with 2-kW_{el} output. A thermal energy storage unit with phase change materials (PCM) will be designed to control the energy input and output all day long until up to 4 h after the sunset. With this prototype, the 60% of the required building energy demand will be covered, as well as the energy costs and greenhouse gas (GHG) emissions will be reduced 20% in comparison to the best existing technologies.

The main parts of the prototype are presented in Figure 1:

- Concentrating solar collectors (CSP): The CSP system is based on linear Fresnel mirrors which are considerably easier and cheaper to manufacture than their parabolic equals. The system incorporates a sun tracking mechanism and can supply heat transfer fluid (HTF) flow at 295ºC.
- PCM thermal energy storage: the storage block has two different main components, the PCM tank and the enhanced heat sink, which are connected by heat pipes. The novelties of this unit are the PCM compound with the tuned melting temperature for heat storage, and the reversible heat pipes capable of transferring heat at the required high heating rate in both directions.
- Micro-organic Rankine cycle plant: micro-ORC technology is equipped with a high speed permanent magnet AC alternator able to supply 2 kW_{el}.

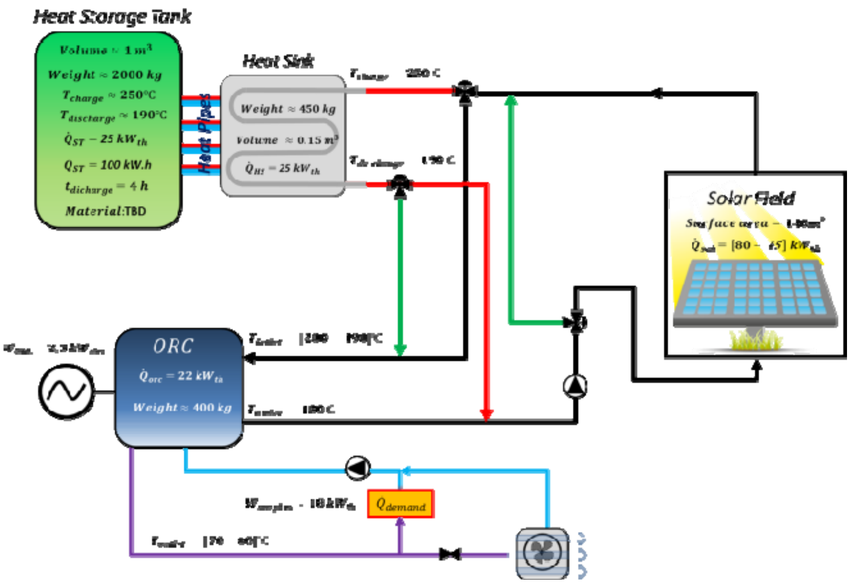

Figure 1. Innova MicroSolar system diagram

The main objective of this paper consists in performing a state-of-the-art on the different typologies of residential buildings and their estimated energy demand for Italy, Spain, France, Germany and UK. On one hand, this information will include specification of details on the architecture such as: building envelope, their insulation properties, range of dimensions of living space, domestic hot water (DHW), and space heating systems. On the other hand, the annual energy demands for heating, DHW, and electricity will be collected. This information will be used as input data to define and adapt the final design of the system, which will include different building typologies, climate conditions, and energy demand among other technical requirements.

Moreover, the reference scenario could be used to evaluate the potential applicability of other renewable existing technologies and to establish a comparative framework in terms of quantitative values.

2. Comparative analysis of energy demand and CO_2 emissions of residential buildings

Some projects co-founded by Intelligent Energy Europe (IEE) such as, DATAMINE, TABULA, and EPISCOPE (episcope.eu/iee-project) have created a data base about buildings stock energy performance in Europe. Thus, they developed a structure for exchanging and comparing energy performance indicators between more than 12 different EU countries. Further steps resulted an agreed systematic approach to classify building stocks according to their energy related properties, age, size and further technical parameters. The main outcome of these projects was an interactive database named TABULA WebTool created to share useful information with the scientific community and building experts from European countries.

After performing an in-depth analysis of these three consecutive European projects (2006-2016) a standardized building classification was detected. In addition to this information, the energy demand for heating and DHW and the related CO_2 emissions sorted by building typology, age classes, and different climatic conditions were compared. Table 1 shows the classification that divides the EU building stock into four general typologies: single family house (SFH), terraced house (TH), multifamily house (MFH) and apartment block (AB).

Table 1. Example of the standardized building classification by TABULA.

Single family house (SFH)	Terraced house (TH)	Multifamily house (MFH)	Apartment block (AB)
			

Since databases present different age classes by country (six in Spain, 12 in Germany, ten in France, eight in Italy, and eight in UK), an overall building classification grouped into three different age classes, from 1970 to 1985, from 1986 to 2000, and from 2001 to 2016 was used to unify and compare all the countries within the same age bands. Also, the climatic conditions inside a country were divided into three different classes: hot, temperate, and cold.

3. Results

Due to the huge variation on climatic conditions across Europe, the scope of this paper is focused only on the representative temperate climatic conditions of the countries presented in Table 2. The results are organized according to the main outcomes from the aforementioned findings divided in energy demand for heating and DHW and the derived CO_2 emissions.

Table 2: Temperate climates of the analysed countries

Country	Spain	Italy	France	Germany	UK	Sweden
Climate	Atlantic	Middle	H2	Kassel	England	Zone 2

3.1. Annual energy demand for heating and domestic hot water

Figure 2 shows the energy consumption for heating and DHW in temperate climatic conditions sorted by country, building age class, and typology of buildings. As it was expected, apartment blocks showed the lowest values in terms of energy demand in comparison to single family houses and terraced houses for all the analysed EU countries. These results emphasize the importance of the building shape that presents higher compactness (lower form factor between the building surfaces in contact with the non-heated areas and total air volume of the building) in apartment blocks and multifamily houses, so requiring less energy for heating. Additionally, many variations in terms of energy demands for heating and DHW were observed for the same building typology when countries and building construction periods were compared for temperate regions.

Since simple construction systems with low insulation levels were common in old building typologies (1970-1985), European energy policies towards more efficient buildings had a direct impact on reducing the energy demand of buildings. This decreasing trend can be seen in Figure 2. For instance, the newest building typologies in Spain (2001-2016) consume around 50 % less energy for heating and DHW compared to old building types (1970-1985). Similar energy trends were observed in Germany, France, Italy and also UK, nevertheless, in northern countries such as Sweden thicker insulation levels were implemented before the considered period in this study showing a slight decreasing trend.

Regarding the thermal transmittance coefficient of buildings envelopes, the walls of a single family house in Germany (1986-2000) has 0.35 $W/m^2{\cdot}K$ while in Spain the same building characteristics and period shows the double (0.60 $W/m^2{\cdot}K$). However, as shown in Figure 2, for the specific construction period of 1986-2000 the German single family house consumes 190 $kWh/m^2{\cdot}year$ for heating and DHW in temperate climatic conditions while in Spain the same building typology requires only 60 $kWh/m^2{\cdot}year$. As expected, northern countries such as Sweden, UK, and Germany show higher energy demands for heating purposes than southern countries such as Spain and Italy, even using the double of the insulation level on building skins. This evidence highlights the relevant impact of the climatic conditions in the final energy consumption of a building.

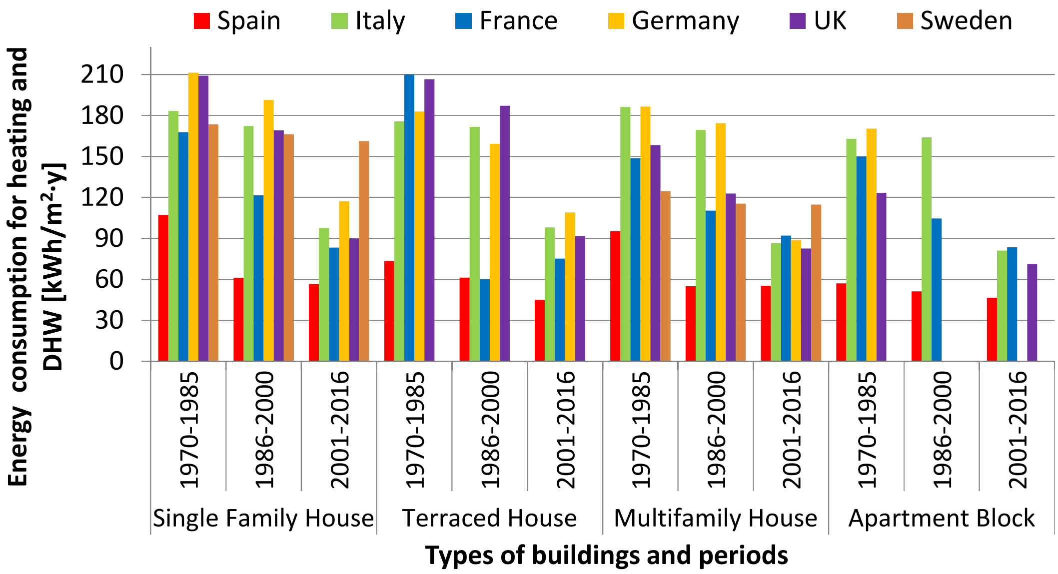

Figure 2. Energy consumption for heating and domestic hot water in temperate climatic conditions by country

In southern countries such Spain, Italy, and some regions of France, in which Mediterranean climatic conditions are hot, the domestic hot water can account for more than a half of the total energy consumption of a building. As an example, a single family house in Spain (1986-2000) accounted for 41.8 kWh/m^2·y of consumed energy to cover heating and DHW demand (Figure 2) and 20.2 kWh/m^2·y come only from DHW requirements. However, in the opposite site, northern countries such as Germany or Sweden have higher rates in terms of energy consumption for heating in comparison to the energy consumption for domestic hot water. For a similar case scenario in Germany, the calculated delivered energy for heating and DHW of a single family house, from 1986 to 2000, was 188.5 kWh/m^2·y while only 21.1 kWh/m^2·y were for DHW requirements.

These examples highlight the great potential applicability of new and innovative technologies such as the micro solar heat and power system in different countries and different building typologies.

3.2. Annual CO_2 emissions

Figure 3 shows the expected trends in reducing the carbon dioxide emissions in all studied countries organized by building typology and age classes. All the building typologies show a reduction of the CO_2 emissions when age classes have compared, being the newest period (2001-2016) the lowest emissions. These results could be directly related to the reduction in the energy demand for heating purposes. However, multifamily houses in UK show a higher CO_2 emissions levels (Figure 3) despite the fact that their energy consumption is lower (Figure 2) than other building typologies. That difference is due to the heating technology considered on TABULA WebTool. Terrace houses supply the heating by condensing boilers while multifamily houses (from 1970 to 2000) use electrical heaters; and the CO_2 emissions per electrical kilowatt in UK is high because of the energy mix. For that reason, the Innova MicroSolar prototype can achieve its energy savings goal but depending on the current technology installed it may not fulfil the requirements on the CO_2 emissions. For instance, multifamily houses located in UK which were built from 1970 to 1985 emit 0.58 CO_2 kg/kW, these emissions decreased to 0.28 CO_2 kg/kWh in multifamily houses built from 2001 to 2016 due to the implementation of condensing boilers for the heating and domestic hot water demand.

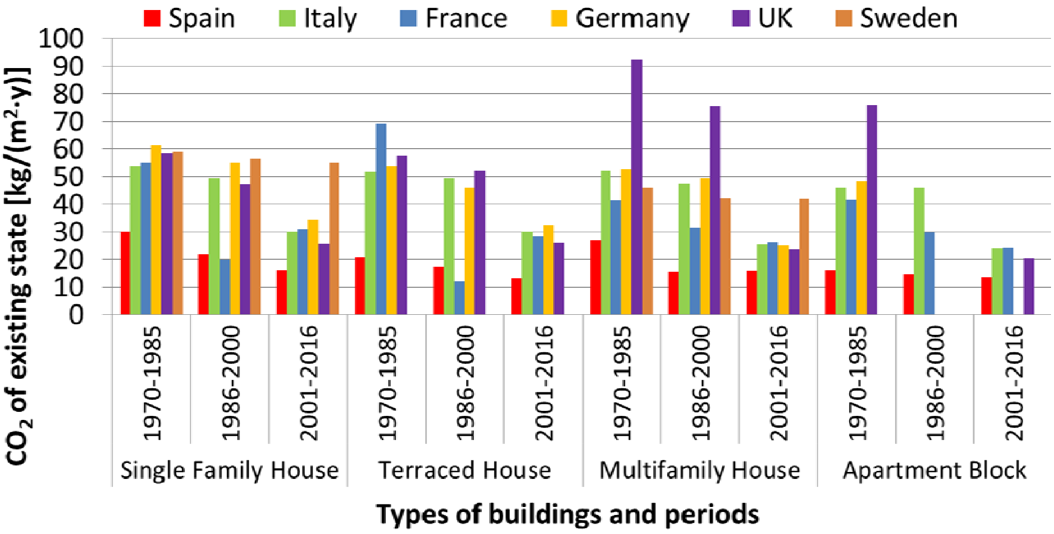

Figure 3. CO_2 emissions in temperate climatic conditions

4. Conclusions

After a comprehensive literature review in terms of energy demand for the most common domestic residential buildings in different European countries, the following are the main outcomes of this study:

- A residential building classification divided into four main typologies have detected for the aforementioned European countries: single family house (SFH), terraced house (TH), multifamily house (MFH) and apartment block (AB).
- The energy policies proposed in many European countries towards more sustainable buildings had a direct impact in reducing the energy demand in buildings, as well as the related CO_2 emission. Nonetheless, the overall trends show an increment due to other factors such as the increment of the households, the floor area per capita and the population among others.
- The DHW demand of a building is mainly attributed to the human behaviour and the performance of the system while the heating demand is generally related to the climatic conditions and the building insulation level.
- The estimated range of the energy consumption for heating and DHW was from 46.5 kWh/m²·y for new apartment blocks in a temperate Spanish climate to 210 kWh/m²·y for old French terraced house (1970-1985) in the same climatic conditions.

- The savings in terms of CO_2 emissions are directly related with the energy savings. However, the estimated reduction of the CO_2 emissions by the prototype will depend on the current technology installed to supply the heating and DHW demand.

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