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Energy mapping of existing building stock in Spain

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Energy performance certificate databases are a key tool for mapping national building stock and thus fostering greater overall energy efficiency. This paper presents an insight into the energy performance of residential and tertiary sector buildings in Spain, through an analysis of the first 129,635 energy performance certificates issued for existing buildings, collected by the Catalan Institute of Energy. Most of the residential buildings or building units that were studied were "E" class (53.6%). Single-family houses were found to use more energy on average (248.0 kWh_p/m^2) than individual dwellings (183.2 kWh_p/m^2). Tertiary sector buildings were found to have slightly better energy performance (26.4% of buildings were rated "D class"), with an average energy consumption of 317.8 kWh_p/m^2. Modern buildings consume less energy, as they must meet the higher energy performance requirements stated in thermal building regulations. Residential buildings or building units located in hotter climate zones consume slightly less energy than those located in colder zones, mainly because heating accounts for a high percentage of overall energy expenditure (70–75% in residential buildings). A significant proportion of the energy consumed in tertiary sector buildings is for lighting (37.2%). This research defines the current energy consumption baseline of existing buildings in Spain. The results can help to prioritize energy conservation efforts according to building type, construction period, climate zone and specific end-uses. They may also help public authorities to plan future energy policies, and construction practitioners to identify market segments and business strategies.

1. Introduction

The building sector currently accounts for 40% of energy use in most countries (European Union, 2012, 2013) and has the greatest energy saving potential (European Commission, 2011), with estimated potential energy savings of 1509 million tonnes of oil equivalent (Mtoe) by 2050 (International Energy Agency, 2010). However, to achieve effective energy saving and carbon reduction, we must fully understand the energy performance of the building sector (Jiang et al., 2013). In this context, an energy performance certificate database provides a ready-to-use source of information on the building stock (Buildings Performance Institute Europe, 2014).

The Energy Performance of Buildings Directive (EPBD) (European Union, 2002) was transposed in Spain by the Technical Building Code (Spain, 2006), Royal Decree 1027/2007 approving Spanish Thermal Building Regulations (Spain, 2007a), and Royal Decree 47/2007 approving the basic procedure for energy certification of new buildings (Spain, 2007b). The certification of existing buildings was subsequently enforced through Royal Decree 235/2013 (Spain, 2013). Thus, energy performance certificates are mandatory for existing residential and tertiary sector buildings or building units that have been sold or rented to a new tenant since June 2013. Royal Decree 235/2013 also covers public buildings or parts of public buildings that have a floor area of over 250 m^2 and are frequently visited by the general public. According to Royal Decree 235/2013, energy certificates must be issued by building-related technicians (engineers or architects). The energy certificate is valid for a maximum of ten years and must be renewed after

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this period. However, the owner may voluntarily update the certificate when renovations may have changed the energy label.

The label is based on the carbon dioxide (CO_2) emissions per square meter generated by the building or the building unit in one year, and it is expressed as a letter ranging from A (the most efficient building) to G (the least efficient building). In line with the International Organization for Standardization (2013), transitions between classes are defined according to three labelling indexes (Table 1). In cases where a sample is available for comparison (such as in residential buildings), the labelling index is defined as the ratio of the building's energy performance indicator to the corresponding average value of the sample (Pérez-Lombard et al., 2009).

The C_1 labelling index refers to new residential buildings and is calculated according to Eq. (1), where I_o represents the CO_2 emissions generated by the building, calculated according to Annex I of Royal Decree 47/2007 (Spain, 2007b), $\bar{I}_r$ is the energy performance regulation benchmark and corresponds to the average CO_2 emissions in residential buildings that strictly meet the requirements stated in the Technical Building Code (Spain, 2006), and R is the ratio between $\bar{I}_r$ and the CO_2 emissions corresponding to the 10% percentile of residential buildings that strictly meet the requirements stated in the Technical Building Code (Spain, 2006). Table 2 shows the transition values, taking into account that the average ($\bar{I}_r$) and dispersion values (R) of new residential buildings depend on the building type and the climate zone.

$$C_1 = \frac{\left(\frac{I_o}{\bar{I}_r} \cdot R\right) - 1}{2 \cdot (R - 1)} + 0.6 \quad (1)$$

The C_2 labelling index refers to existing residential buildings and it is calculated according to Eq. (2), where I_o represents the CO_2 emissions generated by the building and calculated according to Annex I of Royal Decree 47/2007 (Spain, 2007b), $\bar{I}_S$ is the building stock benchmark and represents the average CO_2 emissions in existing residential buildings in 2006, and R' is the ratio between $\bar{I}_S$ and the CO_2 emissions corresponding to the 10% percentile of the existing residential building stock. Table 3 shows the transition values for existing single-family houses and multifamily-blocks according to the climate zone.

$$C_2 = \frac{\left(\frac{I_o}{\bar{I}_s} \cdot R'\right) - 1}{2 \cdot (R' - 1)} + 0.5 \quad (2)$$

When a comparison with other buildings is not feasible, for example, in the case of buildings devoted to other uses, a self-reference approach is used and the labelling index shows the saving percentage in relation to the reference building performance (Pérez-Lombard et al., 2009). In this case, the C labelling index is calculated according to Eq. (3), where I_o represents the CO_2 emissions generated by the building, calculated according to Annex I of Royal Decree 47/2007 (Spain, 2007b), and I_{rf} denotes the CO_2 emissions of the reference building.

$$C = \frac{I_o}{I_{rf}} \quad (3)$$

The energy performance certificate generally includes data that identify the building or part thereof that is being certified, the technician who certified the building, and the procedure used to obtain the rating. The energy performance certificate also states the label that was obtained, so buildings can be directly compared (García, 2006). Annex I of the energy performance certificate describes the building's main energy characteristics (including general information such as useful floor area, a picture, and a map showing the location), data related to the thermal envelope that distinguishes between opaque closures and openings (including their surface area, thermal transmittance and solar factor), and data related to heating, cooling and hot water systems (including their power rating, efficiency and energy source). The energy performance certificate for tertiary sector buildings also includes information about secondary heating and cooling systems, cooling towers, ventilation, pumping and lighting systems. Occupancy and use patterns are also detailed in energy performance certificates for tertiary sector buildings. Annex II of the certificate quantifies heating and cooling energy demands or the amount of energy that has to be provided to keep the temperature of the rooms at the required level, calculated according to the climate zone and the physical characteristics of the building. Annex II also provides detailed information on energy consumption and emissions, including partial indicators related to heating, cooling, sanitary hot water and lighting (in tertiary sector buildings). The energy consumption represents the amount of energy the systems use to maintain the temperature of a building at the required level, and to provide hot water and the required lighting levels. It depends on factors such as the annual variation in climate conditions, the range of thermal comfort, the efficiency of the systems, and their use. Although it is not yet mandatory, Annex III of the energy performance certificate provides specific recommendations on how to improve the performance of the building or building unit, and the corresponding potential reduction in energy demand, energy consumption and emissions that could be achieved if the recommendations are applied.

All aspects related to the control, inspection and registration of buildings' energy performance certificates are the responsibility of regional governments (Andaloro et al., 2010). In Catalonia, in the northeast of Spain, energy performance certificates are collected by the Catalan Institute of Energy (ICAEN) and the most relevant information, including the full address of certified buildings or building units and the emissions label, is available to the general public through an online register (Catalan Institute of Energy, 2014).

The aim of this paper is to provide an insight into the energy performance of residential and tertiary sector buildings in the northeast of Spain, through an analysis of energy performance certificates issued eight months after the entry into force of the energy certification regulation. Besides defining current energy consumption baselines, the results of this research will guide policy makers and relevant stakeholders on future policy development, to further enhance energy efficiency in the building stock. The results will also help construction practitioners to overcome barriers such as a lack of information when they are defining market segments and business strategies.

Table 1
Energy performance rating for residential buildings and buildings devoted to other uses.

Energy label	Residential buildings	Buildings devoted to other uses
A	$C_1 < 0.15$	$C < 0.40$
B	$0.15 \le C_1 < 0.50$	$0.40 \le C < 0.65$
C	$0.50 \le C_1 < 1.00$	$0.65 \le C < 1.00$
D	$1.00 \le C_1 < 1.75$	$1.00 \le C < 1.30$
E	$C_1 > 1.75$ and $C_2 < 1.00$	$1.30 \le C < 1.60$
F	$C_1 > 1.75$ and $1.00 \le C_2 < 1.50$	$1.60 \le C < 2.00$
G	$C_1 > 1.75$ and $1.50 \le C_2$	$2.00 \le C$

Source: adapted from Spain (2007b) and Institute for Energy Diversification and Saving (2011).