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Energy mapping of existing building stock in Spain

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ABSTRACT

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.

Keywords:
energy performance certificates, energy certification, energy consumption, buildings, Spain

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 1,509 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 (Jian 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 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).

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

Table 1. Energy performance rating for residential buildings and buildings devoted to other uses.
Source: adapted from Spain (2007b) and Institute for Energy Diversification and Saving (2011).

The C_1 labelling index refers to new residential buildings and is calculated according to Equation 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), $\overline{I_r}$ 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 $\overline{I_r}$ 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 $(\overline{I_r})$ and dispersion values (R) of new residential buildings depend on the building type and the climate zone.

$$C_1 = \frac{\left(\frac{I_O}{\overline{I_r}} \cdot R\right) - 1}{2 \cdot (R-1)} + 0.6 \qquad [1]$$

Energy label	Single-family houses			Multi-family blocks		
	B3	C2	D3	B3	C2	D3
A	$E_1 < 5.83$	$E_1 < 7.97$	$E_1 < 10.31$	$E_1 < 3.77$	$E_1 < 5.37$	$E_1 < 7.02$
B	$5.83 \leq E_1 < 14.58$	$7.97 \leq E_1 < 12.92$	$10.31 \leq E_1 < 16.71$	$3.77 \leq E_1 < 9.42$	$5.37 \leq E_1 < 8.70$	$7.02 \leq E_1 < 11.38$
C	$14.58 \leq E_1 < 19.27$	$12.92 \leq E_1 < 20.02$	$16.71 \leq E_1 < 25.67$	$9.42 \leq E_1 < 12.45$	$8.70 \leq E_1 < 13.49$	$11.38 \leq E_1 < 17.64$
D	$19.27 \leq E_1 < 30.98$	$20.02 \leq E_1 < 30.79$	$25.67 \leq E_1 < 39.84$	$12.45 \leq E_1 < 20.02$	$13.49 \leq E_1 < 20.74$	$17.64 \leq E_1 < 27.13$
E	$30.98 \leq E_1$	$30.79 \leq E_1$	$39.84 \leq E_1$	$20.02 \leq E_1$	$20.74 \leq E_1$	$27.13 \leq E_1$

Table 2. Transition values between classes expressed in Kg of CO_2/m^2 for new single-family houses and multifamily-blocks according to the climate zone.

The C_2 labelling index refers to existing residential buildings and it is calculated according to Equation 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), $\overline{I_S}$ is the building stock benchmark and represents the average CO_2 emissions in existing residential buildings in 2006, and R' is the ratio between $\overline{I_S}$ 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.

$$C_2 = \frac{\left(\frac{I_O}{\overline{I_S}} \cdot R'\right) - 1}{2 \cdot (R' - 1)} + 0.5 \qquad [2]$$

Energy label	Single-family houses			Multi-family blocks		
	B3	**C2**	**D3**	**B3**	**C2**	**D3**
E	$E_2 < 50.70$	$E_2 < 54.00$	$E_2 < 74.30$	$E_2 < 37.20$	$E_2 < 41.30$	$E_2 < 50.70$
F	$50.70 \leq E_2 < 59.32$	$54.00 \leq E_2 < 64.80$	$74.30 \leq E_2 < 89.16$	$37.20 \leq E_2 < 42.03$	$41.30 \leq E_2 < 48.32$	$50.70 \leq E_2 < 60.84$
G	$59.32 \leq E_2$	$64.80 \leq E_2$	$89.16 \leq E_2$	$42.03 \leq E_2$	$48.32 \leq E_2$	$60.84 \leq E_2$

Table 3. Transition values between classes expressed in Kg of CO_2/m^2 for existing single-family houses and multifamily-blocks according to the climate zone.

Source: drawn up by the authors using information available at Institute for Energy Diversification and Saving (2011).

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 Equation 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, 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.

The paper is organized as follows. After this introduction, the second section describes the method used in the research, and the third section discusses the results. Finally, in the conclusions, wider implications and future research issues are highlighted.

2. METHOD

Data extracted from the energy performance certificates collected by the Catalan Institute of Energy (ICAEN) were used in this research. The study included 129,635 energy performance certificates submitted by technicians in Catalonia (northeast of Spain), from the entry into force of Royal Decree 235/2013 (Spain, 2013) in June 2013 until March 2014. Due to confidentiality issues, all data that could identify the building, the building unit, the owner or the technician were deleted. For each energy performance certificate, the following variables were collected: emissions label (expressed as a letter ranging from A to G), emissions (measured in kg of CO_2/m^2), energy label (expressed as a letter ranging from A to G), primary energy consumption (measured in kWh_p/m^2), building type (multi-family block, individual dwelling in a multi-family block or tertiary sector building), year of construction, procedure used to obtain the label, climate zone where the building or the building unit is located, its floor area (measured in m^2), and the energy consumption related to heating, cooling, hot water and lighting systems (expressed in kWh_p/m^2). The database was originally in Microsoft Excel and was later exported into SPSS for analysis.

Taking into account the regional approach of the energy certification scheme in Spain and the latest data available at national level (Spain, 2015), the sample used in this research represents approximately 20% of the energy performance certificates currently issued in Spain.

2.1 BUILDING TYPE

In accordance with the structure of the Spanish building stock, records from the ICAEN energy performance certificate database included a total of 10,465 multi-family blocks (8.1%); 95,857 individual dwellings in multi-family blocks (73.9%); 12,654 single-family houses (9.8%); and 10,673 tertiary sector buildings (8.2%). Only 6 missing values (0.0%) were found in the database.

2.2 CONSTRUCTION YEAR

The energy performance of Spanish buildings was initially regulated by the compulsory basic building norm NBE-CT 79 on thermal conditions in buildings (Spain, 1979). This prescriptive code was in force from 1980 to 2006, and set minimum thermal requirements for individual building envelopes by establishing maximum heat transmission coefficients, and a maximum overall heat transmission coefficient for the entire building (Gangolells and Casals, 2012). The Spanish Technical Building Code (Spain, 2006) entered into force in 2008 and currently regulates the energy performance of new buildings in Spain through Section HE-1 on Energy Demand Limitation. Thus, three construction periods were considered in the analysis: (i) prior to 1980, when there was no thermal protection for buildings or building units; (ii) 1981-2007, when buildings or building units were built under NBE-CT 79 (Spain, 1979); and (iii) after 2008, when buildings or building units were erected under the Technical Building Code (Spain, 2006). As expected, the sample included 75,598 energy performance certificates (58.3%) of buildings or building units built prior to 1980; 40,977 energy performance certificates (31.6%) of buildings or parts of them erected in the 1981-2007 period; and 9,696 energy performance certificates (7.5%) of buildings or building units built after 2008. A total of 3,384 records (2.6%) had missing values.

2.3 CLIMATE ZONES

Twelve climate zones are defined in the Spanish Technical Building Code (Spain, 2006) on the basis of winter climate severity (WCS), which is identified by a letter, and summer climate severity (SCS), which is represented by a number (Figure 1). Winter climate severity (WCS) and summer climate severity (SCS) depend on average degree days, based on 20ºC in winter (January, February and December) or summer (June, July, August and September) respectively, calculated hourly and then divided by 24, and either the average accumulated overall insolation for the corresponding period [kWh/m^2] or the number or sun hours. Areas with higher winter climate severity (or higher letters in the alphabet) have cold winters, whereas areas with higher summer climate severity (or higher numbers) have hot summers. Buildings listed in the energy performance certificate database belong to the C2 climate zone (95,902, 74.0%), the B3 climate zone (13,895, 10.7%) or the D3 zone (4,419, 3.4%). As expected, the highest percentages of energy performance certificates were found in the most populated areas. It is assumed that all locations in a province generally have the same climate zone as their capital. However, the Spanish Technical Building Code (Spain, 2006) provides a correction for the climate severity of locations whose altitude differs by more than 200 m from the corresponding capital. Winter and summer climate severity can also be calculated if enough climate records are available. For this reason, the database also includes 7,932 energy performance certificates of buildings (or parts of them) located in the C1 climate zone (6.1%); 3,130 in the D1 climate zone (2.4%); 968 in the E1 climate zone (0.7%); and 221 in the D2 climate zone (0.2%). A few cases were found in the A3, A4, B4, C3 and C4 climate zones (57, 0.0%). For simplicity, the results take into account only the main climate zones (C2, B3 and D3 zones). In this case, 3,131 records were found to have missing values (2.4%).

Winter Climate Severity		Summer Climate Severity	
A	WCS≤0.30	1	SCS≤0.60
B	0.30<WCS≤0.60	2	0.60<SCS≤0.90
C	0.60<WCS≤0.95	3	0.90<SCS≤1.25
D	0.95<WCS≤1.30	4	WCS>1.25
E	WCS>1.30		

Figure 1. Climate zoning based on winter climate severity and summer climate severity in the Technical Building Code (Spain, 2006).

According to Royal Decree 235/2013 (Spain, 2013), general or simplified procedures recognized by the Spanish Ministry of Industry, Energy and Tourism can be used to obtain an energy performance certificate. The vast majority of energy performance certificates included in the database were obtained using CE3X software (128,742, 99.3%). Only 907 (0.7%) certificates were based on the results of other verified software tools. In this case, the database only had 6 missing values.

3. RESULTS AND DISCUSSION

The primary energy consumption of multi-family blocks, individual dwellings in multi-family blocks and single-family houses was found to be highly positively skewed (Figure 2 and Table 4). Distributions are bounded at zero as the primary energy consumption cannot be negative and small numbers are rare. These frequency distributions match up with the one found by Xiao et al. (2012) for office buildings located in the United States. On the contrary, the frequency distribution of Chinese office buildings revealed two peaks. The majority of buildings were found to be centralized over a lower energy range, while the minority was found to be distributed at a higher energy range. According to Xiao et al. (2012), this can be attributed to the rapid developing process undergone by China during the recent decades involving the construction of lots of new large-scaled buildings pursuing a higher standard of living, and thus, consuming more energy.

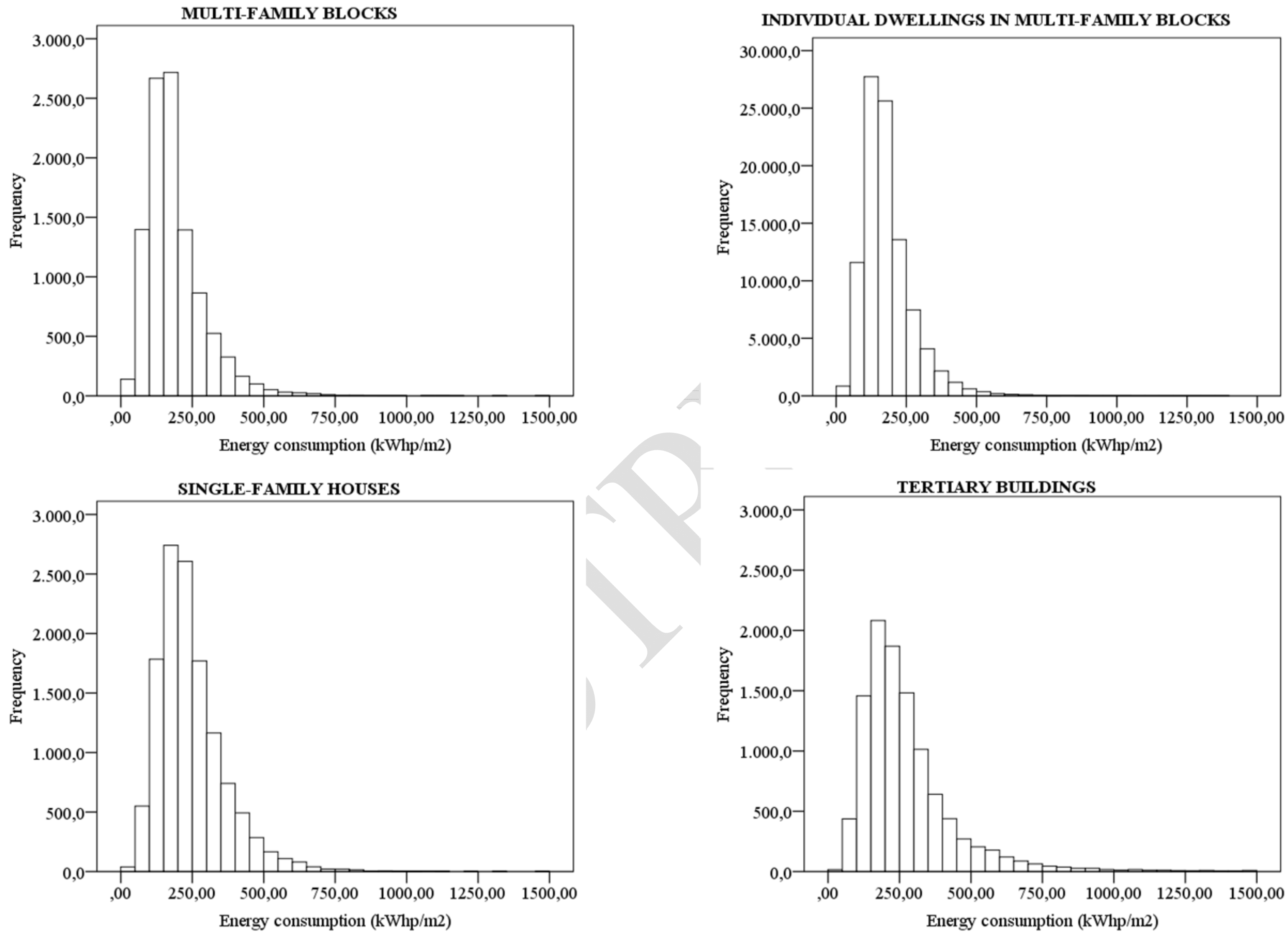

Figure 2. Frequency histogram of the primary energy consumption [kWh_p/m^2] according to building type.
Source: Drawn up by the authors using data from the ICAEN database, March 2014.

		Multi-family blocks	Individual dwellings in multi-family blocks	Single-family houses	Tertiary buildings
N	Valid	10,465	95,857	12,654	10,673
	Missing	0	0	0	0
Mean		190.9	183.2	248.0	317.8
Standard error of the mean		1.175	0.422	1.359	18.934
Median		165.3	163.0	222.4	235.3
Mode		144.7	128.3	450.1	175.9
Standard deviation		120.2	130.8	152.8	1,956.1
Skewness		7.105	51.683	16.352	93.023
Standard error of skewness		0.024	0.008	0.022	0.024
Kurtosis		149.9	5,744.8	675.4	9,205.9
Standard error of kurtosis		0.048	0.016	0.044	0.047
Percentiles	25	122.8	122.2	165.3	169.1
	50	165.3	163.0	222.4	235.2
	75	230.6	219.1	300.1	330.5

Table 4. Descriptive statistics for the primary energy consumption [kWh_p/m^2] according to building type.
Source: drawn up by the authors using data from the ICAEN database. March 2014.

The energy consumption of multi-family blocks was found to amount to 190.9 kWh_p/m^2 in Spain. Most of the multi-family blocks (50.2%, 5,249 certificates) were certified as E class (Figure 3). G class blocks comprised 26.1% of the sample (2,730 certificates), D class blocks amounted to 10.0% (1,049 certificates), and those with an F rating represented another 10.0% (1,041 certificates). According to the results, a small percentage (3.1%) of multi-family blocks were C class (320 certificates). A and B energy ratings were very scarce (3 certificates [0.0%] and 68 certificates [0.7%], respectively).

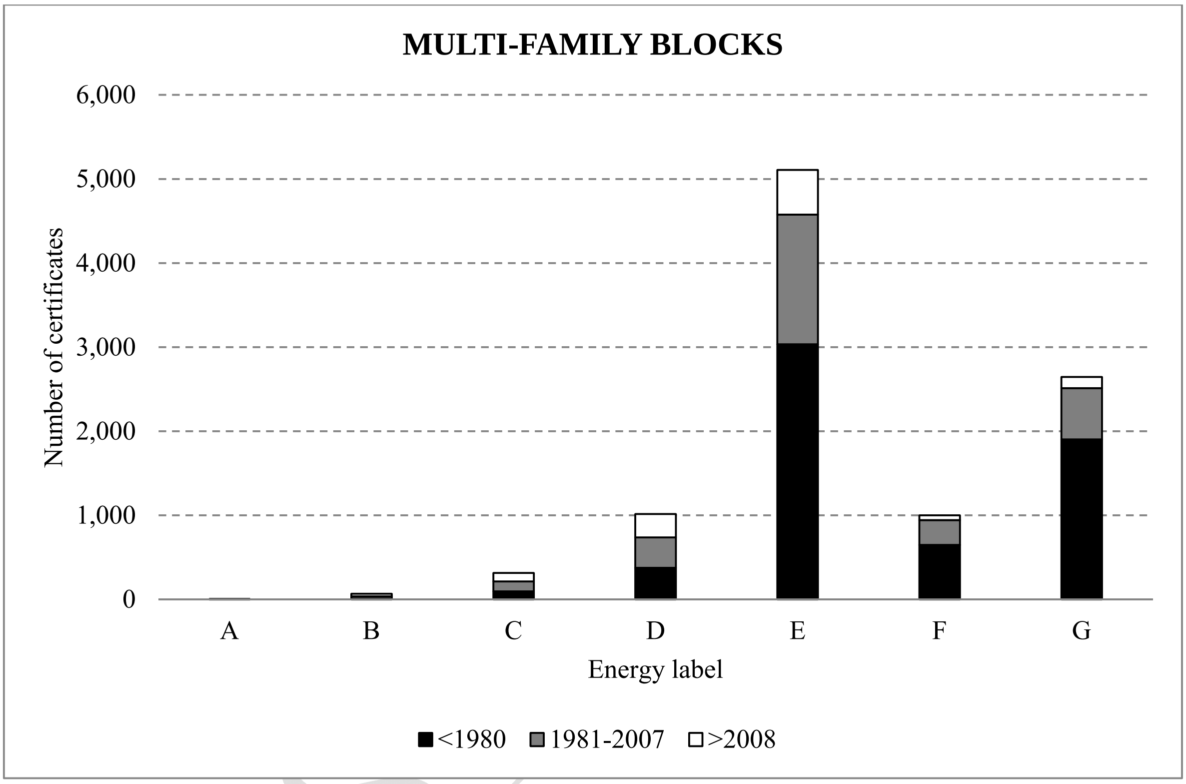

Figure 3. Number of energy performance certificates issued for multi-family blocks according to the construction period in Catalonia.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

Individual dwellings in multi-family blocks had similar energy consumption (183.2 kWh_p/m^2). Most individual dwellings in certified multi-family blocks were also rated as E class (55.0%, 52,717 certificates), followed by those rated G class (25.5%, 24,411 certificates) and F class (9.6%, 9,202 certificates). Individual D class dwellings represented 8.0% of the sample (7,623 certificates), whereas those labelled C class represented 1.7% of the sample (1,601 certificates). Finally, 259 individual dwellings were rated B class (0.3%), and 31 A class (0.0%) (Figure 4).

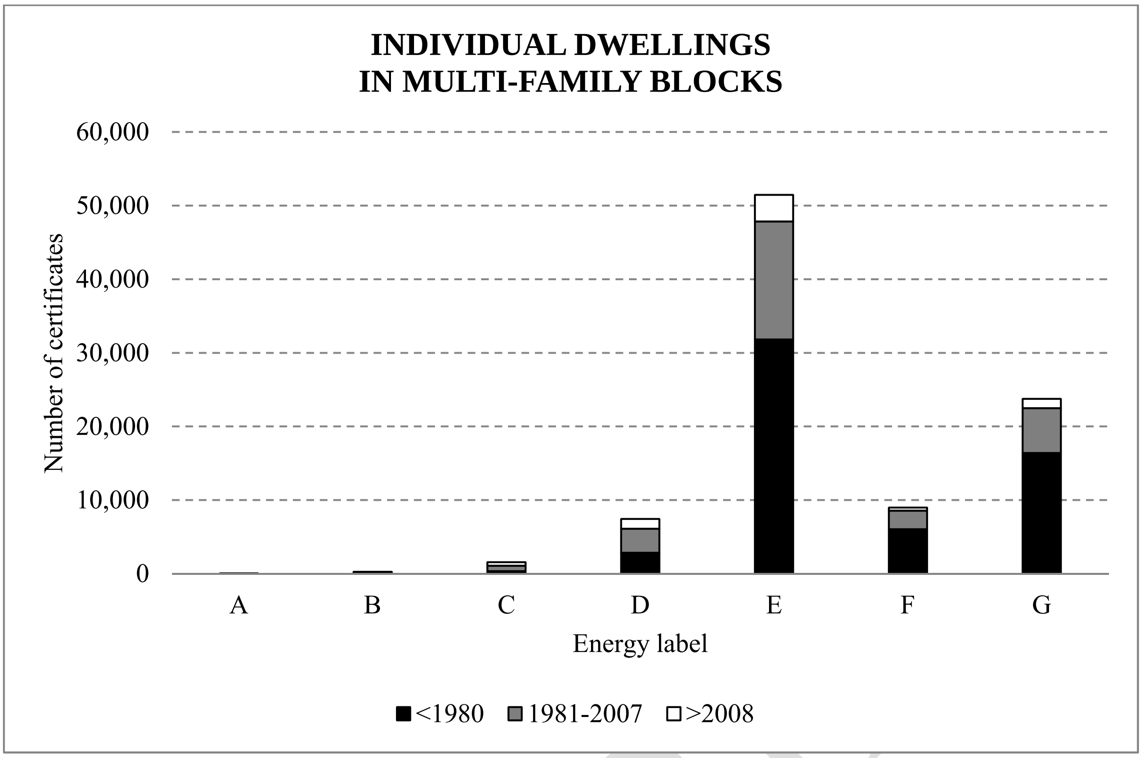

Figure 4. Number of energy performance certificates issued for individual dwellings in multi-family blocks according to the construction period in Catalonia.
Source: Drawn up by the authors using data from the ICAEN database, March 2014.

Multi-family blocks and individual dwellings in multi-family blocks had a similar energy profile. However, single-family houses consumed more energy on average (248.0 kWh_p/m^2) than apartments. The lower energy consumption in apartments may be partially explained by the lower exposure to outdoor temperature, as well as the fact that they are bordered by other buildings and have fewer windows. However, an evaluation of the energy label showed that they had a similar energy profile. Most of the sample had a low rating (Figure 5). E class single-family houses comprised 45.7% of the sample (5,775 certificates), whereas those labelled G class represented 28.9% (3,653 certificates), and those with an F label amounted to 13.9% (1,753 certificates). A total of 1,137 single-family houses were certified as D class (9.0%), whereas 280 had a C label (2.2%). Finally, only 44 single-family houses had a B label (0.3%) and 8 had an A label (0.1%).

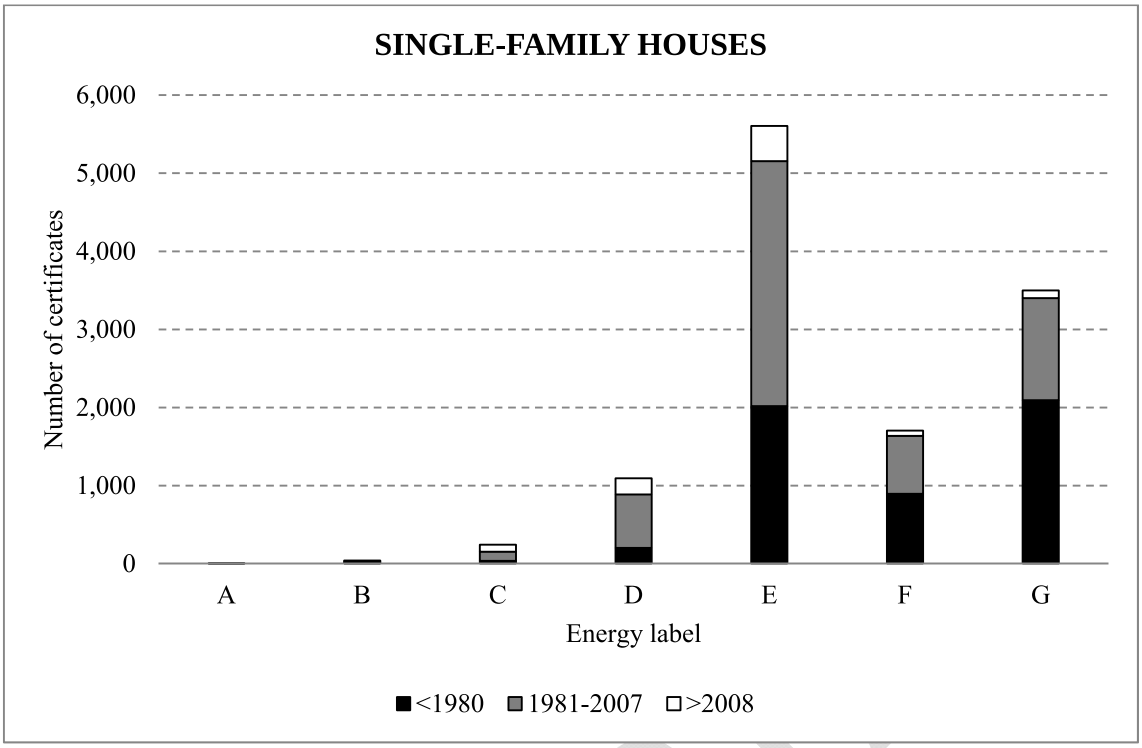

Figure 5. Number of energy performance certificates issued for single-family houses according to the construction period in Catalonia.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

The vast majority of residential buildings or building units erected before 1980, and thus thermally unprotected, were rated E, F or G class (94.3%). Only 5.7% had an A, B, C or D label. As shown in Table 5, their average primary energy consumption per floor area was 204.8 kWh_p/m^2 (multi-family blocks), 190.8 kWh_p/m^2 (individual dwellings in multi-family blocks), and 286.8 kWh_p/m^2 (single-family houses).

Average primary energy consumption [kWh_p/m^2]			
Building type	**Construction period**		
	<1980	**1981-2007**	**>2008**
Multi-family block	204.8	179.3	144.7
Individual dwellings in multi-family blocks	190.8	174.6	154.4
Single-family houses	286.8	225.2	174.6
Tertiary sector buildings	336.3	290.3	218.2

Table 5. Average primary energy consumption [kWh_p/m^2] according to building type and construction period.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

In the analysis of buildings erected under NBE-CT 79 (Spain, 1979), the percentage of high-rated residential buildings or building units (A, B, C or D energy labels) increased to 14.4%. The average primary energy consumption per floor area in buildings or building units erected during the 1981-2007 period was found to be significantly lower than the corresponding figures for the previous period: 179.3 kWh_p/m^2 (multi-family blocks), 174.6 kWh_p/m^2 (individual dwelling in multi-family blocks) and 225.2 kWh_p/m^2 (single-family houses) (Table 5).

Finally, the highest ratings (A, B, C or D energy labels) were given to 29.3% of buildings erected since 2008 under the Spanish Technical Building Code (Spain, 2006). According to the results, multi-family blocks have an average primary energy consumption of 144.7 kWh_p/m^2, whereas individual dwellings in multi-family blocks consume 154.4 kWh_p/m^2 and single-family houses use 174.6 kWh_p/m^2 on average (Table 5). The results show the effectiveness of the latest regulations in diminishing buildings' energy consumption and corroborate the findings reported by Dascalaki et al. (2013).

Residential buildings or building units with low energy performance labels (E to G) are predominant in all climate zones, and comprise between 70.4% (multi-family blocks in the B3 climate zone) and 92.4% (individual dwellings in multi-family blocks located in the C2 climate zone) of all certified buildings. According to the results shown in Table 6 and along the lines of the results reported by Dascalaki et al. (2010), residential buildings or building units located in milder climate zones in winter (B3 and C2) generally have slightly better energy performance than those located in coldest climate zones in winter (D3).

Average primary energy consumption [kWh_p/m^2]			
Building type	**Climate zone**		
	B3	**C2**	**D3**
Multi-family block	160.0	192.3	263.8
Individual dwellings in multi-family blocks	174.5	182.3	223.7
Single-family houses	250.7	244.3	294.6
Tertiary sector buildings	293.0	323.8	340.5

Table 6. Average primary energy consumption [kWh_p/m^2] according to building type and main climate zone.
Source: drawn up by authors using data from the ICAEN database, March 2014.

As reported by Dascalaki et al. (2013), the data also reveal that single-family houses use on average more energy than multi-family blocks and individual dwellings in multi-family blocks in all climate zones (Table 6). The difference is even greater in the case of single-family houses built before 1980 that did not meet any thermal regulations (Table 5). Old single-family houses (erected before 1980) used 50.3% more energy than individual dwellings from the same period. This percentage fell to 29.0% for buildings from the 1980-2007 period, and 13.0% for houses erected after 2008.

According to the results (Figure 6), the average primary energy consumption of apartments (including multi-family blocks and individual dwellings in multi-family blocks) ranges from 129.9 (multi-family blocks built after 2008 in the mildest climate zone in winter [B3]) to 467.7 kWh_p/m^2 (multi-family blocks built before 1980 in the coldest climate zone in winter [D3]). In single-family houses, buildings erected after the introduction of the Spanish Technical Building Code 2008 in the B3 climate zone (166.3 kWh_p/m^2) consumed the least energy, whereas single-family houses that were built in the D3 climate zone before the introduction of thermal regulations consumed the most energy (490.2 kWh_p/m^2).

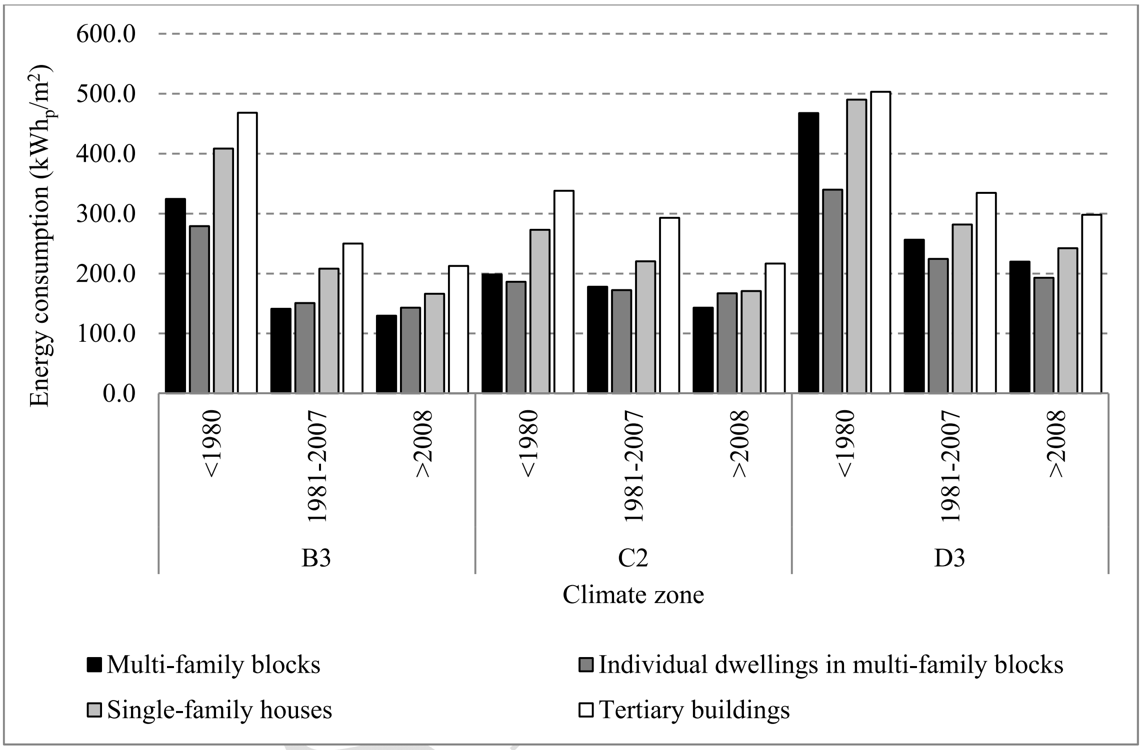

Figure 6. Average primary energy consumption [kWh_p/m^2] according to building typology, climate zone and construction period.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

A closer look at the distribution of energy end-uses in apartments (including both multi-family blocks and individual dwellings in multi-family blocks) reveals that most of the energy is used for heating (around 70%). The hot water system is responsible for around 20% of the total energy consumption, and cooling accounts for another 10% (Figure 7). As expected, the energy consumption attributed to heating is even higher in single-family houses (75.6%) (Figure 7). According to the results, the heating system in newer buildings consumes less energy (Table 7).

Although a reduction in heating automatically increases the percentage of all other contributions, more energy is used for cooling in new buildings or building units, because inhabitants now seek greater thermal comfort (Table 7). A study of the impact of a building's or building unit's location on its energy consumption revealed that heating systems always consume more energy in the coldest zone (D3) (Table 8). The results also show that there is no clear relationship between the energy used for cooling and the climate zone.

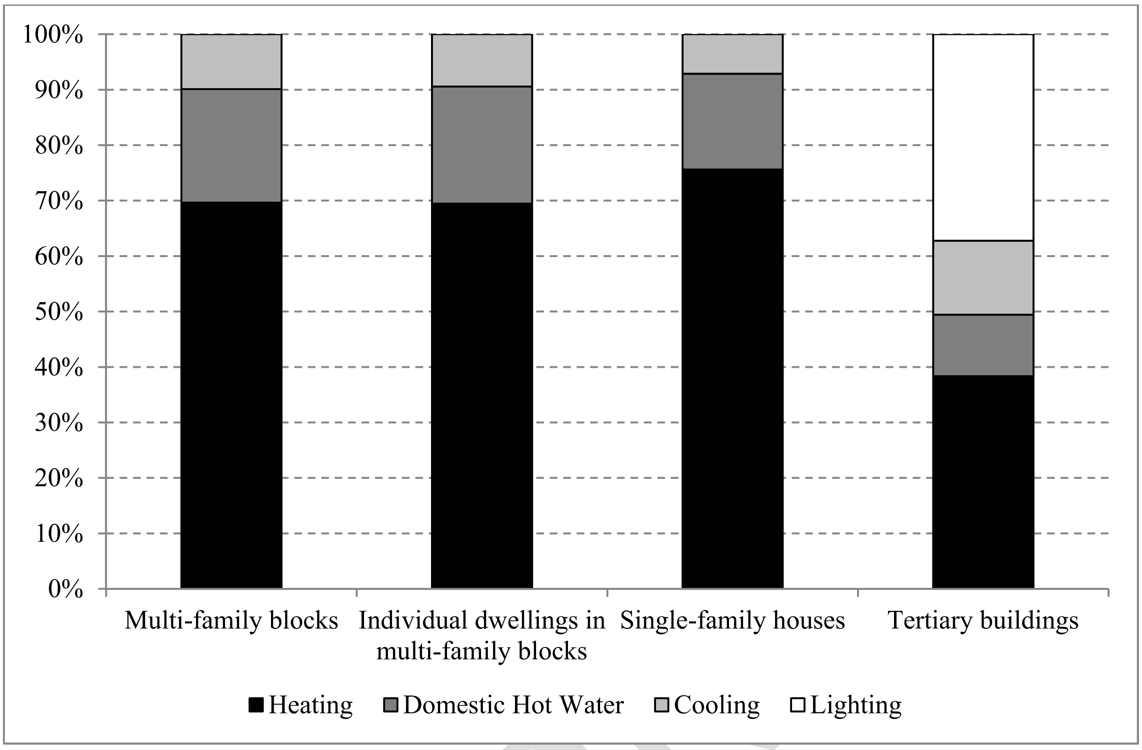

Figure 7. Breakdown of energy consumption according to building typology and end-uses.
Source: drawn up by authors using data from the ICAEN database, March 2014.

	Average primary energy consumption [kWh_p/m^2]											
	Multi-family blocks			**Individual dwellings in multi-family blocks**			**Single-family houses**			**Tertiary sector buildings**		
	<1980	**1981-2007**	**>2008**	**<1980**	**1981-2007**	**>2008**	**<1980**	**1981-2007**	**>2008**	**<1980**	**1981-2007**	**>2008**
Heating system	145.0 (72.5%)	115.1 (65.1%)	89.7 (62.5%)	137.4 (72.2%)	114.6 (65.7%)	92.7 (60.1%)	224.6 (78.4%)	165.9 (73.7%)	115.6 (66.2%)	120.4 (35.8%)	126.0 (43.7%)	93.2 (43.3%)
Hot water system	38.6 (19.3%)	40.1 (22.7%)	31.4 (21.9%)	38.0 (20.0%)	39.7 (22.8%)	37.5 (24.3%)	47.9 (16.7%)	39.7 (17.6%)	33.4 (19.1%)	38.0 (11.3%)	30.3 (10.5%)	18.8 (8.7%)
Cooling system	16.3 (8.1%)	21.6 (12.2%)	22.4 (15.6%)	16.0 (7.9%)	20.0 (11.5%)	24.1 (15.6%)	14.1 (4.9%)	19.6 (8.7%)	25.5 (14.6%)	39.8 (11.8%)	47.1 (16.4%)	50.1 (23.3%)
Lighting system	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	137.7 (41.0%)	84.6 (29.4%)	53.2 (24.7%)

Table 7. Average primary energy consumption [kWh_p/m^2] according to building type, end-uses and construction period. Source: drawn up by the authors using data from the ICAEN database, March 2014.

	Multi-family blocks			Individual dwellings in multi-family blocks			Single-family houses			Tertiary sector buildings		
	B3	**C2**	**D3**	**B3**	**C2**	**D3**	**B3**	**C2**	**D3**	**B3**	**C2**	**D3**
Heating system	108.0 (68.1%)	129.9 (69.1%)	209.3 (79.4%)	119.9 (68.8%)	125.7 (69.0%)	173.1 (77.4%)	192.1 (76.6%)	183.2 (75.0%)	238.3 (80.9%)	126.9 (43.6%)	119.7 (37.1%)	199.2 (59.0%)
Hot water system	31.6 (19.9%)	39.6 (21.1%)	36.4 (13.8%)	34.9 (20.0%)	39.9 (21.6%)	33.1 (14.8%)	40.9 (16.3%)	43.2 (17.7%)	41.9 (14.2%)	22.6 (7.8%)	36.2 (11.2%)	31.2 (9.2%)
Cooling system	19.0 (12.0%)	18.4 (9.8%)	17.9 (6.8%)	19.4 (11.2%)	17.0 (9.3%)	17.3 (7.8%)	17.8 (7.1%)	17.8 (7.3%)	14.3 (4.8%)	43.9 (15.1%)	42.7 (13.2%)	35.2 (10.4%)
Lighting system	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	n.a. n.a.	97.4 (33.5%)	124.2 (38.5%)	72.1 (21.4%)

Table 8. Average primary energy consumption [kWh_p/m^2] according to building type, end-uses and climate zone.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

Tertiary sector buildings had slightly better energy performance, with an average energy consumption of 317.8 kWh_p/m^2. In this case, the main energy label was D class (26.4%, 2,818 certificates), followed by E class (22.8%, 2,433 certificates) and C class (19.8% 2,112 certificates) (Figure 8). In terms of the distribution of energy performance certificates according to the construction period, modern tertiary sector buildings erected under the Spanish Technical Building Code (Spain, 2006) had better energy performance than older ones. The average primary energy consumption of new tertiary sector buildings was 218.2.4 kWh_p/m^2 (Table 5), and 60.3% of these buildings had an A, B, C or D energy label. The primary energy consumption of buildings erected under the first thermal regulation in Spain, NBE-CT 79 (Spain, 1979), during the 1981-2007 period was 290.3 kWh_p/m^2, whereas buildings constructed before 1980, when there were no thermal regulations in force, consumed an average of 336.3 kWh_p/m^2 (Table 5). The percentage of high-rated tertiary sector buildings (including A, B, C and D energy labels) was 49.4% for buildings erected before 1980. Similarly, and according to the results shown in Table 6, tertiary sector buildings located in the D3 climate zone consumed slightly more energy per square meter than those located in hotter climate zones.

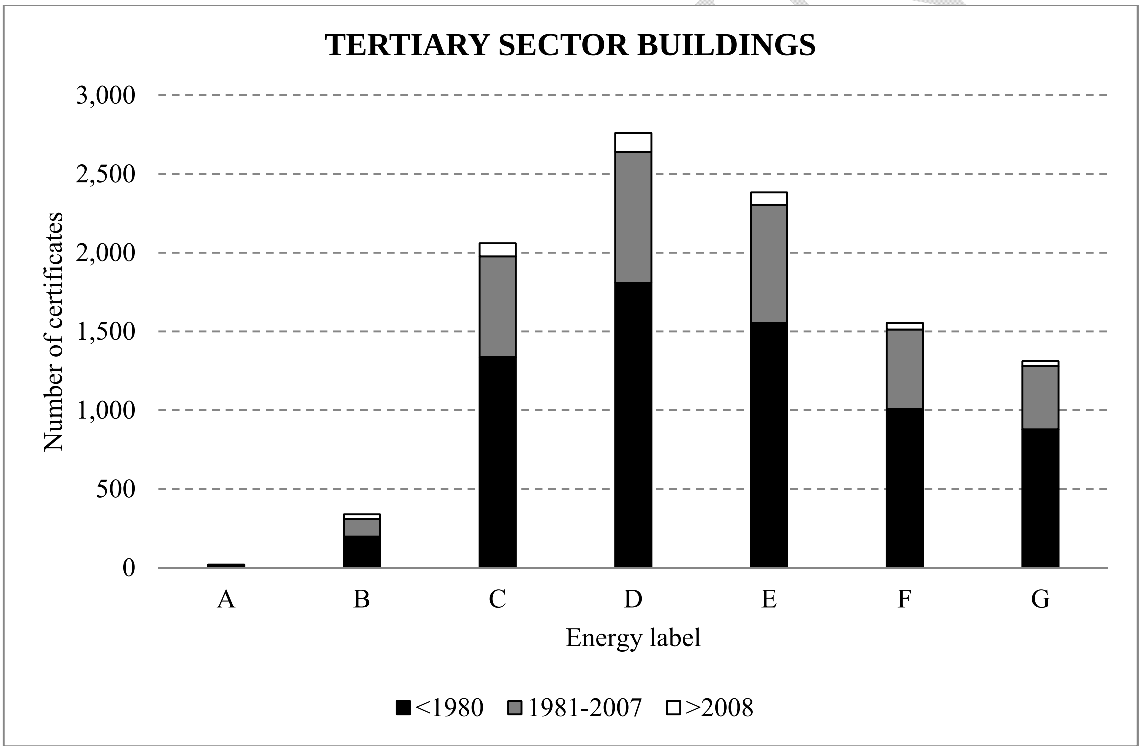

Figure 8. Number of energy performance certificates issued for tertiary sector buildings according to the construction period in Catalonia.
Source: drawn up by the authors using data from the ICAEN database, March 2014.

The consumption of tertiary sector buildings oscillated between 212.6 (mildest climate zone in winter [B3], after 2008) and 503.4 kWh_p/m^2 (coldest climate zone in winter [D3], before 1980) (Figure 6). In tertiary sector buildings, 38.3% of the total energy consumption was for heating. A similar percentage was attributed to the lighting system (37.2%), whereas the rest of the energy was consumed for cooling (13.3%) and the hot water system (11.1%) (Figure 7). Newer buildings consumed less energy for lighting, as they used more efficient systems (from 137.7 kWh_p/m^2 to 53.2 kWh_p/m^2). The energy consumption for heating and cooling purposes was also lower in new tertiary sector buildings (Table 7). The energy consumption for heating was higher in buildings located in the coldest area (199.2 kWh_p/m^2 in the D3 climate zone). As in the case of residential buildings, there was no clear relationship between the energy consumed for cooling and the climate zone (Table 8).

Retrofitting of buildings is one of the main challenges to promote building energy efficiency (Li and Shui, 2014). The results obtained in this research allow energy conservation efforts to be prioritized according to building type, construction period, climate zone and specific end-uses, and can be useful when planning financial incentives and subsides to further encourage homeowners to implement energy-efficient refurbishment measures (Stieß and Dunkelberg, 2013). The results can also help refurbishment contractors and companies to identify the most attractive market segments for energy services, especially within the residential sector (Labanca et al., 2015). The largest energy saving potential is associated with single-family houses erected before 1980 and located in the coldest zone in winter (D3), as these buildings consume the most energy (490.2 kWh_p/m^2), followed by other single-family houses from the same period located in the warmest climate zone (B3) (408.6 kWh_p/m^2). Single-family houses erected during the 1981-2007 period located in the D3 zone should also be addressed, as they consume 281.9 kWh_p/m^2. Taking into account the high exposure of single family houses to outdoor temperature, adding extra insulation to building facades would significantly diminish current energy consumption ratios. Major interventions would include fixing insulation to the inner or outer surface of external walls. In single-family houses erected between 1981 and 2007, the insulation of cavity walls, increasing the thickness of existing insulation or changing the existing insulation for a different material with higher thermal performance would effectively contribute to achieving higher energy efficiency levels. Furthermore, window replacement, which is currently being funded by the Spanish government, would also lead to a reduction in the energy consumption of single-family houses. The replacement of existing boilers for heating and hot water generation by condensing boilers with high energy performance, and the replacement of existing air conditioning systems by highly efficient variable flow heat pumps are also expected to increase energy efficiency. Space requirements related to the installation of biomass boilers or solar thermal collectors do not prevent single-family houses from adopting these renewable energies. Although they do not reduce the energy demand of single family houses, they provide a unique opportunity to reduce the generation of CO_2 emissions.

Multi-family blocks and individual dwellings in multi-family blocks built before 1980 in the coldest climate zone (D3) should also be prioritized, as their energy consumption stands at 467.7 and 340.0 kWh_p/m^2, respectively. Apartments in the warmer climate zone (B3) erected before 1980 (324.6 kWh_p/m^2 in multi-family blocks and 279.2 kWh_p/m^2 in individual dwellings in multi-family blocks) should be addressed in second place. In this case, all the homeowners in a block must agree to upgrade the building envelope. The most exposed units (such as those under the roof or those with the most exterior walls) will benefit more from an upgrade of the roof, but the refurbishment cost will be equally shared by all the owners in the building. Thus, replacing windows and installing shading devices seems to be the easiest way to enhance the energy performance of individual dwellings. High energy performance condensing boilers and highly efficient variable flow heat pumps are also good options for reducing the energy consumption of apartments.

It is important to highlight that ownership is a key factor in the implementation of energy conservation measures. Taking into account that most energy conservation measures do not entail an immediate investment return, tenants are often reluctant to finance energy renovations. Similarly, the investor-user dilemma hinders the implementation of energy-related refurbishments in rented properties.
Non-residential buildings erected before 1980 and located in the D3 zone have the greatest energy saving potential, as they consume the most energy (503.4 kWh_p/m^2). They are followed by non-residential buildings erected in the B3 climate zone in the same construction period (468.3 kWh_p/m^2). As already envisaged by Choudhary et al. (2012) and Howard et al. (2012), non-domestic buildings show a large variability in terms energy consumption due to their inherent complexity and heterogeneity and thus, cases should be examined individually before suitable energy conservation measures are recommended.

4. CONCLUSIONS

As buildings tend to have long lifespans and there is currently low turnover in the sector, new building codes are not expected to have a significant impact on the building stock as a whole in the short- and medium-term. Thus, to maximize the energy saving potential of the building sector, we must focus on the existing building stock. To do this effectively, we must first understand the energy efficiency of this stock. In this context, energy performance certificates and their corresponding registers are key policy instruments to foster greater overall energy efficiency.

This study investigated the energy performance of residential and tertiary sector buildings through a statistical analysis of almost 130,000 energy performance certificates collected in Spain since the entry into force of regulations on the energy certification of existing buildings. The sample represents approximately 20% of the energy performance certificates currently issued in Spain. In general, most of the buildings showed a poor energy performance profile. E class was the most predominant energy label within certified residential buildings or building units (53.6%), followed by G class (25.9%) and F class (10.1%). Tertiary sector buildings had slightly better energy performance. In this case, the predominant label was D class (26.4%), followed by E class (22.8%) and C class (19.8%). The current percentage of certified buildings or building units (around 6-8%) is expected to increase in the next few years. However, the percentages of different labels are not likely to vary greatly within the current context of economic recession if energy saving measures in existing dwellings are not extensively promoted and partially funded.

This research mainly contributes to defining the current energy consumption baseline of existing residential and tertiary sector buildings in Spain. For the first time, the findings provide an insight into the energy performance of existing buildings in Spain, and can be extrapolated to a wider building stock including other southern European countries, which account for 36% of the total stock in Europe (Buildings Performance Institute Europe, 2011). The results of this study also have direct implications for governments setting future energy policies related to refurbishment, including funding mechanisms, future revisions of building regulations and codes, public awareness programs, etc. Reliable information on the performance of national building stock can be used to prioritize energy conservation measures according to spatial geography, building type, construction period and specific end-uses. Construction practitioners can also benefit from the research results, as there is currently a lack of information in this area. Refurbishment contractors and companies providing energy services can use the data to help identify market segments and business strategies.

Old buildings consume more energy as they do not meet the energy performance requirements stated in current thermal building regulations. Buildings or building units located in hotter climate zones consume slightly less energy than those located in colder climate zones, mainly because most energy is used for heating (around 70-75% in residential buildings). Single-family houses use on average more energy than individuals dwellings, because they are usually more exposed to outdoor temperature. This difference was even greater in single-family houses that are thermally unprotected (built before 1980). In tertiary sector buildings, the heating system used 38.3% of the energy consumption, whereas the lighting system accounted for 37.2%. The energy efficiency of lighting systems was found to be significantly better in new tertiary sector buildings.

Further research should consider the complexity and heterogeneity of buildings in the tertiary sector, as this may lead to significant differences in average primary energy consumption. In order to obtain a more accurate picture of energy consumption in tertiary sector buildings, major end-uses and variations in usage patterns and energy intensities should be taken into account. The development of visualization strategies based on a geographic information system (GIS) could also be useful to show the results geographically. Users' behaviour should also be explored, as it may play a significant role in the energy bill. Finally, in order to effectively assess the energy consumption of the building sector, embodied energy should be taken into account, as it constitutes a large share of the life-cycle energy consumption of buildings.

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