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# A tool for verifying energy performance certificates and improving the knowledge of the residential sector: A case study of the Autonomous Community of Aragón (Spain)

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ABSTRACT

The analysis of energy performance certificates is one method of better understanding the current constructive reality of the building stock and of generating knowledge that is applicable to energy planning in the residential sector. The objective of this study is to develop a correction algorithm for energy performance certificates to assess the residential building stock of a country by region. The selected case study of the Autonomous Community of Aragón aims to advance the energy and environmental assessment of the residential building stock of climate zones with temperate and cold winters in Spain. The results reveal that 49.71% of the energy performance certificates in Aragón contain incorrect information. Additionally, the average primary energy consumption varies between 203.9 kWh/m$^2$·year and 282.0 kWh/m$^2$·year based on the climate zone, and the associated emissions vary between 44.1 kg $CO_2$/m$^2$·year and 63.6 kg $CO_2$/m$^2$·year. In addition to highlighting the differences between urban and rural areas, the obtained results are compared to published results of similar studies in other Autonomous Communities. This study serves as a basis for outlining optimal future energy and environmental scenarios, wherein public administrations can promote measures for energy rehabilitation and improve energy savings and efficiency.

## 1. Introduction

The European Union's main legislation covering the reduction in the energy consumption of buildings consists of the 2010 Energy Performance of Buildings Directive (European Union, 2010) and the 2012 Energy Efficiency Directive (European Union, 2012). An energy performance certificate (EPC) is obligatory for buildings and houses upon their rental or sale, and all new buildings must be nearly zero-energy buildings by 2020. The different Member States of the European Union must also establish minimum requirements for the energy efficiency of buildings and, through national action plans for energy efficiency, outline building renovation strategies in the long term. Currently, the European Commission has the goal of promoting the use of smart technology and simplifying existing standards (European Commission, 2016).

Each Member State has adapted and implemented the Energy Performance of Buildings Directive (Andaloro, Salomone, Ioppolo, & Andaloro, 2010). Spain, for example, through the Basic Document for Energy Savings in the Technical Building Code (CTE-DB-HE) (Spanish Ministry of Housing, 2006), has established obligatory energy requirements for newly constructed buildings and for building rehabilitation. Royal Decree 235/2013 (Spanish Ministry of the Presidency, 2013) approved the basic procedures for developing energy performance certifications for buildings. Compliance has been obligatory since June 1, 2013, although it was voluntary prior to this date. In Spain, the different Autonomous Communities are responsible for the evaluation, control, and registration of EPCs.

The primary energy consumption and $CO_2$ emissions of the residential sector can be determined based on the data contained in the EPCs (Pérez-Lombard, Ortiz, González, & Maestre, 2009). Numerous energy-related studies have been performed in different countries in southern Europe. Panayiotou et al. (2010) and Fokaides, Maxoulis, Panayiotou, Neophytou, and Kalogirou (2011) evaluated improvements in the primary energy consumption of the building stock in Cyprus resulting from the implementation of the Energy Performance of Buildings Directive, and Fokaides, Christoforou, and Kalogirou (2014)

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outlined possible future scenarios. In addition, the residential building stock of Portugal was characterized based on its EPC database, and the corresponding energy demand was evaluated by Magalhães and Leal (2014). Furthermore, Dall'O', Sarto, Sanna, Tonetti, and Ventura (2015) demonstrated the use of EPCs to create indicators for regional energy planning in the Lombardy Region of Italy. Florio and Teissier (2015) analyzed the primary energy consumption of the residential building stock of France. Similarly, in Greece, the national EPC database was used to understand and analyze the energy profile of the building stock (Dascalaki, Kontoyiannidis, Balaras, & Droutsa, 2013); an additional study on the primary energy consumption and $CO_2$ emissions of the residential building stock was performed with EPC data (Droutsa, Kontoyiannidis, Dascalaki, & Balaras, 2016). Droutsa, Kontoyiannidis, Dascalaki, and Balaras (2014) used energy conservation measures proposed in the EPCs to evaluate the energy cost, possible savings and rehabilitation scenarios applicable to the building stock. Finally, in Spain, the primary energy consumption of the building stock was studied in the Autonomous Community of Cataluña (Gangolells, Casals, Forcada, MacArulla, & Cuerva, 2016), as was the primary energy consumption and $CO_2$ emissions in the residential sector of the Autonomous Community of La Rioja (López-González, López-Ochoa, Las-Heras-Casas, & García-Lozano, 2016a). The studies of Gangolells et al. (2016) and López-González et al. (2016a) were performed based on analyses of the available EPCs.

The quality of EPC data is important in studies and analyses of the residential sector (Ahern, Norton, & Enright, 2016; Mangold, Österbring, & Wallbaum, 2013). To ensure data quality, a method is needed to rapidly and reliably detect incorrect EPCs. Buratti, Barbanera, and Palladino (2014); Khayatian, Sarto, and Dall'O' (2016), and López-González, López-Ochoa, Las-Heras-Casas, and García-Lozano (2016b) developed algorithms with this objective. Buratti et al. (2014) defined an index using data extracted from the EPC records of buildings from the Umbria Region (Italy). The developed artificial neural network evaluated the global primary energy index based on the following data: degree days, heat transmission surfaces, the heated volume, the floor area, the use of buildings, types of heating and domestic hot water plants, fuels used, $CO_2$ emissions and the primary energy limit index for heating. Then, the declared and the calculated global primary energy indexes of the buildings can be used to verify the existing EPCs based on the proposed index. Khayatian et al. (2016) evaluated the heating energy demand indicator to validate self-declared EPCs in the Lombardy Region (Italy) using an artificial neural network. The floor area, surface area, building volume, thermal transmittance values, construction period and year, and winter degree days were used to develop the algorithm. In addition, in Spain, with the evolution of the CTE-DB-HE framework, the method of assigning climate zones, a key step in implementing EPCs, has been modified. Therefore, López-González et al. (2016b) developed several algorithms to verify and classify EPCs and then homogenize them for energy planning in the Autonomous Community of La Rioja (Spain). The registration date, building type, climate zone, municipality code, primary energy consumption and rating, and $CO_2$ emissions and rating from the EPCs were used in the developed algorithms. Following this procedure, these algorithms, including statistical treatments of the EPC databases, are improved in the present study.

The objective of this study is to develop a correction algorithm for EPCs to analyze the residential building stock of a country on a regional basis. In this case, the algorithm is applied to the Autonomous Community of Aragón in Spain. Then, an energy and environmental analysis of the residential building stock is performed with the goal of better understanding the existing residential building stock of Spain. This study is performed in Microsoft Excel and Matlab. The obtained results can be used by different countries to appropriately direct their efforts in energy planning policies and the rehabilitation of the residential sector. In this context, the main objective is to improve the energy efficiency of buildings and to reduce both the primary energy consumption and $CO_2$ emissions, thereby contributing to the objectives established in Europe by 2020 and 2030. The remainder of this paper is organized as follows. The methods followed are described in Section 2. Then, Section 3 presents the developed algorithm that is applied to EPCs in Aragón. The results obtained with the algorithm are detailed at the energy and environmental levels in Section 4 for the residential building stock of Aragón. Finally, Section 5 presents the most important conclusions.

## 2. Methodology

### 2.1. Baseline data

The data extracted from the EPC records of buildings from the Department of the Economy, Industry, and Employment of the Government of Aragón (Government of Aragón, 2016) were used in this study. In total, 36,072 EPCs from the residential sector, registered since Royal Decree 235/2013 (Spanish Ministry of the Presidency, 2013) came into effect on June 20, 2016, were analyzed. The information in these EPCs was entered into a Microsoft Excel file and was imported into Matlab for processing.

The following information was extracted from each EPC: the certificate number, date of registration, date of validity, building type (individual dwellings in multi-family blocks, multi-family blocks, and single-family houses), municipality, province (Huesca, Teruel, and Zaragoza), construction year, construction standards (Legislation prior to 1961 [ < 1961], Standards of the Ministry of Housing of 1961 [1961–1980], Basic Building Standards for Thermal Conditions of 1979 [1981–2007], and the Technical Building Code [ > 2007]), living space (in $m^2$), primary energy consumption (in $kWh/m^2 \cdot year$) and rating (scored from A to G, with A being the best score and G the worst), and $CO_2$ emissions (in $kg\ CO_2/m^2 \cdot year$) and rating (scored from A to G, with A being the best score and G the worst).

Table 1 shows the number of baseline EPCs used to calculate the primary energy consumption and $CO_2$ emissions by building type and rating obtained. Because the EPCs do not include the climate zone, this information must first be determined, given that climate zone data are

**Table 1**
Number of EPCs for primary energy consumption and $CO_2$ emissions by building type and rating obtained, extracted from the EPC Government records for buildings in Aragón (Government of Aragón, 2016).

| | | Primary energy consumption rating | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ emissions rating | Null | A | B | C | D | E | F | G |
| Individual dwellings in multi-family blocks | A | | 4 | 1 | 3 | 7 | 10 | 1 | 11 |
| | B | 6 | 1 | 35 | 13 | 4 | 22 | 3 | 8 |
| | C | | | 7 | 462 | 196 | 31 | 4 | 9 |
| | D | 6 | | 3 | 37 | 2736 | 1150 | 13 | 12 |
| | E | 6 | | 1 | 5 | 232 | 16,310 | 1215 | 80 |
| | F | 1 | | | 1 | 5 | 1065 | 1460 | 984 |
| | G | | | | 2 | 6 | 29 | 459 | 5488 |
| Multi-family blocks | A | | 1 | | | | 1 | | |
| | B | 1 | | 6 | 1 | | | | |
| | C | 1 | | 4 | 55 | 4 | | | 2 |
| | D | | | | | 40 | 23 | | 1 |
| | E | | | | | 1 | 216 | 14 | |
| | F | | | | | | 20 | 22 | 8 |
| | G | 2 | | | | | 1 | 7 | 89 |
| Single-family houses | A | 1 | 5 | 4 | | 7 | 6 | 1 | 5 |
| | B | 1 | | 32 | 6 | 3 | 7 | | 3 |
| | C | 2 | | 3 | 161 | 42 | 12 | 1 | 6 |
| | D | 1 | | | 15 | 377 | 127 | 4 | 9 |
| | E | 1 | | | | 45 | 1246 | 79 | 16 |
| | F | | | | | | 243 | 244 | 23 |
| | G | | | | | | 15 | 168 | 487 |