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Policy Perspective

Heating demand as an energy performance indicator: A case study of buildings built under the passive house standard in Spain

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ABSTRACT

This paper aims to identify more simplified and appropriate energy performance indicators (EPIs) for residential buildings during their operational stage. The Spanish Energy Performance Certification methodology is used to evaluate the energy performance rate (EPR) of a selected sample of Passive House (PH) buildings. Results of the study indicate: all the certified PH buildings analyzed are nearly zero-energy buildings (NZEBs) under the Spanish certification system; disaggregate indicators (particularly heating and cooling demand), appear to be suitable EPIs for comparing buildings among different certification schemes and labels; the new Technical Building Code (TBC) offers greater flexibility in terms of creating NZEBs than previous laws, having the advantage that it involves very different (albeit closely linked) economic sectors, and represents a step forward in accomplishing the NZEB goal, and a clear boost to the renewable energies and energy efficiency in the Spanish building sector. However, it only states aggregate EPIs as limiting values, which may alter competition between different energy carriers/solutions. On the other part, the requirement level of the new TBC in relation to energy demand still needs to be verified. Moreover, the use of aggregate EPIs does not necessarily pave the way towards the “passive building” concept.

1. Introduction

According to the United Nations Framework Convention on Climate Change (UNFCCC), signed by 154 countries (Rio de Janeiro, 1992), the signatory countries voluntarily committed themselves to reducing their greenhouse gas (GHG) emissions to reasonable levels in future years. Building sector emissions grew from 2.5 $GtCO_{2eq}$ in 1970 to 3.2 $GtCO_{2eq}$ in 2010, and the major contribution to building emissions still came from Organization for Economic Co-operation and Development (OECD) countries. Within the European Union (EU), buildings account for approximately 40% of the EU’s final energy consumption, therefore efforts should focus on the design phase, considering buildings as smart, low or nearly zero-energy buildings (NZEB) (European Commission, 2011a, 2011b, 2017, 2011a).

Efficiency indicators relate the output to the resource required to generate that output (such as time, money and manpower) (de Wilde, 2018). Energy efficiency is related to doing more with the same amount of energy (Abu Bakar et al., 2015; Haas, 1997). However, energy efficiency is only one of the performance aspects of buildings (de Wilde, 2014). Indeed, the term building performance analysis is complex and could mean a number of different concepts (de Wilde, 2018; Geraldi and Ghisi, 2020). Building energy performance is defined as the amount of energy needed to meet the energy demand associated with a typical use of the building which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting (European Commission, 2016). It is usually related to the amount of energy consumed to provide adequate environmental quality and to satisfy the buildings’ functions (Geraldi and Ghisi, 2020). As affirmed by several authors, common values for factors that define building energy performance do not yet exist in the international framework (D’Agostino and Mazzarella, 2019; de Wilde, 2018; Rodríguez-Soria et al., 2014).

1.1. *Aggregate and disaggregate energy performance indicators and energy performance rates*

Many different methods and indicators have been proposed to monitor and evaluate the energy performance of buildings (Abu Bakar et al., 2015; D’Agostino and Mazzarella, 2019; David et al., 2014; de Wilde, 2018; Ecofys, 2014; Geraldi and Ghisi, 2020; Hwang et al., 2020; Kim et al., 2019, 2019; Pérez-Lombard et al., 2009; Reuter et al., 2020; Rodríguez-Soria et al., 2014; Velasco-Fernández et al., 2020; Yoon and

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Acronyms

DHW	Domestic hot water
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EEI	Energy Efficiency Index
EPI	Energy Performance Indicator
EPL	Energy Performance Label
EPR	Energy Performance Rate
EU	European Union
EUI	Energy Use Intensity
GHG	Greenhouse Gas
HVAC	Heating, ventilation and ai-conditioning system
NZEB	Nearly Zero-Energy Buildings
Cnrpe	non-Renewable Primary Energy Consumption
OECD	Organization for Economic Co-operation and Development
PH	Passive House
PHPP	Passive House Planning Package
PER	Renewable Primary Energy
C_{pe}	Primary Energy Consumption
PER	Renewable Primary Energy
TBC	Technical Building Code
UNFCCC	United Nations Framework Convention on Climate Change

Park, 2017). Good reviews of existing methods for undertaking energy performance analyses can be found in Abu Bakar et al. (2015), Geraldi and Ghisi (2020) and de Wilde (2018). According to different authors, it is, however, surprising how little discussion exists today about the usefulness or appropriateness of energy performance indicators (EPIs) for measuring the energy performance of buildings (David et al., 2014; Kim et al., 2019; Yoon and Park, 2017).

A distinction can be made between aggregate and disaggregate EPIs. According to Kim et al. (2019), an aggregate EPI is where different end-uses (such as heating, cooling and lighting), are combined into one (Kim et al., 2019). Furthermore, the inclusion of other parameters (such as the type of technical heating or cooling systems), could also be considered to distinguish between aggregate and disaggregate EPIs (e.g., heating demand, which is a disaggregate EPI, versus heating consumption, which is an aggregate EPI). As Ferrari and Zanotto (2016) explained, to adequately assess the final energy consumption of a building (i.e., aggregate EPI), the specific thermal efficiencies of the heating and cooling systems have to be considered after calculating the building's heating and cooling needs. Subsequently, in order to summarize the different energy sources involved in the building's overall heating and cooling processes, all the final energy consumption values (both fuel and electricity-based), have to be converted into primary energy values[1] (Ferrari and Zanotto, 2016, p. 121). The energy demand of a building (i.e. aggregate EPI) is the useful energy needed to maintain the comfort conditions inside the building, and can be divided into energy demand for heating, cooling, domestic hot water (DHW) and lighting (i.e., disaggregate EPIs), and expressed in [kWh/(m^2y)], considering the useful floor area of the building's habitable spaces (Spain, 2013a). The energy consumption in buildings is largely dominated by the heating, ventilation and air-conditioning system (HVAC), followed by lighting (Abu Bakar et al., 2015; de Wilde, 2018). In the EU residential sector, 67% of energy consumption results from space heating, 13% from water heating, and 0.4% from space cooling (Las-Heras-Casas Jesús et al., 2021), while the cooling energy demand of EU buildings is concentrated in Southern Europe (particularly in Italy, Spain, Greece, and Portugal) (Ferrari and Zanotto, 2016; Las-Heras-Casas Jesús et al., 2021). Even if still residual, some authors outline the rising importance of cooling consumption in future climate change scenarios (Bienvenido-Huertas et al., 2021; Larsen et al., 2020). Therefore, heating (and also cooling demand, especially in certain Southern regions), could be considered essential disaggregate indicators for measuring the energy performance of buildings. By way of example, in Bosnia and Herzegovina, the indoor air temperature is the only parameter used to determine thermal comfort and internal air quality, and the energy need for heating is the only indicator currently used to determine the energy efficiency of buildings (Gajić et al., 2019).

Among the most commonly used aggregated EPIs is the energy use intensity (EUI) (i.e., total annual energy consumption divided by gross floor area) (Kim et al., 2019; Yoon and Park, 2017). As noted by Kim et al. the problem with the EUI as an EPI is that it only provides a rough indication of energy performance. The quantity of end-uses (at least heating, cooling, and hopefully others) should be known in order to make the results more indicative, (Kim et al., 2019). The energy efficiency index (EEI) (i.e., the ratio of the energy input to the factor related to the energy using component), is also mentioned as being a fundamental EPI when it comes to measuring energy performance in buildings (Abu Bakar et al., 2015). However, this EPI could be considered both aggregate and disaggregate, depending on how the building's level of efficiency is measured.[2] In Spain, the "global indicators"[3] for obtaining the Spanish energy performance certificate (EPC) are the annual CO_{2e} emissions and the annual non-renewable primary energy consumption (C_{nrpe}) (IDAE, 2015) (i.e., aggregate EPIs).

A building energy rating is expressed through several indicators, used to explain the reasons for good or bad energy performance of the building, and to provide useful information on the aspects to be taken into account when proposing recommendations to improve such performance (IDAE, 2015). The building's energy performance rate (EPR) is determined based on its calculated or actual energy use, reflecting the typical energy use of the building (including its space heating, space cooling, domestic hot water, ventilation, built-in lighting and other technical building systems) (European Union, 2018). The energy performance of a building is commonly expressed through indicators, indices and ratings/letters using a conventionally determined scale (usually on an annual basis). This scale varies from greater to lesser efficiency and determines the building's energy performance level (IDAE, 2015). In order to calculate a building's EPR, an adequate EPI should be selected (European Union, 2012). The expression "energy rating system" may be used as an equivalent of the building energy classification (i.e., a method for assessing energy quality), while "building energy labeling", which is the determination of a building's energy performance class (or label), requires the development of a scale related to the labeling index (Pérez-Lombard et al., 2009).

1.2. Nearly zero-energy buildings, energy efficiency and certification system in Spain and the passive house system

Building energy efficiency requirements in the EU are provided for in Articles 4, 5 and 6 of Directive (2002)/91/EC on energy efficiency,

[1] It should be noted that, for electricity consumption in particular, the corresponding primary energy use may vary significantly depending on the mix of electricity generation sources in the country concerned.

[2] For example, see Section *2.2.*, where the EEI is used as a disaggregate EPI.

[3] The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (Ministerio para la Transición Ecológica y el Reto Demográfico, 2019). Therefore, this global indicator can be considered as a synonym of the aggregate indicator.

subsequently transposed into Spanish national law through the Spanish Technical Building Code (TBC) (Spain, 2006). The adoption of Energy Performance of Buildings Directive (2010)/31/EU (now EPBD recast) (European Union, 2010) led to the TBC being updated by means of Order FOM/1635/2013, September 10 (Spain, 2013a), later amended by Order FOM/588/2017 (Spain, 2017). The EPBD recast represents the fundamental legislation aimed at promoting improved energy performance of buildings within the EU framework (European Union, 2010). It is subsequently reinforced by Directive (2012)/27/EU on energy efficiency (European Union, 2012), and amended by Directive (2018)/844 on the energy performance of buildings (European Union, 2018) (López-Ochoa et al., 2021). The EPBD recast requires all new buildings in the EU to be NZEB by 2020. An NZEB is defined as a very energy efficient building, where, insofar as possible, the low amount of energy required should be covered by energy coming from renewable energy sources (European Commission, 2016; European Union, 2010). However, EU legislation does not provide any specific EPIs to determine the EPR of buildings in a harmonized way, nor does it provide any specific quantitative limit for the maximum energy demand that NZEBs have to achieve. Instead, Member States are at liberty to establish their own energy performance certification system and indicators (Martínez-de-Alegría et al., 2016). To date, no common definition of the NZEB concept exists in the EU (BPIE, n.d.). As explained by Wells et al. (2018), the NZEB is a confusing concept that can be used to describe a building with very different characteristics (e.g., a building with equal energy generation to usage; with very low energy demands; with energy costs of zero or a building with net-zero GHG emissions) (Wells et al., 2018). According to Spanish legislation, an NZEB is a new building that meets the requirements established in various sections of the TBC[4] (Spain, 2017). In 2019, a fundamental amendment of this TBC was issued through Royal Decree 732/2019 (Spain, 2019a).

When comparing the Spanish certification system and the passive house (PH) system, it is crucial to distinguish between a label and a certification. A “label is any claim made on a product”, which may or may not be regulated by a government agency. By contrast, a certification is a label that can only be used if a product meets those standards set and regulated by a government agency (i.e., all certifications are labels, but not all labels are certifications) (Choi, 2014). According to this definition, an example of an energy performance label (EPL) is the certificate issued by the Passive House Institute (PHI), which is an independent research institute founded in Germany (PHI, 2018a). The PH concept is based on heat loss reduction, which is achieved through an efficient heat recovery system, high thermal insulation and a raised thermal capacity of the envelope (in order to keep the energy inside) (Feist et al., 2005; Tabatabaei Sameni et al., 2015). These types of buildings offer high living comfort (with around 15%–20% of the space-heating-demand compared to conventional new buildings), while the extra costs only increase building costs by about 10% (Schnieders and Hermelink, 2006). Several studies have also suggested different improvement strategies to mitigate the overheating problems detected in such buildings (Figueroa et al., 2021). In any event, this standard has frequently been proposed as a proxy of the NZEB under the definition stated by the EPBD recast (Consoli et al., 2017; Guillén-Lambea et al., 2016), and has been also considered by the European Commission as a first step towards the NZEB concept (Atanasiou, 2011).

A fundamental policy tool for promoting energy efficiency in EU buildings is the EPC (European Union, 2003). In 2010, the EPBD recast reinforced the role of EPCs, meaning EPCs have to include a building’s energy performance (including reference values, such as minimum energy performance requirements), with the aim of making it possible to compare and assess its energy performance. The EU legislation on EPCs is partially transposed into Spanish legislation through Royal Decree 235/2013 (Spain, 2013b). This Royal Decree approves the procedure for certifying energy efficiency in both new and existing buildings.

The objective of this paper is to deepen the search for EPIs that improve the comparison of energy performance assessments for residential buildings during their operational stage. The analysis is based on a sample of PH buildings, and uses the disaggregate EPI for heating demand to make a comparison between the Spanish certification system (whose target is to achieve NZEB as per the EPBD Directive), and the PH system, with the aim of obtaining a “passive building” (i.e., to reduce a building’s energy demand as far as possible). Additionally, a review of the current TBC has been undertaken, focusing on the main changes established as regards the EPIs for measuring the energy performance of residential buildings. The rest of the article is organized as follows: Section 2, Methodology; Section 3, Results; and finally, Section 4, Conclusions.

2. Methodology

The present study is based on a sample of 69 Spanish buildings from the Passive House Institute database (PEP, 2017). Note that not all buildings contained in the sample have a PH certificate (i.e., 45% are certified and 55% are non-certified buildings). This sample has been supplemented and checked with data from the database on the Spanish Passive House Platform (*Plataforma de Edificación Passive House*) (PEP, 2017). The final number of buildings contained in the sample is 71, from which 73% of the buildings selected are single-family detached homes (i.e., 62 buildings), and the rest are non-residential buildings. Considering the limited number of non-residential buildings included in the sample, as explained in section 2.1.3., the study as regards the calculation of the EPR has been limited to new residential buildings.

In the following section (Section 2.1), certain methodological differences are highlighted between the two systems under study, and the EPI selected is described. In Section 2.2., the methodology to calculate the EPR for the buildings selected under the Spanish certification system is described. Taking into account that the buildings under study have been built before 2018, the legislation considered to estimate the EPRs has been the former one (Spain, 2006, 2013b). As mentioned, in 2019, substantial modifications were made as regards the use of EPIs in this Spanish law. Section 3.2 analyzes the main novelties in Royal Decree 732/2019, amending the TBC for residential buildings that affect those EPIs (Spain, 2019a).

2.1. Methodological differences of the certification systems under study and selection of the energy performance indicator

2.1.1. Differences between the energy performance indicators under the two certification systems

As mentioned above, the “global indicators” for calculating the EPR according to the Spanish Certification System are: the annual CO_{2e} emissions and the annual non-renewable primary energy consumption (C_{nrpe}). The Spanish TBC states that, in the case of residential building interiors, these global or aggregate indicators include the impact of heating, cooling, production and distribution services (i.e., the lighting service is excluded) (Spain, 2013b, 2019a, 2019a). According to former law, the “complementary” indicators for residential buildings were (IDAE, 2015; Spain, 2013b):

i) the annual energy demand for heating;
ii) the annual energy demand for cooling;
iii) the annual consumption of non-renewable primary energy disaggregated by services;
iv) the annual CO_{2e} emissions disaggregated by services;

[4] To be considered an NZEB, on average, the annual consumption of residential buildings ≤60 kWh/m^2 [kWh/(m^{2}y)] of total primary energy and ≤30 kWh/m^2 [kWh/(m^{2}y)] of non-renewable primary energy (Ministerio de Transportes Movilidad y Agenda Urbana and Ministerio de Ciencia e innovación, 2020).

v) the annual CO_{2e} emissions disaggregated by electricity consumption and by other fuels.

As regards the PH system, different categories of buildings can be found. The categories Passive House Classic, Plus or Premium can be achieved depending on the primary energy renewable (PER) demand and generation of renewable energy, where all electricity uses that are within the thermal building envelope are taken into account in the energy balance (including lighting). All the categories cited must fulfill the following 5 criteria: i) heating and ii) cooling demand (+dehumidification contribution$^{)}$: ≤15 [kWh/(m^{2}y)] (as alternative criteria: heating & cooling load ≤10 W m^2); iii) Pressurization test result n50: ≤0.6 [1/h]; iv) The "global indicator" (i.e. the Renewable Primary Energy (PER) demand (i.e., the total energy to be used for all domestic applications: heating, hot water and domestic electricity) ≤ (60, 45, 30 [kWh/(m^{2}y)] for classic, plus, premium, respectively); v) Renewable energy generation: ≥ (-, 60, 120 [kWh/(m^{2}y)] for classic, plus, premium, respectively) (for more details, see PHI, 2016).

Table 1 shows the energy consumption in the residential sector broken down by use. As illustrated, the highest consumption corresponds to the heating demand, which accounts for approximately 44% of the total energy consumption, followed by lighting and domestic appliances, which account for around 30% of the total.

Bearing in mind that heating is the largest single end-use within buildings (currently accounting for 42 EJ (36%) of total building energy consumption (International Energy Agency (IEA), 2019)), and that this service is also the largest energy consumer in the set of services and equipment available in Spanish residential buildings, it has been chosen as the most suitable EPI for this case study.

2.1.2. Differences as regards the external requirements

The external requirements used to calculate EPIs are not harmonized between the two systems under study. These external requirements refer to the calculation methodology of the climate zones where the buildings are located. In the case of the PH system, the climate zone is currently determined through the Passive House Planning Package (PHPP), which is based on an individual climate data set. Within this system, seven climate zones are established for all the countries, which establishes certain performance levels for building elements, e.g., U-values for windows and doors and carpentry in refurbishments depending on the zone (PHI, 2018b, 2015).[5] In any case, this analysis considers the climate zones specified by the Spanish TBC (see Section 2.2. for details). Although different studies have shown the wide disparities that exist as regards the climate zones and the heating and cooling demand in different regions of Spain (Bienvenido-Huertas et al., 2021), the present study does not take these disparities into account.

Table 1
Energy consumption in the residential sector broken down by use (GWh) in 2017.

Type of use	2017 (GWh)	%
Heating	76	44.47045056
domestic hot water (DHW)	30.5	17.84669397
lighting and appliances	51.5	30.13458163
Kitchen	12.9	7.548273844
Total	**170.9**	**100**

Source: (Ministerio de Transportes Movilidad y Agenda Urbana, 2020)

2.1.3. Differences as regards the thermal comfort and building uses

Different models are available for evaluating thermal comfort. However, today there is no absolute value that defines thermal comfort (Figueroa et al., 2021). The range of temperatures that determine the comfort conditions of residential buildings are not harmonized between the two systems under study. Spanish legislation considers a range between a minimum of 17 °C and a maximum of 27 °C, depending on the time of day and season (Spain, 2013a). The comfort conditions used by the PHPP system to estimate the heating demand are within a range of 20 °C in winter and 25 °C in summer, 24 h a day (PHI, 2018b, 2017). Given that the PH system is more demanding, it seems more practical to use data from the PH database and then load the corresponding EPR in accordance with Spanish legislation.

There is also a number of differences as regards different building uses (e.g., residential and non-residential) and building types (single buildings and blocks and new/existing/refurbished buildings). Only new buildings have been considered in the present study (more details in Section 2.2).

2.2. Calculation of the energy performance rate and energy performance certificates

In Spain, the energy performance certification of a finished building (or part of it) is the process of verifying EPR conformity, which is obtained by comparing the building project with the finished building (or part of it), leading to an EPC being issued for the finished building (Spain, 2013b). Since January 14, 2016, only EPCs produced using the latest updated version of the unified tools LIDER-CALENER (HULC) (as the general method), CE3, CE3X or CERMA (as simplified methods) have been accepted by the Registries in the Spanish Autonomous Communities. Since July 5, 2018 energy efficiency certificates produced using the latest updated version of CYPETHERM HE Plus, SG SAVE and CE3X Complement for new buildings have also been admitted by these Registries (Spain, 2019b). All the documents recognized are considered equivalent for energy certification, although, in certain cases, there may be as much as a 26% difference when determining CO_2 emissions (Carpio et al., 2015).

As regards the Spanish building certification system, the first provision of Royal Decree 235/2013, states that since June 1, 2013, it is mandatory to issue an EPC for the purchase/sale/rental of new and existing buildings. The corresponding energy efficiency class is assigned in these certificates, taking into account the annual CO_{2e} emissions and the annual non-renewable primary energy consumption (C_{nrpe}). For new buildings (i.e., buildings constructed after 2006), the scale, from highest to lowest efficiency, uses the ratings or classes A, B, C, D and E, extending up to ratings F and G for existing buildings (i.e., built prior to 2006) (IDAE, 2015). As our sample of buildings contains buildings constructed or refurbished from 2009 onward, all the buildings (new and refurbished) have been considered new buildings, in accordance with the Spanish certification system. The procedure to obtain the EPR for new buildings in accordance with the Spanish certification system is as follows: the EPR value (in our case C_1) sets the limits for the different energy rating scales for new buildings (i.e., built since 2006). C_1 is defined for the heating demand variable by equation (1) (IDAE, 2011a, 2012, 2015) (Note that for the calculation of the EPR of buildings from 2019 onwards, the novelties provided by the new TBC (Spain, 2019a) should be applied).

$$C_1 = \frac{\left(\frac{I_0}{I_r} R\right) - 1}{2\,(R-1)} + 0.6 \tag{1}$$

[5] In addition to complying with these values, the building energy consumption is calculated using the climate data that are reviewed and accepted by the PHI (which are those that appear by default in the latest version of the PHPP). A climate data tool makes it possible to search for the closest geographical climate data sets stored in the PHPP. "With this tool you can retrieve global climatic data (except for Antarctica) in the Passive House Planning Package (PHPP) format, which is based on satellite data obtained from NASA Langley Research Centre Atmospheric Sciences Data Centre POWER Project, assessed and formatted by the Passive House Institute" (PHI, 2018b, 2015).

where:

- C_1: Energy performance (qualification) index or energy performance rate (EPR) for buildings constructed since 2006. This depends on the boundary between the classes we are considering and is calculated based on the heating demand variable.
- I_0: Heating demand for the target building (I_{object}). The variable heating demand is determined by measuring the useful energy required to meet the building's annual energy demand. Data for I_0 are obtained from the Passive House Institute database (PEP, 2017).
- I_r: Energy indicator for the reference building ($I_{regulation}$). This is the average value of the selected indicator (i.e., heating demand) for the reference stock of new buildings (i.e., constructed since 2006) for private residential use (dwelling). The methodology and data for obtaining $I_r$can be consulted in (IDAE, 2015, 2009).
- Energy efficiency Indicator $= \frac{I_0}{I_r}$
- R: Dispersion of energy efficiency indicators. Data for R are obtained from (IDAE, 2015). This depends on the locality and concept (i.e., heating demand) to be evaluated.

Considering several assumptions and normalizations, the limits of the scale (which serves all indicators, all degrees of similarity, and all climates) in terms of C_1 for new buildings to obtain the corresponding EPC are:

Class A if $C_1 < 0.15$.

Class B if $0.15 \leq C_1 < 0.50$.

Class C if $0.50 \leq C_1 < 1.00$.

In order to obtain R for each building, its specific climate zone has to be determined. There are different methods for obtaining the climate zone of each building (e.g., they can be obtained directly from the software proposed by the Spanish government for obtaining the energy certificate for each building, i.e., LIDER-CALENER (HULC), CE3, etc.). For this study, data on altitude are obtained from Google Earth (Google, 2017). Data on town population sizes are obtained from (INE, 2017).

The Spanish TBC defines twelve climate zones based on winter climate severity (WCS), and summer climate severity (SCS). These WCS and SCS zones are calculated based on the number of days at the average temperature (based on 20 °C in summer and winter), calculated hourly and then divided by 24, and also the average accumulated overall insolation (measured in kW/m^2) for the corresponding period or number of sun hours. Climate zones for winter climate severity are identified by a letter: α, A, B, C, D, and E, ordered from lowest to highest severity. Climate zones for summer climate severity are identified by a number: 1, 2, 3, and 4, and are also ordered from lowest to highest severity (Gangolells et al., 2016; Spain, 2006, 2013a).

The usage profiles are those given in Appendix C of DB-HE Section HE1 of the TBC (DB-HE profiles) (Spain, 2013a) and they differentiate between residential and non-residential or tertiary use (all the non-residential buildings have been excluded from the present analysis). The Spanish system also distinguishes between single-family dwellings and blocks, as well as between buildings constructed before and after 2006 (IDAE, 2015, 2012, 2011b, 2009; Spain, 2013a).

As regards the PH system, although previously there were different criteria for residential and non-residential PH buildings (PHI, 2013b; 2013a), currently no distinction is made between the demand limit for residential or tertiary buildings (PHI, 2018b). To sum up, as our sample of buildings corresponds to buildings constructed or refurbished after 2009, they have been included within the category of new buildings according to the Spanish certification system. The energy demand of the buildings was calculated considering the thermal transmittance (i.e., the U-value, measured in W/m^2K) which, as explained, depends on the climate zone in which the building is located, and also on the different uses of the buildings (e.g., residential and non-residential) and type of buildings (single and block buildings).

3. Results and discussion

3.1. Energy performance rates and energy performance certificates of the selected buildings

Table 2 shows the annual primary and heating demand of the detached single-family houses in the selected sample (i.e., 73% of the sample). The specific space heating energy demand for new buildings varies from 1 to 39 [kWh/(m^2y)], with an average value of 12.59 [kWh/(m^2y)]. Two new detached single-family houses (i.e., 2.8% of the total) that did not conform with the aforesaid criteria were detected. These were two houses with a space heating demand of 23 and 39 [kWh/(m^2y)] (respectively), and they are both non-certified buildings according to the PH label. In the case of refurbished detached single-family houses, the space heating demand varies from 9 to 33 [kWh/(m^2y)], with an average value of 19.23.

The total primary energy requirement of new detached single-family houses fell within a range of 41–124 [kWh/(m^2y)], with an average of 92.04. Only one building did not fit the primary energy demand (or the space heating demand, as explained in the previous paragraph) criteria, however, it is also a non-certified buildings according to the PH label. In the case of refurbished buildings, the primary energy requirement varies from 51 to 84 [kWh/(m^2y)], with an average of 71.75 [kWh/(m^2y)].

Using the annual heating demand of each new building as an EPI, and considering i) its climate zone; and ii) the type of building (i.e. residential building block or single-family houses), then equation (1) is applied in order to obtain the EPR (i.e., C_1) for each building (see Table 3).

Considering the limits of the scale established under the Spanish system, the EPC of the residential buildings contained in the sample are shown in Table 3. The results illustrate that, out of the 62 buildings of the sample, only 5 buildings would obtain a “B label”, and the rest (i.e., around 92%) would obtain an “A label”. From the sample of new residential buildings (i.e., 53), only 2 buildings would obtain a B label. As expected, these are non-certified PH buildings.

Having calculated the EPR and EPC for the buildings selected, please note the following problems that have been identified:

✓ *There are significant differences in the external requirements for calculating the energy demand for buildings (i.e.,* the lack of harmonization of the method for determining the climate zones where the buildings are located). This problem has been already mentioned by many authors (Hermelink et al., 2013; Rodríguez-Soria et al., 2014; Salmerón et al., 2013; Walsh et al., 2017). As stated by Walsh et al. (2017), despite climatic zoning being an essential element of most building energy efficiency programmes, there is currently no single, widely-accepted scientific technique for determining it (Walsh et al., 2017). According to the report entitled ‘European climate zones and bio-climatic design requirements’, a uniform system for climate classification and climate design zones in Europe will be very useful.

Table 2
Average, minimum and maximum annual heating demand and primary energy requirements of detached single-family PHs in Spain.

Detached single-family PHs				
	Specific Space Heating Demand (kWh/m^2/year)			
		Average	Minimum	Maximum
	New-built (sample: 47 buildings)	12.59	1	39
	Refurbished (sample: 4 buildings)	19.23	9	33
	Specific Primary Energy Demand (kWh/m^2/year)			
		Average	Minimum	Maximum
	New-built (sample: 47 buildings)	92.04	41	124
	Refurbished (sample: 4 buildings)	71.75	51	84

Source: Own work based on data obtained from (PHI database 2017, PEP, 2017)

Table 3
Results on the energy Performance rate (EPR) of selected residential buildings (new and refurbished).

Certified	Region	City	Postal code	Climatic zone	TW*	BT**	Ir (single house)	Ir (block dwellings)	Io (kWh/m2y)	R (single house)	R (block dwellings)	C1	Calculated Label
No	La Rioja	Agoncillo	26160	D2	NB	DSFH	78		18	1.5	1.7	−0.05	A
Yes	**Valencia**	**Alicante**	**3724**	**B4**	**NB**	**DSFH**	**33.5**		**12**	**1.5**	**1.7**	**0.14**	**A**
No	Castilla y León	Arcones	40164	E1	R	DSFH	103.3		33	1.4	1.7	−0.09	A
Yes	**La Rioja**	**Arrúbal**	**26151**	**D2**	**NB**	**SDH**	**78**		**14**	**1.5**	**1.7**	**−0.13**	**A**
Yes	**Navarra**	**Azcona**	**31177**	**E1**	**NB**	**DSFH**	**103.3**		**14**	**1.4**	**1.7**	**−0.41**	**A**
Yes	**La Rioja**	**Baños de Río Tobia**	**26230**	**D2**	**NB**	**DSFH**	**78**		**15**	**1.5**	**1.7**	**−0.11**	**A**
No	Cataluña	Barcelona	8017	D2	R	TH	78		18	1.5	1.7	−0.05	A
No	País Vasco	Bilbao	48004	C1	NB	MFD	35.2	35.2	11	1.5	1.7	0.07	A
Yes	**Cataluña**	**Cantonigros**	**8569**	**E1**	**NB**	**DSFH**	**103.3**		**14**	**1.4**	**1.7**	**−0.41**	**A**
No	Castilla y León	Cármenes, León	24037	E1	NB	DSFH	103.3		15	1.4	1.7	−0.40	A
Yes	**Castilla y León**	**Carrión de los Condes**	**34120**	**E1**	**NB**	**DSFH**	**103.3**		**13**	**1.4**	**1.7**	**−0.43**	**A**
Yes	**Cataluña**	**Castelldefels**	**8860**	**C2**	**NB**	**DSFH**	**53.3**		**14**	**1.5**	**1.7**	**−0.01**	**A**
Yes	**Cataluña**	**Castellterçol**	**8183**	**D1**	**NB**	**DSFH**	**78**		**13**	**1.5**	**1.7**	**−0.15**	**A**
No	Cataluña	Cerdanyola del Vallès	8290	C2	NB	DSFH	53.3		1	1.5	**1.7**	**−0.37**	**A**
Yes	**Cataluña**	**Collsuspina**	**8178**	**E1**	**NB**	**DSFH**	**103.3**		**12**	**1.4**	**1.7**	**−0.45**	**A**
No	Asturias	Cudillero	33154	C1	NB	DSFH	53.3		14	1.5	**1.7**	**−0.01**	**A**
Yes	**País Vasco**	**Durango**	**48200**	**C1**	**R**	**MFD**	**35.2**	**35.2**	**16.01**	**1.5**	**1.7**	**0.28**	**B**
No	Andalucía	Escuzar	18130	C3	NB	DSFH	53.3			1.5	1.7	−0.40	A
Yes	Navarra	Ezcároz	31690	E1	NB	DSFH	103.3		17	1.4	1.7	−0.36	A
No	Islas Baleares	**Génova**	**7015**	**B3**	**NB**	**DSFH**	**33.5**		**14**	**1.5**	1.7	0.23	A
No	Cataluña	Gironella	8680	D2	NB	DSFH	78		13	1.5	1.7	−0.15	A
No	Islas Canarias	**Granadilla de Abona**	**38618**	**α3**	**NB**	**DSFH**	**23.6**		**1**		**1.7**	**1.10**	**B**
Yes	Aragón	Grañen, Huesca	22260	D3	NB	DSFH	78		13	1.5	1.7	−0.15	A
No	Madrid	Guadalix de la Sierra	28794	D3	NB	DSFH	78		14	1.5	1.7	−0.13	A
No	Cantabria	Guriezo	39788	C1	NB	DSFH	53.3		14	1.5	1.7	−0.01	A
No	Cataluña	L'Alzina de Ribelles	25748	D3	NB	DSFH	78		12	1.5	1.7	−0.17	A
No	Asturias	Llanera	33425	D1	NB	DSFH	78		9	1.5	1.7	−0.23	A
No	Cataluña	Lleida	25198	D3	NB	TH	78		8.5	1.5	1.7	−0.24	A
No	Cataluña	Lleida	25198	D3	NB	TH	78		7	1.5	1.7	−0.27	A
Yes	Islas Baleares	Llucmajor	7620	B3	NB	DSFH	33.5		8	1.5	1.7	−0.04	A
No	Madrid	Madrid	28794	D3	NB	DSFH	78		12	1.5	1.7	−0.17	A
No	Madrid	Madrid	28043	D3	R	AH	53	53	33	1.5	1.7	0.53	A
Yes	Madrid	Madrid	28023	D3	NB	DSFH	78		11	1.5	1.7	−0.19	A
Yes	Madrid	Madrid	28043	D3	R	DSFH	78		10.9	1.5	1.7	−0.19	A
No	Cataluña	Matadepera	8230	D1	NB	DSFH	78		14	1.5	1.7	−0.13	A
Yes	Andalucía	Mijas	29650	C3	NB	DSFH	53.3		8.8	1.5	1.7	−0.15	A
No	Galicia	Moaña	36958	C1	NB	DSFH	53.3		7	1.5	1.7	−0.20	A
Yes	Andalucía	Moraleda de Zafayona	18005	C3	NB	DSFH	53.3		6	1.5	1.7	−0.23	A
Yes	Asturias	Muros de Nalón	33138	D1	NB	DSFH	78		15	1.5	1.7	−0.11	A
No	Aragón	Ontinar de Salz	50810	D3	NB	DSFH	78		11	1.5	1.7	−0.19	A
Yes	Cataluña	Palau-solità i plegamans	8184	C2	NB	DSFH	53.3		9	1.5	1.7	−0.15	A
No	Cataluña	Palau-solità i plegamans	8184	C2	NB	DSFH	53.3		9	1.5	1.7	−0.15	A
Yes	Cataluña	Palau-solità i plegamans	8184	C2	NB	DSFH	53.3		9	1.5	1.7	−0.15	A
Yes	Madrid	Rivas Vacianadrid	28521	D3	NB	DSFH	78		14	1.5	1.7	−0.13	A
Yes	Navarra	Roncal	31415	E1	NB	DSFH	103.3		14	1.4	1.7	−0.41	A
No	País Vasco	San Sebastian	20009	D1	R	AH	53	53	15	1.5	1.7	0.02	A
No	Cataluña	Sant Cugat del Vallès	8024	C2	R	DSFH	53.3		9	1.5	1.7	−0.15	A
Yes	Islas Baleares	Sant Llorenç de Balafia	7812	B3	NB	DSFH	33.5		9	1.5	1.7	0.00	A
No	Cantabria	**Santander**	**39011**	**C1**	**R**	**DSFH**	**53.3**		**24**	**1.5**	1.7	0.28	**B**
No	Cantabria	Santander	39012	C1	R	SDH	53.3		13	1.5	1.7	−0.03	A
No	Galicia	Santiago de Compostela	15896	C1	NB	DSFH	53.3		23	1.5	1.7	0.25	**B**
No	Andalucía	Sevilla	41005	B4	NB	TH	33.5		13	1.5	1.7	0.18	**B**
No	Cataluña	Tossa de Mar	17320	C2	NB	DSFH	53.3		39	1.5	1.7	0.70	A

(*continued on next page*)

Table 3 (*continued*)

Certified	Region	City	Postal code	Climatic zone	TW*	BT**	Ir (single house)	Ir (block dwellings)	Io (kWh/m2y)	R (single house)	R (block dwellings)	C1	Calculated Label
No	País Vasco	Trokoniz	1193	E1	NB	DSFH	103.3		13	1.4	1.7	−0.43	A
No	Asturias	Tuernes	33425	D1	NB	DSFH	78		9	1.5	1.7	−0.23	A
Yes	Asturias	Vega de Poja	33519	D1	NB	DSFH	78		9	1.5	1.7	−0.23	A
No	Asturias	Villademoros, Valdés	33788	D1	NB	DSFH	78		12	1.5	1.7	−0.17	A
Yes	Asturias	Villanueva de Pría	33591	C1	NB	DSFH	53.3		12	1.5	1.7	−0.06	A
No	País Vasco	Vitoria	1194	E1	NB	DSFH	103.3		15	1.4	1.7	−0.40	A
Yes	País Vasco	Vitoria-Gasteiz	1192	E1	NB	DSFH	103.3		14	1.4	1.7	−0.41	A
Yes	País Vasco	Vitoria-Gasteiz	1007	E1	NB	DSFH	103.3		15	1.4	1.7	−0.40	A
No	Castilla y León	Zaratán	47610	D2	NB	DSFH	78		12	1.5	1.7	−0.17	A

Type of Work (TW*): New Building (NB); Refurbished (R)); Building Type (BT**): Detached single family house (DSFH); Semi-Detached House (SDH); and Terraced house (TH) are considered single houses; Multi Family Dwelling (MFD) and Apartment House (AH) are considered block dwelling; R corresponds to the dispersions for the heating demand in new private residential buildings.
Source: Own elaboration

Therefore, the European heating index (EHI) and the European cooling index (ECI) (which fit well with the Köppen-Geiger classification) are proposed. Based on this, updating of the NZEB zoning map is proposed (BEAR NOVATEC, 2016). On the other hand, some authors indicate that present climate classification in Spain could not accurately represent the energy demand for heating and cooling, and they suggest that the methodology as regards current climate zones should be reconsidered within new amendments of the TBC (Bienvenido-Huertas et al., 2021).

✓ *There are differences as regards the methodologies chosen to calculate the EPRs in the two certification systems under study.* Apart from the differences regarding the usage profiles (e.g., residential and non-residential buildings, single-family, etc.), the following differences should be noted:
  i. Different parameters are included in the calculation of the global EPR (e.g., lighting is not included in the Spanish "global indicator", but is included in the PH "global parameter);
  ii. As regards thermal comfort, different temperature ranges are considered (e.g., a range of 17–27 °C depending on the time of day and the season in the Spanish system, and between 20 °C in winter and 25 °C in summer, 24 h a day in the PH system).

3.2. Novelties in Royal Decree 732/2019 amending the Technical Building Code for new buildings

Royal Decree 732/2019 amending the TBC (Spain, 2019a) includes novelties (compared to the previous document (Spain, 2013a)), particularly with regard to the energy saving document (art. 15 "DB HE Energy saving"; Section HE 0 Limitation of energy consumption).

According to the previous document (Spain, 2013a), Total non-renewable primary energy consumption ($C_{nrpe,lim}$) is expressed as equation (2):

$$C_{nrpe,lim} = C_{nrpe,base} + F_{ep,sup} / S \quad (2)$$

where:

- $C_{nrpe,lim}$ = the limit value for the total non-renewable primary energy consumption for heating and cooling, and domestic hot water (in kWh/(m^{2}y), considering the useful space of living areas.
- $C_{nrpe,base}$ = base value for the total non-renewable primary energy consumption, depending on the climate zone were the building is located (see values in Table 4).
- $F_{ep,sup}$ = correction factor by surface of total non-renewable primary energy consumption (see values in Table 4).

Table 4
Base value by surface of Total non-Renewable Primary Energy Consumption for new private residential buildings and correction factors.

	New buildings and extensions					
	A	A	B	C	D	E
Cnrpe, base	40	40	45	50	60	70
Fep,sup	1000	1000	1000	1500	3000	4000

Source: (Spain, 2013)

As stated in Royal Decree 732/2019 amending the TBC (Spain, 2019a), the C_{nrpe} and total primary energy consumption (C_{pe}) for new buildings shall not exceed the limits expressed in Table 5.

- *Energy Consumption*: the energy that needs to be supplied to systems (existing or assumed) to provide different energy services (i.e., heating, cooling, ventilation, domestic hot water, humidity control in private buildings – note that lighting is not considered in such buildings), taking into account the efficiency of the systems used, expressed in [kWh/(m^{2}y)]. This energy consumption can be expressed as final energy consumption (by energy vector) or C_{pe} and can refer to the set of services (total) or to a specific service.
- *Total Primary Energy Consumption (C_{pe})*: the overall value of the primary energy that needs to be delivered to the systems. It includes both the energy supplied and produced on site, as well as that extracted from the environment.
- *Non-Renewable Primary Energy Consumption (C_{nrpe})*: the non-renewable part of primary energy that needs to be supplied to systems. It is determined by taking into account the value of the passage coefficient of the non-renewable component of each energy vector.

Therefore, it can be assumed that the $C_{nrpe,lim}$ is:

- $C_{nrpe,lim}$ = limit value for the non-renewable primary energy consumption for heating, cooling, and domestic hot water (in kWh/(m^{2}y)) considering the useful space of living areas.

To sum up, the new legislation establishes the following fundamental novelties:

a) *It distinguishes between the C_{nrpe} and the C_{pe} and establishes different limits for each indicator (see Section H0 in* (Spain, 2019a)*), establishing more restricted limits for the C_{nrpe} compared to the previous legislation*: this is illustrated when comparing Tables 4 and 5, which show: i) that the limit is much more restrictive for C_{nrpe} with Royal Decree 732/2019 (Spain, 2019a) compared to the previous law (Spain, 2013a); (e.g., in the case of new buildings located in α climate zone,

Table 5
Limit value of Total non-Renewable Primary Energy Consumption and Total Primary Energy Consumption for new private residential buildings according to Royal Decree 732/2019.

Cnrpe, lim							Cpe,lim					
α	A	B	C	D	E	—	α	A	B	C	D	E
20	25	28	32	38	43	EN	40	50	56	64	76	86

Source: (Spain, 2019)

the $C_{nrpe,\ lim}$ is 20 (see Table 5), while Table 4 shows that the previous legislation stated a limit for $C_{nrpe,\ base}$ of 40); ii) that the limit for C_{pe} is much less restrictive when compared with the limit for C_{nrpe} (e.g., in the case of new buildings located in α climate zone, the $C_{nrpe,\ lim}$ is 20, while the $C_{pe,\ lim}$ is 40 as shown in Table 5). Therefore, this new legislation offers flexibility as regards the total amount of primary energy that can be consumed by buildings, which could be supplied with renewable energies, for example. This could mean a clear boost to the use of renewable energy to supply energy to new buildings in Spain.

b) *Secondly, while the previous legislation provided limits for the energy demand for cooling and heating (see* Section HE 1 in (Spain, 2013b)), *the new Royal Decree avoids including these indicators as a limiting value.* Instead, the energy demand is indirectly limited by 5 new conditions (which relate to transmittance of the envelopes (U-values), the factor that measures the decompensation between them, the solar control and the permeability of the envelope (see new Section HE 1: Conditions for the control of energy demand in (Spain, 2019a)). These 5 conditions, taken as a whole, should represent a limit to the total energy demand. However, whether or not this limit is more restrictive compared to previous legislation still needs to be verified with real values, as do the new restriction levels that have been imposed. The Spanish TBC establishes limit values for thermal transmittance of the external envelope based primarily on the climate zone where the building is located. Accordingly, each Spanish province is assigned to a climate zone, and the limits are defined depending on the altitude of the municipality in question. However, as pointed out by Bienvenido-Huertas et al. (2021), this approach may lead to disparities between Spanish provinces. These authors also affirm that the current TBC represents a radical change in the standards for building insulation. Lowering the limits for the U-values may produce significant reductions in the heating and cooling demand, but it may be difficult to balance both of them, particularly in climates with broad temperature variations between summer and winter (Bienvenido-Huertas et al., 2021).

The new approach in the TBC clearly gives flexibility to those responsible for applying the regulations (i.e., architects, builders, etc.), providing a choice between:

i) focusing on reducing energy demand, i.e., maximizing the use of better insulation or reducing thermal bridging, etc. (i.e., closer to the "passive building" concept);
ii) improving the efficiency of heating or cooling systems in order to achieve the ultimate goal of the law (i.e., to not exceed the established primary energy consumption of each building);
iii) including the use of renewable energies in order to achieve the ultimate goal of the law.

The problem of establishing only energy consumption indicators (i.e., aggregate EPIs) and eliminating the energy demand (i.e., disaggregate EPIs) as a limiting value (even in an indirect way) could pose additional challenges: as mentioned above, combining different end uses into one could lead to ambiguity (Kim et al., 2019). As explained, energy consumption is the energy needed to meet the energy demand of different energy services, taking into account the efficiency of the systems used (Spain, 2013a). By contrast, energy "demand depends basically on climate and the building's characteristics, and is independent of heating system performance and social factors. This is why it was considered a more reliable criterion" (Monzón and López-Mesa, 2017). For example, electricity conversion factors do not affect the annual heating demand calculation. As explained by ADAPT "the conversion factors and the choice of calculation method will alter the competition among different energy carriers/solutions, and thus potentially have a strong impact on energy system development" (ADAPT, 2013). The good news is that the current EPC establishes an obligation to include information on a building's heating and cooling demand in the project documentation, and that the building is classified considering a scale (A-G) according to said consumption[6] (Ministerio para la Transición Ecológica y el Reto Demográfico, 2019).

Finally, the new TBC states limits to lighting consumption in tertiary buildings (such as schools, business …), through the basic energy saving document section 3 (DB HE3) (i.e., the so called "*valor de eficiencia energética de la instalación* (VEEI)") (Spain, 2019a). However, as is the case of the former legislation, lighting consumption inside residential buildings is excluded from those limitations. Therefore, this may lead to the paradox that a residential building is considered to be an NZEB as stated by current Spanish law (see section 1.2.), but the energy consumption of which considerably increases from the use of lighting and domestic appliances.

Table 6 below illustrates that lighting consumption accounts for 4.1% of the total of final consumption, while domestic appliances account for 19.4%, (neither of these consumptions are limited by the TBC). Together, lighting and appliances account for around 23.5%.

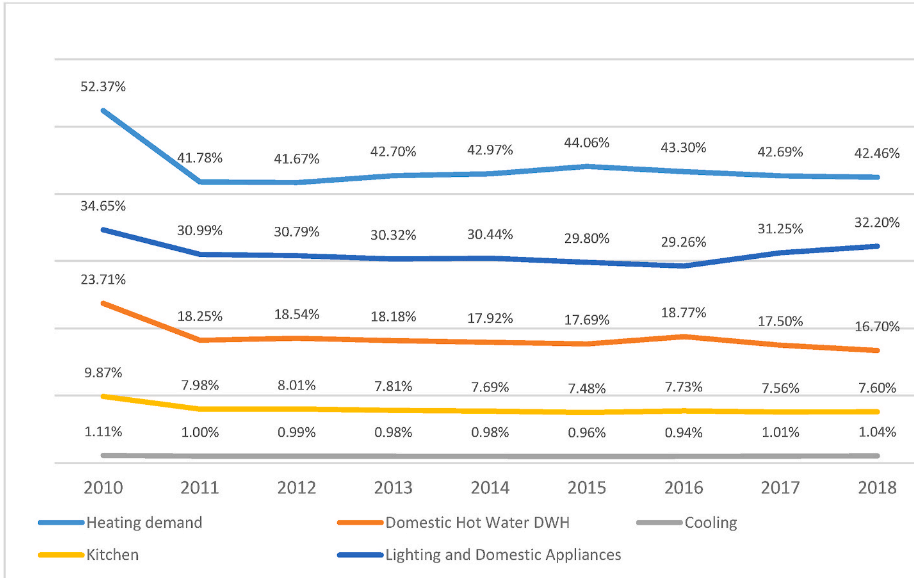
Fig. 1 illustrates evolution of final energy consumption by uses in Spain (in %) for the period 2010–2017. The Figure shows the increasing relevance of lighting and domestic appliance energy consumption 2011–2017 period. Limiting these consumptions may also be essential in order to contain the energy consumption in the residential sector. In any case, in order to carry out an adequate analysis of the problem, it is necessary that the data provided by the Ministry be disaggregated, distinguishing between lighting and domestic appliances.

Table 6
Structure of total final consumption (%) according to services in the residential sector 2011.

Type of use	%
Heating demand	47%
Hot Sanitary Water	18.90%
Kitchen	7.40%
Cooling	0.80%
Lighting	4.10%
Domestic Applyances	19.40%
Standby	2.30%

Source: (IDAE, 2011)

[6] e.g. heating demand [kWh/(m^{2}y)] < 34.1 for Class A.



(Ministerio de Transportes Movilidad y Agenda Urbana, 2020)

Fig. 1. Structure of total final consumption (in %) according to services in the residential sector 2011 (Ministerio de Transportes Movilidad y Agenda Urbana, 2020).

4. Conclusions and policy implications

Currently there is no harmonized NZEB concept in the EU framework, making it difficult to compare the ambition level in terms of the energy performance achieved by different NZEBs located in different countries. European legislation does not include any specific common criteria or quantitative requirements for calculating the EPR of buildings.

Current research is continuing to search for EPIs that improve the analysis and comparison of the building energy performance of residential buildings during their operational stage. To achieve this, the study uses heating demand as the main EPI based on the Spanish building certification system, obtaining the EPR of a sample of new residential buildings that follow the PH system. Results of this study illustrate that:

✓ As expected, the entire sample of selected buildings certified with the PH label would obtain an "A label" under the Spanish certification system. Consequently, Spanish buildings certified as PH would fit within the NZEB concept as defined by current Spanish law. It should be noted that wide disparities exist as regards the climate zones in Spain. However, the cooling demand in different provinces are not taken into account for the calculation of the EPRs in this case study. Bearing in mind that the PH system provides the same limits for heating and cooling demand, similar results should be obtained for the cooling demand indicator. However, further research is required to confirm this assumption.

✓ Fundamental differences have come to light regarding the methodological assumptions made by the 2 systems under study. These differences reveal the difficulty of comparing the energy performance of buildings through different certification systems or labels and, therefore, of harmonizing the NZEB concept and its homogeneous definition within the EU. The main differences that have come to light are:
   ➢ On the one hand, those linked to external requirements. This fact outlines other problems, such those related to the lack of an internationally harmonized methodology for determining climate zones, and the specific problems detected as regards the current climate zone methodology in Spain;
   ➢ On the other, differences regarding the concept of thermal comfort and also the inclusion of different parameters when calculating their respective EPRs (e.g., lighting).

These differences reveal how difficult it is to establish a harmonized EPI in order to compare the level of energy performance achieved by buildings. These facts are also key to explaining the selection of disaggregate EPIs as the most suitable for current analysis, as they avoid some of the abovementioned distortions. Moreover, disaggregate EPIs also avoid possible distortion related to the performance of technical systems (such as heating and cooling systems), and electricity conversion factors. Even if still residual, the rising of importance of cooling consumption in future climate change scenarios is being outlined by different studies. Therefore, heating, and also cooling demand especially in certain Southern regions, are fundamental disaggregate indicators for measuring the energy performance of buildings.

Fundamental novelties have been provided in the new TBC concerning the EPIs used to obtain the corresponding EPR for buildings. The following conclusions can be drawn from these novelties:

a) New legislation establishes differentiated limits for the total primary energy consumption (C_{pe}) and total non-renewable primary energy consumption (C_{nrpe}) of residential buildings, offering flexibility for former, but considerably limiting the latter. Under this new approach, NZEB design can be addressed not only through the passive component of the building (i.e., energy demands), but also through high efficiency installations (i.e., energy consumption), or through the inclusion of renewable energies. Therefore, this provides greater flexibility to those responsible for applying regulations when developing the building. Consequently, this new approach has the advantage of involving the following different (albeit closely linked) economic sectors: building constructors; manufacturers and marketers of heating and cooling systems for these buildings; and manufacturers and marketers of renewable energy systems for these buildings.
b) Only energy consumption indicators (i.e., aggregate EPIs) are stated as limiting values. The heating and cooling demands (i.e., disaggregate EPIs) are eliminated and are only limited indirectly. It should be noted that this policy decision might pose the following additional

challenges: combining different end-uses into one could lead to ambiguity, and the choice of the calculation method for the aggregated EPIs selected may alter competition between different energy carriers/solutions, and "thus potentially have a strong impact on energy system development" (ADAPT, 2013).

As there is no common definition of the NZEB concept, each Member State is free to establish its own definition (within the framework of existing EU legislation). Indeed, NZEB may be a confusing concept that can be used to describe a building with very different characteristics. However, during this study, two different approaches towards the NZEB concept have become evident:

1. The approach which focuses efforts on reducing comfort energy requirements for buildings (i.e., by making more "passive buildings").
2. The approach which focuses efforts on promoting the efficiency of technical systems and renewable energies.

We consider that both perspectives may be complementary, adequate and fundamental when it comes to achieving NZEBs. Therefore, finding an adequate balance between these would seem to be essential. It can be also concluded that:

i. Firstly, the new Spanish TBC has focused on the second approach (i.e., offering flexibility to the C_{pe}, while limiting the C_{nrpe}). This perspective represents a step forward towards achieving the NZEB goals, as stated by the EU, as well as clearly boosting the country's renewable energies and the energy efficiency of the technical systems needed to supply building energy demands. Therefore, it is an adequate policy option that tends to reduce GHG in the Spanish residential sector, so the policy should continue to be followed.
ii. Secondly, as explained by some authors, the new TBC represents a radical change in building insulation standards (Bienvenido--Huertas et al., 2021). However, the new TBC only limits heating and cooling demand indirectly. The degree of requirement of the new CTE with respect to the limit of heating and cooling demand still needs to be verified with real values.
iii. Thirdly, according to the Spanish TBC, lighting consumption is not limited for the interior of residential buildings. Considering the increased relevance of lighting and domestic appliance energy consumption, maybe this fact should be somehow reconsidered. In any case, in order to carry out an adequate analysis of the problem, it is necessary that the data provided by the Ministry be disaggregated, distinguishing between lighting and domestic appliances.

On the other hand, we also consider that priority should be given to the first approach, focusing on reducing comfort energy requirements by making buildings more bio-climate responsive (i.e., keeping heating and cooling as limiting factors, rather than only limiting energy consumption as provided by the new TBC). As affirmed by the Spanish Passive House Platform (*Plataforma de Edificación Passive House* (PEP)), it seems more reasonable that the path towards achieving low consumption, tending towards zero consumption, should be through a drastic reduction in demand to eventually make up the shortfall with renewable energy, generated on-site if possible (PEP, 2018). Moreover, this perspective may be crucial to achieving reductions in energy consumption in the building sector over the very long term, particularly as buildings, once designed and constructed, are more difficult to modify than the technical systems installed. Finally, the obligation to show the heating and demand value on the EPC is a good measure, even if it is not a limiting value.

CRediT authorship contribution statement

Itziar Martínez-de-Alegría: conception of the presented . **Rosa-María Río:** Supervision, of the project. **Enara Zarrabeitia:** data modelling; contribution ot the final version of the manuscript (i.e. erratum corrections and final adjustments). **Izaskun Álvarez:** development of the theory and the methodological model as well as preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation), data modelling; provision of the financing of the project.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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