

Article

Does the Energy Performance Certification Effectively Support Building-Energy Efficiency and Resilience to Climate Change?

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Abstract

Given the impacts of the building sector on energy consumption and greenhouse gas emissions, the European Union has defined regulations to improve buildings' energy performance. Among these provisions, there is the requirement, in each member state, to set up a framework for the energy performance certification of buildings; this is a tool to quantify and unequivocally identify the overall energy performance of buildings based on accountable and comparable criteria. Did member states implement similar approaches in their definitions of their energy certification framework and goals? Does this approach provide an effective solution to drive building-energy efficiency and sustainability improvement? This work investigates and compares the process of the energy certification of buildings in two European countries: Italy and Belgium. The purpose is to identify the pros and cons of the framework in each country, in addition to the similarities and differences between them. The comparative analysis showed non-negligible differences between the two approaches, in terms of both methodology and outcomes. The climate context was found to play a key role in determining the methodological discrepancy. Moreover, both of the developed approaches show balanced pros and cons that should be further questioned to provide shared tools that can effectively support building-energy efficiency enhancement and resilience to climate change.

Keywords: building energy efficiency; climate change; resilience; energy performance certification; high-performance buildings



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1. Introduction

Building-energy efficiency improvement is a requirement that cannot be further postponed. Indeed, buildings are responsible for about 40% of the energy consumption, and 36% of greenhouse gas emissions, in Europe [1] Therefore, at the same time, building-energy performance represents an issue to be faced and an opportunity to be seized [2].

In this view, the energy performance certification of a building is the process of providing a certificate called, in the standardized international nomenclature, the Energy Performance Certificate (EPC) [3]. This certificate reports the relevant information relating to how the building was constructed in terms of thermal-energy performance and energy consumption. Therefore, the application of energy certifications for buildings and dwellings is well acknowledged as a tactic to (i) illuminate many of the realities of construction, (ii) improve the efficiency of existing buildings, and (iii) endow residential sector planning

with a more realistic vision [4]. According to current regulations [5–7], this certification is a mandatory document which is to be provided for new buildings, renovations involving over 25% of the built surfaces (walls and roofs), and public buildings, as well as to the buyer or tenant when selling or renting a building. The purposes of the energy performance certification are (i) to provide clear and transparent information on the energy quality of buildings, (ii) to define the general and acknowledged methodology used to calculate the energy performance of buildings, and (iii) to promote building-energy consumption reduction by identifying the energy performance shortcomings of buildings. Moreover, this certification could be used as an effective and accountable tool for energy planning [4] and energy policy definition [8]. Also, the certification could represent a suitable method for collecting comparable and “certified” data about the energy profiles of existing building stock [9].

Buildings are classified according to the results of a certain calculation, in terms of energy performance, through a dedicated system. Therefore, building-energy certification should support the improvement of building-energy efficiency [10] and provide guidelines and support for practitioners in order to ensure users’ well-being and environmental sustainability, while being consistent with construction practices [11]. Moreover, Lakić et al. [12] demonstrated that when the EPC also includes a description of the cost-saving effects of efficiency improvements, people are more willing to pay for higher levels of energy performance. Similarly, a study performed by Amecke [13] analyzed the degree to which EPCs have helped purchasers of owner-occupied dwellings in Germany to incorporate energy efficiency into their purchasing decisions; the results showed that changes must be applied to the design process to further increase the impact and effectiveness of both energy performance certificates and energy efficiency.

However, building-energy performance certification schemes rely on assumptions rather than real energy consumption [14]. Therefore, they may lead to higher energy costs and carbon emissions during actual operation if they fail to assess the expected energy performance [15] correctly. This is the so-called energy performance gap [16], which is due to several different factors [17], including, in particular, the energy-consumption behavioral factors [18]. Several research studies and projects focus on the improvement of the energy performance certification process [19]. For instance, Salvalai and Sesana [20] framed a low-cost and non-invasive monitoring approach for existing residential buildings’ real data collection. Similarly, Gonzalez-Caceres et al. [21] proposed a procedure to evaluate energy-efficiency measures in building renovation through energy certification, which involves measurements, model validation, and life-cycle analysis of the building to obtain realistic benefits and costs. Walsdorf-Maul et al. [22] proposed further development of the EPC by considering both energy efficiency and sustainability (technical, economic, and social) aspects of the whole building life cycle. Within the same context, studies on the use of an energy certification-based database to identify energy planning purposes were carried out by Dall’O et al. [23], by considering an application use case in northern Italy.

Semple and Jenkins [24] have examined the methods used for building-energy performance certification in six European countries, including Italy, and showed non-negligible variation in these methods across the analyzed countries. Understanding the input-data requirements, as well as the actual variations and their implications could help frame a more homogeneous approach and best-practice sharing among European countries. Moreover, Andaloro et al. [25] performed a comparative analysis of progress towards implementation of the energy certification of buildings in the countries of the European Union (EU), aiming to (i) assess the experience gained in this field in Europe, considering the highly diverse settings of different nations, and (ii) examine the extent to which Directive 2000/91/EC has been implemented. In the same context, Abela et al. [26] investigated whether the calcula-

tion methodologies currently in use for the generation of EPCs in the Mediterranean region are appropriate, utilizing comparative testing using the differing national methodologies from Cyprus, Italy, Malta, and Spain on four tested case-study dwellings.

Within this panorama, this study investigates and compares how the required processes within the energy performance certification are implemented in different European member states. More specifically, the analysis focuses on the similarities and differences between two countries, i.e., Belgium and Italy, which are characterized by different boundary conditions, aiming to complement the abovementioned existing literature on the investigated topic.

The aims are to (i) identify the peculiarities of the approach adopted in each country, (ii) highlight the pros and cons, and (iii) establish potential best practices to be shared. The overarching objective is to examine and reconcile the disparities between EPCs implemented at the level of the individual member state and to develop critical reflections that may contribute to more effective strategies for enhancing building-energy performance, in alignment with forthcoming international targets. To this end, Belgium and Italy have been selected as case studies, as they embody two markedly contrasting contexts with respect to climate, geographical characteristics, and regulatory frameworks. Their comparison is thus intended to capture the spectrum of extreme conditions that may be observed across European countries.

Therefore, this work addresses the following research questions: Have member states implemented similar or comparable approaches in the definition of the energy certification framework? Does each approach provide an effective and replicable solution to drive building-energy efficiency and sustainability improvement (especially in view of climate-change resilience in the building sector)? In fact, the analysis and review of the existing scientific literature reveal that research in this field still lacks the integrated and comprehensive approaches and frameworks to be applied in order to achieve energy efficiency and carbon emissions reduction goals at both the national and international levels.

European Regulatory Framework

In Europe, the starting point for energy performance certification is provided by the Energy Performance of Buildings Directive (EPBD) (the initial directive and its recasts) [5–7]. The first EPBD, 2002/91/EC [5], among other areas of emphasis, stressed that major buildings renovations can enhance their energy performance. This directive establishes the need for (i) energy certificates, (ii) a general framework for the methodology used to obtain them, and (iii) minimum requirements for new constructions and major renovations. Moreover, it confirms that the calculation methodologies defined by the member states at the national or regional level must necessarily include the following aspects:

- Thermal characteristics of the construction components (envelope and internal partitions);
- Heating and hot water supply system;
- Air-conditioning system;
- Ventilation system;
- Built-in lighting system (mainly for the non-residential sector);
- Position and orientation of the building;
- Passive solar systems and solar shading;
- Natural ventilation;
- Indoor climatic conditions.

The EPBD recast in 2010/31/EU [6] introduced a major topic, i.e., the setup for Nearly Zero-Energy Buildings (nZEBs). As regards the energy certificates, several details were added, including the reference to the cost-optimum level in the energy certificate, the

emphasis on recommendations in the energy certificates, the display of energy certificates in buildings, and the various situations when an energy certificate needs to be provided.

Finally, the EPBD recast in 2018/844/EU [7] further revised and updated the building-energy performance regulatory framework. The energy performance was expressed by a numeric indicator of primary energy (in kWh/m² y) calculated according to ISO standards and weighted according to the energy carrier factor. It gave the option to provide additional indicators about the total, non-renewable, and renewable levels of the primary energy, and greenhouse gas emissions. The European regulatory framework provides the following guidelines for the certification of energy performance:

- The EPC needs to be provided for buildings that are newly constructed/retrofitted, sold, or rented;
- Buildings with a total useful floor area of over 250 m² that are occupied by public bodies and visited by the public need to have an EPC;
- The regulations are valid for both buildings and units;
- The validity of an EPC shall not exceed 10 years;
- The certification needs to be carried out by a qualified expert.

As for nZEBs, the European framework provided the requirement for each country to define plans to increase the number of nZEBs at the country level, and the deadline after which it would be compulsory for new constructions to be nZEB, starting with public buildings, which had a more stringent deadline. According to [6], a Nearly Zero-Energy Building is “a building with very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.” The EU stated that, by 2020, all new buildings had to be nZE. The determination of being nZE depends on the primary energy use (expressed in kWh/m²), and the target value needs to be determined by each member state separately.

2. Methodological Approach

As already discussed, EPCs are enacted at the level of individual households within member states, based on local regulations promoted by the EPBD. However, different countries have implemented different strategies, considering their differing perspectives and local boundary conditions.

This work compares the methodological frameworks developed and used by two reference countries characterized by extremely different boundary conditions in terms of climate [27], geographic extent, and population density, i.e., Italy and Belgium, trying to identify the crucial differences between them and the discrepancies that can be found in Europe despite the general framework established by the legislation. In particular, the proposed approach and analysis consists of the following steps:

- Collection and comparative analysis of official documents: Selected documents issued by government authorities or accredited offices in the two countries were gathered (as detailed in Sections 3.1.1 and 3.2.1) and thoroughly analyzed.
- Identification of the status quo: The current situation was assessed in terms of (i) the general regulatory framework, (ii) the climatic context, (iii) construction characteristics, (iv) the EPC setup procedure and (v) core specifications, (vi) the nZEB definition, and (vii) the primary tools employed within the EPBD framework.
- Critical analysis of national approaches: The advantages and limitations of the identified national approaches were examined to highlight the most important insights and lessons learned.

The ultimate objective is to propose insights relevant to comprehensive and replicable procedures that can be applied at a broader scale in European countries to enhance energy-efficiency levels and, consequently, reduce the environmental impact of the building sector.

3. Local Frameworks

The following sub-sections report the main characteristics and indications of the local regulatory frameworks in Italy and Belgium, respectively, regarding the energy performance certification process.

3.1. Italy

3.1.1. The General Framework

Following the first EPBD [5], the first guidelines for the energy certification and classification of buildings were published in 2009 with the Ministerial Decree D.M. 26/06/2009, “Linee guida nazionali per la certificazione energetica degli edifici”. Moreover, Presidential Decree n. 59/2009 provided information about the calculation methodology and the minimum requirements for the energy systems (heating, cooling, and domestic hot water). In Italy, this process is managed at the national level. The authority that supports the definition, implementation, and monitoring of national policies and their associated processes is the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

The first EPBD recast [6] provided several important novel elements that had a big influence on the procedures and standards in Italy. Law n. 90/2013 introduced the actual energy performance certificate (EPC), called, in Italian, APE (“Attestato di Prestazione Energetica”). Moreover, the Ministerial Decree D.I. 26/06/2015 [28], which is based on the two Legislative Decrees n. 192/2005 and n. 311/2006, updated the guidelines for building-energy certification and classification. Among other elements, it provides the minimum energy performance requirements for buildings and their components, and the methodologies used to determine the primary energy needs and determine the level of renewable energy used.

The latest EPBD recast [7] resulted in further regulatory updates in Italy. The Ministerial Decree regarding energy efficiency, D.M. 06/08/2020, defined stricter technical requirements and established a large incentive for implementing energy-efficiency measures, i.e., the so-called “Ecobonus”. This incentive involved 110% cost refunds, through tax deductions, for construction works that provided improvements of at least two energy classes in residential buildings. Furthermore, Legislative Decree n. 48/2020, which replaced Law n. 90/2013 and amended Legislative Decree n. 192/2005, modified the calculation method used to determine the energy performance, provided additional minimum requirements, and introduced a new national portal for energy performance, a national-level database of buildings’ energy performance.

3.1.2. The Climate and Geographic Context

Italy, with a geographic extent of about 302,100 km² and a population density of 206 people per km², can be divided into several climate zones according to the Köppen–Geiger climate classification [29] (Figure 1). The most significant zones are described in the following:

- Csa: Warm Mediterranean climate, covering Sicily, Sardinia, and large parts of the Italian mainland;
- Csb: Temperate-summer Mediterranean climate, covering the Campania area and the highest points of the islands;

- Cfa: Warm ocean climate/humid subtropical climate, covering the Adriatic coastal areas and the Po valley;
- Cfb: Temperate oceanic climate, covering the pre-Alps;
- Dfb: Temperate continental climate/humid continental climate, covering the Alps;
- Dfs: Cool continental climate/subarctic climate, covering the summits of the highest Alps;
- ET: Tundra climate, covering the summits of the highest Alps.

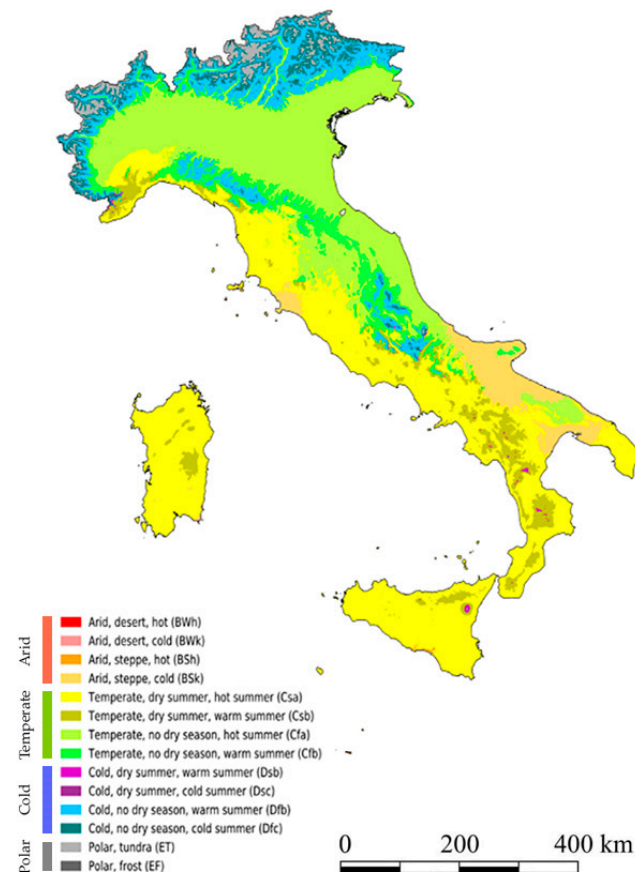


Figure 1. Köppen–Geiger climate classification map for Italy (1980–2016) [29].

In Italy, the national climate-zone classification results in impacts on the energy certification and the energy requirements for buildings, which are set based on the climate zone (as detailed in Section 3.1.5). The determination of the climate zone is based on the local number of heating degree days (HDD), not on the Köppen–Geiger classification. HDD are calculated using the sum of the positive differences between a reference temperature (20 °C) and the average daily temperatures for the whole heating period. Accordingly, the country is classified into six climate zones as follows:

- Zone A: <600 HDD;
- Zone B: 601–900 HDD;
- Zone C: 901–1400 HDD;
- Zone D: 1401–2100 HDD;
- Zone E: 2101–3000 HDD;
- Zone F: >3000 HDD.

Generally, southern regions are characterized by lower numbers of HDD and higher numbers of CDD (cooling degree days), while the situation is vice versa for northern regions. In sum, all Italian zones are heating-dominated and cooling-dominated. According

to Eurostat calculations [27], in 2022, the annual numbers of HDD and CDD in Italy were 1735 and 375, respectively.

3.1.3. The Construction Characteristics

In Italy, construction characteristics are defined by D.I. 26/06/2015 [28] with respect to a few relevant parameters:

- The air-conditioned volume V (m^3) is the indoor volume served by a heating, ventilation, and air-conditioning system;
- The heat loss surface S (m^2) is the surface that protects the air-conditioned volume V ;
- The shape ratio S/V is the ratio of the heat loss surface S and the air-conditioned volume V ;
- The solar reflectance provides the ratio of the solar radiation that is reflected by the external building envelope surface, which is expressed as a dimensionless parameter on a scale from 0 to 1;
- Thermal bridges are those points on the heat loss surface where there is a geometric or material discontinuity.

3.1.4. The EPC Setup Procedure

In Italy, there is a unique process of energy performance certification used in issuing the Energy Performance Certificate (EPC) [28]. The certificate provides information about the energy characteristics of the building, in addition to recommendations. Four types of bodies can issue the EPC: (i) qualified reporters, (ii) public authorities with appropriately qualified staff members, (iii) public inspection organizations, and (iv) energy service companies with appropriately qualified staff members.

The process of the acquisition of the EPC starts with the determination of the required information about the building, the acquisition of which, for existing buildings, requires a field survey. The building is evaluated based on the minimum requirements for the specific climate zone and with respect to a “reference building” defined in compliance with the regulatory requirements for nZEBs. Therefore, the characteristics of the reference building, such as the requirements for nZEBs (as detailed in Section 3.1.6), vary among the climate zones. The reference building is a theoretical model, with standard envelope and system parameters, used as a benchmark to evaluate the performance of real buildings. The comparison is carried out based on energy performance indices. Therefore, the building is assigned to an energy class, based on the comparison of its energy performance to that of the reference building. The classes are from A4, the best, to G, the worst. A building assigned to a class between A1 and A4 has better energy performance than an nZEB, in the context of Italian regulation.

3.1.5. Core Specifications of the EPC

In Italy, the energy performance of constructions is evaluated by comparing the building with a reference. Said comparison is carried out using the Global Primary Energy $EP_{gl,tot}$ [28], expressed in $kWh/(m^2y)$, and more precisely, the non-renewable share of this index: $EP_{gl,nren}$. In residential buildings, this index quantifies the level of non-renewable primary energy required for winter and summer heating and cooling, domestic hot water production, and ventilation (in addition to lighting and vertical transport for non-residential buildings). Upon calculation, the $EP_{gl,nren}$ is compared to the non-renewable energy performance of the reference building $EP_{gl,nren,rif}$, i.e., a similar building (the same geometry, use and type of construction, climatic zone, and dimensions) equipped in accord with the minimum requirements for a new building [28]. Then, the building is classified using the set of predetermined energy classes described above in Section 3.1.4. Table 1 shows the

reference limits to be considered in the classification process. As evidenced in the findings, the threshold values vary as a function of the performance of the reference case and are additionally conditioned by the climatic zone and the degree-day profile of each location.

Table 1. Assessment of the energy class (Italy).

	Class A4	$\leq 0.40 \cdot EP_{gl,nren,rif}$
$0.40 \cdot EP_{gl,nren,rif}$	Class A3	$\leq 0.60 \cdot EP_{gl,nren,rif}$
$0.60 \cdot EP_{gl,nren,rif}$	Class A2	$\leq 0.80 \cdot EP_{gl,nren,rif}$
$0.80 \cdot EP_{gl,nren,rif}$	Class A1 (reference case)	$\leq 1.00 \cdot EP_{gl,nren,rif}$
$1.00 \cdot EP_{gl,nren,rif}$	Class B	$\leq 1.20 \cdot EP_{gl,nren,rif}$
$1.20 \cdot EP_{gl,nren,rif}$	Class C	$\leq 1.50 \cdot EP_{gl,nren,rif}$
$1.50 \cdot EP_{gl,nren,rif}$	Class D	$\leq 2.00 \cdot EP_{gl,nren,rif}$
$2.00 \cdot EP_{gl,nren,rif}$	Class E	$\leq 2.60 \cdot EP_{gl,nren,rif}$
$2.60 \cdot EP_{gl,nren,rif}$	Class F	$\leq 3.50 \cdot EP_{gl,nren,rif}$
$3.50 \cdot EP_{gl,nren,rif}$	Class G	$> 3.50 \cdot EP_{gl,nren,rif}$

Apart from the energy classification, specific requirements are also indicated in terms of the overall heat-transfer coefficient, which is not directly indicated in the EPC, but affects the final calculation. The current legislation sets maximum values for the overall transfer coefficient—expressed in W/m^2K —for both new constructions and important renovations of the first level, as a function of the climate zone and the S/V ratio. In contrast, for extension-based work and important renovations of the second level, the determination only depends on the climate zone (see Table 2).

Table 2. Overall heat-transfer coefficients for new constructions and first- and second-level renovations (Italy).

Climate Zone	Type of Building/Work	Shape Ratio (S/V)	Maximum U-Value
A/B	New or	$S/V > 0.7$	0.58
	1st lev. ren.	$0.7 > S/V > 0.4$	0.63
	2nd lev. ren.	$S/V < 0.4$	0.80
C	New or	-	0.73
	1st lev. ren.	$S/V > 0.7$	0.55
	2nd lev. ren.	$0.7 > S/V > 0.4$	0.60
D	New or	$S/V < 0.4$	0.80
	1st lev. ren.	-	0.70
	2nd lev. ren.	$S/V > 0.7$	0.53
E	New or	$0.7 > S/V > 0.4$	0.58
	1st lev. ren.	$S/V < 0.4$	0.80
	2nd lev. ren.	-	0.68
F	New or	$S/V > 0.7$	0.50
	1st lev. ren.	$0.7 > S/V > 0.4$	0.55
	2nd lev. ren.	$S/V < 0.4$	0.75
F	New or	-	0.65
	1st lev. ren.	$S/V > 0.7$	0.48
	2nd lev. ren.	$0.7 > S/V > 0.4$	0.53
		$S/V < 0.4$	0.70
		-	0.62

The energy certificate should also differentiate the thermal performance of the building in winter and summer, which is accomplished by reporting the “energetic quality of the construction” (Table 3) in terms of

Table 3. Assessment of winter and summer energy performance (Italy).

Winter Energy Performance		Quality
$EP_{H,nd} \leq 1 \cdot EP_{H,nd,limite}$		High
$1 \cdot EP_{H,nd,limite} \leq EP_{H,nd} \leq 1.7 \cdot EP_{H,nd,limite}$		Medium
$EP_{H,nd} > 1.7 \cdot EP_{H,nd,limite}$		Low
Summer Energy Performance		Quality
$A_{sol,est}/A_{sup-utile} \leq 0.3$	$Y_{IE} \leq 0.14$	High
$A_{sol,est}/A_{sup-utile} \leq 0.3$	$Y_{IE} > 0.14$	Medium
$A_{sol,est}/A_{sup-utile} > 0.3$	$Y_{IE} \leq 0.14$	Medium
$A_{sol,est}/A_{sup-utile} > 0.3$	$Y_{IE} > 0.14$	Low

- The heating-energy performance during the winter period, expressed by the $EP_{H,nd}$ in kWh/(m²y);
- The average periodic thermal transmittance Y_{IE} (in W/m²K), excluding vertical surfaces exposed to the north, and the equivalent summer solar area for units of usable area $A_{sol,est}/A_{sup-utile}$ in summer. In cases in which the construction has only north-exposed vertical surfaces, the Y_{IE} is equal to 0.14.

3.1.6. The nZEB

Italy transposed the European directive into its regulatory scheme by defining new rules for the energy performance of new buildings and those undergoing major renovations. D.I. 26/06/2015 establishes the required characteristics of an nZEB [28] in terms of the external envelope components' maximum limit U-value, maximum solar heat gain coefficient for transparent surfaces (including solar shadings) (g_{gl+sh} [-]) and solar heat gain area, energy systems efficiency, and energy requirements for ventilation and lighting. The limit values for each feature vary according to the climate zone where the building is located. According to these provisions, all buildings meeting the requirements envisaged by the decree itself and the obligations to integrate renewable sources provided in Legislative Decree 3 March 2011, n. 28 are nZEBs. It is also required that the effectiveness of using cool roofs for enhancing summer passive-cooling performance be verified in terms of the cost-benefit ratio. Furthermore, as already discussed, the reference building used in the EPC calculation is an nZEB of class A1, which is the minimum level that must be attained by all new buildings built, starting January 2021.

3.1.7. The Calculation Tool

In Italy, all energy calculations carried out within the EPC process are to be directly carried out by the professional chosen to be in charge of the certification, using dedicated software released by private companies, according to the 26/06/2015 D.I. [28]. Several tools exist that can be used for the calculation, e.g., TerMus Acca, Termolog Logical Soft, DOCET, BLUMUTICA, and Edilclima. Although no restrictions exist on the use of these tools, all of them need to be accredited and compliant with the Ministerial Decree. According to the legislative documents and the regulations set up by the ENEA, there are no specific requirements regarding construction nodes in terms of the EPC. However, the model needs to be produced according to the restrictions provided in UNI TS 11300:2014 [30] and UNI EN ISO 14683:2018 [31].

3.2. Belgium

3.2.1. The General Framework

In Belgium, the European EPBD has been fully implemented on the regional level by various pieces of legislation. Indeed, starting from 2008, the responsibility of converting

the EPBD in Belgium was handled exclusively by the three regions in the country (i.e., the Flemish Region, Walloon Region, and Brussels–Capital Region). This resulted in slightly different approaches in each region, although with the same targets and requirements. The Flemish Flanders Region is the most advanced in terms of implementing the EPBD (and therefore, this region is referred to in the detailed analysis). In this region, for most buildings, the chosen methodology is a calculated rating (public buildings are an exception).

In each region, an organization was created to manage all procedures and control facilities (i.e., Vlaams Energie en Klimaat Agentschap—VEKA (Flemish Energy and Climate Agency), Wallonie énergie, and Leefbaar Brussel). Also, the organization set up the framework of the energy performance certification, including the classification of building requirements and the calculation methods. The targets for energy performance became stricter in 2009. The first relevant pieces of legislation were the Flemish Energy Decree of 8 May 2009, the Brussels Ordonnance of 7 June 2007, the Walloon Decree of 28 November 2013, and the Walloon Government Decision of 15 May 2014 [32].

The first EPBD recast [6] also resulted in relevant updates in Belgium. In 2012, the net amount of energy needed for a residential construction was introduced as a requirement, and in 2014, the amounts of renewable energy were defined for residential buildings, schools, and offices. In 2017, constructions were classified into three types: residential, non-residential, and industrial. Net energy needs criteria were also applied for non-residential constructions, and requirements were introduced for new constructions in the industry. In 2018, all requirements became stricter.

The latest EPBD recast [5] involved, in Belgium, from 2019, stricter requirements for the minimum amounts of renewable energy, especially for non-residential constructions. For instance, the Flemish decree of 30 October 2020 introduced a legal framework in the Flemish Energy Decree of 8 May 2009 that imposes new obligations for real estate located in the Flemish Region.

3.2.2. The Climate and Geographic Context

In Belgium (geographic extent of about 30,700 km² and population density of 351 people per km²), there are only two climate zones, according to the Köppen–Geiger climate classification [29], as shown in Figure 2:

- Cfb: Temperate ocean climate, covering most of Belgium;
- Dfb: Warm humid continental climate, covering the eastern part of Belgium.

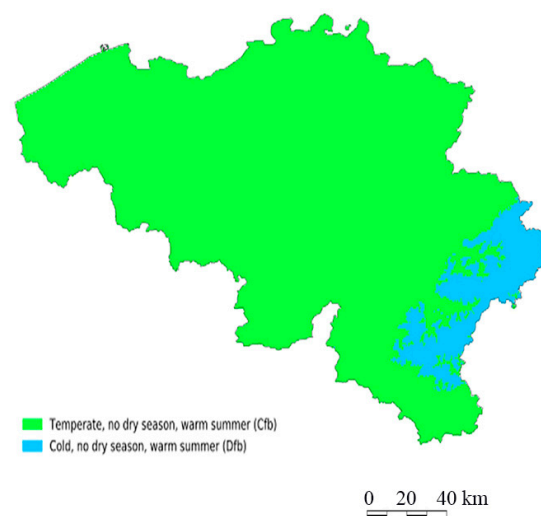


Figure 2. Köppen–Geiger climate classification map for Belgium (1980–2016) [29].

The Belgian energy certification framework is not affected by climate zoning and does not refer to DD; this variable is not a relevant parameter for the energy performance analysis.

Belgium has mainly a heating-dominated climate. According to Eurostat calculations [27], in 2022, the annual HDD and CDD in Belgium were 2377 and 28, respectively. However, due to climate change, summer overheating and the associated cooling needs are becoming more and more important in all European countries. Building-energy performance requirements must consider this evolving trend.

3.2.3. The Construction Characteristics

The characteristics of construction, as defined in Belgium, are much more extensive, compared to Italy [33]:

- The protected volume V (m^3) is defined as the volume of all rooms that are thermally shielded from the outside environment, the ground, and all adjacent rooms that do not belong to the protected volume;
- The heat loss surfaces A_T (m^2) are the surfaces that protect the protected volume;
- The total useful surface (m^2) is the sum of the useful surfaces of all floors inside the protected volume;
- The compactness C is the ratio between the protected volume V and the heat loss surfaces A_T ;
- The form efficiency is the alternative parameter for small constructions, in which the heat loss surface is compared with an equivalent spheric area.

These parameters are similar to those defined by the Italian regulatory framework. The main difference is that construction nodes are defined in the Belgian framework, instead of thermal bridges. Two kinds of construction nodes are defined:

- Linear construction nodes occur when (i) two different components of the heat loss surface merge; (ii) the insulation layer is interrupted linearly, for at least 40 cm, by a material with a higher thermal conductivity; or (iii) a component is attached to another component on the border of an adjacent lot.
- Pointed construction nodes occur as a pointed rupture of the insulation layer of a component of the heat loss surface.

3.2.4. The EPC Setup Procedure

In Belgium, there are two types of energy performance certification, which remain constant despite the regional implementation approach:

- The Energy Performance Certificate—The EPC (Energie Prestatie Certificaat) assessment provides information on the energy performance of existing buildings for the purchase or rental of buildings, and recommendations. The assessment is executed by an EPC-reporter and is valid for 10 years [34].
- The Energy Performance and Indoor Climate—The EPB (Energie Prestatie en Binnenklimaat) assessment provides information on the energy performance of new constructions or deep building renovations. The assessment is executed by an EPB-reporter and is valid for 10 years [35].

Moreover, separate EPC systems exist for residential, non-residential, and public buildings. The process of the acquisition of the EPC/EPB seems more complex in Belgium, since the energy class is defined only in the EPC. For the EPB, in contrast, the process phases are more elaborate and have stringent requirements for the collection of supporting documentation during the process. In particular, a ventilation design document is required in order to develop and finalize the EPB declaration.

3.2.5. Core Specifications of the EPC

In Belgium, each new and existing residential building undergoing a deep renovation must fulfil requirements relating to energy performance (E-level) and insulation (U-values), the amount of renewable energy, and indoor air quality. New buildings also need to comply with comfort-based limits (risk of overheating and ventilation).

The E-level denotes the overall energy performance of a building, quantified as the annual primary energy consumption expressed relative to a standardized reference consumption. This depends on several elements such as the specific thermal insulation, the systems, the access to sunlight, the air density, the orientation and the compactness of the construction, and the losses because of ventilation. Said E-level is expressed by a dimensionless indicator, which is defined based on the yearly primary energy consumption expressed in MJ. Afterward, the conversion is made to kWh/m². For residential constructions, the maximum E-levels are E30 and E60, which are the limits for new constructions and those undergoing deep renovations, respectively.

Concerning U-values, different limits exist for different construction parts, e.g., doors, windows, walls, etc. [33]. This requirement is valid for all kinds of construction types and all kinds of construction works. The maximum U-values need to be determined according to the scheme described in Table 4.

Table 4. Overview of maximum U-values in Belgium since 2012 for different elements.

	Maximum U-Value (in W/m ² K)			
	From 2012 to 2013	In 2014	In 2015	From 2016
Roofs, ceilings to attics	0.27	0.24	0.24	0.24
Outer walls	0.32	0.24	0.24	0.24
Floors on ground or above cellars	0.35	0.30	0.30	0.24
Windows (profile + glazing)	2.20	1.80	1.80	1.50
Glazing	1.30	1.10	1.10	1.10
Insulated existing walls (outside)	-	-	0.24	0.24
Insulated existing walls (cavity)	-	-	0.55	0.55
Insulated existing roofs (IEF)	-	-	0.24	0.24
IEF in contact with the outdoor	-	-	0.24	0.24

Regarding renewable energy, i.e., energy from natural and inexhaustible sources (wind, sun, water, and earth-heat), the minimum amount to be guaranteed is a primary energy quantity per gross area per year, and is equal to 15 kWh/m²y.

Indoor air quality is either assessed as basic ventilation (minimal and controlled ventilation) or as intensive ventilation; intensive ventilation is generally used in cases involving insufficient basic ventilation, hot weather, or the presence of chemical products. No fixed limits exist for the case of intensive ventilation; indeed, the value depends on the size and the function of the room. Finally, the limits on thermal comfort refer to reducing the risk of overheating, namely, the possibility of discharging excessive heat during hot periods. The overheating indicator $I_{\text{overh,seci,m}}$ (kH) expresses the chance of overheating; for this, there is a maximum value calculated per energy sector.

3.2.6. The nZEB

As requested at the European level, Belgium introduced the nZEB concept defining specific requirements that need to be fulfilled to reach the nZE status [33]: (i) the value of the E-level has a maximum of E30 and (ii) the construction has to comply with the design requirements valid from the year 2021. The envelope components' U-values need to be compliant with the following specifications:

- Glass → U_{\max} : 1.1 W/m²K;
- Windows (glass + frame) → U_{\max} : 1.5 W/m²K;
- Walls, floors, and roofs → U_{\max} : 0.24 W/m²K;
- Doors and gates → U_{\max} : 2 W/m²K.

The construction needs to produce at least 15 kWh/(m²y) of renewable energy. Since 2021, all new constructions need to be Nearly Zero-Energy Buildings.

3.2.7. The Calculation Tool

In Belgium, all energy calculations for EPC purposes must be carried out using one specific piece of software. The software is officially released by Energie Vlaanderen and is called 3G. However, the professional in charge of the calculation can choose how to model the influence of the construction nodes from among the following methods:

- Option A: This is the detailed method, in which the effect of the construction nodes is calculated by modeling the constitutive materials and geometries;
- Option B: This is the method utilizing the EPB-accepted construction nodes, which uses a fixed surcharge for every EPB-accepted construction node and Option A for the remaining ones;
- Option C: This is the lump surcharge, in which the designer does not attempt to reduce heat losses at the construction nodes, but simply uses a lump surcharge on the U-value (0.10–0.20 W/m²K).

3.3. Comparison Between the Two Frameworks

The following, Table 5, summarizes the key differences and similarities between the Italian and Belgian EPC frameworks. Moreover, Table 6 specifically provides a more detailed comparative evaluation of the classification systems for new constructions and deep building renovations in the two countries, i.e., the Italian energy classes and the Belgian E-level.

Table 5. Summary comparison between the Italian and Belgian EPC frameworks.

Dimension	Italy	Belgium
Regulatory framework and management	National level	Regional level (same national targets and requirements, but different processes)
Geographic context	Geographic extent: 302,100 km ² Population density: 206 people per km ²	Geographic extent: 30,700 km ² Population density: 351 people per km ²
Climate context	<ul style="list-style-type: none"> • National climate classification (6 zones) • Divided into 7 Köppen–Geiger climate zones • Both heating-dominated and cooling-dominated climate zones 	<ul style="list-style-type: none"> • No national climate classification • Divided into 2 Köppen–Geiger climate zones • Mainly heating-dominated climate zones
Influence of climate context on EPC	Energy requirements of buildings depend on the climate zoning	Energy certification framework not affected by climate zoning
Main construction characteristics	<ul style="list-style-type: none"> • Shape ratio S/V • External envelope solar reflectance • Thermal bridges 	<ul style="list-style-type: none"> • Compactness C • Construction nodes
EPC setup procedure	Unique process	Two different processes, depending on the building typology and the purpose: <ul style="list-style-type: none"> • Existing building purchase/rental • New construction/renovated building)

Table 5. Cont.

Dimension	Italy	Belgium
Types of EPC and terminology	Only one: APE (“Attestato di Prestazione Energetica”)	Two alternative types (selected according to the previous point): <ul style="list-style-type: none"> • EPC (“Energie Prestatie Certificaat”) • EPB (“Energie Prestatie en Binnenklimaat”)
Certification procedure	Energy performance indices use a comparison with a reference building (class A1 building, i.e., nZEB)	Fulfillment of requirements on energy performance (E-level), renewable energy, and indoor air quality
Classification	10 energy classes (from A4—most efficient—to G—least efficient)	Directly based on the E-level value
Energy performance index	Global Primary Energy – $EP_{gl,tot}$ [kWh/m ² y]	E-level [kWh/m ² y]
Core specifications	<ul style="list-style-type: none"> • Heat-transfer coefficient (U-values) [W/m²K] • Average periodic thermal transmittance Y_{IE} [W/m²K] • Solar heat gain coefficient for transparent surfaces (including solar shadings) g_{gl+sh} [-] • Solar heat gain area [m²] • Energy systems efficiency 	<ul style="list-style-type: none"> • (U-values) [W/m²K] • Renewable energy integration [kWh/m²y] • Ventilation rate • Overheating indicator $I_{overh,seci,m}$ [kH]
nZEB definition	Class A1 building achieving minimum requirements for core specifications and minimum renewable sources integration according to Legislative Decree 3 March 2011, n. 28	A building with E-level \leq E30 achieving minimum requirements for core specifications, including minimum integration of renewable sources
Calculation tool	Several alternative tools (need to be accredited and compliant with the regulation)	Unique tool (variation only in the modelling of the influence of the construction nodes)

Table 6. Comparison between the Italian energy classes and the Belgian E-level for the EPCs of new constructions and deep building renovations.

Dimension	Italian Energy Classes	Belgian E-Level
Number of classes	10 energy classes: from A4 (most efficient) to G (least efficient)	Numerical E-level score—the lower, the better
How the class is identified	Relative building overall energy performance (heating, cooling, and DHW, plus lighting and vertical transport for non-residential properties) against a reference building of identical geometry, exposure, location, and use	Absolute estimated primary energy use in kWh/m ² y
Interpretation	Reflects overall energy improvement potential (includes actionable recommendations)	Direct energy metric, with clear numerical meaning (lower scores, meaning higher efficiency; benefit from incentives)
Class required for the nZEB	A1	E30

4. Discussion

The comparison between Italy and Belgium (see Table 7) highlights the manner in which EPCs are simultaneously technical instruments and governance tools, and shaped by institutional choices, climatic contexts, and socio-technical traditions. This duality

creates opportunities for contextual adaptation but also contradictions that complicate EU-wide standardization.

Table 7. Critical elements and policy takeaways from the Italian and Belgian EPC frameworks.

Dimension	Critical Elements Observed	Policy Takeaway/Recommendation
nZEB criteria	Italy: Relative classes (A1 minimum) create ambiguity across contexts. Belgium: Absolute E-level thresholds are more transparent but less adaptive.	Move toward hybrid nZEB definitions: EU-level absolute baseline (kWh/m ² , CO ₂) + relative improvement targets. Consider dynamic EPCs that update with renovation stages or real-time performance.
Climate integration and resilience	Italy: Explicit climate zoning and passive summer requirements, but complex. Belgium: Ignores zoning, limited resilience (overheating only).	Introduce an EU-wide resilience indicator (cooling demand, overheating risk, and passive adaptability). Encourage zoning only where climatic diversity justifies it, using Köppen–Geiger classes as reference.
Classification systems	Italy: User-friendly but less comparable. Belgium: Precise but less intuitive.	Develop a dual-communication system: technical E-levels for professionals + simplified labels for citizens. Link labels to financial incentives and personalized renovation roadmaps.
Envelope performance (U-values, S-level)	Italy: Climate-specific U-values, but no compactness index. Belgium: Unified U-values + S-level, but less climate-sensitive.	Define EU adaptive U-value ranges tied to climatic zones; promote S-level or equivalent compactness metrics EU-wide. Connect envelope indicators to resilience goals (summer comfort, passive gains).
Construction nodes	Italy: No requirements beyond ISO, risk of neglecting thermal bridging. Belgium: Detailed node modelling increases accuracy, but resource intensive.	Mandate minimum EU standards for thermal bridge treatment but allow tiered compliance pathways (basic vs. advanced). Integrate construction nodes into embodied carbon and circularity assessments.
Certification software	Italy: Multiple accredited tools → variability and potential bias. Belgium: Single regional tool → uniformity but limited flexibility.	Require cross-validation of all EPC tools against EU benchmark datasets. Promote digital EPC platforms with open APIs to connect with BIM models, IoT sensors, and smart meters.
User comprehensibility and incentives	Italy: EPC classes better for public communication. Belgium: Numeric E-level clearer for experts but less engaging for users.	Couple EPC scores to gamified feedback apps and green mortgages. Use digital EPCs as gateways to tailor renovation advice, subsidies, and energy communities.
Generalizability of lessons	Italian model is hard to apply in decentralized states. Belgian model may not scale in diverse climates.	Encourage EU knowledge-sharing platforms showcasing approaches that work in different governance settings. Develop a taxonomy of EPC approaches (centralized, regional, and hybrid) to guide adaptation.
Overall takeaway	EPCs comply with EPBD but diverge in governance, technical robustness, and user relevance.	Evolve EPCs into next-generation socio-technical tools: harmonized EU macro-limits + flexible national/regional frameworks, enriched by digitalization, resilience metrics, and behavioral engagement.

A key contradiction emerges in the definition of nZEB criteria. Italy defines an nZEB in terms of energy classes relative to a reference building (minimum A1), while Belgium sets absolute E-level thresholds (E30). Both comply with the EPBD but operationalize “nearly

zero” in fundamentally different ways—relative benchmarking vs. absolute values. This discrepancy risks undermining comparability and raises questions about the feasibility of a unified EU trajectory toward climate neutrality.

Climatic differentiation adds another layer. Italy integrates both national climate zones and Köppen–Geiger classifications, embedding heating and cooling needs into EPC calculations, with specific indicators used for summer performance (e.g., periodic thermal transmittance, solar gain). Belgium, by contrast, largely disregards climate zoning, reflecting its more homogeneous, heating-dominated conditions (see Figure 3).

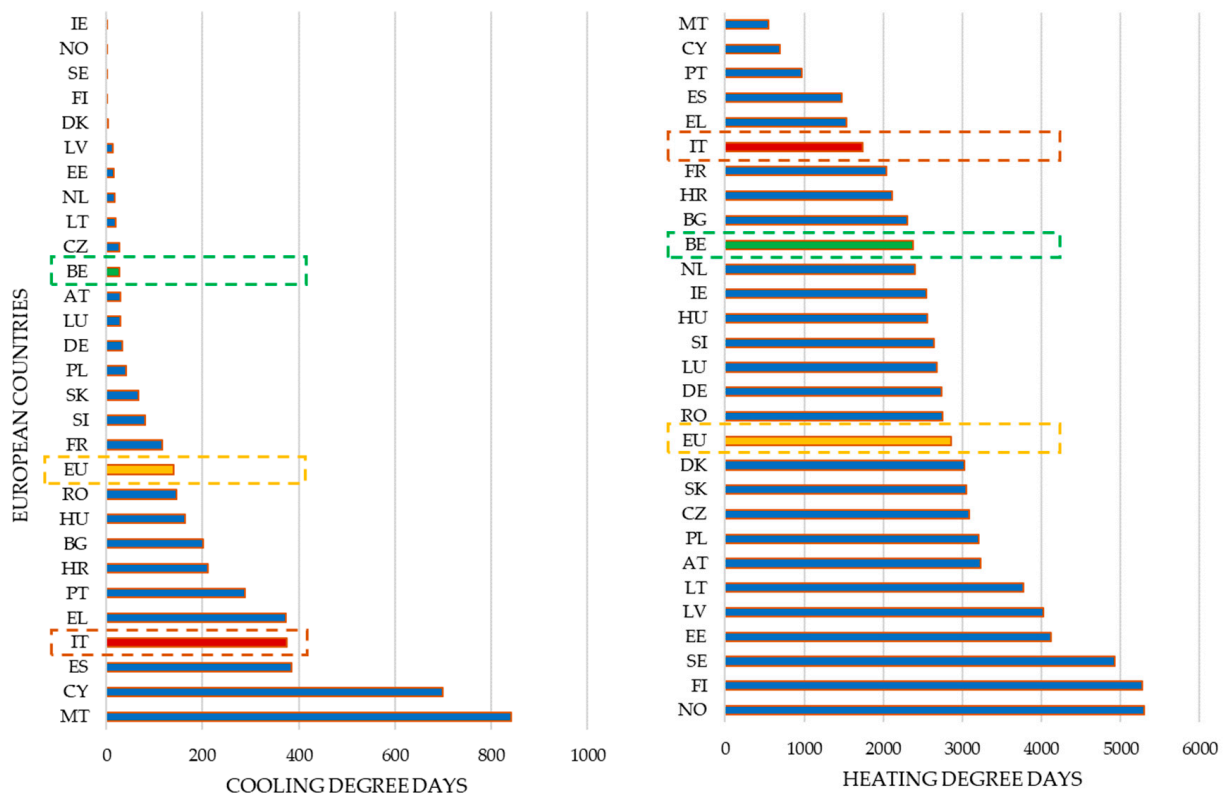


Figure 3. Differences in HDD and CDD in European countries [27]. The colored dashed boxes highlight the analyzed countries, i.e., Italy and Belgium, and the average value for Europe.

While this simplifies procedures, it underestimates vulnerabilities to climate change, particularly overheating. Here resilience becomes crucial: Italy’s EPC framework incorporates passive summer performance, whereas Belgium only considers overheating as a secondary risk. More explicit integration of climate resilience indicators (cooling demand, passive design, and adaptability) could strengthen EPCs as tools for climate adaptation.

Classification systems also reflect divergent philosophies. Italy’s energy classes are intuitive for users but can obscure comparability across borders. Belgium’s E-level provides a precise numerical metric, transparent for experts but less accessible to the public. The absence of a hybrid model—one that combines numerical transparency with user-friendly classes—represents a missed opportunity for EU-wide comprehensibility. Linking EPC outputs more directly to financial incentives and to actionable renovation recommendations could help bridge the performance gap by enhancing behavioral engagement.

Differences in calculation tools further complicate standardization. Italy authorizes the use of multiple accredited software tools, which may foster innovation but risk inconsistency and bias, depending on the tool selected. Belgium mandates the use of a single regional tool, ensuring uniformity but potentially stifling innovation and limiting adapt-

ability. From a European perspective, interoperability and cross-validation of software outputs would mitigate these risks, ensuring both consistency and flexibility.

Finally, the broader implications of EPC frameworks deserve emphasis. EPCs are increasingly embedded in real estate transactions, renovation policies, and financial incentives. Their credibility depends not only on technical robustness but also on user comprehensibility, digitalization, and behavioral relevance. The simplified indicators (classes, E-levels) need to align with market instruments (loans, subsidies), while digital EPCs could support dynamic monitoring, data integration, and user engagement. These socio-economic dimensions are as important as technical metrics, if EPCs are to function as levers for both decarbonization and resilience.

Overall, the Italian and Belgian cases expose the inherent tension in EU energy governance: harmonization ensures comparability and credibility, while contextualization ensures relevance and legitimacy. Future revisions of the EPBD should therefore pursue a layered model: harmonized macro-limits (e.g., minimum U-values, inclusion of overheating and passive-cooling criteria, and EU-wide indicators of resilience) combined with flexible sub-frameworks tailored to climatic and institutional realities. Only through such a layered governance approach can EPC evolve into effective instruments for both climate mitigation and adaptation as well as environmental impact reduction across diverse European contexts.

5. Conclusions

All in all, both approaches reveal strengths that could be mutually reinforcing in the perspective of EU-wide standardization. Italy could benefit from Belgium's detailed methodology for modelling construction nodes, provided that this is streamlined and aligned with ISO standards to facilitate comparability across countries. Conversely, Belgium's single-software approach could be liberalized to stimulate innovation and flexibility, while ensuring compliance with official requirements. In parallel, Italy's use of energy classes offers a communicative advantage for end-users and could complement Belgium's more technical E-level system, supporting both transparency for experts and comprehensibility for citizens.

The analysis also highlights that current nZEB definitions and EPC frameworks remain heavily biased toward winter performance. Italy already integrates requirements to improve passive summer behavior, but these are limited to heating and cooling degree days and thus risk overlooking the broader climatic variability captured, for instance, by the Köppen–Geiger classification. In light of climate change, the resilience of buildings in summer—including overheating risk, passive-cooling potential, and adaptability—must become a core dimension of certification. Looking ahead, EPCs in Europe should evolve from static, compliance-based tools into layered governance instruments, combining harmonized macro-limits for comparability, flexible sub-frameworks adapted to national or regional contexts, and forward-looking dimensions such as resilience, user comprehensibility, and digitalization.

Furthermore, linking EPC outputs to financial instruments and behavioral engagement—for example through green mortgages, targeted subsidies, dynamic renovation advice, or digital feedback platforms—can enhance both compliance and actual energy performance. By integrating technical robustness, climate resilience, and user-centered incentives, EPCs can become more than a regulatory obligation: they can serve as effective levers for achieving EU-wide decarbonization goals while supporting citizens and stakeholders in the transition toward sustainable, climate-resilient buildings.

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Abbreviations

The following abbreviations are used in this manuscript:

EPC	Energy Performance Certificate
EU	European Union
EPBD	Energy Performance of Buildings Directive
nZEB	Nearly Zero-Energy Building
APE	Attestato di Prestazione Energetica (Energy Performance Certificate, in Italian)
HDD	Heating Degree Days
CDD	Cooling Degree Days
EPC	Energie Prestatie Certificaat (Energy Performance Certificate, in Dutch)
EPB	Energie Prestatie en Binnenklimaat (Energy Performance and Indoor Climate, in Dutch)
IEF	Insulated Existing Roofs

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