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Review

Linking Energy Poverty with Thermal Building Regulations and Energy Efficiency Policies in Portugal

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Abstract: Energy-poverty (EP) must be considered an energy-related issue since buildings are a central part of people's daily lives. Thus, it has an important role in energy-related policy implementation. Even though the European Union (EU) has endorsed general energy efficiency through the Energy Efficiency Directive and Energy Performance of Buildings Directive recast, it was the Clean Energy Package for all Europeans that clearly highlighted EP. The growing concerns with EP have also been emphasised in subsequent directives and initiatives. Despite some regulatory framework and the milder climate situation, the proportion of the population experiencing thermal discomfort in southern and eastern European countries, namely in the winter season, is relatively high, reflecting the poor thermal performance of building stock, low family incomes and high energy prices, among others. The current work analysed the EP evolution in Portugal in the EU context, and the Thermal Building Regulations and Energy Efficiency Policies developed, aiming to add insight into the effectiveness of those policies concerning EP mitigation in Portugal as an EU Member state. Moreover, a critical debate on the potential to lower the EP Portuguese situation was also an objective to pursue. It is plausible to admit that reducing EP by acting on residential building stock, namely through the increase of energy efficiency and comfort, plays a key role in improving the living conditions, namely of vulnerable households and deprived areas. This will also decrease energy consumption and dependence while further promoting a smarter, sustainable and inclusive society, contributing to economic growth.

Keywords: residential buildings; thermal building regulation; energy performance certificate; energy efficiency; energy poverty

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1. Introduction

1.1. Scope

Climate change awareness is a major issue for the European Union (EU), and has been under scrutiny by governments and authorities during recent decades. Developed European nations' buildings can emit about 36% of the greenhouse gases (GHG) [1], and consume 41% of the total final energy, making them the largest energy customer in Europe [2]. Both GHG and energy consumption are expected to increase due to current trends in population growth and urbanization. Since the building sector significantly impacts economic, environmental and social pillars, their high ecological footprint raises serious concerns. Thus, efforts have been made to shift the sector's paradigm, which is mainly dependent on technical climate control systems and high embodied energy building materials, to a more holistic, sustainable and passive approach. This has contributed to a global amendment of thermal building standards [3]. The new building sector paradigm rethinks the design, built and operating stages, by way of, for example, designing new low- or zero-energy buildings, increasing the amount of energy produced from decarbonizing sources, retrofitting existing buildings to reduce energy consumption and dependence as well as constantly improving energy efficiency measures, which foresee regular research and development of state-of-the-art technologies or solutions.

Nevertheless, with the 2015 Paris Agreement (PA), there has been a paradigm shift in society, with the explicit recognition that only with the contribution of everyone is it possible to fight climate change and stop global warming on the planet. As a result, the European Commission has created a series of strategic packages to respond to this global challenge in different areas. The Clean Energy Package for all Europeans [4] must be pointed out. This package [4] was presented in 2016 to promote the energy transition in the 2021–2030 decade, complying with PA and contributing to economic growth and job creation. In brief, the Clean Energy Package for all Europeans calls for all Member States (MS) to present an Integrated National Plan for Energy and Climate for the 2030 horizon addressing goals and objectives regarding GHG, renewable energies, energy efficiency, energy security, internal market and research, innovation and competitiveness, including a solid plan and methods to achieve them. Additionally, for the first time in the EU, energy poverty (EP) is clearly highlighted. A unanimous EP definition is still lacking; however, it can be said that a household experiences EP when essential energy services in the home, such as adequate warmth, cooling and lighting, cannot be afforded.

EP is a severe threat to Europe, and it is estimated that more than 50 million European families live in EP, experiencing significant thermal discomfort, mainly in the winter season [5]. EP impacts on human health and well-being, and it has been associated with respiratory and heart diseases, and excess winter mortality and morbidity, namely for the vulnerable population, as stated in previous studies [6–12]. According to Geddes et al. [6], there is a strong relationship between cold housing temperatures and cardiovascular and respiratory diseases. Besides, children living in cold homes are more than twice as likely to suffer from various respiratory problems than children living in warm homes. The elderly population is susceptible to cold weather, the main source of excess winter deaths [7]. Concerning mental health and well-being, adults and adolescents are the most affected by cold housing [6,10]. A population living in EP is more likely to have poor emotional well-being and depression [11].

Throughout the literature, it is stated that EP essentially occurs in a scenario of low family income, poor quality dwellings with defective insulation and energy inefficient houses and high energy prices [13–15]. Besides, unexpected situations, such as the actual COVID-19 pandemic, can be linked to the temporal increase in EP, mainly due to increased energy pricing and unemployment. EP has been recently addressed among EU countries, such as France [16,17], Italy [18], Greece [19], Spain [20] andPortugal [21–23], and even in studies at EU scale [24–27]. Those findings evidence the diverse geography of EP at the national and EU level; however, it seems particularly prevalent in southern and eastern EU countries [14,25,28,29].

Furthermore, since the economic crisis in Europe in 2008, southern and eastern EU countries experienced a rapid EP increase as a side effect. It was estimated that, in 2012, 21% of the population of southern and eastern European countries lived within the EP scenario, while in the same year, it was predicted to be 3.5% concerning northern and central European countries. Although EP seemed to decrease slightly in 2016, to 12.6% and 2.0%, for southern and eastern and northern and central European countries, respectively, the economic crisis exposed the structural weakness of the root causes of EP, mainly in the southern and eastern group [30].

Among southern EU countries, the Portugal case needs some reflection, namely due to the following reasons: (i) the residential final energy consumption has been far above the majority of other EU MS, even considering Spain or Italy, which present similar climate conditions [31]; (ii) the residential building stock is aged [32] and thus not properly energy efficient, with high energy needs required to fit minimal comfort [33,34]; (iii) it is estimated that more than one third of the Portuguese building stock needs some intervention and approximately 50% of these require deep renovation to achieve minimal comfort requirements [35] that will move households to an economically poor situation [36,37];

(iv) households use decentralized or low-efficiency HVAC systems [13]; (v) significant percentage of the Portuguese population still lives in EP [13,21] linked to the residential buildings' thermal performance; (vi) the Iberian Peninsula is expected to be one area considerably impacted by global warming, with potential impacts for heating and cooling energy demands [38,39]; (vii) finally, the electrical energy and natural gas prices for household end users (including taxes and levies) are among the highest in the EU [40].

1.2. Research Significance and Objectives

Despite being a Mediterranean climate EU country, a considerable percentage of Portuguese households still live in EP. For a long time, the thermal discomfort experienced by Portuguese families was not relevant, mainly for economic reasons. It can be said that the extreme heating season is short (from 1 to 3 months a year, between December and February), and the extreme cooling season is even briefer (less than one month, between July and August), thus covering the EP perception. EP was absent from any policy frameworks until 2010 when the social energy tariff emerged due to the severe economic crises. Afterwards, some measures have been adopted in Portugal, at the national and regional level, tackling EP directly or indirectly, as subsided schemes for promoting energy-saving and Renewable Energy Systems (RES) technologies. Thus, two questions arise: how has thermal discomfort been overcome with energy efficiency measures through residential building thermal regulation adopted in the last years, and do those regulations somehow alleviate EP?

These thematic lines are highly linked, but their relationship is not linear. The current work aims to add insight into the effectiveness of the regulation and policies that have been adapted to reduce EP in Portugal as EU MS and translate the results into a source for a critical debate on the potential to lower the EP Portuguese situation.

The authors first present a short context of the Portuguese climate and residential building stock and energy consumption (Section 2). Section 3 presents an overview of the EP concept and its effects on society, analyzing EP indicators and the main public policies tackling it. Later the authors focus on the evolution of thermal building regulation focused on residential building stock and implementation of the energy certification system in Portugal (Section 4). Afterwards, Section 5 explores general synergies and trade-offs between these fields of enquiry. Finally, Section 6 summarizes the main conclusions of this review.

2. Portuguese Specific Context

2.1. Mainland Climate

Despite being a relatively small continent, Europe has a great variety of climates. According to the classification initially developed by Wladimir Koppen over a hundred years ago and adapted by Peel et al. [41], Europe has a climate predominantly categorized into three types: cold—letter D, temperate—letter C and polar—letter E.

Portugal and Spain form the Iberian Peninsula, and Portugal is the westernmost country of Europe. Portugal recorded the third-lowest number of heating degree-days and the fifth-highest number of cooling degree-days among EU MS in 2020; thus, it can be considered one of the warmest countries in Europe [42].

According to Wladimir Koppen's classification, Mainland Portugal's climate is temperate. The temperate climate is divided into two regions, which are: (i) hot-summer Mediterranean climate region (Csa) with temperate climate with dry and warm summers; and (ii) warm-summer Mediterranean climate region (Csb) with dry and mild summers [43]. Serra da Estrela is located in the transition between the temperate and humid regions of the temperate oceanic domain (Csb), in the north, and the hot and dry summer regions, of Mediterranean influence, in the south (Csa).

The climate of mainland Portugal has a strong influence on the Atlantic Ocean and the Mediterranean Sea. The Mediterranean Sea causes high temperatures and low rainfall, and is felt mainly in the summer in the south and east region. On the other hand, the

Atlantic Ocean influence is responsible for high precipitation and the attenuation of dry and cold winds from the Peninsula's interior, and it is felt primarily in winter, namely in the northwest of the mainland territory.

The average annual temperature varies between 12 °C in the northern mountainous areas and more than 18 °C in the south and the Guadiana basin. The national annual average is situated at 15.2 °C. However, the average monthly values vary regularly throughout the year. There are regional variations in its distribution; for instance, Beira Baixa and Alentejo achieve a maximum air temperature of 36 °C in July due to very hot summers. Furthermore, very cold winters occur in Northeast regions, with temperatures around 0 °C [43]. More information about the Portuguese climate can be found elsewhere [43].

2.2. Residential Building Stock and Energy Consumption Pattern

The Portuguese building stock is represented by 86% of residential buildings, corresponding to about 2.46 residential buildings and 7.03 million dwellings [32] for about 10.5 million inhabitants in an area of 92,226 km^2.

As can be perceived in Figure 1, the Portuguese residential building stock is old. Buildings dating back to 1945 or earlier comprise 14% (corresponding to 1.00 million dwellings), and approximately 60% were built before 1990 (4.02 million dwellings, see Figure 1) [32], prior to the first thermal regulation in the country. In addition to being old, Portuguese building stock presents poor thermal characteristics, low penetration of space conditioning systems alongside the low efficiency [44]. It also must be noted that 25% of the total number of buildings are Historic, namely constructed before 1960 and about a half of these buildings were designed using traditional systems, with stone masonry and wood floors and roofs (without concrete). Moreover, these buildings' historical and architectural value makes them sometimes incompatible with traditional thermal improvement technologies or solutions, such as insulation measures [35].

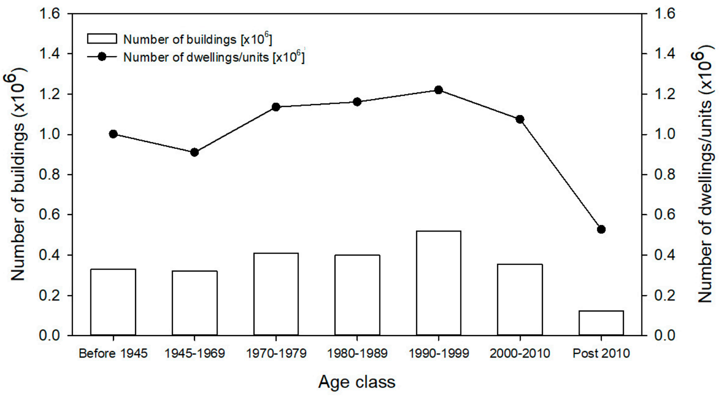


Figure 1. Building stock in Portugal considering construction age class (data source [32]).

Portugal followed the trend of the remaining European countries, and thermal characteristics (U-value) of the main constructive elements (walls, windows, roof and floor) has been improving, as depicted in Figure 2. The most significant reductions in U-values coincide with the publication of buildings' thermal performance regulations (1990, 2006, 2013), further discussed in Section 4. Structural elements are usually stone or brick masonry, or reinforced concrete. Stonemasonry and wooden roofs and floors are characteristic of older buildings. Nowadays, reinforced Portland cement concrete in the bearing structure is the most common constructive practice, similar to other European countries.

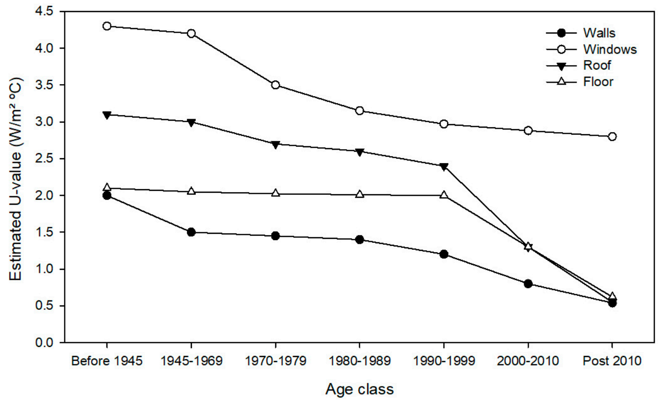


Figure 2. Estimated U-Value for building envelop elements of Portuguese building stock considering construction age class (data source [32]).

Figure 3 presents the residential building's energy consumption concerning the last decade (2010–2019) [45]. It can be perceived that cooking was the prevalent energy consumption end-use (2010–2019 average, 37.7%), followed by space heating (2010–2019 average, 24.4%). It must be stressed that the space heating energy consumption for that decade was far above the EU average (which was approximately 60%).

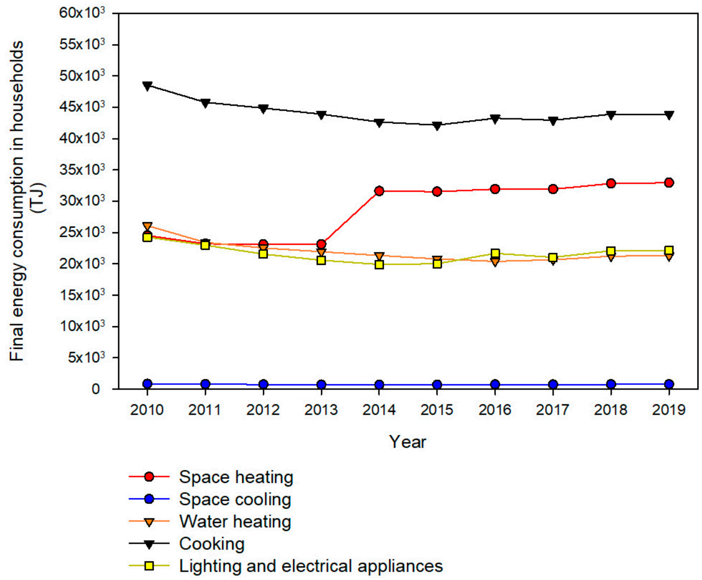


Figure 3. Households' energy consumption by use (data source [45]).

Analysis of the energy sources for household space heating show, as can be seen in Figure 4, that biomass was the primary source of energy used (2010–2019 average, 57.5%), noting however that heating heat pumps already represents a significant share of energy consumption in this type of use (30.7% in 2019), as well as electricity (2010–2019 average, 15.1%; however, it has been decreasing). Natural gas and solar energy show a reduced expression, as depicted in Figure 4 in (2010–2019 average, 0.5% and 1.2%, respectively).

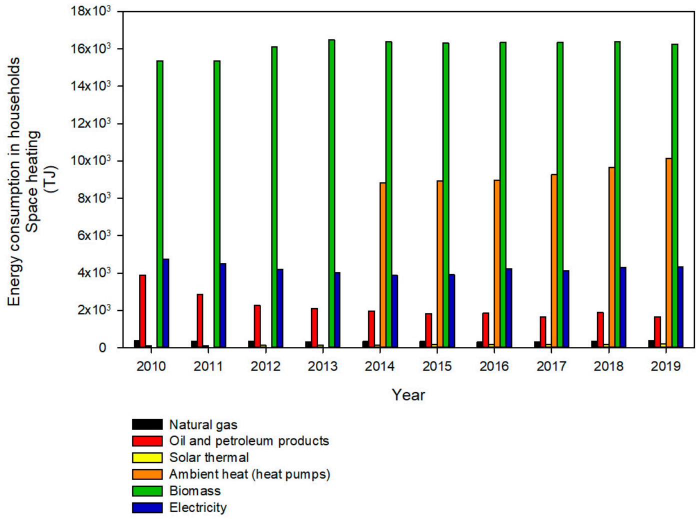


Figure 4. Energy consumption in households for space heating by source (data source [45]).

3. Energy Poverty in Portugal and EU Context

3.1. Energy Poverty and Consequences

Originally, EP derived from fuel poverty, a concept that appeared in the United Kingdom in the 1970s, due to the energy crisis. In 2000, the first government actions to combat EP occurred through The Warm Homes and Energy Conservation Act [46]. Since then, the theme has been explored in several countries, including France [16,17], Italy [18], Greece [7,19], Spain [20] and Portugal [13,21–23].

Among several definitions available in the literature, according to the EU Energy Poverty Observatory (EPOV) [5], EP lacks essential energy services in the home, such as adequate warmth, cooling, lighting and the energy to power appliances. Usually, EP is associated with a combination of factors: low household incomes, high energy expenditure and inefficient buildings and appliances.

One of the main features of EP is the inability of many households to maintain their homes at minimum comfort levels in terms of the average indoor temperature throughout the year, considering the weather conditions discrepancy. The World Health Organization (WHO) recommends indoor temperature in the range 18 °C–24 °C. Prolonged exposure to significantly lower or higher temperatures may be a proximate cause for the outbreak of physical and mental illnesses, especially in vulnerable groups, such as the elderly, chronically ill people, children and pregnant women.

The adverse consequence of cold indoor temperatures to health has been under scrutiny and thus associated with increased blood pressure, asthma symptoms, cardiovascular and respiratory diseases, exacerbation of existing musculoskeletal problems, poor mental health, and slight illnesses such as colds and flu [6–12]. A positive association between EP and obesity was recently stated [47]. Cold homes may also contribute to excess winter mortality and morbidity (EWM), namely in the elderly population, attributed to both respiratory and cardiovascular disease [12]. According to the WHO, cold housing is expected to be responsible for 30% of the EWM in Europe [14]. Even though the studies relating to cold weather and morbidity/mortality are still scarce, EWM is supposed to be associated with housing quality and performance, especially thermal insulation [9].

Particularly in children, EP impairs weight gain, development and educational attainment, well-being, reduces nutritional opportunities and choices, and increases the risk of accidents and injuries at home, namely in cold conditions [6,48,49]. EP also affects other areas, such as worksite or study areas, with social consequences through stigmatization and reduction in social interaction [50].

Poor mental health is also manifest in the literature as a side effect of an EP living scenario [6,51,52]. Living in poor housing may cause anxiety, stress and depression associated with balancing bills, heating needs and debt.

Another type of EP is the inability to cool houses in the face of heat peaks, which is also associated, in certain countries, with a higher frequency of intra-annual periods of heat, higher average temperatures and consequently with the occurrence of acute episodes of illness. The lack of cooling capacity of the house to maintain a comfortable indoor temperature, regardless of the temperature outside, is also an indication of EP, since the household cannot afford the necessary equipment and/or support an expense in energy consumption that would allow comfort, besides the deficiency's energy performance of the house itself. The literature is scarce concerning this issue.

However, in Portugal, as a country in which social effects, particularly on health, occur cyclically with some accuracy, it is worth noting the existence of the ICARO Project [53], by the Ricardo Jorge Institute, which is an instrument of observation of the effect of extreme climatic factors on human health. This national project encompasses research, surveillance and monitoring of the effect of heatwaves on human mortality and morbidity.

3.2. Main Actions and Policies Tackling EP

Despite the lack of a dedicated and exclusive authority to EP and a structured strategy addressing it, many initiatives and policies have focused on energy efficiency and building thermal performance, which may indirectly decrease EP. This section examines some activities tackling EP-related actions and policies. A non-exhaustive list of legislations and actions on EP in the EU is presented in Table S1 in Supplementary Data Section.

A shared EU energy policy did not exist in any articulate form until 2007 [5]. Efforts were made in the mid-2000s, introducing Directive 2003/54/EC and Directive 2003/55/EC, providing market regulation electrical energy and natural gas and highlighting the need to protect vulnerable citizens against eventual electricity disconnection afford incapacity. Nonetheless, in July 2007, European consumers benefited from the liberalized electricity and gas market with the Second Energy Package. However, some MS implemented rules insufficiently or imposed delays and still left many consumers without choices. Thus, the straightforward Third Energy package was adopted in 2015 [53], which included rules to assist European energy consumers and protect their rights. The growing trends of EP were highlighted in subsequent Directives and initiatives such as with the Energy Union in 2015 [54] and Vulnerable Consumer Working Group in 2016 [55]. The "Clean Energy for All" must be emphasised (in 2016) as well as the development of EPOV (2018). EPOV monitors EP in EU through several indicators, both quantitative and qualitative (discussed further in Section 3.3), providing an open-access source and thus supporting energy-related target decisions at local, national and EU levels [5,56].

Two other pillars have supported the EU energy policy: the Europe 20–20–20 Strategy and the Energy Roadmap 2050. The 20–20–20 Strategy looks for a 20% reduction in EU GHG emissions from 1990 levels, an increase of 20% in the proportion of EU energy produced from renewable resources and a 20% improvement in the EU's energy efficiency. The Energy Roadmap objects to reducing EU emissions by 80% by 2050 through the decarbonization programme.

Furthermore, EU has been enforcing change in the construction sector paradigm providing Directives to enhance the energy efficiency of buildings and decrease their ecological footprint, such as the Energy Efficiency Directive (EED, 2012/27/EU) and the Energy Performance of Buildings Directive recast (EPBD, 2010/31/EU). These directives may have a relevant role for EP mitigation since they influence a recognized EP driver, i.e., the energy performance of buildings [57]. A more detailed overview of Thermal Building regulation is presented in Section 4.

The aforementioned EU policies have been transposed into national legislation among MS, resulting in national or regional measures. Four types of measures can be identified and often implemented to tackle EP directly or indirectly [16,58]:

- Consumer Protection (e.g., special tariffs, disconnection protection);
- Financial Interventions (e.g., short term solutions through payment);

- Energy savings measures and RES integration (subsided schemes for the promotion of energy-saving and RES technologies);
- Information Provision (e.g., awareness campaigns, energy-saving tips).

Selected national and regional measures for Portugal are presented in Table S2 in the Supplementary Data Section, and those are clustered according to the previous classification. As can be perceived, the Portuguese measure to combat EP relies on Consumer Protection and Energy savings clusters.

National legislation exists solely for special energy pricing regarding the Consumer Protection category. Thus, the energy cost in Portugal is moderated by, namely, (i) a social tariff rate providing access to energy services at more affordable prices to vulnerable consumers, and (ii) extraordinary social support, which is an extraordinary and temporary measure adopted by the government, associated with the increase in electricity consumption during a specific season (e.g., winter months) or situation (e.g., quarantine due to COVID-19) (see Table S2, Supplementary Data Section). Vulnerable consumers are accessed through the national welfare system's criteria The social tariff was implemented in 2010 and since then has been revised periodically to include more groups of vulnerable consumers (see Table S2, Supplementary Data Section). It should be pointed out that, as a result of an in-depth review undertaken in 2016 (Decree-Law 7-A/2016), electrical energy in social beneficiary households increased from 200,000 to more than 800,000 (covering 14% of residential electricity consumers), while increases were seen for natural gas from 15,000 to 35,000 (2.6% of natural gas consumers). The significant difference among electrical energy and natural gas social beneficiary households seems to be related to the lack of standard eligibility criteria, in which the social electricity tariff is more comprehensive as it includes an income condition, and to the fact that the Portuguese electricity network is more developed compared to the natural gas network [59].

Concerning the energy efficiency of the building stock, some policy measures have been implemented in the last decade in Portugal. A compilation of such measures is presented in Table S3 in the Supplementary Data Section; however, some points are worth mentioned here. Under the National Action Plan for Energy Efficiency (PNAEE 2016), required by the Clean Energy Package for all Europeans and EED, the Energy Efficiency Fund launched "Aviso 25" [60]. "Aviso 25" aims to promote the rational use of energy in the building sector, which represents around 30% of total energy consumption in Portugal. The beneficiaries of this programme are owners of existing residential or service buildings under private law, which can contribute to the goals defined in PNAEE or national energy efficiency targets under the implementation of EED. "Aviso 25" finances 60% of energy efficiency measures of the beneficiaries, such as the requalification of domestic hot water heating systems, efficient windows installation and requalification of thermal insulation according to the Regulation on Energy Performance of Commerce and Services Buildings (RECS). Even though this grant scheme is not explicitly targeted at energy-poor households, it prioritizes older buildings and primary energy savings.

In addition, soft loan-based schemes for building renovation have been implemented at a national level, such as "Casa Eficiente" [61] and IFFRU [62] (see Table S2, Supplementary data Section). "Casa Eficiente" is suitable for all homeowners, as well as renters, with permission from the owner. The interventions covered by the programme aim to boost energy efficiency, use renewable energies, increase water efficiency, and improve environmental performance through applying thermal insulation in walls, replacing frames, optimizing elevators, installing solar photovoltaic panels, installing solar thermal systems, and acquiring high energy and water efficiency appliances, among others. On the other hand, IFFRU soft loan-based scheme targets buildings older than 30 years in a precarious conservation state, and it supports building envelope renovations, HVAC systems replacement, and installing renewable energy systems. Later, in September 2020, a new financing scheme nominated "Support Programme for More Sustainable Buildings" was implemented. This initiative was part of the government's Economic and Social Stabilization Program, and it aims to improve buildings' energy performance. It has a non-refundable budget of EUR 4.5 M for energy efficiency projects, financing up to 70% of the building envelope interventions, HVAC systems replacement and hydric efficiency [63].

Low-income Portuguese households may particularly benefit through programmes sponsoring enhancements in vulnerable, disadvantaged communities and social neighbourhood households (see Table S2, Supplementary data Section). The first measure has been implemented since 2007 with some revisions in 2014 to incorporate eligibility criteria, aiming to improve the housing comfort of vulnerable households. In 2017, the "Integrated Action Plans for Disadvantaged Communities (PAICD) and Energy efficiency (EE)" was implemented These schemes are nationally funded but regulated on the regional, municipal and social neighbourhood levels [63].

Very recently, the National Energy and Climate Plan 2030 (PNEC 2030) [64] was approved in Portugal, and with this, EP is directly highlighted. Regarding this topic, PNEC 2030 aims to fight EP moving to a more integrative approach through, namely, (i) promote a long-term strategy to fight EP; (ii) establish a national EP assessment and monitoring system to locate and count the number of households living in EP; (iii) pursue mechanisms to protect vulnerable consumers and possible new strategies; (iv) develop programmes to promote and support energy efficiency and the integration of renewable energies to alleviate EP; (v) promote and support local strategies to fight EP; (vi) disseminate information to alleviate EP.

3.3. EP Indicators Analysis

Among the literature, three main drivers are widely recognized as consensus for determinants of EP, namely: low household incomes, the low energy efficiency of the dwelling and home appliances and high energy prices [14,25,46,65,66]. Nevertheless, EP is a multidimensional phenomenon and understanding it only results in the three aforementioned factors might be simplistic. In fact, EP results from more profound structural determinants, such as governmental, political and social aspects. Discussion regarding that subject can be found elsewhere [14,15]. EP is a complex phenomenon; thus, several EP indicators have emerged in the literature. An organized literature review and analysis of EP indicators can be found in [66]; however, some details must be pointed out. Economic domain indicators seem to have a key role in measuring EP and are the most commonly used indicators, such as efficiency–consumption relationship, income and energy consumption. However, social and environmental elements should also be considered, and EP measurement systems must include these three dimensions. Most EP evaluation indicators are simple to calculate and can be easily applied to any country or region. More complex methodologies also have emerged, but they require detailed assumptions and comprehensive data sources, and thus are very time-consuming.

Among the literature, the most popular EP indicators are 10% indicator, Low Income High Cost (LIHC), Twice the National Median Indicators (2 M), Minimum Income Standard Indicator (MIS) and After-Fuel-Cost Poverty Indicator (AFCP). Other indicators from European Union Statistics on Income and Living Conditions (EU-SILC) can be interesting, such as the percentage of pollution, which is unable to keep the home adequately warm (or cool), and the percentages of houses presenting leaking roofs, damp walls/floors/foundations, rot in window frames and the percentage of households with arrears on utility bills. The current work is focused on EP indicators available in EPOV [5]. EPOV was put forward in Clean Energy For All European packages and emerged in 2018, to monitor EP through data collecting though several databases, such as the European Union Statistics on Income and Living Conditions (EU-SILC) and Household Budget Survey (HBS). Several EP indicators are provided by EPOV, including four primary indicators and 19 secondary indicators [5]. Two of the four primary EP indicators are based on self-reported experiences of limited access to energy services, namely, (i) share of population having arrears on utility bills and (ii) share of population not able to keep their home adequately warm (both based on EU-SILC data). The other two indicators for EP are (iii) the M/2 indicator which represents the percentage of households whose absolute energy expenditure is below half the national median and the (iv) the 2 M indicator, which translates the percentage of households in which the energy expenditure in income is more than twice the national median share (both based on HBS). A list of EP indicators and the main description of each one can be found in [5].

Figures 5 and 6 present two times of evolution, since 2004 of EP indicators in the EU and Portugal related to housing, namely, share of population not able to keep their home adequately warm and share of the population with leak, damp or rot in their dwelling, respectively. As can be perceived, the percentage of European households unable to keep home adequately warm was kept roughly constant, with a maximum of 10.8% in 2012 and 2013, and a minimum of 7.0% in 2019. However, thermal discomfort still affects a considerable percentage of the population in Portugal, where maximum and minimum peak values of 28.3% and 18.9% were observed in 2014 and 2019, respectively, as depicted in Figure 5. Since 2014, Portuguese households unable to keep their home adequately warm have decreased. The data collection is based on a survey; thus, values are self-reported [67].

The building envelops condition indicators, accessed by the share of population with leak, damp or rot in their dwelling, presented in Figure 6, which seem unsatisfactory, considering that, in 2019, 24.4% of the population lived with leaks, damp or rot in their dwelling. At the EU level, this corresponded to 12.7%. This discrepancy comes from a wide variation among MS [68].

Surprisingly, the total population falling behind on utility bills is slightly higher at the EU average level than Portugal, see Figure 7. Particularly for this EP indicator, Portugal performs better than most of MS; however, this could be misleading since biomass is the main households energy source for space heating (as discussed in Section 2.2 and Figure 4), and energy bills do not comply with this source of energy [22].

Although the association between cold weather and health issues has been stated among the scientific community, populations across southern and eastern Europe still experience significantly more deaths in winter than in non-winter seasons. Share of excess winter mortality (EWM) is a secondary indicator of EP, and according to the last available data on EPOV, dating from 2014, depicted in Figure 8, in Portugal, an excess winter mortality/morbidity of 24.9% was observed, the second-highest value among EU MS [69]. In fact, Portugal is one of the southern countries with Ireland that have higher mortality in the winter season. EWM ranged from 7.8% (Slovakia) to 28.3% (Malta) at the EU level, with an average of 13.9% for the EU. It is worth mentioning that southern European countries, with milder climates and less severe winters, exceeded EVM of northern and central countries, which may be due to improved housing quality and adequate and effective insulation of housing, although with much harsher winters. EP is felt relatively more in the countries in the south, from a health perspective, assessed by EWM indicator.

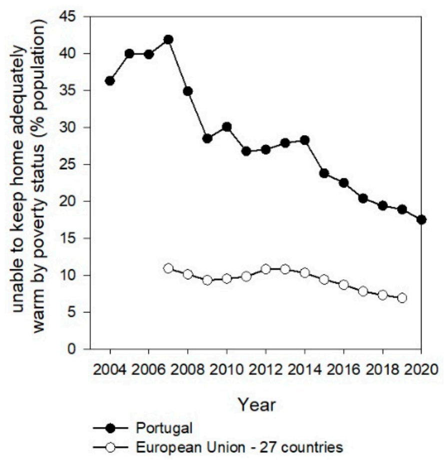


Figure 5. Proportion of inhabitants unable to keep home adequately warm (data source [67]).

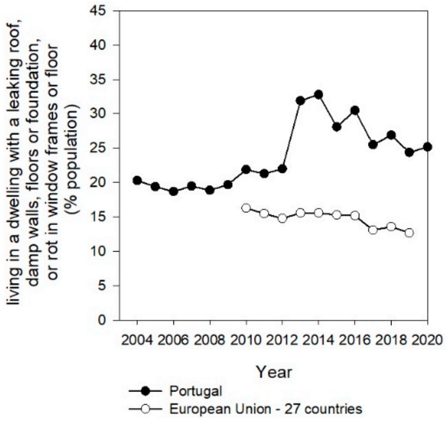


Figure 6. Proportion of inhabitants living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor (data source [68]).

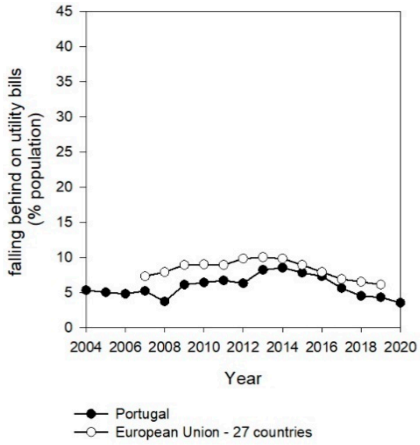


Figure 7. Share of the total population falling behind on utility bills (data source [70]).

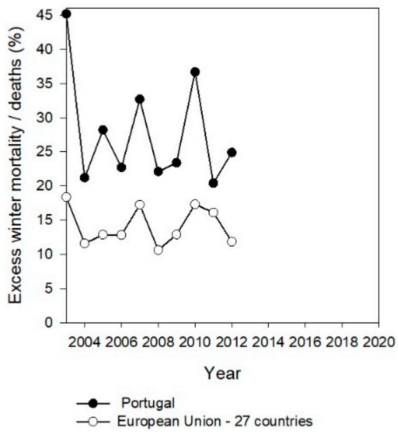


Figure 8. Share of excess winter mortality/deaths (data source [14]).

Regarding household incomes and energy expenses, some indicators are suggested by EPOV, as M/2 and 2 M, as previously referred. However, these indicators are very recent and little data are available, as can be reported in [5]. Thus, the authors address the median equivalized net income by households at the EU level and Portugal, as shown in Figure 9. The median equivalised net income by households at EU scale has been slowly increasing up to 2014, achieving EUR 15,114 per household. Afterwards, it evolved more substantially, and it was EUR 17,366 per household in 2019. The median equivalized net income by households in Portugal ranged from EUR 6921 in 2004, reaching an all-time high of EUR 10,800 in 2020. Portugal presents a median equivalized net income 44% lower than the EU average [9]. Besides, it must be noted that poverty risk was defined as EUR 6480/year per household, and therefore, 19.8% of the Portuguese population were in poverty risk and/or social exclusion in 2020 [71].

The energy prices for household consumers, with taxes and levies, are also considered an EP (secondary) indicator (see [5]). Electricity is the main energy source consumed by households (46.4% in 2020), followed by biomass, representing 18.4%. Natural gas consumption has been increasing due to the expansion of the Natural Gas network, accounting for 12.4% (compared to 9.0% in 2010) [72]. Natural gas is not as common in Portugal as in other European countries. Indeed, many households do not use natural gas, and many have no connection to the natural gas network. This is often the case in rural areas and the country's island communities. In those areas, gas is supplied by bottled gas or outdoor tanks. Bottled gas is available at most fuel stations and larger supermarkets, and there are also delivery services operating throughout the country. Natural gas gained importance very recently, and only in 2020, it was the third main source of energy in the domestic sector in terms of consumption, over bottled gas (12.2%). LPG and fuel were used by 4.4% and 4.1% of Portuguese households and 2.1% concerning solar energy [72].

Considering the focus of the current paper and previous analyses, the authors present the electrical energy and natural gas prices for the EU and Portugal. However, some points must be tackled. The evolution of energy prices, namely electrical, is consequence of international market trends as well as national circumstances and the multiple energy changes. During the last decade, the energy sector has been deeply changing due to the privatization of publicly owned utility companies, the vertical breakdown of network activities and the energy market liberalization. Even though these measures aimed to reduce end-use prices, this was not always achieved by regulatory reforms, especially concerning domestic energy tariffs [28]. Each household's effective price per electric energy unit exhibits widespread variety in Portugal, depending on the individual supply conditions contracts. Concerning taxation, is it noted that in October 2011, VAT applied to electrical energy and natural gas changed from 6% to 23%. Later, in July 2019, the VAT on these energy sources returned to 6%, however with limitations, as low power energy (3.45 kVA) and consumption at low pressure not exceeding 10,000 m^3 per year for electricity and natural gas, respectively.

Figure 10a,b depicts the development of electricity prices in the band DC 2500–5000 kWh/year consumption, with and without taxes and levies, for household consumers in the EU and Portugal since 2008. EU mean electricity price without taxes and levies (Figure 10a, black slice bars) increased slightly until the second half of 2013 when it was 0.1498 EUR/kWh. From 2014 to 2020, it remained relatively stable. In the second semester 2020 electrical energy EU average price without taxes and levies was 0.1537 EUR/kWh (and 0.2134 EUR/kWh with all taxes). The taxes and levies at the EU level have been increasing, with slight variations between 20–29% of the electrical billing. Concerning the Portuguese scenario, depicted in Figure 10b, between 2011 and 2014 the electrical energy price (without taxes and levies) increased almost at a constant rate up to 0.1379 EUR/kWh, and afterwards, it occurred a significant drop to 0.1232 EUR/kWh in 2015. Later on, the electricity price increased again up to 2016 and has decreased since then to about 2011 price (0.1255 EUR/kWh). However, the weight of taxes and levies has increased substantially, from 17% in 2008 to 40% in 2020 (see Figure 10b). Thus, the total price for household consumers, i.e., including taxes and levies, was 0.2134 EUR/kWh in the second half of 2020 compared to 0.1504 €/kWh in the first half of 2008. The raw electrical energy price is lower in Portugal than the EU average; however, the actual prices, including all taxes, are one of the highest among EU MS.

Figure 11a presents the development of natural gas prices for household consumers in the EU since 2008. Overall, there was an upward trend in natural gas total EU prices from a low 0.0558 per EUR/kWh in 2009 to a peak of 0.0746 per EUR/kWh in 2013. It decreased from 2013 to 2017 but is underway to increase over 2018 before dropping significantly in 2020. The second semester 2020 raised at 0.0698 EUR/kWh, lower than 2019 in the same period (0.0720 EUR/kWh). However, the decrease is less pronounced when including taxes, since taxes increased from 25% in 2008 to 32% in 2020. Figure 11b statistic shows the natural gas prices for household end-users in Portugal from 2008 to 2020. Since 2010, natural gas prices increased to 0.0723 EUR/kWh in 2017 and have been approximately stable. In the second half of 2020, the natural gas price was 0.0562 EUR/kWh. However, taxes have been a burdening weight on gas prices for household end-users, increasing year by year up to 28% in 2020. Natural Gas also is one of the most expensive in Portugal between other EU MS.

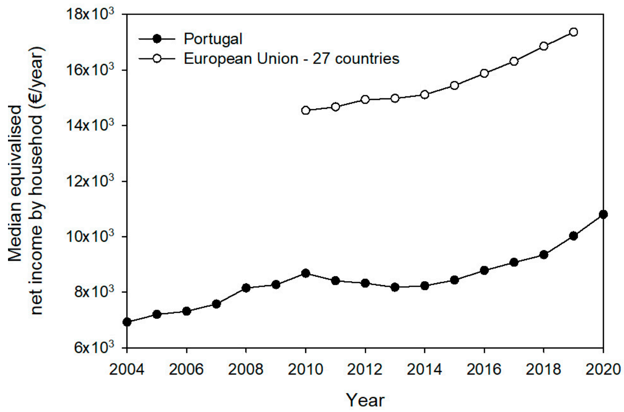


Figure 9. Median equivalized net income by household for EU and Portugal (data source [73]).

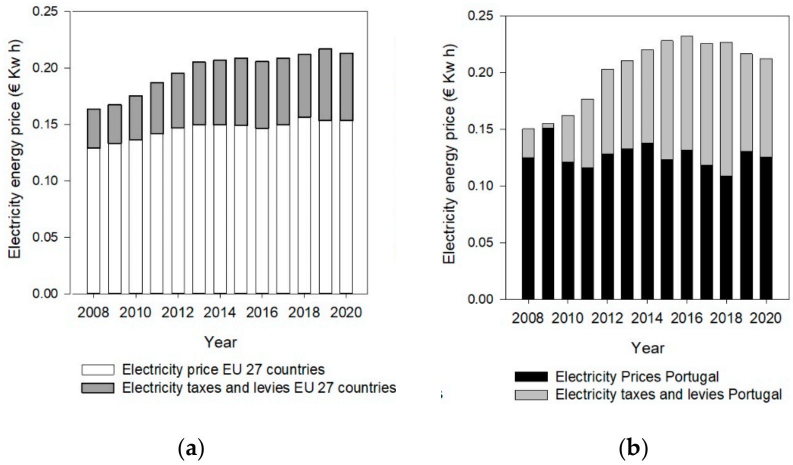


Figure 10. (**a**) Electricity prices for household consumers regarding: (**a**) EU-27 countries and (**b**) Portugal (data source [40]).

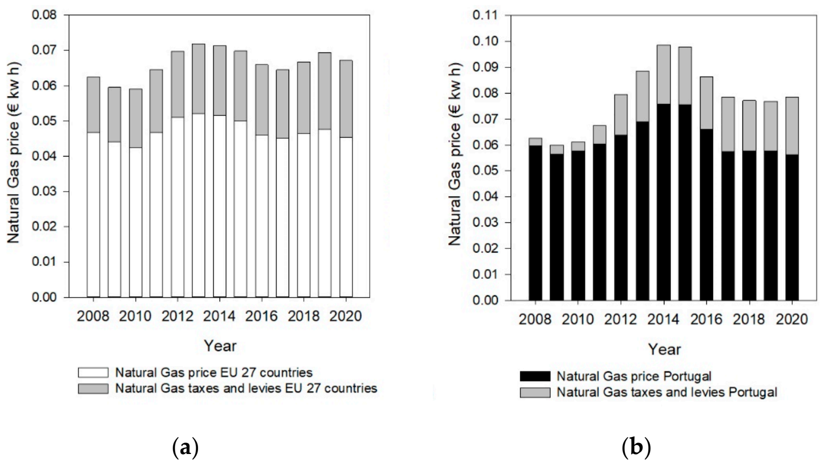


Figure 11. (**a**) Natural Gas prices for household consumers regarding: (**a**) EU-27 countries and (**b**) Portugal (data source [40]).

4. Thermal Buildings Regulation in Portugal and EU Context

4.1. Thermal Buildings Regulation Evolution

The thermal building performance has an important role in improving the energy efficiency of the building stock, as well as and contributing to occupants comfort, providing a healthy environment and well-being. Thus, thermal building regulation evolution impacts buildings energy efficiency and might indirectly decrease EP. Table 1 systematises (non-exhaustively) the timeline of the main thermal building regulation emerging and evolving in Portugal within the European context between 1990 and 2021. It follows some description of the main motivations and scope of such regulation evolution.

Table 1. Timeline of main thermal building regulations in Portugal and Europe between 1990 and 2021.

Year	Thermal Buildings Regulation	Legal Reference Document
1990	First version of the Portuguese thermal building legislation (RCCTE)	Decree-Law 40/90
1998	Regulation on conditioning systems in buildings (RSECE)	Decree-Law 118/98
2002	EPBD	Directive 2002/91/CE
2006	- Portuguese energy certification system and indoor air quality (SCE) - Regulation on conditioning systems in buildings (RSECE) - Regulation of buildings' thermal behaviour (RCCTE)	Decree-Law 78/2006 Decree-Law 79/2006 Decree-Law 80/2006
2010	EPBD recast	Directive 2010/31/UE
2013	- Portuguese energy certification system and indoor air quality (SCE) - Regulation on the energy performance of residential buildings (REH) - Regulation on the energy performance of service buildings (RECS)	Decree-Law 118/2013
2014	RERU establishes exceptional and temporary measures for administrative simplification of processes of urban rehabilitation	Decree-Law 53/2014
2018	EPBD recast	Directive 2018/844/UE
2018	Energy Efficiency Directive	Directive 2018/2002/EU
2019	Revocation of RERU	Decree-Law 95/2019
2020	Establishes the requirements applicable to buildings to improve their energy performance and regulates the Energy Certification System for Buildings	Decree-Law 101-D/2020
2021	Long-Term Strategy for the Renovation of Buildings (ELPRE)	Ministers Council Resolution No. 8-A/2021

Since the 70s, a difficult economic situation has affected Europe. The first oil crisis emerged, leading to an exponential increase in energy costs. Since then, the energy supply needs has become a significant concern. In addition, the more demanding requirements concerning hygiene and comfort of building conditions required strategies to improve and optimize the thermal comfort of the occupiers. Those issues were translated into several regulations and policies emerging and continuously revised and/or improved.

Thermal Performance Building regulation (RCCTE) was published in 1990, and it was the first Portuguese energy performance of buildings regulation (see Table 1). This document imposed requirements on the design of new or major renovated buildings to safeguard indoor thermal comfort, minimizing energy needs in summer and winter and associated pathologies. It must be pointed out that the RCCTE introduced thermal insulation in construction in Portugal, and the low requirement was designed to "raise awareness" of thermal concerns in design, insulation and shading, with a review planned within five years. However, the market evolved beyond those requirements, often using more isolation after a few years than the RCCTE required.

Subsequently, in 1998, the Air-Conditioning Energy Systems Codes (RSECE) was created. This regulation aimed to improve the thermal comfort of buildings occupants and indoor air quality (IAQ), mainly by improving the thermal quality of the surroundings, intervening in the design and construction phases. Thus, RSECE complements RCCTE, by regulating the installation and use of indoor environment comfort energy systems in buildings and supporting a rational use of energy by introducing some measures. Some examples of such measures are setting limits on the maximum power climate systems to be installed and avoiding oversizing, as market practice showed to be common, sometimes to compensate a deficient project, avoiding unnecessary investments.

Unfortunately, these two regulations were not enough to reduce the energy consumption of buildings and make them more efficient. In practice, most of the construction stakeholders seemed indifferent concerning RSECE. Thus, the installation of air conditioning systems was dealt with, mostly directly between suppliers and customers, and RSECE in practice was exclusively referred to by designers or installers or, simply, by equipment suppliers. However, while the first RSECE was in force, growing demand for HVAC systems occurred in Portugal, from the simplest and small ones, in the residential and small services sector, to large complex systems, especially in tertiary sector buildings. This arises in response to populations' standard living improvement and their superior requirements in terms of comfort and the high growth rate of the built-up park.

Nevertheless, at the end of the 2000s, despite low energy prices, concerns about GHG emissions also grew, emphasizing fossil energy resources. Thus, the United Nations approved the Kyoto Protocol in 1997, restoring GHG emissions from 2008–2012 to 1990 levels. EU countries agreed to achieve an 8% reduction in emissions compared to 1990, between 2008–2012, on a division at the country level and considering the development of the different economies. Besides meeting the Kyoto targets, in Europe, there was also the "Security of Supply" concern, in which Europe would import roughly 80% of its "energy" in 2020. In this context, Energy Performance in Buildings Directive (EPBD) was issued in 2002 by Directive 2002/91/CE 2002, aiming to improve the energy performance of buildings in the Community. This Directive obliged EU MS to impose the following requirements: (i) Methodology for calculating the energy performance of buildings; (ii) Minimum requirements for new buildings; (iii) Minimum requirements for major building renovations existing with more than 1000 m^2; (iv) Energy certification of buildings in order to, among others, inform the citizens about the thermal quality of buildings when constructing, selling or renting them; (v) Regular inspection of boilers and air conditioning installations and, in addition, evaluation of the heating installation when the boilers are more than 15 years old. The EPBD also specified that the energy performance certification system (ECS) must embrace all residential and service buildings, public or private.

EPBD 2002 was transposed at the national level by the Decrees 78/2006, 79/2006 and 80/2006 approving Buildings Energy Certification System and indoor air quality (SCE 2006), the Air-Conditioning Energy Systems Codes (RSECE 2006), the Regulation of Thermal Behavior Characteristics of Buildings (RCCTE 2006), respectively, as systematized in Table 1. These three decrees completely changed the paradigm of buildings' thermal performance and energy efficiency requirements.

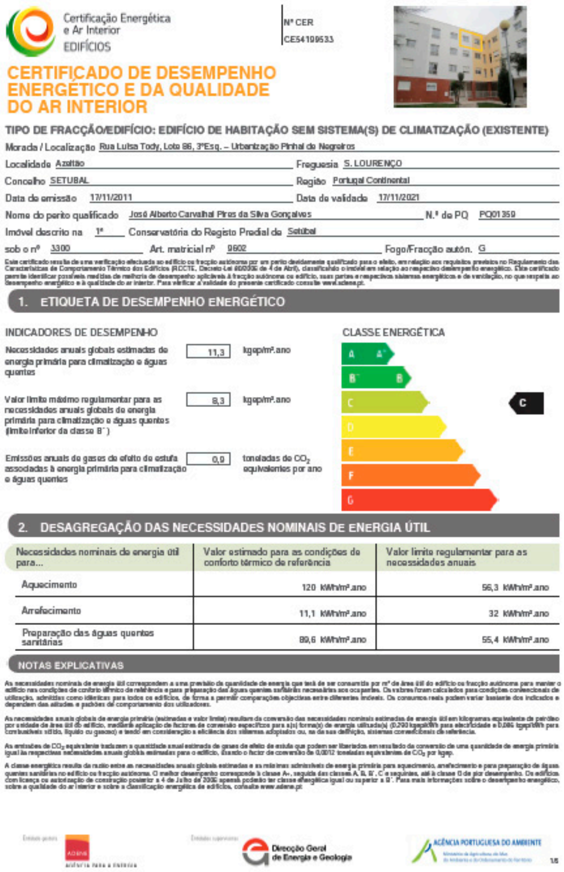
SCE (Decree-law 78/2006) had some particularities, such as, it adopted a regulatory framework in which all numerical performance objectives (Energy Requirements, U values, shading, among others) were referred to transitory provisions; any target value could be changed at any time by Ministerial Ordinance, without the need to publish a new

Decree-Law. This type of structure made it possible to keep the requirements of the RCCTE updated through periodic technical interventions when appropriate; however, it never happened. In the case of new buildings or existing buildings subject to major interventions, Energy certification intends to inform future users on potential energy consumption and its costs during the operation phase of the building. In existing buildings, energy certification is intended to provide information on economically viable performance improvement measures that the owner can implement to reduce their energy costs and, at the same time, improve the building's energy efficiency. Additionally, IAQ was stated through the mandatory introduction of fresh air into the occupied spaces. The inclusion of the IAQ component associated with the Energy Performance Certification process was a national initiative.

On the other hand, the revision of the RSECE complying with EPBD 2002, toke in that time fourfold objective: (i) Define the thermal comfort and hygiene conditions that must be required in the different spaces of the buildings, in line with the respective functions; (ii) Improve the overall energy efficiency of buildings, not only concerning air conditioning, but in all types of energy consumption, promoting their effective limitation to acceptable standards, whether in existing buildings, buildings to be built or in major rehabilitation interventions for existing buildings; (iii) Impose efficiency rules to air conditioning systems that improve their effective energy performance and guarantee a good IAQ, both at the project, installation and operation phases, through proper maintenance; (iv) Regularly monitor the maintenance practices of HVAC systems as a condition for energy efficiency and IAQ in buildings.

While the first version of the RCCTE (1990) intended to limit potential consumption and was relatively undemanding due to economic viability issues in light of potential low consumption, RCCTE 2006, although with a similar structure, was more ambitious. RCCTE 2006 introduced a set of new concerns that were misplaced in the previous version, namely, the quality requirements for the environment have increased about 50% in terms of mandatory thermal insulation; it became essential to define the heating, cooling and hot water systems and the predicted energy source; a more effective verification of regulation application before, during and at the end of the construction phase, to guarantee a practical application of new thermal regulation and the emission of energy performance certificate. The version of the Regulation of Thermal Behavior Characteristics of Buildings (RCCTE) of 4 April 2006 maintained the objectives of the previous regulation: to control energy consumption and increase the level of the thermal performance of the building envelope. In addition to dividing the needs between the heating and cooling seasons, already contemplated in the 1990 regulation, it added the energy needs for the preparation of domestic hot water, supported by updated climatic values, a consequence of the obligation to implement systems that use renewable energy (as solar panels). This regulation established maximum values for the nominal energy needs for heating, cooling and preparing domestic hot water and the global primary energy needs, which could not be exceeded for any covered residential or service building. Besides a set of minimum characteristics required for the thermal properties of the surroundings, RCCTE 2006 aimed to minimize pathological situations in the building elements, increase their durability, and meet comfort requirements without excessive energy expenditure.

The aforementioned regulations gave rise to the energy performance certificate (EPC), as depicted in Figure 12. The energy classification corresponded to nine levels from A+ to G of energy label obtained from the combination of several building characteristics, such as envelope behaviour, solar orientation, lighting, HVAC systems, water heating, and others. Since 2006, the management entity ADENE [4] has changed to those decrees to clarify or rectify the legislation.


Certificação Energética e Ar Interior EDIFÍCIOS

Nº CER CE54199533

CERTIFICADO DE DESEMPENHO ENERGÉTICO E DA QUALIDADE DO AR INTERIOR

TIPO DE FRACÇÃO/EDIFÍCIO: EDIFÍCIO DE HABITAÇÃO SEM SISTEMA(S) DE CLIMATIZAÇÃO (EXISTENTE)

Morada / Localização Rua Luisa Tody, Lote 86, 3ºEsq. – Urbanização Pinhal de Negreiros

Localidade Azeitão Freguesia S. LOURENÇO

Concelho SETUBAL Região Portugal Continental

Data de emissão 17/11/2011 Data de validade 17/11/2021

Nome do perito qualificado José Alberto Carvalhal Pires da Silva Gonçalves N.º de PQ PQ01359

Imóvel descrito na 1ª Conservatória do Registo Predial de Setúbal

sob o nº 3300 Art. matricial nº 9602 Fogo/Fracção autón. G

1. ETIQUETA DE DESEMPENHO ENERGÉTICO

INDICADORES DE DESEMPENHO

Necessidades anuais globais estimadas de energia primária para climatização e águas quentes 11,3 kgep/m².ano

Valor limite máximo regulamentar para as necessidades anuais globais de energia primária para climatização e águas quentes (limite inferior da classe B⁻) 8,3 kgep/m².ano

Emissões anuais de gases de efeito de estufa associadas à energia primária para climatização e águas quentes 0,9 toneladas de CO_2 equivalentes por ano

CLASSE ENERGÉTICA

2. DESAGREGAÇÃO DAS NECESSIDADES NOMINAIS DE ENERGIA ÚTIL

Necessidades nominais de energia útil para...	Valor estimado para as condições de conforto térmico de referência	Valor limite regulamentar para as necessidades anuais
Aquecimento	120 kWh/m².ano	56,3 kWh/m².ano
Arrefecimento	11,1 kWh/m².ano	32 kWh/m².ano
Preparação das águas quentes sanitárias	89,6 kWh/m².ano	55,4 kWh/m².ano

NOTAS EXPLICATIVAS

Figure 12. Example of a Portuguese Energy Performance certificate (SCE Decree 78/2006).

In 2010, Directive 2002/91/EC was revised to further tighten the requirements according to the Action Plan for Energy published in January 2007 and adopted by the EU Council of Ministers in May 2007. Directive 2010/31/EU, i.e., EPBD recast, deals with new EU"20–20–20" objectives, which were, in brief, reduce by 20% the emissions of GHG compared to 1990 levels, increase by 20% the energy efficiency in the EU and to reach 20% of renewables in total energy consumption in the EU. The main objective of EPBD recast was also to improve the energy performance of buildings in the European Union and thus establish the following requirements: methodology for calculating the integrated energy performance of buildings and building units; minimum requirements for new buildings and building units; minimum requirements for existing buildings and building units and building components subject to major renovations; minimum requirements for the constructive elements of the building envelope with a significant impact on the energy performance of the envelope when renewed or replaced; minimum requirements for technical building systems when a new system is installed or when the existing system is replaced or improved; mandatory certification of buildings and building units; regular inspection of heating and air conditioning installations; and independent control system for energy performance certificates and inspection reports.

EPBD recast (2010) was transposed into national law through Decree 118/2013, on 20th August, merging, in the same document, the Certification System Building Energy (SCE), the Regulation on the energy performance of residential buildings (REH) and the Regulation on the energy performance of service buildings (RECS), in addition to a set of orders and resolutions to support it. The base legislation of the new SCE (Decree 118/2013 of 20 August) has already been revised several times since 2013, namely by Decrees: 68-A/2015 of 30-04; 194/2015 of September 14; 251/2015 of November 25, 28/2016 of June 23, 52/2018 of August 20 and, finally, 95/2019 of July 18. The various Ordinances, Dispatches and associated laws also underwent some changes.

Thus, Decree 118/2013 ensured the transposition of the directive in question and a review of national legislation and improving the systematization and scope of application of SCE, REH and RECS. Furthermore, the clear separation of REH and RECS, the former focusing exclusively on residential buildings and the latter on commercial and services, facilitates the technical treatment and administrative management of the processes, at the same time, it recognizes the technical specificities of each type of building in what is most relevant to the characterization and improvement of energy performance.

The definition of requirements and the assessment of energy performance of buildings is based on the following pillars: in the case of residential buildings, the thermal behaviour and efficiency of the systems assume a prominent position, while in the case of commercial and services buildings, installation, management and maintenance of technical systems are essential. General principles are also defined for each pillar, materialized in specific requirements for new buildings, buildings subject to major intervention and existing buildings.

In addition to updating thermal quality requirements, energy efficiency requirements are introduced for the main types of technical building systems. Thus, HVAC, domestic hot water, lighting, use of renewable energy and energy management are also subject to minimum energy efficiency standards. Moreover, the promotion of renewable energy sources is maintained, with clarification and reinforcement of methods for quantifying their contribution, and with a natural emphasis on the use of the solar resource, which is abundantly available in our country. Likewise, through the definition of adequate forms of quantification, passive systems or solutions are encouraged, and the optimization of performance results from less use of active HVAC systems. In this context, the concept of building with almost zero energy needs arose, which would become the standard for new construction from 2020, or 2018, in the case of new buildings by public entities and a reference for major interventions in the existing building. This standard combines the reduction, to the greatest extent possible and based on a cost-benefit logic, of the building's energy needs, with energy supply through renewable energy. It is also worth mentioning the recognition of the pre-certificate and the SCE certificate as technical certifications to clarify their application in terms of consultation and inspections, making such technical certifications mandatory in the instruction of urban planning operations.

Regarding the IAQ policy, it is considered of utmost importance to maintain the minimum fresh air flow values per space and the protection thresholds for indoor air pollutant concentrations to safeguard the health and well-being of building occupants. In this context, it should be noted that natural ventilation is now favoured at the expense of mechanical ventilation equipment to optimize resources, energy efficiency and cost reduction. IAQ audits are also eliminated, maintaining the need to control sources of pollution and the adoption of preventive measures, both in terms of design and operation stages, to comply with legal requirements for the reduction of possible risks to public health.

The aforementioned regulations end in an upgraded EPC, depicted in Figure 13. The energy certificate complies with a new energy label with eight levels from A+ to F (Figure 13). This new Energy Performance Certificate, valid for ten years, must include the energy performance of the building and the minimum energy performance requirements. Besides, it includes new additional information, namely, the annual energy consumption of non-residential buildings and the percentage of energy from renewable sources regarding total energy consumption, recommendations for the cost-effective improvement of the energy performance of the building or dwelling, and it can also include an estimation of the amortization periods of the investment or cost–benefits throughout its lifecycle cost (see Figure 13).

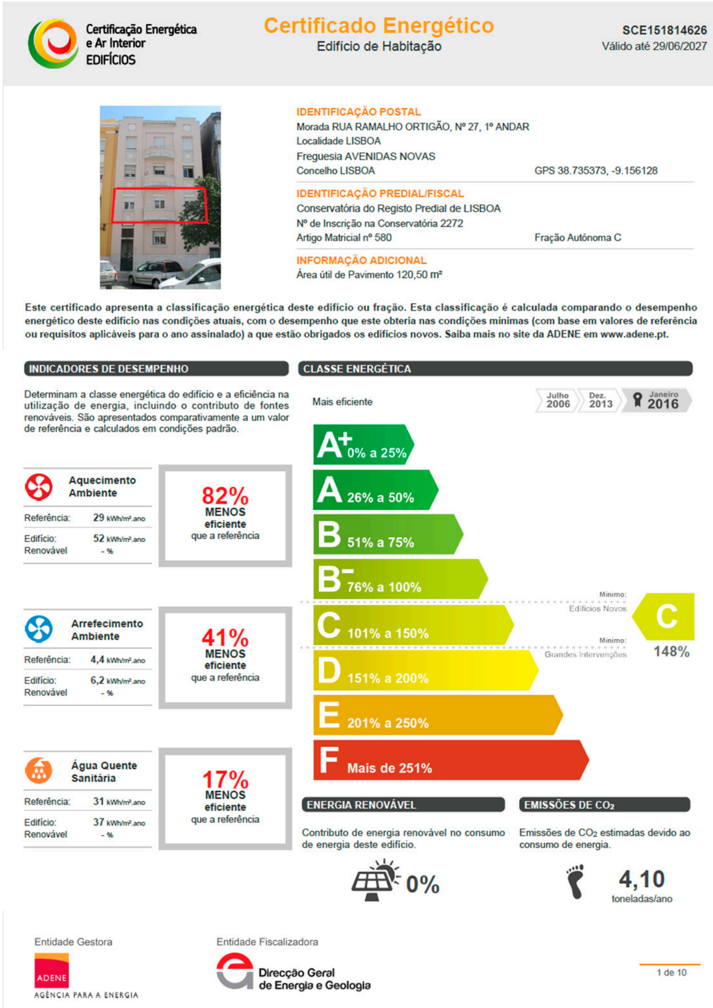


Figure 13. Example of a Portuguese Energy Performance certificate (Ordinances No. 349-A/2013; Order No. 15793-C/2013).

As part of the Clean Energy for All Europeans package (2016), in 2018, the Directive 2018/844/EU amended the EPBD 2010 (Directive 2010/31/EU), and together with the Energy Efficiency Directive (2018/2002/EU), provide the EU's commitment to modernize the building sector to ensure an energy efficient and low carbon building stock in each MS, contributing to climate goals for Europe by 2050, such as reducing CO_2 emissions in the EU by 80–95%.

Decree No. 101-D/2020 transposed Directive 2018/844/EU to Portugal, defining the requirements applicable to the design and renovation of buildings to ensure and promote the improvement of their energy performance by setting requirements for their upgrading and renovation. This scheme creates the conditions for rehabilitation to be the main form of intervention in the buildings, mainly for housing purposes. Decree No. 101-D/2020 entered into force very recently, on 1 July 2021.

Still under the transposition of Directive 2018/844 and Energy Efficiency Directive 2018/2002/E (Decree No. 101-D/2020), Resolution of the Council of Ministers No. 8-A/2021, was published, approving the Long-Term Strategy for the Renovation of Buildings (ELPRE). ELPRE establishes goals e 2030, 2040 and 2050 horizons, compared to the records of 2018, considering the national building stock, namely: (i) Renovated building area, in the proportion of 363,680,501, 635,637,685 and 747,953,071 m^2 for 2030, 2040 and 2050, respectively; (ii) Primary energy savings, in the percentage of 11%, 27% and 34% for 2030, 2040 and 2050, respectively; (iii) Reduction of indoor thermal discomfort (in hours), in 26%, 34% and 56% for 2030, 2040 and 2050 horizons, respectively.

4.2. Energy Certification System for Residential Buildings Overview

As presented in the previous section, the thermal building regulation has been in EU agenda, aiming to provide thermal comfort without the excessive use of energy, minimizing the occurrence of pathological effects deriving from condensation in the surrounding elements, constantly promoting the energy efficiency and the use of renewable energies, among others.

Portugal implemented actual SCE through Decree 118/2013 of 20 August. As depicted in Figure 13 (Section 4.1), the energy performance classification of a building or building unit follows a pre-defined scale of 8 classes (A+, A, B, B−, C, D, E and F), in which the A+ class corresponds to a building with best energy performance, and class F corresponds to a building with the worst energy performance. Although label classes are applicable for residential, commercial and service buildings, each one has different indicators and classification procedures. However, both residential, commercial and new service buildings are mandatory to present an energy class between A+ and B−, while buildings subject to major interventions must present a minimum energy performance C. Regarding existing buildings, energy performance may present any classification between A+ and F (see Figure 13, Section 4.1). For both pre certificates, new building certificates and existing building certificates, the energy class is determined through the energy class ratio, R_{Nt}, calculated according to the following equation (Order No. 15793-J/2013):

$$R_{Nt} = \frac{N_{tc}}{N_t} \tag{1}$$

where N_{tc} corresponds to the value of the nominal annual primary energy needs and N_t corresponds to the regulatory limit value for the nominal annual needs of primary energy, both calculated following REH. Afterwards, the energy class is determined according to Table 2 (see also Figure 13).

Table 2. Energy performance class for residential buildings according R_{Nt}.

Energy Label Classification	R_{Nt}
A+	$R_{Nt} \leq 25\%$
A	$26 \leq R_{Nt} \leq 50\%$
B	$51 \leq R_{Nt} \leq 75\%$
B−	$76 \leq R_{Nt} \leq 100\%$
C	$101 \leq R_{Nt} \leq 150\%$
D	$151 \leq R_{Nt} \leq 200\%$
E	$201 \leq R_{Nt} \leq 250\%$
F	$R_{Nt} \geq 251\%$

Concerning residential buildings, in brief, REH establishes the requirements for residential buildings, new or subject to major interventions, as well as the parameters and methodologies for energy performance classification, in nominal conditions, of all residential buildings and their technical systems, in order to constantly promote the improvement of the respective thermal behaviour, the efficiency of their systems and the minimization of the risk of occurrence of superficial condensation in the surrounding elements. In cases of major intervention, the energy requirements are distinguished depending on the construction period, according to Table 3. Concerning quality requirements, only the elements intervened are the target, namely opaque envelope and glass elements. Besides, the ventilation systems/elements maintain the minimum indoor air renovations. Whenever domestic hot water systems are part of the intervention, installing solar thermal systems or other systems admitting an equivalent production of domestic hot water is mandatory. However, the limitation of primary energy needs is relaxed by 50% compared to new buildings.

Table 3. Maximum energy needs for major renovated residential buildings according to REH.

Age Class	Maximum Warming Needs	Cooling Needs
Before 1960	No requirements	No requirements
1961–1990	plus 25% compared to new building	plus 25% compared to new building
After 1990	plus 15% compared to new building	plus 15% compared to new building

Since the Portuguese energy certification system and indoor air quality (SCE) establishment in 2006 through Decree 78/2006, the EPC is mandatory for both new, major renovated buildings and existing buildings, the lasts in the case of commercial transactions.

Thus, it is of utmost importance to monitor the energy efficiency of the building stock, though EPC is a key driver for further energy-related target definition regulations, policies, programmers and initiatives.

Figure 14 shows the temporal evolution (2008–2020) and distribution by energy label classes of the certificates issued (coloured bars plot) and the total certificates emitted each year (line plot). In addition, Figure 15 depict the energy performance certificates emitted in the same period by class of document, i.e., a certificate for the existing building or new building or pre-certificate (certificate at project phase). However, regarding the class, some points must be emphasized. The distribution by classes is not equivalent in the two moments of the legislation (RCCTE and REH), namely because the technical systems have a much greater weight in the energy class in the previous version (RCCTE) than in the current version. Thus, besides a general analysis, the authors considered two periods, 2008–2013, which refers to RCCTE, and 2014–2020 regarding REH.

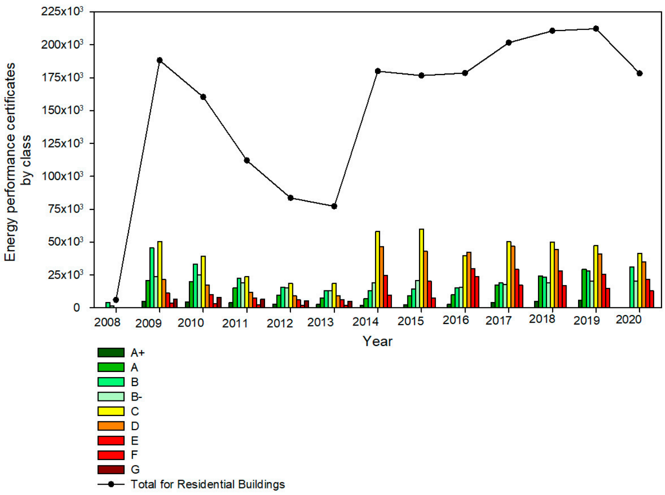


Figure 14. Energy performance certificates emitted between 2008–2020 in Portugal by label class (data source [74]).

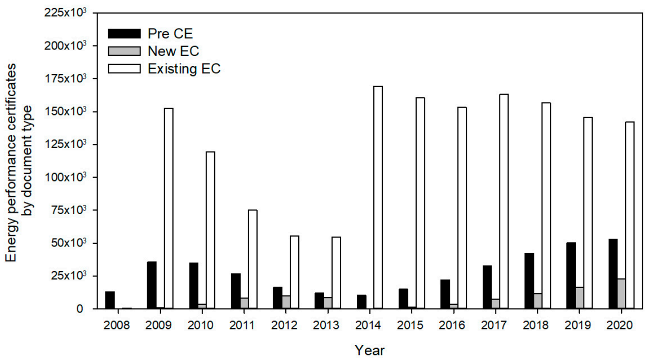


Figure 15. Energy performance certificates emitted between 2008–2020 in Portugal by CE type (data source [74]).

Since the entrance of Building Certification System legislation (July 2007) and until 2020, about 2.0 million energy certificates were issued in Portugal, of which 32.1% were issued under the RCCTE (2007–2013) and 67.8% under the REH (2014–2020). Among all emitted certificates, 77.1% refers to existing buildings, 4.7% to the new building and the remainder refers to pre-certificates. The temporal evolution of the number of certificates reflects the national construction market. The parcel of certificates issued for new buildings has been significatively reduced since their obligation began at a time of disinvestment in the sector (SCE, Decree 78/2006), namely due to European economic crises [25]. On the other hand, the number of certificates referring to major interventions or just due to transaction operations (sale or rental) is the majority of EPC emitted, since the legal obligation, and as a result of some dynamization of the rehabilitation and real estate sector, mainly in large cities, like Porto and Lisbon.

Concerning the EPC energy class distribution, 14.7% of certificates were issued between 2008 and 2013, while RCCTE were A-rated or more, and 36.9% and 24.0% had the B and C ratings, respectively. The majority of certificates in that period, 37.6%, were classified with energy labels D or lower. After REH implementation by Decree 118/2013 and up to 2020 (period 2014–2020), 7.3% of CE have an A rating or more, while 20.9% and 26.2% have B and C ratings. The majority, 43.9%, were still classified as D or less. Analyzing Figure 14, it can be perceived that between 2008 and 2013, the number of EPC decreased year by year, and since then, it has been roughly increasing up to 2019.

5. Synergies and Trade-Off between EP and Thermal Building Regulation and Energy Efficiency Policies

Even though the improvement of buildings' energy efficiency is usually empirically connected to EP, the relationship between these themes is not linear. It is, however, recognized that buildings may have a role in EP alleviating. Thermal building regulation context influences EP by improving the thermal comfort of the population in such a situation by reducing the energy needs of the building, namely for heating. Additionally, this will put forward other advantages on economic, environmental, social and healthy spheres. These connections are presented in Figure 16 along with a summary of the key points discussed in the current section. Four links are identified through which thermal building regulation and policies may influence the levels of EP and vice versa. It follows some discussion on such links.

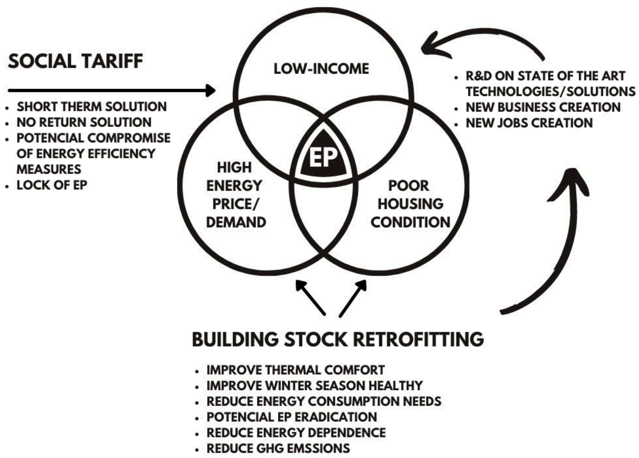


Figure 16. Contributing factors addressing EP and their relation.

- Link 1: Improvement of the thermal comfort

Previous research has confirmed the paradox involving EU MS in the Mediterranean basin: even though winters are milder in those countries, they persistently account for high percentages of the population not able to keep home adequately warm. Portugal is a temperate climate country, as presented in more detail in Section 2.1; however, thermal discomfort is significantly higher compared to other countries with harsher winter seasons and lower temperatures, such as in Nordic countries. This is mainly because Nordic countries have generally adopted stricter energy performance standards than the remaining EU MS countries. Besides, European economic crises have further exacerbated EP situation with the rapid increase in unemployment and income inequality [75].

According to EPOV, a significant portion of the Portuguese population recognizes being unable to keep their home adequately warm, as depicted in Figure 5 (Section 3.3). Up to 2007, about 40% of Portuguese residents were unable to keep their home adequately warm, drastically decreasing to 28.5% in two years. Since then, and up to 2014, it has increased slightly to 30%, and then diminished. This apparent "peak" pattern corroborated the European economic crises and observed other EP indicators (Figures 6, 7 and 11). In 2019, it is still estimated that 18.9% of the Portuguese population could not keep their home adequately warm compared to 7.0% at the EU level.

Considering the EPC analysis presented in Section 4.2 (see Figure 14), Portuguese residential building stock is still characterized by class D or less. Since 2008–2013 (during RCCTE), 37.6% of emitted EPC were class D or less, while between 2014–2020 (during REH) the values increased to 43.9%. However, these distributions by classes are not at all equivalent. Notably, as presented in Section 2.2, that the Portuguese residential building stock is old, in which approximately 60% were built prior to 1990 (see Figure 1) [32] even before the first national thermal regulation (RCCTE). Nevertheless, according to an ISEG study on EP in Portugal, 75% of national buildings do not have thermal insulation. In other words, to guarantee this range of thermal comfort, people have to resort to heating and cooling devices, when this would be unnecessary or very much reduced if the houses had a different quality of construction. This follows Figure 6 data (Section 3.3), illustrating that a significant part of the Portuguese population lives in poor housing conditions. Furthermore, in Portugal, there is no culture of air-conditioning the house in terms of comfort—the most common are first resorting to several layers of clothing and blankets in winter and fans in summer. Thus, most homes in Portugal do not even have the equipment to air-condition their house efficiently.

Thus, energy-efficient refurbishment solutions are of utmost importance to alleviate EP, namely, the low-income households. For instance, according to data from the UK, about one million low-income households overcome EP situations through implementing energy efficiency and renewable energy measures, such as insulation, high-efficiency heating systems and solar water heating. In fact, until 2008, almost 3.9 million measures have been fixed, complying with about 2 million UK households, costing GBP 3.6 billion [76]. That investment has resulted in significant EP alleviation in which nearby 70% of the recipient households escaped from that poverty.

Some policies have been implemented in Portugal to improve thermal building performance, as explained in Section 3.2, including for vulnerable households. Even though the effect of thermal building regulation and energy efficiency policies on EP alleviation is not still available, as best of the author's knowledge, it is recognized that the EPBD (Directive 2002/91/CE) was the biggest revolution in Thermal performance building regulation, transposed than to Portugal in 2006 through the Decrees 78/2006, 79/2006 and 80/2006 (as detailed in Section 4.1). Based on data collected, an empirical analysis through scatter plot, the number of EPC emitted has some relation with thermal discomfort on the winter season, as shown in Figure 17. It seems plausible to admit that it had impacted the percentage of the Portuguese population experiencing thermal discomfort during the winter season. Thermal comfort is a cultural and subjective concept since each person has different thermal sensitivities. Even though questionnaire-based surveys present certain limitations, they may also offer advantages compared to objective measures. For instance, they may identify households that are hidden by quantitative indicators, such as energy expenditure or falling behind on utility bills. This is mainly because uncovered households do not spend a disproportionate amount on energy services. After all, they are rationing their consumption or do not have the technical resources to properly heat spaces. This type of EP household is challenging to identify [77].

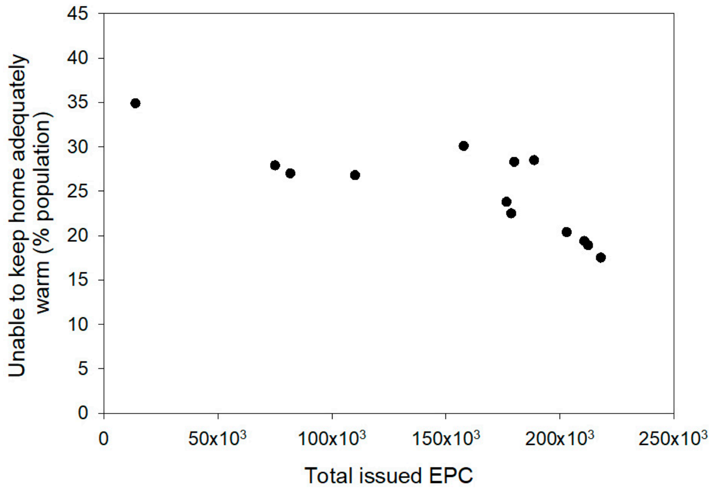


Figure 17. Scatter plot of issued EPC and proportion of inhabitants unable to keep home adequately warm.

- Link 2: Social tariffs versus energy efficiency housing measures

The high incidence of EP in Mediterranean countries has already been attributed to the overall poor quality of residential building stock, namely, insufficient or inadequate thermal insulation and the non-centralized or even lack of efficient systems heating [78]. A recent study found that approximately 75% of the Portuguese building stock does not have adequate thermal insulation. In other words, to guarantee the minimum thermal comfort, Portuguese households need to heat and cool spaces [36]. In Portugal, space heating is the second highest use in a household's energy consumption (ca 27% of total energy consumed), after cooking, as aforementioned in Section 2.2. The antagonism scenario occurs at EU level, in which space heating is the highest energy demand consumption.

Low-income households have been frequently observed as an important cause of EP, since that population often lives in poorer-quality housing and has restricted budgets to employ on energy and even on other goods and services. Thus, they might consider rationale energy usage prioritizing cooking, or using low-cost energy heating sources, as biomass (see Figure 4), mostly on non-centralized systems. This is also mainly because energy prices have been increasing faster than household income, and thus, additional households might be placed under the EP scenario. In fact, EP levels of a certain country are very sensitive to energy prices variation. Even though the technological evolution has allowed electricity production costs to decrease over the last few years, consumers did not benefit from this circumstance as this reduction was often offset, for example, by taxes or network costs. This situation represents a serious problem due to the negative impacts it has in terms of EP.

As discussed in Section 3.3, Portugal presents as one of the highest electrical energy prices among MS, progressively reducing the purchasing power of households. In that context, some MS, as Portugal, have addressed EP through social tariff policies, among other measures. Even though they may offer a temporary solution to EP (during a transition), social tariffs can be counterproductive and potentially lock vulnerable households living in EP since they may discourage investment in energy efficiency at the household level. This is mainly because social energy tariffs cover real energy prices and thus deliver wrong economic signals resulting in a capital stock whose efficiency is lower than that justified by economic rationality considerations [79].

As previously discussed in Section 3.2, EP potential eradication measures comply with consumer protection (e.g., special tariffs, disconnection protection), financial interventions (short term solutions through payment), energy savings measures and RES integration (subsided schemes for the promotion of energy-saving and RES technologies) and information provision (e.g., awareness campaigns, energy-saving tips). However, this integrated vision is not yet the reality in Portugal, in which the social tariff has been the permanent policy to combat EP. As this problem crosses a significant part of the Portuguese population, the government's intervention is urgent because reducing the energy price of the vulnerable population does not solve the fundamental problem, which is the buildings. Even though social tariff is important since it constitutes a relief to the family budget, it is an incomplete instrument in the fight against EP as it does not address the problem at its genesis. A more structural way to solve the problem involves investing in the quality of construction of houses and energy-efficient equipment. Hence, the recent initiative of the Portuguese government, such as more sustainable buildings (see Table S2 in Supplementary data section), is a positive step, as it contemplates a series of benefits and supports for the Portuguese to achieve more efficient building stock.

Additional long-term building energy qualification programmes are needed to reduce the number of homes promoting EP, including the insulation of facades, roofs, doors and the replacement of windows with efficient alternative solutions. However, for this lever marked difference in EP levels, the efficiency levels achieved must be state-of-the-art. Current state-of-the-art design, know-how and technologies, namely through the passive measures, such as wage on electricity generation from low- and zero-carbon technologies, retrofit existing buildings to reduce energy consumption and improve energy efficiency, will ensure that heating and cooling energy costs might be significantly reduced. That approach can potentially contribute to EP mitigation.

- Link 3: Restricted energy regulations may marginalise EP

The current scenario of Portuguese building stock invites rehabilitation works. On the other hand, the growing energy consumption needed to ensure indoor thermal comfort is worrying, given the significant weight that this consumption represents in total energy, especially in some regions of the country with a more severe climate, assigned to GHG emissions that have caused evident climate changes in recent years.

To combat energy consumption demand, governments, including the Portuguese, reinforced regulatory thermal buildings and extended these requirements to existing buildings to be incorporated during eventual rehabilitation works. However, the old and/or poor-quality houses, in many cases, require deep rehabilitation to achieve a minimum of thermal comfort and energy efficiency. The cost of that intervention is higher and mostly not affordable, even with financial assistance. Moreover, most low-income households in Portugal also live in poor energy performance housing [36], there is also a population not economically poor experiencing EP. It seems that there is a point when households will have to invest so much in energy qualification measures for housing to get out of the thermal discomfort that they start to be economically poor [36,37].

The European energy efficiency and thermal building regulations have somehow been far from the real building stock scenario among several MS, as Portugal. While the energy performance of new buildings is improving, there is still a large housing stock built using older, outdated or even without standards. As referred in Section 2.2, 14% of Portuguese buildings date back to 1945 or earlier, and approximately 60% were built prior 1990 (see Figure 1, Section 2.2) [32] before the first thermal regulation existence in the country. Therefore, those buildings have no or sub-standard thermal protection and are thus highly energy inefficient compared to current requirements. Moreover, natural ageing also affects the building performance or even exposes construction process errors, plaguing the current occupiers. It is striking that over 25% of the total population of Portugal live in deplorable conditions, as can be perceived in Figure 6 (and discussed in Section 3.3). Thus, policy integration is crucial since considerable investment costs and policy efforts are required for the large-scale implementation of deep energy efficiency solutions, namely in existing old buildings. For the specific case of Portugal, financial schemes have been implemented at the national and regional level, including specifically for vulnerable consumers (see Section 3.2) to improve thermal comfort and energy efficiency of houses. However, the outcomes of such programmes are not effectively known. Moreover, access to such programmes is limited considering income or housing criteria, and the bureaucracy may make it difficult.

Only in 2021, under the transposition of Directive 2018/844 and Directive 2012/27/EU on energy efficiency (Decree-law No. 101-D/2020), Resolution of the Council of Ministers No. 8-A/2021 approved the Long-Term Strategy for the Renovation of Buildings. For the preparation and implementation, the Long-Term Strategy for the Renovation of Buildings, the energy consumption profiles and thermal comfort indices of the existing building stock were analyzed, as well as listed the associated benefits, such as the improvement of labour productivity and the health of populations for EP alleviation. Moreover, expected costs arising from implementing such policies and measures were calculated, considering specificities of buildings to be included, such as typology and geographic location. ELPRE includes intervention in the surroundings of buildings, replacing existing systems with more efficient ones, promoting energy from renewable sources, and adopting technical solutions appropriate to buildings' energy efficiency. ELPRE also complies with the creation and/or development of financing programmes for renovation and investment mobilization, public and private, and the reinforcement of incentive policies and market monitoring. According to National Energy and Climate Plan 2030, ELPRE is also an instrument for EP mitigation. However, the cost-efficiency of such programmes must be integrative, i.e., not only considering direct costs and benefits of a single policy field. Energy-efficient programme measures applied to building stock will benefit the national economy, environment and health.

- Link 4: Economic, social and environmental and health benefits

It is expected that energy-efficient programmatic measures applied to building stock will benefit the national economy, environment and health.

Inappropriate indoor housing conditions may be a source of serious health problems. As presented in Section 3.1, prolonged exposure to significantly lower (<18 °C) or higher temperatures (>24 °C) have been associated with the outbreak of physical and mental illnesses, especially in vulnerable groups, such as the elderly, chronically ill people, children and pregnant women, such as increased blood pressure, asthma symptoms, cardiovascular and respiratory diseases, exacerbations of existing musculoskeletal problems and anxiety and depression. In the winter season, cold homes can impact excess mortality/morbidity. Thus, improving housing conditions, with comfortable indoor temperatures and adequate IAQ, will benefit the population for improved health, namely, vulnerable and low-income households. This will consequently decrease the hospital admissions and the cost to the National Health System.

On the other hand, optimizing the available financial resources to fight EP and improve low-income households is a challenge for Portugal. Thus, thermal and energy solutions involved in the refurbishment process houses and the retrofitting of poor areas should be cost-effective and contribute as far as possible to improving the energy performance holistically. Thus, EP can put forward cutting-edge research and development on cost-effective passive energy-saving technologies to overcome new economic opportunities and the market's stimuli and promote employment creation [19,79]. This is particularly important for the economy and social status of deprived areas. Furthermore, beneficiaries of energy-efficient reformed houses will be less dependent or even independent of social tariffs, reducing the burden in public budgets to support the EP while helping households to improve their social status and dignity. In addition, building retrofitting will reduce the energy demand and, consequently, the energy dependency and GHG emissions.

In sum, the energy performance of a dwelling is thus a key factor in permanently alleviating household energy poverty or maintaining it while also providing outcomes on economic, social and environmental pillars.

6. Conclusions and Final Remarks

EP is a major issue in the EU and is expected to increase due to growing energy prices and ongoing economic adversities, such as the current unexpected pandemic situation and climate change. Although fighting EP has not been a central issue for the EU, it might shrink climate change and economic inequalities as well as improve health, since buildings are a central part of people's daily lives and where they spend a large part of their days.

As can be perceived from previous sections, EP has been tackled indirectly among EU policies, through Directives dealing with different issues (such as thermal building regulation, internal market regulation for gas and electrical energy) as well as through several initiatives (such as the Third Energy package, Energy Union, Clean Energy for All). Even though an authoritative body to focus exclusively on EP is missing in the EU, EPOV may be considered the first step towards an integrated approach. Additionally, recent concerns about the EP situation among several MS put forward the need for policies across the EU exclusively dedicated to EP. Moreover, a comprehensive analysis of the EP phenomena in each MS is essential to understand its national and even regional particularities and develop conscientious policies, initiatives and regulations.

The current study aimed to contribute awareness to the Portuguese EP scenario evolution and actual situation and provide critical debate on the potential measures to alleviate EP. The energy performance of residential buildings in Portugal provides insight into the energy needs of the building according to their age. The Portuguese building stock is old, and still a significant part of the population lives in poor quality houses. Furthermore, the relationship between the low net income households and energy affordability is highlighted to determine EP in Portugal and other European countries. Even though improving building energy efficiency will not solve all energy issues, such as climate change, security of supply or poverty, it can be an important means of alleviating them. This study highlights that retrofitting existing buildings and improving their performance and comfort can reduce energy consumption and needs and improve energy efficiency, thereby reducing heating and cooling energy costs. Hence, this mitigation strategy can reduce EP and provide economic, social, environmental and health benefits.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en15010329/s1, Table S1: Timeline of key legislations and actions on the topic of EP in EU (non-exhaustive list). Table S2: Measures adopted in Portugal to tackle EP directly or indirectly.

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Nomenclature

GHG	Energy-related greenhouse gas
ELPRE	Long-Term Strategy for the Renovation of Buildings
EP	Energy Poverty
EPBD	Energy performance of buildings Directive
EPC	Energy Performance Certificates
EPOV	European Union Energy Poverty Observatory
EU	European Union
EU-SILC	European Union Statistics on Income and Living Conditions
EWM	Excess winter mortality
HVAC	Heating, Ventilating and Air Conditioning
HBS	Household Budget Survey
IAQ	Indoor Air Quality
MS	Member state
PA	Paris Agreement
RCCTE	Regulation of Thermal Behavior Characteristics of Buildings
RECS	Regulation on the energy performance of service buildings
REH	Regulation on the energy performance of residential buildings
RES	Renewable Energy Systems
RSECE	Air-Conditioning Energy Systems Codes
SCE	Buildings Energy Certification System
WHO	World Health Organization

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