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Review of 50 years of EU energy efficiency policies for buildings

M. Economidou [a], V. Todeschi [a,b], P. Bertoldi [a,*], D. D'Agostino [a], P. Zangheri [a], L. Castellazzi [a]

[a] European Commission, Joint Research Centre, Directorate for Energy, Transport and Climate, Italy
[b] Politecnico di Torino, Italy

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ABSTRACT

The reduction of energy demand in buildings through the adoption of energy efficiency policy is a key pillar of the European Union (EU) climate and energy strategy. Energy efficiency first emerged in the EU energy policy agenda in the 1970s and was progressively transformed with shifting global and EU energy and climate policies and priorities. The paper offers a review of EU energy policies spanning over the last half century with a focus on policy instruments to encourage measures on energy efficiency in new and existing buildings. Starting from early policies set by the EU in response to the Oil Embargo in the 1973, the paper discusses the impact of EU policies in stimulating energy efficiency improvements in the building sector ranging from the SAVE Directive to the recently 2018 updated Energy Performance of Buildings Directive and Energy Efficiency Directive. The review explores the progress made over the last 50 years in addressing energy efficiency in buildings and highlights successes as well as remaining challenges. It discusses the impact of political priorities in reshaping how energy efficiency is addressed by EU policymakers, leading to a holistic approach to buildings, and provides insights and suggestions on how to further exploit the EU potential to save energy from buildings.

Contents

* Corresponding author at: European Commission, Joint Research Centre (JRC), Directorate C–Energy, Transport and Climate, Energy Efficiency and Renewables Unit, Via E. Fermi 2749, Ispra, VA, Italy.
E-mail addresses: marina.economidou@ec.europa.eu (M. Economidou), paolo.bertoldi@ec.europa.eu (P. Bertoldi).

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1. Introduction

Energy production and consumption have a significant impact on climate change due to their contribution in atmospheric emissions of CO_2 resulting from fossil fuels. With the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Conference in 1992 and the subsequent Kyoto Protocol in 1997, climate change received widespread recognition as one of the most urgent global issues and remains a key priority for governments around the world to-date. Actions to limit global warming have been intensified in more recent years, with the Paris Agreement at COP 21 in December 2015 marking the latest major milestone in global climate change negotiations [1–2]. Through the Paris Agreement, participating countries are called to set targets to limit the global average temperature rise to "well below" 2 °C above pre-industrial levels, with the view to pursue further efforts to limit the temperature rise to 1.5 °C above pre-industrial levels [3]. The agreement aims to "reach global peaking of greenhouse gas (GHG) as soon as possible" and "achieve a balance between anthropogenic emissions by sources and removal by sinks of GHG in the second half of this century"[3]. Energy efficiency (EE) and energy demand reduction have been highlighted as key mitigation options by several IPCC Assessment Reports and UNFCCC documents, protocols and international agreements [4].

In the European Union (EU), energy production and use is responsible for 80% of all GHG emissions. Accounting for about 40% of EU's final energy and 36% of CO_2 emissions, buildings are associated with a significant untapped energy saving potential [5]. Much of the energy currently used in buildings is wasted due to outdated construction practices, use of inefficient systems or appliances and lack of effective technical control systems. There are, however, several well-proven solutions that can limit this energy waste in buildings. For example, demand for heating and cooling in buildings can be drastically reduced through thermal insulation, efficient glazing solutions, elimination of thermal bridges and leaks, and installation of efficient heating/cooling generation and distribution systems [6,7]. Additional measures may cover other technical building systems such as air-conditioning, ventilation, hot water production and lighting systems. Beyond active solutions, passive design options such as optimised spatial planning, building orientation, natural ventilation strategies and effective use of thermal mass, passive solar systems for heating and cooling [8,9] have an important role to play in reducing energy consumption and improving thermal comfort. Smart metering systems can be used to better control supplied services, inform occupants about their behaviour and encourage energy conversation measures [6,10].

Many of the aforementioned energy efficiency measures can generate significant energy savings, thereby limiting the overall contribution of the sector to global warming. Beyond energy savings, the installation of these measures can preserve scarce natural resources, contribute to the national security of supply of energy importing countries, reduce local pollution, improve the competitiveness of companies, reduce household energy expenditure, eradicate fuel poverty, create local jobs and improve indoor environment quality. Many of these additional benefits have been broadly discussed in the literature [11–13]. Despite the plethora of their benefits and well-documented cost effectiveness actual investments in energy efficiency remain at suboptimal levels and not in par with their potential. In the literature, the "energy efficiency gap", defined as the difference between the actual and optimal level of energy efficiency, has been extensively studied [14,15]. A number of barriers including perceived uncertainty and possible risks inhibit the widespread application of energy efficiency measures in buildings [16]. Loss aversion can partly justify the "energy efficiency gap" where individuals appear to neglect cost-effective energy efficiency investments [17,18]. Other barriers relate to the cost of financing the upfront investments, lack of information, split incentives, complex decision-making processes and difficulties in accessing capital [19]. Vogel et al. [20] identify 38 barriers to energy efficiency in buildings, categorized into three analytical decision-levels: (1) project level (lack of interest, information, etc.); (2) sector level (barriers at the industrial level, e.g. resistance

Table 1
Categorization of policy measures [Source: Bertoldi & Economidou., 2018].

Regulatory	Building codes; Minimum energy performance standards (MEPR) for new and existing buildings; Energy efficiency standards for appliances & equipment; Refurbishment obligations; Procurement Regulations; Phase-out of inefficient equipment.
Financial and fiscal	Grants/subsidies; Preferential loans; Tax incentives; Energy taxation.
Information and awareness	General Information; Information campaigns; Information Centres; Energy Audits; Energy labelling schemes; Governing by Example; Information exchange; Awareness campaigns; Demonstration programmes.
Qualification, training and quality assurance	Professional training; Training courses; Vocational education, quality standards.
Market-based	Incentives facilitating Third Party Financing/ ESCOs; Energy Efficiency Obligation Schemes (EEOSs); White certificates; Incentives for the producers of innovative technologies; Technology deployment schemes.
Voluntary action	Voluntary certification and labelling programs; Voluntary and negotiated agreements.
Infrastructure investments	Investments in transportation infrastructure (e.g. railways, road networks), Energy infrastructure (e.g. generation plants, electrical grid, substations, and local distribution); Smart meter roll-out.
Other	Other measures that do not fall under one of the above categories (e.g. research innovation and innovation programme, demonstration projects).

Table 2
Overview of main energy efficiency policy initiatives taken at the EU level over the last 50 years.

Type of policy	Description	Reference
Resolutions	Council Resolution 75/C 153/2 of 17 December 1974 concerning Community energy policy objectives for 1985	1975/C 153/2
	Council Resolution 80/C 149/1 of 9 June 1980 concerning Community energy policy objectives for 1990 and convergence of the policies of the Member States	1980/C 149/1
	Council Resolution 86/C 241/01 of 16 September 1986 on new Community energy policy objectives for 1995 and convergence of the policies of the Member States	1986/C 241/01
Regulations	Regulation 305/2011/EU of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC	2011/305/EU
Directives	Council Directive 1978/170/EEC of 13 February 1978 on the performance of heat generators for space heating and the production of hot water in new or existing non– industrial buildings and on the insulation of heat and domestic hot-water distribution in new non-industrial buildings	1978/170/EEC
	Council Directive 1989/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products	1989/106/EEC
	Council Directive 1992/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels	1992/42/EEC
	Council Directive 1992/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances	1992/75/EEC
	Council Directive 1993/76/EEC of 13 September 1993 to limit carbon dioxide emissions by improving energy efficiency (SAVE)	1993/76/EEC
	Directive 1996/57/EC of 3 September 1996 on energy efficiency requirements for household electric refrigerators, freezers and combinations thereof	1996/57/EC
	Directive 2000/55/EC of 18 September 2000 on energy efficiency requirements for ballasts for fluorescent lighting	2000/55/EC
	Directive 2002/91/EC of 16 December 2002 on the energy performance of buildings	2002/91/EC
	Directive 2005/32/EC of 6 July 2005 establishing a framework for the setting of eco-design requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council	2005/32/EC
	Directive 2006/32/EC of 5 April 2006 on Energy End-use Efficiency and Energy Services and Repealing Council Directive 93/76/EEC	2006/32/EC
	Directive 2009/125/EC of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products	2009/125/EC
	Directive 2010/31/EU of 19 May 2010 on the Energy Performance of Buildings (recast)	2010/31/EU
	Directive 2012/27/EU of 14 November 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC	2012/27/EU
	Directive 2018/844/EU of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency	2018/844/EU
	Directive 2018/2002/EU of 11 December 2018 amending Directive 2012/27/EU on energy efficiency	2018/2002/EU
Communications	EC, 1987. Towards a continuing policy for energy efficiency in the European Community. COM (1987) 223 final. Brussels, 13.05.1987	COM(1987) 223
	EC, 1998. Energy Efficiency in the European Community - Towards a Strategy for the Rational Use of Energy. COM (1998) 246 final. Brussels, 29.04.	COM(1998) 246
	EC, 2000. EU policies and measures to reduce greenhouse gas emissions: towards a European Climate Change Programme (ECCP). COM (2000) 88 final. Brussels, 08.03.2000	COM(2000) 88
	EC, 2000. Action Plan to Improve Energy Efficiency in the European Community. COM (2000) 247 final. Brussels, 26.04.2000	COM(2000) 247
	EC, 2000. Green Paper on Towards a European Strategy for Energy Supply. COM (2000) 769 final. Brussels, 29.11.2000	COM(2000) 769
	EC, 2005. Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final. Brussels, 22.06.2005	COM(2005) 265
	EC, 2006. Communication from the Commission - Action Plan for Energy Efficiency: Realising the Potential. Brussels, 19.10.2006	COM(2006) 545
	EC, 2007. An energy policy for Europe. COM (2007) 1 final. Brussels, 10.1.2007	COM(2007) 1
	EC, 2011. A Roadmap for moving to a competitive low carbon economy in 2050. COM (2011) 112 final. Brussels, 8.3.2011	COM(2011) 112
	EC, 2015. Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM (2015) 80 final. Brussels, 25.2.2015	COM(2015) 80
	EC, 2019. The European Green Deal. COM (2019) 640 final. Brussels, 11.12.2019	COM(2019) 640
Recommendations	Council Recommendation of 4 May 1976 on the rational use of energy in the heating system of existing buildings	76/493/EEC
	Council Recommendation of 4 May 1976 on the rational use of energy for electrical household appliances	76/496/EEC
	Council Recommendation of 4 May 1976 on the rational use of energy by promoting the thermal insulation of buildings	76/492/EEC
	Council Recommendation of 25 October 1977 on the regulation of space heating, domestic hot water production and the metering of heat in new buildings	77/712/EEC
	Council Recommendation of 5 February 1979 on the reduction of energy requirements for buildings in the Community	79/167/ECSE

to change); (3) and contextual level (institutional framework, regulations, policies, etc.).

In order to overcome these barriers, governments have adopted several energy efficiency programmes, policies or packages of poli-

Table 3
Literature review on EPBD and EED, and the impact assessment in buildings.

Topic	Subtopic	No. of papers	Source
1.	a. International climate agreement	8	Wiel et al. [40],Dehousse & Zgajewski [70],da Graça Carvalho [71],Kinley [1],Bertoldi [4],Ringel & Knodt [73], Tobin et al. [2],Veum & Bauknecht [72]
	b. Energy efficiency and barriers in buildings	15	Blumstein et al. [35],Hirst & Brown [14],Jaffe & Stavins [15],Brown [21],Míguez et al. [63],Atanasiu & Bertoldi [56],Backlund et al. [69],Pelenur & Cruickshank [17],Wilson et al. [19],Vogel et al. [20],Martínez-Molina et al. [8],Martinopoulos et al. [6],Aslani et al. [7],Blázquez et al. [9],Cooremans & Schönenberger [16]
	c. Energy efficiency policies and energy security	44	Kestner [60],Ryan [46],Axelrod [44],Elagöz [59]; Fee (1992a); Fee [52–53],Loveday [49],Elagöz [42],Bassi [47]; Lay-cock et al. (1995); Caluwaerts et al. [45],Swisher [43],Waide et al. [55],Pesch [51],Laponche & Tillerson [67],Leth-Petersen & Togeby [28],Richalet et al. [65],Sjöström et al. [48],van Wees et al. [61],Bertoldi et al. [57], Geller et al. [41],Konidari & Mavrakis [166],de Alegría Mancisidor et al. [62],Nash [58],Vivoda [34],Alpanda & Peralta-Alva [32],De Paepe et al. [54],Kanellakis et al. [29],Månsson et al. [38], Sovacool & Saunders [39], Rosenow et al. [23], Bluszcz [33], Brown & Huntington [36], Freed & Felder [12],Kern et al. [22],Laes et al. [26], Mutani & Todeschi [13],Bertoldi [64],Camarasa et al. [27],Fawcett & Killip [11],Heutel [18],Šprajc et al. [31], Bertoldi [24],Bertoldi & Mosconi [173]
2.	a. Overview of EPBD	8	Cohen et al. [74],Santamouris [76],Dascalaki et al. [77], ÓBroin et al. [107],Papadopoulos [37],Fokaides et al. [75],Blumberga et al. [78],Thonipara et al. [25]
	b. Minimum energy performance requirements	2	Sorrell [79],Serrano et al. [81]
	c. Energy performance certificates	22	Beerepoot & Sunikka [85],Fuerst & McAllister [100],Amecke [89],Bull et al. [90],Kok & Jennen [99],Bio Intelligence Service et al. [82],Hyland et al. [93],Högberg [94],Arcipowska et al. [84],Cerin et al. [95],Murphy [101],Davis et al. [86],Fuerst et al. [96],de Ayala et al., [83],Chegut et al. [97],Hårsman et al. [87],Wahlström [102],Fregonara et al. [98],Olaussen et al. [103],Pascuas et al. [88],Li et al. [91],Semple & Jenkins [92]
	d. Inspections of boilers and air-conditioning systems	3	Barma et al. [105],Fleiter et al. [104],Kozarcanin et al. [106]
	e. Cost-optimal methodology	12	Kurnitski et al. [108],Corgnati et al. [110],Hamdy et al. [109],Corrado et al. [111],Becchio et al. [114],Congedo et al. [112],Sağlam & Yılmaz [113]; Ashrafiana et al. [115]; Brandão de Vasconcelos et al. [116],Ortiz et al. [117],Buso et al. [161],Zangheri et al. [118],Karásek et al. [119]
	f. Nearly zero energy buildings	17	Torcellini et al. [159],Kapsalaki et al. [126],Annunziata et al. [122],Panagiotidou & Fuller [160],Lindkvist et al. [134],Kylili & Fokaides [125],D'Agostino et al. [123],D'agostino & Zangheri [124],Attia et al. [132],Oregi et al. [130],D'Agostino & Parker [127],Rodrigues et al. [131],Asdrubali et al. [121],Belussi et al. [128],D'Agostino & Mazzarella [174],Dunlop [133],Chastas et al. [129]
	g. Energy performance of buildings standards	4	Roulet & Anderson [135],Hogeling & van Dijk [136],Hogeling [137]; van Dijk & Hogeling [138]
3.	a. Overview of ESD and EED	10	Fawcettet al. [68],Economidou et al. [172],Bertoldi & Boza-Kiss [140],Rosenow et al. [139],Bertoldi & Economidou [30],Ringel & Knodt [73],Malinauskaite et al. [142],Nabitz & Hirzel [141],Tsemekidi-Tzeiranaki et al. [5]; Zangheri et al. [10]
	b. Long-term Renovation Strategies	4	Castellazzi et al. [143],Sesana & Salvalai [146],Castellazzi et al. [144],Sebi et al. [145]
	c. Central government buildings	4	Czakó [148],Economidou et al. [149],Tsemekidi-Tzeiranaki et al. [5]; Zangheri et al. [147]
	d. Split incentives	4	Bird & Hernández [153],Economidou & Bertoldi [151]; Castellazi et al. [150]; Economidou & Serrenho [152]
	e. Metering and billing	6	Fischer [155],Karlin et al. [157],Zvingilaite & Togeby [156],Castellazzi [154],Canale et al. [158]; Zangheri et al. [10]

cies [14,21–24]. In the EU, buildings have been an integral part of the EU energy and climate policy for several years. Energy efficiency policies for buildings can impact all end uses ranging from heating and cooling to lighting and appliances [25–26]. They can take the form of regulatory or control instruments, building codes, consumer information campaigns and economic or financial incentives [27]: [28]. Instruments of regulatory nature can include requirements on various household appliances, products, systems or entire buildings. Many of the energy efficiency measures can be encouraged or mandated through individual policies or policy packages [29]. So far, the evaluation and assessment of existing policies for EE in buildings (Table 1) suggest that there is no single policy that alone can achieve a substantial transformation of the existing building stock and reduce significantly energy consumption [30].

The present work offers a review of 50 years of the EE policies adopted by the EU and some of the policies adopted by its Member States (MSs) since the 1970s in order to improve the energy security and equity, reduce the impact on the environment, and increase the competitiveness of the European economy [31].

The paper is organized as follows. Section 2 describes the methodology used for assessing policy documents and published articles. A review of the early beginnings of the EU energy efficiency policy for buildings is presented in Section 3. Section 4 describes the 2000 and 2006 Action Plans that have aimed to set a strategic vision for EE improvements in Europe. To reach the targeted reduction of energy consumption and consequently GHG emissions in buildings, the EU has developed two main Directives: the EPBD[1], and the EED[2], described in Sections 5 and 6, respectively. Section 5 presents, inter-alia, an in-depth overview of the energy performance certificate (EPC) instrument (Section 5.1.2), the cost-optimal methodology (Section 5.2.1) and the concept of nearly zero energy buildings (Section 5.2.2). The discussion and conclusions are presented in the final sections.

2. Methodology

In order to understand how the EU policies have been effective in transforming the building stock and in reducing the energy consumption in new and existing buildings, this article investigates EU energy efficiency policy initiatives affecting the building sector (Table 2). An extensive literature review was performed to analyse in detail the EE policies and the impact on the energy consumption in buildings (Table 3). The review was based on the Web of Science and the Scopus databases to collect publications on EU energy efficiency policies related to buildings, including definitions/descriptions, assessment on economic and environmental effectiveness

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AL%3A2018%3A156%3ATOC&uri=uriserv%3AOJ.L_0.2018.156.01.0075.01.ENG.
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375279076&uri=CELEX:52013DC0762.

and notable examples of implementation in Europe. In particular, the literature review covered the following topics:

- Energy efficiency and consumption in buildings:
  - International climate agreement;
  - Energy efficiency and barriers in buildings;
  - Energy efficiency policies and energy security.
- Energy Performance of Building Directive (EPBD):
  - Overview (re-cast 2010 & 2018);
  - Minimum energy performance requirements (MEPR);
  - Energy performance certificates (EPC) including their role and impact on sales;
  - Inspections of boilers and air-conditioning systems;
  - Cost-optimal methodology introduced by EPBD 2010;
  - Nearly zero energy buildings (nZEB)
  - Energy performance of buildings standards
- Energy Services Directive (ESD) and Energy Efficiency Directive (EED):
  - Overview (re-cast 2018);
  - Long-term Renovation Strategies;
  - Central government building;
  - Split incentives;
  - Metering and billing.

3. Early beginnings of EU energy efficiency policy for buildings

The development of energy policy was at the heart of the European project, with the ECSC Treaty (establishing the European Coal and Steel Community) in 1951 and the Euratom Treaty (establishing the European Atomic Energy Community) in 1957. In the 1970 s and 1980 s, the initial emphasis of energy policies was on the security of energy supply as result of the Oil Embargo in the 1970 s [32–34]. Following the oil crisis in OECD countries in the 1973–1974, energy efficiency started to emerge as an important policy response to enhance oil security [35–37]. At the time, energy security was associated with "security of oil supply", but was later evolved to focus on other energy carriers including natural gas and renewable energy [38].

Following the first oil crisis, the European Council adopted a Resolution promoting energy savings in 1974 with the goal of reducing the rate of energy consumption growth and reach by 1985 a level 15% below the January 1973 estimates (Council Resolution of 17th December 1974, OJ C 153/2). In 1980, the European Council introduced a target for energy intensity and adopted policies including energy pricing measures (Council Resolution of 9th June 1980, OJ C 149/1). The Council Resolution of 16th September 1986 (86/C 241/01, concerning new Community energy policy objectives for 1995 and convergence of the policies of the Member States[3]) emphasized the need to search for balanced solutions as regards energy and the environment, make use of the best available and economically justified technologies and improve energy efficiency. This Council Resolution represented the first EU policy initiative adopting an EE target with the aim to achieve greater energy efficiency in all sectors and to tap into various energy saving possibilities. The EE target was defined as a minimum 20% improvement in the "efficiency of final energy demand" -defined as the ratio of final energy demand to gross national product- by 1995.

In 1987, the Commission Communication entitled "Towards a continuing policy for energy efficiency in the European Community" (COM(1987)223 final) proposed fourteen energy efficiency measures to Member States to help achieve the 1995 target. Seven out of the fourteen recommended policies were related to the provision of consumer information, seen as essential element to trigger investments in energy efficiency in a period of low oil prices.

In 1990, the climate change issue started to emerge and in the same year the European Council of Environment and Energy Ministers agreed on 29 October 1990 to stabilise total CO_2 emissions in 2000 at the 1990 levels.

Following the first Intergovernmental Panel on Climate Change (IPCC) Assessment report and establishment of the UNFCCC at the Rio Summit in 1992, the mitigation of climate change impacts became a key component of the EU energy policy along with the security of energy supply and competitiveness of energy users [4,39–40]. It was highlighted that EE contributed to three pillars of energy policy: the reduction of energy demand (and the related CO_2 emissions), the reduction of energy imports to meet energy service demand, and the cheaper energy services due to the reduction in energy use [41].

In the field of energy performance of buildings, the existence of large variations in energy performance levels and norms at Member State level gave a reason to consider policy action at the EU level [42–43]. The early EU energy efficiency policies for buildings constituted the "Construction Products Directive" in 1989, the "Boiler Directive" in 1992 and the "SAVE Directive" in 1993[44].

3.1. The construction products Directive (CPD)

The "Construction Products Directive" (CPD) (89/106/EEC)[4] intended to ensure that reliable information was presented in relation to the performance of construction products used in buildings and civil engineering works [45,46]. This was achieved by developing a common technical language through the introduction of harmonized standards [47,48].

The CPD provided four main elements: i) a common system of technical specifications; ii) an agreed system of verification of conformity; iii) a framework of stakeholders; iv) the CE marking of products [49]. While the requirements introduced by the CE marking included "energy economy and heat retention", the CPD did not explicitly address energy performance of construction products [50]. Instead, it called for construction works and its heating, cooling and ventilation installations to be designed and built in a way that ensured "low" energy use [51]. The CPD was repealed and replaced by the "Construction Products Regulation" (CPR) (Regulation N. 305/2011)[5] in order to simplify and clarify the previous framework, and to improve transparency and effectiveness of existing measures.

3.2. The boiler Directive (HWBD)

Heating and hot water boilers were the first building technical equipment to be covered by EU legislation in 1978, by the Council Directive 78/170/EEC on the performance of heat generators for space heating and the production of hot water [52–53]. The directive left to MSs the level of efficiency performances, this resulted in very different levels. The directive also covered the insulation of heat and domestic hot-water distribution networks in buildings. As the largest share of the energy in buildings is used for space heating and hot water production the Commission proposed a major legislative initiative on energy efficiency of boilers, which at the time were mostly of very low energy efficiency levels [54]. The Directive on Hot Water Boilers (HWBD) 92/42/EEC[6], adopted in 1992, introduced common efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels in all MSs. It covered

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31986Y0925(01)&from=IT.

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31989L0106.

[5] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32011R0305.

[6] https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:31992L0042.

standard boilers, low-temperature boilers and gas-condensing boilers with an output of between 4 kW and 400 kW.

A key requirement of the HWBD was the use of clear and consistent energy efficiency labels on hot-water boilers, enabling easy comparisons and bringing them in line with energy labelling practices for domestic appliances[7]. Similar Directives were adopted in 1996 introducing efficiency requirements for domestic refrigerators and freezers (1996/57/EC) [55]and in 2000 for ballasts for florescent lighting (2000/55/EC). These Directives were the predecessors of the Directive 2005/32/EC establishing a framework for the setting of eco-design requirements for energy-using products[8], which set out efficiency requirements for energy consuming products [56–58].

3.3. The SAVE Directive

The "SAVE" Directive[9] (93/76/EEC) of 1993 represents the first major EU policy on energy efficiency [59–61]. Earlier efforts such as the Council recommendations dating back to 1976 and 1979[10] provided policy suggestions on how to improve efficiency of heating systems, thermal insulation and electrical appliances. The Directive required Member States to draw up and implement programmes to improve energy efficiency, with the aim to limit CO_2 emissions and to promote the rational use of energy [53,62]. At that time, EU and national policy makers considered that building efficiency standards, mainly expressed as insulation requirements (minimum U value), were of national matter, in line with the principle of subsidiarity [63]. The issue was that, while a number of EU Member States such as Denmark and Germany, had already adopted mandatory building standards of various levels of stringency, several southern European countries did not have any mandatory building codes [64]. The SAVE Directive, therefore, called for all Member States, through its Article 5, to draw up and implement programmes introducing sufficient thermal insulation provisions in new buildings. The language used in the Directive, however, was not strong enough to oblige MSs to adopt efficiency requirements or fix a minimum level for the thermal insulation of buildings.

Other building-related requirements in the SAVE included the preparation and implementation of programmes for: i) the certification of buildings with the description of the building energy characteristics in order to provide to the consumer information on the EE level [65]; ii) the billing of heating, air-conditioning and domestic hot water based on actual consumption including the right for building occupants to regulate their own consumption of heat, cold or hot water; iii) the facilitation of third-party financing[11] for energy efficiency investments in the public buildings; iv) the thermal insulation of buildings, v) the regular inspection of heating installation larger than 15 kW and vi) the energy audits of undertakings with high energy consumption.

In 1998 the Commission presented a Communication (COM (1998) 246 final) highlighting the potential for energy efficiency improvements until the year 2010. The Communication identified an economic saving potential in building of 22% by 2010 compared to 1995. The Communication analysed the nature and types of barriers to the exploitation of this potential, reviewed the adopted programmes and proposed elements for a strategy and priorities to exploit the available potential. In particular, it proposed the revision of the SAVE directive for buildings and reinforcement of appliances standards.

The SAVE Directive was partly replaced by the Directive on the Energy Performance of Buildings in 2002 (as regards the efficiency standards, certification and boiler inspection articles), and the remaining articles were replaced by the Directive on energy end-use efficiency and energy services in 2006.

4. The energy efficiency action plans & climate energy targets

Since 2000 the Commission has published several Energy Efficiency Action Plans laying out its strategic vision and proposing actions such as new policies or strengthened existing measures. The following sections present the main elements of the Commission Energy Efficiency Action Plans in 2000, 2006 and 2011, and the Energy Union in 2015.

4.1. The 2000 energy efficiency action plan

The implementation of the SAVE Directive was not as fast, strong and successful as expected, which had not sufficiently exploited the large energy saving potential of the sector. This was in part due to the failure of MSs to adopt efficiency requirements or standards in their national building codes or the adoption of weak national standards. This underlined the need to increase thermal insulation in existing buildings, install energy efficient equipment, and expand certification and granting of licenses. After the adoption of the Kyoto Protocol in 1997, the EU committed to a binding 8% GHG emission reduction target in the period 2008–2012 compared to 1990. This triggered the enactment of stronger energy and climate policies [4]. The Kyoto agreement on the reduction of CO_2 emissions, renewed the need of commitment and promotion of energy efficiency in a more active way (COM(2000)247 final). The 2000 Action Plan [41,66] proposed several reinforced actions, building on the SAVE Directive provisions on buildings. The Action Plan acknowledged the fact that different implementation and enforcement approaches of the SAVE Directive led to mixed results. The Commission in its 2000 Action Plan highlighted the need to amend the SAVE Directive, define more concrete measures and strengthen reporting and compliance procedures. While a more co-ordinated and harmonised approach was recommended in the Action Plan, the freedom for Member States to set their own efficiency requirements was also stressed. This Action Plan has nonetheless served as a key trigger that shaped the policy cycle leading to the development of the EPBD in 2002 (see Section 5) [67].

4.2. The 2006 Energy Efficiency Action Plan

In 2006 the European Commission published its second Energy Efficiency Action Plan[12] [54,68–69]. Its scope was to control and reduce energy demand and to take targeted action on consumption and supply with the intention to save 20% of annual consumption of primary energy by 2020 compared to baseline energy consumption forecasts for 2020. This objective corresponded to achieving approximately a 1.5% saving per year up to 2020. The policies and measures in the 2006 Action Plan were based on the consultations launched by

[7] Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances - OJ L 297, 13 October 1992.

[8] Directive 2005/32/EC amending Council Directive 92/42/EEC, Directives 96/57/EC and 2000/55/EC. It was then replaced with Ecodesign of Energy Related Products Directive 2009/125/EC.

[9] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31993L0076:EN:HTML.

[10] Council Recommendation of 4 May 1976 on the rational use of energy in the heating system of existing buildings; Council Recommendation of 4 May 1976 on the rational use of energy for electrical household appliances; Council Recommendation of 4 May 1976 on the rational use of energy by promoting the thermal insulation of buildings; Council Recommendation of 5 February 1979 on the reduction of energy requirements for buildings in the Community

[11] Third-party financing is a typical implementation of an ESCO project in a building with the provision of auditing, installation, operation, maintenance and financing with the payment based on the achieved energy savings.

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l27064.

the 2005 Green Paper on Energy Efficiency (COM(2005)265 final). The Green Paper on the European Energy Strategy underlined the need to strengthen EU's energy efficiency policy.

The plan identified an energy saving potential of 27% compared to the business as usual consumption for residential buildings by 2020 and 30% for commercial buildings. The Communication proposed an overall realistic energy saving target of 20% to be achieved by 2020 through new measures and the strengthening of existing policies. In particular, the plan called for a drop in the EPBD threshold of 1000 m^2 for the mandatory energy efficiency improvements in major renovations of existing buildings and mandated very low energy consumption (e.g. Passive House levels) levels for new buildings. The policy debate that followed this action plan lead to the 2010 revision of the EPBD. The Action Plan included all measures with the best cost-efficiency ratio, i.e. those with the lowest environmental cost over the life cycle, which do not overrun the budget for investments in the energy sector.

Following the 2006 Action Plan in March 2007, EU leaders committed Europe to become a highly energy-efficient, low carbon economy and agreed on the targets, known as the "20-20-20" targets, by 2020 [70], which were formulated as:

- A 20% reduction in greenhouse gas emissions compared to 1990 levels;
- An increase in the share of energy from renewable energy sources to 20%;
- Improvements in energy efficiency that lead to 20% EU primary energy savings.

4.3. The 2011 Energy Efficiency Action Plan

In 2011 the new Commission presented the Roadmap for moving to a competitive low carbon economy in 2050[13] introducing new far-reaching targets to promote energy security, energy equity, and environmental sustainability: a cut in GHG emissions of 40% in 2030, 60% in 2040 and 80–95% in 2050 compared to 1990 levels [71]. At the same time the Commission adopted a new Energy Efficiency Action Plan [69,71]. Given the large energy saving potential of building renovations, the Plan stressed the need of more energy renovations in private and public sectors and introduced energy efficiency criteria for public buildings. In particular, the Plan proposed the requirement to renovate at least 3% of central government buildings every year. At that stage, the potential energy savings in residential buildings had been largely unexploited. MSs were thus encouraged to set up tools, instruments and measures to stimulate more energy performance upgrades of buildings in the private sector. Some measures introduced by the Plan were directed towards addressing the issue of 'split incentives', promoting the use of cogeneration combining electricity generation and district heating systems (wherever possible) and facilitating the use of tools such as energy performance contracting, energy audits, and ESCOs.

In 2014, the EU adopted energy and climate targets for 2030 as part of the Intended nationally determined contributions (INDC) to UNFCCC process leading to the Paris agreement. These were defined as: a 40% reduction in GHG emissions compared to 1990 levels, a minimum 27% share of renewable energy consumption, and at least 27% energy savings [4,72]. In 2018, following the discussions on setting the legal basis for the targets, the renewable and energy efficiency targets were modified to 32% and 32.5%, respectively.

[13] COM(2011) 112 final (https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF).

4.4. The energy Union and the role of energy efficiency

The Energy Union Strategy[14] "Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy" (EC, 2015), adopted on 25th February 2015, [72–73] reinvigorated the need to increase support for the transition towards a more sustainable consumer and business behaviour and promotion of secure, sustainable, competitive and affordable energy. The Energy Union Strategy focused on five dimensions: (i) security, solidarity and trust; (ii) a fully integrated internal energy market; (iii) energy efficiency; (iv) climate action, decarbonising the economy; and (v) research, innovation and competitiveness. The goal of the dimension on energy efficiency was to reduce dependence on energy imports, limit GHG emissions, improve energy security, drive new jobs and promote economic growth. The Energy Union Communication called for a revision of the EPBD (Section 5.3) and of the EED (Section 6) and for the introduction of a new governance of energy and climate action plans.

5. The Energy Performance of Building Directive

The first cohesive European legal act on energy policy in buildings was the Energy Performance of Buildings Directive (EPBD, 2002/91/EC). Introduced in 2002, it aimed to tap into the large cost-effective saving potential of the sector (namely 22% in a 10-year period) underlined by several Commission Communications[15]. With this initiative, the European Union transposed a key article of its founding Treaty[16] (new Article 191 on environmental protection), based on the idea to, inter-alia, improve the security of energy supply, increase employment and eliminate large differences observed between Member States.

In compliance with the EPBD Article 11, after the official transposition by the Member States (due by 4th January 2006) and the first years of implementation, the Commission started to evaluate the Directive in light of the experience gained during its application. Following this evaluation, the EPBD underwent a recast procedure in order to clarify and strengthen several provisions, the result of which was the adoption of the EPBD recast 2010/31/EU of 19th May 2010. Overall, the EPBD policy framework laid down the foundation for:

- setting minimum energy performance standards in new buildings and existing buildings under major renovation;
- ensuring that prospective buyers or renters are well informed and thereby encouraged to choose higher than minimum standards in their decision making processes;
- speeding up the rate at which investors engage in energy efficiency projects (including through finance).

The following sections give an overview of the first EPBD (2002) and describe the re-cast of EPBD in 2010 and its amendment in 2018.

5.1. EPBD 2002

With the Directive 2002/91/EC of 16th December 2002, the European Parliament and the Council introduced a joint energy performance calculation methodology for buildings. The following main areas of action were identified:

[14] COM(2015)080 final (https://www.eea.europa.eu/policy-documents/com-2015–80-final).

[15] COM (2001) 226, COM (2000) 769 of 29 November 2000 and COM (2000) 247 of 26 April 2000.

[16] https://eur-lex.europa.eu/collection/eu-law/treaties/treaties-force.html.

national minimum requirements and specific energy performance measures for new buildings and large (more than 1000 m^2) existing buildings undergoing major renovation (Section 5.1.1);
specific provisions for the set-up of mandatory national energy performance certificate (EPC) schemes for both new and some categories of existing buildings, including the need to display EPCs together with recommended indoor temperatures in large public buildings (Section 5.1.2);
revised conditions for the inspection of boilers and heating/-cooling systems, made by qualified and accredited experts (Section 5.1.3).

In accordance with the European subsidiarity principle and considering the local peculiarities and climatic differences, Member States were asked to transpose the EPBD provisions within a three year period. Given the novelty of the Directive, in particular in relation to building codes and certification schemes [74–76], the progress of the transposition in several Member States was rather slow [75,77–78]. Member States were therefore given the possibility to apply for an additional period of three years (until 2009) to comply with the provisions of the Directive.

5.1.1. ***Minimum energy performance requirements (Articles 4–5)***

The adoption of minimum energy performance requirements in buildings represented a major step forward [37] despite the existence of some prior experience in a small group of countries comprising Germany, France, UK, Denmark, Italy and the Netherlands. This early adopter group moved from the "first" generation of building codes in the 1970 s–1980 s (mainly consisting of thermal insulation requirements in the form of U-values) to the "second" generation of integrated building codes in the late 1990 s. The second generation was developed with a view to regulate energy performance of buildings in a more holistic approach and give freedom to building designers to meet a targeted energy performance in function of building requirements, costs and other factors [79,80]. The EPBD aimed to bring up to speed all Member States and set a common approach on the calculation of energy performance of buildings [81]. Under the EPBD provisions, the minimum energy performance requirements applied to both new and large (over 1000 m^2 useful floor area) existing buildings under major renovation, where energy performance of a building was defined as the amount of consumed or calculated energy use, typically measured in kWh/m^2 per year. The latter was estimated based on different needs associated with a standardized use of the building. This amount had to be reflected in one or more numeric indicators, taking into account:

- outdoor and indoor climatic conditions;
- position and orientation of the building;
- thermal characteristics of the envelope (including air-tightness);
- passive solar systems and solar protection;
- natural ventilation and passive strategies;
- heating, hot water, air-conditioning and ventilation installations;
- built-in lighting installations (mainly for the non-residential sector);
- own-energy generation.

5.1.2. *Energy performance certificates (Article 7)*

Energy performance certification is an ambitious and mandatory information scheme set up by Member States in compliance with the EPBD Article 7. According to the EPBD provisions, EPCs with a 10-year validity must be made available to prospective buyers or tenants in real estate transactions. Using the integrated methodological approach adopted under Articles 4–5, EPCs are a concise document displaying the energy performance of a building or building unit —based on an energy class or continuous scale rating system— together with recommended actions on how to improve the existing energy performance. In accordance with the EPBD Annex 1, energy performance can be defined as either calculated or monitored energy consumption of a building. The primary scope of EPCs is to guide prospective buyers or renters in their decision making process, increase demand in buildings of high energy efficiency and act as a driver for more energy renovations [82,83]. Beyond their important awareness raising dimension, EPCs can also be used to monitor the overall energy performance of the building stock, thereby bringing more transparency in the property market [84–86].

The scope and implementation details of the enacted EPC schemes varied greatly from country to country. Variations cover qualification systems for certifiers, dependent quality control systems, EPC registers, etc. [84]. While EPC registers and quality control measures were established in most Member States, a general underlying issue is the lack of access to trustworthy information which leads to reluctance in renovation decisions according to Hårsman et al. [87]. A survey carried out in eight European countries revealed low trust in EPCs among real estate agents, representing a key hurdle to their success [88]. Even though the use of EPCs generally improved after the EPBD recast, further remaining changes to the design of EPCs have been identified by several researchers [89–90]. Li et al. [91] stressed the need of upgrading the next generation of EPCs to a more comprehensive and reliable information source and Semple and Jenkins [92], who studied EPC methodological differences between countries, pointed out the need of a more flexible approach.

The relationship between energy performance and property value, which is generally studied in hedonic-price techniques, remains a complex and under-researched topic in part due to data limitations. Despite this, several studies have identified a positive correlation between energy performance and property value. These include studies on the Swedish, Irish, Italian, Spanish, UK and Dutch which all show that real estate markets value energy efficiency [83,93–98]. Premiums for energy efficiency ranged from 1.8 to 5% for UK, 2.0–6.3% for Dutch, 6–8% for Italian and 5.4% and 9.8% for Spanish dwellings [83,96–98]. For commercial properties, an empirical analysis showed that inefficient buildings of EPC labels D or below were linked to rental price levels around 6.5% lower compared to energy efficient ones [99]. On the other hand, some studies identified a negligible or weak relationship between energy performance and property value [86,89,100–103]. In some cases, this weak relationship was found in markets which have been showed by other studies to value energy efficiency, pointing out to the need for further research.

5.1.3. ***Inspections of boilers and air-conditioning systems (Articles 8–9)***

Another important EPBD measure, which was first introduced in the SAVE Directive, relates to regular inspections and assessment of efficiency of boilers and air-conditioning systems (Articles 8 and 9). With space heating accounting for at least 50% of residential energy consumption, thus representing the most important end-use [104], proper maintenance, periodic inspections, and awareness raising actions cannot only ensure safety but help reduce energy consumption [105]. In compliance with Articles 8–9, boilers with an effective rated output of more than 10 kW should be regularly inspected to improve their operating conditions. As efficiency of boilers drops with time without proper maintenance, inspections of entire heating installations with boilers of more than 15 years old should be carried out, and advice be given on alternative solutions to limit carbon dioxide emissions. Similar measures need to be implemented, for the first time also in relation to cooling systems, in particular in larger service buildings. This provision is of foremost importance due to the rising cooling needs throughout Europe linked to climate change [106].

5.2. EPBD 2010

In 2009 the European Commission presented the recast of the EPBD[17] (2010/31/EC, EPBD Recast) with the aim to strengthen some original EPBD provisions and capture additional energy savings as stated in the 2006 Action Plan. The main purpose of the EPBD recast was to ensure that national Minimum Energy Performance Requirements adopted by Member States had similar ambition levels in terms of energy savings and greenhouse gas emissions reduction. This is because some national standards were not ambitious and cost-effective enough [107]. To this end, Article 5 of the EPBD recast introduced the cost-optimal methodology as the guiding principle for setting building energy requirements and Article 9 introduced the concept of "nearly zero-energy buildings" (NZEBs) according to which all new private buildings will have to comply with nationally defined NZEB standards by January 2021.

The new EPBD also eliminated the threshold of 1000 m^2 for existing buildings under renovation to meet energy performance standards and installation requirements. In addition, energy performance requirements were introduced for technical building systems (heating, hot water, ventilation, cooling, air conditioning). The provisions related to the EPCs and inspection of heating and air-conditioning systems were reinforced to make them more effective. The EPBD recast aimed to raise the importance of financial incentives to promote energy renovations and required Member States to identify and submit to the Commission national financial measures to improve energy efficiency. From the Commission's side, support was made available in terms of structural funds, European Investment bank funds and other EU funds.

5.2.1. The cost-optimal methodology (EPBD Article 5)

As indicated in the EPBD recast, in 2012 the Commission provided the delegated Regulation 244/2012 (accompanied by official Guidelines) related to the comparative methodology framework of cost-optimal levels to be used by Member States to benchmark their buildings standards. The methodology is based on the principle of the cost-benefit analysis and can be calculated from two economic perspectives: the financial and the macroeconomic, which refer to different discount rates (lower in the macroeconomic one) and cost items. While the financial perspective includes taxes, the macroeconomic considers greenhouse gas emission costs.

The calculation approach can be summarized in six steps:

- Establishment of reference buildings by selecting real or virtual buildings representing the building stock. Member States shall define them for at least four building categories, both for new and existing buildings (residential single-family, residential multi-family, offices, and another non-residential type). For new buildings, the energy performance standard in force can be assumed as base case, while for the existing stock at least two construction periods have to be considered as reference;
- Identification of energy efficiency and renewable measures to be implemented in new or existing buildings, including different packages of measures or measures of different levels (e.g. different insulation levels), which must respect the EU and national legislation on construction products, comfort indoor and indoor air quality;
- Calculation of the (net) primary energy consumption based on the current National or CEN standards (i.e. EPBD methodology) for each selected building variant;
- Calculation of the global cost at each step using the Net Present Value based on 30 years for residential and 20 years for non-residential buildings. The included cost categories are: initial investment costs, running costs (i.e. energy, operational, maintenance, replacement costs), disposal costs, final value and the cost associated to CO_2 emissions (only for the macroeconomic perspective);
- Identification of cost-optimal levels for each reference building expressed in primary energy consumption (kWh/m^2 year or in the relevant unit). Cost-optimal levels can be calculated for both macroeconomic and financial perspectives, but normally derived with the second one;
- Evaluation of the gap with current minimum energy performance requirements. If the difference is more than 15%, Member States are asked to justify the gap or define a plan to reduce the gap.

Key calculation parameters in the cost-optimal calculation are: the discount/interest rate, the annual increase of energy prices, as well as primary energy factors associated to different fuels. The EPBD delegated Regulation required Member States to develop sensitivity analysis to evaluate the robustness of these parameters, and possibly also future technology price development.

A number of recent researchers tested the cost-optimal methodology applied in different EU countries [108–119]. Member States sent their calculation reports to the Commission in 2013 and 2018. While the assessment of the latest results is still ongoing, the analysis of the first ones revealed an overall rather positive picture regarding both the conformity to the official requirements and the plausibility of the final outputs [120].

5.2.2. Nearly zero energy buildings (EPBD Article 9)

The concept of nearly zero energy building (NZEB) was introduced in the EPBD recast. It establishes that new buildings occupied by public authorities have to be NZEBs by 31st December 2018, while all new buildings by 31st December 2020. An NZEB is defined as a building of very high energy performance, where the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby. The concept of NZEBs can be summarized in the diagram of Fig. 1.

According to the EPBD, Member States were requested to report NZEB definitions, reflecting on national, regional or local conditions. Their reports had to include quantified information on the meaning of "very high energy performance" and "very significant extent by energy from renewable sources" as well as a primary energy indicator (expressed in kWh/m^2). This can be referred to total non-renewable or renewable energy use [121,122].

Benchmarks for the energy performance of NZEBs are reported in Table 4 for different climatic zones as published in the EU Commission Recommendation 2016/1318 of 29th July 2016 (on Guidelines for the promotion of nearly zero energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero energy buildings).

The Member State progress towards NZEBs definitions was assessed by D'Agostino et al. [123], based on NZEB National Plans, information from the EPBD Concerted Action (CA), Energy Efficiency Action Plans (NEEAP), and National Codes. Member States have now endorsed EU requirements in their Regulations and set numerical indicators for new and existing buildings aiming to reach the NZEB level. Some key points can be summarized as follows [124]:

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0031.

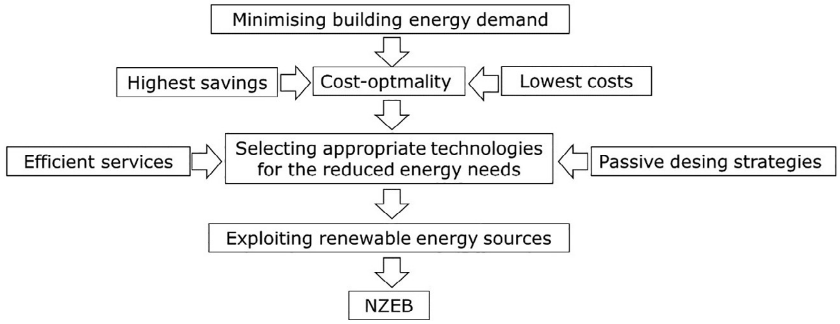

Fig. 1. Concept of a NZEB [Source: [174]].

Table 4
NZEBs level of performance (kWh/m^{2}y) per building type according to the European climate.

Climate	Single family house			Office		
	net primary energy	*primary energy*	*on-site RES*	*net primary energy*	*primary energy*	*on-site RES*
	[kWh/m^{2}y]					
Mediterranean Catania (others: Athens, Larnaca, Luga, Seville, Palermo)	0–15	50–65	50	20–30	80–90	60
Oceanic Paris (others: Amsterdam, Berlin, Brussels, Copenhagen, Dublin, London, Macon, Nancy, Prague, Warszawa)	15–30	50–60	35	40–55	*85–100*	45
Continental Budapest (others: Bratislava, Ljubljana, Milan, Vienna)	20–40	50–70	30	40–55	85–100	45
Nordic Stockholm (others: Helsinki, Riga, Stockholm, Gdansk, Tovarene)	40–65	65–90	25	55–70	85–100	30

- Heating, domestic hot water (DHW), ventilation, and cooling are the main included energy uses. Auxiliary energy and lighting are taken into account in the majority of Member States, while several also include appliances and central services;
- Energy balance calculations are derived as the difference between primary energy demand and generated energy over a one-year period;
- Single building or building unit are the most frequent physical boundaries in energy performance calculations;
- Conditioned area is the most agreed upon choice in relation to normalization factors.
- On-site generation is the most common RES option, but some MSs also consider external and nearby generation;
- The most used technologies are PV, solar thermal, air- and ground-source heat pumps, geothermal, passive solar, passive cooling, wind power, biomass, biofuel, micro CHP, and heat recovery.

Different system boundaries and energy uses cause a high variation within the described definitions [125]. The level of energy efficiency, the inclusion of lighting and appliances, as well as the recommended renewables to be implemented vary across Europe [126].

In addition to provide definitions, Member States are requested to draw up national plans and adopt measures, policies and financial incentives for the promotion of NZEBs. However, while reaching the NZEBs target in new buildings appears to be feasible according to studies on energy performance optimization [127] the challenge remains for existing buildings [128]. According to [129], an economic and environmental assessment could identify the uncertainty in system boundaries [130], using it to assess the lack of information in the design stage of building retrofitting through a streamlined approach [131].

The current renovation rate has been assessed between 0.5% and 2.5% per year with buildings dating between 1945 and 1980 having the largest energy demand [132]. Moreover, the existing stock is characterized by a high heterogeneity in terms of uses, climatic areas, construction traditions and systems.

Different barriers persist towards NZEBs renovation. These are mainly technical, financial, social, political and institutional. It is frequent that existing structures limit the choice of the technical solutions that can be used, especially in buildings of architectural value. Furthermore, technical solutions may be expensive and request a high investment. A limited access to investments and the non-adequacy of financial models of micro-credit institutes are other open issues. The payback period for renovation may take between 15 and 30 years, and often residents do not benefit from it. Recently, the importance of social barriers has risen [133]. These include: lack of knowledge, user behaviors, and interest in energy efficiency. Communication and information between the involved actors and organizations, as well as with residents, are key factors for a successful NZEB renovation. Communication of best practices and end-user behaviour are other aspects to be considered towards a wide NZEB retrofit implementation [134].

5.2.3. Energy performance of buildings standards

The European standardisation bodies, and in particular CEN, had a key role for enabling the implementation of the EPBD in Member States. The 2002 EPBD Article 3 requested Member States to apply a methodology for calculating the energy performance of buildings based of the general framework set out in the EPBD Annex. The European Commission issued on 30 January 2004 a standardisation mandate to CEN, CENELEC and ETSI for a methodology calculating the integrated energy performance of buildings and estimating the environmental impact (M/343)[18]. CEN introduced a common framework for a methodology of calculation of the total energy performance of buildings [135]). Under the mandate M/343, 28 European standards (EN) have been developed, covering the building energy performance calculation methods, the technical system inspection procedures and other relevant issues [136]. The CEN Technical Committees, which contributed to the preparation of the standards included: CEN/TC 89 (Thermal performance of buildings and building components); CEN/TC 156 (Ventilation for buildings); CEN/TC

[18] Available at https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=refSearch.search&lang=EN

169 (Light and lighting); CEN/TC 228 (Heating systems in buildings); CEN/TC 247 (Building automation, controls and building management) [135]. The relation between these standards is described in the "Umbrella Document" (CEN Technical Report TR 15615)[19].

With the recast of the EPBD in 2010, a new mandate (M/480) was issued by the European Commission to CEN to further develop the set of EPB standards to be used by Member States for the implementation of the Directive. This resulted in the set of 52 EPB-standards. The standards were reformulated in order to avoid ant ambiguity in the national transposition [137]. Several CEN Technical Committees have developed the standards as during the first phase: TC 89, TC 156, TC 169, TC 228, TC 247, while CEN/TC 371 provided the overall coordination. Some of (11 of the 42) first generation of EBP standards are EN-ISO standards. Revision of these standards requires co-operation with the ISO /TC 163/WG 4 [137]. In order to co-ordinate the revisions of EN-ISO standards required under mandate M/480 CEN/TC 371 established a liaison with ISO/TC163/WG4 [137]and finally produced the EN-ISO series 52,000 including more than 32 standards entirely dedicated to energy performance of buildings. Some of (11 of the 42) first generation of EBP standards are also EN-ISO standards. Revision of these standards requires co-operation with the ISO /TC 163/WG 4. In order to co-ordinate the revisions of EN-ISO standards required under mandate M/480 CEN/TC 371 established a liaison with ISO/TC163/WG4 and finally produced the EN-ISO series 52,000 including more than 32 standards entirely dedicated to energy performance of buildings [137]. The final package of the Energy Performance of Buildings standard under mandate M/480 has been published in summer [138]. This set of standards allow to evaluate the overall energy performance of a building. A number of key EPB standards are available at global level (the EN ISO 52,000 family of standards) [138].

5.3. EPBD 2018

In order to implement the Energy Union Strategy[20], in November 2016 the Commission adopted a package of measures (the Winter Package) to revise the EED and EPBD and align them to the new 2030 energy and climate targets. The EPBD amendment procedure started at the end of 2016 and ended on 30 May 2018 with the approval of Directive 2018/844/EU. The Commission also launched a new buildings database – the EU Building Stock Observatory[21] – to track the EP of buildings across Europe. In order to stimulate and increase the level of direct investment towards the renovation of the building stock, the Commission launched the 'Smart Finance for Smart Buildings' initiative, which aims to unlock an additional EUR 10 billion of public and private funds.

On 19th June 2018 the new Directive (2018/844/EU, EPBD) was published and the revised provisions entered into force on 9th July 2018. This revision introduces targeted amendments to the current EPBD aimed at accelerating the cost-effective renovation of existing buildings, with the aim of a decarbonized building stock by 2050 and the mobilization of investments to reach this goal [25]. The revision also supports electro-mobility diffusion by mandating electro-mobility infrastructure deployment in buildings' car parks. It also introduces new provisions to enhance smart technologies and technical building systems, including building automation.

Member States have 20 months to transpose the Directive into national laws (namely by 10th March 2020). In particular, the 2018 EPBD includes the following provisions:

- Member States shall establish more effective long-term renovation strategies (LTRS), identifying an adequate set of financial measures and consulting stakeholders in the preparation and implementation of their strategies;
- Stimulate cost-effective deep renovation encouraging more holistic approaches in energy renovation projects. The possibility of using Building Renovation Passports (BRP) and trigger points in the life of the building is also given. Member States need to identify these trigger points as part of their LTRS and in accordance with national practices. The introduction of an optional scheme for individual BRP is included for the first time in the LTRS context of the requirements that Member States prepare for their building stock;
- The Commission will develop common European schemes for rating the smart readiness of buildings, which will be optional for Member States;
- Smart technologies and ICT in buildings will be promoted, for example through requirements on the installation of building automation and control systems and on devices that regulate the indoor temperature from the building level down to the room level ensuring that buildings operate efficiently;
- E-mobility will be supported by introducing minimum requirements for electric recharge points over a certain size of the building and other minimum infrastructure are introduced for smaller buildings;
- Member States shall express their national energy performance requirements in ways that allow cross-national comparisons;
- improving the transparency and quality of the EPCs;
- Health and well-being of building users will be promoted, for instance through an increased consideration of air quality and ventilation;
- Combatting energy poverty and reducing the household energy bill by renovating older buildings.

6. The Energy Services Directive (ESD) and Energy Efficiency Directive (EED)

The Energy Services Directive (ESD – 2006/32/EC) is broadly considered as successor of the SAVE Directive and the predecessor of the EED. Adopted in 2006, the ESD laid out the foundation for setting indicative national targets equivalent to at least 9% energy savings by 2016 and introduced reporting obligations through the preparation of National Energy Efficiency Plans (NEEAPs) [30,73]. Whilst the ESD did not have any specific focus on buildings, it included some provisions on metering and billing, financing and energy performance contracts. These provisions were strengthened in the subsequent EED, discussed below.

The legal basis of the 2020 targets and other provisions stipulated in the 2011 Energy Efficiency Action Plan (section 4) was established in the Energy Efficiency Directive (EED, 2012/27/EU) which was adopted in December 2012 as part of the European Energy and Climate Package [139].

The Directive quantified the 20% energy efficiency target in terms of absolute primary and final energy consumption levels by 2020 and required MSs to contribute to the overarching EU target by setting their own energy efficiency targets at national level. While these targets are of indicative nature, the Directive set several mandatory EE policy measures to help reach the target, focusing on all stages of the energy chain from production to end use. The most important EED articles on buildings included the requirement for the public sector to renovate its central government building stock (Article 5), the setup of metering and billing requirements measures (Articles 9–11) [10] and establishment of long-term strategies for national building stock renovation (Article 4). The Directive also included provisions to promote energy performance contracting in the public sector (Article 18) [140], to remove

[19] TP CEN/TR 15615:2008, available at https://standards.iteh.ai/catalog/standards/cen/d7208116-9623–4117-8d99-4c81230c6f5e/cen-tr-15615–2008
[20] COM/2015/080 final.
[21] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/eu-bso_en.

split incentives (Article 19a) and to establish mandatory audits for large companies (Article 8) [141]. Lastly, the Directive pushed to open up energy markets to demand response (Article 15) and establish Energy Efficiency Obligation Schemes mandating energy companies to achieve 1.5% annual energy savings for final consumers every year (Article 7) [68,142]. In 2018 the EED was amended (2018/2002/EU) to provide a legal frame for the 2030 energy efficiency targets and extend article 7 to 2030.

6.1. Long-term renovation strategies (EED Article 4/ EPBD Article 2.a)

To tap into the large cost-effective energy saving potential of energy renovations across the EU, Member States were asked to develop long-term renovation strategies with the view of mobilising energy efficiency investments in residential and commercial buildings. These strategies, which represented the first strategies of this kind, aimed to act as a guiding tool for Member States in the decarbonisation transition of their building stocks. The EED did not mandate specific policy interventions/measures to be included in the strategies nor did it require setting up renovation targets. Instead, the strategies were drawn up to provide:

1. an overview of the country's national building stock;
2. identify key policies to stimulate renovations;
3. provide an estimate of the expected energy savings and wider benefits;
4. identify cost-effective approaches by building type and climatic zone;
5. encompass a forward-looking perspective to guide investment decisions.

While high compliance with the above 5 elements was in general achieved in both the originally submitted national strategies in 2014 and subsequent updates in 2017 [143,144], the ambition level, scope and depth of analysis varied significantly from country to country. In particular, data gaps in the non-residential sector were identified as well as lack of modelling and clear and ambitious targets. The updated strategies of 2017 provided a more in-depth analysis of national building stocks and more rigorous scenario analysis of possible intervention options. On the other hand, the evaluation and monitoring of implemented policies and the development of specific monitoring indicators remained weak points of the strategies [144]. While there is no yet evidence in the literature on the actual impact of these strategies in generating energy savings or indeed in mobilising investments, several new policy measures have been put in place as a result of the development of these strategies [145,146].

As anticipated above, with the revision of the EED and EPBD in 2018, Article 4 of EED was moved to the amending EPBD Article 2a. To address some of the above shortcomings, the amended EPBD introduced a number of key changes with the view of enhancing the role of these strategies as 'roadmaps' with an action plan on how to transform their building stock to a highly energy efficient and decarbonized building stock by 2050 and specific milestones for the years 2030 and 2040. Even though the new strategies are not required to include quantifiable targets, they must be supported by measurable progress indicators and must explain how they contribute to the overall 32.5% energy efficiency target for 2030 (as part of the implementation of the Energy Efficiency Directive). It goes further by emphasizing that the strategies must facilitate the cost-effective transformation of existing buildings into nearly zero energy buildings (NZEBs), a provision already included in Article 9.2. Emphasis is also given for the worst-performing segments of the national building stock, actions to alleviate energy poverty and efforts to accelerate energy efficiency gains in public buildings.

6.2. Central government buildings (EED Article 5)

To reinforce the role of the public sector in the clean energy transition, Member States were asked to renovate 3% of the total floor area of heated and/or cooled buildings owned and occupied by their central government every year in order to meet the minimum energy performance requirements set in application of EPBD Article 4. Given that the setup of minimum energy performance requirements for existing buildings alone cannot stimulate energy renovations, the rationale of this EED provision was for the public sector to showcase a lead-by-example approach, paving the way for ambitious renovations at a wider scale across many sectors. To provide more flexibility to Member States, the EED provided an alternative route under the condition that equivalent energy savings to the ones generated by mandatory renovations are achieved through other cost-effective measures including deep renovations and behavioral change measures.

In the first 5 implementation years since 2014, progress has remained relatively slow, with around one third of the Member States reaching their annual renovation target or equivalent energy savings [5,147]. The public commitment towards high energy efficiency building stock has somewhat weakened by the introduction of the alternative route with only 11 out of 28 Member States choosing to pursue central government renovations (default approach). Given that new public buildings must comply with NZEB levels from 2019 onwards, the gap between new and existing public buildings in terms of energy performance levels is expected to be widened in the coming years. This demonstrates the need to strengthen public commitment to improve energy efficiency of their properties and take more EU-wide action to tackle some of the barriers specific to the public sector [148,149].

6.3. Split incentives (EED Article 19a)

In view of addressing split incentives in the building sector, the EED Article 9a called for Member States to evaluate and, if necessary, take appropriate measures to remove regulatory and non-regulatory barriers to energy efficiency. While the EED does not mandate specific measures to tackle split incentives, it mentions several possible solutions including rules for dividing costs and benefits between owners and tenants and measures regulating decision-making processes in multi-owner properties. Measures to address split incentives include regulatory measures -e.g. rent law amendments and minimum energy performance standards in rented properties, administrative rules (e.g. revisions in governance structure of jointly-owned apartment buildings) and various financial and fiscal incentive schemes [150–152]. While it is clear that a one-size-fits-all solution cannot address all particularities across various segments of the building sector or national conditions, a number of common principles can be highlighted [150,151,153]. These include a more active engagement of building occupants in energy saving practices, the development of agreements benefitting all involved actors, acknowledgement of real energy consumption and establishment of cost recovery models attached to the property instead of the owner. As the EED did not stipulate any obligatory actions, an assessment carried out to identify the progress towards implementing EED Article 19, has revealed uneven progress by Member States in tackling the issue of split incentives [152]. Some countries have no yet relevant measures in place measures, highlighting the need for further policy action in this area.

6.4. ***Metering and billing (EED articles 9–11)***

To promote energy savings through behavioural change, the EED (2012/27/EU) introduced a mandatory requirement of

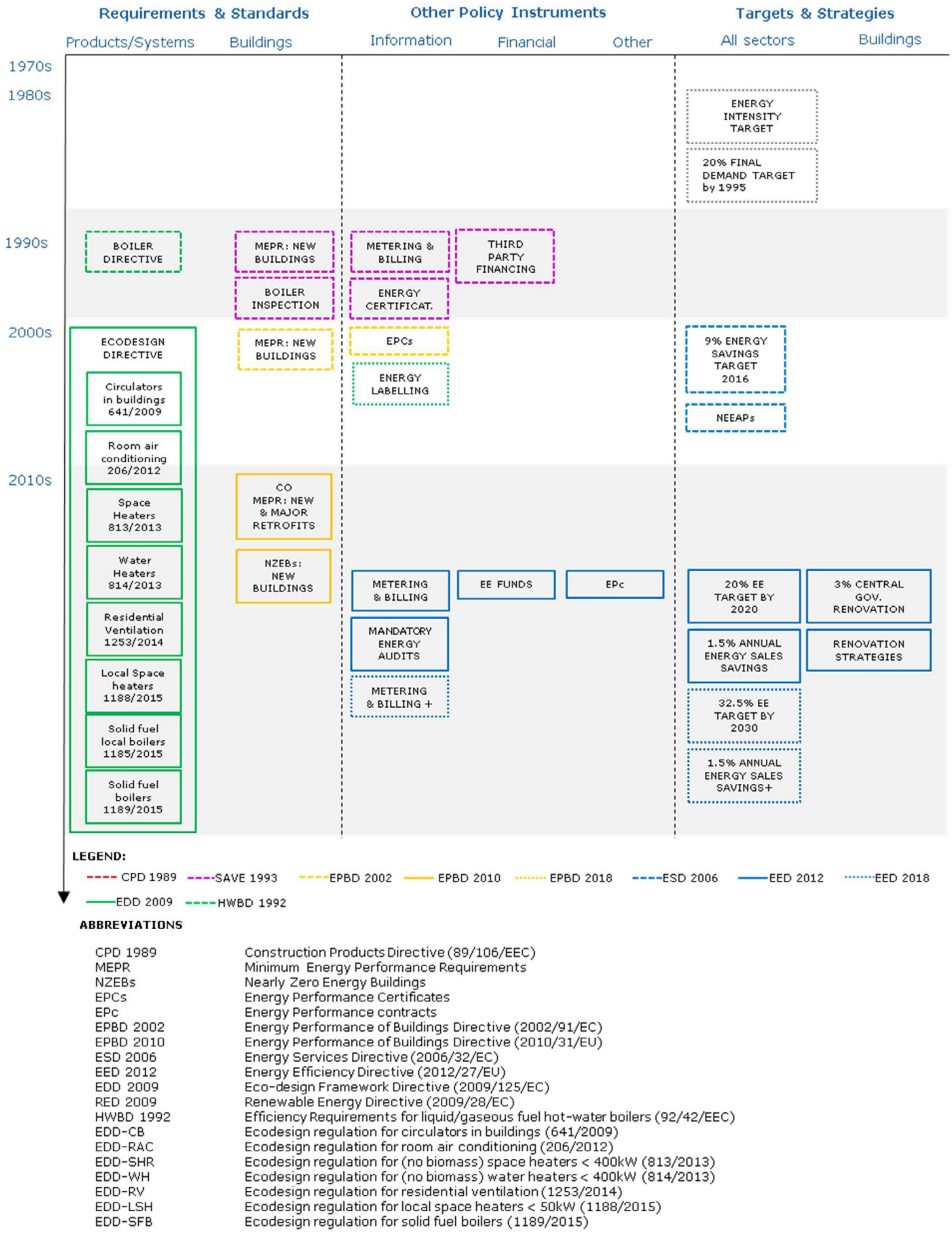

Fig. 2. Overview of 50-year policy evolution in the area of energy efficiency in buildings in the EU.

consumption-based cost allocation and billing of heating cooling and hot water in multi-apartment and multipurpose buildings with collective heating/cooling systems. The general idea behind these provisions was to ensure that users of such buildings had the right incentives and sufficient information to adopt energy-efficient practices [154]. Many studies [155–157] have demonstrated that providing consumption feedback to energy users can influence their behaviour, which can lead to an average 5–10% final energy consumption reduction in households [10]. Effectiveness of such measures depend on several conditions: feedback type and frequency, the accuracy of metering systems, the availability of heating controls and the capability of maintaining energy savings habits over the time.

Although the EU has promoted energy consumption individual metering for energy consumption since 1976/1977[22], the EED rep-

[22] Council Recommendation of 4 May 1976 on the rational use of energy in the heating systems of existing buildings (76/493/EEC); Council Recommendation of 25 October 1977 on the regulation of space heating, domestic hot water production and the metering of heat in new buildings

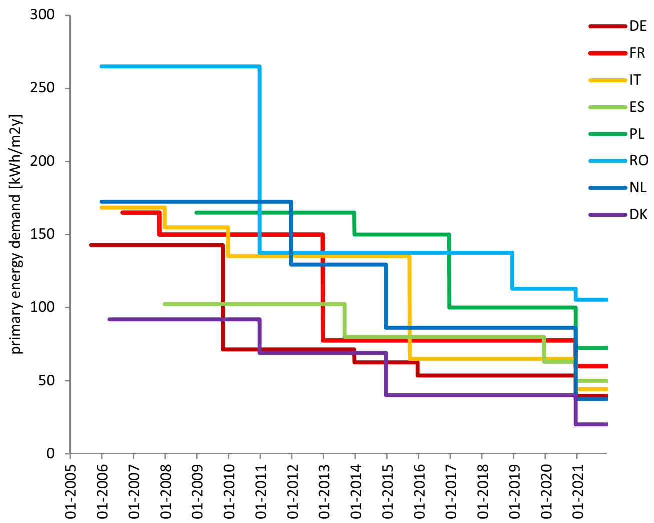

Fig. 3. Improvement of residential minimum energy performance requirements in some key Member States, since the entry in force of the first EPB Directive.

resents the legal foundation for accurate metering and billing of energy individual consumption in multi-apartment and multi-purpose buildings in the EU. Relevant articles include: Article 9 on energy metering, Article 10 on billing information and Article 11 on cost of access to metering and billing information. Due to differences in climatic conditions, building stocks and user habits, EU Member States adopted different allocation rules that led, in some cases, to a series of technical, legal and consumer protection issues [158]. These were subsequently addressed in 2018 with the provisions of the amended EED, that introduced stronger rules on metering and billing of thermal energy by giving consumers clearer rights to receive more frequent and more useful information on their energy consumption.

7. Discussion

Since the initial focus of energy security in the 1970s, energy efficiency policy, which spans over 5 decades, has made considerable strides in terms of scope, scale and ambition (Fig. 2). The early requirements on construction products set in 1989 (CPD 1989) and boilers in 1992 (HWBD 1992) were gradually transformed into a set of comprehensive energy standards for individual building technical systems (Ecodesign 2005) and energy performance requirements for entire buildings (EPBD 2002 and EPBD recast 2010). The shift to a holistic approach has been a particularly important development for the sector itself, opening possibilities for innovation and offering flexibility to designers, architects and engineers for cost-optimised solutions. This holistic approach, which was supported by the development of CEN standards, paved the way for fairer cross-country comparisons, the introduction of cost-optimality concepts in building codes and the application of energy efficiency requirements in renovations. For construction products and technical systems, the EU policies have brought the much necessary equivalence of standards in products in the European market, facilitating trade of building products across borders.

Looking at the results achieved under the drive of the European policies, it is interesting to observe how the national minimum energy performance requirements (applied for new buildings and major renovations) have evolved during the period covered by the EPBDs (around 15 years from the first transposition due by January 2006). Fig. 3 shows the main regulatory steps in terms of primary energy requirements for an average residential building in the most populated EU countries, including Denmark which has long been recognised as a frontrunner in energy building codes. It can be derived that the NZEB requirements under EPBD (last level starting from the 1st January 2021) are on average 67% lower than the national requirements in 2006. This reflects a notable improvement for the countries, attained progressively over a relatively short period through reiterations of at least three legislative steps.

Along with energy requirements, the building concept has also continuously evolved over the last decade. Starting from high performing buildings, several definitions have been launched (e.g. Zero Emission Building, Zero Carbon Buildings, Autonomous, Net Zero Source/Site Buildings [159,160]. In this context, the NZEBs marked a new EU official definition (EPDB 2010 recast), which establishes how buildings should use nearly zero energy and produce renewables, adopt cost-optimal technology choices, and guarantee a healthy and comfortable environment. Despite these important milestones achieved through European legislations, the envisaged match between cost-optimal and NZEB energy performance level remains debated. Especially for existing buildings, studies investigating the possible energy/financial performance gaps between the two levels [118] can inform policy-makers about how demanding the forthcoming market transition towards an energy efficient building stock will be [161].

Concerns also rise as different studies highlighted that reaching the NZEBs target is achievable, but the selected design choices vary when the environmental perspective is enhanced. The importance of a life-cycle assessment has been highlighted as suitable for buildings [162], however this approach is not commonly applied for data and calculation obstacles. Furthermore, the literature is pointing out the importance of the embodied energy inclusion within the energy performance [163,164]. When part of the calculations, the energy used to extract raw resources, process materials, assemble components, transport, construction, maintenance, repair, deconstruction and disposal, severely impact the energy consumption (from 30% to 70%) and the technologies chosen for NZEBs [165,166]. Although the importance of the embodied energy inclusion in the energy performance was already pointed out around the 1990s [167], the literature is more and more emphasizing its central role over the last decade [163,164,168]. When part of the calculations, the energy used to extract raw resources, process materials, assemble components, transport, construction, maintenance, repair, deconstruction and disposal, severely impact the energy consumption (from 30% to 70%) and the technologies chosen for NZEBs [165,166]. When a building achieves the nearly zero energy goal, the majority of the life cycle energy remains in the embodied energy of its materials and systems [169]. Therefore, as energy efficiency continues to decrease the operating energy —as a result of building codes, stringent regulations and efficient systems-more focus and practice guidance should be given to the inclusion of embodied energy in future policies [170,171].

Important developments have also occurred in the diversification of instruments and tools deployed in energy efficiency policy, moving from policies solely comprising building codes up until the 1990s to comprehensive policy packages from the 2000s onwards. While the SAVE Directive of the preceding decade included many thematic areas which are of key relevance even today (e.g. metering/billing, energy certifications, third party financing, etc.), it was the legislative framework set out by the EPBD in 2002, ESD in 2006 and EED in 2012 which mandated the implementation of a wide range policy instruments at national level. As discussed in Section 5, the EPBD called for Member States to develop comprehensive requirements in their building codes but at the same time introduced information tools such as energy performance certificate schemes and inspection programmes for thermal systems. The Energy Efficiency Directive mandated energy audits in industry and SMEs, introduced metering and billing provisions and

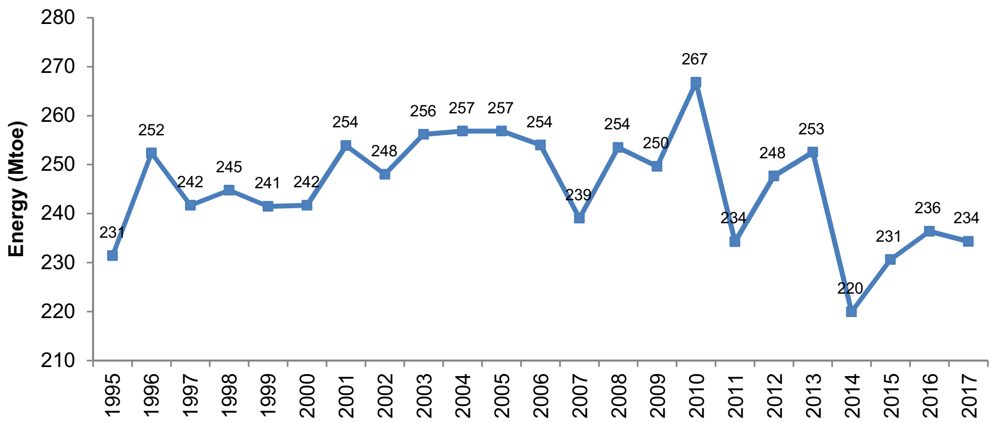

Fig. 4. Residential energy consumption in EU-15 (1990–2017).

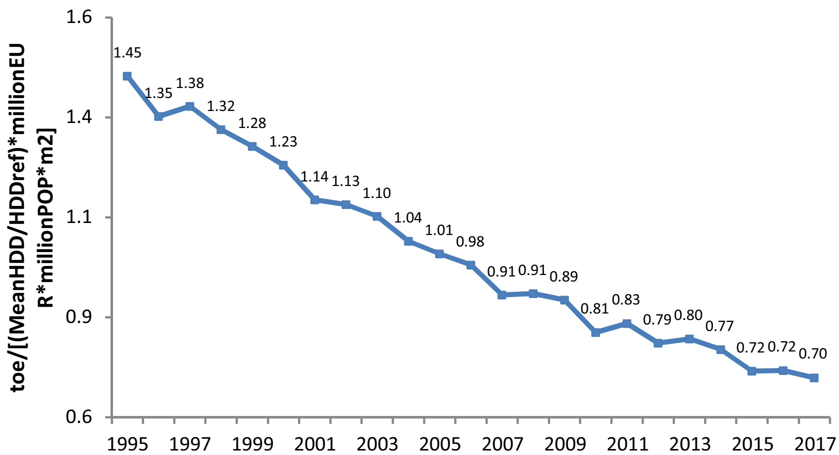

Fig. 5. Residential energy consumption climatic corrected per capita, per average floor area of dwellings and per adjusted disposable income of households in EU-15 minus PT & BE (1995–2017). Portugal (PT) and Belgium (BE) were excluded from the analysis due to unavailability of floor area data.

encouraged the set-up of energy efficiency funds and use of energy performance contracting in public sector buildings. Despite some of the shortcomings of these policies discussed in this paper, these measures, ranging from Regulations to information tools or awareness raising campaigns, and from educational/training programmes to financial instruments are integral parts of all national policy packages today.

Beyond individual policy measures, comprehensive policy packages require the setting of quantitative and measurable targets, allowing policymakers to track overall progress and give clear direction to all involved stakeholders [22]. Whilst there has not been a specific target for the sector itself to date —with the application of the 1995, 2016, 2020 and 2030 targets on an economy wide level— buildings have always played a prominent role in the achievement of energy efficiency targets [172]. The only exception is the specific yearly public sector target of 3% of central government floor area renovation prescribed by the EED in 2012. While the progress for this target has been slow, it has also highlighted important lessons for the future set-up of specific building-specific milestones for the years 2030, 2040 and 2050 stipulated by the EPBD 2018.

To support the development of these packages, the National Energy Efficiency Action Plans (NEEAPs) and Long-Term Renovation strategies — first introduced by the ESD 2006 and EED 2012, respectively — served as key strategic planning tools, placing energy efficiency at the heart of energy policy. The introduction of the more recent National Energy and Climate plans through the adoption of the Energy Union Governance Regulation of 2018 [73] strengthens the role of these coherent packages of policies in the overall efforts to curb climate change and allow for synergies and interconnections with other policy areas such as renewable energy and decarbonisation policies.

The overall impact of energy efficiency policies in buildings remains an open research question and debated topic in the policy-making sphere [107,173]. By looking at final energy consumption trends in the residential sector in the period from 1995 to 2017 in the EU-15 (Fig. 4), it can be observed that consumption has remained relatively stable over the studied period with the exception of variations linked to fluctuations of outdoor climatic conditions.

During the studied period, some energy consumption drivers such as total population, household disposable income and building size have been on a rising trend as a result of the attainment of higher living standards over time. As presented in Tsemekidi-Tzeiranaki et al. [5], these drivers act as a driving force of energy consumption due to improved thermal comfort, more square meters per capita (also due to a smaller household size and increase in the number of single person households), larger population and more and larger appliances. In Fig. 5, the final residential consumption normalized to take into account all key drivers-climate, income, population and building size-in the EU-15 minus Portugal and Belgium follows a clear declining trend. This analysis points to reduction of 52%, suggesting a strong possible impact of the buildings energy efficiency policies implemented at European, national and local levels.

8. Conclusions

The EU has adopted policies and programmes to promote general energy efficiency since the 1970s and since the 1980s focusing on buildings. These policies have been progressively reinforced to meet commitments for combatting climate change under the UNFCCC and for increasing the security of the energy supply. Policies at EU level include a framework to set national building codes, EU Regulation for efficiency requirements for energy using equipment, Directive for the removal of barriers to investments in energy efficiency, and finally financial support to energy efficiency. Despite earlier efforts, the major steps in boosting energy efficiency have stemmed from the EPBD (2002), the Ecodesign (2005) and the ESD (2006), as well as the additional improvements and strengthening from the EPBD recast (2010) and the EED (2012).

The adoption of more stringent building standards and requirements for boilers has contributed to a decline in heating energy consumption, which is the major energy use in the building sector in the EU. As indicated, the EPBD has been a major EU policy for driving energy efficiency improvements in buildings. The move from prescriptive requirements such as U-values for building walls to performance requirements through the adoption of EPBD has enabled the introduction of cost optimality concepts in building codes and application of net zero energy levels for new buildings in the recast EPBD. Not only this, but the EPBD called for MSs to set standards for existing buildings when renovated. Despite these positive developments, the responsibility for setting standards levels has remained at the discretion of individual Member States, leading to large discrepancies in ambition among Member States.

It is also particularly important to highlight many additional policies implemented in this period by individual Member States, with some Member States (e.g. Denmark) anticipating EU efforts or going beyond. Several MSs have introduced information mechanisms through national and local energy agencies offering advice to building owners and public authorities. Others have also offered a broad range of financial incentives to facilitate investments in energy efficiency in existing buildings. These incentives range from low or zero interest loans (e.g. in Germany and France) to subsidies (grants, tax deduction, white certificates) in Italy, France and Spain. Given the low rate of new constructions in Europe, it is essential to focus on existing buildings by triggering energy retrofits and/or including energy efficiency measures in routine building maintenance works. To this end, it is key to provide more targeted consumer information (e.g. through enhanced energy performance certificates) and financial support through tailored instruments, which empower final users to invest in energy efficiency.

A key point of future policies is that buildings are increasingly expected to meet higher performance requirements, reaching a positive balance between the produced and required energy. Currently, the scientific community is stressing the need and advantages of a new dimension of interconnected buildings, going from the building level to the district one. Smart technologies and electrical mobility play a central role in this vision, where aspects such as safety, resilience, and user awareness become more and more crucial.

Another important aspect is the inclusion of climate change impact on buildings. New extreme, short periods of intense cold or heat are likely to have an influence on both heating and cooling loads as well as best efficiency measures chosen to reach the NZEB target. Research is moving towards this direction, as policies are doing. This stresses the need to examine how climate change will impact buildings, as those built or refurbished today will be in use for decades. Therefore, a synergy with the climatic, societal and technical state of progress will be increasingly essential for a widespread NZEB diffusion, overcoming common technical, financial, social, and educational barriers.

Finally, a solid financial component on energy efficiency has a key role in the transition towards climate-neutral buildings, with a need for more targeted financial mechanisms, new financial models and more active participation of financial institutions. The Smart Finance for Smart Buildings Initiative launched in 2016 by the European Commission aims to further mobilize private financing in buildings, ensure effective use of public EU funding and identify ways to de-risk energy efficiency investments. Under the European Green Deal[23] proposed by the European Commission in 2020, the "renovation wave" initiative is expected to create a tailored policy framework to mobilize all stakeholders in the buildings sector, address any regulatory or other barriers and scale up new innovative mechanisms. This should ultimately act as a catalyst for innovation and bring new opportunities which will not only enhance the energy performance of European buildings but will also ensure future resilience to climate change risks and adequate living conditions for all Europeans.

9. Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Declaration of Competing Interest

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

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