Review of building energy performance certification schemes towards future improvement

Li, Y. [1]*, Kubicki, S. [1], Guerriero, A. [1], Rezgui, Y. [2]
1 = Luxembourg Institute of Science and Technology LIST, 5, avenue des Hauts-Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg
2 = BRE Trust Centre for Sustainable Engineering, Cardiff University, Cardiff CF24 3AA, UK
* = corresponding author email: yu.li@list.lu

Abstract

The building sector accounts for 40% of the total energy consumption in the EU. It faces great challenges to meet the goal of transforming the existing building stocks into near zero-energy buildings by 2050. The development of Energy Performance Certificate (EPC) schemes in the EU provides a powerful and comprehensive information tool to quantitatively predict annual energy demand from the building stock, creating a demand-driven market for energy-effective buildings. Properties with improved energy rating have had a positive impact on property investments and rental return because of the reduced energy bills. In addition, the EPC databases have been applied to energy planning and building renovations. However, it should be mentioned that the current evaluation system faces problems, such as not being fully implemented, delivering low quality and insufficient information to stimulate renovation, therefore requiring improvements to be made. This paper provides a review of the current EPC situations in the EU and discusses the direction of future improvements. The next generation EPC should rely on BIM technology, benefit from big data techniques and use building smart-readiness indicators to create a more reliable, affordable, comprehensive and customer-tailored instrument, which could better represent energy efficiency, together with occupants' perceived comfort, and air quality. Improved EPC schemes are expected to play an active role in monitoring building performance, future energy planning and quantifying building renovation rates, promoting energy conservation and sustainability.

Highlights

- Presentation of a brief review of the EPC-related directives
- Review and comparison of the development of the EPC in EU member states
- Discussion of the utilization of the EPC at the urban scale
- Identification of the existing issues and shortcomings in the current EPC
- Proposal of future improvements for the EPC

Keywords

Energy performance certificate; Building energy demand; Building renovation; Energy planning; Database; Sustainable development; Smart building

Word Count: 10376 words

List of abbreviations

EU, European Union; CO_2, Carbon Dioxide; EPC, Energy Performance Certificate; EPBD, Energy Performance of Buildings Directive; NZED, Nearly Zero Energy Building; MS, Member State; BPIE, Building Performance Institute Europe; BIM, Building Information Modelling; HVAC, Heating, Ventilation and Air Conditioning

1 Introduction

The building sector is one of the most important energy consumers in the European Union (EU), responsible for approximately 40% of the final energy demand and 36% of Carbon Dioxide (CO_2) emissions [1], [2], [3]. More specifically, the residential sector contributes to 66% of the energy consumption and 64% of the emissions in the EU buildings [4]. In addition, around 75% of the existing 210 million homes in the EU are energy inefficient, and 75% to 80% of them will be still in use by the year 2050 [5]. As a result, buildings represent the greatest potential for energy savings and carbon footprint reduction. The EU has proposed a set of directives to phase out inefficient buildings. The Energy Performance of Buildings Directive (EPBD), which is the major legislative and policy instrument in the EU focusing on both existing and new buildings, requires the transformation of existing buildings into Nearly Zero Energy Buildings (NZEBs) by 2050. Thus, the building sector is facing great challenges to meet the EU decarbonization agenda, and make this sector energy efficient. Energy Performance Certificate (EPC) plays a prominent role in this process as it provides transparent information with respect to energy performance. It was introduced in 2002 by the EPBD (Directive 2002/91/EC) [6] as a mandatory requirement in the EU member states (MSs) when constructing, selling or renting a building or dwelling. The EPC shall include energy requirements for the building and reference values such as current standards and benchmarks. Meanwhile, the certificate shall be accompanied by recommendations for cost-optimal or cost-effective energy improvement. Once the EPC is issued, it is valid for 10 years provided that no significant change is made to the house within that time period. A recast of the EPBD in 2010 (Directive 2010/31/EU) [7] put forward additional requirements to strengthen and improve the quality of the EPC. In particular, the EPC should be stated in the advertisement for any property placed on the market for sale or rent, and should be handed over to the new buyers and tenants. The recast creates an opportunity for the EPC to play an active role in the real estate market. It was subsequently endorsed by Directive 2012/27/EU [8], which underlined that compliance with the energy efficiency requirements for the purchase of buildings by the central government shall be verified by the recast. Subsequently, Directive (EU) 2018/844 [9] proposed an amendment to Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. It highlighted the importance of improving the transparency and quality of the EPC. The timeline for EU directives related to the EPC is depicted in Fig. 1. It has been confirmed by surveys and reports from Building Performance Institute Europe (BPIE) that EPCs are among the most important information sources regarding building energy performance in the EU's building stock [10], [11]. Each MS has developed its own approaches for EPCs working on their implementation, but the main objective is the same, promoting improvements in building energy performance to reduce carbon emissions.

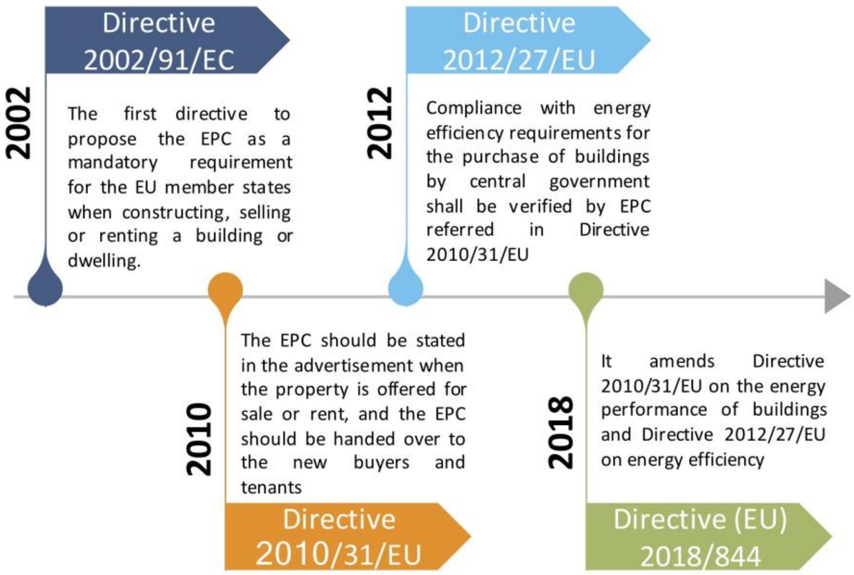

Fig. 1 Timeline for EU Directives related to the EPC

As the information conveyed by the EPC allows an estimation of building energy demand, it can serve as a powerful instrument to create a demand-driven market for energy-effective buildings. It has positively influenced the real-estate market, with its influence being more significant in the sales segment [12], [13]. Two major groups are identified as the main beneficiaries of the EPC: a) tenants, and b) property owners and potential buyers. A survey carried out in Belgium [14] showed that around 50% of buyers and 37% of renters stated that the EPC had an impact on their choices. 30% of buyers and 18% of renters used the EPC for price negotiation. Properties with improved energy efficiency have attracted a price premium in the house rental and sales market as they involve reduced energy costs, directly reflected in the properties' energy bills. The positive impact on property investment and rental return has been recorded in countries where the EPC is properly implemented. Studies show that, in the same location, energy-efficient houses rent or sell faster and at a higher price than those with a lower-grade energy performance [15]. For example, rental tenants and building investors in the UK, Ireland, Germany and Denmark are willing to pay more for energy-efficient building stocks [12], [13], [16], [17]. A study investigated the relationship between energy consumption and financial performance in Germany using hedonic methods [17]. The results revealed that a 1% reduction in energy consumption positively generates a 0.015% growth in total return on buildings and boosts rental price by 0.08%. The same method was adopted to investigate the relationship between the energy-performance rating and market price of residential houses in Dublin [18]. The authors claimed that on average, every 50 kWh/m^2/year energy reduction is associated with a 1.5% increase in the list price.

The EPC has induced the decision for building renovation [19] [20]. A survey involving 12 EU countries revealed that 73% of the respondents consider EPC as an important driver for building renovation [19]. The recommendations accompanying the EPC provide guidance to building owners for potential improvements. Meanwhile, the energy labels allow them to benchmark energy conservation before and after a retrofit. Therefore, the EPC can be used for decision-support planning to encourage individuals to undertake building refurbishment. The potential for energy conservation through building renovation is widely recognized as being able to provide a greater saving than that which could be achieved with new buildings [12]. The European Commission has estimated that renovation can provide energy savings of up to 46% between 2021 and 2030 [21]. Building renovations, such as improving the insulation of windows, walls and roofs, replacing old heating systems, adopting heat recovery systems and employing smart control systems, have been proven to be effective approaches to reduce energy demand from heating, cooling, ventilation, and artificial lighting, and to promote a comfortable indoor climate [22], [23], [24]. Currently, most EU citizens live in privately owned residential buildings. Property owners do not undertake energy-efficient renovation, mainly because of a lack of knowledge of the resulting benefits, a lack of access to technical advice, and a lack of financial support [25], [26], [27]. The EPC information (including envelope U-values, air conditioning system, fuel source and recommendations) can be used to identify the priorities for building renovation in a targeted way. Thereafter, property owners decide to what extent they would like to upgrade their properties through the energy labels. Another important reason for property owners not acting on the recommendations for home improvement is the cost implication [28]. To overcome the financial obstacle of transforming the real estate market to meet the energy and climate goals for 2050, political support is critical. A series of subsidy systems have been set up in MSs to encourage property owners to carry out building renovation, whereby homeowners can be incentivized to upgrade their homes to higher performance levels. Such ‘green’ policies, in turn, promote a higher adoption of EPC [29].

Despite the perceived benefits of the EPC and current adoption rates by policymakers, real-estate companies, and research institutes [21], there are still problems to overcome to achieve large-scale acceptance across the EU. Previous studies in EPC have observed (1) a lack of data quality for energy performance evaluation, (2) insufficient information to motivate renovation, (3) limited implementation to provide a robust information source for energy planning in some countries [16] [30] [31] [32]. More specifically, the calculated energy use in EPC does not reflect actual energy consumption. The EPC delivery process can be subjective, and, as a result, data quality can be easily influenced by the energy assessors because of the standard assumptions made in the process of producing the certificate [30]. In addition, energy performance is an important factor for building renovation. However, the EPC overlooks some important determinant attributes such as indoor air quality and daylight, which can negatively impact on occupants’ experience in buildings [33].

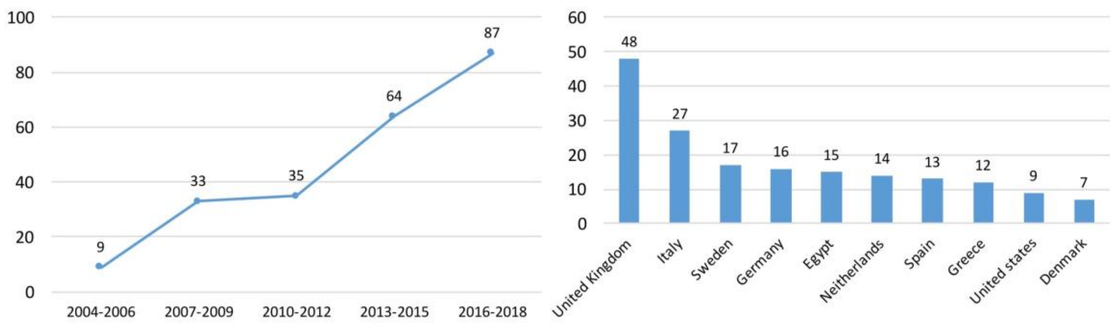

Fig. 2 EPC publication in Scopus by year (left) and country (right)

Our paper endeavors to bridge the above gaps while paving the directions for future research. This review is mainly based on the current literature publications as well as reports from the EPBD and BPIE. The study has an agenda-setting dimension and as such provides clear recommendations on future research to transcend current barriers to a large scale adoption of the EPC. The Scopus scientific search engine was employed to identify authoritative publications in the domain. The search has been directed using the keyword “energy performance certificate” that is included in ‘article title, abstract and key words' by year and country, as illustrated in Fig. 2. It is worth noting that since the first paper publication in 2004, the amount of publications has observed a steady and significant increase, with most of the papers from European countries. Meanwhile, this paper is the outcome of an EU project (BIMEET [34]), which aims to leverage the uptake of BIM (Building Information Modelling) in delivering energy efficient buildings. Identifying the problems within the current EPC schemes in EU and providing expert training courses for improving the EPC generation process is one of the tasks of the project. Thus, this study is focussed on the EPC adoption within the EU. The next section presents the status of the EPC in the EU, followed by an overview of the EPC's contribution to quantifying building energy performance, building energy planning and building refurbishment at the urban scale or national scale. Section 4 conveys valuable insights into the problems in the current EPC system. The potential areas for enhancement are elaborated in the subsequent section. The last section concludes the paper.

2 The EPC development and comparison in the EU

EPBD requires the EU MSs to apply a national and standardized methodology for assessing individual building energy performance. Each MS is flexible to design its own EPC scheme to appropriately fit its national context. The development of EPCs is diverse among the MSs. The EPC implementation, calculation methodology, energy indicators, prices, quality control measures, and methods for generating recommendations are presented in this section.

2.1 EPC implementation

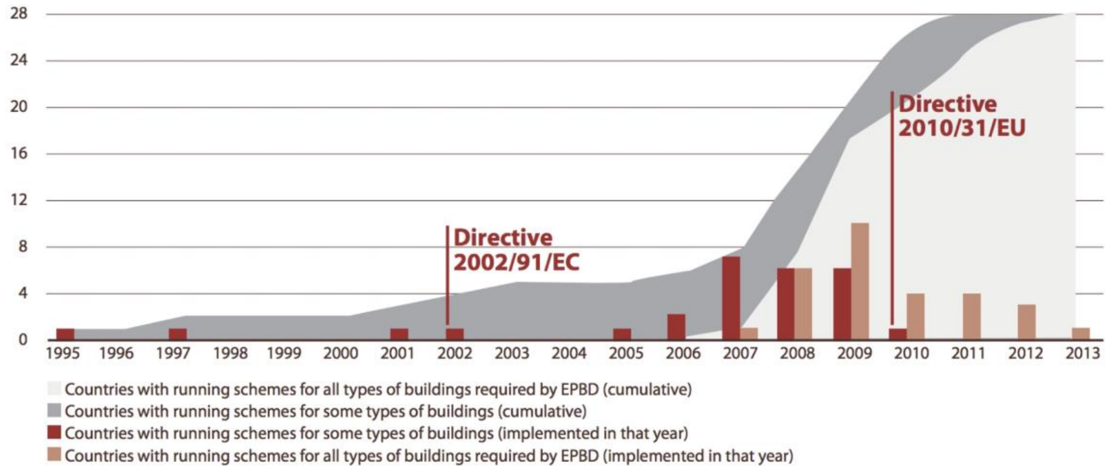

Fig. 3 Implementation timeline of EPC systems across the EU [21]

Prior to the compulsory implementation of the EPC scheme in 2002, only a few countries, such as Denmark, the Netherlands and some regions in Austria had similar systems in operation to evaluate the effectiveness of their building energy performance. Nevertheless, the mechanism was new to most of the MSs and had to be designed from scratch. Expectations were high at its debut. It was considered as a pioneering instrument to overcome the information deficit barrier [27]. All MSs were expected to implement effective schemes at the latest by 4 January 2009 to all types of buildings, including:

1) All newly constructed buildings or buildings undergoing major renovation;
2) All buildings rented or sold out to new tenants or buyers;

3) All buildings with a total floor area of over 1000 m^2, which are occupied by public authorities or frequently visited by the public. The threshold was reduced to 500 m^2 from 9 January 2013 and to 250 m^2 from 9 July 2015.

The design and implementation of the EPC is a demanding task, requiring the political, technical and socio-economic aspects to be taken into account. Finally, the implementation was slow. The timeline for the implementation of EPC systems across the EU is demonstrated in Fig. 3. Most countries had schemes running for certain types of buildings, but only seven countries had implemented the EPC scheme for all types of buildings by the beginning of 2009. By 2013, all MSs had implemented the EPBD requirements into their national legislation.

2.2 Framework for EPC calculation methodology

Directive 2002/91/CE [6] pointed out that the EPC should include the energy performance of a building. Nevertheless, there is no general methodology or tool prescribed for EPC calculation across all MSs. This is left to the discretion of member states to devise their own methods for calculating building energy performance, with an application at national or regional level [6]. It has resulted in notable methodological differences across MSs for energy performance calculation. However, the Directive 2002/91/CE proposed a general framework for EPC calculation which is improved on a continual basis. The Directive requires: (1) the calculation methodology to consider the location and orientation of the building, outdoor and indoor climate, thermal characteristics of the building, heating installation and hot water supply, air conditioning and ventilation, lighting installation, and passive solar protection systems; (2) the positive influence shall take into account active solar system and other generation from renewable energy sources, electricity generation from CHP, district heating and cooling system, and natural lighting; (3) the calculation shall classify buildings into different categories, including single-family house, apartment blocks, office buildings, education buildings, hospitals, restaurants and hotels, sport facilities, retail trade and wholesale buildings, and others. Few years later, Directive 2010/31/EU [7] proposed additional requirements. It noted that energy performance of a building should be on the basis of actual or calculated annual energy consumption for the purpose of meeting heating and cooling needs to satisfy the envisaged temperature condition and domestic hot water needs. A numerical indicator and an energy performance indicator should be included to express primary energy used, derived from national or regional weighted average primary energy factors. More recently, Directive (EU) 2018/844 [9] further amended the Directive 2010/31/EU, by prescribing that the energy performance of a building should be expressed using a numeric indicator for primary energy use expressed in $kWh/m^2/y$. Additional numeric indicators for renewable primary energy use and carbon emissions ($kgCO_2$ $eq/m^2/y$) should also be defined. Finally, the EPC methodology is being further developed to give due consideration to technical building systems and promote innovation.

2.3 EPC energy indicators

Under the EPBD, the EPC must contain information indicating energy needs of a building in order to evaluate its energy performance [6]. The energy performance indicators presented in the EPCs are measured in $kWh/m^2/y$. For most countries, they take the form of energy labels (e.g. A to G, where A is the most energy-efficient grade and G is the least energy-efficient grade). In other countries, take Poland for example, a continuous scale is used. An analysis of energy labels from 16 EU countries/regions is shown in Fig. 4. The figure was produced according to the EPC data retrieved from the Building Stock Observatory, national databases and Concerted Action EPBD reports from

2014 to 2017, using the latest data available for each country. Some countries, which either do not have a central register or where the number of EPCs is too limited to extrapolate to the whole population, are excluded. From the figure, it is easy to conclude that the majority of the buildings are energy-inefficient with label D or worse performing than D. However, most of the newly constructed buildings are in the energy label category A or B [35]. Denmark and France enjoy the largest share for label A, but still only achieved 8% and 7%, respectively. The building decarbonization vision for 2050 implies that the vast majority of buildings should be highly energy-efficient with label A, which means that only a small proportion of the building stock has achieved this target. In summary, a huge amount of the building stocks should be retrofitted to a higher energy class to fulfill the NZEB commitment.

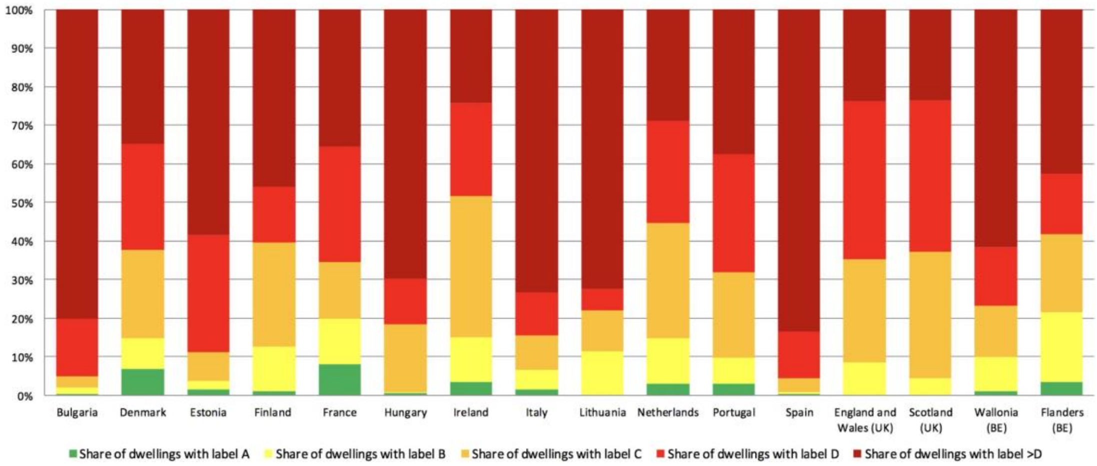

Fig. 4 Distribution of the building stock in the EU per EPC energy label [36] (The calculation and definition methods for energy labels vary in different MSs. Label A represents the most efficient buildings for all countries)

2.4 EPC price

The EPC is an important information tool for real estates, owners and occupiers, but producing the EPC itself comes at a cost, which should be borne by the building owner. The cost has been an obstacle for implementing the scheme [37]. The EPC prices in most countries are driven by the market and are associated with the efforts required for collecting input data, e.g. type of properties, location, size, etc. The EPC should be produced at an affordable price to meet various expectations for specific information, demanding a trade-off between cost and content. For example, physical presence is not always considered mandatory for gathering input information in order to limit the price, although on-site inspection may identify additional building problems and therefore provide more effective tailor-made recommendations. The EPC cost for a single residential building is shown in Fig. 5. For most of the countries, the EPC cost for a residential house is between €100/300. The prices do not have a strong correlation with the country's economic condition. For non-residential buildings, the price is typically between €1-2/m^2 [15].

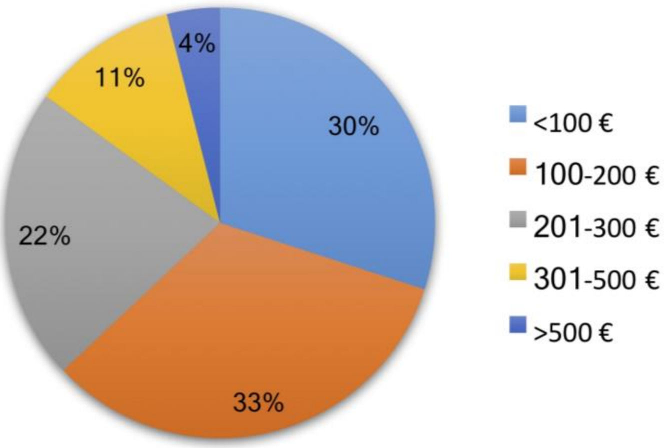

Fig. 5 Cost of single family homes for 2014 in the EU [15]

2.5 EPC database

Building a central EPC register to collect EPC data is not compulsory under EU legislation, but most MSs have set up national- or regional-level databases to check the compliance with EPBD requirements, track the progress of policy implementation in the building sector and identify the buildings requiring renovation. The database refers to an electronically centralized system, which periodically gathers and updates all certificates. The first MSs to set up an EPC database were Austria (2005), Bulgaria (2005), Denmark (2006), and Belgium – Flanders (2006). By 2014, 22 MSs had established centralized EPC registers, with the Czech Republic, Latvia, Luxembourg, and Poland preparing to launch their database systems. In all MSs, it is the obligation of the assessor to upload EPC information into the database [21]. These registers vary in terms of the data upload procedure, data format, data management, and data sharing. In some countries, such as France, some regions in Italy and Wallonia in Belgium, data upload is an obligatory step for issuing an EPC, and is done automatically by connecting the software to the EPC register directly, whereas in countries such as Greece, Ireland, Malta, Norway, and Sweden, the validation process requires the upload of a data protocol. In other countries, the assessors are supposed to manually upload or share it with the official secretariat, which is responsible for the data transfer. Accessibility to the database varies. In some countries, public access to the database or aggregated results are available while in other countries, it is only granted for authorities or selected organizations. Open access is provided for selected EPC information from the database in countries such as Denmark, the Netherlands, Sweden, and Norway, and the EPC rating is available by searching for the address or postcode. The situation for the EPC database across the EU is demonstrated in Fig. 6.

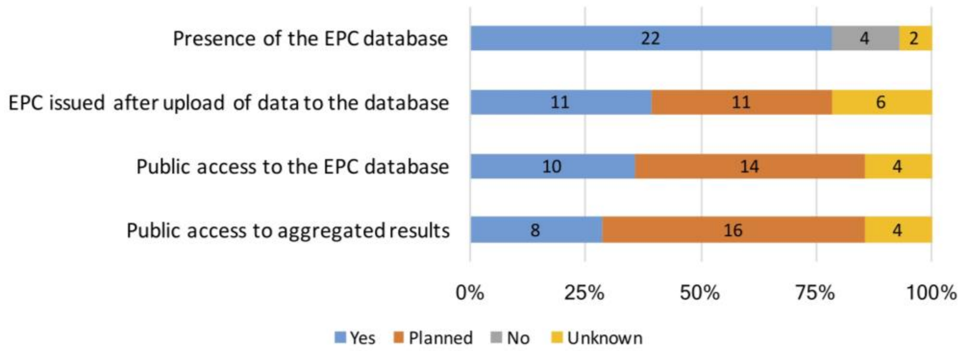

Fig. 6 The situation for the EPC database across the EU in 2014 [21]

2.6 Quality control for the EPC

The first EPBD (Directive 2002/91/EC) set a general framework for EPC implementation. The recast (Directive 2010/31/EU) and the Directive (EU) 2018/844 introduced additional requirements to improve the quality of the EPCs. To date, EPC schemes have not yet been fully implemented in all MSs and quality varies greatly among the MSs. To enhance the credibility of the EPC and to promote wider acceptance, it is necessary to further improve the quality of the EPC at the national level. A reliable and trustworthy EPC enhances the confidence of the potential buyer to purchase a higher energy performance level building and the building owner to retrofit his/her property into a higher energy level. The quality of the EPC depends on a broad range of factors, including validation of the input data, the adopted methodology and software, and the competence of the energy assessor. The qualification of the assessor is considered the most influential aspect affecting the quality of the certificate [21], as the assessors are responsible for collecting input information, making relevant assumptions and calculations, providing recommendations, and finally, issuing the certificate. The European standard (EN 16247-5:2015) [38] has specified the competence requirements for energy auditors. MSs have flexibility to define the accreditation and training systems for the qualified experts at a national level. Fig. 7 presents a country-by-country overview of the requirements for qualified energy assessors. Most countries have set minimum requirements (minimum education requirements or prior professional experience) to be a qualified expert. A compulsory examination to check the energy assessors' qualifications is recognized as the best practice, and this has been implemented in 23 MSs. Mandatory training is only required in 13 countries when there is a lack of education or professional experience. 15 MSs have established continuous professional training for a periodic renewal of the license. Fig. 8 demonstrates independent quality control for the EPC across the EU. It has been implemented in 21 EU MSs. In 11 countries, quality control for the EPC calculation software has been finalized. The first quality control of input data was conducted through the calculation tool [21]. In addition, 19 countries rely on the database for EPC quality control, supporting data verification and random sampling. On top of the independent quality control system, eight countries have developed control systems for qualified experts, who may receive a penalty for false certification.

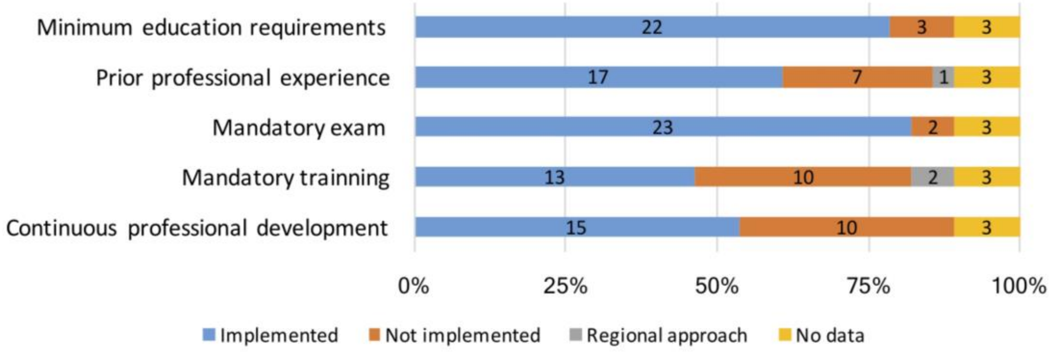

Fig. 7 Requirements for qualified energy assessors across EU-28 in 2015 [39]

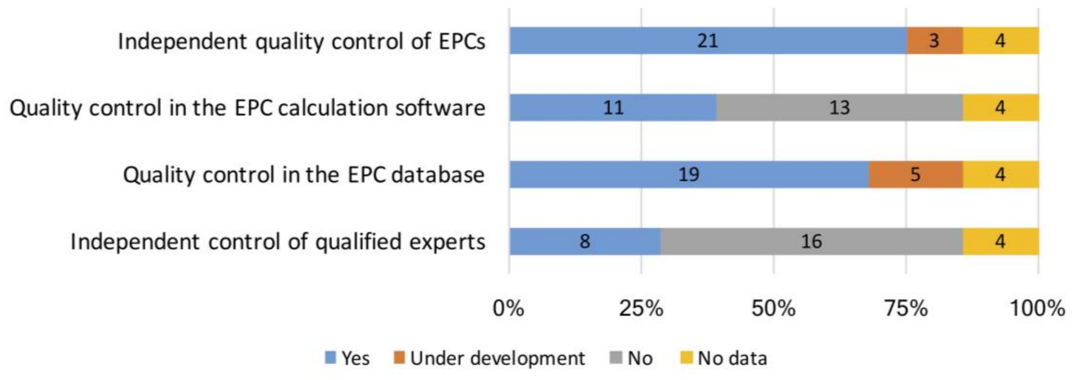

Fig. 8 Independent quality control for EPC across EU-28 in 2014 [21]

2.7 EPC recommendations

Providing recommendations is compulsory when producing EPCs. They are also the most important information source for owners to access expert suggestions for using the buildings more effectively and for potential improvements on their properties. The inclusion of concrete recommendations increases the perceived usefulness of the EPC [40]. The quality of the recommendations is determined by the EPC delivery approaches. In some countries, the recommendations are automatically generated or filtered by qualified experts from a standard list, which includes increasing insulation, replacing windows, and upgrading boilers. Delivering more customized measures would increase the cost of EPCs since some problems (e.g. air leakage, heating and cooling settings, and pipe insulation) can only be detected through on-site inspection [26]. Nevertheless, most of the building owners are seeking a cheap and fast option [26]. Around a quarter of the countries do not have a standard list, and the recommendations are produced based on the experience of the qualified experts. The methods for producing EPC recommendations are presented in Fig. 9.

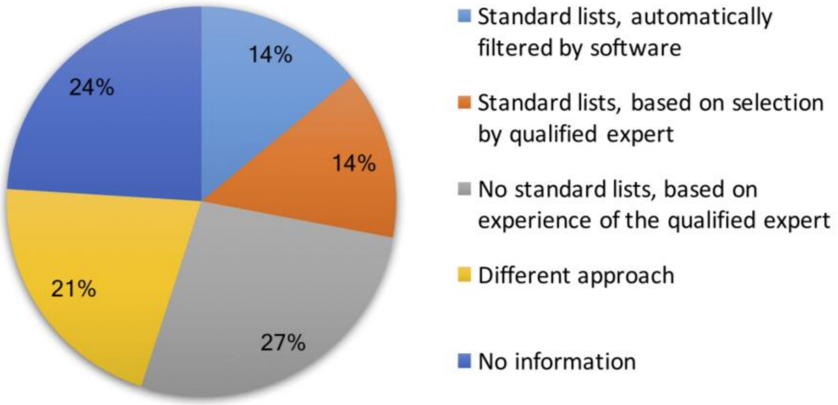

Fig. 9 Options for generating recommendations [15]

3 The utilization of the EPC at the urban scale

EPCs are the most valuable information source in terms of building energy performance as only professionals and experts are authorized to generate them. They allow an energy-related comparison of buildings and therefore empower the prospective tenants and buyers to make informed choices. They also motivate building owners to retrofit their properties to higher energy levels. Since the implementation of the EPC, there is a broader awareness of energy efficiency among the public reflected in the increased demand for energy-efficient buildings.

Apart from being used as a single building information document for individuals, the EPC information can be utilized in other contexts. To meet the ambitious goals set for 2050, buildings require urgent interventions to be more energy-efficient. EPCs play a crucial role in the process of steering the building sector towards ambitious energy-saving targets. The extensive data source for all the certificated buildings can be summarized to deliver useful information for energy-related policies and to adjust building energy related regulations at the urban scale [31]. A number of European countries have stored EPC data in regional or national databases. The larger and most advanced databases cover a high proportion of the national building stock. Although the databases do not cover all buildings, the analysis can be extrapolated to approximate the status of the building stock at the urban scale [41]. The insights from the database system can be applied for regional or national building performance evaluations [42] [43] and form a basis for other policy instruments such as energy planning [4] [44] [45] and building renovation planning [3].

3.1 Monitoring building energy performance at the urban scale

Improving building energy performance is among the major objectives for energy and climate policies in the EU. The EPC, which has been implemented for a number of years, provides valuable information regarding building physics, U-values, energy demand and other related information. The wealth of data available in EPC databases can be used to create a fully representative picture of the energy profiling of our building stock in Europe, thus providing an invaluable instrument to informing policy and decision making [46]. It allows authorities to evaluate the thermal quality of the building stock [43] [47], to track the evolution of building energy performance [43], and to check the level of compliance with national building codes [48] at the urban scale. Since the implementation of EPC, the energy labelling showed a negative relationship with the age of the dwellings [33]. Manipulating and analyzing huge data sets is increasingly cheaper and easier in the Big Data era. The analysis results can also be applied to propose the minimum requirements (typically U-value requirements for windows and exterior walls, overall heat loss or heat gains, minimum energy efficiency standards) on new buildings and existing buildings that are subject to renovation or under consideration for renting. For example, the UK introduced a new policy in private rented property that came into force in April 2018 [49]. Landlords in Wales and England must ensure that their buildings used for renting have achieved a minimum EPC rating of E, even when there is no change in tenancy. Meanwhile, the monitoring of building energy performance can track the progress of policy implementation with regard to building energy efficiency. The EPBD has put forward the NZEB requirement for all new buildings by the end of 2020 and some MSs have chosen to link NZEB with the best energy performance classes specified in the EPC [50] [51]. The effective implementation of these policies could reduce carbon emissions and energy consumption, which helps to address climate and energy problems.

3.2 Energy planning for the building sector at the urban scale

The EPC database is not only an information tool for monitoring and mapping building stocks, it is also a supporting tool for (1) quantifying energy demand, and examining the energy sources used in the building sector, (2) reporting on energy savings following the implementation of energy efficiency measures, and (3) launching the investment strategies to enhance the share of renewables [44]. It has been used as a standardized method to evaluate building energy consumption and energy rehabilitation potential in many EU countries [45] [52]. Through monitoring the EPC at the urban scale, affordable or financially attractive plans can be made to motivate and incentivize house owners' voluntary participation in energy-saving measures, to encourage residents' involvement in carbon reduction campaigns, and to strengthen the role of the EPC in the context of energy planning [53]. Experience in the EU shows that the financial incentive investment is a win-win situation due to the increased job opportunities and tax revenues [54]. Subsidy programs for PV, wind power, solar thermal heating and heat pump-based systems are very popular in the MSs. Energy planning, together with subsidy programs, increase energy efficiency while promoting the use of renewable energy. The database can also be applied to set up policy targets and regulations, such as requirements for the use of fossil fuel equipment (minimum efficiency or installed capacity), and steps for the replacement of fossil fuel boilers by alternative energy supply solutions. In addition, based on the database, national and local authorities are able to identify when and where the policy implementation may need adjustment (e.g., certain areas probably require higher investment to promote the use of renewable energy). Apart from using the EPC database separately, energy programs can be better planned in combination with other databases. For example, reliable information from the EPC database, together with data from other relevant databases, helps local authorities in Scotland to plan energy-saving based on the level of fuel poverty [15].

3.3 Building renovation planning at the urban scale

Retrofitting the existing building stock is a priority for energy-saving in the EU [12]. The saving is more obvious when the retrofit entails not only building envelope thermal performance improvement but also the replacement of the old heating systems [16], [55]. MSs have set up renovation plans according to EPCs. For example, the UK government proposed a retrofit program to upgrade all fuel poor dwellings rated as EPC level D or below to a minimum of level C by 2030 [48]. The EPC can be used as a pivotal instrument to monitor and evaluate the renovation rate of the building stock, to examine the effectiveness of on-going renovation measures, and to impact on related financial incentive policies [55]. It has been applied to compare energy-saving before and after renovation and offers an objective evidence of the quality of the energy-related renovation.

Despite the proven environmental and social benefits, and despite the technical and economic feasibility, the annual building renovation rate in the EU is still low, at around 1.2% per annum [5]. Based on the current renovation trend in EU countries, it will be difficult to meet the carbon mitigation target by 2050. It is therefore important to identify the number and type of buildings that are not being considered for retrofit and that could be upgraded to a higher degree of energy efficiency through examining a large range of EPC documents. Information in terms of building energy consumption and potential energy savings are the key elements for launching energy efficiency policies to stimulate the transformation into energy-efficient buildings. Authorities can make plans for building renovation rates to achieve large-scale NZEB or even positive energy buildings based on the database at the regional or national level. Several countries, including Germany, France, and Belgium, have proposed using building renovation passports, developed based on the EPC, to outline a long-term roadmap for building renovations. They strive to accelerate the renovation rate from 1.2% per annum to 3% to achieve highly-efficient building stock by 2050 [5].

Additional costs for refurbishment and a lack of knowledge regarding the financial benefits after renovation are the major reasons that hinder the clients from implementing energy-saving measures. Subsidies can be granted for buildings that will meet a certain energy level after renovation, reducing the perceived risks of investing in energy efficiency [56]. The certificate can then be used as a necessary evidence document to obtain the financial subsidies or supports. By 2015, 10 MSs had asked for EPCs in order to claim such subsidies, normally both before and after renovation [15]. The grants can be shifted to preferential loans to create a sustainable renovation market. Embedding EPCs into national renovation policies will be the best driver to reduce energy consumption in the building sector and promote sustainable development. Based on the EPC, the renovation rate may be documented easily and strategic actions can be monitored and optimized on a regular basis. Therefore, the long-term renovation roadmap is in consistence with the EU visions and ambitions.

4 Issues within the current EPC framework

The EPC has been considered as an important building document, allowing individuals to access trustworthy information. In addition, it is also an important energy policy instrument to orient the real estate market and building sector toward energy-efficient buildings. EU members have implemented EPC schemes, following their own approaches. However, the implementation of the EPC has been slow and it is not sufficiently enforced in the MSs because of a lack of information, awareness, quality, and user-friendliness, resulting in a limited market penetration and acceptance among users [11], [57], [58]. During the implementation of the EPC, new issues emerged: how reliable is the certificate? To what extend it has influenced the real-estate market? Is there any quality control or is it just a piece of paper used purely for administrative checks? Can it be used to make informed decisions for building renovation or policymaking?

Researchers found mixed results while investigating the EPC and they are not optimistic about the current EPC. Some think it is a waste of money to obtain a copy of an EPC certificate and others state that the information provided is too general and does not indicate specific parameters regarding thermal comfort and air quality, which are recognized to be the most important indicators to homeowners [16], [59]. In some places, there is still a lack of general awareness about the EPC. The EPC remains an administrative burden and people feel obliged to have an energy efficiency rating. For example, in Germany, the EPC is not considered a reliable tool to motivate building renovation and is viewed as an administrative obligation [11], [58]. Meanwhile, the impact of the EPC on real estate and building renovation is limited in some countries [60]. A survey in the UK revealed that the EPC has little influence on people's decisions to buy or rent properties [28]. Only 18% of recipients are affected by the information and more than 80% think the influence is minor or negligible. Another survey conducted in the Netherlands showed that only 10% of the sample stated that the EPC had influenced them in the process of property purchase [61]. More recently, a survey in Denmark revealed that the EPC is regarded as a reliable and easy-to-understand energy efficiency information source by the respondents, but homeowners believe that the EPC in its current form does not have adequate information to encourage them to undertake home renovation work [16]. Energy efficiency is hindered by other factors while making the decision for a home retrofit as reducing energy bills is not their priority. The EPC should go beyond energy performance to integrate more indicators that are important to improve the quality of life and wellbeing. The expected impact of the EPC on the real-estate market is not fully attained [62]. A cross-country survey was conducted to assess whether the EPC was capitalized upon in the housing market for rental and sales transaction in 12 EU countries [63]. Though 11 of the analyzed countries exhibited a price surplus in sales and rentals, and the surplus in the sales sector was more noticeable, it should be noted that one country (the Netherlands) showed a slight decrease. The results also indicated that, for some real estate agents and property owners, the EPC is considered an unnecessary additional cost and a bureaucratic burden. Some clients only care about the certificate because it is a mandatory document to complete the transaction. Another research conducted in the Norwegian housing market demonstrated that the energy labels have a slightly negligible effect on the positive price premium [18]. The authors claimed that even without the EPC, the price impact-related information can be detected through visual inspection (e.g. triple- or double-glazed window, heat recovery system).

The reliability and credibility of the EPC is also questioned by some property owners and real estates, resulting in a lack of confidence in the return on the investment [63]. According to a report published by the EPBD, only 60% to 80% of the EPCs checked are of good quality [15]. In some countries, the quality is even worse. A study conducted in Aragón (Spain) revealed that around half of the EPC information is incorrect [64]. The substantial gap between the EPC and the actual energy demand makes it difficult for policymakers to successfully make plans for future strategies. The competency of the assessors is an important reason for these gaps as currently most EPC calculations rely on a range of standard inputs or default inputs. The default values are decided by energy assessors, which can easily affect the final results. A case study was carried out in Italy [65] to investigate the influence of energy assessors on energy classification. The calculation results from 162 independent trainee assessors for the same single detached house showed that no two values were identical. The differences were mainly caused by a misunderstanding of input data, such as thermal bridges, boiler efficiency, geometrical data, and domestic hot water production. The energy labels range from label A to label E and around 70% of them were in Label D. A similar result is evidenced by an experimental study from the UK [66]. The methodologies adopted for EPC calculation also affects the calculation results. Abela et al. [62] compared energy demand results of the EPC's national calculation method in Cyprus, Italy, Malta and Spain against outputs from simulation software and monitored energy data. They concluded that calibration of the certification methodology is required to provide a more accurate overview of building energy performance.

The EPC database was constructed in most countries for policy-making. However, the EPCs have not yet been fully implemented and sufficiently enforced. In some countries, the EPC database only covers a small amount of the building stock, which cannot be extrapolated to represent the actual situation at the national scale for energy planning.

The next problem concerns occupants' behavior and building smartness. The occupant's behavior is one of the concurrent and chronic reasons for the deviations as their knowledge and degree of environmental awareness are disparate. The adoption of building automation systems and building smart management systems, which have been proven to be effective approaches for energy-saving, were not accounted in the calculation tools [67]. This results in the difference between predicted and actual energy consumption, and hinders the evolution toward future smart buildings.

The presence of the information in a paper or electronic format should be regulated. A case study carried out in Germany revealed that the conclusions in the EPC were too complicated and technical for consumers to understand, resulting in wrong expectations [15]. Some also pointed out that the recommendation was just a vague guide for potential improvements which did not consider the real energy consumption and clients' requirements [26]. Only 17% of the people acted on the recommendations in a survey carried out in UK [28]. Upgrading the property to improve its energy efficiency would involve a great financial investment. The vague recommendations were inadequate to persuade them to renovate. They noted moreover that the EPC does not clearly indicate how a higher level would positively impact the comfort and well-being of the occupants.

Another problem pertains to the display of the EPC in the advertisement and public buildings. Advertising the EPC in the commercial media is mandatory, which is supposed to raise awareness of the building energy performance among the public. Still, a certain number of houses posted online for renting or for sale do not list their energy performance. In addition, there is a lack of legislation to restrain the format in which the EPC should be advertised in commercial media in order to avoid providing misleading or fraudulent information. For example, some use creative solutions such as C- or D+ [15], which do not exist in the national legislation, for advertisements so that it appears to be better than it actually is. Buildings occupied by the public are expected to set a good example and play a leading role in boosting the energy-efficiency awareness of the public by demonstrating the EPC within the building. According to EPBD Article 12 [7], the EPC must be published in buildings with a total floor area of over 250 m^2, which are occupied by public authorities, or frequently visited by the public. However, there is still a general lack of compliance even though it is written into the law.

In summary, building owners and prospective investors are facing great challenges to improve their buildings' energy performance, which are often associated with cost, a time burden and uncertainty about the planned value. Despite the promise of an attractive return in building retrofits, the lack of confidence in the EPC and the prohibitive costs of carrying out due diligence create barriers to implementing the action. Energy efficiency in buildings is, to some extent, disregarded. The implementation issues and a lackluster attitude from users call for an urgent improvement in the current EPC to trigger a further evolution of the EPC, establishing a more user-friendly and comprehensive instrument, and promoting long-term energy strategies for building sustainability.

5 Discussion towards next generation EPCs

The EPC was expected to influence real-estate owners to invest in buildings, both in terms of new buildings and renovating existing ones, yet it is still not fully motivating the public to improve the performance of their properties due to a wide range of existing problems. The problems calling for an upgrade of the current EPC system so that it can better represent building performance and advance into the next generation EPC+, an enhanced vision for the future of the EPC. The design and implementation of the EPC+ is a demanding and complex task. Multiple aspects affecting the scheme should be taken into consideration, which should also fit into the existing legislative regimes, including building standards and building codes [21]. The long-term development of the EPC schemes requires securing adequate support from authorities, individuals, real-estate actors and energy experts. Thereby, the EPC+ will be recognized as a powerful market tool to create demand for building performance improvement, rather than being viewed as an administrative obligation. The EPC+ will be a trustworthy, accessible, transparent, and comprehensive information source to provide guidance in the area of building performance improvement. It helps policymakers to evaluate housing quality, to define the rate of building renovation, to decide to what extent the buildings should be renovated, and to make targeted investments. Meanwhile, it facilitates the unlocking of the financial barrier for building performance improvement. The ultimate goal is to create a demand-driven market for energy-performance improvement from the building sector and support the transaction into low-carbon real estate. This section proposes the improvement from seven perspectives that endeavor to address the following questions:

1) How to speed up the EPC process with a reduced EPC cost? (Section 5.1)
2) How to enrich the EPC information to create a desire for building performance improvement? (Section 5.2)
3) How to improve the transparency of the EPC and enhance its role in energy planning? (Section 5.3)

4) How to improve the quality and reliability of the EPC? (Section 5.4)
5) How to boost the development towards smart buildings? (Section 5.5)
6) How to improve the uptake of the recommendations to promote extensive building renovation? (Section 5.6)
7) How to improve public awareness to promote large-scale acceptance? (Section 5.7)

5.1 Integration with BIM models to speed up the data consolidation process

Data acquisition and data processing for producing EPCs can be different depending on the adopted tools. For most of the EPC tools, the information consolidation process is not linked with the design process. The energy assessor has to collect sufficient project information to produce the certificate. At present, the EPC calculation relies heavily on default values, to avoid carrying out costly data collection exercises, and simplified models, to reduce the amount of data required as inputs. Furthermore, the time spent in gathering data hinders the progress for EPC generation and increases the time needed to obtain the certificate. The EPC+ will be based on BIM, which is a process for the generation and management of digital information that represents the physical and functional characteristics of buildings [68] [69]. A fully developed BIM model should contain all the required information for EPC calculation, complying with the framework for EPC calculation discussed in Section 2.2. DesignBuilder [70] has set a good example for EPCs generation from BIM models by importing gbXML file created in Revit, ArchiCAD and other BIM tools supporting gbXML data. It claims that DesignBuilder is the fastest and easiest way for EPC generation in UK. Generating EPCs from BIM models creates a replicable and robust approach to evaluate energy labels, which substantially decreases the time and efforts required for data acquisition. The process also reduces potential mistakes made while manually inputting the parameters for producing EPC. Meanwhile, the designer can be aware of the energy performance at the design stage and make improvements to the building's energy performance accordingly. However, interoperability is a problem existing between different tools. Therefore, standards should be set to eliminate inconsistency between tools in order to avoid potential mistakes.

5.2 Inclusion of more key performance indicators to enrich the EPC

The indicators presented in the EPC contribute to clients' awareness of building energy performance and their willingness for improvement. Energy consumption and energy costs are the major indicators in the existing EPC document. However, energy is not often the major argument for building renovations, and different homeowners perceive it from different perspectives. Europeans spend 90% of their time indoors [71]. It is thus important to ensure a comfortable indoor climate. Even though thermal and acoustic comfort, indoor air quality, and daylight are among the primary drivers for building renovation, they are not considered in the EPC. Therefore, the EPC+ should build a more comprehensive and meaningful set of indicators to create the desire for long-term improvement in building performance to optimize comfort levels, indoor air quality, and health. Meanwhile, benchmarking with the best practice for performance improvement should be provided from a specific aspect, which empowers the owners to best benefit from the certificate.

5.3 EPC database to increase information transparency and assist energy planning

Market participants and the building value chain selectively discard some information – information that is valuable to foster sustainability and competitiveness in the market. To promote information transparency, the EPC+ calls for building a trustworthy, reliable, and up-to-date electronic database at the national level by gathering all the existing EPC documents. Most MSs have set up centralized

EPC databases. However, the databases should be further developed to meet the requirements. The database should contain at least the necessary information to reproduce the certification, including the registration number, validity date of the registration, building type, year of construction, floor area, heated floor area, energy label, energy consumption per year, carbon emission, energy-saving recommendations, and information about the energy assessor. The database should also document the changes over the lifetime of a building. The information is updated after renovation, but the old information will remain accessible, thereby ensuring that the EPC+ becomes a lifetime pass to support continuous improvement. It is pivotal to ensure that only authorized experts can input or make changes to the database.

Data availability and accessibility helps users to understand the full value of the EPC. The stored information and statistics in the database could be used to create a user-friendly data-sharing platform, which is freely available to homeowners and prospective owners or renters to make comparisons with the assessment from another representative dwelling in the same block. Currently, some of the databases are accessible to the public while some are only available to authorities or research entities because of the policies regarding data privacy. Countries with strict data privacy regulations shall find a solution to tackle the problem. Denying access to the database protects data privacy, but it is considered as a disadvantage in the efforts to improve information transparency and reinforce public awareness of energy efficiency. Homeowners may advertise wrong information because studies have shown that buildings with better energy performance rent or sell faster with higher prices. Limited access may be provided to the public, which means accessibility is only granted to specific information complying with data protection or privacy requirement regulations. Other information that can be used to identify the building, such as the detailed address, building unit and owner's name, may be anonymized to the public. Therefore, the database allows the clients a convenient approach to check whether or not the published information is correct according to the respective reference number in order to avoid information asymmetry.

The centralized database also provides added value to better exploit the benefits of the EPC, such as monitoring and compliance checks. The information extracted from the database can be used to crosscheck the correctness of a specific certificate through data mining [72], thus improving the quality of the certificate and strengthening the monitoring of EPC compliance at both regional and national levels [15]. If a large discrepancy is detected between the newly produced EPC and the one in the database that is built within the same area and same period, the certifier ought to be physically present on-site to check the authenticity of the data used as the input for the calculation. In addition, the database can be used for data analytics purposes by using statistical analysis methods. Universities or research institutes can actively access the database for research purposes by registering or authenticating their identity. Studies have been carried out to evaluate the thermal performance of the residential building stock and their potential for improvement [41]. Policymakers can rely on these studies for energy planning. More details have been discussed in Section 3. By linking the data with other regulations or databases, such as minimum standards to obtain financial support, minimum standards for building materials, and the building material passport database, energy planning for future schemes can be better informed.

5.4 Quality control of the EPC to enhance credibility and reliability

Credibility and reliability are the most important factors in evaluating the successful implementation of the EPC [31], [73], [31]. It has been used as an eligibility criterion to obtain financial supports or subsidies for improved energy efficiency. In this context, it is paramount to set up a well-functioning system for the quality control of the EPC. If the data quality is questionable, it would be misleading to use such metrics to inform future energy planning policies. Actions should be taken to improve the quality of the EPC. One of the main challenges is to decide what measures should be taken to advance the current EPC towards the trustworthy EPC+. This can be approached from three perspectives: 1) input data; 2) energy assessor; and 3) software-applied.

The input data is one of the most valuable elements for determining the quality of the final results. For newly constructed buildings, data availability is good. However, because of the deviations between design and as-built, the actual values are difficult to identify. The assessors are supposed to adapt the inputs to improve their accuracy. For most of the building stocks requiring renovation, building documents are not available. In such circumstances, a 'good' EPC that can best represent the building energy performance would be rather expensive. An apparent controversy exists: the EPC should transmit accurate information for investments, but it would be costly to gather the required input information. To lower the cost of EPCs and make them acceptable to citizens, most EPCs are produced by using a range of default values that may prevent the report from conveying the reality. Given the fact that default values deviate more or less from the real values, it is not surprising that the EPC results are different from the measured energy demands. It is recommended to further develop the default input values to be more realistic and representative while keeping down the cost for producing the EPC.

The competence of the certifier is the most influential factor affecting the accuracy of the EPC. Experience in the EU shows that without the quality control or validation rules, a number of avoidable mistakes made by the experts can have a huge impact on the EPC energy rating. It is crucial to ensure that only qualified or accredited energy experts are able to issue EPCs to specific building types, as some critical building parameters, such as U-values and air infiltration rate, are based on experts' assumptions rather than physical measurements. Though the experts can also calculate the U-values based on layer composition [74], it still does not reflect the real thermal performance and it remains unclear how often this more detailed measure is applied. The compromised solution loses some of the intended value of the EPC to act as a valuable information source for providing insights into a building's energy performance. Experts often have to adjust the values according to specific cases to ensure the quality of the results. Therefore, it is important to make sure different assessors, or even the same assessor on two different days, will produce broadly the same score. To guarantee the experts' competence in the process of accreditation, mandatory training programs and exams are required to verify the qualification of the accredited assessors. In the meantime, additional training should be provided if the potential assessor does not meet the educational level required (such as university degree in mechanical/civil/energy engineering), or does not have a number of years of relevant professional experience. Expert skills should be differentiated according to the type of buildings and complexity of the technical system (e.g. residential and non-residential buildings, low technology or high technology buildings). More expertise is required for advanced or innovative systems. The certifiers should take continuous professional development and a periodically renewal of the license, so that the qualified experts are kept up-to-date with the national legislations and tools. The authorities should conduct regular examinations to ensure that the assessors demonstrate the competence required when providing the service. To achieve a more effective implementation, the assessors should be subjected to certain consequences/penalties in the event of non-compliance. The sanction can be a monetary fine or penalty points. In serious conditions, the assessor may face the suspension of his/her license or withdrawal of his/her accreditation.

Another important factor affecting the accuracy of the certificate is the tools adopted. It is crucial to ensure only officially approved and verified software can be applied for certification. The limitation is that the performance of some advanced or innovative technologies are not accounted for in the evaluation tools [67]. A typical example is the smart control and automation system. Therefore, EPC tools should be updated in time, if necessary, to reflect technical progress in the building sector. Introducing smart control system can save up to 26.36% of the building energy [67]. Calibration and validation of the input data is another approach to improve the quality of the certificates. This can be done by coupling validation measures into the tools to avoid inaccurate input data, typically, warning for invalid inputs - above or below threshold values. The central database provides an easy and effective way to check compliance before uploading to the database. The tool relies on the existing database to validate the certificate through digital analysis approaches, for example, machine learning [30].

As well as avoiding incorrect EPC results during the process of issuing the certificate, it is also important to guarantee that the information transferred to the EPC database is reliable and accurate. This may be done by using Blockchain Technology to track the steps for information transfer. The verified database can then be used for building renovation and energy planning to consolidate the transition towards the NZEB ambition.

5.5 Taking human intervention and building smart readiness into account

The energy consumption of a building can be classified into the envelope system, HVAC (Heating, Ventilation and Air Conditioning) systems, and electrical devices. A calculation based on standard inputs is the best way to assess building energy performance without considering the influence of users. The use of HVAC systems and electrical devices is difficult to quantify as the occupants' behaviors and preferences (hours of operation, internal temperature and control strategies, etc.) are difficult to forecast, contributing significantly to the performance gap between the predicted and actual energy consumption of the building. An occupancy assessment should be carried out to obtain additional information such as the number of fridges, cookers, air conditioning, occupancy level, occupancy schedule, shower types, boiler capacity, energy bill statement, income range, and use of automatic controls to enhance the reliability of the results. Poor operation practice is an important reason for the deviation. One solution is to train and raise the awareness of the occupants, encouraging them to adapt their preferences to energy-saving options. Another solution is to adopt smart technologies due to their potential to increase energy efficiency and improve occupants' comfort within the building. Electronic monitoring and control has exhibited the ability for energy-saving through effective regulations. However, most of the national EPC tools do not capture the contribution of smart technologies and innovation systems [67]. It is important to ensure the inclusion of these systems in the calculation methodologies to promote the design of NZEBs. The development of the smart systems is often ahead of the capabilities of the calculation tools. Thus, flexibility should be permitted to account for such systems. In addition, the EPC should be further developed to include smart readiness indicators so that the certificate will motivate the deployment of innovative technologies and promote the efforts for effective energy saving, stimulating investors for technological innovation and making the "smartness" more approachable. Building smart readiness technology is based on an assessment of the smart ready devices in building, which is intended to raise awareness of smart technologies, motivate people to invest in smart innovation and support innovation in the building sector [75]. Rating the smart readiness of a building should be based on the building's capability to adapt its operations to occupants' needs and the grid supply for energy efficiency and indoor climate improvement [9]. The EN 15232 [76], which is an overarching standard to evaluated the impact of building automation and control systems on building energy performance, can be used to help identifying the relevant smartness for building smart readiness [76]. A great uptake of the smart capability, such as smart meters, building automation and control system, and self-regulation devices for an indoor climate improvement, can assist in creating a healthier and more comfortable indoor environment while lowering the impact on energy and the climate. In order to better benchmark the influence of human intervention and smart technology, it is recommended to include supplementary consumption data (e.g. two to three years of realistic energy use) after the certificate is produced. A combination of calculation rating and actual operation rating is a cost-effective approach to best represent the building energy performance.

5.6 More detailed recommendations to promote extensive renovation

Producing recommendations for energy-saving measures is a compulsory task when generating the EPC. The recommendations presented play a vital role in homeowners' subsequent decisions. One of the reasons that the EPC is not considered a decisive aspect for building performance improvement by building renovation investors and potential purchasers is that the current information provided by the EPC is too general [16]. In some countries, the recommendations are vague standard statements regardless of the building's actual status, without comparing them to some standard typical patterns or the expected performance under the same conditions. The recommendations should provide more detailed information for cost-effective upgrading of the building performance, based on realistic energy savings that could be achieved in the implementation of these measures, and should not lead to false expectations. The EPC+ will be able to provide personalized instructions on renovation options to quantify energy savings and related costs, taking into account outdoor climatic conditions and indoor climate requirements. It is better to provide an estimation of cost payback periods for pragmatic improvements over its lifecycle, accounting for potential access to financial incentives and subsidies schemes as well as annual energy savings, to eventually make the improvements viable and to increase the uptake of the recommendations. The EPC+ should also include energy-saving measures for using the building effectively at the operation stage. Therefore, the EPC+ could be a more practical and tailor-made instrument with personalized instruction for homeowners and prospective investors. However, the tailor-made recommendation may result in a substantial price increase in the EPC, which should not be ignored. Meanwhile, recommendations should be made to promote the use of renewable energy and reduce environmental impact.

5.7 Improving the EPC presentation to enhance public awareness

Disclosing building energy performance information to the public was expected as an important policy to control buildings' energy demand and reduce carbon emissions [77]. The presentation of the information contributes to the customers' willingness for energy-efficient buildings, which should be concise and clear enough whilst providing a maximum of specific information to meet various expectations. User-friendliness will be a priority for the EPC+. Efforts should be undertaken to make sure that important information is appropriately presented. The use of technical language shall be reduced to a minimum in order to make it easier for the general public to understand. Clear guidelines are required on how this information should be advertised in commercial media (including electronic media) to ensure visible and meaningful publication. The publication of reference numbers should be mandatory in the advertisements, allowing prospective buyers and tenants to check the respective information in the database. In addition, the EPC should be displayed in public buildings. The obligation to display the EPC in public buildings helps to strengthen the role of the EPC by boosting public awareness. Norway sets a good example for this [15]. Any non-residential buildings with an area over 1000 m^2 must display the EPC and one person is appointed to be responsible for it. The consequences for non-compliance are clearly specified.

6 Conclusion

The building sector is under great pressure for decarbonization. The EPC, which was expected to be an important driver to promote building energy performance improvements, plays a crucial role in this process. At present, the EPC has been implemented in all MSs. In addition, the EPC database and quality control measures have been established in most MSs. The aggregated EPC information from the database can be used for monitoring buildings energy performance, energy planning and building renovation planning. However, there are some existing problems that prevent it from serving as a reliable and trustworthy information tool to motivate large scale building renovation. The current data show that only a small amount of building stock has achieved label A, which meets the requirements for NZEB. The lack of access to trustworthy information and financial support leads to hesitation with regard to retrofit decisions, resulting in a low refurbishment rate in the EU. In order to strengthen the role of the EPC in the real-estate market and energy planning, MSs should continuously improve the EPC so that it can speed the transaction into NZEBs. The improvement can be implemented from the following perspectives:

- Integrating BIM models to create a replicable and robust approach for EPC generation by speeding up the data acquisition process while keeping costs low.
- Exploring a comprehensive set of indicators to boost the availability of information and promote the desire for deep renovation.
- Establishing a trustworthy and reliable database to ensure information transparency and facilitate building energy-related policy planning.
- Setting up a well-functioning system to enhance the quality of the EPC from the perspective of input data, energy assessor and software applied.
- Accounting for human interaction and building smart readiness to stimulate advances towards smart buildings.
- Providing more tailor-made recommendations for the cost-effective upgrading of the buildings.
- Developing clear guidance on the EPC presentation to make the information accessible and to enhance public awareness on energy efficiency.

The discussion towards the next generation EPC provides some insights that deserve attention in future evolutions. The advancement will strengthen the value of the EPC for successful market incorporation. The next generation EPC will be a comprehensive information source, which goes beyond building energy efficiency by involving indoor climate, wellbeing, smartness, etc. Thus, EPC can influence real-estate and building owners to invest more in building performance improvement. It will be a decisive decision-supporting tool for tenants and potential buyers, and will provide guidance on cost-optimal building renovation for building owners. The full implementation of the EPC can better represent the building performance at the regional or national scale to facilitate building energy performance monitoring, building energy planning and building renovation planning, and therefore reduce building energy consumption, decrease environmental impacts and improve inhabitants' quality of life.

There is a lack of comprehensive overview of the available data in the EPC used in each country across the EU. Future work will explore the information that is available to deliver the EPC in each country.

Acknowledgements

The authors acknowledge the financial support of the European Commission (H2020) to the BIMEET project, grant reference: 753994. Permission has been granted for use of figures in the paper.

Declarations of interest: none

References

[1] Ibañez-Puy M, Vidaurre-Arbizu M, Sacristán-Fernández JA, Martín-Gómez C. Opaque Ventilated Façades: Thermal and energy performance review. Renew Sustain Energy Rev 2017;79:180–91. doi:10.1016/j.rser.2017.05.059.

[2] Li Y, Rezgui Y, Zhu H. District heating and cooling optimization and enhancement – Towards integration of renewables, storage and smart grid. Renew Sustain Energy Rev 2017;72:281–94. doi:10.1016/j.rser.2017.01.061.

[3] Filippidou F, Nieboer N, Visscher H. Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database. Energy Policy 2017;109:488–98. doi:10.1016/j.enpol.2017.07.025.

[4] López-González LM, López-Ochoa LM, Las-Heras-Casas J, García-Lozano C. Energy performance certificates as tools for energy planning in the residential sector. The case of La Rioja (Spain). J Clean Prod 2016;137:1280–92. doi:10.1016/j.jclepro.2016.08.007.

[5] Fabbri M, Groote M De, Rapf O. Building Renovation Passports: Customised roadmaps towards deep renovation and better homes. Build Perform Inst Eur 2016:46. http://bpie.eu/wp-content/uploads/2017/01/Building-Passport-Report_2nd-edition.pdf (accessed July 12, 2018).

[6] European Commission. Directive 2002/91/EC of the European Parliment and of the Council of 16 December 2002 on the energy performance of buildings 2002. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0091&from=IT (accessed July 22, 2018).

[7] European Commission. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings 2010 2010. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=IT (accessed July 22, 2018).

[8] European Commission. Directive 2012/27/EU of the European Parliament and of the Council of 25 December 2015 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC 2012:56. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF (accessed September 8, 2017).

[9] European Commission. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance) 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG (accessed December 19, 2018).

[10] Buildings Performance Institute Europe. Energy Performance Certificates across Europe: From design to implementation 2010:71. http://www.buildup.eu/sites/default/files/content/BPIE_EPC report 2010.pdf (accessed December 3, 2018).

[11] Sesana MM, Salvalai G. A review on Building Renovation Passport: Potentialities and barriers on current initiatives. Energy Build 2018;173:195–205. doi:10.1016/J.ENBUILD.2018.05.027.
[12] Chegut A, Eichholtz P, Kok N. Supply, demand and the value of green buildings. Urban Stud 2014;51:22–43. doi:10.1177/0042098013484526.
[13] Hyland M, Lyons RC, Lyons S. The value of domestic building energy efficiency — evidence from Ireland. Energy Econ 2013;40:943–52. doi:10.1016/J.ENECO.2013.07.020.
[14] IBRoad project. Factsheet: Belgium - Flanders Current use of EPCs and potential links to iBRoad 2018:10. http://bpie.eu/wp-content/uploads/2018/01/iBROAD_CountryFactsheet_BELGIUM-Flanders-2018.pdf (accessed November 23, 2018).
[15] Concerted Action EPBD. 2016 Implementing the Energy Performance of Building Directive (EPBD). ADENE; 2015. https://www.dropbox.com/s/vaq0h8if64ypmlh/CA3-BOOK-2016-web.pdf?dl=0 (accessed July 25, 2018)
[16] Haunstrup Christensen T, Gram-Hanssen K, de Best-Waldhober M, Adjei A. Energy retrofits of Danish homes: is the Energy Performance Certificate useful? Build Res Inf 2014;42:489–500. doi:10.1080/09613218.2014.908265.
[17] Cajias M, Piazolo D. Green performs better: energy efficiency and financial return on buildings. J Corp Real Estate 2013;15:53–72. doi:10.1108/JCRE-12-2012-0031.
[18] Stanley S, Lyons RC, Lyons S. The price effect of building energy ratings in the Dublin residential market. Energy Effic 2016;9:875–85. doi:10.1007/s12053-015-9396-5.
[19] Charalambides AG, Maxoulis CN, Kyriacou O, Blakeley E, Frances LS. The impact of Energy Performance Certificates on building deep energy renovation targets. Int J Sustain Energy 2019;38:1–12. doi:10.1080/14786451.2018.1448399.
[20] Comerford DA, Lange I, Moro M. Proof of concept that requiring energy labels for dwellings can induce retrofitting. Energy Econ 2018;69:204–12. doi:10.1016/J.ENECO.2017.11.013.
[21] Arcipowska A, Anagnostopoulos F, Mariottini F, Kunkel S, Rapf O, Atanasiu B, et al. Energy performance certificates across the EU A mapping of the national approaches. Build Perform Inst Eur 2014:60. http://bpie.eu/wp-content/uploads/2015/10/Energy-Performance-Certificates-EPC-across-the-EU.-A-mapping-of-national-approaches-2014.pdf (accessed July 29, 2018).
[22] Dodoo A, Gustavsson L, Le Truong N. Primary energy benefits of cost-effective energy renovation of a district heated multi-family building under different energy supply systems. Energy 2018;143:69–90. doi:10.1016/J.ENERGY.2017.10.113.
[23] Gustafsson M, Gustafsson MS, Myhren JA, Bales C, Holmberg S. Techno-economic analysis of energy renovation measures for a district heated multi-family house. Appl Energy 2016;177:108–16. doi:10.1016/J.APENERGY.2016.05.104.
[24] Moschetti R, Brattebø H, Skeie KS, Lien AG. Performing quantitative analyses towards sustainable business models in building energy renovation projects: Analytic process and case study. J Clean Prod 2018;199:1092–106. doi:10.1016/J.JCLEPRO.2018.06.091.
[25] Baek C, Park S. Policy measures to overcome barriers to energy renovation of existing buildings. Renew Sustain Energy Rev 2012;16:3939–47. doi:10.1016/J.RSER.2012.03.046.
[26] Gonzalez Caceres A. Shortcomings and suggestions to the EPC recommendation list of measures: In-depth interviews in six countries. Energies 2018;11:2516. doi:10.3390/en11102516.
[27] Murphy L. The influence of the Energy Performance Certificate: The Dutch case. Energy Policy 2014;67:664–72. doi:10.1016/J.ENPOL.2013.11.054.
[28] Lainé L. Room for improvement - The impact of EPCs on consumer decision-making 2011:1–12. https://webarchive.nationalarchives.gov.uk/20130103091354/http://www.consumerfocus.org.uk/publications/room-for-improvement-the-impact-of-epcs-on-consumer-decision-making (accessed December 4, 2018).
[29] Rodrigues L, Garratt T, Ebbs N. Is added sustainability equal to added value? Energy Convers. Manag., vol. 63, Pergamon; 2012, p. 203–7. doi:10.1016/j.enconman.2012.01.042.
[30] Hardy A, Glew D. An analysis of errors in the Energy Performance certificate database. Energy Policy 2019;129:1168–78. doi:10.1016/J.ENPOL.2019.03.022.

[31] Pasichnyi O, Wallin J, Levihn F, Shahrokni H, Kordas O. Energy performance certificates — New opportunities for data-enabled urban energy policy instruments? Energy Policy 2019;127:486–99. doi:10.1016/J.ENPOL.2018.11.051.

[32] Mangold M, Österbring M, Wallbaum H. Handling data uncertainties when using Swedish energy performance certificate data to describe energy usage in the building stock. Energy Build 2015;102:328–36. doi:10.1016/j.enbuild.2015.05.045.

[33] Fuerst F, McAllister P, Nanda A, Wyatt P. An investigation of the effect of EPC ratings on house prices. 2013. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/207196/20130613_-_Hedonic_Pricing_study_-_DECC_template__2_.pdf (accessed April 25, 2019)

[34] BIMEET. https://www.vtt.fi/sites/bimeet (accessed June 22, 2019).

[35] Gaglia AG, Dialynas EN, Argiriou AA, Kostopoulou E, Tsiamitros D, Stimoniaris D, et al. Energy performance of European residential buildings: Energy use, technical and environmental characteristics of the Greek residential sector – energy conservation and CO_2 reduction. Energy Build 2019;183:86–104. doi:10.1016/J.ENBUILD.2018.10.042.

[36] Buildings Performance Institute Europe. Factsheet 97% of Buildings in the EU Need to be Upgraded 2017:2. http://bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf (accessed October 11, 2018).

[37] Andrić I, Pina A, Ferrão P, Fournier J, Lacarrière B, Le Corre O, et al. Assessing the feasibility of using the heat demand-outdoor temperature function for a long-term district heat demand forecast. Energy Procedia 2017;140:102–14. doi:10.1016/j.egypro.2017.11.127.

[38] European Committee for Standardization. Energy audits - Part 5: Competence of energy auditors 2015. https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT:38140&cs=1DDCED282F157438DDF0C1C74C98FE122 (accessed January 8, 2019).

[39] Buildings Performance Institute Europe. Qualification and accreditation requirements of building energy certifiers in EU28 2015:8. http://bpie.eu/wp-content/uploads/2015/09/BPIE-EPCsFactsheet-2015.pdf (accessed January 3, 2019).

[40] Backhaus J, Tigchelaar C, De Best-Waldhober M. Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive 2011:47. https://www.ecn.nl/docs/library/report/2011/o11083.pdf (accessed December 19, 2018).

[41] Streicher KN, Padey P, Parra D, Bürer MC, Patel MK. Assessment of the current thermal performance level of the Swiss residential building stock: Statistical analysis of energy performance certificates. Energy Build 2018;178:360–78. doi:10.1016/J.ENBUILD.2018.08.032.

[42] Droutsa KG, Kontoyiannidis S, Dascalaki EG, Balaras CA. Mapping the energy performance of hellenic residential buildings from EPC (Energy Performance Certificate) data. Energy 2016;98:284–95. doi:10.1016/J.ENERGY.2015.12.137.

[43] Magalhães SMC, Leal VMS. Characterization of thermal performance and nominal heating gap of the residential building stock using the EPBD-derived databases: The case of Portugal mainland. Energy Build 2014;70:167–79. doi:10.1016/J.ENBUILD.2013.11.054.

[44] Dineen D, Rogan F, Ó Gallachóir BP. Improved modelling of thermal energy savings potential in the existing residential stock using a newly available data source. Energy 2015;90:759–67. doi:10.1016/J.ENERGY.2015.07.105.

[45] López-Ochoa LM, Las-Heras-Casas J, López-González LM, Olasolo-Alonso P. Towards nearly zero-energy buildings in Mediterranean countries: Energy Performance of Buildings Directive evolution and the energy rehabilitation challenge in the Spanish residential sector. Energy 2019;176:335–52. doi:10.1016/J.ENERGY.2019.03.122.

[46] Collins M, Curtis J. Bunching of residential building energy performance certificates at threshold values. Appl Energy 2018;211:662–76. doi:10.1016/J.APENERGY.2017.11.077.

[47] Kelly S, Crawford-Brown D, Pollitt MG. Building performance evaluation and certification in the UK: Is SAP fit for purpose? Renew Sustain Energy Rev 2012;16:6861–78. doi:10.1016/J.RSER.2012.07.018.

[48] Europese Commission. Evaluation of Directive 2010/31/EU on the energy performance of buildings. 2016. doi:SWD(2013) 93. https://ec.europa.eu/energy/sites/ener/files/documents/2_en_autre_document_travail_service_part1_v2_0.pdf (accessed May 4, 2019).
[49] The Private Rented Property minimum standard – landlord guidance documents - GOV.UK. UK Gov 2017. https://www.gov.uk/government/publications/the-private-rented-property-minimum-standard-landlord-guidance-documents (accessed December 4, 2018).
[50] European Commission. Commision Recommendation (EU) 2016/1318 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. Off J Eur Union 2016:12. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=RO (accessed December 18, 2018).
[51] Groezinger Jan, Boermans Thomas, Ashok John, Seehusen Jan, Wehringer Felix SM. Overview of Member States information on NZEBs Working version of the progress report - final report. 2014. https://ec.europa.eu/energy/sites/ener/files/documents/Updated progress report NZEB.pdf (accessed May 3, 2019)
[52] Florio P, Teissier O. Estimation of the Energy Performance Certificate of a housing stock characterised via qualitative variables through a typology-based approach model: A fuel poverty evaluation tool. Energy Build 2015;89:39–48. doi:10.1016/J.ENBUILD.2014.12.024.
[53] Filippidou F, Nieboer N. Energy efficiency measures implemented in the Dutch non-profit housing sector. Energy Build 2016;132:107–16. doi:10.1016/J.ENBUILD.2016.05.095.
[54] Saheb Y, Bódis K, Szabó S, Ossenbrink H. Energy renovation: The trump card for the new start for Europe 2015:103. doi:10.2790/39989.
[55] Majcen D, Itard L, Visscher H. Actual heating energy savings in thermally renovated Dutch dwellings. Energy Policy 2016;97:82–92. doi:10.1016/J.ENPOL.2016.07.015.
[56] McGilligan C, Sunikka-Blank M, Natarajan S. Subsidy as an agent to enhance the effectiveness of the energy performance certificate. Energy Policy 2010;38:1272–87. doi:10.1016/J.ENPOL.2009.10.068.
[57] Farahani A, Wallbaum H, Dalenbäck J-O. The importance of life-cycle based planning in maintenance and energy renovation of multifamily buildings. Sustain Cities Soc 2019;44:715–25. doi:10.1016/J.SCS.2018.10.033.
[58] Amecke H. The impact of energy performance certificates: A survey of German home owners. Energy Policy 2012;46:4–14. doi:10.1016/j.enpol.2012.01.064.
[59] Watts C, Jentsch MF, James PA. Evaluation of domestic Energy Performance Certificates in use. Build Serv Eng Res Technol 2011;32:361–76. doi:10.1177/0143624411404486.
[60] Taranu V, Verbeeck G. A closer look into the European Energy Performance Certificates under the lenses of behavioural insights—a comparative analysis. Energy Effic 2018;11:1745–61. doi:10.1007/s12053-017-9576-6.
[61] Murphy LC. Policy instruments to improve energy performance of existing owner occupied dwellings. Delft University of Technology, 2016. doi:10.7480/abe.2016.17.
[62] Abela A, Hoxley M, McGrath P, Goodhew S. An investigation of the appropriateness of current methodologies for energy certification of Mediterranean housing. Energy Build 2016;130:210–8. doi:10.1016/J.ENBUILD.2016.07.056.
[63] Zebra 2020- nearly zero-energy building strategy 2020: Strategies for a nearly zero-energy building market transition in the European Union 2016. http://zebra2020.eu/website/wp-content/uploads/2014/08/ZEBRA2020_Strategies-for-nZEB_07_LQ_single-pages-1.pdf (accessed July 25, 2018).
[64] Las-Heras-Casas J, López-Ochoa LM, López-González LM, Paredes-Sánchez JP. A tool for verifying energy performance certificates and improving the knowledge of the residential sector: A case study of the Autonomous Community of Aragón (Spain). Sustain Cities Soc 2018;41:62–72. doi:10.1016/J.SCS.2018.05.016.
[65] Hårsman B, Daghbashyan Z, Chaudhary P. On the quality and impact of residential energy performance certificates. Energy Build 2016;133:711–23. doi:10.1016/J.ENBUILD.2016.10.033.
[66] DECC. Green Deal Assessment Mystery Shopping Research: Mystery shopping of customer

experiences of Green Deal Assessments. 2014. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/388197/Green_Deal_Assessment_Mystery_Shopping_FINAL_PUBLISHED.pdf (accessed April 24, 2019)

[67] López-González LM, López-Ochoa LM, Las-Heras-Casas J, García-Lozano C. Update of energy performance certificates in the residential sector and scenarios that consider the impact of automation, control and management systems: A case study of La Rioja. Appl Energy 2016;178:308–22. doi:10.1016/J.APENERGY.2016.06.028.

[68] Eastman CM, Teicholz PM, Sacks R, Lee G. BIM handbook : a guide to building information modeling for owners, managers, designers, engineers and contractors. Third edit. 2018.

[69] Gupta A, Cemesova A, Hopfe CJ, Rezgui Y, Sweet T. A conceptual framework to support solar PV simulation using an open-BIM data exchange standard. Autom Constr 2014;37:166–81. doi:10.1016/J.AUTCON.2013.10.005.

[70] DesignBuilder Software Ltd - Home. https://designbuilder.co.uk/ (accessed June 17, 2019).

[71] Rapf O, Mariottini F, Lottes R, Kunkel S, Danciu S, Faber M, et al. Renovation strategies of selected EU countries 2014:68. http://bpie.eu/uploads/lib/document/attachment/86/Renovation_Strategies_EU_BPIE_2014.pdf (accessed December 18, 2018).

[72] Khayatian F, Sarto L, Dall'O' G. Application of neural networks for evaluating energy performance certificates of residential buildings. Energy Build 2016;125:45–54. doi:10.1016/J.ENBUILD.2016.04.067.

[73] Jenkins D, Simpson S, Peacock A. Investigating the consistency and quality of EPC ratings and assessments. Energy 2017;138:480–9. doi:10.1016/J.ENERGY.2017.07.105.

[74] Li Y, Rezgui Y. A novel concept to measure envelope thermal transmittance and air infiltration using a combined simulation and experimental approach. Energy Build 2017;140:380–7. doi:10.1016/j.enbuild.2017.02.036.

[75] Verbeke S, Ma Y, Van Tichelen P, Bogaert S, Gómez Oñate Waide Strategic Efficiency V, Waide ECOFYS P, et al. Support for setting up a smart readiness indicator for building and related impact assessment Final report 2018:288. https://smartreadinessindicator.eu/sites/smartreadinessindicator.eu/files/sri_1st_technical_study_-_final_report.pdf (accessed November 9, 2018).

[76] prEN 15232. Energy performance of buildings — Impact of Building Automation Control and Building Management. 2006. http://www.cres.gr/greenbuilding/PDF/prend/set4/WI_22_TC-approval_version_prEN_15232_Integrated_Building_Automation_Systems.pdf (accessed April 26, 2019)

[77] Lee H, Lee M, Lim S, Lee H, Lee M, Lim S. Do consumers care about the energy efficiency of buildings? Understanding residential choice based on Energy Performance Certificates. Sustainability 2018;10:4297. doi:10.3390/su10114297.