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Assessing building energy performance and energy policy impact through the combined analysis of EPC data – The Italian case study of SIAPE

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ABSTRACT

Energy Performance Certificates (EPCs) and EPC digital registers are key tools to evaluate different aspects of the building stock and its energy consumption. This paper presents several detailed energy performance evaluations on the Italian buildings based on a sample of over 2,000,000 EPCs extracted from the national EPC register (SIAPE), contributing to the definition of an updated energy performance baseline of the Italian building stock. This is the first work using the Italian EPC register to define such a baseline to the extent of the authors' knowledge. Furthermore, combined analyses of EPC data were carried out to obtain information on the influence of the Italian energy regulations on building characteristics and on the effectiveness of energy strategy application for building renovation.

This study underlines the relevance of EPC registers and how the combined analysis of EPC parameters can provide a large amount of useful information on several aspects of the building stock, allowing the monitoring of the impact of the Italian energy policy framework on buildings energy performance. Finally, based on these results, the paper supports public authorities and decision-makers in planning and developing future energy programs and identifying the best practices on the Italian territory.

Abbreviations

CRESME	Centre for economic, sociological and market research in buildings (Centro ricerche economiche, sociologiche e di mercato nell'edilizia, in Italian)
CTI	Italian Thermotechnical Committee
DHW	Domestic Hot Water
EED	Energy Efficiency Directive
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development EP_{gl}: global energy performance index [kWh/m^{2}y]
$EP_{gl,nren}$	global energy performance index for non-renewable energy sources [kWh/m^{2}y]
$EP_{gl,ren}$	global energy performance index for renewable energy sources [kWh/m^{2}y]
$EP_{H,nd}$	thermal performance for heating needs of the building envelope [kWh/m^{2}y]
EPBD	Energy Performance Building Directive
EPC	Energy Performance Certificate
EU	European Union
DBMS	Data Base Management System
ISTAT	Italian Institute of Statistic (Istituto Nazionale di Statistica, in Italian)
MS	Member State
N	number of the sample
RES	Renewable Energy Source
RB	Reference Building
SIAPE	Italian Informative System on Energy Performance Certificates (Sistema Informativo sugli Attestati di Prestazione Energetica, in Italian)
NZEB	Nearly Zero-Energy Building
TBS	Technical Building System
XML	eXtensible Markup Language

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1. Introduction

The European Union strongly promotes measures and strategies aimed to decrease the contribution of the civil sector on final energy consumption and CO_2 emission and achieve the 2050 EU targets. The promotion of building energy performance has been set in the EU mainly by the regulatory framework composed by the Energy Performance of Buildings Directive 2002/91/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU (EED). Thanks to its revision steps, the Directives 2010/31/EU (EPBD recast) and 844/2018/EU, the EPBD has been enriched with new and more stringent requirements over time. Along this way, several tools have been developed in the last 20 years to gradually increase the knowledge about the European buildings and estimate the evolution of their energy performance with energy efficiency strategies, building characteristics, and construction technologies. Energy Performance Certificate (EPC) digital registers are a powerful tool to perform these evaluations as they make it possible to combine all the EPC data and compare them with the building requirements issued by law over time. Furthermore, EPC registers provide several data to analyze building energy performance and develop different applications deeply. The EU has not set the implementation of EPC registers as mandatory. However, almost all the Member States (MSs) voluntarily developed a national EPC register (Gokarakonda et al., 2020) as it is the most effective solution to monitor and control the EPC information, as required by EU (Arcipowska et al., 2014).

This study carried out an extensive analysis using the Italian EPC Data Base Management System (DBMS), called SIAPE. The obtained results contribute to the definition of an updated energy performance baseline of the Italian building stock and the evaluation of the effects of energy policies and energy strategies on the Italian territory.

The paper is organized as follows. The Introduction (Section 1) presents an overview of the existing applications developed through EPC data analysis (Section 1.1) and illustrates the aim and the contributions of the proposed work (Section 1.2). Section 2 is divided into three parts: Section 2.1 provides basic knowledge about the Italian energy regulatory framework; Section 2.2 describes more in detail the Italian EPC methodology and digital register (SIAPE); Section 2.3 shows the process adopted to obtain the results, which includes the validation of the EPC data sample and the check of its robustness in describing the energy performance of the Italian building stock. Section 3 shows in detail the results of this work, first providing general information on the energy performance assessment of the Italian buildings (Section 3.1) and then focusing on the impact of energy strategies (Section 3.2) and energy policy application (Section 3.3). Finally, Section 4 summarizes the research findings and highlights the main policy implications provided by this work and its future developments.

1.1. Background

Pasichnyi (Pasichnyi et al., 2019) provided a comprehensive Literature review on existing applications on EPC data and analyzed them by EU MS, EPC data feature, auxiliary input data, application domain, and temporal distribution. He found that EPC data are mainly used to map building energy performance by analyzing the calculated and actual energy consumptions and the building data (general information, geometry, envelope, etc.). According to (Volt et al., 2020), instead, among the EU MSs the data more often collected in EPC digital registers are firstly the energy rating and the assessor data, and then the energy consumption (calculated and actual), the technical building system (TBS) data, the building data, and the recommendations.

The role of the EPC in the promotion of building energy performance and in the evaluation of the impact of energy efficiency actions is well-known (Amecke, 2012; Khazal and Sønstebø, 2020; Li et al., 2019; Murphy, 2014). EPC is a powerful tool to predict potential energy savings and scenarios and to guide decision-makers in the choice of suitable energy policies (Curtis et al., 2015; Delmastro et al., 2016; Fonseca and Oliveira Panão, 2017; Gouveia and Palma, 2019; Guariso and Sangiorgio, 2019; Hong et al., 2013). In Literature, several works used this information to describe the building stock through the definition of reference buildings (RBs) (Ali et al., 2020; Dineen et al., 2015; Gangolells et al, 2020a, 2020b, 2020a; Kragh and Wittchen, 2014; Mutani et al., 2020a; Österbring et al., 2016; Streicher et al., 2018) or to show building energy performance at national (Dascalaki et al, 2010, 2013, 2010; Droutsa et al, 2016, 2017, 2016; Gangolells et al, 2016, 2019, 2016; Hjortling et al., 2017; Johansson et al., 2017; Magalhães and Leal, 2014) and local (regional or city) levels (Armitage et al., 2015; Buratti et al., 2015; Fabbri et al., 2012; Gouveia and Palma, 2019; Hong et al., 2014; López-González et al., 2016; Mutani et al., 2020b). These previous works are summarized in Table 1 where the information on building use, EPC sample, and analyzed EPC parameters is highlighted.

As highlighted by (Pasichnyi et al., 2019), the EPC information more often analyzed is the energy consumption and the building data; nevertheless, several studies also evaluated the building energy performance related to the construction year and the climate context, as shown in Table 1. It is worth noting that the purpose for EPC issuing is often not studied, even if it provides information on the reason why the EPC is issued (e.g., sale, rent, new building, etc.). In this work, the purpose for EPC issuing was deeply investigated as a key factor in interpreting and monitoring the energy performance of the building stock.

1.2. Aim and scope

Since 1976 (Law 373/1976), the Italian government has issued several laws and decrees aimed to strongly improve the energy performance of new and renovated buildings. First, building energy performance certification was introduced in 2005 (Legislative Decree 192/2005). Then in 2015, the Ministerial Decree 26/06/2015 established the new current EPC scheme and issued the national EPC DBMS, called SIAPE, which was developed in 2016 by the Italian energy agency ENEA. SIAPE (ENEA, 2020) collects the EPCs from the regional digital registers and allows analyzing energy performance and other characteristics of the Italian building stock.

According to the Italian Report on Building Energy Certification (Basili et al., 2020), about 4.500.000 EPCs were issued in Italy from 2016 to 2019 referring mostly to the residential stock and, then, commercial buildings, offices, and buildings for industrial activities. The stock certified by EPC covers approximately 10% of the Italian building units, according to building unit census in (Stemperini, 2021). SIAPE currently contains about 2,000,000 EPCs issued from October 2015 to December 2020 since not all the Italian Regions have joined the DBMS yet. However, as shown in Section 2.3, the SIAPE EPC sample was considered representative of the entire Italian building stock since it shows similar distributions compared with national census data and other EPC information provided directly from Italian Regions and Autonomous Provinces.

The contribution of this paper is twofold. First, it provides an updated energy performance baseline of the Italian building stock using the national EPC data for the first time since the SIAPE public portal was published in November 2020 (ENEA, 2020). Most of the previous studies based on large datasets to assess the energy performance of the Italian building stock derived their results from Regional EPC registers (Buratti et al., 2015; Caputo and Pasetti, 2017; Dall'o' et al., 2012; Fabbri et al., 2012; Mutani et al., 2020b, 2020a) and other national sources (e.g., ISTAT census) and EU projects (e.g., *IEE-TABULA*, *IEE-EPISCOPE*). In addition, the mentioned datasets do not contain recent data about new and renovated buildings (Ballarini et al., 2014; Caputo et al., 2013; Caputo and Pasetti, 2017), neither updated information on energy performance indices. The second contribution evaluates the ef-

Table 1
Main works in Literature using EPC registers for building energy performance assessment.

Location	Authors	Building use	N. EPCs	Main EPC parameter used[a]
Denmark	Kragh and Wittchen (2014)	Residential stock	~235.000	BE, BT, Y
Greece	(Dascalaki et al, 2010, 2013); (Droutsa et al., 2016); (Droutsa et al., 2017)	Building stock; Residential stock; Non-residential stock;	~250–355,00 ~650,000	ECo, CO_2, ECa, Y, CZ, BT, BU, HVAC, RES
Ferrara, Italy	Fabbri et al. (2012)	Historical building stock	~1,080	ECo, BU, P
Piedmont Region, Italy	(Mutani et al, 2020a, 2020b, 2020a)	Residential stock	~240,000–870,00	ECo, Y, CZ, P, BT, S
Umbria Region, Italy	Buratti et al. (2015)	Building stock	~6,500	ECo, CO_2, Y, BT
Ireland	(Ali et al., 2020; Dineen et al., 2015)	Residential stock	~250,000–260,000	ECo, Y, BT, S, BE
Portugal	(Gouveia and Palma, 2019; Magalhães and Leal, 2014)	Residential stock	~260,000–520,000	ECo, CO_2, Y, CZ, S, BE
Spain	(Gangolells et al., 2016); (Gangolells et al., 2019); (Gangolells et al, 2020a, 2020b, 2020a)	Residential and tertiary stock; Offices; Offices	~129,000; ~6,000; ~13,700	ECo, CO_2, CZ, P, BT, S, Y, RES
La Rioja, Spain	López-González et al. (2016)	Residential stock	~26,800	ECo, CO_2, Y, CZ, BT, BU, S, TBS, RES
Sweden	(Hjortling et al., 2017; Johansson et al., 2017)	Building stock	~190,000–138,000	ECo, Y, CZ, BT, BU
Gothenburg, Sweden	Österbring et al. (2016)	Building stock	n.d.	ECo, Y, BT, S, TBS
Swiss	Streicher et al. (2018)	Residential stock	~10,400	Y, BT, BE
England and Wales, UK	(Hong et al., 2014); (Armitage et al., 2015)	Schools; Offices	~7,700 ~2,600	ECo, CO_2, Y, BT, S, BE, HVAC, ECa

[a] BE = characteristics related to building envelope and its components (thermal property, materials, etc.); BT = building type/number of stories; BU = building use; CO_2 = CO_2 emission; CZ = climatic zone; ECa = energy carrier; ECo = energy consumption; P = purpose for EPC issuing; RES = renewable energy used/renewable energy sources; S: any dimensional parameters related to the building and its components (usually the heated floor area); TBS = technical building system characteristics (usually HVAC); Y = construction year/age of the building.

fects of energy policies and energy strategies on the Italian territory through the combined analysis of EPC data.

In this paper, the evolution of the CO_2 emission and the Energy Performance Indices were used to compare the energy behavior of existing, renovated, and new buildings varying the building characteristics, such as construction year and building use. The presented analyses make available a large amount of additional information to monitor the effects of the application of energy regulations. The obtained results underline the relevance of EPC information and its combined analysis to provide useful data on several aspects of the building stock. They also are a support for public authorities and decision-makers to identify areas with the major need of renovation and develop future energy policies. Furthermore, these analyses allow identifying best practices on the Italian territory, and they can also be applied and repeated in other MSs characterized by the same policy context.

2. Material and methods

2.1. Background on Italian energy regulatory framework

The evolution of the building energy performance is strictly related to the update of energy policies and laws. For this reason, the main steps of the Italian energy regulation were briefly summarized in Table 2.

As shown in Table 2, the Legislative Decree 28/2011 sets as mandatory the production from Renewable Energy Source (RES) for buildings undergoing "relevant renovation". This category includes existing buildings characterized by a useful net area greater than 1,000 m^2 and undergoing a complete renovation of the building envelope. Therefore, relevant renovations are included in 1st level major renovations, even if addressed to a different building target.

The Legislative Decree 192/2005 was further modified after issuing the Legislative Decree 48/2020, which is the transposition of the Directive 2018/844/EU. However, this last implementation did not affect the EPC template and its calculation methodology; for this reason, it was not shown in the energy regulation review.

2.2. Italian EPC methodology, relevant parameters, and digital register

The main contents of the current Italian EPC template were defined in the Decree-Law 63/2013. It established that EPCs should describe building energy characteristics to inform final users on the parameters affecting the management cost of the building and its environmental impact; EPC information should also guide final users towards more conscious energy choices. Furthermore, the current EPC calculation methodology, template, and minimum requirements were specified in the Ministerial Decree 26/06/2015 series, which harmonized and uniformed the EPC scheme at a national level. Before this regulation, the EPC scheme was set on a regional base.

To better comprehend the following results, it is necessary to provide some basic knowledge about the Italian energy certification methodology and parameters. EPC usually refers to building units or buildings composed of single units, such as hotels, office buildings, and independent houses. Hereafter the word "building" refers to these categories. The EPC is mandatory for new buildings, sales, rents, major and minor renovations, and other more specific cases, such as public buildings opened to the public. This information is shown in the purpose for EPC issuing, which is a key parameter in interpretating the results obtained from EPCs. The Italian Ministerial Decree 26/06/2015 provided important technical requirements differing from the type of refurbishment:

- new buildings, and 1st level major renovations,
- 2nd level major renovations and minor renovations.

New buildings also include those undergoing demolition-reconstruction and undergoing expansion greater than 15% of the initial gross heated volume or greater than 500 m^3. Hereafter the term "new buildings" includes all the cases just mentioned. The major renovation refers to the refurbishment of more than 25% of the surface of the building envelope and can be further divided as follows:

- 1st level: affects more than 50% of the total gross dispersant surface of the building and includes the replacement of heating and/or cooling TBS;

Table 2
Italian energy regulation review.

Italian Regulation	Implemented EU Directive	Impact on building and TBSs
Law 373/1976		First requirements for building thermal insulation. First obligations in TBS design, equipment, and management. Introduction of the global volume coefficient of thermal dispersion dependent on the climatic zone.
Law 10/1991		Promotion of rational energy use, energy savings, and FER use. Control measures on the insulation level of walls and ceilings. Mandatory technical report on compliance with the requirements.
Presidential Decree 412/1993		Introduction of the Normalized Energy Need limit based on the heated volume and the Degree Days; Introduction of the global seasonal performance of the heating system.
Legislative Decree 192/2005	2002/91/EC	Definition of the calculation methodology for building energy performance. Introduction of energy minimum requirements and energy certificates. Mandatory inspections to check the efficiency of the TBSs
Legislative Decree 311/2006 (integration of the Legislative Decree 192/2005)	2002/91/EC	Introduction of the Energy Performance index for winter heating demand (EPi). Minimum requirements of the EPi for residential and non-residential buildings depending on the climatic zone and the building form factor. The requirements become more stringent according to a road map which defined the thresholds for the following building construction periods: 2006, 2008, 2010. Verification of the thermal transmittance values of the building envelope components exposed to outdoor conditions or communicating with non-heated zones. Introduction of the Energy Qualification Certificate (AQE in Italian) reporting building primary energy needs, energy label, and corresponding maximum admissible values.
Ministerial Decree 26/06/2009	2002/91/EC	National guidelines for building energy certification.
Legislative Decree 28/2011	2009/28/EC	Mandatory cover by FER of the energy needs for new buildings (including those undergoing demolition-reconstruction) and buildings subjected to “relevant renovations”, with the following thresholds: • 2013: almost 20% FER covering; • 2017: almost 35% FER covering; • 2018: almost 50% FER covering. Mandatory clause in sale and rent transactions where the landlord or the buyer declares its knowledge about the building energy efficiency.
Law 90/2013	2010/31/EU	New definition of the EPC format (from AQE to APE, in Italian). Mandatory issuing of the EPC for rents as well as for sales.
Ministerial Decree 26/06/2015	2010/31/EU	New national guidelines for building energy certification. New EPC calculation methodology and introduction of the RB. New minimum requirements for new buildings, 1st level major renovations, and nearly Zero-Energy Building (NZEBs), with the following thresholds: • 1st phase 2015: all; • 2nd phase 2019: public buildings; 2021: all.

- 2nd level: affects more than 25%–50% of the total gross dispersant surface of the building and may include the replacement of heating/cooling TBS.

The minor renovation is a refurbishment that involves less than 25% of the building envelope surface and/or consists of a new installation or total or partial replacement of the heating system, increasing the building energy performance. The more stringent minimum requirements are set for new buildings and 1st level major renovations. However, the EPC template does not specify the level of major renovation; therefore, this category includes buildings with different technical requirement references.

The methodology to calculate the EPC outputs was set by the UNI/TS 11300 technical standard series and it always considers a standard use of the building. The global energy performance index (EP_{gl}) is the overall primary energy of the building expressed in kWh/m^{2}y and is the sum of the energy performance index of each installed energy use: heating (mandatory for all buildings), DHW (required only for residential buildings), mechanical ventilation, cooling, artificial lighting (not considered in residential buildings), people and things transportation such as elevators and escalators (not considered in residential buildings). The presence of the heating system is mandatory for both sectors, according to the Ministerial Decree 26/06/2015. Furthermore, the EPC for the residential sector can not include in the calculation the energy demand for artificial lighting and transportation, while these energy uses are taken into account in non-residential buildings if present. Therefore, the non-residential sector is composed of a great variety of building uses and is extremely variable compared to the residential one where buildings are usually equipped with similar TBSs.

The EP_{gl} can also be expressed as the sum of the contribution by non-RES ($EP_{gl,nren}$) and RES ($EP_{gl,ren}$) for all energy uses. Additional information on the general equations used to calculate the EP_{gl} can be found in (Corrado et al, 2016, 2017).

Another important outcome included in the EPC is the quality of the building envelope in limiting heating dispersion during the winter season, which is represented by the index $EP_{H,nd}$ and is expressed in kWh/m^{2}y. The $EP_{H,nd}$ is influenced by specific requirements on the envelope transmittance, which are set for minor and major renovations, and new buildings.

Finally, the EPC template also shows the theoretical CO_2 emission produced by TBSs, expressed in kg/m^{2}y and calculated by Eq. (1).

$$CO_2 = \frac{\sum_i E_i \times f_i}{S} \qquad \text{Eq. 1}$$

where E_i is the energy supplied to the building by the *i-th* energy carrier, f_i is the emission factor of the *i-th* energy carrier, and S is the net surface of the building. The emission factor of each energy carrier has been set by ENEA and CTI and can be found in (ENEA and CTI, 2015). As in other MSs, the primary energy and the CO_2 emission shown in the Italian EPC template are based on theoretical calculation. Several studies estimated the gap between actual consumption and the one shown in the EPC (Abela et al., 2016; Cozza et al., 2020; Filippidou et al., 2019; La Fleur et al., 2017; van den Brom et al., 2019). Nevertheless, the EPC is still a powerful source of building information, helpful to monitor their energy performance, the variation of their characteristics, and the application of different energy policies over time.

The EPC template also includes general information on the TBSs type and efficiency and the energy performance indices of each energy use. However, it would be possible to analyze this information in detail only when the connection between the EPC and the TBSs digital registers will be implemented.

The Italian energy certification includes ten energy labels, from A4 to A1 and then from B to G, where A4 is the more energy-efficient label and G the less one. The energy label is obtained by comparing the $EP_{gl,nren}$ value of the examined building with the one of the Reference

Building (RB). According to the Ministerial Decree 26/06/2015, the RB is equal to the real one in terms of geometry, location, orientation, building use, and boundary conditions. The energy and thermal properties of its envelope comply with the minimum requirements set by law; its TBSs are the same as the ones of the real building, but their efficiency is standard and set by law. In this way, the RB characteristics change for each building making the RB extremely variable from case to case.

EPCs are issued by Regions and Autonomous Provinces and collected in their local registers. By March 31st of each year, Regions and Autonomous Provinces should send EPCs issued the previous year to the Italian Informative System on Energy Performance Certificates (SIAPE in Italian), which is the EPC DBMS established by the Ministerial Decree 26/06/2015. SIAPE was implemented by ENEA in 2016 and is currently maintained by ENEA. Its primary purpose is to provide a detailed and updated overview of energy efficiency performance of the Italian building stock. Through the integration with other national and local databases, it will become a multifunctional and strategic planning tool able to identify areas with a greater need for building energy renovation and support the development of energy policies at national and local scales.

EPC data are transmitted from local EPC registers to SIAPE through a standard XML format. Furthermore, Regions and Autonomous Provinces should forward the results of the annual controls on their EPCs. The EPC transmission started in 2017, and the process is still ongoing; after the 2021 deadline, SIAPE contains 2,027,100 EPCs issued between 2015 and 2020 with the contribution of 10 Regions and 2 Autonomous Provinces (Fig. 1).

Before being collected into SIAPE, the EPC data go through a validation process composed of two steps. The first one is performed by the Italian Thermotechnical Committee (CTI), which tests and certifies commercial energy software used by assessors. This test ensures the compliance of the software results against different reference values according to the maximum deviation defined by law. The second control level is carried out by Regions and Autonomous Provinces on the data in their local EPC registers, as issued by the Ministerial Decree 26/06/2015 and the Presidential Decree 75/2013.

2.3. Methodological approach

In this paper, the main parameters shown in the Italian EPC template were analyzed and combined to provide an extensive assessment of the energy performance of the Italian building stock focusing on the impact of the energy regulatory framework and the energy strategies. The analysis process carried out to obtain the results is shown in Fig. 2.

First, the SIAPE data were subjected to an additional control step carried out by ENEA to verify the consistency of different parameters, such as climatic zone, dimensional data (heated volume and surface, heat dispersant surface), the purpose for EPC issuing, construction year, building use, energy performance indices, and CO_2 emission. This additional step brought the analyzed sample from 2,027,127 to 1,813,940 EPCs, excluding about 10.5% of the data.

Then, the reliability of SIAPE EPCs in representing the Italian building stock characteristics was analyzed by comparing other data from national censuses and previous Literature (Basili et al., 2020; ISTAT, 2011; Stemperini, 2021). This analysis showed the robustness of SIAPE data in describing the Italian building stock and its energy evolution. Fig. 3 shows the comparison between the number of Italian municipalities and municipalities whose data are stored into SIAPE by climatic zones (from A, the hottest, to F, the coldest). Considering the whole Italian territory, approximately 65% of the municipalities are present in SIAPE. The greatest differences are observed for climate zones A, B, C, and D; on the other hand, there is a good approximation with climatic zone E (−24%), which includes more than 50% of the Italian territory, and with climatic zone F (−15%).

By comparison with (Stemperini, 2021), the EPCs into SIAPE represent approximately 5.5% of the Italian building units and 9.2% and 6.5% of the heated area of residential e non-residential stocks, respectively (Table 3); the distribution between residential and non-residential stock almost corresponds to the national one. The residential stock certified into SIAPE was also compared to the residential stock by construction period (ISTAT, 2011). The percentage distribution, shown in Fig. 4, highlights similar trends except for the stock built in 1971–1980, which is less represented in SIAPE than in the census distribution.

The SIAPE sample was also compared with the EPC data stated by Italian Regions and Autonomous Provinces in 2019 (Basili et al., 2020).

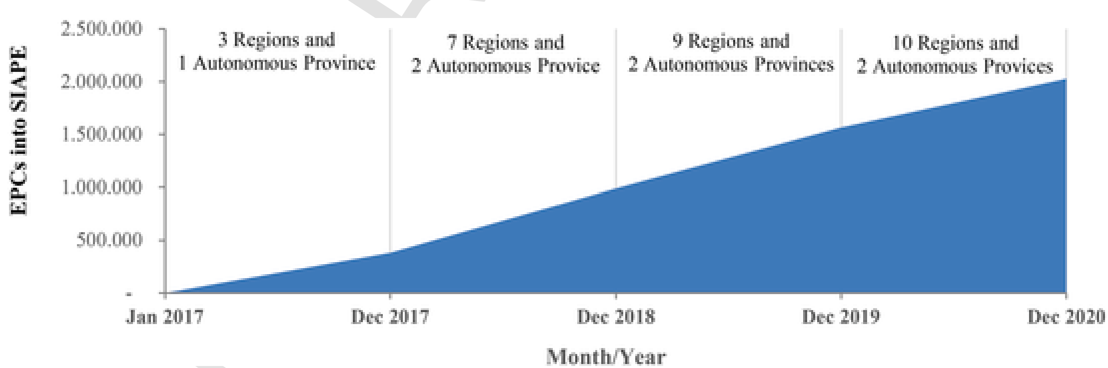

Fig. 1. Increase of EPC number stored into SIAPE from January 2017 to December 2020.

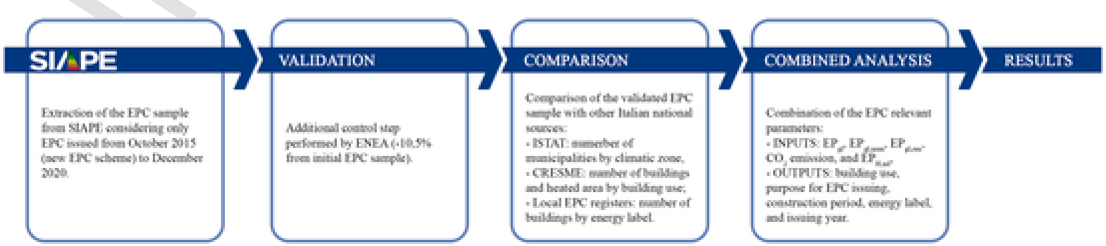

Fig. 2. Flowchart of the analysis process.

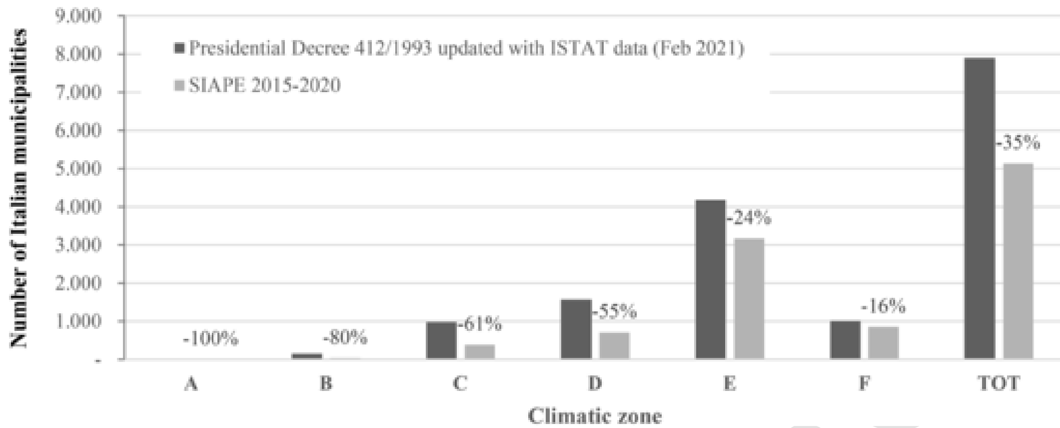

Fig. 3. Comparison between Italian municipalities and municipalities with data stored into SIAPE by climatic zone. The distribution of the Italian municipalities by climatic zone is set by the Presidential Decree 412/1993 updated by ENEA with ISTAT data (ISTAT, 2021) in 2020.

Table 3
Comparison between the Italian building stock (Stemperini, 2021) and the SIAPE EPCs (ENEA, 2020).

	Italian Building stock			SIAPE	
Building Use	Buildings	Building Units	Heated area [$m^2 \cdot 10^6$]	N. EPCs	Heated area [$m^2 \cdot 10^6$]
Residential	12,420,403	31,996,915	3,049.8	1,731,129	280.9
Non-residential	877,623	5,387,994	2,021.0	295,998	130.5
Residential (%)	93.4%	85.6%	–	85.4%	–
Non-residential (%)	6.6%	14.4%	–	14.6%	–

Based on this information, approximately 4,500,000 EPCs were issued from 2016 to 2019, and the energy label distribution was provided by Italian Regions and Autonomous Provinces on a sample composed of about 3,800,000 EPCs. This sample was compared with SIAPE (Fig. 5), showing approximately the same distribution. Almost 60% of the EPCs fall in the less efficient energy labels (F and G), while labels E, D, and C cover approximatively 16%, 11%, and 5% respectively; the more efficient buildings represent less than 10%.

Thanks to the previous analyses, SIAPE EPCs were considered representative of the Italian building stock and the certified one.

The Italian EPC calculation methodology (Section 2.2) makes the RB extremely variable, and, consequently, the energy label alone can not provide a comprehensive energy performance evaluation. Furthermore, the EPC calculation methodology and, consequently, the energy label can differ among EU MSs, making it necessary to provide more parameters to better evaluate the Italian building stock also by other Countries. For these reasons, the outcomes of this paper are mainly expressed through the EPC indices illustrated in Section 2.2 and were then disaggregated with further EPC information: building use (residential and non-residential), the purpose for EPC issuing (sale, rent, new construction, major and minor renovation, and other), construction period, energy label, and issuing year. Furthermore, the evaluation of the $EP_{gl,nren}$ and the CO_2 emission were provided with general information on the percentage of installed TBS. More in detail, these combined analyses allowed evaluating:

- the impact of the application of energy performance strategies (Section 3.2), through the analyses of the purpose for EPC issuing in residential and non-residential buildings. The mean values and the percentiles of the $EP_{gl,nren}$ and the CO_2 emission were calculated for each issuing purpose to estimate the difference between existing old buildings and new and renovated ones. These analyses were also provided with information on the percentage of the most installed TBSs for existing, new, and renovated buildings. The quality of the building envelope in limiting heating dispersion during the winter season was evaluated by the mean values of $EP_{H,nd}$. Furthermore, these values were also calculated for the RB in new buildings, major and minor renovations and compared with the ones of the real building to analyze if it meets the building envelope requirements and quantify its room for improvement;

Fig. 4. Comparison between the Italian residential building units (ISTAT, 2011) and the residential building units certified into SIAPE EPCs (ENEA, 2020) by construction period (limited to 2011).

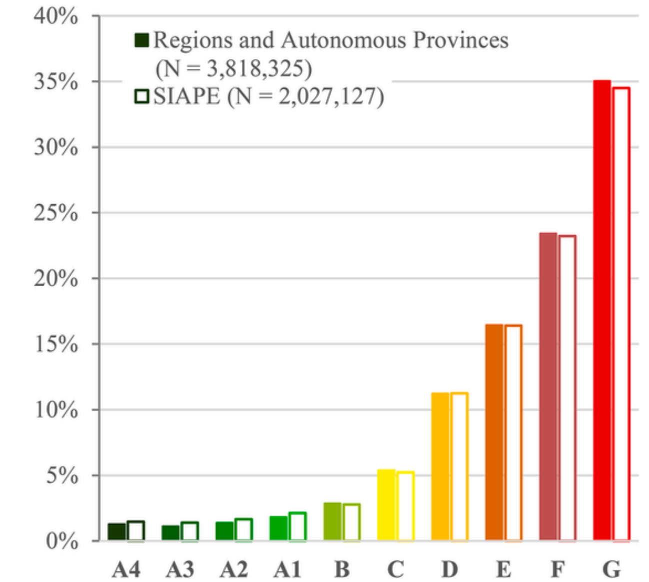

Fig. 5. Percentage distribution of EPCs stored into SIAPE (ENEA, 2020) and EPCs issued in Italy in 2016–2020 (Basili et al., 2020) by the energy label.

- the impact of the energy efficiency regulation, analyzing the evolution of the energy performance indices and the CO_2 emission for residential and non-residential buildings by construction period. The construction period was set according to the Italian energy regulatory framework (Table 2): before 1945, 1945–1976, 1977–1991, 1992–2005, 2006–2015, 2016–2020. These analyses were also provided with information on the percentage of the most installed TBSs by construction period. Then each construction period was investigated through the mean values of the $EP_{H,nd}$ to evaluate the evolution of the performance of the building envelope in winter over time. Finally, the RES use requirements were evaluated by quantifying the $EP_{gl,ren}$ mean values against the $EP_{gl,nren}$ values by construction year for existing non-renovated and new buildings. In this case, the construction year 2011 was used as a threshold to investigate the evolution before and after implementing of the Legislative Decree 28/2011. The RES use was also estimated for major and minor renovation by issuing year, which represents in this case the year when the building was renovated.

The building use was grouped into two categories: residential and non-residential. According to the Presidential Decree 412/1993, the latter includes all the building uses other than houses, apartments, and comparable categories. Consequently, the non-residential sector is composed of a great variety of buildings in terms of equipment, geometry, size, and, consequently, RB; on the other hand, residential buildings are more homogeneous into the sector. The assessment of non-residential buildings by EPC data needs more detailed analyses, which will be the subject of future works.

3. Results and discussion

3.1. Overview on the energy performance of the Italian building stock

This section provides an insight into the evolution of the Italian building energy performance for the residential and non-residential sectors. The results refer to the overall primary energy covered by non-RES ($EP_{gl,nren}$) and the related CO_2 emission, as defined in Section 2.1, by EPC issuing year and energy label. The results of this Section provide information noticeable in the outcomes of Section 3.2 and Section 3.3 and useful for their correct interpretation. These considerations are a consequence of the EPC calculation methodology introduced in Section 2.2 and Section 2.3.

Table 4 and Table 5 show the $EP_{gl,nren}$ and CO_2 emission trends respectively, highlighting the relative difference among different EPC issuing years (from 2015 to 2020).

The results show a significant overall decrease from 2015 to 2020 for both sectors probably due to the following:

- The increase of the percentage of new and renovated buildings being certified by EPC,
- The increase of the percentage of recent buildings being sold and rent over time.

In general, it is possible to notice a discrepancy between the relative difference 2015–2016 and 2016–2017 probably due to the lack of data contained into SIAPE in the first year after its implementation (Fig. 1). After that period, the annual relative difference tends toward a stabilization. For this reason, in the following Sections, the analyses by issuing year take only the period 2017–2020 into account.

Fig. 6 shows the primary energy covered by non-RES and the CO_2 emission of residential and non-residential buildings by energy label expressed as mean values and percentiles.

Some of the considerations resulting from the previous analysis are noticeable also in the outcomes of the following Sections:

1. The $EP_{gl,nren}$ and the CO_2 emission are characterized by similar distributions as a result of the theoretical calculations implemented in the Italian EPC methodology,
2. As the non-residential stock is usually characterized by higher number of energy uses and installed TBSs, the mean values of the energy performance indices and CO_2 emission are always higher than the ones of the residential stock.

The residential sector is characterized by upward trends of the $EP_{gl,nren}$ and CO_2 emission mean values, increasing as the energy label is less efficient. The same trend is shown by the median values, which get

Table 4
Energy performance of residential and non-residential buildings (ENEA, 2020): $EP_{gl,nren}$ mean values by issuing year of the EPC – (N = 1,813,940).

Issuing year	Residential			Non-residential		
	N. EPCs	$EP_{gl,nren}$ [kWh/m^{2}y]	*Annual relative difference*	N. EPCs	$EP_{gl,nren}$ [kWh/m^{2}y]	*Annual relative difference*
2015	21,223	254.2		6,169	535.2	
2016	144,199	247.6	−2.6%	36,560	430.0	*−19.7%*
2017	238,899	225.6	−8.9%	48,610	393.7	*−8.4%*
2018	377,164	211.6	−6.2%	65,457	360.3	*−8.5%*
2019	412,972	205.7	−2.8%	69,719	332.1	*−7.8%*
2020	340,381	202.5	−1.6%	52,587	322.3	*−3.0%*

Table 5
Energy performance of residential and non-residential buildings (ENEA, 2020): CO_2 emission mean values by issuing year of the EPC – (N = 1,813,940).

Issuing year	Residential			Non-residential		
	N. EPCs	CO_2 emission [kg/m^{2}y]	*Annual relative difference*	N. EPCs	CO_2 emission [kg/m^{2}y]	*Annual relative difference*
2015	21,223	49.6		6,169	112.7	
2016	144,199	55.7	*12.3%*	36,560	89.0	*−21.0%*
2017	238,899	45.5	*−18.3%*	48,610	82.5	*−7.4%*
2018	377,164	42.6	*−6.5%*	65,457	75.7	*−8.2%*
2019	412,972	41.3	*−3.0%*	69,719	70.6	*−6.8%*
2020	340,381	41.2	*−0.4%*	52,587	68.7	*−2.6%*

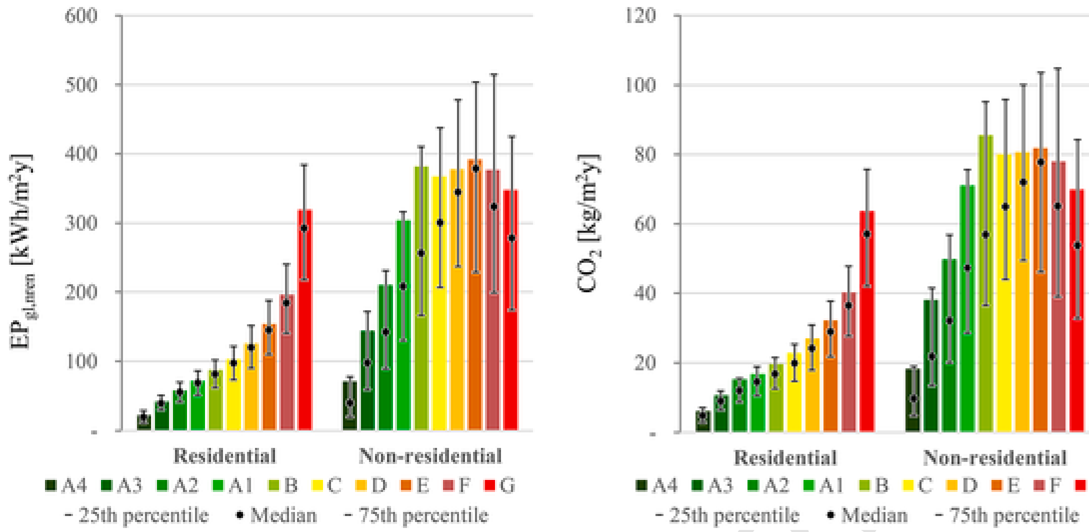

Fig. 6. Energy performance of residential and non-residential buildings (ENEA, 2020): mean values and percentiles of the $EP_{gl,nren}$ and the CO_2 emission by energy label – (N = 1,813,940).

closer to the mean ones as the energy label is more efficient, underlining a homogeneous and uniform distribution of the RB within each energy label. The G label presents the larger deviation between mean and median values; this fact is caused by the criteria set by law to assign the G label, where an upper limit value is not defined in order to include every building whose energy performance is worse than the F label. As expected, the non-residential sector shows a less regular trend of the mean values with two anomalous peaks (corresponding to B and E labels) and a sudden decrease after the E label. The median distribution is more linear, but also presents a pronounced drop after the E label.

The analysis of the TBSs also indicates a variation in the building equipment of both sectors. Heat pumps and condensing boilers are mainly installed in buildings rated from A4 to A1. In contrast, the percentage of standard boilers increases with the worsening of the energy label. About 10% of the DHW is produced by electrical boilers in residential buildings from E to G energy labels in residential buildings. In comparison, this kind of TBS is generally installed in 5–10% of the non-residential sector regardless of the energy label. In both sectors, the production from RES (mainly photovoltaic and solar thermal systems) increases with the efficiency of the building. The energy performance of non-residential buildings is also influenced by lighting and transportation systems; buildings rated from A4 to B mostly present a LED lighting system, while those rated from C to G are incandescent and fluorescent lamps. In general, the primary energy and the CO_2 emissions grow with the number of energy uses and related TBSs in the building. However, higher energy consumption does not necessarily correspond to lower energy labels because the Italian EPC calculation methodology is based on different RBs (Section 2.2). Therefore, the energy label of a non-residential building equipped with several but efficient TBSs could be better than the one of a non-residential building equipped with fewer TBSs characterized by low energy performance. Moreover, the wide range of data dispersion between 75th and 25th percentile values also suggests several energy and building uses in the same energy label.

3.2. Impact of the application of energy efficiency strategies

The evaluation performed on the Italian EPCs shows that the two most recurring purposes for EPC issuing are sales and rents, which cover almost 85% of the analyzed sample; minor and major renovations, and new buildings represent less than 10%. The trend of the purpose for EPC issuing is shown in Fig. 7.

The purpose for EPC issuing is also an effective parameter to monitor the application of energy efficiency measures (Fig. 8).

The considerations 1 and 2 listed in Section 3.1 are applicable also to the results shown in Fig. 8. The variation of the $EP_{gl,nren}$ and the CO_2 emission in the non-residential sector is strongly highlighted in the differences between 25th and 75th percentiles. Sales and rents show the highest mean and median values of the $EP_{gl,nren}$ and CO_2 emission since these transactions usually do not take any efficiency action into account. In fact, the buildings falling in these two categories are mostly equipped with standard and electrical boilers for heating and DHW production, respectively, and incandescent and fluorescent lamps (only in non-residential buildings). At the same time, heat pumps are installed only for cooling, and RES production is almost absent. On the contrary,

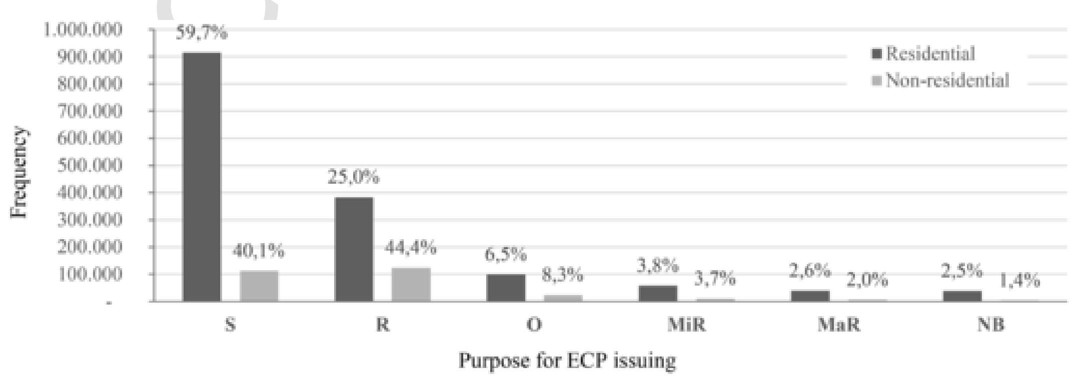

Fig. 7. Number of Italian EPCs by purpose for EPC issuing (ENEA, 2020) (S = sales; R = rents; O = others; MiR = minor renovations; MaR = major renovations; NB = new buildings) – (N = 1,813,940).

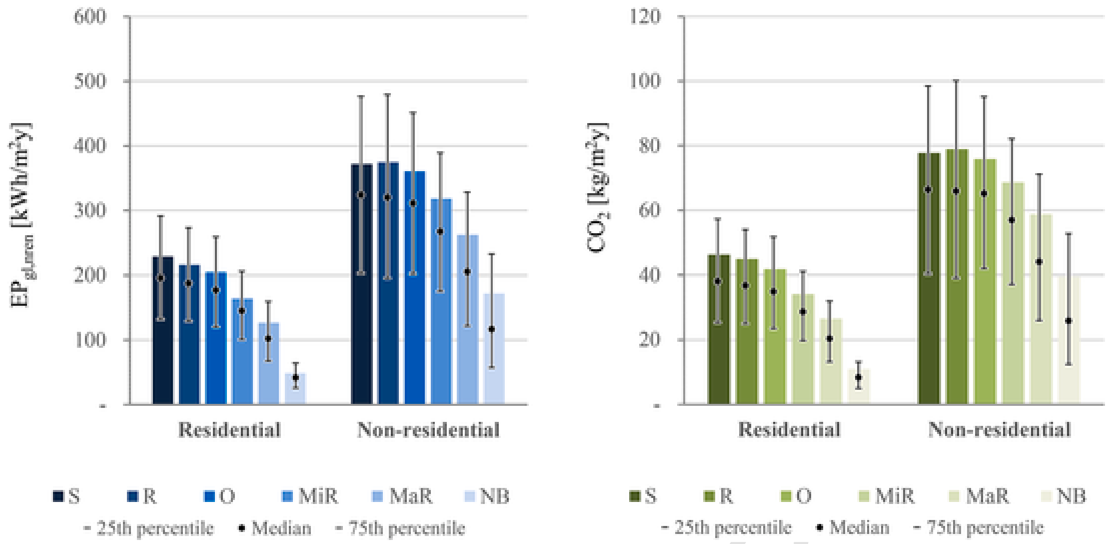

Fig. 8. Influence of energy efficiency strategies on residential and non-residential buildings (ENEA, 2020): mean values and percentiles of the $EP_{gl,nren}$ (left) and the CO_2 emission (right) distributions by purpose for EPC issuing (S = sales; R = rents; O = others; MiR = minor renovations; MaR = major renovations; NB = new buildings) – (N = 1,813,940).

minor and major renovations, and new buildings are characterized by greater decreases of the primary energy covered by non-RES and the CO_2 emission. New buildings show the lowest values in residential and non-residential sectors thanks to the stringent requirements for the building envelope and the installed TBSs (mostly condensing boilers and heat pumps) and the production by RES. Buildings undergoing minor and major renovations show an increase in the energy performance compared to sales and rents; however, this improvement should be expected to be higher for major renovations since they include 1st level major renovations (Section 2.2). The difference in the energy performance between major renovations and new buildings may suggest that the first include several 2nd level major renovations, which are characterized by less ambitious requirements. This assumption may also be confirmed by the analysis of the distribution by energy label of minor and major renovations (Table 6), where the results show higher effectiveness of the major renovations in improving the energy label (about 30% from A4 to A3 against 10% of minor renovations). Still, more than 25% of the buildings in this category fall in the worst rating (E-G). Furthermore, the TBS analysis highlights a decrease from minor to major renovations of standard boilers in favor of condensing boilers (residential sector) and heat pumps (non-residential sector) and an increase of RES production systems. However, these improvements are considered small compared to the ones between major renovations and new buildings.

The purpose for EPC issuing was further investigated analyzing the thermal performance of the building envelope during winter ($EP_{H,nd}$) for each category (Fig. 9a). Furthermore, the mean values of the $EP_{H,nd}$ were compared with the ones of the RB to control if the requirements of the building envelope performance are met for new buildings, major and minor renovations (Fig. 9b).

Sales, rents, and the category "other purposes for EPC issuing" show the higher values of the $EP_{H,nd}$ since there are no mandatory requirements for these categories. However, the slightly improvement between sales and rents may suggest that the buildings included in the second category are more often renovated before being rented. Only residential new buildings meet the requirements for the quality of the building envelope in winter showing approximately the same mean value of the RB (NB_{RB}). Instead, in both sectors, major and minor renovations are still very far from reaching the corresponding values of the RB (MaR_{RB} and MiR_{RB}).

3.3. Impact of energy efficiency regulations

The EPC distribution by construction period (Section 3.1) for residential and non-residential stocks is shown in Fig. 10. As shown in Fig. 4, according to (ISTAT, 2011), approximately 60% of the residential building stock was built before 1976 and three years before the first Italian energy regulation (Table 2). This information is confirmed also for the non-residential sector where almost 60% of the EPC refers to buildings built before 1976. Thus, an elder building stock is one of the reasons for the low energy performance of the Italian buildings.

Most of the EPC sample refers to buildings built between 1945 and 1976 for the intensive postwar reconstruction. After that period, it is noticeable a higher increase in the non-residential sector between 1977 and 2005 compared to the residential one; this is due to the growing construction of new buildings for industrial and sporting activities (Basili et al., 2020). From 2006 to 2020 the distribution between the two sectors is almost equal.

The application of different energy regulations in the past years and their effect on building energy performance can be evaluated by analyzing the $EP_{gl,nren}$ and the CO_2 emission trends by the selected construction periods (Fig. 11).

The considerations 1 and 2 listed in Section 3.1 are applicable also to the results shown in Fig. 11. In general, the higher the building age, the higher its primary energy and CO_2 emission in both sectors. More in detail, it is possible to quantify how the application of every energy reg-

Table 6
Percentage of EPC issued for minor and major renovations by energy label (ENEA, 2020) – (N = 113,640).

Purpose for EPC issuing	Energy Label									
	A4	A3	A2	A1	B	C	D	E	F	G
Minor renovation	1.0%	1.6%	2.9%	4.6%	7.3%	11.4%	18.9%	19.8%	18.0%	14.5%
Major renovation	5.4%	5.5%	9.4%	12.1%	12.2%	13.4%	15.0%	11.6%	8.8%	6.5%

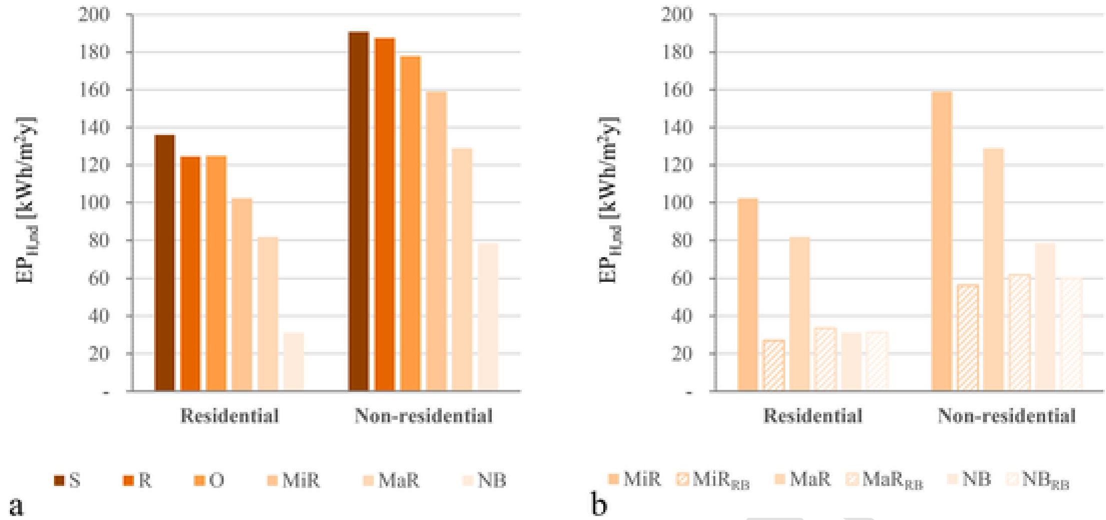

Fig. 9. Mean building envelope performance during the winter season ($EP_{H,nd}$) by purpose for EPC issuing (a) and comparison with the ones of the RB for new buildings, major and minor renovations (b) (ENEA, 2020) (S = sales; R = rents; O = others; MiR = minor renovations; MaR = major renovations; NB = new buildings; MiR_{RB} = RB values related to minor renovation requirements; MaR_{RB} = RB values related to major renovation requirements; NB_{RB} = RB values related to new buildings requirements) – (N = 1,813,940).

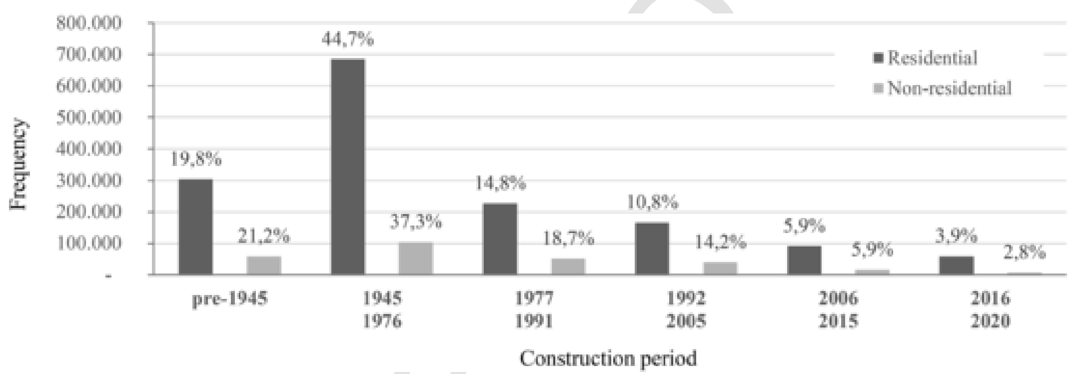

Fig. 10. Number of EPCs by construction period (ENEA, 2020) – (N = 1,813,940).

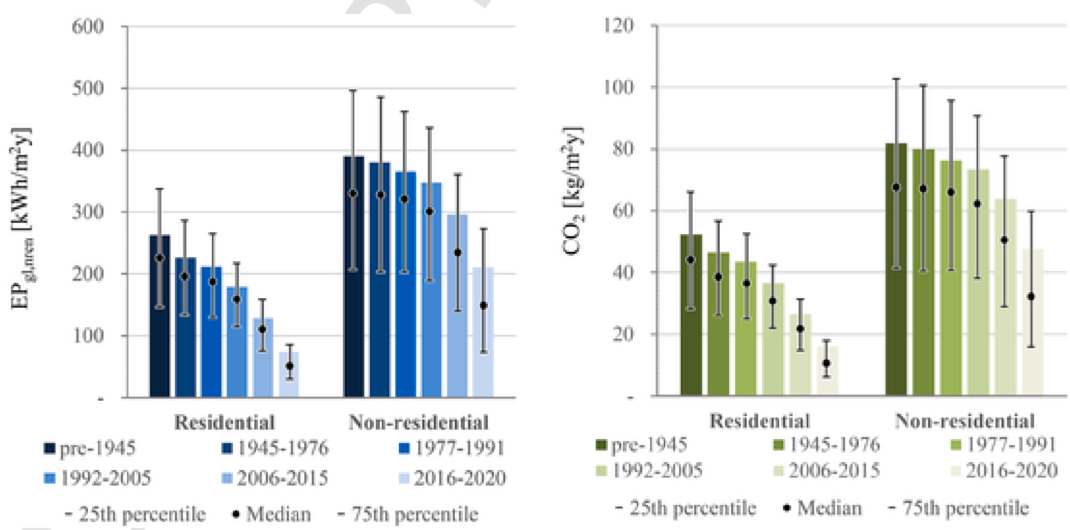

Fig. 11. Energy regulation influence on residential and non-residential buildings (ENEA, 2020)): mean values and percentiles of the $EP_{gl,nren}$ (left) and the CO_2 emission (right) distributions by construction period – (N = 1,813,940).

ulation affected the building energy performance. Buildings built before 1973 show approximately the same mean values and distances between 25th and 75th percentiles of the F and G energy labels (Fig. 6). However, it is possible to notice a decrease before and after 1945, probably due to the technology development in the building sector and the first use of wall gaps. This phenomenon is particularly evident in the residential sector, which was more affected by the postwar reconstruction. In fact, at a national level, houses and buildings built in that period were characterized by the first use of concrete pillars and, consequently, of infill walls (made of bricks or hollow bricks) combined with insulation (Marzo Magno and Iori, 2012). It is also possible to notice a small percentage of buildings equipped with wood stoves, which almost disappears after 1945. Instead, the use of standard boilers increases until 2005, and there is a sudden increase of condensing boilers only after that construction period. The improvement of the building energy performance shows a good change after 2005 when the Legislative Decree 192/2005 entered in force. The variation of the $EP_{gl,nren}$ and CO_2 emission mean values before and after 2005 is more than 25% for the residential sector and approximately 15% for the non-residential one. This improvement due to the new regulation requirements is also underlined by the variation in the range between 25th and 75th percentiles before and after 2005. Finally, the implementation of the EPBD recast, the Ministerial Decree 26/06/2015, introduced more stringent requirements for new and restored buildings leading to a higher increase in buildings energy performance. The percentage difference before and after 2015 is approximately 40% for residential buildings and from 30% ($EP_{gl,nren}$) to 20% (CO_2) for non-residential ones.

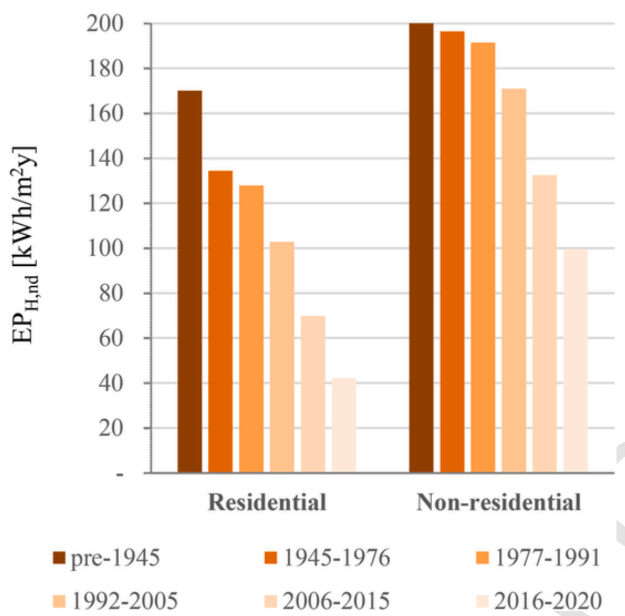

Fig. 12. Mean building envelope performance during the winter season ($EP_{H,nd}$) by construction period for sales, rents and new buildings – (N = 1,577,313).

The effects of specific regulatory requirements on the building envelope can be evaluated through the analysis of the $EP_{H,nd}$. The thermal performance of the building envelope during the winter season is shown in Fig. 12 for the residential and non-residential sectors and by the construction period. Minor and major renovations and the category "other purposes for EPC issuing" were excluded from the following analysis to consider the building envelope performance improvement due only to energy regulation requirements for new construction depending on the building age.

The distribution of the $EP_{H,nd}$ in the residential sector before and after 1945 shows the same improvement underlined in Fig. 11 because of the first use of new building materials and techniques. However, only a little variation in both sectors from 1945 until 1992, where the first effects of the introduction of the Normalized Energy Need limit are noticeable. This parameter was issued by the implementation of the Law 10/1991, the Presidential Decree 412/1993 (Table 2). The envelope contribution in reducing the heating energy demand significantly increases over time, especially in the residential sector where the mean values of the $EP_{H,nd}$ is less than 50 kWh/m^{2}year for new buildings.

The Italian EPC data allow also monitoring the evolution of RES use combined with the application of the Italian Legislative Decree 28/2011, which transposed the Directive 2009/28/CE. The comparison between the $EP_{gl,rn}$ and the $EP_{gl,ren}$ for buildings referred to the "new buildings" category and built before and after 2011 is shown in Fig. 13.

The evolution of RES use in residential new buildings follows an upward trend where the RES coverage thresholds set by the Legislative Decree 28/2011 (2013–25%, 2017–35%, 2018–50%) are almost reached. The same trend is not observed in non-residential buildings where RES use is more limited and decreases between 2019 and 2020. However, as specified in Section 2.1, the different energy use requirements for residential and non-residential sectors in the EPC calculation do not allow a direct comparison of RES contribution. The non-residential sector needs to be analyzed in-depth taking each building and energy uses into account. This further analysis would be the subject of future works.

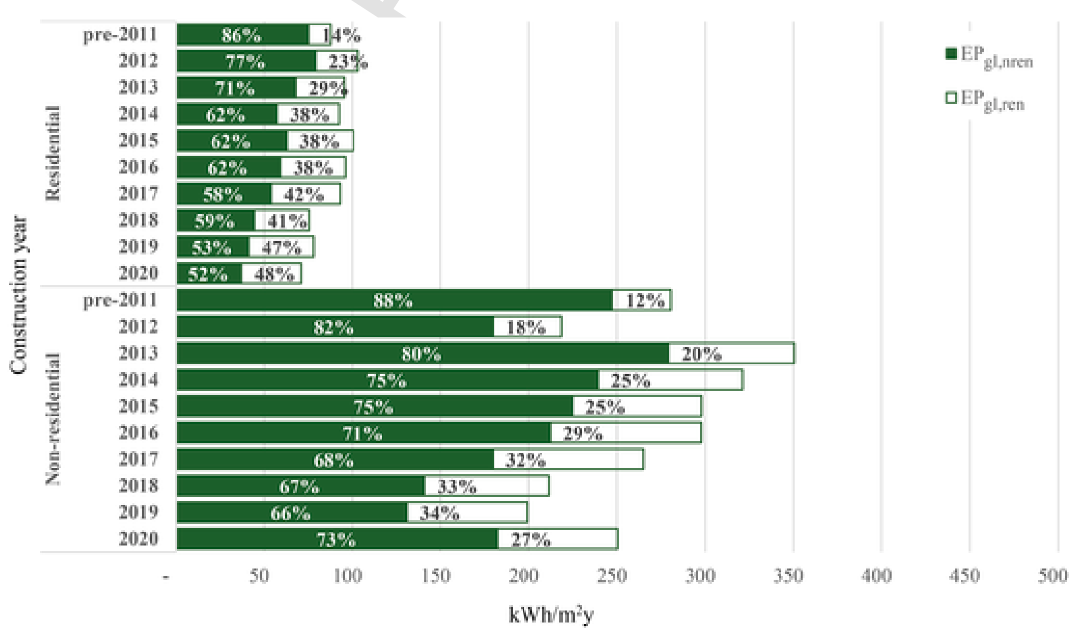

Fig. 13. Comparison between the $EP_{gl,nren}$ and the $EP_{gl,ren}$ for residential and non-residential buildings referred to the "new buildings" category and built before and after 2011 (ENEA, 2020) – (N = 42,001).

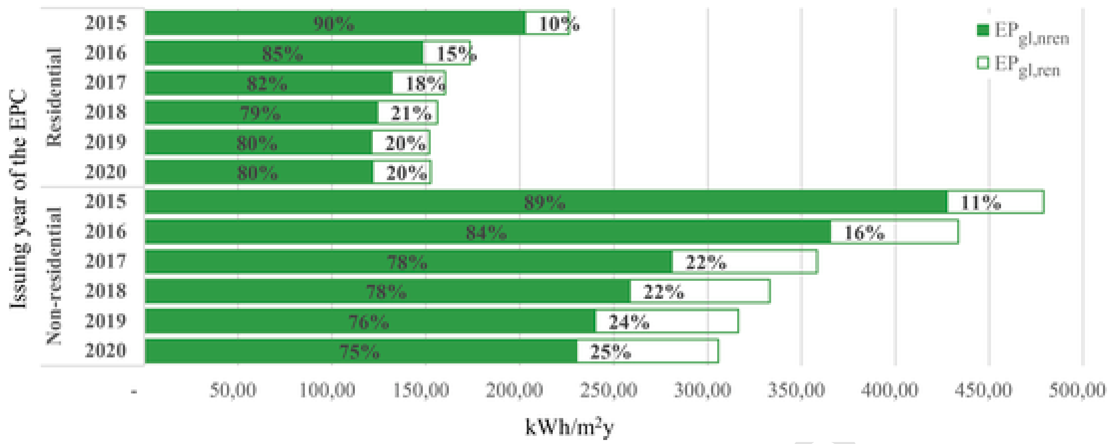

Fig. 14. Comparison between $EP_{gl,nren}$ and $EP_{gl,ren}$ for residential and non-residential buildings undergoing major renovation from 2015 to 2020 (ENEA, 2020) – (N = 44,935).

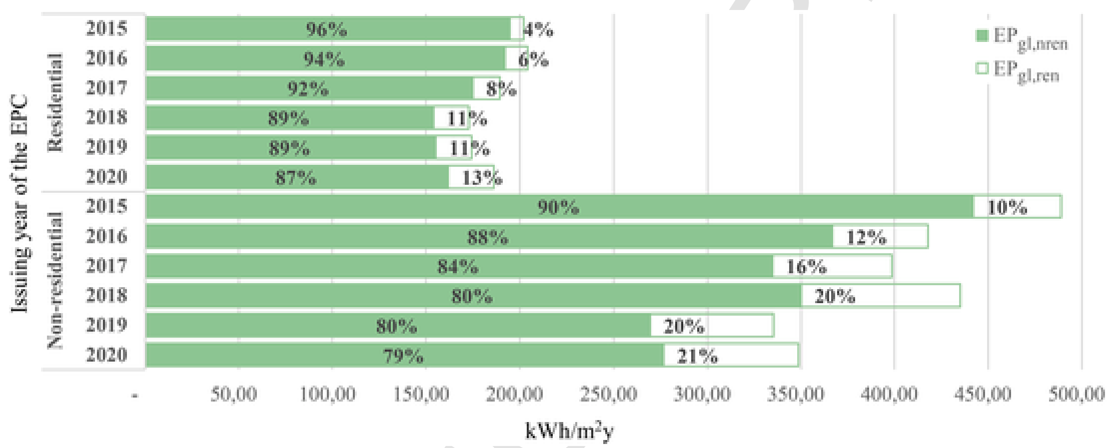

Fig. 15. Comparison between $EP_{gl,nren}$ and $EP_{gl,ren}$ for residential and non-residential buildings undergoing minor renovation from 2015 to 2020 (ENEA, 2020) – (N = 68,705).

The previous investigation was carried out for minor and major renovations considering the issuing year of the EPC in place of the construction year. Consequently, the results referred to a shorter period (2015–2020). The comparison between the EP_{gl} for renewable and non-renewable energies for major and minor renovations is shown in Fig. 14 and Fig. 15 respectively.

According to the $EP_{gl,nren}$ results by the purpose for EPC issuing (Fig. 8), the contribution of the minor renovation to energy efficiency is lower than the one of major renovations, since the first ones are not subjected to the requirements of the Legislative Decree 28/2011. However, even if major renovations affect the global energy demand more, the distribution between the $EP_{gl,nren}$ and the $EP_{gl,ren}$ underlines a lower RES use. As mentioned in Section 2.1, the distinction between 1st and 2nd major renovation levels is not specified in the Italian EPC template. For this reason, it is not possible to accurately evaluate whether the requirements set by the Legislative Decree 28/2011 are reached. However, it is possible to notice that the percentage of RES use does not increase after 2018, especially in the non-residential sector.

4. Conclusions and policy implications

This study investigated the energy performance of Italian residential and non-residential buildings by analyzing about 2,000,000 of EPCs collected in the EPC DBMS (SIAPE) and issued from 2015 to 2020. The obtained results highlight how SIAPE and EU EPC registers are key instruments to implement and monitor energy policies and support policymakers and actors involved in energy efficiency topics. The paper shows how EPC combined analyses allow obtaining several outcomes and information to increase the awareness on the building environmental impact. The main energy and emission indicators calculated according to the national EPC scheme were analyzed in detail, allowing quantitative and qualitative updated assessments of the Italian building stock.

Over a half of Italian buildings are characterized by very low energy performance, corresponding to energy labels F and G. These performances are due mostly to the age of the building stock (more than 60% built before the first energy regulation) and to the small number of new and renovated buildings (less than 10%). The results show a wide difference in the variation of the RB depending on the building use. The residential sector is characterized by an increase of the primary energy as the energy label is less efficient; this is evidence of the uniformity of the RB in all the residential stock. Instead, the non-residential sector shows trends without a regular correspondence between the primary energy and energy label because of the great variety of building and energy uses in the sector. The main EPC indices and the CO_2 emission were also analyzed by the purpose for EPC issuing; this parameter has been considered as a key factor in the interpretation and monitoring of the energy performance of the Italian building stock. New buildings are characterized by the highest performance in terms of $EP_{gl,nren}$ and CO_2 emission mean values corresponding to the energy labels from A4 to B. All the results by the purpose of EPC issuing show a sudden decrease between new buildings and major renovations even if the requirements by new and 1st level renovation (included in the major renovation category) should be the same. However, renovated buildings can not be further analyzed because of the slight information on the EPC template and the fact that SIAPE contains EPC referred to a short period (from the end of 2015 to the beginning of 2021). The authors would conduct this analysis when SIAPE includes EPCs of the same building before and after renovation. The application of new energy regulation was evaluated through the evolution of the main EPC indices and CO_2 emission by construction period showing the higher impact before the implementation of Directives 2002/91/EC (Legislative Decree 192/2005) and 2010/31/EU (Ministerial Decree 26/06/2015). Finally, the RES use requirements were analyzed showing that only the residential sector almost reaches the goals set by the Legislative Decree 28/2011 for new buildings.

The combined analysis presented in this paper is a useful tool to support for policymakers during the decision process for the building stock renovation. Even if the Italian EPC template does not include the actual building consumption, it still provides several data to monitor the evolution of the energy policies and the improving of the building energy performances and the TBS technologies. Furthermore, the integration of these results with the information collected in other national and local registers (e.g., national tax deductions registers, TBS regional registers, etc.) would allow further detailed investigations in the fields of energy and sustainability policies, such as the costs of avoided CO_2 emission (e.g., in terms of cost-effectiveness of national policies or market penetration of innovative technologies). At a local level, policymakers can apply the proposed analyses, for instance, to implement sustainable development plans, such as Covenant of Mayor's SECAPs or 2030 Metropolitan Agendas for Sustainable Development. This synergy among several registers could be realized through different tools, such as Geographical Informative Systems (GISs), which would permit the identification of vulnerable areas to address dedicated sustainable policies.

SIAPE and EPC DBMSs are important tools to monitor national building energy performance and compliance with the energy regulatory framework. The analyses proposed in this study can be easily repeated in other MSs, helping harmonize the results on the implementation of EU energy policies. Along this way, it would be possible to provide several data on MSs' building stock to support the European Commission implementing building renovation strategies and developing the European Building Stock Observatory (European Commission, 2016).

CRediT authorship contribution statement

Francesca Pagliaro: Conceptualization, Methodology, Writing – review & editing, Validation, Formal analysis, Writing – original draft, Supervision. **Francesca Hugony:** Conceptualization, Methodology, Writing – review & editing, Formal analysis, Writing – original draft. **Fabio Zanghirella:** Conceptualization, Methodology, Writing – review & editing, Formal analysis. **Rossano Basili:** Conceptualization, Methodology, . **Monica Misceo:** Conceptualization, Methodology, Writing – review & editing. **Luca Colasuonno:** Conceptualization, Methodology, . **Vincenzo Del Fatto:** Software, Writing – review & editing, Validation, Formal analysis, Data curation.

Declaration of competing interest

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

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