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Assessing energy efficiency at urban scale through the use of energy performance certificates: An application in the Emilia-Romagna region, Italy

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ABSTRACT

Energy retrofitting of residential buildings is considered a challenge to be tackled not only at building level, but also at urban scale, to give a stronger impulse for a concrete transition towards climate neutrality. This paper presents an easy-to-use analysis method based on the elaboration and scaling-up of data collected through the energy performance certificates (EPCs) to identify different urban energy zones distinguished by their energy performance index. This method is therefore conceived for better informing urban planning decisions, thus boosting more effective energy-sensitive urban planning strategies and eventually to foresee dedicated financial instruments to act in the more energy demanding areas of the city, establishing priorities for integrated strategies. This analytical method has been applied and tested in one municipality in the Emilia-Romagna region, Italy, where the recent urban planning law is pushing municipalities towards the development of urban planning strategies oriented to drastically improve the energy efficiency of the existing building stock. Results show that only a small number of areas manage to reach a good performance with fairly low levels of energy performance index, with the most critical situation found in the most central areas of the capital and in the hamlets.

1. Introduction

In Europe, the role of energy efficiency in the building sector for achieving a sustainable growth has become more and more relevant in the recent years. The need to reduce land take and soil sealing (European Commission, 2012), has led to a number of policies trying to limit the city expansion in the countryside, enforcing instead the renovation of the existing building stock. However, renovating the building stock is a big challenge. According with the EU Building Stock Observatory, in most European countries half of the residential stock was built before 1970 underlying obsolescence of technological systems and facilities as well as low performances in terms of energy efficiency (European Commission, 2022). Buildings in the EU are the largest energy consumer in Europe with 42 % of consumption, followed by transport (31 %) (European Court of Auditors (ECA), 2020), and are responsible for 36 % of greenhouse gas emissions (ENEA, 2020). Specifically, residential buildings are responsible for 27 % of energy consumption in the European Union (Eurostat, 2023), and cover a major part of the existing building stock with a percentage of about 75 % in terms of floor area (Buildings Performance Institute Europe, 2011).

Energy consumption by households has always seen an overall rising trend, only in the last decade it has started to slightly decrease (Tsemekidi Tzeiranaki et al., 2020), demonstrating the positive effects of the numerous targeted policies put in place in this sector in recent years, such as: the Energy Performance of Buildings Directive 2002/91/EC (EPBD) and its recast in 2010 (EPBD, 2010/31/EU) further updated with the 2018/844/EU directive, introducing more and more stringent energy efficiency measures and requirements in connection to major renovations (Pagliaro et al., 2021); the 2012 Energy Efficiency Directive (EED, 2012/27/EU) requiring that Member States establish long term

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strategies for the renovation of their national building stocks. The directive stressed the need to provide an overview of the national building stock based, as appropriate, on statistical sampling. More recently the EED has been updated and strengthened through the amended EED (EED II, 2018/2002). The 'Covenant of Mayors' initiative goes in the same direction by encouraging European cities to combat climate change by developing Sustainable Energy Action Plans (SEAPs) at local level which are a basis for future implementation of specific projects on energy efficiency and use of renewable energy sources. The more recent Green Deal of 2019 proposes the Renovation Wave initiative and the consequent European Climate Law of 2021, aimed at increasing the rate and quality of renovation of existing buildings and thereby helping decarbonise the building stock. By setting the target of reducing GHG emissions by at least 55 % by 2030 compared to 1990, and achieving climate neutrality by 2050, the Member States should double the annual energy renovation rate of residential and non-residential buildings by 2030 and maintains this trend till 2050. Moreover, the Land use and forestry regulation for 2021–2030, adopted in May 2018, asks EU Member States to ensure that accounted greenhouse gas emissions from land use, land use change or forestry are balanced by at least an equivalent accounted removal of CO_2 from the atmosphere in the period 2021 to 2030 (European Commission, 2020), thus accounting the contribution of land use change in GHG production and removal. Finally, as part of the European Green Deal, the Commission proposed on 4 March 2020 the first European Climate Law (Regulation (EU) 2021/1119), to enshrine the 2050 climate-neutrality target into law, thus implying a strong commitment for drastically reducing CO_2 emissions in all sectors.

This scenario imposes a big challenge to Member States in order to boost energy efficiency and renovation policies. The annual deep renovation rate of the building sector stands at only 0.2 % on average in the EU (European Commission, Directorate-General for Energy, 2019). Estimations from BPIE show that if the EU wants to achieve both the 2030 climate target and climate neutrality by 2050, this figure must drastically increase to reach 3 % by 2030 and be maintained up to 2050 (Buildings Performance Institute Europe, 2021).

The introduction of a vast range of incentive-based policy instruments has been accompanying these regulatory initiatives, with the aim of pushing towards a stronger reduction of energy consumption and CO_2 emissions. In particular in Italy, volumetric incentives have been largely adopted for boosting the energy retrofitting of existing buildings as revenue for financing the interventions (Conticelli et al., 2017). These policy instruments have also been trying to concentrate on the redevelopment of the built environment instead of expanding the city outside its existing boundaries, thus obtaining a win-win situation of improving the energy efficiency of the existing building stock and reducing land take.

This makes energy retrofitting a challenge to be tackled not only at level of the single building, but also at urban scale, to give a stronger impulse for a concrete transition towards climate neutrality. Indeed, as stressed by several authors, (Asarpota & Nadin, 2020; Cajot et al., 2017) in the last years the urban scale and form have received particular attention regarding energy issues, as cities can strongly influence the medium and long-term future of energy transition.

In fact, several methods have been developed for assessing the urban fabric performance in terms of energy efficiency (Ali et al., 2020; Belussi et al., 2017), representing a valid support for urban planners to orient more targeted strategies aimed at undertaking a deep renovation and energy retrofitting. By using a bottom-up model (Kavgic et al., 2010), this paper presents an easy-to-follow analysis method based on the elaboration and scaling-up of data and information related to the energy efficiency of buildings or dwellings usually collected by local authorities and agencies through the energy performance certificates (EPCs).

The data contained in EPCs are used by public authorities to improve energy planning and support decision-making processes (Collins & Curtis, 2018; Pagliaro et al., 2021). Indeed, the information that is collected and used to elaborate the certificates is relevant to improve the current energy building performance and achieve sustainability goals (Charalambides et al., 2019). In this regard, EPCs have been used associated with the identification of the building archetypes (Ali et al., 2018; Miguel-Herrero et al., 2019; Streicher et al., 2019), or to validate sophisticated data-driven and AI urban building energy models (Johari et al., 2023; Sun et al., 2022). Recently, Terés-Zubiaga et al. (2023) and Fabbri and Gaspari (2021) used the EPCs to map energy poverty at urban level in Spain and in Italy, although they highlighted some barriers like having more than one EPC per buildings, being usually referred to a single apartment. Few studies are also proposing to scale-up EPC data to draft consideration at cadastral parcel scale (Belussi et al., 2017; Fabbri & Gaspari, 2021; Gaspari et al., 2020) trying to support policy-making. However, an expeditious methodology based on the use of EPCs information at urban scale to support the definition of energy-related policies is still to be developed and require further research (Gaspari et al., 2020).

The proposed approach is based on the identification of sample buildings (Dall'O', Galante, Torri, et al., 2012). The aim is to structure an analysis framework able to effectively address targeted regeneration strategies at district level. This process is conceived for better informing urban planning decisions, thus boosting more effective interventions and strategies for an overall regeneration of the building stock that comprises also energy improvements. This analytical method has been applied and tested in one municipality in the Emilia Romagna region, Italy, where an innovative regional urban planning law approved in 2017 has been pushing municipalities towards the development of urban planning strategies oriented to drastically improve the energy efficiency of the existing building stock through urban planning strategies, while reducing land take. According to this aim, a targeted diagnosis of the energy gaps shown by the built environment is required in the urban plans.

The result of the application of the proposed method allows urban planners to orient energy sensitive urban planning strategies and eventually to foresee dedicated financial instruments to act in the more energy demanding areas of the city, thus establishing priorities for integrated strategies.

Following the present introduction, Section 2 focuses on the description of the Italian context when it comes to the energy consumption of the built environment and of the main actions and incentives in place for its reduction, with a specific attention on the urban planning dimension and the Emilia-Romagna context.

Section 3 describes in detail the methodology adopted for the assessment of the energy performance of the built environment aiming not at reaching a deep knowledge of the energy performances of single buildings, but at identifying homogeneous clusters of buildings and consequently at supporting decision-makers to propose tailored intervention strategies and policies for large urban areas.

The methodology has been applied to the municipality of Castelfranco-Emilia, in the Emilia-Romagna region, Italy, and Section 4 is dedicated to describing the undertaken steps and obtained results. Finally, Section 5 includes the discussion of the results and Section 6 concludes the article.

2. The Italian context

In Italy the building sector is the largest contributor to energy demand being responsible for the 44 % of the energy consumption. In particular, residential buildings are the main energy consumers accounting alone for the 57 %, with lower levels of energy performance in respect to the European benchmark (Italy for climate, 2021). Indeed, around 60 % of the residential buildings in Italy were built before 1970, a few years before the introduction of the first law regarding energy savings in buildings (1976) (Dall'O', Galante, Pasetti, et al., 2012). Therefore, a concrete and significant reduction of energy consumption without retrofitting existing dwellings is impossible to achieve and considerable actions on existing buildings are required (Ascione et al., 2013). Moreover, by renovating existing buildings and making them more attractive, it is possible to achieve also other positive side effects, such as reducing land take and increasing the market value of the retrofitted buildings.

Besides, Italy is facing a more critical situation than in other EU countries, since most of the households are homeowners, with dwellings in condominiums and high fragmentation of the home properties. This property fragmentation hampers the investments on building renovation. To overcome this obstacle, a vast range of incentives have been introduced by the State to encourage homeowners to invest in the retrofitting of their properties. However most of them seem to not being so effective in terms of producing deep renovations of existing buildings (Conticelli et al., 2017) and have been considered not sufficient for driving a wide transition towards low carbon buildings and neighbourhoods.

2.1. Policy instruments stimulating energy retrofitting in Italy

In Italy, the most diffused instruments for boosting building renovations in terms of energy efficiency in the building sector are regulatory and binding tools, such as energy efficiency laws, building regulations and energy certification obligations (Magnani et al., 2020).

The first and most important laws introduced at National level to reduce energy consumption in buildings are the Law No. 373/1976 and the Law No. 10/1991. The former, containing the first constraints on the amount of power that could be used for wintertime heating, has been a first cornerstone for building designers that started considering energy consumption in their projects. The latter represents the first Italian legislative framework concerning energy efficiency, by regulating the design of the building together with its heating system. It made the first steps towards the introduction of the energy certification of buildings by introducing specific procedures for determining their energy efficiency.

Following the introduction of the directive 2002/91/EC, the Italian government approved the Legislative Decree No. 192/2005, supplemented by Legislative Decree No. 311/2006, thus introducing a methodology for calculating the energy performance of buildings, the application of minimum requirements in terms of energy performance of new buildings and the energy certification of buildings. In Italy, the calculation process behind the energy certification of buildings, which is inspired by the European standard EN ISO 13790:2008, is summarized by a series of National standards UNI TS 11300 (part 1–6).

With the Ministerial Decree 26/06/2015, a new EPC scheme was set, while in 2020 the Italian national government ratified the EED and EPBD respectively with two legislative decrees: n. 73/2020 and n. 48/2020. Unfortunately, these measures have been not sufficient for drastically improving the energy efficiency of the entire building stock, because the most part of the existing buildings, which are the most critical in terms of energy consumption and dispersions, were not affected by these dispositions that mainly apply to public buildings.

Therefore, a range of voluntary instruments such as tax deductions and volumetric bonuses have been widely proposed in recent decades for encouraging the renovation of the existing buildings, even if incentive-based policy instruments have been used worldwide since the 1970s for enhancing energy efficiency in buildings (Atanasiu et al., 2014). Tax deductions for energy retrofitting have been introduced since 2006 primary at National level and have been increasing since then, giving a huge impulse to the construction sector in the field of building renovation and benefits in terms of improved energy efficiency and awareness of the homeowners (ENEA, 2020). Recently, with Law-Decree. n.o. 34/2020 and subsequent modifications, the extraordinary financial measure called "Superbonus" has been introduced, with the primary aim of revitalising the construction sector and the relaunch of the Italian economy after the Covid-19 related crisis through deep energy retrofitting interventions. It consists in the possibility for building owners to benefit of a reimbursement, under the form of tax deductions, of the 110 % of expenses incurred for energy retrofitting interventions that has been formally notified by the end of 2022. Despite the measure is receiving wide attention by the owners (ENEA, 2020), it is going to an end, being not sustainable for the National government in the long period.

Volumetric incentives received particular attention since 2009 with a policy measure called "Second Housing Plan" (Piano Casa 2), adopted at national and regional level for stimulating the economic growth of the Country by supporting the building sectors. The rationale of the measure was to allow additional volumetric additions for interventions improving the architectural and/or energy quality of buildings.

This measure was questioned by scholars and public authorities sensible to environmental issues because it was granting extra development rights without considering the overall carrying capacity of the urban environment. In particular, they questioned the mere spread of indirect incentives such as the possibility of adding new volumes to the existing buildings without considering side effects that can compromise the functioning and liveability of the urban environment. Consequently, some regional institutions, which in Italy have regulative powers in several fields, among which urban planning is comprised, introduced this measure in their regional urban planning laws, linking the possibility of developing volumetric additions with the mandatory energy retrofitting of the existing volumes and the assessment of the overall sustainability of the intervention.

Indeed, volumetric incentives, even if improving the energy performance of the building, can lead to the overloading of existing urban networks and systems, traffic congestion and soil sealing. For this reason, it is necessary to frame energy retrofitting within diversified densification strategies based on the real and different criticalities of the existing building stock and related opportunities of renovation given by other drivers, such as building function, urban location and current energy performance. Embracing this urban perspective allows to identify priority areas of intervention where to foster more impactful energy retrofitting interventions.

2.2. The Emilia-Romagna policy framework

The Emilia-Romagna Region has adopted an innovative regulatory framework in the field of urban planning that asks for designing more ambitious plans also in terms of energy efficiency, the urban planning law no. 24/2017. The logic of the new law is to block the urban expansions to allow driving the businesses of the real estate market towards a deep renovation of the urbanized areas. This challenge is tackled, on one hand, by setting a regional target of 3 % of maximum net land take by 2050, which must be achieved with the concur of all the Municipal Urban Plans and, on the other hand, by pushing towards a diffused and deep regeneration of the built environment to increase the cities' resilience and sustainability.

To achieve this urban regeneration, it becomes necessary to improve the knowledge of the built environment in terms of its general and specific performance, with a clear focus on energy efficiency.

Notably, the law expressly asks to draw up the census of buildings with poor building quality with regard to energy efficiency, to diagnose the main shortcomings that need to be addressed through targeted regeneration strategies led by the urban plan. This implies a highly in-depth knowledge of the building stock, starting from the scale of the building unit to which energy efficiency data can generally be associated. Clearly this level of detail does not normally belong to the urban scale; the urban plan, cannot cover the deep knowledge of the single buildings all over the city. Therefore, new analytical approaches are needed to better inform specific energy-sensitive interventions depending on the different energy performance of the building stock detected at urban level. These approaches should be easy to be replicated by public officials and technicians and the required data need to be easily accessible and collected by local authorities to allow the integration of energy-sensitive strategies within urban planning objectives, leading towards more efficient and effective interventions (Asarpota & Nadin, 2020; Cucchiella & Rotilio, 2021).

3. Materials and methods

The objective of this section is to describe an expeditious method to investigate the energy efficiency of the residential building stock in order to evaluate the intensity and type of the desired retrofitting interventions and consequently to orient specific and more targeted energy sensitive strategies to be included in the Municipal Urban Plan. This analytical method aims at supporting urban planners to promote urban regeneration by granting incentives or setting binding requirements targeted to specific areas of the city.

There are several methods for modelling the energy consumption of residential building stock (Costanzo et al., 2019; Mutani & Todeschi, 2020; Reinhart & Cerezo Davila, 2016), which can be classified into three main categories: top-down, bottom-up, and hybrid methodologies (Kavgic et al., 2010; Mutani et al., 2019). In the present study a building physics bottom-up method (Kavgic et al., 2010) is adopted, by defining sample (or typical) buildings which resemble the energy behaviour of similar buildings in terms of age and uses, and assigning these behaviors to clusters of buildings with the same features. More in detail and similarly to other studies (as described in Belussi et al. (2017)), the proposed method combines empirical and disaggregated data coming from the EPCs with the age, type and use of the buildings in order to identify energy zones, distinguished by their energy performance index, that are quite homogeneous in terms of building features and related energy performance. As shown in Fig. 1, the methodology is structured in four main steps, and starts with the collection of data and the definition of homogenous urban areas. The energy performance index is then obtained by scaling-up the average energy performance indicator of each residential unit that has an EPC to the building to which it belongs, associating it to other buildings with similar characteristics. Following this first assessment phase, the method is based on the identification of homogeneous urban zones to which a similar energy performance and behaviour can be associated. Homogeneity is usually determined through a variety of building and urban parameters such as age, physical, geometric, and typological characteristics as well as height and surface-to-volume (S/V) ratio and characteristic of the heating systems (Mutani & Todeschi, 2020).

One advantage of this method is the usage of data that are usually collected and managed by most of the Italian public administration through geographic information systems (GIS), thus overcoming the lack of data that municipalities, especially medium and small size municipalities, frequently experience. In fact in Italy, EPCs are systematically collected by ENEA, the National Agency for Energy, which is also in charge for the analysis and systematization of EPCs and of energy saving interventions occurred yearly as well as the requests of tax incentives connected with energy retrofitting interventions (Fracastoro & Serraino, 2011). To this aim a ministerial database of EPC managed by ENEA and called Information System on Certificates of Energy Performance (SIAPE) was set in 2016, representing the national repository of EPCs. EPCs are collected by Regions and Autonomous Provinces in their local registers and transmitted to SIAPE each year (Pagliaro et al., 2021). Data in the SIAPE can be accessible to public authorities and can be potentially georeferenced through the address of the real estate units.

Among building parameters, the most interesting information is the building construction period, since it can be considered as a proxy of the normative gap buildings can show with regards of the current energy efficiency requirements. This information is crucial especially when other details are not available in the datasets owned by Municipalities. In addition, buildings of the same age frequently have similar structures and construction techniques and consequently similar energy performances. In this research we used age and use for classifying similar buildings in terms of energy behaviour. Building type and height are also used for identifying homogeneous urban areas in terms of building and urban indicators.

In the following paragraphs, each step of the proposed methodology is described more in detail, followed by its application to the Municipality of Castelfranco-Emilia in Italy.

The elaborations have been developed through ArcGis and benefitted from datasets and information that are open source or easily accessible in Regional or National databases.

3.1. Preliminary tasks: data sources collection and homogeneous urban areas definition

3.1.1. The EPCs

In order to develop the method, two main data sources are needed. The first one is represented by EPCs in which the most relevant data for the analysis of the buildings' energy performance is the global non-renewable Energy performance index ($EP_{gl,nren}$) expressed in kWh/m^{2}y. The $EP_{gl,nren}$ evaluates the non-renewable annual primary energy requirement for the single house unit, taking into consideration the single energy performance indexes that evaluate the primary energy required for heating ($EP_{H,nren}$), producing domestic hot water ($EP_{W,nren}$), cooling ($EP_{C,nren}$), ventilation ($EP_{V,nren}$), lighting ($EP_{L,nren}$) and elevators ($EP_{T,nren}$). The higher the amount of the energy required, the weaker the energy performance of the dwelling is. EP is also influenced by the building shape (S/V and typology) being high for single-family houses (which have a S/V near to 1 or above), while it decreases for multi-storey buildings and condominiums units, where S/V is lower.

Up to 2015, Italian EPCs contained information about energy consumption only linked to heating and production of domestic hot water. From 2015 on EPCs also detail the energy consumptions linked to the other services (i.e. cooling, ventilation, lighting and elevators). This fact underlines that the level of information contained in EPCs is changed during the years becoming more and more detailed.

The systematic collection of EPCs done by ENEA provides the energy performance for single real estate units, therefore providing a very high, but still partial, degree of detail. In fact, this level of in-depth analysis of the data does not belong to the urban planning scale and above all fails

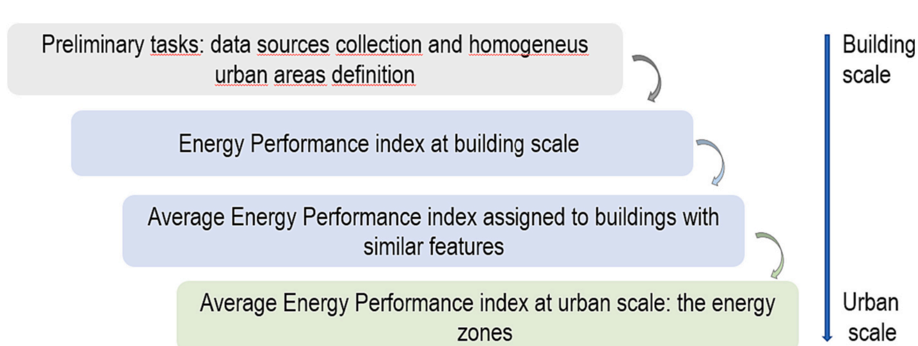

Fig. 1. Methodology adopted in the research.

to cover the entire building heritage in a truly widespread manner; moreover, in Italy EPCs are usually produced in case of new construction or radical transformation of existing buildings or units, or simply when a real estate unit is sold or rented.To upscale the information provided by the EPCs to an urban scale, in this research a more sophisticated analytical procedure has been developed. The method concentrates on residential mixed-use zones (which are characterized in this study by a big prevalence of residential buildings where other uses are mainly located in ground floors of buildings), therefore uses data gathered form residential units' EPC. EPCs of commercial and industrial and units comprised in the mixed-use areas have been discarded since EPC calculation was different for these uses up to 2008 (i.e. energy consumptions were scaled with volume and not with the floor area) and results are not comparable with residential buildings ones.

3.1.2. Homogeneous urban areas definition

Another set of data considered as an input of the method relates to the definition of homogeneous zones that should contain buildings and urban tissues with similar features in terms of morphology, uses and mainly age. The possibility to identify those characteristics is very important, being the basis for scaling up the data from the building scale to the urban scale.

Above all, the age of construction is a fundamental data for obtaining information about the energy efficiency of the buildings, therefore it is important to set proper age classes based on key milestones in terms of energy efficiency improvements in buildings. This is effectively done by considering key norms and laws that changed the requirements about the energy performance of buildings (Pagliaro et al., 2021). In Italy the most relevant norms are the ones listed in Table 1.

Finally, functional zoning allows to characterize the different urban areas in terms of urban uses. In fact, different urban zones usually present homogeneous uses that allow to identify common energy behaviors of buildings.

Since in Italy, until a few decades ago, municipal urban plans have been based on functional zoning, the average age of buildings and urban uses are easily obtained both by consulting the urban plans maps and by surveying public officials. Functional zoning can also give information on the maximum height of buildings and their typology.

The main task of this phase is therefore to assign these features to each building item and recording this information into the building shapefile. Consequently it is possible to identify and map areas with similar features in terms of age of buildings, building height, building type, urban uses and overlay them in order to identify areas with homogeneous features as a whole.

3.2. Energy performance index at building scale

Since $EP_{gl,nren}$ is a parameter valid just for each apartment, in order to have an overview of the entire building's performance a scaled-up index is needed. Indeed, the method allows to calculate a $EP_{gl,nren,\ avg}$ consisting in a weighted average of energy performance $EP_{gl,nren,i}$ made from all the housing units within the same building:

$$EP_{gl,nren,avg} = \frac{\sum_{i=1}^{n} EP_{gl,nren,i} \bullet Su_i}{\sum_{i=1}^{n} Su_i} \left[\frac{kWh}{m^2 \bullet year}\right] \tag{1}$$

where:

n is the total number of housing units within the building whose EPCs are available,

$Su_i\left[m^2\right]$ is the floor area of the i-housing unit,

$EP_{gl,nren,i}\left[\frac{kWh}{m^2 \bullet year}\right]$ is the total energy performance index of the i-housing unit.

After this operation, each building, where at least one residential EPC has been released, represented by a residency number (and/or cadastral data) obtains an average $EP_{gl,nren,avg}$. This dataset contains the so called “sample buildings”, that will be used to scale up their energy performance characteristics to residential buildings with similar features.

3.3. Average energy performance index assigned to buildings with similar features

This second stage of the methodology aims at assigning an $EP_{gl,nren}$ to all the residential buildings in the city. We consider residential buildings also those which host other uses at the ground floor. The age of the buildings as been used as a proxy for undertaking the assignment.

Therefore, a preliminary step is to group the sample buildings into the age classes identified before and calculate a weighted average ($EP_{gl,nren,mean}$) which represent a mean $EP_{gl,nren,avg}$ for each age class:

$$EP_{gl,nren,mean} = \frac{\sum_{j=1}^{m} EP_{gl,nren,avg\ j} \bullet Su_j}{\sum_{j=1}^{m} Su_j} \left[\frac{kWh}{m^2 \bullet year}\right] \tag{2}$$

where:

m is the total number of sample buildings included in a given age class,

$Su_j\left[m^2\right]$ is the floor area of the j-sample building,

$EP_{gl,nrenavg,j}\left[\frac{kWh}{m^2 \bullet year}\right]$ is the energy performance index of the j-sample building, calculated in the previous step.

By considering the age classes, it is now possible to associate the $EP_{gl,nren,mean}$ to residential buildings comprised in the same age class, thus transposing the energy efficiency performance of the sample buildings to buildings which are similar in age of construction.

3.4. Average energy performance index at urban scale: the energy zones

The last stage of the method is represented by the scaling up of the energy efficiency performance obtained for each building to the urban scale. To this aim, the homogeneous urban areas identified in the initial phase of the study represent the basis for this scaling up, since they comprise buildings that are quite similar in terms of age and morphology, thus showing similar performance in terms of energy efficiency.

Thus, considering the homogeneous areas already defined, this stage consists of assigning an energy performance index to each area according to the $EP_{gl,nren,mean}$ assigned to buildings inside them.

The calculation to be developed to assign an average $EP_{gl,nren,area}$ at urban scale is again a weighted average of the $EP_{gl,nren,mean}$ assigned to buildings in each area:

Table 1
Identification of relevant Italian Regulations on energy efficiency in buildings (authors' elaboration form Pagliaro et al., 2021).

Italian Energy Regulation	Main contents in terms of energy efficiency of buildings
Law 373/1976	First requirements for building thermal insulation
Law 10/1991	Control measures on the insulation level of walls and ceilings. Introduction of EPC.
Legislative Decrees 192/2005 (implementation of 2002/91/EC) and 311/2006	Definition of the calculation methodology for building energy performance. Introduction of energy minimum requirements.
Ministerial Decree 26/06/2009 (implementation of 2002/91/EC)	National guidelines for building energy certification.
Ministerial Decree 26/06/2015 (implementation of 2010/31/EU)	New national guidelines for building energy certification. New EPC calculation methodology and introduction of the RB

$$EP_{gl,nren,area} = \frac{\sum_{k=1}^{l} EP_{gl,nren,mean,k} \bullet Su_k}{\sum_{k=1}^{l} Su_k} \left[\frac{kWh}{m^2 \bullet year}\right] \quad (3)$$

where:

l is the total number of buildings included in a given area,

$Su_k\left[m^2\right]$ is the floor area of the k- building of the given area,

$EP_{gl,nren,mean,k}\left[\frac{kWh}{m^2 \bullet year}\right]$ is the energy performance index of the k-building in a given area, calculated in the previous step, $EP_{gl,nren,area}\left[\frac{kWh}{m^2 \bullet year}\right]$ is the energy performance index of the given area.

4. An application to a real case study: the town of Castelfranco Emilia, Italy

Castelfranco Emilia is a municipality with a population of around 33.000 inhabitants, located in the Padania Valley, along the roman Emilia Road, between the two main cities of Bologna and Modena. The municipality is comprised in the Emilia-Romagna Region, Italy.

Its administrative territory comprises the main town, Castelfranco, and four hamlets: Gaggio, Manzolino, Piumazzo, Cavazzona, which are spread in the plain around Castelfranco (Fig. 2). The municipality is now developing the initial analysis for designing the new urban plan according with the new regional law, therefore was interested in developing a detailed analysis of the characteristics of the building stock, including energy efficiency which has become even more important after the energy crisis of the last months.

4.1. Preliminary tasks: data sources collection and homogeneous urban areas definition

As described in Section 3, the two main data sources refer to the EPCs and the building morphology and uses. Therefore, these two sets of data have been collected and systematized for Castelfranco Emilia, according to the proposed method.

4.1.1. The EPCs

The EPCs of buildings in Castelfranco Emilia have been acquired from ENEA and the ones obtained are those released since 2009.

As explained before, in EPCs made before 2015 $EP_{gl,nren}$ was obtained by considering the contribution of the non-renewable primary energy consumptions linked to heating and domestic hot water production only. After 2015, $EP_{gl,nren}$ theoretically contains the contribution linked to cooling and ventilation (if a cooling and/or a ventilation system are present in the building). In order to extract from EPCs homogeneous information, the energy consumptions linked to cooling and ventilation are not considered for EPCs made after 2015.

Around 1290 EPCs related to residential units have been systematized in this first phase through a spreadsheet, where the energy performance index $EP_{gl,nren}$ is correlated with the unit floor area and local address of each real estate unit recently built, sold or rented. A preselection of residential units has been made, since the method is targeted to estimate the energy efficiency of residential buildings and consequently of residential mixed-use areas.

4.1.2. Homogeneous urban areas definition

The building stock of the main urban centre and of the hamlets has been analyzed in terms of morphology, by considering the following features:

- building height (number of floors);
- building typology;
- building age.

The building stock has been also analyzed in terms of uses, to exclude

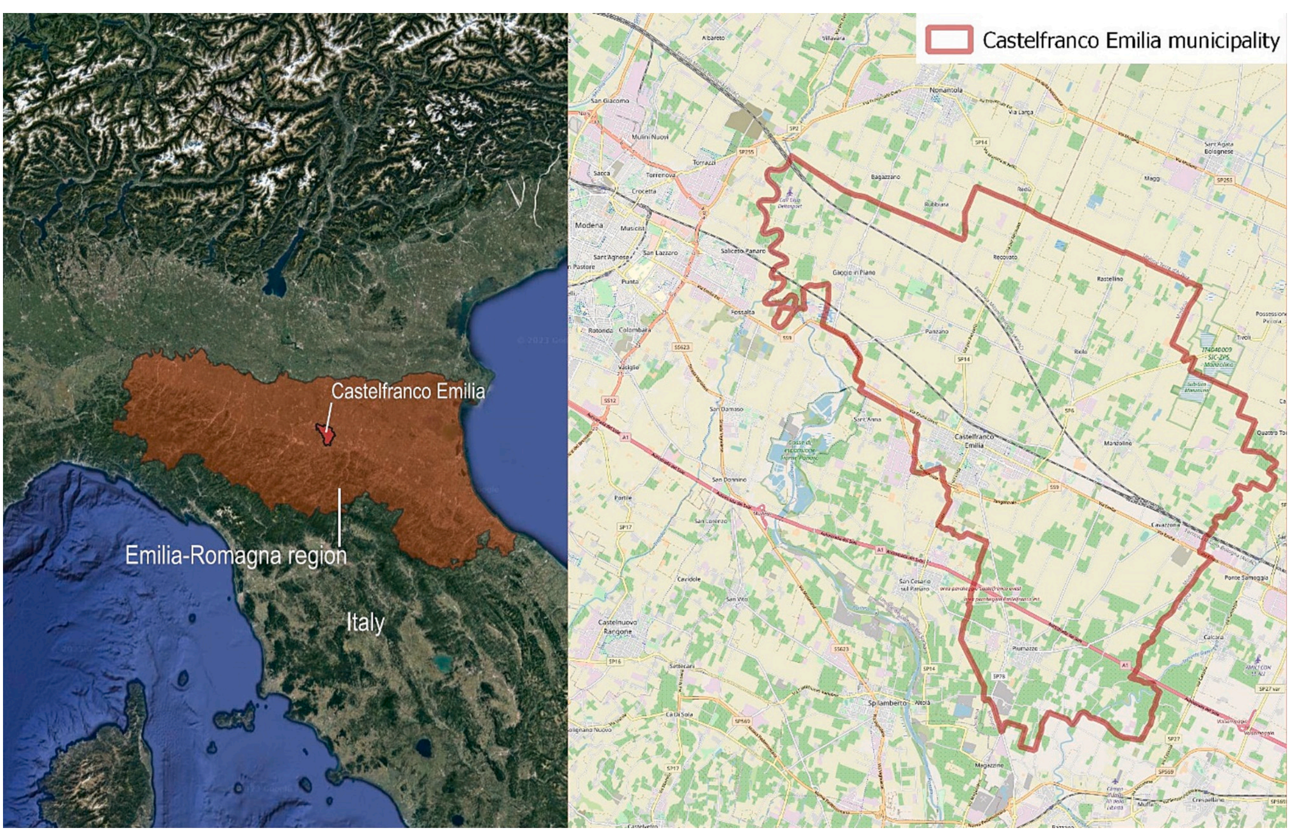

Fig. 2. Territorial framework of Castelfranco Emilia and the four hamlets.

from the analysis the buildings that are not residential or with a prevalence of residential units. This analysis allowed to identify urban zones with homogeneous morpho-typological and functional characteristics, thus presenting similar behaviors in terms of energy performance.

4.1.2.1. Building height. Building height has been reported in Fig. 3 in terms of number of floors, excluding basements and uninhabitable attics from the count. This feature has been obtained from the municipal GIS that comprises a shapefile containing the buildings (polygons) and their basic geometric features such as number of floors, height and covered area. The figures obtained show a clear prevalence of low-rise buildings, with 2 and 3 floors, which reflects a typical situation of a small Italian urban centre. However, there are many 4-storey buildings, while there are very few buildings with 5 floors or more.

4.1.2.2. Building typology. Building typology is an architectural feature that is usually detected in Italy for performing urban planning analysis (Micha, 1984) to identify urban morphology, densities and housing dwelling types and, consequently, to determine different urban planning rules for their transformation. This feature is particularly relevant for characterizing residential buildings and areas, and mainly deals with building geometry but is also linked to energy performance of buildings, as some studies have already highlighted (Ballarini et al., 2017). In particular, the TABULA project (Corrado et al., 2014) identified several building typologies in terms of energy efficiency and one of the criterion is the architectural building type, that is linked to the shape of the building and consequently its energy efficiency. In TABULA four main architectural building types are foreseen for the Italian context: single family house (SFH), terraced house (TH), multi-family house (MFH), apartment block (AB). The building typology was assigned to residential buildings located in the urban area of the main town and in the four hamlets by considering data already present in the urban plans and documents owned by the municipality and complemented through direct surveys based on Google map viewer and onsite visits. The main building types are identified as follows:

- SFH: it includes both courtyard building, intended as single-family or multi-family building forming a single building with a central internal courtyard, and single-family villa consisting in building isolated and freely arranged on the lot, generally with limited height;
- TH: terraced building like historic or modern single-family or multi-family building, originating from the aggregation of autonomous blocks, with maximum 3 floors;
- MFH: small building consisting in single-family or two-family building, characterized by a compact plan and a height limited to 2 or 3 floors, generally equipped with a common stairwell;
- AB: it includes both condominium and tower building. The former is intended as multi-family and multi-storey building, mainly developed in length and with a common central stairwell serving 2 or more flats per floor, generally arranged in a central position on one of the two main elevations or in the unlit centre. The tower building is a multi-family and multi-storey building, developed mainly in height, with a compact plan and central stairwell common to several apartments per floor.

Fig. 4 shows the distribution of the building typology in the municipality of Castelfranco-Emilia. The prevailing is small building, followed by condominiums and detached villas.

4.1.2.3. Age of buildings. The representation of this information was made by age groups, considering the most significant regulations and laws that increased the energy efficiency performance required for new buildings.

Two georeferenced databases were used: the former concerns the building permits for new construction interventions, presented to the Municipality since 1990; the latter concerns the structural permits for minor interventions on the existing buildings, collected since 2000. For buildings prior to 1990, which are the majority, the construction age was assigned on the basis of the information collected in the documents of the current Municipal Urban Plan, which considers decades as age groups, related in particular to the historicity of the building. Therefore, a third dataset has been created, comprising buildings built before 1990 and not included in the previous databases. By analyzing the 3 datasets, it was possible to identify six age groups, which address the most significant dates in which energy efficiency standards were introduced in Italy and in Emilia-Romagna, as shown in Table 2. The most recent age group is made by buildings built after 2010. We decided not to identify more recent age groups because in Emilia Romagna and more generally in Italy the construction sector fell into a deep crisis after 2008, blocking almost all the new constructions for a decade. After this period the new urban planning law entered into force, drastically reducing new residential building construction. For instance, after 2018 only 10 buildings have been built in Castelfranco Emilia, therefore a new age group was considered as not significant in this application. Fig. 5 shows a map with the classification of buildings according to the age groups in Castelfranco main town, while data for the entire Municipality are provided in Fig. 6.

4.1.2.4. Urban uses. The detection of the different activities hosted in buildings permits to identify homogeneous conditions in terms of use; for the reasons already explained above, the analysis was then limited to predominantly residential urban zones. The main uses identified according to the classification of the Municipal Building Regulations are:

- housing;
- commercial and retail;

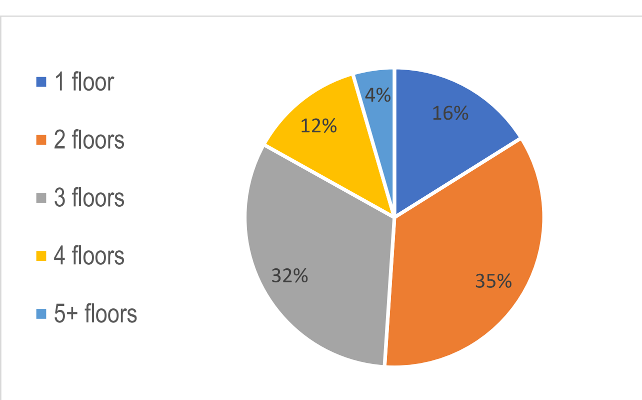

Fig. 3. Height of buildings expressed in number of floors.

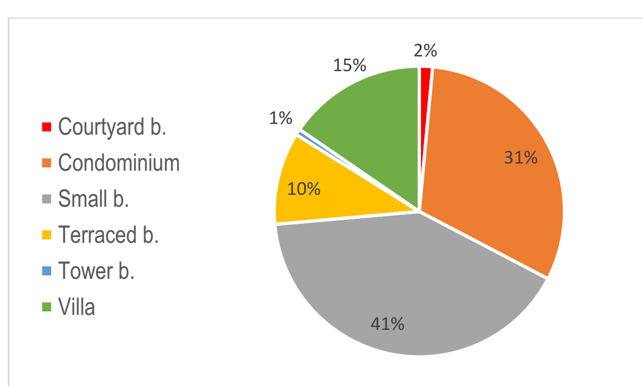

Fig. 4. Residential buildings typology.

Table 2
Age groups identified for classifying the building stock.

Age group	Relevance
before 1945	Building date that identifies historic buildings, as a convention set by the Ministry of Cultural Heritage in Italy
1945–1978	L. 373/1976 Rules for the containment of energy consumption for thermal uses in buildings
1979–1989	L. 10/1991 Transitional rules for the containment of energy consumption
1990–2005	Legislative Decree no. 192/2005
2006–2009	Ministerial Decree 26/06/2009
After 2010	

– industrial-manufacturing;
– offices;
– tourist-accommodation;
– special public interest uses.

The attribution of this characteristic was performed starting from the functional zoning present in the municipal urban plan enforce and verifying the data with field surveys and via google map viewer.

Out of the total number of buildings surveyed, around 87 % of them have a predominantly residential use, 6 % of buildings host public uses while around 4 % contain industrial uses, concentrated mostly in the industrial centers of the capital and in the hamlets of Piumazzo and Cavazzona. Even more scarce is the presence of buildings with a predominantly commercial use, with just a percentage of only 2 % (Fig. 7). However, it is important to underline that many retail and commercial activities are spread on the ground floor of buildings which, overall, are indicated as residential. These data have been georeferenced by assigning this feature to the building shapefile.

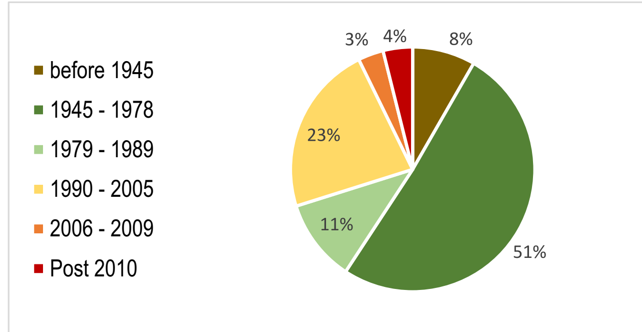

Fig. 6. Age of buildings.

4.1.3. Homogeneous urban areas definition

In order to scale the data collected and analyzed at building scale and to proceed with the assessments at the urban scale, identifying territorial units containing buildings with homogeneous age, morphological and functional characteristics is necessary. Homogeneity is essential in order to carry out a correct upscale of the information collected during the analysis, from the building to the urban scale. Therefore height of buildings, building types, urban uses, and age of buildings have been mapped for identifying areas with similar features and then overlayed for identifying homogeneous urban areas with similar features as a whole.

The following types of homogeneous urban areas have therefore been identified:

– historical built-up area;
– first residential development;
– second residential development;

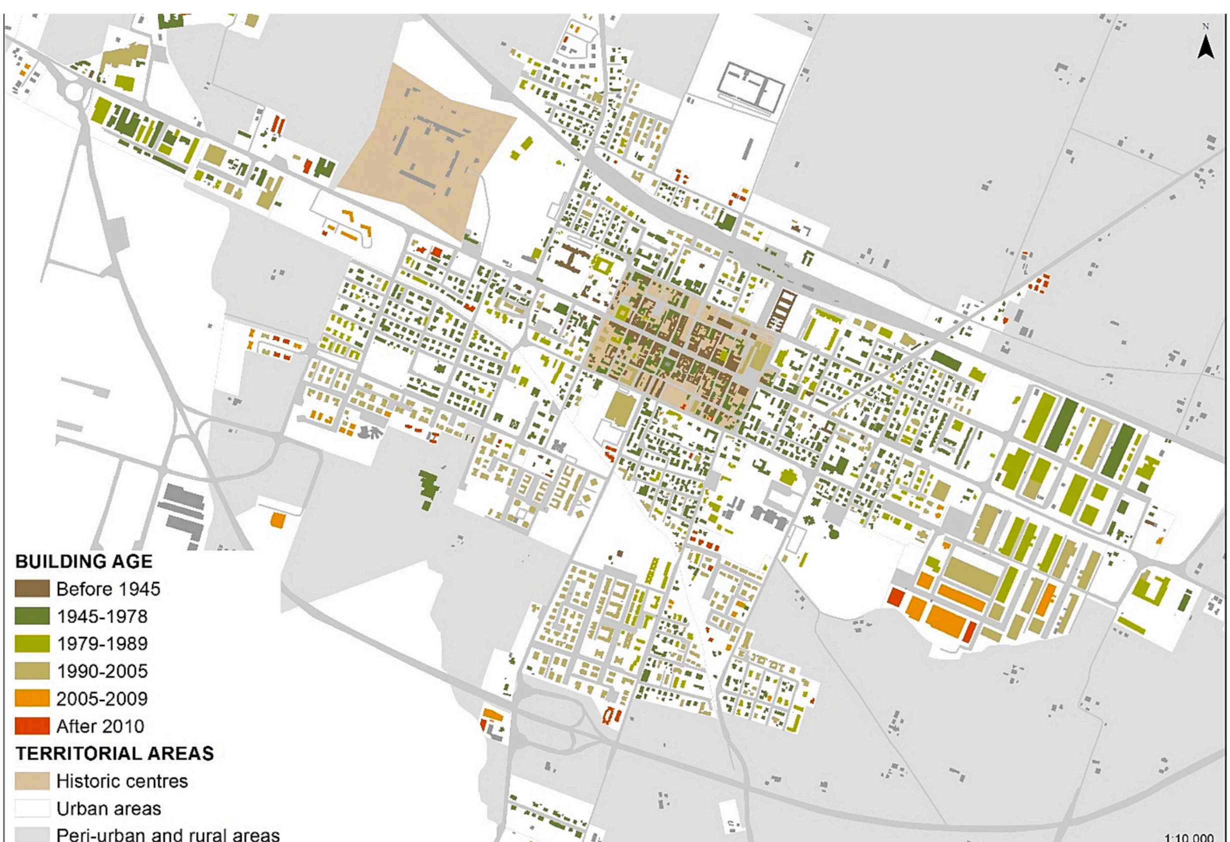

Fig. 5. Age of the building stock map of Castelfranco main town.

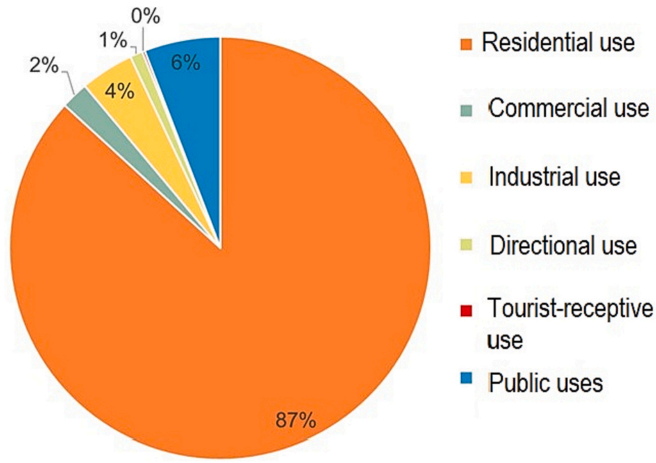

Fig. 7. Distribution of buildings according to the hosted use.

– third residential development;
– historic industrial development;
– new industrial development;
– school-sports hub;
– health centre hub;
– railway hub.

The capital has been divided into 29 homogeneous areas, while Piumazzo has been divided into seven areas, Cavazzona into five territorial units, Manzolino into seven areas, and finally, Gaggio is characterized by five areas (Figs. 8 and 9). This preliminary subdivision has made it possible to diversify the urbanized territory of the capital and the hamlets in a rather detailed way, bringing out a certain variety.

4.2. Energy performance index calculation at building scale

In this phase, a $EP_{gl,nren,avg}$ was assigned to the sample buildings with a residential function on the basis of the collected EPCs . Therefore, the $EP_{gl,nren}$ available for the residential units belonging to the same house number were used to calculate the $EP_{gl,nren,avg}$ for the whole building by using Eq. (1).

Thanks to this, it was possible to draw up a map of the sample buildings based on their $EP_{gl,nren,avg}$. The mapped sample buildings covered approximately 20 % of the total number of the surveyed buildings .

For a better data visualization, the $EP_{gl,nren,avg}$ values have been divided into 8 intervals that comprise the buildings according to their energy efficiency. The ranges have been defined indicatively based on the regional classification system defined by Resolution no. 156 dated 04/03/2008, based on 8 "fixed" energy performance classes reported in Table 3. It is worth mentioning that this method for identifying the energy classes is now replaced by the "virtual reference building" (VRB) method. Following this new method, each building can be coupled to a VRB which is identical to the real one as for geometry, orientation, location in the climatic zone and use but owns predetermined thermal characteristics and energy parameters. The value of the energy performance index ($EP_{gl,nren,Lst}$) obtained for the VRB identifies the ranges of

Fig. 8. homogeneous urban areas in the capital.

Fig. 9. homogeneous urban areas in the hamlets.

Table 3
Energy performance classes adopted in this study.

$EP_{tgl,nren}$ classes [kWh/m^2 year]
< 25
25–40
40–60
60–90
90–130
130–170
170–210
> 210

the Energy Performance classes.

In the method proposed in this paper the fixed ranges individuated in Emilia-Romagna by the Resolution n.156/2008 are used because it is not of primary importance the right individuation of the energy class but rather the knowledge of the absolute value of the specific energy consumption linked to each building, in order to identify its "energy impact" at urban scale. In addition, this choice allows to simplify the method because the determination of a VRB for each residential unit of the urban area can be avoided.

4.3. Average energy performance index assigned to buildings with similar features

Thanks to the preliminary analysis that led to the definition of the homogeneous urban for each building a date or period of construction, it was possible to correlate the age of construction with the $EP_{gl,nren,avg}$ obtained for the sample buildings (Eq. (1)), thus calculating a $EP_{gl,nren,mean}$ for each age group identified (Eq. (2)). This calculation is fundamental for assigning an $EP_{gl,nren,mean}$ – which is the average value listed in Table 4 to other buildings not provided by an EPC but included in the same age group.

The identification of $EP_{gl,nren,mean}$ for age classes allows to draw some preliminary considerations:

- Due to the age of construction, buildings prior to 1945 generally have very low energy performance. In fact, the collected data resulted in an average $EP_{gl,nren,mean} > 210$ kWh/m^2 year. On these buildings, interventions for improving the energy efficiency are complicated given their architectural heritage value that often does not allow deep interventions altering the original architectural features;
- buildings built between 1945 and 1989 still have a very low energy efficiency ($EP_{gl,nren,mean} > 210$ kWh/m^{2}year);

Table 4
Identification of $EP_{tgl,nren,mean}$ based on sample buildings for each age group and correlation with the $EP_{gl,nren,avg}$ classes.

Building age	$EP_{gl,nren,mean}$ based on sample buildings [kWh/m^2 year]	$EP_{gl,nren,avg}$ classes [kWh/m^2 year]
before 1945	294	$EP_{gl,nren,avg} > 210$
1945–1978	277	$EP_{gl,nren,avg} > 210$
1979–1989	237	$EP_{gl,nren,avg} > 210$
1990–2005	189	$170 < EP_{gl,nren,avg} < 210$
2006–2009	107	$90 < EP_{gl,nren,avg} < 130$
after 2009	55	$40 < EP_{gl,nren,avg} < 60$

- buildings built after 1990 show a general improvement in energy performance, thanks to the effects of Law 10/1991 which began to regulate the design of buildings and systems with a stronger attention to energy saving;
- Almost all buildings built after 2005 have a satisfactory energy performance. This is in line with the publication of the new rules on the containment of energy consumption in Italy which ratifies the directive on the energy performance of buildings (2002/91/EC), demonstrating the effectiveness of the measure. The consequent introduction of the Ministerial Decree 26/06/2009 further improved the energy performance of buildings, registering a strong decrease of the $EP_{gl,nren,mean}$ resulting in 55 kWh/m^{2}year for sample buildings built after 2009.

After having calculated the $EP_{gl,nren,mean}$ for sample buildings the consequent step was the assignment of those $EP_{tgl,nren,mean}$ to all the rest of the residential mixed use buildings being built in the same age period.

As explained in the method, the construction period was considered as the fundamental feature for identifying quite similar energy behaviors between buildings belonging to the same age class. It is relevant for identifying similar envelope and system characteristics, which are typical of the various periods and, consequently, similar $EP_{tgl,nren}$. We therefore proceeded by considering the age class of the buildings for assigning the $EP_{gl,nren,\ mean}$ of sample buildings of the same period (Figs. 10 and 11).

The result of this operation shows that almost the 85 % of the total buildings has very poor performances ($EP_{gl,nren,mean} > 130$ kWh/m^{2}year) and >60 % of the buildings presents extremely poor energy performance ($EP_{gl,nren,mean} > 210$ kWh/m^{2}year). Instead, buildings have more acceptable energy performances ($EP_{gl,nren,mean} < 40$ kWh/m^{2}year) appear to be less than the 10 % of the total; moreover, they are normally located in the extreme suburbs of the urban centres (see Fig. 12).

4.4. Average energy performance index at urban scale: the energy zones

The last step of the analysis concerns the identification of energy performance classes at urban level.

As explained in the methodology, this further step is essential to bring the information obtained at the building level to the urban scale, which is essential to define energy efficiency policies and strategies in the municipal urban plan.

For this purpose, we considered the homogeneous areas previously identified and we calculated a weighted average $EP_{gl,nren}$ by considering the $EP_{gl,nren,mean}$ assigned to all the buildings included each area.

The final result was the identification of a $EP_{gl,nren,area}$ for each area that has been identified according to the energy efficiency classes already recognized by using Eq. (3), thus identifying specific energy zones.

What emerged from this last calculation is that most of the urban areas are affected by a prevalence of buildings with $EP_{gl,nren,mean} > 210$ kWh/m^{2}year, while only a small number of areas, where buildings built in the most recent period are prevalent, manage to reach a fairly low $EP_{gl,nren,mean}$. The most critical situation is found in the most central areas of the capital and also in the hamlets (see Figs. 13 and 14).

5. Discussion

The application of the proposed method made it possible to identify energy zones, i.e. homogeneous urban zones where the energy performance shown by sample buildings was assigned to similar buildings in

Fig. 10. attribution of the $EP_{gl,nren,mean}$ class to all the residential buildings in the capital based on their age class.

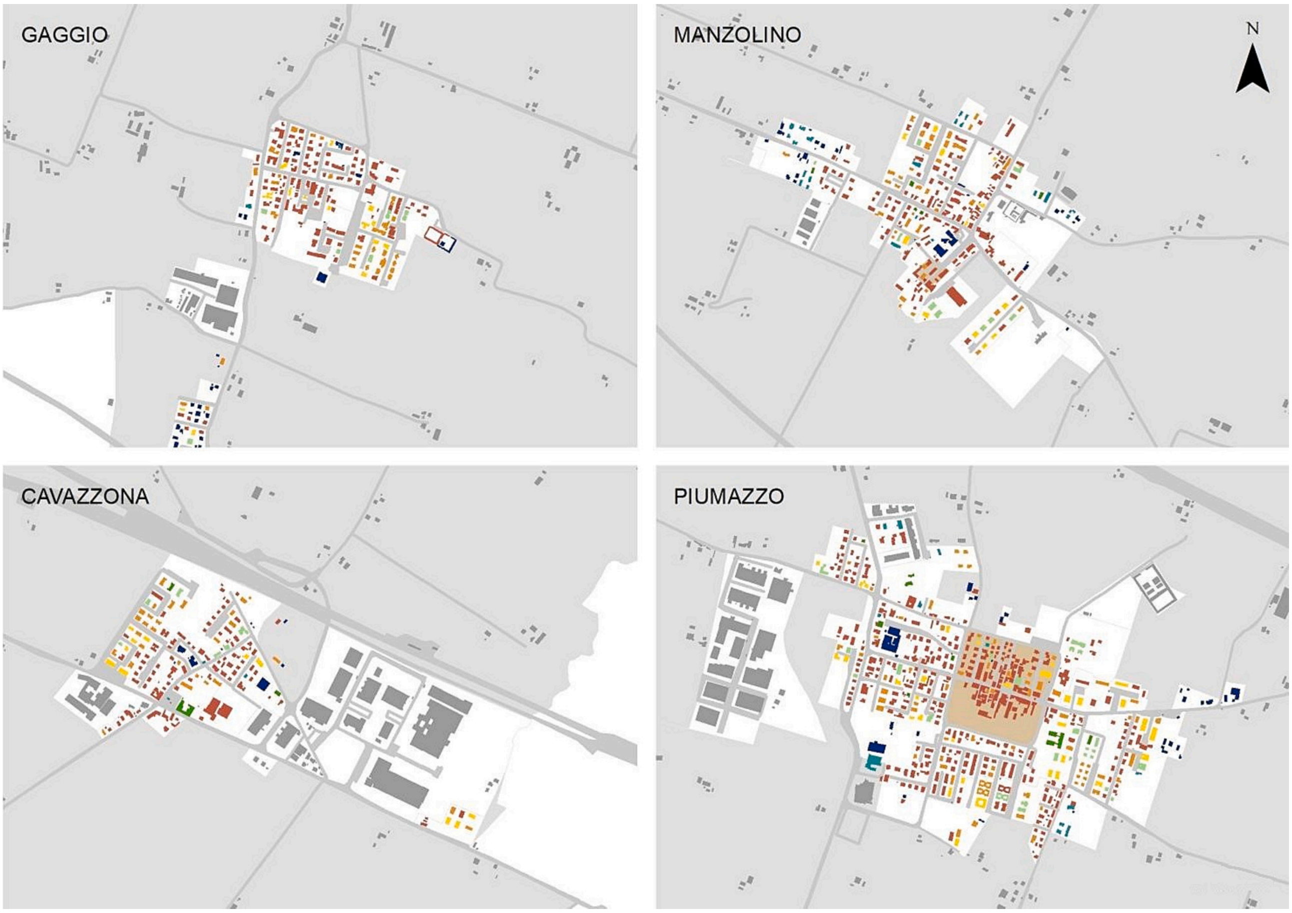

Fig. 11. attribution of the $EP_{gl,nren,mean}$ classes to all the residential buildings in the hamlets based on their age class.

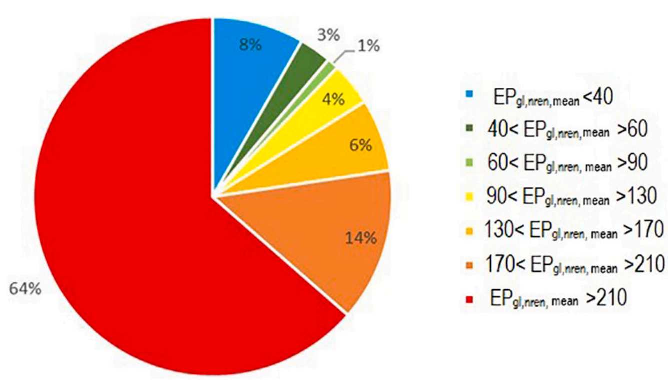

Fig. 12. Distribution of buildings according to the $EP_{gl,nren,mean}$ classes.

terms of energy behaviour, allowing to scale up these properties from the single building to the urban zone, thus addressing important challenges set at international and European level. Some studies propose similar expeditious methods, based on morphological features (Ali et al., 2020; Belussi et al., 2017) while others use the information included in the EPCs to scale it up to similar buildings. The novelty of this method is to merging these two elements into one expeditious method that scale up information usually collected at building scale to the urban one, contributing to the need of defining an expeditious process in support of decision-making for the development of urban strategies (Gaspari et al., 2020). In fact, the application of this method intends to better orient possible energy efficiency strategies to be included in the municipal urban plan or in sectorial plans such as the SEAPs, first of all by recognizing the needed intensity of diversified retrofitting interventions according to the extent of the gap to be remedied and consequently adopting adequate and more targeted urban planning policies, such as for example the use of volumetric incentives.

In Table 5, a first insight concerning possible energy retrofitting strategies to be included into the urban plan is described by considering the $EP_{gl,nren,area}$ classes in which each area felt.

Buildings inside energy zones with $EP_{gl,nren,area}$ values higher than 130 kWh/m^2year generally require rather heavy energy efficiency interventions involving both the envelope and the systems, to bridge the gap between the current $EP_{gl,nren}$ and the one requested by current regulations. Differently, when $EP_{gl,nren,area} < 130$ kWh/m^2year, lighter interventions involving the heating and cooling system of the buildings are needed to improve the energy performance towards the target set by the regulations, for instance improving the use of renewable energy. These considerations are relevant for the urban planning process that is not focused on setting specific standards at building or system level, which are generally managed by building regulations and specific laws affecting the building design and construction phase, but rather on establishing where and upon which conditions to apply forms of incentives (Conticelli et al., 2017) that should be primarily targeted at those areas that are more critical as regards to the achievement of adequate levels of energy efficiency. With respect to these general criteria, an exception must be made for historic areas, where there are buildings of historical-architectural value for which the same provisions of Legislative Decree 192/2005 and 311/2006 and the more recent Legislative Decree 28/2011 derogate from the obligations relating to energy efficiency in the face of protection and conservation needs, in cases where compliance with the provisions would imply an unacceptable alteration of their historical and/or aesthetic value.

Fig. 13. Energy zones in the capital.

In terms of future improvement of the method, the results of this analysis might be integrated by considering other sustainability conditions of the identified areas, such as the quality of the urban systems and facilities as well as the presence of degraded and underused areas. This integrated view of the urban challenges will be the basis for drafting the specific discipline of each urban area as well as urban strategies that can be more effective in addressing net zero energy targets and districts. Conversely the method application could be less effective when it comes to urban areas that are highly heterogeneous in terms of uses, thus determining the identification of very small homogeneous urban areas. In this case the urban-scale analysis risks becoming weaker.

6. Conclusions and policy implications

With the 2018/844/EU and 2012/27/EU directives and the more recent European Climate Law (Regulation (EU) 2021/1119), the European Commission set important milestones and targets requiring that Member States establish effective and long-term strategies for building stocks renovation. To this aim, the urban scale is becoming increasingly relevant for leading energy sensitive strategies with significant impacts on energy transition (Asarpota & Nadin, 2020; Cajot et al., 2017) and several methods have been identified for scaling up energy performance from building to urban scale. In this paper, a bottom-up method (Kavgic et al., 2010) for assessing the energy performance of the residential building stock at urban scale is proposed. This method is based on the collection of information on energy performance of sample buildings contained into the EPCs and the consequent scaling up of this information at urban scale, thus characterizing an average energy behaviour of buildings within different urban contexts through an expeditious process, providing recommendations at urban level going beyond the building or the plot scales. This method allows to identify specific energy urban zones where to implement dedicated and more targeted energy improvement strategies managed by the urban plan. Indeed, the method is able to estimate energy gaps at level of urban zones and consequently to determine the extent of the most relevant energy retrofitting interventions to reach the energy performance set by the current energy efficiency regulations and norms.

A potential limitation of the study is that it can be perceived as quite simplistic. However, one of the main added values of the proposed method lies upon this lack of precision. In fact, it is easily exploitable among local administrations that cannot always count on well-trained and high-skilled technicians for managing complicated modelling processes as well as on funds for acquiring sophisticated data or elaborations. The application of the four-steps method described in this paper assists practitioners and technicians along the whole process for obtaining concrete results. Moreover the data needed for applying the method are easily available to local administrations because the acquisition of these data and information – i.e. EPCs and morphological features and uses of buildings – is already systematized within the administrative and planning procedures. Moreover they do not need sophisticated elaborations for being used, however the method allows to obtain a more accurate precision in terms of estimation of energy efficiency than the mere use of the building age, which is frequently used for estimating the energy performance of the building stock at urban scale. In fact even though the feature leading the attribution of sample buildings' energy performance is the building age, the adoption of the $EP_{gl,nren}$ gathered from the EPCs allows to take into account those energy retrofitting interventions that increase the performance of buildings of

Fig. 14. Energy zones in the hamlets.

Table 5
Desirable urban scale strategies on the various energy zones according to their energy efficiency.

$EP_{gl,nren,area}$ classes (kWh/m^2year)	Area type	Proposed strategies
$EP_{gl,nren,area} > 210$	Low performance	Deep energy retrofitting (envelope+ system)
$170 < EP_{gl,nren,area} < 210$		Potential extensive use of volumetric and fiscal incentives
$130 < EP_{gl,nren,area} < 170$		Need to develop integrated regeneration strategies for deep renovation
$90 < EP_{gl,nren,area} < 130$	Medium performance	Light energy retrofitting (system)
$60 < EP_{gl,nren,area} < 90$		Potential marginal use of volumetric and fiscal incentives
$40 < EP_{gl,nren,area} < 60$		Light refurbishments

the same construction period, thus allowing to update the initial estimation made with the first running of the method. This ensures an easy replicability and increased precision of the method if we consider that the systematic collection of EPCs and their transmission to local authorities is already well structured since decades, and it covers a good number of buildings (in Italy it is around 10 % of the total buildings units (Pagliaro et al., 2021), and this number has been increasing over time, pushed by fiscal incentives and regulations. Therefore, the databases are continuously improved and increased with new or updated EPCs, therefore the method can progressively be more precise and easily support the monitoring of the energy efficiency strategies put in place by urban planning policies (Pagliaro et al., 2021). Indeed a new EPC is requested for energy retrofitting interventions, improving the energy performance of the sample buildings ($EP_{gl,nren,mean}$) and consequently the energy performance of the different zones ($EP_{gl,nren,area}$).

CRediT authorship contribution statement

Elisa Conticelli: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Stefania Falcioni:** Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. **Giulia Marzani:** Data curation, Formal analysis, Software, Visualization, Writing – review & editing. **Gian Luca Morini:** Conceptualization, Validation, Writing – review & editing. **Simona Tondelli:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

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