On the use of an energy certification database to create indicators for energy planning purposes: Application in northern Italy

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ABSTRACT

Energy certification of buildings, mandatory under the European Directive EPBD provides interesting data on the thermo-physical properties and geometry of existing buildings. Although the energy certi-ficate is intended to provide the characteristics of individual buildings, so stimulating the real estate market toward ever better energy performance, data management of the certificates issued over time, using a national or regional energy cadastre, makes available a data base which is useful for energy planning in the building sector.

This paper provides the needed results of a benchmarking study on data from the energy cadastre of the Lombardy Region, northern Italy. By integrating data from the energy cadastre (175.778 energy certificates) with the statistical data obtained from the national census, indicators were obtained on the energy performance of existing buildings.

The energy indicators obtained, characterised by building type and construction period, normalised as a function of Degree-Days, become an effective tool for energy planning at local and regional scales. In the specific case, the energy indicators have been used to estimate the potential for energy retrofit of existing buildings in the Lombardy Region. The same indicators can also be used by municipalities for energy planning at the municipal or district level.

1. Introduction

Of all the recognised economic zones worldwide, the European Union is that whose legislators are most dedicated to measures taken to attenuate climatic change effects. Europe is indeed responsible for close on 40% of world energy consumption (Commission of the European Communities, 2006) and the strategic programming instrument employed to ensure the promotion of energy efficiency in buildings is Directive 2002/91/EC (Council of the European Union, 2002). This important Directive, named Energy Performance of Building Directive (EPBD), had the merit of introducing for the first time in the EU the energy certification of buildings which all Member States have transposed into national or regional legislation.

Buildings' energy certification is principally aimed at providing clear guidelines for their energy performance so that an improvement is ensured for the quality of the energetics both of new and of existing buildings in a given area.

In existing buildings for which the energy performance is normally known to be poor, users and citizens have found therein the stimulus to implement strategies for energy retrofits (i.e. thermal insulation of the building envelopes, installation of high performance systems, use of renewable energy sources, etc.) in order to reduce energy consumption.

The impact of energy certification on the building sector is

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currently a key issue. Amecke (2012) analyses, to what extent Energy Performance Certificate (EPCs) have assisted purchasers of owner-occupied dwellings in Germany in adding energy efficiency to their purchase decision priorities. The result of the study, while emphasising the critical aspects of this tool, points out the potentials of the EPCs once some barriers are removed. The impact of EPCs, albeit limited to the rental and capital values of commercial property assets in the UK, is the focal point of a paper of Fuerst and McAllister (2011). The study is based on a cross-section of 708 commercial properties. The conclusion of the authors is that energy labelling is, as yet, not obtaining the desired effect on Market Values and Market Rents. The study's conclusions must however be put in the context of 2011 when the culture of energy certifi-cation was not yet widespread. Similar findings are reported in the study of Parkinson et al. (2013) which investigates whether energy performance certification is an indication of workplace quality.

The EPCs have had a greater impact in northern Italy. As regards new buildings (i.e. those buildings constructed after the implementation of energy certification) the possibility, and in some cases the obligation, to exhibit the energy label with the energy class of the buildings indicated, have orientated the real estate market towards buildings with higher performance: Class A, Class A+ up to Nearly Zero Energy Building (NZEB) standard.

Lombardy (northern Italy) represents an interesting case since a regional policy firmly directed at the promotion of energy efficiency in buildings has been implemented. In this region within a few years (from 2007 to 2013) the market associated with high energy-performance of buildings had already grown substantially: in fact close on 7500 EPCs for buildings of Class A and Class A+ have now been issued (Dall'O' et al., 2013a).

Considering that the existing building stock is numerically significant, and that the energy quality of existing buildings is very low, it is precisely within this context that the instrument of the energy certification is able to offer its full potential. Although energy certificates are intended to provide the characteristics of individual buildings, data management of the certificates issued over time, using the national or regional energy cadastre (the term "Cadastre" denominates the official register of energy certificates), makes available a database useful for energy planning in the building sector. The management of data coming from energy certificates which are produced over time can become an input database tool to support energy policies i.e. energy planning at national, regional or local level.

The issue of energy certification of buildings, its applications in various sectors, even within the energy planning at various scales, is of current interest and the subject of several studies.

Ascione et al. (2013) propose a particular analytical method whose aim is to characterise energy performances for both new and existing buildings, in the winter and in the summer season. With reference to the complete urban context, the method is transferred into Geographical Information Systems (GIS). The key objective of their work, applied to the entire historical centre of the city of Benevento in southern Italy, is the evaluation of its building stock for the identification of critical aspects, in order to encourage effective building design for new structures and proper, suitable refurbishment of those already existing.

Energy certification of buildings has been applied without homogeneity by different countries. In a recent paper some authors (Choongwan et al., 2014) propose a system of energy certification of residential buildings starting from the analysis of the different certification schemes used. The proposed system can allow a policymaker to establish a reasonable and fair energy efficiency rating system for existing residential buildings and can encourage the voluntary participation of all residents in the energy saving campaign.

A much debated point is the accuracy of data from energy certificates. The hypothesis of their possible use does in fact bring to the fore this important issue. Tronchin and Fabbri (2012), in their research work, state that the EPC's effectiveness is dependant upon two elements: the accuracy of independent experts' eva-luation of energy performance and the capabilities of the energy classification and of the energy performance scale to really control the fluctuations in the energy index which arise from differences in input measurements. The results of the work (162 independent technicians examined the same building) reveal which part of confidence intervals depends upon a misunderstanding of soft-ware and the tolerance that the energy certification ranges have for the fluctuations that arise in energy indices. A similar issue was investigated in the paper of Corrado and Houcem (2008).

The evaluation of the potential of energy savings of retrofitting residential building stock is an important issue in the framework of the energy policy to be applied in the building sector. Some authors (Dall'O' et al., 2012) propose a methodology characterised by an innovative approach that considers the actual technological and economic constraints of the implementation of feasible en-ergy efficiency measures. The analysis was applied to five muni-cipalities in the province of Milan (Italy) which have signed the Covenant of Mayors, committing to meet and exceed the 20% CO_2 reduction objective of the EU by 2020.

A paper by Weiss et al. (2012) addresses the question of how to improve or supplement the political instruments in Germany for increasing refurbishment rates and tap these potential savings, considering the barriers responsible for the differences between potential and actual energy retrofit rates. Megalhaes and Leal (2014) investigate the characterisation of thermal performance and nominal heating gap of residential building stock using EPBD-derived databases. The results of the study, conducted in Portugal, confirm the viability, usefulness and richness of using the EPBD-derived databases. In the specific case the authors show a mix of natural improvement with boosts from regulations, with crucial developments observed after 2006, reflecting the positive impact of the EPBD.

Other studies covering the issue of energy performance evaluation of building stock, using energy indicators also coming from certification schemes, are proposed by many authors: Caldera et al. (2008), Dascalaki et al. (2010, 2011), Pérez-Lombard et al. (2009), Reis and Escórcio (2012), McKenna et al. (2013), Tsanas and Xifara (2012).

A methodology orientated towards the identification of build-ing energy quality at the urban scale is described in the work of other authors (Dall'O' et al., 2011). The methods presented in this study-paper were substantially based on pre-existing, available information about the building stock i.e. that from cartographic documentation, thematic maps, geometric data and other such sources. Data on building energy performance were collected by means of energy audits on sample buildings, which were selected through a statistical analysis. Using the instruments of a GIS platform, the integration of two data sources provides an economical but comprehensive framework of building energy performance.

The authors, at that time, did not have data available from the energy cadastre and the feedback on the energy performance of the buildings was made by detailed analysis, through energy audit, of a number of statistically representative sample buildings. The availability of data coming from the energy cadastre opens new opportunities for the development and application of new methodologies.

This paper provides the needed results of a benchmarking study on data from the energy cadastre of the Lombardy Region, northern Italy. By integrating data from the energy cadastre (850.970 energy certificates) with the statistical data obtained from the national census, indicators were obtained on the energy performance of existing buildings. This research work not only provides for the first time a method to create energy indicators, starting from data taken from energy certificates in an area as numerically large as is the Lombardy region (population of about 9.922 million inhabitants), but also applies these indicators within the Regional Energy Plan.

2. The regional cadastre of energy certificates

2.1. The energy certification scheme in the Lombardy Region

The government of the Lombardy Region, located in northern Italy, was the first in Italy to have autonomously transposed Directive 2002/91/EC (Council of the European Union, 2002) into its own (thus regional) legislation, in compliance with Article 17 of Legislative Decree No. 192 (Italian Government, 2005) (compliance clause). In this manner with a law of the region (Lombardy Region, 2006) Lombardy ensured the adoption of the new rules concerning building energy certification, in accordance with the directive and the general principles covered by (Italian) Legislative Decree No. 192.

The operatively of the certification was enacted by the Regional Council Decree No. VIII/5018 (Lombardy Region, 2007a), which was then expanded upon by the Regional Council Decree No. VIII/ 5773 (Lombardy Region, 2007b).

Director General's Decree No. 5796 (Lombardy Region, 2009) involved updating of calculation procedures, whilst Decree No. 2554 (Lombardy Region, 2011) was essentially approval of the energy performance certificate verification procedure.

Regional Committee Decree No. VIII/5018 also gives details of the energy performance indicator calculation method which takes into consideration the use of energy for heating, cooling, ventilation, and domestic hot water. In order to help the calculations required for EPCs purpose, the Lombardy Region supply a software called CENED+, and which could be downloaded directly, free of charge, from the official website of the Regional Accreditation Body (RAB). The new calculation methodology is more sophisti-cated and complete, and far more similar to that used nationally (UNI/TS 11300), and indeed to the European standards issued by the European Committee for Standardization (CEN) on the basis of European Commission Mandate 343, supporting EPBD implementation in the Member States. It integrates the latter so as to allow for the most varied building-plant systems which may exist. For the energy balance calculation on the building envelope, both the regional and national standards largely refer to Standard 13790-08 (ISO-CEN, 2008).

The Lombardy Region is the first Italian region to implement the EPBD, moreover regional policy to promote energy efficiency has been very effective and determined. For these reasons, in the Lombardy region 51.2% of Italian EPCs have been recorded (Boffa et al., 2013): a very considerable percentage when one considers that, according to ISTAT (National Institute of Statistics), only 16.4%of the Italian population lives in Lombardy.

2.2. The regional accreditation body

The Lombardy Region had entrusted CESTEC (Centro Lombardo per lo Sviluppo Tecnologico e Produttivo dell'Artigianato e delle Piccole Imprese) a company wholly under its ownership, with the role of RAB for energy certifiers. As of January 1st 2013 CESTEC was then taken over by Finlombarda which has now become the RAB, to whom the tasks assigned include

- provision for energy certifier accreditation,
- creation and management of an cadastral energy register of buildings,
- development of software which assists in the calculations necessary for building energy certification,
- update of the calculation procedure used for the determination of a building's energy performance, and the forms which must be used as a part of the certification process,
- regular monitoring of the impact of the provision for energy certification on end-users, from the points of view of bureaucracy, cost and benefits,
- regular assessment of the impact of the provision for energy certification on the regional real estate market, as well as on builders, manufacturers of materials and components, and companies producing HVAC Systems or offering services for installation and maintenance,
- provision for scientific and technical advice in assistance to regional and local and bodies and to certifiers within the region, so as to ensure the effectiveness and uniformity of the implementation of energy efficiency standards and
- adoption of those measures necessary for the revocation and suspension of accreditation.

"Via the building energy cadastre which Finlombarda administers, it is possible to monitor, in real time, the evolution of the housing market in Lombardy" (Dall'O' et al., 2013a).

2.3. Characteristics of the energy cadastre

In Lombardy Region the energy certification procedure requires that the energy assessor, registered in the regional professional register of energy assessors, must transfer the entire set of the data contained in a single EPC into the regional cadastre, automatically: in this way the energy certificate database is updated in real time.

In order to promote transparency of public administration, the Lombardy Region, as of 2013, has released the data on the EPCs (https://www.dati.lombardia.it/). Relevant data of each EPC can be read on-line by any citizen. Alternatively, the entire database of energy certificates can be downloaded in order to allow off-line processing.

Table 1 shows the available data: these refer to the main characteristics of the energy certificates.

The published database does not contain all the characteristics of the buildings but only the main ones; however these are sufficient for our purposes. In the event that it is necessary to investigate in greater detail, it is possible, through the identification code of the EPC, to request from the RAB the complete database of the building investigated.

3. Description of the methodology

3.1. Methodological approach

Energy certification of buildings allowed the Lombardy Region to acquire a considerable amount of information about the housing stock: at the date of September 15, 2013 the total number of registered EPCs, referred to the residential sector, amounted to 1,154,610. In the energy cadastre of the Lombardy region EPCs relative to the other sectors (schools, offices, industrial, commercial, etc.) are also stored: it should however be recalled that this study was limited to the residential sector.

A first analysis of the database of the energy cadastre made it possible to delete records corresponding to the buildings in which the fields were incomplete, after this data-cleaning process, the number of EPCs was reduced to 850,970.

The EPCs in the database refer to certifications that may relate to entire buildings or individual flats. The objective of the study,

Table 1
Structure of the database of the EPC cadastre.

Symbol	Field description	Units
EPC #	Energy Performance Certificate Code	–
A_{ID}	energy assessor ID number	–
Loc	location (municipality)	–
DD_W	winter standard Degree-Days	°C
BT	building type (e.g. residential, school, office, etc.)	–
CY	construction year	–
Mot	motivation for issuance of the certificate (e.g. for sale, for lease, for redevelopment, etc.)	–
A_g	gross floor area	m^2
A_n	net floor area	m^2
V_g	gross volume	m^3
V_n	net volume	m^3
S	dispersant surface	m^2
GO_R	glass surface/opaque surface ratio	–
U_e	average *U*-value of the building envelope	W/m^2 K
U_r	average *U*-value of the roofing	W/m^2 K
U_w	average *U*-value of the windows	W/m^2 K
U_b	average *U*-value of the basement	W/m^2 K
EC	energy class (ranging from A+ to G)	
ET_H	heat demand indicator	kWh/m^2 y
EP_H	primary energy indicator	kWh/m^2 y
Vent	ventilation type (e.g. natural, mechanical, etc.)	–
AC	air changes	1/h
P	boiler capacity	W
HT	heating system (e.g. boiler, heat pump, CHP, etc.)	–
Ft	fuel type (e.g. gas, oil, etc.)	–
SPV	solar PV system type (e.g. monocrystalline silicon, amorphous silicon, etc.)	–
PV	solar PV surface	m^2
STH	solar thermal type (e.g. flat plate, vacuum, etc.)	–
TH	solar thermal surface	m^2

however, was to define the characteristics of entire buildings. In order to achieve this goal, only records in which all surfaces of the building envelope (roofs, walls, basement) had a value greater than 0 were selected. After this processing it was found that of the entire archive the certifications that refer to complete buildings are 233,212.

The climatic characteristics of the Lombardy region are very diverse, so far as winter conditions are concerned, the standard Degree-Days (DD) ranging from 2040 to 4648. The UNI EN ISO 15927-6:2008 standard (UNI EN ISO, 2008) specifies the definition, the calculation method and the presentation method of the data related to the cumulative temperature differences (Degree-Days), employed to estimate the energy utilised for heating the buildings in question. Such data are generally expressed in degree-hours or Degree-Days and are often indicated simply as “heating degree hours” or “heating degree days”.

The values of ET_H and EP_H of each energy certificate were influenced, according to the official calculation procedure (Lombardy Region, 2007a, 2007b) by the local DD_W. In order to make the information contained in the database independent from the value of the local DD_W, all values of ET_H and EP_H were normalised using the following equations:

$$ET_{H,NOR} = \frac{ET_H \cdot DD_{W,AVE}}{DD_{W,ACT}} \tag{1}$$

and

$$EP_{H,NOR} = \frac{EP_H \cdot DD_{W,AVE}}{DD_{W,ACT}} \tag{2}$$

where $ET_{H,NOR}$ and $EP_{H,NOR}$ are respectively the values of the heat demand indicator and the primary energy indicator for heating, $DD_{W,ACT}$ is the value of the standard Degree-Days for the location considered (municipality) whilst $DD_{W,AVE}$ is the average value of DD_W weighted on the area of the territory in question (this value for Lombardy Region was estimated to be 2514).

3.2. Check the consistency of data

The platform of the energy cadastre of the Lombardy Region does not verify the consistency of the data contained in the EPCs downloaded. For this reason it was necessary to clean up the database by removing all records that contain obvious errors.

The analysis of possible errors has been a rather difficult phase. Some errors emerge by checking the single data points: if the *U*-value (overall heat transfer coefficient expressed in W/m^2 K, calculated accordingly) of a building structure is too high or too low, or equal to zero, it is appropriate to delete the record. Some errors, however, emerge only on the basis of indicators that can be derived from the available data shown in Table 1: dividing the value of the net volume V_n by the net floor area A_n, for example, it is possible to obtain a good approximation of the value of the average height of the rooms, and observe whether this value is reasonable. Table 2 shows the parameters used to filter the data in the first screening.

So far as the net floor area A_n is concerned, one must bear in mind that, according to the Italian Laws (Italian Government, 2005) EPCs are not expected for entire buildings with a net floor surface < 50 m^2. The average height is calculated dividing the net volume (V_n) by the net floor area (A_n): building regulations in Italy do not permit the construction of buildings with a height of less than 2.4 m, on the other hand it is very unlikely that residential buildings have a height greater than 6 m. The lower limit for the net volume is derived by multiplying the minimum surface area (50 m^2) by the minimum height (2.4 m).

For the limits of the ratio of total envelope surface and heated volume, the simulations were made with simple geometries that have allowed the exclusion of values outside this range.

The range of the *U*-values were determined with reference to the schedules given in the technical standards to support the energy certification (UNI, 2008): a further screening was done by analysing the buildings according to their construction period.

The limits of the ratio ET_H/EP_H have been defined considering the minimum output performance values of the components of the installations (emission, distribution, control and generation) as foreseen by the standard (UNI, 2008), considering traditional boilers as the heat generators, whereas the maximum values are

Table 2
List of the parameters used to filter the data contained in the energy cadastre.

Parameter description	Unreliability of the parameter
Net floor surface (A_n)	$A_n < 50$ m^2
Net volume (V_n)	$A_n < 120$ m^3
Ratio of dispersant surface and heated volume (S/V_g)	$S/V_g < 0.2$ or $S/V_g > 1.5$
Calculated average height (V_n/A_n)	< 2.4 m or > 6 m
U-values for opaque surfaces	$U < 0.15$ W/m^2 K or $U > 2.60$ W/m^2 K
U-values for transparent surfaces	$U < 0.8$ W/m^2K or $U > 6.00$ W/m^2 K
Heat demand indicator/primary energy indicator (ET_H/EP_H)	< 0.5 or > 1.5

obtained by considering the maximum output performance with electrical heat pumps as the heat generators.

At the end of screening, the number of buildings considered reliable was reduced to 175,778: this means that, in the absence of a check on EPCs when they are inserted, 24.6% of the energy certificates contain information with risk factors.

3.3. Definition of the analysis matrix

The Italian national census (http://www.istat.it/it/) classifies the existing buildings on the basis of two parameters of interest:

- construction period and
- number of flats per building.

The construction period can be reasonably related to the construction technology involved, while the number of apartments per building characterises the size of the building and the S/V ratio.

Concerning the first parameter, the buildings were divided into 7 classes: the construction period is one of the items of information contained in the EPCs database and therefore readily available.

For the second parameter, number of flat per building, all the buildings were clustered according to the classification range proposed by ISTAT: six classes distributed from 1 to >31 flats per building. The clustering according to the six classes, starting from the EPCs of the energy cadastre, was possible because the field "number of flats per building" was available for each EPC.

Table 3 shows the matrix used for the building classification in accordance with the parameters chosen. The matrix that has emerged consists of $7\times6=42$ cells.

The choice of this matrix is important because it is compatible with the data available via the national census and, as shall be seen later, allows the creation of interesting synergies between the energy cadastre and the database of the national census.

3.4. Definition of representative buildings

The next step of the procedure aims to define a matrix, like that in Table 3, but in which will be identified a selection of representative buildings of the existing building stock. This step is important as it allows one to define the indicators in order to characterise the geometrical, thermo-physical and energy performance of the existing building stock.

The study conducted by Dall'O' et al. (2011) showed a good correlation, within the same period of construction, between the value of the normalised ET_H (heat demand indicator) and the value of S/V (ratio of total envelope surface and heated volume).

The current situation might be changed since a certain number of buildings, taking advantage of the economic incentives and tax deductions in recent years, have been renovated (building envelope with improved performance), so whilst belonging to a period of construction, do not conserve the energy performance that they had originally at the time of construction.

Starting from the data of EPCs, one can subdivide the matrix of Table 3 into submatrices on the basis of the following criteria:

- buildings which preserve their original energy performance;
- buildings which have been partially retrofitted to improve their energetics (replacement of windows); and
- buildings which have undergone complete energy retrofit (replacement of windows and building envelope insulation).

The possibility of obtaining three matrices is very useful since it allows one to test the potential for improving energy performance.

In order to effect the selection, "bin"s of a size equating to 20%of the standard deviation of the U-values of the opaque walls have been defined and the number of buildings falling into each "bin" category has been calculated in order to construct the distribution of the number of buildings as a function of the said parameter. The same procedure was applied to the U-values of the doors and windows (Fig. 1).

Fig. 2 carries an example of the distribution obtained for opaque walls where two groupings of U-values are apparent, owing to the fact that several buildings have undergone improvement and upgrading works. Those buildings with a U-value greater than 0.9 have been considered to be non-upgraded, whilst the remainder have been considered as upgraded. The same procedure has been applied for the doors and windows. For the buildings of more recent construction this grouping of the values was not apparent.

At this stage three classes of buildings are highlighted: buildings that preserve their original energy performance, buildings that have been partially retrofitted to improve their energetics (window replacement) and buildings that have undergone a complete energy retrofit (replacement of windows and building envelope insulation). However the definition of the representative buildings that constitute the final matrices do require additional steps, including data-filtering.

Thus after having defined the three classes of building, always constructing the distributions of the number of buildings as a function of other indicators e.g. the average U-value of the roof, the average U-value of the basement, ET_H, EP_H, the ratio between the heating capacity and the net floor surface, the overall average efficiency of the heating system (expressed as ET_H/EP_H) and the S/V ratio, a sequential filtering operation was then performed, as exemplified in Fig. 3, adapting the widths of the filtration windows in such a way as to obtain not more than 10 sample buildings for each cell.

This frequency analysis is used to select the really significant samples, eliminating those characterised by the parameter values which are least recurrent. The analysis was performed for each of

Table 3
Number of selected EPCs for construction period and number of flat per building.

Construction period	Number of flats per buildings						Records	%
	1	2	3–8	9–15	16–30	>31		
<1930	19.578	607	428	189	208	54	21.064	12.0
1930–1945	8.297	205	171	182	170	66	9.091	10.6
1946–1960	15.980	573	401	443	604	310	18.311	10.4
1961–1976	27.635	1.597	1.296	1.373	1.568	730	34.199	19.5
1977–1992	27.180	921	349	230	201	131	29.012	16.5
1993–2006	32.053	515	165	61	81	30	32.905	18.7
After 2006	27.130	546	1.507	1.064	660	289	31.196	12.3
Total	157.853	4.964	4.317	3.542	3.492	1.610	175.778	100.0

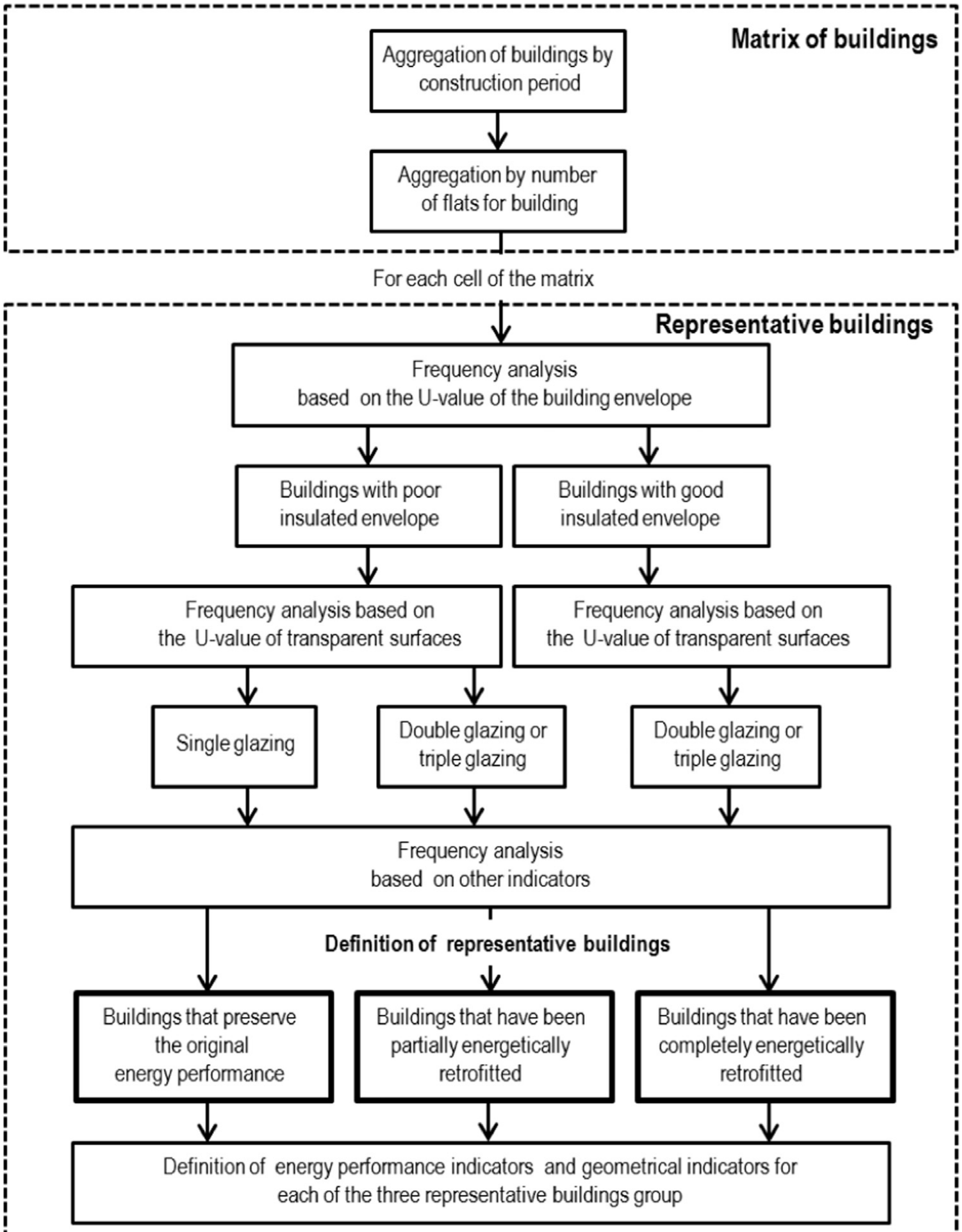

Fig. 1. Diagram of the procedure for the definition of the representative buildings within each cell of the matrix of Table 3.

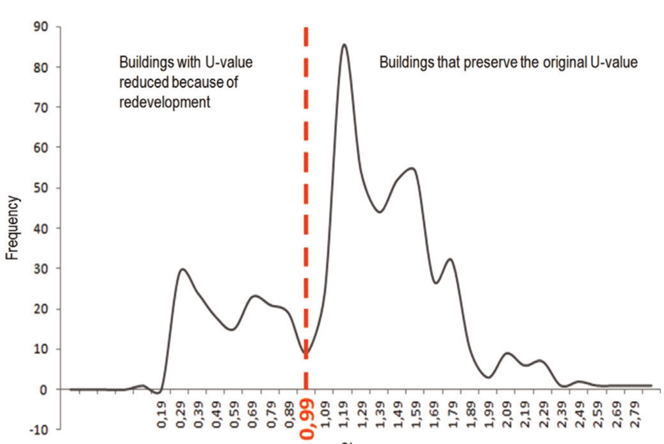

Fig. 2. Example of the frequency distribution of the buildings as a function of *U*-value.

the 42 cells of the matrix and was therefore quite complex.

4. Results and discussions

4.1. Evaluation of performance indicators for the representative buildings

The final result of this statistical analysis is represented by three matrices, as shown in Tables 4 and 5, but with the number of samples per single cell decidedly reduced.

From Tables 5 and 6 one can see that the values of the average heat requirement ET_H and the primary energy demand for heating EP_H decrease with the construction period (given in chronological order), with the entry into force of the regulations for reductions in energy consumption, and with the increase in the size of buildings (S/V ratio increases thereby giving rise to less envelope surface for the same heated volume).

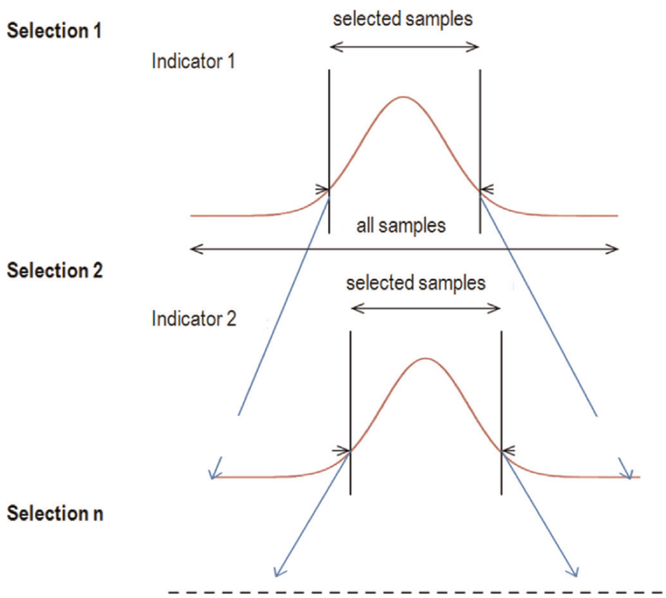

Fig. 3. Diagram for selection of representative buildings.

Table 4
Average value of ET_H (kWh/m^2 y) for the representative buildings, broken down by period of construction, number of flats per building and conservation status.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MA1.1 – buildings that preserve their original energy performance						
< 1930	287	276	199	149	140	150
1930–1945	290	279	187	152	142	159
1946–1960	292	265	189	161	147	141
1961–1976	275	250	193	169	154	139
1977–1992	230	215	184	163	150	127
1993–2006	118	113	98	71	64	53
> 2006	52	50	42	40	39	36
MA1.2 – buildings that have been partially energetically retrofitted to improve energetics						
< 1930	232	215	165	136	134	129
1930–1945	239	227	163	139	134	115
1946–1960	237	225	178	137	129	124
1961–1976	237	215	166	138	129	122
1977–1992	176	159	149	128	123	114
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–
MA1.3 – buildings that have undergone complete energy retrofit						
< 1930	83	74	58	55	60	77
1930–1945	80	68	56	75	52	61
1946–1960	82	80	61	48	65	68
1961–1976	90	84	76	84	81	71
1977–1992	90	79	70	64	72	66
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–

The energy performance indicators reported are interesting and useful because they are derived from information obtained from energy certificates on real buildings. The comparison between the data of the matrix MA1.1 and those of the matrix MA1.3 expresses the real potential of the improvement of the building envelope energy performance, whilst comparison between the data of matrix MB1.1 and of matrix MB1.3 expresses the potential real improvement of the energy performance of retrofit actions which may also affect plant.

Table 5
Average value of EP_H (kWh/m^2 y) for the representative buildings, broken down by period of construction, number of flats per building and conservation status.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MB1.1 – buildings that preserve their original energy performance						
< 1930	386	374	271	201	196	237
1930–1945	391	377	287	234	221	251
1946–1960	392	379	290	231	206	186
1961–1976	372	354	263	227	202	185
1977–1992	311	303	254	213	196	178
1993–2006	160	142	130	91	82	64
> 2006	59	52	44	43	41	39
MB1.2 – buildings that have been partially retrofitted to improve energetics						
< 1930	302	287	222	192	182	180
1930–1945	311	305	219	183	166	162
1946–1960	321	304	247	191	184	168
1961–1976	316	288	220	195	180	154
1977–1992	236	215	193	162	160	157
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–
MB1.3 – buildings that have undergone complete energy retrofit						
< 1930	101	85	65	60	60	93
1930–1945	102	78	61	88	53	91
1946–1960	108	101	74	57	93	110
1961–1976	109	99	95	115	114	110
1977–1992	113	105	90	107	109	93
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–

Table 6
Average *U*-values (W/m^2 K) of the opaque vertical envelope for the representative buildings which preserve their original energy performance.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MC1.1 – buildings that preserve their original energy performance						
< 1930	1.46	1.62	1.44	1.36	1.32	1.22
1930–1945	1.33	1.41	1.38	1.37	1.37	1.39
1946–1960	1.39	1.35	1.36	1.30	1.25	1.21
1961–1976	1.35	1.34	1.27	1.29	1.28	1.27
1977–1992	0.99	1.10	1.15	1.01	1.22	1.39
1993–2006	0.65	0.70	0.64	0.60	0.59	0.66
> 2006	0.28	0.28	0.27	0.30	0.29	0.29

4.2. Evaluation of performance indicators of the building envelope for the representative buildings

Matrix MC1.1, shown in Table 6, expresses the average *U*-values of the opaque vertical envelope for the representative buildings which preserve their original energy performances. One can

Table 7
Average *U*-value (W/m^2 K) of the opaque vertical envelope for the representative buildings which have undergone complete energy retrofit.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MC1.2 – buildings that have undergone complete energy retrofit						
< 1930	0.45	0.40	0.38	0.42	0.46	0.60
1930–1945	0.49	0.36	0.49	0.41	0.25	0.51
1946–1960	0.45	0.45	0.40	0.38	0.50	0.51
1961–1976	0.39	0.43	0.52	0.67	0.61	0.53
1977–1992	0.41	0.46	0.46	0.41	0.51	0.52
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–

Table 8
Average U-value (W/m^2 K) of the roofs for the representative buildings that preserve the original energy performance.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MD1.1 – buildings that preserve their original energy performance						
< 1930	1.54	1.55	1.40	1.49	1.53	1.54
1930–1945	1.57	1.52	1.47	1.46	1.38	1.49
1946–1960	1.51	1.42	1.44	1.36	1.42	1.43
1961–1976	1.50	1.45	1.26	1.44	1.40	1.42
1977–1992	1.20	1.38	1.39	1.27	1.37	1.52
1993–2006	0.61	0.67	0.63	0.51	0.56	0.70
> 2006	0.27	0.26	0.28	0.26	0.26	0.26

Table 9
Average U-value (W/m^2 K) of the roofs for the representative buildings which have undergone complete energy retrofit.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MD1.2 – buildings that have undergone complete energy retrofit						
< 1930	0.34	0.32	0.30	0.31	0.29	0.39
1930–1945	0.41	0.27	0.26	0.43	0.26	0.30
1946–1960	0.54	0.61	0.30	0.39	0.39	0.52
1961–1976	0.41	0.44	0.40	0.41	0.56	0.61
1977–1992	0.48	0.41	0.50	0.44	0.48	0.50
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–

observe that the values of the thermal transmittances decrease as a function of the construction period (where the periods are in chronological order), in accordance with the national and regional laws on energy saving which have made compulsory better thermal insulation of the building envelopes.

Matrix MC1.2, shown in Table 7, expresses the average U-values of the opaque vertical envelope for the representative buildings which have undergone complete energy retrofit. One observes a dramatic reduction of the U-values, particularly for the oldest buildings. The thermal insulation of the external walls in existing buildings normally is made using the External Thermal Insulation Composite Systems (ETICS) technology (Dall'O', 2013).

Matrix ME1.1, shown in Table 10, expresses the average U-va-lues of the transparent surfaces for the representative buildings which preserve their original energy performances. The values of the thermal transmittances decrease after 1993–2006 construc-tion period, in accordance with the national and regional laws on energy saving.

Matrix ME1.2, shown in Table 11, expresses the average U-values of the transparent surfaces (e.g. windows) for the representative buildings which have undergone complete energy retrofit. In this case the old single glazed windows are replaced with double-glazed or triple-glazed windows.

4.3. Evaluation of geometrical indicators for the representative buildings

The data provided by the national censuses normally refer only to the net floor area of the flats of the existing building stocks. In order to assess the energy performance of buildings, and to estimate quantitatively the energy retrofit scenarios, data regarding the building envelopes, divided up by types of structure (e.g. opaque walls, transparent walls, roofs, basement) are essential. Using the information obtained from the database of representative buildings is possible to derive indicators which, multiplied by the net floor area for each cell of the matrix, allow one to obtain the required values:

- Matrix MF1.1, shown in Table 12, expresses the ratio between the opaque surfaces of the vertical building envelopes and the

Table 10
Average U-value (W/m^2 K) of the transparent surfaces for the representative buildings which preserve their original energy performance.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
ME1.1 – buildings that preserve their original energy performance						
< 1930	4.87	4.78	4.67	4.66	4.46	4.75
1930–1945	4.97	4.93	4.89	4.96	4.95	4.95
1946–1960	4.91	4.92	4.94	4.91	4.94	4.95
1961–1976	5.04	4.97	4.92	4.93	4.93	4.92
1977–1992	4.90	4.96	4.93	4.95	4.83	4.83
1993–2006	3.00	2.99	2.76	2.77	2.89	2.80
> 2006	1.57	1.56	1.65	1.58	1.55	1.68

Table 11
Average U-value (W/m^2 K) of the transparent surfaces for the representative buildings which have undergone complete energy retrofit.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
ME1.2 – buildings that preserve their original energy performance						
< 1930	2.03	1.77	1.68	1.67	1.66	2.19
1930–1945	2.16	1.74	1.58	1.57	1.50	2.08
1946–1960	2.07	2.15	1.74	1.70	2.41	2.57
1961–1976	1.94	2.13	2.11	2.81	2.18	3.47
1977–1992	2.35	2.26	1.95	2.74	3.39	2.60
1993–2006	–	–	–	–	–	–
> 2006	–	–	–	–	–	–

Table 12
Ratio between the opaque surfaces of the vertical building envelopes and the net floor area.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MF1.1 – average on all buildings						
< 1930	0.48	1.51	0.85	0.72	0.76	0.75
1930–1945	0.54	1.54	0.81	0.62	0.54	0.95
1946–1960	0.61	1.53	0.79	0.80	0.60	0.73
1961–1976	0.57	1.48	0.96	0.88	0.63	0.72
1977–1992	0.39	1.25	1.06	0.91	0.72	0.75
1993–2006	0.46	1.24	1.00	1.15	0.90	0.82
> 2006	0.41	1.50	1.12	1.19	1.10	0.98

Table 13
Ratio between the transparent surfaces of the vertical building envelopes and the net floor area.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MF1.2 – average on all buildings						
< 1930	0.173	0.157	0.173	0.183	0.170	0.193
1930–1945	0.165	0.196	0.191	0.200	0.203	0.181
1946–1960	0.169	0.185	0.188	0.183	0.189	0.200
1961–1976	0.193	0.197	0.190	0.170	0.190	0.177
1977–1992	0.187	0.170	0.177	0.187	0.190	0.193
1993–2006	0.183	0.189	0.216	0.206	0.220	0.196
> 2006	0.180	0.220	0.200	0.210	0.230	0.250

Table 14
Ratio between the roofs surfaces and the net floor area.

Construction period	Number of flats per building					
	1	2	3–8	9–15	16–30	> 31
MF1.3 – average on all buildings						
< 1930	1.17	0.60	0.59	0.43	0.45	0.44
1930–1945	1.18	0.65	0.68	0.52	0.45	0.38
1946–1960	1.16	0.59	0.63	0.41	0.42	0.29
1961–1976	1.17	0.58	0.64	0.40	0.38	0.32
1977–1992	1.18	0.56	0.61	0.38	0.40	0.29
1993–2006	1.10	0.60	0.59	0.40	0.40	0.28
> 2006	1.20	0.63	0.58	0.36	0.41	0.29

net floor area.

- Matrix MF1.2, shown in Table 13, expresses the ratio between the transparent surfaces of the vertical building envelopes and the net floor area.
- Matrix MF1.3, shown in Table 14, expresses the ratio between the roofs' surface and the net floor area.

4.4. *The use of indicators to support energy planning*

The indicators derived from the analysis of the database of the energy cadastre of the EPCs in Lombardy Region can be used in the form of matrix, in the context of energy planning, both at regional and local level (municipal level).

The starting point for further processing is the availability of a matrix (construction period – number of flats per building) in which each cell is given the value of the total net area of the existing building stock: in the case of Italy, this matrix can be derived from the data of the national census. The structure of the matrix, and consequently the number of cells over which the existing building stock is divided, depends upon the availability of data and can be adapted accordingly.

Having available the matrix that defines the net floor areas, which can be denominated the M0.0 matrix, and the matrices with the indicators described above, the calculations are simple and can be performed using a spreadsheet, through normal operations of addition, subtraction, multiplication and division between cells.

The following equations shows some examples of calculation which can be performed using the matrices from Tables 4 to 14.

The global opaque surfaces of the building envelopes GS_O could be calculated using Eq. (3):

$$GS_o = M0.0 \cdot MF1.1 \quad (3)$$

Similarly the global transparent surfaces of the vertical building envelope GS_T and the global surfaces of the roofs GS_R could be calculated with Eqs. (4) and (5):

$$GS_T = M0.0 \cdot MF1.2 \quad (4)$$

$$GS_R = M0.0 \cdot MF1.3 \quad (5)$$

The average energy efficiency η_H of the heating systems could be roughly estimated using Eq. (6):

$$\eta_H = MA1.1/MB1.1 \quad (6)$$

if we consider buildings that preserve their original energy performance, or using Eq. (7) if we consider buildings which have undergone complete energy retrofit:

$$\eta_H = MA1.3/MB1.3 \quad (7)$$

Using the matrices it is possible to make more complex calculations, for example it is possible to estimate the potential energy savings that could be achieved through a complete redevelopment of existing buildings that preserve the original energy performance ES_G, as shown in Eq. (8):

$$ES_G = MA0.0 \cdot (MA1.1 - MA1.3) \cdot B_{NR} \cdot B_{RP} \quad (8)$$

where B_{NR} defines the share of existing buildings that preserve their original energy performance and B_{RP} defines the share of buildings which can reasonably be upgraded considering both the technical constraints and economic constraints. As regards the latter aspect, Dall'O' et al. (2012) propose a methodology for evaluating the potential energy savings of retrofitting residential building stocks. The paper describes an innovative approach for the analysis of the potential energy savings of retrofitting existing building stocks. In particular, this study considers the actual technological and economic constraints of the implementation of feasible energy efficiency measures.

The definition of a matrix that has as coordinates the construction period and the number of flats per building provides a high flexibility in the estimation of the scenarios: in fact, it is possible to limit the calculations to a portion of the matrix.

4.5. *Application of the methodology for calculating the energy savings potential in the Lombardy Region*

The Lombardy Region is currently updating its Regional Energy and Environmental Plan. For the evaluation of the potential for energy savings in the residential sector, the Region used this method, based on statistical data of the existing building stock.

A limit of the proposed method lies in the fact that all the energy assessments are based on a theoretical calculation: in fact the energy performances calculated for the preparation of EPCs refer to the technical standards and take account of a standard use of the building. In other words, the real energy consumption of buildings can be different from the theoretical one and consequently even the potential for savings may be different.

In order to bring the assessments of potential savings calculated on the basis of the needs arising from standardised algorithms, related to energy certification, into line with actual consumption measured on the residential sector, it is necessary to define the relationship between the two variables involved.

The Lombardy Region has estimated that the theoretical consumption for space heating in the residential sector is 27% higher than the actual one. Therefore in its analysis it has taken account of this corrective index (Finlombarda, 2014).

The analysis conducted by the Lombardy Region, considering the feasibility indicators proposed by Dall'O' et al. (2012), assumed three scenarios: the simple replacement of windows (from single to double pane glass) leads to a reduction in overall consumption of 7%, the replacement of windows and the total redevelopment with only ETICS leads to a reduction in consumption of 41%, whereas window replacement and the redevelopment of the opaque walls using also other techniques, where ETICS is not ap-plicable (e.g. thermal insulation of wall cavity or insulation from inside), leads to a reduction in consumption of 62%. The assess-ments carried out by the Lombardy Region highlight the theore-tical potential of energy retrofit in the residential sector. Although the economic aspects may constitute obstacles in promoting en-ergy efficiency, the definition of potential with an analytical ap-proach such as the one described is a good starting point.

5. Conclusions and policy implications

In territorial energy planning, both at regional and at local (municipal or of a zone of a town) scale the sector of residential buildings offers great opportunities. Improvement in energy performance through policy strategies which promote retrofit works on the existing building stock contributes substantially to a reduction in the emissions of CO_2 and of gaseous pollutants and at the same time can activate a local market in energy efficiency and create jobs.

A more complete approach to the definition of energy upgrading strategies must take account not only of the technical aspects (for example identifying the best solution) but also of the economic (find that solution which for the same improvement in the energy performance costs less), political and social factors. The necessity of actuating local policies for energy upgrading of existing buildings with an approach of this kind becomes apparent from research work of Dall'O' et al. (2013b) which analyses the application of Multi-Criteria Methodology to Support Public Administration Decision Making Concerning Sustainable Energy Action Plans. The methodology, based on the ELECTRE III method, was applied to a medium-size municipality in the Lombardy Re-gion of Italy.

However whatever the type of analysis employed, knowledge is required of the key data concerning existing building stock, both in quantitative (number of buildings) and qualitative terms (e.g. construction type, standard of maintenance, quality of energetics, etc.) and this is often a problem. It is one thing to analyse a few buildings, and in this case it is necessary to perform an energy audit for each one of them, it is quite another to analyse the buildings of an entire territorial area which can also be extensive.

The research work presented here proposes for the very first time an integrated approach and provides a relatively simple procedure for characterising, even to a highly detailed degree, the building stock of a densely populated region such as the Lombardy Region of Italy. The methodology proposed, applied in this particular study in the context of the territory of the Lombardy Region, does lend itself also to application in other contexts, provided that data relating to energy certificates are available, better if in a digital format. Considering that all the nations of the European Union have the obligation to apply energy certification to build-ings, these data are generally available.

The innovative element of this study consists of the fact that the characterisation of the building stock does not require field investigations across the territory, measurements nor energy audits but is rather based upon existing information which is already available; this being that of the energy certificates registered in the databases.

Building energy certification, as introduced by the EPBD, provides individual information on building energy performance. In many cases these data are managed centrally by an energy cadastre and the information in the archives may also be used for other purposes.

The work described in this paper analyses the data in the energy cadastre of the Lombardy Region and proposes a methodology to obtain from such a source reliable indicators that could be used to support local and regional energy policies.

The proposed methodology, starting from the aggregate data for the building stock subject to energy certification, through the filtration procedures described in this paper permits the construction of a matrix within which the most representative buildings are defined. This characterisation of building stock is very useful, not only for elaborating projections about possible energy upgrading policy strategies but also for taking action which permits monitoring of the evolution of performance indicators of the energy quality of the building heritage concerned.

Once the matrix has been set up, it can be applied not only for enacting energy policies at a regional level but also at a lower territorial level, for example on a municipality or locality scale. Amongst the energy policy strategies which can be supported by this tool are to be considered: the evaluation of the potential of energy retrofit actions on the existing building heritage, the consequent reduction in the emissions of greenhouse gases, the economic evaluation of energy retrofit strategies, the identification of fields of application for innovative technologies, for example the installation of heat pumps to replace condensing boilers and the diffusion potential of renewable energy sources (solar heating, photovoltaics). The methodology proposed can moreover be useful in facilitating the monitoring phase of Sustainable Energy Action Plans (SEAP) foreseen by the Covenant of Majors.

The method's flexibility is demonstrated by the use of the indicators presented and described in Section 4.4 by means of which it is possible to perform, in a simple manner, through operations with the matrices, quantitative evaluations, for example the evaluation of the overall surface of the outside walls which could be thermally insulated or indeed the total area of the doors and windows to be replaced. It is also possible to make performance evaluations, since the matrices also consider data such as for example the *U*-values of the various building structures.

A problem which emerged from the data analysis concerns the reliability of EPCs stored: in our case 24.6% of the energy certificates contain information with risk factors i.e. they have been certified with data that are not reasonable or indeed clearly wrong. The implementation of procedures for filtering data, to be activated when downloading EPCs certainly reduces the possibility of having wrong energy certificates. The availability, in our case, of a consistent database has helped us to obtain reliable data with which to build the indicators.

The objective of our study was that of obtaining data on representative buildings and it is for this very reason that filtering activities proved necessary in order to eliminate the records containing risky information. In a case in which the objective is that of verifying the correct application of energy certification, the analysis of the database can bring to light exactly those records containing incongruous elements, providing precise indications of the energy certificates which should be checked.

The definition of a matrix that has as coordinates the construction period and the number of flats per building provides a high flexibility in the estimation of the scenarios: through the matrix, in fact, the policy maker is able to promote strategies energy retrofit in a selective manner. The political decision-maker thereby has an instrument which permits the promotion of targeted actions of diverse nature (for example financial support for energy upgrading) in buildings belonging to a certain period of construction or in buildings of a small or medium size.

The energy performance calculated in EPCs are based on theoretical calculations of primary energy consumption in standard conditions. The Lombardy Region, who applied the method in the context of the Energy and Environmental Regional Plan, has estimated that the theoretical consumption for space heating in the residential sector is 27% higher than the actual one. The comparison between real consumption data and the theoretical consumption data could be made on a statistically representative sample of buildings: the organisation of the data on the basis of the matrix provides a useful reference for the selection of samples.

The matrices obtained for representative buildings are sufficiently coherent and useful to provide a frame of reference for the consistency of existing residential buildings as a whole. For the first time an analysis is proposed which is able to express statis-tically reliable information, a good starting point to promote en-ergy policies at regional or local level.

The implications for policy making of the results of this study are significant. The method of analysis does in fact lend itself to becoming a useful instrument, and above all simple to use, not only in planning energy retrofit strategies in the residential building sector (starting from data which are certain) but also in measuring the effects of such policies over time. As previously mentioned, the setting up of a matrices permits one to intervene in a selective manner, concentrating the strategies on particular types of building, for example as a function of the number of flats per building, but also on those associated with specific threshold dates in construction technology.

The items of information contained in the matrices are also quantitative and arrive at interesting details: it is for example possible to establish what is the thickness of the insulating material that should be added to a given structure, or indeed how many windows must be replaced. The technical evaluations, always extended to a part of, or the entire building stock, can be made also in terms of the economics (i.e. the investments necessary in order to attain certain given objectives of energy efficiency) and, from these items of information, one can estimate the market implications (e.g. the number of jobs created in a specific sector).

In more general terms the method can be employed as a support for the elaboration of SEAP, of municipal energy plans and of regional energy plans, both in the programming phase and in that of monitoring and checking.

Finally an interesting application of this method is that of the evaluations which the E.U. Member States will have to make for the calculation of cost-optimality of minimum energy perfor-mance requirements foreseen in art. 5 of Directive 31 (European Parliament, 2010): the matrices elaborated by the method proposed in this paper provide a precise and very detailed characterisation of building types with a statistical approach which is built on a significant information base.

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