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Estimation of building energy performance for local energy policy at urban scale

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Abstract

Cities play a key role in sustainability policies aimed at reducing environmental impacts and increasing energy efficiency in the building sector. At urban level, the analysis models are split in bottom-up and top-down types as a function of the methodological approach of input data processing, aggregated in the first case and disaggregated in the second one. The present paper describes the methodological approach adopted for the implementation of a bottom-up model able to estimate the energy performance of buildings and to define an energy diagnosis process at urban scale. Starting from the information provided by tools available at the Public Authorities and at the most relevant statistical studies on the national energy market, the model provides an estimation of the energy consumption and performance of buildings. The model is applied to a real district of Bologna and the derived spatial database allows the energy performances of buildings to be mapped.

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Keywords: Energy diagnosis; consumption; GIS; energy policy

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1. Introduction

The widespread knowledge of the building stock characteristics is crucial for the development of effective energy policies aimed at reducing energy consumption and greenhouse gas emissions. This led over the years to the development of a branch of research with the purpose to identify methods and tools able to characterize the urban fabric from the energy point of view, moving from the assessment of the individual building [1] to the district and the city as a whole [2]. This change of vision permits to plan targeted operations and to direct the resources to the most significant interventions.

Assessment models of the urban fabric performance are divided into two main approaches depending on the input aggregation level: top-down and bottom-up models [3]. Top-down models are based on aggregated input at different scale levels according to the objective; this approach describes the energy behavior of the area object of the study, providing global and wide-scale energy refurbishment solutions (e.g., regional [4] and national scale [5]). Bottom-up models instead are based on the analysis of disaggregated data, at the individual building or group of buildings level, extracted to represent the energy behavior of the built environment under investigation. This approach provides for the use of statistical models and building physics-based models [6]. The described models are not alternative; in fact several studies have combined the peculiarities of both methods in order to develop integrated approaches able to describe punctually the energy behavior of the urban area [7]. In this wide scenario, bottom-up models have met a huge success, thanks to the numerous initiatives at national [6] and international level [8, 9], implemented over the years with the aim of defining methodologies for the comparison of buildings' energy behavior. The use of reference buildings in particular, as defined by the European Directive [10], has provided an important stimulus in the application of these tools for mapping the energy consumption and performance of buildings at urban scale.

Starting from the analysis of the urban fabric of Milan, [11] defines 56 combination of archetypes by combining 4 base reference buildings, characterized by different surface to volume ratios (S/V), number of floor and size, with seven ages and two building use. The procedure allows the author to map the energy consumption and the potential refurbishment of the urban fabric, subdivided according to the census areas, by comparing the real characteristics of the building stock with the defined archetypes. [12] applies two different bottom-up models to analyze the energy consumption of the residential buildings at urban scale of the city of Turin: the first one based on the definition of specific reference building as a function of the S/V and the construction periods, the second one based on a linear regression of real energy consumption of sample buildings. The same authors developed a top-down model for the assessment of the non-residential buildings, at census scale. In [13] the authors analysis the potential for renovation of the overall building stock of the city of Kočevje by defining the initial state of buildings before renovation (concerning both thermal envelope components and heating systems). The researches described below use GIS tools to represent the current state of urban fabric [14] and the potential of renovation. Some authors have passed the boundary of energy consumption incorporating other kind of evaluation such as the thermal comfort [15], the environmental impact related to the life cycle [16], material distribution [17], etc.

The paper presents the first step of a wider methodology based on a multilevel energy diagnosis that provides the use of different sources for the analysis of buildings energy behavior at urban scale, from standard to real information. In particular, the methodology described below is based on the available open-source information about the building stock aimed at mapping the current energy performance of the building of a city and at identifying the potential of renovation. The methodology provides the analysis of both residential and non-residential buildings. Using a GIS tool specific maps are produced. The methodology is applied to a neighborhood of the city of Bologna. The system allows a diffuse energy diagnosis of the building stock and it can support the public administration to develop targeted energy policies.

2. Methodology

The bottom-up methodology proposed for mapping the energy consumption of buildings is based on the analysis of the available information provided by open-source database needed to characterize the building stock from a geometrical, morphological and energetic point of view. Through the use of this information it is possible to define a reference buildings' matrix specific for the considered area that constitutes the calculation basis of the system.

The system considers both residential and non-residential buildings from TABULA [8] database and the Energy Performance Certificates (EPC). In this contest, different authors analyze the convenience in using standardized data to describe the behavior of urban building stock, derived from referenced database [18, 19] or EPC [20, 21, 22].

2.1. Data sources

The definition of the bottom-up model requires the analysis of the information provided by different sources. As described above, the system is based on open-source database so as to allow the replicability of the methodology in different contexts. The buildings' matrix is built using data derived from the TABULA building typology database for residential buildings and the register of EPCs for non-residential buildings. In particular, the data from TABULA are calculated in standard conditions (temperature, internal gains, using profile, etc.), comparable with the EPC calculation, considering the climatic conditions of the case study. For non-residential buildings the EPCs' data are statistically analyzed in order to define specific reference buildings for each intended use. The morphological and geometrical data are derived from the *Sistema Informativo Territoriale* (SIT), available at each Italian public administration that allows the management of cartographic data and geo-referenced spatial information. More in detail, the information derived from this source refers to the data necessary to identify a building in term of physical boundaries, dimension (surface and volume) and intended use. The *Carta Tecnica Comunale* (CTC) identifies the shape of each building providing geometrical information such as building height, volume and plan dimensions necessary to define the S/V ratio. The *Piano di Governo del Territorio* (PGT) or *Piano Regolatore Generale* (PRG) collects information about the prevailing intended use of building (in future development of the model and in a more detailed level the definition of the percentage of intended use for each building is scheduled). Finally the use of urban Census data allows the identification of the period of construction. This source contains information about census sections corresponding in most cases to a block or a part of it, i.e. a group of buildings. A frequency analysis allows the period of construction to be attribute to all buildings belonging to the census section. The data described above are available in vector format files (ESRI shapefile) and are analyzed with GIS tools [23]. In particular through spatial vector overlaying function [24], the attributes of PRG and Census shapefiles are appended to the CTC shapefile attribute table. The resulting CTC-Census-PRG shapefile attribute table represents the starting database useful to perform the calculation of energy related indicators for each building within CTC shapefile. Starting from these data, it is possible to create a database for the mapping of buildings energy performances at urban scale, as described below.

2.2. Model

The core of the bottom-up model is the definition of the building' matrix. This table is realized by combining the information derived from existing databases about: intended use, period of construction and S/V. The first step is the classification of buildings according to the intended use. In this sense the buildings are classified in 7 categories: residential, manufacturing, recreational/cultural, school, health, commercial, office. For the residential buildings 4 subcategories are considered as a function of the S/V ratio: single family house, terraced house, multifamily house, apartment block. In particular, a specific S/V range is associated to each building typology and construction period. Since part of the S/V ratio of different typologies overlap, a unique correspondence between typology, construction period and S/V ratio has to be set determining a medium representative value extracted from the S/V trend graph, from which a specific range can be defined and associated to a unique construction period and building typology. For the period of construction 8 ranges are considered: before 1900, from 1900 to 1919, from 1919 to 1945, from 1945 to 1960, from 1960 to 1975, from 1975 to 1991, from 1991 to 2005, after 2005. The outputs of the buildings' matrix are the thermo-energy indices characterizing building's behavior: energy needs for heating and domestic hot water (DHW); primary energy for heating and global; average thermal transmittance of walls, roofs, basements and windows; annual efficiency factor for heating, DHW and as a whole; CO_2 emissions. In this way a base matrix of 80 reference buildings is created. To extend the analysis to the urban fabric the indices of the buildings' matrix is assigned to each real building according to the intended use, period of construction and S/V ratio for residential use. These information are defined by analyzing the data sources described in 2.1. The previous data are structured in a csv file and, through the building ID ("cat" field), linked to the CTC shapefile as attribute table.

Due to the statistical approach adopted in this method, the energy performances are calculated by the comparison between the individual building characteristics with those contained in the buildings' matrix, built from the extrapolation of data from the reference DB. At the current state the model is performed from an "on paper" point of view, using whole information about buildings' characteristics. A further study may compare the single buildings characteristics with real on-site monitoring data in order to note the results' gap between statistical and real data. Finally, any hypotheses of refurbishment both at envelope and plant level provide useful information about the achievement of the energy efficiency requirement at urban level. Any refurbishment hypothesis is structured in a specific csv file.

3. Results

The model has been applied to a portion of the district of Navile of the city of Bologna, placed in the North of the municipal area. The analysis of the available database shows how most of buildings of the considered area were built in the period between 1920 and 1970, result validates by the comparison with historical maps. All the intended uses provided by the model are present on the territory. Residential buildings are prevalent with a percentage of about 83% of the total. The manufacturing system represents the 11% and the educational buildings about the 4%. The remaining percentage is divided by the other intended uses. The application of the model allows the mapping of the energy performance of buildings of the considered area. Among the other indices, in Figure 1 the distribution of the global primary energy (EP_{gl}) and the average thermal transmittance of the walls (U value) are respectively shown as examples. The pattern of buildings tending to orange and red reveals the energy and thermal performance of the considered area. From the energy point of view, the primary energy of about 60% of buildings falls within the range 260-300 kWh/m^{2}y and about 95% is higher than 180 kWh/m^{2}y. The results of the thermal performance of the envelope follow the same trend. The most frequent values of the thermal indices related to the opaque envelope fall within the highest range of the U value, i.e. ">1.4 W/m^{2}K". The performance of the transparent envelope follows the same trend with about 80% in the range "4-5 W/m^{2}K". Finally, the global efficiency factors show the diffusion of traditional plant systems with poor performance. This analysis provides a picture of the actual energy state of the neighborhood stimulating the need to plan possible refurbishment actions.

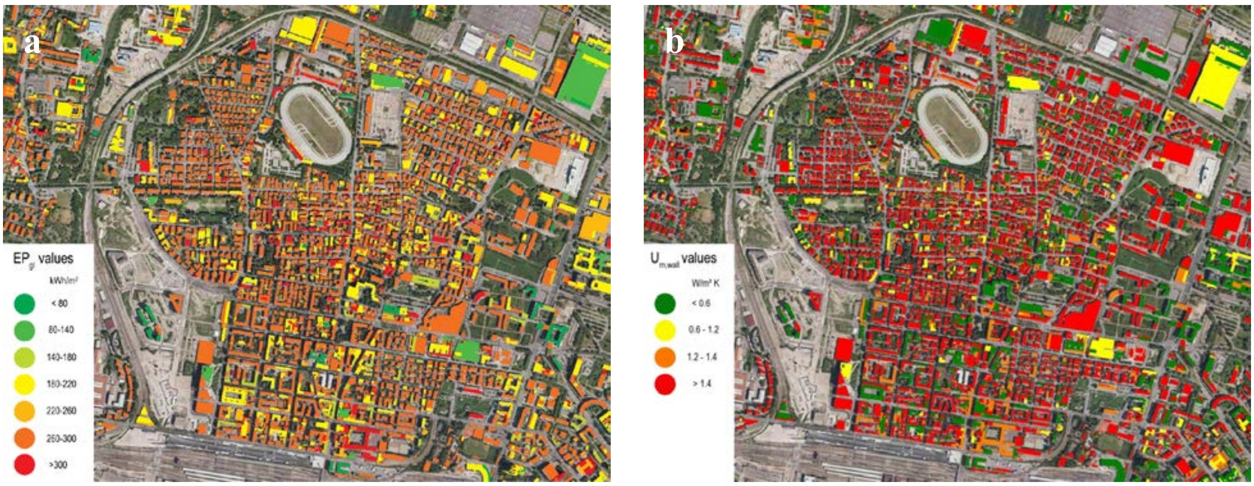

Fig. 1. Current situation: (a) Distribution of global primary energy of buildings; (b) Distribution of average thermal transmittance of walls.

In order to answer to these needs, two strategies are pursed: the former provides the improvement of the thermal performance of the envelope, the latter the installation of high performance plant. For all the intended use, the following requirements are considered: 0.34 W/m^{2}K for the walls, 0.30 W/m^{2}K for the roofs, 0.33 W/m^{2}K for the basements and 2.2 W/m^{2}K for the windows. For the plant a high-efficiency heat generator is considered. The results are shown in Figure 2. Both figures highlight a deeply improvement of the energy performance of the considered urban context. With the application of the first strategy the global primary energy decreases up to value ranging from 80 to 140 kWh/m^{2}y for the 70% of buildings and from 140 to 180 kWh/m^{2}y for the 29% of buildings, with a global reduction of about 49%. The energetic benefit of the second strategy is lower with a global reduction of about 25% and with about 70% of buildings in the range of 180-220 kWh/m^{2}y. The results are in compliance with the proposed interventions. Future developments of the methodology provide the integration of the economic analysis, among other assessments, in order to evaluate the feasibility of refurbishment strategies.

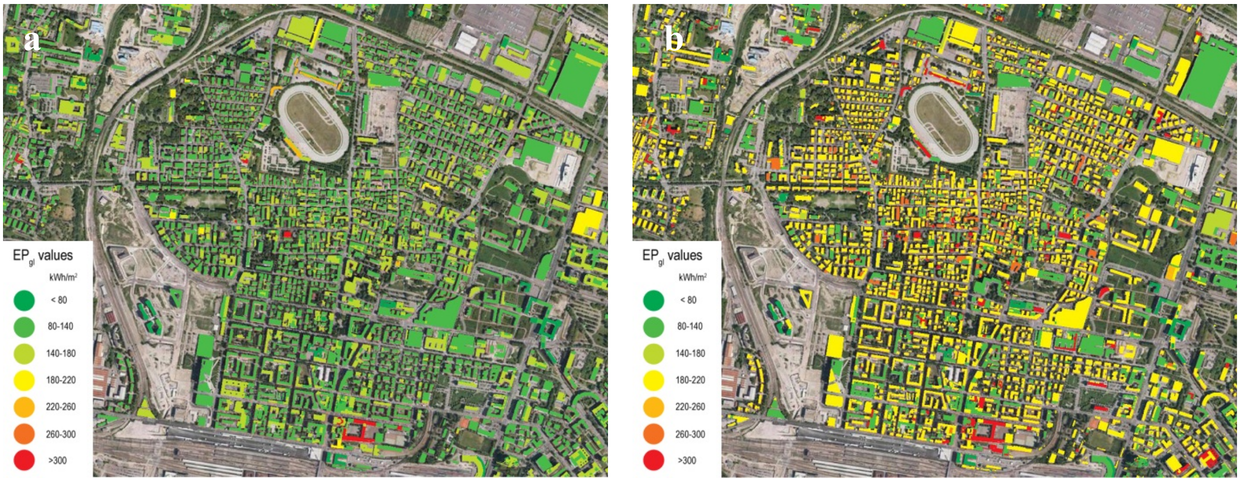

Fig. 2. Distribution of global primary energy of buildings after refurbishment: (a) Thermal performance of envelope; (b) High performance plant.

4. Conclusion

This paper describes a methodology for the assessment of buildings energy consumption at urban scale, starting from open data available at Public Authorities with application in energy planning of an urban area, with a bottom-up perspective. Currently the developed methodology is based on standard data and using free GIS tools. The presented method is designed as a scalable method according to the needs of the public administrations, being able to move from the urban to district or neighborhood scale. The method is built to allow replicability and to be fast for a first mapping of energy consumption of urban areas.

The use of public data has required a preliminary phase of information quality assessment, both for the building's matrix realization and for the GIS tool application. This allowed to remove incoherent data, therefore representing the real characteristics of the urban area, considered from a morphological, geometrical and energy-efficiency point of view. From this real basis of the considered territory it was possible to verify, by way of example, the effectiveness of some retraining interventions at urban scale, aimed at the achievement of specific energy targets.

Future developments will see on one side the use of real consumption data and on the other the integration of other variables such as the users' comfort, the cost connected to refurbishment interventions, etc. and the application of specific indicators for a broader assessment of the urban context, guiding the decision-making process towards efficient and effective interventions.

The aim of the model is to provide to the Public Authorities a tool for the energy policy, identifying energy intensive areas and providing useful refurbishment solutions from a performance point of view. The interaction with the municipality is a need for the development of the model in a further step of the project.

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