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Original article

# A parametric method to assess the energy performance of historical urban settlements. Evaluation of the current energy performance and simulation of retrofit strategies for an Italian case study

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ABSTRACT

Retrofit strategies at urban scale may play a strategic role in promoting the regeneration of existing towns and revitalizing the local building market, particularly in case of historical urban settlements where economic/societal changes have been amplified by natural calamities, accelerating depopulation and depletion of the local productive network. The paper presents the results of a statistical analysis and a detailed energy calculations applied to a historical town, partially abandoned after the 2009 Italian earthquake. In order to identify suitable retrofit guidelines, a baseline energy performance of the whole town was required. Given the use of the energy performance certificates (EPC) per each building was not feasible, a parametric approach was applied to the entire cluster to determine the town's baseline consumption and to test energy retrofit scenarios. This parametric energy calculation method, coherent to the Italian National legislation, was calibrated thanks to a bottom-up approach, allowing the calculation of the building's performance by surveying limited data, therefore easing the entire process and optimizing the Municipality's limited financial resources. The final results could allow the Municipality to endorse energy policies to revitalize the whole town.

## 1. Introduction

The definition of policies, funding schemes and incentives for energy efficiency could effectively support historical buildings' upgrade and urban centres' regeneration, while helping Italy in the achievement of the EU targets [1,2], thus playing a pivotal role towards a sustainable future [3]. The integration between energy efficiency and heritage buildings has always been difficult until recent times, when a concept of 'energy improvement', antithetical to the one of the compliance with pre-defined minimum performance thresholds, has opened new perspectives by means of improving the buildings' energy response through appropriate solutions that do not compromise the cultural values [4].

For historical villages, where the heritage significance is connected also to the dimension of the urban aggregate, it would be prudent to intervene in a choral level rather than on individual units. In these cases, the definition of energy retrofit strategies needs to be investigated at the district level before moving to the single building. Moreover, where degradation is combined with the devastating effects caused by natural phenomena (such as earthquakes, floods, etc.), the need for regeneration goes beyond energy purposes, becoming a strategy for promoting revitalisation and discouraging abandonment.

The implementation of retrofit procedures for large clusters is strongly related to their energy assessment and, therefore, to the accessibility to quantitative and qualitative information on existing building's types and technologies. Kavgic et al. [5] have critically analysed and compared the available bottom-up and top-down methods for energy consumption evaluation in residential

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**Nomenclature**

| | |
|---|---|
| $EP_{gl}$ [$kWh_p/m^2$ year] | Building Primary Energy Performance Index |
| $EP_i$ [$kWh_p/m^2$ year] | Building Primary Energy Performance Index for winter heating |
| $EP_w$ [$kWh_p/m^2$ year] | Building Primary Energy Performance Index for domestic hot water (DHW) production |
| $EP_{i,env}$ [$kWh_t/m^2$ year] | Building envelope-related thermal Energy Performance Index |
| $Q_{H,tr}$ [$kWh_t$ year] | Normalized envelope thermal loss due to heat transfer, including envelope components and thermal bridges, in winter scenario |
| $Q_{H,ve}$ [$kWh_t$ year] | Normalized envelope thermal loss due to ventilation exchange in winter scenario |
| $Q_{int}$ [$kWh_t$ year] | Normalized occupancy/internal thermal gain for the reference archetype building |
| $Q_{sol}$ [$kWh_t$ year] | Normalized solar thermal gain for the reference archetype building |
| $A_n$ [$m^2$] | Net internal floor-area for the reference archetype building |
| $A_g$ [$m^2$] | Ground floor gross-area/building footprint area of a building |
| F | Number of occupied floors in a building |
| $h_g$ [m] | Building mean gross height (ceiling-to-ceiling) |
| S [$m^2$] | Building exposed surface area |
| $S_W$ [$m^2$] | Wall-related exposed surface area |
| $S_{W,ext}$ [$m^2$] | External-walls surface area, comprising only the walls exposed outside |
| $S_{W,adj}$ [$m^2$] | Shared-walls surface area, including the walls adjacent to unoccupied buildings |
| P [m] | Building perimeter on ground |
| $C_{ex}$ | Coefficient of exposition, which defines how much wall-area is exposed outside according to the “building typology” criterion |
| $C_{oc}$ | Coefficient of occupation, which defines how much wall-area is adjacent to unoccupied buildings |
| $H_{tr}$ [W/K] | Building heat transfer coefficient |
| $A_k$ [$m^2$] | Exposed surface area of the *k*-th envelope component of the real building |
| $U_k$ [$W/m^2K$] | Thermal transmittance of the *k*-th envelope component of the reference Archetype building |
| $C_{mp,k}$ | Heat transfer multiplying coefficient, enhancing the related *k*-th envelope component in case of performance-improving features |
| $\eta_{g,H}$ | Overall efficiency of the heating system |

buildings in order to understand the most suitable approach for exploring the technical and economic effects of different $CO_2$ emissions reduction strategies over time. The bottom-up approach is used also by Fabbri et al. [6] to study the qualitative aspects of heritage buildings, energy saving strategies and building conservation together with the quantitative aspect of aggregate buildings in the historical centre of Ferrara, Italy. Ascione et al. [7] suggest a method for monitoring the energy quality of the building stock of entire urban areas that was applied to the historical centre of Benevento, Italy, and then transferred into a GIS-based tool for the use of local government units for advanced energy planning and territorial control in energy supply. As stated by Dall'O' et al. [8], an understanding of the energy performance in buildings in a municipality or an entire district is considered as an important aspect for promoting sustainable planning strategies for the energy renovation process in low-performance existing buildings. Lastly, Bizzarri [9] presented an estimation of a large city-scale voluntary retrofit energy policy, with a specific focus on historic buildings, testing its effectiveness over the bottom-up energy plan of the city of Reggio Emilia, Italy.

The studies mentioned above demonstrate that large-scale energy retrofit strategies need to be supported by on-site audit procedures for the collection of relevant data. However, field analysis can be very time-consuming and cost-demanding, and not be compatible with the management of environmental emergencies (such as the need of revitalising an entire cluster after a natural disaster) or with the operating costs available to municipalities in semi-abandoned areas. All the studies cited above did not have to deal with the restrictions of situations as such and could therefore follow standard procedures, although simplified. This research aims to fill this gap as the suggested simplified site survey methodology and the following energy evaluation could support this need in a timely and effective manner.

## 2. Research objectives and limitations

### 2.1. Objectives

To efficiently test targeted energy retrofit strategies, district-level energy baseline needs to be acknowledged, although the conventional audit method, based on the individual energy analysis per each building, is unfeasible because slow and cost ineffective. The study proposes a parametric and statistically-based energy assessment method to accomplish district-level audits in a timely manner, as basis for parametrically-defined energy improving actions.

Secondary objectives of the research are:

- achieving the baseline energy performance data for the case study;
- finding and implementing the historical buildings' original environmental features, enhancing and recovering their environmental and energy self-control capability, i.e. the so-called “environmental metabolism” [10];
- identifying suitable and feasible energy retrofit actions;
- achieving district/urban scale-related energy balances as result of simulating the above energy retrofit actions.

### 2.2. Limitations

The research considers the following limitations:

- the study focuses on the energy performance of the building envelope ($EP_{i,env}$) and includes the systems for an overall energy performance evaluation ($EP_i$) via a parametrical approximation;
- no instrumental direct assessment was run on the buildings' envelope. Since the town is almost entirely abandoned, indoor and outdoor temperatures are equal and IR-Thermography and Thermal-Flux assessments would have not given any valuable results. Other useful methods, such as sonic and ultrasonic trials, were excluded because require to be combined to other instrumental analysis (i.e. the above-mentioned IR-Thermography or Thermal-Flux assessment) to provide acceptable energy-related results;
- due to the absence of occupants in the abandoned buildings (largest share in the town), human comfort conditions could not be directly assessed, therefore have been defined as per regulation standards [11–13] for both pre- and post-retrofit energy calculation;
- air infiltration through degraded window components (interface wall/window frame and warped wooden frame itself) suffered by the oldest buildings were not accounted in this study due to

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