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A supporting method for selecting cost-optimal energy retrofit policies for residential buildings at the urban scale

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HIGHLIGHTS

- A bottom-up methodology to aid decision-making in the planning process is presented.
- The approach simulates the stock evolution from an energetic, social and economic perspective.
- Identifying buildings to be prioritized can significantly reduce the global cost on the long-term.
- The energy savings potential of the stock can be evaluated through the cost-optimal methodology.
- Socio-economic analysis is crucial to understand the attended perception of a policy by investors.

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ABSTRACT

Nowadays, in Europe, the main challenge is not only the construction of new high performing buildings, but also the promotion of proper retrofit actions on existing buildings. In the on-going transition towards low carbon cities, tools to support local municipalities are fundamental.

To scale up results achieved at single buildings to group of buildings and to reflect the dynamics of the buildings stock with acceptable computational costs, new approaches are needed.

This paper presents a new bottom-up methodology to aid decision-makers in the planning process; the approach enables to simulate and analyse the evolution of the building stock from an energetic, economic and social perspective over long-term horizons. The approach is based on analytic hybrid methodologies for building energy performances assessment and on Geographic Information System for the creation of a database and thematic maps. In particular, the approach: 1) identifies the cost-optimal mix of successful renovation packages; 2) identifies buildings that needs to be prioritized; 3) considers the impact of socio-economic factors on policies implementation. The method is validated through urban calibration coefficients dependent on the city energy balance.

Results show that this approach can support different stakeholders in selecting specific strategies depending on the desired goals.

1. Introduction

It is well known that most of the energy consumption is nowadays concentrated in cities (United Nations, 2015). Moreover, in Europe, the increasing urbanization level will enforce the current trend in consumption growing forecasted to be up than 75% of the total primary energy consumption in 2030 (EU THINK project, 2011). Buildings are responsible for 30% of global final energy consumption and urban buildings represent 60% of total building final energy use (IEA ETP, 2016). Most of existing European buildings are quite old (built before the '80s) and characterized by low energy performance (BPIE, 2011). Considering the long life of the buildings and the low demolition rate that characterize the European tradition, it is clear that the proper refurbishment of buildings has a great potential to make successful the proposed energy savings goals. Many effective analyses have been performed at single building level (Becchio et al., 2012) in which high quantity of data are available, but still few comprehensive analyses are presented from an urban perspective. This is related to the complexity and quantity of information that is needed and the computational time of their elaboration. A first step toward the study of aggregation of buildings has been the definition of a methodology for identifying the Reference Buildings (Corgnati et al., 2013); Reference Buildings are able to represent in a simplified, but realistic way, the average building stock in terms of functionality and energy performances and can be used for the

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Nomenclature

Abbreviations

AB	Apartment block
APE	Energy Performance Certificates
BAU	Baseline scenario
DH	district heating
EP	energy performance
FEAS	feasibility scenario
GIS	Geographic Information System
MF	multi-family
O&M	yearly operation and maintenance cost
PRI	prioritization scenario
RB	Reference Buildings
REN	Renovation scenario
S/V	surface to volume ratio
SF	Single Family
SH	space heating

Symbols

a_i	inflation rate of the time step i
C	construction period
C_e	yearly energy cost
C_a	yearly cost (O&M, running cost, substitution cost)
$C_{G,b}$	global cost of the building stock
$C_{G, sb}$	global cost at single building level
C_I	investment cost
F	feasibility Index
f_a	age factor (the percentage of population with an age in the range of 25–69 years)
f_{ed}	education factor (the percentage of people with high school diploma or higher instruction level)
f_{em}	employment factor (the percentage of employed people considering only the active population of 15–74 years old)
f_f	family factor (the percentage of families composed by 1 or 2 components)
f_o	building's occupation factor (the percentage of occupied building)
f_p	property factor (the percentage of families that own their apartment)
f_{pc}	period of construction (the percentage of buildings built before 1960)
f_{sb}	single building factor (the percentage of buildings with only 1 or 2 families)
r	buildings renovation rate
R_d	discount rate
$V_{ex, TOT}$	existing volume
V_f	residual value
$V_{ren, TOT}$	total retrofitted volume

evaluation of future energy performance in existing dwellings. In fact, they allow modeling a city/group of buildings' evolution taking in mind that specific design features should be then decided at the single building level. Many researchers are recently focusing their attention on urban energy planning and building stock analyses. In particular, (Fracastoro and Serraino, 2011) combined statistical census data and building standard information for assessing the energy performance of a large scale building stock; (Theodoridou et al., 2011a) conducted a similar work for statistically analysing the Greek building stock and for classifying the building typologies (Theodoridou et al., 2011b). At the urban level, (Theodoridou et al., 2012) identified main variables to be considered for urban sustainable analyses; (Ascione et al., 2013) proposed to use urban maps for visualizing the effect of different energy strategies in terms of energy savings potential; (Ballarini and Corrado, 2009) compared results achieved by regulation's calculation methods with measured data on a large amount of urban buildings in order to understand the role of occupant behavior and to investigate the way to find energy reference values of the building stock; (Dall'O' et al., 2012) proposed a GIS-based methodology for the understanding of the energy performance in buildings in an entire municipality considering energy audit input data; a similar approach has been developed by (Fabbri et al., 2012) that, with the aid of GIS tools, analysed the energy savings potential of the heritage in an urban area in Italy; (Caputo et al., 2013) developed a methodology to characterize the energy performance of the built environment on a long-term horizon.

All the reviewed researches allow assessing the approximated energy performance level of the stock but donot permit to estimate which are the economic and social costs associated with the renovation of the building stock over long-time horizons.

Building inhabitants and the social context can influence the success of green policies (Gamba, 1994; Mesch, 1996). Concerning the Italian reality, (Caputo and Pasetti, 2015) highlighted the main barriers that slow down the refurbishment of buildings in medium/small municipalities. They sent questionnaires directly to the municipalities and the goal of the research has been to propose solutions for overcoming the identified energy planning barriers. They recognized as main impediments the: i. Regulatory framework that does not propose common models or obligation about energy planning; ii. Data availability; iii. Lacks in the technical and non-technical preparation of municipal administrators and iv. Low involvement of citizens. In other researches, (Pisello and Asdrubali, 2014) estimated the potential of the human-based energy retrofit, intended as occupants' actions, in producing energy benefits. These researches are useful for understanding how a positive involvement and correct awareness of inhabitants may lead to great benefits in terms of energy savings and spread of conservation measures. Starting from these considerations and results, this paper has a different perspective and aims at correlating the building occupant's willingness to invest in energy retrofit with some socio-economical characteristics.

The aim of this paper is to develop a Geographic Information System (GIS)-based methodology for helping decision making in performing long-term energy planning considering the real buildings' heritage and its population characteristics. The paper proposes an approach for investigating the socio-economic feasibility and technical suitability, from a policy perspective, of different renovation measures at the urban level. The evaluations are based on space heating (SH) energy consumptions that represent the most energy intensive service of the North of Italy. It is a bottom-up hybrid methodology helpful for 1) defining and quantifying the building archetypes (Reference Buildings RBs) of an urban area and assessing their space heating energy performances; 2) identifying buildings in compelling need of renovation; 3) identify the cost-optimal mix of refurbishment measures at an urban scale and 4) performing medium/long-term scenarios analyses. In particular, with respect to previous analyses, it allows assessing the building stock evolution not only from an energetic and environmental perspective but also from a socio-economical one. The cost-optimal methodology proposed in the EPBD recast