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On the ranking criteria for energy retrofitting building stocks: Which building goes first? The role of the building size in the establishment of priority lists

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ABSTRACT

The energy retrofit of the existing building stocks is considered a preeminent strategy to lowering the energy consumption of the building sector. Other than the definition of the most successful combination of energy saving measures, the definition of a suitable ranking of all the buildings of the stock, on which implementing established energy retrofit measures, is quite a relevant issue. The most eligible criterion for prioritizing the buildings seems their energy consumption because it combines the building energy performance and their size.

To investigate the role played by the building dimension in determining the order of priority of all the buildings of a given stock, this paper presents and compares different hierarchical orders of 25 existing buildings that were obtained with and without consideration of the size of the buildings. Results show that, when the size of buildings is covered in the calculations, the generated prioritized order differs significantly. In addition, it has found that the entity of the variations compared to the hierarchy that does not contemplate the size of buildings, is logarithmically correlated with the net surface. Additionally, some concerns have arisen regarding the role of the EP index for the building energy classification.

1. Introduction

The European Union (EU) is strongly committed to reducing the greenhouse gases emissions and has formulated increasing CO_2 reductions and energy efficiency goals for the next decades. In fact, in its environmental plan, titled "Climate and Energy Package" (the so-called "package 20-20-20"), it has set, as main goals, a reduction of at least 20% of the greenhouse gas emissions, a reduction of at least 20% of the energy consumption, and the use of at least 20% of renewable energy, compared to levels occurred in the year 1990. The EU expects to achieve these goals in 2020 [1]. In 2014, the EU has released a document, named "2030 Framework for climate and energy", where more ambitious goals, to be achieved within the year 2030, were established. That is: to reduce the EU domestic greenhouse gas emissions of 40% compared to the 1990 level; to increase the share of renewable energy of at least 27% of the overall energy consumption compared to the 1990 level; to achieve at least 27% energy savings compared with the business-as-usual scenario [2]. Additionally, in the document "Roadmap for moving to a competitive low-carbon economy", the EU has stated to expect a reduction by 2050 of greenhouse gases emissions up to 80–95% compared to 1990 levels through domestic reductions alone [3]. In this context, it is worth also citing the EU commitment to the establishment of an Ecolabel brand that is able to certify the overall environmental performance of buildings [4,5].

In this EU environmental policy framework, the building sector is believed to be a key-segment to achieving the above-mentioned energy efficiency targets because of the great amount of energy consumed in buildings. Indeed, the construction sector is responsible for approximately 40% of the total final energy consumption in the EU Member States [6]. To improve the energy efficiency of this sector and mitigate its energy consumption, the EU has issued many directives, among which, those on the energy performance of buildings, *i.e.* the 2002/91/EU [7] (the so-called "EPBD") and the 2010/31/EU (the so called "EPBD *recast*") [8], are certainly worth a citation.

A preeminent strategy to reduce the energy consumption of the building sector consists in focusing not only on the construction of new high performing buildings but also on the energy retrofitting of existing building stocks. This latter is considered, indeed, one of the key areas to achieving the abovementioned EU energy effi-

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ciency and climate goals. In the EU directive 2012/27/EU [9] is, in fact, specified that "· · ·Member States should establish a long-term strategy beyond 2020 for mobilizing investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. . .".

Literature energy data on the EU Member States building stocks show quite a high energy consumption, indeed. For instance, Dascalaki et al. [10] have reported on a sample of 250 buildings (75% of which were residential) in Greece, whose average annual energy consumption ranged between 108 kWh/(m^2 y) and 371 kWh/(m^2 y); Mangold et al. [11] have referred to 6 cities located in Sweden, whose annual energy usage is on average equal to 184 kWh/(m^2 y); Ballarini et al. [12] have presented the primary energy needs for space heating and domestic hot water (DHW) production of five countries (Italy, Denmark, Czech Republic, Germany and Greece) ranged approximately between 150 kWh/(m^2 y) and 340 kWh/(m^2 y); and Di Turi and Stefanizzi [13] have reported on the energy performance of the building stock of the city of Bari (Southern Italy), indicating energy needs ranging from 193.90 kWh/(m^2 y) (for constructions built before the 1960s) to 64 kWh/(m^2 y) (for the buildings designed in 2008).

Therefore, it is evident the necessity to energy renovate the existing building stocks. Two plausible reasons can be posited to motivate such a great energy needs: the old age of the buildings and the use of low energy efficient equipment.

Literature shows that the implementation of typical energy retrofit measures (ERMs) in existing building stocks might lead to quite a high energy savings after For instance, the above cited Ballarini et al. [12], have found that the energy savings obtainable from the "standard" refurbishment ranged between 41% and 75%, while from the "advanced" refurbishment they ranged between 49% and 86%; Mastrucci et al. [14] have found an energy saving potential rate for space heating and DHW production of the building stock of Rotterdam ranged between 41% and 68% (for buildings built in the range before 1964), between 40% and 61% (for buildings built in the range 1965–1974), between 24% and 40% (for buildings built in the range 1975–1991), and between 4% and 13% (for buildings built in the range 1991–2005).

Currently, the EU housing stocks, at different scales (national, regional, or local) are undergoing an energy retrofit process that is monitored within the European research project IEE-EPISCOPE (IEE-Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks, 2013–2016) [15] (www.episcope.eu). The achievement of the EU climate protection targets through this retrofit process is checked within the project too.

Evidently, the prediction of the potential impact of energy retrofit measures and the selection of effective strategies to improve the existing building stocks' performance, require a good and as much as possible detailed knowledge of the current energy needs of the buildings. The approach that is commonly used for modeling the energy consumption in housing stocks in several countries consists in the use of a bottom-up model that is based on the "building typology" [12,16,17]. This approach has been applied by the thirteen countries that were involved in the Typology Approach for Building Stock Energy Assessment (TABULA) project (2009–2012) [18]. This European project was aimed to define a harmonized methodology to describe the European building typologies and reference building types, so making easier the energy analyses of building stocks.

The building stock analysis is a topic largely addressed by researchers all over the world. The issues addressed in literature are mainly about the energy classification of the building stocks, the validation of methods for the calculation of the building stocks' energy consumption, and the priority-setting process of interventions that could be implemented to improve their energy efficiency. In more detail, some literature studies introduce methodologies for estimating the energy consumption of building stocks [14,19–22]; some report on energy mapping of existing building stocks [23,24]; some provide estimations of the potential energy savings after the implementation of a set of ERMs on national [25], regional [17], local [11,13,24] building stocks; and some other present comparative analyses, from the energy point of view, of building stocks in different EU countries [26–28]. The environmental impact caused by the energy retrofit of a building stock [29] and the economic and social costs associated with the building stock retrofitting over long time [11] are also issues addressed in the literature.

Current available analyses of existing building stocks seem to be aimed primarily to define the most effective energy retrofit measures, in order of singling out possible and successful energy retrofit strategies, while little attention and not in-deep investigation seems, to the best of our knowledge, to be paid to the prioritization process of the buildings of a given stock. Literature suggests some possible criteria for hierarchizing the buildings of a given stock in. For instance, Mastrucci et al. [14] have proposed to use the type or age of buildings. Another suggested criterion is the energy intensity, EP, that is expressed in kWh/(m^2 year) or kWh/(m^3 year). In this respect, Mangold et al. [11], for instance, in their work have set a specific energy consumption benchmark of 150 kWh/(m^2 year) and considered all the buildings that use more than this value as a priority group for energy retrofitting. Delmastro et al. [30] have suggested prioritizing buildings in terms of both the energy intensity, EP, and the volume distribution (that is stock frequency of the Reference buildings).

Indeed, many energy analyses of buildings are based on the EP index, and therefore, in order of determining a hierarchical order of the buildings, the use of this index would be quite natural, especially by Public Administrations that are called to energy retrofit cluster of buildings. However, it has not overlooked that this parameter only provides an information regarding the energy consumed for each squared meter of the building, without giving any information about the whole amount of the energy consumed by the building. This latter is determined by the heated volume of the building, and so, in turn, by its surface area and height. Consequently, hierarchical orders of the buildings only based on this parameter, without any consideration of the size of the buildings, could not reflect the real intervention priorities of the stock.

In this paper, we questioned about the role played by the buildings' dimension in the establishment of priority lists of the buildings of a given stock. To do this, we have considered two possible ranking criteria (one accounting for the size of the buildings and one excluding it) that Public Administrations might usefully adopt to prioritize buildings, and listed in order of priority 25 residential buildings located in Sicily (Southern of Italy) only with respect to these two criteria. These buildings have been selected based on the method proposed in [31]. The energy performance of the buildings was assessed by using the Italian building energy simulation tool, DOCET© [32]. This tool is recognized by governmental authorities and is widely used by technicians that work for the Public Administrations. It allows determining the "standard" energy consumption of the building and its energy class in accordance with the current Italian standard for the evaluation of the energy requirements for building climatization, *i.e.* UNI TS 11300 [33–38].

The structure of the paper is as follows. Section 2 presents a brief description of the possible selected criteria based on which especially the Public Administrations could prioritize buildings of a given stock. Section 3 provides some data regarding the case study and the energy performance calculation methodology used in the analysis. Section 4 presents the lists of priority of the selected buildings that were determined with respect to the chosen crite-