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Energy refurbishment of the Italian residential building stock: energy and cost analysis through the application of the building typology

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ABSTRACT

The European residential building stock is largely composed of buildings with poor energy performance, therefore basic retrofit actions could lead to significant energy savings. However, energy refurbishment measures should be identified in accurate way, taking into account the technical viability and aiming both to increase the building energy performance and to restrain the costs.

The present article investigates the effects of different measures applied to the Italian residential building stock by using the building typology, which consists of 120 building types, representative of six construction ages, four building sizes and five climatic zones. A quasi-steady state model has been used to calculate the energy performance; the economic evaluation has been carried out as specified in the EU cost-optimal comparative methodology (Directive 2010/31/EU). The most effective measures and packages of measures, in terms of energy saving and global cost reduction, are identified and discussed.

The results are addressed to important purposes for energy policy, as for instance: (a) to provide political authorities with the most effective energy efficiency measures as to encourage retrofit processes through the allocation of financial incentives, (b) to offer a knowledge-base for developing energy refurbishment scenarios of residential building stocks and forecasting future energy resource demand.

1. Introduction

The conclusions of the European Union Council of June 2011 on the Energy Efficiency Plan 2011 point out that buildings represent 40% of the European Union final energy consumption (Council of the European Union, 2011). Member States should set up a strategy to invest in the building energy refurbishment, so as to increase the energy performance of the building stocks in the long run. According to European Directive 2012/27/EU on energy efficiency, "*the strategy that must be established by each Member State should address cost-effective deep renovations, which lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels*" (European Union, 2012b).

The existing building stock presents a high potential for energy savings and greenhouse gas emissions reduction: the European residential building stock is largely composed of buildings with poor energy performance, therefore even basic refurbishment actions can determine noticeable energy and environmental savings (Ballarini et al., 2014). However, energy refurbishment measures have to be identified in an accurate way, taking into account the technical viability and aiming both to increase the building energy performance and to restrain the investment costs. According to European Directive 2010/31/EU (EPBD *recast*), the building energy performance should be increased by applying energy efficiency measures that consider, among other things, the indoor climate, the local conditions and the cost-effectiveness. The latter aspect implies that the minimum energy performance requirements set by the local regulations are addressed towards those portions of the building that are relevant for the energy performance, like for instance the building envelope and the thermal systems (European Union, 2010).

Several studies have investigated and applied systematic methodologies to identify the most effective retrofit measures and to assess the energy performance of buildings both at micro level (e.g. the building scale) and at macro level (e.g. the building stock). An overview of studies concerning the investigation and evaluation of energy performance and economic feasibility of different retrofit technologies for building application is provided by Ma et al. (2012). According to the researchers, the retrofit technologies can be grouped in: supply side management (e.g. technologies using renewable energy sources),

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Nomenclature

Symbols

A	area [m^2]
C	cost [€]
E	energy [kWh]
EP	energy performance [kWh m^{-2}]
f, R	factor [-]
Q	thermal energy [kWh]
U	thermal transmittance [W m^{-2} K^{-1}]
V	volume [m^3]
Val	value [€]
η	utilization factor [-]

Subscripts

a	annual
aux	auxiliary (energy)
C	space cooling
del	delivered (energy)
disc	discount
env	envelope
exp	exported (energy)
F	final
f	floor
g	gross, global
gn	gains
H	space heating
I	investment
in	input
int	internal
ls	losses (energy)
lw	lower
nd	need (energy)
nren	non-renewable
nrh	non-recovered (energy losses)
out	output
P	primary (energy)
rh	recovered (energy losses)
sol	solar
tr	thermal transmission
up	upper
ve	ventilation
w	windows
wl	wall (opaque vertical envelope)

Abbreviations and acronyms

AB	apartment block
DHW	domestic hot water
HDD	heating degree days
HG	heat generator replacement
MFH	multi-family house
OP	opaque envelope thermal insulation
SFH	single-family house
TH	terraced house
TS	thermal solar system installation
W	windows replacement

demand side management (e.g. building thermal insulation, solar shading devices, heat recovery) and change of energy consumption pattern (i.e. change in the occupant behaviour). A review of decision support tools for building refurbishment is provided by Ferreira et al. (2013). The tools have been classified in five groups according to their objectives: (1) improving of energy and environmental performance, (2) economic analysis, (3) life cycle assessment, (4) environmental sustainability evaluation, and (5) general methods. The methods based on maximising energy and environmental performance are widespread, even if the models based on economic and financial parameters are applied too, as in the work of Martinaitis et al. (2007). Anyway, the majority of studies deals with the combined analysis of economic and energy saving implications in the building refurbishment. For instance, Verbeeck and Hens (2005) analyse different energy efficiency measures and find out the optimal hierarchy considering the balance between costs and benefits; Asadi et al. (2012) present a multi-objective optimization model aimed at maximising the energy savings and minimizing the retrofit cost; Karmellos et al. (2015) provide a methodology to optimally prioritize the energy efficiency measures in terms of their energy behaviour and the initial cost, and also developed a software tool to be used by the decision makers.

More recent studies specifically focus on the analysis of cost-effective energy efficiency measures for the refurbishment of residential buildings. In northern Europe, Niemelä et al. (2017) analyse cost-optimal retrofit measures for deep renovations of typical Finnish buildings. The authors find out that the heat generator (more specifically, the heat pump) provides the best economic viability, while the additional thermal insulation on the external walls is not cost-effective. In southern Europe, Ortiz et al. (2016) develop cost-optimal studies for retrofitting residential buildings in Barcelona through the assessment of the global cost in 30 years of building lifetime. The implementation of passive strategies (e.g. thermal insulation of the building envelope) and the replacement of heat generators with condensing boilers reveal to be among the cost-effective options. In an Italian research study, Ferrari and Zagarella (2015) analyse reliable renovation measures for two national climatic zones, i.e. thermal insulation of the building envelope, HVAC system, thermal solar and photovoltaic systems, and their related costs with the aim to carry out cost-effectiveness evaluations in subsequent researches. Penna et al. (2015) investigate energy and cost-optimal packages of energy efficiency measures for a global renovation of residential buildings in two Italian climatic zones; both conventional and advanced measures are considered. The authors point out that public incentives are always necessary to favour the technical solutions that also maximise the indoor comfort conditions.

A review of studies focussing on the modelling techniques used for assessing the energy consumption of residential building stocks is provided by Swan and Ugursal (2009). Two distinct approaches are presented, top-down and bottom-up models. The former represents the energy consumption of the building stock as a function of different variables (e.g. macroeconomic indicators, climate, energy price). The latter, which is deeply investigated by Kavgic et al. (2010), may be used to assess the energy consumption of representative buildings and then to extrapolate it to higher territorial scale (e.g. region, country). Weighting factors can be used to assess energy savings and CO_2 emissions reduction strategies from building types to building stocks, as pointed out by Mata et al. (2013a). A precondition of the bottom-up approaches is the assumption that certain parameters of the building have a significant impact on its energy performance; for instance, a statistical method from Aksoezen et al. (2015) showed that there is a strong interdependence between energy consumption, compactness factor of the building and its construction period.

In this context, the building typology approach, which consists in the use of representative buildings or building types identified and classified in function of specific aspects (e.g. building use, building age, building size, climatic zone), is widespread. The main applications of the building typology consist in investigating the most effective energy