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University building: Energy diagnosis and refurbishment design with cost-optimal approach. Discussion about the effect of numerical modelling assumptions

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ABSTRACT

The paper discusses a methodological approach for designing energy refurbishment measures basing on a deep energy diagnosis with in-situ measurements that allow the complete characterizations of building /HVAC system and the indoor conditions. Then, the Cost-Optimal approach is applied to compare several retrofit scenarios considering interventions both on the building envelope and on plant systems. The case study is a University building in heating dominated climate of South Italy. According to a macroeconomic perspective, with a discount rate of 3%, the package of energy efficiency measures that combines installation of heat recovery systems, regulation dispositive for HVAC and LED lamps with automatic control induces considerable energy saving and reduction of polluting emissions (−33%) as well as the largest reduction in the overall cost (−35%).

Moreover, the importance to use validated models is examined exhaustively by proposing a sensitivity analysis on uncertainties due to modelling assumptions mainly referring to the adoption of stochastic schedules for occupant behaviour and equipment or lighting usage. First of all, this analysis shows that the calibration indexes are always dissatisfied; besides it is demonstrated that refurbishment design can appear more convenient, with wrong assumptions. For instance, one of proposed scenario brings to energy saving of −41% and reduction of global cost of around −36%.

1. Educational building: Energy efficiency design

The trend of energy use in European non residential buildings is roughly in line with their share of floor area. The highest total energy use is within shops (28%), offices (26%) and educational (12%) edifices. There is a great variability in the energy consumptions of European countries but these are related mainly to heating service and electricity. For instance, annual heating is 96 kWh/m^2 in Ireland [1], 192 kWh/m^2 in Slovenia [2] and 157 kWh/m^2 in the UK [3], close to 100 kWh/m^2 in northern and central Italy [4].

Educational buildings account for the largest share of the oldest buildings, since around 75% was constructed before 1980 [5]; this allows to evidence that the great challenge, also in this sector, is not in fabricating new nZEB, but in retrofitting existing buildings towards nZEB through cost-optimal approach [6]. It is also simple to understand the high potential for energy savings in the Mediterranean area, where, in spite of having mild temperatures, there is high energy consumption in winter due to the low energy performance of existing building stock [7].

Moreover, educational buildings are seen as community centres of activity and learning by local authorities, as such there is an emphasis to make schools exemplar buildings within the community and demonstrate best practice with regards to high performance low and zero-carbon design [8]. Optimizing energy consumption of buildings during operation can significantly reduce their impact on the global environment [9]. On this matter, Sesana et al. [10] have presented an overview on retrofitting approaches, in particular for the university communities, highlighting the importance to promote green building initiative on campuses. Moreover, the study proposed by Salvalai [11] based on the classification and analysis of 38 school buildings in Lecco municipality, want provide replicable guidelines useful to the Public Administration in planning of energy retrofit interventions, in defining the total

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Nomenclature

Symbols

C_a	Annual costs, € or €/m^2
C_c	Annual cost of greenhouse gas emissions, € or €/m^2
C_g	Global cost referred to starting year, € or €/m^2
C_I	Investment cost, €/unit or €/m^2
$CO_{2,eq}$	Carbon dioxide equivalent emissions, kg
CV(RMSE)	Coefficient of variation of the root mean squared error, %
ecW	Adoption of electrochromic glass
ERR_{month}	Error in the monthly consumption, %
$ERR_{average\ year}$	Mean error in the annual energy consumption, %
E_G	Energy request of natural gas, kWh
E_{el}	Electricity request, kWh
ep12	Insulation of wall and external ceiling with the expanded polystyrene
EP	Primary energy demand, kWh or kWh.m^{-2}
f_{pv}	Present value factor, %
g	Solar factor
Ho	Horizontal overhang shades of 0.5 m
HVAC	Heating, Ventilating and Air Conditioning
leW	Installation of low-emissive glazed windows
LED	Installation of LED lamps
LEDC	Installation of LED lamps and control system
M	Annual maintenance operation and repair and service factor, %
MBE	Mean bias error, %
n	Number of years considered for the cost
p	Lifespan of building elements and systems
pL	Projection Louvre of 0.5 m
REC	Installation of the heat recovery system
REG	Installation of regulation systems
R_d	Discount factor (or rate), %
R_i	Inflation rate, %
R_r	Real interest rate, %
RB	Reference Building
rw12	Insulation of wall and external ceiling with rock wool
r_ep12	Insulation of roof slab with the expanded polystyrene
r_ep12al	Insulation of roof slab and application of reflective paint
sW	Installation of selective glazed windows
t	Thickness, m or cm
T_{a_max}	Maximum value of temperature
T_{a_mean}	Mean value of temperature
T_{a_min}	Minimum value of temperature
U	Thermal unitary transmittance, W/(m^2·K)
V_f	Residual value at the end of the calculation period, € or €.m^{-2}
Y_{IE}	Periodic thermal transmittance, W/(m^2·K)

Greek symbols

Δ	Difference, dimensionless
τ	Calculation period, number of years

investment amounts and the consequent raising of necessary investments. Moreover,

Irulegi et al. [12] have proposed a method to define and assess strategies to achieve NZEB in university buildings based on student comfort analysis under real conditions. For the University of the Basque Country, their results show a potential energy saving of up to 58%. Muñoz et al. [13], using a school case study, have demonstrated that for ranking NZEB standard, LCEA approach should be taken into account. Indeed, their results have shown that, despite the building shows a low thermal transmittance of enclosures and it also incorporates renewable energies, it cannot be considered as NZEB because the PEC varies from 91.2 to 161.4 kWh/m^2 y.

Bernardo et al. [14] have proposed an energy and indoor climate integrated approach to assess eight representative school buildings throughout the Portuguese mainland territory. A methodology involving dynamic building simulation and inside temperature measurements has been successfully applied to evaluate the energy performance of Villa Mondragone, property of the University of Rome Tor Vergata [15]. Moreover, the study of Katafygiotou and Serghides [16], basing on monitoring and questionnaires in a secondary school in Cyprus, has confirmed that the indoor climatic conditions are in many cases unsatisfactory for the occupants. About it, in case of educational buildings with large transparent surfaces on the facades, a proper choose of workplace location, can determine important cooling energy savings without invasive measures as shown by Kalmar [17]. Pritoni et al. [18] have described a software tool that solicits thermal feedback from students, and analyses its impact on energy use and energy management procedures.

Semprini et al. [19] have developed diagnosis and energy audits for the School of Engineering in Bologna. Results of the microclimate monitoring campaign in different classrooms show how the lack of thermal control, together with poorly insulated envelopes' components, determine high energy consumption. Allab et al. [20] have presented an audit protocol including simultaneously energy efficiency and indoor climate quality issues using as case study a French university campus.

Ascione et al. [21] have proposed a multi-objective optimisation process for the energy refurbishment of a building of University of Sannio. In this case, the most profitable configurations of energy retrofit include installation of an air-source heat pump for the space heating and of a full-roof PV system. Ferrari and Beccali [22] have explored some retrofit options for an existing office building for a university department of Milan. The results demonstrated that the retrofit solutions that do not include improvements on the building envelope are generally the most cost-effective options.

Instead, Niemelä et al. [23], for typical educational buildings in Lappeenranta University of Technology, with cold climate, have shown that the cost-effective solutions include renovation of the original ventilation system, a ground source heat pump system, new energy efficient windows and a relatively large area of PV-panels.

Tadeu et al. [24] have assessed the relevance of applying the real options theory and return on investment criteria to the cost optimality of energy efficiency measures in the retrofit of buildings. Instead, Bras et al. [25] have observed that reaching better levels of energy performance might be very difficult or not cost-effective in some Portuguese cities.

Finally, it can be underlined that there are also several European projects conducted in the Mediterranean Zone [26–28] for improving the sustainability of educational buildings.

In this context, this paper discusses the critical issue of dealing the energy refurbishment of a University building in heating dominated climate of South Italy, in order to select efficiency measures that allow the improvement of comfort condition, the reduction of polluting emissions during the exercise phase of building and the global cost. About this point, to select the Cost-Optimal configurations, the Energy Performance of Buildings Directive [29] with the Delegated Regulation 244/2012 (EC, 2012) has been followed [30]. The results could be useful to implement refurbishment strategy for buildings in similar climatic conditions.

Accurate information and modelling are important aspects for reliable energy simulation. If input parameters are not carefully provided