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Energy refurbishment of a University building in cold Italian backcountry. Part 2: Sensitivity studies and optimization

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Abstract

The first part of this study provided a discussion about the methodological approach for designing energy refurbishment measures of buildings. The case study is a building owned by University of Molise, in Campobasso, a cold Italian city. The reference scenario is a numerical model built after deep investigations, and thus surveys, questionnaires, documents and experimental measurements on the real building. Then, a calibrated energy model was presented. In this second part, starting from the calibrated model, some energy retrofit measures have been implemented. The obtained results allow to discuss two key points for researches in matter of energy refurbishment of buildings: a) the importance of using validated models to simulate the present performance; b) the environmental benefits and the economic implications of a deep energy refurbishment.

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Keywords: Energy audit; Energy simulation; Modelling calibration; Energy saving; Occupant behaviour; University building.

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1. Short summary of the first part of the paper

According to the common guidelines of the new millennium, buildings have to strongly improve their energy performances, in order to reduce the impact of human activities and life on the global warming of cities and, more in general, of our common Earth.

Starting from the Energy Performance of Building Directive, in this original version [1], the role played by buildings was clarified, and thus the fact that these are responsible of about the 40% of energy requests of European countries and connected polluting emissions.

The same principles and more ambitious targets were explained by the EPBD Recast version, and thus the European Directive 2010/31/EU [2]. Here, as well as also in the more general “Energy Efficiency Directive”, namely the 2012/27/EU [3], also the exemplar role of the public hand was underlined, so that the same prescriptions requested to all buildings are a little bit anticipated or stricter for buildings owned by public institutions or used for public purposes. It should be noted that, in spring/summer 2018, a further revision of the EPBD is ready to be released [4].

As stated by the EU Delegated Regulation [5], both design of new buildings and energy refurbishments of existing edifices have to be performed according to cost-optimal criteria.

In this vein, the first part of this study has deeply analyzed peculiarities, uses, thermo-physics and characteristics of an existing public building (University of Molise), with the aim of evidencing criticalities and to perform a reliable and optimized energy refurbishment, in order to show also the demonstration role of University in matter of reduction of energy usages and polluting emissions related to energy-intensive buildings.

The investigated building, called “II Edificio Polifunzionale”, is shown in figure 1. As discussed in the part 1 of this study, some criticalities emerged by the investigations, among which the high winter indoor temperatures and the absence of a suitable regulation of heating system. That study ends with the definition and calibration of a suitable energy model.

Figure. 1. a) and b) pictures of the building and c) volumetric aerial photo.

2. Assumption of energy modelling: parametric investigations

Starting from the reference scenario (RB) discussed in the part 1, a sensitivity analysis is presented in order to understand what is the error due to wrong characterization of the envelope or to assumptions about the behavior of occupants. More in detail, starting from the calibrated model, in which the measured value of thermal transmittance equal to 0.415 W/m^2 K was used, two different scenarios are tested, by varying the value of thermal transmittance of the most recurrent stratigraphy.

- For the first scenario (U1), the value of the transmittance calculated in according to ISO 9869 has been used, by knowing the materials and the structure of the wall.

- For the second scenario (U2), by supposing that the materials and the type of wall are unknown, the value of thermal transmittance that refers to the most recurring type of construction in the period of this building has been used; it is equal to 0.59 W/m^2 K [6].

For what concerns the occupant's behaviours, starting from adopted schedules, determined on the basis the available information and documents gathered during the audit phase and that have allowed a good calibration of the energy model, ten different scenarios are tested. For all, the operating schedules of the heating and cooling systems of the reference building have been maintained. The first seven scenarios have been obtained by changing only the programs for occupation rate and operation of the equipment and lighting system. While, in the last three scenarios, all thermal zones have been modified simultaneously, and therefore, for some zones, also the value of internal loads has been changed.

The first scenario (S1) has been obtained by considering the schedules of UK's National Calculation Method for a University building, available in DesignBuilder [7], the well-known program interface of EnergyPlus [8]. About it, it should be noted that whole energy simulation software, better if operating under transient conditions of heat transfer (like the aforementioned ones), are necessary for taking into account all thermal and energy phenomena, and thus for having reliable energy performance from numerical studies.

Always starting from the reference building case, the second, third and fourth scenarios have been created like respectively the medium-intensity-use scenario (S2), low-intensity-use scenario (S3), and the high-intensity-use scenario (S4), respectively. For the fifth (S5), sixth (S6) and seventh (S7) scenarios, the schedules have been randomly generated. Moreover, in the eighth scenario (S8), the schedules defined for the offices' reference building have been used for all the thermal zones. Finally, for the last two scenarios, the default values available in DesignBuilder for office zones (S9) and for classrooms zones (S10) have been used, respectively.

In Table 1, the gas (E_ng) and the primary energy for electricity uses (E_el) requests have been reported, as well as the equivalent carbon dioxide emissions (CO$_2$), the operating costs (CE) and the values of calibration indexes for natural gas (MBE_ng and CV_ng) and electricity (MBE_el and CV_el) for the reference building and all simulated scenarios.

Table 1. Effect of modelling assumptions regarding occupation, equipment and lamps

	E_ng (MWh/y)	E_el (MWh/y)	CO$_2$ (t/y)	CE (€/y)	MBE_ng (%)	CV_ng (%)	MBE_el (%)	CV_el (%)
RB	1010	1000	584	166196	3.4	13	2.1	6.9
U1	977	994	575	163592	6.4	16	3.1	7.2
U2	1040	1000	590	168043	0.6	12	2.1	6.8
S1	990	1862	920	254564	5.2	15	-97	87
S2	1020	831	521	149212	2.0	12	21	20
S3	1220	508	430	127928	-17	27	58	53
S4	1040	1262	689	195243	0.4	11	-27	25
S5	1180	989	603	173464	13	21	6.1	11
S6	962	988	570	162041	7.8	18	3.8	12
S7	735	994	529	148578	30	44	3.2	12
S8	1120	1400	762	214570	-7.8	17	-43	40
S9	960	1708	854	236717	8.5	15	-79	71
S10	924	1037	582	164706	11	18	-1.7	12

These results suggest that inaccuracies for the envelope description produce very limited errors. About it, it should be noted that the variation on total energy primary request is -1.9% with U1 scenario and +1.5% for scenario U2. Also, the validation indexes are quite satisfactory and the models could be considered validated. The only problem is the value of indexes for gas request in the U1 scenario.

The results evidence, moreover, that a greater error could be made when the description of thermal zones does not take into account a realistic profile of use. More in detail, when conventional profiles are used (S1), the primary energy need increases of +41% mainly for what concerns the electricity prevision; in this case, the exercise cost is higher (+53%) compared with RB and all calibration indexes are out of range.

For the low-usage profile (S2), it can be noted that the reduction of equipment and lighting uses determine an increase of heating request, but the primary energy need is lower than RB (-14%), as well as the polluting emissions (-26%) and the exercise costs (-23%).

Finally, when the thermal zones are not differentiated, and the same schedule is assigned indistinctly, the error is higher, with variation of +33% for S9 with increment of +42% of exercise costs.

3. What does it change in building energy saving prevision?

In this section, the impact of model assumptions on the evaluation of energy saving and economic feasibility due to energy retrofit measures are analyzed.

According to some important criticalities identified during the audit phase, some energy efficiency measures have been investigated and described in the following bulleted list:

- Envelope insulation: insufflations with cork for walls with air cavity (INS) or application of thermal plaster, 3 cm, on all inner walls (TI);
- WD: replacement of windows, with the installation of triple low-emissive glazing system, with argon-filled cavity and an aluminium frame with thermal break;
- SS: installation of fixed shading systems, which consist in external horizontal louvre systems;
- BL+CH: replacement of HVAC generation system with more efficient boiler and electric heat pump/chillers;
- REG: installation of regulation system for HVAC system;
- LED: replacement of lighting systems with LED lamps;
- LEDC: replacement of lighting systems with LED lamps and automated controls;
- PV: replacement of photovoltaic system and installation of photovoltaic glass in place of the current roof skylights.

More than 20 measures/packages of energy efficiency measures have been simulated and the energy saving, carbon dioxide emissions, investment and exercise costs have been determined.

Figure 2 shows the net present value (NPV) for a lifetime of 20 years, by considering 3% as discounting rate, and the primary energy saving (ΔEP) for each energy retrofit measure.

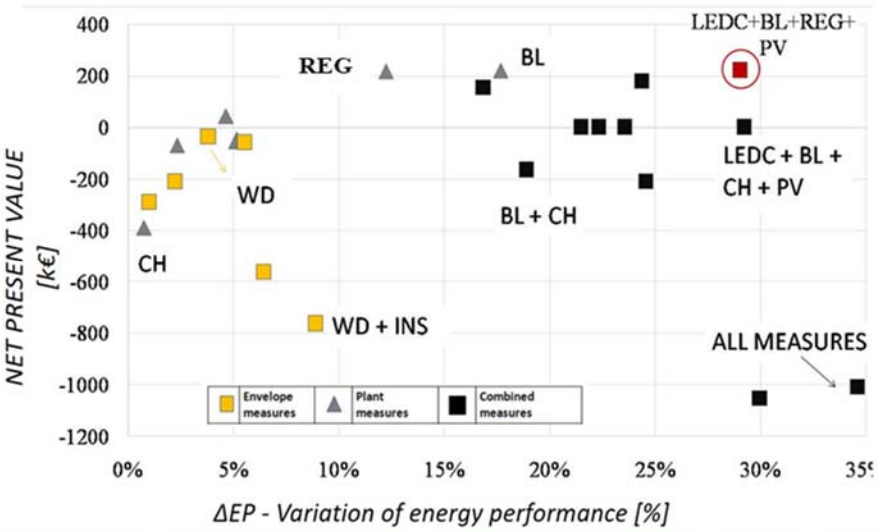

Figure 2. Economic evaluation: comparison of the different retrofit solutions

Several packages are characterized by discounted payback period of around 19-21 years and, when the NPV is positive, these refer to interventions concerning plant systems. For instance, the replacement of boiler and of the current PV panels, allows ΔEP ≈ 22% and NPV≈ 1561 €. On the other hand, the replacement of windows determines ΔEP ≈ 3.8% and NPV≈ -36000 €.

More in general, the measures only on building envelope (squared yellow points) are usually not profitable with negative NPV; the best one in term of energy saving (ΔEP ≈ 6.45%) has a NPV≈ -562 k€, and it involves the replacement of windows and insufflated insulation.

Conversely, refurbishment measures on plant systems and the combination of them are very often profitable; for instance, the installation of devices for indoor temperature regulation provides a ΔEP ≈ 12.3%, with a NPV≈ +218 k€.

According to energy saving results, the best package is characterized by applications of all measures (ΔEP ≈ 34.6%) but it has not considerable discounted payback period and the NPV is around -1000 k€.

Indeed, the most interesting retrofit measures package, that is a compromise between energy and economic performances, (red circled point) consists in:

a) installation of two condensing boilers,
b) installation of regulation system for HVAC system at room level (single-room thermostats),
c) replacement of lighting systems with LED lamps with automated controls,
d) replacement of photovoltaic system with installation of more efficient panels and photovoltaic glasses in place of the current roof skylights.

By adopting all energy efficiency measures from a) to d), the discounted payback is 12 years, with energy saving of around 29%. A sensitivity analysis has been then performed by considering only the package aforementioned (LEDC+BL+REG+PV).

More in detail, for scenarios listed in table 1, energy demands, CO_2 emissions and NPV, have been calculated applying the best retrofit package for all of them. Indeed, the aim is to underline the effect of the modelling assumptions for the description of thermal zones on economic profitability and energy saving evaluation.

Figure 3 proposes simulation results where, for each scenario, the reference one is shown in table 1. The red circular point is the best configuration for building model already proposed in figure 2. It is evident that, by using simplified model, the refurbishment design can appear more or less profitable than the case with well-calibrated model.

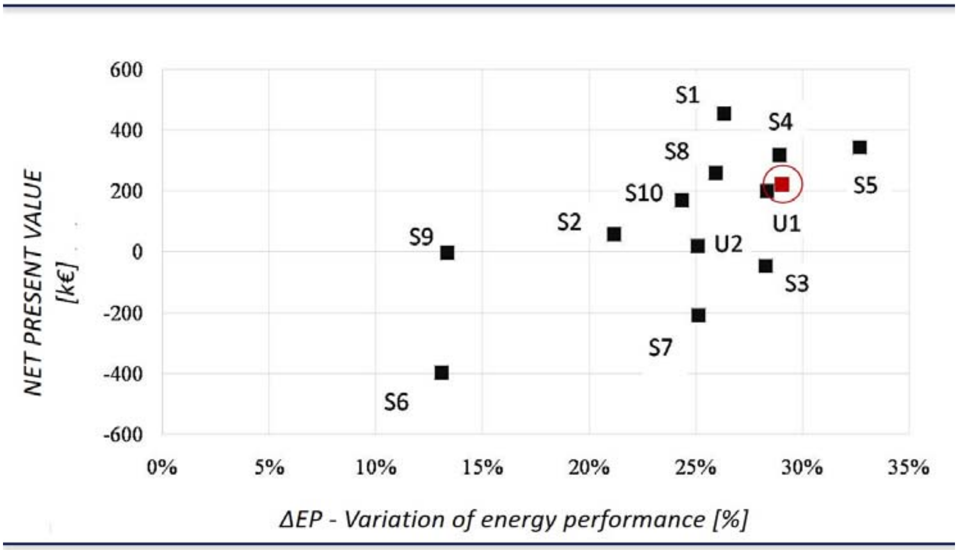

Figure 3. Effect of modelling assumptions: simulation error using different scenarios.

More in details, the simulation scenario S1 determines the most profitable prevision, since the energy saving reaches +26% with discounted payback of 9 years and NPV equal to 454 k€.

Also, for scenarios S4 (ΔEP ≈ 28%, DPB ≈ 10 years and NPV ≈ 317 k€), S5 (ΔEP ≈ 28%, DPB ≈ 10 years and NPV ≈ 342 k€) and S8 (ΔEP ≈ 26%, DPB ≈ 12 years and NPV ≈ 259k€), the prevision of refurbishment results is more advantageous compared to the calibrated model.

The scenario U1 is comparable with the real one, since the discounted payback is 13 years and NPV is around 197 k€. Conversely, in case of U2, a greater difference in the economic profitability is evident, with NPV of 18 k€ and discount payback of 19 years and energy saving equal to 25%.

For all other scenarios, the refurbishment does not allow to obtain good economic results. Indeed, the NPV is negative and thus the discounted payback is higher than 20 years. A bad case is S7, which NPV ≈ -209 k€ and ΔEP ≈ 25%, while the worst one is S6 for the which NPV of -397 k€ and energy saving equal to 13%.

The results show that occupant behavior, more than approximation on the envelope, can distort the energy performance of the building system and also the refurbishment design can appear more or less profitable than the reality. In this way, this part of work shows that an incorrect characterization of the envelope and even more the adoption of default schedules brings to results for the energy performance very far from real performance. Moreover, the adoption of simulation models is a good practice, but only if all variables are checked, monitored and suitably evaluated as shown in the first part of work.

Conclusions

For an educational (University) building of the Italian backcountry, built during the last years of previous millennium, energy retrofit designs performed on calibrated numerical models (transient energy simulations) revealed that energy efficiency measures focused on the HVAC equipment and lighting system have the highest potentiality in terms of energy saving and environmental benefits, compared to the envelope's energy efficiency measures.

Indeed, all actions designed for refurbishing active energy systems allow a good economic profitability and the improvement of the indoor thermal conditions. Conversely, the sensitivity analyses on the characterization of the envelope and the schedule - with which occupants, equipment and lighting system usages are described – have shown that the adoption of default schedules brings results for the energy performance very far from real performance and the refurbishment design can appear more or less profitable.

For energy designers, engineers and architects, this kind of analysis is useful to understand the importance of an accurate definition of building present performance, by considering as necessary a direct census of occupant's behaviors during the first diagnosis phases, as shown in the first part of this research.

It is clear that the adoption of simulation models is a good practice both for designing high performance buildings and for the refurbishment of existing buildings, but only if all variables are checked, monitored and suitably evaluated. Moreover, a sensitivity analysis could be performed during the design phase. Finally, the modelling of the occupant behavior has more impact that error or suitable evaluation of some envelope design parameters.

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