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Energy audit and performance optimization of a residential university building in heating dominated climates of Italian backcountry

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Highlights

An approach for energy refurbishment design based on in-situ measures and dynamic simulation is proposed. A multi-objective optimization problem is set by developing the energy model of a University building in middle-cold climate of a southern Italian region. Energy and environmental effects of several retrofit actions are evaluated.

Abstract

The paper proposes a novel holistic methodology to design the refurbishment of educational buildings in heating dominated climates of Mediterranean regions. The proposed approach is based on the solution of a constrained multi-objective problem by means of genetic algorithm implemented in EnergyPlus. The optimization process regards energy, and environmental objectives as well as the occupants' thermal comfort. The case study of a student dormitory of Campobasso (Italian backcountry city) is proposed. The optimal set of energy efficiency measures shows approximately 55% of the energy saved during the heating season and 24% during cooling season.

Keywords

Energy retrofit, Dynamic simulation modelling, Optimization algorithm, Student dormitory, Mediterranean region

1. STATE OF ART AND PAPER AIM

Buildings are responsible for approximately 40% of the energy consumption and 36% of the CO_2 emissions in the European Union. Since about 75% of existing buildings is energy inefficient, their renovation [1] plays an important role to reach the energy savings and environmental objectives before year 2050 according to competitive and climate neutral economy proposed in the communication n. 773 of 2018 [2].

Educational buildings account for the largest share of the oldest stock [3] thus the great challenge is not in fabricating new high efficient edifices, but in retrofitting existing ones.

Magrini et al. [4] discussed some aspects of energy audit and potential

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interventions in reference to the University of Pavia. Bellia et al. [5] showed, with cost-optimal methodology, that for an office University building in South Italy, the adoption of heat recovery systems, regulation dispositive for HVAC and LED lamps with automatic control, induces considerable the energy saving and the reduction of polluting emissions (-33%) as well as the largest reduction in the overall cost (-35%). Based on the analysis of twelve residential buildings in the University of Malaya campus, Jamaludin et al. [6] concluded that the adoption of internal courtyard and balconies allow to achieve a desired efficient use of electricity, in the range of 24 to 34 kWh/ m^2year. The energy management system upgrade, by integrating an automatic control solution, appears to be the most important and effective measure in a French university campus [7]. The results of the energy analysis for the School of Engineering and Architecture in Bologna showed an energy saving of about 15% with operations building management and over 30% with improvements of the heating system and windows [8]. For the Faculty of Technology in Zagreb, the most energy efficient actions include thermal insulation of the inner surface, thermal insulation of all flat roofs, replacement of the windows and doors and the installation of a door for wind protection [9].

Irulegi et al. have proposed a method to achieve the nearly zero goal in university buildings based on student comfort analysis under real conditions in the Architecture Faculty in San Sebastian (Spain) [10]. Similarly, for the climate of south Italy, Ascione et al. [11] have introduced a novel approach applied concerning costs, incentives, indoor comfort, and energy demands for heating and cooling. In their case study, the cost-effective refurbishment reduces the primary energy demand up to a value of 12 kWh/m^2a, so that the building can be surely considered as nZEB.

The previous analysis allows to underline that available research results concern buildings that differ substantially in terms of morphology, typology, construction characteristics and climatic conditions. There are not studies for cold climates in Mediterranean countries and a methodological approach for multifunctional university buildings has not been introduced. The present work discusses the applicability of a multi-stage and multi-objective optimization methodology in order to select energy efficiency measures for a multifunctional University that hosts offices, lecture rooms, dormitories, in cold climate of a Mediterranean region. The aim is to highlight the importance of applying a holistic approach for the selection of refurbishment measures, based on a deep energy diagnosis with in-situ measurements. Moreover, the results of the case study provide evidence to designers, that the reduction of energy needs, the improvement of comfort condition and the reduction of polluting emissions during operating phase is feasible.

2. A METHODOLOGY FOR ENERGY RETROFIT DESIGN

According to the previous research investigation, there are not many works available for university buildings, thus, some innovative aspects are highlighted in this paper. First of all, the selection of the building typology is based on its different annual energy balance compared to other educational or residential buildings. This difference is due to the multipurpose occupation of the proposed University building, containing several offices, together with lecture rooms but also dormitories etc. Moreover, the proposed paper is aimed to introduce a methodological approach for the selection of energy refurbishment measures, concerning similar typology and usage buildings, basing on a deep energy diagnosis with in-situ measurements. These allow the complete characterizations of building /HVAC system and the indoor conditions, mainly related to thermo-hygrometric and lighting comfort. Indeed high performance and economical effective refurbishment can be obtained only if in the early design stage, designers have appropriate building performance information for a certain destination of use and climatic condition. The proposed approach consisted of a multi-step optimization process with two sequential phases. Initially, the simulation model of the reference building is defined as the model with the energy performances deriving from the present building envelope and active systems configuration and validated. The proposed approach for energy audit is divided into 5 sections: 1) architectural and historical investigations; 2) building envelope audit; 3) technical system and equipment characterization; 4) building uses and thermal zones definition; 5) energy building data.

The first step of the research has been to collect data from its construction regarding architectural constraints or previously structural works. Subsequently geometrical data related to the building envelope and active systems has been collected through in-field measurements. Among these are in-situ measurements, thermography and invasive tests such as endoscopic examinations and core samples. For HVAC and lighting systems, datasheets and inspections of these systems can be used. These results can be supported by using measurements of flow and temperature of cooled or heated water. Thermography can be used to facilitate a qualitative evaluation of temperature uniformity of emitters and generation systems used.

The characterization of thermal zones in buildings and its specific areas will aid in establishing which equipment is suitable for each area. Questionnaires can be used to understand occupants' needs in comfort levels for specific areas within a building. An environment can also potentially benefit through the use of plants which can aid in comfort or performance levels. The spatial distribution of the measurements can be established with a careful analysis of the building taking into account the subdivision into homogeneous zones for internal loads, exposure, and type of lighting sources. Usually, it can be considered appropriate to monitor the air temperature, the relative humidity and air speed as indicators of thermo-hygrometric conditions and the total luminous flux for different natural and artificial light scenes.

Finally, the energy consumptions must be analysed, by averaging the monthly billings of all used vectors of 3 or more years.

The proposed approach applied to the case study, assures the reliability of the building energy model that has to be calibrated before its usage. A comparison between the simulation outputs and the measured energy data is conducted in order to determine the deviation and the relevant uncertainty of the numerical model according to the "Whole Building Level Calibration with Monthly Data" approach, described by the M&V Guideline [12]. The error in the annual energy consumption ($EER_{\text{average year}}$) should be ± 10%, the mean bias error (MBE) within the limit values of ± 5% and the coefficient of variation of the root mean squared error CV(RMSE) ± 10%.

In the second phase, a multi-objective optimization is considered in order to provide the best trade-off among transparent envelope solutions, insulation of the building and radiative characteristics of the roof. The multi-objective optimization problem was set by developing the energy model with Design Builder [13], which allows the use of a Genetic Algorithm based on the NSGA-II method [14], by setting a maximum number of generations to 200; each generation including maximum 20 designs. The multi-objective optimization is an advanced technique that can be used in a design process in order to identify, in a more efficient way than a parametric analysis, the design options that best meet the performance objectives set.

Since several solutions can represent sub-optimal trade-offs, the decision-maker can select the most appropriate according to personal criteria [15]. In particular, the final outcome is the Pareto [16] front which is the set of the non-dominated solutions.

3. CASE STUDY

3.1. GENERAL DESCRIPTION

Campobasso is a city of Italian backcountry, within the Italian climatic zone

“E”, characterized by 2346 Heating Degrees-Day (baseline 20°C). It has cold winters with frequent snowfalls and medium warm summers; the mean daily temperature in July 2017 was 24-25 °C with peak values of 29 °C [17].

The ‘Student House - Vazzieri’ (fig.1) has been recently constructed, in 2012, financed by ministerial funds and partly by the University budget. The building is surrounded by the University library, the sports hall and the University canteen. Briefly this building has been selected because of its typical reinforced concrete structure which is also found in several edifices built in Italy and Europe in the last 30 years, without particular attention to insulation. It is also a public building that can have an exemplary role for other future projects with similar typology buildings in the same region.

3.2. ENERGY AUDIT AND SIMULATION MODEL

In order to simulate reliable energy performances, the numerical model has been characterized by data acquired by means of in-situ surveys, interviews with managers and occupants and in-field measurements.

The building has an articulated geometry, with the main face along the East-West axis andfour usable floors above the ground. The gross volume is 8’990 m^3 and the surface to volume ratio is 0.38 m^{-1}. At the ground floor, there are some laboratories and administrative offices and a museum. More in detail, there is a library with a meeting room, a cloakroom, a laundry room, a waiting room as well as large offices close to the entry point. At the same level, there are separated spaces for common services (TV room, internet, music, games and spaces for collective study). Near the entrance there is a covered parking area of 310 m^2. The students’ dormitory is on the first, second and third floor. On the first level there are 11 single rooms, 6 double rooms and equipped kitchen area. There are only three bedrooms on the second floor, of which two doubles. On the third floor there are 11 single rooms, 8 double rooms

Figure 1. Building view and location (Campobasso).

and a kitchen area. For the most accurate prediction of the real conditions, surveys concerning occupation period, typical behaviour patterns and indoor comfort conditions have been conducted. Data for characterized thermal zones have not been derived from a large-scale questionnaire, but some questions have been done to occupants contextually to the survey. More in detail, the questions included, the duration of the time spent per day inside the building, the description of the indoor conditions in winter and summer and the main criticalities found in these buildings.

All technical sheets and design documents have been made available by the University's technical office. Thus the characterization of building envelope, supported by infrared thermography (Figure 2a), has been made. The building has reinforced concrete structure; the vertical opaque envelope has mixed brick-concrete composition, with 5 cm of expanded polystyrene, for an overall transmittance (U) of around 0.39 W/(m^2 K) and periodic thermal transmittance (Y_{IE}) of 0.078 W/(m^2 K) with surface mass (M_s) of 361 kg/m^2, values calculated according to the appropriate standards [18-19]. Ceiling and roofs have mixed structures, given by the parallel presence of concrete beams, joists and interposed hollow bricks. The main characteristics of building envelope are reported in table 1. The floor on the ground level is made of 24-cm-long predalless elements, with an intermediate layer of expanded polystyrene, base in low-density cement and ceramic tiles, for an overall thickness of 0.39 m. The thermal transmittance is 0.39 W/(m^2K) and the periodic thermal transmittance is 0.048 W/m^2K. At the present state, the studied building insulation performance is not in accordance to the Italian normative for building under refurbishment [20]. Based on this normative, the wall and the floor of the ground level should have U value corresponding to 0.26 W/(m^2 K) while the limit value for the ceiling is 0.22 W/(m^2 K). This difference results in high transmission losses and has a negative impact on the heating needs and comfort conditions for occupants. Based on the calculated values, during the summer period the building envelope has a good performance. Indeed the limit value for Y_{IE} is 0.10 W/(m^2 K) while the surface mass is higher than 230 kg/m^2.

Building element	t (m)	U (W/m^2K)	Y_{IE} (W/m^2K)
Vertical external wall (concrete / expanded polystyrene / bricks)	0.41	0.39	0.078
Floor on ventilated crawl space (predalles / expanded polystyrene /cement / ceramic tiles)	0.39	0.39	0.048
Ceiling (predalles type/ cement / ceramic tiles)	0.44	0.38	0.035
Pitched roof (predalles type / expanded polystyrene / tiles)	0.32	0.40	0.081

Table 1. Thermo-physical characteristics of opaque envelope.

The window-to-wall ratio is 18%, and the main type of window is a double glazed element (4/12/4 mm) with air gap and aluminium frame. The transparent component has thermal transmittance U_g of 2.87 W/(m^2 K) while the solar factor (g) is 0.742 and there is no external shading system, except internal curtains.

Bedrooms of all floors and also all rooms of the 1st and 3rd floors have a water-heating system with cast iron radiators or fan coils. Instead, the ground floor and the 2nd floor have a mixed air/water system, given by combination of fan-coil and air handling units only for Museum and common areas. This system provides heating, cooling and ventilation. Domestic hot water is produced by three condensing boilers with total nominal power of 285 kW. Cool water is supplied by electric air chillers with nominal power of 137 kW. There are two air handing units without heat recovery. The building consists also of several zone thermostats, which control the temperature of radiators and fan coils by means of three-way valves between the delivery and the return duct; while in the air handling units, regulation is carried out by acting on the flow of the fluid. Finally, there is hot water storage with capacity of 2000 L. According to the Italian normative [21], the heating period starts on October 15th and finishes on April 15th, with a daily operating schedule of 12 h in the coldest months and 6 hours during October and April. The cooling period refers to July (12 hours daily). The heating and cooling set point temperatures are set to 22 °C and 26 °C respectively.

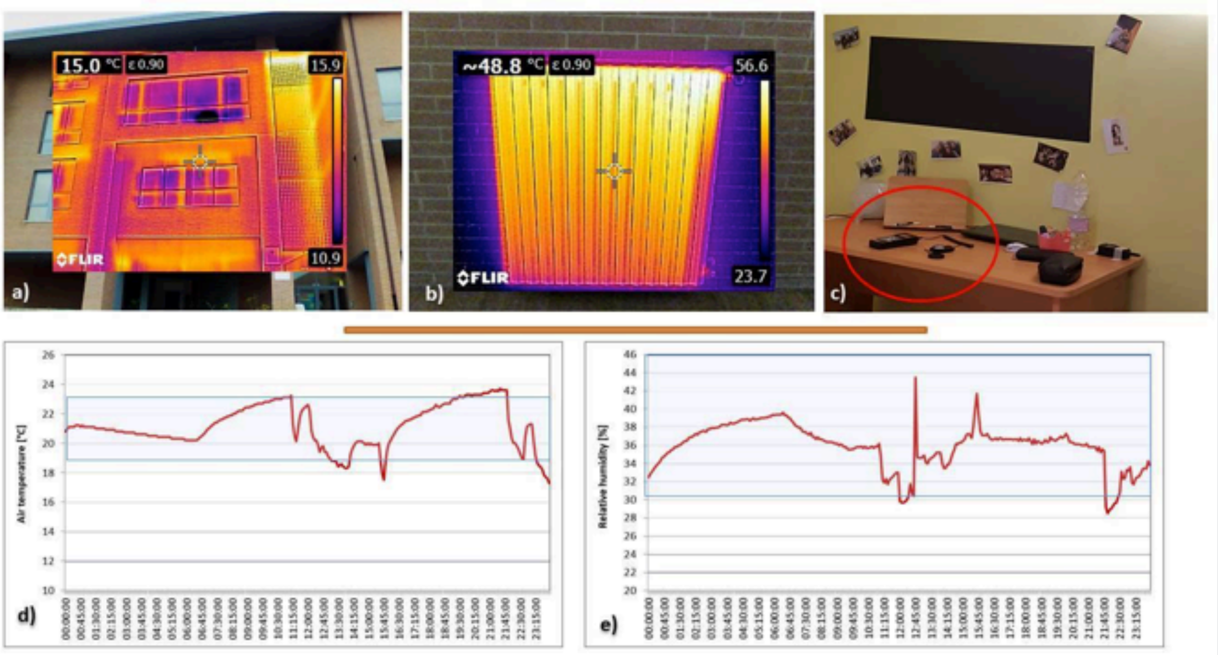


Figure 2. a) envelope thermograph; b) radiator thermograph; c) light level monitoring; d) monitored air temperature for bedroom at 1st floor; e) monitored relative humidity for bedroom at 1st floor.

In regards to the lighting system all bedrooms and bathrooms are equipped with fluorescent lamps (112 W and 36 W respectively).

Infrared thermography of heating generation equipment and emitters is depicted in Figure 2b. In Figure 2c the installation of measurements for monitoring light level is shown. The measurements of temperature and air speed for air emitters indicate that the speed is always within the range of comfort zone but the temperature is greatly higher than comfort values.

For specific rooms, air temperature, relative humidity and lighting level have been monitored for periods between February and March 2018, with a time-step of 5 minutes. The results of monitored temperature and relative humidity are presented below. The recorded values for a bedroom (28 m^2) at 1st floor with south-west exposure with one radiator and one large window are reported in Figures 2d and 2e, with reference date the 19th March and external temperature between 0 to 5 °C. The figure presents also the comfort range which is highlighted with blue background, in the graphs [22]. The maximum recorded value is 23.7°C and the minimum 17.3 °C for air temperature, meanwhile the relative humidity remains low with mean daily value of 36%. These conditions correspond to several rooms, with T up to 20 °C and humidity levels constantly lower than the threshold of 50%. The interviews of the occupants revealed frequent discomfort conditions.

Measurements of illuminance level (Figure 2c), on working desk, have been done considering different natural and artificial scenarios with a sampling time of 10 minutes. In detail, the following scenarios have been considered: 1) curtains opened and lamps turned off; 2) curtains closed and lamps turned on. These measures have been compared to the standard UNI EN 12464-1 [23] with positive results for several common areas; nonetheless, the bedrooms show very poor illuminance level, as could be seen in table 2 both with natural than artificial lighting. It has to be considered that the acceptable value is 300 lux for bedroom and kitchen while it is 500 lux in study areas. The values, in the 1st scenario, are often less than the limit ones, probably also because the measurements were carried out during early afternoon of overcast days.

		Mean illuminance [lux]	Minimum illuminance [lux]	Maximum illuminance [lux]
Bedroom I floor	Scenario 1	6	4	8
	Scenario 2	149	107	154
Kitchen II floor	Scenario 1	257	238	259
	Scenario 2	644	641	731
Study room II floor	Scenario 1	189	184	210
	Scenario 2	493	486	529
Bedroom III floor	Scenario 1	72	71	77
	Scenario 2	163	93	164

Table 2. Measures of illuminance level (13-14/03/2018).

Finally, air change equal to 0.5 ACH has been considered.

Figure 3 compares the real building and its simulation model rendering. The model calibration was based on energy needs/demand data from 2014 to 2017. The calibration error in the annual energy consumption is +1.1%, the MBE is +0.1% and the coefficient of variation of the root mean squared error is 5.3%. The same evaluations have been performed for electricity, with a very good agreement. Briefly, the ERR $_{\text{average}}$, year was 5.0%, the mean bias error was 1.2% and the CV (RMSE) was 9.4%.

3.3. SELECTION OF ENERGY EFFICIENCY MEASURES FOR BUILDING ENVELOPE

The energy audit has given suggestions about the following possible energy efficiency measures, summarized in table 3 with their nomenclature and the indication of thermal transmittance values. More in detail, the selected measures are:

- Increment of thermal insulation of building envelope by considering the application of 5, 8 or 10 cm of glass fibre board (λ≈0.037 W/m K) for walls, 7, 10 or 12 cm of insulation for roof, 4, 7 or 9 cm of glass fibre board for the slab on the ground; these represent different scenarios compared to the Italian normative, where the lower value of insulation allow to reach the prescribed value.
- Adoption of different finishing layers for roof by varying its solar reflectance (SR) between 0.3 and 0.9.
- Replacement of the windows with more efficient solutions, combining different types of window frames, glasses, as well as various external shading systems.

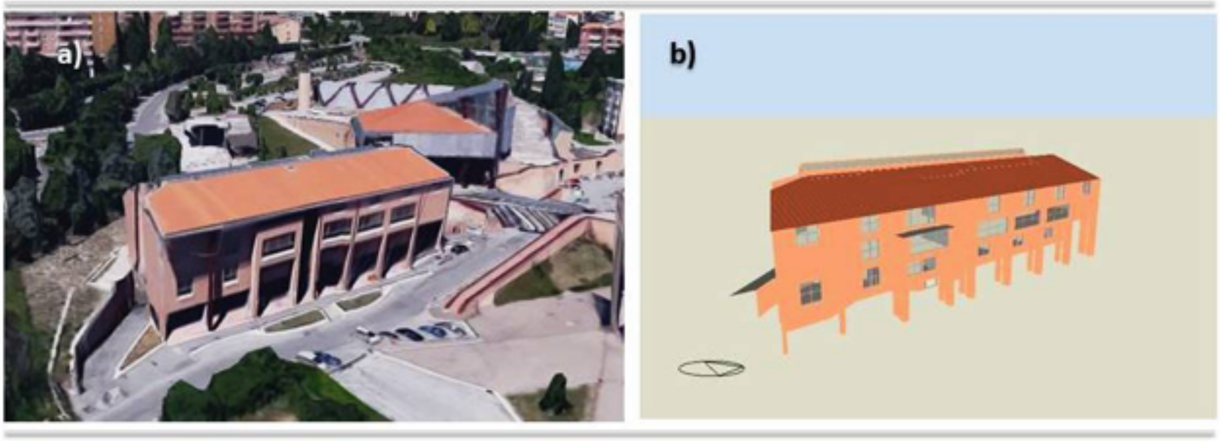


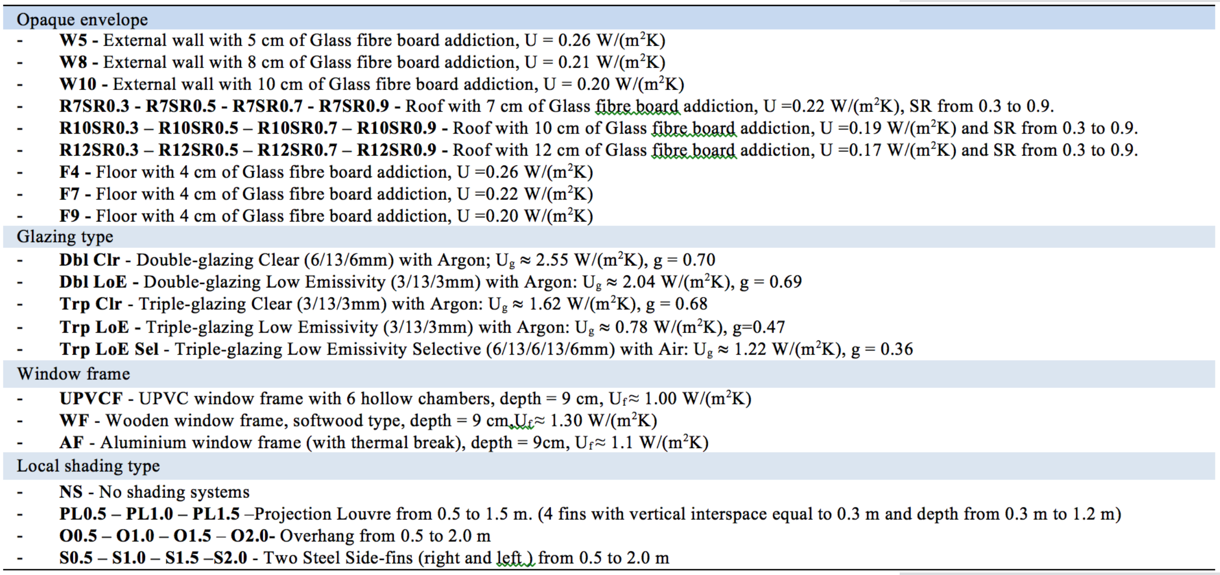
Figure 3. East side: a) real building; b) rendering of simulation model.

In this study the measures on the air-conditioning system have been not considered. Indeed the installed equipment is quite new and these have good performance. However in further studies the building-HVAC system optimization will be discussed.

For the considered case study, the minimization of heating and cooling load has been taken into consideration for the application of optimization tool. This choice has be done because the minimization of energy demand is considered the first step in high efficiency design. Indeed when the aim is the nearly or net zero energy target, the building must have very low energy request covered mainly by renewable sources. Furthermore, the proposed study takes also into account the indoor thermal comfort, using the hours of discomfort as a limiting constraint for determining the Pareto front solutions. Comfort conditions have been expressed as the combination of humidity ratio and operative temperature included in the ASHRAE 55-2004 summer (0.5 Clo) or winter (1.0 Clo) clothes region. This option implies that solutions failing the constraint requirements are not included in the Pareto Front.

4. REFURBISHMENT DESIGN OPTIMIZATION: RESULTS AND DISCUSSION

The simulation model suggested that the overall primary energy demand (EP) is 174.2 kWh/m^2, considering the net conditioned area (2558 m^2) and by assuming the average efficiency of Italian power system of 51%. This energy demand corresponded to operating costs of 47’476 €/y considering the natural gas cost of 0.095 €/ kWh$_{gas}$ and electricity cost of 0.234 €/kWh$_{el}$. Moreover, it



Opaque envelope

- **W5 -** External wall with 5 cm of Glass fibre board addiction, U = 0.26 W/(m^{2}K)
- **W8 -** External wall with 8 cm of Glass fibre board addiction, U = 0.21 W/(m^{2}K)
- **W10 -** External wall with 10 cm of Glass fibre board addiction, U = 0.20 W/(m^{2}K)
- **R7SR0.3 - R7SR0.5 - R7SR0.7 - R7SR0.9 -** Roof with 7 cm of Glass fibre board addiction, U =0.22 W/(m^{2}K), SR from 0.3 to 0.9.
- **R10SR0.3 – R10SR0.5 – R10SR0.7 – R10SR0.9 -** Roof with 10 cm of Glass fibre board addiction, U =0.19 W/(m^{2}K) and SR from 0.3 to 0.9.
- **R12SR0.3 – R12SR0.5 – R12SR0.7 – R12SR0.9 -** Roof with 12 cm of Glass fibre board addiction, U =0.17 W/(m^{2}K) and SR from 0.3 to 0.9.
- **F4 -** Floor with 4 cm of Glass fibre board addiction, U =0.26 W/(m^{2}K)
- **F7 -** Floor with 4 cm of Glass fibre board addiction, U =0.22 W/(m^{2}K)
- **F9 -** Floor with 4 cm of Glass fibre board addiction, U =0.20 W/(m^{2}K)

Glazing type

- **Dbl Clr** - Double-glazing Clear (6/13/6mm) with Argon; $U_g \approx 2.55$ W/(m^{2}K), g = 0.70
- **Dbl LoE -** Double-glazing Low Emissivity (3/13/3mm) with Argon: $U_g \approx 2.04$ W/(m^{2}K), g = 0.69
- **Trp Clr** - Triple-glazing Clear (3/13/3mm) with Argon: $U_g \approx 1.62$ W/(m^{2}K), g = 0.68
- **Trp LoE -** Triple-glazing Low Emissivity (3/13/3mm) with Argon: $U_g \approx 0.78$ W/(m^{2}K), g=0.47
- **Trp LoE Sel** - Triple-glazing Low Emissivity Selective (6/13/6/13/6mm) with Air: $U_g \approx 1.22$ W/(m^{2}K), g = 0.36

Window frame

- **UPVCF** - UPVC window frame with 6 hollow chambers, depth = 9 cm, $U_f \approx 1.00$ W/(m^{2}K)
- **WF** - Wooden window frame, softwood type, depth = 9 cm, $U_f \approx 1.30$ W/(m^{2}K)
- **AF** - Aluminium window frame (with thermal break), depth = 9cm, $U_f \approx 1.1$ W/(m^{2}K)

Local shading type

- **NS** - No shading systems
- **PL0.5 – PL1.0 – PL1.5** –Projection Louvre from 0.5 to 1.5 m. (4 fins with vertical interspace equal to 0.3 m and depth from 0.3 m to 1.2 m)
- **O0.5 – O1.0 – O1.5 – O2.0-** Overhang from 0.5 to 2.0 m
- **S0.5 – S1.0 – S1.5 –S2.0** - Two Steel Side-fins (right and left) from 0.5 to 2.0 m

Table 3. Energy efficiency measures description.

corresponded to polluting emissions of 107.4 tCO_2 assuming emission factor for the combustion of natural gas and for electricity, respectively equal to 0.205 kg/kWh and 0.551 kg/kWh_{el}. The energy demand for space heating accounted for 43% of the primary demand. Electricity demand for summer cooling was approximately 4.2% of the total electricity demand (107.7 GWh_{el}) and lighting consumption was approximately the 28%. Regarding the whole building, the discomfort hours over the year were equal to 2354 h. This value has been set as the base for further optimization, thus all resulted points determine better comfort condition than in the present state of the building. Finally, the base case is characterized by heating thermal need of 177 MWh and cooling thermal need of 1’526 kWh.

The optimization tool has been applied. More in detail the genetic algorithm starts from a population of randomly generated individuals, in this case the efficiency measures, and with an iterative process, for each generation, the fitness of every individual is evaluated. The fitness is the value of the objective functions. The more fit measures are stochastically selected from the current population, and it is modified (recombined and possibly randomly mutated) to form a new generation. The new generation of candidate solutions is then used in the next iteration of the algorithm. Finally 487 solutions (combinations of the energy efficiency variables applied to the state of fact) have been identified and these are shown in figure 4. Herein, the point of base case has not be represented for a better readability of graph, because it would require a different resolution for the axes, considering its heating energy need. In figure 4, the position of solutions that consider only interventions on opaque envelope are depicted with orange color; only three combinations result by applied algorithm. One of these considers only the intervention on the roof with thermal insulation (7.0 cm) and reflective paint, one only the insulation of the wall (W5) and the last one is a combination of all insulation scenarios for the opaque envelope.

The blue points represent the packages of measures only on the transparent envelope. The adoption of triple glazed windows is more frequent than double glasses as well as the adoption of wooden frame. The projection Louvre is never considered.

For further reduction, combined measurement has to be taken into account. The package of measures with the worst performance is evidenced (black point). It corresponds to roof insulation with 7.0 cm of glass fibre panel without the use of reflective coating.

The solution of optimization problem generates a Pareto front with yellow points (13 in total). Pareto front considers triple low-emissive glazing system for all cases. No unique solution can be found for local shading: in 4 points there are 1.0 m projection Louvre, in 3 solutions Overhang and Side-fins shading and no type of shading system in 3 points. Wooden window frame is the most the most frequent frame type (10 points).

As far as the opaque envelope for the wall is concerned, in all points the common solution was the adoption of the maximum values of insulation material (10 cm for wall, 12 cm for roof and 9 cm for slab on the ground). Only one Pareto point required finishing layers for the roof with a solar reflectance of 0.9. The most frequent values of SR were 0.5 and 0.7, showing that cool roof adoption (SR>0.8) was not an optimal solution for the studied climate zone since an increase of heating load was observed.

Finally, two points have been considered on the Pareto front:

- OpW: the configuration that minimizes the heating load (red point);
- OpS: the configuration that minimizes the cooling load (green point);

The OpW requires the installation of triple low emissive windows with wooden frame, no external shading systems; the walls, roof and ground floor require the maximum thickness of glass fibre board (10, 12 and 9 cm respectively). For the roof, the application of finishing material with 0.5 solar reflectance is the most suitable solution. This configuration allowed energy saving during the heating season of approximately 55% and cooling

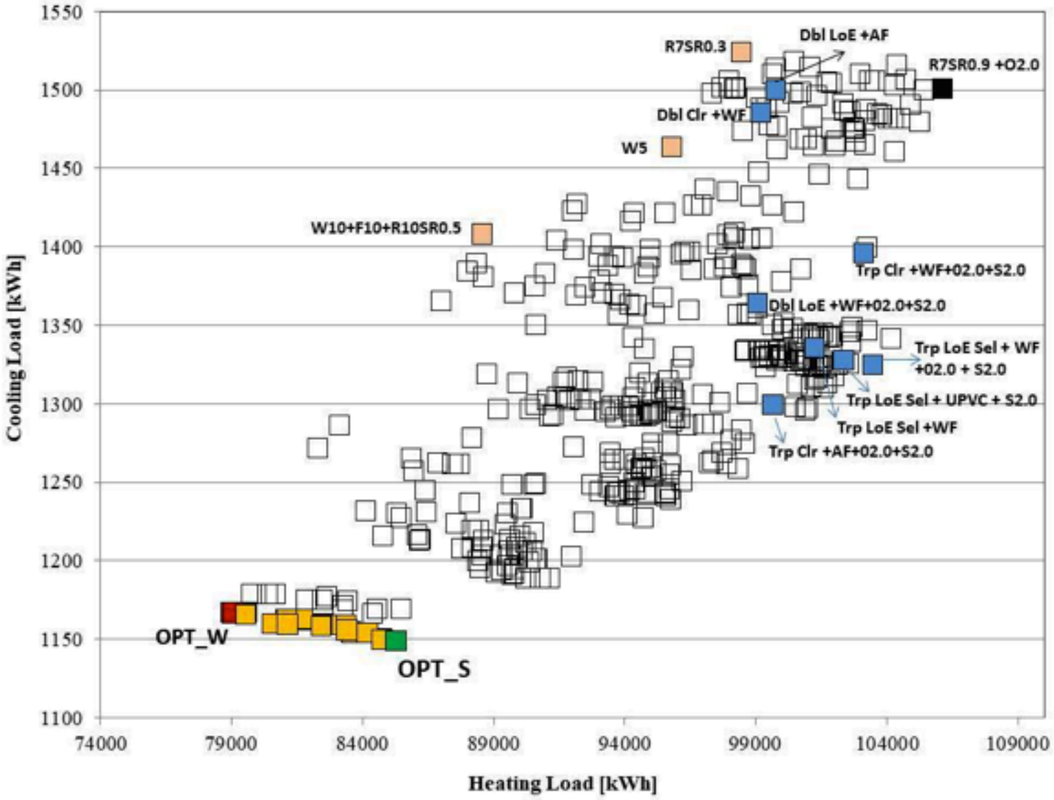


Figure 4. Optimization results for opaque and glazed envelope.

season of approximately 24%. The OpS point is characterized by the same solutions for the opaque envelope of OpW, with roof finishing layer of a SR equal to 0.7. While for the windows the adoption of triple low-emissive glass with UPVC frame is suggested. The external shading should be overhang and side-fins with 2 m projection should be installed. In this case, the heating load is reduced by 52% and the cooling by 25%.

The point that minimizes the total load corresponds to the one that minimizes the heating load (OpW). For this solution, cost analysis has been conducted. More in detail, the intervention on the roof slab requires a cost of around 32 €/m^2 while the wall insulation of 35 €/m^2 and 23 €/m^2 for the floor and last 300 €/m^2 for the whole window replacement. Total investment cost is estimated to be equal to 186’000 €; the energy saving allows to repay the investments in more than 15 years, without considering the national incentives for the energy efficiency. This is an expected payback period when envelope efficiency measures are taken into account, mainly due to high costs for glazing components. However, further analysis will be done with the aim to develop an optimization analysis that will take into account, as objective functions, the primary energy savings and other possible none related energy aspects that can contribute to lowering the payback period of this investment.

5. CONCLUSIONS

The paper presented the application of a multi-stage optimization methodology for the selection of suitable energy efficient measures, in order to improve the energy performance of a University building, in a typical heating dominated climate in Italy. After accurately defining the current state, a multi-objective optimization using a genetic algorithm was performed in order to provide the best trade-off between transparent envelope solutions, insulation of the building and radiative characteristics of the roof.

At the designer level, the outcomes of the case study allow to point out that, at least for educational buildings in medium cold climate, energy efficiency measures on building envelope require the adoption of insulation materials with low conductivity and high mass both for walls and roof. Moreover it is strongly recommended to limit or not use high reflective materials. Furthermore, the use of triple low-emissive systems with wooden frame windows is highly recommended.

Results could be usefully considered by designers because these allow knowing the effect of traditional technologies on tertiary building where heating requests are higher than cooling needs. Well-known technologies are combined for building envelope, by varying singularly and simultaneously, transparent components, type of insulation material and spectral characteristics of roof for commercial available products. Thus, the energy curve could represent a pre-elaborated material, ready to be used for selection of suitable technologies for minimizing the energy request. This can take place without the use of invasive measures together with the improvement of indoor comfort. This can be the starting point for a subsequent heating, ventilation and air-conditioning plant design. It must be underlined that this methodological approach targets the the nearly zero energy building goal; indeed, by minimizing the energy need by means of passive interventions.

6. REFERENCES

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