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Energy Requalification of "Raffaello" School in Pistoia †

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Abstract: In 2017, 46.5% of school buildings in Italy needed urgent maintenance regarding architectural usability and accessibility, but also concerning structural, energy, and environmental aspects. A total of 36% of the energy needs during the operational and management phase of the Italian school sector are required by secondary schools. The main objective of this paper is to propose an integrated (architectural, energy, and environmental) redevelopment for the "Raffaello" School in Pistoia (Italy), aimed at improving the environmental and technological system and decreasing the building's primary energy demand. Here, for the sake of brevity, we will only deal explicitly with energy rehabilitation. The results show that the replacement of the artificial lighting system with LED lamps alone leads to a 45% decrease in primary energy demand.

Keywords: existing school; energy requalification; sustainable school; energy saving

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1. Introduction and Background

The Italian school heritage is undoubtedly old, obsolete, inadequate, and above all characterized by limited energy efficiency and poor environmental sustainability. Several problems characterize the existing schools and they are linked not only to the internal organization, which does not at all meet the requirements of new teaching and pedagogical methods, usability, and safety, but also mainly to energy and environmental issues. In fact, schools are characterized by an excessive yearly demand for primary energy, mainly due to the non-use of renewable sources for energy production. In Italy, in 2018, only 1% of school buildings were in energy class A, while 45.3% were in energy class G [1]. The analysis of the literature shows that many studies on existing school buildings (primary and secondary schools) deal with the evaluation of the best energy refurbishment strategies adopted to obtain a lower annual primary energy demand (especially in terms of energy demand for heating). Some studies also consider the cost parameter. Different analyses are used to outline the type of measure to carry out, such as the comparative cost-optimal methodology, proposed directly by the European Directive 2010/31/EU [2,3] and combined very often with the calculation of the payback period and the CO2 emissions released into the atmosphere [4]. This was performed with the comparison through simulation in a dynamic regime between the existing state and the design state with a proposal of upgrading according to nZEB standards, considering the interventions in terms of cost [5] and performing monitoring on the existing building to validate the simulation models [6] or through the life cycle assessment (LCA) or the application of certification protocols [7,8]. Finally, many authors point out that, in order to significantly reduce primary energy demand, it is necessary to work on the artificial lighting system and on the management of shading systems [9–11].

The main objective of this research work is to propose an integrated requalification (architectural, energetical, and environmental) for the secondary school "Raffaello", designed by Luigi Pellegrin (1925–2001) and built by the company Fratelli Bortolaso of Verona in Pistoia in 1967, taken as a case study. Here, for the sake of brevity, we will only deal specifically with the energy requalification.

2. Method

The methodology for the study of the energy requalification proposal (which is part of an integrated requalification process) is divided into 3 different phases:

- Identification of the energy strategies for the rehabilitation of existing schools. Using the analysis of several case studies of secondary schools that were characterized by energy upgrading after 2008, recurring energy strategies to improve the energy performance of an existing school building were defined.
- Detailed analysis of the case study. The energy performance of the existing state was defined through modelling of the school and energy simulation in a dynamic regime with hourly time step using Design Builder [12]. Heating, cooling, and lighting consumptions were considered because they are the most important contributions to the energy balance of a school building.
- Proposal for the energy requalification of the "Raffaello" School. Different strategies for the energy requalification were proposed and validated through the energy simulations; replacement of the external envelope, replacement of the artificial lighting system (22 lm/W—fluorescent lamps), with a more efficient LED system (120 lm/W with control on natural lighting), replacement of the existing heating system (gas boiler with 50% efficiency), and introduction of cooling, maintaining a natural ventilation of the rooms, and design proposals related to the system; design proposal 1: replacement of the boiler with an air-water heat pump (coefficient of performance = 3.8 and energy efficiency ratio = 3.5) for heating and cooling with a radiant panel as a distribution system; design proposal 2: equal to design proposal 1 in addition to the replacement of the mechanical ventilation system (integrated with heat recovery with 60% efficiency) that is currently not working.

The secondary school "Raffaello" built in 1967 is located in the municipality of Pistoia, belonging to the climatic zone D [13], with a degree day number equal to 1885. Italy, in fact, is divided into 6 climate zones based on the number of the degree day. The building is characterized by a very complex planimetric configuration that also includes a swimming pool, a gym, and an auditorium, perfectly integrated, with the remaining part dedicated exclusively to the school. Although the building is characterized by a very articulated architectural design, it can be inscribed in a rectangle with main dimensions of 80 m $\times$ 60 m; it has total surface area equal to 7196 m^2 and volume of about 37,600 m^3. The architectural and structural design is based exclusively on the repetition of elements with a module of 1.20 m. The school is on 3 floors and has a basement, in which there is the central heating and an air conditioning system.

3. Results and Discussion

The main energy requalification strategies to obtain the reduction of primary energy demand identified in the study of the analyzed buildings and in the literature are improvement of the shading system with both fixed and mobile solar shading systems, replacement of windows, creation of an external insulation layer for the external wall, integration with renewables, installation of a more efficient artificial lighting system, use of rainwater collection systems, and installation of a cooling system to maintain adequate internal comfort conditions even during the summer season.

From an energy point of view, the analysis of the current state of the building highlights the following main problems: the technological solutions for the external wall are not verified in terms of thermodynamic properties or thermal transmittance; the artificial lighting system is outdated, obsolete, and characterized by neon lamps with no automated control, according to the level of illumination guaranteed by natural light. The heating system with gas boiler does not guarantee the average minimum setpoint temperature of 20 °C in the building. The mechanical ventilation system is currently not working, and therefore the air exchange required occurs only through natural ventilation. Consequently, the main proposals for the energy upgrading are: the replacement of the external wall made of prefabricated slabs with a solution characterized by a load-bearing layer made of aerated autoclaved concrete blocks (24 cm), an insulation layer with rock wool (6 cm) and an advanced screen façade with stoneware finishing, the replacement of windows that do not meet the requirements of current energy and safety regulations for schools, the replacement of the artificial lighting system, and a double proposal for upgrading the system, as already described.

The graph in Figure 1 shows the annual energy demand in [kWh/m^{2}a] for heating, cooling, and lighting for the existing design and for design proposals 1 and 2.

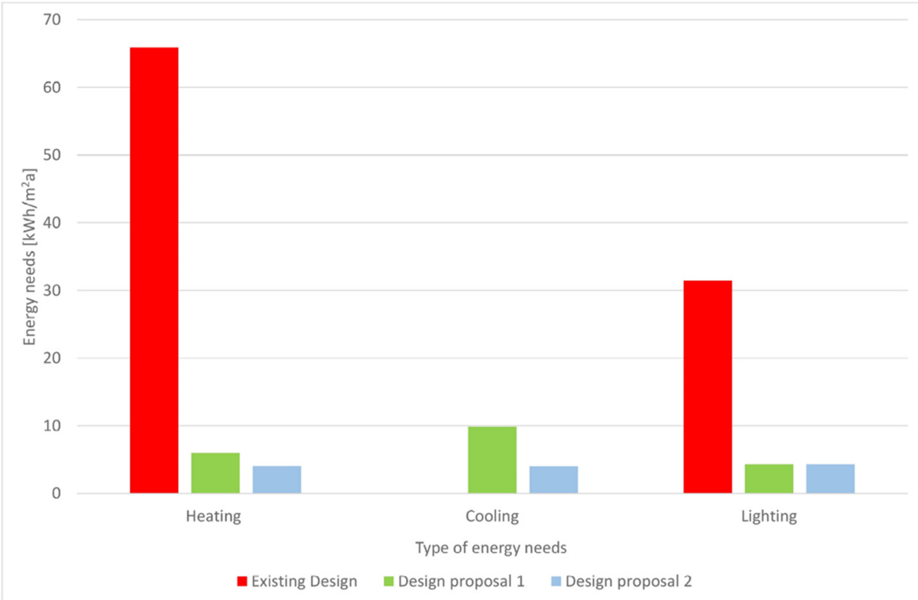

Figure 1. Energy needs [kWh/m^{2}a] for heating, cooling, and artificial lighting.

The graph shows that the energy requalification of the building leads to a significant decrease in both energy consumption for heating, by about 90%, and lighting, by about 85%. This results in a clear improvement in the environmental performance of the building during the operational phase, with a decrease in CO_2 emissions of about 22 kgCO_2/m^{2}a (for heating alone). The energy demand for cooling obviously only appears in design proposals 1 and 2 and it is not significant, thanks to the use of solar shading systems on both the South and East façades of the building. Comparing design proposals 1 and 2, the former has a slightly higher value of energy demand for electricity. This is due to the presence of natural ventilation inside the rooms to ensure air exchange rates and the absence of heat recovery due to mechanical ventilation during the winter season. The graph in Figure 2 shows the primary energy demand for heating, cooling, and lighting for the existing state, design proposals 1 and 2, the replacement of the external envelope, the heating/cooling system, and the artificial lighting system considered separately.

The graph (Figure 2) highlights that, between the existing state and the design proposals 1 and 2, there is a difference for the primary energy demand, considering the conversion factors for each energy vector (gas or electricity from grid without renewables), equal to 66% and 79%, respectively. As already pointed out, the decrease in primary energy demand in design condition 2 is due to the presence of mechanical ventilation with heat recovery. However, just the replacement of existing lamps with a more efficient lighting system with natural lighting control leads to a decrease in primary energy demand of about 45%.

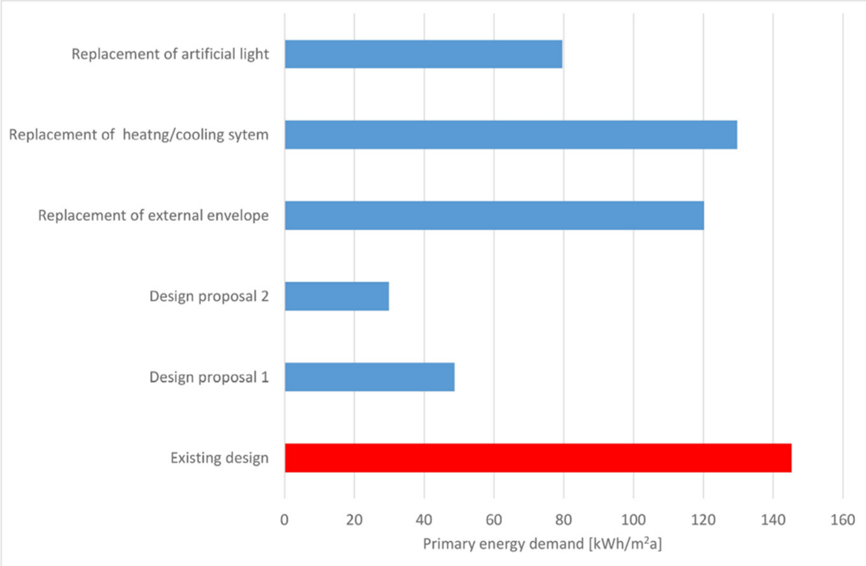

Figure 2. Primary energy demand [kWh/m^2a]. In red, the yearly primary energy demand for the existing design.

4. Conclusions

In conclusion, the main energy redevelopment proposals of the case study concern three main aspects: the external envelope, the artificial lighting system, and the plant system (heating, cooling, and mechanical ventilation). A complementary economic assessment was not carried out to determine the economic sustainability of the different proposed interventions. For this reason, the benefits obtained by considering separately the three main aspects of the proposed energy requalification were analyzed; as for the hypothesis, only one of the three aspects could be carried out without involving the others. The aspect that has the greatest benefit in terms of primary energy demand is the replacement of the neon lighting system with LED lighting, which leads to a reduction of about 45% in annual primary energy demand. The replacement of the external envelope and the heating/cooling system results in a reduction of 17% and 11%, respectively. The energy requalification is defined as "design proposal 2"; although it is the most expensive in terms of cost of the interventions, it certainly ensures adequate conditions for the well-being of the occupants, a correct air exchange, and an undoubted advantage from an environmental point of view during the operation and management costs of the building: the primary energy demand can be reduced to about 39 kWh/m^2a compared to the existing design of the building, which needs 145 kWh/m^2a.

The research can be deepened, using BIM tools for the evaluation of alternative design solutions and different requalification measures also considering their cost. For this purpose, the adoption of the cost optimal methodology could be proposed, as requested by Directive 2010/31/EU. A simplification of calculation and comparison procedures can be achieved, recurring just the BIM model. The BIM model can be used to extract metric calculations useful for quantifying construction costs and to estimate operational costs, thanks to its interoperability with other specifical software.

Author Contributions: F.B., V.D.N., C.C. and N.B. conceived and designed the experiments; C.C. performed the experiments; V.D.N. and C.C. analyzed the data; V.D.N. and C.C. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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