# Energy Performance and Indoor Comfort of a 1930s Italian School Building: a Case Study

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***Abstract*—Reducing energy consumption in the building tertiary sector, which accounts for a big share of the total energy use (and related $CO_2$ emissions) at European and Italian level, represent a strong element of safety for the EU-28. On the other hand, it is important to improve the, often overlooked, indoor comfort conditions of Italian schools since they have a significant impact on the well–being, productivity, health and safety of their occupants. Thus, it is appropriate to take into account the combination of both needs, also in light of the climate change scenario, in order to identify adequate improvement measures and justify such economic investment. This paper brings a contribution to the matter by means of a case study concerning a Sicilian school belonging to the 1930s period, representing an emblematic case of the Italian school construction panorama.**

***Keywords—Building Simulation, Energy Efficiency, Indoor Environmental Quality, Thermal Comfort, School, Building Retrofit.***

## I. INTRODUCTION

As stated in recent reports, buildings' energy consumption accounts for about 36% of the total energy use worldwide [1, 2], 25%÷40% within Europe [3, 4, 5] and 40% in Italy [6, 7] (corresponding to 39%, 35% and 17.5% of the energy-related $CO_2$ emissions, respectively), with the tertiary sector accounting for a big share. Schools, in particular, given their numerosity on the territory, and often their poor maintenance, represent a significant portion of the energy consumers in the tertiary sector. In consideration of this, both the political/legislative authorities together with the scientific community have been engaged in implementing a reliable calculation methodology to assess buildings' energy performance [8] and finding strategies and solutions aimed at improving the sustainability and environmental performance of the entire building sector.

The UN 2030 Agenda for Sustainable Development [9], the 17 Sustainable Development Goals – SDGs [10], the EU "climate and energy package" [11], "climate and energy framework" [12], "long-term strategy" [13, 14], Environment Action Program (EAP) [15] represent the most important global and European reference initiatives. While on national level, the Italy's National Energy Strategy [16], the Integrated National Energy and Climate Plan – PNIEC [17] need mentioning. And, of course, within the standards and regulations those specifically issued for building sector must be cited, namely the European EPBD Directive and its recast [18, 19, 20].

However, in spite of the effort made to put into effect the aforementioned actions, in recent years, the energy consumption in the building sector has experienced an increase, particularly in Italy [3]. That is why, in the last decade a big effort has been made to try finding solutions able to reduce the building energy consumption while also improving the occupants comfort conditions and safety, all the more reason considering that people tend to increasingly spend most of their time in confined spaces.

Indoor Environmental Quality (IEQ) is, in fact, recognized as a fundamental aspect in the design, construction and retrofit of buildings, as indoor conditions have a significant impact on well–being, productivity, health and safety of the occupants, which is even more important when schools are involved. In fact, such category of confined premises is prevalently occupied by subjects (i.e. children), which are more sensitive to the surrounding environmental conditions [21, 22, 23]. The potentials and limits to the improvement of the energy efficiency in schools [24, 25] and the importance of integrating energy and environmental aspects in the school sector has been highlighted by several studies [26, 27], as well as the usefulness of monitoring energy consumption and promoting educational activities intended to maximize the knowledge and foster sustainable behaviors [28, 29].

Another important aspect to consider concerns the fact that the improvement interventions on buildings, in addition to allowing short-term benefits, i.e. improvement of indoor

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conditions, energy saving and structural safety, also set the economy in motion (investment incentive policies through tax deductions and public funding) and contribute to the enhancement of the country's security also from an economic-energy point of view, thus also bringing long-term advantages. Building a European Energy Union that reduces energy dependence on imports, guarantees a secure energy supply leading to a more sustainable economy is actually one of the EU long-term goals [14].

In the light of these considerations it is therefore evident how important it is to carry out a correct and adequate design of the buildings' improvement measures, taking into consideration not only the current environmental conditions but also their future forecasts, especially in view of the increase in temperatures due to climate change, in order to assess the effectiveness of the economic investment.

In this context, and with the aim to contribute in moving forward the knowledge on this specific topic, this paper deals with the evaluation of the combined effects of some retrofit interventions on the indoor comfort and energy savings, under current and future climate conditions. Specifically, the case of a Sicilian school belonging to the 1930s period, which can be assumed as emblematic of the Italian school construction panorama, has been analyzed.

## II. MATERIALS AND METHODS

In the present case study, the dynamic simulation of a school building was carried out in order to evaluate its energy performance and indoor conditions; the structure current state and those consequent to the implementation of a series of hypothesized improvements were assessed. To evaluate the building long-term behavior, and thus obtain information on the usefulness of the planned measures also from the economic investment standpoint, the future evolution of climatic conditions was considered.

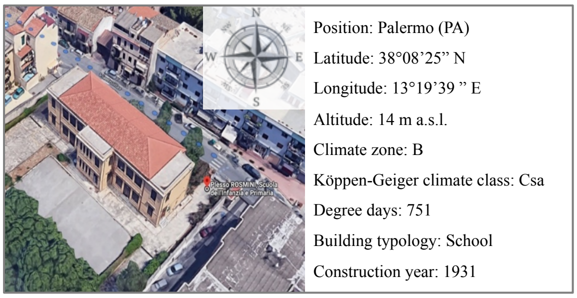
The first step was to collect as much structural, technological and informational data as possible regarding the building and its use, to subsequently proceed with the construction of the dynamic simulation model. In particular, it was decided to simulate the behavior of the building considering both the current climatic conditions (2020) and a projection of the future climatic conditions (reference years were 2050 and 2080), obtaining six simulations: three for the actual scenario, i.e. without improvements, and three for the improved scenario, i.e. with the improvements.

The evaluation of the costs related to such measures was carried out on the basis of the Sicilian "Prezzario Unico Regionale", namely the regional price list [30].

### *A. The Case Study: The Rosmini School in Palermo*

The building is the Rosmini School complex sited in the Cruillas neighborhood of the Sicilian city of Palermo in the South of Italy, characterized by a Mediterranean climate profile, which is typical of Italian coastal and Southern areas. The building, whose general characteristics are reported in Fig. 1, was built in the year 1931 and as other buildings of that period, moreover subjected to poor maintenance as highlighted in Fig. 2, is characterized by poor energy efficiency.

The elongated rectangular structure, Fig. 3, has a covered area of about 350 square meters spread over two floors for a total height of about 7 meters. On the back of the building it is possible to see a protruding body (Fig. 2 and Fig.3), intended to house the toilets. The ground floor and the first floor present the same environments, namely three classrooms and a room for administrative activities (Fig. 3). The structure is made of compact limestone masonry and semi-hydraulic mortar, with the exception of the staircase made of reinforced concrete. The roof is of the terraced masonry type in correspondence with the protruding block, while the central body consists of a sloping pitched roof with tiles. The windows are of the single-glazed type entirely made of wood and are probably deteriorated due to poor maintenance (Fig. 2). No HVAC system is present.



Position: Palermo (PA)
Latitude: 38°08'25" N
Longitude: 13°19'39 " E
Altitude: 14 m a.s.l.
Climate zone: B
Köppen-Geiger climate class: Csa
Degree days: 751
Building typology: School
Construction year: 1931

Fig. 1. General characteristics and south-east elevation view of the Rosmini School building.

Fig. 2. Photographs of the back of the structure (top) and details of the windows (bottom), showing the poor state of maintenance.

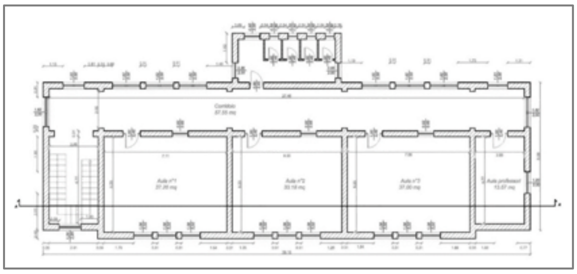


Fig. 3. Reproduction of the building layout.

The main thermo-physical properties of the building's opaque and glazed elements are listed in Table 1, and have been mainly obtained using the UNI/TR 11552 [31].

TABLE I. THERMO-PHYSICAL PROPERTIES OF THE ELEMENTS OF THE CONSIDERED BUILDING.

| Building element | Typology | Thickness (m) | Thermal Transmittance (W/m$^2$°K) |
|---|---|---|---|
| Wooden Roof | Opaque | 0.27 | 0.55 |

| | | | |
|---|---|---|---|
| Masonry roof | Opaque | 0.19 | 1.13 |
| Masonry walls | Opaque | 0.44 | 2.02 |
| Roof slab | Opaque | 0.19 | 1.14 |
| Floor slab | Opaque | 0.36 | 3.21 |
| Foundations | Opaque | 0.40 | 1.81 |
| Windows (single glass) | Glazed | 0.005 | 4.90 |

### *B. Building Simulation Model Implementation*

For the implementation of the building model the very popular OpenStudio simulation code [32] was used to run the dynamic simulations in order to evaluate the indoor comfort, in term of indoor temperatures, and the energy consumption in kWh (referring to the energy consumption in one year of operation, i.e. 8760 hours). As previously mentioned, two different scenarios were implemented, actual scenario and improved scenario, considering three different time-related climate data sets.

To take into account the typologically different spaces into which the building is divided, in the model it was decided to associate a different thermal zone to each space, as shown in Fig. 4.

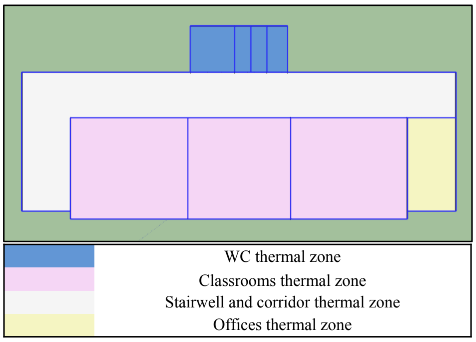


Fig. 4. Thermal zones associated to the different spaces of the building.

Regarding the internal heat gains of the building elements related to thermal comfort [33, 34], that is people, equipment, lighting, infiltration and ventilation, it was decided to adopt values (and relative schedules) based on those reported in the studies conducted by Corgnati et al. [35, 36] and Fabrizio et al. [37]. The internal heat gains adopted values are reported in Table 2, while, as an example, Table 3 shows the schedule, (i.e., the planning of actions and uses related to the individual building element) relating to lighting.

TABLE II. INTERNAL HEAT GAINS' ADOPTED VALUES FOR THE DIFFERENT BUILDING THERMAL ZONES.

| **Internal heat gain element (Unit)** | **Offices** | **Classrooms** | **WC** | **Corridor/ Stairwell** |
|---|---|---|---|---|
| People (N. of people) | 5 | 15 | 5 | 30 |
| Equipment (W) | 1700 | 800 | - | 1000 |
| Lighting (W) | 170 | 1285 | 85 | 460 |
| Infiltration ($m^3/sec/m^2$) | 0.0002 | 0.0002 | 0.0002 | 0.0002 |
| Ventilation ($m^3/sec/person$) | 0.0047 | 0.0047 | 0.0047 | 0.0047 |

TABLE III. SCHEDULE ADOPTED FOR THE LIGHTING ELEMENT.

| **Lighting schedule** | **Functioning hours** | **Adopted value** |
|---|---|---|
| Sept. 16 – Jan. 16<br>Mon. – Fri. | 07:00 – 18:00<br>18:00 – 07:00 | 1<br>0 |
| Sept. 16 – Jan. 16<br>Sat. – Sun. | 08:00 – 18:00<br>18:00 – 08:00 | 0.40<br>0 |
| Jan. 17 – Sept. 15<br>Mon. – Fri. | 08:00 – 16:00<br>16:00 – 08:00 | 0.50<br>0 |
| Jan. 17 – Sept. 15<br>Sat. – Sun. | 00:00 – 24:00 | 0 |

Concerning the climatic conditions, the weather data for Palermo for the year 2020 were retrieved from the EnergyPlus website database [38], while those relating to the years 2050 and 2080 were built using the Climate Change World Weather Generation (CCWorldWeatherGen) tool [38]. This latter uses a morphing technique as statistical downscaling method to develop a future weather file based on an existing .epw file [39, 40, 41].

In all scenarios, a schedule for an ideal HVAC system was implemented, based on assumptions made on its "realistic" use according to the typical time of occupation of the building and characterized by 21°C and 25°C as heating and cooling setpoints' temperatures, respectively. These average values were obtained from simulations previously conducted using the climatic design-days typical of winter and summer conditions for the examined area.

### *C. Energy Improvement Interventions*

The choice of the improvement interventions to implement in the building was made taking into account the peculiarities of the structure and the climatic characteristics of the location, identifying the measures and materials that are best suited to reduce energy consumption, especially that for cooling purposes.

The first intervention consists in applying a coat to the external walls, consisting of wood fiber panels (both for the good insulating capacity and for limiting the emission of pollutants into the environment) which allow an improvement of the thermal resistance passing from a value of 0.49 $m^2K/W$ to a value of 3.11 $m^2K/W$. For this intervention it was considered an average price per square meter of € 75.00, estimating a total cost of € 38400.00.

The second intervention consists in using a thermal plaster for the internal walls. In particular, a premixed clay plaster with reinforcing fibers in cork and natural hydraulic lime was chosen, characterized by high breathability and capable of avoiding the formation of mold or condensation, which allow an improvement of the thermal resistance passing from a value of 0.49 $m^2K/W$ to a value of 1.19 $m^2K/W$. For this intervention it was considered an average price per square meter of € 27.00, estimating a total cost of € 9882.00.

The third intervention concerns the sloping roof, in which it was decided to introduce an insulating material with a thermal displacement value of about 11 hours that is also in this case wood fiber panels, which allow an improvement of the thermal transmittance passing from a value of 0.55 $W/m^2K$ to a value of 0.22 $W/m^2K$. For this intervention it was considered an average price per square meter of € 186.00, estimating a total cost of € 37200.00.

The last planned intervention concerns the replacement of all the fixtures with new elements in wood painted aluminum with double thermal break and double-glazing with internal air gap, which allow an improvement of the thermal transmittance passing from a value of 4.9 $W/m^2K$ to a value of 2.1 $W/m^2K$. For this intervention it was considered an average price per square meter of € 549.00 and € 700.00 for the windows and the front doors, respectively; estimating a total cost of € 41888.00 for the windows and € 6773.00 for the front doors, resulting in an overall figure of € 48661.00.

Energetically improving the considered building through the planned interventions, which have been selected taking into account the cost-benefit ratio, would therefore involve an economic expense of approximately € 134000.

## III. RESULTS AND DISCUSSION

In the following, the outcomes of the simulation scenarios defined in the previous section will be shown and analyzed.

### A. *Actual Scenario*

Table 4 and Table 5 show the results relating to the evaluation of the internal comfort conditions of the different thermal zones in terms of average temperature and relative humidity. By way of example, the data relating to the current state of the structure for the year 2020 are reported (the conditions worsen for the years 2050 and 2080). Specifically, yellow, orange and red indicate that a number of hours comprised in the range 0-2904 (low), 2905-5832 (medium) and 5833-8760 (high) fall within the indicated range, respectively, in accordance with the ones established by the Italian Ministry of Public Education [42].

TABLE IV. ACTUAL SCENARIO INDOOR TEMPERATURE FOR 2020.

| **Temp. Range (°C)** | **Total number of hours per thermal zone** | | | |
|---|---|---|---|---|
| | **WC** | **Classrooms** | **Corridor** | **Offices** |
| < 18 | 1295 | 1387 | 936 | 284 |
| **18 – 22** [a] | 2019 | 4947 | 2276 | 1160 |
| > 22 | 5446 | 2426 | 5548 | 7316 |
| Mean Temp (°C) | 24.8 | 20.7 | 24.1 | 29.1 |

[a] Optimal comfort range according to the Italian Ministry of Public Education.

TABLE V. ACTUAL SCENARIO RELATIVE HUMIDITY FOR 2020.

| **Relative Humidity (RH) Range (%)** | **Total number of hours per thermal zone** | | | |
|---|---|---|---|---|
| | **WC** | **Classrooms** | **Corridor** | **Offices** |
| < 45 | 906 | 798 | 1272 | 943 |
| **45 – 55** [b] | 2488 | 2634 | 2528 | 2550 |
| > 55 | 5366 | 5328 | 4960 | 5267 |
| Mean RH (°C) | 61.6 | 56.2 | 58.4 | 66.7 |

[b] Optimal comfort range according to the Italian Ministry of Public Education.

Regarding the temperatures, it is possible to note how the average temperature is uneven in the various environments. Furthermore, by comparing the values obtained with the suggested ones [42], a critical condition was observed in particular for the offices. However, it should be noted that in these environments the most unfavorable temperature values were found mainly in the hours of the day (and in the periods of the year) in which there are high levels of internal and solar heat gains. As for the relative humidity, also in this case there is a certain inhomogeneity among the different thermal zones, although no high-discomfort condition was observed.

Fig. 5 shows the total annual energy consumption trend of the building for the three considered years. The results, in addition to put in evidence the poor energy efficiency of the building, highlight how, without making any improvements to the structure, the energy consumption progressively increases by 4% in 2050 and 10% in 2080, compared to the value of 97400 kWh (corresponding to 140.09 $kWh/m^2$) estimated for the year 2020.

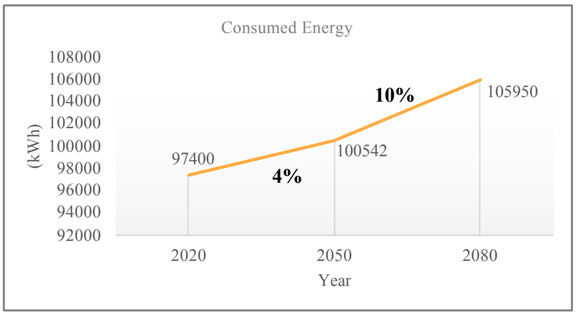


Fig. 5. Energy consumption annual trend for the three considered years (2020, 2050 and 2080) in the actualt scenario.

Table 6 shows the energy consumption breakdown for heating and cooling needs, with a summary estimate of the related costs. It is noted that the energy consumed for heating tends to decrease with the passing of the years, while the energy consumed for cooling tends to increase, a circumstance linked to the expected increase in external temperatures due to climate change.

TABLE VI. ACTUAL SCENARIO CONSUMPTION TREND BREAKDOWN.

| **Year** | **2020** | **2050** | **2080** |
|---|---|---|---|
| **Heating Energy Consumption (kWh)** | 6548.5 | 5088.7 | 3771.6 |
| **Cooling Energy Consumption (kWh)** | 43422.7 | 48024.2 | 54749.8 |
| **Tot. Energy Cost (€) (0,25 €/kWh)** | 12432.82 € | 13278.24 € | 14630.34 € |

### B. *Improved Scenario*

In analogy with what is reported in the previous section, the following Table 7, Table 8, Fig. 6 and Table 8 show, the results for the improved scenario relating to average temperature, relative humidity, total annual energy consumption trend and energy consumption breakdown for heating and cooling needs with related costs, respectively.

TABLE VII. IMPROVED SCENARIO INDOOR TEMPERATURE FOR 2020.

| **Temp. Range (°C)** | **Total number of hours per thermal zone** | | | |
|---|---|---|---|---|
| | **WC** | **Classrooms** | **Corridor** | **Offices** |
| < 18 | 1143 | 1625 | 966 | 24 |
| **18 – 22** [c] | 2679 | 4979 | 3140 | 579 |
| > 22 | 4938 | 2156 | 662 | 6140 |
| Mean Temp (°C) | 22.9 | 20.4 | 22.1 | 28.1 |

[c] Optimal comfort range according to the Italian Ministry of Public Education.

By analyzing the temperature in the thermal zones after the interventions (Table 7) it is possible to see how the average values have reduced, thus approaching the optimal comfort range, albeit a critical situation remains in the offices (already characterized by quite high values in the actual scenario).

TABLE VIII. IMPROVED SCENARIO RELATIVE HUMIDITY FOR 2020.

| **Relative Humidity (RH) Range (%)** | **Total number of hours per thermal zone** | | | |
|---|---|---|---|---|
| | **WC** | **Classrooms** | **Corridor** | **Offices** |
| < 45 | 525 | 818 | 588 | 1186 |
| **45 – 55** [d] | 1734 | 2174 | 2090 | 1916 |
| > 55 | 6501 | 5768 | 6082 | 5655 |
| Mean RH (°C) | 66.6 | 58.2 | 64.2 | 68.5 |

[d] Optimal comfort range according to the Italian Ministry of Public Education.

As for relative humidity (Table 8), there is a rise in the average values in all the thermal zones, however these are not to be considered particularly worrying for the classrooms as they do not differ much from the comfort range. The offices however should be further analyzed to understand whether the hours of the day in which high values were found are actually those during which the building is occupied or not.

Regarding the energy consumption, (Fig. 6 and Table 9), even though an increasing trend in the values can be observed with the passing of the years, the percentage increases are in any case smaller compared to those relating to the actual scenario (Fig. 5 and Table 6).

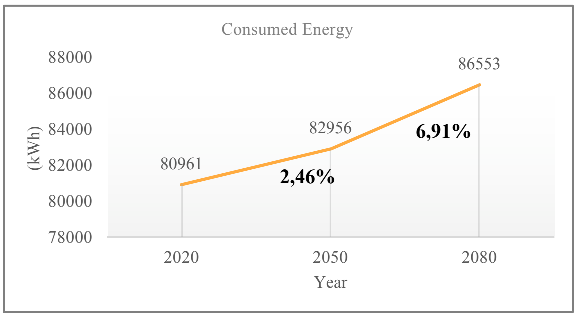


Fig. 6. Energy consumption annual trend for the three considered years (2020, 2050 and 2080) in the improved scenario.

TABLE IX. IMPROVED SCENARIO CONSUMPT. TREND BREAKDOWN.

| Year | 2020 | 2050 | 2080 |
|---|---|---|---|
| **Heating Energy Consumption (kWh)** | 5679.7 | 4670.9 | 3621.1 |
| **Cooling Energy Consumption (kWh)** | 27853.4 | 30857.3 | 35503.9 |
| **Tot. Energy Cost (€) (0,25 €/kWh)** | 8383.25 € | 8882.03 € | 9781.24 € |

### *C. Comparison of the Scenarios and Economic Considerations*

Fig. 7, which illustrates a comparison between the two scenarios, shows how thanks to the planned interventions it is possible to obtain a saving of 17%, related to both the energy consumption and its related costs. With regard to the latter, having established an average electricity cost of € 0.25 / kWh (through market analysis), this would result in an economic saving of approximately € 4100.00 per year.

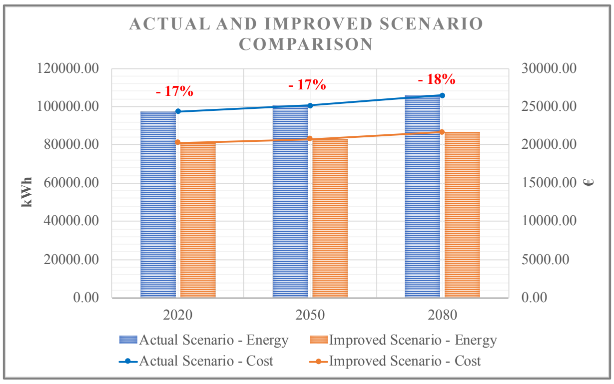


Fig. 7. Achievable energy and economic savings.

Furthermore, regarding the investment costs it must be considered that these can be amortized through incentives and tax deductions (for interventions aimed at making the building energy efficient) specifically dedicated to schools, for a percentage comprised between 50% and 65% [43]. Taking this into account, it was possible to estimate a payback time for the investment of 11 years, with a deduction of € 46900.

Fig. 8 shows more specifically a comparison between cooling and heating consumptions, assessed individually for the year 2020. It can be noted that the cooling consumption reduction is much greater than that related to heating, which in a climatic context such as the one in question is the requirement that is most important to satisfy, confirming an adequate choice of the improvement interventions.

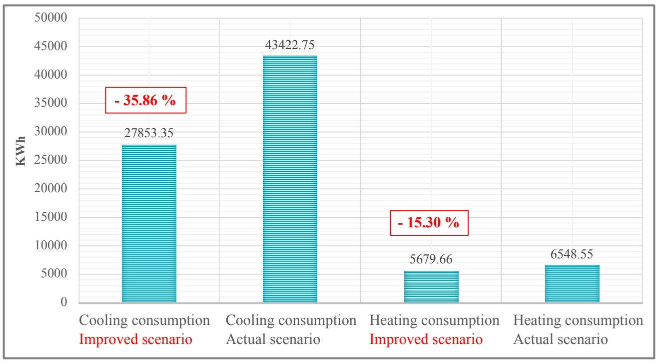


Fig. 8. Comparison between the actual and improved scenario cooling and heating consumptions.

## IV. CONCLUSIONS

The outcomes of the performed analysis put in evidence how an accurate planning and implementation of improvement interventions, according to the characteristics of both the structure (and its intended use) and the site in which it is located (climate and its future change), can contribute to reduce the energy consumption and help in the enhancement of the indoor comfort conditions. Moreover, taking into account the peculiarities of the structure is essential to avoid that the economic investments may not be justified with reference to the possible obtainable benefits.

In conclusion, the case study confirmed how the analyzed building can be considered emblematic of the current Italian school building panorama. In fact, it is just one of the many examples of school buildings that are in precarious conditions and that need to be retrofitted, other than from a structural point of view, also with regard to the energy and internal comfort aspects, especially in light of the climate change, which is expected to lead to a further rise in temperatures.

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