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ISIS Facchinetti: a nearly zero energy retrofit in Italy

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Abstract

The research presented here is about the energy retrofit of an existing high school building close to Varese (Italy). As the building was designed in the 60's with a peculiar architectural language, it has been protected by the conservation authorities. However, the construction system in exposed concrete and the large expanses of single glass make the energy performance of the building very poor. The Provincia di Varese, owner of the building, decided to realize an exemplary retrofit project, which would be the first renovated educational building in Italy in line with the future scenario of Nearly Zero-Energy Building expected from 2019 (2021 for private buildings) by the European Directive 2010/31/UE. In this work energetic and payback analysis are developed to delineate three different preliminary scenarios of intervention. The process has always followed discussions with the conservation authorities, which contributed to the definition of realistic scenarios. Interesting results are obtained: a potential energy demand reduction of 70% can be obtained with the passive solutions proposed; in combination with active strategies (efficient mechanical systems and controls) and with the integration of photovoltaic panels (BiPV), the overall energy need of the building can be reduced to nearly zero.

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Keywords: Nearly Zero Energy Building; Solar Retrofit; Dynamic energetic analysis; BiPV

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1. Introduction

This research work is based on the future scenario of the Nearly Zero-Energy Building standard and on its implementation in existing buildings [1, 2]. The ISIS Facchinetti is a high school building in Castellanza, located between Varese and Milan. It was designed in the 60's by Enrico Castiglioni with a peculiar architectural language and for this reason it has been protected by the conservation authorities. The building net-area is around 27,000 m^2, distributed on 5 floors above grade plus a basement level. The spaces are occupied by classrooms, laboratories for students' activities, and offices for academic and non-academic staff. The structure of the building is in exposed concrete and there is a large amount of single pane steel frame windows, which makes the energy performance of the building very poor. Moreover, since the concrete was not protected it has weathered badly and is now in need of a deep refurbishment.

Fig. 1. ISIS Facchinetti external and internal views

The aim of this study is to delineate different scenarios for a low-energy, solar renovation of the building, since the owner (a public local government, Provincia di Varese) decided to make this an exemplary intervention on the existing public heritage. All design scenarios were discussed with the conservation authorities. In accordance with the client, the goal of the study was to achieve the Nearly Zero-Energy demand for cooling, heating and lighting.

Currently, in Italy there is not yet a clear definition for the Nearly Zero-Energy Building standard, which is due in the next months [3]. It was then decided to follow the general principles of the Directive on the energy performance of buildings (2010/31/EU), which states that "*'Nearly Zero-Energy Building' means a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*". Because the building already exists, and under the control of the conservation authorities, the only possible strategy was improve efficiency first on the envelope side, then on the mechanical systems side and finally to use energy sources that eliminate carbon emissions from the site. In particular, since the building is located in a relatively polluted area, it was decided to avoid any combustion of fossil fuels on site and to rely instead on electricity for the operation of mechanical systems. This energy could then be offset by electricity produced by photovoltaic panels integrated into the building envelope or located in the garden.

With this principles in mind, one of the first steps of the research project regarded the study of the existing façade and has explored the possibility of alternative solutions combining both energy and performance requirements with conservation restrictions. Further analyses were conducted on the MEP (Mechanical, Electrical and Plumbing) systems finding an optimized solution between high energy efficiency and integration. Preliminary studies on an advanced and integrated BMS (Building Management System) system were conducted as well as payback studies.

2. Method

The analyses were conducted on different scenarios, evaluating per each of them the achievable benefit both in terms of energy consumption reduction and payback period. The solutions theorized were discussed with the conservation authorities in order to define concrete and applicable solutions combining both research and high performance with conservators restrictions highlighting the artistic and historic value of the building.

There are examples of studies [4] demonstrating that the effects of each single retrofitting measure cannot be summed, for this reason during the analyses the effect of the combination of the proposed intervention was evaluated.

The first analyses were concentrated on the building envelope, as it was considered as the main responsible for the overall energy need of the building.

For the external glazed façade three different alternatives were investigated and proposed to the conservators (which are summarized in Table 1), and per each of them pro and cons were discussed and considered during the "decision making" process followed with the conservators. Although in literature there are different studies presenting examples of decision making processes as well as multicriteria analyses for retrofit projects [5, 6, 7, 8, 9, 10] in this study it was followed a different approach creating a selection of possible solutions which were discussed at first with the conservators and then analyzed from the energetic and economic aspects. The approach here followed has allowed to effectively comply to both conservators', owner's and energy requirements.

Table 1 Investigated alternatives for the glazed façade

Hypothesis		Pro	Cons
a.	Additional external glazed façade	_Reduction of thermal bridges; _Preservation of the original building envelope (existing windows and exposed concrete) and its protection; _Potential greenhouse effect to improve the passive energy behavior; _Possible integration of solar shading devices;	_Potential alteration of the appearance of the building; _Need to refurbish also the existing damaged windows; _Possible structural problem related to the unknown residual structural resistance of the existing structure (new loads applied);
b.	Additional internal double glazed window	_Reduction of thermal bridges (thermal insulation around the new cavity); _Preservation of the existing windows and of the overall external aesthetic aspect of the building; _ Potential greenhouse effect to improve the passive energy behavior; _Possible integration of solar shading devices;	_Reduction of classrooms net floor area; _Need to refurbish also the existing damaged windows; _Need to protect and treat the existing façade in exposed concrete;
c.	Replacement of all the windows with new high performance and thermally insulated windows	_Minimal aesthetic impact (especially with innovative high performance small section aluminum profile); _No need to refurbish existing windows; _Limited cost if innovative aluminum frame windows are adopted;	_Difficult reduction of thermal bridges; _Need to protect and treat the existing façade in exposed concrete; _Need to define a position for the solar shading devices;

The above three solutions were discussed with the conservators, and the third (replacement of the existing windows) and second (additional internal double glazed window) solutions were preferred.

In addition to the different solutions analyzed for the transparent part of the building envelope other solutions were proposed for the opaque part of the building envelope and, as well as for the transparent one, pro and cons analyses were conducted (see Table 2 for further details).

In the case of the opaque part of the envelope, the conservators were concentrated on the preservation of the external aesthetical and historical aspects of the building. For these reasons the hypothesis of the adoption of an external thermal insulation on the opaque façade was excluded; as the roofs have no particular solutions for the external finishing the conservators agreed in the application of an external thermal insulation.

Table 2 Investigated alternatives for the opaque façade

Hypothesis		Pro	Cons
a.	Internal thermal insulation	_Improvement of the internal acoustic; _Preservation of the external aspect of the façade; _Easy to realize (no external special scaffoldings due to the complex shape of the building);	_Difficulties in thermal bridges resolution; _Need to protect and treat the existing façade in exposed concrete; _Reduction of the internal net floor area;
b.	External thermal insulation	_Reduction and resolution of most of the thermal bridges; _No reduction of internal net floor area;	_Need of "out of shape" scaffoldings with complex geometries; _Change of the external appearance of the building;
c.	Roofs external thermal insulation	_Improvement of roofs thermal performances; _No reduction of internal net area; _Reduction and resolution of most of the thermal bridges;	NA

Combining the third solution proposed for the transparent envelope (solution c. in Table 1) with the possible interventions on the opaque building envelope (solutions a. and c. in Table 2) and on the ventilation of the spaces, preliminary dynamic energetic analyses were conducted.

Therefore for the selected hypothesis of intervention, three further scenarios were outlined:

- replacement of all the glazed part of the façade (sol c. in Table 1) with double glazed windows (U_w = 1.4 W/m^{2}K);
- the first replacement, plus an internal mineral thermal insulation for the walls and an external rigid thermal insulation for the roofs (both 10cm with λ = 0.038 W/mK, sol a. and c. in Table 2);
- the first two replacements plus a mechanical ventilation with high energy efficient heat recovery system (η = 80%, air change = 0.5 vol/h).

The dynamic energetic simulations were conducted using Trnsys 16 (Transient System Simulation Tool) [11] in order to test the different proposed scenarios and to analyze their benefits in terms of energy consumptions. The climate data of the near Malpensa Airport were used, and an internal set point of 20 °C in winter and 26 °C with 60% RH in summer was set.

As for the existing building no energy data were available, except gas and electricity bills and the heating power of the existing gas-fired boilers, a "baseline" model has been preliminary defined. This model was built considering the state of the art of the building and it was validated comparing the results obtained to the energy bills and the heating power of the existing boilers. The "baseline" model was used to compare the achievable benefits with the proposed scenarios.

In parallel to the three different scenarios regarding the building envelope, other studies were conducted to define the heating/cooling system, the BiPV (Building Integrated Photovoltaic) system and the control strategy.

Currently the building has a traditional low efficient heating system (and no cooling) with three gas-fired boilers with a heating power of 1,320 kW each, radiators as emission systems and no control on the supply air.
The building systems studied, on the other hand, include: radiant heating/cooling floors, mechanical ventilation with possible heating recovery system and reversible heat pump. In this case, as the internal existing floor has no particular artistic and aesthetic value, the conservators accepted the solution with a radiant floor emission system but they required a specific control and design of the mechanical ventilation ducts (in order to limit their aesthetic impact).

For the heating generation system three different solutions were analyzed:

- geothermal heat pump – open loop (groundwater aquifer);
- geothermal heat pump – closed loop;
- air condensed heat pump.

Comparative analyses between the existing heating generator and the new heat pump were conducted.
As shown also in [11], in order to let the owner and the conservators to have a more sustainable approach in their decision making process, the analyses considered not only the different energy need but also the different emissions of CO_2 and NO_x. For each scenario energetic and payback analyses were conducted. Moreover, the possible integration of PV systems in the building envelope was explored in order to produce part of the electricity required by the building.
Further discussions with the conservators have interested the BMS system; preliminary analyses have explored the possibility of an integrated building management system combining internal comfort control and internal lighting. The idea is to integrate a monitoring system in order to optimize the energy consumption and the internal comfort. The system is studied in order to optimize also the passive energy behavior of the building (e.g. daylighting control, night cooling, pre-comfort control etc.).

Finally payback analyses were conducted on the different supposed scenarios. In the payback analyses no financial subsidies have been considered.

3. Results and discussion

The dynamic energetic simulations conducted on the different supposed scenarios have demonstrated the achievable benefit in terms of energy need.

For the "baseline" model the results showed an energy need of 108.70 kWh/m^{2}y and a heating power of 3,169 kW.

The significant role on the overall energy need of the transparent part of the building envelope is clearly shown in the results of the energy simulations conducted on the first scenario (solution c. in Table 1) with a reduction of the 32% of the energy need for heating and a maximum heating power of 1,914 kW (- 39.6% if compared to the baseline model).

Furthermore, adding the thermal insulation on the opaque envelope (see chapter 2 for further details) an energy reduction of the 61% was recorded and a maximum heating power of 1,227 kW was estimated (-61.3% if compared to the baseline model).

In the end, focusing only on the passive strategies proposed, adding a heating recovery system on the mechanical ventilation a significant energy reduction of the 72% was calculated with a maximum heating power of 924.6 kW which is less than 1/3 of the existing heating power (-70.8% if compared to the baseline model).

These analyses were conducted on a dynamic energy model of the whole building which, as explained in chapter 2, was validated on the existing building comparing the results of the "baseline" model with the energy and electricity bills. Therefore it is possible to conclude that only with the passive strategies proposed more than the 70% of energy reduction can be achieved.

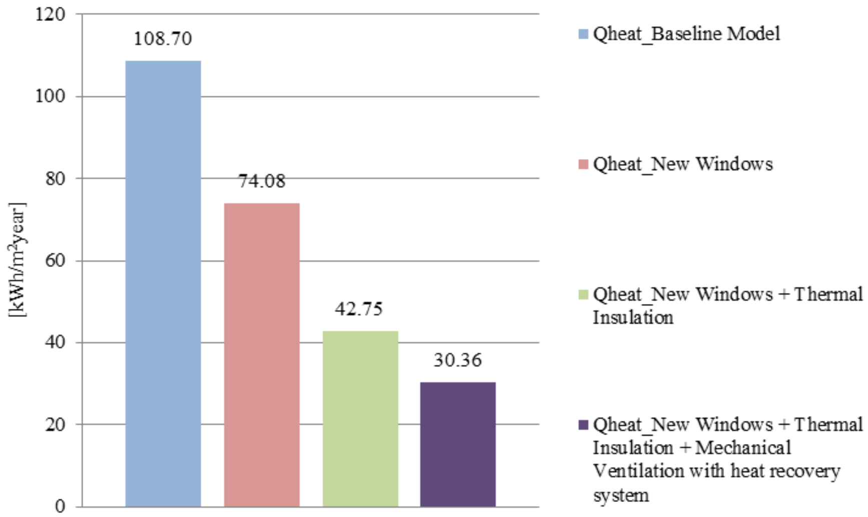

Fig. 2. Heating energy demands of different scenarios compared to baseline model

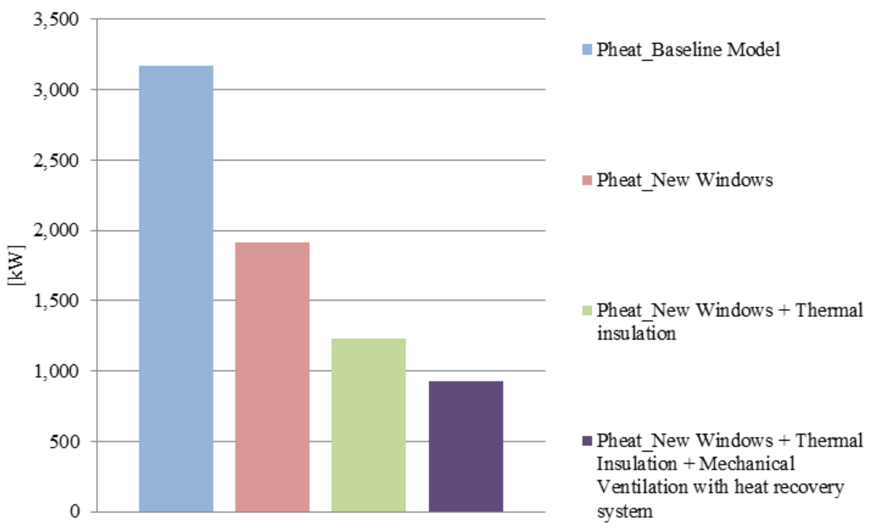

Fig. 3. Maximum heating power compared to baseline model estimated power

As previously introduced even the active strategies different scenarios were studied starting from a simple intervention of replacement of the existing gas-fired boiler with a geothermal heat pump to a combination of the passive and active strategies.

Thanks to the replacement of the existing gas generators only, a significant improvement of the system efficiency and a reduction of pollutant emissions were recorded: a reduction of more than 68% of energy costs, more than 65% of CO_2 emissions and more than 68% of NO_x was achieved. Furthermore the total absence of local pollutant emissions, due to the adoption of an electrical driven heat pump, improves the air quality of the surroundings giving a better environment for the students.

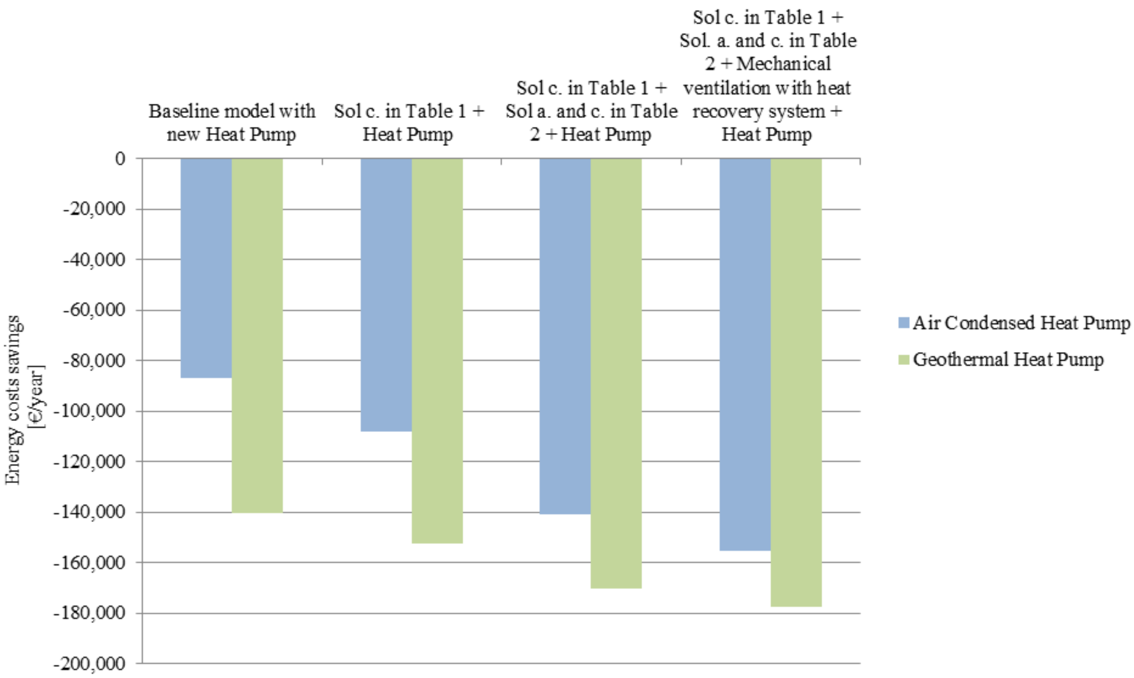

Fig. 4. Energy costs savings. Comparison between air condensed and geothermal heat pump

Taking in consideration also the passive strategies studied, the reduction of energy costs compared to the current "baseline" model is up to 86%, with a reduction of CO_2 emissions up to 85% and a reduction of NO_x up to 86%. This numerically means a reduction of CO_2 emissions of up to 508 tons/year, and of energy costs up to 177,000 €/year.

The analyses were conducted also considering an air condensed heat pump, which have demonstrated a loss of efficiency of around 30% (as it is readable from the Figures 4, and 5).

In order to reduce more the energy consumptions for both lighting and heating, preliminary analyses on a BMS system were conducted. A further potential reduction of the heating energy demand, around 6%, was estimated.

Furthermore the possibility to integrate PV panels on the roofs and on the windows was considered. Due to the historic and cultural value of the building only the roofs, which are not immediately visible, can be really used for the installation of PV panels. In addition, the current roofs finishing with bitumen water proof membrane allows the installation of amorphous siliceous PV cells which can be integrated in the waterproofing membrane itself.

Per each scenarios analyzed the theoretical minimum surface of PV panels that is needed in order to reach a zero energy balance was calculated. For some solutions (the less efficient) it is remarkable that there is no possibility to cover the total energy need only with the installation of integrated PV panels, unless installing PV panels not integrated in the building (see Table 3).

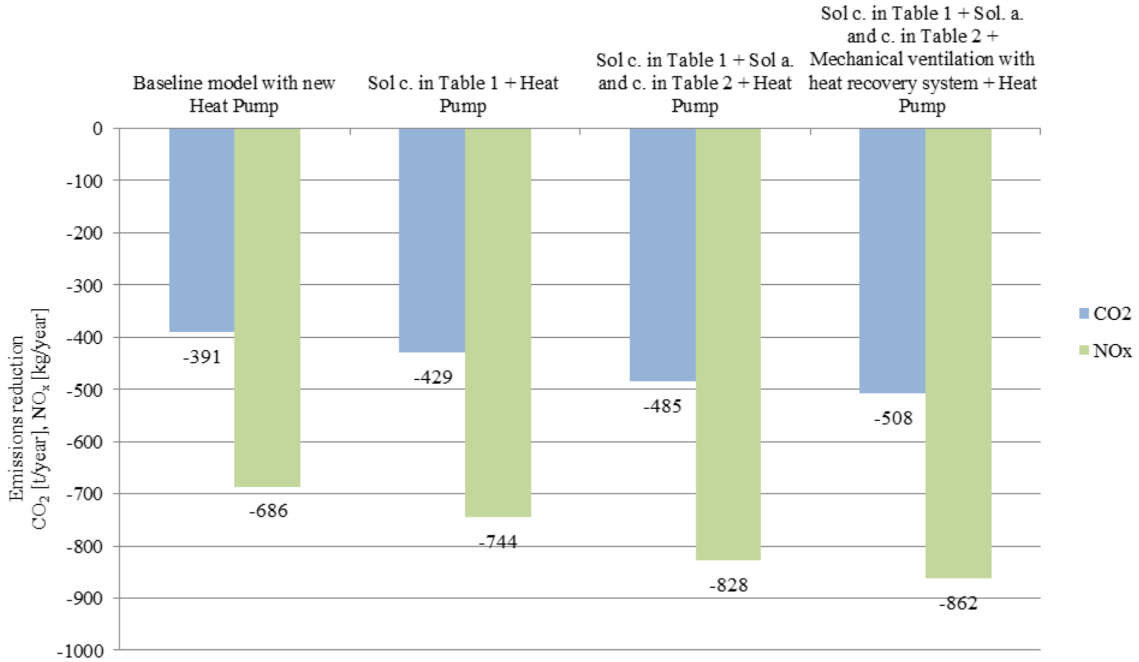

Fig. 5. Reduction of CO_2 and NO_x emissions

Table 3 Comparison between minimum PV areas needed

	Sol c. in Table 1		Sol c. in Table 1 + Sol a. and c. in Table 2		Sol c. in Table 1 + Sol a. and c. in Table 2 + Mechanical Ventilation with heat recovery system	
Heating demand [kWh/year]	1,928,916		1,286,319		1,027,558	
Heat pump technology	Air	Geothermal Heat Pump	Air	Geothermal Heat Pump	Air	Geothermal Heat Pump
Electric consumption [kWh/year]	768,354	421,345	515,389	281,490	412,115	224,932
PV power [kW]	809	443	542	296	434	237
PV area [m^2]	9705	5322	6510	3556	5206	2841

In conclusion of the work, preliminary payback analyses were conducted without considering any financial subsidy. The results show that with a minimal intervention (considering only the installation of new windows, a new air condensed heat pump, and a simple control system) the payback period of the investment will be of 25 years.

Considering instead the best possible intervention (all the passive strategies, new air condensed heat pump, full BMS system) the payback period will increase to 36 years.

It is interesting to underline that, if in the previous solution the installation of PV panels is considered, and no financial subsidy for the installation is taken in account, the payback period reduces dramatically to less than 22 years. This because although the installation of a PV system increases the refurbishment works costs, at the same time it produces the energy that is needed for the building functioning reducing dramatically the billing costs.

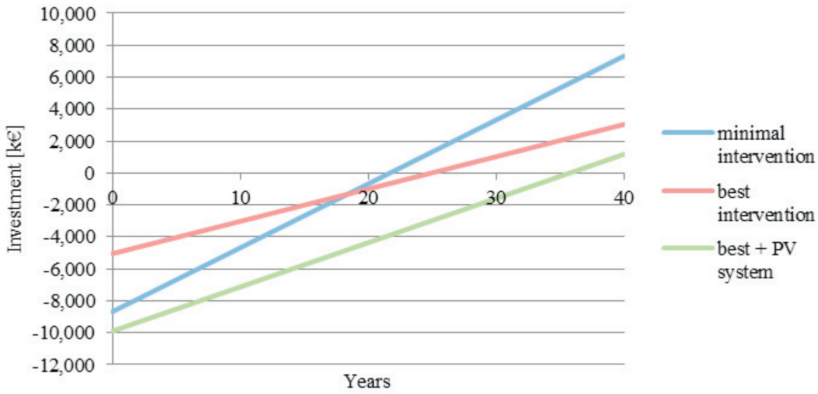

Fig. 6. Payback analyses. Comparison between different possible interventions.

4. Conclusions

The analyses conducted have shown the achievable energy reduction on an existing educational building in Italy, realized with an exposed concrete structure and large glazed façades with a particular historic and iconic value (protected by conservators' restrictions). Interesting results were obtained thanks to the constant dialogue with the conservation authorities. Further studies are required in order to obtain more precise data about costs, internal comfort and payback period.

The validated energy model has demonstrated a potential heating energy need reduction, with the introduction of passive solution (such as new windows and thermal insulation) of up to 70%, and a reduction to 1/3 of the heating power.

In economic terms the introduction of new heating generators combined with passive strategies can signify a saving of 177,000 €/year (which can potentially increase with the lower installation costs of solutions that nowadays are innovative but they are becoming a common practice).

The combination between passive and active strategies can reduce the emissions of CO_2 up to 508 tons/year. And the preliminary payback analyses have demonstrated that also without considering any financial subsidy reasonable payback periods can be reached.

This work has shown the possibility to reach a nearly zero energy building even for a non-residential building with historic and aesthetic value and protected by conservators restrictions.

The difficulty in obtaining a Net Zero Energy Building is clearly demonstrated: economic aspects (no financial subsidies were considered) as well as conservators' restrictions limited the possibility of an integration of a source of renewable energy production.

Although not all the existing school buildings in Italy are the same, the process followed and the approach had can demonstrate the possibility to reach energy need reduction of up to 86% while keeping the aesthetic and historic value of the existing protected building.

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