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Energy and technological refurbishment of the School of Architecture Valle Giulia, Rome

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Abstract

Modern architecture built in historical urban contexts represents a demanding issue when its energy efficiency should be improved. Indeed, the strongest efforts have to be made to maintain the architectural identity and its harmony with the surrounding cultural heritage. This study deals with the main building of the School of Architecture Valle Giulia in Rome, designed by Enrico Del Debbio in the 30's. Further constraints are related to several interventions of airspace expansion starting from 1958 which involved the building starting from 1958. So, preservation would mean highlighting its historic change but, adapting the built environment to the contemporary users' needs. As above-mentioned, the building belongs to the Valle delle Accademie, within the historic park of Villa Borghese, so that to acquire landscaping values. Those latter ones call for ulterior requirements when any new design process is conceived. The study provides a global renewal of the building accounting for the current low Indoor Environmental Quality in both summer and winter seasons and the lack of suitability to the contemporary University student's needs. The interaction between building performance and HVAC systems was studied by collecting data and architectural surveys conducted by all the architects who modified the building. This procedure was chosen since thermo-physical investigations are considered destructive due to required perforations to identify the actual wall layers. Moreover, thermographic surveys were carried out to validate the modelled building response. The result of the study is the identification of viable interventions to improve the accessibility and fruition of the building as well as its energy performance. A specific cost-benefit analysis was done to prioritize the design options along with considering the measures needed to preserve all the architectural features and values.

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Keywords: energy refurbishment; energy efficiency; cultural heritage.

1. Introduction

Construction sector is one of the most responsible GHG emitter and cause of poor air quality [1]. In Italy, after the implementation of European Directive 2009/29/EC, the so-called EU 20-20-20, specific incentive schemes aimed at building energy refurbishment were promoted [2]. In this framework, the energy retrofitting of Valle Giulia, School of Architecture of Rome have been designed to get funding from Conto Termico, i.e. DM 12/28/2012, which is an incentive scheme to promote renewable integration and efficient thermal management of public buildings [3]. Since it is included in the listed buildings group, any design proposal should be based on minimum intervention and reversibility [4] to preserve its architectural values. Materials types and their physical properties play a key role in the interaction with the surroundings in terms of microclimate [5] and energy performance [6,7]. Indeed, the first step to unlock a more economically viable and rational use of energy is the on-site survey and the investigation of original design as well as accounting for modifications made during the building lifespan [8]. This is the method to verify the feasibility for installing cutting-edge technologies in the building [9] or where renewables are available in the surroundings [10], even when the building is located in protected areas [11]. Furthermore, Italian building stock involves large public housing districts where it is possible to design general energy efficiency measures to be always applied since their homogeneity [12,13] as well as cultural heritage calling for specific interventions case by case [14]. This latter is the case of Valle Giulia, School of Architecture which is analyzed in this study.

2. Building history

Italian big cities have replied to the Covenant of Mayors call for implementing renewables by a planned strategy towards the aforementioned EU 20-20-20 targets. Nevertheless, protected areas and UNESCO sites were excluded from this step and city like Rome, with a large cultural heritage, shows high potential in its rural-urban continuum [15,16] but, low renewable energy potential in its center [17].

Valle Giulia, School of Architecture of Sapienza University, is located in the center of Rome, specifically in the Valle delle Accademie. Current layout is mainly due to the works done for the Universal Exhibition of 1911. The main street is Viale delle Belle Arti which leads to the Renaissance villa of Pope Giulio II, who gives the name to the Valley. Nearby, there are buildings of great architectural and cultural values as the Academies and the Culture Centre, the National Gallery of Modern Art and, the case study, i.e. the School of Architecture of Rome [18].

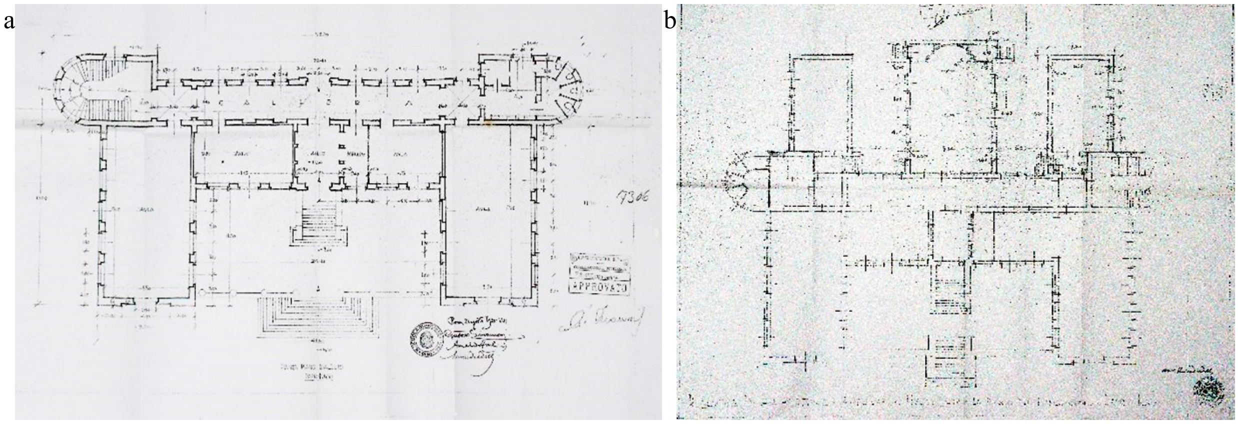

Fig. 1. (a) original plan; (b) plan with the first volumetric addition.

In 1930, Enrico Del Debbio ended the project for the so-called Royal School of Architecture, as shown in Figure

1a. One year later, the building was completed but there was the need for adding further blocks, i.e. two new classrooms and an assembly hall as in Figure 1b. The main volume is built on a high base of white stone. It is in red-brown and characterized by particular solutions of the heads, with ledges cut by the arched windows and the large entrance portal in white stone at the end of a monumental staircase, as in Figure 2. In 1934, a further C-shaped volume was attached in the back. The building had this layout until the '50s.

Fig. 2. Perspective view of Valle Giulia School of Architecture by Del Debbio.

Again Del Debbio in 1953 designed a new modification of the building. Its project is known as Ampliamento I. It consisted of the addition of an L-shaped volume where the main entrance is moved to along with the construction of a new staircase [19]. After 9 years, Ampliamento II project was designed to provide a new assembly hall but the project was not entirely built since the near building of Belgian Embassy.

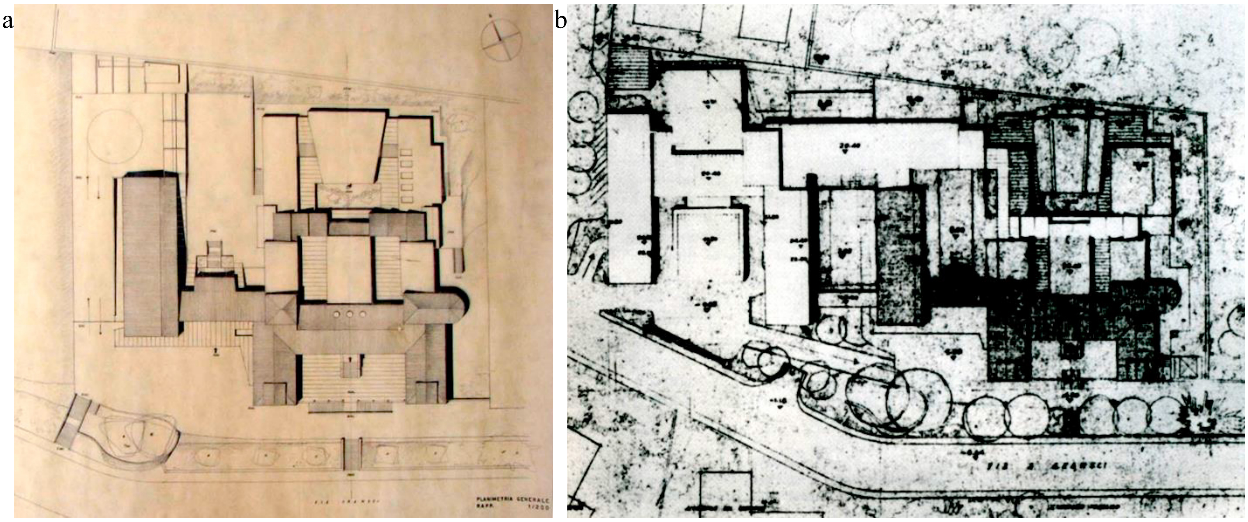

Fig. 3. (a) ampliamento I;(b) ampliamento II.

3. Energy status quo

Once all architectural drawings were collected, an on-site survey was carried out by means of infrared camera, thermographic tools and inspections. Wall stratigraphy typologies were collected and an abacus was made. Four wall stratigraphy were identified: (I) Solid masonry in tuff blocks; (II) Masonry with internal facing bricks, cavity and external facing of solid bricks; (III) Masonry in reinforced concrete and (IV) Solid brick masonry. A similar classification was reported for the openings. Windows technological components are divided into four typologies as well: (I) 4 mm single-glazing iron window where U = 6.14 W/m^{2}K; (II) 4 mm single-glazing aluminum window where U = 6.16 W/m^{2}K; (III) 4-12-4 mm double-glazing aluminum window with air cavity where U = 4.03 W/m^{2}K; (IV) 4-6-4 mm double-glazing aluminum window with air cavity and no thermal bridges where U = 3.64 W/m^{2}K. Referring to shading devices, they are installed inside and two typologies are present: curtains and venetian blinds. The heating is provided to the building by a centralized system composed by two gas boilers, each one with a rated power of 600 kW. Heating terminals are radiators and the control system has only outdoor thermostat, no one inside the buildings. Thus, overheating is often present during the winter due to high heat gains from occupants as well as high solar gains from large windows. Referring to cooling, administrative offices are supplied by mono-split heat pump while main assembly hall is supplied by a chiller with a rated cooling power of 220 kW and two Air Handling Units, each one with a flow of 7,000 m^3/h. Furthermore, classroom 4, 12 and 19 are equipped with fan-coils units and three water chillers. Again, no thermo-controller is present.

3.1. Building energy performance simulation

A simplified dynamic energy model was adopted to perform mono-zone hourly simulations along with economic assessment according to incentive schemes in force in Italy [20].

Simulation outcomes show a global energy performance indicator equal to 226.5 kWh/m^{2}y, as sum of winter heating operation of 147.2 kWh/m^{2}y, of the cooling one equal to 46.2 kWh/m^{2}y, of lighting consumption of 31.7 kWh/m^{2}y and occupancy contribution equal to 1.4 kWh/m^{2}y.

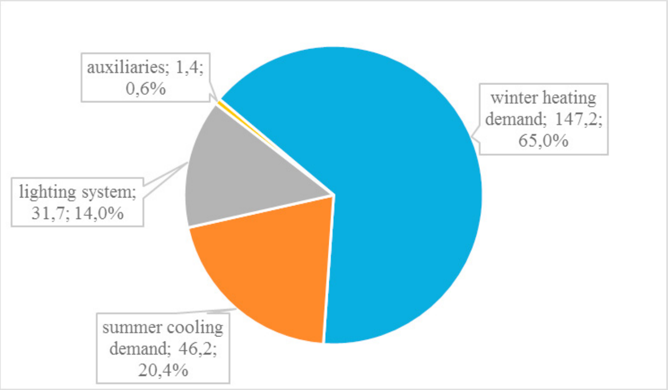

Fig. 4. Total primary energy consumption for final use (kWh/m^{2}y; %).

This value implies a G energy label. The equivalent renewable share of electricity is 10% due to the electricity taken from the Grid. As shown in Figure 4, heating is the main energy-intensive activity. Passive solutions could affect strongly the absolute value of primary energy consumed for heating and cooling. It is noteworthy that, in the case of heating supply, an immediate improvement could be achieved by increasing the efficiency of control system and the generation one, which are currently 0.76 and 0.92, respectively.

3.2. Solar radiation on the building facades

Since solar gains are the main contribution to overheating risk during summer and, as aforementioned, architectural identity of the building must be preserved, a dedicated analysis on solar irradiation distribution on building facades was carried out. To do so, Autodesk Ecotect was used. A map pinpointing the critical zones in terms of solar gains was reported in Figure 5. The daily average solar irradiation ranges between 100 and 1,700 Wh/m^2, showing large differences along the facades.

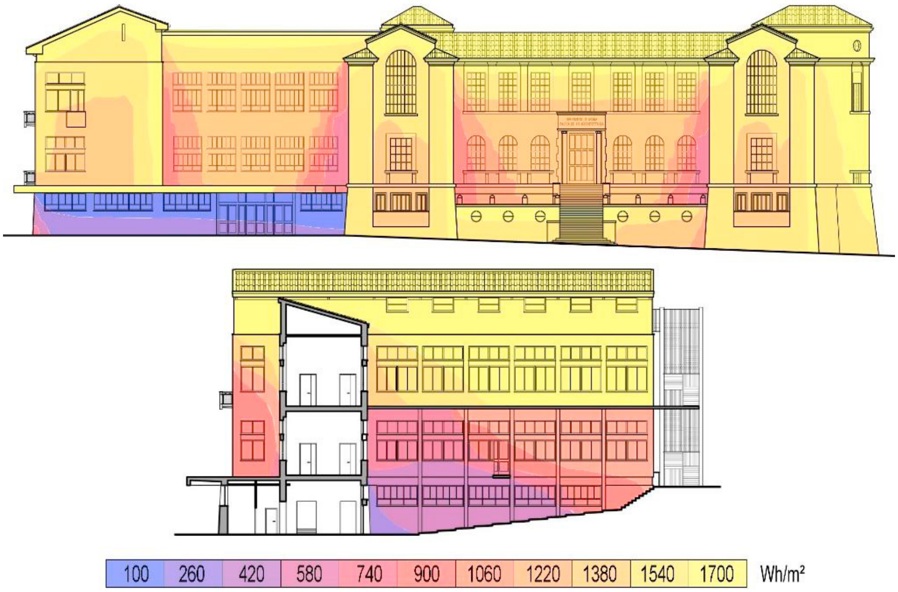

Fig. 5. Solar irradiation during June.

Main hall roof and upper floor facades are the ones which receive highest amount of solar radiation. This analysis is also useful to identify the most suitable surface for integrating PV array to produce renewable energy.

4. Energy refurbishment proposals

Compared to other historical buildings, the School of Architecture kept its intended use. Nevertheless, modern university operation entails a different energy use from the past as well as a different spatial organization. New functions to add as the library-dedicated space, classrooms, local cafeteria and enlargement of rest rooms provide the opportunity to an energy refurbishment project coupled to a more functional design [21]. Historical survey is crucial to recover original identity of the design such as flows and space distribution, sometimes changed over the time. Then, compatible energy retrofitting strategies are presented for improving building envelope performance, solar gain control by shading, installation of more efficient HVAC systems and PV array.

4.1. Building envelope

As above mentioned, the architectural constraints allow few interventions on the building envelope. To improve the performance, an insulation layer was added to the inside face to do not change the facades or when a cavity was available in the wall stratigraphy, it was filled by an insulation foam or panel, as depicted in Figure 6 a and b. The economic feasibility was driven by Conto Termico and an insulation material was chosen to reach a U-value equal or less than 0.26 W/m²K. For installing insulation into the cavity, insufflate of rockwool $\lambda = 0.036$ W/mK by dedicated holes in the wall was designed. While, when the intervention consists of applying a new internal layer, 8 cm solid panel of extruded polystyrene was chosen ($\lambda = 0.023$ W/mK) coupled with a panel of plasterboard. The first intervention is preferable since no surface reduction in the indoor space is provoked along with no condensation phenomena are present.

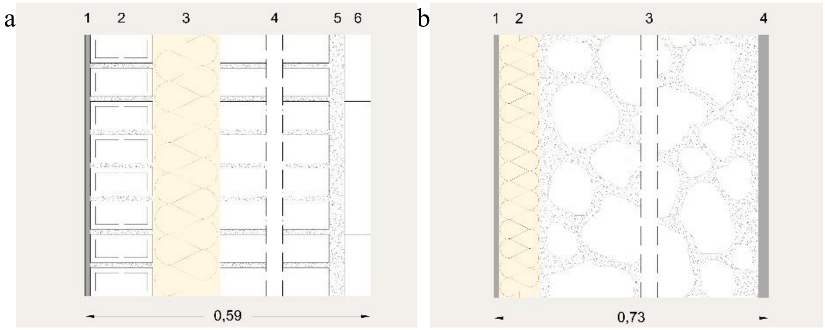

Fig. 6. (a) insulation layer in the available cavity;(b) insulation layer attached to the inside face of the wall.

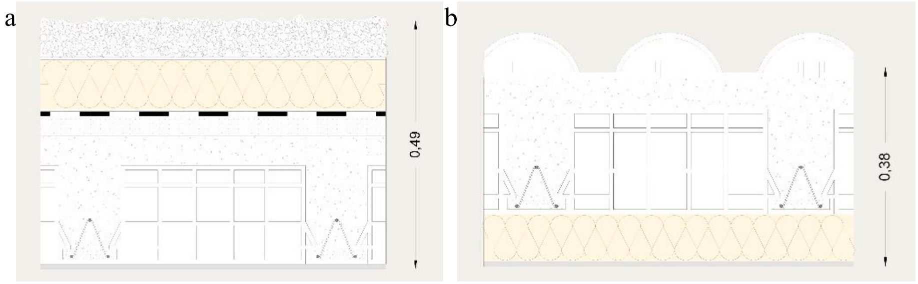

Fig. 7. (a) insulation layer for flat roof; (b) insulation layer for pitched roof.

Similar design for roof stratigraphy in order to reach 0.22 W/m^{2}K. For flat roof, as depicted in Figure 7a, the insulation layer is added at the top by replacing the paving and the water collecting system. Whereas for pitched roof, as shown in Figure 7b, the insulation layer is added to the inner side due to no modifications must be seen.

4.2. Interventions on windows

A first rule to obey was to preserve the windows of original volume according to Restoration Authority request. That meant the possibility to substitute the single-glazing with a new one. The achievable U-value is still high, i.e. Uw=5.89 W/m^{2}K. While, for the windows belonging to Ampliamento I, it is possible to substitute them with low-emissivity double-glazing with Argon in the cavity and aluminum with no thermal bridges frame. The new U-value is Uw=1.75 W/m^{2}K. For the remaining windows, a similar solution was adopted to achieve Uw=1.70 W/m^{2}K.

As shown in Figure 8, shading devices were investigated depending on the possible architectural integration.

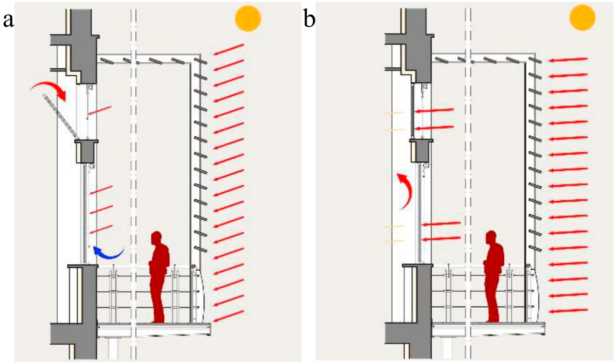

Fig. 8. (a) summer operation; (b) winter operation of windows and shading.

4.3. Relation between shading and roof

Solar shading is used also at roof level. Specifically, the brise-soleil installation is intended for southern-east facades and PV array integrated into the roof of assembly hall along with the HVAC outdoor units. Paving in WPC (Wood Plastic Composite) will help to increase albedo and reduce cooling load. The layout is depicted in Figure 9.

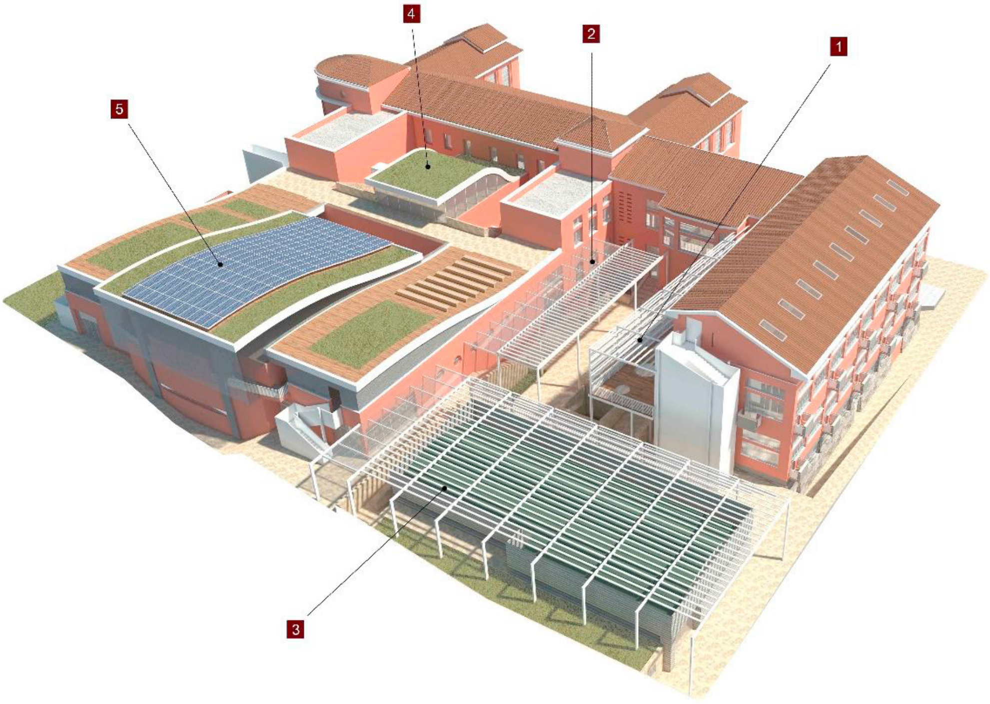

Fig. 9. 1. Brise-soleil; 2. Glass covering; 3. Brise-soleil structure; 4. New cafeteria; 5. Assembly hall.

4.4. HVAC systems

Control is the key strategy to make more effective the existing heating and cooling systems. As regards heating, thermostatic valves are provided at each terminal along with a variable flow pump to manage the heating distribution. Modular condensing boilers are considered to substitute the centralized heating system.

Referring to cooling, the architectural constraints do not allow to equip with it the entire building. Five zones were identified to be supplied by same number of cooling systems. Reversible air-to-air heat pumps are the chosen technological solution, as shown in Figure 10.

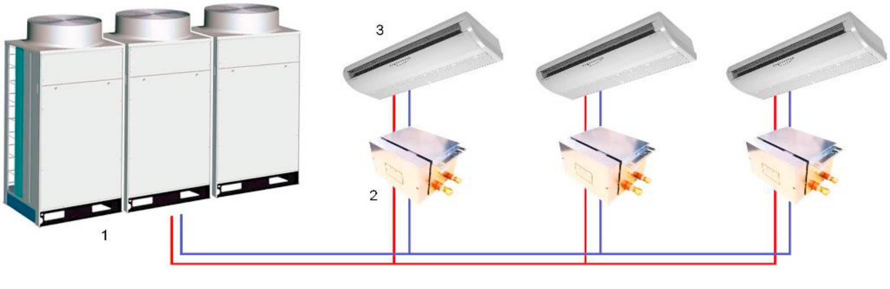

Fig. 10. Cooling system layout during summer: 1. external modules; 2. remote expansion valve; 3. split.

As regards the renewable energy, a PV array with a rated power of 62 kWp is designed. It covers a surface equal to 500 m^2. It is located on the Assembly hall roof. The equivalent energy production is 87,130 kWh/y, being able to meet 22% of the electricity demand, as in Figure 11.

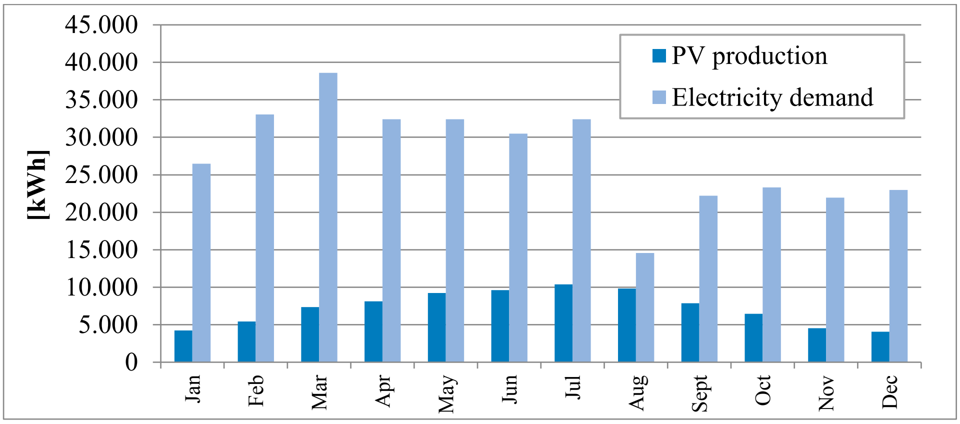

Fig. 11. Monthly electricity produced by PV and electricity demand.

5. Cost-benefit analysis of proposed strategies

For each planned intervention, it was computed its cost together with the achievable amount of subsides according to the incentive scheme Conto Termico.

Table 1. Cost-benefit analysis.

	Investment [€]	EP$_{gl}$ [kWh/m^{2}y]	Yearly cost [€]	Saving [€]	Incentive [€]	Investment share [%]	Payback period [y]
Business as usual		226,5	119.303				
Insulation of external walls	406,505	177,1	91.938	27.365	145.440	35,8%	9,5
Windows substitution	578,724	187,0	97.559	21.744	100.000	17,3%	22,0
Solar shading on windows	187,502	197,0	108.461	10.842	30.000	16,0%	14,5
Insulation of roof surfaces	361,619	177,5	92.279	27.024	144.648	40,0%	8,0
Solar shading on roof	221.529	204,9	111.364	7.939	-	0,0%	27,9
PV array	74.400	203,8	110.960	8.343	-	0,0%	8,9
Heat pump for classrooms	60.350	174,4	101.295	18.008	18.333	30,4%	2,3
Heating control system	37.380	169,9	84.635	34.668	14.952	40,0%	0,7
Condensing boilers	81160	208,4	108.216	11.087	31.200	38,4%	4,5
All the interventions	2.009.169	56,3	30.196	89.107	484.573	24,1%	17,1

Table 1 summarizes all the energy savings and economic parameters, i.e. investment cost, payback period. A first outcome is that, even combining all the interventions together, the achievable performance is 56.3 kWh/m^{2}y, a renewable share equal to 48% entailing a classification C according to Italian Energy Label. This is why preservation was considered first compared to energy efficiency objective function.

The lowest payback period is shown by the thermostatic valves installation, i.e. 0.7 years. Then, Heat pump installation, with 2 years, and gas boilers, with 4.5 years.

Solar shading and new windows have the highest payback period with 28 and 22 years, respectively. The quote of investment covered by the subsides is low, an average value of 24%, since in listed buildings the interventions are much more expensive than in usual building stock. To account for that, an expert opinion could be useful to put together all the stakeholders and their needs for future policy design as done in energy field [22] or when the integration of complex systems should be further assessed [23].

6. Conclusions

The paper presented a cost-benefit analysis of a listed building in Rome, currently used for the same intended use it was designed for. The lack of energy saving measures in the original design as well as the change in the quality demand of energy by the use of modern University called for energy refurbishment design. The idea to preserve architectural values along with aligning the building to current building regulation raises many challenges. Thermal comfort cannot be ignored and it entails further energy expenses when the energy efficiency measures are difficult to be implemented.

New functions such as cafeteria can be installed if its design is a further energy efficiency measure such as providing further shading for summer period. Heat pump and PV are the main driver to integrate renewables and, when the wall stratigraphy is improved, are able to provide more effectively energy to the building. An efficient intervention can be made by solutions already available on the market but taking into account all the relevant constraints when the approach start from an energy renovation attempt rather than a pure approach to the building as a more efficient machine.

A concluding remark is that, for listed buildings, a specific incentive scheme should be developed to account for further cost required by preservation and valorization.

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