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Architectural and energy refurbishment of the headquarter of the University of Teramo

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Abstract

The recent seismic events, which distressed the population of the Central Italy, have caused the incompliance with national safety standards of several historical buildings. In particular, the headquarter of the University of Teramo revealed some structural damages which make necessary to operate a restoration of the buildings. It represents a rare opportunity for investigating possible applications of a cluster of technologies and approaches largely recognized as efficient and high-performing to such particular buildings in order to achieve an upgrading in terms of energy efficiency. The proposal includes the improvement of the exploitation of renewable energy sources through adequate systems, which do not modify the visual perception of the pavilions. In that regards, the required electricity could be produced by a PV roofing installed on the parking area, while a biomass boiler and an absorption chiller could allow supplying the thermal and cooling needs. Furthermore, the rain water recovery system permits to reduce the exploitation of potable water for uses which do not require a high quality, such as irrigation. On the other hand, the envelope energy efficiency could be enhanced by applying passive strategies for reducing the heat losses (*winter conditions*) and gains (*summer conditions*) through façades and roof. The results confirmed the reliability of those interventions and the consequent advantages from an economical and energy point of view.

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Keywords: Energy refurbishment; historical architecture; sustainability; post-seismic reconstruction

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1. Introduction

In restoring buildings, the energy efficiency and the environmental sustainability represent two important topics which are defined in European, national and regional programming tools. In Europe, the first directive about energy savings in buildings is the 2002 EPD-Energy Performance of buildings Directive, Dir. 2002/91/CE, which has been updated in 2010 by Dir. 2010/31/UE. According to that, buildings can account for 40% of total energy consumption and for 35% of greenhouse gas emissions in EU [1].

Following the seismic events that occurred in central Italy, the building industry is currently expanding and this would probably cause the increment of its energy consumption. The reduction of energy requirements for thermal and cooling needs and the exploitation in situ of RES represent two important strategies for reducing the dependency by fossil fuels and greenhouse gas emissions [2]. Those two approaches also play an important role in promoting security of energy supply, technological developments and in creating opportunities for employment and regional development.

Regarding historical buildings, the Italian Code of Cultural Heritage and Landscape [3] obliges the landscape masterplan office to update the lists of buildings to be subjected to specific and significant constraints due to their architectural, historical and cultural value. This list includes also buildings constructed during the first postwar period such as the pavilions assessed as case study. Those constraints usually reduce the number of interventions allowed and the possibility of improving the energy level and the envelope's insulation performance. Thus, the need of operating a restoration of the University of Teramo's campus could represent an opportunity for testing the applicability to architecture with an historical value of some technologies already applied to contemporary buildings such as PV plant for producing electricity, biomass boiler and absorption chiller for supplying the thermal and cooling needs, rain water recovery system for reducing the exploitation of potable water.

In conclusion, the study aims to investigate the efficiency of passive and active strategies applied to the historical pavilion aforementioned. Starting from the actual building configuration, it was improved the envelope's insulation performance level in order to reduce the thermal transmittance. Then, dynamic simulations were conducted in winter and summer conditions for estimating the energy requirements and define the plants' size. Finally, the enhancement was evaluated in terms of building's energy consumption, carbon footprint and economic advantages.

Nomenclature

ADSU	Agency for the Study Rights
RES	Renewable Energy Sources
PV	Photovoltaics
SR	Solar Radiation

2. Case study: the campus of the University of Teramo

The headquarter of the University of Teramo was built on 1929; it is placed very close to the historical walls, near the ancient road connecting the city to the regional administrative center of L'Aquila. The campus is organized in four buildings: Pavilions A and B, the biggest, which are used for the administrative functions, and the other two, a storehouse and an annex. The whole complex is surrounded by greenery and tall trees, providing privacy and nature, if compared to the adjacent neighborhoods.

When it was realized, between the First and the Second World War, the complex was not property of the University of Teramo and it hosted a hospital supporting the medical center. Even if it should had been just a separate headquarter, it rapidly became the hospital core of the area until the last decades of the 20^{th} century. Then, the lot was converted into an academic campus, in which the administrative offices were located. The research conducted about the case study allowed to define its architectural evolution: the original drawings showed the differences between the realized complex and the original design and its variation during its operational stage. In particular, other three pavilions should had been built in addition to the existent two for hosting adequate spaces for specialized medical sections.

Nowadays, the campus appears as it was in 1956, when significant modifications and restorations were completed. On that year, the Pavilion A, that is the representative building owing to its architectural decorations and position, , was refitted and its volume was increased: a new floor was added above the existent three and some elements of parasitic architecture was placed at the ground level. The same interventions were applied to Pavilion B. In addition to that, a partially underground corridor was realized between the two pavilions for guaranteeing a safe passage to the guests [4, 5].

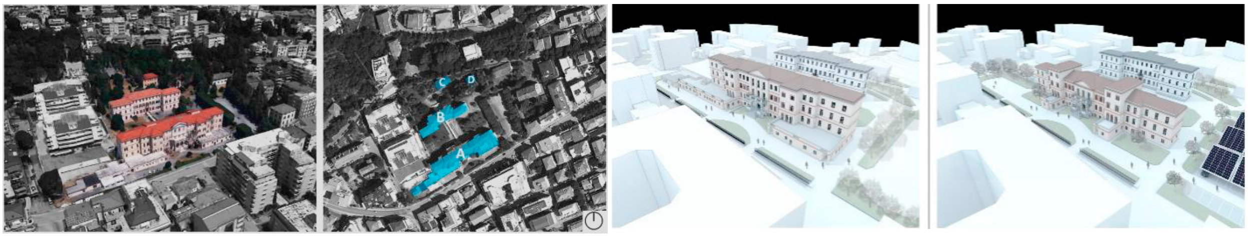

Fig. 1. Overview of the academic campus (a, b) and digital models of Pavilions A and B, before (c) and after (d) the proposed refurbishment.

During the last decades the campus has been dismissed due to the construction of a new academic center closer to the historical core of the city. Nevertheless, the state of decline of the complex has been worsened by the recent seismic events which have significantly damaged historical buildings in the whole central Italy: the former events were begun with the earthquake of L'Aquila (2009); the latter in Amatrice and Norcia (2016) [6]. The area of Teramo has constantly been among the zones, at a distant less than 50 km from each epicenter. The sequence of those events leads to the necessity of refitting the Pavilion A offering an opportunity for its refurbishment, particularly from an energy point of view. On the other hand, the Pavilion B of the academic campus of Teramo seems to be so damaged that it would be probably demolished and rebuilt. For that reason, it has not been further considered on this work.

3. Architectural and energy refurbishment

According to the restraints declared by the landscape masterplan office [7], the ADSU submitted on September 2016 a planning for recovering the campus by reinstating the original configuration of Pavilion A. The proposal included the removal of parasitic architectures and the building's height reduction by demolishing the upper floor added on 1956 [8] as shown in Fig. 1. The renew building should modify its function by hosting an academic library, offices and other services for students such as study rooms. In fact, the whole project comprised the future realization of a student dormitory in place of the demolished Pavilion B.

According to that, the Pavilion A has been designed in order to reinstate the shape modified in 1959, a sort of reaffirmation of the historical and architectural value of the case study. On the other hand, the functions and the systems should represent the modern answers to present issues such as the pursuit of the sustainability. Regarding the rooms arrangement, offices are placed at the first storey, while the second floor hosts a library and food service. The upper levels are occupied by laboratories and study rooms for students.

However, the core of this study is not the architectural redesign, but the sustainability of the installed systems and the efficiency of the applied passive energy strategies. In particular, an internal insulation coating is applied to the envelope permitting to preserve the historical façade, the existent roofing is covered with a ventilated roof, and the old window fixtures are replaced by triple glazed windows. Regarding the active strategies, the proposed energy plants included photovoltaic system, thermal biomass plant fed by wood chips coupled with an absorption chiller, and rainwater recovery system.

4. Dynamic simulations

Once the architectural characterization had been defined, the energy simulation of the building was conducted in Design Builder environment exploiting the EnergyPlus engine for the calculation. The tool was employed for modeling the Pavilion A in order to estimate the energy requirements by considering summer and winter conditions

[9, 10]. The information requested in Design Builder interface can be grouped in few categories: geographic (i), geometric (ii), physics (iii), users-related (iv). The location was set for defining the weather data and evaluating the boundary conditions of the model in terms of temperature and solar loading [11]. Then, the geometric model was coupled with physical information about the employed materials in order to assess some values such as thermal capacity of the envelope, heat gains and thermal dispersions. Finally, it was introduced in the analyses how occupancy can vary during the day, and the different activities conducted in each rooms [12]. For that reason, the building was divided in thermal zones, which are areas with the same requirements in terms of indoor conditions.

Several passive strategies, which are summarized in Fig. 2, were applied to the model in order to reduce the energy consumptions, while improving the comfort level. In particular, the proposal considers an internal insulation layer for saving and maintaining the historical façade, a ventilated roof, triple glazed windows and the addition of acoustic membrane on the false ceiling in order to reduce the indoor noise transmission.

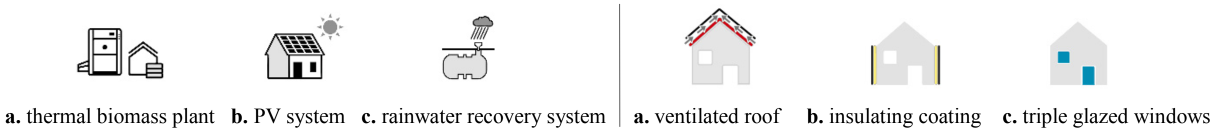

Fig. 2. Applied active and passive strategies. On the left: thermal biomass plant (a), PV system (b), rainwater recovery system (c). On the right: ventilated roof (a), internal insulation coating (b), triple glazed windows (c).

The simulation's results are reported on the bar graph in Fig. 3 which describes the thermal contributions due to heating system, cooling system, solar load through the windows, occupancy, lighting, computers and other devices installed inside the building. The values are expressed in kWh/m^2 considering a heated surface equals to 3500 m^2. The strategies applied permitted to enhance the energy performances of the pavilion, which has a shape factor (S/V) of 0.36, raising the energy class from G (160 kWh/m^2) to C (61 kWh/m^2). In addition to that, the maximum energy requirement for heating are achieved in January when 13,32 kWh/m^2 are supplied in order to guarantee the set point conditions. On the other hand, the peak of the cooling needs is achieved in July, when 9.77 kWh/m^2 are required.

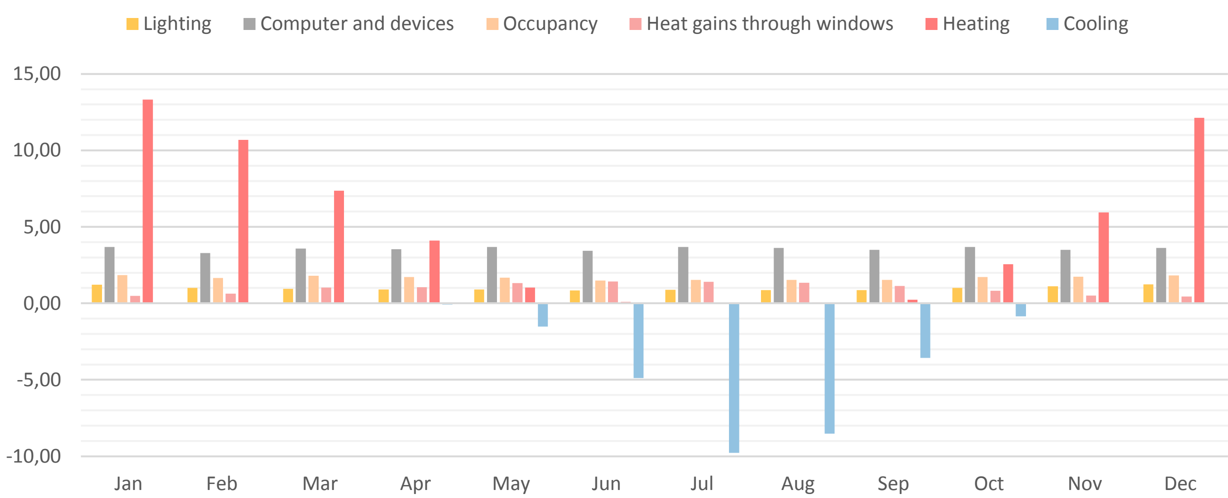

Fig. 3. Monthly-based thermal contributions [kWh/m^2] estimated by Design Builder.

5. Renewable energy plants

The designed energy plants are based on the Renewable Energy Sources (RES) and they covered the energy requirements estimated by dynamic simulations (Fig. 3). Once the typology of the plant was defined, it was sized in all the components [13]. Then, the consequent impact in terms of energy consumption, carbon footprint and economy was assessed in collaboration with the Biomass Research Centre of the University of Perugia with skills in energy from renewable sources [14]. The available technologies for producing thermal and electrical energy were evaluated considering the capital and the operative expenditures. The state of the arts highlighted how the best system for producing electricity at this latitude is the PVs, while regarding thermal energy production, the market on renewables is currently oriented toward the installation of geothermal plants and biomass boilers.

5.1 The PV plant

According to the recent best practices and guidelines which consider the photovoltaic (PV) systems placed directly on the ground as an outdated technology, the proposed PV plant is integrated on the projecting roof above the parking lots. It allows to reduce the ground covering factor, while increasing its permeability. Regarding the plant's size, the current regulation [15] defines the minimum electric power that should be generated from renewable energy sources in situ: for the Pavilion A, this value was calculated in 30 kW considering its footprint and age. In accordance with the urban masterplan [7], the PV panels cannot be installed on the roof surface for maintaining the original visual perception of the historical building.

The design of the PV system started from the architectural and environmental refurbishment of the parking area near to the Pavilion A. The proposal evaluates the arrangement of the parking lots in three groups with perimeter entry streets which permit to distance the PV panels from the tall trees and their shadows. At the end of this first stage, forty parking lots were obtained for the guests of the Pavilion A, almost all of them are protected and shaded by metallic framed projecting roof with an integrated PV system. Although the ideal tilt angle at this latitude is included between 30 and 35 degrees, it was preferred a tilt angle of 20°, counterbalancing the lower solar radiation (SR) caught with a higher panel's efficiency [16].

Secondly, the available SR in the area chosen as case study was calculated by considering the Annual averaged solar radiation on a horizontal plane map of Italy [17] and the specific regulation [15]. The resulting value is 1,531 kWh/m^2 year. The PV panel, produced by Conergy, has a nominal power of 0.28 kW with dimensions 1,650 x 991 mm [18]. Each projecting roof, that is characterized by an area of 80 m^2, permits to dispose up to 40 PV panels, 230 elements totally. The software Sunny Design [19] was employed for estimating the system's main features, accounting the energy annual requirements previously evaluated by Design Builder: the PV plant guarantees about 65 kWh directly exploited by users and up to 18 kWh injected to the electric grid.

5.2 The biomass plant

The utilization of biomass represents an efficient strategy for achieving the reduction of fossil energy source exploitation as confirmed by several studies conducted by the European Renewable Energy Council [20]. Biomass could permit to cover up to the 50 % of the European energy requirements, by contributing at the same time to the achievement of the goals declared on COP 22 in terms of reduction of greenhouse gas emissions [21, 22].

Some economic advantages related to biomass applications recently led to an increment of pellet stoves and wood chips boilers realization, respectively for low-medium and medium-large sized plant [23].

The thermal plant was designed in order to satisfy the requirements in both summer and winter conditions which had been previously assessed during the early stages of this research [11, 24]. In summertime the heat produced by the boiler is addressed to a cooling absorption chiller for conditioning. This category of biomass plants is completely automated and lacking of size-related limits, in fact they are able to generate some megawatts of thermal power by achieving the same performance and comfort level of traditional gas (or gasoline) boilers. The plant is located on a specific basement room, under the street level, in order to make the biomass supply easier. Biomass is stocked six times a year on an adequate environment, characterized by 74 mc storage volume, separated from the boiler for preventing backfiring. The system is completed by a system of collectors (primary and secondary), a cooling tower, a fluid storage, the pumping system and terminals. In that regards, fan coils were chosen as terminal elements due to the impossibility of modifying the ancient floor, made of precious marble and protected by the masterplan restraints.

According to the data evaluated by Design Builder software, it has been defined the boiler's size: it is necessary a boiler that generates at least 175 kW for 240 hours in order to provide up to 42,000 kWh during January, the coldest month. The absorption chiller size should be at least 172 kW. The wood chips boiler model proposed by the market that fits the requirements reported above is the Froeling Tx 200 [25], while the Yazaki WFC-SC 50 was considered as absorption chiller [26] for cooling production, as evaluated in previous projects [27].

5.2 Rainwater recovery plant

In general, the water recovery plant was given with low attention, but the water does is not an unlimited resource. The human behavior and the global warming could rapidly lead towards an unpredictable hydro crisis that would be hardly faced by nowadays society [28]. In particular, the Italian citizens are not a virtuous sample of sustainable water exploitation: actually, Italy is the first member state in Europe and globally the third in terms of water usage [29]. Thus, the storage and reuse of rainwater could permit to reduce the employment of potable water in activity in which it is not strictly required such as irrigation or toilets.

The rainwater recovery represents one of the main topics regarding building sustainability. The proposed plant was designed taking into account the high architectural quality of the case study as well as the bounds imposed by the Superintendence for Artistic and Cultural Resources. For those reasons, it was chosen to locate the storages underground without being visually perceived by users. Their volume was calculated considering the statistical data about the raining phenomenon and the features of intercepting surfaces.

The roof of Pavilion A and the PV projecting roofs installed on the parking area catch the rainwater, then it is transported toward the storage room, that is located below the frontal pedestrian area. As done for the stored volume, the total recovered water was estimated considering the data about raining [30], the flowing coefficient and the efficiency of the filtering system. In accordance to the procedure described above, a 1,543 m^2 area allows to recovery about 1,017,900 liters per year, which can be stored on two tank respectively characterized by a volume of 37.65 m^3 and 31.42 m^3.

Once the available recovered rainwater had been estimated, the its potential employments were defined and quantified. In particular, it was calculated a requirement of 120,000 liters per year due to irrigation of green areas (i) and 1,314,000 liters per year for supplying toilets system (ii). The last was assessed by considering the crowding index based on the different activities hosted at each floor. The analysis highlights how the requirements are higher than the recovered volume, hence it has been decided to exploit the stored rainwater only for supplying part of the toilets system needs.

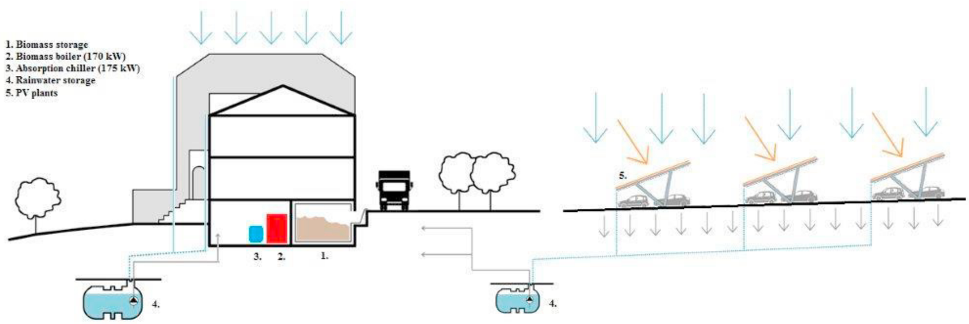

Fig. 4. Scheme of the whole systems.

5.3 Environmental and economic analysis

The production of electricity is entrusted to a photovoltaic system of about 60 kW integrated with the roofing of the parking lots. The total capital expenditure for the PV was evaluated in 142,000 € (comprehensive of the costs for the installations, the panels and the coverage roofing); the produced energy contributes to payback the plant within 4 years and it permits to avoid 39.5 tons of carbon dioxide per year.

Regarding the thermal production, the dynamic simulation estimated a required thermal power of 200 kW, which have been reduced on the designed plant to 170 kW by using two heat storages 5,000 liters each. The table below (Tab. 1) reports a comparison between geothermal plant and biomass boiler in terms of Capex and Opex demonstrating the economical superiority of the second one [31]. The Capex has been evaluated after a deep market survey, while the Opex has been estimated considering the electrical consumptions of the heat pump (Coefficient of Performance of 4.2) and the wood chips consumption for feeding the biomass boiler for heating and cooling, via the absorption chiller.

Table 1. Economics of the two evaluated technologies for the thermal plant.

Geothermal plant		**Biomass boiler**	
Heat pump	65,000 €	Boiler	25,000 €
Drilling fixed share	1,300 €	Biomass storage room	12,000 €
Drilling variable share	190,000 €	Road for trucks	5,000 €
Ground Response Test	6,300 €	Piping	14,000 €
Piping	19,400 €		
Tot. Capex	**282,000 €**	**Tot. Capex**	**56,000 €**
Energy consumptions	81,000 kWh/y	Wood chips	93 tons/y
Tot. Opex	**17,800 €/y**	**Tot. Opex**	**7,000/y**

The environmental impact can be estimated by defining the carbon footprint of the proposed plants. For the production of thermal and cooling energy, the biomass boiler was compared with a methane conventional plant: it was possible to estimate for the biomass boiler the payback period of the investment in 9 years, avoiding the production of up to 80 tons of CO_2 per year. The avoided emissions were calculated considering the emission factor for methane and electricity from the grid [32]. Lastly, a rainwater recovery plant was planned to avoid the waste of 1,300 cubic meters of water per year (about 77% of the entire water consumption for water closed and irrigation).

6. Conclusions

The EU's climate and energy targets, which have been recently included in Conferences of Parties [21, 22], aimed at controlling the world's temperature rise over the next few years. Such a wide and stringent background is added to the many measures and strategies that the local territory has made available to the operators: tax credit measures that include the 65% tax deduction of the energy efficiency intervention [33], and the recent Decree on non-photovoltaic RES [34]. The development of renewable energy, energy efficiency and greenhouse gas emission reduction is advancing, while the electrical market and the renewable energy system itself are facing strong problems and slowdowns.

This work highlights the feasibility of both technical and economic measures for energy redevelopment, demonstrating its environmental value as both energy and economic savings. Such strategies and proposals, due to their feasibility, may be replicable to similar historic buildings, contributing to the post-earthquake reconstruction and the energy upgrading of building heritage. The case study is a university campus set in Viale Crucioli in Teramo where, according to an existing agreement, it will be built up a student residence. The pavilions will accommodate 300 beds, 200 of which are reserved for the students of the ADSU and 2018 will open the construction sites. The executive project has already received 3 M€, allocated in the emergency Earthquake measures [35] while it is waiting to get to know by autumn the decisions regarding participation in the ministerial financing on residential housing for students for a value of 8 M€.

Acknowledgements

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