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Energy Performance Improvements in Historic Buildings by Application of Green Walls: Numerical Analysis of an Italian Case Study

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Abstract

The most commonly used interventions for energy requalification of buildings aim to increase the thermal resistance of the perimeter walls and ceiling and the efficiency of the HVAC system. Windows replacement is also usually foreseen. Moreover, the energy saving strategies have to reduce the energy consumption of the building, taking into account economic aspects and thermo-hygrometric comfort conditions of the occupants. In the case of historic buildings, some architectonical and urban planning restrictions impose to adopt only a few solutions that are well suited with the valuable architectural qualities of the building.

In Italy, there are many historic buildings. They are often located in small towns, such as the case study of this paper, a public historic building, the library "G. Pascoli" placed in S. Severo (FG).

In this paper, the authors propose an energy saving intervention, which consists in the application of a green wall on the back side of the building, being the principal façade subjected to architectural restrictions. The most suitable technological solution for the building considered has been proposed and a numerical analysis of the building's energy performance has been carried out by the software DesignBuilder. The results are satisfactory, being the energy consumptions significantly reduced both in summer and winter conditions.

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1. Introduction

In Italy about 12.5 million buildings can be defined “historic buildings”, as they were constructed before 1945. [1] They are often located in small towns and used as public administration offices, museums or art galleries. Since valuable architectonic features often characterize them, they are bounded to ministerial authorities and Superintendence restrictions in the case of structural refurbishment and/or energy requalification [2,3,4]. In this regard, the Italian Association for Air Conditioning, Heating and Refrigeration (AICARR) has recently published the Guidelines titled “Energy Efficiency in Historic Buildings”, with the goal of giving information about the most appropriate strategies able to improve the energy performance of historic buildings [5]. The necessity to reduce the energy consumption of historic buildings is also underlined by the European Directives [6,7] and the Italian legislation [8,9] on energy performance of buildings.

An original way for the energy refurbishment of historic buildings that safeguards their architectural features is to use green walls able to increase the thermal resistance of the structure and improve its thermal performance.

In this paper, the authors propose to use green walls as energy saving tools in historic buildings, giving in addition the possibility of enhancing the urban design, particularly in small towns, such as the case study of this work. In fact, small urban centers are often characterized by high density of buildings and absence of green spaces, as underlined in [10].

Some research works of recent years focus on the thermal properties of green walls applied on the building envelope with the aim of reducing the energy consumption for heating and cooling. The authors of [11] carried out an experimental analysis on reduced scale test rooms with green walls systems on the walls and the cover in semi-arid regions, and showed that both indoor thermal comfort and outdoor thermal environment are improved using green systems. In [12] the authors underline that urban plants contribute to reduce also the winter heating demand of buildings. In [13] the authors examine the possible effects of vertical green walls on the energy performance of buildings, through an experimental activity carried out in a park in Singapore.

Vertical Greenery Systems (VGS) can be used as passive tools reducing solar heat gains and cooling air by evapotranpiration, giving a dual contribution to energy saving in buildings. Moreover, they can give large-scale advantages when used to reduce the phenomenon of heat island, as underlined in [14]. Finally, in [15] the authors underline the great energy saving potential of green walls in buildings. On the other hand, they complain of a low diffusion of this technique in some areas of the world, and the need to carry out research activities on the most important aspects of the problem that are not yet sufficiently known.

This paper focuses on the energy requalification of a historic building located in S. Severo (FG), a small urban area in Puglia region, Italy. The authors proposed to install a VGS on the back facade of the building with the aim of achieving a significant energy saving for heating and cooling and an enhancement in urban design that is particularly significant in a small town lacking of green areas as S. Severo. The analysis was carried out by the software DesignBuilder in dynamic conditions, estimating the improvement of the building's energy performance, as well as the advantages in terms of internal comfort, also taking into account the economic aspects.

2. Description of the building

The historic building object of this research is the library "G. Pascoli" located in San Severo (FG). Born as a school building in 1858, it was refurbished in 2009 through an intervention that did not change its historical identity but allowed a functional recovery.

The building has three floors, with a maximum height of 11 meters and extends for a gross surface area of about 880 m^2 and a total volume of 4,000 m^3. The facades are covered with a typical stone of the place while the supporting structure is in solid brickwork. In Figure 1 the east side (main front) and the west side (back front) of the building are shown. The supporting structure consists of 600 mm tuff layer with 70 mm mortar and 10 mm internal plaster. It has a thermal transmittance of 1,04 W/m^2K, out of law prescriptions for the thermal zone in which the building is located. The floors are 300 mm thick with single-fired tiles or, in some rooms, in stone slabs, with a layer of 120 mm insulating screed.

Fig. 1. (a) East façade; (b) West façade of the building.

The fixtures are made of RAL color painted wooden double windows, with 6 openable mirrors. The sub-frame consists of a wooden and glass section frame (4 + 9 + 4). The thermal transmittance is 3.1 W/m^2 K. The interior side of the walls is coated with pre-mixed plaster and subsequent application of water-based paint.

3. DesignBuilder simulation in the existing configuration

A three-dimensional model of the building was simulated in dynamic condition by the software DesignBuilder. The building is located in S. Severo (FG), thermal zone D, 1494 Degree Days. Meteorological data were taken from the Italian climate data collection "Gianni De Giorgio" (IGDG). Set-point temperatures were fixed according to the Italian decree (D.P.R. 74/2013 art.3) that determines a winter value of 20 °C and a summer value of 26 °C. The heating season is going from October to March and the cooling from April to September. For the HVAC system the simple model option was selected and different templates were used for the different thermal zones both for heating and cooling, and also for occupancies.

In order to verify the numerical model, real energy consumption data from 2013 to 2016 were taken into account. Figures 2 shows the real energy consumption of electricity and gas. We note non-homogeneous trends in the yearly energy consumption. About electricity, there is a low demand in 2013 and similar consumption in 2014-2016. The gas consumption trend is more regular, with a peak in February, March and December 2013. Since consumption data of the year 2015 were available from the Italian climatic data collection "Gianni De Giorgio", they were used to verify the implemented numerical model. In Figure 3 the comparison between real and DesignBuilder data is shown, respectively for electricity and gas consumption. A good agreement is verified.

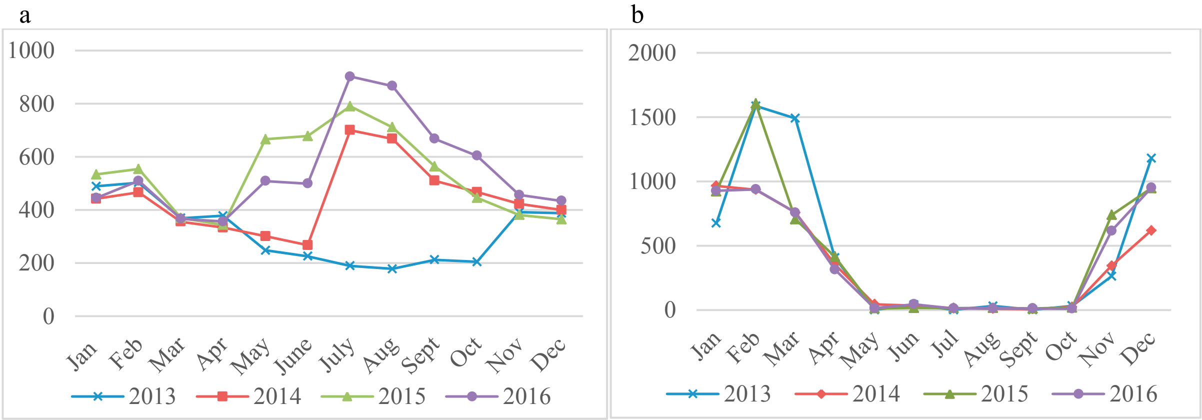

Fig. 2. (a) Real electricity consumption (kWh); (b) Real gas consumption (m^3) - from 2013 to 2016.

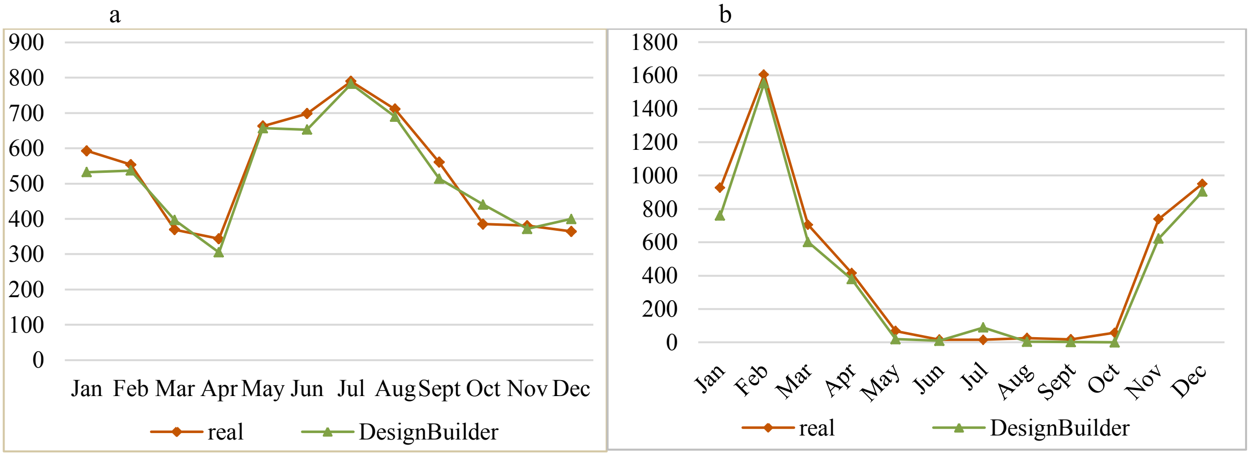

Fig. 3. Comparison between real and DesignBuilder data: (a) electricity consumption (kWh); (b) methane gas consumption (m^3) - year 2015.

3.1. Thermo-hygrometric comfort indexes

In Figure 4, the PMV and PPD trend is shown. It is evident that optimum values of comfort indexes take place only in intermediate seasons, while in the warmest months (from June to September) and in the coldest ones (from December to February) PMV values are out of optimal ranges. This is obviously confirmed by the PPD index.

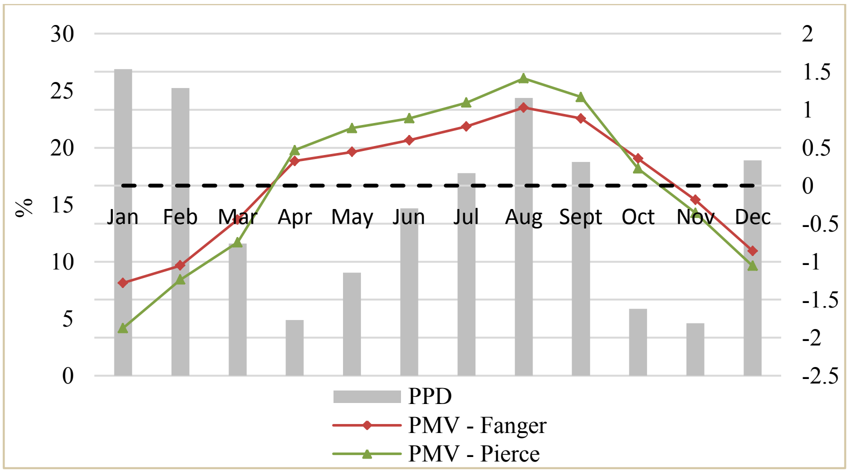

Fig. 4. Comfort indexes (PMV) and Percentage of Persons Dissatisfied (PPD) in the existing configuration.

4. Application of green-wall

The energy improvement intervention consists of the installation of a green wall on the west side of the building (the back front), with the aim of verifying the capacity of the vertical green system to reduce the surface temperature of the wall and consequently give a significant contribution in reducing the energy consumption of the building.

The east and west façades receive, in fact, considerable amount of solar heat gains, respectively in the morning and in the afternoon, and transparent surfaces are subjected to glare phenomena. On the other hand, solar radiations are necessary for the life of plant species and these can offer an effective shielding action against summer heat gains. Since the east side is the main front of the building, the authors hypothesized to install the vertical green system on the west wall, without modifying the east façade. As shown in Figure 5, the west wall of the building consists of three parts, respectively of 45.3 m^2, 140.6 m^2 and 45.3 m^2. The total treated surface is 231 m^2.

Fig. 5. View of the back side (west oriented) of the building.

In order to guarantee the best thermal performance without massively intervene on the building, which has a remarkable historical identity, a self-supporting steel structure was chosen. It consists of vertical support elements (140 x 140 mm), fixed to the ground and anchored to the main structure at the top and every 2 m by means of low drilling pins, in order to avoid sudden changes due to seismic and wind stresses. The steel horizontal profiles (0.7 x 0.9 mm) are connected to the vertical ones at variable intervals and they support the containers in cross-linked polyethylene containing a light substrate for the growth of plant species and equipped with a flexible metal blade for their expansion. The steel structure is placed at a distance of 50 mm from the main wall in order to guarantee an effective inter-structure ventilation and avoid phenomena due to the humidity created by the substrate (Figure 6).

The vertical green system does not cover the building's windows, ensuring the availability of a sufficient amount of natural light, as requested by the use as library, and favoring free solar heat gains during winter season, without intervening on the important historical details of the openings themselves. Finally, irrigation is guaranteed through an integrated drip irrigation system. The chosen plant species is named *Parthenocissus tricuspidata*, an evergreen plant, resistant to frost and with a very high average life. It does not need great amount of substrate and irrigation and is suitable for the highest summer temperatures typical of the Mediterranean climate. It is characterized by a Leaf Area Index (LAI), that's the area in projection of the leaf surface per unit area, between 0.25 and 1.5 (Figure 7). Furthermore, it has a reflectivity in the visible, infrared and ultraviolet range, of 0.22, an emissivity of 0.95 and a surface thermal absorption of 0.9-0.98.

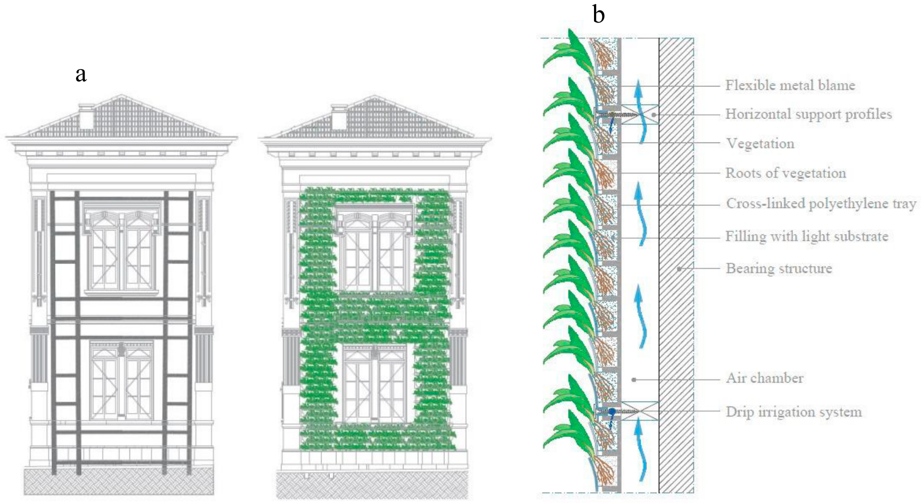

Fig. 6. (a) Technological structure supporting the VGS; (b) Stratigraphy of the VGS.

Fig. 7. LAI "Leaf Area Index".

5. DesignBuilder simulation after the installation of the VGS

The simulated model was modified in order to evaluate the energy performance of the building achieved adding the VGS on the west wall of the building. The VGS is an adjoined thermal resistance able to reduce winter thermal losses and summer heat gains.

Table 1 shows the month and yearly consumption regarding electricity and gas before and after the application of the VGS. A significant energy saving is achieved both for cooling and heating, as highlighted by the results. Considerable electricity reduction takes place during summer season, in particular from June to September, due to a decreased energy demand for cooling, as shown in Figure 8. Besides, from December to February a considerable energy saving takes place regarding gas due to a reduction of heating consumption of the building. It is evident in Figure 8. The maximum electricity reduction is 35.2 % in August, while the maximum gas consumption reduction is 35.4 % in February. The whole reduction is 17.8 % about electricity and 28 % about gas.

Table 1. Electricity and gas consumption before and after the installation of the green wall.

		Existing electricity consumption *(kWh)*	Improved electricity consumption *(kWh)*	Electricity consumption reduction %	Existing gas consumption *(m^3)*	Improved gas consumption *(m^3)*	Gas consumption Reduction %
1	January	522.4	512.6	1.9	919.7	632.1	31.3
2	February	557.0	550.2	1.2	1554.8	1004.5	35.4
3	March	366.7	344.5	6.1	700.4	546.9	21.9
4	April	345.0	288.9	16.3	403.0	332.0	17.6
5	May	657.1	539.5	17.9	14.8	13.7	7.3
6	June	672.9	502.8	25.3	12.4	12.0	3.0
7	July	782.3	527.9	32.5	9.7	9.3	3.4
8	August	689.8	446.8	35.2	12.9	12.7	0.9
9	September	554.0	379.8	31.4	10.0	9.7	3.2
10	October	440.4	379.5	13.8	16.4	15.6	5.0
11	November	371.6	367.8	1.0	711.8	568.3	20.2
12	December	369.8	361.9	2.1	933.8	657.7	29.6
	Total	6329	5202.3	17.8	5299.6	3814.5	28.0

The comfort indexes are significantly improved after the installation of the green wall, as shown in Figure 9. The PPD index is always less than 20% and only in the warmest months of the year (form June to August) and in the coldest ones (from December to February) it is higher than 10%.

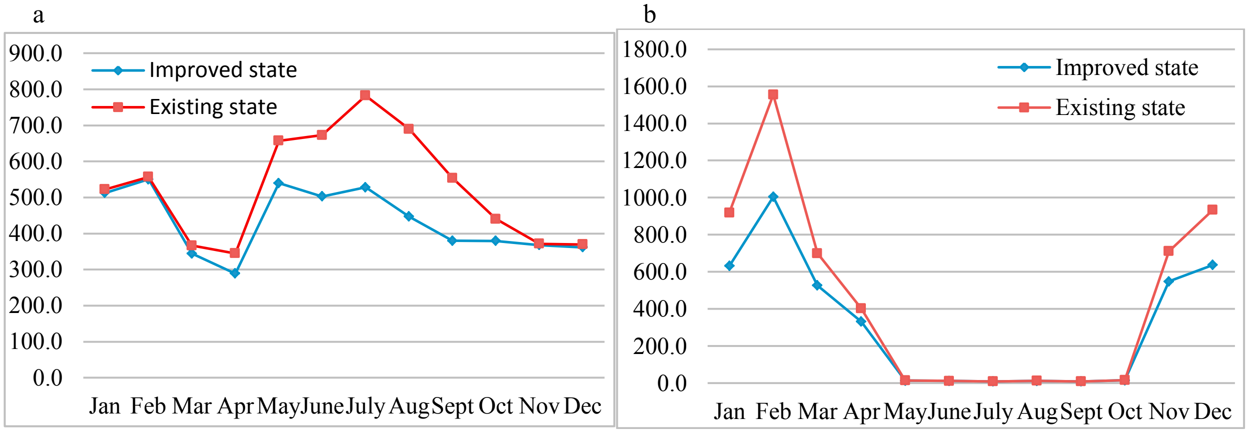

Fig. 8. Energy consumption before and after the installation of green wall, (a) electricity (kWh); (b) Gas (m^3).

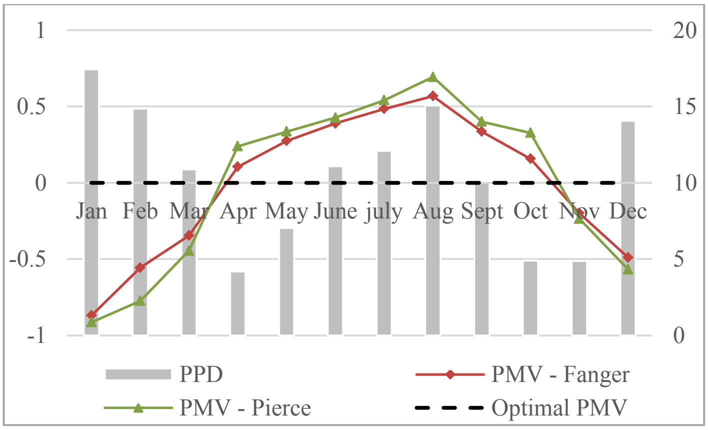

Fig. 9. Comfort indexes after the installation of the green wall.

6. Economic analysis

The main costs for a green wall are classifiable in initial, ordinary and extraordinary costs. In this case, the initial costs include purchasing and installing the support structure, as well as purchasing and planting the plant species. The maintenance of plant species, i.e. gardening, cultivation, pruning and irrigation are included in ordinary costs. Finally, extraordinary costs include the maintenance of the supporting structure and the substitution of non-living plant species. Sometimes it happens that, because of extraordinary adverse weather conditions, it is necessary to replace almost all the plant species. This is a considerable cost, especially in the case of rare plant species.

The authors considered a cost of water for irrigation of 2.50 €/m^3 with a water consumption of about 2 m^3/month. The costs of steel and installation were taken from the regional price list of Puglia Region. Besides, it is assumed that extraordinary maintenance works take place every 10 years, and the total quota is diluted in annual partial quotas of 1/10.

About revenues, it is necessary to specify that the green walls have psycho-physical benefits that are not quantifiable economically. The greatest economic benefits derive from the reduction of energy consumption. Currently, the cost of energy are 0.25 €/kWh for electricity and 0.70 €/m^3 for methane gas.

Considering only the costs and benefits deriving from the intervention, a simplified economic balance was carried out to establish the time necessary to amortize the initial outlay. The initial expenditure will be amortized in about 7-8 years, as shown in Figure 10.

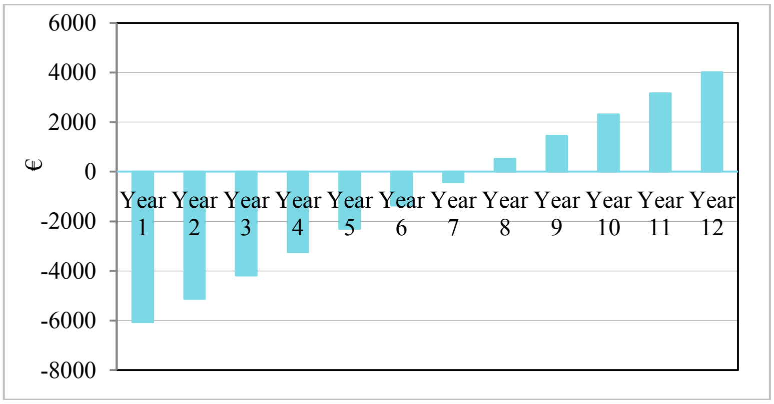

Fig. 10. Economic balance between costs and benefits.

7. Conclusions

This paper concerns the analysis of the energetic performance of the library “G. Pascoli”, a historic building located in S. Severo (FG), a small urban center in Puglia, Italy.

The authors showed that significant energy benefits are achieved by the installation of Vertical Greenery Systems (VGS) in compliance with the architectonic value of the building and enhancing the urban design, particularly in a small town as S. Severo, which is lacking of green areas. They proposed the application of a self-supporting green wall on the back façade of the building (west oriented) and carried out a dynamic analysis through the software DesignBuilder with the aim of evaluating the energy saving due to this intervention, while taking into account economic aspects and thermo-hygrometric comfort indexes. The results show that VGS allow achieving considerable energy savings, regarding both electricity and gas consumption, and improvement of comfort indexes.

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