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Energy performance of film membranes in the retrofitting of Architectural Heritage: an Italian case study

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Abstract

During the last decades, the development of architectural textiles led to significant innovations in the building industry. Designers, producers and researchers have invested in the technical development of textile envelopes with the aim of improving the structural performances of existing building in a cost-effective and sustainable way without sacrificing the aesthetical aspects of the historic buildings. The optimization of technical textiles properties focused particularly on the production process, on the lifespan and the end of life scenarios. Despite the technological progress, the performance of the membranes in terms of internal comfort and energy consumption still represents a critical issue constantly investigated by the academics in this field. In parallel, recent research on the use of membrane structures in historical buildings provided important references and data on the advantages of textiles application in the protection and promotion of the architectural heritage thanks to their intrinsic lightness and reversibility. For this reason, it is fundamental to evaluate the effects that the integration of film membranes has in these valuable structures in terms of energetic behaviour.

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The aim of the paper is to analyse the potentiality of membrane usage in the energetic retrofitting interventions. The Authors will present and analyse the hypothesis of a temporary roof installation in the courtyard of a historical building located in the town of L'Aquila (Italy) and severely damaged by the 2009 earthquake. The paper includes the results of a dynamic simulation of the entire building, carried out with the software "Design Builder", which allowed the assessment of the project from the environmental point of view on the basis of the energy consumption.

Keywords: performance, energetic retrofitting, CO_2 reduction, internal comfort, temporary roof, valuable courtyard, dynamic simulation

1. Introduction

Historic buildings have a crucial role in the exploitation of the cultural and economic potential of existing cities. Due to the numerous threats, such as an increasing level of pollution, gentrification and natural disasters, the government department responsible for monuments are constantly under pressure to ensure an adequate level of protection without interfering with the regular use of the building.

The use of lightweight membrane structures for the protection of historical sites has been successfully experimented in several key projects. The foldable roof for the Rathaus's courtyard in Vienna (Tillner, 2003) and the ETFE roof for the Palacio de Igartza, a small fortress-palace built in the 13th century in Beasain, Guipúzcoa, North of Spain (Tejera J., Monjo-Carrió J., 2010) are only two of the successful projects based on lightweight membrane structures added to historic buildings to improve the weather protection (Rosina et al. 2011) without damaging the existing buildings or compromising their structural performance.

In addition, recent projects investigated the potential of temporary membrane structures for the development and exploitation of the potential of historic buildings in the improvement of areas of the cities still underutilised. Artistic installations for the Milan Design Week, such as "Invisible Borders" (Beccarelli et al., 2016) by MAD architects and "Off the Cuff" (Beccarelli et al., 2017) by DR+R, can attract thousands of visitors in few days offering free access to public buildings and unique experience. The constructive discussion with the government department responsible for monuments shows that membrane structure can be successfully used to improve the current state of historic building

However, the increase in the number of textile interventions on cultural heritage requires detailed analyses on the impact of the membranes on the energy behaviour of valuable masonry buildings (Llorens and Zanelli, 2016; De Vita et al., 2018). This paper shows the potential of a temporary textile cover in the internal courtyard of a historic building in the city of L'Aquila, and its positive impact on the energy performance of the building.

2. Case study: *E. De Amicis* school

2.1. The history of the building and its morphology

The construction of the building was commissioned by *S. Giovanni da Capestrano* to host the "S. Salvatore" major hospital, next to the Basilica of S. Bernardino, and it was completed in 1457. In 1779 the building hosted a Medical School as well, until the second half of the 17th century, when it was occupied by a military dispensary. In the first years of the 18th century the building became a school, until the earthquake that occurred in L'Aquila on April 2009. It is now damaged and abandoned, waiting to be restored to its original state.

The building has a rectangular shape with an inner courtyard and consists of 3 levels covered by pitched roofs (Figure 1). The ground floor has a difference in level from the south to the north side of nearly three meters, resolved by a set of stairs on the north side; for this reason, the courtyard is flat, and it is surrounded by a colonnade which sustains a hallway on the first and second floor. On the second floor, the hallway and the southern part of the building have a lower roof which is surrounded by walls that share the same roof as the perimetral walls of the East, North and West side (Figure 2).

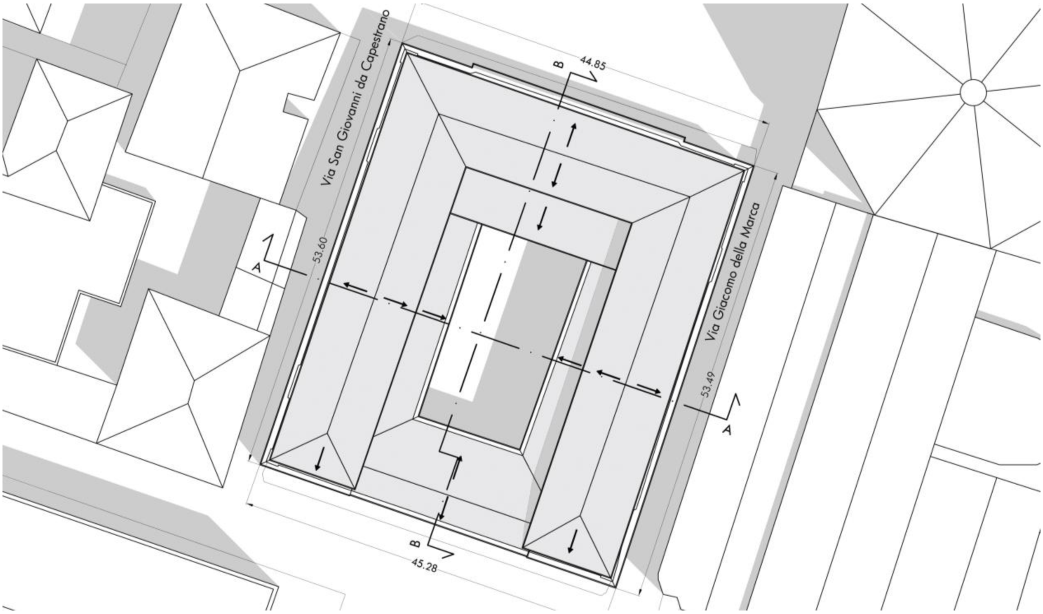

Figure 1: Roof plan of the building and context.

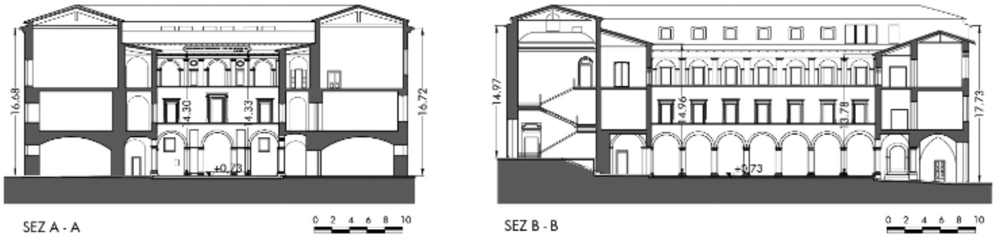

Figure 2: Transversal (left) and longitudinal section (right) of the building.

2.2. The restoration plans

The restoration plans of the historic building foresee the reconstruction of it as it was before the earthquake with the integration of all the necessary structural and energetic improvements. This research project proposes, along with the restoration plans, the covering of the inner courtyard. Such covering would be able to guarantee the use of the courtyard space even in case of adverse climatic conditions, giving the school the possibility of exploiting the courtyard during the educational activities.

The municipal administration is still developing a long-term plan for the building, one of the most important ones of the city, but it suggested that an alternative use of the building could be the transformation from a school to a social aggregation point for the city, offering a wide range of services for the population. In this case, the courtyard would represent a buffer space and a connection between the two squares adjacent to the building: the square of the municipal Theatre and the square of *S. Bernardino* Church.

For what concerns the covering of the courtyard itself, this research project proposes an adaptive textile roof, whose transparency could be altered through the use of printed patterns, if needed. The advantages of using textiles, especially if compared to a traditional transparent roof made of glass, are: a good reversibility, a low impact on the existing building in terms of both structural weight and installation repercussion, and effectiveness in preserving the architectural features of a building (Figure 3). In fact, parts of the courtyard roof can be demounted if the users require it, without compromising the architectural values and historical integrity of the intervention area.

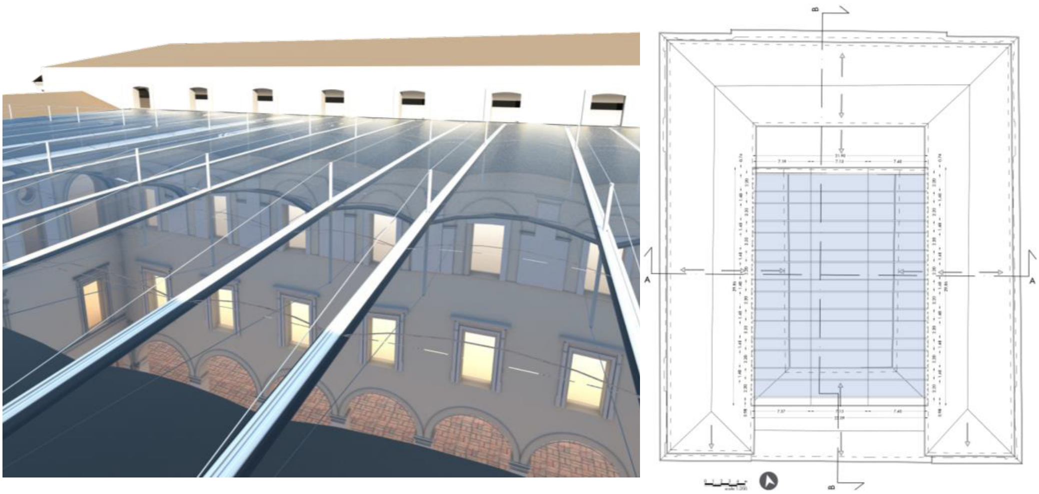

Figure 3: Rendered image of the ETFE roof seen from the top (left), installation of the ETFE roof (right).

3. The design of the courtyard textile roof: an adaptive retrofit solution

The textile roof structure is based on fixed steel beams designed to minimize the material usage. The frame is based on four edge beams and 16 double UPN160. In order to reduce the cross section despite the ambitions long span, steel bars are placed at 1/3 and 2/3 of the UPN beams and put into compression by tensioned cables. The UPN160 beams inside the frame form a series of rectangles, of 2 different widths, which are covered with ETFE cushions with an aluminium frame.

The greater challenge of this project is the measure of the energetic improvement generated by the textile installation. The energy saving has been predicted through dynamic simulations by using Design Builder software.

3.1. The dynamic model

An energetic simulation is a mathematical model of the thermo-physical building behaviour. The geometry of the structure is the basis of the initial input data. A model for energetic simulations is simplified in comparison to the architectural model to which it refers. Usually an object consisting of curved elements is discretized with a certain number of surfaces, but in this work, considered the relatively small curvature of the cushions (transversely), the textile roof is modelled as a plane surface. External loads, on the other hand, depend exclusively on the weather data used in the simulation. One of the main objectives of energy simulation software is to compare different scenarios to analyse energy consumption. In this paper specifically the energy strategy is the introduction of the courtyard roof.

In order to analyze and compare the effect that the membrane roof has on the energy behaviour of the building, two identical models have been designed: one without the coverage of the courtyard and the other with the textile integration (Figure 4). In the development of the model, the location data of L'Aquila have been set in the *Location* template using the weather data of Campobasso, available in the library of the software and with climatic conditions similar to the city of L'Aquila.

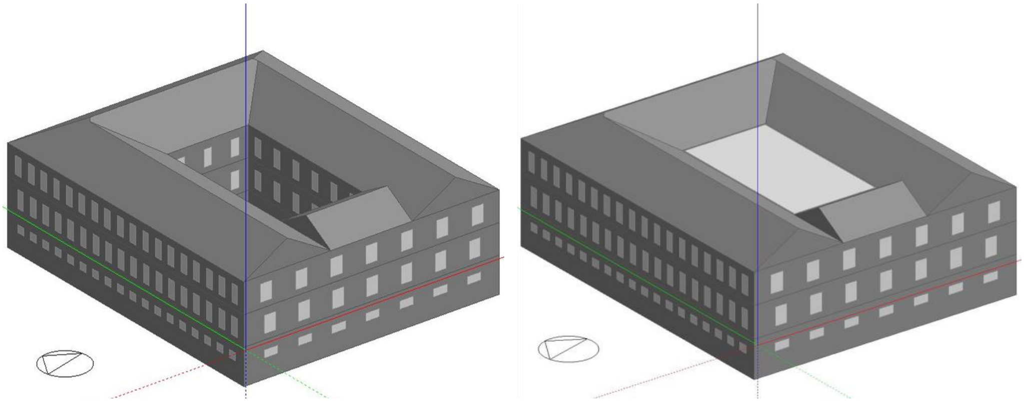

Figure 4: Design Builder model of the building without the ETFE courtyard covering (left) and with the ETFE courtyard covering (right).

The two models have the same geometry and orientation but were handled differently: the first one has one *zone* (building) with its correspondent activity while the second one has two *zones* (building and atrium) and one activity for each zone. For what concerns the building the *Activity* was set to "Generic Office Area" in both models; instead, for the *atrium*, the Activity Template was set to "None". Even if the building will host social events, they would only be occasional and take place when there are no office or school activities; so, the average occupancy density of the courtyard was set to 0.05 people/m^2. during the Office Circulation Schedule, with a "Standing/walking" Activity.

In regard to the *Construction* template, the pitched roof was chosen from the software gallery, while the exterior walls, which consist of a masonry wall plastered on both sides, were created using data from literature (De Vita et al., 2018). Three different wall thicknesses were constructed in the model, representing the average masonry thickness for each level (Table 1). The presence of the courtyard made the creation of a *void,* which is not considered by the software as part of the building, necessary in the first model. In the second model, instead, the courtyard was made in the rectangular building through partition walls and a glazed roof.

Table 1: Masonry wall characteristics used in the model

Construction elements	Thickness [mm]	Density [kg/m^3]	U-Value [W/m^{2}K]
Perimeter wall - level 1	1600	2100	0.647
Perimeter wall - level 2	1400	2100	0.796
Perimeter wall - level 3	800	2100	1.390

The Wall-to-Window ratios were calculated for the *Openings* and assigned to each different wall, and the window template was chosen according to the Italian Standards. In the second model, the roof of the atria had to be transparent, so it was necessary to create an opening extended through the whole roof surface and the layout of the glazing was set to "100% roof glazing" (De Vita 2018). For the membrane to be assimilated to a glass surface, the textile coverage was modelled starting from the "Project roof glazing": within the tab of the physical and optical properties of the glass, the characteristic values of the designed membrane (ETFE of 200 μm) have been inserted from literature (Cremer et al., 2017) (Table 2). The cushion was modelled designing two transparent ETFE layers separated by an air gap of 10 cm. Since with the use of Design Builder software it is not possible to reproduce the curved geometry of the cushions, the model of the textile roof was realized through a simple plane. The surface through which the courtyard exchanges heat with the exterior was similar to the real one (≃ 350 m^2), as well as the number of partitions and the characteristics of the aluminium frame.

Table 2: Textile roof characteristics used in the model

Construction elements	Thickness	Conductivity	Solar transmittance	U-Value [W/m^{2}K]
ETFE - clear	200 μm	0.24	0.930	-
ETFE - clear cushion	200 μm + 10 cm air gap + 200 μm	-	0.883	5.977

The *Lighting* template was automatically generated by the software according to the previously set *Activity* template. For the *HVAC* template, instead, an Air to Water Heat Pump (ASHP) heating system, was set up; the system provides the building with the DHW as well and it is powered by the natural gas network. As well as the designed covering, the model of the covering allows natural ventilation, to avoid problems of moisture and condensation.

A comparison of the results from the dynamic simulation enabled the functioning of the cushions roof. The textile model used to carry out the dynamic simulations was developed by the authors using literature results (Chilton, 2004; De Vita et al., 2018).

The period chosen for the simulation coincides with the whole solar year: from January 1th to December 31th.

3.2. Simulation results

The following outputs from the dynamic simulations were analyzed and summarized in figure 4, 5 and 6:

- CO_2 emissions calculated from total fuels with operating HVAC system;
- Electricity consumption with operating HVAC system;
- Natural Gas consumption with operating HVAC system;

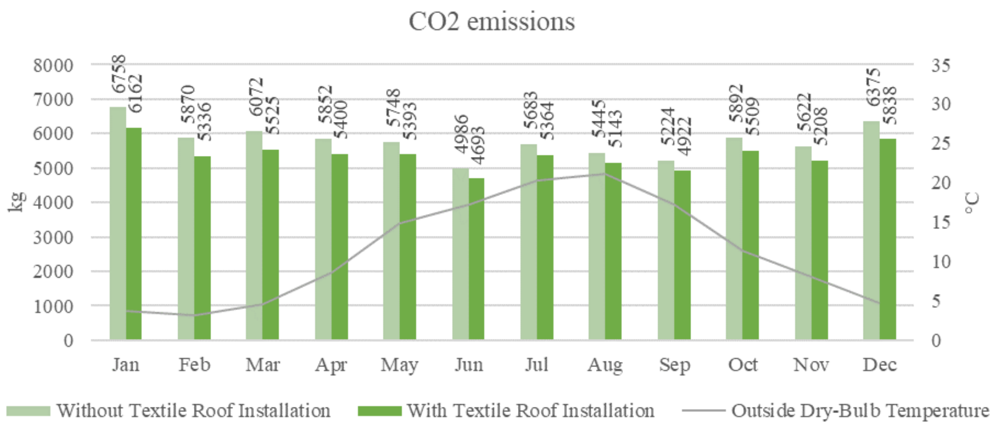

Figure 4: Chart showing the CO2 emission levels in the building during 12 months without the textile roof installation and with it.

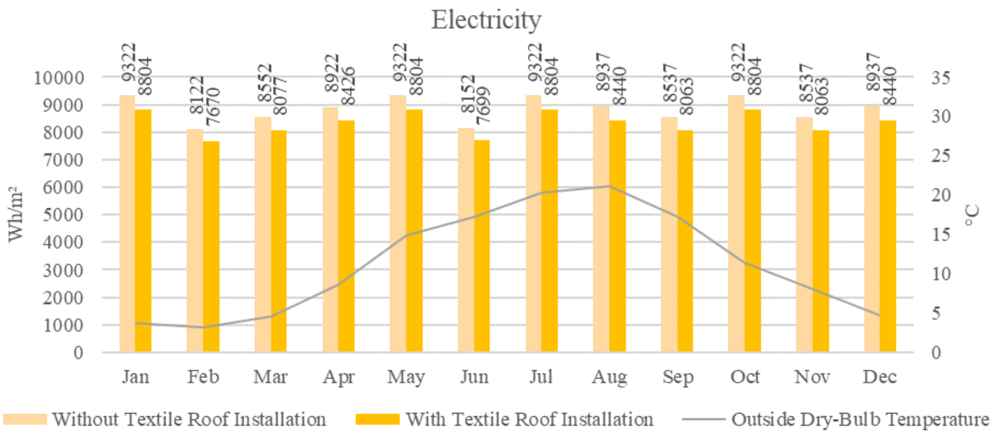

Figure 5: Chart showing the Electricity consumption levels in the building during 12 months without the textile roof installation and with it.

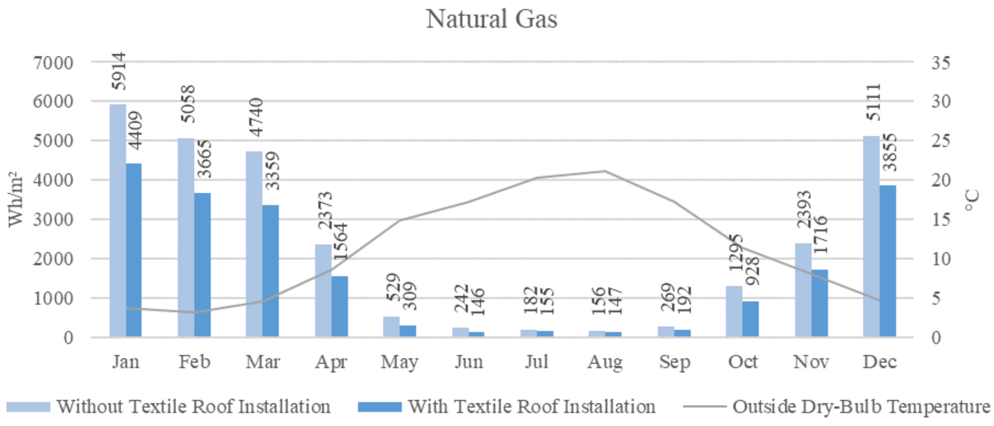

Figure 6: Chart showing the Natural Gas consumption levels in the building during 12 months without the textile roof installation and with it.

Figure 4 shows the reduction of the CO_2 through the installation of the textile roof ranges from 10% (colder months) to 6% (warmer months). The use of ETFE roof solution can even reduce the Electricity fuel of about 6% (Figure 5). The most relevant results from the dynamic simulations show that, although the percentage reduction of Natural Gas consumption level is placed between 25% (colder months) and 42% (warmer months), in winter the textile roof allows to achieve the highest energy saving, considering both the CO_2 emissions and the total fuels.

5. Conclusion

The relevance of this work consists in the possibility of managing the performance of historical buildings through the integration of membranes. The challenge that this study presented was to predict the energetic behaviour of masonry structures combined with textiles using dynamic simulation software, thus allowing the definition of the optimal technological configuration. The results of this study are extremely relevant considering that the choice of textile materials is often based on aesthetic and reversibility aspects whilst energy saving is not yet fully envisaged.

References

De Vita M., Beccarelli P., Laurini E., De Berardinis P. (2018), Performance Analyses of Temporary Membrane Structures: Energy Saving and CO_2 Reduction through Dynamic Simulations of Textile Envelopes, *Sustainability,* 10(7), DOI: 10.3390/su10072548.

De Vita M., Bartolomucci C., De Berardinis P. (2018), *L'adozione dei tessili tecnici come soluzione di retrofit energetico del patrimonio culturale*, ReUSO 2018, VI International Congress, Messina, Italy, 11-13 Ottobre 2018, pp. 1513-1524.

Llorens J., Zanelli A. (2016), *Structural membranes for refurbishment of the architectural heritage*, Procedia Engineering, Vol.155, pp. 18-27.

Chilton J. (2004), Internal environment, in *The European Design Guide for Tensile Surface Structures: Tensinet*, Eds. B. Forster, M. Mollaert, Vrije Univ.: Brussel, pp. 97-146.

De Vita M., Mannella A., Sabino A., Marchetti A. (2018), *Seismic Retrofit Measures for Masonry Walls of Historical Buildings, from an Energy Saving Perspective*, Sustainability, 10(4), DOI: 10.3390/su10040984.

Tillner S. (2003). *Mobile Hofüberdachung in Wien, Deutsche Bauzeitschrift*, Wien, 4/2003, S. pp. 48-53.

Tejera J., Monjo-Carrió J. (2010), *Heritage preservation strategies through textiles, In: Tensile Architecture: Connecting Past and Future*, Proceedings of the TensiNet Symposium, 16-18 September 2010, Sofia, Bulgaria, pp. 1-11.

Rosina, E., Zanelli, A., Beccarelli, P., Gargano, M. and Romoli, E. (2011), *New procedures and materials for improving protection of archaeological areas Materials Evaluation*. 69(8), pp. 979-989.

Beccarelli P., Maffei R. and Binda R. (2016), ETFE envelopes for the building sector In: Proceedings of the 11th Conference on Advanced Building Skins, pp. 720-729.

Beccarelli P. and Maffei R. (2017), *Engineering and fabrication of the "Off the Cuff" pavilion*, Fuorisalone 2017, Milan, in: Structural Membranes 2017 VIII International Conference on Textile Composites and Inflatable Structures 9-11 October 2017, Munich, Germany.