Removable textile devices to improve the energy efficiency of historic buildings

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Abstract – The paper aims to present innovative studies concerning removable devices for enhancing thermal performance or mitigating criticalities in listed buildings. The first concerns a "high tech" curtain studied for preventing air drafts from the windows, causing different forms of decay in the Sala delle Asse in Castello Sforzesco (Milano), world known for the Leonardo Da Vinci fresco. The second body of research deals with a new type of "arazzo" (removable and usable seasonally) to improve the insulation of the walls. The study case regards the collection of historic "arazzi" in Sala della Balla, in Castello Sforzesco as well.

The focus is to investigate how the main properties of the removable devices affect the thermal exchange with the air and the surfaces where they are applied. A third study case is a masterpiece of listed modern architecture, Casa del Fascio in Como, where the new uses require cooling with the addition of a shadowing system.

Keywords – removable devices, historical buildings, energy efficiency, conservation

1. INTRODUCTION

The use of removable devices and systems is not common for mitigating environmental impact on buildings at present. Nevertheless in the past, removable systems were used for improving comfort: expensive and precious tapestries, curtains (inside windows, along porches and loggias), and double window frames that included rolling shutters between the frames. The devices, tools and systems require proper management and maintenance, they differ and their thermal behaviour is hard to model because the calculation of the improvement in performance is still approximate. On the other hand, they have the advantage of constituting additional and complementary protection with the existing vertical closures, improving the performance and thermal properties of traditional materials and building techniques. Moreover, they are removable, reversible, compatible with the existing buildings and not necessarily expensive. Hence, they meet the conservation requirements. In some cases, at temperate climate, their contribution is higher than contemporary insulation inside the rooms: in fact, the latter causes an increase of temperature inside the buildings in the hot seasons, therefore the seasonal removability in case of a new system constitutes a great advantage.

For these reasons, the appreciation of removable devices has been increasing in scientific literature in the last years (not in the professional practice yet), especially with regard to shadowing systems and solar screens. In Italy since

2006, the legal framework created significant tax reductions for their application. Since 2009, shadowing systems are compulsory in the refurbishment of existing buildings[1] 2009 was, in fact, the year in which the question of summer air conditioning use was set inside legislation, thus explaining the introduction of shielding. In reality, the use of mobile devices, as will be seen in the following, are useful both for the cold and the hot season, as well as for controlling the infiltration of air from the windows. The replacement of glass with higher performance materials is not always the best solution given the need not to decrease winter heat accumulation while dampening the flow of heat entering during the summer (what was done in the past, for example, in the "barchessa" in the Venetian villa, the pergola with deciduous vegetation).

The theme is also reflected in the Guidelines that the Ministry of Cultural Heritage has issued for the improvement of the energy efficiency of cultural heritage (2015), which also deals with strategies for cooling.

Our experimentation, obtained with different and combined diagnostic and simulation methods, intends to demonstrate their effectiveness also from a quantitative point of view, and even if currently applied to very important case studies and therefore to listed buildings, it should be possible to extend the devices also for the improvement of any class of buildings not necessarily subject to protection.

2. STUDY CASES

The first study case is Sala delle Asse at Sforza Castle, in Milan [1]. Over recent years, a consistent phase of study went on for planning the most effective restoration intervention of Leonardo paintings and monochromes. The analysis and microclimatic monitoring of the last 8 years resulted in diagnostic of some causes of thermal/humidity imbalances inside the room, despite of the lack of heating/cooling [2].

Due to the damage (especially salt diffusion, which is still spreading) [3] on the precious decoration, the authors' assignment was to study and prototype a system to mitigate the air flux entering through openings, especially the northwestern window. In fact, the protection by law of any existing feature/part of the buildings prevented the substitution of the window frames in the castle. This is the reason why the authors developed an innovative kind of internal screen, following a challenging set of requirements:

- the minimization of the fixing points of the frame to the historical walls of the castle;
- the UV and fire protection of the textile membrane;
- the reduction of the air flows from the window through the screen;
- the full size of the 4x6 m screen on one hand, and the easy removability and wash-ability on the other.

1 The designer assesses and evaluates the effectiveness of the glass screen for reducing the energy request due to the air-conditioning plants (DPR 59/09 art. 4 comma 18 a).

The optical, thermal and mechanical behaviour of six different kinds of knitted textiles were compared and three options of installation procedures were evaluated. Eventually a full size, double curved, textile screen, supported by an ultra-lightweight FRP bending active thin frame would be tested, with the final aim of measuring, on site, the daytime lighting and breath-proof quality of the final screen.

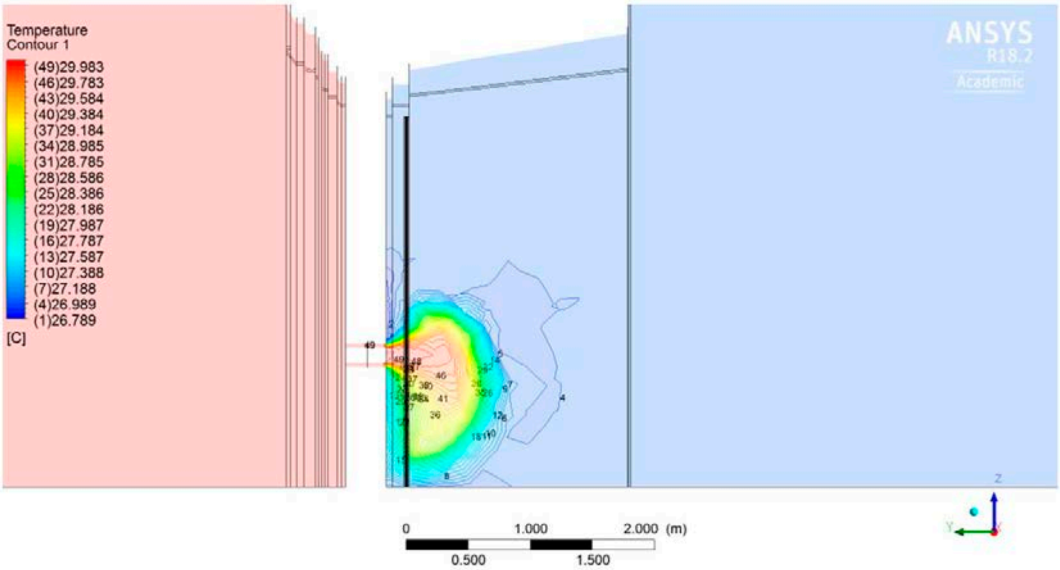
With the aim of optimizing the prototype project, especially its performances of reducing the warm air draughts in summer, the authors simulated the location of the curtain by Ansys software. Computational Fluid Dynamics (CFD) is, in fact, a useful tool for the evaluation of the microclimatic conditions in cultural heritage [4]. A thermo-fluid-dynamic was used for the verification and validation of the project hypothesis. The numerical analysis allows the researchers to define devices with low energy consumption and compatible with the restrictions that protected historical buildings require. The fundamental aspect of CFD is meshing the fluid continuous medium and the possibility of affording complex 3D geometries and physical environmental phenomena at different scales.

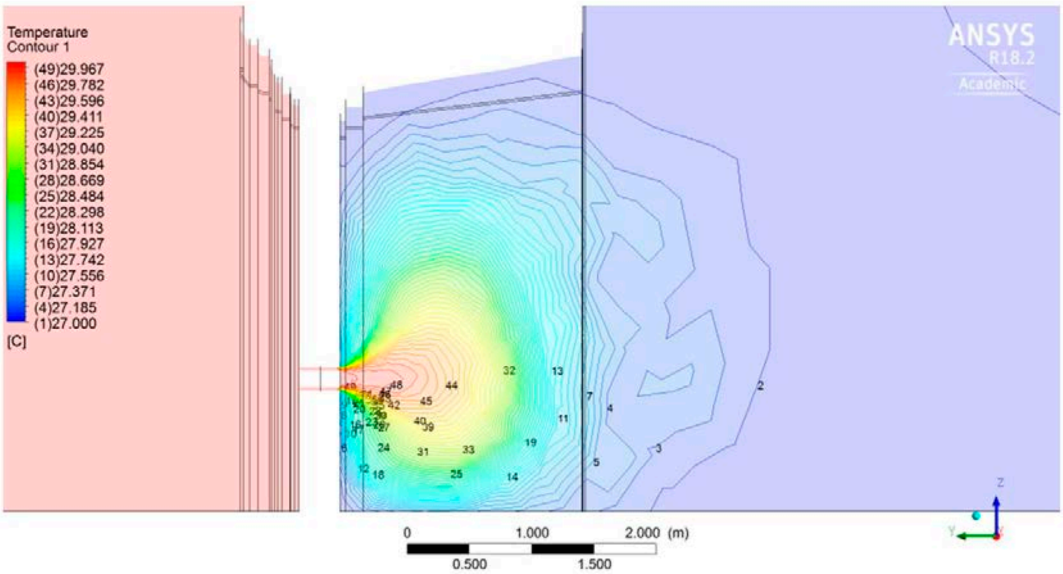
At the Sforza Castle, ANSYS Fluent software was used to model the space inside the room, for studying the best location of the curtain to insert for improving the north western window frame tightness and mitigating the thermal dispersion. Four simulations resulted: the graphic output is through plans, sections, and graphs.

Their comparison shows that solution 1 is the best fit (the curtain is at the inner side of the window). In fact, the plan in Figure 1 shows the wider distribution of externally created heating flux (3 m^2), whilst Figure 2 shows a sharp reduction of the heating flux (less than 1 m^2) close to the window if the curtain is set very close to the interior window frame. The improvement in terms of energy efficiency is appreciable for preventing the extension of air mass, showing the temperature variation. Nevertheless, due to the kind of the modeled fabric (large amounts of voids) the presence of the curtain does not substantially reduce the thermal variation due to the heating flux (in the worst case, it is almost 3.5 C° in August, at 7 pm).

Another type of research carried out in Castello Sforzesco was to test the traditional devices for improving temperature comfort inside the buildings: one of the rooms in the museum hosts 12 historic, precious tapestries dating back to 1510, hanging on their horizontal support, at few centimetres from the wall. The large room has three sides almost completely covered with the tapestries, two of these sides are external.

The thermal properties of the tapestries has been investigated through active IR Thermography (10 minutes of heating by irradiation of a halogen lamp), and passive and surface temperature measurement by contact probes. As shown in the temperature graph (Figure 3), the surface temperature is much higher on the side under direct irradiation than on the side towards the wall. In fact, the increase of temperature of this second side is only about 0,5 °C. Moreover, on this rear side, the increase of the temperature started 8 minutes after the beginning of the heating. Therefore, the tapestry behaves as insulating material: it has a high





Figures 1 and 2. 3D model of the NO window (conceptual and wireframe), above with the curtain close to the window, below without the curtain.

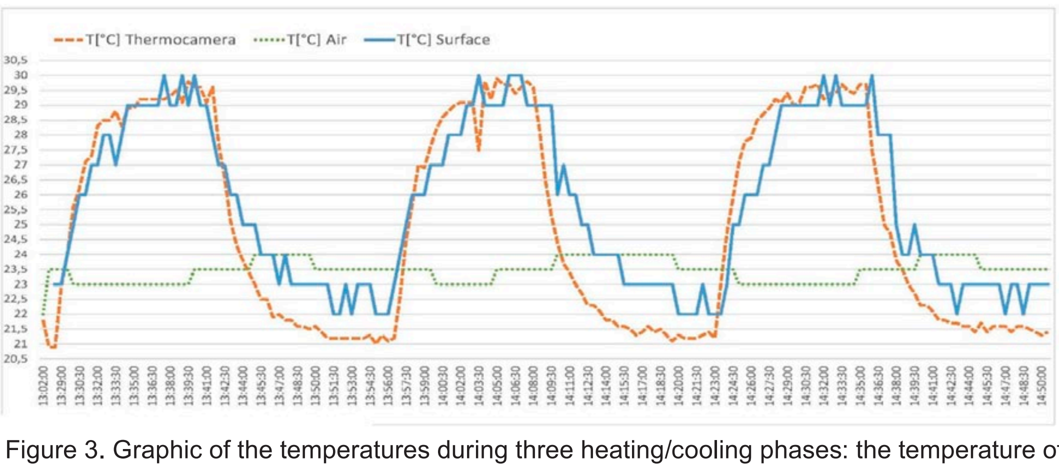


Figure 3. Graphic of the temperatures during three heating/cooling phases: the temperature of the tapestry surface, red line (by IRT), blue line (by contact probe); temperature of the side of the tapestry toward the wall and air trapped in the tapestry knots, green line (by data-logger).

increase of temperature under irradiation, but it does not transmit it. At last, the graph shows, the procedure of measurements is also reliable, because the obtained results are almost the same, assuring the repeatability of the measures.

Another study, with the aim of comparing the efficacy of a removable solution, based on a textile system, with a more traditional one, such as an internal insulation, has been developed creating a multi-layered insulating textile-based kit. The innovative wallpaper kit has a finishing textile layer and an insulating one, which are completely independent, combining properties of advanced technical textiles and high performance insulating materials in few millimetres of thickness. The new prototypes[2] were installed inside the building “La Nave” in the Leonardo campus, Politecnico di Milano, designed by Gio Ponti, a famous architect active from the nineteen-twenties to the seventies, and built in 1965. It is typical of the massive constructions of the period with low levels of thermal insulation. The thermal performances of the new textile wallpaper were measured and compared to two more traditional internal thermal insulation systems (wet assembled, thicker than the new textile wallpaper, not reversible) (Figure 4).

The results of the tests are interesting, because the performances of the bilayer textile and aerogel are comparable with the one of the interior traditional insulation. In addition, the new wallpaper is suitable for application on historic buildings; therefore, a further step of the research includes the technical design of a removable, flexible, adaptable support that does not require permanent anchorages [5].

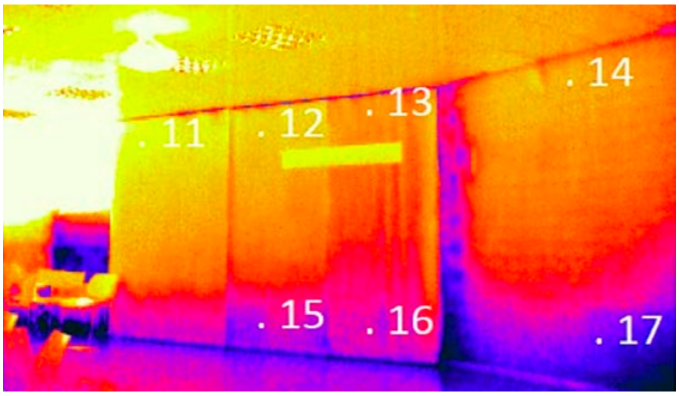


Figure 4. RT thermogram of the three materials applied on the surface and inside the dead space of the cavity masonry (perlite). Range of temperatures 17.5–21.5 °C. Numbers 11–17 locate the small areas where the researchers calculated the minimum, average, maximum temperatures.

2 For the experiment, the authors selected a coated and 2-layer laminate (bi-laminate) textile. Characteristics of the textile used in the experiment are: Self-supporting & finishing a) Textile Brand name TO-OPT-072, weighting 146±6 g/m2, Bi-laminate – white composition of 100 % polyester + 100 % PTFE membrane, Laminated-waterproof-vapour-permeable. The thermal behaviour of the insulating layer is: average water vapor resistance: Ret = 39.04 m2Pa/W; average thermal resistance Rct = 0.125 m2K/W; lambda-value = 0.036 W/mK. The choice of the textiles manufactured by Polish textile manufacturer Optex S.A. depended on its availability on the market, price and the aesthetic requirement.

Another research line focuses on solar screens. The Department for Cultural Heritage promoted this study on “Casa del Fascio” in Como (Figure 5). The building is one of the masterpieces of the Italian Modern Movement. In 1936 Giuseppe Terragni accomplished it. At present, it is an administration headquarter and in the near future it will become a museum. The building technique is experimental and light; furthermore, the percentage of the transparent envelope is high, therefore its use is not comfortable during the cold and hot seasons. In the first phase, the authors monitored the microclimate variables (RH and T °C) for 18 months by 6 data loggers.

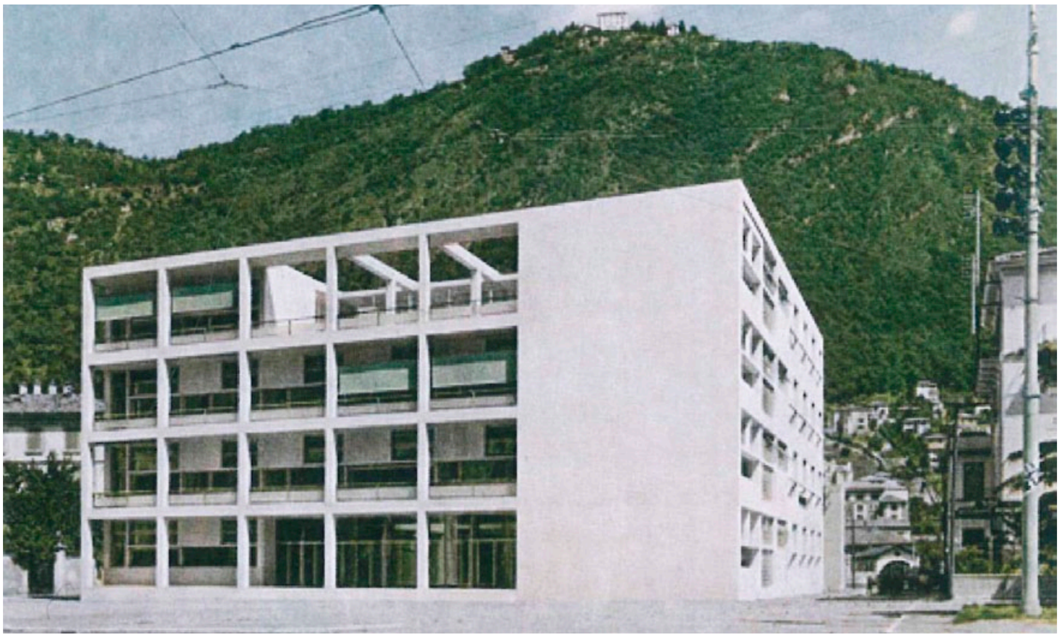


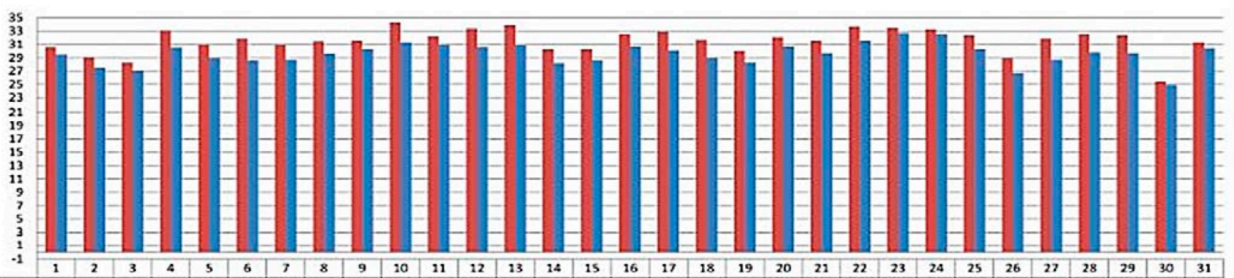
Figure 5. Old photo of the main façade on Piazza del Popolo, with the original green roller curtain system.

Despite the heating system being on, the air temperature inside the rooms in winter seldom reached 20 °C; during the summer, monitoring recorded very high temperatures, very close to the exterior ones due to the low thermal inertia of the envelope. In addition, inside, the poor ventilation decreases comfort, already inadequate for human presence. On the basis of the monitored data and building characteristics, an energy simulation at dynamic condition (Energy plus software) was carried out, considering 31 climatic zones. The results of experimental data validated the model. Following this, the model simulated the effects of different design solutions[3] between June and September (Figure 6). According to Terragni’s original solutions, no longer in use,[4] the addition of high performance curtains and shadowing systems to the exterior side of the envelope in

3 In addition to the restoration of the blinds (already existing, but in poor condition) and the restoration of windows, the introduction of curtains with the ‘Soltis 92’ fabric for the façade and ‘Tempotest Star FR’ for the internal shaft was simulated.

4 Terragni provided protection systems through external curtains on the façade, where there is the maximum summer radiation, in correspondence with the iron window frames along the shaft walls that surround the atrium and along the façade on the northwest side, corresponding to Via Pessina.

the courtyard can help [6]. The comparison of different materials and systems for shadowing was based on protection from solar irradiation, natural lighting, visual permeability, privacy, natural ventilation, thickness, weight, fire and wind proof characteristics.[5]



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LUGLIO STATO DI FATTO	30,6	29,1	28,3	33,1	31	31,9	31	31,5	31,6	34,3	32,2	33,4	33,9	30,3	30,3	32,6
LUGLIO STRATEGIA 1	29,5	27,5	27	30,5	28,9	28,6	28,7	29,6	30,3	31,3	31	30,6	30,9	28,2	28,6	30,7

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
LUGLIO STATO DI FATTO	32,9	31,7	30	32,1	31,6	33,7	33,5	33,3	32,4	28,9	31,9	32,6	32,4	25,4	31,3
LUGLIO STRATEGIA 1	30,1	28,9	28,3	30,7	29,7	31,6	32,7	32,6	30,3	26,7	28,7	29,8	29,7	24,9	30,4

Figure 6. Explanatory diagram of the lowering of the monthly internal average temperature caused by the adoption of a shadowing strategy in July (blue column) compared to the actual situation (red column).

3. CONCLUSIONS

Learning from the past, the authors are trying to better understand how to obtain devices improving the energy efficiency of ancient buildings and, consequently, user comfort, where it is often impossible to adopt standard interventions. The goal is balancing the different needs of conservation and energy efficiency [7].

The current study cases show different solutions of great interest, perfectly fitting the goal. In Castello Sforzesco and La Nave, tapestry installation allowed to qualitatively evaluate that the tapestry behaviour differs from the contemporary textile. During the heating and cooling phases, the tapestry showed the characteristics of good insulating materials that firstly, reduce the contribution of conduction, despite the properties of the new textile in La Nave, that fast reach and hold the temperature of the air. In the Casa del Fascio, the added protection decreases the average monthly temperature up to 3 °C in the eastern-western zones.
On the other sides of the building, the decrease is lower, around 1,5 °C and 2 °C from June to September, due to different solar ray inclination.

The next research step will focus on three aspects:

1) a complete characterization of the historic textile, used for tapestry and textile coating of the interior sides of walls, with the aim of reproducing similar optimal thermal behaviour with high tech textiles, reducing the costs, the thickness, weight, and improving the performance;

5 Different materials were considered, analyzing their radiative optical properties and performances related to the type of shielding, the geometry and the positioning. Families of products belonging to nets or canvas (metallic or plastic), bidirectional or three-dimensional metal sheet (pressed or perforated element), technical textiles and filters were examined. A survey was then carried out on fabrics already on the market that can be divided into three types: with spreading behaviour, coated or spread. For the façade: Tempotest star screen of Parà; Superscreen, Superscreen metal and Vertigo of Silent Gliss Italia; Screen g2 metal of Mottura, Soltis 86 and Soltis 92 of Serge Ferrari were considered. For the internal shaft: Tempotest, Tempotest star light, Tempotest star FR. A schedule was compiled for each to allow for comparison.

2) modelling the behaviour of historic and modern prototypes to evaluate the improvement;
3) designing the support of the modern textiles, according to the requirements of conservation (reversibility, non-invasivity, least impact on the existing structures, etc).

The authors also evaluated other solutions not presented in this paper, because of their limited contribution and the necessity of high scale building modification.

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