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Retrofit of the existing buildings using a novel developed aerogel-based coating: results from an in-field monitoring

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ABSTRACT
The energy retrofit of existing buildings and more in general building rehabilitation represents an important challenge in EU countries since a large part of their building stock is old, poorly insulated and affected by pathologies, i.e. mould growth, with relevant implications on users health other than aesthetical drawbacks. Unfortunately, the energy retrofit of existing buildings and particularly when dealing with historic buildings presents several issues, i.e. the compatibility between the identified solutions and the heritage value or the reduction of the internal space if internal solutions have to be adopted.
An emerging solution to address the target of the energy efficiency, according to the abovementioned issues, is the application of advanced materials characterized by high thermal performance and thus allowing to keep low layer thickness.
In the framework of an on-going Wall-ACE Horizon 2020 project, a set of aerogel-based novel super insulating plasters, particularly suitable for internal and external application on existing walls is under development. As far as the interior layer is concerned, so far two different aerogel-based products have been developed: an interior plaster and a thermal coating were developed respectively aimed at reducing the heating energy needs and mitigating thermal bridges mould issues.
The paper reports the first results of the laboratory tests carried out on the thermal coating Moreover, a monitoring activity in a 1920s building in Torino (Italy, Lat.45°N, Long 7.65°E) was carried out to characterize the actual thermal performance of the insulating layer and to assess the technical and the hygrothermal compatibility of the intervention.
The monitoring results highlight that the application of a thin thermal coating finishing layer can lead to a significant increment of the indoor surface temperature of ~1.5°C with a decrease of the wall heat losses of ~30%. Moreover, a mitigation of the effect of the thermal bridge was also observed with an increment of the node surface temperature (wall-window frame) of up to 2°C.

KEYWORDS
Aerogel, coating, finish rendering, plaster, thermal performance

INTRODUCTION

The building sector is responsible for nearly 40% of the total energy consumption in Europe (Directive 2010/31/EU). About 50% of the European stock was built before the first thermal regulations in 1970s (EU Buildings Factsheets). Italy is a clear example, in fact, more than 60% of residential buildings were built before 1976, the year the first law on energy savings, and the 30% of buildings (12.5 million buildings) is dated before 1945 (ISTAT 2011), therefore, characterized by traditional construction systems. About 1.8% of this Italian

building stock can be classified as cultural heritage, according to the definition of the Legislative Decree no. 42 of 22/01/2004 pertaining to the Cultural Heritage and Landscape Code, that means subject to protection by the competent Ministerial Authorities.
In the last decade, the importance of energy efficiency and thermal comfort in historical buildings has increased immensely and, the most recent research shows a shift in viewpoints. While energy retrofits were previously seen as a potential threat to the character and fabric of historic and traditional buildings, they are now seen largely as an opportunity to protect these buildings and respond to global environmental concerns (Webb A.L - 2017))
There is a growing body of research facing the challenge of merging energy efficiency measures and internal thermal comfort with the requisite of maintaining the cultural and historic significance of buildings (De Bouw M. et al. - 2016). Among the technical solutions to reduce thermal losses, technologies for the indoor insulation are the most suitable for this purpose (Walker R. and Pavía S. - 2018). Innovative materials and products like aerogel-based plasters and renders shall be explored because of their reduced thickness of installation and their high insulation potential.
In the framework of an on-going Wall-ACE Horizon 2020 project a novel aerogel-based thermal coating has been developed, with the main aim of mitigating thermal bridges and mould growth issues.
In this paper first results coming from laboratory tests and in-field monitoring are presented.

METHODS

A novel aerogel-based thermal coating, here called R4, was developed adopting both mineral and organic binders, with Kwark® granular aerogel (produced by Enersens), perlite, glass and ceramic spheres used, in various percentage, as lightweight aggregates (LWA).
A first series of preliminary tests, aimed at determining its thermal and mechanical properties were carried out in the laboratory to check its conformity to the market and its potentials in mitigating thermal bridges and avoiding mould growth. A monitoring campaign was then set-up and carried out on a case study building, in order to test its behaviour under actual operating conditions.

Laboratory test

The laboratory tests were aimed at determining the dry bulk density, the mechanical resistance and the thermal conductivity of the material.
The density was measured by weighing a specimen with a known volume of 0.4 x 0.4 x 0.05 m, previously dried in a climatic chamber (ACS DM 340, figure 1c) until any weight variation of more than 0.2%, occurs. Flexural and compression strength tests were carried out adopting prismatic samples according to UNI EN 1015-11:2007 (figure 1b). The dried specimen was also adopted for the thermal conductivity measurements carried out according to UNI EN 12667:2002, through a heat flux meter apparatus (Lasercomp FOX 600, figure 2d).

a) b) c) d)

Figure 1: a) Coating sample surface aspect; b) Flexural strength measurement; c) Climatic chamber (ACS DM 340); d) Heat flux meter (Lasercomp FOX 600).

Application phase and in-field monitoring

In addition to laboratory measurements, an assessment of the behaviour under actual operating condition was performed aimed at investigating aspects related to the technical feasibility as well as energy effectiveness. A monitoring campaign on a 1920s building located in Turin (Italy, Lat. 45°N, Long. 7.65°E) was thus set-up and carried out. From the energy point of view, the aim of the in-situ measurements was to evaluate the capacity of the R4 coating, on one hand, to reduce heat losses through the solid masonry wall and on the other hand to mitigate thermal bridging effect due to the increasing of the wall indoor surface temperatures. An east-oriented room was chosen and two identical walls, named TW and RW, respectively the wall with the thermal coating (figure 3a) and the reference one (figure 3b) were continuously monitored.

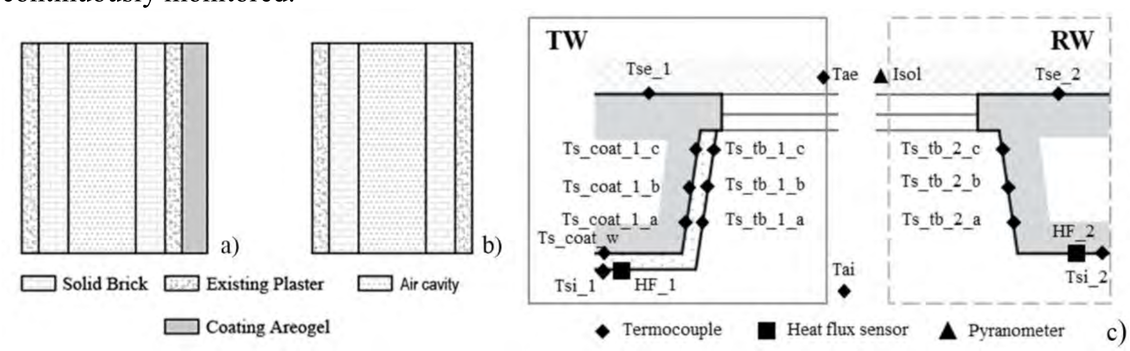

Figure 3: a) Coated wall (TW); b) Reference wall (RW); c) Schematic sensors position

a) b) c) d)

Figure 4: a) Primer application; b) Mixing; c) Coating application; d) Final thickness;

The coating was prepared and applied on TW and the related thermal bridge. To improve the adhesion of the thermal coating on the existent wall, a mono-component primer in thin layer

was firstly applied (figure 4a). The thermal coating, mechanically mixed with ~1:1 water ratio, was manually applied to reach a thickness of 12-15 mm (figure 4b, c, d).
For the monitoring campaign, carried out according to UNI ISO 9869-1:2015, temperature and heat flux sensors were placed both on TW and RW and on the relative thermal bridges. As reported in figure 3c, two heat flux sensors were applied in the centre of walls. T-type thermocouples were placed for measuring air and surface temperatures both on the walls and in the thermal bridges zones[1], in addition, thermocouples were also placed at the interface between the thermal coating and the wall (TW) (figure 3c).
In order to measure the incident solar radiation, a pyranometer sensor was adopted. To force the temperature difference between indoor and outdoor, reaching at least 10 °C, the indoor setpoint temperature maintained at 23 ± 1°C.

RESULTS AND DISCUSSION

Physical properties

Laboratory test showed generally good properties (table 1). The density of dried specimen is ~50% lower than the value obtained from thermal insulating coat without aerogel grains (R0 table 1). As far as mechanical properties are concerned, flexural strength assumed the value of 0.8 MPa. Thermal conductivity was 0.051 W/mK for the dried specimen, that is ~65% lower than the λ-value assumed by mineral-based thermal insulation coating (R0 table 1).

Table 1: Results of laboratory measurements carried out on R4 sample

Sample	Density [kg/m^3]	Flexural strength [MPa]	λ [W/mK]		
			$T_{avg\ 10°C}$	$T_{avg\ 25°C}$	$T_{avg\ 40°C}$
R4	326	0.8	0.051	0.052	0.053
R0	617	1.1	0.138	0.143	0.151

Monitoring results

The temperature and heat flux analyses were focused on the last week of the entire monitored period; these days (from 26th February to 05th March) were considered the most representative due to the low solar radiation value and low external air temperature (figure 5).

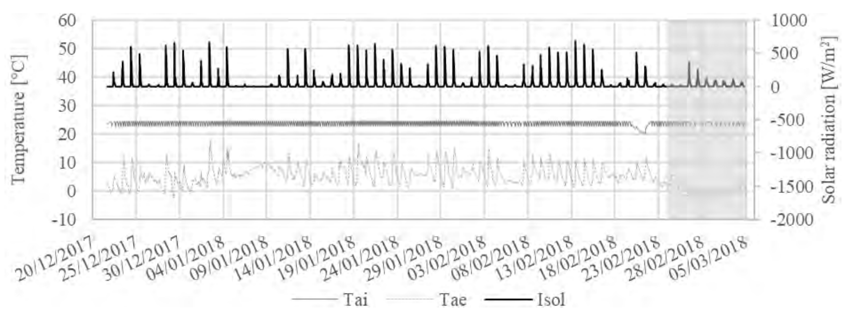

Figure 5: Boundary conditions

In figure 6a the boxplot analysis of the surface temperatures of the TW and RW in the centre of the walls and along the thermal bridge is reported. The graph shows an increase on W1 temperature surface due to the presence of the thermal coating. Particularly, near to the

[1] It is worth to be mentioned that the measurement set-up does not allow to quantify the linear thermal transmittance. For this sake, the measured wall-edge temperatures can be used to validate heat transfer models able to quantitatively assess the incidence of the thermal bridges.

window frame (●), the surface temperature increases of ~2°C compared to the uncoated surface. The thermographic analyses highlight the temperature increase on the TW thermal bridge due to the presence of the thermal coating (figure 7b, 7c). Looking at the TW external surface the temperature is, as expected, lower than that of RW, reaching a value below zero, which can determine freezing problems in rain-exposed façade (figure 6b, 7c). As well as the increasing of the internal surface temperature, a noticeable reduction of about 30% of the heat flux on the thermal coated wall, when compared to the RW wall (figure 7c), can be observed.

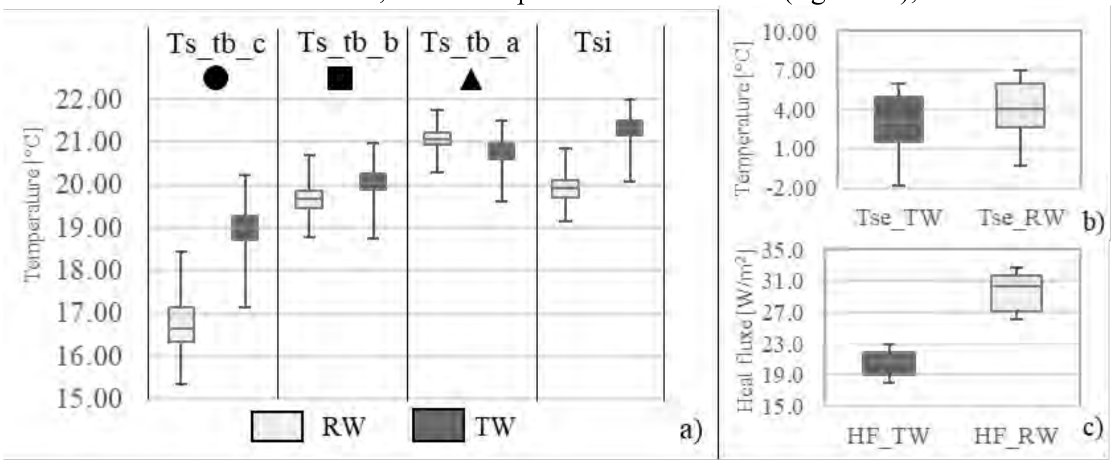

Figure 6: a) Thermal bridges and walls surface temperature monitored; b) external surface temperature monitored; c) Heat flux measured on TW and RW.

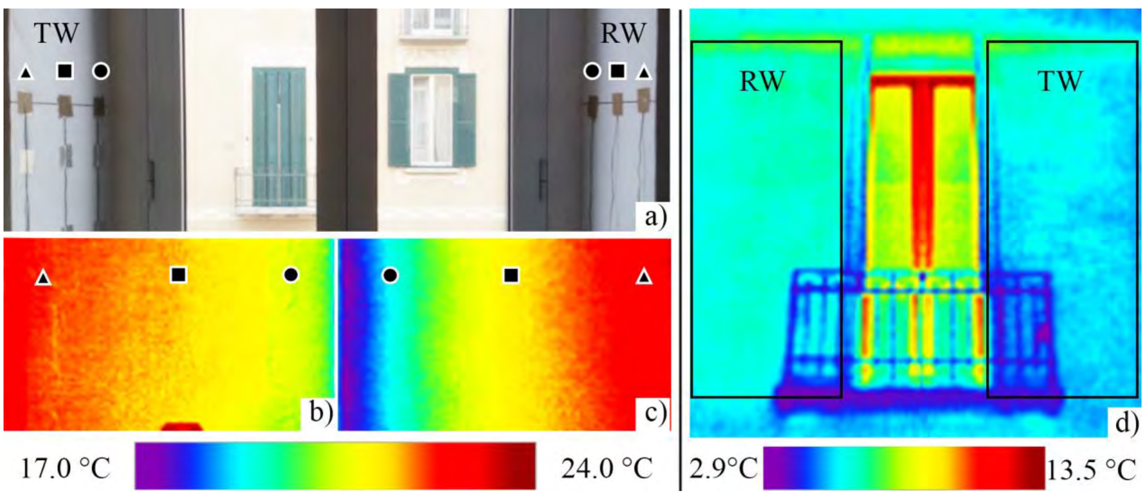

Figure 7: a) Thermocouples on thermal bridges; b) Infrared image of TW thermal bridge; c) Infrared image of RW thermal bridge; d) External infrared image.

CONCLUSIONS

In the framework of a Horizon-2020 project 'Wall ACE' a novel aerogel-based thermal coating finishing for interior insulation was developed.
As a first research step, the main physical properties of the developed material were assessed through laboratory analyses. The thermal results of the selected product show a low thermal conductivity value of ~0.05 W/mK. Furthermore, the material was applied to a 1920' demonstration building in Turin. The thermal behaviour of the retrofitted wall was monitored for an entire winter season after the application and was compared with an uncoated reference wall. The monitoring results highlight that the application of a thin thermal coating finishing

layer can lead to a significant increment of the indoor surface temperature of ~1.5°C with a decrease of the wall heat losses of ~30%. Moreover, a mitigation of the effect of the thermal bridge was also observed with an increment of the node surface temperature (wall-window frame) of up to 2°C. The obtained results reveal that the developed thermal coating finishing present a non-negligible reduction of the heat losses as well as significant mitigation of the condensation risks in thermal bridges demonstrating the suitability of the developed product for the application in all the buildings in which usual thick internal insulating solutions cannot be addressed for space, historical and technical constraints.

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