Energy retrorofit of residential buildings with a novel super-insulating aerogel-based plaster

AiCARR Journal / Vol 61, n. 2, 44 - 48, 2020

Elisa Fenoglio[1], Stefano Fantucci[1], Marco Perino[1], Valentina Serra[1]*, Marco Dutto[2], Valentina Marino[2]

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Riqualificazione energetica di edifici residenziali con un nuovo intonaco superisolante a base di aerogel

[1] Politecnico di Torino – Department of Energy, C.so Duca degli Abruzzi 24, Torino, Italia
[2] Vimark Srl – Strada Spartafino 2, Peveragno, Cuneo, Italia

*Corresponding author:
Prof. Valentina Serra
Department of Energy
Politecnico di Torino
C.so Duca degli Abruzzi 24, Torino
valentina.serra@polito.it

DOI: 10.36164/AiCARRJ.61.02.02

Abstract

The interest on superinsulation materials is growing, as particularly suitable in energy retrofit interventions due to the possibility to achieve relevant improvements even when used in low thickness. In this field, a specific EU funded H2020 project, named Wall-ACE, was carried out in the last three years, connecting products manufacturers, researchers and buildings owners, with the common goal of developing and testing a set of new aerogel based insulating products to be used in new and existing buildings. The study here presented reports the results of the research activity developed by the Authors on a novel aerogel based internal plaster. Firstly a set of analysis at material level was carried out to identify the most effective mixture able to achieve the target value of thermal conductivity <0.03 W/mK. Then the application on a demonstration building allowed evaluating the actual thermal resistance achievable under real operating conditions. Finally, simulations at building scale were performed to determine the energy-saving potential of this retrofit tecnique.

Keywords:
- Aerogel
- Aerogel based plaster
- Energy retrofit
- Building envelope
- Superinsulation

Sommario

Sta emergendo un crescente interesse nei confronti di materiali superisolanti per il retrofit energetico, dato il loro elevato potenziale nel raggiungere gli obiettivi prestazionali imposti dalla legislazione energetica, anche quando utilizzati in spessore ridotto. In questo contesto è stato finanziato il progetto Horizon 2020 Wall-ACE (2016-2019), mirato a sviluppare una serie di nuovi prodotti per l'edilizia a base di aerogel attraverso un approccio collaborativo tra partner industriali, centri di ricerca e proprietari e gestori di patrimoni immobiliari. Le analisi su un intonaco isolante per isolare le pareti perimetrali dall'interno, condotte a differenti scale, costituiscono l'oggetto dell'attività di ricerca specificatamente condotta dagli Autori. A valle di una dettagliata caratterizzazione termica, l'intonaco con le migliori prestazioni è stato applicato a un edificio di social housing a Torino per testarne la fattibilità tecnica e le prestazioni termiche in reali condizioni di esercizio. Infine, attraverso una serie di simulazioni energetiche dinamiche, è stata valutata la potenziale riduzione della domanda energetica a scala di edificio.

Parole chiave:
- Aerogel
- Intonaci a base aerogel
- Retrofit energetico
- Involucro edilizio
- Materiali superisolanti

Introduction

The European Union targets for 2030 require at least a 40% cut in greenhouse gas emissions and a 32.5% improvement in energy efficiency [1]. Since the largest part of the energy demand is related to the building sector [2], it is of paramount importance to improve the thermal performance of buildings, whether new or existing. Analysing the key numbers in Italy, it is clear that the main issue is to find solutions for the existing building stock, since it represents the largest and poorly insulated portion of the entire building sector. Interventions on existing buildings have to be carefully managed, due to the relevant constraints that have to be faced, i.e. related to the heritage value, the limited internal space, the irregular surfaces, the thermal bridge incidence, and the hygrothermal compatibility. A growing interest on super-insulating materials, e.g. aerogel based, is emerging and research on this topic is strongly pushed and funded by European Union. In this framework the Horizon 2020 project Wall-ACE [3] has been carried out in the last three years aimed at developing a set of novel building materials for both new buildings and existing ones, moving from the product development scale to the real buildings application, through a collaborative approach among the different actors involved in the projects, as products manufacturers, research institutes and buildings owners/managers/installers.

The aerogel is a super insulating lightweight material characterized by a thermal conductivity lower than 0.02 W/mK (Soleimani Dorcheh e Abbasi, 2008; Ruben et al., 2011; Cuce et al., 2014) that makes it suitable for the application as building insulating material, alone or embedded in various products, e.g. renders, plasters or coatings (Stahl et al., 2012; Buratti et al., 2016; De Fatima et al., 2016; Berardi, 2018; Pedroso et al., 2020; Ganobjak et al., s.d.)

The analysis carried out on several case study buildings have shown the suitability of this material for the energy retrofit (Schuss et al., 2017; Stahl et al., 2017; Ganobjak et al., s.d.). Five final products were developed in the project, based on Kwark®aerogel developed by the partner Enersens [4] according to a patented process: an external insulating render, an internal insulating plaster, an internal coating finishing, an insulating patching filler and aerogel filled bricks. Since these solutions are characterized by a super insulating performance, a target value for the thermal conductivity was set at 0.03 W/mK (except for the insulating filled bricks). A detail of the main characteristics of the listed products is reported in Table 1, while in Figure 1 the different Wall-ACE products are shown.

Table 1 – **The Wall-ACE products**

Tabella 1 – Prodotti Wall-ACE

Product	Manufacturer	Application	λ-value [W/mK]	ρ [kg/m³]
Insulating render	Quick-Mix	External	0.027	203
Internal insulating plaster	Vimark	Internal	0.027	136
Internal coating finishing	Vimark	Internal	0.028	136
Insulating patching filler	Toupret	Internal	0,034	193
Aerogel filled bricks	LEIPFINGER BADER	-	0.084	-

The products listed before were optimised and analysed at different levels: at material scale, at component and at building level through in-field application and through dynamic thermal simulations. The laboratory tests were aimed at optimizing the formulations in order to achieve the required target λ-value and at determining

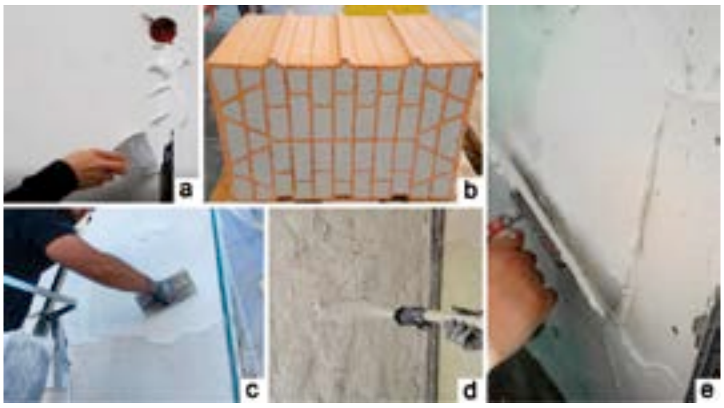

Figure 1 – **a) the insulating patching filler; b) the aerogel filled bricks; c) the insulating render; d) the internal insulating plaster; e) the thermal coating finishing**

Figura 1 – a) lo stucco riempitivo isolante; b) i mattoni con riempimento di aerogel; c) l'intonaco esterno isolante; d) l'intonaco interno isolante; e) la rasatura isolante

other additional properties (e.g. mechanical and hygrothermal properties, VOC emission, sound absorption) for a complete material characterization. The analyses at component level were carried out through in-field applications on real buildings located in different EU countries (Italy, France, United Kingdom, Switzerland) in order to test the products' thermal behaviour under different boundary conditions. Moreover, numerical simulations were performed both at component level to assess the performances of different materials configurations (Fantucci et al., 2020) and at building scale to investigate the energy demand reduction achievable by using the Wall-ACE products as a retrofit solution in representative building typologies.

This paper deals with the thermal insulating plaster developed to be used on the indoor side of the wall, being this activity specifically carried out by the Authors.

The Wall-ACE aerogel based thermal insulating plaster

The developed aerogel based thermal insulating plaster is mineral-based and applicable both manually and with a spraying machine in thickness that can range between 2 and 10 cm. Several formulations were produced and tested. First results not achieving the target value but quite promising from the thermal point of view, were presented in (Fantucci et al., 2018) and (Fantucci et al., 2020). The results of the overall analysis related to the last thermal insulating plaster formulation matching a thermal conductivity lower than 0.03 W/mK ± 3%, is hereafter presented.

Test at material level

As far as the thermal conductivity measurement is concerned, the EN 12667 Standard (CEN, 2001) was used, reporting the methodology for material characterised by medium-high thermal resistance. In this specific case a heat flux meter apparatus (Figure 2, Table 2) was adopted. According to this method, prismatic samples (~40x40x5 cm) of the thermal plaster were prepared. The specimens were thus dried in oven until constant mass was reached and then sealed in a vapour-tight envelope to avoid any water vapour migration from the ambient to the sample or vice versa during the test. Once placed the sample between the instrument plates a temperature difference between the plates was set (e.g. 20 °C) and through the collected data of heat flux and surface temperatures, the λ-value was thus measured. In order to evaluate the reproducibility of the results, two samples of each plaster formulation were tested. Moreover, a cross comparison test on the same formulations was performed by the certified lab of the University of Stuttgart, demonstrating a very good agreement.

AiCARR Journal / Vol 61, n. 2, 44 - 48, 2020

Through the same HFM, adopting a procedure detailed in (Tleoubaev and Brzezinski, 2007), the specific heat capacity value was also determined so to have actual data to be used in thermal simulations.

Table 2 – Technical data of the HFM adopted

Tabella 2 – Specifiche tecniche del HFM utilizzato

	Range	u.m.
Thermal conductivity range	0.01–0.2	W/mK
Accuracy	±1	%
Reproducibility	±0.5	%
Temperature control accuracy	±0.01	°C
Temperature range	-10 to 65	°C
Thickness accuracy	±0.025	mm
Measurement area	254 x 254	mm
Maximum sample size	610 x 610	mm
Maximum sample thickness	203	mm

Figure 2 – a) The HFM apparatus for the thermal conductivity and specific heat capacity measurement; b) the climatic chamber adopted for the sample conditioning; c) sample size for the thermal conductivity and specific heat measurement

Figura 2 – a)Il termoflussimetro adottato per le misure di conduttività termica e di calore specifico; b) la camera climatica utilizzata per il condizionamento dei campioni; c) dimensioni dei campioni di materiale per condurre i test

In Table 3 the results are reported. As it is possible to notice the thermal conductivity reached a very low value, below the target set in the project proposal. For an internal plaster this is a very promising result since even when applied in low thickness, it is possible to achieve a very high thermal resistance with a minimum reduction of internal space, which can constitute a relevant barrier when intervening from inside.

Table 3 – Results of the thermal insulating plaster test and comparison with Italian limit value (MiSE, 2015)

Tabella 3 – Risultati dei test sull'intonaco termoisolante e confronto con il valore limite italiano (MiSE, 2015)

	λ [W/mK]	c_p [kJ/kgK]
Thermal insulating plaster	0.027	998

In-field measurements

In the testing phase under real operating conditions, the internal plaster was applied on a 1920 building located in Turin (Italy) owned and managed by the social housing organization ATC (Agenzia Territoriale per la Casa del Piemonte Centrale). The long-term campaign measurement was carried out on two identical solid brick walls (thickness 52 cm), with the same orientation (S-E), facing the same indoor environment and presenting the same thermal transmittance, as verified through a pre-test measurement campaign (Figure 3b). A wall was selected as reference wall (RW), the other was retrofitted with a ~4.5 cm layer of thermal insulating plaster (PW) manually applied. Generally, these materials are applied in thickness of ~5 cm, but in this case being the existing wall surface quite irregular, after the material application, on the measurement area, an average thickness of 4.5 cm was determined.

Figure 3 – a) The ATC building selected as pilot site; b) the plaster application; c) the walls selected for the monitoring; d) the sensors adopted for the monitoring

Figura 3 – a) L'edificio ATC selezionato come caso studio; b) la fase di applicazione dell'intonaco; c) le pareti selezionate per l'applicazione e il monitoraggio; d) i sensori adottati per il monitoraggio

The methodology adopted for the in-situ measurement and the determination of the thermal transmittance followed the ISO 9869-1 Standard (ISO, 2014) post processing the data to obtain the thermal transmittance with the progressive average method. The thermal transmittance was measured for both the walls (RW and PW) in order to determine the increment of thermal resistance due to the insulating plaster layer. Moreover, the actual in-field thermal conductivity of the plaster layer was assessed. To perform this direct measurement a heat flux meter was placed on the internal plaster surface along with two thermocouples located respectively on the internal surface and on the plaster-wall interface; the thickness of the plaster layer was determined by several measurement in different points. Through the reverse formula for the thermal resistance calculation, it was possible to assess the in-field thermal conductivity. Results of a representative week in April is reported in Figure 4. According to the schedule of the project, measurements on this last formulation had to be carried out in the spring season. Nonetheless, the temperature difference between inside and outside was maintained sufficiently high, choosing a week with low outdoor temperature and by setting the room temperature at around 27 °C with a radiator heating system.

The in-field application highlighted the technical feasibility of the solution, showing as the products could be easily applied adopting conventional tools, and demonstrated how 4.5 cm layer of this thermal insulating plaster could allow to reduce of ~60% the thermal transmittance of the wall (from 1 to 0,42 W/m²K). The thermal conductivity of the plaster layer was 21% higher than those measured in laboratory, due mainly to the higher moisture content in the actual operating conditions. Further measurements are on going.

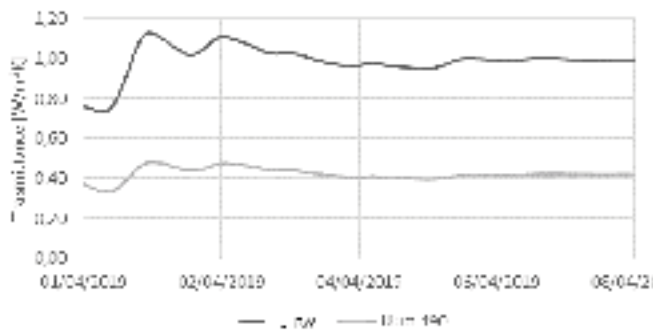

Figure 4 – In-field measured thermal transmittance

Figura 4 – Trasmittanza termica misurata in campo

Generalization and scalability of the intervention

In order to evaluate the generalization and scalability of the interventions the Authors with the support of the social housing building stock owners and managers, ATC and CASE (Torino, Italy), carried out an extensive research aimed at selecting representative case studies to be used for assessing the energy demand reduction potential due to this specific intervention on external and party walls.

The case studies were identified exploring the ATC database reporting the main features of about 1 thousand buildings owned/managed by ATC, according to the following criteria: year of construction; external envelopes assembly, surface/volume ratio, as shown in Figure 5. The analysis was limited to the buildings with more than 70 years, since, being considered under protection according to the Italian legislation (Italian Government, 2004), limited external interventions are allowed and the application of an internal thermal plaster can represent the most suitable retrofit strategy. For each category thus, the number and the percentage of buildings were assessed to select the case studies that largely represents the entire building stock and annual dynamic energy simulations were performed. The analysis here reported considers just the buildings built before 1949 and characterized by the same technology as the pilot site adopted for the monitoring (solid brick wall).

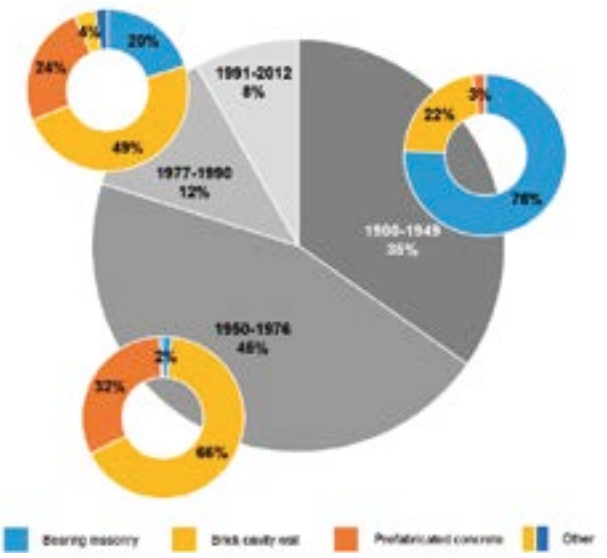

Figure 5 – ATC buildings per construction period and building envelope assembly's typology

Figura 5 – Patrimonio edilizio ATC diviso in base a periodo di costruzione e tipologia di involucro

The dynamic thermal simulations were performed using Design Builder and Energy Plus. The properties of the building opaque element were set according to the data measured during the in-field monitoring, while the transparent element was set according to the database information. The outdoor climatic conditions are those of Turin, Italy (Lat. 45°N, Long. 7.65°E), while for the indoor conditions the setpoint operative temperature was 20 °C in winter and 26 °C in summer respectively. The ventilation rate was set at 0.5 ACH.

It's important to underline that no model validations have been done, since the scope of the simulation was just to roughly estimate the energy efficiency improvement related to the application of the developed thermal insulating plaster at building level, not to investigate the outcome of a more general deep renovation approach on existing buildings, which should include other key interventions (i.e. on glazing and HVAC systems). These results represent the first step towards an overall technical and economical feasibility analysis. A first simulation was thus performed on the building "as it is" without any retrofit intervention, then the building was retrofitted with a 6 cm layer of internal thermal insulating plaster. The plaster thickness was defined in order to achieve the U-value required by the Italian regulation for the zone "E" (MiSE, 2015): U = 0.28 W/m²K +30% in case of internal retrofit (Table 4).

Details on case study assumptions are reported in Figure 6.

Table 4 – U-value simulated for the selected building

Tabella 4 – Valore di trasmittanza simulato per l'edificio selezionato

U value [W/m²K]		
Existing	Retrofit 6 cm	Limit value D.M. 26/06/15
1.22	0.34	0.36

CASE STUDY	
	Via Arquata
Building	
Construction Year	1920
Typology	Bearing wall with solid brick
ATC building [%]	27
Floor area [m²]	960
Gross opaque envelope [m²]	1244
Net opaque envelope [m²]	1076
Transparent [m²]	164
U opaque envelope [W/m²K]	1.2
U opaque partition [W/m²K]	1.8
U transparent envelope [W/m²K]	5.7

Figure 6 – Main features of ATC case study

Figura 6 – Caratteristiche principali del caso studio analizzato

In this case study it is evident that the largest part of energy losses (49%) are related to the external walls and the party walls adjacent to unheated space (Figure 7); it means that a retrofit intervention on that elements represents a very efficient measure, which allows achieving a heating energy demand reduction of about 40%.

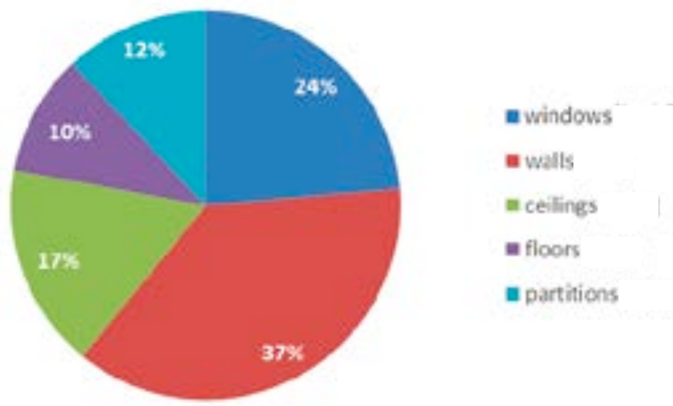

Figure 7 – Heat losses incidence through different building envelope elements

Figura 7 – Incidenza delle dispersioni termiche attraverso i diversi componenti dell'involucro edilizio

The simulation results are reported in Table 5. As expected, the energy demand related to heating is predominant and an increase in insulation slightly entails the cooling needs in the summer season.

Table 5 – Energy demand reduction for the simulated case study

Tabella 5 – Riduzione della domanda energetica del caso studio simulato

	Existing	Retrofit [6 cm]	reduction [%]
Heating need [kWh/m²]	193.23	116.78	40
Heating + cooling need [kWh/m²]	206.46	135.43	34

Considering the high number of ATC buildings presenting very similar conditions (around 270 buildings roughly with a floor area of 270000 m² in Torino), the impact of this solution when scaled-up is quite powerful, in terms of energy saving and reduction of CO_2 emissions.

Barriers exists and strong efforts have to be directed to make these solutions affordable. Much has been done towards the improvement of thermal and mechanical performance and related to technical feasibility, making these products ready for the market, but more actions have to be taken to reduce the high cost of the aerogel material which still remain a key constraint.

CONCLUSIONS

The study reports the results of an extensive analysis performed on a new aerogel based internal insulating plaster developed in the framework of the European Horizon 2020 Wall-ACE. The analyses were carried out at material, component and building level. The tests at material level show that this product can reach very low thermal conductivity values (<0.03 W/mK) still maintaining acceptable mechanical properties. The application and monitoring of the product on a real building and under actual operating conditions confirm the easy applicability of the product and the high thermal insulating performance. A thermal transmittance reduction of ~60% was achieved by applying a 4.5 cm layer of plaster. Finally, to evaluate the energy-saving potential achievable with an extensive retrofit intervention, a set of simulations were performed. A quite high energy saving level can be achieved (40%) and a huge energy saving potential can be expected when scaling-up to the entire building stock owned by ATC presenting the same features (around 27%). Hygrothermal measurements are still on-going and hygrothermal simulations will be carried out to deeply investigate the compatibility of this material with existing assemblies.

ACKNOWLEDGEMENTS

The research project Wall-ACE received funding from the EU Horizon 2020 research and innovation programme under the Grant Agreement No. 723574.

The authors thank the project partners ATC (Agenzia Territoriale per la Casa del Piemonte Centrale) and CASE to have made available the demonstration building and ENERSENS to have provided the Kwark aerogel for the development of the thermal insulating plaster and coating. Moreover, the authors wish to thank Prof. Riccardo Pollo and Arch. Matteo Giovanardi who provided support on the ATC building stock database and Giulia Grosso, Federico Lubrano and Ulderico Marco Trocino for their contribution during the experimental and simulation activities.

REFERENCES

Berardi, U. 2018. Aerogel-enhanced systems for building energy retrofits: Insights from a case study. Energy and Buildings, 159(15), 370-381.

Buratti C., Moretti E., Belloni E. e Agosti F. 2016. Aerogel Plasters for Building Energy Efficiency. In: Nano and Biotech Based Materials for Energy Building Efficiency, Ch. 2. Berlin: Springer.

CEN. 2001. Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Products of high and medium thermal resistance. Standard EN 12667. Bruxelles: European Committee for Standardization.

Cuce E., Mert Cuce P., Wood C. J., Riffat S.B. 2014. Toward aerogel based thermal superinsulation in buildings: A comprehensive review. Renewable and Sustainable Energy Reviews, 34, 273-299.

De Fatima Júlio M., Soares A., Ilharco L. M. e Flores-Colen I. 2016. Silica-based aerogels as aggregates for cement-based thermal renders. Cement and Concrete Composites, 72, 309-318.

Fantucci S., Fenoglio E., Isaia F., Serra V., Perino M., Dutto M., et al. 2018. Development of aerogel based internal thermal plasters for the energy retrofit of existing buildings: First results. Proceedings of the 4th International Conference On Building Energy & Environment 2018.

Fantucci S., Fenoglio E., Serra V., Perino M., Dutto M., Marino V. 2020. Hygrothermal Characterization of High-Performance Aerogel-Based Internal Plaster. In: Littlewood J., Howlett R., Capozzoli A., Jain L. (eds) Sustainability in Energy and Buildings. Smart Innovation, Systems and Technologies, vol. 163. Springer.

Ganobjak M., Brunner S., Wernery J. s.d. Aerogel materials for heritage buildings: Materials, properties and case studies. Journal of Cultural Heritage, in press. https://doi.org/10.1016/j.culher.2019.09.007.

ISO. 2014. Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance Heat flow meter method. Standard ISO 9869-1, Geneva: International Standardization Organization.

Italian Government. 2004. Codice dei beni culturali e del paesaggio, ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137. Gazzetta Ufficiale n.45 del 24.02.2004, S.O. n. 28. Roma: Poligrafico di Stato.

MISE. 2015. Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici. D.M. 26 giugno 2015. Gazzetta Ufficiale n.162 del 15.07.2015, S.O. n. 39. Roma: Poligrafico di Stato.

Pedroso M., Flores-Colen I., Dinis Silvestre J., Gomes M. G., Silva L., Sequeir P., de Brito J. 2020. Characterisation of a multilayer external wall thermal insulation system. Application in a Mediterranean climate. Journal of Building Engineering, July. https://doi.org/10.1016/j.jobe.2020.101265.

Ruben B., Bjørn P. J., Arild G. 2011. Aerogel insulation for building applications: A state-of-the-art review. Energy and Buildings, 43, 761–769.

Schuss M., Pont U., Mahdavi A. 2017. Long-term experimental performance evaluation of aerogel insulation plaster. Energy Procedia, 132, October 2017, 508-513.

Soleimani Dorcheh A., Abbasi M. 2008. Silica aerogel; synthesis, properties and characterization. Journal of materials processing technology, 199(1-3), 10-26.

Stahl T., Brunner S., Zimmermann M., Ghazi Wakili K. 2012. Thermo-hygric properties of a newly developed aerogel-based insulation rendering for both exterior and interior applications. Energy and Buildings, 44(1), 114–117.

Stahl T., Ghazi Wakili K., Hartmeier S., Franov E., Niederbergere W., Zimmermann M. 2017. Temperature and moisture evolution beneath an aerogel based rendering applied to a historic building. Journal of Building Engineering, 12,140-146.

Tleoubaev A., Brzezinski A. 2007. Thermal Diffusivity and Volumetric Specific Heat Measurements Using Heat Flow Meter Instruments. Thermal Conductivity 29 / Thermal Expansion 17 Conference at Birmingham. Alabama, USA.

WEB REFERENCES

[1] https://ec.europa.eu/clima/policies/strategies/2030_en. [last access 29/10/2019] 2030 climate & energy framework.

[2] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/overview. [last access 29/10/2019] Energy performance of buildings.

[3] https://www.wall-ace.eu/ [last access 28/10/2019] Wall-ACE. 2019.

[4] http://enersens.fr/fr/kwark-granules/ [last access 29/10/2019] KWARK GRANULE.