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Development of a super-insulating, aerogel-based textile wallpaper for the indoor energy retrofit of existing residential buildings

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Abstract

Retrofitting the residential building stock poses a major challenge for the European building sector in the coming years. It is also crucial to achieve the decarbonisation goals set by the EU's Energy Roadmap 2050. The EASEE research project, funded by the European Commission, addressed this issue by developing a holistic approach to envelope retrofitting.

This paper presents an innovative technical solution developed within this research project: a lightweight, aerogel-based wallpaper that can be easily installed on the inner side of perimeter walls. The system is composed of an aerogel-impregnated textile layer, forming the insulating core, and a fabric finishing that can be easily installed and replaced thanks to a bespoke tensioning device.

The development of the system is explained starting from the identification of the challenges related to the application of an insulating layer to the internal face of an existing wall. These include building physics, as well as operational aspects to reduce disturbances of users. The insulating layer, based on a textile mat impregnated with aerogel, was tested and characterised at laboratory scale to ensure its high thermal performances and its permeability to water vapour. The fabric finishing system was also designed to provide the possibility of easy tensioning and disassembly for cleaning or replacement. An innovative device, based on plastic zips, was developed and patented within the project. As part of the process, specific studies were developed about cold bridges, thermal capacity and environmental impact of the system.

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The wallpaper was finally tested and monitored to assess its in-situ thermal performance and the assembly procedure on a building at Politecnico di Milano.

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Keywords: energy retrofit; textile components; SiO₂ aerogel; indoor insulation; performance assessment.

1. Introduction

Buildings are responsible for 36% of the European Union's energy consumption and 40% of its greenhouse gas emissions [1], with 63% of the latter related to the residential sector [2]. While ambitious goals have been set for new buildings, which have to comply with the Nearly Zero Energy standard by the end of 2020 [3], it cannot be underestimated that the substitution rate of existing buildings with new ones is very low, so that 50% of today's building stock will still be in use in 2050 [4]. Buildings dating from 1945 to 1970, poorly insulated and often with obsolete heating systems, account for around 70% of the total, while those built after 1990 to better energy standards account for only 1% [5].

The energy retrofit of existing buildings is then a crucial strategy that must be implemented at a large scale to achieve the ambitious de-carbonisation goals that the European Union has set for 2050 [6]. The importance of building retrofit, with a specific focus on the envelope performance, has been recognised widely [7, 8] and renovation activities constitute already around 50% of the turnover of the construction industry in Europe [9].

Among the large amount of buildings realised in the past with scarce or no attention to energy efficiency, there are 10 million multi-storey residential blocks with distributed ownership [10], which share a number of common features such as a mostly linear façade clad in render or bricks, a limited number of protruding elements like balconies and mechanical shafts and a majority of cavity walls with limited or no insulation [11].

The recent FP7 EASEE research project (*Envelope Approach to improve Sustainability and Energy efficiency in Existing multi-storey, multi-owner residential buildings*) [12] delivered new modular and fault-tolerant solutions for the envelope retrofitting in this specific type of buildings, ensuring an important reduction of building energy demand through a variety of systems employing simplified dry construction processes and installation procedures that minimise discomfort for the occupants [13]. The early decision to focus on the vertical, opaque envelope takes into account the comparatively limited surface of the roof in multi-storey buildings and the fact that single-glass windows have been very often already replaced by owners with insulating glass because of the economical effectiveness of this solution. Another assumption of the project was that the slow rate of renewal of existing buildings is also due to the way these retrofit operations are typically conducted, with non-skilled workforce and labour-intensive procedures that make costs escalate. The discomfort caused to inhabitants by long construction times, installation of scaffolding and the related dust and noise are other reasons that limit the wide-scale diffusion of retrofit operations in practice and that the EASEE project targeted to solve.

The aim of the collaborative research presented in this article, developed within the EASEE project as part of a specific work package, was to develop an innovative and reliable solution for the inner thermal retrofitting of perimeter walls. Indoor solutions are normally less effective than those applied from the outside, in particular because of the inevitable interruption of insulation at the connections of walls and floor slabs. Besides leading to increased heat losses, in some climatic conditions the discontinuous thermal insulation can lead to condensation and moisture issues [14]. However, in the existing building stock there are situations when the use of indoor insulation solutions is inevitable: typical examples include heritage buildings with listed facades, perimeter walls whose thickness cannot be increased because of distances from nearby buildings, and multi-owner buildings where an agreement about interventions on the shared parts (e.g. the façade) cannot be reached.

This article describes the development of one of the insulating solutions within the EASEE project: a textile-based system with limited thickness and simplified installation. The process is presented from the conceptual identification of the required performances to the installation of a proof of concept, tested at laboratory scale, on a test wall at Politecnico di Milano.

2. Design goals and identification of the solution

The first step in the development of the indoor insulation solution was the identification of required functionalities and the choice of the most appropriate lightweight materials that would constitute the new system. This activity was carried out in parallel with a market analysis about potential competitors and existing patents; the results highlighted that, although thin and lightweight solutions are commercially available, scope for innovation remains in the insulating materials themselves, in their price and in the operational and assembly issues of the complete components.

The following (non exhaustive) list of main requirements emerged from the first phase of work and set the targets for the subsequent development activities:

- relatively high thermal resistance (achieving a U-value of $0.2 \text{ W/m}^2\text{K}$ in the colder climates, for the insulating solution and the existing wall combined, was identified as desirable);
- competitive price compared to other internal insulation products in the market;
- limited thickness of the additional layer (a maximum of 8 cm was identified);
- controlled fire behaviour;
- ease of installation (D.I.Y., do-it-yourself, in some alternatives);
- ease of transportation and storage;
- appealing, flexible, varied and durable finishing layers.

Since they are directly facing the internal environment, and are in contact with the users, these solutions also carry additional requirements about aesthetics, tactile properties and non-toxicity. Moreover, the overall thickness of the installed system is critical for the economic viability of the retrofit operation.

After the evaluation of a few alternatives, the choice fell on a kit based on textile products: an insulation layer made of a porous, flexible support impregnated with silica aerogel, delivering low thermal conductivity and limited thickness; and a finishing layer that can be installed and fastened with a bespoke system and can be removed for maintenance or replacement. This solution was defined “permeable insulating wallpaper” because, besides providing thermal insulation, it is open to water vapour diffusion – which is a crucial aspect from the point of view of building physics – and it can be glued to the existing wall like a standard wallpaper.

3. Development and characterisation of the aerogel layer

The first step for developing the insulation layer was the selection of the most suitable textile matrix fit for the aerogel impregnation process. A fire-retardant polyester non-woven felt (average thickness 6 mm) has been chosen among different fibrous synthetic materials. The reason was the chemical compatibility and a good combination of mechanical strength and flexibility after impregnation.

The silica-aerogel is a low weight, and generally translucent, nanoporous material with very high porosity (> 90%), high surface area ($> 600 \text{ m}^2 \text{ g}^{-1}$) and low density ($0.08 - 0.2 \text{ g cm}^{-3}$). Aerogel itself has low thermal conductivity, around $15 \text{ mW m}^{-1}\text{K}^{-1}$, because of high porosity, low gaseous conduction and low radiative conduction. The silica aerogel impregnation process, which has been used, consists of allowing sol-gel synthesis among cross-linked fibres using silicon-based compounds (polyethoxydisiloxane, PEDS) as precursors through ageing, hexamethyldisiloxane silylation and subcritical drying. Since the air space between the fibres of the textile matrix has been filled by aerogel, a thermal conductivity reduction of the fibrous material and a solution to mechanical limitations of aerogel structure have been obtained.

A discontinuous layer of polyethylene powder has been melted on both sides, in order to permit the adhesion with finishing textile layers that encapsulate the aerogel. Also the finished textile glued on the top has been selected after characterization tests, in order to guarantee the water vapour permeability. The selected one is a tri-laminated polyester fabric.

The insulating composite material has been tested following the directives of the reference standards in order to have complete data to describe the hygrothermal behaviour. The measured properties are: density by means of volume and weight; thermal conductivity at dry and moist condition (EN 12667 and EN 12664); water vapour transmission properties (EN ISO 12572); hygroscopic sorption properties (EN ISO 12571); long-term water

absorption by total immersion (EN 12087). The water absorption coefficient by partial immersion (EN ISO 15148) has not been carried out because of the uncertainty of the results due to the low thickness of the insulation and hydrophobicity. The main values obtained by test are collected in Table 1.

Table 1. Main hygrothermal values from characterization tests.

Density (kg m ⁻³)		Thermal conductivity (mW m ⁻¹ K ⁻¹)		Hygroscopic sorption w (kg m ⁻³)		Water absorption w (kg m ⁻³)		Water vapour resistance (-)		
ρ _{dry}	135.8	λ _{dry}	25.0	w _{RH 0%}	0	w _{1h}	1.44	Aerogel+	μ _{dry}	4-6
ρ _{50%}	136.3	λ _{30%}	25.5	w _{RH 30%}	0.33	w _{24h}	3.23	PES	μ _{wet}	2-4
		λ _{50%}	25.6	w _{RH 50%}	0.54	w _{28d}	11.12	Aerogel+	μ _{dry}	4-6
		λ _{80%}	25.8	w _{RH 80%}	0.85			PES+PE	μ _{wet}	2-4
		λ _{87%}	26.2	w _{RH 87%}	0.94			Aerogel+	μ _{dry}	12
		λ _{w 1h}	27.2					PES+PE+fabric	μ _{wet}	-
		λ _{w 24h}	35.4							

The thermal conductivity has been measured by means of guarded hot plate method using a custom built device. It works with single small and flat sample with high thermal resistance. The optimal dimension of the sample is 65 x 65 mm, which corresponds to the dimension of the device plates. The warm side at 30°C has a measurement area of 25 x 25 mm, the cold plate was cooled to 12°C. The thermal conductivity has been measured at dry state (RH 0%), after drying the samples at 65°C until equilibrium. The samples have been then conditioned at different relative humidity until equilibrium (30%, 50%, 80% and 87% at $T 23 \pm 0.5^\circ\text{C}$) and immersed into water for 1 h and 24 h. The aim was to evaluate the increasing of the thermal conductivity at different step of moist condition. It has been carried out measuring the change in mass at each step, with the same procedure used for the hygroscopic sorption tests. After the achievement of the equilibrium, the samples have been inserted into a vapour tight plastic envelope in order to limit water vapour migration during the test on guarded hot plate apparatus. As result the thermal conductivity λ_{dry} is equal to $25.0 \pm 0.5 \text{ mW m}^{-1}\text{K}^{-1}$ (starting value at 0%) and it reaches $35.4 \pm 2.7 \text{ mW m}^{-1}\text{K}^{-1}$ with higher moisture. It means that the increasing is small and it is due to the low water content in the material thanks to the good hydrophobicity of the aerogel. The standard deviation is higher for higher values of water content due to the decreasing of thermal conductivity during the test with the time, as the warmer part of the sample is drying. The loss of water during test was ensuring lower than 0.1% of the weight. The results of thermal conductivity against water content are reliable obtaining a quadratic polynomial curve with coefficient of determination $R^2 = 0.999$ [15].

The low water absorption has been demonstrated also by means of long term immersion into water up to 28 days. In fact, the maximum value corresponds to 11.12 kg m^{-3} , about 7% of the weight of the sample.

The water vapour permeability has been measured using the cup tests method under isothermal condition: dry cup 0/50, using molecular sieve desiccant to reach 0% of relative humidity inside the cup, and wet cup 50/93, using ammoniumdihydroxide solution to reach 93% of relative humidity inside the cup. In both case the cups have been placed in a climatic room at constant temperature $23 \pm 0.5^\circ\text{C}$ and constant humidity $50 \pm 3\%$.

The permeability of the aerogel composite material has been measured both alone and with the added layers: discontinuous polyethylene gluing layer (PE) and the finishing fabric. In case of high water vapour diffusion (when the equivalent air layer thickness value s_d is less than 0.1 m like in this case), an increasing of uncertainty in the results has been expected. No difference occurred with or without polyethylene thanks to the discontinuity of the layer, guaranteeing low value of water vapour resistance μ_{dry} between 4 and 6 (-) at dry condition and μ_{wet} between 2 and 4 (-) at wet condition when the vapour transport decreases due to the liquid transport within the pores. Even if the finishing polyester fabric rises μ_{dry} at 12 (-), the value is still low and suitable for the inner retrofit (Table 1).

4. Development of the finishing layer with bespoke fastening system

As mentioned in section 2, the wallpaper system is based on two completely independent layers. The underlying idea was to provide an insulating layer glued to the existing wall and a finishing layer that would be applied and tensioned with a simple device (suitable for D.I.Y. installation), while preserving the possibility to replace it in the

future for any reason, like washing, substituting a failing element, improving the performances (e.g. adding radiant fabric, integrated LEDs, etc.) or simply changing the appearance of the wall. This ruled out any solution implying glues or other products making disassembly problematic.

However, the different components are conceived as parts of a single kit, that in principle can be bought at a local D.I.Y. store, transported easily thanks to its lightness, and stored in limited spaces. All the assembly operations can be performed with common tools, such as scissors, cutter, hammer and flatiron.

Besides fulfilling the requirements listed in section 2, the system guarantees an easy dismantling of the finishing layer, which is completely dry-assembled; this aspect reduces also the installation time thanks to the lack of delays due to drying of materials. The only wet process is the application of glue on the existing wall, required to apply the insulating layer.

Another peculiar aspect concerns the geometrical adaptability of the proposed solution, which allows the application of the system on (not always planar) existing walls, following their forms also in correspondence of the corners, thanks to the physical flexibility of all the components of the kit.

The wallpaper solution is also designed to allow the diffusion of water vapour thanks to the choice of materials for glue, insulating layer and finishing fabric, which was identified as a coated bi-laminate composed of 100% polyester + 100% PTFE membrane, weighing $146 \pm 6 \text{ g/m}^2$.

Several prototypes have been developed and tested to identify a tensioning solution for the finishing layer that would satisfy the requirements outlined above and, at the same time, avoid the deterioration and tearing of fibrous fabric (such as one made in cotton) that is a limit of existing systems, as proven by the early tests.

A first solution (Fig. 1) was based on aluminium profiles at the top and bottom of the wall, fixed with 3+3 screws per metre. Fixing the fabric finishing required the formation of a slot at the top, where a Keder flexible bar (in PVC) was inserted; this edge was then pushed into the upper aluminium profile. The lower edge would be tensioned and fixed to the bottom profile, with a critical aspect related to the limited adjustability of the fabric length.

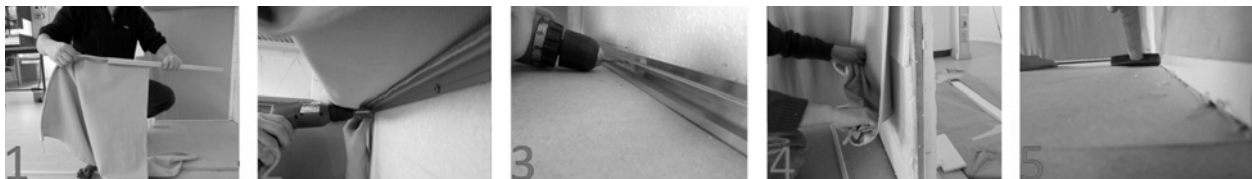


Fig. 1. Sequence of assembly, solution no. 1: 1 - inserting fabric with Keder bar in the upper profile; 2 - fixing the upper profile; 3 - fixing the lower profile; 4 - fabric tensioning; 5 - fabric fixing at the bottom edge.

A second solution consisted of a lower aluminium profile and an upper pressure PVC zip (Fig. 2). The latter is fixed to the wall with a textile fixing system, which has to be placed before the installation of the insulation material. This allows to adjust the length of the fabric. The lower profile is instead fixed to the wall through screws (3 per metre).

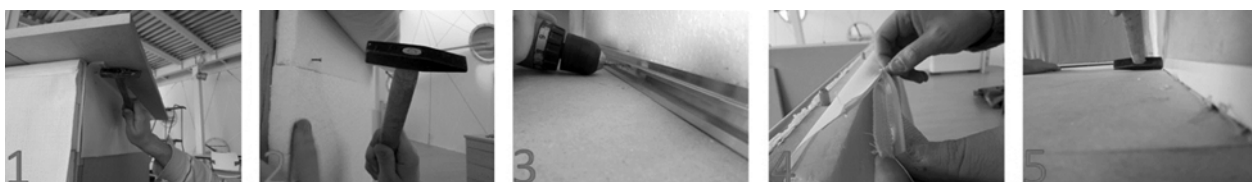


Fig. 2. Sequence of assembly, solution no. 2: 1 - fixing the PVC strip to the wall; 2 - installing the insulation layer in front of the PVC strip; 3 - fixing the lower profile; 4 - connecting the finishing fabric to the PVC strip with a plastic cursor; 5 - fabric fixing at the bottom edge.

The final solution is based on a system of plastic zips, commercially available, that are fixed to the wall on one side and then connected to the fabric finishing on the other. The top connection to the existing wall is based on a PVC strip carrying a plastic zip with a slider on one edge; this PVC strip is fixed to the wall with nails and/or glue. A

similar system, albeit with a different fastener to the fabric finishing, based on simple pressure, is used at the bottom of the wall. The corresponding plastic zips are applied on the finishing textile via a thermo-adhesive tape that is simply ironed on the fabric. One of the most interesting aspects of this solution is its inherent flexibility, allowing adaptation also to walls that are not perfectly flat.

5. Testing on demonstration walls

The first test wall chosen for the real scale tests is a part of an eight-storey building, built in 1965 and situated at the university campus of Politecnico di Milano. The façade is an unventilated cavity wall, composed of, from outside to inside: vitrified grey ceramic tiles (dimensions: 15 x 7.5 x 0.7cm), cement base render (2.5 cm), first layer of hollow bricks (12 cm thick), an unventilated air cavity (34.5 cm thick), second layer of hollow bricks (8 cm thick) and internal cement lime based plaster with a gypsum finishing (1.5 cm). The whole thickness of the wall before retrofit is 59.2 cm. The inner surface covered by this insulating system is 3.37 m², with 7 mm thickness and weight of 1.7 kg m⁻².

The insulation layer, made of the aerogel-impregnated fabric mat described above, was glued to the existing wall with a breathable mineral mortar specifically developed for the research project. The finishing fabric was then applied in front of the insulation with the tensioning system described in the previous section (Fig. 3).



Fig. 3. The assembly of the first prototype of the insulating wallpaper, July 2014.

A continuous monitoring campaign has been carried out from December 2013 until March 2015, including 7 months before retrofit and 8 months after retrofit (July 2014).

Humidity and temperature sensors (THs) were installed on the external and internal surface before retrofit. Heat flux meter (HFM) has also been installed on the internal surface at a height of 1.35 m from the floor level.

Inside and outside air temperature and air relative humidity (THa) data were also collected. Outside, a self-aspirating solar radiation shield protected the sensors. A solar pyranometer measured the irradiance (W m⁻²) on the wall. After the retrofit, additional THs sensors have been installed on the internal side at the same position in height as the previous ones, on the warm side of the insulation layer. Two extra sensors have been installed inside the air cavity, at a distance of about 3 cm from the surface of the inner bricks.

Data have been acquired, stored and transferred by means of a wireless communication system and GPRS modem. The measured values have been used for the calculation of the thermal conductance Λ and of the thermal transmittance U of the wall, before and after retrofit.

The relative humidity measured at the different positions across the wall section was useful for defining the moisture profile, considering also the effect of the rain. The results obtained using the calculation methods according to ISO 9869-1 are summarized in Table 2. $\Lambda_{ST,DRY}$ is based on calculation with tabulated (or measured, in case of the insulation layer) λ values, but with a reference temperature $T = 10\text{ }^{\circ}\text{C}$ and at dry condition $RH = 0$. Λ_{AM} is the mean asymptotical value with standard deviation, obtained by measurements using the average method. Λ_{DYN} is the mean value with standard deviation obtained by means of dynamic method analysis with LORD. The U-value has been calculated indirectly, using the reference values $R_{si} = 0.13\text{ m}^2\text{K W}^{-1}$, $R_{se} = 0.04\text{ m}^2\text{K W}^{-1}$. The difference between Λ_{AM} and Λ_{ST} is up to 16.8% for the base wall, which reveals the underestimation extent at steady and dry state. The difference between Λ_{AM} and Λ_{DYN} is 0.88% for the base wall and 0.1% after retrofit. U-value decrease of 24.1% is obtained after retrofit.

In terms of relative humidity and water content profile, no condensation phenomena occurred at the inner surface of the monitored real scale installation, but a deep analysis was needed. Those points have been studied also by means Transient and Heat Moisture calculation, by comparison between model and measurements [16].

Table 2. Thermal performance of the wall obtained by monitoring and different calculation methods.

	$\Lambda_{ST,DRY}$	Λ_{AM}	$\Lambda_{DYN (LORD)}$	U_{ST}	U_{AM}	$U_{DYN (LORD)}$
	$(W m^{-2}K^{-1})$					
Before Retrofit	1.069	1.249 ± 0.062	1.260 ± 0.004	0.905	1.028	1.038
After Retrofit	0.829	0.902 ± 0.045	0.903 ± 0.001	0.726	0.780	0.783

In July 2015, a second test wall was retrofitted with the insulating wallpaper at Politecnico di Milano. The purpose of this second experimental campaign was to refine and finalise the designed tensioning system for the fabric finishing layer, using a room that reproduces the same type of construction technology (cavity walls in hollow bricks) and geometry (corners, windows, shutter box etc.) of a common apartment building. It was then possible to use the demonstration activities as a simulation of a real construction site, testing the procedures required for the installation of the indoor retrofit kits, the potential problems that would arise in a realistic situation, the problems of fitting the dimensions of the insulating panels to the actual geometry, etc. (Fig. 4).



Fig. 4. Test of the insulating wallpaper with the final solution for the tensioning system, July 2015.

The installation of the internal retrofit solution to the demonstration walls at Politecnico di Milano has proven extremely useful to test the operational aspects of designing, producing and installing the wallpaper.

The insulating panels have demonstrated good adaptability to the actual geometric conditions of the site, while it appears that some automated design tool for the breakdown of the wall into standard-sized insulating panels would be useful to reduce the design time. The system for the application of the fabric finishing has proven easy to put in place and use. The adaptation to the geometry of the wall, and the use of the plastic zips for fastening, have proven effective and sufficiently reliable for the demonstration activities. Following these results, a patent request has been submitted to Italian authorities for the fastening system.

6. Other issues related to the performance of the system

Dynamic energy simulations were performed to understand the climate adaptation of the designed components in a number of cities across Europe. Besides the most suitable thickness of the insulating layer, one of the main questions to tackle was the role of the thermal capacity of the internal finishing layer on reducing the overheating effect, especially when retrofitting takes place in warmer climates. Simulations were conducted in three cities, i.e. Gdansk (Poland), Milan (Italy) and Palermo (Italy) using TRNSys simulation software. The results were compared on two levels. The first level compares the Discomfort Degree Hours (DDH) for cold and hot hours (DDHc and DDHh), as well as for the cooling and heating loads. The second level of the analysis features internal room air, operative and surface temperatures (TAIR, TOP and TSI), and is diagnosed on a more detailed level.

Results of the dynamic simulations show that in a residential situation, with limited window to wall ratio (WWR) and controlled shading, it appears that the choice of different materials for the inner finishing layers does not affect significantly the thermal performance and comfort, independently of the climate. However, the addition of insulation layer improves summer conditions also in warm climates, provided shading and ventilation are correctly managed.

Cold bridges analyses were conducted using DARTWIN software for ten critical points in a multistory building (Fig. 5), where each point was analyzed using different insulation positions and its depth into the interior space. The analyses were conducted in three climates, i.e. Stockholm (Sweden), Milan (Italy) and Agrigento (Italy). The aim of this study was to understand the needs of adaptation to different climates, the impact of the added insulation on the inside surface temperatures in the worst case scenario, as well as the risk of condensation.

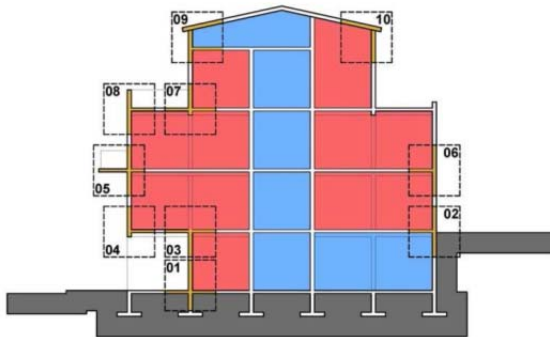


Fig. 5. Main critical points chosen for the thermal bridges analyses.

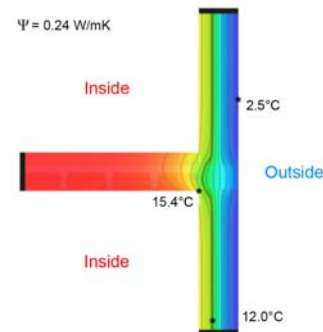


Fig. 6. Example of a case result.

Results show that, when insulating only the external wall from the inside (i.e. without extending the insulation layer on the slabs or internal walls), the thermal linear transmittance ψ (Psi) is often high. Solutions with vertical internal insulation only do not seem particularly critical (Fig. 6), but if some horizontal insulation is added, a “sandwich” 50 cm deep is enough to reduce cold bridging effects. However, in the case of insulating only one part of the horizontal surface (e.g. slabs), the condensation line tends to come closer to the non-insulated corner, which results in a higher condensation risk. From the simulations conducted, insulating both parts of the horizontal surface

(e.g. ceiling and floor) gives the best results, however, it might require a more complex intervention (partial removal of flooring etc.).

In accordance with ISO 14040 Environmental management [17], the Life Cycle Analysis (LCA) framework was selected for a comparative analysis, where the main goal was to investigate the environmental impact of three different solutions of internal retrofitting installation. The LCA application was conducted at the design stage, in order to confirm or help the design of the kits' components, with the aim of developing environmentally efficient solutions. Its application to different internal retrofitting systems aimed especially:

- to help the improvement of the design of the fixing systems, which had to be minimal in dimension and weight and easy to be set up;
- to understand the ratio between the environmental impacts of the fixing devices of each system and these of the insulating and cladding layers [18].

The LCA system boundaries were limited to the pre-use phase (raw material extraction of materials, material processing, and manufacturing of components). In order to design and compare the different indoor retrofitted designed kits, the functional unit for the LCA study was determined to be a wall surface of 3 m² (1 m long x 3 m high), the same modular dimension built up for the test wall mentioned in section 5. The SimaPro 7.3.2 database served as the primary source for obtaining the life cycle inventory data of all manufacturing process voices related with the building materials involved in the comparisons. CML 2 Baseline 2000 (V2.05) [19] and EPD 2008 [20] were used for the LCIA weighting of the inventoried processes.

The environmental impacts of the textile wallpaper (no. 3 ahead) were compared with two innovative, but more traditional, indoor retrofitting kits: a prefab kit (no. 1) and a deployable wall (no. 2). Each kit solution consists of an insulation layer, a finishing/cladding layer, fixing profiles and tools. In the third kit three different variations were assessed: with aluminium fixing systems (3.1), with upper aluminium profile and bottom PVC rigid profile (3.2) and with upper and bottom PVC flexible profiles (3.3). Their environmental impact assessment has been carried out at the building system scale, finding out the environmental loads of each kit component, to underline the potential and limits of each one. Intermediate LCAs have been although computed at the material stage, in order to understand, from the eco-efficiency point of view, the advantage/disadvantage of choosing super-insulating materials and to guide the selection of the material for finishing layers and of the fixing system of the enhanced wallpaper. Different fixing systems considered for the tensioning of the textile finishing have been considered and compared: PVC rigid profile, aluminium rigid bars, aluminium rigid bars with a PVC fastening profile, flexible PVC strip with PVC zip, flexible PVC strip and cotton belt with PVC zip. The objective of the comparison was to find out the optimal solution, in terms of flexibility and adaptability, together with the reduction of their weight and the environmental impacts.

At the building system scale, the results of the environmental impact assessment of the three designed kits show the contribution of the insulation layer (PET + Aerogel, 35 mm – grey) and, separated, that of the fixing system and the finishing layer (the other colours) (Fig. 4). The results show that, for most of the indicators, the most eco-efficient kit is the enhanced textile wallpaper with 2 PVC zips (top and bottom), due principally to the lightness of the solution compared with the other configurations. Focusing on the eco-efficiency of this last kit, it has to be underlined that the choice of the finishing layer could change the results.

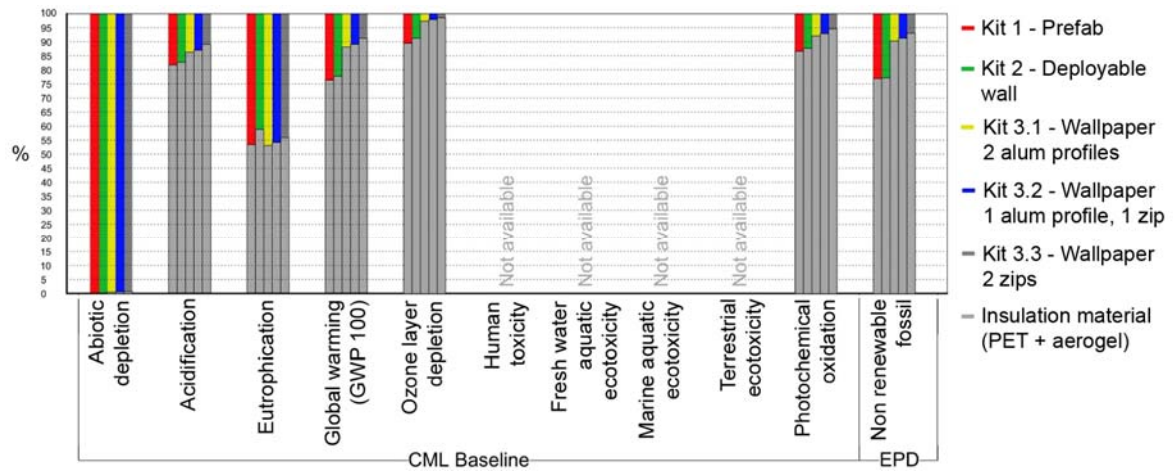


Fig. 7: Comparison between the environmental impacts of different indoor retrofit kits [%].

7. Conclusions and outlook of future work

The design and research activities described in this article led to the development, characterisation and testing of an innovative kit for indoor thermal retrofitting composed of an insulating layer based on silica aerogel and a finishing system with a bespoke fastening system. The latter is now undergoing a patenting process for future commercial application, although some aspects about joints and assembly sequence require further development. The wallpaper system achieved a TRL (technology readiness level) of 6 (technology demonstrated in relevant environment).

Acknowledgements

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