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TECHNICAL TEXTILES AND THIN INSULATION MATERIALS. NEW SCENARIOS FOR THE ENERGETIC RETROFITTING

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Abstract

In the building sector, there is a growing interest in the technical textiles, in particular as components for facades and also as potential replacements for the current options that seek energy efficiency through mass. The role of textiles in retrofitting from inside rooms is gaining more importance. The traditional wallpaper is evolving to interactive renovation possibilities by smart textiles, till to the thermal retrofitting. The paper deepens the feasible integration between wall covering textiles and thin super-insulating materials, coupling thermal function with sensorial and aesthetic ones. The goal is to identify which materials are suitable to achieve the new smart component.

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Keywords: Wallpaper; retrofitting; smart textiles; insulation materials; interactive surface.

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1. Introduction

In the last decades the European Community has developed an energetic strategy that more and more takes into account the indissoluble link between energetic politics, environmental changes and environment's protection [1]. In this context should be considered that the building sector is one of the key consumers of energy in Europe where energy use in buildings has seen overall a rising trend over the past 20 years. In 2009, European households were responsible for 68% of the total final energy use in buildings [2]. Their construction technology is marked by the usage of massive materials, heavy, characterized by high thicknesses, both for the newly constructed building's interventions that for the already existent building's interventions. But the current tendencies show that the lifestyles are changing and new materials are becoming more and more important in the conservative world of the constructions. Among these materials, the textiles are taking over more and more market shares. They have been

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used for many years mainly as waterproof membranes and traditional wallpapers, while recently they are becoming more often the key component of innovative textile façades, shading systems and even components for the aesthetic and thermal retrofitting, thanks to flexibility, lightness, thinness and aesthetic qualities. Globally their characterization is improving and their function transformed the idea of a simple finishing layer into the concept of a dispenser with multiple functions. New textiles, so called "smart textiles", integrate in the membrane itself a high-technology content, seeming invisible. They become sensible, almost get sensorial qualities, becoming receptive to the pressure, the heat, the sounds, etc.

Focusing on the increasing need of building retrofitting and stating the current social trends towards individualization of use of living spaces in Open Buildings [3], with the introduction of architectural components with shorter use-life, such as finishing components, partitioning, ceilings, the role of textiles from the inside retrofitting is gaining more importance. The traditional wallpaper, with the minimal function of finishing layer with a wide range of pattern, is evolving to interactive renovation possibilities by smart textiles, till to the thermal retrofitting by coupling of thin insulation materials.

Nomenclature

U	thermal transmittance	ρ	density
R	thermal resistance	ε	emissivity of the surface
λ	thermal conductivity	h_r	radiative coefficient
d	insulation thickness	+ %	percentage improvements in thermal resistance

2. Objectives

By deepening the evolution of the traditional wallpaper towards new forms of interactive walls and the state of the art of the smart textiles, the study aims to foresee new components coupling a thermal function of the wallpaper with the sensorial and aesthetic ones. The objective is to suggest new possible combinations in order to guarantee: energy saving, high-technology content with new functions, restoration of the wall's aesthetic features, dematerialisation of the thicknesses. The main core of the paper is the computation of the thin insulation materials' contributes, as potential and functional addition to a new concept of "thermal" wallpapers.

3. Methodology

The paper firstly investigates the state of the art of smart textiles, in order to understand which could be able, for their features, to represent a wall covering of the insulation layer from inside the buildings, with the possible additional functions. The state of the art, we are considering, overcomes of the traditional concept of wall covering, e.g. plasters, painting, tiles, glued or nailed wallpapers, and shows the most advanced development of "smart textiles" as new active/interactive wallpapers.

Then flexible and thin insulation materials, able to be the insulation layer in a thermal retrofitting from inside the building are analysed. Their physical behaviours are deepened and compared, focusing on steady state of the thermal performances according to the standard UNI EN ISO 6946-2008, with a thickness of 7.5 mm as requirement, to be compatible with a "thermal" wallpaper (tab. 1). The economical impact of these insulation materials, rated using the available market products with a thickness $d \leq 10$ mm, was computed (the functional unit used is $R=0.1 m^2K/W$). A least the rate of the R increase, by coupling with low-e finishing textiles, according to UNI EN ISO 6946-2008, was assessed and the performance increase obtainable with PCM textiles, starting from literature data, was analysed.

The thermal computations were conducted on a brickwork cavity wall (30cm thick) with a $U = 1.1 W/m^2K$.

4. Smart textiles for smart wall covering

Smart textiles, thanks to their ability to response to a stimulus and/or thanks to their high-technology content, can guarantee additional functions. With the basic technology already available, the area of intelligent textile materials, like electrically conductive yarns and pressure sensitive fabrics, and that of sensitive textile materials, like electro active, color and optically changing materials, the textile industry is going to have a cutting-edge change. On one hand, with advanced textile finishing procedures, *thermochromic, photochromic, solvatochromic textiles* are growing and under development. The chromic textiles change their color reversibly according to external environmental conditions, for this reason they are also called chameleon fibers [8]. These textiles, thanks to pigments applied to any textile substrate, can be "activated" through different types of stimuli: heat for the Thermochromics textiles (fig. 1b); light for the Photochromics ones; liquid or gas for the Solvatochromic ones. They could be used to show an alert level in a particular situation. The first and the second types could be very useful in museums to show a too high temperature/illumination of an area near movable and immovable artworks. Similarly, in the future, the third one could be used in houses, schools and offices to indicate a possible alert level. On the other hand, the new knitting textile technologies allow the integration of special devices and wires to obtain advanced lighting, heating and electronic textiles: luminescent one (e.g. Nature Ray Charles Wallpaper® - Camilla Diedrich walls), interactive one (Living Wall – Media Lab MIT - http://highlowtech.org), heating one (e.g. Power Heat® – Sefar – www.sefar.com), lighting one (e.g. I-tex® - Sioen – www.sioen.com), and with sensors or actuators and conductive fabrics (e.g. Texe - www.plugandwear.com, PowerSens® – Sefar – www.sefar.com).

Between the luminescent textiles, which reply to a stimulus (Photoluminescence, Electroluminescence and Optoluminescence), the optoluminescent ones were already used as wallpaper. The designer Camilla Diedrich developed luminescent wallpaper, *Fiber Optic Wallpaper* (Fig. 1a): the "glow wallpaper" comes up with the aim of conferring a new feature to the surface, to create lighting effects and guarantee a soft lighting.

A scenario could be the union between these textiles and the insulation layer, satisfying at the same time both the needs of energy consumptions control and the aesthetic and personalisation requirements of the final user.

Smart fabrics and interactive textiles (SFIT), made of fibrous structures able of sensing, actuating, generating/storing power and/or communicating, are under research and development with strong interest during the last 10 years [9]. Some of them have already been used as interactive Wallpaper. The *Living* Wall (fig. 1c) consists of sheets of paper painted with electrical circuitry and a set of detachable electronic modules for processing, sensing, and wireless communication. It is sensitive to the pressure and to the movements [10].

A future scenario of application could be the use of this interactive textile in a retrofitting intervention, increasing the services and the functions for the users into a single component.

The heating textile, actually used in various sectors, from the automotive to the furniture one, consists of a fabric PET monofilament knitted together with conductive fibres. The conductive fibres are heated up under an electric impulse generating heat, reaching till 1000 W/m^2. A future scenario of application could be a wall radiant heating integrated in a wall covering.

Fig. 1. (a) Fiber Optic Wallpaper, C. Diedrich (Source: www.magnifiermag.com/category/design/); (b) Thermochromic wallpaper (Source: xaviersegers.wordpress.com); (c) Living wall, interactive wallpaper [10]

5. Advanced insulation materials for smart thermal wall coverings

The new concept foresees a new era for the wallpaper, by the interaction and integration of smart wall covering with the insulating layer, aiming to a retrofitting intervention from inside the building, challenging a thickness of 7 mm, and to guarantee in one component installation thermal comfort, energy saving, a new aesthetic feature and a "new domotic system", all without produce building site diseases to the users. This approach means to work empowering the materials characteristics. The analysed insulation materials are divided into three categories *(Tab.1)*:

- (W) Thermal wallpaper: insulation materials for inner applications characterised by the superficial fit-out of one of the two faces in nonwoven. This surface has to be thought directly painted or equipped with textile, guaranteeing the possibility of its subsequent substitution without the damage of the insulation layer.
- (T) Traditional insulation materials with λ included between 30 ÷ 50 mW/mK.
- (S) Super-insulation materials with values of λ among the lowest of those currently available on the market. A

felt bathed with Aerogel of silica (λ=14 mW/mK) is considered.

Table 1. Insulation materials proprieties (authors' elaboration)

Code	Materials	d (m)	λ (W/mK)	ρ (Kg/m^3)	Weight (Kg)
			Thermal Wallpaper		
W1	Latex	0.005 and 0.01	51	186.4	1.04 and 2.08
W2	EPS + Graphite	0.004	32	15	0.06
			Traditional insulation materials		
T1	Polyethylene	0.006	43	70	0.42
T2	Polyester	0.01	32	130	1.3
T3	Kenaf fibers	0.005	35	120	0.6
			Super insulation materials		
S1	PET + Aerogel	0.005 and 0.01	14	150	0.75 and 1.5

5.1. Performance comparison between the different insulation materials

In retrofitting from inside the external walls, the minimal thickness of the insulation material is a key aspect both to reduce interstitial condensation risks that to minimize the room useful surface occupied by the overlay. The analysed materials (tab. 1) have a thickness between 4÷10 mm. However, not always using these thicknesses means an increase of R in order to guarantee an important energy saving and to justify the intervention. In Fig. 2, through the comparison of the different insulation materials with d=7.5 mm, the key role of the super-insulation materials in the investigation of new thermal wallpaper stands out. By traditional insulation materials the increase of R is always under 30% and, in the case of latex (W1), the increase is 16.5%. Among these materials polyester (T2) guarantees an R increase of 25%. To improve the efficiency, the super-insulation materials (S1) have to be considered, allowing an R increase of +59.4%. With them it is possible to increase up to +78%, being into the range ≤10 mm (tab. 2).

Table 2. Evaluation of the R increase and economical impacts of different insulation materials

R base envelopes	Code	d (m)	R Ins (m^{2}K/W)	+ %	€/m^2	€ / (0.1m^{2}K/W)	d (m)	R Ins (m^{2}K/W)	+ %
0.909091 m^{2}K/W	W1	0.005	0.098	+10.78	12.5	12.75	0.0075	+0.15	+16.5
		0.01	0.196	+21.56	22.55	11.48			
	W2	0.004	0.125	+13.75	N.A.	N.A.		+0.23	+25.3
	T1	0.006	0.14	+15.40	13.5	9.64		+0.17	+18.7
	T2	0.01	0.31	+34.10	16.5	5.32		+0.23	+25.3
	T3	0.005	0.143	+15.73	6.00	4.19		+0.21	+23.1
	S1	0.005	0.36	+39.60	48.40	13.44		+0.54	+59.4
		0.01	0.71	+78.09	60.70	8.55			

Another fundamental aspect is the economical impact of the different solutions recommended. In tab. 2 are highlighted the big differences, in terms of €/m^2, that exist among the different categories of rated materials. In the extremes T3-S1 the difference of cost is over 50 €/m^2. However these values are not directly comparable one to each other, because of the different insulation power. So the costs for R = 0.1 m^{2}K/W have been rated. The result of the comparison shows that the traditional insulation material with the best ratio costs/profits is the T3 (fibers of Kenaf) with an increased R under T2 (6= -2%) and a lower cost/m^2 (with R 0.1 m^{2}K/W) around 1 €/m^2. The material S1 d=10mm, the most disadvantageous from the economical point of view in a first analysis, is coherent with the other materials: + 4.2 €/m^2 if compared with the T3 and – 4.36 €/m^2 if compared with the W1.

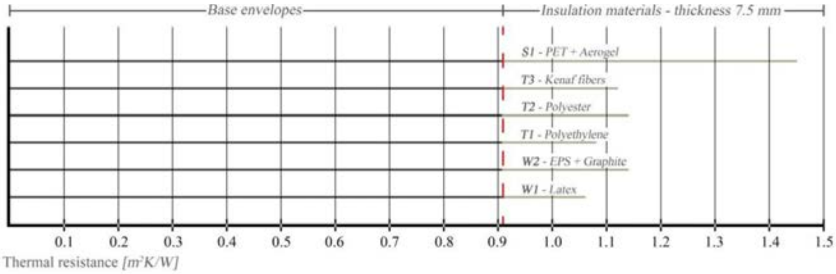

Fig. 2. Comparison between the R of the insulations materials (with the same thickness of 7,5mm) (authors' elaboration).

5.2. Synergetic union between insulation layer and finishing textiles

The finishing textile layer can have different functions. On the one hand, can increase the thermal insulation of the wall covering solution, and from the other hand can manage the task of "dispenser" of the functions.

Low-e Textile (Reflective) can be conceived as a part of an effective wall covering system, able to guarantee, on one hand, the aesthetic features of the wall and, on the other hand, the maximization of the thermal performances in the 0.6 mm thickness. Finishing low-e textile acts on the radiative coefficient value [h_r] increasing the internal surface resistance [R_{si}]. Usually the traditional wallpaper have a value of S that is included between 0.85-0.9 [4], and then near to the value of ε =0.9 used by the standard UNI EN ISO 6946 for the evaluation of the R_{si} of an inner wall. As a consequence textiles or traditional wallpapers do not increase significantly the wall's insulation power. Reducing the values of S of the textile wall covering is possible to increase in a significant way the R value (fig.3). The textiles available on the market have very various ε values: e.g. Polyamide ε =0.69, Polyester ε =0.7, Velveteen ε =0.75, Cotton ε =0.71. [5]: they are too high values to affect in a significant way the increase of the R_{si}.

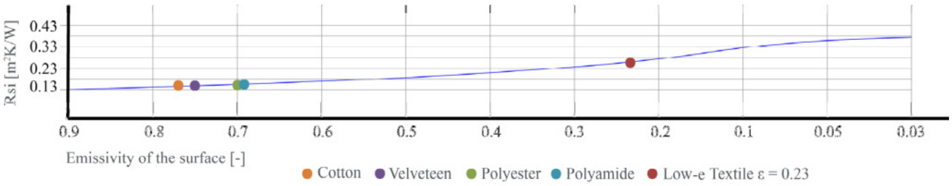

Fig. 3. Relation between different values of ε calculated at 293.15 °K and indoor superficial thermal resistance (authors' elaboration)

However, years of researches allowed obtaining textiles with S that are lower than ever. For example the low-e textile (Fig. 3) has a value of ε = 0.23 and allows an increase of 200% of the R_{si} value with a shift from 0.13 m^{2}k/W (with ε = 0.9) to 0.26 m^{2}k/W (with ε = 0.23). The value R_{si} = 0.26 m^{2}k/W includes the value R_{si} = 0.13 m^{2}k/W stated by the standard and already calculated in the value of the base wall's R_{tot}. As a consequence the total increase of R due to the textile is of 0.13 m^{2}k/W. Considering the examined sizes, this value allows to increase the total R of the wall of about the 14%, maintaining the same thicknesses (Tab. 3).

Table 3. Thermal performance of the insulation system + low-e finishing textile (authors' elaboration)

Code	d ins *(m)*	R b. env. *(m^{2}K/W)*	R Ins. *(m^{2}K/W)*	R F1 *(m^{2}K/W)*	R Tot. *(m^{2}K/W)*	+ %
W1 + F1	0.0075	0.909091	0.15	+0.13	1.19	+ 30.77
W2 + F1			0.23		1.27	+ 39.56
T1 + F1			0.17		1.21	+ 32.97
T2 + F1			0.23		1.27	+ 39.56
T3 + F1			0.21		1.25	+ 37.36
S1 + F1			0.54		1.58	+ 73.62

The attitude of *Phase Change Materials* PCM in the construction sector was largely studied. In particular Barbara Pause, who patented a PCM wall covering [6] and the Brighton University with OMNOVA Wallcovering Ltd (UK) [7] have studied phase change wall covering textile solutions. The phase change phenomenon allows the inside temperature regulation, specifically during the summer. In order to better understand the potential and the limits of these systems, two graphs [6], are shown below (fig. 3) and demonstrate the temperatures trend inside a room equipped with and without PCM. From the graphs the PCM's tendency to reduce the heat peaks stands out, specifically in the case of the ceiling application (Fig. 3a).

The coupling of these textiles with a thermal insulation material could increase both the artificial thermal inertia, thanks to the PCM, and the wall's thermal resistance as well, thanks to the insulation material's layer.

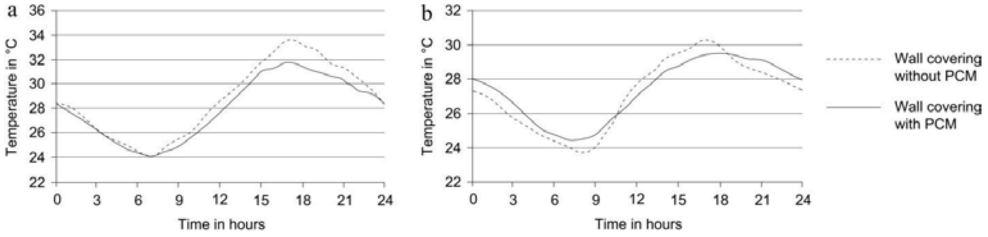

Fig. 3. (a) *Daily temperature development on the ceiling of a model room equipped with and without PCM*; (b) *Daily temperature development on Walls of a model room equipped with and without PCM (Source: Barbara Pause's patent)*

6. Final considerations

The study demonstrate the growing potentials of the coupling of textiles with thin insulations materials as the technical answer to the internal thermal retrofitting, showing at the same time the possibility to obtain good thermal performances. The addition of smart technologies into the textiles offer to the end-users very thin smart components. The wall covering component, we identified in the study, together with the aesthetic function, allows a significantly increase of the thermal resistance of the insulation system (with Low-e), improves the inside comfort in the summer (with PCMs), gives to the wall new functions through its application, without ever increase the total thickness of the system "insulation + finish". Instead the traditional thermal insulation and wall covering installation, they could improve also the installation phase, by avoiding the typical problems of the traditional installations, usually with a building site for long time and diseases for the inhabitants. Further investigation will be needed in order to optimize the manufacturing techniques of new textile-based insulating components, within the development of the most effective fixing system, in relation to the different existing walls morphologies.

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