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Coupling VIPs and ABPs: assessment of overall thermal performance in building wall insulation

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Abstract

Super Insulating Materials (SIMs) such as Vacuum Insulation Panels (VIPs) and Aerogel Based Products (ABPs), are characterised by lower thermal conductivities if compared with traditional insulating materials.
The objective of the present work is to suggest a new technical solution to reduce the thermal bridging effects in buildings SIMs assemblies. A typological façade where VIPs and ABPs are coupled was numerically analysed to assess the global average thermal transmittance. Moreover results were compared with common solutions based on VIPs coupled with traditional insulating materials (EPS, MDF), considering both thermal and economic aspects.

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Keywords: Vacuum Insulation Panels; ABP; thermal bridge; structural joints; numerical analysis; façade average thermal transmittance.

1. Introduction

In the building sector one of the most followed way to promote the reduction of energy consumption is to impose very low values for the thermal transmittance U [1] of the building envelope. To this purpose many innovative building solutions and materials were developed, such as Super Insulating Materials (SIMs). SIMs are characterised by a lower thermal conductivity if compared with traditional ones: so they are useful not only in the case of new construction but also in case of energy refurbishment, where the space available for the insulation is restricted. Despite their excellent thermal characteristics, SIMs are still not widely used: this can be mainly attributed to lacks of knowledge about their thermal performances in actual building applications, obviously without neglecting their higher price compared to traditional insulating systems.

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This study deals with Vacuum Insulation Panels (VIPs) and the effects of coupling them using Aerogel as structural joint, in comparison with junctions obtained by other standard insulating materials (EPS - Expanded Polystyrene or MDF - Medium Density Fibreboard). The aim was to demonstrate the advantages in coupling SIMs (VIPs + ABPs), in order to improve their building application and development.

VIPs were widely investigated for their intrinsic characteristic (core material typology [2,3] and envelope [4]), and for their drawbacks [5,6] and environmental impact [7]. Considering VIPs effective thermal behaviour in buildings constructions several experimental, numerical and analytical investigations were carried out, as well as real measurements on site. These investigations were related to VIP assemblies (VIP panels coupled with a joint made of different material) [8,9,10,11] and the main focus of researches concerned the decrease of performance due to the thermal bridges along panel edges. In [12] VIPs assemblies were inserted between adjunctive thermal resistances, to evaluate their contributions on the overall thermal performances of the joint.

ABPs properties and potential for building applications were also yet analysed in several researches, summarised in [13]. Aerogel use as structural joint is proposed in this paper, in order to optimise the global thermal performances of VIPs assemblies (by coupling two SIMs).

Studies are carried out for assessing the overall thermal performance of a typological façade where VIPs are coupled with different joint materials (Aerogel, EPS and MDF). The overall thermal transmittance of the façade considering different types of structural joint material was calculated with the aim to show the advantages in coupling VIPs and Aerogel. Results are also integrated through an economic analysis, to understand the real influence on the overall cost for the different joint material solutions.

2. Methodology

In this paper several investigations were carried out, in order to characterise the VIPs assemblies properties, and to show the influence of different joint material both considering the overall thermal performances and the economical aspects.

2.1. Average thermal transmittance of a typological façade model (opaque components)

In order to carry out the analyses, a typological façade was considered. In the following bullet the main characteristics are presented.

- Geometries and thicknesses of internal wall and floor/ceiling from UNI EN ISO 13791:2012 (Table 13 – Type no.2 and no.3) [14];
- External masonry in solid wall, as indicated in UNI TS 11300-1:2008 [15];
- VIPs used as external insulation layer (VIPs thickness = 10mm), and covered with a cladding plasterboard layer (10mm thick);
- In order to reduce the construction site assortment, only one VIPs size (500x600mm) and plasterboard cladding size (1270x1540mm) were considered;
- Structural joints in Aerogel, EPS or MDF, with 36mm wideness (or more where the distance between panels is higher for geometrical reasons, or around the window).

In the numerical model (Figure 1), different types of thermal bridges were considered:

- Air joint between two VIP panels directly coupled together: width of air joints equal to 2mm around (linear thermal transmittance $\psi_{Air\ joint}$ [W/mK], length $l_{Airjoint}$ [m]);
- Structural joint (made of Aerogel, EPS or MDF): width equal to 36mm (red colored) or more (yellow colored) (linear thermal transmittance ψ_{Joint} [W/mK], length l_{Joint} [m]).

The analyses were carried out neglecting thermal bridges related to windows, because the aim of this research was to establish the average thermal transmittance of the opaque envelope only.

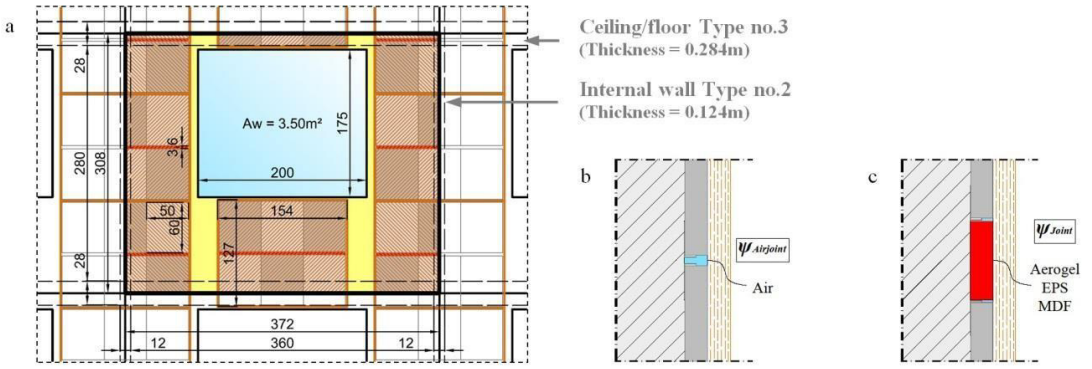

Fig. 1. (a) Façade geometries. Individuation of different linear thermal transmittance. (b) $\psi_{Air\ joint}$; (c) ψ_{Joint}.

The thermal bridging effects of air joints and structural joints coupled with VIPs were evaluated through the 2D numerical energy balance method, validated in [12] and according to UNI EN ISO 10211:2008 [16]. The thermal properties of each layer of the solid wall were defined with the references values provided by UNI TS 11300-1:2008 [15], while the insulating materials thermal properties (VIPs, Aerogel, EPS and MDF) were measured in a guarded hot plate [12].

2D numerical analyses were performed with software Physibel BISCO, following the same calculation methodology adopted in [12] and [13]. BISCO outputs provide heat flux and temperatures through the input section, and allows to calculate thermal bridge linear thermal transmittances (ψ [W/mK]) in accordance with UNI EN ISO 14683:2008 [17]:

$$\psi = \frac{\phi - \frac{1}{R_{TOT}} \cdot l \cdot \Delta\vartheta}{\Delta\vartheta} = \frac{\phi - \frac{1}{R_i + R_e + \frac{s}{\lambda_{cop}}} \cdot l \cdot \Delta\vartheta}{\Delta\vartheta} \quad (1)$$

Where:

- Φ is the thermal flux obtained from BISCO [W/m];
- $R_i + R_e$ is the thermal transmission resistance of the inner and outer façade [m^2K/W];
- s is the VIP thickness [m];
- λ_{cop} is the undistorted centre of panel thermal conductivity [W/mK].

Moreover the undistorted thermal transmittance of the insulated solid wall, neglecting thermal bridges, was evaluated in accordance with [18], considering the different insulating materials analyzed (U_{VIP} and U_{Joint}: $U_{Aerogel}$, U_{EPS} and U_{MDF}).

Finally the average thermal transmittance U_{avg} [W/m^2K] of the solid wall façade model was estimated by Equation (2) and (3), for each coupling between VIPs and other insulating materials (on the basis of the heat transmission coefficient H_{tr} *[W/K]*).

$$H_{tr} = U_{VIP} \cdot A_{VIP} + \psi_{Joint} \cdot l_{Joint} + U_{Joint} \cdot A_{Joint} + \psi_{Airjoint} \cdot l_{Airjoint} \quad (2)$$

$$U_{avg} = \frac{H_{tr}}{A_{TOT}} \quad (3)$$

Where:

- U_{VIP} [W/m^{2}K] and A_{VIP} [m^2] are the thermal transmittance and the area of the portion of solid wall insulated only with VIPs. U_{Joint} [W/m^{2}K] and A_{Joint} [m^2] are the thermal transmittance and the area of the portion of façade insulated with the other insulation materials (Aerogel, EPS or MDF);
- A_{TOT} [m^2] is the total surface of the opaque building envelope;
- $\psi_{Air\ joint}$, $l_{Airjoint}$, ψ_{Joint}, and l_{Joint} are the linear thermal conductivity and the length of the different thermal bridges considered.

2.2. Economic analysis

The use of Super Insulating Materials and their couplings (like VIPs and Aerogel proposed in this paper) provides higher energy performances and thermal insulation than traditional ones. But how their use influence the economic balance in building is not widely investigated. An estimation was indeed carried out through Equation (4), considering the typological façade model geometry described in 2.1, and an average market based price of each material considered (VIPs + Aerogel, or + EPS, or + MDF as structural joint).

$$PC_{Insulatinglayer} = \frac{C_{Insulatinglayer}}{A_{TOT}} = \frac{A_{VIP} \bullet PC_{VIP} + A_{Jo\,int} \cdot PC_{Jo\,int}}{A_{TOT}} \quad (4)$$

Where PC_{VIP} and PC_{Joint} [€/m^2] are the specific cost of VIPs and joint materials, which multiplied for their quantity and summed each other give the total cost of the insulating layer $C_{Insulating\ layer}$ [€]. The $PC_{Insulating\ layer}$ was the specific cost of the whole insulating layer (VIPs + Joints) [€/m^2]. After that the percentage increase in cost and thermal performance was calculate, in order to understand the real advantages relative to each joint material.

3. Results and discussions

Analyses were carried out with the aim to assess the global thermal performances of VIPs assemblies at building scale, evaluating the advantages in use of Aerogel as structural joint instead of other traditional materials (EPS and MDF).

3.1. Average thermal transmittance of a typological façade model (opaque components)

First kind of analyses were aimed at assessing the linear thermal transmittance of VIPs assemblies, composed by two VIPs coupled with both air joints ($\psi_{Air\ joint}$) or structural joints (ψ_{Joint}).

But how the choice of the joint material really affects the overall thermal performance of a building façade could be better evaluated through the calculation of the building envelope average thermal transmittance U_{avg}.

First of all the façade thermal transmittance U was calculated considering different insulating material used as structural joints (Table 1). Results in Table 1 also show the increasing in U_{avg} between the configuration VIP + Aerogel (reference value) and the other insulating material considered as structural joints. Coupling VIPs and EPS causes an increasing with respect to the reference value of the thermal transmittance equal to 16%, and the thermal performances are still worse if MDF was used (28% U_{avg} increasing). Through a comparison between the different values of U_{avg} (for each configuration analysed) and the U_{VIP} was observed a loss of performance that ranges from 34% (Aerogel joints) to 55% (EPS joints) and 71% (MDF joints). This demonstrates the thermal advantages obtained by SIMs coupling.

Table 1. Average thermal transmittance - U_{avg} - of the typological façade model. (With window thermal bridge).

	A [m²]	U_{VIP} [W/m²K]	A_{VIP} [m²]	Ψ_{Joint} [W/mK]	l_{Joint} [m]	$\Psi_{Joint>36mm}$ [W/mK]	$l_{Joint>36mm}$ [m]	U_{Joint} [W/m²K]	A_{Joint} [m²]	$\Psi_{Air\ joint}$ [W/mK]	$L_{Air\ joint}$ [m]	$\mathbf{U_{avg}}$ [W/m²K]	$\Delta U_{avg\text{-}VIP}$ [%]	$\mathbf{\Delta U_{avg}}$ [%]
Aerogel				0.024		0,024		**0.678**				**0,491**	34%	
EPS	7.98	**0.367**	6.70	0.036	9	0,048	11.78	**0.865**	1.29	0.011	8.2	**0,571**	55%	**16%**
MDF				0.050		0,057		**1.034**				**0,627**	71%	**28%**

3.2. Economic analysis

Thermal influence of structural joint material was clearly demonstrated, highlighting the advantages of SIMs coupling (VIPs + ABPs). However, Super Insulating Materials are characterised by higher cost if compared with other building materials, so they might affect greatly the building construction economic balance. Anyway VIPs are significantly more expensive than other materials used as structural joints (Aerogel included). Moreover VIPs are used in greater quantities on the façade. For these reason the element which mainly influence the insulating layer overall cost of a typological façade is VIP. Results of the economic analysis described in Section 2.2 (summarised in Table 2) prove this phenomenon.

Table 2. Economic analysis.

Material	A [m²]	PC_{VIP}/PC_{Joint} [€/m²]	C_{VIP}/C_{Joint} [€]	$C_{Insulating\ layer}$ [€]	$PC_{Insulating\ layer}$ [€/m²]	$\Delta PC_{Insulating\ layer}$ [%]	U_{avg} [W/m²K]	$\mathbf{\Delta U_{avg}}$ [%]
VIP	6.15	108	664	755,7				
Aerogel	1.83	50	92	666.945	95		0,491	
EPS	1.83	1.50	3	675,18	84	**-12%**	0,571	**16%**
MDF	1.83	6	11		85	**-11%**	0,627	**28%**

The use of EPS or MDF as structural joint, instead of Aerogel, causes a reduction in cost of 12% and 11% respectively, but also an average thermal transmittance U_{avg} increasing of 16% (EPS) and 28% (MDF), as shown in Figure 2.

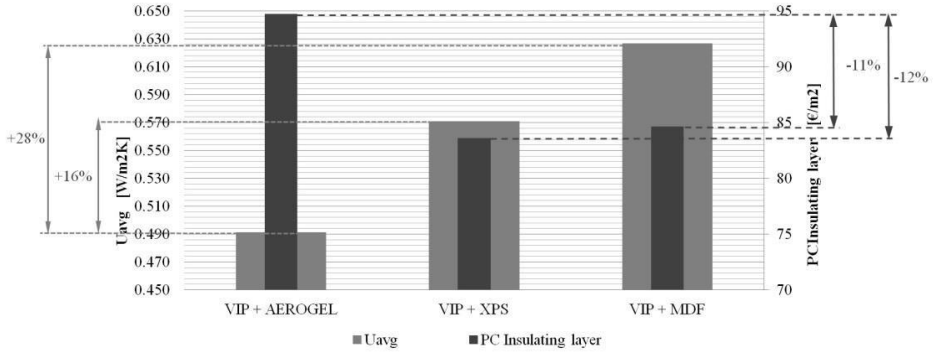

Fig. 2. Gradient of Façade parametrical cost, compared with the respective ΔU_{avg}, for three different material joints (Aerogel, EPS, MDF).

4. Conclusions

Vacuum Insulation Panels, and more generally SIMs, are characterised by high insulating powers, which could allow to reduce the thickness of building envelope insulating layer. However, their employ is still thwarted by the lack of a reliable calculation method of their performance on site, making these technologies less competitive.

Specifically with regard to VIPs, future researches could have the aim to provide the application bases and guidelines, identifying optimal assembling solutions. Since laths and battens are often essential for VIP application

in vertical envelopes and in specific cases needing dimensional flexibility (e.g. corners or windows), SIMs coupling (VIPs + ABPs) can be realised to maximise the exploitation of their potential, reducing the thermal bridging effects.

A further step to foster the SIMs spread is to understand their influence from the economic point of view. A double analysis (economical and thermal) was carried out on a typological façade model, in order to compare the results of different assembling materials (Aerogel, EPS and MDF). As expected the cost increasing due to coupling VIPs and Aerogel assemblies is almost negligible providing on the contrary a great increasing of SIMs assembly insulating performances. This trend is due to the higher cost and quantity of VIPs in comparison to other structural material used as joints.

For all these reason, SIMs coupling could be a solution to optimise VIPs performances, and might be the right direction for the optimization and deployment of these technologies.

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