BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1, 2013
Secţia
CONSTRUCŢII. ARHITECTURĂ

A PARAMETRIC STUDY OF THERMAL PERFORMANCE OF AN EXTERIOR WALL INSULATED WITH VACUUM INSULATION PANELS

BY

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Received: September 15, 2012
Accepted for publication: October 29, 2012

Abstract. The requirements regarding thermal insulation of the new buildings and thermal rehabilitation of the existing buildings tend to reach a threshold of insulation which allows to fulfill the necessary requirements for a low-energy building. To achieve this level of thermal insulation involves using either thick layers of conventional insulation (polystyrene, mineral wool, etc.) or high thermal performance materials.

Vacuum insulation panels are high performance thermal insulation characterized by very low thermal conductivity, from 5 up to 8 times lower than conventional thermal insulation. Vacuum insulation panels consist of a core (the main component being in generally fumed silica) surrounded by a multilayered film. The assessment of the thermal performance of these elements requires the evaluation of the linear thermal transmittance due to themal bridges which occur at the edge of the panels.

The results of a parametric study of the thermal performance of an exterior wall insulated with vacuum insulation panels are presented. The study highlights the parameters with the largest impact on the effective heat transfer coefficient of the wall.

Key words: vacuum insulation panels; thermal bridge; innovative materials; numerical simulation.

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1. Introduction

The requests, more and more restrictive, regarding the performance of existing and new buildings, leads to adoption of new measures in order to meet the requirements. The building field is responsible for more than 40% of final energy consumption which makes the construction sector to be a domain with a large impact on energy efficiency.

Providing an envelope with a higher degree of thermal insulation the amount of energy neccessary for space heating or cooling of a building can be reduced. By using high performance thermal insulation materials, like vacuum insulation panels, it is possible to achieve the required *U*-value for the opaque elements of the envelope with only few centimeters of insulation.

2. **Thermal Performance of the Exterior Wall Insulated with Vacuum Insulation Panels**

2.1. Thermal Insulation Model

The wall insulation system analysed assumes the use of two VIPs layers arranged as shown in the Fig. 1. The panels are semi-protected (see Fig.2) with only three faces covered with extruted polistyrene.

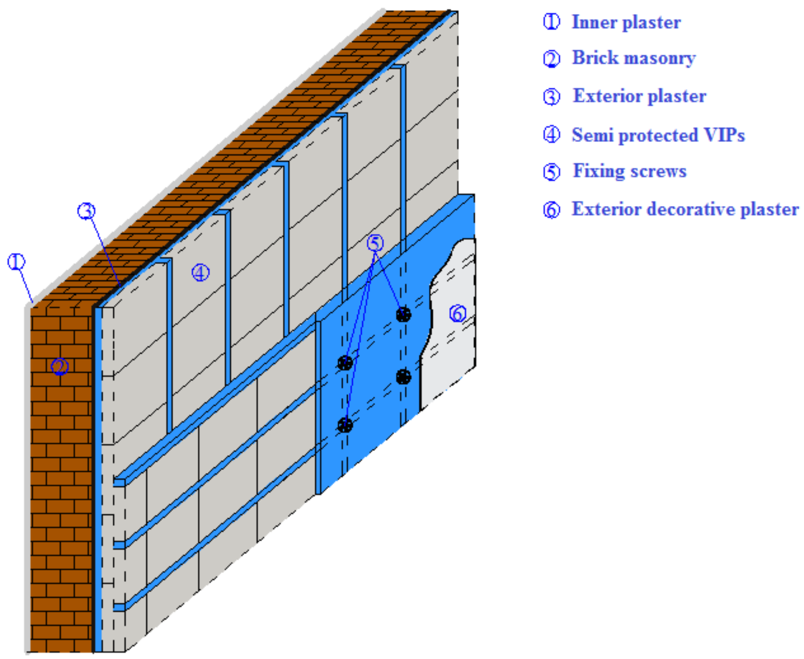

Fig. 1 – Thermal insulation system.

The VIPs type 1 are displaced on the exterior face of the wall as in the Fig. 3. The VIPs type 2 are arranged so that the joint between VIPs type 1 to be in the central area of VIPs type 2.

This kind of arrangement has the advantage to reduce the thermal bridge effect specific to the connection between two adjacent panels, by the displacement of the third panel centered on the axis of the thermal bridge.

The parametric study involved the calculation of the insulated wall effective *U*-value for different thicknesses of the vacuum insulation panels and frontal extruted polistyrene layer of the vacuum panels type 2 (Fig. 2). The analysed combinations are presented in Table 1.

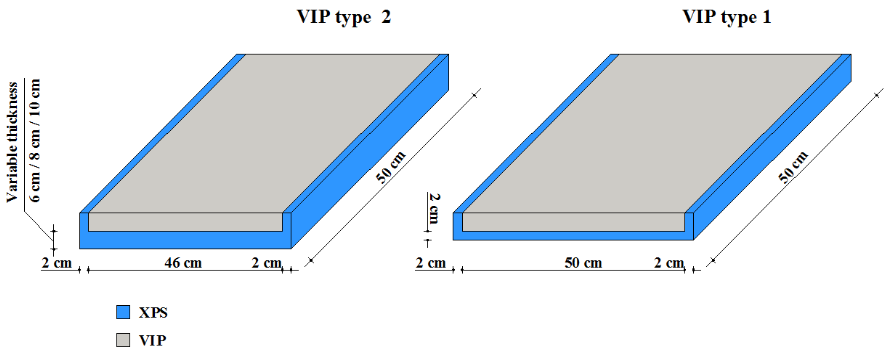

Fig. 2 – The structure of the two types of vacuum insulation panels.

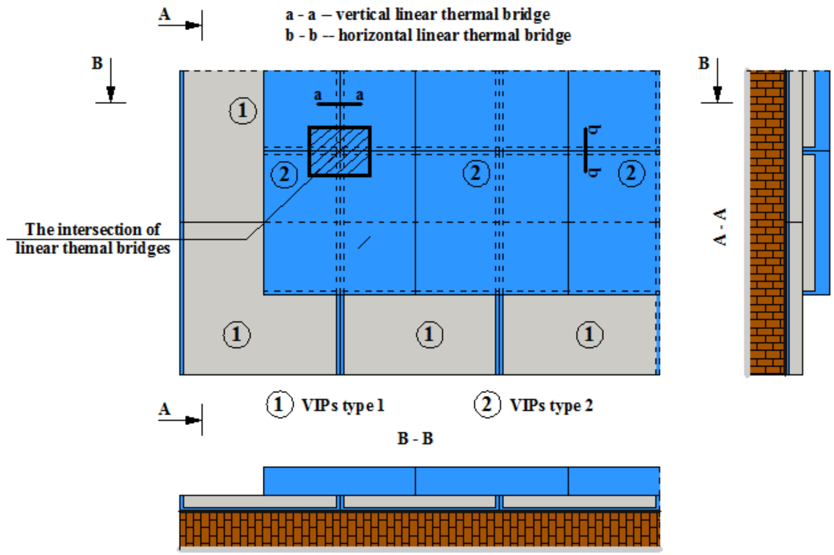

Fig. 3 – The arrangement of the panels and the linear contructive thermal bridges.

Table 1
The Analysed Combinations

Combinations name	The variable parameters		
	VIPs thickness, [cm]		The frontal XPS layer thickness of the VIPs type 2, [cm]
	type 1	type 2	
C1	2	2	6
C2	2	2	8
C3	2	2	10
C4	4	2	6
C5	4	2	8
C6	4	2	10
C7	2	4	6
C8	2	4	8
C9	2	4	10

Due to the very thin envelope of the vacuum insulation panels, the first step regarding the evaluation of the effective *U*-value of the insulated brick wall (U_{eff}), for all the combinations considered, was the determination of the value for effective thermal conductivity of the VIPs ($\lambda_{VIP,\ eff}$), which includes the thermal

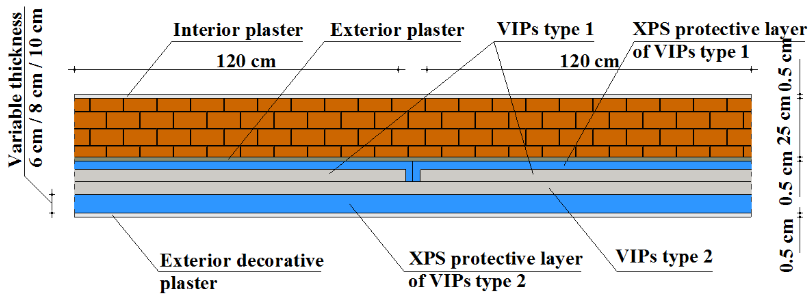

Fig. 4 – Numerical model considered for the determination of the linear thermal transmittance specific to the constructive vertical linear thermal bridge.

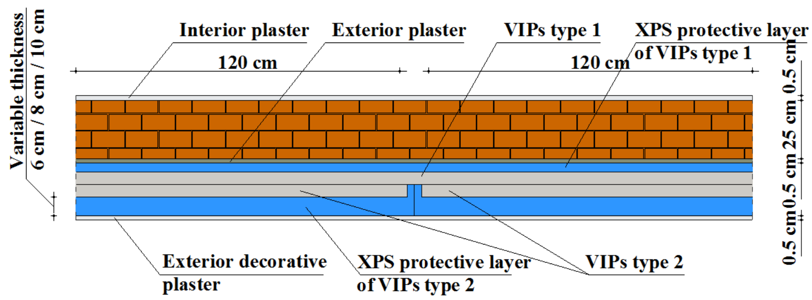

Fig. 5 – Numerical model considered for the determination of the linear thermal transmittance specific to the constructive horizontal linear thermal bridge.

bridge effect due to the envelope of the panel. This first step was neccesary to simplify the numerical model considered for the determination of the linear thermal transmittance specific to the constructive thermal bridges (Figs. 4 and 5), alowing to model the vacuum insulation panels as a homogeneous material characterized by an effective thermal conductivity ($\lambda_{VIP,\ eff}$).

2.2. Results

The linear thermal transmittances of the panel`s edge were determined by numerical simulations, using ANSYS v.12 program. The input data and the boundary conditions considered in the numerical simulation are listed in Table 2. The envelope of the VIPs was considered to be a metallized foil type MF, which is one of the most used barrier foil.

Table 2
Boundary Conditions and Input Data

Boundary Conditions		
Climate	α, [W/(m^2.K)]	*T*, [K]
Indoor	8	293.15
Outdoor	24	252.15
Input Data		
Material	Thermal conductivity, λ W/(m.K)	Thickness, [m]
Interior plaster	0.87	5×10^{-3}
Brick masonry, ρ=1,475 kg/m^3	0.70	0.25
VIPs envelope (MF3)*	0.89	98.3×10^{-6}
VIPs core	0.008	0.02 / 0.04
Extruded polysteryne (XPS)	0.042	variable
Exterior plaster / Exterior decorative plaster	0.93	5×10^{-3}

*Willems *et al.*, 2005.

The effective thermal conductivity of the VIPs ($\lambda_{VIP,\ eff}$) was determined with the relation (Willems *et al.*, 2005):

$$\frac{\lambda_{\text{VIP,eff}}}{t_p} = \frac{\lambda_{cp}}{t_p} + \psi_{\text{VIP}} \frac{P}{A_p} \text{ and consequently } \lambda_{\text{VIP,eff}} = \lambda_{cp} + \psi_{\text{VIP}} \frac{t_p P}{A_p}, \qquad (1)$$

where: t_p is the VIP total thickness, [m], λ_{cp} – the thermal conductivity specific to the central area of the panel, [W/(m.K)], ψ_{VIP} – the linear thermal transmittance of the panel's edge, [W/(m.K)], P – the perimeter of the panel, [m], A – the panels area, [m^2].

The values of the effective thermal conductivity of the VIPs ($\lambda_{VIP,\ eff}$) are presented in the Fig. 6. Having this values, the next step was the evaluation of linear thermal tansmittance due to the constructive thermal bridges (Fig. 3) namely

a) $a – a$, vertical linear thermal bridge;

b) $b – b$, horizontal linear thermal bridge;

c) punctual thermal bridge at the intersection of the linear thermal bridges (Fig. 7).

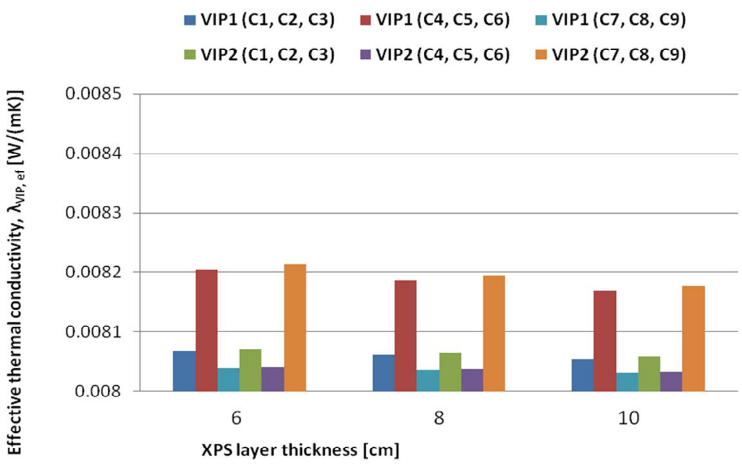

Fig. 6 – Effective thermal conductivity of VIPs *versus* frontal XPS layer thickness of the VIPs type 2.

Table 3
Effective Thermal Transmittance of the Insulated Wall

Combination	Linear thermal transmittance, ψ_1, [W/(m.K)]	Linear thermal transmit-tance, ψ_2, W/(m.K)	Punctual thermal transmit-tance, χ, W/(K)	Thermal transmittance, U, [W/m^2.K]	Effective thermal transmittance, U_{ef}, [W/m^2.K]
C1	0.0028	0.0027	0.00040	0,.35	0.163
C2	0.0024	0.0023	0.00039	0.127	0.152
C3	0.0021	0.0021	0.00031	0.120	0.141
C4	0.0039	0.0015	0.00038	0.102	0.130
C5	0.0035	0.0013	0.00037	0.097	0.122
C6	0.0032	0.0012	0.00029	0.093	0.115
C7	0.0015	0.0038	0.00043	0.102	0.130
C8	0.0013	0.0035	0.00037	0.097	0123
C9	0.0012	0.0031	0.00030	0.093	0.115

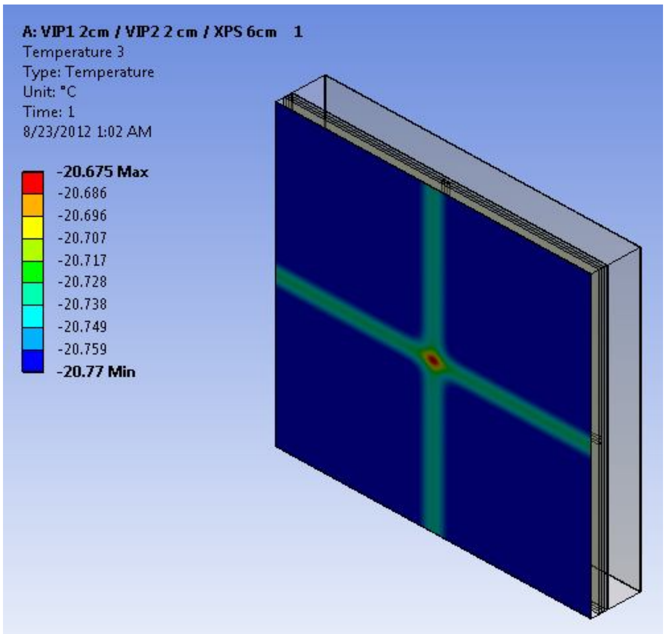

Fig. 7 – Thermal bridges effect on superficial thermal field.

The obtained values for the effective thermal transmittance of the insulated wall (U_{eff}) shows that the constructive thermal bridges have a major influence on thermal performance of the insulation solution (Table 3), this influence being more important with the increase of the unidirectional thermal transmittance of the wall. The negative contribution, with the biggest values, of the linear thermal bridge on the overall thermal transmittance of the wall, U_{eff}, is obtained

Table 4
The Effect of the Constructive Thermal Bridges on Unidirectional Thermal Transmittance of the Insulated Wall

Combination	ΔU		$\Delta U_{\psi 1}$, [%]	$\Delta U_{\psi 2}$, [%]	ΔU_{ψ}, [%]	ΔU_{χ}, [%]
	W/(m.K)	%				
C1	0.028	21	8	8.3	16.3	4.7
C2	0.025	19.7	7.3	7.6	14.9	4.8
C3	0.022	18.2	7	7	14	4.2
C4	0.028	27.1	5.9	15.3	21.2	5.9
C5	0025	25.9	5.4	14.4	19.8	6.1
C6	0.022	24	5.2	13.8	19	5
C7	0.028	27.5	14.9	5.9	20.8	6.7
C8	0.025	25.9	14.4	5.4	19.8	6.1
C9	0.022	23.7	13.4	5.2	18.6	6.1

for the combinations C4 and C7, percentange increase of the thermal transmittance due to linear thermal bridges (ΔU_ψ) being higher than 20% (Table 4). A decrease of ΔU_ψ is obtained by increasing the thickness of the protective frontal XPS layer of the VIPs type 2.

Even if the contribution of the punctual thermal bridges is small, comparative with the contribution of the linear thermal bridges, it can not be neglected.

3. Conclusions

Vacuum insulation panels have a low thermal conductivity which characterizes the central area of the panel. For an appropriate approach concerning thermal insulation properties of VIPs, a special attention should be paid for the thermal bridge that occurs at the panels edge.

This study is concerned with the thermal performance of an outer brick wall insulated with vacuum insulation panels. The study results shows that applying the proposed thermal insulation solution it is possible to be obtained very low values for the walls effective thermal transmittance. This level of insulation is requested for low energy buildings which have been started to be developed more and more lately, due to the energy crisis. The advantage reached by using vacuum insulation panels is that the total thickness of the thermal insulation layer is significantly lower than the total thickness obtained in the case of a traditional thermal insulation solution (like with polysteryne or mineral wool).

Acknowledgements. This paper was realised with the support of EURODOC “Doctoral Scholarships for research performance at European level” project, financed by the European Social Found and Romanian Government. The authors would like to express their gratitude to the Department of Civil Engineering and to Professor Adrian Radu for their support.

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STUDIU PARAMETRIC PRIVIND PERFORMANȚA TERMICĂ A UNUI PERETE EXTERIOR IZOLAT CU PANOURI VIDATE TERMOIZOLANTE

(Rezumat)

Cerințele privind izolarea termică a clădirilor noi şi reabilitarea termică a clădirilor existente tind către un grad de izolare termică care permite îndeplinirea cerințelor de izolare specifice clădirilor cu consum redus de energie. Atingerea acestui nivel de izolare implică fie adoptarea unor grosimi mari de izolație termică în cazul utilizării materialelor tradiționale (polistiren, vată minerală etc.), fie utilizarea unor materiale cu performanțe termice superioare.

Panourile vidate termoizolante (PVT) sunt materiale cu performanțe termice superioare caracterizate printr-o conductivitate termică foarte redusă, de 5 până la de 8 ori mai mică decât cea a materialelor convenționale de izolare termică. Panourile vidate sunt alcătuite dintr-un miez (componenta principală a miezului fiind silicea pirogenetică) încapsulat de o anvelopă multistratificată. Evaluarea performaței termice a acestor tipuri de materiale necesită evaluarea transmitanței termice liniare a punții termice de contur datorate modului de alcătuire a panourilor vidate.

Se prezintă rezultatele unui studiu parametric privind performanța termică a unui perete exterior izolat cu panouri vidate. Studiul evidențiază parametrii cu impactul cel mai mare asupra coeficientului de transfer termic efectiv ce caracterizează peretele.