Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 151 (2016) 206 – 213

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Ecology and new Building materials and products, ICEBMP 2016

Study of the use of vacuum insulation as integrated thermal insulation in ceramic masonry blocks

Jiří Zach[a], Vítězslav Novák[b,*]

[a] Senior researcher, Brno University of Technology, Faculty of Civil Engineering, Admas Centre, Veveří 331/95, 602 00 Brno, the Czech Republic

[b] Ph. D. Student, Brno University of Technology, Faculty of Civil Engineering, Admas Centre, Veveří 331/95, 602 00 Brno, the Czech Republic

Abstract

Vacuum insulation panels (VIP) are thermal insulation materials with very low thermal conductivity. VIPs are commonly used in a broad spectrum of technical fields; however, they only see a small-scale application in civil engineering. The reason is mainly their high price and difficulty of installation. VIPs are very vulnerable to mechanical damage, which typically causes the loss of their thermal insulation properties. This paper deals with the possibility of effective incorporation of these insulation materials into masonry blocks designed for exterior walls, where VIPs become integrated insulation. This application minimises the hazard of mechanical damage provided the insulation is placed in the block correctly. In this paper, four kinds of materials, applicable as the core of VIPs, are compared. This is a standard mineral wool, commercial VIP based on pyrogenic silica and two experimental types of VIPs based on cotton. Four application possibilities were proposed and thermal properties of individual variants were compared.

Peer-review under responsibility of the organizing committee of ICEBMP 2016

Keywords: Vacuum insulation panel; thermal conductivity; masonry element; masonry constructions

* Corresponding author. Tel.: +420-737-041-975.
E-mail address: novak.v@fce.vutbr.cz

Peer-review under responsibility of the organizing committee of ICEBMP 2016
doi:10.1016/j.proeng.2016.07.391

1. Introduction

The current share of energy needed for heating and cooling of buildings is 40 % of the total energy consumed. The high amount of energy needed for heating and ventilation has a negative impact on the environment, especially in terms of CO_2 emissions and the exploitation of non-renewable material resources (fossil fuels). Improving the energy performance of buildings is one of the key contemporary topics worldwide. In Europe, the thermal protection of buildings is regulated by the Directive 2010/31/EU of the European Parliament and Council. One of the ways of improving the energy performance of buildings described therein is the improvement of the thermal properties of building envelopes [1,2].

The building envelopes of masonry buildings (constructed as single-wythe structures) can be improved by several means. The thermal conductivity of the material of the building blocks can be reduced, their geometry (both internal and external) and thickness can be modified or they can have thermal insulation incorporated inside (integrated thermal insulation). Concerning ceramic masonry blocks, it appears that this way is the most promising and will enable further improvement of the thermal insulation properties of masonry without the need for increasing its thickness excessively.

2. Vacuum insulation panels (VIP)

VIPs are a new progressive type of thermal insulation with extremely low thermal conductivity. They consist of two basic parts – the core and the envelope. Each part has its specific function and must meet specific requirements. The VIP core is made from an insulation material with a very fine pore structure and extremely low thermal conductivity at low pressure. The function of the core is to maintain a constant near-vacuum negative pressure inside the insulation. It also protects the insulation from mechanical damage.

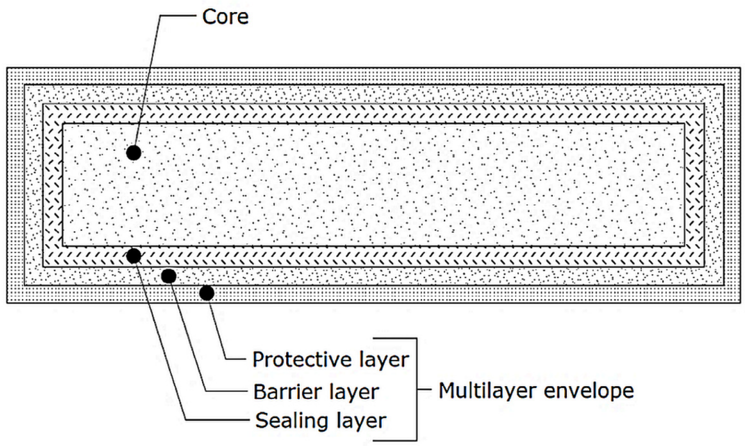

Fig. 1. VIP diagram.

VIPs have significantly lower values of thermal conductivity than thermal insulation commonly used in construction today. They are 5 to 10 times better than that of the common thermal insulation; specifically 0.003 – 0.008 $W \cdot m^{-1} \cdot K^{-1}$. Thanks to this, the use of VIPs significantly improves the thermal insulation properties of the whole structure. However, VIPs are rather fragile, since they lose their unique properties upon mechanical damage. Nowadays, VIPs are frequently used in refrigeration, whether in refrigeration boxes, temperature controlled vans or home appliances. In these applications, VIPs are firmly incorporated into the plastic or metal walls of these devices.

2.1. VIP core

The VIP core consists of an insulation material with very fine open pores and is vacuum-sealed inside the VIP. After vacuum sealing, the thermal conductivity drops and the low-emission insulation envelopes (or the addition of special admixtures) reduce heat radiation through the insulation. Thanks to these factors, the finished VIP has very good thermal insulation properties. The core also provides the characteristic mechanical properties to the whole panel. Generally, the smaller the core pores are, the lower values of thermal conductivity can be achieved at a higher pressure. The pores of the insulation must be open in order to enable the reduction of the internal pressure to a near-vacuum. The core must also be able to withstand great compression caused by the pressure difference between the inside (low) and outside (high) of the panel. Nowadays, VIP cores are usually made of silica aerogels, polyurethane and polystyrene foams and fibreglass. Recently, melamine formaldehyde fibres have also begun to be used [1,3,4,5]. Brno University of Technology is conducting research in the utilisation of fibrous materials as VIP cores.

2.2. VIP envelope

The purpose of the envelope is to seal the material away from air and water vapour. This maintains vacuum inside the VIP. If air or vapour enters inside the VIP, its thermal insulation properties change. The VIP envelope is often formed by several layers, each of which has its function. The inner layer is always the sealing one. It is typically made of polyethylene. On the outside of the sealing layer, there is the barrier layer keeping air and water away. It is mostly made of laminated material or aluminium foil. Aluminium foil also limits heat transfer by radiation (due to its low emissivity). The outer layer is the protective layer. Its purpose is to protect the whole panel against mechanical damage [1,6].

3. The use of VIP in civil engineering

VIPs have been known for a long time; first experiments with them were conducted in the early 20th century. However, the first experiments with using them in civil engineering did not take place until 1999. There are two main hazards connected with the use of VIPs in construction [4].

The first is their susceptibility to mechanical damage, which significantly reduces the characteristic properties. Because of this risk, it is necessary to be extra careful during the transportation and handling of VIPs. Also, their dimensions cannot be modified and they cannot be perforated (perforation is only possible in specially prepared points). VIPs are therefore difficult to fasten onto the building envelope without thermal bridges forming between the panels.

Some manufacturers try to minimise the problem with the mechanical vulnerability of VIPs by incorporating them in sandwich panels.

The second reason why VIPs see infrequent use in civil engineering is their price. The price of the insulation is determined mainly by the high price of the materials used in the panel core. In other fields, contrary to civil engineering, this fact is acceptable, since VIPs are applied on much smaller areas. However, in terms of the total costs of a building, the application of existing VIPs in the building envelope is still too expensive.

If VIPs are to find broader use, it is necessary to look not only for a safe and easy way of their installation in the building envelope, but also a suitable and affordable thermal insulation material for the panel core. These requirements could be met by using VIPs as integrated thermal insulation in the cavities of ceramic masonry blocks, where the VIP core is made from plant fibres, which are abundant in sufficient quantity.

4. VIPs as insulation integrated into ceramic masonry blocks

The application of VIPs in the cavities of masonry blocks offers an alternative to the contemporary practice of applying VIPs in building envelopes [7,8,9]. An advantage of this application is increasing the protection of VIPs against mechanical damage, as the panel is incorporated into the block itself and thus protected. In order to avoid an excessive price increase per block (caused by integrating VIP in the cavities of masonry blocks) it is necessary to choose an affordable material for the panel core.

Brno University of Technology has been researching and examining the application of VIPs with the core made from natural fibres, while comparing them with common types of VIPs. The result should be single-wythe masonry with the lowest possible thickness and the best possible thermal insulation properties.

4.1. Design of the VIP application

The commonly used block for exterior walls with the thickness of 300 mm was chosen for the testing of the integration of VIPs into ceramic masonry blocks. It is a masonry element, which normally does not meet the ever stricter requirements on thermal insulation. The values of thermal transmittance coefficient of the THERM-type block at wall thickness of 300 mm are within 0.25 – 0.70 $W \cdot m^{-2} \cdot K^{-1}$.

The internal geometry of the block was chosen with the application of VIPs in mind. Thus, the chosen block had large cavities, arranged in 5 rows aligned perpendicularly to the thermal flux; the width of each cavity is 40 mm. The calculations were performed using the value of the ceramic body's thermal conductivity of 0.275 $W \cdot m^{-1} \cdot K^{-1}$. A diagram of the chosen block and its internal geometry is in Figure 2 below.

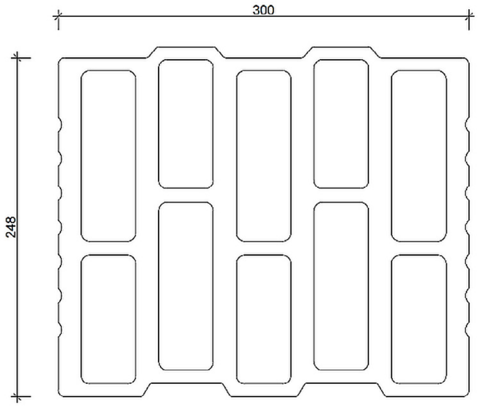

Fig. 2. Geometry of the block.

In order to avoid mechanical damage to the VIP during its integration into the cavities, a special system of insulation was designed for the integration procedure. The system consists of a 20 mm thick VIP, which is placed between two slabs of mineral wool. The slabs are 12 mm thick. During application, they are compressed to 10 mm, which secures the VIP in place inside the block. The mineral wool also protects the VIP from mechanical damage. The walls of the cavity are lined with protective geotextile. Figure 3 shows a diagram of the whole system.

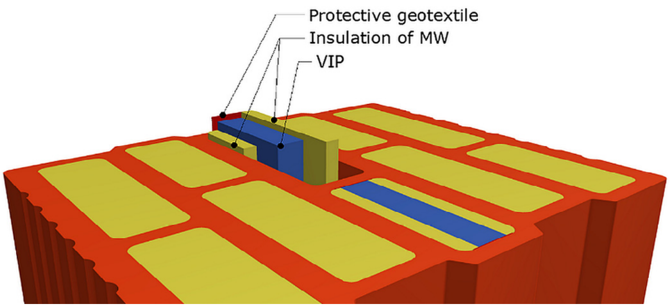

Fig. 3. Diagram of filling a block cavity with a VIP.

4.2. Materials and methods

Two types of VIP were chosen as thermal insulation integrated into the cavities of ceramic blocks. One was a commonly used VIP with the core made of pyrogenic silica and the other was the newly developed VIP with the core made from cotton fibres. For comparison, a calculation with mineral wool insulation was also performed. The details of the samples are in the list below:

- (REF) basic mineral fibre Mineral Wool insulation with thermal conductivity of 0.035 $W \cdot m^{-1} \cdot K^{-1}$.
- (VIP 1) commercial VIP based on pyrogenic silica with thermal conductivity of 0.007 $W \cdot m^{-1} \cdot K^{-1}$.
- (VIP 2) experimental VIP based on defibred cotton (normal quality) core insulation with thermal conductivity of 0.006 $W \cdot m^{-1} \cdot K^{-1}$ (the value was rounded up to thousands).
- (VIP 3) experimental VIP based on defibred cotton (high quality) core insulation with thermal conductivity of 0.004 $W \cdot m^{-1} \cdot K^{-1}$ (the value was rounded up to thousands).

* in VIP 2, normal quality waste cotton is used with mean density of around 120 $kg \cdot m^{-3}$, VIP 3 is high quality waste cotton with purity above 95 % used with high density of around 200 $kg \cdot m^{-3}$.

Different variants of filling the cavities of the blocks were chosen for the determination of the properties. The VIPs were applied in four different variants for the purposes of simulation. The first variant had the VIPs in the middle, 3rd row of cavities, the second one in the 2nd + 4th row, the third in the 2nd + 3rd + 4th row and the last variant had VIPs in all rows, i.e. 1st – 5th. The remaining rows were always filled with an insulating material of MW (REF). The VIP location in the 2nd, 3rd and 4th row has a significant advantage, compared to VIPs in the 1st and 5st rows. They offer increased protection to the VIP against possible mechanical damage caused by perforation by anchoring elements in the ribs and cavities of the blocks. The variants are shown in Figure 4.

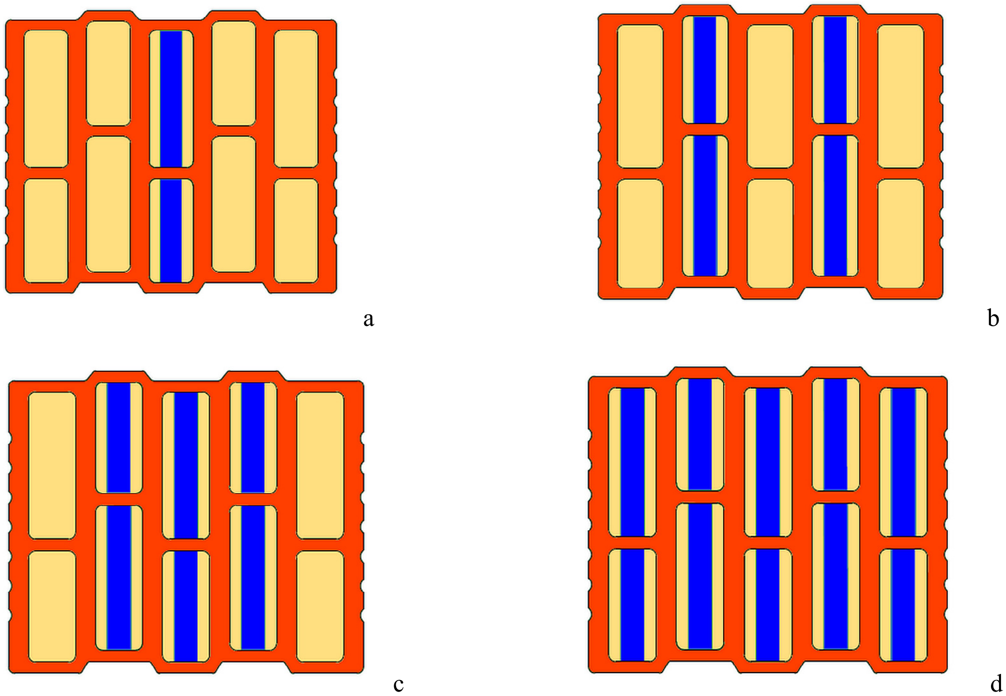

Fig. 4. Variants of fitting VIPs in the cavities, (a) VIPs in 3rd row of cavities, (b) VIPs in 2nd + 4th row of cavities, (c) VIPs in 2nd + 3rd + 4th row of cavities, (d) VIPs in all rows 1st – 5th.

5. Calculation of the thermal insulation properties of blocks with integrated VIPs

The calculations were performed on a typical masonry cut-out in accordance with EN 1745. It was exposed to the action of a thermal field $\theta_1 = \theta_i = + 21$ °C, $\theta_2 = \theta_e = - 15$ °C. The calculation was performed using the finite element method according to EN ISO 6946. Thermal-technical properties of the masonry building materials were chosen in accordance with the values listed above. The equivalent value of thermal conductivity of air in the head joint cavities in the direction of the heat flow was determined according to EN ISO 6946.

Table 1. Equivalent value of thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$).

Location of VIP	REF	VIP 1	VIP 2	VIP 3
3rd row	0.078	0.070	0.069	0.067
2nd + 4th row	0.078	0.063	0.062	0.060
2nd + 3rd + 4th row	0.078	0.058	0.056	0.052
1st – 5th row	0.078	0.049	0.047	0.043

Table 2. Thermal resistance of the block ($m^2 \cdot K \cdot W^{-1}$).

Location of VIP	REF	VIP 1	VIP 2	VIP 3
3rd row	3.853	4.307	4.356	4.482
2nd + 4th row	3.853	4.727	4.815	5.038
2nd + 3rd + 4th row	3.853	5.217	5.366	5.745
1st – 5th row	3.853	6.097	6.341	6.952

Table 3. Heat transfer coefficient of the block ($W \cdot m^{-2} \cdot K^{-1}$).

Location of VIP	REF	VIP 1	VIP 2	VIP 3
3rd row	0.249	0.224	0.221	0.215
2nd + 4th row	0.249	0.204	0.201	0.192
2nd + 3rd + 4th row	0.249	0.186	0.181	0.169
1st – 5th row	0.249	0.160	0.154	0.141

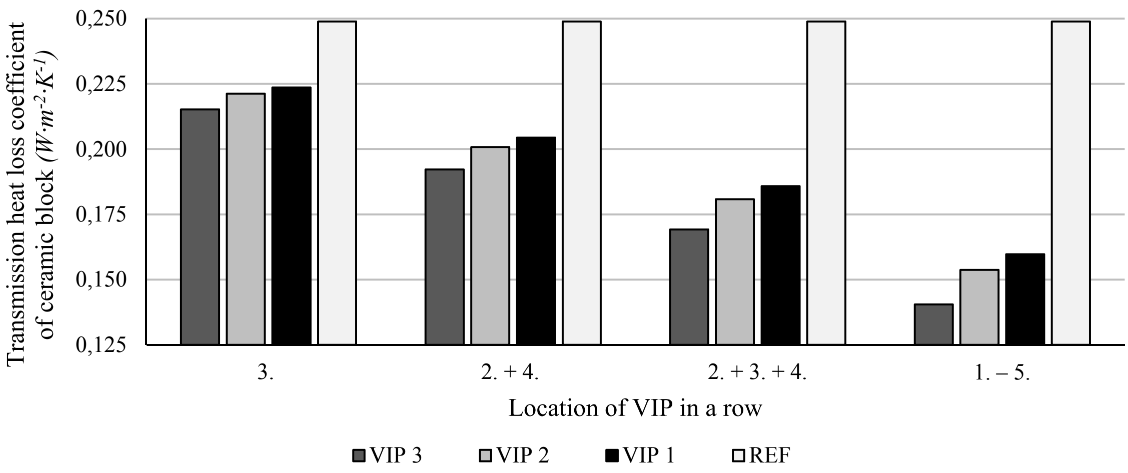

Fig. 5. Chart of the heat transfer coefficient of the blocks containing VIPs.

6. Evaluation of results

The results how that the use of VIPs as an integrated thermal insulation in the cavities of ceramic blocks has a positive effect on the value of heat-technical properties of the blocks. A specific comparison of the application of VIPs in the selected variants is shown in the Table 4 and Fig. 6 below.

Table 4. Percentage improvement in thermal insulation properties (%).

Location of VIP	VIP 1	VIP 2	VIP 3
3rd row	11.8	13.1	16.3
2nd + 4th row	22.7	25.0	30.8
2nd + 3rd + 4th row	35.4	39.3	49.1
1st – 5th row	58.2	64.6	80.5

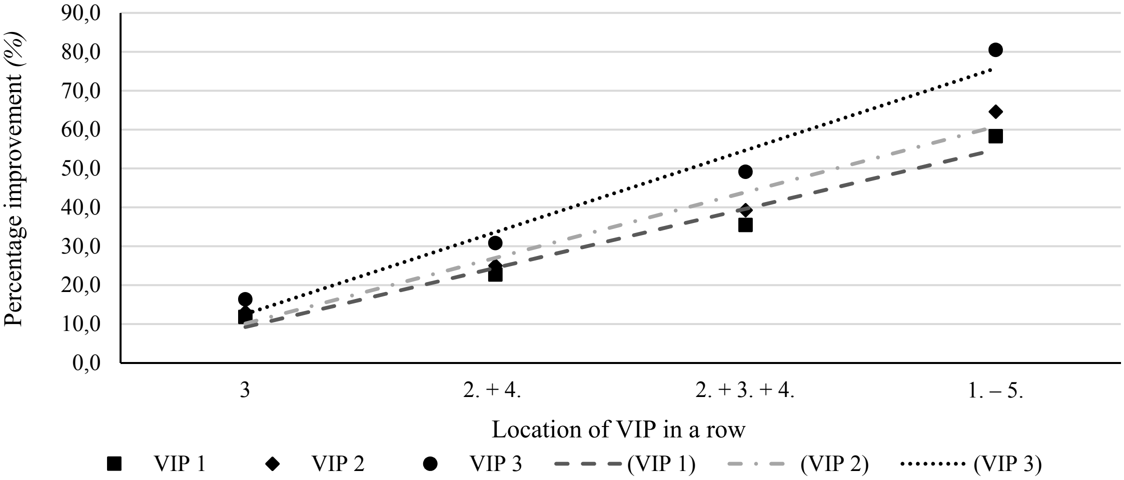

Fig. 6. Chart of gradual improvement of thermal insulation properties with the use of VIP.

When VIPs were applied in one row of cavities (3rd), an improvement by 12 – 16 % was achieved, when VIPs were applied in two rows (2nd + 4th), an improvement by 23 – 31 % was achieved, when VIPs were applied in three rows (2nd + 3rd + 4th), an improvement by 36 – 49 % was achieved and when VIPs were applied in all rows, an improvement by 58 – 81 % was achieved. It is therefore apparent that in order to achieve a more significant improvement in the properties of the masonry pieces, VIPs must be placed in at least two rows.

The variant of VIP fitting into the central rows (2nd, 3rd and 4th) also has several other positives. VIPs are adequately protected against mechanical damage from the interior and exterior. When the VIPs are fitted closer to the centre of the block, it is easier to implement other construction details, for example, the installation of windows and doors. The number of rows filled with VIPs is also important in terms of costs, as fitting more rows increases the price per one block. Given these facts, the variants with one row (3rd) and two rows (2nd + 4th) fitted with VIPs were chosen for further study in model situations.

7. Conclusion

Based on the research performed, it was found that VIPs can be successfully integrated into the large cavities in ceramic blocks. A system for fixation of VIPs in cavities was made. The VIP based on recycled cotton was identified as potentially advantageous, as there is a promise of lower prices compared with VIPs based on SiO_2 [10]. Furthermore, it was found that a significant improvement in thermal insulation properties is achieved by applying VIPs in at least two rows of cavities. It is more preferable to place the VIPs closer to the centre of the block. In this position, the VIPs are better protected against mechanical damage.

The topic of VIPs and their application in civil engineering has been addressed in a number of scientific investigations. However, the application of VIPs in the cavities of ceramic blocks is a new solution, which carries certain advantages.

It can be concluded that the application of VIPs in ceramic concrete blocks can significantly improve the thermal insulation properties of single-wythe structures. From the perspective of the VIPs, it is not necessary to address the complicated problems with anchoring (in the case of vertical structures, this is mostly problematic) and the VIP is protected against mechanical damage in the ceramic block, which ought to ensure its long service life in the structure.

Acknowledgements

This paper was written under the project No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by the Ministry of Education, Youth and Sports under the "National Sustainability Programme I" and under the project of the Technology Agency of the Czech Republic ref. n. TA04020920.

References

[1] S. E. Kalnæs, B. P. Jelle, Vacuum insulation panel products: A state-of-the-art review and future research pathways, Appl. Energ. 116 (2014) 355–375.

[2] Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast), Official Journal of the European Union (2010).

[3] V. Nemanič, M. Žumer, New organic fiber–based core material for vacuum thermal insulation, Energ. Buildings 90 (2015) 137–141.

[4] S. Brunner, K. G. Wakili, T. Stahl, B. Binder, Vacuum insulation panels for building applications – Continuous challenges and developments, Energ. Buildings 85 (2014) 592–596.

[5] H. P. Ebent, J. Fricke, U. Heinemann, Vacuum insulation panels – From research to market, Vacuum 82 (2007) 680–690.

[6] M. Alam, H. Singh, M. Limbachiya, Vacuum insulation panels (VIPs) for building construction industry – A review of the contemporary developments and future directions, Appl. Energ. 88 (2011) 3592–3602.

[7] F. E. Boafo, J. T. Kim, Z. Chen, Configured cavity-core matrix for vacuum insulation panel: Concept, preparation and thermophysical properties, Energ. Buildings 97 (2015) 98–106.

[8] A. Lorenzati, S. Fantucci, A. Capozzoli, M. Perino, The effect of different materials joint in vacuum insulation panels, Energy Procedia 62 (2014) 374–381.

[9] P. Johansson, C. E. Hagentoft, A. S. Kalagasidis, Retrofitting of a listed brick and wood building using vacuum insulation panels on the exterior of the facade: Measurements and simulations, Energ. Buildings 73 (2014) 92–104.

[10] A. Korjenic, V. Petránek, J. Zach, J. Hroudová, Development and performance evaluation of natural thermal-insulation materials composed of renewable resources, Energ. Buildings 43 (2011) 2518–2523.