Subject Review

TOWARDS LOW ENERGY BUILDING USING VACUUM INSULATION PANELS. ADVANTAGES AND DISADVANTAGES

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ABSTRACT

The increasing interest in building developments with very low energy consumption, energy-positive or passive houses has directed the attention of those involved in this area to high thermal performance insulation materials, like vacuum insulation panels (VIP). Vacuum insulation panels are part of high thermal performance insulations, which attempts to be introduced and used in the construction field. The main interest for these materials is due to their thermal properties, namely to their very low thermal conductivity (of 5 to 8 times) compared with traditional thermal insulation materials (mineral wool, extruded/expanded polystyrene). The thermal conductivity of thermal insulation widely used, hence traditional or classical insulation names, as expanded polystyrene (EPS), extruded polystyrene (XPS), mineral wool or polyurethane foam (PUR) has typical values between 0.03 and 0.05 W/(mK). Using these types of insulations to fulfill performance envelope elements in terms of energy, leads to the adoption of an increased insulation thickness. Vacuum insulation panels may offer new solution for high performance insulation with a thickness in order of a few centimeters compared to the conventional insulation. Vacuum insulation panels can be used as independently insulation, replacing entirely the conventional ones or as additional insulation.

Keywords: vacuum insulation panels; thermal conductivity; passive house; thermal insulation.

REZUMAT

Interesul crescând pentru realizarea unor construcții cu consum foarte mic de energie, energopozitive, sau a caselor pasive, au direcționat atenția celor implicați în acest domeniu către materialele termoizolante performante, printre care se numără şi panourile vidate (VIP – Vacuum Insulation Panel). Panourile vidate fac parte din categoria termoizolațiilor performante, care se încearcă a fi introduse şi utilizate în sectorul construcțiilor. Interesul major pentru aceste materiale se datorează proprietăților termice pe care le au şi anume o conductivitate termică foarte scăzută (de 5 până la de 8 ori) în comparație cu materialele tradiționale (vata minerala sau polistiren extrudat/expandat). Conductivitatea termică a izolațiilor termice utilizate la scară largă, de unde şi denumirile de izolații tradiționale sau clasice, precum polistiren expandat (EPS), polistiren extrudat (XPS), vată minerală sau spumă poliuretanică (PUR), are valori tipice cuprinse între 0,03 şi 0,05 W/(mK). Utilizarea acestor tipuri de izolații pentru obținerea unor elemente de anvelopă performante din punct de vedere energetic, conduce la adoptarea unor grosimi sporite de termoizolație. Panourile vidate pot oferi noi soluții pentru termoizolații performante cu grosimi de ordinul a câtorva centrimetri, în comparație cu materialele termoizolante tradiționale. Panourile vidate se pot folosi fie ca termoizolație de sine stătoare, înlocuind izolațiile clasice, fie ca şi o izolație adițională la o termoizolație uzuală.

Cuvinte cheie: panouri vidate termoizolante; conductivitate termică; casă pasivă; izolație termică.

1. INTRODUCTION

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.

Romania, as a member state of the European Union, has to adopt a legislative framework and a national strategy whose measures aims the reducing of GHG and energy efficiency in the building sector, under new Directive 2010/31/EU *of the European Parliament and of the Council*. One of the most challenging objectives of the Directive, is to achieve buildings which primary energy consumption has to be less than or equal to the production of energy from renewable sources (starting with December 31, 2018 for the buildings occupied and owned by public authorities and starting with December 31, 2020 for all new buildings regardless of destination).

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. 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 INSULATION

2.1. Traditional thermal insulation

The total heat transfer, regarding conventional thermal insulation (XPS, EPS, mineral wool), is dominated by the contribution of the gas phase (see fig. 1). In the cellular and porous materials, the heat is transmitted through four distinct mechanisms: convection (λ_c), conduction through the solid phase (λ_s) and through the gas phase (λ_g) and radiation (λ_r) (Simmler et al., 2005).

$$\lambda_t = \lambda_c + \lambda_s + \lambda_g + \lambda_r \qquad (1)$$

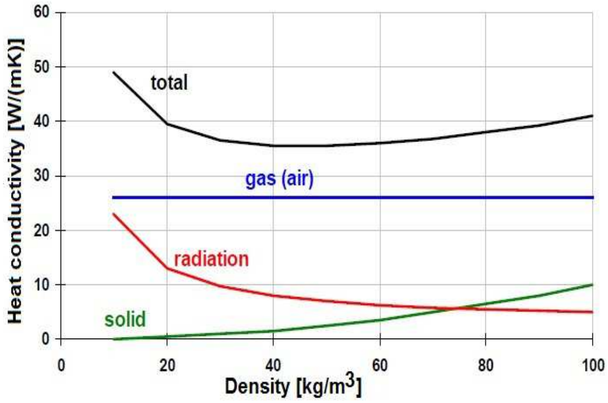

Fig. 1. Thermal conductivity of conventional insulations (Simmler et al., 2005)

The thermal conductivity of thermal insulation widely used, hence traditional or classical insulation names, as expanded polystyrene (EPS), extruded polystyrene (XPS), mineral wool or polyurethane foam (PUR) has typical values between 0.03 and 0.05 W/(mK). Using these types of insulations to fulfil performance envolope elements in terms of energy, leads to the adoption of an increased insulation thickness.

Thus, the idea of a potential progress arises, regarding the increase of thermal insulation capacity by reducing the partial or total the contribution of the gas phase in heat transfer through the material. New techniques are developed based on new technologies (Simmler et al., 2005):

- microporous structures;
- vacuum technologies;
- special gases.

The first applications of these techniques has proven that can be achieve values of 0.005 W/(mK) for thermal conductivity.

2.2. Vacuum insulation panels

A vacuum insulation panel (VIP) is a high thermal insulation product made of a micro or nanoporous material, which it is sealed into a barrier envelope after the evacuation (see Fig. 2).

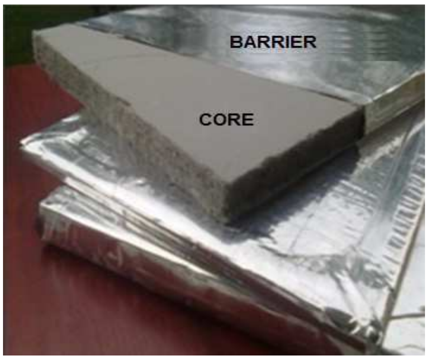

Fig. 2. Vacuum insulation panels

The core material has to fulfil some conditions to be suitable for the role that it has to play, such as very small pores and a 100% open cell structure in order to evacuate any gas from the material and to reduce the gaseous conductivity (Baetens et al., 2010). The resistance to compression has to be high enough so that the pores to do not collapse when the evacuation is applied and it has to be as impermeable as possible to infrared radiation. The material that is commonly used in present for the production of vacuum insulation panels is the pressed powder board of fumed silica, material that meets the requirements listed above.

The second component of the VIP it is the barrier that is responsible to maintain the inner pressure of the panel at imposed values. Currently, there are used three types of envelopes, which are presented in fig. 3.

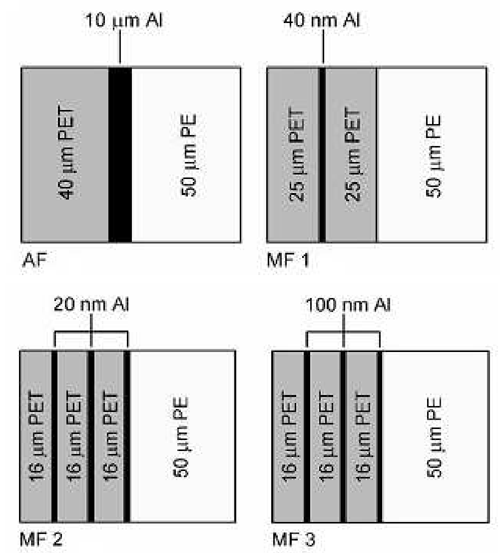

Fig. 3. Sections of the commonly VIP envelope types (Willems et al., 2009)

The aluminium foil (AF), consists of a central laminated aluminium layer, which is covered on one side with a PET layer and on the other side with a PE layer. The second type, the metallized film (MF), it is made by up to three layers coated PET films and an inner PE layer. The third type it is represented by the polymer films which can contain different plastic layers. The PET (polyethylene terephthalate) layer serves as a scratch-resistant layer, while the inner PE (polyethylene) layer it is the sealing layer. The aluminium layer is used for his capacity of having a low water vapour and gas permeation.

The third constituent of the VIP are the desiccants and the getters. These materials can be part of the core or not. Their presence in the structure of the VIP depends on the type of core material. Their role is to absorb the water vapour (the desiccants) and the gas molecules (the getters) thus maintaining the inner pressure to a certain value. Beside these types of chemicals, in the VIP core structure can be found also opacifying materials, which must reduce the radiant conductivity or different types of fibres to increase the compression resistance of the core.

The main interest for VIP is due to their thermal properties, namely to their very low thermal conductivity (of 5 up to 10 times), compared with traditional thermal insulation materials (mineral wool, EPS, XPS or PUR).

2.3. Low energy buildings

The promotion of sustainable development has led to a growing interest in the development of efficient energy buildings. Whether they are called Zero Energy Buildings (ZEB), Passive Houses (PH), Low-Energy Buildings (LEB), Very Low Energy Buildings (VLEB) or Nearly Zero Energy Buildings (NZEB), all aim to ensure the indoor conditions with as low energy consumption as possible. The development of these types of buildings involves two kinds of measures: active measures and passive measures.

For each type of building listed before, an envelope with a high thermal resistance is necessary. The increase of thermal resistance of building envelope belongs to the passive measures category.

To increase thermal resistance of an opaque element of the building envelope implies two sorts of measures:

- use of increased thermal insulation thickness;
- use of high thermal performance insulation materials.

Frequently, the first measure is not a possible option, due to technological or design reasons. This kind of situations are for the most times met in the rehabilitation sector where space becomes a sensible problem and where the new thermal insulation must fill in the space of the old one, but, at the same time it has to improve significantly the thermal resistance of the rehabilitated element. Therefore, the only viable choice remains the adoption of high thermal performance materials, such as vacuum insulation panels.

2.4. VIP properties

The most important property that makes vacuum insulation panels become an attractive material is the high thermal resistance, compared to conventional thermal insulations.

In the case of a homogeneous material, the *U*-value is given by:

$$U = \frac{1}{R} \quad (2)$$

where *R* is the unidirectional thermal resistance in [(m^{2}K)/W].

Regarding vacuum insulation panels, equation (2) is not adequate for the evaluation of the *U*-value, as the panel edges form strong thermal bridges. According to the Romanian norm C107/2005, the *U*-value of a structure with thermal bridges included (in our case, VIP) is calculated with the equation:

$$U_{VIP} = U_{cp} + \frac{\sum_i \psi_i l_i}{A} + \frac{\sum_j \chi_j}{A} = U_{cp} + \frac{\psi_{vip} P}{A} \quad (3)$$

where: U_{cp} is the unidirectional thermal transmittance (specific to the central area of the panel) [W/(m^{2}K)], Ψ_i is the linear thermal transmittance of the linear thermal bridge "*i*" [W/(mK)], l_i is the length of the linear thermal bridge "*i*" [m], χ_j is the punctual thermal transmittance of the punctual thermal bridge "*j*" [W/K], *P* is the perimeter of the panel [m] and *A* is the area of the structure [m^2].

The effect of the punctual thermal bridge over the thermal transmittance is insignificant, so the third term of equation (3) can be neglected.

Expressing the thermal transmittance versus thermal conductivity, we obtain:

$$\frac{\lambda_e}{t_p} = \frac{\lambda_{cp}}{t_p} + \frac{\psi_{vip} P}{A} \Leftrightarrow \lambda_e = \lambda_{cp} + \psi_{vip} \frac{t_p P}{A} \quad (4)$$

where λ_e is the equivalent thermal conductivity of the vacuum insulation panel [W/(mK)], λ_{cp} is the thermal conductivity of the panel central area [W/(mK)] and t_p is the panel thickness [m].

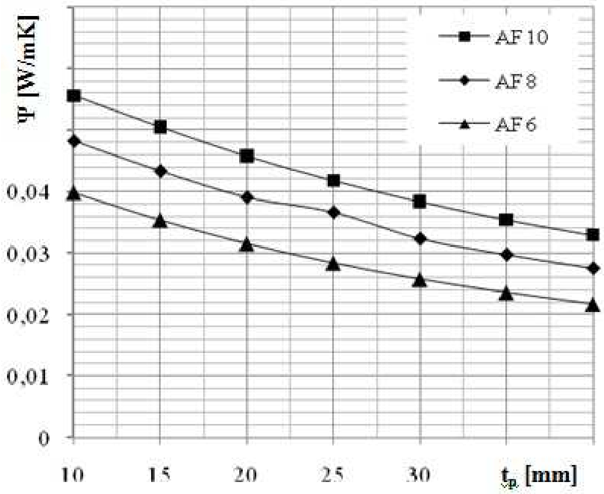

Fig. 4. Linear thermal transmittance as function of panel thickness (VIP with different laminated foil) (Ciobanu et al., 2011)

It can be observed that the equivalent thermal conductivity of VIP depends on the thermal conductivity of the central area of the panel, the linear thermal transmittance and on the value of the *P/A* ratio (see fig. 4).

The vacuum insulation panels are fragile materials. They should not be the subject of a mechanical action and they should not be drilled or cut. If so, the inner pressure will rise and the thermal conductivity will increase. It must be noted that, in the case of fumed silica-based VIP, at an inner pressure value equal with the atmosphere pressure the VIP thermal conductivity (specific to the panel center area) is two times lower than the thermal conductivity of the conventional insulation, and it is around 0.02 W/(mK) (Binz et al., 2005).

Regarding the fire behavior, the core of the VIP is not flammable. A special attention should be paid to the barrier, which is a flammable material (Simmler et al., 2005).

3. CONCLUSIONS

The use of VIP instead of conventional thermal insulation materials has the advantage of decreasing the insulation layer thickness. However, the use of vacuum insulation panels involves some several measures that have to be taken into account:

- implementation of a previously established plan, which has to contain the number of the panels, the position of each panel in relation with the area of the element which will be insulated. This measure is necessary as VIP can not be dimensionally adjusted on site;
- introduction of a ventilation mechanism, to provide the necessary amount of fresh air in the building. This measure is necessary as VIPs are straight barriers against mass transfer.
- the installation of the VIP must be done by qualified workers, due to their fragility;
- VIP must be stored in spaces fulfilling several conditions (they have to be a stored in a dry space)
- for each case, a special attention should be paid to the thermal bridge that occurs at the panels edge. The heat loss varies from one case to another, from one type of VIP to another, from one type of joint to another etc.
- regarding the price, currently VIP has a higher price than the common thermal insulation, but their use can became viable in the cases where the buidings are located in areas where the price of the land is high.

However, several disadvantages can be avoided by integrating VIP in prefabricated insulation elements. Thus, the risk of damaging the panels during handling and during the execution time decreases significantly.

The VIP price will decrease once they will be produced on large scale and by more companies.

The lack of data obtained in situ about their service life makes them to be regarded with less confidence by the builders.

The elaboration of a standard which to establish the way to evaluate the VIP properties can lead to a production increase and hence to an increase of their use.

Due to the increasingly restrictive requirements in terms of energy efficiency, the research and the development of new high performance materials becomes necessary.

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