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VACUUM INSULATION PANELS. THERMAL ANALYSIS OF WALL SANDWICHES

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Abstract: *The paper analyzes the behaviour of Vacuum Insulated panels VIP as a component of new sandwich panels having an improved performance concerning the insulation characteristics. The solar radiation can has an impact during the heating season if the glass do not block the radiation to be transmitted further to the VIP. Special properties can show during the winter season especially when low intensity radiation exists. The analysis show the possibility to improve the VIP sandwich panel with an advantage related to a reduced thickness compared to traditional polystyrene insulation.*

Key words: *vacuum insulation panel, thermal transmittance.*

1. Introduction

Today the 210 million buildings existing in EU are responsible for approx 40% of the primary energy consumption and about 36% of all greenhouse emissions. The Energy Performance of Building Directive (EPBD) settled as a target to reduce this consumption in order to restrict the global warming to 2 ^{o}C per year, i.e. a global CO_2-emission mitigation of at least 50% below the 1990 level (well beyond the level required by the Kyoto Protocol) [1].

Standard insulation materials as expanded polystyrene, foamed polyurethane, fiberglass etc. considered as good insulation after the 1973 oil crisis became a problem for the architects because of their thickness (30…50 cm) necessary to respond for the technical constrains but not conform with the. Researches performed since then concerning well defined external load have been focused on small temperature spread across the specimen and selected boundary emissivity. Results of this research are vacuum insulation panel (VIP), vacuum insulation glass (VIG) etc.

VIP, see Figure 1, is a strongly non homogeneous insulation product: the contact between the solid particles of its vacuum

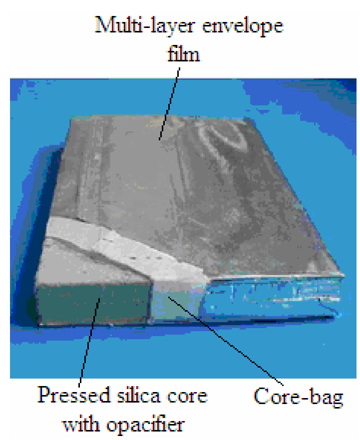

Fig. 1. *Components of a VIP*

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packed-core material has been reduced to a minimum resulting in a very low conductivity (0.006 to 0.008 W/(m·K) for normal applications) [6].

VIG consists in an assembly of two glass panes separated by a vacuum insulation (0.1 Pa or less), connected by an airtight edge seal, see Figure 2. Each pane is coated with a highly infrared-reflecting layer to minimize thermal radiation. To prevent the collapse of panes a matrix of spacers is provided.

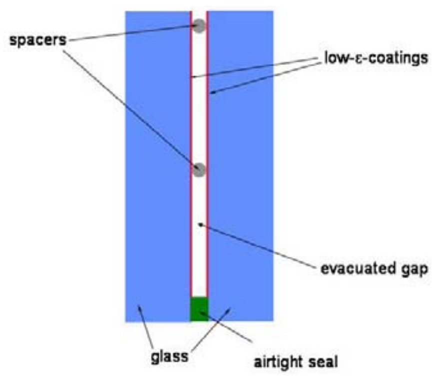

Fig. 2. *Principle of VIG construction* [4]

Novel design based on these new products appeared, see Figure 3, having a wall structure as shown in Figure 4 and described below:

Gypsum plaster board	2x12.5 mm
Mineral wool	60 mm
Sheet steel, hot galvanized	1.5 mm
Microtherm VIP element	25 mm
Sheet aluminum, clear anodized	2 mm
Air gap and adhesive	1 mm
Glass with black layer behind	6 mm
Rear ventilation up to one-storey	20 mm.

Fig. 3. *Single-family house with VIP-Multiplac wall elements*

High, movable, sliding sandwich panel providing glare and sun protection and light control.

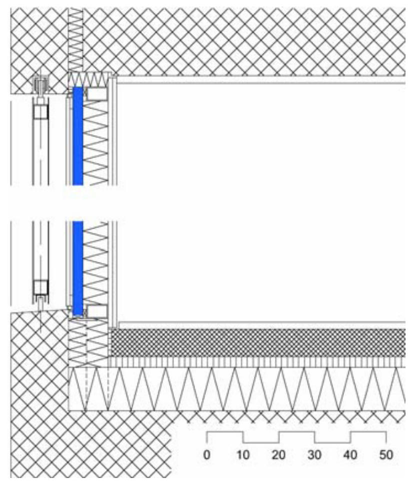

Fig. 4. *Section of façade with VIP-Multiplac wall elements*

The warm façade benefits from the VIP performance but the effect of sunshine on the glass, which is backed by a black layer and adhered to the façade element, is uncertain [5].

2. The Sandwich Panel Analysis

Curtain wall systems are modern issues used in actual buildings new and retrofitted. When using the VIP in a sandwich panel having a design as shown in Figure 5 the solar irradiation is supposed to have an influence on the system transmittance. For this reason the effect of solar irradiation and of the outside temperature together with the air cavity thermal resistance on the transmittance will be analyzed.

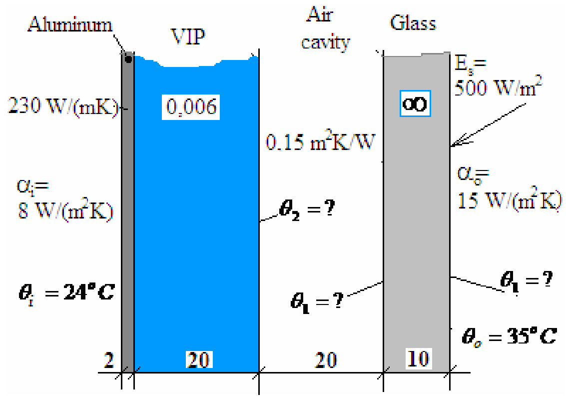

Fig. 5. *The design of the analyzed sandwich panel*

2.1. The mathematical model

The considered elements for the analysis are:

- α_0/α_i outside/inside superficial heat transfer coefficients,
- $R_{VIP}/R_{alu}/R_{int}/R_{cav}$ thermal resistances of: VIP/aluminium sheet/interior air layer/air cavity,
- E_s solar irradiance,
- α_s/τ_s solar absorptance/transmittance,
- $\Theta_0/\Theta_i/\Theta_1/\Theta_2$ temperature of the outside air/interior air/glass in contact with air cavity/VIP in contact with air cavity.

The heat balance equations for the system are:

$$\begin{cases} \alpha_0(\Theta_0-\Theta_1)+\alpha_s E_s = \dfrac{\Theta_1-\Theta_2}{R_{cav}}, \\ \dfrac{\Theta_1-\Theta_2}{R_{cav}}+\tau_s E_s = \dfrac{(\Theta_2-\Theta_i)}{R_{VIP}+R_{alu}+R_{\text{int}}}. \end{cases} \quad (1)$$

Solving for the temperatures existing on glass surface in contact with the interior air cavity Θ_1, and on VIP surface in contact with the interior air cavity Θ_2 respectively, and for the values presented in Figure 5 a high temperature on the VIP surface adjacent to the air cavity results because of the solar gain Θ_2 = 113.2 ^{0}C: the sandwich panel acts as a solar collector [2].

The glass solar properties considered in the evaluation are:

- absorptance, $\alpha_S = 0.06$,
- transmittance, $\tau_S = 0.75$.

The resulting heat rate:

$$\dot{q}_s = \frac{(\Theta_2-\Theta_i)}{R_{VIP}+R_{alu}+R_{\text{int}}} = 26.8\,\text{W/m}^2, \quad (2)$$

(and corresponding to an exterior temperature of 122 ^{o}C) leads to an apparent thermal transmittance value:

$$U_s = \frac{\dot{q}_s}{\Theta_o-\Theta_i} = 2.05\,\text{W/m}^2. \quad (3)$$

This value is considerable higher than that existing in case of no solar irradiance: U_{ns} = 0.272 W/m^2:

$$U_{ns} = \frac{1}{\sum R_i} = \frac{1}{\dfrac{1}{\alpha_i}+\dfrac{d_{alu}}{\lambda_{alu}}+\dfrac{d_{VIP}}{\lambda_{VIP}}+R_{air\ cav}+\dfrac{d_{glass}}{\infty}+\dfrac{1}{\alpha_o}}. \quad (4)$$

2.2. Factors of influence

A study of influences for different conditions has been carried out based on the model presented before. The thermal transmittance U lowers with the VIP thickness and trend is more evident for higher solar irradiance. In absence of solar radiation the thickness of the VIP does not have a significant influence on the thermal transmittance and these values are quite small. The solar radiation heats the surface of the VIP and the heat rate is in principal due to this high temperature of the VIP/air cavity interface.

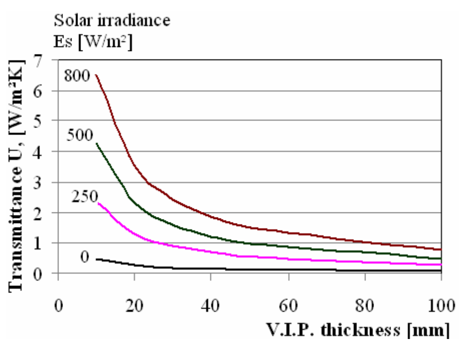

Fig. 6. *The thermal transmittance of the panel correlated with the VIP thickness*

As can be seen in Figure 6 a VIP thickness of 20 mm can be considered as a good value.

In fact, the thermal transmittance depends linearly on the solar irradiance as shown in Figure 7 and, as a paradox, is becoming

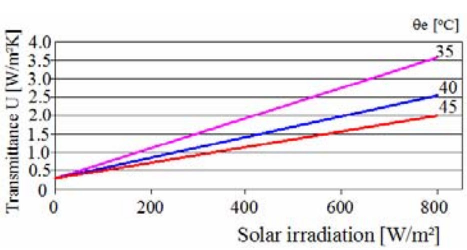

Fig. 7. *The influence of solar irradiance on thermal transmittance of a sandwich panel having in its composition a 20 mm VIP*

smaller when the ambient (exterior) temperature is rising: this happens because the major influence is the solar irradiance.

From the equation (3) it can be noticed that a higher ambient temperature leads to a higher temperature differential and consequently to a smaller thermal transmittance. For a higher solar irradiance the sandwich panel do not behave as good as in the absence of solar radiation. Hence, a lower solar transmittance τ will block a higher amount of solar radiation to arise on the VIP surface leaving its temperature at values more moderate. This will create a smaller temperature differential in relation to the interior temperature and thus a reduced value of the thermal transmittance will result.

Figure 8 presents the thermal transmittance U correlated with the solar transmittance τ of the glass for two values of solar irradiance, 500 W/m^2 and 800 W/m^2.

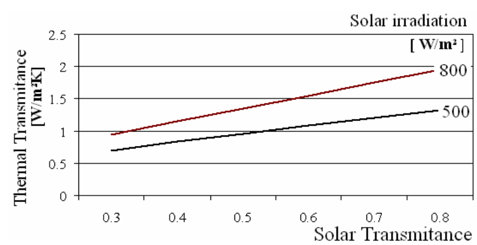

Fig. 8. *The thermal transmittance U as a function of solar transmittance τ of the glass*

In general, the glass presents a selective transmittance depending on the incidence angle: for higher values of the incidence angle the transmittance is lowering rapidly as shown in Figure 9.

Some special sorts of glass have an enhanced selective transmittance property which is useful for the summer/winter seasons: during the summer the incidence angle is higher then in winter. As a result the solar gain is “accepted” during the heating season but blocked during the cooling season.

Combining this property with an air draft through the air cavity resulted from the density differential produced by the heating of the air a cooling effect of the surface of VIP is obtained, see Figure 10.

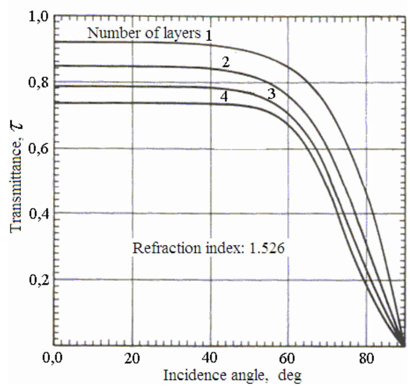

Fig. 9. *The transmittance τ of ordinary glass as a function of incidence angle*

Condensate from rear ventilation must be avoided, which is relatively easy: the VIP must be applied tightly with as few cavities as possible to the outside wall and gaps and joints carefully taped on the room side.

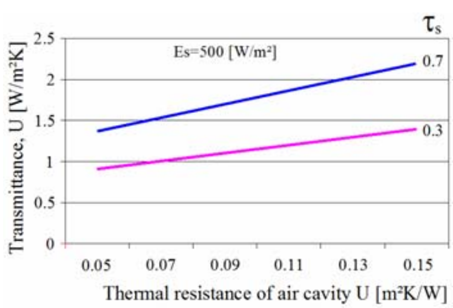

Fig. 10. *The transmittance U as a function of the thermal resistance of the cavity and for a solar irradiation of 500 W/m^2*

The latter measure is also a reliable way of avoiding condensate from vapour diffusion in the wall construction. VIP are inherently vapour tight (in the sense of processes relevant to building physics), so that primarily the gaps and joints must be taped.

Adjacent hollow ceilings, where usually no vapour barrier can be installed, should where possible at least be stuffed or blown with fibre insulation to make sure that no convective moisture transport to the cold surfaces can occur.

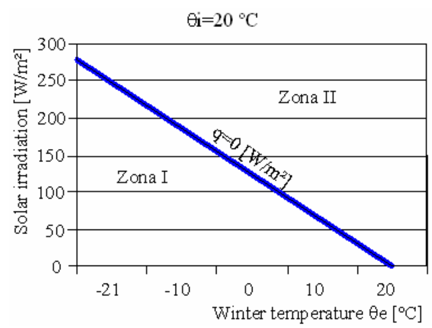

Fig. 11. *The solar irradiation correlated with winter temperature for an interior temperature of 20 °C*

For the winter season, making the inside air temperature equal to the surface temperature of VIP (in contact with the air cavity) $\Theta_2 = \Theta_i$ the equations (1) give the value of the solar irradiation for which no heat transfer from inside to outside the building exists $q = 0$. Figure 11 shows two areas separated by a $q = 0$ line:

- the area under the line is specific for building heat losses,
- the upper area is characteristic for building heat gain, for a reduced solar irradiation, even if outside temperature is much more lower than the interior ambient one.

3. Conclusions

At EU level it is considered critical that the energy efficiency improvement measures proposed can have a strong impact on the consumption of the primary energy sources.

Deep energy renovation of a building means extensive works to a building in accordance with the definition in the recast

Energy Performance of Buildings Directive (2010/31/EU) set out at 3.6 above that, while preserving any noteworthy architectural character, significantly improves the energy performance of the building such that it achieves a level of performance equivalent to factor 2 (50%), factor 4 (75%), factor 6 (84%) or factor 10 (90%) improvement in its energy performance as compared to its pre-renovation performance [3].

It is therefore necessary to set out national roadmaps or renovation action plans with clear guidelines on renovation of the existing building stock taking into account the cost-optimal levels of renovation for different sectors of the building stock, as well as nearly zero energy aspirations.

New materials and technologies are under research and having improved performance tend to be implemented in practice. Their impact must be evaluated to prevent future unpleasant consequences.

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