Development of Innovative Insulation Systems on the Basis of Vacuum Insulation Panels

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1 Introduction

Within an ongoing project between the Fraunhofer Society and German Manufacturers new components for vacuum insulation panels (VIPs) are in development. Alternative approaches for high barrier films and core materials are investigated. An alternative barrier film shall be the basis for new vacuum insulation panels, however parallel to the barrier development new insulation systems using commercial films are being tested.

For the building application in a first step exterior insulation finish systems have been worked out. VIP prototypes have been produced with a commercial barrier film and used in different prototype systems. Characterisations by measurement and by simulation of the thermal bridges of complete wall constructions give insight into properties of various constructive variants. Appropriate solutions for mounting were proposed and tested in demonstration objects. This presentation focuses on the properties of the prototype systems and results from the test facade of Fraunhofer ISE whilst other demonstration objects are presented in [Zwerger, 2005].

2 Barrier film development

2.1 Film design

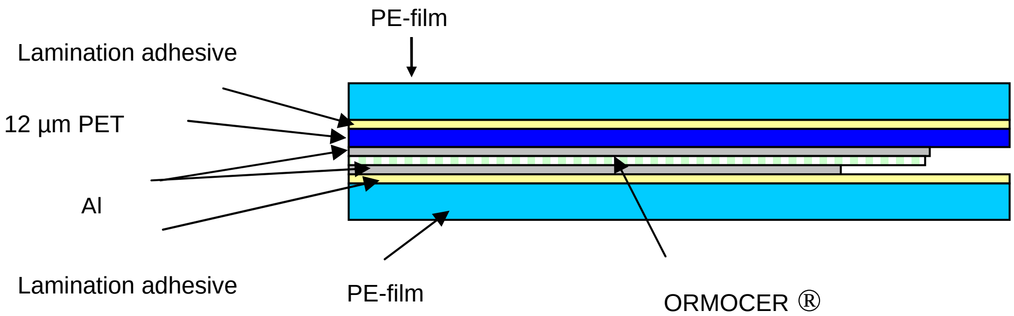

Figure 1: Schematic barrier film design using aluminum-ORMOCER®-barrier technology

Commercial barrier films use a multilaminate approach with several aluminium layers on e.g. high-barrier PET. An alternative layer composition for the barrier film uses ultra thin aluminium layers and ORMOCER® lacquers as a very promising base unit. The ORMOCER® lacquers and the aluminium form an interface which is believed to improve the barrier substantially. Within the project a screening of possible base films, aluminium coated films with and without lacquers has taken place. However, due to the properties of the delivered films the results were not sufficient. The potential of the ORMOCER® lacquer can only be realized if certain specifications are met by the coated film. Therefore we decided to select a base film with known properties, coated the film and applied the standard lacquer without optimisation. The resulting laminate is a compound having two metallic layers, a lacquer and two glue layers for the exterior poly-ethylene films shown in Figure 1. With that prototype we reached without further optimisation an oxygen permeability OTR of less than 0.01 cm^3/m^2 d bar for 23°C 75% relative humidity and a water vapour transmittance WVTR of 0.04 g/m^2d for 38°C / 90 ->0% relative humidity.

2.2 Optimisation potential

The presented barrier film concept reached without further optimisation the performance of the commercial barrier film used by our partner Porextherm, Kempten, in the production of VIP panels for the building sector. There is a substantial potential for further improvement:

- development of an adapted ORMOCER® lacquer
- according to theoretical simulations a thinner lacquer layer gives further improvement
- thickness of the thin aluminium layers

From theoretical estimations an improvement for WVTR in the order of one to two orders of magnitude seem possible. In addition the PE-sealing films shall be made thicker (to improve processability) and flame retardent additives have to be integrated. At the moment the preparation of optimised laminates is one the way, however results cannot reported yet.

3 VIP-Panel characterization

The properties of barrier films do not necessarily stay constant when processed in the manufacturing of a VIP-panel. In addition to permeability the thermal properties of the film influence the thermal performance of the evacuated panel at the edges. The thermal conductivity of the film may be estimated if the film layer thicknesses are known. It is however possible to estimate the lateral conductivity also by comparison of thermal bridge modelling with experimental results from a hot-plate.

3.1 Permeability

Panels with different thickness and produced with different barrier films have been tested for permeability. Films have been cut from central, edge and corner positions and characterised afterwards. The results showed a degradation of oxygen and water vapour permeability in the corners up to one order of magnitude. The comparison of three different commercial films showed, that not only the absolute barrier properties but also the relative decrease due to the position varies between the products.

3.2 Heat transport

The heat transport through an area A of VIP panels is usually characterised by a center U-value and a linear thermal conductance Ψ associated with the edge length L:

$$U = U_0 + \frac{\Psi \cdot L}{A}$$

When two panels are positioned one next to the other the linear conductance Ψ is consisting of the two contributions $\Psi_{1/2}$ from each panel alone: $\Psi = 2 \cdot \Psi_{1/2}$.

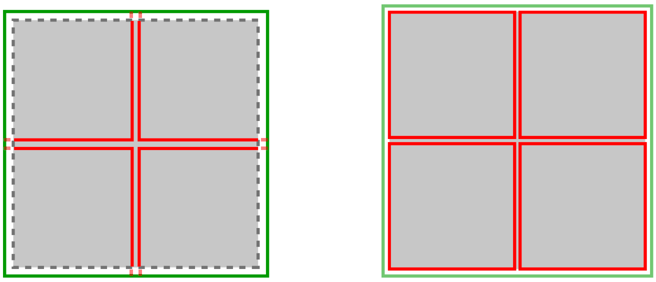

Figure 2: Illustration of the influence of edges (red) on measured U-value (left) and on averaged U-value (right). Measuring (left) or calculating (right) zones are grey.

In a hot-plate apparatus we measured with different panel sizes the heat transport through different configurations. Here we measured the heat flux through an area with e.g. 4 panel in 4 quadrants of the measuring area (s. Figure 2 left). When this active area has sides a and b we get

$$U_{meas} = U_0 + \frac{2 \cdot (a+b) \cdot \Psi_{1/2}}{a \cdot b}$$

In other cases, when we estimate the effect of the edge losses on the thermal performance of a building we are interested in average U-values. These have to be calculated in a different way:

$$U_{avg} = U_0 + \frac{4 \cdot (a+b) \cdot \Psi_{1/2}}{a \cdot b}$$

In order to estimate the film conductivity for modelling we measured different panel sizes of prototypes in a small hot-plate apparatus. The three cases investigated had 0, 1 or 2 edges across the active measuring area. We tested two panel prototypes, produced by Porextherm, packed and sealed in a different way. One panel "VIP1" has flaps (two films sealed) at the sides, folded to the back, the other panel "VIP2" has the sealing partly across the core area and not at the sides, thus trying to reduce the edge losses substantially. Because of imperfect rectangular geometry especially of VIP1 there was always some air gap between the panels, estimated on the average 2-4mm.

Figure 3: VIP panel types „VIP1" and „VIP2"

We modelled the barrier films as 100µm films with an effective thermal conductivity. By comparing the results an effective conductivity of 1.5 W/m·K showed a good correspondence between simulated (with 2D-programm Flixo 3.12) and measured values of the thermal bridges. We modelled boundary conditions for the hot-plate covered with 3mm thick heat flux-plates using a finite but large surface coefficient on both sides of the plate. Apart from the barrier film conductivity λ also an air gap between panels (with a half-width $L_{1/2}$ from edge to symmetry plane) increases the linear thermal conductance (Figure 4). Therefore the film conductivity cannot be exactly determined, as an assumption of an effective air gap between the real VIPs in the hot-plate apparatus is not exact. However from both variations one may reasonably say that the barrier film conductivity λ_{eff} (for film thickness 100µm although the real barrier film might have a different thickness) is in the range of (1.5 +- 0.4) W/mK. The two panel types VIP1 and VIP2 showed rather different thermal bridge effects as expected (Figure 5).

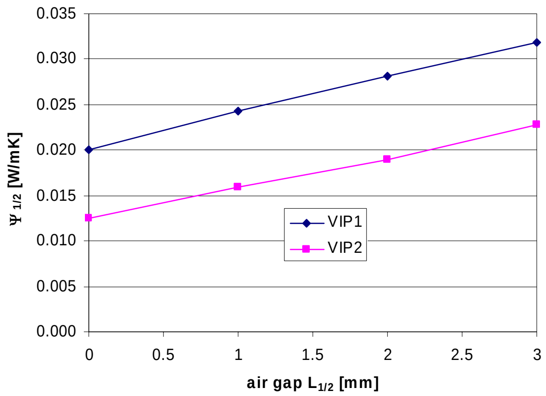

Figure 4: Linear thermal conductance for one panel edge depending on associated (half) air-gap to next panel ($L_{1/2}$ is air gap from panel edge to symmetry plane)

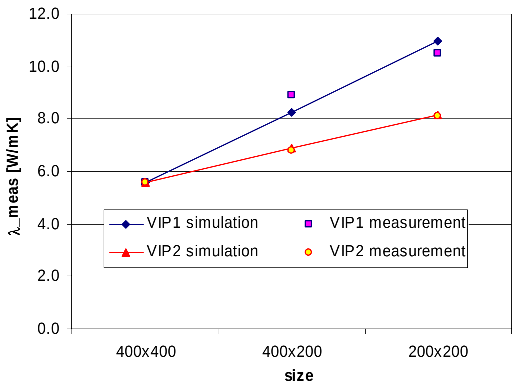

Figure 5: Comparison of effective measured conductivity (including thermal bridges) for VIP1 and VIP2 panels and different sizes (in mm)

As a conclusion one might say that with 100µm barrier film both types VIP1 and VIP2 can be simulated and results agree well, if one assumes no air gap between VIP2-types and 2x1.5mm air gap between two VIP1 types.

4 Exterior Wall Insulation Systems (EWIS)

4.1 Design

Together with the company Sto AG we investigated several concepts for external wall insulations systems based on vacuum insulation panels. System A is a VIP completely surrounded by 20mm polystyrene foam (EPS). This system showed relatively large thermal bridges and surface temperature variations, therefore in practice it had to be combined with an additional layer of 80mm EPS. The whole idea of a slim VIP-insulation is contradicted, moreover the system is expensive. Therefore System B is favoured where EPS-layers of 5mm and 20mm thickness are laminated on top of the VIP.

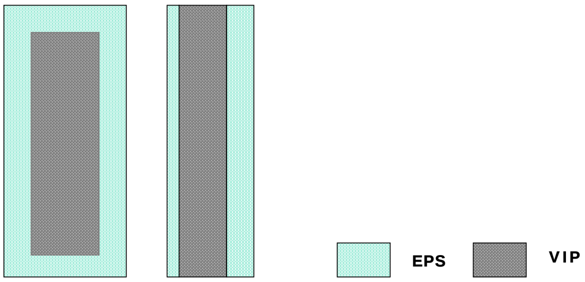

Figure 6: Basic systems A and B for encapsulating VIP in polystyrene foam EPS

The risk for system B is the unprotected edge. We investigated the influence of small variations in this region on the performance.

4.2 Heat transport

System B requires ideally completely rectangular shapes of VIP. In practice especially with VIP1 this is not the case. Therefore we investigated the effect of air gaps at the edge between the modules.

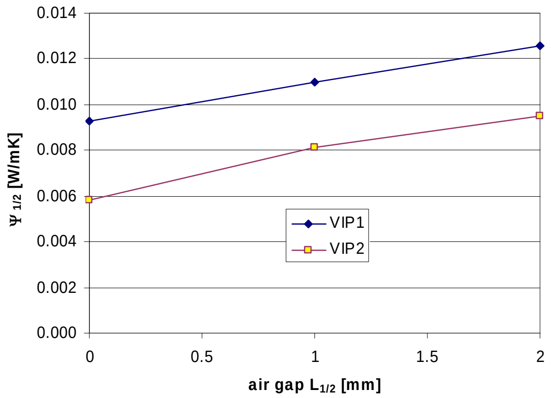

Figure 7: Effect of air gaps on linear conductance $\Psi_{1/2}$ between the vacuum panels for VIP1 and VIP2 in system B type external wall insulation systems (simulated with Flixo3.12)

The air gap may be only in the panel layer when there is e recess between EPS layer and VIP. If not, even the EPS plates will not be close together and an air gap is formed through the whole panel system. When recessed on purpose, we investigated the impact of protection. Figure 8 shows the effect of 2mm PU-foam or Silicone protection instead air gap on the Ψ-value.

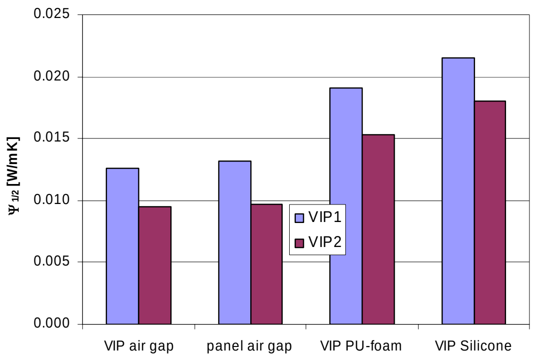

Figure 8: Effect of 2mm recessed air gap (VIP layer), 2mm air gap between VIP and EPS, 2mm recess filled with PU-foam and silicone for protection on $\Psi_{1/2}$-value.
Attention: 2mm is half the distance between two panels (panel to symmetry plane)

Of course different thermal bridges lead to different surface temperature variations (which ideally in demonstration walls might be monitored by infrared thermography).

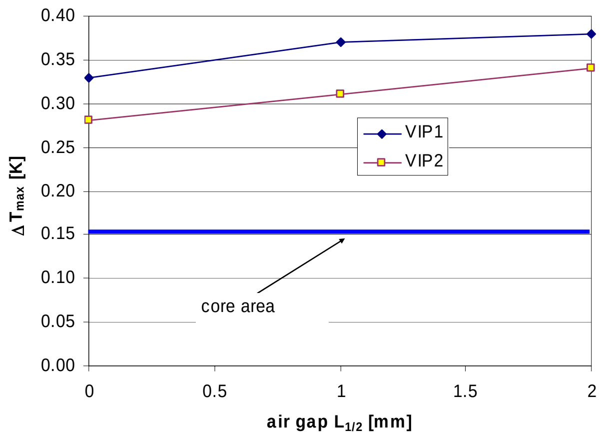

Figure 9: Maximum surface temperatures of EWIS for 0°C ambient temperature (Value at undisturbed core area shown as line)

When PU-foam is used for protection (λ=0.25 W/m·K), a huge increase of the average U-value of a wall may occur, depending on the average panel size covering the wall. Therefore we have to look for better solutions. Foamed rubber is (λ=0.05 W/m·K) is improving the performance substantially.

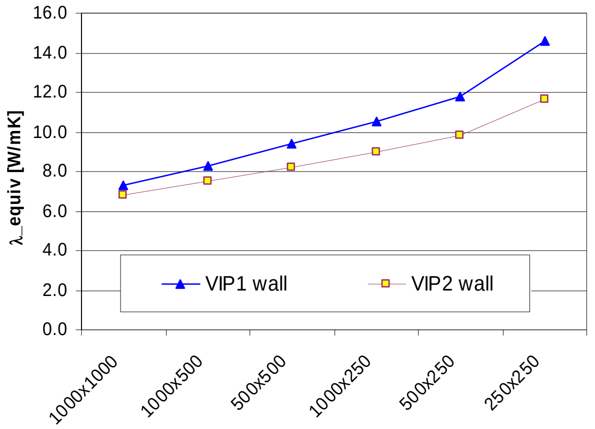

Figure 10: Increase of equivalent conductivity of the VIP in an external wall insulation system type B when 2mm foamed rubber is used as protection of the VIP

5 Test site

Within the project a east oriented facade of an existing building of Fraunhofer ISE was renovated with another EWIS type and is being monitored.

5.1 VIP system

The VIP system this time consist of the VIP-plate covered with a thin layer of plaster base. This system is glued to the wall and afterwards covered with a mesh reinforced plaster layer for protection.

Figure 11: View of EWIS system at Fraunhofer ISE glued to wall (left) and covered with plaster (right)

5.2 Monitoring

Before mounting heat flux, humidity and temperature sensors were mounted into the wall surface – some at positions behind a VIP, some in the region with 4 corners (Figure 12).

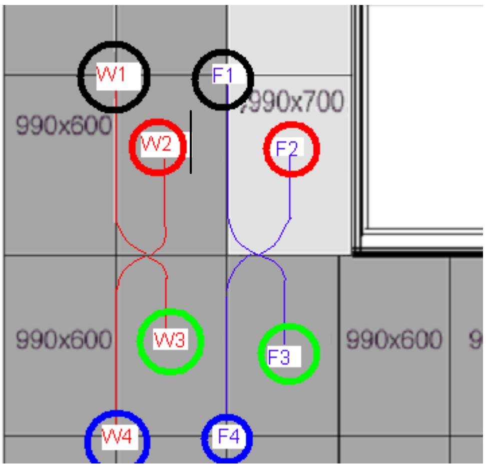

Figure 12: Positioning of sensors in facade (W – heat flux plates, F – humidity and temperature sensors)

5.3 Results

As expected the heat fluxes are larger in corner areas, temperatures lower. Figure 13 shows the continuous monitoring of one week heat flux, temperature and outdoor temperature.

Using the average values for several days one may determine approximately the U-value from wall surface to ambient (for the EWIS system without bricks) by dividing average heat flux by the difference between wall temperature and ambient temperature. This is not exact because the temperature and heat flux sensors are not at the same place. One problem is that the interior wall is not homogeneous warm, as there is a heating element behind the monitored area producing inhomogeneous temperature distribution. However, the approximate increase from center to 4-corner region is correct (see also Figure 14), as experimentally we get U_0=0.27+-0.02 W/m^2·K and U_{corner}=0.63+-0.06 W/m^2·K, whilst theoretically we simulated U_0=0.27 W/m^2·K and U_{corner}=0.60 W/m^2·K.

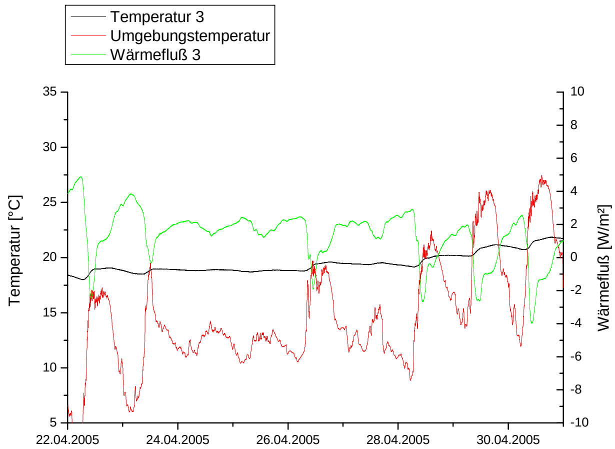

Figure 13: Continuous monitoring of 9 days in April 2005: heat flux, temperature and outdoor temperature (central position behind VIP, position 3)

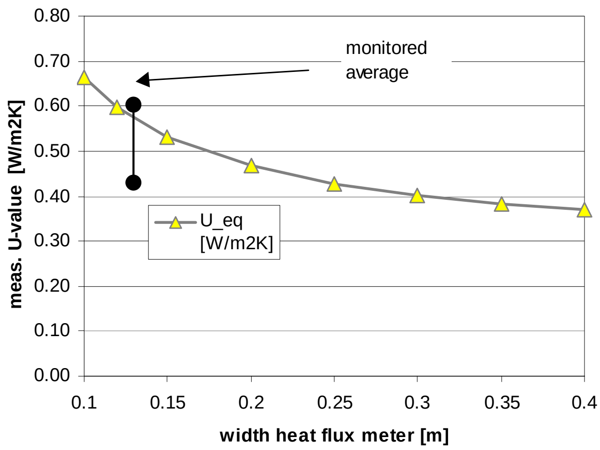

Figure 14: Equivalent U-value determined by square heat flux meters in position 1 (4 corners) of different size (as simulated theoretically) – experimental heat flux meter 12cm x 12 cm

6 Summary

A potential new barrier film design has been presented which reached the state of the art performance of commercial films without optimisation steps. Improved versions shall be developed within the next months. The thermal bridges for VIP based insulation systems are important for characterising the energy performance of a wall. Barrier film conductivity, sealing position and air gaps between panels are important parameters. The laminated EWIS type reduces the problem of thermal bridging, however good solutions for edge protection are necessary. One possibility seems to be to use foamed rubber. The test facade at Fraunhofer ISE confirms theoretical predictions, but shows also the critical handling of the unprotected VIP panels.

7 Reference

[Zwerger, 2005] ***Integration of VIP's into External Wall Insulation Systems,*** 7th International Vacuum Insulation Symposium, September 28-29, 2005, Zurich, Switzerland