Forschungsinstitut für Wärmeschutz e.V.
Munich

RESEARCH REPORT

- Abstract -

Research project:	Optimization of the energetic qualities and the cost effectiveness of VIP panels by optimal combination of silica, mineral fibre and EPS insulating material
Short title:	Energetic and economic optimization of VIP panels
Research institution:	Forschungsinstitut für Wärmeschutz München e.V. FIW München Lochhamer Schlag 4 82166 Gräfelfing Germany
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1 Objective of the research task

A VIP is a heat insulation element consisting of a pressure-resistant support core, currently most often fumed silica, and an envelope. Aside from fumed silica, different open-pore fibre, powder or foam products varying with regard to thermal conductivity qualify for use as support core (Figure 1). Aluminium laminated films (ultra-barrier films) and metallised plastic films (high-barrier films) are used as envelope.

Within the context of this project, research was done on how the combined use of conventional insulating materials and fumed silica can improve the product vacuum insulation panel (VIP) with respect to energetics and improve its cost effectiveness. Studies regarding covering layers and edge designs build a bridge from the mere panel qualities to the application in construction.

The emerging constraints and areas of conflict were analyzed and suggestions made on the implementation of the knowledge gained in the production of the panels. Considerations on the cost effectiveness of panel production and on the use of panels within buildings substantiate the great potential of the vacuum insulation panels with respect to high-quality energetic sanitation and a sustainable, substantial reduction of the emission of greenhouse gases.

2 Execution of the research task

The heat transfer in porous insulations is described in detail by J. Fricke et.al. in the textbook Vakuum-Isolations-Paneele für Gebäude [*Vacuum insulation panels for buildings*] [1], among others. It is comprised of the following contributions.

- Heat transfer via the solid skeleton λ_F in W/(m·K)
- Infrared radiation transfer λ_S in W/(m·K), and
- Thermal conduction of the inactive gas λ_G contained therein in W/(m·K)

A further term λ_K contains the coupling effects of the different transport paths and describes, for example, the short-circuit mechanisms for the heat in the cavities between the particles of the scaffolding, including by accumulated humidity.

$$\lambda = \lambda_G + \lambda_F + \lambda_S + \lambda_K \qquad W/(m \cdot K)$$

In order to reduce the thermal flow through a substance, the individual contributions must be reduced. The radiant heat transfer can be reduced by the use of clouding agents in the support core, as is the case, for instance, with the insulating material Neopor®, an expanded polystyrene with clouding agents, which has been widely used in recent years. Thermal conduction through the solid skeleton must be kept as low as possible by using frequently interrupted and branched structures divided into very small sections. With respect to gas heat conduction in the pores, the sufficiently known relationship between pore size, pressure and effective thermal conductivity give rise to the following considerations:

a) In case of an enlargement of the pores, the pressure must be reduced if one wishes to maintain thermal conductivity
b) Upon decreasing the size of the pores and maintaining constant pressure, reduced thermal conductivity results

By theoretical approximation to the qualities required of new support core materials, the required parameters for production are isolated. The gas density of the envelope is the decisive factor for the life span of the VIPs, which are intended to last 30 to 50 years for building applications. During said time, the internal pressure must by no means exceed 100 mbar when using microporous silica.

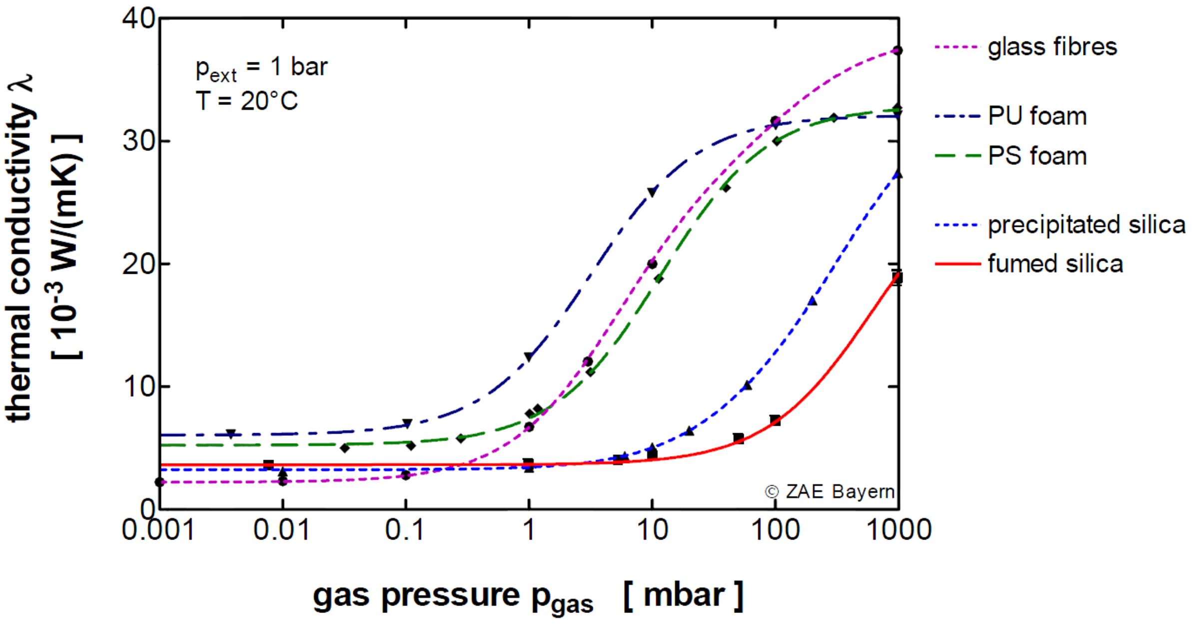

Figure 1: Thermal conductivity λ in W/(m·K) of different core materials dependent on the gas pressure pgas in mbar from [2]

Simmler et.al. [2], in case of silica VIP, give a reference value for maximum permeation rates of 10^{-2} cm³/(m²·d·bar) for dry gases and 10^{-4} g/(m²·d) for water vapour. Permeation rates for water vapour (WVTR) through high-barrier laminates can currently reliably be measured only up to approx. 5 x 10^{-4} g/(m²·d); permeation rates for oxygen O_2TR only up to approx. 1 to 10 x 10^{-2} cm³/(m²·d·bar) [3].

For the use of alternative support cores, considerably lower permeation rates are required. For this reason, data on permeation and aging behaviour of the films and panels can be obtained almost exclusively indirectly, i.e. via measuring thermal conductivity. Direct measurement of the internal pressure via the film liftoff procedure is difficult in case of fibre-filled VIP due to the uneven structure of the VIP surface.

The detailed evaluation of the heat conductivity measurements conducted at the FIW Munich from the past 8 years within the framework of the approval examinations of several manufacturers, results in the boundary conditions for the films with regard to permeation and aging behaviour. So-called "aging factors" can be derived from comparisons of the aging behaviour (degradation) of vacuum panels from research projects (e.g. study "VIP construction" [4]) and own studies, with said aging factors enabling conclusions on the durability of VIP when used in construction.

An important point for the optimization of the VIP system is the thermal bridge of the film at the edge. The thermal losses are influenced by the type of edge design (single-layered or multi-layered), the barrier material of the envelope film, the thickness of the barrier layers, the filling material possibly present in the joint between two panels, and covering layers on the panels. Via numerical calculations for VIP of varying thickness the thermal bridge effects at the edge under above-mentioned influencing factors can be determined.

Taking into consideration the theoretically determined influencing factors from the preliminary examinations, the calculations on the thermal bridge effect at the edge and the analysis of the available measurements from the approval procedures, prototypes and test panels are manufactured and examined. Measurements are taken of the thermal conductivity before and after various storage times and storage conditions.

At this point in time, vacuum panels are still considerably more expensive compared to other insulating materials. Fumed silica is very energy-intensive during production and requires sophisticated industrial manufacturing equipment. In addition, the production of the films used constitutes a very complex process, making them expensive as well. The manufacturing process requires numerous individual steps – in particular in the case of custom-made panels – still largely requiring manual work at this point in time. In the context of the research work, two constructions each for new construction and the refurbishment of old buildings with and without VIP are examined with respect to costs and achievable proceeds.

3 Summary of results

3.1 Panel components and thermotechnical characteristics

3.1.1 Films

The metallised films currently available on the market are not suitable for enveloping VIPs with fibre filling or other support core materials which are of a less detailed pore structure than fumed silica. In the case of the metallised films, a reduction of permeation and the improvement of the film characteristics upon aging are indispensable.

With aluminium laminated films, very low permeation rates can be realized. However, they display such great thermal bridge effects at the edges that their application for panels consisting of numerous small components is not recommended. The comparison of the thermal bridge effects of an aluminium laminated film with a metallised film shows the immense differences for single- and multi-layered edge designs for VIP of 20 to 40 mm thickness (Figure 2). If the thickness of the aluminium layers of these laminated films can be reduced in future without a significant increase in permeation, these films can in future be used for fibre-filled VIPs.

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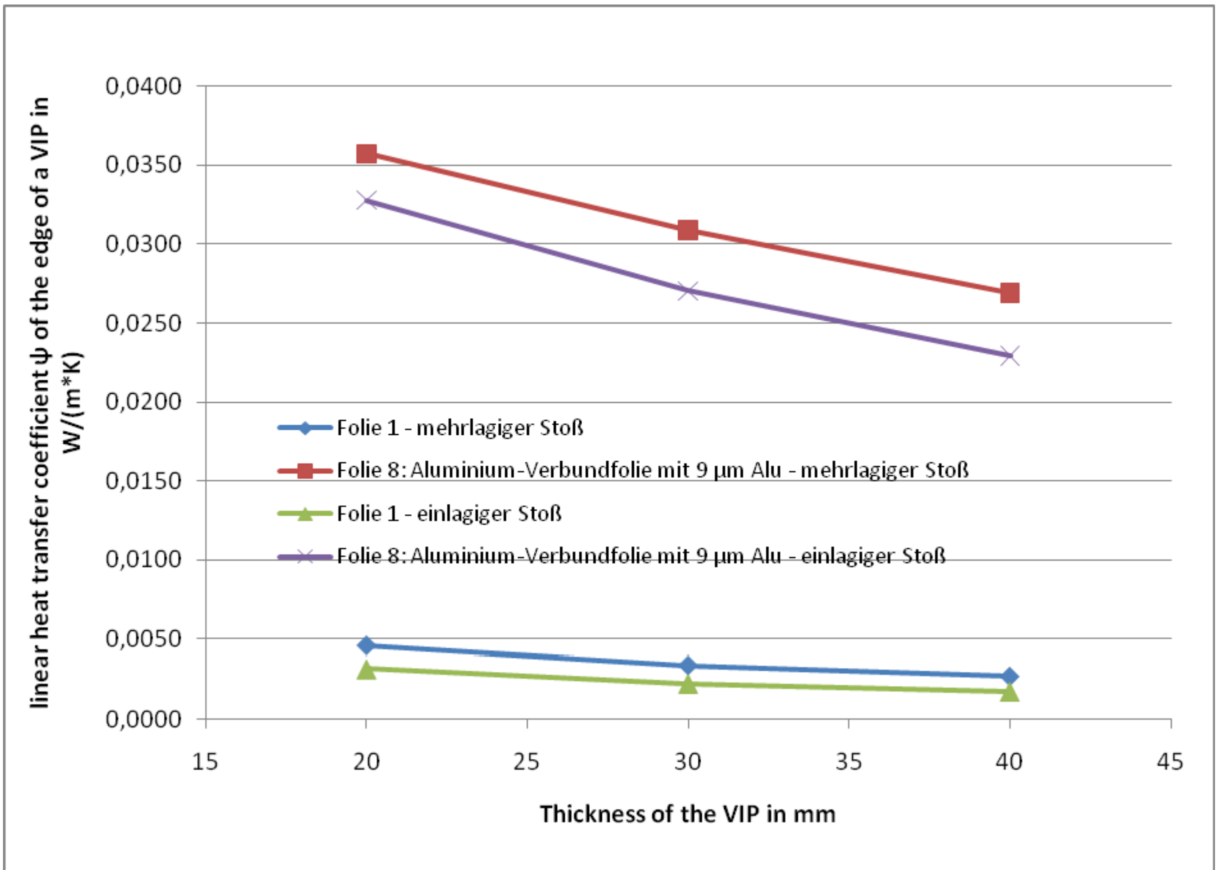

Figure 2: Comparison of the length-specific heat transfer coefficients for the single-layered and multi-layered edge design for film 1 (metallised) and film 8 (aluminium laminated film) for VIP of 20 mm to 40 mm thickness

By using stainless steel or inorganic substances with crystal structure (e.g. SiO_2) as barrier material, a considerable reduction of the edge thermal bridges is achieved, which would enable the use of the very dense laminated films even for small-format panels. When combining the reduction of the layer thickness of the barrier and the replacement of aluminium by another barrier material, the use of fibres as support core should be re-examined.

3.1.2 Support cores

Fumed silica is currently indispensable as support core material. At best a portion of the silica might be replaced by e.g. fibres in the foreseeable future upon using very dense films. The requirement for the vacuum (internal pressure below 0.1 mbar) requires great care in the production of the cores from fibre materials. These must be completely free from grease and must not contain any binding agents whatsoever. In contrast to fumed silica, drying at a minimum of 140°C for several hours is also indispensable in order to remove even the smallest residuals of adherent water from the fibres.

Examined were layerings of silica and fibre material as support core, however mixtures of loose fibres and silica are also conceivable. In this context, a small portion of the expensive silica can be replaced by cheaper fibres. The "VIP in VIP" approach results in the lowest increases in thermal conductivity in the first aging step. However, an enhanced edge effect on the partially twice adjoining film occurs, which is probably responsible for the initial values of thermal conductivity being slightly above those of the panels enveloped just once.

3.1.3 Thermal bridge effect at the edge

The mathematical examination of the thermal bridges at the edge of the elements for the first time quantitatively confirms the theoretical considerations regarding the production parameters of VIP envelopes. In this context, it is of particular importance to manufacture panels of maximum possible size, with only the shorter rim with the less favourable edge design being welded (multi-layered edge). By this simple measure alone, by the arrangement of the welding areas on the surface areas instead of at the edges of the longer rims, the edge effects can be considerably reduced.

The thickness of the used layers of the materials, in particular those of the aluminium layers, also have decisive influence on the thermal bridge at the film edge. A good dimensional stability and perpendicularity of the VIPs is a prerequisite for the precisely fitting installation of adjoining panels. The gaps between the panels can then remain small, which considerably defuses the thermal bridge at the edge. If gaps between the panels cannot be completely avoided, they should be filled with an insulating material of as little thermal conductivity as possible in order to minimize the thermal bridge effects.

The thermal bridge effects are only reduced by covering layers made of insulating materials on the surface areas of the VIP. Even thin panels made of wood-based materials result in the thermal bridge at the edge being greater than for a VIP without covering layer due to the transverse conduction in the covering layers. This in particular applies to covering layers made of metal, e.g. of steel or aluminium sheets as is common for some sandwich constructions (Figure 3).

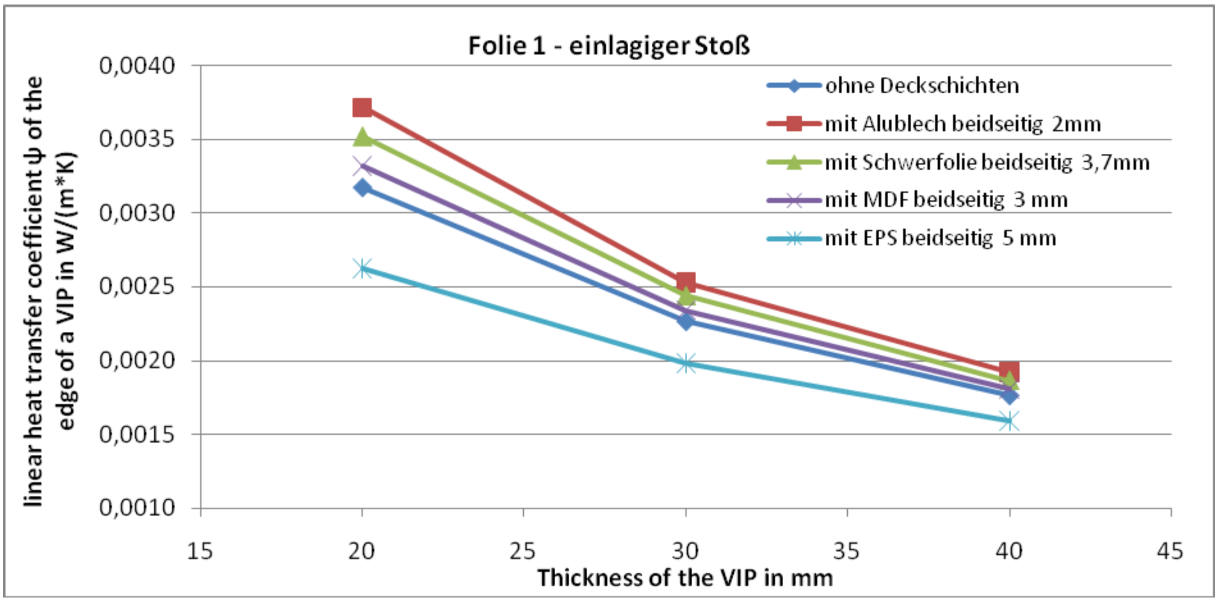

Figure 3: Influence of the covering layer material on the length-specific heat transfer coefficient for the single-layered edge and VIP of 20 mm to 40 mm thickness

3.1.4 Protective layers

From a thermotechnical point of view, protective layers on the panels are therefore rather unfavourable. They are, however, very useful for the handling of the panels as well as for transport and processing. Many materials are used as protective layers, e.g. insulating materials, lignin and wood-based materials, massive synthetics and also metals. Although massive materials provide better protection against damage during transport and against climatic conditions, attention should be paid to using protective layers made of insulating materials, as these reduce the thermal bridge effect at the film edge. The protective effect of robust insulating materials (e.g. XPS and PUR panels) should be sufficient if the panels are handled with appropriate care.

3.2 Production, application and cost effectiveness

3.2.1 Panel production

In order to produce a thermotechnically good VIP, great care and accuracy are required in all stages of production. Of particular importance is the quality control of the base materials – in particular of the film. A film lot of inferior quality cannot be offset by any other production measure. Regular control of the permeation characteristics is indispensable. If the permeation rate is too high, panels with fibre filling cannot be produced in the first place. The risk with silica support cores is a too fast degradation, which may go unnoticed at first, as silica is much more undemanding than fibre with respect to pressure increase in the panel.

The drying of the silica cores is current practice in the manufacturing of the panels available on the market. If other support core materials are used, the standard drying is far from sufficient. Here there are greater requirements for the vacuum, and it must be ensured that adherent water is completely baked out. In order to be able to produce fibre-filled panels, drying of the support cores for several hours at approx. 140°C is required.

The requirement for the internal pressure upon evacuation is derived from the size of the pore spaces. Since the pore spaces are considerably larger for fibre fills than for fumed silica, the requirements with regard to the quality and durability of the vacuum are also much higher. For the support cores examined, a target value for internal pressure of below 0.1 mbar is derived from the geometry of the fibres and the density of the support core in order to permanently suppress the air-heat conduction.

3.2.2 Application and service life

The currently applied aging process for vacuum panels in applications for general building-authority approval results in a failure of the panels in the case of fibre-filled

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panels. The simple temperature storage without humidity-freeze cycle test alone already leads to such a considerable pressure increase in the panel that the air-heat conduction is no longer suppressed and the thermal conductivity of the fibre-filled panel significantly increases. Even at room temperature, the permeation of the films is too high to maintain internal pressures below 0.1 mbar for any longer period of time.

3.2.3 Costs and economic efficiency

In the case of the expensive silica panels available on the market, the application can already be economically represented under good revenue conditions. By replacing, or partially replacing, silica by mineral fibres, the application of VIP could in future possibly be economically represented even in case of lower proceeds per square metre of effective area sold.

The leaner constructions, aside from larger effective areas, result in additional benefits which have to date not been fully examined, e.g. reduced costs for fixtures, roof overhangs, window reveals, connection components. In his paper for the 2nd VIP-Bau Conference 2005, Carsten Grobe for example describes such connection components and, in one case, compares the costs of a conventional solution at the eave connection to the solution using VIP [5]. Due to the still new construction with VIP, many connection solutions on the building are still being improvised and manually produced. If VIP construction becomes more widespread, cheaper solutions ready for series production will become realizable in future.

In order for VIP construction to prevail, the quality of the products and the construction work must be adequate and durable. With regard to silica VIPs, a few general building regulations approvals with external control have already been introduced. In addition, some manufacturers have applied for an RAL quality mark for vacuum insulation panels. Such quality-assuring measures help deepen the trust in VIP technology and support ever wider acceptance of VIP construction.

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