Development and First Experiences of a Prefabricated VIP-Sandwich-Element for Fast and Secure Application on Building Surfaces

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1 Introduction

The requirements for heat insulations on building envelopes are increased especially in last years. There are different reasons for this development. Some reasons for instance are the pollution of the atmosphere by $C0_2$ and the rising costs of energy. New ideas of house construction with a high thickness of conventional insulation material were developed in the 1990s.

Since a new generation of high insulating materials (vacuum insulations panels - VIP) is available, a few testing buildings were erected using VIP on different parts of their envelope, especially in the last 5 years. One aim for using VIP has been the requirement to reduce the thickness for instance for outer walls in new or renovated buildings with ensured high thermal insulation at the same time. Experiences from these buildings show that a special secure handling during transportation to and on the building site is required, because the risk to damage the panels is high before the VIPs are fixed on the building surface. On the other hand reported examples of VIP applications on buildings surfaces [Zwerger 2005] show that the appearance of damages are possible after a certain time of usage although the function of the VIPs after their application was proved by thermograph measurements.

Using the experiences from other buildings which are available at that point, a development team of members of the University of Rostock, the University of Applied Sciences of Wismar, a private company with experiences on the area of curtains walls (Adco-Company Rostock) and an architectural office (Institute for Building, Energy and Light, drawings in these report), were founded to prepare the use of VIPs with follow aims:

- Possiblity of using VIP in new buildings and buildings which have to be renovated (application on new and old building surfaces)
- High thermal insulation together with a reduced thickness in comparison with a conventional insulation system
- High fitness for purpose during the life time
- Comprehensive protection for the VIPs
- Possibility of checking the inner pressure of the VIPs before using
- Fast and secure installation of the VIPs on the building site
- Possibility of dismounting

As a result of the team work a VIP-sandwich-element with a special way of mounting was developed.

2 Construction and Application

2.1 Specimen

To fulfil the aims above a VIP-sandwich element were developed with the dimensions of about 2 meters in the length, 1 meter in the height and a total thickness of about 30 mm. Four VIPs each with length to height relation by about 500 mm to 1000 mm are grouped within the element. Each VIP is separated to the neighbour-VIP by a thin strip of PE-foam for reducing the risk of damage during the lifetime caused by different thinkable forces between the VIPs.

To provide convection between the outer (cold) and the inner (warm) surfaces, the 4 VIPs of a Sandwich-element are covered by foil of PE-foam.

The surfaces on both sides are floatglas (4 mm) on the inner side and ceramics (3 mm) or printed floatglas (4 mm) on the outside.

Own calculations showed [Winkler 2003] that the influence of heat loss caused by thermal bridges within of VIP-construction is able to reduce the thermal insulation of a VIP down to ordinary thermal insulation. So special attention was paid to the edge around the sandwich-element. To reduce the width as well as to reduce the influence of a thermal bridge it was decided not to use a spacer between the surface materials. During the work of assembling the VIP-sandwich-element, only a thin strip of glue in the edges were used to keep both surfaces and the whole element together. Additional these glue on the edges protect the VIPs until the Sandwich-Element is transported to the building site.

2.2 Application on the Building Envelope

After transportation to the building site the sandwich-elements were mounted on a sub construction which is known from curtain-wall-systems. This sub constructions consists of perpendicular aluminium profiles with a distance of 500 mm to another. The profiles themselves will be kept point like (Figure 2). The cavity between the profiles can be used as adjustment plane of an existing wall and is filled up with a conventional insulation material.

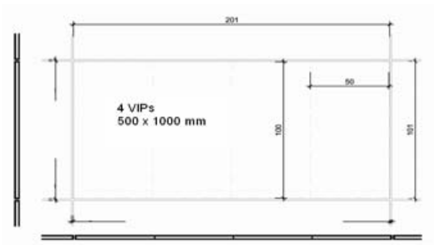


Figure 1:VIP-sandwich-element

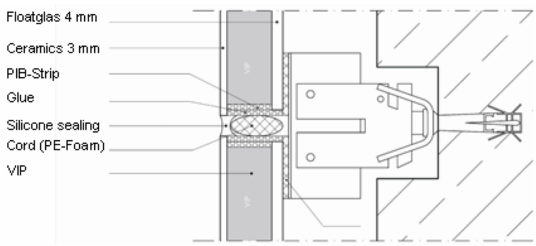


Figure 2: Joint of two VIP-sandwich-elements

Is the VIP-sandwich-element fixed to the sub construction, the load on the outer surface (wind load) will directly transported to the existing wall over the edges around without any additional attachments and without to debit the VIPs (structural glazing technique).

A cord of PE-foam with a relatively low thermal conductivity was placed into the joint between adjacent VIP-sandwich-elements to reduce the heat loss due to conduction, radiation and also as the base of exterior silicone sealing.

3 Theoretical analysis of the VIP-sandwich-element

3.1 Distortion-behaviour

A construction drawing for mounting the VIP-sandwich-elements on a testing wall is shown in figure 3. To avoid any damages (for instance cracks within the surface material) during the period of using (estimated 30 years) and to reduce the additional heat loss caused mainly by the joints between the VIP-sandwiches the follow effects has to be investigated:

- Bending behaviour of the VIP-sandwich-element under thermal an wind loads
- Lateral deformation under temperature load
- Minimal allowable width of the joint

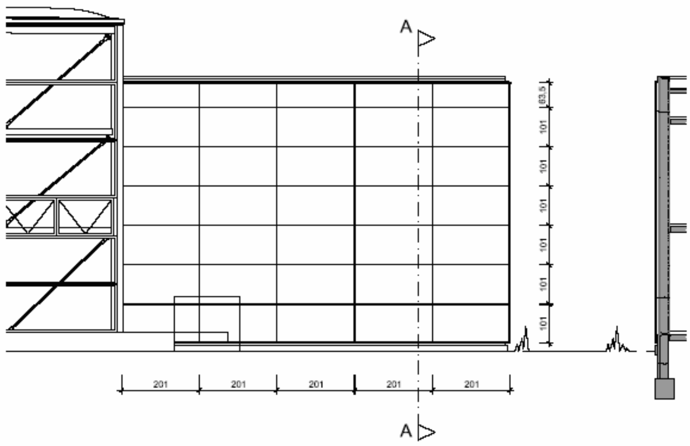


Figure 3: Construction drawing for VIP-sandwich-elements on a testing building (gable)

Bending behaviour of the VIP-sandwich-element

A frequently discussed question is the bending behaviour of a sandwich-element especially when the temperature difference between the inner and outer surface of an element is high as it can be expected in VIP-constructions and the different layers of an element has a high consistency to each other so that it can be transmitted shear forces.

As explained in the chapter “specimen” above the risk of bending should be low because the outer surface material (ceramics) only is joint to the inner surface and sub construction in the edges around. On this way a minimal movement of the different layers within a VIP-sandwich is possible, so it is assumed that shear forces have no influence and can not lead to a bending problem of the whole element.

Elongation under temperature load / minimal width of the joint between the VIP-sandwich-elements

As explained above only an expansion of the outer surface material within of the material itself can be expected looking at a possible outside temperature difference during a year. For this case the maximum value of elongation can be estimated with the follow equation:

$$\Delta l = \alpha \cdot l_o \cdot \Delta T \qquad [1]$$

With a assumed temperature difference of ΔT = 80 K (in summer 60°C and in winter –20 °C surface temperature) and an α-value for ceramics of $\alpha = 7{,}0*10^{-6}$ (glass $\alpha=1{,}0*10^{-5}$) the elongation for the longest side can be achieved with about 1.1 mm for ceramic and 1.6 mm for glass.

Width of joint

If the mounting of the VIP-sandwiches will done at an outside temperature of about 10 to 20 °C the minimal width of the joint between two adjacent VIP-sandwich-elements can now be determined to 8 mm, where the maximum compressibility of the sealing material (normally 25%) is considered too.

3.2 Thermal analysis

For further calculations (total heat loss of a building, for construction of the heating system) it is important to know the effective thermal transmittance coefficient U_{eff} of the VIP-sandwich-element. The U_{eff}-Value was determined with following equation:

$$U_{eff} = \frac{U \cdot A + \sum_{k=1}^{K} \psi_k \cdot l_k + \sum_{h=1}^{H} \chi_h}{A} \qquad [\,2\,]$$

With

U [W/mK]	ideal, undisturbed VIP or sandwich
A [m²]	Area of the VIP or sandwich
l_k [m]	length of the thermal bridges

The linear (ψ in W/m K) and local (χ in W/K) transmittance coefficients were calculated in accordance with [ISO 10211] (equations [3] and [4]):

- in a 2D – finite difference calculation with [HEAT2]

$$\psi = L^{2D} - U \cdot b \qquad [\,3\,]$$

With

L^{2D} [W/mK]	total thermal transmittance due to ΔT = 1 K
b [m]	length of the element

- in a 3D – finite difference calculation with [HEAT3]

$$\chi = L^{3D} - U \cdot A - \sum_{m=1}^{M} \psi_m \cdot l_m \qquad [\,4\,]$$

With

L^{3D} [W/K] total thermal transmittance due to ΔT = 1 K

To enable comparisons with conventional heat insulations systems and for a simplified determining of U-Values of composite walls a effective thermal conductivity λ_{eff} of the whole VIP-sandwich-element can be calculated as following:

$$\lambda_{eff} = \frac{d}{\frac{1}{U_{eff}} - R_{si} - R_{se}} \qquad [5]$$

With

d [m] total thickness of a VIP-sandwich-element

All calculations were done for two cases:

a) The thermal conductivity of a VIP within the Sandwich-Elements is λ = 0,005 W/mK (conductivity in centre of panel and under consideration of the additional edge heat loss of barrier envelope)

b) The thermal conductivity of a VIP within the Sandwich-Elements is λ = 0,010 W/mK (including the conductivity in the centre of panel, edge effect, aging and a security factor)

Furthermore the follow thermal bridges where investigated:

1) Linear thermal bridges in edges along a VIP-sandwich

2) Linear thermal bridge within a VIP-sandwich along the joint between two adjacent VIPs (Figure 1)

3) Local thermal bridges in a corner (4) of a VIP-sandwich

4) Local thermal bridge in an edge of VIP-sandwich, where the linear thermal bridges of number (1) and (2) meet themselves

Results

Table 1: Results of thermal calculations

Case	a)	b)	Description
λ_{VIP} [W/mK]	0,005	0,01	Conductivity of a VIP within the VIP-sandwich
U_{eff} [W/m²K]	0,430	0,630	Effective thermal transmittance of the VIP-sandwich
λ_{eff} [W/mK]	0,0125	0,0190	“overall” conductivity of a whole VIP-sandwich-element

The following graph shows the influence of linear and local thermal bridges. Because of paying attention especially to thermal bridges during the development process of the VIP-sandwich-element the influence of these kind for additional heat loss is reduced (ψ) respectively negligible (χ).

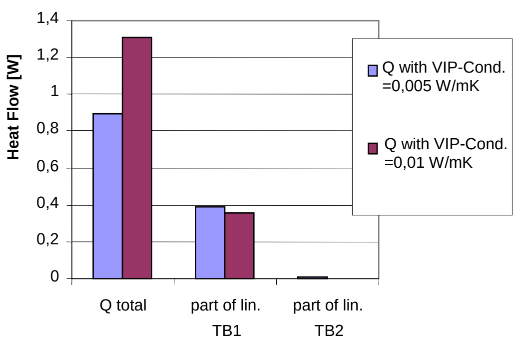


Figure 4: Influence of linear thermal bridges of a VIP-sandwich (heat flow applied to 1 K temperature difference)

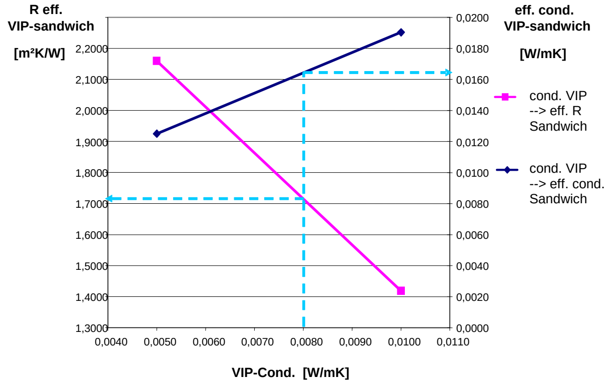


Figure 5: Range of effective thermal conductivity and resistance of a VIP-sandwich in dependence of VIP-conductivity

Remarks to Figure 4 and Figure 5: "VIP-Cond." means thermal conductivity λ of a VIP; "eff. cond. VIP-sandwich" means λ_{eff} of a VIP-sandwich-element.

In dependence on the conductivity of the VIPs, the thermal bridge effect can be seen in Figure 4.

Figure 5 shows the range of "overall" effective thermal conductivity λ_{eff} and resistance of a VIP-sandwich-element $R_{eff.}$ in dependence on the thermal conductivity of the used Vacuum-Isolation-Panel. If a VIP with an other conductivity will used, the thermal resistance and conductivity of the whole Sandwich-Element can be easily estimated on this way.

3.3 Analysis of the hygrothermal behaviour of a testing wall with a VIP-sandwich-element

If a vapour barrier in a building element is used and not situated near to the inner surface then the risk of condensation within a building element can be represent in dependence on the thermal resistance of materials from the inner surface to the vapour barrier. That means that a high risk of condensation exists, if VIPs are used for instance for renovations of older buildings, where the exterior walls have a certain thermal resistance and the VIPs will be mounted on the outside of the building. Further disadvantageous conditions are in this case a low thermal conductivity of the VIPs, so that the temperature between the VIP and the existing wall is low during the winter period.

Summarizing, the risk of condensation when using the VIP-sandwich-elements on the outside of an existing wall should be investigated under the follow disadvantageous conditions:

- The existing wall has a relatively high thermal resistance (for older buildings)
- The thermal conductivity of the used VIPs is λ = 0,01 W/mK
- The possibility of a damaged (air filled) VIP is taken into account (λ = 0,019 W/mK)
- The joint between two VIP-sandwiches leads to lower temperatures in this area compared with the centre of the VIP-sandwich-element (not content in these report)

The hygrothermal calculations were done using the material properties of an outside wall of a testing building in the city of Wismar, where the first application of the VIP-sandwich-elements is intended (Figure 3). The building was built at the end of the 1960s and has a relatively good thermal insulation. The testing wall consists of 20 mm cement-plaster, 200 mm lightweight concrete (thermal conductivity of λ = 0,36 W/mK) and 60 mm normal concrete on the outside, with a thermal transmittance coefficient of U = 1,30 W/m²K.

The VIP-sandwich-elements will be mounted on the testing wall as it is described on page 122, fulfilling the cavity behind the VIP-sandwich-elements between the sub construction with about 60 mm mineral wool (additional thermal resistance).

The calculations were done using the Wufi-Program [Wufi Pro], for one dimensional hygrothermal investigations of building components. It can be assumed that the relative air humidity in the mineral wool behind the VIP-sandwich-elements differs over the year and that the maximum will reached within the winter period. To control if an enrichment of water in these area take place the calculation was done over a period of 4 years with the climate conditions of a test reference year (TRY) of Kassel.

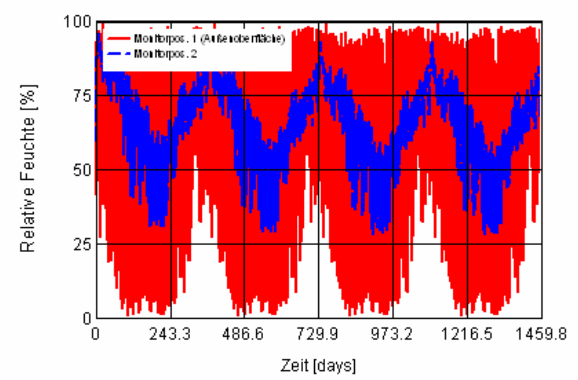


Figure 6: Relative humidity in the mineral wool plane (dark area) behind the VIP-sandwich-elements for the case of not damaged VIP

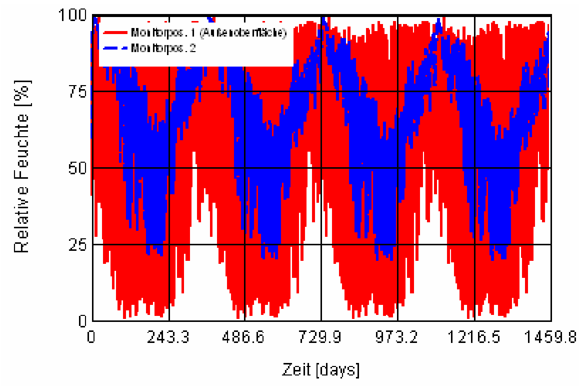


Figure 7: Relative humidity in the mineral wool plane (dark area) behind the VIP-sandwich-elements for the case of damaged VIP

Results

For the case of not damaged VIP within the VIP-sandwich-element the risk of condensation is low (Figure 6).The relative humidity doesn't reach the 100%-limit. If a VIP is damaged, condensation can be expected behind the VIP-sandwich-element for a short period. Figure 7 shows the water within the material which remains very short time, so the risk of an water-enrichment within the construction is very low.

Beside this, it can be assumed that because of the difference of the partial pressure of water vapour (within the mineral wool) behind the damaged VIP and the undamaged VIPs surround a pressure equalization take place, so that the risk of condensation additional is reduced.

4 Experimental investigations

4.1 Experimental set up

To compare the results of the theoretical analysis with the real behaviour and to receive an high security for the outside application, experimental investigations were made with VIP-sandwich-elements mounted on a wall in a climate chamber.

Figure 8: Assembling of the testing wall with VIP–Sandwich-Elements

Figure 9: Finished testing wall with VIP-sandwich-elements mounted in the steel frame of the climate chamber

The load bearing wall consists of 100 mm concrete. The aluminium profiles of the sub construction is held at three one directional moveable points (above, middle, down). 4 VIP-sandwich-elements (2 with dimensions of about 1000 x 1000 mm and 2 with 1000 x 2000 mm) were glued on the sub construction. The cavity between the profiles were filled up with 60 mm of mineral wool.

To investigate the behaviour of the different possible outside surface materials, three VIP-sandwiches were equipped with ceramics and one with unprinted floatglas (Figure 9).

The specimens were tested in a climate chamber under steady-state conditions (warm side 20 °C; cold side -5 °C). The follow investigations were done in the climate chamber to determine

- Lateral deformation
- Thermal heat loss

Experimental investigations on hygrothermal behaviour of the testing wall in the laboratory (especially behind the VIP-sandwich) were not made because of the long term character of this kind of measurements. These measurements will be made under natural conditions after mounting the VIP-sandwiches on a testing building.

4.2 Experimental investigations of the distort behaviour

To confirm the assumption described on page 123 and 4 the elongation and bending of the VIP-sandwich-elements were observed until steady-state conditions were reached in the climate chamber. For this purpose 42 measurement-points with 64 measurement-lines between them were glued on the outside surface as shown in Figure 10 and Figure 11.

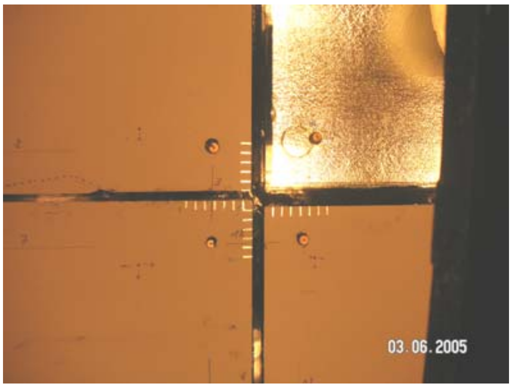


Figure 10: Measurement-points in the junction-area of 4 VIP-sandwich-elements

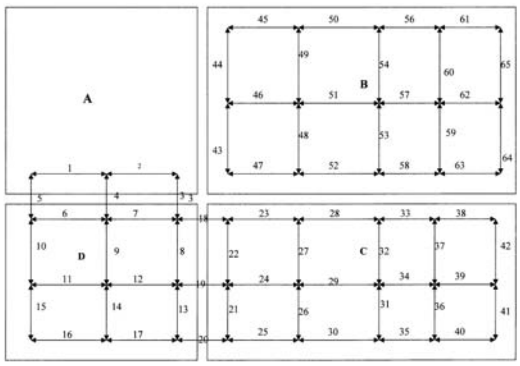


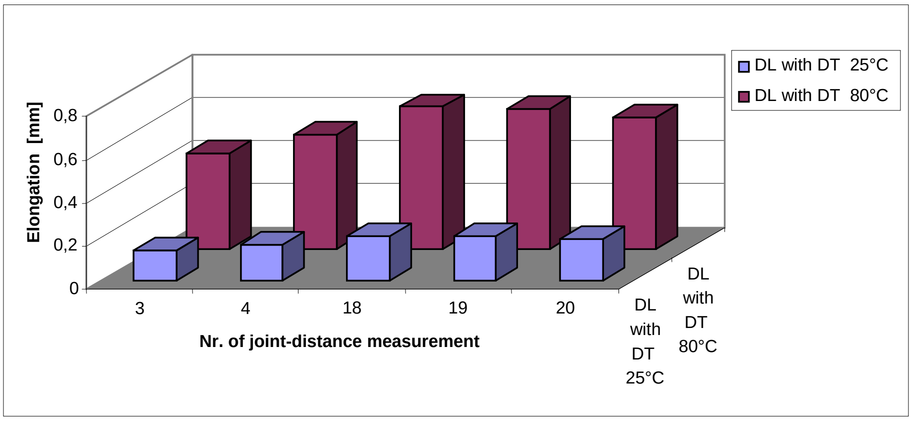
Figure 11: Distribution of measurement-points over the whole testing wall.

Bending behaviour of the VIP-sandwich-element

During the time until steady-state conditions were reached, the bending of the outer surface were checked a few times by using a simple straight edge. As expected above there was no measurable bending on the outer surface.

Lateral deformation under experimental temperature load

The follow graphic shows the difference of the joint-width after reducing the temperature in the cold area of the climate chamber from about 20 °C to -5°C (ΔT = 25°C) and with that result projected to a temperature difference of ΔT = 80°C.



Remark to Figure 12: "DL" means the elongation of joint Δl and "DT" means the temperature difference ΔT.

Figure 12: Elongation of joint-width under temperature load

The comparison of the measured and projected results (Figure 12) with the permitted value of 2 mm for maximum expansion or compression of a sealing material (25% of 8 mm) shows that the permitted value will not be reached.

4.3 Thermal investigations in the climate chamber

To confirm the calculated thermal behaviour, the influence of the thermal bridge effect was investigated in the climate chamber. As a result from the thermal calculations above, it can be assumed that the linear thermal bridges on the edges around a VIP-sandwich-element (Figure 2) have the biggest influence of an additional heat loss and should be more analyzed.

Because of the kind of experiment (measurement of different kinds with one experimental setup, not using the "black box" method) a direct measurement of the additional heat flow over the joint between the adjacent VIP-sandwich-elements is not possible. But comparing the temperature spreading over a joint once calculated and once IR-measured should deliver information about the quality of the calculations. If the accordance of temperatures is good the calculations of thermal transmittance shows the right results. To approve this, metal strips (with low long wave emission compared to the surface around, Figure 10) were glued on the outside surface to straighten out an IR-picture and to assign a surface temperature to the distance from the middle of the joint. To estimate the surface resistance on both side of the testing wall, measurements of the heat flow, surface temperatures and air temperatures were done. After the steady state conditions in the climate chamber were achieved IR- Pictures were taken.

Numerical analyzes with the HEAT3-Programm were done with the model of experimental specimen and the same boundary conditions as measured in the climate chamber.

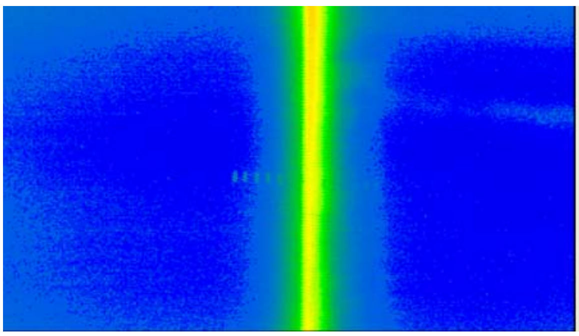


Figure 13: IR-Picture of the joint between two VIP-sandwich Elements mounted on the testing wall

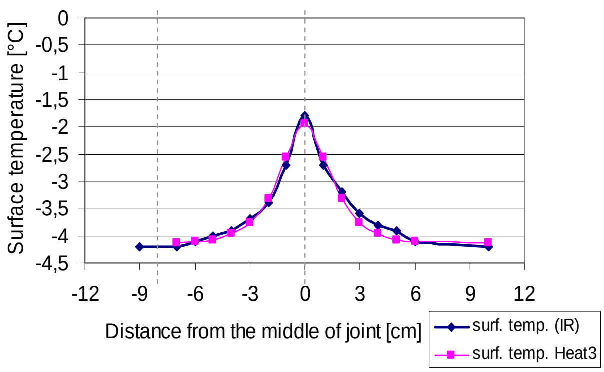


Figure 14: Comparison of IR-taken and calculated surface temperatures near an edge of a VIP-sandwich used on the testing wall

Results:

As demonstrated in Figure 14, a good accordance exists between measured and calculated surface temperature of the experimental setup. So it can be assumed that all thermal properties of the used materials are exactly chosen and the calculation of the additional heat loss over the joint shows usable results.

5 Abstract

For old buildings, which have to be reconstructed to a modern thermal protection standard, the application of a prefabricated VIP-sandwich-element was investigated regarding maximal achievable thermal protection by using VIPs and concerning the avoidance of any structural damages caused by these special VIP-applications.

In the field of thermal protection it could be demonstrated that the use of the presented VIP-sandwich-element caused an additional heat loss of about 52% compared to a Vacuum-Isolation-Panel using the design value for thermal conductivity of a VIP. In this value of 52% the influence of the material of a VIP-sandwich-element itself as well as the attachments to the load bearing wall was considered.

The investigation of the distort behaviour showed that the minimized joint-width (8 mm) between the VIP-sandwich-elements due to thermal elongation not lead for instances to cracks within the sealing material of the joint. For particle use tolerances should be taken into account.

Hygrothermal calculations for the application of the VIP-sandwich-element on a gable of a testing building shows, that there is no risk for condensation behind the VIP-sandwich-elements as long as they are not damaged. In the case of an air filled VIP, condensation is possible for a short period which will not lead to an unallowable enrichment of water over a longer period. Further investigations have to be done to investigate the risk of condensation behind the joint of two VIP-sandwich-elements.

6 References

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