Long-term performance of vacuum insulations panels in buildings and building systems

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Abstract:
The extremely low thermal conductivity of vacuum insulation panels (VIP) leads to less required insulation thickness in different applications. This paper aims to present our research findings related to the long-term performance of VIPs based on measurements during the last five years. The measurements were performed both in laboratory and in field where the real condition are present. The performance of an exterior wall retrofitted with VIPs and a hybrid insulated district heating pipe were observed. The expected service life of both application are more than 50 years. Thus, the long-term performance of the VIPs is of interest. The results of the evaluation indicate that there is no considerable performance degradation after five years in the wall application and after three years in the hybrid insulated pipes. The results are promising. However, it is still too soon to make final conclusions of the entire service life performance of the applications.
Keywords:
Field study, laboratory study, numerical model, retrofitting, district heating

1. Introduction

The extremely low thermal conductivity of vacuum insulation panels (VIP) leads to less required insulation thickness in different applications. This is especially beneficial in metropolitan areas with high rental costs and in cultural heritage buildings where the space for insulation is limited. Since the beginning of the 1990s several buildings have been insulated with VIPs. A survey of 19 buildings in Germany showed that there is a low degree of damages after the VIPs have been installed in the building [1].

VIPs are also used in pipe insulation. The district heating system was introduced in Sweden in the 1940s and today over 20 000 km of pipes are placed in the ground. In the future buildings are expected to demand less energy for heating. Therefore, the heat transfer per meter pipe is expected to decrease. Many energy companies are also facing large renovation needs in their pipe systems. By using VIPs for hybrid insulation of district heating pipes the heat losses in the system can be reduced.

Discussions are ongoing among researchers in the field on how to evaluate the long-term performance of VIPs. One suggestion is to measure the increase of the internal pressure and weight of VIPs stored in 23°C and 50% relative humidity (RH) initially, after 3 months and after 6 months. An accelerated ageing measurement procedure is also proposed where the thermal conductivity is assumed to be only dependent on the increased gas pressure inside the VIPs. The final thermal conductivity after storage in a cycling climate for 8 days and then in 80°C for 180 days is regarded as the 25 year value. However, the real condition of a specific application could be far from these conditions. In buildings VIPs seldom are directly exposed to moisture and temperature because they are embedded in materials in the wall, floor or ceiling. In district heating, VIPs are exposed to temperatures above 100°C and they are in a dry environment with high concentrations of the gas cyclopentane.

The service time of both application mentioned above are more than 50 years. Thus, the long-term performance of the VIPs is of interest. This interest is also expressed by IEA/EBC Annex 65 Long-Term Performance of Super-Insulating Materials in Building Components & Systems. This paper aims to discuss and identify the boundary conditions present in buildings and district heating pipes and their effect on the service life of VIPs. The evaluations were performed in laboratory and in field where the real condition are present. The results related to the long-term performance evaluation of VIPs during the last five years are presented and discussed.

2. VIPs in an exterior wall

A building from 1930 was insulated with VIPs in the exterior wall. Fig. 1 presents the elevation and section of the façade with the 20 mm thick VIPs which are protected by 30 mm mineral wool.

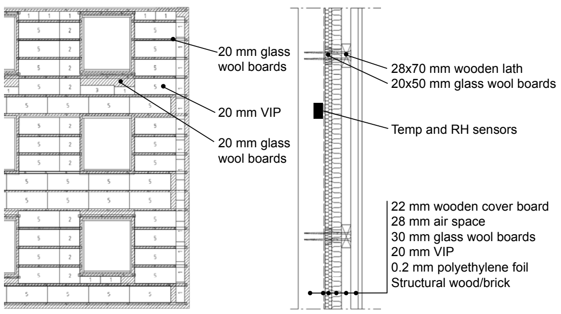

Fig 1: Case study building wall with VIPs.

To enable installation of the wooden cover board on the exterior of the insulation, mineral wool boards were cut in 20 mm thick strips and placed in the junction between two VIPs. During the construction 3 VIPs out of 180 (1.7%) were damaged and changed to new panels [2].

There are temperature and RH sensors installed in the wall on the interior of the VIPs, and sensors also monitor the interior and exterior climate. The wall was finished in August 2010 and there are now more than 4 years of complete data available. To evaluate the performance change with time the temperature measurements have to be corrected for the different indoor and outdoor conditions. A dimensionless temperature factor for the temperature in the wall can be calculated by using Eq. 1:

$$f = \frac{T_{indoor} - T_{sensor}}{T_{indoor} - T_{outdoor}} \quad (-) \qquad \textit{(Eq. 1)}$$

where

T_{indoor}	=	indoor temperature
T_{sensor}	=	sensor position temperature
$T_{outdoor}$	=	outdoor temperature

The lower the temperature factor is, the higher the thermal insulation on the exterior of the sensor. On the interior side of the wall the temperature factor is 0 and on the exterior side it is 1. The temperature factor in the wall is compared to a non-insulated reference wall during January 2011 to 2015 in Fig. 2.

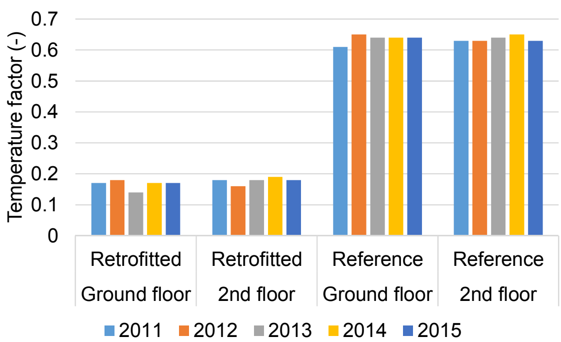

Fig 2: Temperature factor for the wall with VIPs compared to a non-insulated reference wall for January, 2011 to 2015, calculated using Eq. 1.

The wall with VIPs has an average temperature factor of 0.17 while it is 0.64 for the non-insulated reference wall. The temperature factor is stable during the five years which means there is no significant change of the heat flow or temperature profile in the wall. During these four years the temperature and RH at the center of the VIPs was on average 22°C and 37% RH while it varied between 14-30°C and 20-51% RH. Inside the building the temperature was between 20-33°C and 18-79% RH while it was -13-36°C and 10-100% RH outdoor.

3. VIPs in hybrid insulated district heating pipe

VIPs have a large impact on the thermal performance of hybrid insulated district heating pipes [3, 4]. The VIPs are combined with polyurethane foam insulation as presented in Fig. 3.

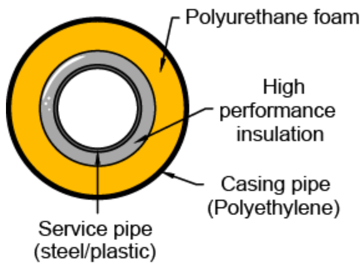

Fig 3: Concept for hybrid insulated district heating pipes with VIPs and polyurethane foam insulation.

One main concern is the long-term durability of the VIPs. In district heating pipes the temperature can reach 120°C. This is higher than the temperature limit for conventional VIP envelopes. Berge and Adl-Zarrabi [4] stored VIPs at different temperatures in an oven. Some VIPs lost their vacuum already at temperatures around 70°C.

In a pipe the temperature will not be evenly distributed throughout the cross section of the insulation, but will rather form a gradient. A hypothesis is that the sealing of the VIP envelope is the weak point of the diffusion barrier. Strategic location of the sealing could significantly improve the high temperature durability of the VIPs. For example the sealing could be located towards the colder side of the pipe.

The effect of the sealing location was tested in laboratory by measuring the temperature at different positions in a district heating pipe insulated with an 8 mm thick VIP surrounded by polyurethane foam. The relative thermal conductivity, p_λ, of the VIP and the polyurethane was calculated by Eq. 2 based on [5], assuming a constant heat flow.

$$p_\lambda = \frac{\lambda_2}{\lambda_1} = \frac{(T_1 - T_2)\cdot \ln(r_3/r_2)}{(T_2 - T_3)\cdot \ln(r_2/r_1)} \quad (-) \qquad \textit{(Eq .2)}$$

where

λ	=	*thermal conductivity of layer n*
r	=	*radius to the boundaries*
T	=	*temperature at certain distance*

The inner pipe of the district heating pipe had a radius of 45 mm (r_1) giving an outer radius of the VIP layer at 53 mm (r_2) and the outer radius of the polyurethane foam was 90 mm (r_3). The resulting temperatures are shown in Fig. 4.

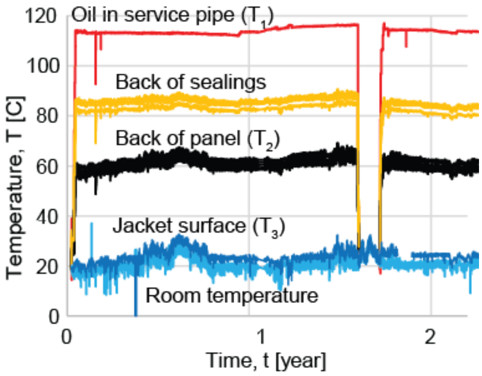

Fig 4: Temperatures at a number of positions in hybrid insulation district heating pipes tested in laboratory.

The temperature in the service pipe is 115°C, while the temperature in the VIP envelope is less than 90°C and the temperature on the exterior of the vacuum insulation panels are around 60°C. After more than two years, no temperature increase can be detected.

To estimate the thermal performance of the VIPs, making sure that they were not installed filled with air, the relation between the thermal conductivity of the polyurethane foam and the VIP was calculated according to Eq. 2. The calculation gave a relation between the materials of 4.4. This show that the VIP have a consistent superior thermal performance compared to the polyurethane foam. Similar results have also been seen in field measurements [6].

4. Results and discussions

The results of the evaluations indicate that there is no considerable performance degradation after five years in the wall application and after three year in the hybrid insulated pipes. The results are promising. However, it is still too soon to make final conclusions of the entire service life performance of the applications.

During the construction of the wall several practical issues where highlighted. It is important to provide standardized fastening methods to minimize thermal bridges. Also damages of VIPs during construction and condensation risks in the wall have to be paid close attention, especially at the thermal bridges. The quality assurance of VIPs if embedded in another material such as polystyrene have to investigated since they cannot be easily controlled on the construction site in this case.

For the hybrid insulated pipes, the VIP performed much better in the complete hybrid insulation set-up than expected from laboratory evaluation of the panels by themselves. This can be explained by a number of factors where the nature of the film and its properties need better specification. There could also be problems with the humidity and delamination of the film inside the pipe. Also the melting temperature of the polymer film might be different between VIPs used in the laboratory and field evaluations. More investigations are also need of the dominant permeation which could be through the sealing and not through the envelope itself. In that case, the location of the sealings, in relation to the temperature gradients, could be of large importance.

5. Conclusions and outlook

VIPs are already used in many buildings and building systems. However, the long-term performance of the product is not entirely investigated. The ongoing monitoring of the applications presented in this paper will reveal the long-term performance of VIPs in real conditions. The work in IEA/EBC Annex 65 will reveal answers to several of the other important issues raised in this paper.

Acknowledgements

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References

[1] Heinemann U, Kastner R. VIP-PROVE: Vakuumisolationspaneele - Bewährung in der Baupraxis. Wissenschaftliche Begleitforschung. Schlussbericht Energieoptimiertes Bauen, ViBau Report ZAE 2-1210-11 (2010) (VIP-PROVE: Vacuum insulation panels - Testing in construction practice. Scientific evaluation. Final report energy optimized construction). [In German]. Bayerisches Zentrum für Angewandte Energieforschung e.V. ZAE Bayern, Würzburg, Germany, 2010.
[2] Johansson P, Sasic Kalagasidis A, Hagentoft C-E. Retrofitting of a listed brick and wood building using vacuum insulation panels on the exterior of the facade: Measurements and simulations. Energy and Buildings 2014;73(April 2014):92-104.
[3] Berge A, Adl-Zarrabi B. Using high performance insulation in district heating pipes. 13th international symposium on district heating and cooling, Copenhagen, Denmark: District energy development center; 2012, p. 156–62.
[4] Berge A, Adl-Zarrabi B. Evaluation of vacuum insulation panels used in hybrid insulation district heating pipes. 14th international symposium on district heating and cooling, Stockholm, Sweden: Swedish district heating association; 2014, p. 454–61.
[5] Hagentoft C-E. Introduction to Building Physics. Lund, Sweden: Studentlitteratur; 2005.
[6] Berge A, Adl-Zarrabi B, Hagentoft C-E. Field measurements district heating pipes with vacuum insulation panels. Submitted to Renewable Energy, 2015.