Thermal Properties and Service Life of Vacuum Insulation Panels (VIP)

H. Simmler and S. Brunner

Empa, Swiss Federal Laboratories for Materials Testing and Research,
Ueberlandstr. 129, CH-8600 Duebendorf, Switzerland
hans.simmler@empa.ch, samuel.brunner@empa.ch

ABSTRACT

Highly efficient thermal insulation of the building envelope demands for layers up to 40 cm thickness. This often causes problems regarding architecture and loss of space, especially in building renovation. An attractive alternative is the recently introduced vacuum insulation panel (VIP) having a 5 to 8 times lower thermal conductivity than conventional thermal insulation. Aging effects and service life are crucial aspects of those high performance insulation systems, as gas permeation through the envelope barrier may drastically reduce the insulation efficiency. In the present contribution aging mechanisms and experiments as well as service life estimates investigated within IEA Annex 39 subtask A are reported. In-situ monitoring data taken from a flat roof construction are compared with results from a prediction model that is based on aging characteristics determined by laboratory experiments for constant temperature and humidity conditions.

KEYWORDS

Vacuum insulation, physical properties, aging, service life, monitoring.

INTRODUCTION

The vacuum insulation panel (VIP) is a high performance insulation component for the building envelope, introduced into the construction technology in the last few years (IEA Annex 39, 2005). Its high thermal resistivity – five to eight times higher compared with conventional insulation materials – makes it suitable for designing energy efficient buildings even with slim insulation layers. For example, VIP is beneficially applied in accessible flat roof areas of buildings, thus achieving equal levels of indoor and outdoor zones (Figure 1). Large potentials are apparent also in building renovation where little space for insulation is available.

Basically the manufacture of VIP is simple. A layer of a porous core material is sealed in a gas tight envelope at low air pressure. While open cell polystyrene foam has been used for many years by the refrigeration industry, fumed silica powder (SiO_2 agglomerates) has become the main core component in VIP for building application. The main reason is the large suppression of gaseous conduction even at a pressure around 1 mbar, which is a benefit of the very small pore size below 100 nm (Figure 2). Furthermore, SiO_2 is chemically inert and non combustible. Additional core ingredients are glass or polymer fibres for structural reasons, and opacifier to

eliminate radiative heat transfer. The thermal conductivity of the dry core at 1 mbar is around $4 \cdot 10^{-3}$ W/(m K). Massive aluminium foils used as barrier in the early stage of VIP production are favourable regarding the permeation properties, but thermal bridge effects around the panel edges are too high for building applications. Actual barrier materials are laminates of up to three aluminium coated polymer films (PET, PP) and an additional PE layer for thermally sealing the envelope. As an example, the edge effect of those barriers is in the order of 20 percent compared to the one-dimensional heat flow through an ideal 100 x 100 x 2 cm^2 core (Ghazi et al., 2004). It is evident that the conservation of the initial low pressure and dry state inside a VIP is the main concern when thinking of a long-term application in buildings. A service life of 30, 50 or more years is expected from a built-in component because replacement is often expensive or almost impossible. Therefore, acceptable pressure increase is limited to about 2 mbar per year.

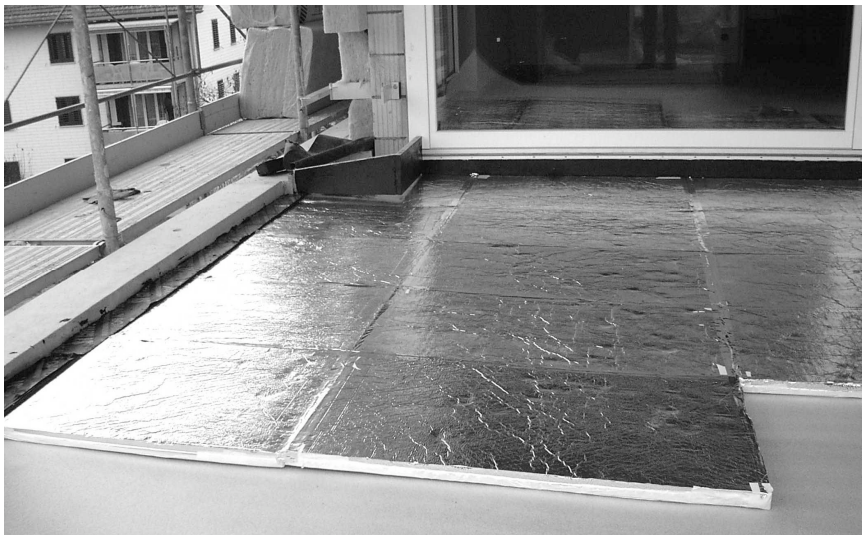

Figure 1: Slim insulation of a balcony area giving equal levels for indoor and outdoor zones.

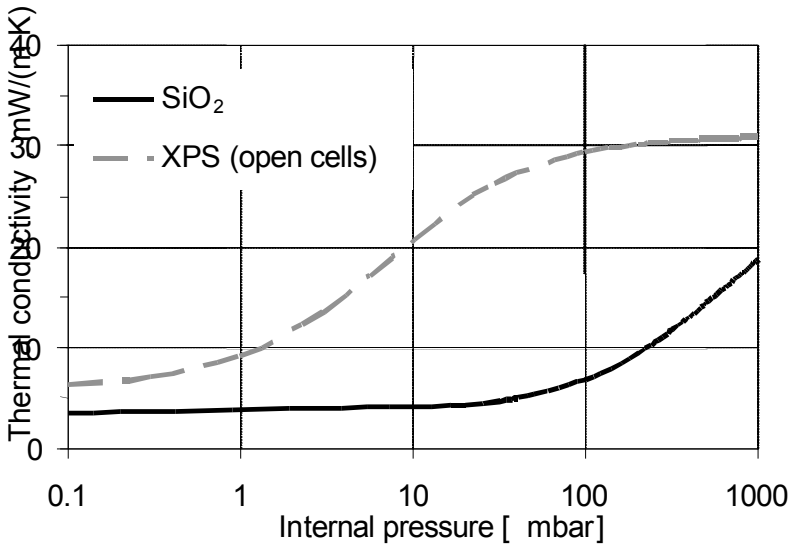

Figure 2: Thermal conductivity of nano-porous fumed silica (SiO_2) and open cell extruded polystyrene foam (XPS) as a function of gas pressure.

HYGRO-THERMAL AGING EXPERIMENTS

Aging of VIP was investigated by means of exposure to various conditions in a climate chamber (Simmler et al., 2005). Moisture content and the internal pressure (by detection of the equilibrium pressure in a depressurization chamber) were determined in regular time intervals. The 20 mm thick square specimens with side length 250 mm ("small") and 500 mm ("large") were recent VIP products on the European market with a threefold metallised polymer laminate barrier.

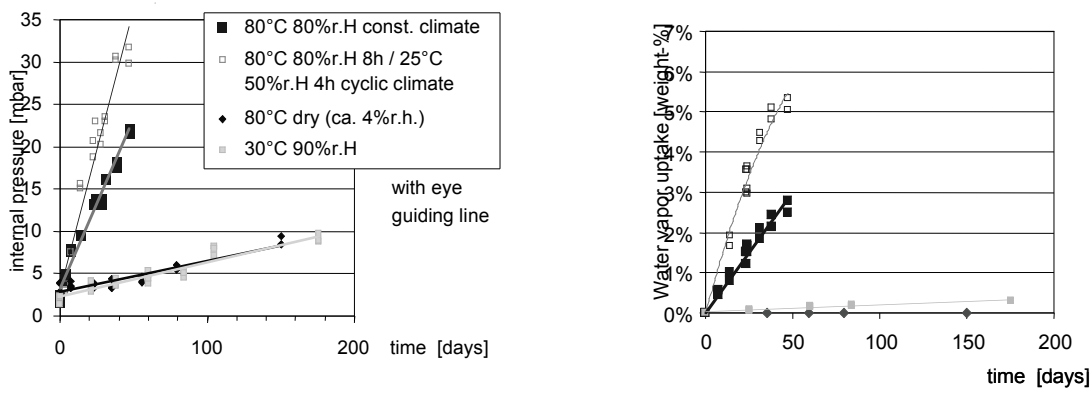

Figure 3: Increase of internal pressure (a) and moisture content (b) in "small" VIP at elevated temperature / humidity. The measurements were done at room temperature after cooling down the samples for some hours.

As shown in Figure 3 both the pressure increase and the water uptake strongly depend on the climate conditions. At 80°C and high humidity, the degradation is rather fast. Also at low humidity the pressure increase is too fast for long-term application. Based on similar measurements at reference conditions 23°C / 50% RH calculated format dependent yearly rates are indicated in Figure 4 for two 20 mm thick VIP products with various square panel formats up to 1 x 1 m^2. For those conditions the rates are in a suitable range for building application. There is a clear trend toward lower pressure increase rates for larger formats due to the less contributing perimeter. The format dependence is less significant regarding moisture accumulation, since the surface contribution is more dominant. In summary, these VIP products show sufficiently low leakage rates for long-term service under reference conditions for formats 0.5 x 1.0 m^2 or larger.

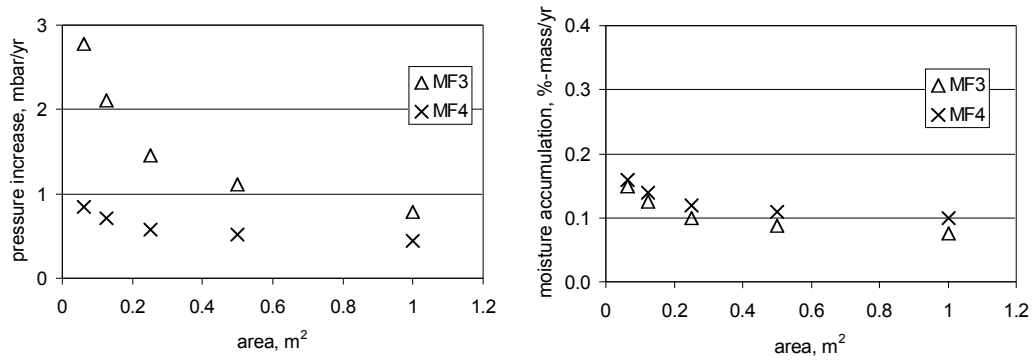

Figure 4: Moisture accumulation and pressure increase rates at 23°C, 50% RH (1 bar) for various VIP formats, based on the values in Table 2 (uncertainty 10 to 15%).

MONITORING OF VIP IN A FLAT ROOF APPLICATION

An existing flat roof construction, located near Zurich (Switzerland), was chosen for investigation. The sequence of construction layers is listed in Table 1. Square VIP type MF3 (c.f. Figure 4) were installed in two square areas, one of them equipped with temperature and humidity sensors on both VIP surfaces near the centre and at the cross joints. The other area was prepared for repeated opening because the internal pressure and moisture content was determined in the laboratory.

TABLE 1: Construction layers of a flat roof with VIP insulation.

Layer	d [mm]
Crushed gravel	30
Bituminous water barrier (3 layers)	10
Protective layer	7
VIP	20
Protective layer	5
Water barrier (previous construction)	10
Porous concrete (previous construction)	200

The data recording was started in June 2004 and is continued presumably for three or more years. The temperature and humidity progression for one year is shown in Figure 6. The temperature on the outside VIP surface shows a typical yearly cycle with peaks close to 60°C. The relative humidity around the VIP is almost independent from the temperature variation, which is explained by moisture buffering in the surrounding materials. A slow continuous increase is seen presumably due to vapour desorption from the protective layer underneath the VIP, which was slightly wetted during the installation. Pressure and moisture content increase rates are shown in Table 2. The values are 2 – 3 mbar and about 0.1 – 0.2 %-mass per year.

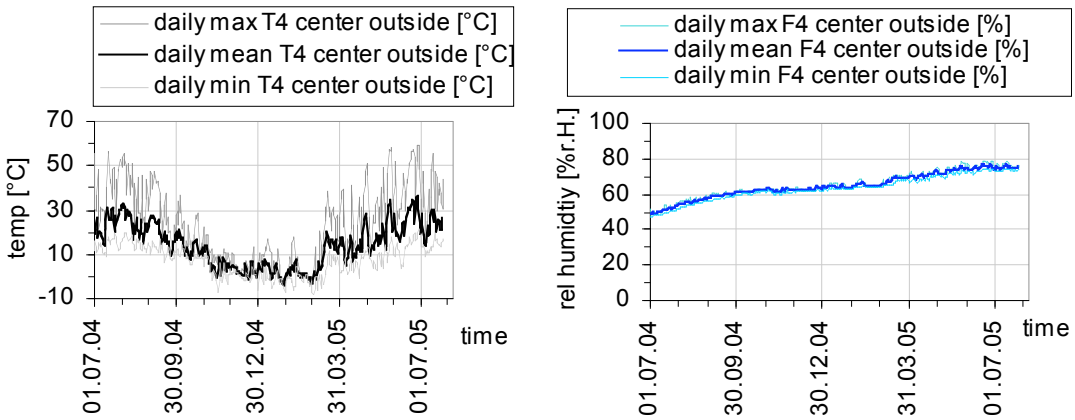

Figure 6: Monitored temperature and humidity conditions on the outside VIP surface.

COMPARISON OF REAL AND LABORATORY DATA, SERVICE LIFE MODEL

To compare the monitoring results with laboratory-based accelerated aging, permeation data were determined in the laboratory at various temperatures and 80 % RH, which corresponds to the average cavity situation in the application. The pressure increase rate p_a is indicated in Figure 7 in a log (p_a) versus 1/T plot. The

linear shape of the plotted data clearly indicates an Arrhenius-like behaviour of the acceleration function, which was also found at low vapour pressure for various barrier materials (Schwab, 2005).

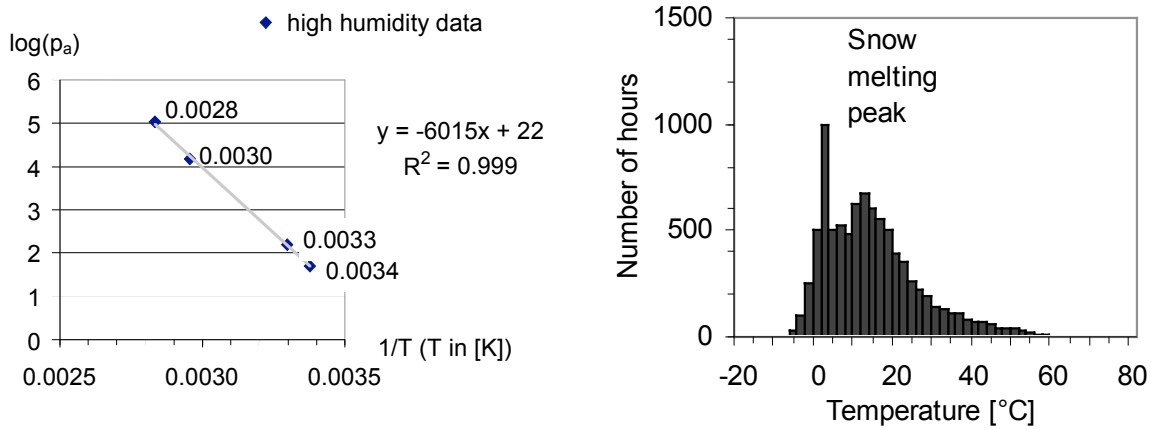

Figure 7: Arrhenius plot of pressure increase rates (left), histogram of hourly surface temperatures measured for one year (right).

The Arrhenius fit parameters A and E_a, obtained from the data in Figure 7, are used to determine an effective temperature $T_{effective}$ and to estimate the pressure increase rate with respect to dynamic boundary conditions as follows:

$$p_a = \sum_i A \exp\left(-\frac{E_a}{RT_i}\right)\Delta t_i \Big/ \sum_i \Delta t_i \equiv A \exp\left(-\frac{E_a}{RT_{effective}}\right) \qquad (1)$$

A similar approach is applicable to the yearly moisture content increase rate X_{wa}. Measured and calculated pressure and moisture content increase rates are summarized in Table 2. The pressure increase rates based on $T_{effective}$ are in good correspondence with the measured values, keeping in mind that several assumptions and simplifications were made in the calculation. If the average temperature is used, the result is lower compared to the measured value, thus underestimating the non-linear impact of high temperatures.

TABLE 2: Comparison of measured and calculated aging data for the inside and outside surface of a 20 mm VIP layer in a flat roof construction.

Panel size	Quantity	Calculation based on the temperature data (1 year)			Measurement	
	[mbar/yr]	Inside	Outside	Mean		
25 x 25 x 2 cm^3	p_a ($T_{effective}$)	2.72	2.89	2.8	2.9	±0.2
	p_a ($T_{average}$)	2.48	1.70	2.1		
50 x 50 x 2 cm^3	p_a ($T_{effective}$)	2.04	2.17	2.1	1.9	±0.2
	p_a ($T_{average}$)	1.86	1.27	1.6		
	[%-mass/yr]					
25 x 25 x 2 cm^3	X_{wa} ($T_{effective}$)	0.26%	0.29%	0.28%	0.22%	±0.04%
	X_{wa} ($T_{average}$)	0.23%	0.16%	0.19%		
50 x 50 x 2 cm^3	X_{wa} ($T_{effective}$)	0.15%	0.17%	0.16%	0.13%	±0.02%
	X_{wa} ($T_{average}$)	0.14%	0.09%	0.11%		

The results for the moisture content increase rate are less unambiguous. The overall agreement is o.k., but the non-linear weighting seems to give a somewhat too high rate. One reason may be an observed drying effect due to the repeated opening of the test area. With arithmetic averaging the result is again below the experimental value.

To predict the long-term progression of the thermal conductivity, the measured data in Table 2 were up-scaled to a standard panel format 100 x 60 cm^2. For this dimensions the rates are p_a = 1.5 mbar/yr and X_{wa} = 0.10 %-mass/yr. According to [3] the predicted thermal conductivity increase as a function of time t (in years) is

$$\Delta\lambda \cong 0.035 \cdot p_a \cdot t + 0.50 \cdot X_{W,equilibrium} \cdot (1- \exp((-t/\tau)), \text{ in } 10^{-3} \text{ W/(m K)} \qquad (2)$$

where the time constant for moisture saturation is

$$\tau = X_{w,equilibrium} / X_{wa} = 64.0 \text{ yr, with } X_{w,equilibrium} \approx 6.4 \text{ \%-mass at 80 \% RH} \qquad (3)$$

The expected change of the thermal conductivity is $2.3 \cdot 10^{-3}$ W/(m K) after 25 years, which is the standard period for the specification of long-term properties of thermal insulation products in Europe [5]. Assuming an initial value of $4.5 \cdot 10^{-3}$ W/(m K) the thermal conductivity after 25 years is approximately $7 \cdot 10^{-3}$ W/(m K). At present there are not enough means to quantify the uncertainty of this prediction.

CONCLUSIONS

The investigations at Empa and other laboratories show that the new high performance thermal insulation panels based on evacuated fumed silica sealed in a polymer laminate including several thin metal coatings have the potential to meet the requirements both for long-term building application and acceptable bridge effects through the edge zone.

Monitoring data from a flat roof with VIP insulation show aging effects of the panels that can be quantified with reasonable accuracy after a period of one year. The results seem to confirm the application of simple service life models based on laboratory aging data at constant conditions. Thus a service life of several decades seems to be possible in suitable constructions. Monitoring results from longer periods are needed to rate other potential aging mechanisms and to strengthen confidence in the vacuum insulation technology.

References

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