Vacuum Insulation Systems – Possible Applications and Design Considerations

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1 external view of the VIP facade of a hospital in Erlenbach (ZAE)
2 general structure and elements of a vacuum insulation panel (VIP)
3 different available vacuum insulation systems
4 vacuum insulation systems, combinations and light transmittance

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Vacuum insulation systems are currently one of the most important fields of innovation in the construction sector, and are receiving more and more attention from all quarters. In contrast to the majority of products used in the construction field, they are highly complex systems. Using them therefore presents the risk of a number of possible mistakes; they call for a high level of competence from both the designer and the user. Within a conventional insulating material, thermal transport is typically made up of 20–30 % thermal radiation, 5–10 % thermal conduction through the material of the framework, and about 65–75 % thermal conduction through the enclosed gas. The common operating principle of vacuum insulation systems is therefore to minimise the transmission of heat through the most important of these routes, the gas, by evacuating the unit. In order to maintain the vacuum in this kind of insulation system over a long period, it is necessary to surround the evacuated space by a gas-proof envelope consisting, for instance, of glass, metal, plastic or a composite plastic membrane. The enclosed space can either be empty, or it can be filled with a core material whose cells are entirely open and which can therefore be

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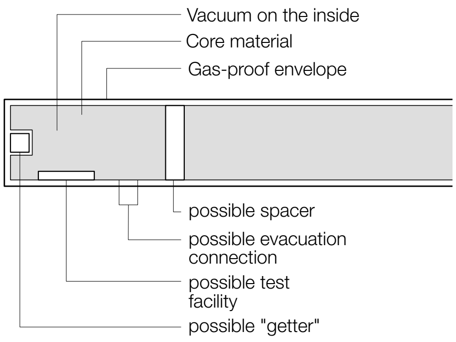
evacuated. Depending on the level of induced vacuum, the system must be capable of resisting a significant proportion of atmospheric pressure (equivalent to up to about 10.3 tonnes/m^2).
Ill. 4 provides an overview of the individual components and their possible combinations, and of the light transmission offered by the various insulation systems.

Core material
In the construction sector we are concentrating, at present, primarily on opaque systems with micro-porous insulation cores. Most of these consist of glass-fibre reinforced, fumed silica, and have the sort of structure suggested by ill. 2.
This is because this group of materials has a very high porosity combined with a pore size that is itself small enough to strongly suppress the gas conduction effect. Even at atmospheric pressure, therefore its thermal conductivity, approx. 0.018 W/mK, is significantly below that of the surrounding air at approx. 0.026 W/mK. These relationships have the further effect that the thermal conductivity drops sharply even at relatively soft vacuums, already coming close to its minimum of 0.004 W/mK at approx. 10 mbar. Thus, the demands on the manufacturing process are reduced, and higher gas permeation rates can be tolerated in the envelope material and the joints (seals or welded seams). This therefore leads, above all, to a longer potential functioning life, since this is determined by the maximum acceptable pressure rise in the system.

Envelope material
Two groups of materials are being used here, and they lead to two very different systems: metallised plastic composite foil, and stainless steel plate. The literature generally refers to the first group as Vacuum Insulation Panels (VIP), and to the second as Vacuum Insulating Sandwiches (VIS) (ill. 7).
Transparent high-barrier membranes, based entirely on polymers and coated with SiOx, do not yet achieve the necessary permeation rates, but are under further development.

Quality control
The thermal conductivity of a vacuum insulation system depends primarily on the internal gas pressure and on the moisture content of the core material. The first physical magnitude can therefore, in principle, be used for quality control, provided the initial gas pressure and the moisture in the system are known. If internal effects such as the evolution of gas are neglected, any pressure rise that occurs depends, in the first place, on the quality of the envelope material and of the edge spacer. Since it is almost impossible to detect leaking panels by purely visual means, in particular when they have already been fitted and have been covered, procedures for measuring the internal pressure offer the only possible method of quality control. The particular difficulty associated with this for vacuum insulation systems is that the checks – even for concrete guarantee reasons – must cover the production chain from beginning to end, starting with manufacture and including transport, storage and fitting. Because of this necessity for multiple checks to be carried out at various locations, there is a particular need for procedures that give quick results and that are uncomplicated. Methods that do not require penetration of the envelope, and which can be used even if the panel is only accessible at certain points, are preferable. In principle, the function of vacuum insulation systems that have been fitted can also be demonstrated using thermographic recording techniques. Supplementary evacuation of individual panels is also possible on systems with stainless steel envelopes.

Thermal conductivity groups – classification
No products from the vacuum insulation systems sector have yet been approved for use in construction. Generally speaking, manufacturers only quote thermal conductivity values that apply to the undisturbed panel surface in the centre of the panel. In practice, however, this figure will never be achieved when the panel is fitted. Achievable U-values (and therefore “average” thermal conductivity figures) are primarily deter-



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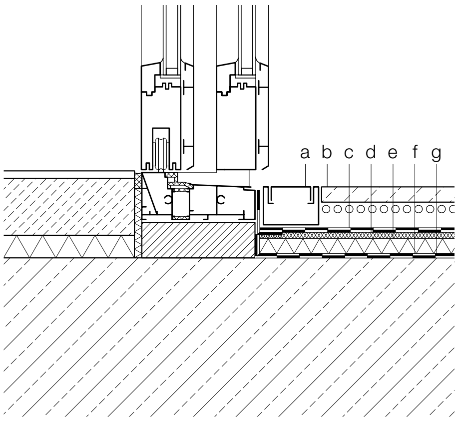


sill-free terrace construction through the use of high-performance insulation

a drainage channel with 50 mm grating
b 52 mm concrete slab with chippings
c 2 mm fleece underlayer
7 mm bituminous water barrier
d 8 mm building protection matting
e 20 mm high-performance insulation VIP
f 5 mm protective matting
g 3 mm bituminous vapour barrier

mined by the geometry, the choice of material, and the way in which the edges are formed and joined.

Ecology
In the light of the present state of knowledge, the following can be said: the total material expense is relatively small, due to the high efficiency. In the systems used so far in the construction sector, the silica boards (apart from the stainless steel in VIS) represent the major weight. Like the enveloping stainless steel, it can be reused without difficulty. Once the systems have been vented, they can be dismantled into their component parts without great difficulty. They then contain no composite materials, and can be recycled. The composite membranes used so far cannot be immediately re-used, but they represent a low proportion of the weight, and can be partially recycled.

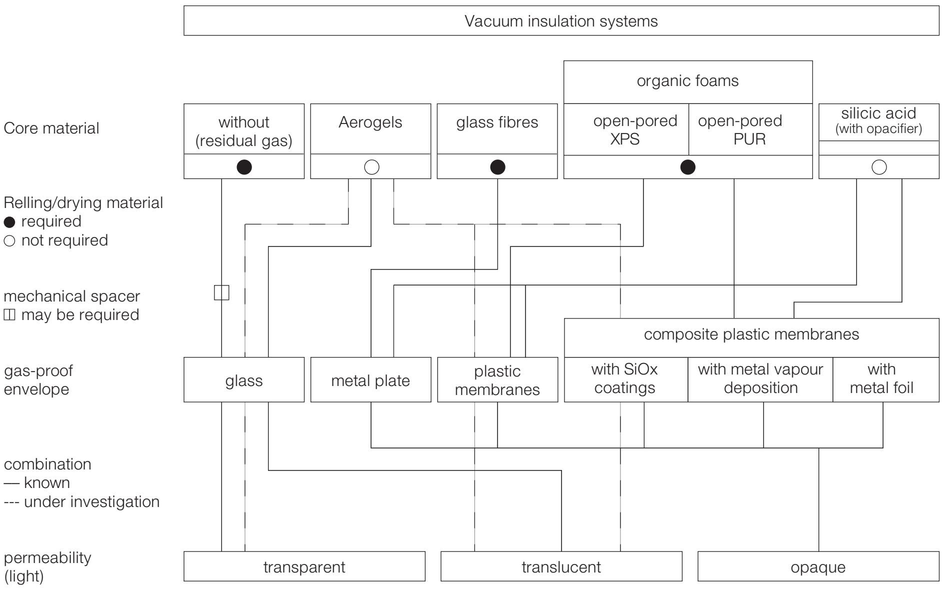
Design notes

Sensitivity
Panels with membrane envelopes, in particular, are extremely mechanically delicate. The handling of unprotected panels on the building site is therefore critical. A high level of prefabrication permits them to be fitted under protected, controllable conditions, and is therefore preferable. It is, moreover, advantageous to protect the panel faces with adjacent soft layers, such as soft fibreboard or thin layers of foam material. It must also be borne in mind that vacuum insulation systems must never be penetrated. This, together with the further requirement that they are fitted without being subjected to tension, radically restricts the possible methods of fastening. It is also necessary to explain to the user that nothing can be attached to the affected areas by drilling or nailing at any later stage.

Thermal bridges
Every thermal bridge means that the average thermal insulation figure is reduced. It also increases the energy requirement, and presents a risk of condensation. Because of their geometry, vacuum insulation systems themselves cannot help but create thermal bridges, since their edges always have higher thermal conductivity than the centres of the system units. The magnitude of the effect at these potential joint locations depends on exactly how the edges of the system are formed, on the geometry and dimensions, and on the particular situation where the system is fitted. The use of high-performance insulation makes the problem of thermal bridges more acute: the significantly lower insulation thickness in combination with the minimisation of thermal conductivity across the main area gives every thermal bridge a greater significance than it would have with conventional insulating materials. Even though condensation cannot form within the vacuum insulation system itself, since they are absolutely vapour-proof, it is the nature of the system that the joints represent even more significant weak spots. The non-destructive diffusion behaviour must be demonstrated here in detail with the necessary care.

Format
The preferred format is that of rectangular panels, whose right-angle edges have the most accurate geometry possible. A range of other shapes is nevertheless also possible, although these are usually associated with considerable expense in manufacture as well as with a reduction in the expected service life. A fundamental feature of all vacuum insulation systems is that the format of panels that have once been manufactured cannot be changed. Later modifications are impossible. This is of particular importance at the design stage when the tolerances are considered. Because of the more acute problem of thermal bridges, the demand for accurate dimensioning is particularly high for the application of vacuum insulation systems. A further aspect is the economically-driven pressure to have only a small number of possible formats.
Standard formats offer a further advantage, in that additional supplies can be delivered at short notice, since they can be stocked in a warehouse and do not have to be specially manufactured.

Exchangeability / accessibility
Because, in contrast to conventional insulating materials, vacuum insulation systems



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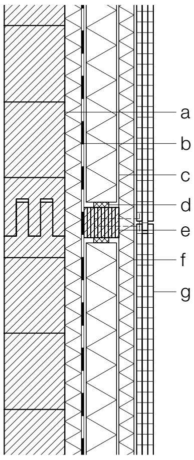

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5 two-family house in Munich, Architect: Florian Lichtblau
6 Wall structure with vacuum insulation
  a 80 mm solid spruce wooden wall
  b 22 mm soft wooden fibre board
  c 40 mm vacuum insulation
  d surrounding compressible strip
  e 40/45 mm laminated wood bearers
  f 20 mm soft wooden fibre board
  g 22 mm three-layer board
7 Comparison of vaccum insulation systems (VIP and VIS)

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can fail, it is helpful if they can be exchanged without too much difficulty. The structure must therefore be built in such a way that it is possible to access either the individual panels or the sub-system that holds them.

An example application:
Panels for stanchion-transom facades
Vacuum insulation systems can be fitted into existing stanchion-transom systems with relatively little difficulty. They can also be exchanged, since the thickness of the resulting system is quite similar to that of the usual thermally-insulating multiple glazing. It is of particular relevance here that with these systems – in contrast to conventional insulating panels that are significantly thicker – it is possible for the glazing to be flush – mounted on the inside of the facade as well. Unit thicknesses of approx. 32 mm are enough to achieve U-values of approx. 0.16 W/m²K in the centre of the panels. This is a reduction of about 75 % in comparison with the best thermally-insulating multiple glazing currently available (where the U-value in the centre of the glass is approx. 0.65 W/m²K). The panels developed by ZAE-Bayern (Bavarian Centre for Applied Energy Research) for a hospital in Erlenbach provide an example of such a variant. (ill. 1)

		VIP	VIS
Envelope material		metallised high (Al-layer 1 µm)	0.6–4 mm stainless-steel plate
Core material		Fumed silica	Fumed silica
Edge spacer		Membrane seal	Welded stainless-steel foil 0.20–0.27 mm
Evacuation process		Manufacture in vacuum chamber	Via evacuation flange
Thickness	[mm]	10–50 (typically 20)	10–40
Thermal conductivity (Centre of panel)	[mW/(mK)]	4.2	5.3
… at an internal pressure	[mbar]	< 5	1
Thermal bridging effect of the edge spacer		low	high
Thermal conductivity when vented	[mW/(mK)]	20	20
Specific thermal capacity	[kJ/(kgK)]	0.8 (core plate)	0.8 (core plate)
Weight	[kg/m³]	160–180	160–180 (+ envelope material)
Temperature range for-continous use	[°C]	–30 to 80	–200 to > 1000
Air humidity range for continous use	[% rel. air hum.]	0 bis 60 (bis 40 °C)	depending on alloy
Acceptable peak temperature- (short exposure, <15 min)	[°C]	80–120 (depending on membrane)	> 1000
Pressure loading capacity		150–160 kPa (at 10 % deformation)	> 7.5 t/m²
Flexural strength		not available	high, depending on plate thickness
Quoted functioning life	[years]	No data	3–50 years, > 100 years, if it can be evacuated in situ
Mechanical sensitivity		very high	low
Repairable		no	yes, if accesible
Fire protection classification	in acc. with DIN 4102-6	(B2 is maximum possible)	A1
General Buildings-Inspectorate Approval		under preparation	under preparation
max. dimensions, l × w	[mm]	2200 × 1000 (depending on vacuum chamber), standard 1000 × 500/1000 × 600	8000 × 3000 (depending on plate size)
Manufact. tolerance, l or b/s	[mm]	–5 to +2 / ±1	± 2

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In this kind of application, the U-value of the facade as a whole depends heavily on the size of the panels, and on the relative proportions of the edges (edge spacer panels and stanchion/transom construction) to the flat areas. In the same way as other sandwich solutions, a large measure of mechanical protection is given to the vacuum insulation system because the panels can be fabricated at the factory and are protected from then on. This greatly simplifies handling throughout the whole process chain, up to and including fitting. On the other hand it is no longer possible, using existing test methods, to check the VIP quickly after it has been mounted between the protective layers. Present technology only permits determination of the thermal image when assembled. Compensation for one disadvantage of the system is offered by the possibility of almost entirely ruling out damage (venting) to the VIP during transport and assembly. An additional advantage can be seen in the reduction in weight and space offered by these panels as compared with conventional insulation panels. This not only applies to them when they are fitted, but to a lesser extent also during transport and assembly.

Economy
A general replacement of conventional insulating materials by vacuum insulation materials can certainly not be expected. These new, high-performance systems will, however, find applications wherever their primary feature – maximum insulating effect with minimum thickness – brings enough functional, design, economic or aesthetic advantage to justify what, so far, has been a significantly higher initial investment. In many cases this will be particular locations of special importance within a building. Only in unusual cases will it involve the entire building shell, for instance in locations where useful area is extremely expensive. It will be used in new constructions, but will also become important to renovation work, where there is often insufficient room for adequate insulation to be installed when conventional insulating materials are used.