IEA/ECBCS - Annex 39
High Performance Thermal Insulation

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1 Vacuum insulation for buildings

1.1 Development of insulation standards

Most insulation materials have been developed before 1950 but the extensive use of thermal insulation started only after the oil crisis in 1973. Since the oil crisis, the thermal insulation of buildings became the key element to prevent heat losses and to improve energy efficiency. For a long time, 10 cm of standard insulation such as expanded or extruded polystyrene, foamed polyurethane (PU), fibreglass, etc, were considered as good insulation. But energy specialists calculated that the economically optimised thickness should be 30-50 cm depending on the climatic conditions. Today, many existing building regulations and standards demand U-value that is approximately equal to 0.2 W/(m2·K) for roofs and walls, which means about 20 cm thick insulation layers. Many architects have a problem with such regulations. They want to create spaces, not insulated bunkers. The problem of thick insulation layers is especially critical in the case of renovated buildings where there are severe limitations on space and also many other technical constraints.

1.2 Energy in buildings

The effect of a major adoption of the VIP (Vacuum Insulation Panel) technology by the construction industry on environment is expected to be huge. The official numbers for the EU given below show that using VIP in buildings could account for most of the target of 8% reduction in emission of greenhouse gases (Kyoto Protocol).

The total final energy consumption in the EU in 1997 was about 930 Mtoe (Million tons oil equivalent). A simplified breakdown of this demand shows the importance of buildings in this context: 40.7% of total energy demand is used in the residential and commercial sectors, most of it for building-related energy services (Table 1). It should also be pointed out that approximately 10% of the consumed energy in buildings comes from renewable energy sources. Space heating is by far the largest energy end-use of households in EU Member States (57%), followed by water heating (25%). Electrical appliances and lighting make up 11% of the sector’s total energy consumption. For the commercial sector the importance of space heating is somewhat lower (52%), while energy consumption for lighting, office equipment and "other" (water heating, cooking and cooling) are 14%, 16% and 18%, respectively.

Table 1: Energy consumption of buildings in Europe. (Source: Directive of the European Parliament And The Council on the energy performance of buildings.)

Residential Sector	[%]	Commercial	[%]
Space Heating	57	Space Heating	52
Water Heating	25	Water Heating	9
Electric Appliances	11	Lighting	14
Cooking	7	Office Equipment	16
		Cooking	5
		Cooling	4

From these numbers it can be derived that more than 25% of EU energy consumption and also CO2 emissions are caused by heat transfer processes in buildings, which directly depend on insulation standards. It has to be kept in mind that these heat transfer processes not only do occur in the building envelope but also in boilers, refrigerators and freezers and cold storage rooms.

1.3 Potential impact of VIP for building insulation

In 1995, there were roughly 150 million dwellings in the EU-15; 32% of this stock was built prior to 1945, 40% between 1945 and 1975 and 28% between 1975 and 1995. The ratio, housing starts vs. housing stocks, varies between 1 to 2%. Therefore the reduction in CO2 emissions by using VIP technology depends largely on how well the new technology is adopted in retrofitting the old building stock, which to a large extent (around 50%) is not insulated at all. This success depends not only on the technical solutions but also on regulations and energy prices. However, it can be assumed that the energy consumption of the dominating old buildings can be reduced by a factor of three. This means that the EU CO2 emissions would be reduced by about 8%, which is the reduction the EU agreed on in the Kyoto Protocol. Since VIP-based systems are thinner and their recycling economically attractive, the resource intensity will be lower than for conventional solutions. Additional important impacts are reduction in adverse environmental effects of transporting fuel (sea and land) to and inside Europe and also reduction in the rate at which the global energy reservoirs is depleted. Furthermore, if one takes into account that use of the VIP technology is not limited to Europe only, the numbers can be more impressive.

1.4 Vacuum Insulation today

Currently VIP have only limited use, mainly in top models home refrigerators/freezers and cold shipping boxes. Japan controls more than 50% of the small global VIP market with several million panels per year. The VIP market in Japan is fast growing. The common core materials are fumed and precipitated silica, open-cell PU and several types of fibreglass. Both metallized-film and aluminium-foil laminates are being used to seal the vacuum.

For buildings, most of the VIP activity is still in the R&D phase with some demonstration projects. Germany and Switzerland are the only countries where a market in its early stage has been established. Fumed silica boards are being used almost exclusively. Fumed silica is the best core material due to the small size of the pores and the low heat conductivity of the powder. There are only three producers of fumed silica in the world, and two of them are large EU companies: Wacker (Germany), Cabot (USA) and Degussa (Germany).

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Germany and Switzerland were the first two countries supporting R&D activities with the aim of introducing VIP-technology to the building industry. In 2000 Switzerland decided to launch the topic on an international level. This happened in the frame of the IEA (International Energy Agency) Implementing Agreement called ECBCS (Energy Conservation in Buildings and Community Systems). Implementing Agreements are a kind of international networks of national representatives with the aim of coordinating applied research in the field of energy.

Annex 39 is the 39th research program of ECBCS. It was officially adopted by the Executive Committee of ECBCS in November 2000 and started with an international conference in January 2001. Since the topic was new to the research community, it was quite difficult to set up a work plan with the participating institutes.

Structure of Annex 39

The project team from six countries (see table below) worked on two main tasks:

- Subtask A: **Vacuum Insulation Panels (VIP) and its components**.
  Relevant (building application) properties of today available VIP, with emphasis on service life prediction.
- Subtask B: **Application of VIP in buildings**
  - design guidelines
  - documentation of realized applications

Accomplishments

Subtask A: Panels

- Core: Properties of fumed silica as core material of VIP
- Envelope: Methodology and measurements for ultra high barrier films
- Panels: Measurements and modelling of aging mechanisms of VIP
- Quality assurance, product declaration and design values: Overview on important standards concerning product declaration and quality monitoring procedures. VIP-design values used in Switzerland.

Subtask B: Applications

- Design guidelines: Thermal bridge effect of envelope films, sandwich constructions, edge spacer and ventilated curtain wall systems.
- Life Cycle Analysis of VIP
- Practice report: 20 building applications were documented and analysed. Information is available on: construction, building physics (thermal bridges, vapour diffusion, etc.), experiences from planning & execution procedure, costs, benefits and risks.
- Recommendations: Guide for practitioner when VIP are used a) on the construction site or b) in prefabricated components.

Website: www.vip-bau.ch *(in English and German)*

Participating institutes

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Subtask A			
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3 Outlook
Key-factors for the future success of VIP in buildings

During this research program vacuum insulation has developed rapidly. At the beginning VIP was hardly known in the building branch and only a few pilot applications were realized. Only little was known concerning key questions as durability, gas tightness of envelope materials, behaviour under humid and hot conditions. Today it can be stated that VIP properties are well known and some important weaknesses have already been eliminated.

We now have well documented experiences from the building site which have been implemented by the building industry for their VIP developments. The VIP production has been professionalized and the VIP have been better adapted to the needs of building applications.

Today we see a very broad interest in the VIP technology from the building branch and large number buildings in which VIP have been applied. But the quantitative wide use of vacuum insulation is still hindered by mainly two factors:

- high price
- lacking confidence in VIP technology and their use in building applications

Today cost

The work under the annex has shown that for the design of vacuum insulated constructions one may not use the thermal conductivity of VIP just after production of 0.004 W/(m·K) but 0.006 to 0.008 W/(m·K).

Table 2: Swiss design values (safe values) of Center-of-panel thermal conductivities (λ_{cop}) for aluminium and polymer based multiple metallized barrier envelopes.

Center-of-panel conductivity values		λ_{cop}
AF: aluminium foil films	[W/(m·K)]	0.006
MF: metallized polymer films	[W/(m·K)]	
small panels: 50 x 50 x 2 cm^3		0.008
larg panels: 100 x 100 x 2 cm^3		0.007

In façade constructions for instance there will be thermal weaknesses, as cold bridges by the envelope material (see figure below) and the fastening system that will lead to mean thermal conductivities of the insulation layer of at least 0.010 W/(m·K).

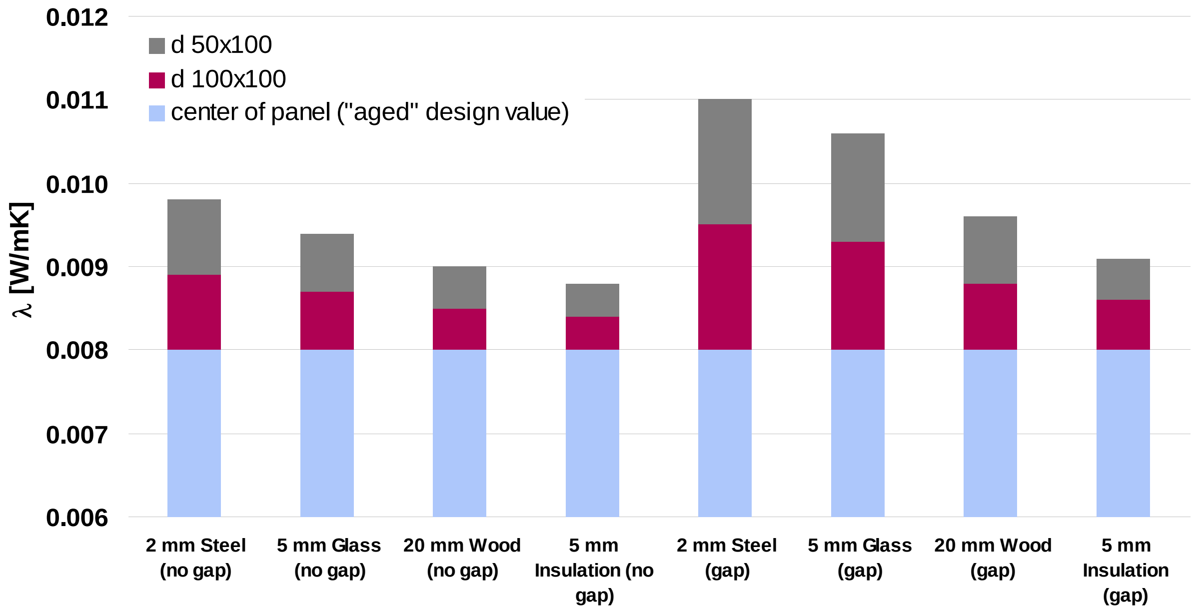

Figure 1: Thermal bridge edge effect of different adjacent materials on overall conductivity (λ_{eff}) of a panel with MF-envelope and a center-of-panel conductivity of $8 \cdot 10^{-3}$ W/(m•K). "d 100x100" is the increase for a panel of 100x100 cm^2 compared to λ_{cop} and "d 50x100" is the increase for a panel of 50x100 cm^2 compared to the lager format.

A passive house façade (U-value of 0.15 W/(m^2·K) would therefore need at least 8 cm of vacuum insulation which means insulation cost of 320 €/m^2 (Swiss prices). Even when gains by space savings and constructional simplifications are considered, the resulting costs are in many cases not competitive.

Table 3: Cost of a VIP Passivhaus façade compared with a conventional solution

Façade insulation of a Passivhouse

Buidding dimensions		
length	10	m
width	10	m
height	3.2	m/story
number of stories	2	-
façade area	**256**	**m2**

Insulation	**thickness [cm]**	**volume [m^3]**	**cost**	
fiber or foam	40.0	102	**32 €/m^2**	
cost			8'192 €	
VIP	8.0	20	**320 €/m^2**	
cost			81'920 €	
difference			**73'728 €**	
saved volume			82 m^3	
saved area			26 m^2	**cost factor**
cost of saved area			**2'880 €/m^2**	**160%**
Swiss average new residential buildings			**1'800 €/m^2**	
Fumed Silica core			**2'000 €/m3**	
Share of Fumed Silica on VIP price			0.50 -	

Unfortunately today just little advantage is taken of the regained liberty to develop low U-value building parts with new slim designs. VIP is mainly used in special applications where further advantages are obtained. In renovations by the use of VIP, additional expenses can be avoided, as for instance the lengthening of the roof when insulating the façade. Often VIP is used as a problem solver, e.g. for terrace insulation, VIP is here the only possibility to prevent a step between the heated room and the terrace.

That today the rather crucial direct use of unprotected panels has become the common practice on building sites, has its reason probably also in the high VIP prices. Only very innovative producers of prefabricated insulated building parts (sandwich panels, doors, façade systems etc.) do invest in the new technology. Many others hesitate because they assess VIP as too expensive to be used in their products.

Cost reduction potentials

It is known that the materials (core and envelope materials) represent quite a high portion of the total cost. Based on information of a fumed silica producer the cost of the core material contributes up to 50% of the end user price of VIP. With the envelope materials, it can be assumed that it is mainly the production quantity which defines the price. However, fumed silica is already a mass product. Physically it seems to be possible to reduce the portion of fumed silica in the board or to replace it with a cheaper material (e.g. organic foam). In particular the latter requires tighter films to maintain a lower pressure in the panel. Such high barrier films are not only needed for VIP with other core materials but also for (building) applications in more humid / hotter environments. This kind of extreme high barrier film is also developed for other applications (e.g. OLED) which have similar demands. It is therefore quite probable that they will be available soon.

Furthermore the production of VIP is still dominated by expensive manual work. But the portion of the automated production steps has increased in the last years. This development must lead to a price reduction in the near future.

For the next five to ten years, it can be assumed that VIP solutions will remain more expensive than conventional constructions with the same U-value. This is also caused by the fact that conventional insulations are being improved.

Quality assurance

Annex 39 has also contributed to increased confidence in VIP. For instance it was shown that the environment in the main building applications allow a VIP service life of 50 years and more.

Actions are needed in the field of quality assurance. It has to be made sure that the VIP applied in a building do not get damaged during handling and installation processes. Through systematic measurements of the internal pressure of the panels, defective specimens can be tracked down and crucial processes identified. The today available measurement technology is only partially suitable for quality control of the whole process chain. Ongoing developments lead to the conclusion that in the near future a cheaper and more easily applicable measurement device will be available.

Official certification

Another obstacle are missing product approvals for VIP and VIP based systems for buildings.

4 More information

www.vip-bau.ch	Annex 39 website
www.vip-bau.de	German website on VIP building applications (ZAE-Bayern)