International Energy Agency

Energy Conservation in Buildings
and Community Systems Programme

High Performance Thermal Insulation Systems

Vacuum Insulated Products (VIP)

Proceedings of the International Conference and Workshop

EMPA Duebendorf, January 22-24, 2001

Edited by:

Mark Zimmermann, Hans Bertschinger

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Workshop on HiPTI (Annex 39:)

Introduction

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In energy technology, the last century was the century of thermal insulation. Most insulation materials have been developed before 1950 but the extensive use of thermal insulation started only after the oil crisis. First building envelopes were insulated in the sixties and used layers about 3 cm cork to prevent condensation. 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 insulation were considered as good insulation. But energy specialists calculated that the economically optimised thickness should be 50 cm and more.

Today, many existing building laws and standards demand U-values for roofs and walls of around 0.2 W/(m^2·K) which means insulation layers of about 20 cm. Many architects have a problem with such regulations. They want to create spaces, not insulated bunkers. And for many applications, for retrofit, for technical installations and for appliances thick insulation layers are often not appropriate. The extra costs for adaptation or for space loss are often high and would justify a more expensive, more efficient insulation material.

Whereas glazing systems have been substantially improved during the last decade, opaque insulation has remained relatively unchanged. The best available glazings achieve a thermal conductivity of 0.009 W/(m·K) (U-value of 0.35 W/(m^2·K) at a thickness of 23 mm). This is achieved by applying low-e coatings and special gas fillings.

On the other hand, traditional insulation uses air as the isolator. Thus the thermal conductivity of air at 0.025 W/(m·K) sets the limit of performance for such material.

To overcome this, new techniques are being developed based on the following technologies:

- microporous structures,
- vacuum technologies,
- special gas fillings.

First applications have proven that such insulation techniques can achieve a thermal conductivity of about 0.005 W/(m·K), thus permitting insulation layers of 5 to 10 times thinner than conventional insulation materials.

Market studies have shown a vast potential for the application of these high performance insulation techniques. Such insulation layers have already been shown to be effective, especially in the areas of:

- appliances such as refrigerators, deep freezers, stoves, storage
- tanks and transport containers,
- heaters, chimneys, and pipe work,
- façade elements and light weight construction, and
- internal insulation of walls.

Current demonstration applications are mainly based on microporous, evacuated and sealed insulation materials. These have proven good performance, but they have also shown the need for further industrial development.

Therefore, the Energy Conservation in Buildings and Community Systems Programme of the International Energy Agency (IEA) has decided to start a research and development programme on High Performance Thermal Insulation Materials (Annex 39).

There will be an initial one year preparation phase beginning in January 2001. The workshop following this conference will be the «Kick-Off Meeting» for all interested Annex participants. Currently, representatives from Austria, Belgium, Canada, Denmark, France, Germany, Italy, Netherlands, Sweden and Switzerland have expressed an interest in taking part in this collaborative research. In addition, Switzerland has offered to take on the role of lead country.

It is envisaged that this Annex will concentrate on insulation materials and systems with a thermal conductivity of less than 0.015 W/(m·K). Presently, only vacuum technologies, preferably in combination with microporous structures, achieve this performance. Therefore Vacuum Insulated Products (VIPs) and their applications will form the basis of investigation.

Four Subtasks are proposed:

Subtask A: Basic concepts and materials

- New concepts for HiPTI will be examined and evaluated. Suitable concepts will then be implemented as prototypes. Also, existing products will be analysed and their heat conductivity, life span and cost characteristics will be optimised. This will include support structures of HiPTI, possible package films and gutter materials for extending product life span. Quality monitoring will be examined in addition.

Subtask B: Application and system development

- In cooperation with the building industry, existing and new insulation materials will be further developed into useable construction systems.

Subtask C: Demonstration

- Applications of HiPTIs will be demonstrated and performance data collected. Practical experience will also influence the development and improvement of construction systems. Furthermore, construction personnel will be trained in the correct use of HiPTIs.

Subtask D: Dissemination

- Strategies to address and inform opinion leaders and manufacturers, as well as construction companies and their clients, will be developed. Taking the experience from the demonstration projects into account, appropriate information material and application guidance will be produced and distributed.

This conference will give an introduction and a state of the art survey of these techniques and will inform participants of planned research work.

The goal is start an new initiative to investigate new options for high performance thermal insulation systems, to improve their quality and the knowledge for a successful application. It is not the intention to replace conventional and well known insulation materials and technologies. High Performance Insulation should became an new and attractive option for special application where available space is limited or extra costs for thick layers would be high.

The role of High Performance Insulation in energy efficiency

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Summary

In the last twenty years thermal insulation standards for buildings and technical equipment has risen considerably. In the same period, windows technology has been improved in parallel, which is not the case for conventional opaque thermal insulation. This led to the astonishing situation, that in today's windows technology, the thermal conductivity is two times smaller than in an ordinary thermal insulation. (0.02 W/(m^2·K) versus 0.04 W/(m^2·K)).

As a consequence, thermal insulation thickness of building envelopment has risen from 0.02 m to 0.15 m for ordinary new houses and to 0.35 m for very low energy houses e.g. with passive standard. In such a house, more than 30 % of the volume is used by the insulation. New vacuum insulation panels have thermal conductivity values, which are ten times smaller (0.004 W/(m^2·K) instead of 0.04 W/(m^2·K)) than in conventional insulation materials. Already today the net space gain can led to an economical use of this materials in new buildings.

In the retrofit sector there are many buildings which will allow only small insulation thickness because otherwise to much room space or height is lost or the adaptation of many construction details is simply to expensive when using high insulation thickness. This means that a great number of existing buildings only with HiPTI can match today's and future demand for thermal insulation.

As the future of HiPTI seems great which such an outlook, much work needs to be done, to develop today's vacuum insulation to proven and reliable construction systems to fulfil customers demands.

1. Structure of High Performance Insulation (VIP in this case)

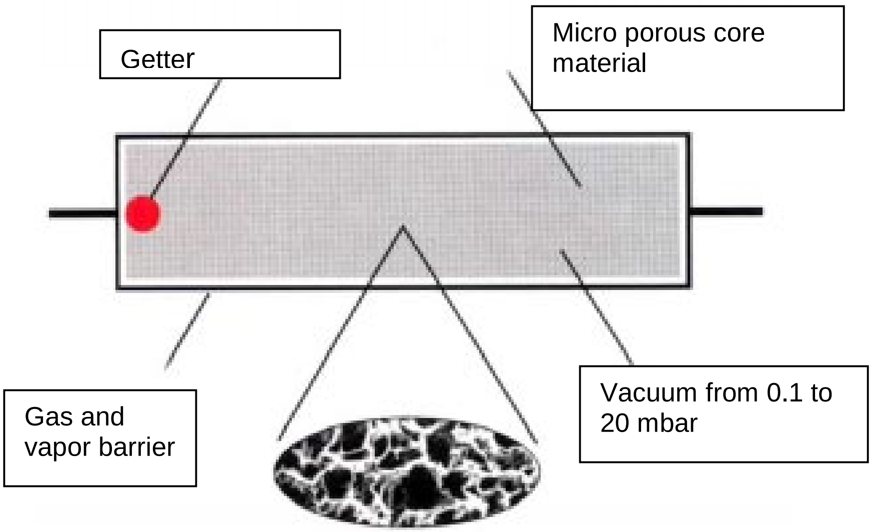

Figure 1:Principle elements of a vacuum insulation panel (VIP)

Fumed silica and aerogels are the most widely proposed micro porous materials for VIP. Fumed silica is an industrially produced material, which has been optimised for vacuum insulation in the last years, it even don't need any getter when the gas barrier foil is intact. Progress is still necessary and possible in the field of gas and vapour barriers.

2. Thermal conductivity of VIP

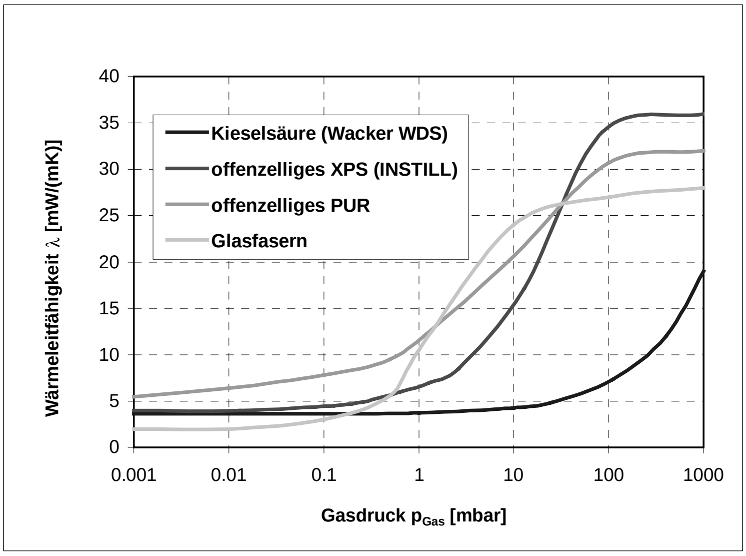

Figure 2: Heat conduction of different types of VIP in function of gas pressure

Up to now, fumed silica and aerogels, which should have roughly the same thermal properties, are the best-suited materials for the use in buildings. They have a very low thermal conductivity which remained constant up to 20 mbar, they do nut burn and have interesting acoustic properties.

3. Economical aspects

Ground cost

In a low energy house (passive standard), the insulation volume is about 30 % of the building volume. By a given allowed site exploitation, the needed ground surface will increase accordingly. When using VIP or other High Performance Insulation (HiPTI), it is possible to save costs, while offering to the customer the same usable area (room and garden).

Gaining usable floor space

With a given site surface, normally it will be possible to let more room space when using less insulation thickness. Assuming a flat of 100m^2 which cant be let for CHF 1700.-/month, the value of gained space is about CFH 3'400.-/m^2, in order to get a yield of 6 %, related to the invested capital. (12·3400/(0.06·100). With the space gained you can calculate the maximum price for an m^3 of HiPTI. Figure 3 shows admissible insulation cost in function of the value of space that has been gained.

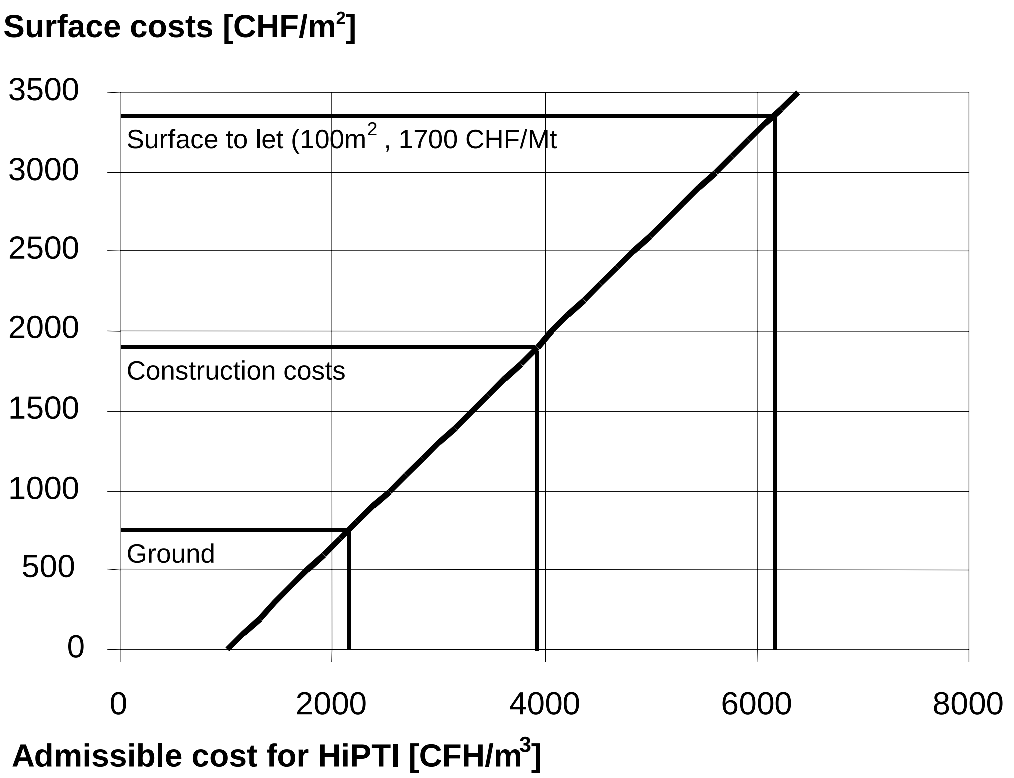

Figure 3: Admissible costs per m^3 for HiPTI in function of the value of the saved usable floor space. Conditions: thickness of thermal insulation 2.5 instead 12 cm, room height 2.6 m, 200.- CFH/m^3 for ordinary thermal insulation

4. HiPTI in new buildings

The above calculation shows, that HiPTI in new building can be of great economical interest because of saving ground space, or even better, to rent more room space with a given area of the construction site. Therefore HiPTI should be considered in every project for a new building.

5. HiPTI in existing buildings

In the case of existing buildings the situation is more complex. In many cases it is possible to use exterior wall insulation without loosing floor space or without the need of having a bigger building site. Therefore in retrofit, HiPTI is only economically interesting, when insulation leads to the loose of floor space, room height or if the adaptation costs would be to high when using conventional materials. The following cases are of interest:

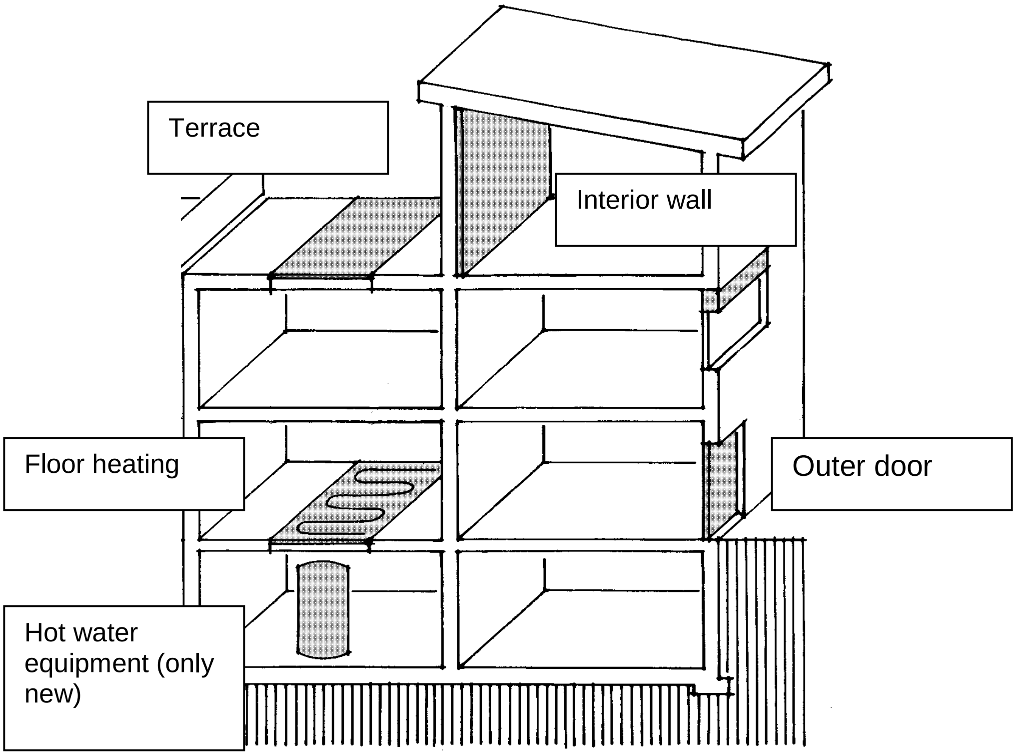

Figure 4: Interesting HiPTI application in retrofit

6. Is HiPTI ready for the building market?

Obviously it is not; otherwise we would not be here today. What must be done in the next few years?

Basic materials and concepts

Improve existing products; ensure mainly durability and lifetime

Systems and applications

Develop complete systems that are usable in the common building business (e.g. VIP floor heating systems, high insulated boilers, interior wall insulation systems ...)

Demonstration projects

Improve know-how of building professionals. Demonstrate the use of available VIP and other HiPTI systems in real applications

Literature

Hp. Eicher, M. Erb, A. Binz; Hochleistungswärmedämmungen, Bericht BFE, Dezember 2000

Physical Aspects of Heat Transfer and the Development of Thermal Insulations

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Summary

Thermal transport in insulations with its three modes, solid conduction, gaseous conduction and infrared-radiative heat transfer is described and discussed. As an example for conventional insulants thermal transport in EPS foams is explained. Heat transfer in aerogels serves as an example for nanostructured insulation materials. Evacuated nanoporous thermal insulations provide the lowest possible conductivities (about 0.003 to 0.004 $Wm^{-1} K^{-1}$) and thus the largest thermal resistance for load-bearing insulants. They are most tolerant against pressure increase. The anticipated lifetime for optimized vacuum insulation panels ist large enough to allow for their application in buildings. Finally switchable thermal insulations are described, which are well suited to harvest solar thermal energy for heating purposes.

1. Introduction

Conventional insulants, as fibers, powders or foams suppress convection, which is due to the partition of the insulating spacing into sub-mm cells or pores. Typically the thermal conductivity λ is in the range 0.035 to 0.060 $Wm^{-1} K^{-1}$ (see figure 1). Such insulants, to some extent, also reduce radiative transfer via absorption and/or scattering of infared radiation. At room temperature the radiative conductivity λ_r may vary in the range 0.001 to 0.010 $Wm^{-1} K^{-1}$. Contrary to just air-filled or evacuated spacings solid insulating materials cause transport via solid conduction. The corresponding conductivity λ_s is the smaller, the lower the density of the insulant becomes and the smaller the conductivity of the fibers, the powder grains or the foam backbone is. λ_s varies between 0.001 and 0.030 $Wm^{-1} K^{-1}$.

Fully developed in conventional insulants is the gaseous conduction; this heat transfer mode mostly is the dominating one, adding $\lambda_g \approx 0.025\ Wm^{-1} K^{-1}$at room temperature to the total conductivity.

In general the three conductivities λ_r , λ_s and λ_g are non additive: coupling or bridging effects tend to increase the total conductivity beyond the mere sum, i. e.:

$$\lambda > \lambda_r + \lambda_s + \lambda_g.$$

For example, in powder fills with many point-like contacts the conduction in the gas phase thermally bidges the point contacts and leads to dramatic coupling effect; contrary, in foams and aerogels with a coherent solid skeleton the coupling effect between solid and gaseous thermal conduction ist negligible. In this case

$$\lambda \approx \lambda_r + \lambda_s + \lambda_g$$

holds.

The systematic improvement of thermal insulation was studied and described in a pioneering work in the nineteen sixties by M. G. Kaganer [1].

2. Conventional Insulants

As an example let us consider the thermal conductivity of EPS or styrofoam (figure 2):

The gaseous conductivity λ_g is more or less independent of density (it only shows a small decrease at higher density, which is caused by the decreasing pore volume). The solid conductivity increases roughly proportional to the density. For foams with $\rho \approx 15$ kg m^{-3} one gets $\lambda_s \approx 0.001$ Wm^{-1} K^{-1}.

As the thermal radiation for most insulants (more exactly: optically thick ones) is propagating via diffusion, a simple dependence for λ_r holds:

$$\lambda_r \sim T^3/E,$$

where E is the extinction coefficient ([E] = 1/m), and T the temperature.

Furthermore

$$E = 1/\ell = \rho\, e,$$

with ℓ being the mean free path of the IR photons and e being the mass specific extinction. For a value $e \approx 100$ m^2 kg^{-1} and for $\rho \approx 15$ kg m^{-3} one gets $E \approx 1500$ m^{-1} or $\ell \approx 0.6$ mm.

From the above equations we derive that $\lambda_r \sim 1/\rho$. For $\rho \approx 15$kg m^{-3} EPS foams one gets $\lambda_r \approx 0.011$ Wm^{-1} K^{-1}.

The total conductivity for EPS foams with $\rho \approx 15$ kg m^{-3} thus is

$$\lambda \approx \lambda_g + \lambda_s + \lambda_r = (0.025 + 0.001 + 0.011)\ \text{Wm}^{-1}\ \text{K}^{-1} = 0.037\ \text{Wm}^{-1}\ \text{K}^{-1}.$$

If a few weight percent of an opacifier, e. g. carbon black, silicon carbide or iron oxide are integrated into the foam, the specific extinction can be increased considerably and the radiative conductivity lowered correspondingly. The total conductivity then can be as low as 0.032 Wm^{-1} K^{-1}. Such EPS-foams are grey instead of white.

3. Nanostructured Insulants

Nanostructured silica insulants can either be made in a flame process or a wet chemical sol-gel process; the resulting materials are called fumed silica and aerogels [2], respectively. Let us consider thermal transport in aerogels as an example. The solid thermal conductivity here varies according to $\lambda_s \sim \rho^{\alpha}$, with $\alpha \approx 1{,}5$ (see figure 3). For $\rho \approx 150$ kg m^{-3} the solid conductivity is about 0.005 Wm^{-1} K^{-1}.

The fact that $\alpha > 1$ can be explained by the many dangling ends (especially for small densities) of the tenuous structure which is made up of pearl - string - like entities, while in EPS foams a much more efficient interconnection between the foam cells exists.

For a thickness of about 1 cm the radiative transport is diffusive in the 10 µm wavelength region for SiO_2 - aerogels but is nearly ballistic in the 3 to 6 µm range. To prevent IR photons in this wavelength range from being transferred directly from the hot to the cold broundary, it is absolutely necessary to add an opacifier to the aerogel. Carbon black is a good choice, the aerogel then has a dark appearance. The radiative conductivity for opacified aerogels is in the 0.001 Wm^{-1} K^{-1} range at room temperature.

As the pores in aerogels are about 50 nm, the gaseous conduction is suppressed, even at 1 bar. With a mean free path of 70 nm for air molecules at this pressure the Knudsen number (mean free path divided by cell size) is of the order of 1. The air molecules collide about as often with each other or with the pearl-strings of the aerogel skeleton. Thus the gaseous thermal conductivity is not 0.025 W^{-1} K^{-1}as in EPS foams but only 0.005 to 0.010 Wm^{-1} K^{-1} (see fig. 3).This partial suppression of gaseous conduction at ambient pressures is typical for nanoporous materials.

The overall conductivity for opacified SiO_2 aeorogels at 1 bar is below 0.020 WM^{-1} K^{-1}; for resorcinol-formaldehyde aerogels a conductivity as low as 0.012 Wm^{-1} K^{-1} for a density of 150 kg m^{-3} was measured [3]. Somewhat higher values (0.015 to 0.020 Wm^{-1} K^{-1}) are obtained for ground aerogel.

4. Evacuated Insulants

The suppression of gaseous conduction occurs, if the Knudsen number becomes much larger than 1. For thermoflasks with spacings between the cylindrical walls in the 1 mm to 1 cm range a vacuum of below 10^{-4} mbar is required (figure 4). The atmospheric pressure (10 tons per m^{2}) has to be sustained by the glass or steel walls of the flask. Radiative thermal transport in this case is the only remaining loss mode, which depends on the emissivity of the walls and their temperatures.

If instead of cylindrical or spherical volumes flat panels are to be evacuated the atmosphreric pressure load has to be sustained by a load-bearing fill, e. g. a fiber, foam or powder board. As one learns from figure 4 the requirements for evacuation are the least for nanostructured fills. In this case evacuation to 10 mbar is sufficient to eliminate gaseous conduction. The material, which is suitable for such an application and commercially available in large quantities, is fumed silica. The material consists of agglomerates of SiO_2, which are built up of aggregates, which countain primary particles. Mixed with an opacifier the hydrophilic high porosity powder is pressed into boards with densities in the 100 to 200 kg m^{-3} range. The thermal conductivity of such a board as a function of gas pressure is shown in figure 5. Fully evacuated the conductivity is between 0.003 and 0.004 Wm^{-1} K^{-1}. For 40 mbar the conductivity is around 0.005 Wm^{-1} K^{-1} and at 1bar a conductivity of 0.018 Wm^{-1} K^{-1} is measured. Such boards, if evacuated and wrapped in vacuum tight, high barrier foils maintain their low thermal conductivity ($\lambda <$ 0.005 Wm^{-1} K^{-1}) for years and even for tens of years. They are thus most suitable even for applications in buildings, where lifetimes of decades are required. In the worst possible case, if for example the barrier foil is punctured, the conductivity rises to about 0.018 Wm^{-1} $K^{-1}$and thus is still only half as large as for styrofoam boards. Constructive means e. g. a protective glass covers can eliminate such a worst case.

5. Switchable Thermal Insulation

Birds adapt to the changing temperatures during the year quite well: In summer their feather plume is slim, the porosity is small and the bodyheat can be dissipated efficiently; in winter the feathers are turned into a fluffy, highly porous "ball" which reduces the heat loss sufficiently for survival. Another approach is chosen to vary the heat transfer in a flat steel panel, welded around an evacuated fiber board: a small amount of hydrogen, which has a high conductivity, is released by a metal hydride getter upon heating. Thus the thermal conductivity of the panel can be increased from 0.002 to 0.100 Wm^{-1} K^{-1} (figure 6). If the getter heater is switched off again, the H_2 is readsorbed and the thermal conductivity drops back to 0.002 $Wm^{-1}K^{-1}$. Such a device (figure 7) is ideal for solar thermal usage. During night and cloudy winter days the panel remains in the highly insulating state; this state is also kept during hot summer days, to avoid overheating. During sunny winter days the panel is in the conducting state, allowing heat to flow into the interior of the house.

References

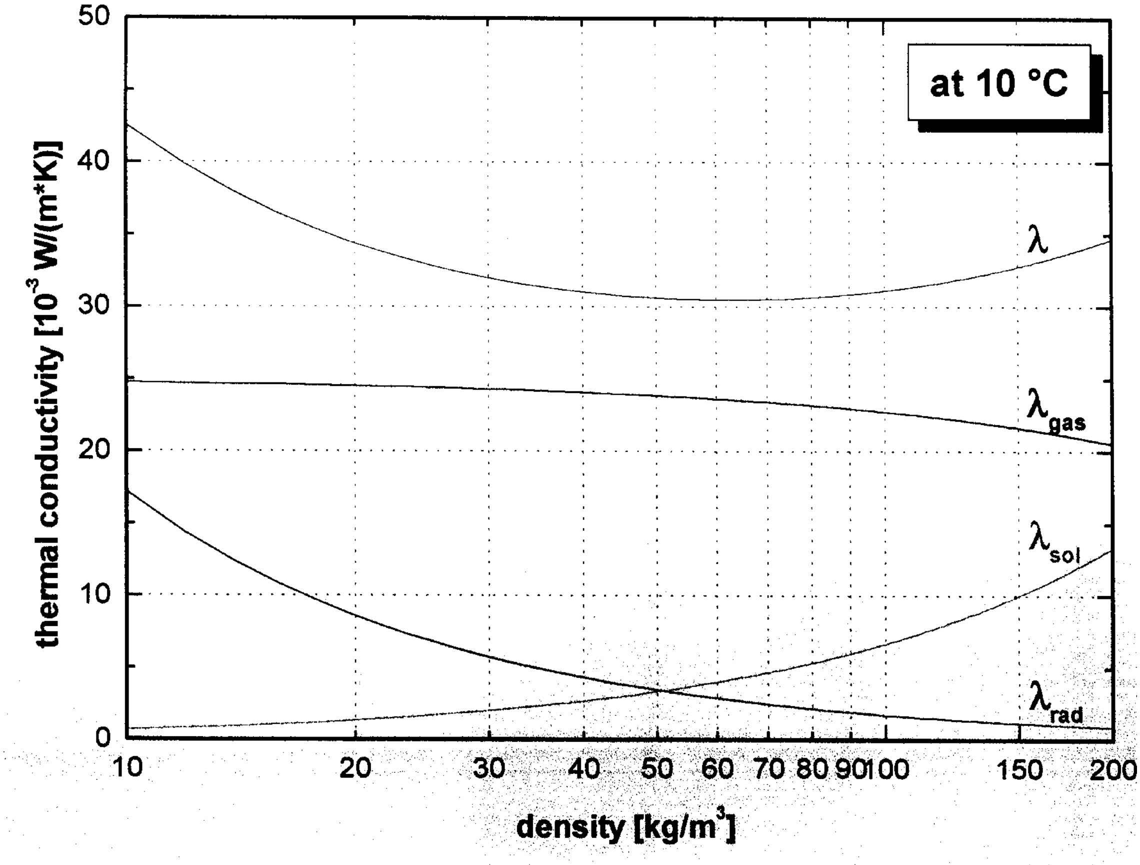
[1] M.G. Kaganer, Thermal Insulations in Cryogenic Engineering, Irael Program For Scientific Translation LTd. (1969)

[2] J. Fricke , Scientific American May 1988, p. 92

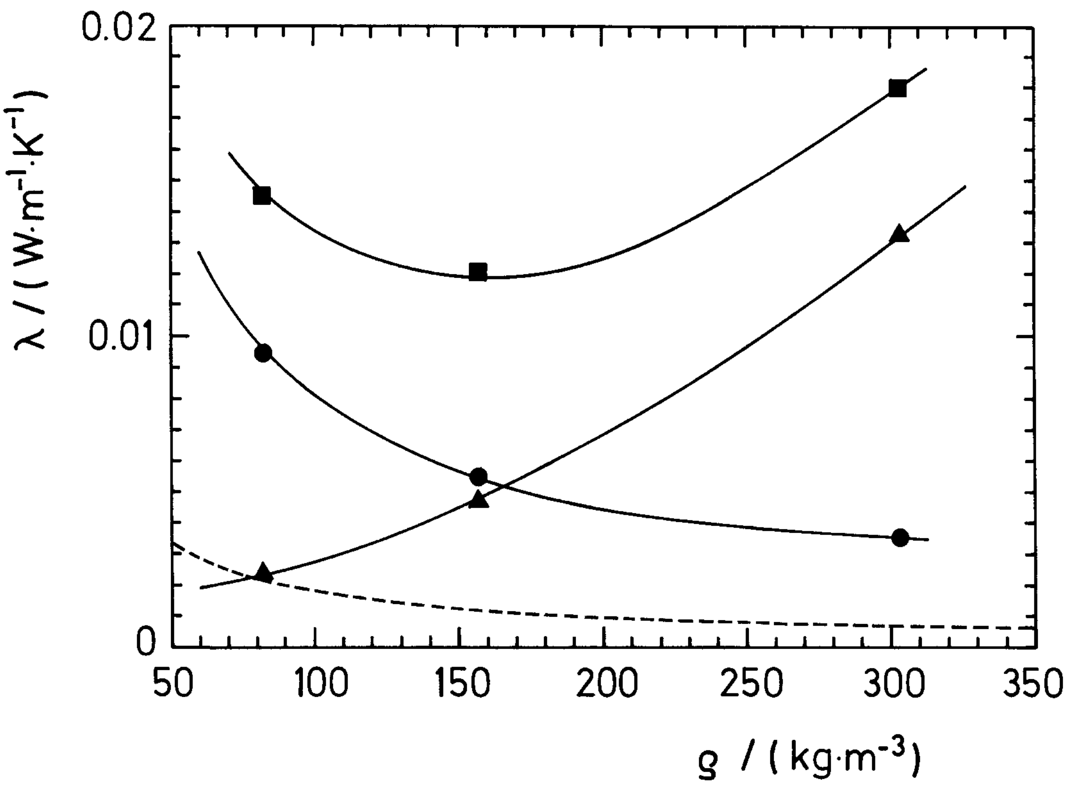
[3] X.Lu et al, Science 255,971(1992)

Figure Captions

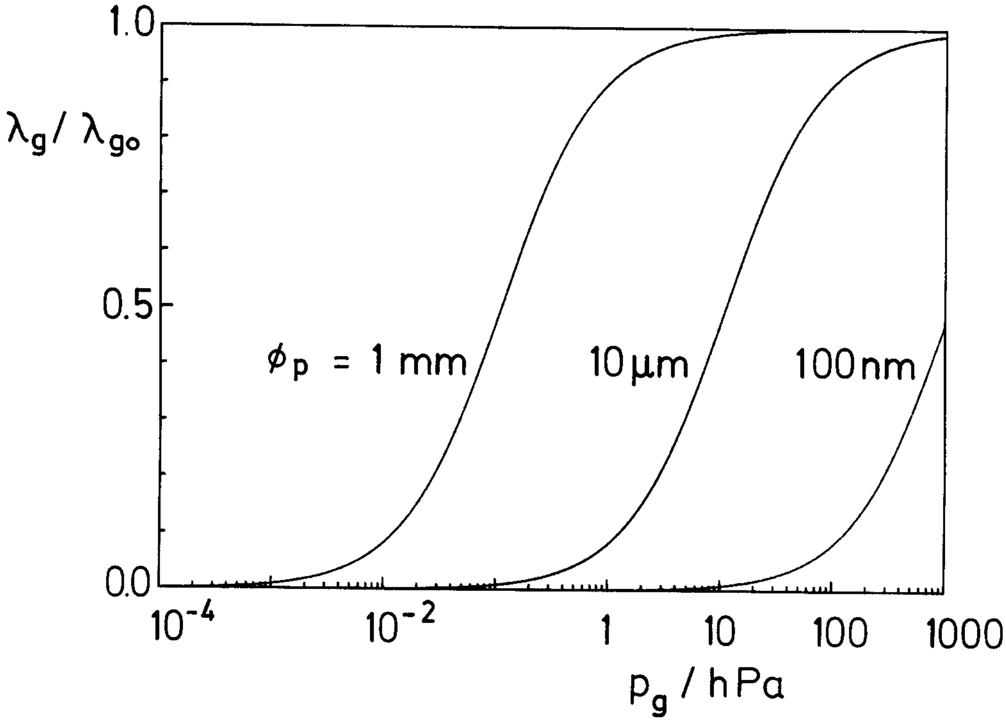
1. Overview on different insulation materials



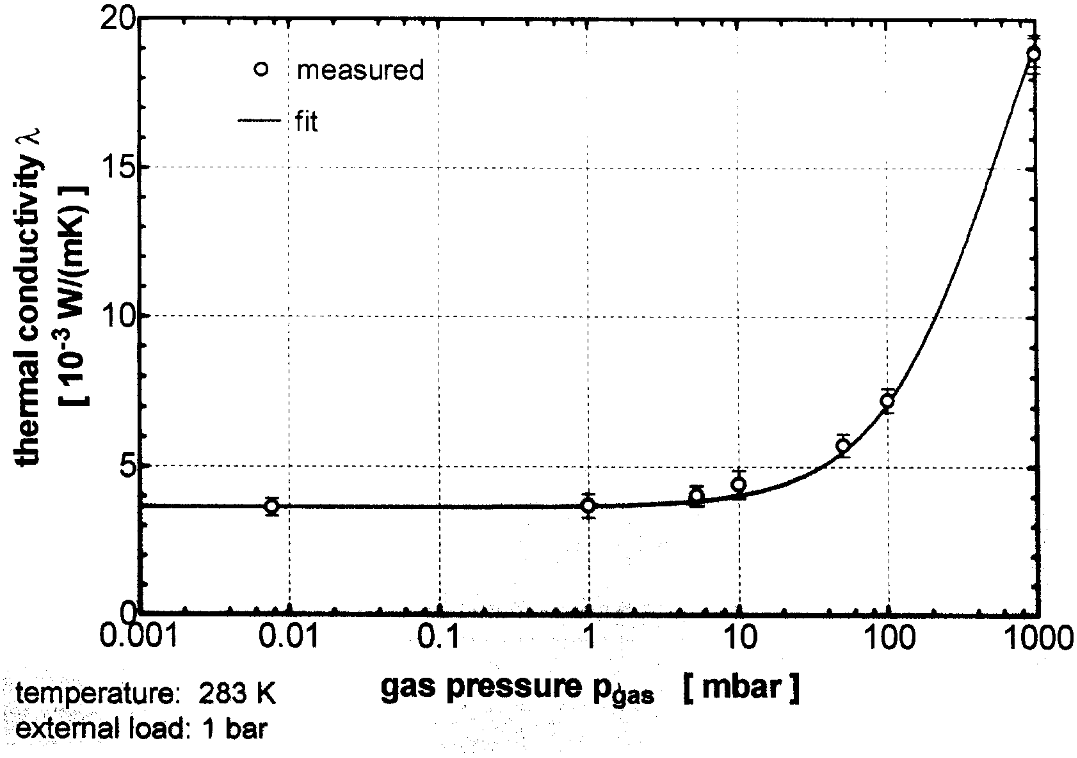
2. Total thermal conductivitiy and its components of a cellular foam as a function of density



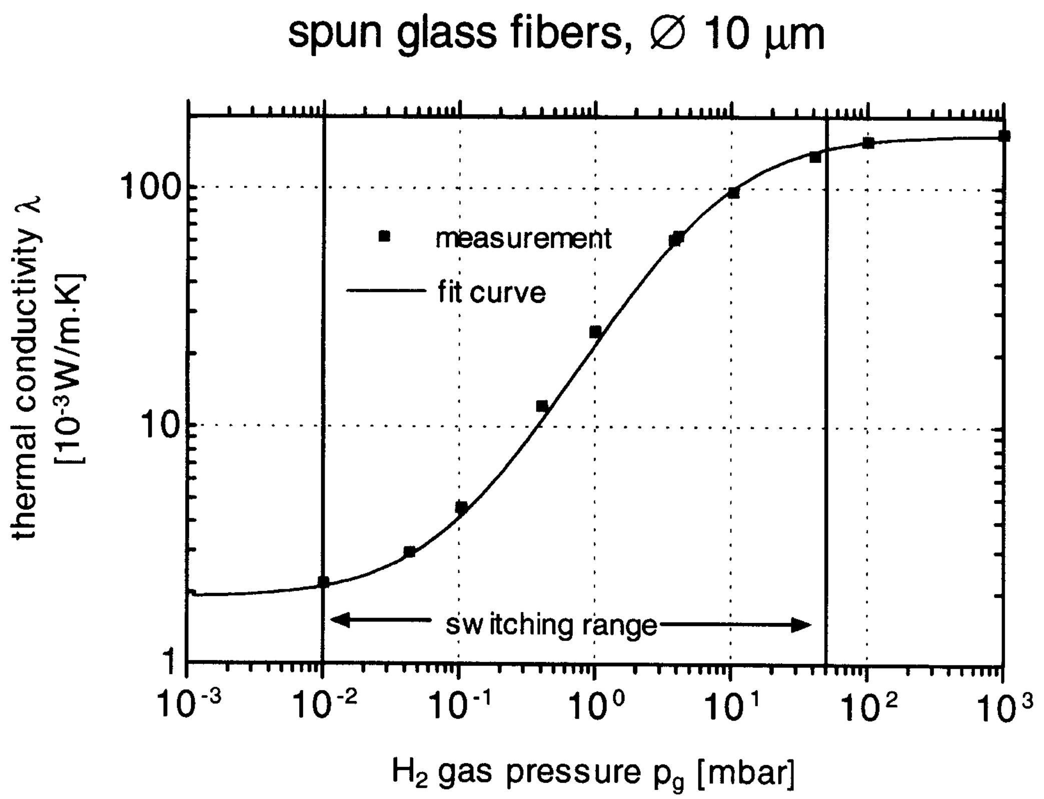
3. Total thermal conductivity (■), gaseous conductivity (●) solid conductivity (▲) and radiative conductivity (---) of an opacified SiO_2 aerogel versus density



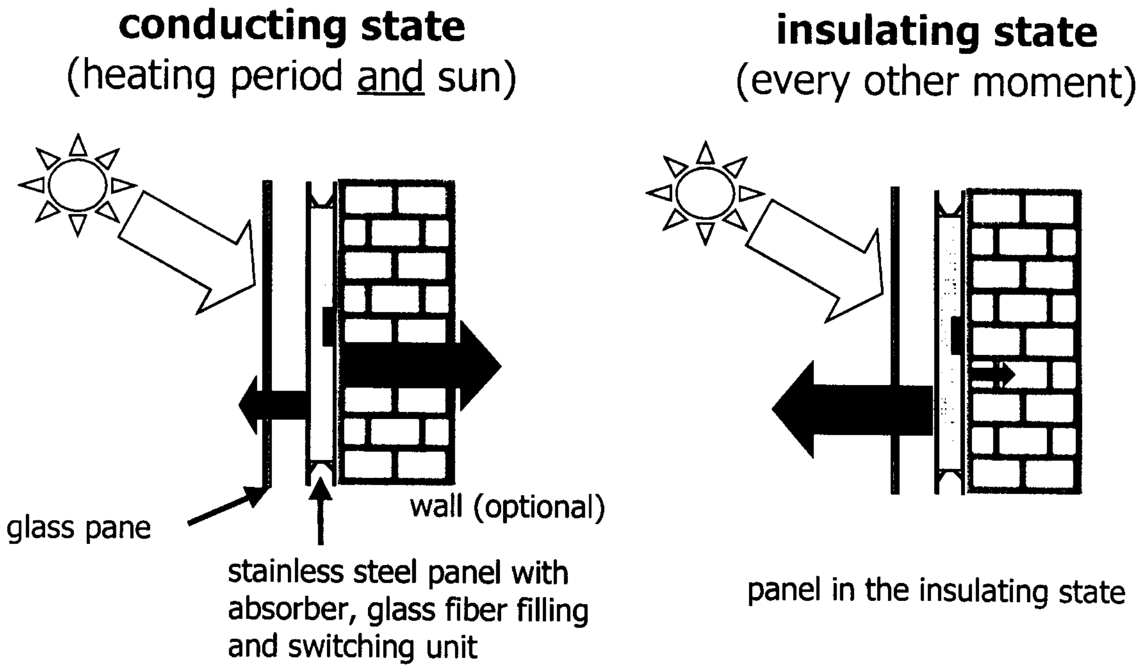
4. Relative thermal conductivity as a function of air pressure, with the pore width as a parameter



5. Thermal conductivity for a fumed silica board as function of gas pressure



6. Thermal conductivity of a glass fiber board as a function of H_2 pressure



7. Application of switchable insulations for solar thermal usage

Insulated Glazing / Current Status of Technology

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Summary

Today for applications like facades mainly insulated glazing with so called Low-E coatings are used. Coatings produced in Magnetron Sputtering technology deliver the best results with emissivity levels of 3 %. For double insulated glazing with air spacing of 12 mm and krypton gas filling U-values of 0.9 W/m^2K are achieved, while in triple glazing configurations with 2 coatings and two 10 mm air spacing filled with krypton gas, U-values of 0.5 W/m^2K are achieved. But these days highly selective glazing becomes more and more important. These are glazing configurations with coatings that combine very low emissivity and reduced total energy transmission while simultaneously having a high light transmission level.

Insulated Glazing: Current Status of Technology

Modern Insulated Glazing as a foundation for the whole window

Still in the beginning of the 1980's, windows were thought to be the weakness of a building's architecture. In the meantime, the efforts to improve the U-value of insulated glazing has made dramatic progress. An IG U-value of 0.5 W/m^2K is possible now thanks to modern insulated glass technologies. Today, the glazing is a highly insulating factor of the building architecture that is almost as effective, in insulating, as the fixed walls. This glazing has become an important element to help modern architecture's preference for transparent and abundant natural light.

The Relevant Parameter For The Window U-Value

The insulating capability of modern insulated glazing is, in general, higher than that of the window frame. An improvement of the window U-value can be achieved by choosing a good insulating glass as well as optimizing the ratio of IGU area to window frame area. That means big windows are better than small ones and small frames are better than wide ones.

High Comfort of Living

Today, big windows are not a problem either in terms of energy conservation or in terms of comfort. With good insulated glazing not only can the use of energy be dramatically reduced, but comfort can also be improved. A good insulation tends to make higher surface temperatures on the interior side of the glazing. The comfort, especially near the window and for big windows, is increased this way. With additional attention to the insulation of the edge of the glazing, the risk of humidity condensation will be reduced to a minimum.

Coatings and Gas-Filings

Insulated coatings are used to reduce the energy radiation which is massive on the glass surface. A pure silver layer is used as the relevant element to reduce the energy radiation. A measure for the efficiency of the insulated coating is the emission capability of the coated surface, the "emissivity" (ε). The lower the ε-value the better the U-value of the insulated glass element. For years, insulated glass has been coated with transparent heat-reflective layers. Ort a global basis the most advanced coating technology used is: multi-chamber high vacuum magnetron sputtering. In this process, several metal or metal oxide layers with thickness' of a few nanometers are deposited in an electromagnetic process in a high vacuum. A U-value of 1.0 W/m^2K for the glazing is the standard in Switzerland today. This number is achieved by a double glazing with an optimized magnetron heat-reflective coating and an argon or krypton gas filling (with an air-space of 12-20mm.) An optimized heat-reflective coating in this case means a coating which is a little more complex and has a slightly thicker silver layer than those heat-reflective coatings that came to market in the 1980's and are standard today.

ε-values of various Magnetron heat-reflective coatings

• SILVERSTAR W standard-coating (4-layers)	ε =	7 %
• SILVERSTAR V optimized coating (6-layers)	ε =	4 %
• SILVERSTAR SELEKT heatrefl./sunprot. (9-layers)	ε =	3 %
comparison : regular glass (not coated)	ε =	84 %

In general, improving the efficiency of a coating i.e., the reduction of the emission capabilities, causes a lower g-value. On the other hand, with gas-filings the U-value can be reduced only slightly but without changing the g-value. The gas-specific optimization of the width of the airspacing of the double glazing plays an important role in the efficiency of the gas filings.

The air-spacings of the double glazing can contain the following gases:

- air
- Argon (Ar)
- Krypton (Kr)
- mixture of Argon and Krypton (Ar/Kr)

The following U-Values can be achieved with Krypton- or Argon/Krypton fillings:

SILVERSTAR V	2x	1.0 W/m^{2}K
SILVERSTAR SELEKT	2x	0.9 W/m^{2}K
SILVERTAR V	3x with 2 coatings	0.5 W/m^{2}K
SILVERSTAR SELEKT	3x with 2 coatings	0.5 W/ m^{2}K

With xenon filings in double glazing 0.8 W/m^{2}K and triple glazing with two coatings even 0.4 W/m^{2}K can be achieved. These numbers have only theoretical value. Xenon is a rare gas as well, but is existing only in small percentage points in the atmosphere. The production of xenon gas is only possible in small amounts and therefore, expensive. In addition, there is not enough xenon gas for insulated glazing available.

Double-Insulated Glazing with U-Values Below 1.0 W/m^{2}K

Environmental awareness and responsible construction demands more and more insulated glazing with U-values below 1.0 W/m^{2}K . Not in every case, triple glazing elements can be used. Very often, construction and insulated glazing technology do not allow their use. In some cases, doubleinsulated glazing with two magnetron coatings and krypton filings are used and U-values of 0.8 W/m^{2}K achieved.

		U-value (W/M^2 K)	LT	g-value
• SILVERSTAR V II	2x	0.8	69%	46%
• SILVERSTAR SELEKT II	2x	0.8	71%	41%

SILVERSTAR SELEKT: a Special Glass

Space that is designed to use many windows , as modern architecture likes to do, demands a good insulating glazing during the heating period. This is the only way to achieve a comfortable interior climate and a reasonable level of energy consumption. In the summer and partly in the annual transition periods rooms behind glass facades can become very warm caused by the greenhouse effect. The only way to prevent this is an efficient solar reflective glass. SILVERSTAR SELEKT plays a special rote among the insulated glazes. It's complex coating, consisting of nine individual layers, not only makes for a high quality insulation but also for an efficient protection against the sun. Compared to other classic solar reflective glazes, the solar energy protection of SILVERSTAR SELEKT does not reduce the light transmission. The coating is capable to react differently to solar radiation in different wavelength ranges. Sunlight i.e. radiation in the visible part of the spectrum (between 380 and 780nm) is transmitted while high energy radiation of the solar spectrum (above 780nm) will be reflected. The result of this coating technology is a high light transmission level with a low total energy transmission level. This is called "high selectivity." Selectivity means the ratio between light transmission level and total energy transmission level.

Selectivity = Light transmission level : Total energy transmission
Selectivity of SILVERSTAR SELEKT = 73% : 41% = 1.78

In reality, high selectivity means a lot of daylight without overheating the interior. This is an advantage for our modern architecture. Now the question arises: "Can SILVERSTAR SELEKT be used without any further solar reflective application?" Normally, windows which are in the direction of the sun need an additional solar protection, even if they use SILVERSTAR SELEKT. This can be done by shutters or blinds (or other window coverings) that are used during the high daytime temperatures and Jong daylight periods in the summertime. The advantage of highly selective glazing is not necessarily in substituting conventional sun-protective applications but in reducing their usage. But, one must consider that whenever a mechanical sun-protection is used, almost all daylight as well as the view is lost.

Vacuum Insulation Panel with fumed silica

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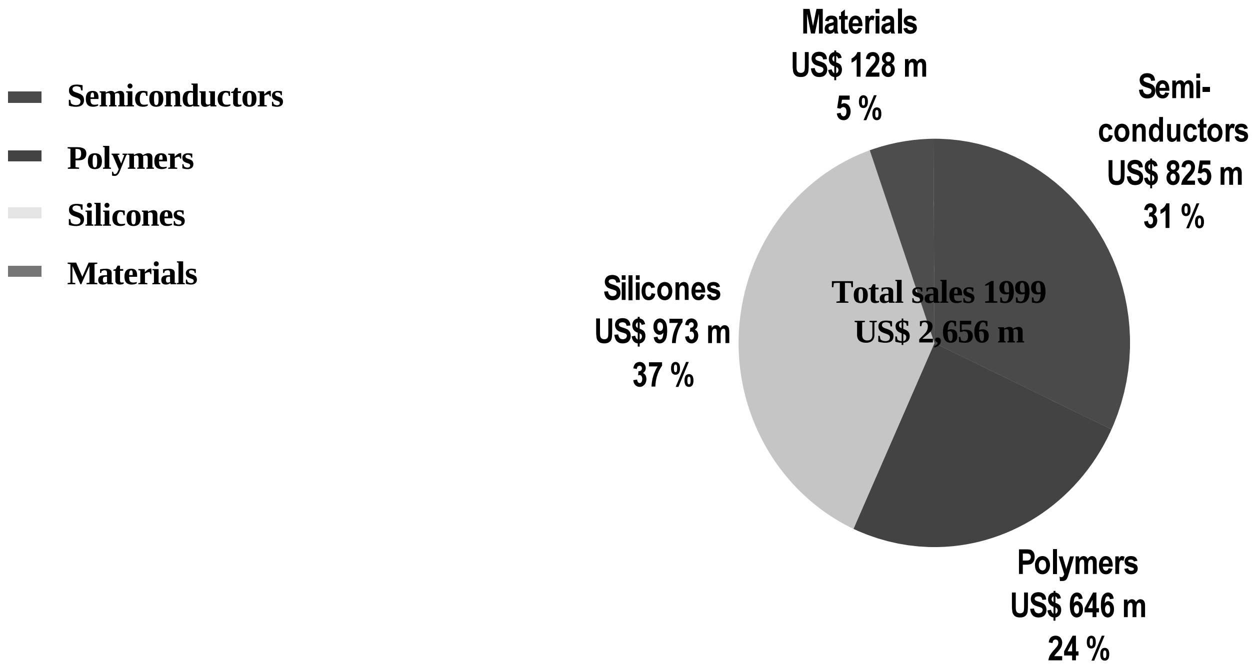
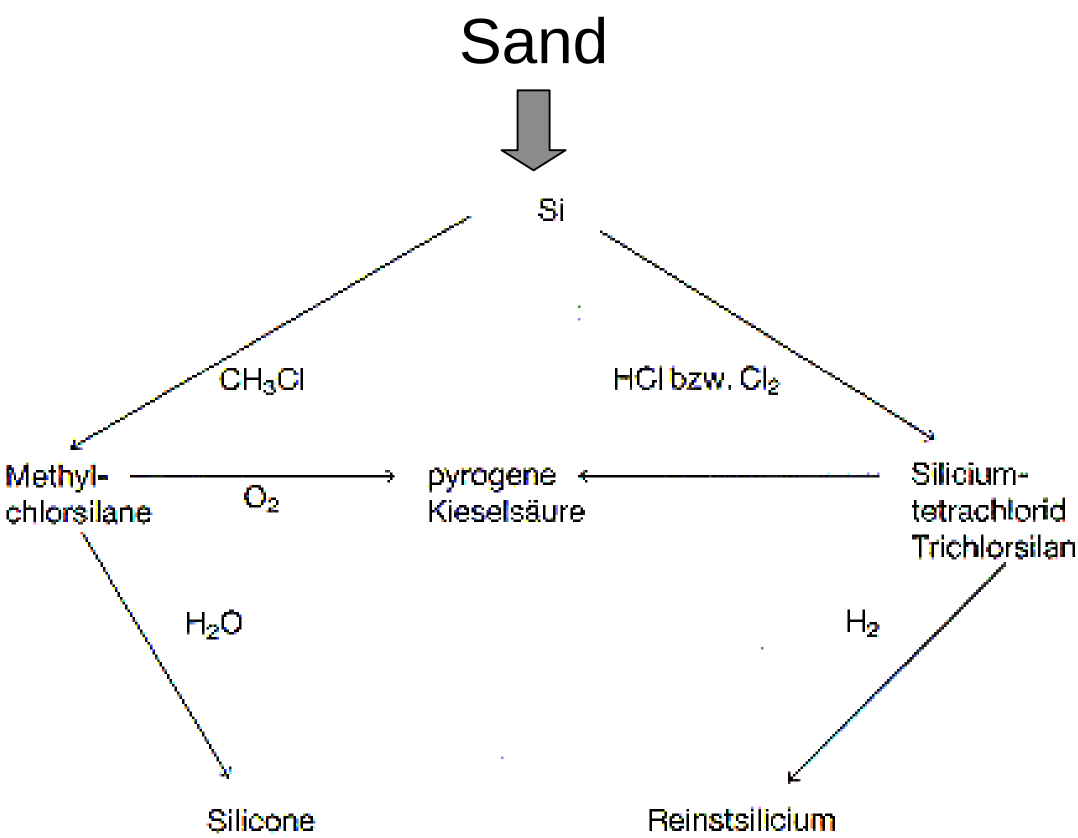
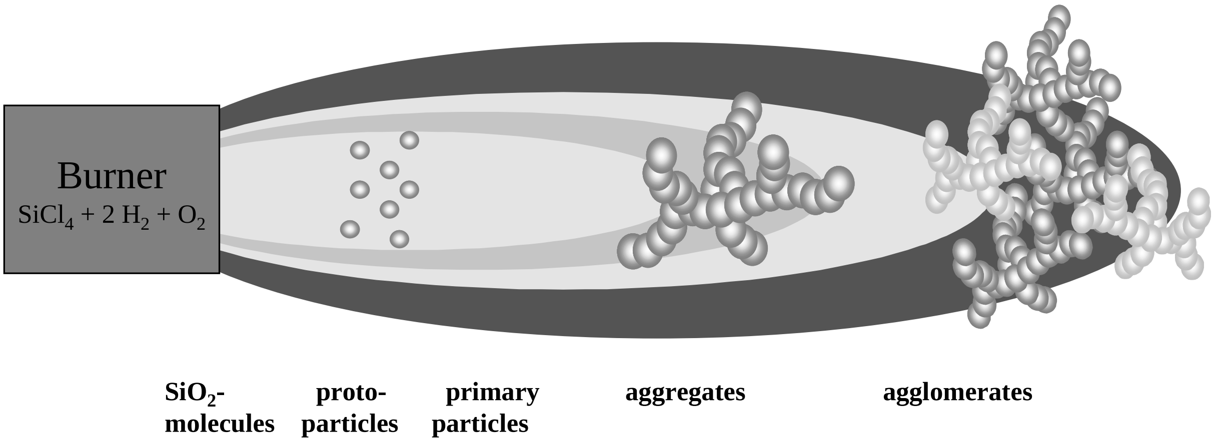
Core Businesses





Fumed Silica
Production Process in a Flame

$$SiCl_4 + 2\,H_2 + O_2 \rightarrow SiO_2 + 4\,HCl$$

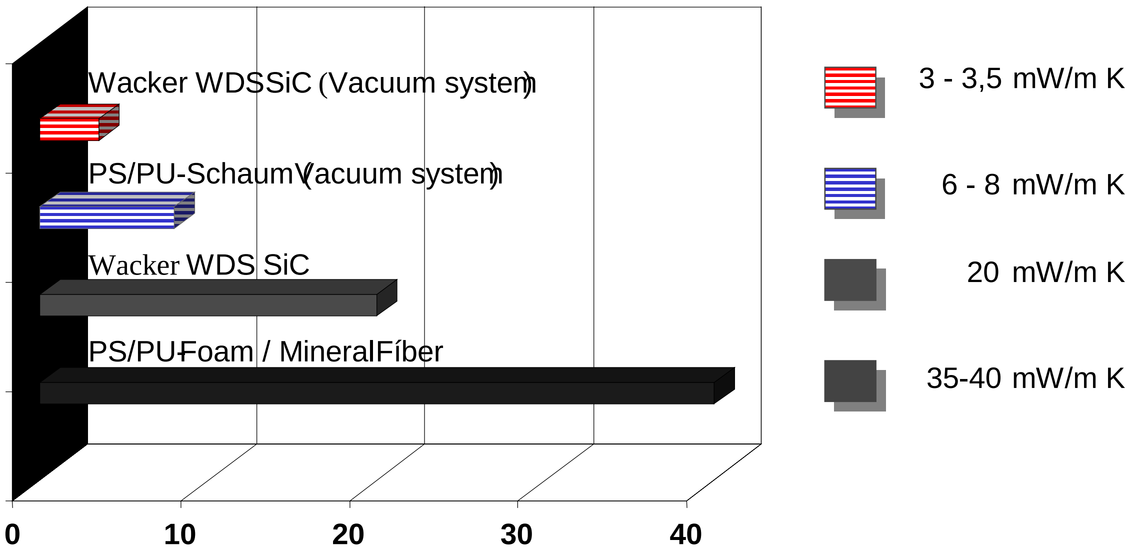


Application of Wacker WDS® SIC

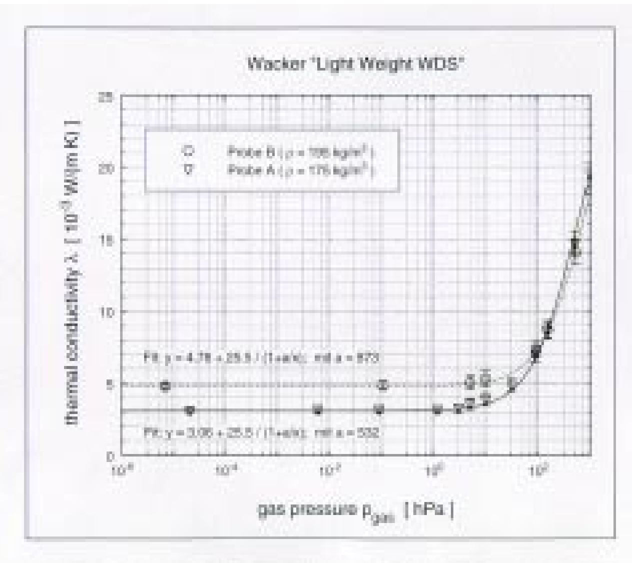
Wacker WDS SiC HT
Wacker WDS SiC NT

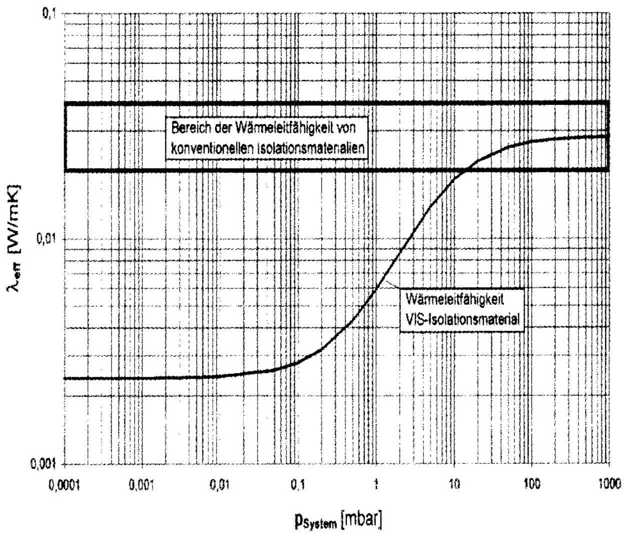
- automotive industry
- fuel cell
- fire protection
- pipe in pipe
- vacuum insulation
- appliance industry

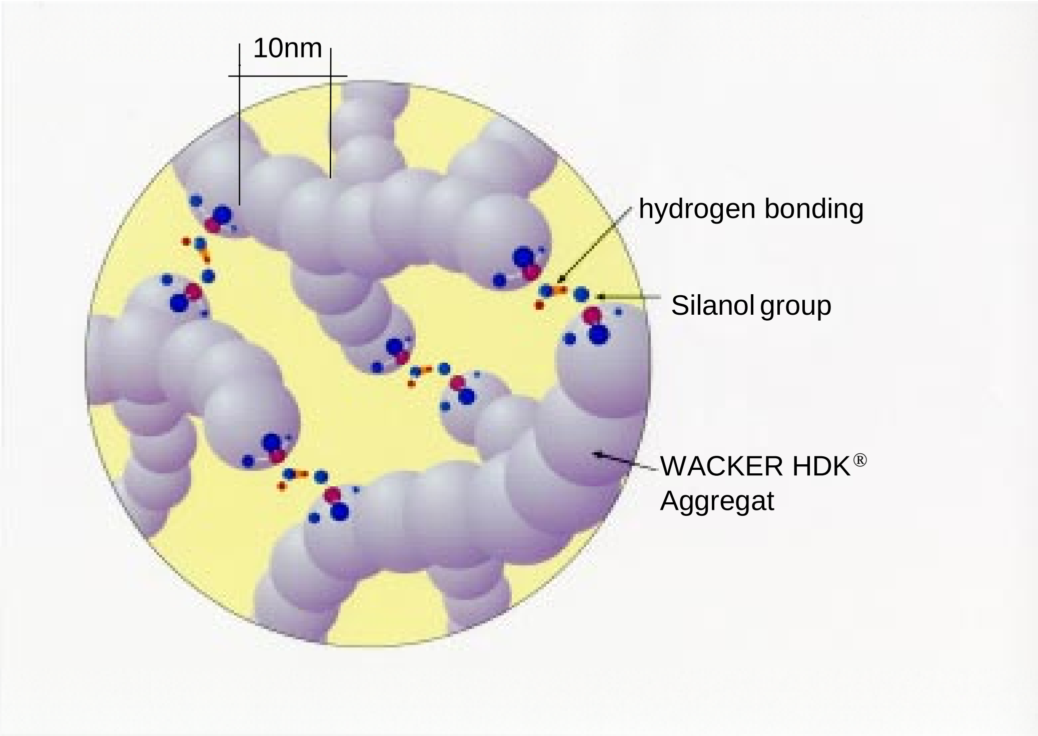
Comparison of insulation systems



λ vs p



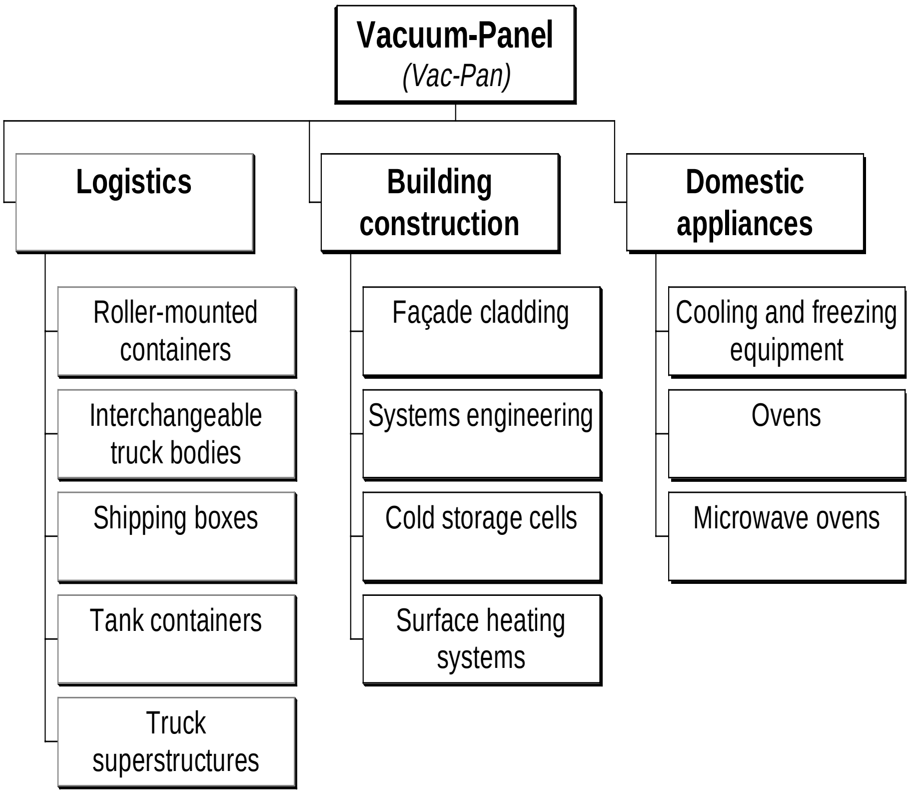




Application

Applications of VIP´s in industrial insulation fields

- High Temperature Super Conductor Transformator
- HCl Container
- Truck container
- Facade cladding systems
- Automotive industry/Battery Technology
- Fuel Cells


Vacuum-Panel
(Vac-Pan)
Logistics
Building construction
Domestic appliances
Roller-mounted containers
Interchangeable truck bodies
Shipping boxes
Tank containers
Truck superstructures
Façade cladding
Systems engineering
Cold storage cells
Surface heating systems
Cooling and freezing equipment
Ovens
Microwave ovens

Nanogel™

Production , Properties , Applications

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Introduction

The history of aerogels started in 1931 when Kistler made the first aerogels in a supercritical drying process . The expensive process and costly rawmaterial like Tetraethoxysilane where the roadblocks for a successful commercial production of aerogels in large industrial scale for more than a half century .

This scenario changed in early 1990ies when new research results from the University of New Mexico generated silica aerogels in a non-supercritical drying process 1).

Easy available and cheap raw material , waterglass and the new low-cost drying process motivated Hoechst and Cabot to think about a industrial production processes for aerogels . Booth Companies started independent research and commercialisation programs for aerogels.

In 1998 Hoechst sold their aerogel development program to Cabot .

Cabot joint both development programs together and two pilot plants in Tuscola/Ilinois and Frankfurt Germany work for process and application development .

The next step , a semi-commercial plant will start with a capacity of 10 .000 m³/year Nanogel™ aerogels in spring 2002 .

The Industrial Production Process

The basic raw material for the Nanogel™ production is waterglass (sodium silicate) . Waterglass is a widely used basic rawmaterial for metal casting , mining and the production of precipitated silicas .

In a polymerisation process under acid conditions the waterglas silica particles are formed to a hydrogel . The side-conditions of the polymerisation like pH , temperature , silicate concentration and time define the properties of the final aerogel , e.g. density , porosity , strength and surface area .

The hydrogel is already the final high porous silica particle with pores in the size of 10-
20 nm but this pores are filled with water .

The direct drying under ambient conditions destroy the pores in the gel and the volume of the gel shrinks by a factor of 5- 10. This shrinkage caused by the capillary forces is irreversible and called the collapse of the gel.

Shrinkage can be eliminated by supercritical drying , but this drying process under high pressure conditions is seen as to costly for a large scale industrial production of aerogels .

The ambient pressure drying is based on internal surface modification by silation of the wet gel or hydrogel . Gels with hydroxyl groups covered by reaction with silanes still shrink during ambient drying but they do not collapse , the absence of free hydroxyl groups allow the gel to spring back its original shape 1) .

Properties of Nanogel™ Aerogels

As the name itself already says, more the 90 % of the aerogel is air which is surrounded by a porous SiO_2 structure . Aerogels are nanoporous insulation materials that means the pores are smaller than the mean-free-path of the gas molecules (e.g. in case of air at 0° C 60 nm) and this nanoporosity leads to excellent thermal insulation properties .

Surface:	hydrophobic (hydrophilic)
Particle size:	5 µm - 5 mm
Particle shape:	round or rocky
Particle density:	around 120 kg /m³
Bulk density:	around 80 kg/m³
Light transmission:	translucent , opaque , opacified
Surface area:	up to 800 m²/g
Porosity:	> 90 %
Thermal Conductivity:	15 mW/mK

This basic properties are can be modified for every application of Nanogel™ aerogels .

Applications of Nonogel™ aerogel

A)Translucent insulating light systems

The light transmission (visual and solar) of a 2 cm Nanogel™ layer is in the range of 70 – 80 % , the thermal conductivity around 19 mW /mK .

The solar energy can pass through the aerogel into the building , and the excellent thermal insulation of the light element minimise the thermal loss of the building.

The design of highly insulation glazing with U values of 0,4 W/ (m^2K) and g-values of 0,4 . x) which bring diffuse natural light in the building has been demonstrated by the ZAE 2) .Besides glass , other transparent materials e.g. polyester , polycarbonate ,

can envelope the transparent aerogel . This translucent elements bring promising new opportunities for the design of passive solar applications in construction .

Applications in construction :

Translucent wall/window elements

Sky light systems / sky-domes

Solar collectors for roof and wall

B) Vacuum insulation panels

Current vacuum insulation panels (VIP's) are made with core material out of open cell organic foams or inorganic material like precipitated silica's or fumed silica's . The microporous structure of the fumed silica cores tolerate less vacuum versus the organic foam 4) . VIP cores based on aerogels show similar flat pressure/ thermal conductivity graph . The benefit of the new fiber reinforced Nanogel™ is the reduction in panel density by 40 % , which translates to a significant potential cost reduction for the VIP´s .

In the near future we will see Nanogel™ VIP cores with a overall density of about

110 kg/m^3 and a correlated silica density of 55 kg/m^3 3).

Applications in construction :

Roller shutter housings

Floor insulation

Roof insulation

Door filling

Pipe and storage tank insulation

C) Nanogel™ Composites

In some applications does the granular aerogel not fit – solid boards or panels are required . For forming a boards , the Nanogel™ particle need a binder , to form the aerogel granules to a solid board . Composites out of Nanogel™ particles and organic binders bring promising performance for new insulation solutions in construction and industrial insulation applications . Aerogel composites can designed with a thermal conductivity in the range of 20 –25 mW/ mK , this is a reduction of 30 % versus current foam or fiber insulation materials . Besides the board application of Nanogel™ , this composites can be applied in a spray technology .

Applications in construction

Roof insulation
Sandwich façade boards
Rehabilitation of buildings
- Vapour permeable insulation elements

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D.Smith, D .Stein,J.Anderson, W.Ackerman , J. Non Cryst.Solids 186 (1995)104

A.Beck, M.Reim,W.Körner, J.Fricke, Ch.Schmidt,F-J Pötter Highly Insulating Aerogel Glazing , Eurosun 2000 Kopenhagen

S.Rouanet, H.F.Eberhard , J.Floess , Novel Aerogels for Optimised Performance in Vacuum Insulation Panels, ISA 6

4) Nanogel™ technical brochure : Original Data Nanopore ,inc.

Nanogel™ is a trademark of Cabot Corp.

Ceramis® Packaging material for VIP

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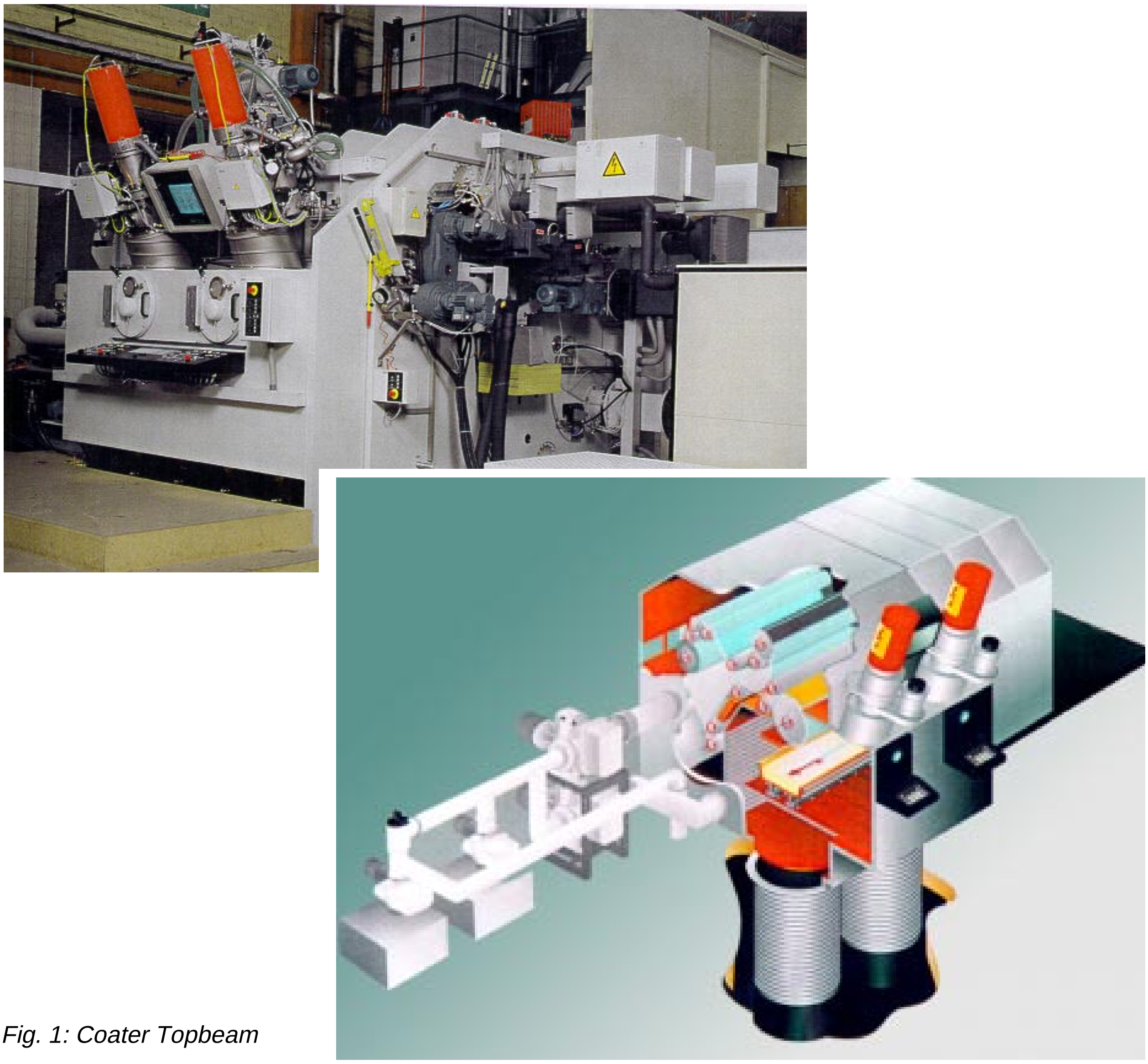

Fig. 1: Coater Topbeam

Summary

- Description of the over wrapping of Vacuum Isolation Panels with a Ceramis®Laminate (case Wacker Chemie GmbH with the Ceramis®Laminate: PET12/SiOx-PET12/PE100)

What is CERAMIS® ?

- Ceramis® – Description of the Electron Beam evaporation coating of Silicon Oxide.
- Advantages of Ceramis®Laminate for VIP.
- Barriers properties against gas, moisture and other exchanges with external environment.
- Mechanical stability (Gelbo-Flex stress, Folding and bending stress, Tension stress).
- Thermal conductivity (non metallic/non foil structure).

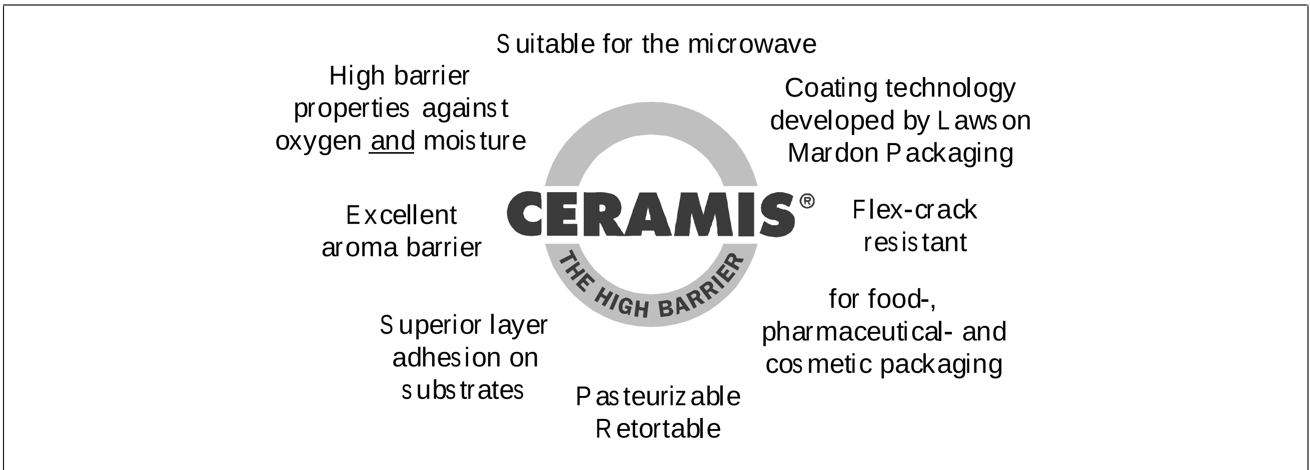

Fig. 1: Ceramic thin-layer coatings

CERAMIS®- Coating Technology

Electronbeam Evaporation with Plasma Pre-treatment

Low cost process

- High web speed (10m/sec) --> high throughput
- Low cost for coating raw materials (< 1 CHF/100m2)
- Coating formulation and technology developed by our own R&D Center

High quality process

- Non-reactive process (non-organic coating)
- Stable process - easy online control
- Excellent adhesion on the backing layer due to surface plasma treatment

Flexible technology

- Applicable on various substrates
- Coating without yellow tint (waterclear)
- Retortable coatings

CERAMIS® Film Grades

- CERAMIS® PET - retortable (CT-A, CT-XA)
- retortable in a laminate structure up to 121°C (250°F), 30 min
- excellent barrier against oxygen and water vapor
- CT-XA grade without yellow tint (waterclear)

- CERAMIS® PET - (CT-D, CT-XD)
- excellent barrier against oxygen and water vapor
- CT-XD grade without yellow tint (waterclear)

- CERAMIS® oPP (CO)
- high oxygen barrier
- excellent water vapor barrier

- CERAMIS® oPA (CA)
  - without yellow tint
  - excellent barrier against oxygen and water vapor
  - superior mechanical strength

Barrier – Properties

Oxygen Barrier , Water Vapor Barrier , Aroma Barrier

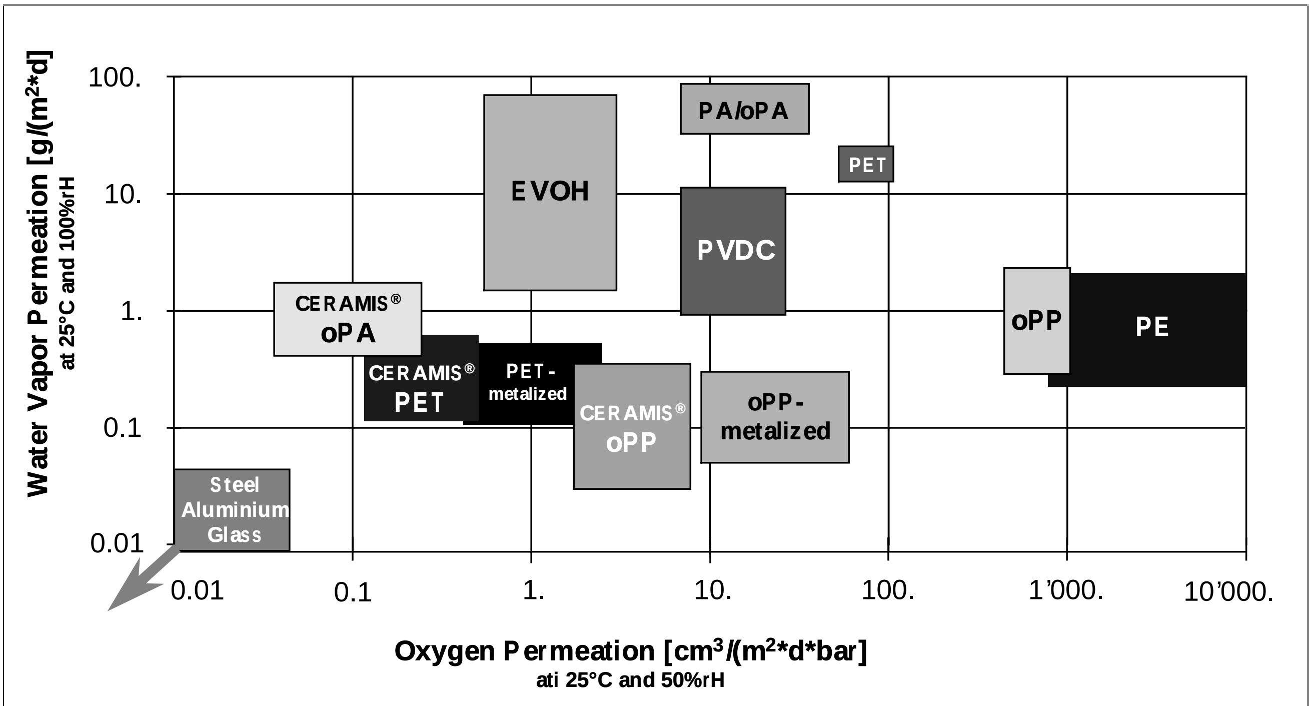

Fig. 2: Barrier - Permeation rates in comparison

Climatic Influence

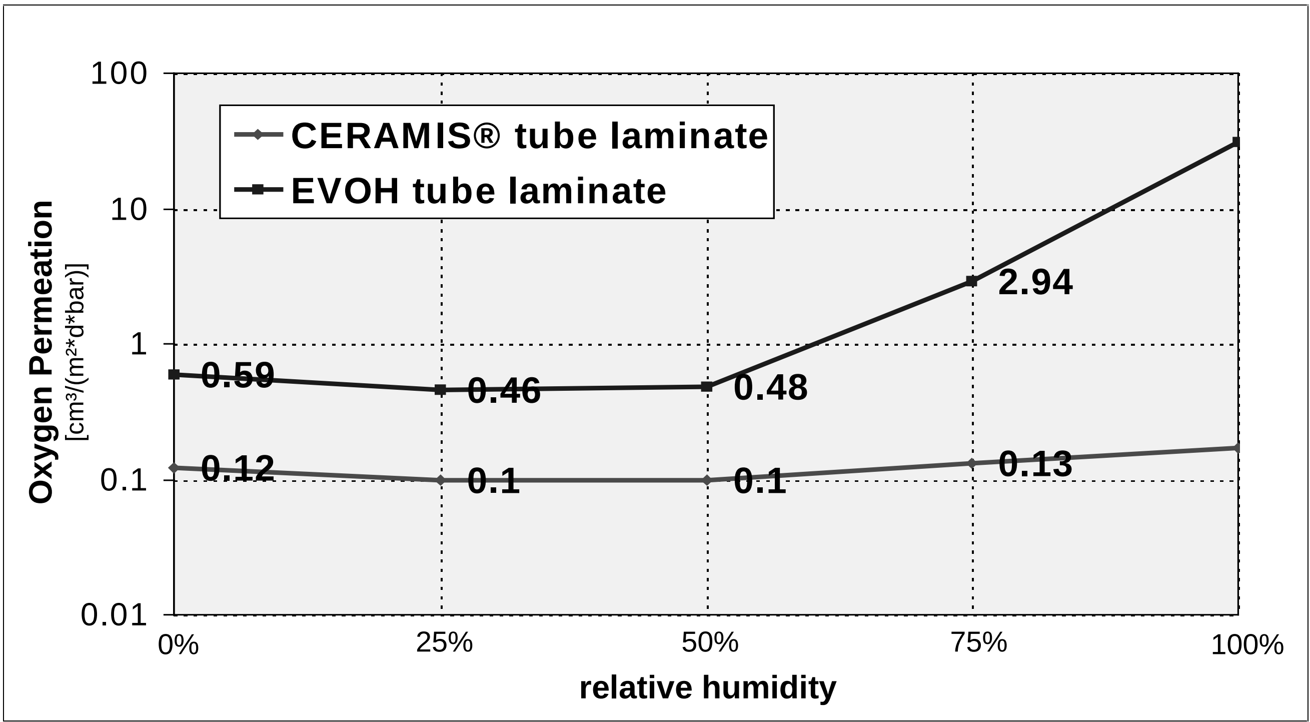

Fig. 3: Mechanical stability - Influence of humidity on oxygen barrier

Limits of use of Ceramis® Laminate for VIP.

Target: Packaging specifications for VIP - Tests and analyses needed for this.

- Limits of temperature resistance for the packaging.
  (Stress tests at temperature of use in defined applications (for fridges, air conditioned systems, solar heating systems, motors, building isolation plates, ...).
- Limits of mechanical and barrier stability through time and stress tests for the packaging.
- Limits of the protection of the packaging through seal areas (exchanges with external environment through the seal of the over wrapping) for the VIP system.

Mechanical stability

- Gelbo-flex stress
- Folding and bending stress
- Tension stress

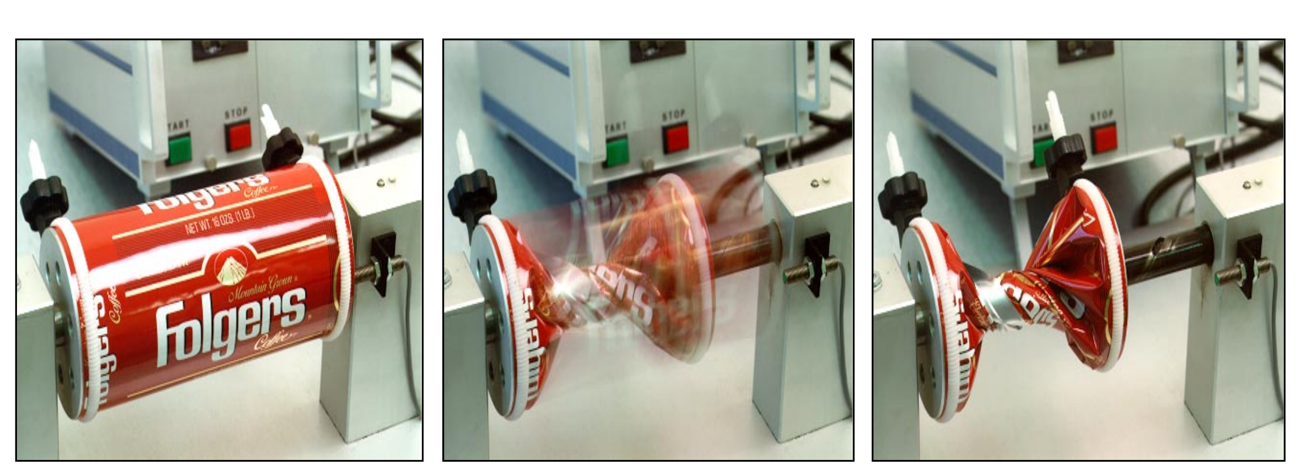

Fig. 5: *Principle of Gelbo-Flex-testing (according to ASTM F 392-74)*

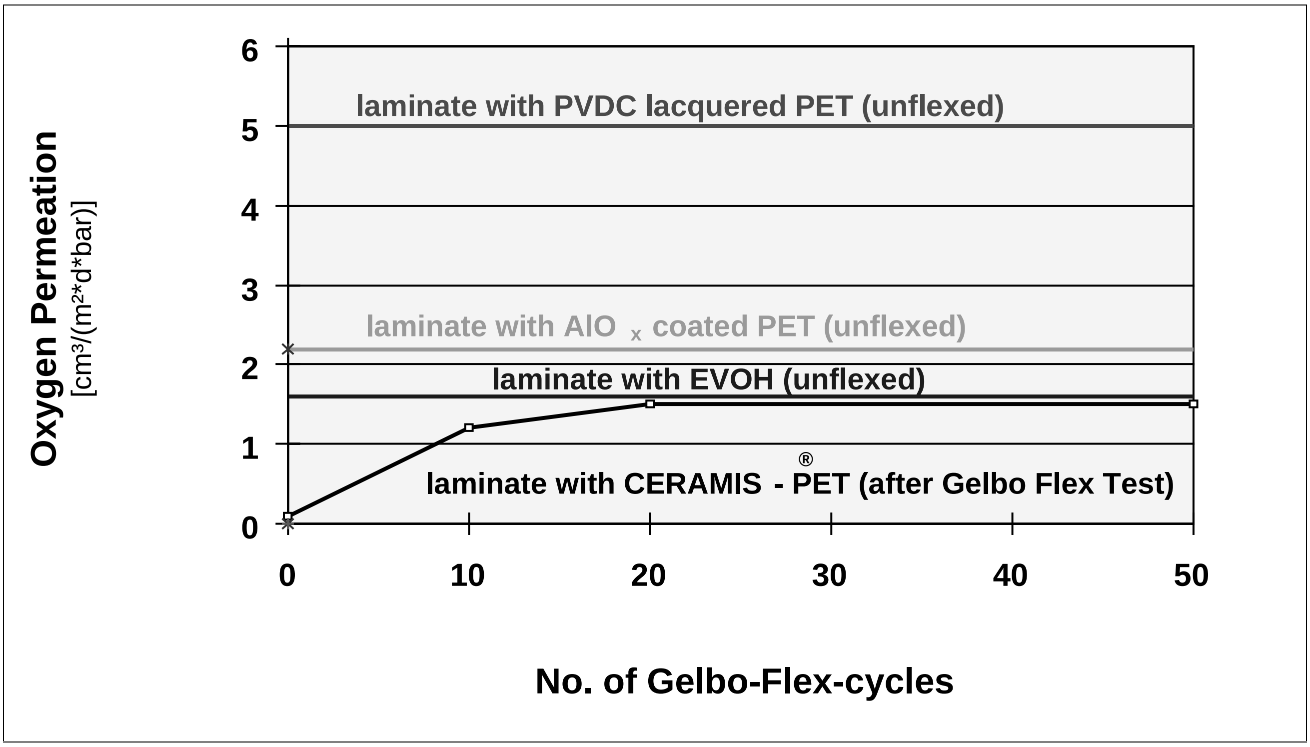

Fig. 5: Mechanical stability - Oxygen permeation after Gelbo-Flex-test

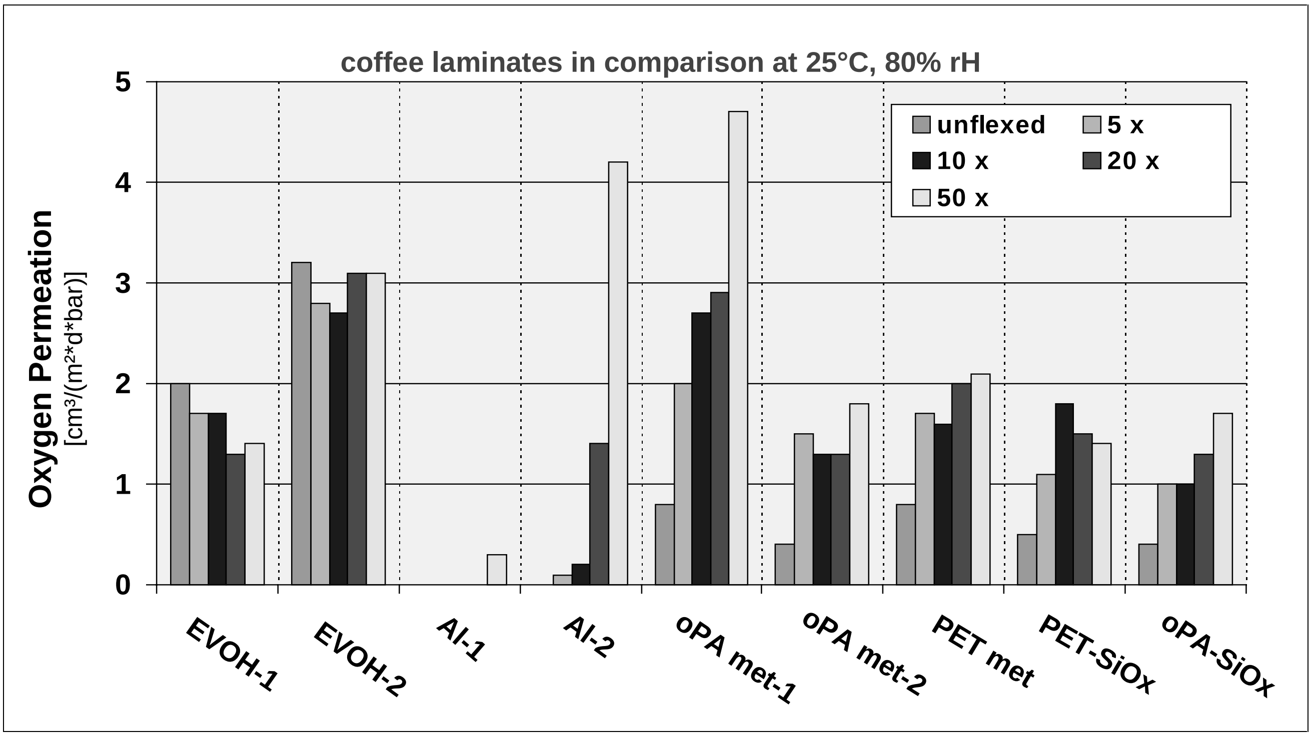

Fig. 6: Mechanical stability - Oxygen permeation after Gelbo-Flex-test

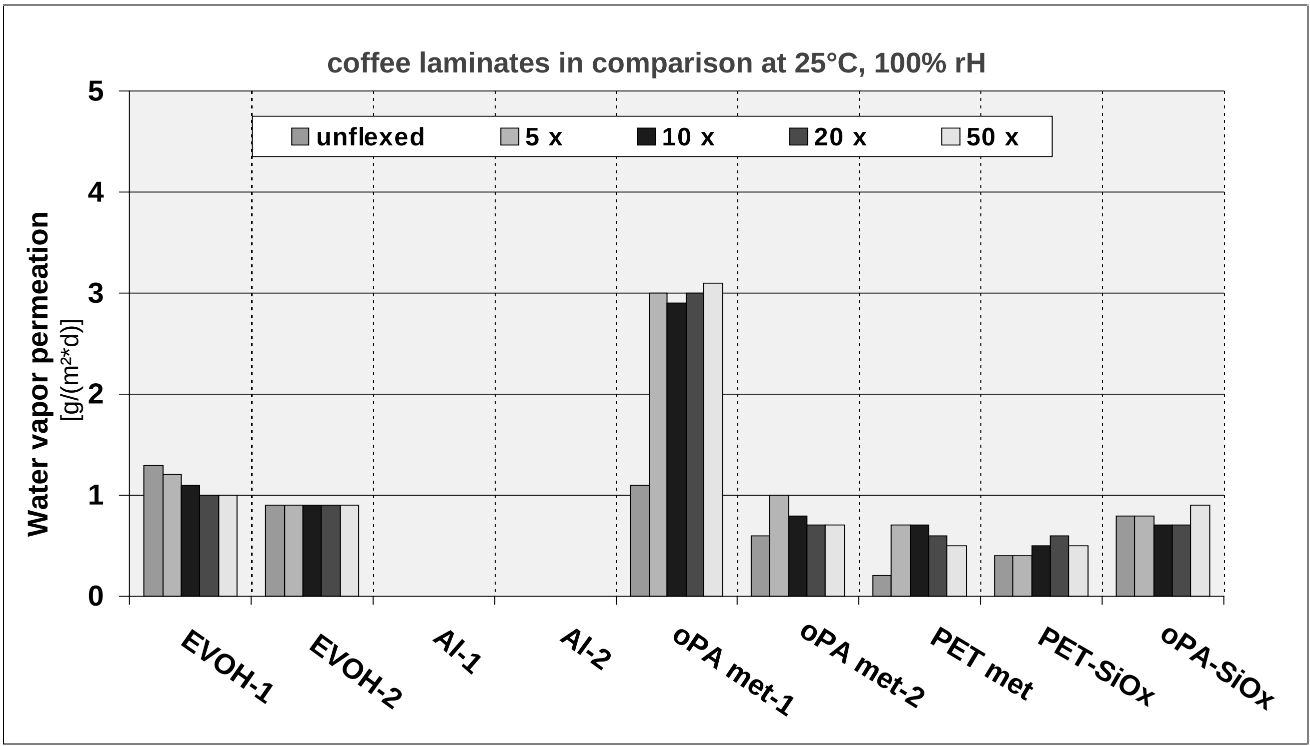

Fig. 7: Mechanical stability – Water vapor permeation after Gelbo-Flex-test

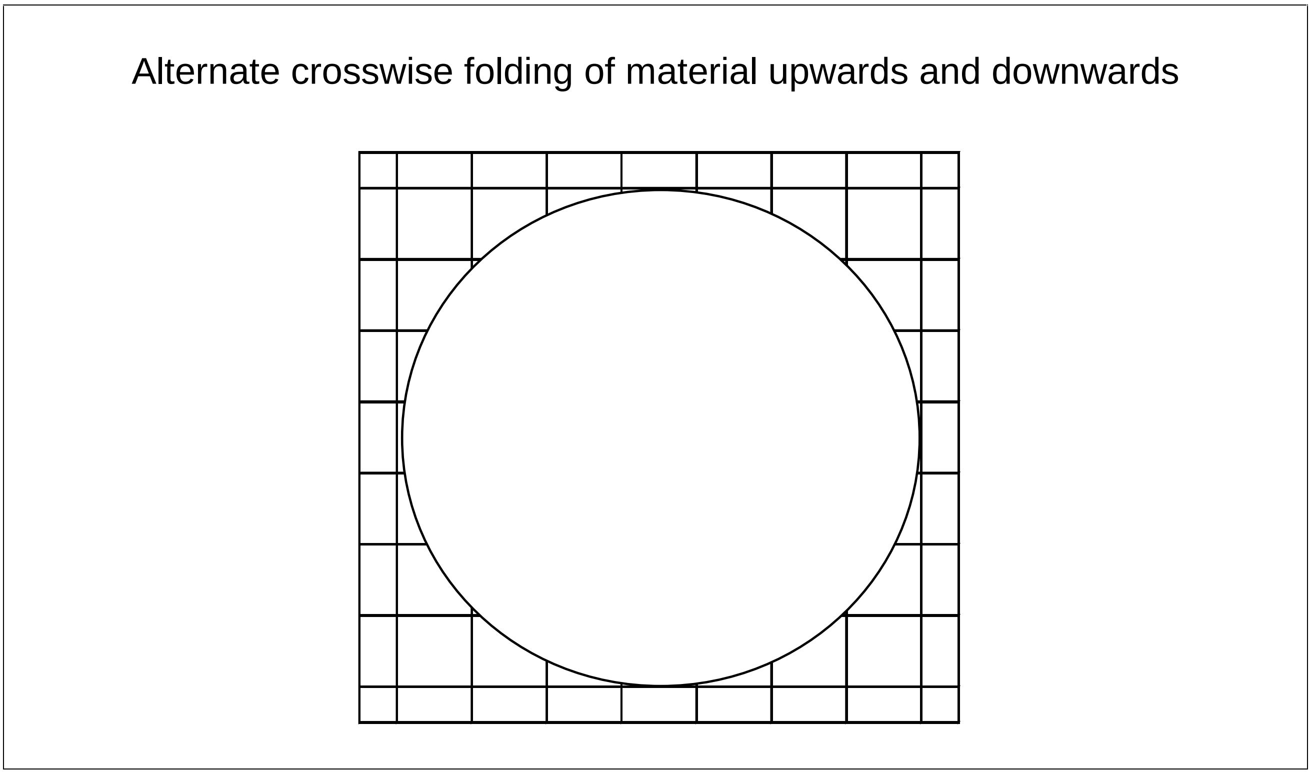

Fig. 8: Mechanical stability - Principle of folding test (According to NF H 00 - 030 french standard)

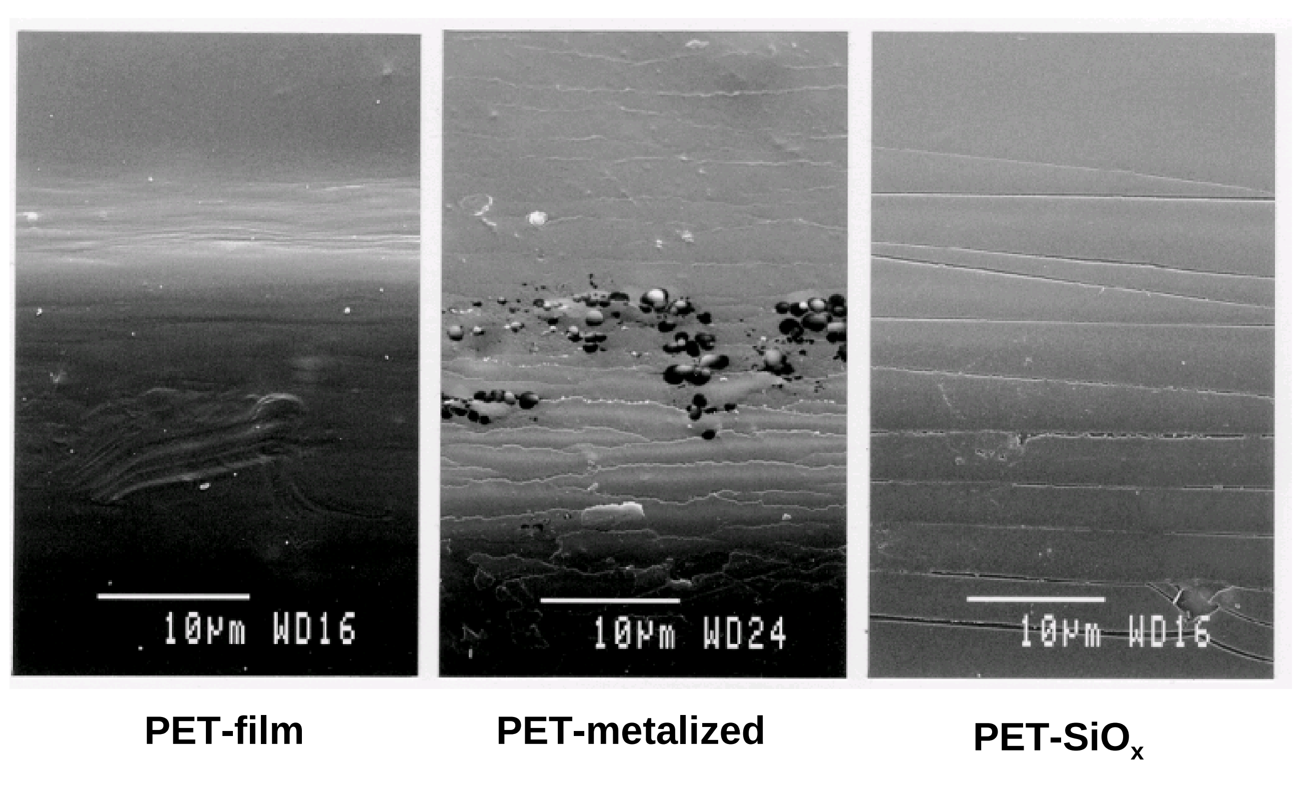

Fig. 9: Mechanical stability - Oxygen permeation after folding test

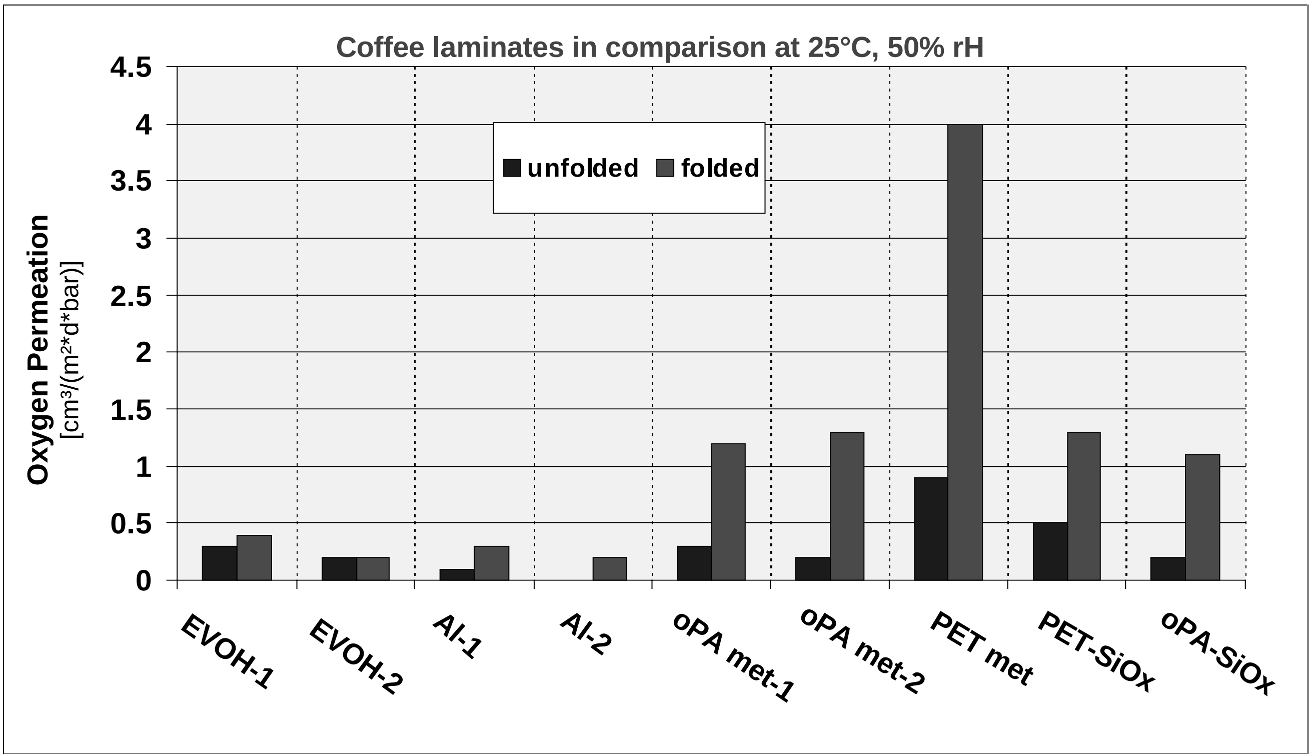

Fig. 10: Mechanical stability - Oxygen permeation after folding test

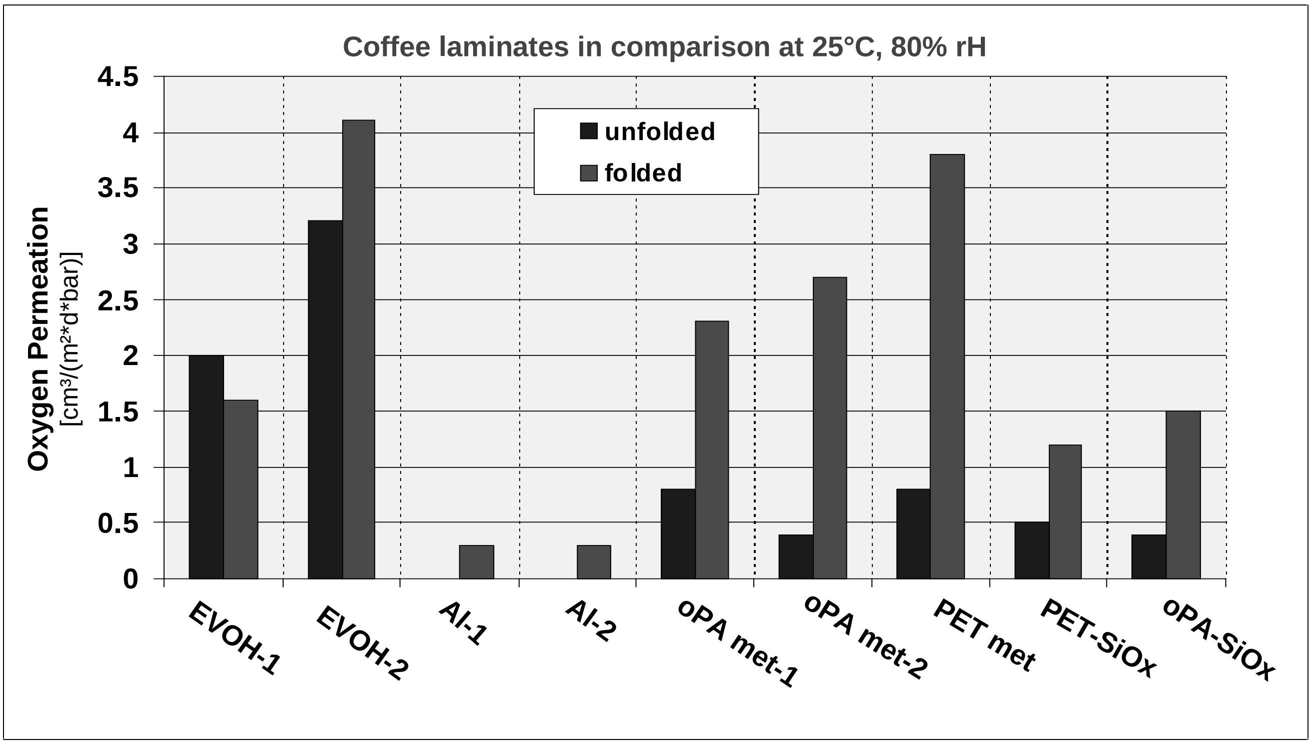

Fig. 11: Mechanical stability - Oxygen permeation after folding test

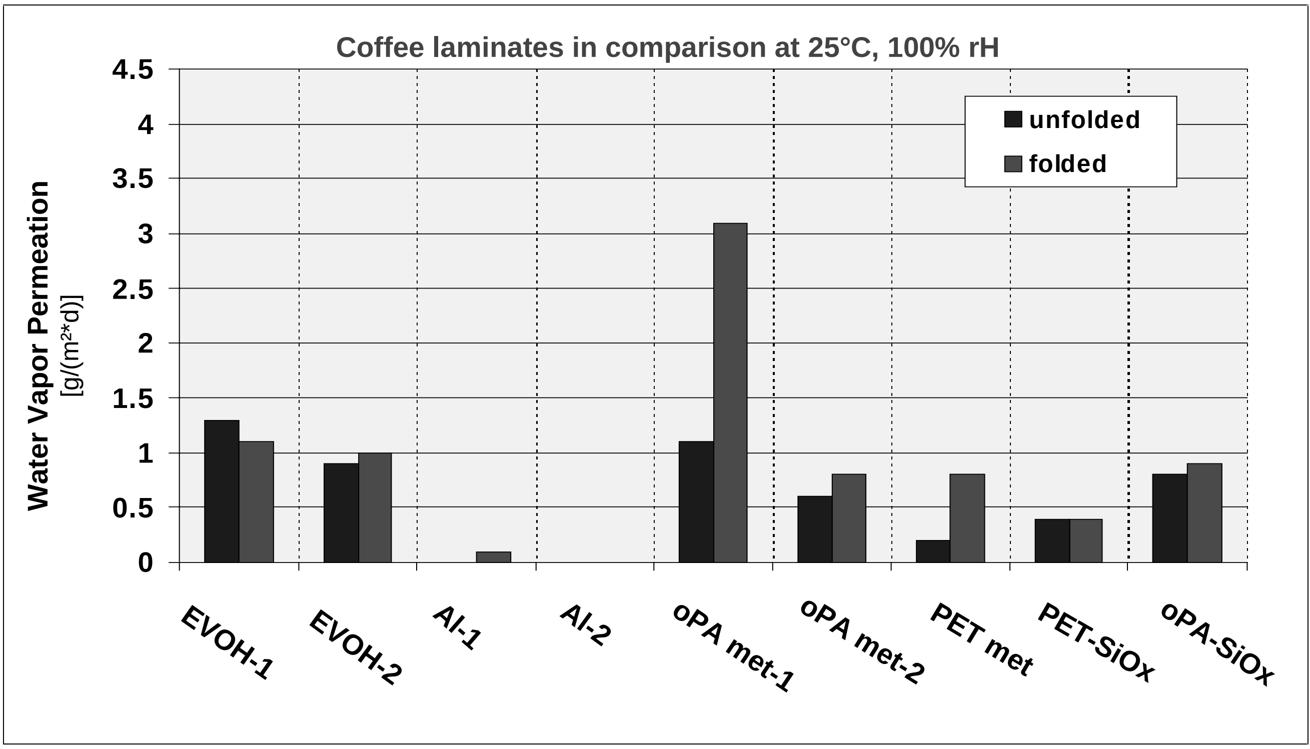

Fig. 12: Mechanical stability - Water vapor permeation after folding test

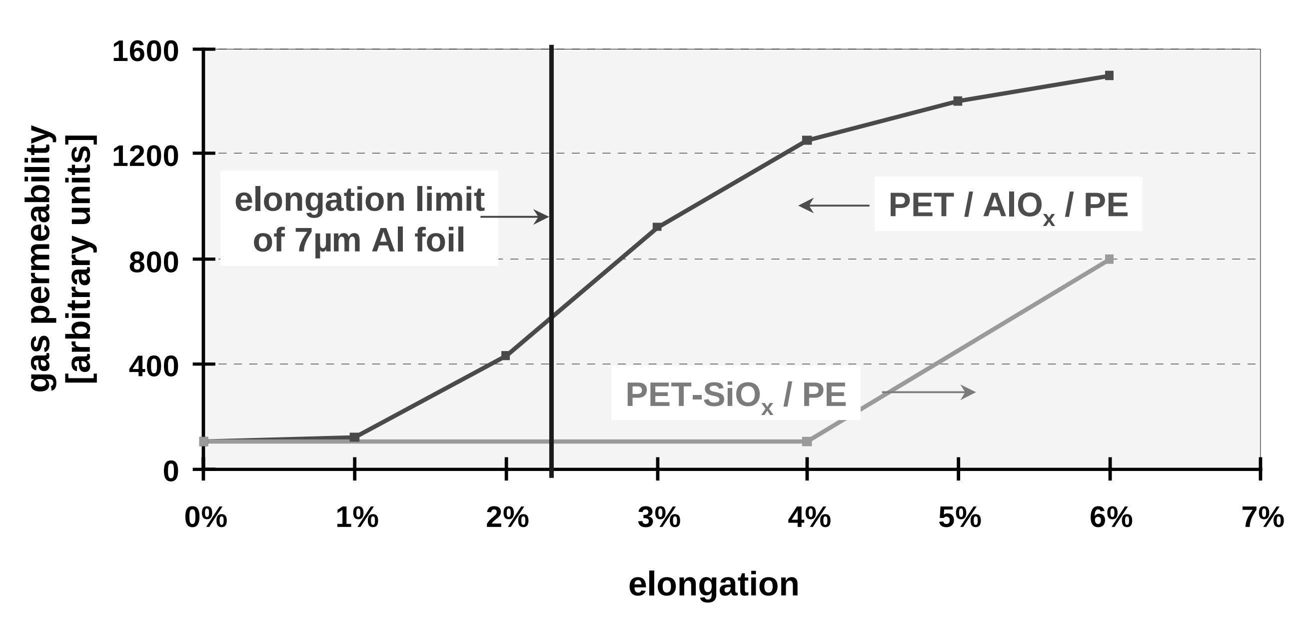

Fig. 13: Mechanical stability - Oxygen permeation after elongation

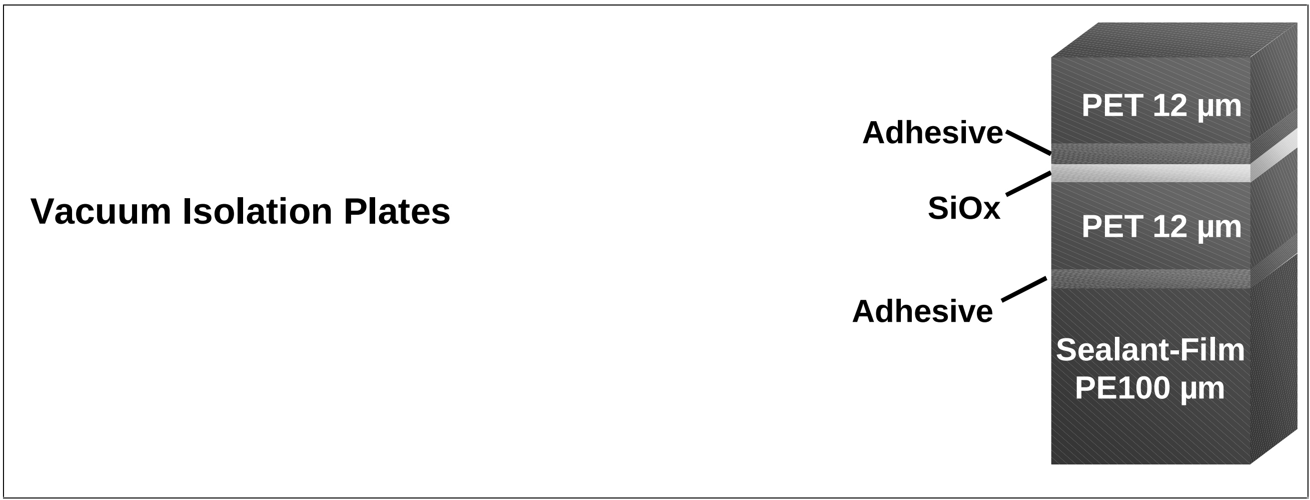

Fig. 14: CERAMIS®Laminate for VIP (CTXD based)

Measurements of physical properties of VIP

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Summary

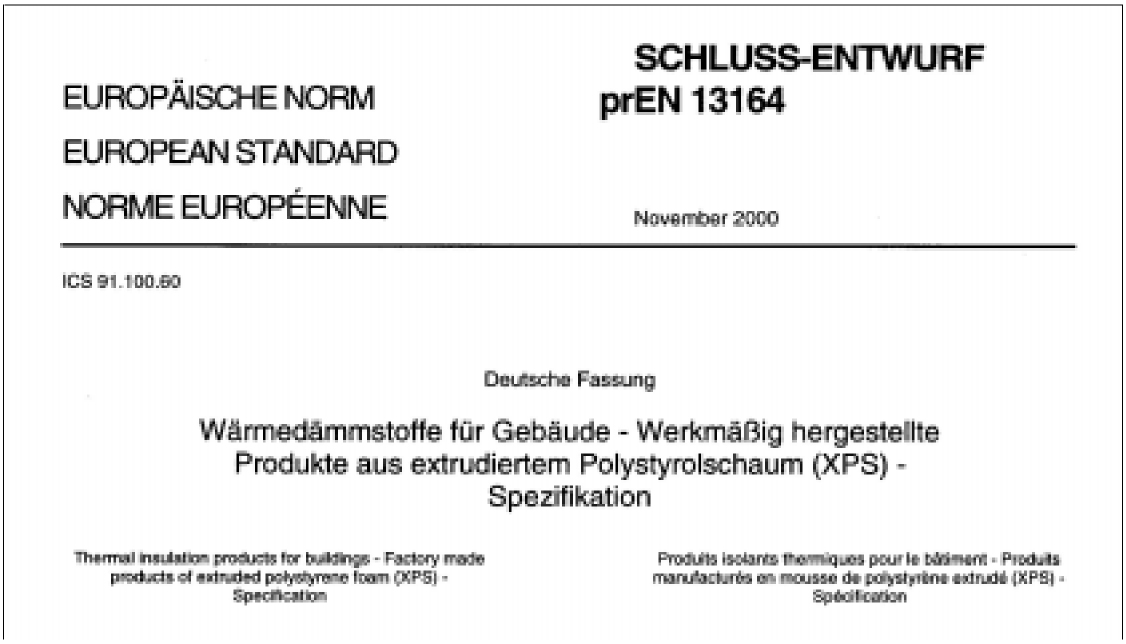
In this contribution, the determination of properties of vacuum insulation boards is compared with the existing standard test methods and product standards for conventional thermal insulation materials for building applications. It is shown how application related properties of VIP could be tested and declared in analogy to conventional materials. Also differences and needs for additional VIP test methods are addressed.

Introduction

In the last years, vacuum insulation panels (VIP) have been developed and optimized to a pre-competitive stage [1]. During this time, a large amount of work has been done on defining harmonized testing and product specification standards for conventional thermal insulation materials by the members of the European Committee for Standarization (CEN). Although VIPs are quite different in some aspects, it is instructive to have a look at the standards for conventional products. Many of the application related requirements are also important for VIP, and a few years from now, there could be one ore more harmonized VIP standard(s) along with specific test methods needed for VIP. In CEN, mainly two technical committees (TC) are involved in standardization on thermal insulation products: In TC 88 – Thermal insulation products for buildings – a number of general and specific test methods have been defined and established [2], and for the main product families, product standards have been developed in collaboration of testing labs and the respective industry [3].

In TC 89 – Thermal performance of buildings and building components – a number of test and calculation methods for the determination of thermal properties of materials, façade components and whole buildings have been defined.

In the following sections, properties of thermal insulation boards are addressed and a comparison between conventional and vacuum insulation products is made. In contrast to most of the conventional products, a VIP is an assembled unit itself. As the focus is on application related properties, only a short remark is made on properties of single bulk or envelope materials.



EUROPÄISCHE NORM
EUROPEAN STANDARD
NORME EUROPÉENNE

SCHLUSS-ENTWURF
prEN 13164

November 2000

ICS 91.100.60

Deutsche Fassung

Wärmedämmstoffe für Gebäude - Werkmäßig hergestellte Produkte aus extrudiertem Polystyrolschaum (XPS) - Spezifikation

Thermal insulation products for buildings - Factory made products of extruded polystyrene foam (XPS) - Specification

Produits isolants thermiques pour le bâtiment - Produits manufacturés en mousse de polystyrène extrudé (XPS) - Spécification

Fig. 1: Draft EN product standard prEN 13164 for extruded polystyrene (XPS) boards.

Properties of materials

From an application point of view, the thermal conductivity of the bulk material in function of the pore gas pressure $\lambda(p_{gas})$ is the property most directly related to the thermal resistance of the final product. For measurement, test equipment according to standards such as ISO 8302 (guarded hot plate) or ISO 8301 (heat flow meter) can be operated in a pressure controlled chamber [4]. In addition the thermal capacity should be known. For a detailed analysis and optimization of a product development process, microscopic properties, e.g. pore size distribution, IR transmission / reflection properties etc. will have to be determined by applying available methods and equipment.

The envelope conserving the low pressure in the bulk material is the most important component with respect to the long-term behaviour of the product. Key property is the gas tightness of the material. For the measurement of gas permeability properties, various standard methods and test equipment are available [5]. Important is also the lateral thermal conductance which may cause a substantial edge conductance (c.f. page 50). Various properties are related to the durability and reliability of a finished VIP, i.e. mechanical strength (e.g. tear strength), resistance to hygro-thermal, chemical or UV impact of plastics or laminates. No reference to the large number of existing standards is made here.

Properties of VIP

Thermal properties

The most important application related property is of course the thermal resistance or "effective" conductivity. For factory made products, the European product standards (Fig. 1) refer to specific test methods [6] and require a manufacturer declared value λ_D (W $m^{-1}K^{-1}$) which shall not be exceeded by 90 % of the production at a confidence level of 90 %. Methods for the determination of such values are described in EN ISO 10456. Furthermore, the declared value shall be valid for a time period of about 25 years, assuming a service lifetime in the order of 50 years. For some foam products with a high closed cell content, e.g. XPS, PUR, PIR, the thermal conductivity just after production increases significantly (depending on the blowing agent) by a more or less slow gas exchange process with the environment. Therefore, the respective product standards (prEN 13164, prEN 13165, prEN 13166) contain specific ageing procedures to be applied before measuring thermal conductivity values for declaration.

Due to the strong dependence $\lambda(p_{gas})$, changes of the cell gas content in VIP should also be taken into account for the specification of a long-term λ-value. As an example, thermal conductivity measurements on a VIP with XPS bulk material sealed with laminated aluminium foil have been performed at EMPA (Fig. 2) before and after a heat ageing procedure adapted from the PUR draft standard prEN 13165, i.e. 8 week storage at temperature of 60°C (PUR: 25 weeks at 70°C). It is observed (Fig. 3) that the thermal conductivity increased from 4 to 10 mW $m^{-1}K^{-1}$. Obviously the vacuum was not broken by a failure of the envelope. Although the effect may be less pronounced for other bulk materials and improved getters, realistic accelerated ageing procedures, possibly with respect to specific applications, should be determined and applied. Another question is the maximum (minimum) service temperature to prevent fast degradation or even failure of the VIP. Future VIP standards should cover the determination of those properties.

Fig. 2: One of EMPA's symmetric guarded hot plate facilities for low conductivity measurements on thermal insulation products (specimen size 750 x 750 mm^2).

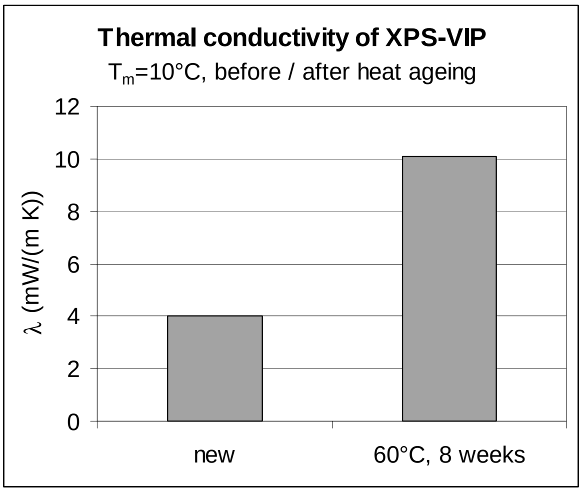


Fig. 3: Thermal conductivity of a VIP before and after application of a heat ageing procedure adapted from the draft EN product standard for PUR foams.

According to the dependence $\lambda(p_{gas})$, p_{gas} is the most sensitive indicator for the quality of a new or aged VIP, allowing for an immediate indirect determination of the thermal conductivity. p_{gas} can be determined approximately by placing the VIP into a vacuum chamber, reducing the pressure until the envelope begins to move away from the bulk material (Fig. 4). If the envelope material is thin and flexible, the interior pressure corresponds approximately to the chamber pressure. This non-destructive method is also applicable in production quality control and could be standardized. Using optical detection, the method could be run automatically and possibly with better repeatability than by a visual check.

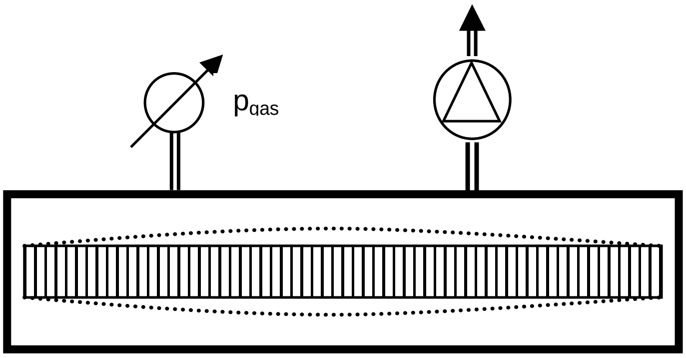


Fig. 4: Approximate determination of interior gas pressure.

In addition to the one-dimensional thermal conductance, an edge conductance Ψ_{edge} due to lateral heat flow in the envelope is present in VIP:

$$\frac{\dot{Q}}{A\Delta T} = \Lambda_{1-\dim} + \frac{U}{A}\Psi_{edge} \quad (\mathrm{Wm^{-2}K^{-1}}),$$

where area $A = a \times b$, circumference $U = 2 \times (a + b)$ with length a and width b.

At EMPA, the edge conductance for 20 mm VIP (pyrogenic silica core) both for laminated aluminium (about 7 µm) and for metalized Mylar envelopes has been determined by guarded hot plate measurements with one linear joint at the center (Fig. 5).

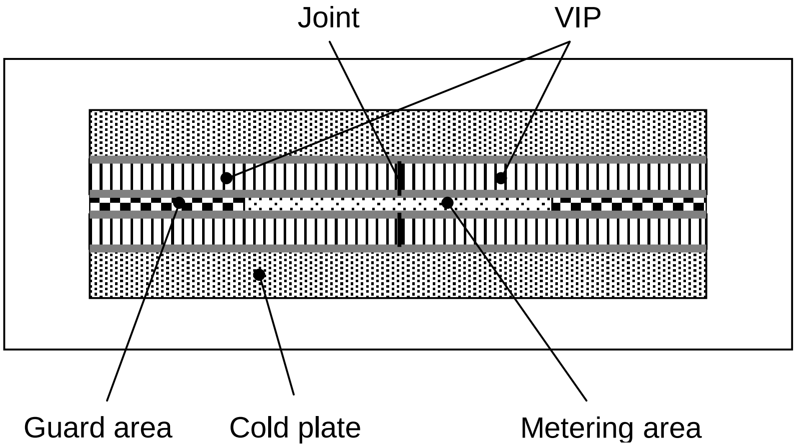


Fig. 5: Measurement of the edge conductance in a symmetric guarded hot plate facility. Two 375 x 750 mm² specimens were placed on each side. The 1-dimensional thermal conductivity was measured with two 750 x 750 mm² specimens.

Resulting Ψ_{edge} values and calculated effective thermal conductivities for a 1 x 1 m^2 board (d = 20 mm) are shown in the following table (Fig. 6).

VIP envelope	Ψ_{edge} W/(m K)	$\lambda_{1\text{-}dim}$ W/(m K)	λ_{edge} W/(m K)	$\lambda_{effective}$ W/(m K)
Laminated aluminium	0.0800	0.0040	0.0064	0.0104
Metallized mylar	0.0065	0.0040	0.0005	0.0045

Fig. 6: Measured edge conductance and effective thermal conductivity of a VIP (1 x 1 m^2, d = 20 mm).

In the case of the relatively massive Al envelope, the edge conductivity is larger than the core contribution. For the metalized high barrier Mylar foil, the effect is in the order of 10 %. Because the geometry factor is

$$\frac{U}{A} = 2\left(a^{-1} + b^{-1}\right),$$

both linear dimensions must be "large" in order to reduce the edge effect. An example is shown in Fig. 7: Although the area in the second case (2.0 x 0.6 m^2) is larger, the effective conductivity is higher than with the 1 x 1 m^2 panel.

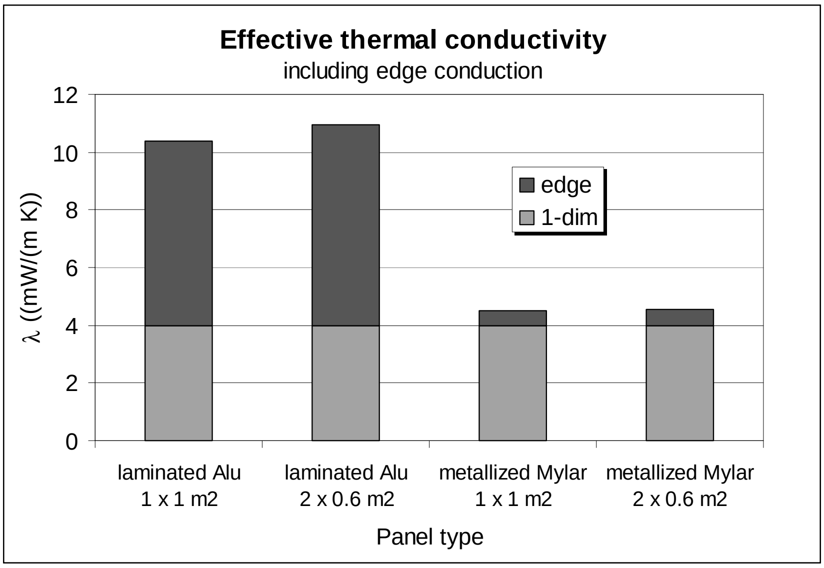


Fig. 7: Comparison of effective thermal conductivities for different panel envelopes and areas.

It is evident that the edge conductance Ψ_{edge} should be determined and declared by the manufacturer similar to the long-term one-dimensional conductivity.

Geometric and mechanical properties

EN standards exist for the determination of "simple" geometric properties like length, width, thickness, squareness and flatness of thermal insulation products (EN 822-EN 825). In the EN product standards, tolerances and declaration rules are stated. These quantities are important for practical reasons of application or further manufacturing, also for VIP. Because of the additional sealing stripe of the envelope, those quantities have to be redefined and declared in a common way.

There is also a number of EN test methods for mechanical (force) properties: compressive and tensile stress behaviour (EN 826, EN 1607), bending strength (EN 12089), behaviour under point load (EN 12430), thickness in floating floor applications (EN 12431), compressive creep behaviour (EN 1606). Depending on the application, some of these properties may be of interest for VIP too. However, the applicability of the methods has to be checked carefully.

Durability / Reliability

Various EN standards are available for testing of the dimensional stability under standard conditions 23°C / 50 % r.H. (EN 1603), specified temperature and humidity conditions (EN 1604), and specified compression and temperature loads (EN 1605). Also for VIP, some of these methods may be important for specific applications. However, the issue for VIP is not just the degradation of certain properties over a long time period (durability).

Other than with conventional insulation products, a dramatic change in the thermal insulation occurs with VIP in case of a failure of the seal or if the vacuum is damaged by another mechanism. Furthermore, the failure will affect at least the area of a whole panel or larger areas in case of a systematic process. Therefore, reliability and durability testing is very important for the acceptance and successful application of VIP. The (expected) long service lifetime and typical loads in building applications have to be taken into account:

- Temperature and humidity variation (most applications)
- Mechanical impact
- Chemical impact (e.g. in contact with concrete, outdoor air)

Suitable procedures have to be discussed and tested.

Acoustic properties

As for conventional thermal insulation boards, the dynamic stiffness (EN 29052-1) will be needed for floating floor applications. In special cases, the sound absorption coefficient (EN 20354) may be of interest.

Properties of VIP construction elements

For assembled construction elements with built-in VIP basically the same standards and tools apply as for conventional elements. They are not listed here in detail. The main focus will be on the measurement and calculation of the U-value of assembled construction elements. Attention should be drawn on thermal bridge and joining details which are more critical in elements containing VIP. In addition to hot box measurements, IR imaging is a suitable method for the detection of thermal weak points (Fig. 8). Accordingly, specific moisture transport and/or condensation questions should be investigated carefully. For many applications, the sound insulation behaviour of a wall or ceiling construction will be needed too.

It is of course not possible to detect and to solve all application related problems "in advance". Some more years of experience will be needed to identify promising application and major problem areas. In particular a detailed knowledge transfer to the building industry and to the public will be necessary if VIPs should become generally available for construction companies or even in the hobby market in future.

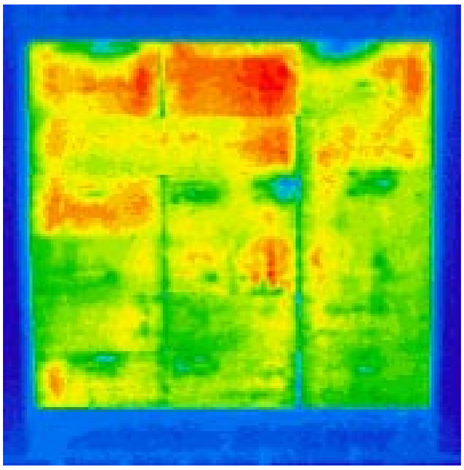


Fig. 8: Calibrated hot box and IR image of a wall element (EMPA).

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[2] General test methods for factory made thermal insulation products: EN 822 – EN 826, EN 1602 – EN 1609, EN 12085 – EN 12091, EN 12429 – EN 12431.

[3] Thermal insulation product standards: prEN 13162 - prEN 13171.

[4] Instituts: e.g. ZAE Bayern, D-97074 Wuerzburg (Gemany); NPL, UK-Teddington Middx., TW11 0LW (Great Britain).

[5] Instituts: e.g. ZAE Bayern, D-97074 Wuerzburg (Gemany); EMPA, CH-9014 St. Gallen (Switzerland).

[6] prEN 12667: Thermal insulation - Determination of thermal resistance by means of guarded hotplate and heat flow meter methods – Products of high and medium thermal resistance.

VIP's for advanced retrofit solutions for buildings

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Summary

During the last few years, building owners and architects have been demanding more efficient insulation materials. The reasons are the rising requirements for the thermal insulation of buildings, and the resulting increase in the thickness of the materials. The necessity for efficient, as well as room-saving insulation materials is felt especially in renovation projects with limited available space. With renovations in particular, the space is often either too expensive or simply not available to meet the current thermal insulation standards. Thanks to the vacuum insulation panels (VIP), an insulation product is now available with which the desired thermal insulation can be achieved with thin panels.

The first promising experiences are being made with VIP in various applications, mainly in renovation projects. The results have convinced us that, over time, such high-performance insulation materials will prevail in building construction.

Range of application for vacuum insulation panels in buildings

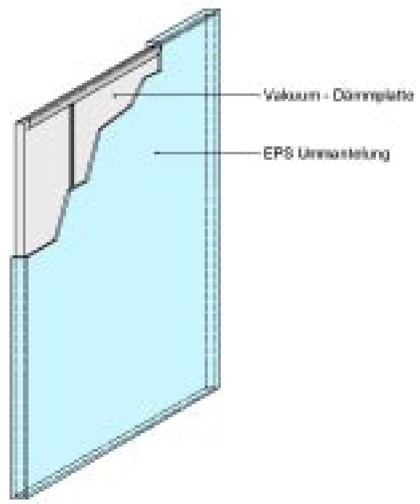
It is necessary to differentiate between applications on construction sites and in workshops. In workshop conditions, the panels can usually be fitted unprotected into prefabricated elements such as walls, doors, roller blind boxes, and window framing. For many applications on site, it is imperative to equip the panels with a mechanical protection.

Application on the building site

Rough construction site conditions, exterior applications

Ideally, under well controlled conditions, unprotected vacuum panels can be applied on site with an acceptable injury risk. For applications in typical site conditions, such as external thermal insulation, pitched or flat roofs, the risk of damage is great. For these applications, it is strongly advised to equip the panels with an adequate mechanical protection.

A cover of the vacuum insulation panels made of EPS, XPS or mineral wool has proven suitable. These insulation elements, developed by ZZ Wancor, can have dimensions of 600 x 1000 mm with



a thickness of 40 mm, for example, and can be applied like conventional insulation panels. Besides the full-size panels, half- and quarter-size panels are available as well as custom-sized ones. Obviously, the panels cannot be cut to size, therefore the borders and joints must be adjusted with conventional insulation material.

Such insulation elements have been installed as internal thermal insulation, in flat roofs and roof terraces, as well as for the framing of windows and exterior doors.

Fig. 1: Mechanical protection through coverage with EPS, XPS or mineral wool

The following advantages of covered insulation panels thus became apparent:

- The panels can be handled as usual, except that they should never be perforated or cut.
- The accuracy of the dimensions is much higher than that of uncovered panels.
- The problem with the panel junctions has been solved by pushing them close together and several mm can even be removed to adjust the panels.
- With a cover of approx. 10 mm and a minimum of precaution during transportation and handling, the panels are sufficiently protected for most applications.

Dry building site, interior application

If the necessary precautions are taken, the interior building environment can be sufficiently controlled for the use of unprotected vacuum insulation panels. In such a typical dry site environment, the workmen are used to deal with delicate construction materials and elements.

To date, the unprotected vacuum insulation panels have been used for the internal thermal insulation of walls and floors.

Fitting into prefabricated building elements under defined workshop conditions

In the well-controlled conditions of a workshop or a factory, the unprotected vacuum insulation panels can be fitted into prefabricated building elements without problems. Border losses are minimized by the high accuracy of the prefabrication, allowing a perfect fit without gaps. Furthermore, the cost of customized panels can be reduced if they are produced in sufficiently large numbers.

To date, ZZ Wancor has fitted unprotected vacuum insulation panels into roller blind boxes, exterior doors and special wall elements used in wood construction.

Experiences made in demonstration projects

Flat roof insulation

In renovations of flat roofs in particular, there is often a limited space available for insulation material, or considerable adjustments have to be made at the joints and seals. Thanks to the vacuum insulation panels, it is now possible to improve the thermal insulation without altering the original thickness of the roof construction.

Thermal insulation of a terrace in Leimbach/TG

The rooftop terrace of a house in Leimbach/TG is a typical application example. The roof covering had become impermeable over time and needed to be replaced along with the soaked cork insulation. Due to the construction, it was impossible to increase the original insulation thickness of 4 cm without having to replace the windows and doors along the entire width of the terrace.

The vacuum insulation panels covered with extruded polystyrene from ZZ Wancor were used. Full- half- and quarter-sized panels were installed like conventional insulation panels. Edges and joints were fitted with panels of extruded polystyrene, covering approximately 10 % of the roof surface. Using a panel only 40 mm thick, a mean U-value of 0.29 W/m²K was achieved over the entire roof, corresponding to a polyurethan panel with a thickness of 90 mm!

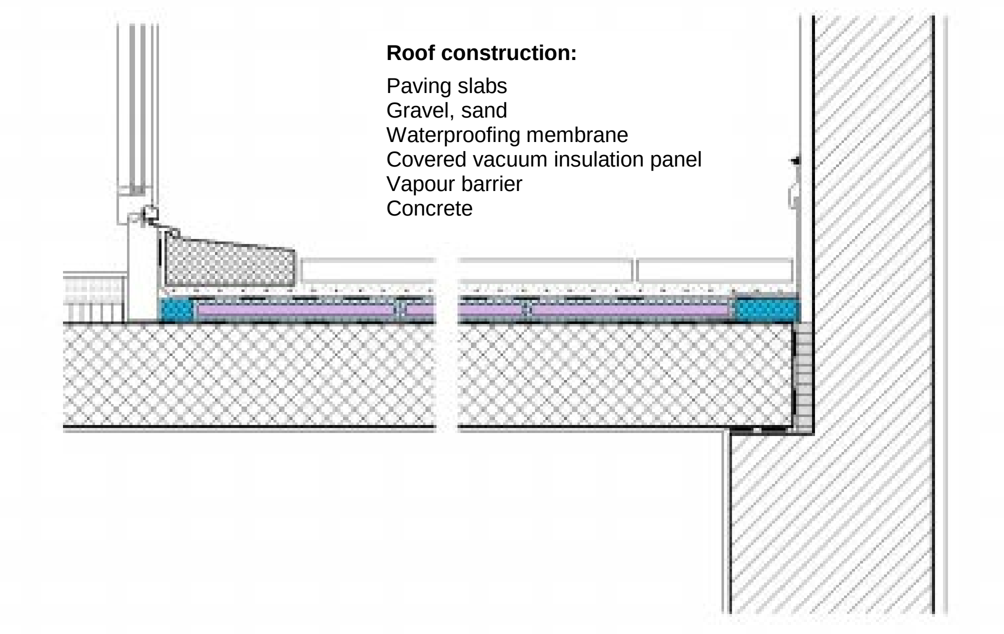


Fig. 2: Cross-section of the terrace construction. The edges were made with extruded polystyrene.

Passive houses in Wolfurt, Vorarlberg

The problems encountered in this project were slightly different. The standard for passive houses requires U-values between 0.10 and 0.15 W/m²K which requires insulation thickness of up to 40 cm (!). With such requirements, it is practically impossible to insulate roof terraces efficiently.

Instead of using 40 cm thick panels of polystyrene, the thermal insulation of the terraces (measuring approximately 30 m²) was carried out with 5 cm thick vacuum insulation panels, achieving the same insulation factor! The edge effect was insignificant since the panels were custom-made and measured 242 x 80 cm, a surface of almost 2 m².

This application revealed how difficult it is to work with unprotected panels on site. Lack of precaution during transportation to the site and during assembly resulted in several damaged panels that needed to be replaced.

Abb. 3a: Passive house in Wolfurt, Vorarlberg (Architect Gerhard Zweier, Wolfurt)

Abb. 3b: Completion of the terrace using 5 cm thick vacuum insulation panels

Insulation of pitched roofs

The insulation on top of pitched roofs' rafters is one more interesting application of covered vacuum insulation panels. Due to design imperatives (visible rafters, increased room height) or because the attic is inhabited, it is often impossible to fit insulation panels between or under the rafters. Moreover, it makes sense to improve the thermal insulation of a roof whenever its tiles need to be replaced. The sole disadvantage of this otherwise superior rafter insulation is the resulting increase in ridge height. Limitations due to construction laws as well as the heightening of the roof requiring adjustments on the eaves and borders of the roof, as well as on the roof windows, can result in increased costs and impair the architecture.

The vacuum insulation panels offer a solution for simple roofs that only need a slight elevation, or none at all. The following example illustrates a renovation proposal for a one-family house near Zürich. Due to the proximity of the airport, vacuum insulation panels covered with mineral wool were selected for noise control.

The insulation panels from ZZ Wancor are fixed seamlessly on top of the vapor-barrier covered timber boards, using a special vapor permeable underlay which is fixed by means of counterbattens. The principle of this construction corresponds to a conventional warm pitched roof construction. The specific weight and the 3 cm width of the mineral wool along the length of the insulation panels has been calculated so that the counterbattens can be fixed through the seams without risks.

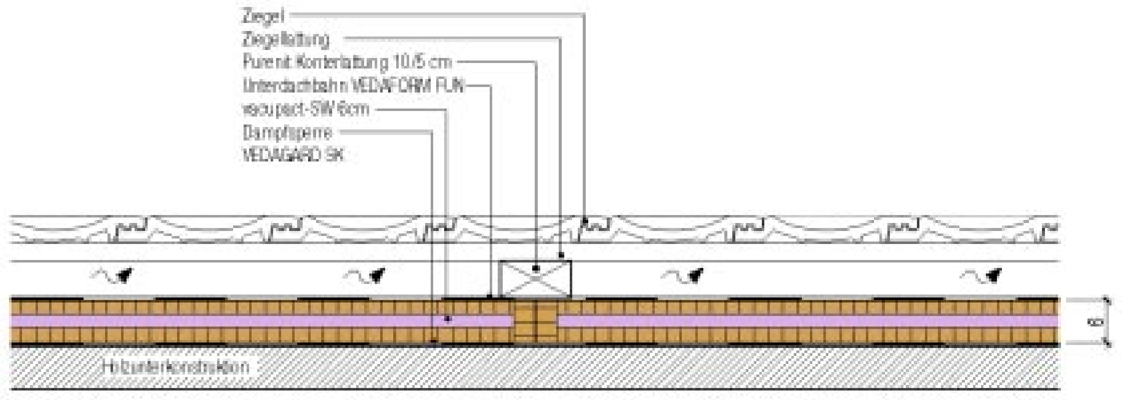
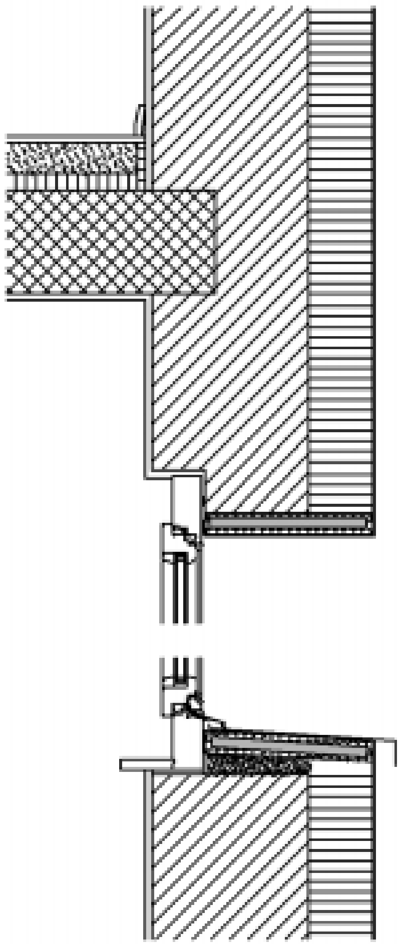


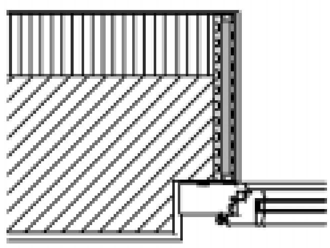
Fig. 4: Construction of mineral-wool covered vacuum insulation panels on a pitched-roof insulation.

Window framing

In older buildings, the windows are often too small measured to today's standards. If the window framing is going to be sufficiently insulated during a thermal renovation, the available daylight will be unbearably reduced. Enlarging wall openings is usually too costly and often impossible due to the technical characteristics of the building. The insertion of VIP around the windows can considerably improve the situation without decreasing the inner lighting.



Cross section



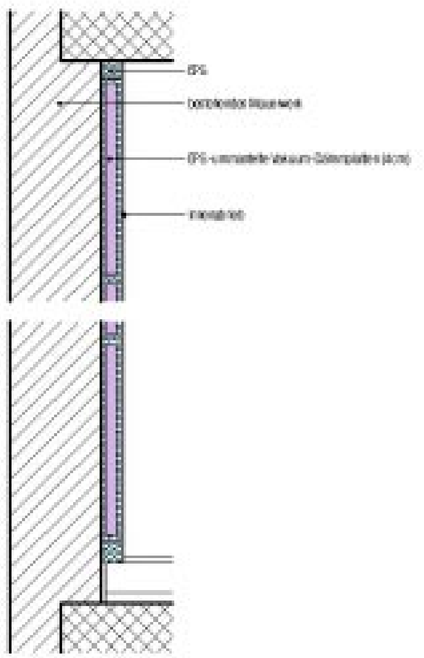
Ground plan

Fig. 5: Cross section and ground plan of a feasible façade renovation. Installing VIP panels around the windows provides an ideal solution to the thermal joints problem without considerable deterioration of the interior daylight situation.

Internal thermal insulation

For renovations, internal thermal insulation is always considered where external insulation is not feasible due to special marginal conditions (with listed buildings for example), or when the expense would be prohibitive, for instance when the façade is still intact.

However, lack of space or connection problems often limit the possible thickness of the internal insulation. In this case as well, vacuum insulation permits an optimal thermal insulation with minimal space loss.



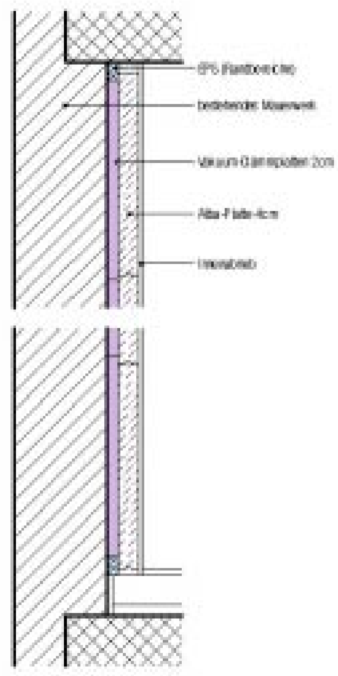
Two variants have been tested in a one-family house from the 30's in Zürich:

Implementation using EPS-lined vacuum insulation panels

In this variant, the covered ZZ Wancor insulation panels were glued onto the 30 cm thick brick wall and covered with plaster, as with conventional EPS-panels. The edges and socket-joints were completed with conventional EPS material.

The owners have to receive appropriate directions concerning this type of wall insulation to ensure that no nails etc. are thoughtlessly driven into them.

Fig. 6a: Sectional drawing of an internal thermal insulation using 4 cm thick EPS-covered VIP panels. This way, a mean U-value of 0.26 W/m²K can still be achieved over the entire wall, with a total thickness (including 5 mm plaster) of only 45 mm.



Implementation with glued panels and a free-standing wall consisting of 4 cm thick gypsum boards

In this variant, the vacuum panels were glued directly onto the wall using a polyurethane glue. The joints were then covered with an aluminum-laminated adhesive tape. Since unprotected insulation panels were used, appropriate care had to be taken with handling on the site. Compared to the first variant, we achieve a better U-value with this construction free of thermal bridges, and we also have the decisive advantage of obtaining a wall that can be used without restrictions.

Fig. 6b: Section through an internal insulation using 2 cm vacuum panels and a 4 cm gypsum wall. A mean U-value of 0.24 W/m²K is achieved with a total thickness of approx. 6.5 cm, including the 4 cm of the gypsum wall.

Floor insulation

A project for the Blood Donor Center Bern AG consisted in a major alteration of a building, including the installation of a deep-freeze room of 50 m² needed to preserve the blood. The only space at our disposal for the floor insulation was the approx. 10 cm of the removed screed. However, the energy laws of Bern require an insulation corresponding to at least 25 cm of polyurethane.

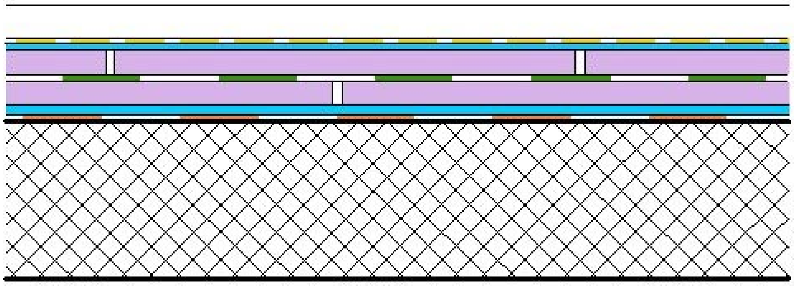


Fig. 7: Section through the floor of the deep-freeze room. The 2 layers of vacuum panels of 25 mm each, correspond to the insulation achieved with an approx. 25 cm thick polyurethane insulation..

Structure of the floor

- Plaster
- Polyethylene-foil
- Protection mat of 6 mm
- 2nd layer of vacuum insulation panels of 25 mm
- 1st layer of vacuum insulation panels of 25 mm
- Protection mat of 6 mm
- Vapor barrier
- Concrete

The problem with the lack of available space was again solved by using the highly insulating vacuum insulation panels. Two layers of vacuum panels were used to improve the safety. The customized panels were staggered to avoid potential thermal bridges over the joints as much as possible. Temperature sensors were installed underneath the insulation panels to ensure a permanent control of their function.

Roller-blind boxes

Due to lack of space, the lintels of roller-blind boxes often prove to be problematic for thermal insulation. A thin thermal insulation provides a satisfactory solution, as seen in the roller-blind boxes used in a one-family house in Meilen.

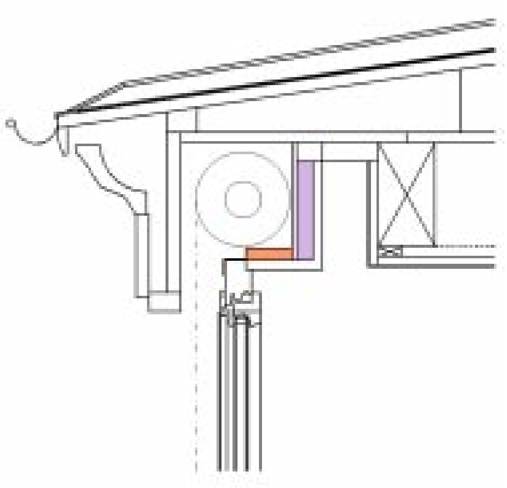


Fig. 8: Installation of vacuum insulation panels in roller blind boxes

Exterior doors

The installation of vacuum insulation panels in exterior doors was carried out as well. This way, the U-value of a door with a standard thickness can be at least halved, thus eliminating one of the last weak points in the thermal insulation of a building.

Existing and future applications for advanced low energy buildings, especially passive houses

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Summary: Advanced low energy houses ... quo vadis?

Unfortunately, extra investment in energy-saving technologies rises in step with declining consumption; this is a fact known by economists as the 'law of diminishing marginal utility'. It is readily illustrated by the costs of increasingly thicker thermal insulation: The last centimetre of, for instance, a 20 cm insulation costs the same as the first centimetre (namely about 0.50 Euros per m²), but only saves a tenth of a litre of heating oil per square metre per year – not much compared to the 10 litres saved by the first centimetre. Consequently, increasing insulation thickness has long been criticized as economically unacceptable. Were the critics right? In very basic terms yes, but the limits are by no means reached as quickly as many have claimed. The tenth centimetre still provides cost-effective heating oil savings, even if oil only costs 11 Eurocents per litre. The fifteenth centimetre still saves oil at investment costs below 22 Eurocents per litre. However, it is clear that the fiftieth centimetre would only become cost-effective at an oil price of about 2 Euros per litre. Such high oil prices will scarcely be reached in the future. The law of diminishing marginal utility applies similarly to improved window glazing and improved heat exchangers for heat recovery (with larger surface).

The better the energy performance of a building, the higher the requisite extra investment – or at least that is how it would seem at first sight! If we remain within the realm of conventional technology, optimum efficiency technology is reached in the range of a low-energy house, at about 70 kWh/(m²a). A typical single-family house with a floor space of around 150 m² then still consumes about 1000 litres of heating oil per year for space heating, costing its occupants about 320 Euros. If the next step to the 3-litre house (30 kWh/(m²a)) is taken, this saves just 180 Euros per year. That is the sum that an economically thinking house-buyer would spend annually on interest and repayment of the debt incurred for the energy-saving investment required to upgrade the building to a 3-litre house, rather than for heating oil. At an interest rate in real terms of 4% per annum, this gives scope for investment of about 3400 Euros; that is how much more the 3-litre house could cost than a normal low-energy house. Using the same calculation, only a further 1700 Euros would be available to upgrade the 3-litre house to a 1-litre house.

However, there is a way out of the trap of diminishing marginal utility: to build both energy-efficiently and at low extra investment cost. The decisive point is this: The scope must be exploited to save *investment costs* through improved efficiency technology. For this, the thermal insulation of the building must be so good that it permits decisive simplification of conventional building service systems, and thus lower investment costs. Precisely this is the passive house approach: ***Passive houses are buildings with such good thermal insulation that heating systems are simplified radically.***

The passive house is the 1-litre house – and is affordable

In the passive house, technology and economics are considered in unison from the very outset. To achieve further improvement above and beyond the low-energy house, it is essential to *recover heat from the extract air*. If no heat recovery system is in place, annual ventilation heat losses amount to about 35 kWh/(m²a) – sufficient fresh air supply is essential for health reasons and to maintain acceptable levels of comfort in the house. These ventilation heat losses can only be reduced by means of heat recovery – and residential ventilation systems with heat recovery are expensive, costing about 5000 Euros in a new-build house. This investment comes on top of the normal cost of building services. Very good heat recovery systems can yield net annual savings of about 50 Euros in operating costs if the electricity consumption for fans and the costs for filters are taken into consideration. This alone cannot justify the high investment costs. *But what if the ventilation system provides space heating at the same time?* The system has to convey fresh supply air to each room in any case; this air can also transport heat. If a building has such good thermal performance that this supply air suffices by itself to ensure comfort, then a further heat distribution system is rendered superfluous. This is the basic principle of the passive house: Excellent thermal insulation plus high-quality ventilation render superfluous the double investment in building services (this is illustrated by the Table).

Standard low-energy house 70 kWh/m²	**Ultra-low-energy house 30 kWh/m²**	**Passive house 10 kWh/m²**
Ventilation without heat recovery	Ventilation with heat recovery	Ventilation with heat recovery
Conventional heating system is requisite	Conventional heating system is still requisite	Supplementary supply air heating suffices
"Simple" building services investment: Heating system ≈10,000 Euros	"Double" building services investment: Heating system ≈10,000 Euros Ventilation ≈ 5,000 Euros	Back again to "simple" building services investment: Ventilation with supplementary heating register suffices by itself ≈10,000 Euros
Precondition: thermal insulation performance compliant with German Building Energy Conservation Ordinance (Energie-Einspar-Verordnung)	Precondition: thermal insulation performance better than German Building Energy Conservation Ordinance Additional cost for this: 1,000 to 3,000 Euros	Precondition: thermal insulation performance far better than German Building Energy Conservation Ordinance, reaching 15 kWh/(m²a) Additional cost for this: ≈6,000 Euros

The heating, ventilation and air-conditioning (HVAC) industry need not fear this development. Total investment in building services remains roughly the same. What the passive house means for building services is, simply, that, at roughly the same level of value added, conventional heating systems are replaced by innovative ventilation systems. In economic terms this at first makes no difference. However, in actual fact the outcome is much better, for throughout building use it yields savings, because the operating costs corresponding to the net energy savings provided by heat recovery are saved. Moreover, there is the important additional benefit of the gain in comfort provided by the ventilation system. This, however, is only possible if the thermal insulation of the building envelope is improved substantially. This again costs money, but not more than the capitalized energy cost savings that the improved insulation yields. The total extra investment required for a passive house compared to a standard low-energy house is made up of the extra cost of the improved thermal envelope (approx. 6,000 Euros incl. windows) plus the cost of the ventilation system, which can be recouped by the simplified building services. In sum, this total extra investment will not be higher than for a 3-litre house, but the energy savings realized are higher – the passive house can therefore be economically superior.

Passive house principles: High-performance innovations – *Thermal insulation*

The thermal insulation of the building envelope of a passive house needs to be improved quite substantially compared to conventional designs. This has two reasons:

- In order to achieve the requisite low heating loads of less than 10 W/m², envelope heat losses need to be minimized ***(heating load requirement)***
- Temperature differences between the indoor surfaces of exterior building elements and the indoor air must be kept small: otherwise radiative temperature asymmetries and undesired indoor air circulation would result, which would impair occupant comfort ***(comfort requirement)***

It has emerged that the second requirement is easier to meet than the first. With normal ceiling heights, draughtlessness and sufficient operative temperatures are achieved in Central European climates if the thermal transmittance (U-value) of the exterior building elements is equal to or less than 0.8 W/(m²K). The indoor surface temperature is then about 17°C (at an exterior design temperature of -10°C, and indoor air temperature of 20°C). The U≤0.8 W/(m²K) requirement is already more than fulfilled today for wall, roof or ceiling constructions in new buildings complying with the 1995 German Thermal Insulation Ordinance (Wärmeschutzverordnung 1995). Under that Ordinance, U-values are already between 0.17 and 0.5 W/(m²K). By contrast, the U_w≤0.8 W/(m²K) requirement can only be achieved for windows by means of high-performance glazing and superinsulated frames.

The demands placed upon the insulation performance of the opaque building elements are thus determined by the first – the heating load – requirement. In what manner the reduction of heat losses is achieved is irrelevant to the function of the passive house. There are various options:

– Reducing exterior surface area by means of compact design:

  This is doubtlessly the most cost-effective approach.

– Improving the utilization of radiation incident on the exterior surface (by means of translucent insulation, semi-translucent insulation, solar facades).

– Enhancing insulation effect by means of ***thicker insulation layers*** or ***reduced thermal conductivity of materials***.

The second of these options can also be calculated by applying an equivalent U-value. If U_{opaque} is the mean U-value of opaque elements of the building envelope and A_{opaque} is the total surface area of these elements, then $A_{opaque} \cdot U_{opaque}$ characterizes the transmission heat loss of all opaque building elements. If we assume, in order to derive simple reference values, that the window U-values of a passive house must be around 0.8 W/(m²K) (they must at all events not be higher; substantially better values are not yet available today), and further consider the functional transmission heat requirement (≤10 W/m²), then, in a first approximation, we find that the equivalent U-values of

opaque passive house envelope elements

must range between 0.1 and 0.15 W/(m²K).

Compared to the values common today, these are exceedingly low U-values. Nonetheless, a broad range of building envelope elements meeting passive house standards is now available on the market [Feist 2001]. The list of products that come into question is growing constantly, e.g.:

- <u>’Classic’ external thermal insulation compound systems ("ethics"):</u>

  A thermal insulation system with 300 mm insulation (thermal conductivity: 0.04 W/mK) with exterior plaster coat, interior masonry and gypsum plaster, gives U≈0.13 W/(m²K) with a total thickness of approx. 500 mm.
- <u>'Classic' light timber construction:</u>

A timber panel element with 280 mm T-beams, rock wool filling (thermal conductivity: 0.035 W/mK), interior and exterior panelling and weather-boarding gives U = 0.12 W/(m²K) with a total thickness of 390 mm.

- Vacuum insulation:
  A vacuum powder panel with a thermal conductivity (λ) of 0.006 W/(mK) and 40 mm thickness already achieves on its own a U-value of less than 0.15 W/(m²K). Together with a thin (e.g. metal) load-bearing structure, a U-value in the region of 0.11 W/(m²K) can be achieved with a total building element thickness of less than 200 mm. This will make extremely thin exterior passive house elements possible in the future. High-vacuum thermal insulation elements with mineral fibre spacers and stainless steel panelling have even lower thermal conductivity and are already available on the market.
- Translucent plaster:
  In these systems, a roughly 150 mm thick semi-transparent insulation layer is protected on the outside with a translucent plaster. Absorption of short-wave global radiation is thus shifted inwards, into the outer region of the insulation layer. The inner, 'dark' region of the insulation layer is requisite above all for summertime thermal insulation. Depending upon the load-bearing structure used, this system has a total thickness of 28 to 35 cm, and an equivalent U-value well below 0.1 W/(m²K).

Two quality parameters are decisive for the efficacy of thermal insulation, and particularly so in passive houses:

– the elimination of thermal bridging, and
– air-tightness.

Both have been discussed at length elsewhere [AkkP 16; Peper 1999]. Built passive houses provide an excellent reference basis, showing that thermal-bridge-free design and extremely low air leakage values below 0.6 h^{-1} are achievable today, with all constructions and all architectural designs.

A note on costs: As shown in [Feist 1997], at current energy prices (0.03 Euro/kWh), the insulation performance of exterior building elements with optimum total cost is between 0.2 and 0.35 W/(m²K) if only the operating cost savings are apportioned to paying back the insulation. Passive house insulations, with $U \leq 0.15$ W/(m²K), are definitely 'thicker' than this micro-economic optimum. For a conventional structure, the insulation material thickness corresponding to $U_{optimal}$=0.2 W/(m²K) is about 180 mm – which is a good low-energy house standard. Conventional passive house insulations are, at 300 mm thickness, more expensive than an optimum-cost insulation by about 5 to 7.5 Euros per m² building element surface in terms of investment cost. The net present value of the additional energy cost savings figures 2.5 Euros per m², meaning that extra costs of 2.5 to 5 Euros per m² remain. The extra investment for the passive house insulation standard amounts to about 2,500 Euros for a single-family house if a careful eye is kept on costs. There is a good prospect of recouping this through lower maintenance costs.

Passive house windows: High comfort included

In the passive house, windows have a key function. The passive house standard can only be attained with window qualities far beyond the conventional. It has been set out above for opaque building elements that in order to provide sufficient occupant comfort without indoor radiators below the element, it is necessary in Central Europe to achieve U-values equal to or lower than 0.8 W/(m²K) (at design temperatures around -10°C). While this requirement can be met for opaque elements without particular difficulty, windows with such a low heat loss are better by about a factor of 2 than the windows with low-emissivity double glazing and wood or plastic frames commonly used today (2001). To achieve the indispensable quality improvement by a factor of 2, it neither suffices to only improve the glazing (triple low-emissivity glazing has U-values between 0.6 and 0.8 W/(m²K)), nor to only use better insulated frames (with U-values between 0.5 and 0.9 W/(m²K)). It is rather essential to combine both, while at the same time reducing substantially the thermal bridging of the spacer at the edge of the glazing. Only the combination of:

- low-emissivity triple glazing +
- insulated frames +
- reduced glazing spacer losses

provides a window suitable for passive houses [AkkP 14].

The greatly improved windows for passive houses currently still have their price; the client must expect extra costs per square metre window area of about 100 Euros. For a typical single-family house, the extra investment for windows complying to passive house standards thus amounts to 3,000 to 3,500 Euros.

Passive house experience in built projects

By the end of 2000, some 800 housing units in passive houses were occupied in Germany.

The technological fundamentals for the passive house are the same as for the low-energy house: good insulation, better windows, comfortable ventilation. Quality improvements in these three spheres have proven themselves and the confidence of users that further improvements will have similarly positive effects has risen.

It was striking in the architectural design competitions held in the course of the past year that issues relating to 'workmanship', such as a well-insulated envelope, thermal-bridge-free design, and airtight design became ever more matter-of-course elements of the designs submitted. Passive house architecture is gradually finding ways to bring the inherent benefits of the concept to the fore. The reduced effort required for building service systems and the inherently good ventilation increase the degree of freedom for the architects.

The responses of occupants are exceedingly positive: "We never froze", "If we were to build a house again, it would certainly be a passive house", "We practically never heated" are typical comments.

Painstaking energy consumption measurements were carried out in a whole series of buildings. The measurements undertaken in the passive house estates are particularly illuminating. The first passive house estate, with 22 terraced houses, was completed in the Dotzheim district of Wiesbaden, Germany, in August 1997 by the developer Rasch & Partner, and has been occupied since then. Here two institutes – Institut Wohnen und Umwelt and the Passive House Institute – carried out detailed measurements. In the 1998/99 measurement year, a measured specific heat consumption (district heat) averaging 13.4 kWh/(m²a) (average across all 22 houses) was found. By chance, this corresponds fairly exactly to the value calculated using our 'Passive House Planning Package' for this estate, namely 13.5 kWh/(m²a). The measurement results in Wiesbaden have now established for a statistically sufficiently large population of users in terraced houses that the passive house standard does indeed deliver in practice the energy savings previously calculated. The data documented here show there has been no significant ventilation by opening windows in the cold season in the 22 passive houses – if there had been, then consumption levels would have been much higher than measured.

Measurement results are now also available for the passive house estate in the Kronsberg district of Hannover, Germany (Fig. 1). In these houses, too, the target was already achieved in the first year, with a measured specific heat consumption of less than 15 kWh/(m²a). The Hannover-Kronsberg passive house estate is one of the German sub-projects within the context of the CEPHEUS (Cost Efficient Passive Houses as European Standards) programme supported by the European Union.

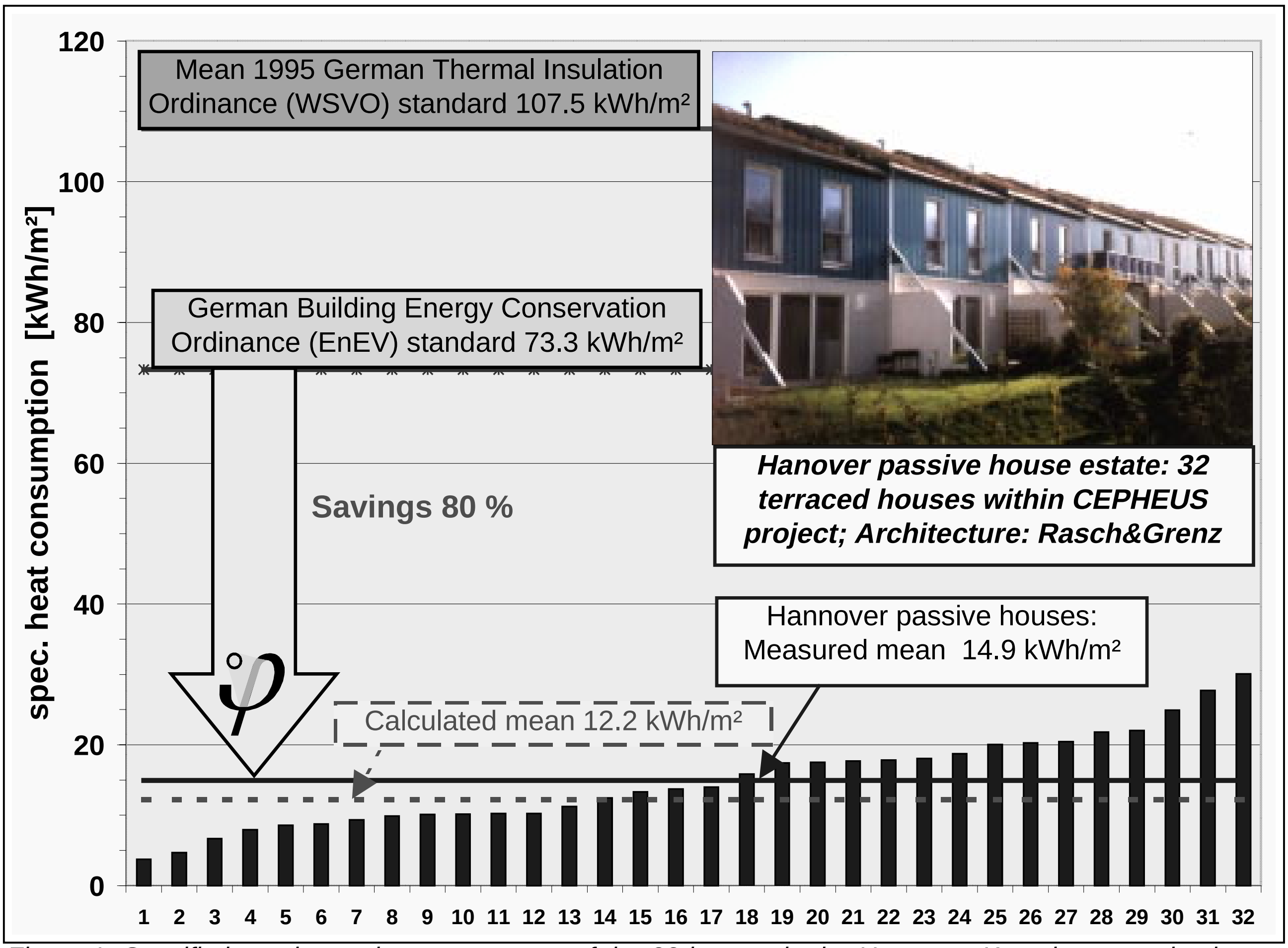

Figure 1: Specific heat demand measurements of the 32 houses in the Hannover-Kronsberg passive house estate (developer: Rasch&Partner): Consumption is lower than in conventional buildings by a factor of 10.

We are awaiting with great interest the results of measurements at the two government-assisted multi-family passive houses in the city of Kassel, Germany (Fig. 2). Here GWG Kassel (Gemeinnützige Wohnungsbau Gesellschaft, a non-profit housing association) has built two large apartment buildings with a total of 40 units to passive house standards. Renowned architects have teamed together to plan these masonry structures, which are also a part of the CEPHEUS project. Here, for the first time, a high-efficiency ventilation system has been used in a multi-storey apartment building in which central heat exchangers are installed on the roofs, but fans are decentralized in the units [Otte 1999].

Figure 2: A CEPHEUS project in Kassel, Germany: Two multi-storey apartment buildings totalling 40 units were built here by GWG Kassel on the site of a former military barracks. Three teams of architects (Prof. Schneider; HHS; ASP) designed the buildings. Vacuum insulation panels are used in some casement doors as opaque filler panels.

Measurement results from two operating years are now also available for the first administrative building built to passive house standards, by the Wagner&Co. company in Cölbe near Marburg, Germany. Measurements are being supported by the Germany Ministry of Economics (within the context of the SolarBau programme, coordinated by BEO/Jülich) and carried out by the University of Marburg. The heat extracted from a microcogeneration system with 12 kW thermal output suffices to heat the 2180 m² floor space of the building. As is characteristic of a passive house, heat is supplied exclusively via the supply air of the high-comfort ventilation system. Summertime comfort in the offices is also convincing: Despite very hot periods, temperatures in the house have been found to generally remain below 26°C. The passive-house office building has no air-conditioning system; the comfortable indoor climate is achieved by means of night-time ventilation (automatically opening skylights), temporary shading and supply air cooling in a subsoil heat exchanger [Wagner 1999].

The number of projects that have now been realized or are under construction has become so large that not all can be described in detail here. Up-to-date project presentations are available at the Passive House Institute's website (www.passivehouse.com).

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VIP's for buildings - Research and Development

IEA / ECBCS Annex 39

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Summary

In the area of building insulation the need for better materials and systems has grown. There are already some products available, e.g. Vacuum Insulation Panels (VIP), which are suitable as a basis for the development of building components with much lower U-Values than what is used today.

The R&D programme 'High Performance Thermal Insulation Systems in Buildings' will answer questions in the area of basic materials, especially VIP, and will support companies to develop HiPTI systems for the building envelope and HVAC components. This support consists in bringing together all relevant expertise from research, development and planning.

The project will be carried out under the IEA Implementing Agreement 'Energy in Buildings and Community Systems' as Annex 39. Its activities are subdivided in three Subtasks: A) Basic concepts and materials, B) Application and systems development and C) Demonstration / Information dissemination.

Insulation and buildings

- Legal insulation standards for new buildings are getting stricter
- Low Energy Building Concepts, with even lower U-Values, are getting more and more popular
- Space in retrofit applications or in HVAC-installations is limited

⇨ To fulfil the new requirements, conventional insulation materials often need too much space, which is
- expensive (new buildings) and/or
- not available (retrofit and HVAC-installations)

In terms of thermal conductivity, windows, particularly glazings, experienced substantial improvements during the last years.

Now it's time to start a similar efficiency development for other building components. Which is exactly the objective of the R&D-programme described below. Its title is:

'High Performance Thermal Insulation Systems in buildings': HiPTI.

Definitions

In the programme we want to work not just on insulation materials, but insulated components for buildings, which we call systems (façade element, door, window frame, etc.). The HiPTI systems we want to develop, should have an overall thermal conductivity of ≤ 15 mW/(mK) in the insulation layer. This means that thermal bridges, which in HiPTI's will get more important, have to be considered carefully. Furthermore, the value mentioned above has to be understood as an average during the life-span of a system.

This definition ensures, that the HiPTI systems as a hole will perform, in terms of heat conductivity, at least twice as good as the best products available today and therefore are definitely interesting for planners (architects, engineers).

Moreover, we want to focus on systems, in which today conventional (opaque) insulations (fibres and foams) are used. Optical properties as translucency or transparency, e.g. 'window technology', are not subject of the programme.

As a consequence of this definition, Vacuum Insulation Panels (VIP) will play a major part in the programme, since no other insulation reaches the required thermal conductivity limit.

General objectives of the R&D-programme

The today situation fulfils the basic requirements to develop and commercialise HiPTI systems. But there are two main areas, where work has to be done, to get the process started as shown in Figure 1.

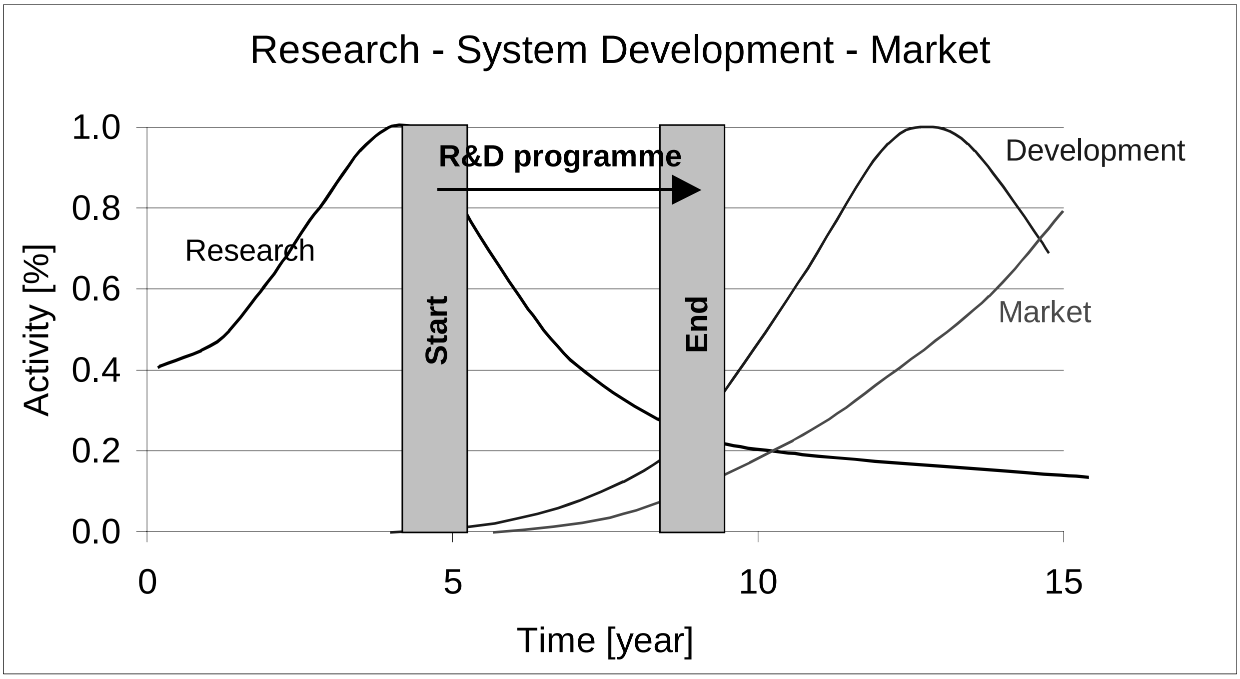


Figure 1: Since several years, a lot of research on VIP has been done. In the HiPTI-programme some remaining but important questions have to be answered. Furthermore the development of HiPTI systems will be initialised and the market stimulated.

1. There are still some technical questions concerning the quality of VIP. These questions need to be answered, to convince the customers of this technology. Customers are the companies, which develop HiPTI systems, planners, which use these systems and building owners.
2. SME's have to be informed about the new technology and supported in their activities to develop HiPTI systems.

At the end of the programme, in all participating countries:

- Some companies developed HiPTI systems, which are available on the market.
- The advantages of HiPTI systems are proven by demonstration projects.
- The market starts growing.
- Not yet involved companies begin their own developments of HiPTI systems.

Interesting Applications

Today and probably in the near future, HiPTI is specifically more expensive than conventional insulation materials, that means you pay more for the same U-Value. In the case of VIP compared to fibre board, the difference is about 200 to 300%. As long as this disadvantage continues, we should use VIP for applications, where the advantage of saved space is worth the higher insulation price. This means, where space is

- expensive and/or
- not available.

In buildings this situation can be found when you want to

- improve U-Values (retrofit)
- reach very low U-Values (low energy houses)

Building envelope	**HVAC components**
timber-frame construction (low energy houses)	storage tank (hot/cold)
metal façade (cassette)	cooling and freezing appliance
façade: inside/outside	tube
panel heating/cooling (floor, wall, ceiling)	duct
flat roof, terrace	
ceiling (basement)	
cold-storage cell and house	
sandwich element	
door	
frame enlargement	
window frame	
blind window	
sliding shutter case	
window shutter	
radiator niche	

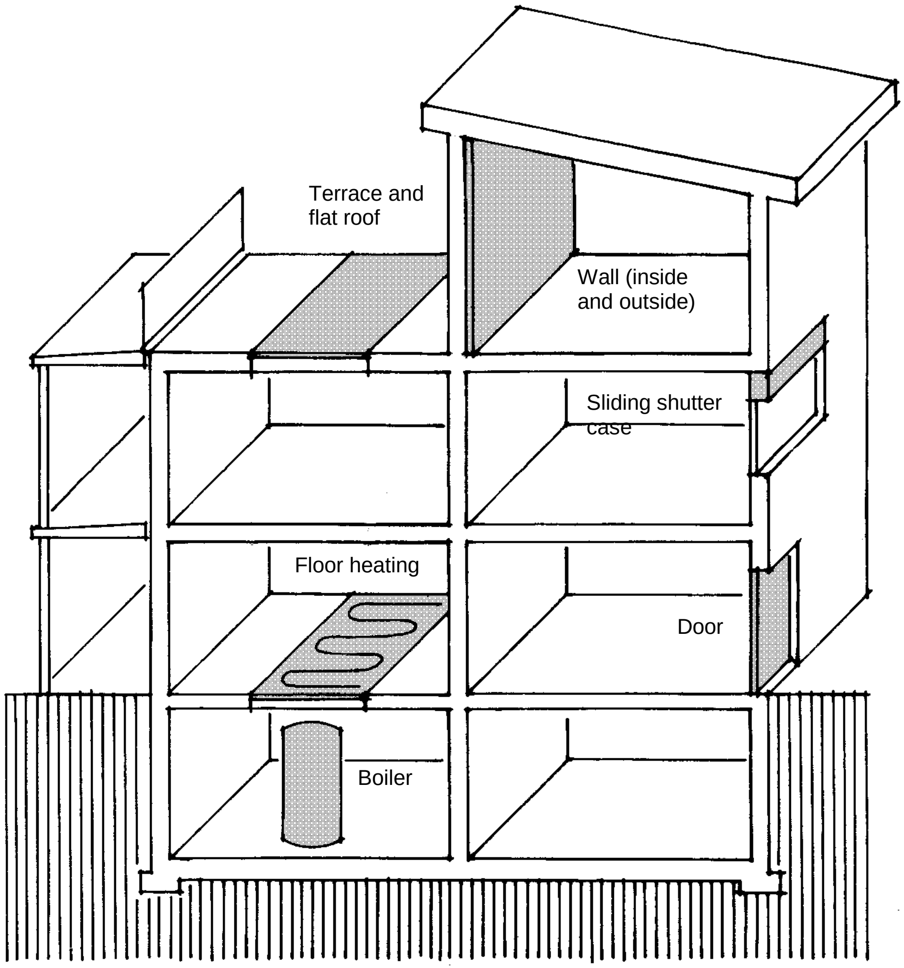


Figure 2: Some interesting applications for HiPTI systems.

Leading Idea

Involving all participants of the market to ensure, that the needs and possibilities of these parties are taken into consideration:

- producers of high performance insulation (VIP)
- companies, which want to develop HiPTI systems
- planners, who use systems (innovative and well-known architects, engineers)
- important building owners (government)

All these partners should work together from the beginning of the Annex activities. Planners and building owners will also act as opinion leaders.

IEA and ECBCS

The project will be carried out under an Implementing Agreement of the International Energy Agency.

International Energy Agency

- autonomous agency linked with the Organisation for Economic Co-operation and Development (OECD)
- 25 Member countries
- based in Paris
- objectives
  - joint measures to meet oil supply emergencies
  - share energy information
  - co-ordinate their energy policies
  - co-operate in the development of rational energy programmes

Implementing Agreement

IEA has a technology and R&D collaboration programme which facilitates co-operation among IEA Member and non-Member countries to develop new and improved energy technologies and introduce them into the market.

Activities are set up under Implementing Agreements which provide the legal mechanism for establishing the commitments of the Contracting Parties (countries) and the management structure to guide the activity.

There are 40 current Implementing Agreements in five groups:

- Information Centres and Modelling
  - Energy and Environmental Information Centres (EETIC)
  - Energy Technology Data Exchange (ETDE)
  - …
- Fossil Fuels
  - Greenhouse Gas R&D Programme
  - Clean Coal Sciences
  - …
- Renewable Energy
  - Bioenergy
  - Hydropower
  - …
- Energy End-Use
  - Advanced Fuel Cells
  - Heat Pumping Technologies
  - Energy in Buildings and Community Systems (ECBCS)

The HiPTI-Project is taking place under the ECBCS Implementing Agreement as Annex 39 (39^{th} project under this Implementing Agreement).

Chairman: Mr Richard Karney (USA)

Vice Chairman: Dr Jorn Brunsell (Norway)

Contracting Parties are 21 countries and the CEC:
Australia; Belgium; Canada; CEC; Denmark; Finland; France; Germany; Greece; Israel; Italy; Japan; Netherlands; New Zealand; Norway; Poland; Portugal; Sweden; Switzerland; Turkey; UK, USA.

Standards in a IEA R&D programme

- The Executive Committee usually designates an Operating Agent for each task who is responsible for management of the collaboration and who provides infrastructure as needed.
- Contracting Parties bear their own expenses and have exclusive rights to the results.
- Annexes usually specify arrangements for handling and protection of information and intellectual property, and provide arrangements for commercial exploitation and distribution of benefits.

Organization of the programme

The work in the programme will be done in three subtasks:

A Basic concepts and materials

Improve existing HiPTI insulation panels to reliable products for building applications.

Necessary properties

- heat conductivity < 15 mW/(mK) as an average over lifetime
- longevity (depending on application: 15 to >50 years)
- easy handling of insulation (for integration in HiPTI system)

B Application and systems development

Develop HiPTI systems based on high performance insulation together with partners from industry and the planning sector.

- building envelope
- HVAC components

C Demonstration / Information dissemination

Realize demonstration projects together with well-known architects and important building owners.

- prove advantages / know still existing problems
- convince opinion leaders
- stimulate the market
- motivate new developments

Proposed management structure of Annex 39

Operating Agent

Responsible for the management of the Annex:

- definition of the general objectives together with the Subtask Leaders
- organizes workshops, seminars and conferences
- provides semi-annually reports to the Executive Committee
- provide to the Executive Committee a final report

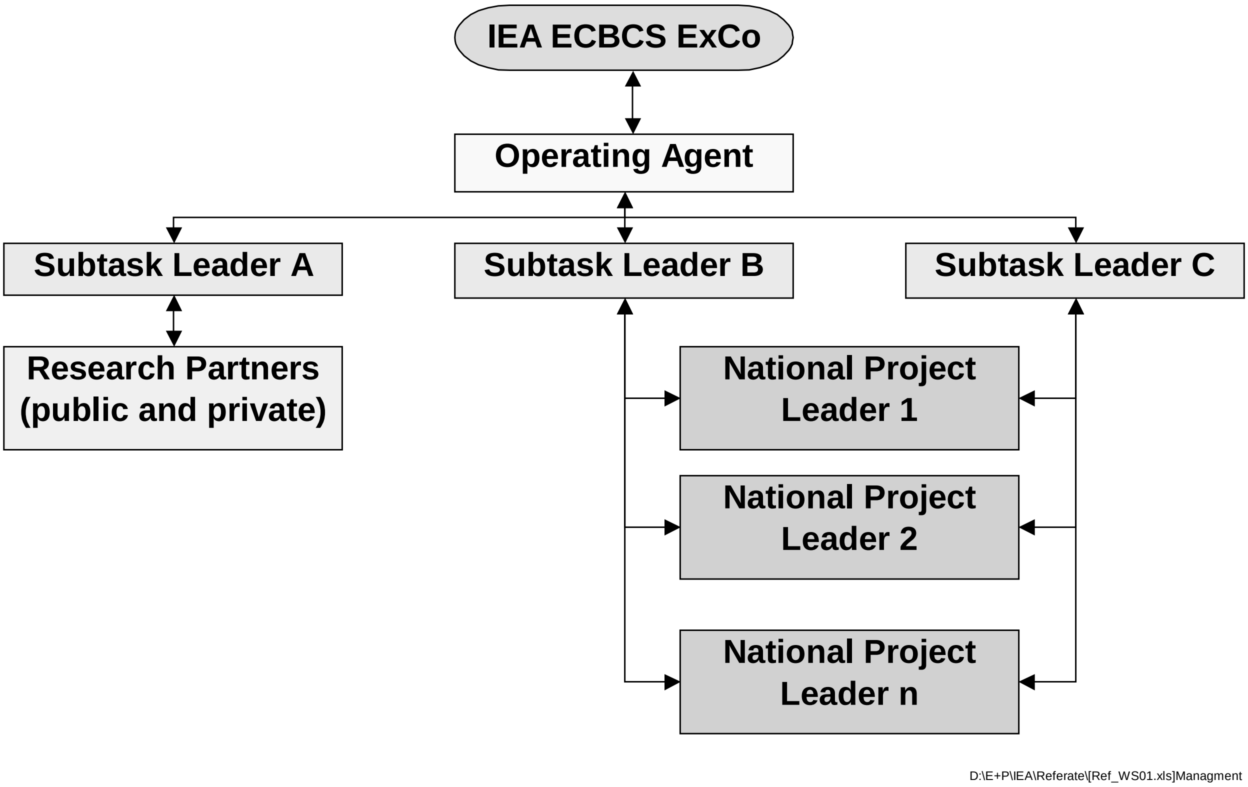


Figure 3: The overall management structure in Annex 39.

Subtask Leaders

Responsible for the management of a Subtask:

- definition of the subtask in accordance with the Annex objectives
- organizes and manages the work (work plan and time schedule)
- avoids duplication of activities within the Annex but also with other projects
- organizes meetings for the Subtask partners
- reports at least semi-annually to the Operating Agent
- provide summary on the work carried out in the Subtask

National Project Leaders

Responsible for the management of the national activities:

- definition of the national activities in accordance with the Subtask Leaders
- funding of the national activities
- in Subtask B and C:
  - management of the national activities
  - reports at least semi-annually to the Subtask Leaders

Results

- HiPTI products available on the market
- guide for companies (potential producers of HiPTI systems)
- web-site with all relevant information and contacts
- (industry association for HiPTI in buildings formed)

Work plan

Start: January 2001
End: December 2004

Preparation Phase
(January2001 - August 2001)

- Workshop
  - discuss / determine Annex objectives
  - discuss / determine methods and time schedule
  - assign work packages (provisional)
  - assign management functions (Subtask Leaders and National Project Leaders)
- Form up project team
- Review: 'What do we (need to) know?'
- Definition and funding of national projects

Subtask A - Basic concepts and materials
(January 2000- February 2004)

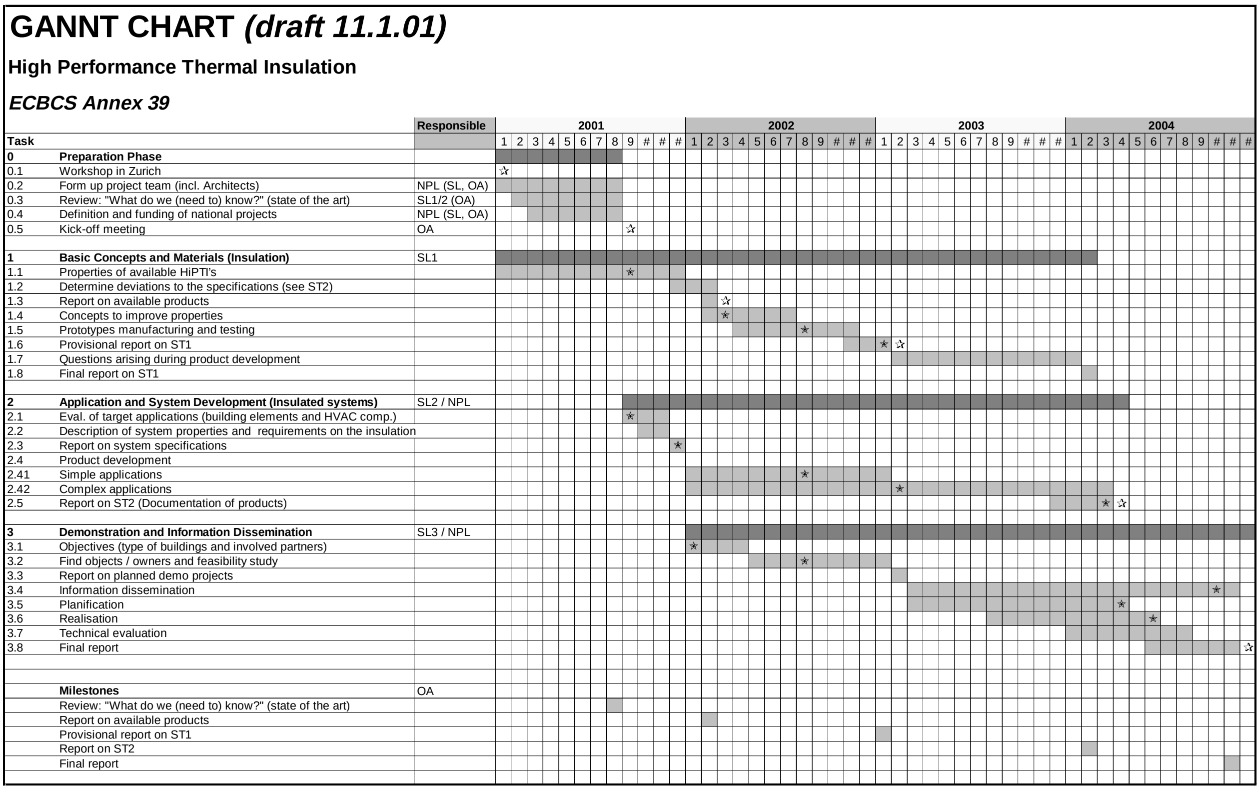
- Properties of available HiPTI (VIP)
- Concepts to improve properties
- Prototypes manufacturing and testing
- Support the development activities in Subtask B

Subtask B - Applications and systems development
(September 2000 - April 2004)

- Evaluation of target applications
- Description of system properties and requirements on the insulation
- Product development

Subtask C - Demonstration and information dissemination
(January 2001 - December 2004)

- Objectives (type of buildings and involved partners)
- Find objects / owners and feasibility study
- Realisation
- Technical evaluation
- Information dissemination



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Glossar
OA: Operating Agent
SL: Subtask Leader
NPL: National Project Leader
ST: Subtask
☆: Annex meeting (all partners)
★: Workshop (partners of the subtask and possibly OA)

Workshop on High Performance Thermal Insulation Systems in Buildings - (HiPTI) Vacuum Insulated Products (VIP)

Programme

Tuesday, January 23, 2001, EMPA

8.30	Opening of workshop secretariat	
9.00	**Welcome and workshop introduction** Proposed goal, project structure, organisation and time schedule	Markus Erb (E+P)
9.20	Subtask A **Basic concepts and materials** Issues to be investigated and possible research approaches	Dr. J. Caps (ZAE)
9.40	Subtask B **Application and system development** Preferred application area for VIPs, economic and applicable solutions	Markus Erb (E+P)
10.00	Subtask C **Demonstration** HiPTI installations in participating countries **Documentation, information and dissemination** Strategies to address opinion leaders, clients and manufacturers	Prof. A. Binz (FHBB)
11.00	Working groups **Discussion of subtasks A , B**	Working groups
14.00	Working groups **Continuation of Subtask discussion of subtasks A, B and starting discussions for Subtask C**	Working groups
16.00	Coffee break	
16.20	**Preparation of working group summaries**	Working groups
17.00	Closure first day	

Wednesday, January 24, 2001, EMPA

9.00	**Presentation of workshop results** General discussion of Subtask A – C proposals	Session Leaders
11.00	**Decision process, action item list, future procedure and dates**	Prof. Dr. Hanspeter Eicher (E+P)
12.00	End of workshop	

INTERNATIONAL ENERGY AGENCY

Energy Conservation in Buildings and Community Systems Programme

High Performance Thermal Insulation (HiPTI)

Annex draft

15.2.2001

1 Introduction

1.1 The Meaning of High Performance Thermal Insulation

A significant part of end energy used in western countries is for heating and hot water production. The amount of energy required depends largely on the thermal insulation.

Efficient thermal insulation is a key issue for reducing CO_2 emissions.

There are two ways of obtaining improved thermal insulation:

- Increasing the thickness of the insulation. A method which has been used for the last 20 years but which has various disadvantages, for example the cost of construction, the loss of space, the lower available space for renting
- Improving the thermal insulation properties by reducing the heat transfer coefficient of the insulation material

The second approach could allow new construction details, easier application in building retrofit and energy efficient appliances (hot water tanks, refrigerators) if the insulation thickness could effectively be reduced.

1.2 Recent developments in the construction sector

Over the last 20 years there have been important developments in the construction sector:

- The construction industry has a need for attractive, practical and feasible insulation techniques for wall, roof and floor construction. The insulation standard has shifted from 1 W/(m^2K) to 0.3 W/(m^2K), and is today moving, in progression towards 0.2 and 0.15 W/(m^2K). Such insulation standard became a prerequisite for sustainable housing, passive houses or advanced retrofit. With this standards an insulation thickness of more than 20 cm in thickness is needed. In new buildings this problem can be solved to a certain degree. But when renovating existing buildings it has become obvious, how unsatisfactory these 15 to 20 cm insulation layers are in terms of the lack of space.
- The U-values of glazing systems have shifted, thanks to the use of IR-reflective layers and special gas fillings from 3.0 W/(m^2K) to 0.4 to 0.8 W/(m^2K). On the one hand this has massively affected the energy consumption of the building and on the other hand it has had, mainly during the last five years, a massive influence on the architecture, where the glassed façades became an important element.

1.3 High Performance Thermal Insulation

The need for more efficient insulation and the availability of improved insulation materials has increased the interest of the construction industry for High Performance Insulation Systems (HiPTI) which are 2 to 5 times thinner than conventional insulation systems.

Definitions

HiPTI High Performance Thermal Insulations are insulation materials or systems which have mean effective λ value smaller than 15 mW/(mK) throughout their life span.

VIP Vacuum Insulation Panels are HiPTI which are evacuated to a technical vacuum in order to further improve the thermal resistance. They normally allow a λ value smaller than 5 mW/(m·K)

2 Aims

The main aim of this Annex is to develop components for buildings based on HiPTI. We call them HiPTI systems (façade element, door, hot water storage, etc.). The successful developments should lead to competitive products which are available on the market. This aim will be achieved in three Subtasks:

2.1 Basic concepts and materials

- Existing products, mainly VIP, will be analysed and their properties optimised in the way, that they meet the requirements of the HiPTI systems in which they will be applied.
- New concepts for HiPTI materials and systems will be examined and evaluated. Suitable concepts will be demonstrated as prototypes.
- Measurement standards concerning product declaration and quality monitoring procedures will be developed.

2.2 Application and system development

Support companies which want to develop HiPTI systems for the building envelope and HVAC components. The support will consist in informing potential companies about HiPTI, form suitable groups for each development project, provide theoretical and practical information (simulation and testing of systems).

2.3 Demonstration and information dissemination

Realize demonstration projects together with well-known architects and important building owners.

- Lessons learned from the demonstration projects will be collected and used for further improvement of the materials and systems.
- Insulation specialists will be trained on site for the correct use of HiPTI's
- Information material will be distributed to increase the interest of construction companies and clients.

3 Means

3.1 Subtasks

Work will be grouped into three subtasks

Subtask A **Basic concepts and materials**

Subtask B **Application and system development**

Subtask C **Demonstration and information dissemination**

3.1.1 Subtask A: Basic concepts and materials

Improving existing solutions

Existing solutions (VIP) should be investigated to improve their technical, economical and ecological characteristics e.g. thermal conductivity, physical and chemical properties, longevity, reliability, production cost, recycling and grey energy content. This includes the basic materials (microporous materials, films and foils, getter materials) and the VIP-production processes (preparation and shape of microporous materials, wrapping and sealing techniques).

Further questions to be dealt with in Subtask A will also arise when subtasks B and C are handled, e.g. there might arise the need for VIP with special shapes (bent panels, panels with holes). Therefore the subtasks must overlap chronologically.

Standards

To improve confidence of customers in the new technology, standards have to be developed. These standards confine type and measurement of product properties which are important for the customer.

Furthermore a method has to be developed which is suitable to determine the quality of built-in VIP (on site).

New concepts

In this section research will be carried with the aim to improve some properties of VIP which are crucial for certain applications. The focus will be on developing HiPTI consisting of relatively small units so that a small scale injury of the VIP envelope (screws, nails) does not lead to a vacuum loss in a large panel. An another task will be to develop HiPTI for tubes which basically requires a flexible system.

3.1.2 Subtask B: Application and system development

The aim is to develop suitable insulation systems for the most important applications, which should be available on the market after termination of the Annex.

The first step is to evaluate the applications in building, which would gain distinct advantages from HiPTI's in terms of energy and/or cost saving.

Co-operation between insulation materials producers, insulation system suppliers, planners and building contractors should lead to specific product profiles. These will include technical as well as economic characteristics. Special attention should be paid to the development of products, which resemble conventional solutions as closely as possible in their application. In this way they can expect to be well received on the market.

In addition new HiPTI systems for critical parts of the building shell and for technical systems should be developed as future technologies for houses with very low energy consumption (e.g. passive houses).

3.1.3 Subtask C: Demonstration and information dissemination

The aims of this part of the Annex are field testing and market introduction of the new products. In collaboration with large, innovative building contractors, architects and opinion leaders (e.g. governmental agencies) demonstration projects will be implemented.

The following objectives should be achieved by the end of the Annex:

- In the important markets for HiPTI (e.g. internal insulation, floor heating, flat roof renovation, hot water equipment, façade cladding systems, doors and so on).
- 10 leading building contractors from the participating countries should have performed and evaluated at least one large project with HiPTI, when renovating housing stock.
- 10 recognised and leading architects should have carried out at least one renovation or new construction project with HiPTI.
- National opinion leaders should have been informed about the HiPTI products and know about the demonstration projects.

- HiPTI products and systems should be available according to market conditions in the participating countries.
- An industry association for HiPTI in Buildings should be formed, to keep international collaboration going after termination of the Annex.

3.2 Management Team/Subtask Leaders

The management team consists of the Operating Agent, and the Leaders of Subtasks A, B and C. For Subtasks B and C each participating country has an own co-ordinator.

4 Results / End Products

4.1 Subtask A

The work carried out in Subtask A should provide an overview of the basic concepts and materials suitable for producing HiPTI.

Above all, vacuum insulations should have been improved to meet the requirements of building applications.

Standards concerning product declaration and quality monitoring procedures are available.

Research publications will document the state of the art, available materials and concepts and recommendations for the use of the different systems in the construction sector.

4.2 Subtask B

HiPTI systems, whose properties have been tested and optimised as regards to usability and life span are available on the market and can be supplied to customers with standard market performance guarantees.

A guideline for the application of new HiPTI insulated constructions and components will be published.

4.3 Subtask C

Every participating country should have implemented HiPTI demonstration covering an area of at least 1'000 m^2. Findings from these projects will be documented and used to improve systems and applications.

Important building contractors, investors and architects should have a basic knowledge of the opportunities offered by HiPTI technologies and how to make use of them.

Opinion Leaders in the construction business should be well informed about the properties of HiPTI and are able to inform customers about their usability.

Information regarding durability over a period of at least three years should be available. Selected durability tests will be constantly performed after Annex termination.

5 Annex Beneficiaries

In general, the activities in this Annex should contribute to the reduction of energy use and CO_2 emissions in the construction sector. It should improve the applicability of HiPTI technologies and demonstrate the benefits to users and opinion leaders in all participating countries. It should allow to attract enough interest to create a market for such systems. On the basis of the experience gained it should lead to further R&D activities and product development, also for other applications than in the construction sector.

6 Time Schedule

The Annex planning phase will take approximately one year. The duration of the Annex, after the planning phase, will be three years.

During the Annex planning phase, the activities for Subtask A (e.g. R&D review, search for industrial partners) can be started.

The table in the Appendix demonstrates the time schedule for the different Annex phase activities.

7 Specific Obligations and Responsibilities of the Participants

Participants in the Annex will be physicists, engineers, representatives of the industry, building constructors, architects and investors.

In addition to the obligations enumerated above:

- Participants will be expected to provide such information as exists in their own countries to facilitate the work of the country dealing with a designated topic;
- Each participant will be expected to act as a primary reviewer for the output of one of the other Participants. This responsibility for detailed review will ensure that the work produced will not reflect any particular national bias, but properly represents consensus of the Participants in the Annex.

8 Specific Obligations and Responsibilities of the Operating Agent

In addition to the obligations previously mentioned the Operating Agent shall:

a. Prepare the detailed Programme of Work for the Annex in consultation with the Subtask Leaders and the Participants and submit the Programme of Work and a time schedule for approval to the Executive Committee;

b. Be responsible for the overall management of the Annex. This includes overall co-ordination, liaison between the Subtask and communications with the Executive committee of IEA, providing information and implementing actions required;

c. Chair each of the full Annex meetings and be responsible for setting each agenda. Assistance at each meeting will be provided by the Participant from the nation hosting the meeting;

d. Prepare and distribute the results mentioned in paragraph 5 above;

e. Prepare joint assessments of research, development and demonstration priorities when desired or necessary;

f. At the request of the Executive Committee, organise workshops, seminars, conferences and other meetings;

g. Propose and maintain a methodology and a format for the submission of information which is collected by the Participants as described in paragraph 4 above;

h. Provide, at least semi-annually, periodic reports to the Executive Committee on the progress and the results of the work performed under the Programme of Work;

i. Provide an annual technical report to the Participants in the Annex;

j. Provide to the Executive committee, within twelve months after completion of all work under the Annex, a final report for its approval and transmittal to the Agency;

k. In co-ordination with the Participants, use its best efforts to avoid duplication with activities of other related programmes and projects implemented by or under the auspices of the Agency or by other competent bodies;

l. Provide the Participants with the necessary guidelines for the work to be carried out in the Subtasks, for reports to be made and information to be distributed;

m. Perform such additional services and actions as may be decided by the Executive Committee, acting by unanimity.

9 Funding

The minimum commitment of each country for Subtasks A, B and C will be 4 person-years in total. It is expected that Subtask A will be carried out by a limited number of participants (about four) with an overall input of about 8 person-years. In the Subtasks B and C all participants are involved. Funding includes working costs, travelling costs and eventual overhead costs. Additional costs may result from material and equipment needed for R&D and demonstration.

For the Operating Agent, additional funding shall allow for an extra 4 months per year of Annex activities, including the attendance of 2 ExCo-meetings per year. For the Leaders of the 3 Subtasks funding shall allow for an extra 2 months per year of Annex activities.

Each Participant shall bear the costs resulting from its work under this Annex.

10 Operating Agent

The Operating Agent for the Annex shall be Dr. Eicher+Pauli AG, Switzerland.

11 Information and Intellectual Property

a. Executive Committee's Powers. The publication, distribution, handling, protection and ownership of information and intellectual property arising form this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.

b. Right to Publish. Subject only to copyright restrictions, the Participants shall have the right to publish all information provided to or rising from this Annex, except proprietary information.

c. Proprietary Information. The Participants and the Operating Agent shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect proprietary information provided to or arising from this Annex. For the purposes of this Annex, proprietary information shall mean information of a confidential nature such as trade secrets and know-how (e.g. computer programs, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes or treatments) which is appropriately marked, provided such information:

- Is not generally known or publicly available form other sources;
- Has not previously been made available by the owner to others without obligation concerning its confidentiality;
- Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information, and of the Operating Agent for appraising proprietary information, to identify the information as such and to ensure that it is appropriately marked.

d. Production of Relevant Information by Governments. The Operating Agent should encourage the governments of all Agency Participating Countries to make available or to identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Annex.

e. Production of Available Information by Participants. Each Participant agrees to provide to the Operating Agent all previously existing information, and information developed independently of the Annex, which is needed by the Operating Agent to carry out its functions in this Annex and which is freely at the disposal of the participant and the transmission of which is not subject to any contractual and/or legal limitations.

- If no substantial cost is incurred by the Participant in making such information available, at no charge to the Annex therefore.
- If substantial costs must be incurred by the Participant to make such information available, such charges to the Annex shall be agreed between the Operating Agent and the Participant with the approval of the Executive Committee.

f. Use of Confidential Information. If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent but shall not become part of reports or other documentation, nor be communicated to the other Participants except as may be agreed between the Operating Agent and the Participant which supplies such information.

g. Acquisition of Information for the Annex. Each Participant shall inform the Operating Agent of Information that can be of value to the Annex, but which is not freely available, and the Participant shall endeavour to make the information available to the Annex under reasonable conditions, in which even the Executive Committee may, acting unanimity, decide to acquire such information.

h. Reports of Work Performed Under the Annex. The Operating Agent shall provide reports of all the work performed under the Annex and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information , in accordance with paragraph (c) hereof.

i. Copyright. The Operating Agent may take appropriate measures necessary to protect the copyright of the material generated under this Annex. Copyrights obtained shall be the property of the Operating Agent for the benefit of the Participants provided, however, that Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee.

j. Authors. Each Participant will, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation from its authors required to carry out the provision of this paragraph. Each Participant will assume the responsibility to pay award or compensation required to be paid to its employees according to the laws of its country.

12 Participants

The Contracting Parties which are Participants in this Annex are the following:

(Provisional, paragraph will be finalized later)

Austria

Belgium

Canada

Denmark

France

Germany

Italy

Netherlands

Sweden

Switzerland

U.K

13 Appendix

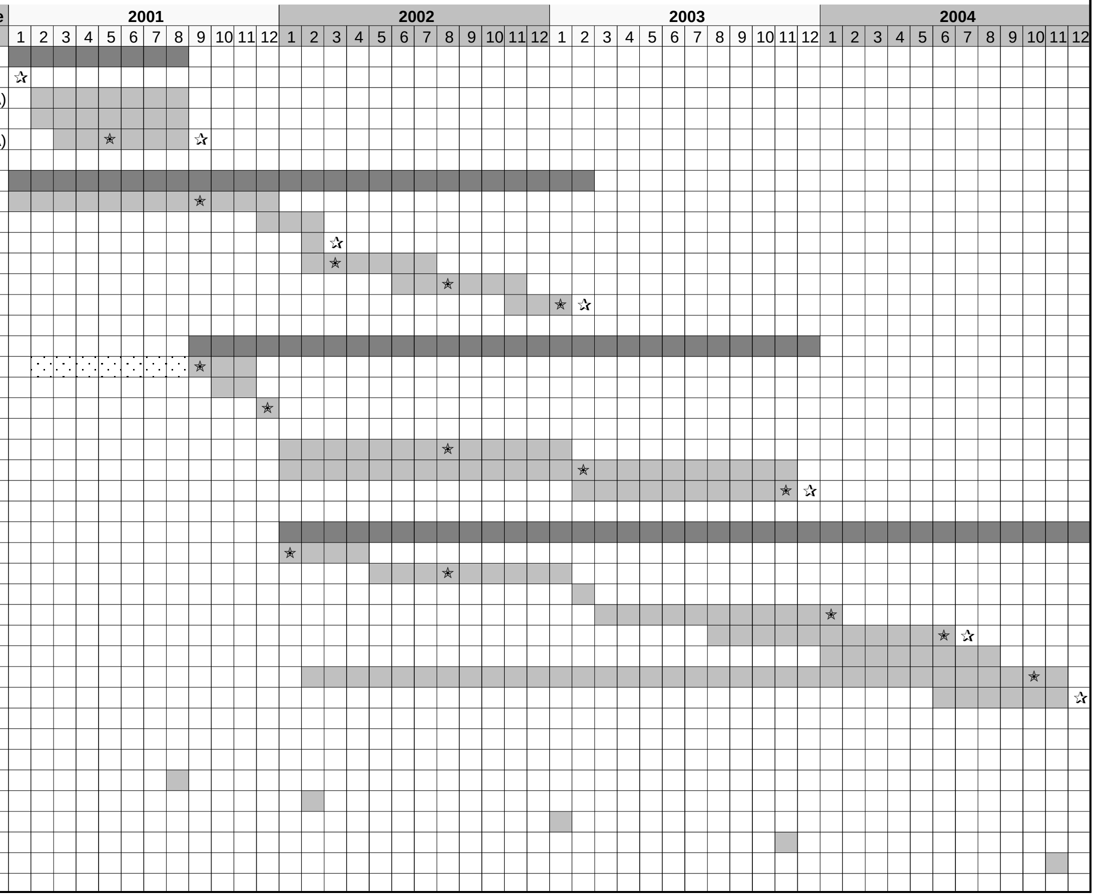
- Time Schedule

Time schedule

High Performance Thermal Insulation

ECBCS Annex 39

Task		Responsible
0	**Preparation Phase**	
0.1	Workshop in Zurich	
0.2	Form up project team	NPL (SL, OA)
0.3	Review on VIP (state of the art)	SL1/2 (OA)
0.4	Definition and funding of national projects	NPL (SL, OA)
A	**Basic Concepts and Materials (Insulation)**	SL1
A.1	Properties of available HiPTI's	
A.2	Determine deviations to the specifications (see ST2)	
A.3	Report on available products	
A.4	Concepts to improve properties	
A.5	Prototyps manufacturing and testing	
A.6	Report on ST1	
B	**Application and System Development (HiPTI systems)**	SL2 / NPL
B.1	Define target applications (building envelope and HVAC comp.)	
B.2	Description of system properties and requirements on the insulation	
B.3	Report on system specifications	
B.4	Product development	
B.41	Simple applications	
B.42	Complex applications	
B.5	Report on ST2 (Documentation of products)	
C	**Demonstration and Information Dissemination**	SL3 / NPL
C.1	Objectives (typ of buildings and involved partners)	
C.2	Find objects / owners and feasability study	
C.3	Report on planned demo projects	
C.4	Planification	
C.5	Realisation	
C.6	Technical evaluation	
C.7	Information dissemination	
C.8	Final report	
	Milestones	OA
	Review on VIP (state of the art)	
	Report on available products	
	Report on ST1	
	Report on ST2	
	Final report	



Glossar

OA: Operating Agent

SL: Subtask Leader

NPL: National Project Leader

ST: Subtask

Duration of Subtask

Duration of activity

Duration of preperatory activity

☆: Annex meeting (all partners)

★: Workshop (partners of the subtask and possibly OA)

Preliminary Study on High Performance Thermal Insulation Materials with Gastight Porosity

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In recent years a lot of work has been done in order to achieve better thermal insulation materials. The focus was set on microporous materials like fumed silica products [1, 2] and also on silica aerogel products [3, 4]. These materials show very low thermal conductivity (< 0,02 W/(m·K) which can be even more decreased if the materials are evacuated. For instance, so called Vacuum Insulation Panels, which consist of evacuated fumed silica, have a thermal conductivity as low as 0,004 W/(m·K). But all these products have in common that they need a vacuum tight envelope and are therefore susceptible to damage during transport and installation on the building site. They also cannot be machined or cut to size.

It has been shown that there is a market for slim insulation materials which can be made 5 to 10 times thinner than conventional insulation as a result of their significant lower thermal conductivity. The object of this investigation was to perform a literature research and to study possibilities for the manufacturing of gastight inorganic materials with very low thermal conductivity to overcome the problems discussed above.

A closer look was taken on cellular or foamed glass which seems to be an ideal candidate for an inorganic gastight insulation material. About twenty independent publications on foamed glass developments were found [5]. Little work has been done in order to decrease the thermal conductivity of the material, most of the researchers concentrated on processing routes and the use of different raw materials, mainly the recycling of waste products. The lowest thermal conductivity reported for foamed glass is approx. 0,04 W/(m·K) [6].

Special attention is paid to composite materials as only such materials are generally considered for insulation purposes. It has to be noticed that a porous materials is considered a composite as it consists of two phases: a solid matrix material and a gas. The thermal conductivity depends on the amount and arrangement of the phases. In case of foamed glass the two phases are glass and pore gas. The glass represents the continuous phase whereas the major phase, the pore gas, is discontinuous (fig.1).

In such a material the pores decrease the thermal conductivity nearly in proportion to the fraction of the porosity [7, 8]. The conductivity can be decreased by controlling the pore content, e.g. it becomes lower if the pores contain a gas with very low conductivity or if they are evacuated. As radiation also plays a role if a material is transparent, these glasses usually contain opacifiers. Heat transfer through radiation across pores is low for small pores at low temperatures. The contribution from radiation becomes higher if the pores are large (a few millimetres and above), in particular if they contain a gas which is transparent for radiation or if they are evacuated [9, 10].

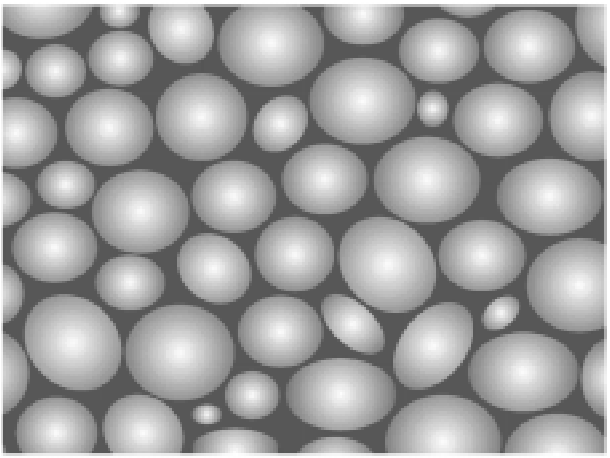

Figure 1: *Simplified schematic structure of a foamed glass (section). The glass (dark) is the continuous phase; the major phase (pores, light) is discontinuous.*

The microporous insulation materials have a very low thermal conductivity (0,02 W/(m·K); not evacuated). This results from the fact that the pore phase is continuous and there are usually only point contacts between the solid particles, an idealised schematic structure of such a material is shown in figure 2a and b. The resulting conductivity is therefore largely determined by the effective conductivity of the pore phase which is usually a gas, e.g. air. The conductivity of any gas is lower than that of any solid material. Furthermore, the conductivity of such materials is dependent on the gas pressure and also the pore size. This means it can be further decreased by evacuating the pore spaces and/or reducing the pore sizes by using smaller grain sizes [8, 9].

Aerogels are also open-pore structures with minimal solid-solid contacts (3 nm according to literature [11]; figure 2 a and c), therefore, the same principle for thermal conductivity applies in these type of materials. Whereas for fumed silica products opacifiers are usually added to suppress radiation this is not necessary for silica aerogels as they are naturally opaque for infrared radiation at low temperatures (below 100°C).

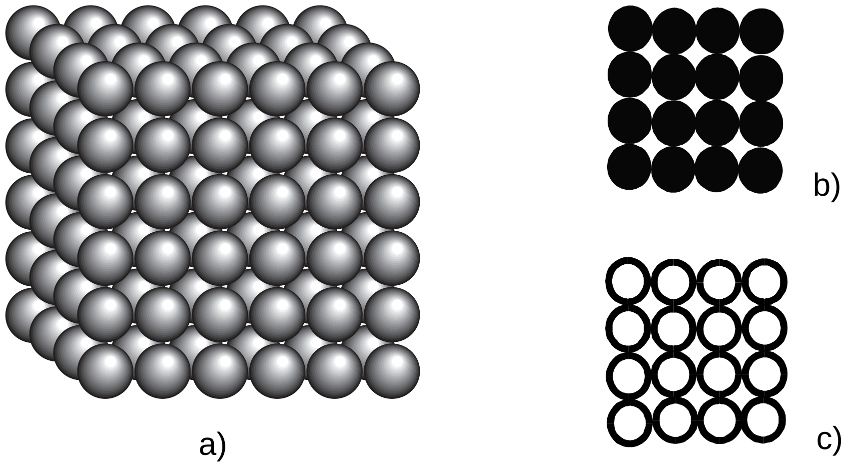

Figure 2: *Strongly simplified schematic structure of microporous insulation materials:*

a) 3-dimensional pore network, solid particles have only point contacts (for both fumed silica products and aerogels);

b) 2-dimensional section through a powder compact (fumed silica);

c) 2-dimensional section through an aerogel.

Up to now very little effort has been put into improving closed pore materials like foamed glass in respect to decrease its thermal conductivity. An approach could be made by designing new structures with gastight porosity but also by improving existing materials. Mathematical calculations show that it is possible to achieve a thermal conductivity as low as the conductivity of microporous materials by reducing the fraction of solid matrix material in a glass foam to a minimum. A further decrease in thermal conductivity and an increase in mechanical stability could be achieved by designing a composite material with a major discontinuous phase which has a very low conductivity, e.g. an aerogel, and an inorganic minor phase which forms only a very fine three-dimensional network around the major phase but still provides sufficient strength and gastightness. It should also be considered to improve foamed glass by optimising its cell structure and the appropriate choice of pore gas and evacuating the pores, respectively.

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Flexible Pipes with High Performance Thermal Insulation

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Introduction

The highest losses on energy don't emerge with the production of heat or cold, but with distribution of it. Conventional High Performance Thermal Insulation (HiPTI) – pipes are difficult in use and need a lot of space. This study shall show, if new forms of pipes are possible and what the main problems of them will be.

Description of the product

It should be possible to solve some problems of conventional pipes with flexible vacuum insulated pipes. This new concept is planned with cheaper plastic pipes instead of steel-pipes insulated with welded chromium steel. The plastic pipe shall be wrapped with a vacuum bandage, which has predetermined cutting places. Therefore, these pipes can be delivered on construction side as rolls and can be cut into specified lengths on place by a craftman. Because of the flexibility of the pipe, you won't have big problems caused by dilatation.

The bandage is formed with micro porous material, and enveloped with two gastight films. To avoid coldbridges, two bandages shall be wrapped in a staggered way (Fig. 1). As protection against mechanical injures, a protective coat comes over the outer bandage.

The predetermined cutting places are a result from welding the two films. Therefore the bandage is divided in chambers. Each chamber is evacuated. That means, if the envelope of the bandage get hurt, not the whole pipe is vacuumless.

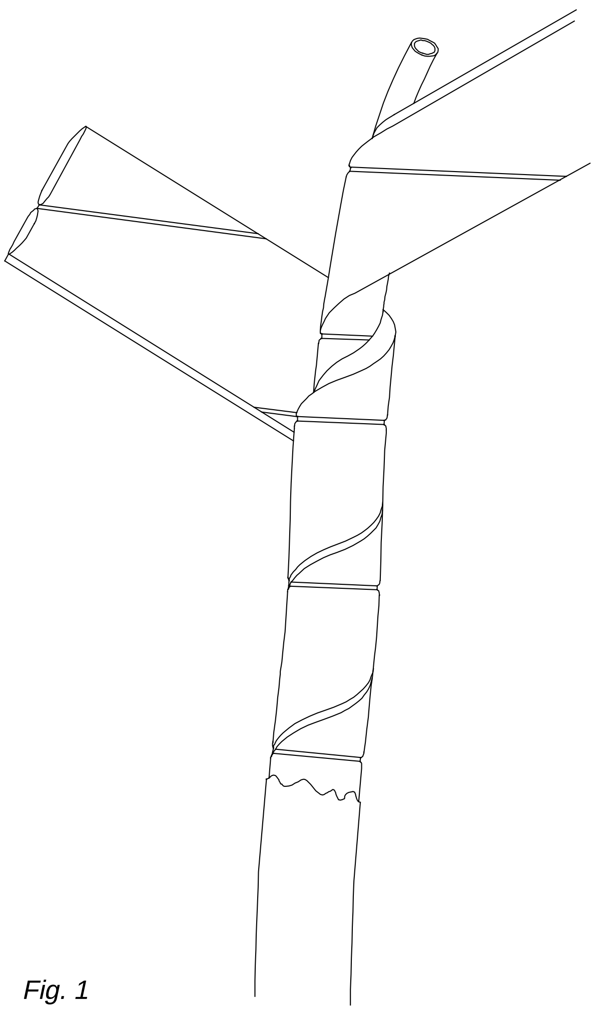

Fig. 1

Goals of the actual study

The study shall deliver a list of problems and questions that must be solved:

- Materials questions (which film, which filling material, how much vacuum etc.).
- Technology questions (how to wrap the bandage, geometrical questions of the chamber, how to apply the pipe).
- Try to produce a sample and make first tests.
- Which industrial partners are interested in a development project.
- How a future development project has to be formulated.

Already known research topics

The gastight film is delicate in usage. This film consists of different layers. The gastight layer may be aluminium or in newer cases siliziumoxid. If the film is folded often or strong, the gastight layer may break. Unfortunately, this fact isn't easy visible without technical help (e.g. microscope). But long time vacuum isn't possible with a defect in the gastight layer. One topic will be, to get less delicate films.

Until now, it isn't very clear, were the most leackages of air into the vacuumed chambers comes from. If the pinholes lying in the film are responsible, further development has to be done in film technology. But we think, more problems result in welding the film. Especially if you have the micro porous material as powder, you will always have some impurity in the weldseam. With that handicap, seams may be leaky. One topic will be, to explore how to weld without impurities.

Depending on used materials, today films have a thermal conductivity in length which are about 50 to 3000 times higher than the conductivity of the filling material. The danger to create coldbridges with films is given. The question will be, how large respectively how small the chambers can be made without noticeable losses. During the running study, we want to compute how small chambers may be, without giving up the demand that we get a high insulation product. (Fig. 2)

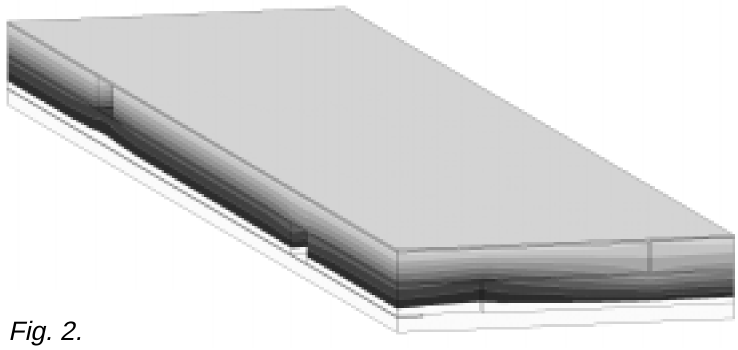

Fig. 2.

To wind stiff bandages around a small pipe may cause unpredictable folding. That means, air will be enclosed and this will produce additional cold bridges. Perhaps we have to cluster the bandage on the inner side. But then the question arises, how many clusters do we need and how is it possible to produce such a clustered bandage.

The stiffness of the bandage comes from the vacuum. Perhaps with krypton as gas inflation, the stiffness can be circumvented. But it is not yet examined, how the mix of penetrating air with krypton will effect the thermal conductivity of the micro porous material.

At least, how can we guarantee, that the embedded insulation won't loose the good characteristic next 25 years?

Conclusion

A lot of questions we have are also interesting for other High Performance Thermal Insulation projects. A lot of them were unique to our specific problem. I'm looking forward, to have a good discussion and I'm hoping to find some answers ore at least to get some ideas.

Evaluation of modern insulation systems by simulation methodes

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Modern insulation systems are loads by several climatic and using effects, which can induce a damaging of the materials. There are mechanical loads by weight, wind, push, ground moving and altering, thermal loads by thermal expansion and tension and hygric loads by wetting processes, grow of mould, salt crystallisation, hygric tension etc. The knowledge about this processes dependent on using and climatic conditions can help to avoid these problems.

Many existing buildings are in bad condition referring to their thermal insulation. That is a result of low heat technical requirements in the past and also caused by damage and weathering of the building stock. To decrease the heat loss of buildings with facades being worth to be kept is it necessary to find adequate solutions.

For an improvement of the heat insulation an very exactly analysing and a better understanding of the properties of the building materials are necessary. Modelling and simulation of the thermal and hygric behaviour can be a good method to evaluate new building construction referring to durability and life cycle.

In the paper are given some example of investigation new systems to find out the possibilities of application.

Introduction

For the preservation of outer facades of buildings which belong to the cultural heritage it is not possible to fix an insulation board at the outside. Therefor it is necessary to develop interior insulation system, which have to be adapted with the old building stock.

Good properties for this aim has insulation material with a ability of water transfer. If the old building has a wooden framework construction the conditions are more severe then in the case of an outside insulation layer. The characteristic of calcium silicate leaded to the development of a special lining board, a alternative system to protective and renovation render systems.

A special interior insulation system is developed with a integrated heating zone in the board. In this way a modern heating system can used, higher surface temperature produces a better human comfort, the heating energy can decreased and the moisture load on the exterior wall can be decreased.

Exterior insulation systems with a transparent heat insulation layer are well known. This systems are very expensive and the thermal load in summer is often to high. These problems have been the reasons to investigate an transparent render or an exterior insulation system based on a combination of an insulation render system and a transparent insulation system. In this way it is possible to get an insulation render system with a partial transparency.

Inside Insulation

In the following chapters the traditional performance evaluation method is compared with the results based on simulation of the heat and moisture transfer and the results for different inside insulation are shown [1],[2]. By using the standard calculation methods no information about the relative humidity and the temperature in the structure is presented to the user and the only parameter, which leads to the performance evaluation is the ratio of the condensing to the evaporating amount of water. In this way one would prefer the variants with high diffusion resistance as the systems with no moisture problems.

Build in moisture during the renovation time or additional water from driving rain, which is one of the main problems for unrendered wooden framework structures [2] is neglected. To account for build in moisture and to get a better inside into the moisture behaviour of the construction one can use simulation tools for the heat and moisture transfer processes in constructions. The models presented in [5] are capable of calculating the moisture transfer in the vapour and the liquid phase and in this way the behaviour of materials with a high capillary water transport ability can be investigated with them.

The moisture content of the structure with an inside insulation has been calculated for 10 years. Over this period the weekly average of the temperature and the relative humidity at the interface between the wooden part and the inside insulation has been stored. The results for the application of mineral wool as interior insulation are presented in Figure 1. The data presented in figure 1 clearly shows the high moisture contents during the cold season which exceed the limiting curve for 16 weeks of exposure and even for 8 weeks of exposure. An additional vapour barrier eliminates the condensation of water, but as seen in figure 2, during the first year nearly no drying of water has happened because of the great vapour resistance to the inside.

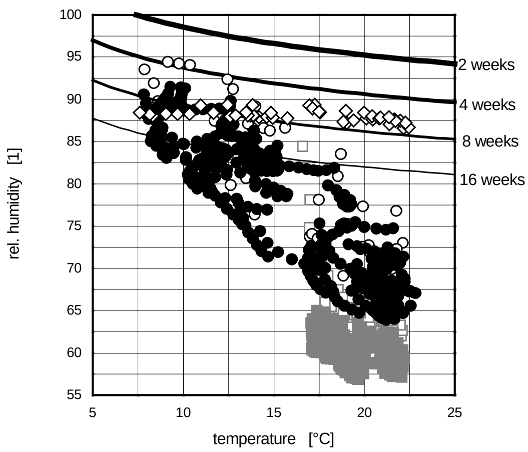

Figure 1: *Weekly average relative humidity against weekly average temperature at the inside of the wooden part for an inside insulation made out of mineral wool without (Var. 1) and with (Var. 2) a vapour barrier. The limiting conditions for the development of the initial stages of mould growth are shown as lines for an exposure time of 2, 4, 8 and 16 weeks [Viitannen 1996].*

- ○ *without moisture barrier, first year*
- ● *without moisture barrier, 2nd -10th year*
- ◊ *with moisture barrier, first year*
- □ *without inside insulation first year*
- ■ *without inside insulation 2nd -10th year*

If an expanded polystyrene is used for interior insulation the drying process of the construction in the first year is very slow. During a lot of weeks the average moisture condition is above the limiting curves.

A rather different behaviour shows an interior insulation with a high capillary force. calcium silicate has the ability to transport water by capillary forces. In this way, if the relative humidity in the inside insulation increases, the moisture content due to sorption of water increases too, and water is transported with capillary forces back to the room. Therefor compatible hygric condition can achieved with this material in the construction. The drying of the construction is fast because of the low vapour resistance of calcium silicate. As one can see only during the weeks with very low outdoor temperatures a relative humidity of 80% is exceeded in the wooden part. Because of the low temperature during those weeks mould growth is not initiated

Inside insulation board with a high salt storage capacity for moisture and salt loaded walls

For the maintenance of moisture and salt destroyed walls are special measures for a continue sustainable redevelopment necessary. Different systems for repair of damages at this time are possible. The most and relative successful used system are protective and renovation render.

In the latest years the department of building physics at the Technical University of Vienna developed an indoor lining board for moisture- and salt damaged buildings [8]. The developed lining board based on calcium silicate. It is a alternative product to protective and renovation render systems.

The lining board is developed for moisture and salt loaded walls. Is the wall destroyed only because of moisture, the calcium silicate lining board can be applicated without treating. There are 3 possibilities for the treatment of calcium silicate lining Boards for using them on moisture and salt loaded walls:

1. complete hydrophobisation,
2. treatment of the surface,
3. reduce the capillary moisture transport from the backside through backside treatment

With variant 1 the biggest reduction of salt entry is possible. An entry of the salt solvent into the lining board is to be possible, like the protection and renovation render. The crystallisation takes place in the capillaries. Most of the capillaries are hydrophobic, that's why only a minimal mass of the solvent can penetrate into the board.

Most investigations takes place about surface treatment, possibility 2. The treatment is optimised between maximum capillary moisture and salt transport into the lining board and a minimum of destruction because of salt crystallisation. The salt crystallisation in our investigations takes place between the treated and non treated parts of the lining board.

The following figure 2 shows the behaviour of the system due to condensation and evaporation in the wall after different treatments of the lining board by using as inside insulation.

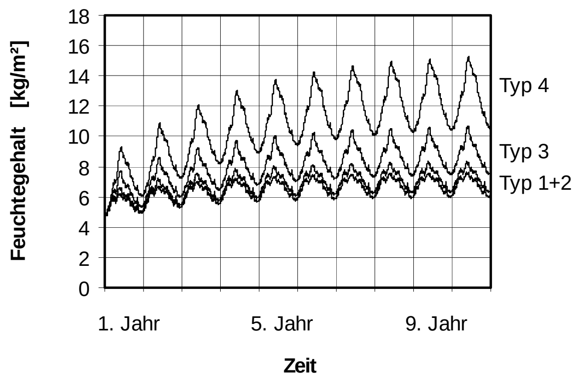

***Figure 2:** Moisture content inside a wall by using different lining boards (types of treatment), without rain load*

For the support of our laboratory tests we have a practical one at Schloß Zell a.d. Pram in Lower Austria. Different variations of the developed slabs are in long time analysis and under continuos control of our department. This test will be used to find a optimised performance at the building site.

Inside Insulation System with a Internal Wall Heating System

To lower additional the heat losses one can use an inside insulation system. The negative effect of such n inside insulation is, depending on the outer render and the used insulation material, an increased moisture load of the construction. The reason is, that in winter the main part of the construction will be cooler and the moisture remain and in the summer the moisture evaporate and moves deeper in the construction. With a special air conditioned zone it is possible to decrease the moisture load. The developed system consist of an insulation layer, an air conditioned zone and a finishing board as the new surface. Furthermore it is possible to use the zone for heating. With the insulation layer the thermal resistance of the construction can be increased and with the conditioned zone the moisture load on the exterior wall can be decreased. Figure 3 shows a sketch of the construction which has been developed.

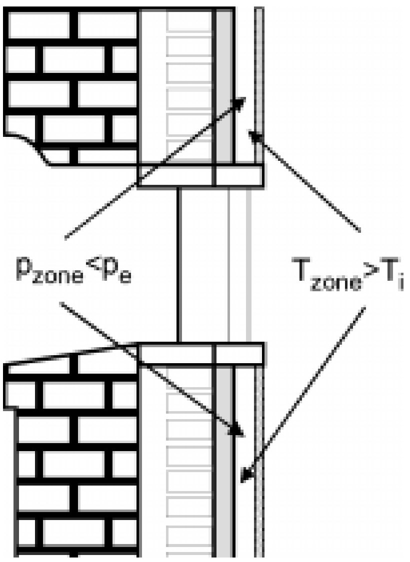

Figure 3: *Interior insulation with an integrated heating system*

The thermal performance of such buildings was investigated to know the possibility to decrease the energy use for heating and the moisture load by condensation. For this aim the energy use of a whole building was calculated in consideration of all components of heat loss, like transmission through walls, windows, roof and ground and ventilation, and of all gains, like radiation and internal gains. Only by a simulation of the annual energy balance of a building the effect of a measure of reconstruction can evaluated in the right way. The energy use of a single family house was calculated. The result of the calculation of the annual energy use of this house for the initial state, that is the state without a inside insulation and a integrated heating system, and of the final state, with buffer zone and inside insulation, is seen in figure 4.

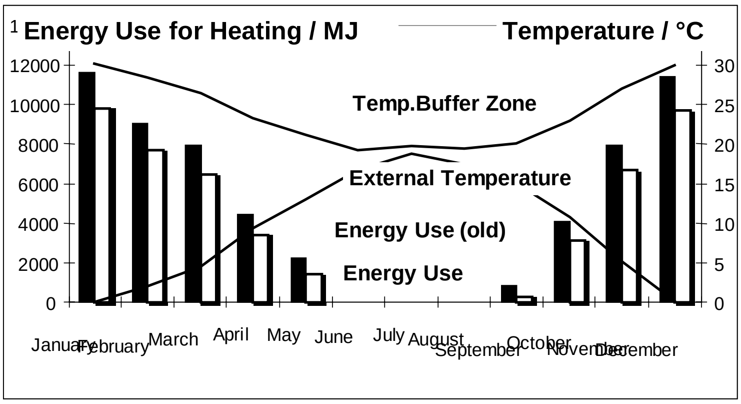

Figure 4: *Annual energy use of a single family house before and after a application of an inside insulation and a heating zone in the wall to exterior. Average monthly external temperature and required temperature of heating zone, integrated in the wall*

In the figure is seen, that a temperature in the buffer zone from twenty until thirty degree Celsius is necessary. This energy supply correspond the energy loss of the wall, floor, ceiling and windows. The temperature of the surface of the wall is in this case between twenty and twenty-five centigrade Celsius. The reduction of heating energy is approximately 30 percents.

This effect can increase if one use better insulation for floor, ceiling and windows and a higher thermal resistance for the additional inside insulation. In this case a little improvement was chosen, that the variation of the thermal conditions of the walls is not so great. The temperature and vapour pressure distribution show interesting behaviour. The temperature of the bricks wall lays between 0°C and 13 °C, that is comparable with the state before use of a inside insulation. If a internal moisture content below 75 % is used, no condensation problem will exist in the wall. By the higher temperature in the buffer zone a condensation can avoid without a vapour moisture barrier. The risk of condensation in the wall construction for the average monthly climatic conditions seems to be very low, because an internal moisture content of more then seventy percents are necessary for this effect. By the help of the temperature in the heating zone a risk can avoid in the whole time period of a year.

Exterior insulation render system with solar radiation transmission

Exterior insulation systems with a transparent heat insulation layer are well known for some years. This systems are very expensive and the thermal load in summer is often to high. These problems have been the reasons to develop an exterior insulation system based on a combination of an insulation render system and a transparent insulation system. To mount the heat insulation system at the outside of a wall a light plastic framework with transparent elements is fixed and the space in between the framework is filled with an insulation render system. In this way it is possible to get an insulation render system with a high thickness and a partial transparency.

To determine the energy saving effect of this system the method for calculating the space heating requirements for residential buildings according to EN 832 has been used. This standard calculation method uses the transmission heat loss of all construction elements from the internal to the external environment, the ventilation losses, the usable internal heat gains and the usable solar gains through windows, sunspaces and opaque elements with transparent insulation. Through to utilisation factors it is not possible to overestimate the impact of solar energy on the space heating requirement.

The thermal performance of an building with a transparent render system at the exterior walls was investigated to know the possibility to decrease the energy use for heating. For this aim the energy use of a whole building was calculated in consideration of all components of heat loss, like transmission through walls, windows, roof and ground and ventilation, and of all gains, like radiation and internal gains. The investigated single house has

99 m² floor and roof, 91 m² opak wall area and 19 m² window area. The heat transmission coefficients of the building elements are 0,5 m²*K/W (floor), 2 W/m²*K (window), 0,8 W/m²*K (ceiling) and 0,8 W/m²*K (wall). To improve the thermal quality an additional inside insulation is used with a thermal resistance R= 0,5 m²*K/W.

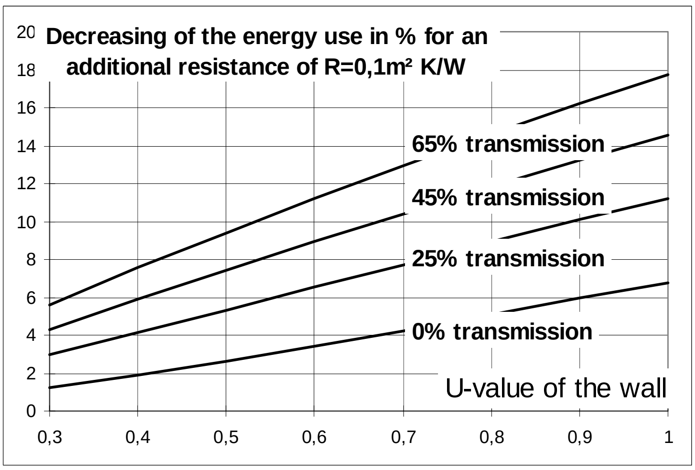

Figure 5: *Reduction of energy consumption for a whole building by using a transparent insulation render.*

Only by a simulation of the annual energy balance of a building the effect of a measure of reconstruction can evaluated in the right way. The energy use of a single family house with the characteristics given in table 1 of building elements was calculated.

In Figure 5 the results are given for several degrees of transparency of the external insulation system.

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Development of vacuum insulation panel with stainless steel envelope

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Co–operating in a European Craft project, a group of SME's and research groups will develop a prototype production line for vacuum insulation panels with rectangular stainless steel envelopes. Objective of the development is to acquire and test the technologies needed for the production line, fit for a broad range of temperatures, filler materials and sizes. The demands are a fast, robust and flexible production method leading to a competitive product. The concept with a stainless steel envelope is chosen because of the possibility of producing hermetically closed panels with a life expectancy > 50 years with low thermal bridges, appropriate for temperatures up to 450 °C. The straight edges make interconnection of panels possible

Introduction

In 1997 a European Craft project was successfully finished: *development of evacuated super insulation panels with a tenfold increase of performance*. The project was aimed at experimentally testing the methods needed for an all-round panel with a life expectancy fit for the building sector. During the project the list of demands was set up, complying with the specific demands of the participants. A common demand was a lifetime of > 50 years with an end pressure of 10 Pa for a temperature up to 80 °C for a 1 m^2 panel. The envelope has to be suited to apply several filler materials and to be interconnected as part of a construction system.

Potential envelope materials and joining methods have been investigated and tested with respect to permeability, outgasing and thermal conductivity. Promising filler materials have been tested for mechanical stability, outgasing and thermal conductivity characteristics. The tests resulted in a choice of a concept for a prototype panel with a stainless steel envelope, some prototype panels have been produced.

In August 2000 a group of SME's and R&D performers started a follow up Craft project: *Development of methods for a prototype production line for vacuum insulation panels.*

Objectives

The main objective of the project is to research and develop methods for the constituent parts of a prototype production line for vacuum insulation panels, leading to a fast and flexible production method for a competitive product. The objectives are:

- 33 Euro/m^2 based on a pilot production capacity of 45,000 m^2/year
- a tenfold increase of thermal insulation value; $2 < \lambda < 5$ $mWm^{-1}K^{-1}$
- flexibility of panel size up to 1,2 x 1 m^2
- construction system for mutual panel connection with low thermal bridges
- new developed laser welding method with laser weld speeds of > 0,1 ms^{-1}
- evacuating time < 500 s, approval measurement within 200 s
- total reduction of ageing by preventing moisture absorption
- life expectancy > 50 years at internal pressure < 10 Pa
- improved fire resistance of panels up to 60 min.
- clean handling due to hermetically closed envelope, causing no health hazards
- completely recyclable at end of life

Research approach

The research focuses on 4 main aspects:

Filler material: **different materials will be used: PUR, XPS and glass fibres**

For the broad application of vacuum insulation panels, fibre filler, polyurethane and polystyrene will be used. The materials will have different application fields. The insulation material must have an open structure to make evacuation to 1 Pa possible. The main fibre and foam properties will be defined, such as solid conduction, cell dimensions, maximum allowable internal pressure, and the possible need of evacuation ducts. Treatment methods such as time and temperature of tempering and flushing with dry nitrogen to remove water will be determined. The need of getter material will be investigated.

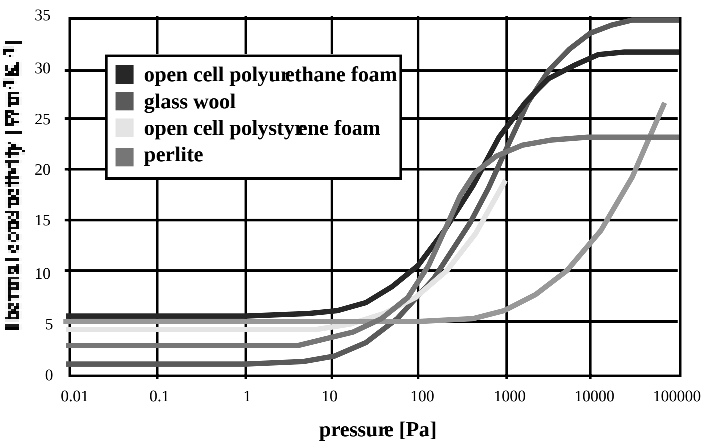

Figure 1: Thermal conductivity as function of the gas pressure for several filling materials

Evacuation method: **a fast method is developed to make a high production capacity possible**

In order to obtain a fast production method the evacuation time of 1 m^2 of vacuum insulation panel should be < 500 s. Possible operations to fill the envelope with fibre/foam board followed by a vacuum pumping step will be investigated. Methods to decrease the pumping time will be determined such as the use of evacuation ducts, the use of getters as *after pump*, and flushing with dry gases to remove water.

Envelope: **the envelope should be hermetically closed with low thermal bridges**

Feasible geometry's of the stainless steel envelope parts will be compared for several purposes and temperature ranges. Related to the degree of ductility, deformation, laser welding properties, and costs aspects.

A mutual connection system for vacuum panels with minimised cold bridges will be designed for application in, a.o., cold stores, fleece facades and buildings.

Different welding principles will be coupled to the preferred envelope geometry's. The penetration weld geometry will be tested in detail, as a function of foil thickness laser pulse frequency, velocity, laser power and positioning accuracy.

A model will be developed to calculate the average thermal conductivity, stresses inside the panel and deformations. The foil thickness is an important parameter for the cold bridges.

Measurement method: **a method is developed to give an indication of the thermal conductivity within 200 s after production**

Methods for testing the thermal/vacuum quality of a panel just after production will be developed. For checking the thermal insulation value of a super insulation panel, innovative measurement techniques have to be used. The thermal conductivity value is around λ = 3 mW/(m·K), much lower than the thermal conductivity of the surrounding air (λ = 26 mW/(m·K)), leading to a difficult measurement. The measurement is needed for a go/no go decision just after production of a panel.

After the research phase a prototype production line will be designed, built and tested. Panels will be produced and tested. Prototype applications will be designed, built and tested.

The stainless steel concept

Commonly, development of vacuum insulation is characterised by a filler material of micro powder or foam (XPS or PUR), wrapped in plastic foils, mostly with a laminated aluminium layer. The foils are sealed, forming flaps at the edges of the panel. The seam welded flaps prevent interconnection of panels, increasing the edge losses. Because the diffusion of gases increases exponentially with temperature, applications above 20 °C are hardly possible. During this project a prototype production line will be developed for panels with different kinds of filler material, and a laser welded rectangular stainless steel envelope. This concept is chosen for the following reasons:

Edge losses

Because of the low λ value of the filler material, and the relative high λ value of the envelope material, the quality of the vacuum insulation panels will be considerably influenced by the envelope material and geometry. In the stainless steel concept we aim at edges of 25 µm, with straight edges. The straight edges make close interconnections possible, the gap between two panels will be in the order of millimetres. This results in a low cold bridge, there are no flaps which will increase the cold bridge.

An aluminium laminate of 7µm aluminium (λ = 237 mW/(m·K)), 12 µm polyester (λ = 0,15 mW/(m·K)) and 50 µm polyethylene (λ = 1,05 mW/(m·K)) has approximately the same effect on the cold bridge as 115 µm stainless steel (λ = 15 mW/(m·K)). Not only the average heat conductivity of a vacuum insulation panel is increased by the edge losses, it also causes cold spots. For determining the influence of the thickness of the edge, a simple 2-dimensional finite element model is written. Fig. 2b shows some results of varying the thickness of the stainless steel edge foil. Fig 2a shows the base geometry and parameters for the calculation. A thickness of 25 µm results in an average heat conductivity of 0,0026 mW/(m·K), increasing the heat conductivity with 30 %, the cold spot is 18 °C. An aluminium laminate would result in an average heat conductivity of 0,0037 $Wm^{-1}K^{-1}$, increasing the heat conductivity with 85 %, the cold spot is 14,5 °C. Decreasing the dimensions of the panel results in higher average heat conductivity's and the same cold spots.

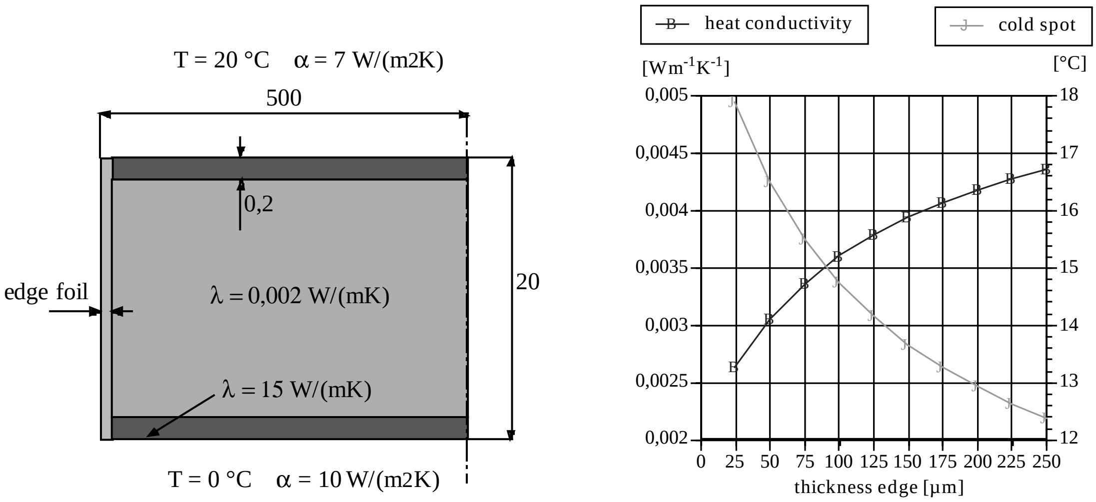

Figure 2: a) base geometry for calculation, b) results of calculation

Life expectancy

For the selected filler material the gas pressure has to stay below 10 Pa. The internal pressure increases by desorbing of gases from filler material and envelope and by gases permeating through the envelope. To obtain a life time of 50 years the pressure increase has to be < 6 10^{-9} Pa s^{-1} (or 0,2 Pa $year^{-1}$). Some continuous tests were done on prototype panels, using a vacovac tube device, measuring the slip of a rotating ball in a tube. The vacovac tube allows for continuous measurement in a closed panel (using a vacuum sluice), see fig. 3a.

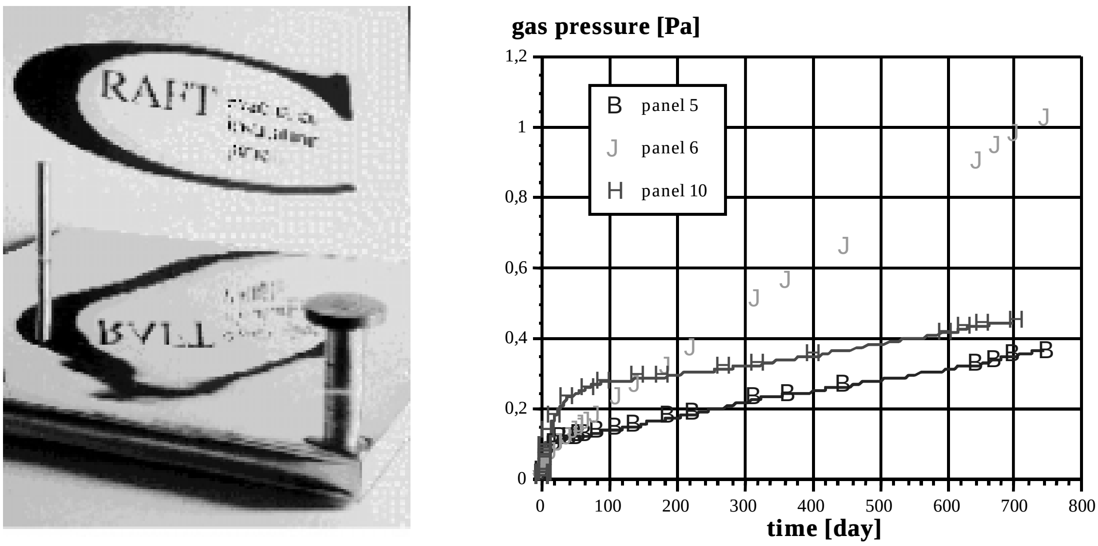

Figure 3: a) evacuated prototype test panel b) pressure rise of panels

The measurements of panel 5, 6 and 10 over a period of more than 2 years are shown in fig. 3b. Panel 5 shows the desired behaviour; desorption of the absorbed gases in the first 50 days and then a constant influx of 0,12 Pa year^{-1}. Panel 10 has been less good degassed, but shows a leak of only 0,11 Pa year^{-1}. Panel 6 is well degassed, but has a small leak in a corner that has been covered with an epoxy resin, causing a leak of 0,47 Pa year^{-1}.

Due to the laser welding the casing is hermetically closed. Fig. 3 gives examples of results of laser welding of thin foils.

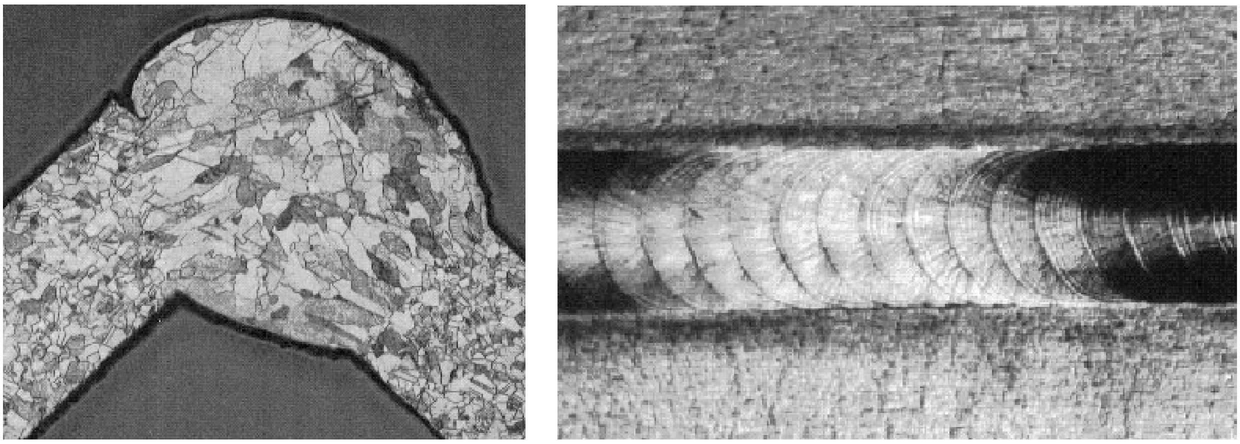

Figure 4: a) cross section of laser weld between two perpendicular foils of 200 µm
b) penetration weld of a foil of 50 µm to 100 µm

Temperature range

Panels with glass fibre as filling material can be used for temperatures up to 450 °C, increasing the application field. Panels with polyurethane and polystyrene as filler material will be cheaper but can be used for temperatures of respectively 120 and 80 °C. The envelope is hermetically closed, the panel is completely enclosed by a metal with a very low diffusivity for gases. An increase in temperature does not lead to a considerable increase in diffusion of gases through the envelope.

Interconnection of panels

The straight edges allow interconnection of panels, which allows building of constructions, with low thermal bridges. The panels do not have flaps which would cause a space between two panels, or increase the thickness of the edge, when folded alongside the edge.

Other

- The concept of the steel envelope and glass fibre as filling material allows to make the panel switchable with respect to thermal conductivity by a factor of > 50. A metal hydride can be used, when heated it will emit hydrogen, causing an increase of thermal conductivity. The hydrogen will be absorbed when the metal hydride is *not* heated, resulting in a super isolated panel.
- for several applications stainless steel is required for hygienically reasons (e.g. cold storage).
- stainless steel is a better material for protection, compared to aluminium or plastic foil.
- no finishing material has to be used
- no corrosion is expected

Conclusions

Stainless steel has some advantages over common used envelope materials for vacuum insulation panels.

- Considering a panel of 1 m^2, the cold bridges are small (30 %) due to the thin edge foils (25 µm), the average heat conductivity is low.
- Due to the hermetic closed envelope, the leak rate is small, the pressure increase is < 0,2 Pa $year^{-1}$ the life expectancy is > 50 years.
- Panels can be used for temperatures till 450 °C, increasing the application field
- The panel promises to be cheap (33 Euro/m^2), when produced in mass production

Workshop on HiPTI (Annex 39)

Proceedings of the workshop

Preface

The Swiss activities in the area of new insulation materials for buildings lead to the conclusion that this topic should be looked at on a international basis. The reasons are to share the necessary expenses for R&D activities, to involve the important producers of the needed materials, which are international companies, and to inform and stimulate the market for such products on a large scale.

The proposal for such a programme was adopted by the Executive Committee of the IEA Implementing Agreement 'Energy in Buildings and Community Systems' (ECBCS) in summer 2000 as Annex 39.

The conference and workshop held in Zurich on January 22 - 24, 2001 aimed at defining more precisely the content of the Annex, find the suitable partners for the work to be done and set up an action item list, leading to the official start of the Annex in September 2001.

1. Conclusions of the working groups

1.1. Subtask A *Basic concepts and materials*

1.1.1. Subject

In Subtask A High Performance Thermal Insulation should be developed which meets the needs of HiPTI systems, i.e. components of building envelope and HVAC systems.

In case of vacuum insulations, Subtask A will deal with production of VIP as a whole. This includes evacuation and sealing of panels.

1.1.2. Discussed topics

Objectives

Test and improve existing materials

Research on alternative concepts

Main tasks

Database

Collection of data for possible materials:

- core materials: foams, fibres, powders
- envelope: films, foils, steel envelope
- getter materials
- application based definition of sytem properties in coordination with subtask B

Improvement of envelope

- better high barrier films and foils
- sealing and packing technology
- reliable and fast test methods

Core material

- powders: lower density, lower conductivity
- high allowable gas pressure
- mechanical properties

Quality tests of vacuum panels

- quality standards
- long life time, high reliability
- ageing methods (function of temperature, mechanical stress, humidity)
- internal gas sensor
- environmental aspects (energy input, recycling, emission)

Standardization of testing methods

- quality standards
- gas and moisture transmission
- mechanical properties
- formats

Models for performance of panels

- calculation methods for performance evaluation

1.2. Subtask B *Application and system development*

1.2.1. Subject

In Subtask B insulation systems for buildings and insulated components (envelope and HVAC) based on HiPTI will be developed and tested.

1.2.2. Discussed topics

Where should we use HiPTI systems

Where place is scarce / expensive

Where temperature difference is high

Where the vacuum insulation can easily be replaced (depending on expectancy of VIP lifespan)

Where VIP is well protected (plaster, metal) against getting punctured by screws, nails etc.

The interesting applications mentioned during the workshop are listed bellow:

Building envelope	HVAC components
timber-frame construction (low energy houses)	solar collectors
external cladding systems	storage tank (hot/cold)
façade renovation system (external/internal)	cooling and freezing appliance
panel heating/cooling (floor, wall, ceiling)	tube (district heating)
flat roof, terrace	duct
ceiling (basement)	heating systems
cold-storage chamber	energy storage container
door	
frame enlargement	
window frame	
roller shutter box	
radiator niche	

There are easier and more complicate applications. The group could not agree on starting with just the easier applications since: 'The more problems you face the more you learn'.

Crucial questions

expectancy of lifetime

guarantee by the producer (probability of failure): an on site monitoring procedure has to be developed.

moisture problems

Standards

Producers of VIP and potential producers of HiPTI systems think, that a process of standardization has to be started. The needed standards comprise:

Quality of VIP: physical properties have to be measured and declared (guaranteed) in a standardized manner (Subtask A). These standards will improve confidence in VIP products.

Formats of VIP: As in the case of conventional products, standard panel formats have to be defined.

Intellectual property

Certain applications will be developed by different companies. These companies must have an advantage from participating in the Annex, so they may not be willing to declare their whole know how. To reduce these problems, it may be a good solution, that specific applications are just developed by one company per country.

Central Services (shared problems)

A catalogue of shared problems has to be worked out and answered in common, as a basis for all companies, which develop HiPTI systems within the Annex.

Projects

In some countries there are already HiPTI projects running or in preparation. Others expressed at least their interest for certain applications or questions:

- Switzerland
  - running projects: façade renovation system (external/internal), flat roof, terrace, door, boiler.
  - projects in preparation: tubes/ducts, foam cover for VIP, testing/calculations on HiPTI systems.
- Germany: has developed VIPs for various applications and is currently running different demonstration projects in buildings in Bavaria.
- France: development of façade cladding systems in preparation. The system will be tested under extreme conditions. France could provide this testing infrastructure for other projects.
- Germany: Is currently running different demonstration projects in Bavaria (building envelope).
- Netherlands: Is interested in façade renovation systems and solar collectors.
- Austria: Could probably work on common questions in the area of building physics (moisture).
- Canada: May be interested in hot water equipment.

1.3. Subtask C *Demonstration and information dissemination*

1.3.1. Subject

In Subtask C successful developments of Subtask B will be applied in suitable buildings. Information from all Subtasks has to be disseminated.

1.3.2. Discussed topics

"Vision" of demonstration projects

Three types of demonstration projects with different goals and requirements:

	Demonstration	Test application
Integral project	Building renewal New office building	
Single elements	Solar collector Façade etc.	Pipe-, ductwork Interior wall-insulation etc.
Characteristics	Integral convincing concept Demonstration of feasibility and reliability	"High risk" concept Experiences and feedback to product optimisation

Scope conditions, requirements and aspects to be considered

Professionalism: professional quality standards of products and project (no do-it-yourself or Disneyland)

Cost effectiveness: Believable demonstration of future economic competitiveness.

Awareness of role and duty of the demonstration part of the project:

- Neutral information (promotion)
- Better products for the consumer

Focus on opinion leading groups: architects, big building owners, consumer?

Use positive side effects and technology trends:

- High-tech aspects
- Architectural and design options

Further procedure

Precise definition of demonstration task profile

Fix priorities, dates, milestones

Get in touch with

- VIP producer
- Element manufacturers
- Investors, building owners
- architects

Clear means and methods

- Competitions
- Subsidies
- Measurement concepts
- etc.

Get the funding

2. Next steps

2.1. National projects

For each present country, a coordinator was assigned (see Appendix) which is responsible for the organisation of a national project until the definite national project coordinator is found. This means he will contact the necessary people to form a national project team. This team has to work out a draft of the national activities. This draft has to be sent to the Operating Agent till April 15.

Each participating country should contribute at least to Subtask B and C. The expected commitment of each country is described in the Annex text.

2.2. Subtask Leader

During the workshop some suggestions concerning the three Subtask Leaders were made (see Appendix). Further suggestions can be made to the Operating Agent till April 15. The decision on the definite Subtask Leaders has to be taken till the next meeting which probably will be on May 22 in Italy.

Persons who are interested in becoming Subtask Leader should be independent of any product relevant to the Annex.

3. Appendix

Project schedule

Date	Action	Responsability
24.01.2001	Workshop, selction of National Coordinators and Subtask leaders	
15.02.2001	Workshop report	M. Erb
15.04.2001	Drafts of national projects must be delivered to Operating Agent	National Coordinators
22.05.2001	Meeting of Operating Agent, Subtask Leaders and National Coordinators in Rom in order to coordinate national projects	M. Erb (general) P. Manini (local)
30.05.2001	Intermediate report to ExCo and workshop participants	M. Erb
15.06.2001	Information of ExCo Members at the ExCo meeting	M. Zimmermann and M. Erb
15.09.2001	Definite text of national projects and finance plan	National Coordinators
24./25.9. 01	Meeting national teams in Würzbürg	ZAE/M. Erb
15.11.2001	ExCo meeting. Official project start	M. Zimmermann

National project coordinators

Austria	Dreyer, Jürgen
Belgium	Hens, Hugo?
Canada	Kumaran, Kumar
Denmark	M. Zimmermann makes another contact
France	Quenard, Daniel
Germany	Caps, Roland / Heinemann, Ulrich
Italy	Manini, Paolo / De Carli
Netherlands	Cauberg, Hans
Sweden	Jóhannesson, Gudni
Switzerland	Erb, Markus
U.K.	M. Salmon/Earl Pereira (will be contactet by Mr. Kumaran)

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