Bavarian Center for Applied Energy Research
(ZAE Bayern)

Vacuum Insulation Panels
Potentials, Challenges and Applications
- an introduction -

Ulrich Heinemann

11th International Vacuum Insulation Symposium
September 19 - 20, 2013, Zurich

MIT SONNE UND VERSTAND.

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CONTENT

- Heat transfer in thermal insulations

- Challenges:
    - ❖ Maintaining the internal gas pressure on the required level
    - ❖ Thermal bridging

- Applications

HEAT TRANSFER MECHANISMS

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- ~~Convection~~
- **Conduction**
  - **Solid conduction** (structure, density, pressure load)
  - **Gaseous conduction** (gas, porosity, structure, pore size)
- **Thermal radiation** (density, “particle size”, $\propto T^3$)

$$\lambda = \lambda_{solid} + \lambda_{gas} + \lambda_{rad} + \lambda_{coupl}$$

SOLID CONDUCTION VIA THE SKELETON

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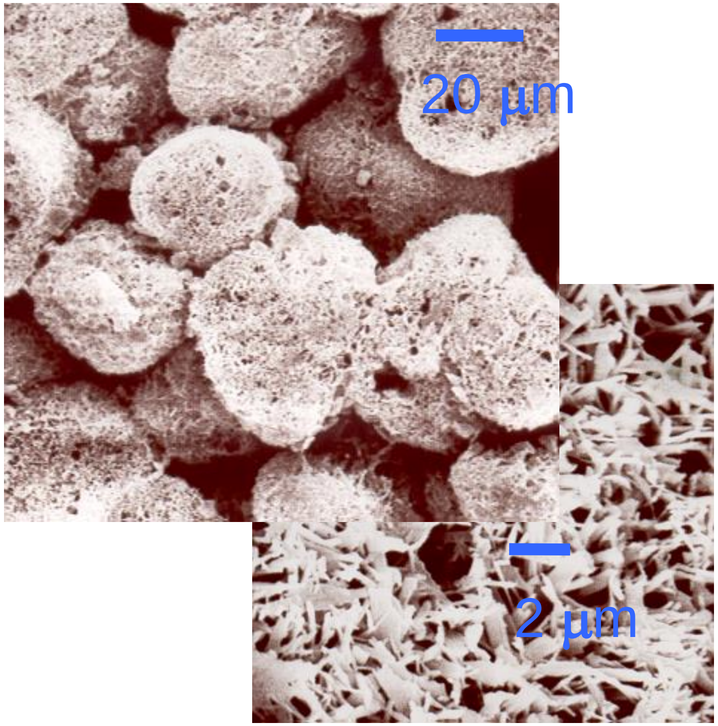
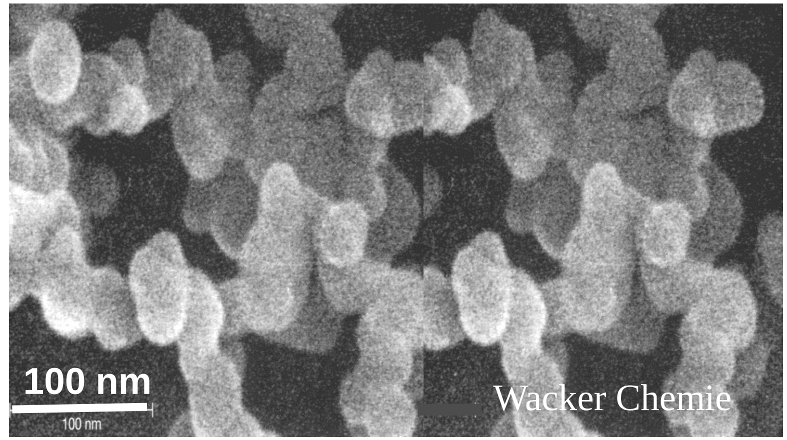
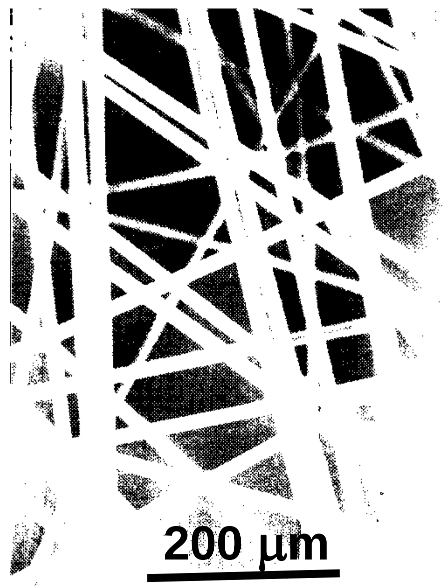


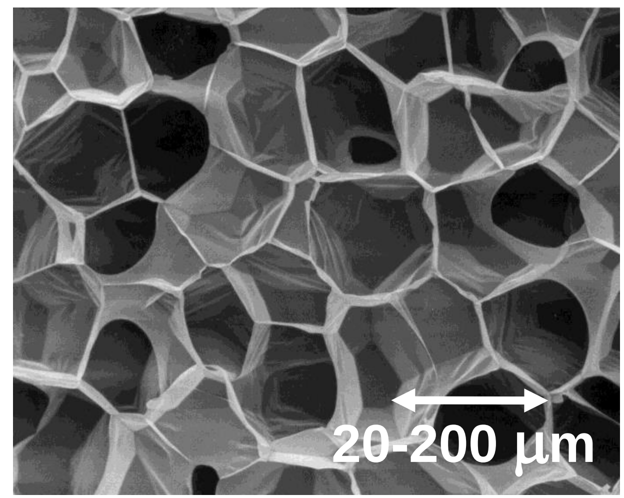
$CaSiO_3$-structure



Fumed silica

Spin glass fibres





PU foam

SOLID THERMAL CONDUCTIVITY

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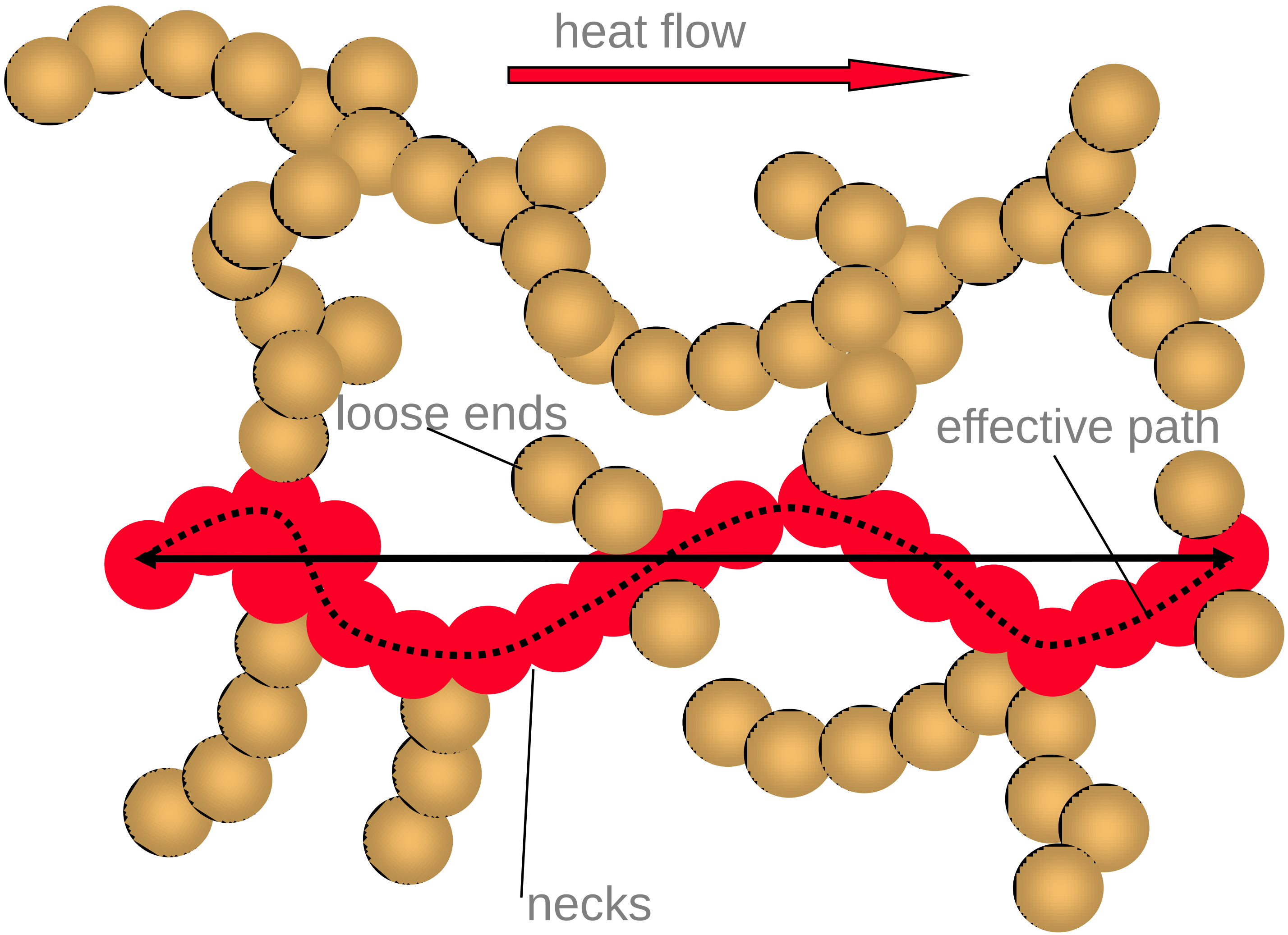

$\lambda_{solid} \sim \rho^{\alpha}$

for foams

$\alpha \approx 1$

for fractal powders

$\alpha \approx 1.5\ldots2$

VARIATION OF PRESSURE LOAD

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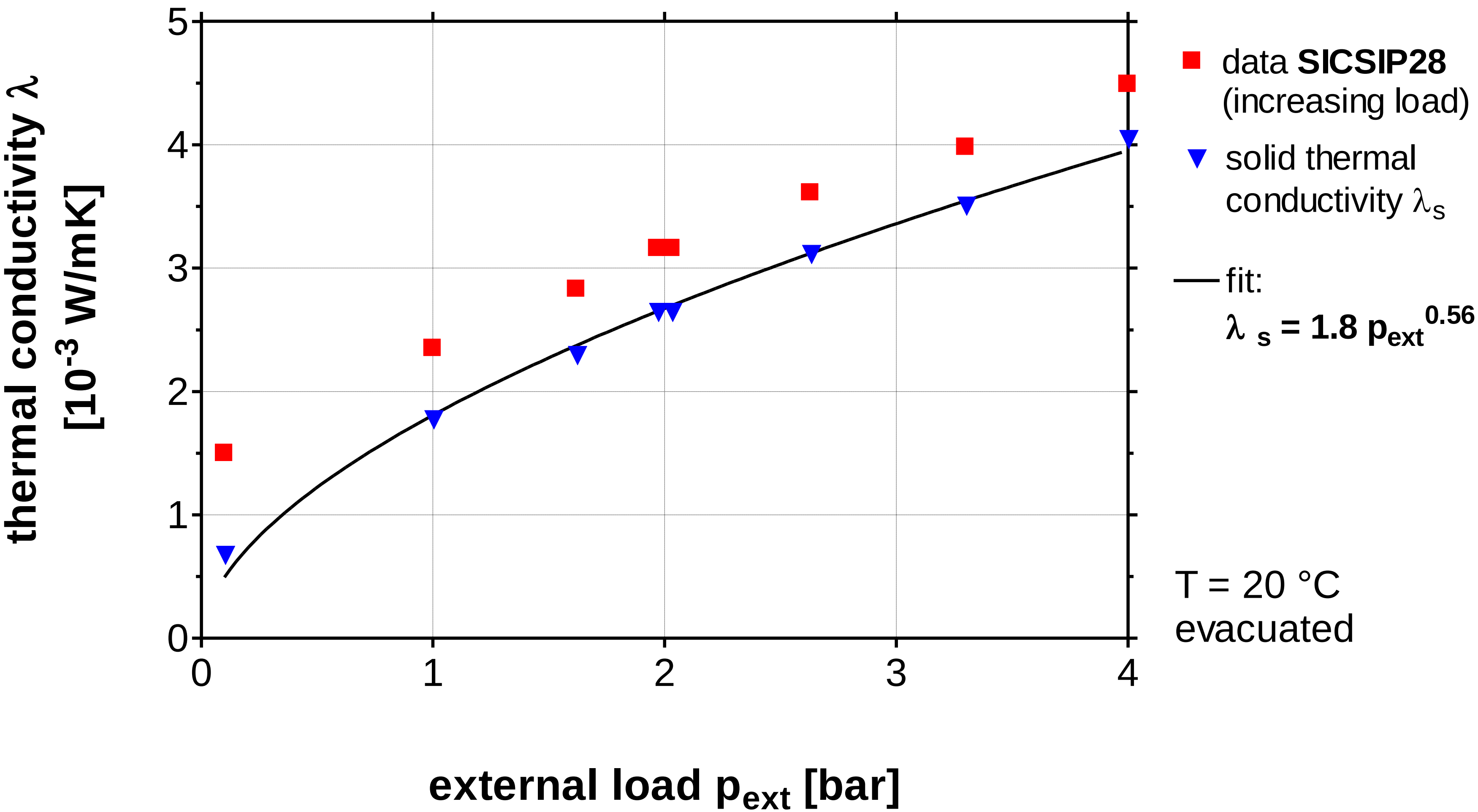

GASEOUS CONDUCTION, MATERIALS WITH MICROMETER STRUCTURE

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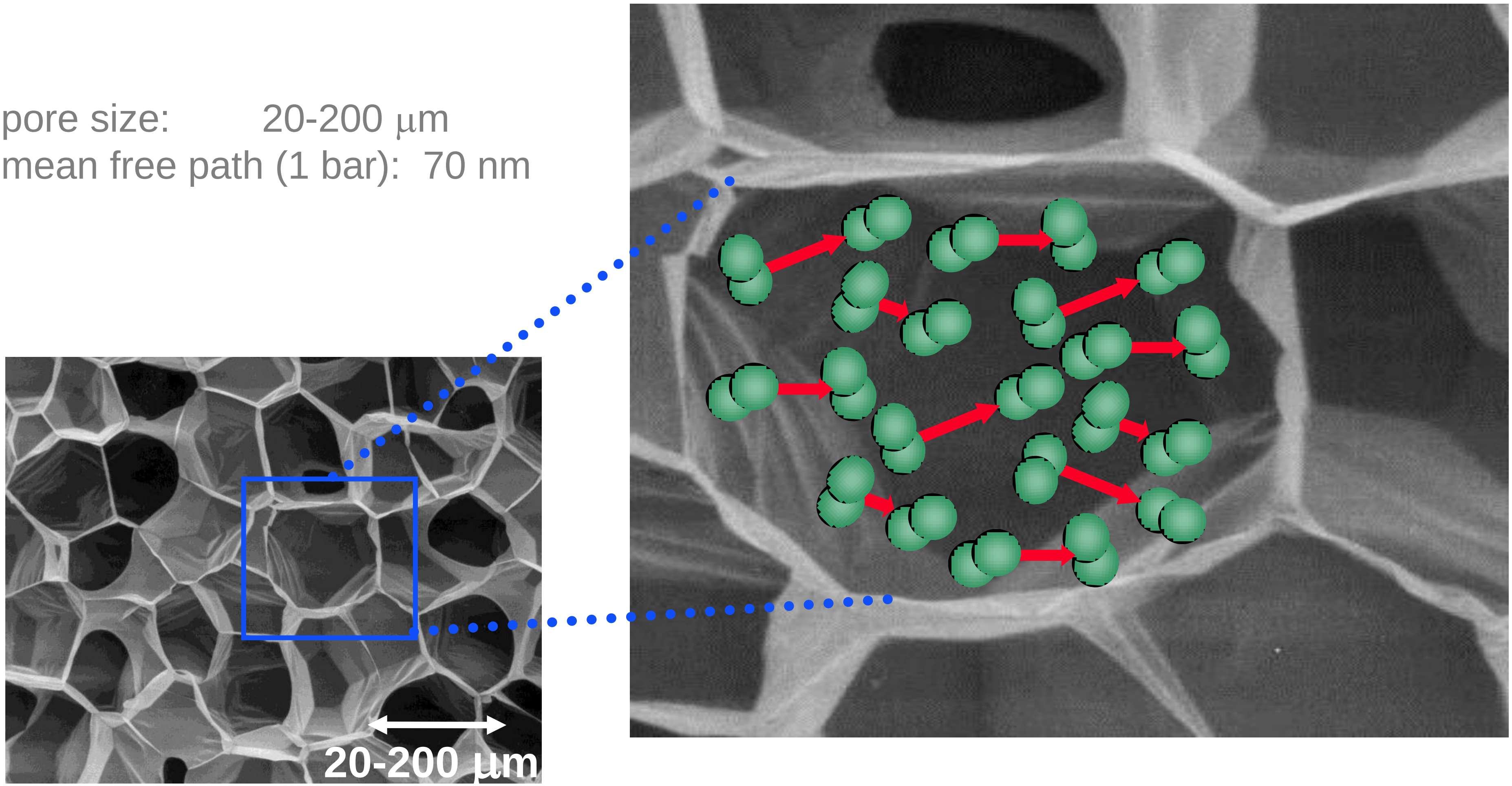
pore size: 20-200 µm
mean free path (1 bar): 70 nm



GASEOUS CONDUCTION,
MATERIALS WITH NANOMETER STRUCTURE

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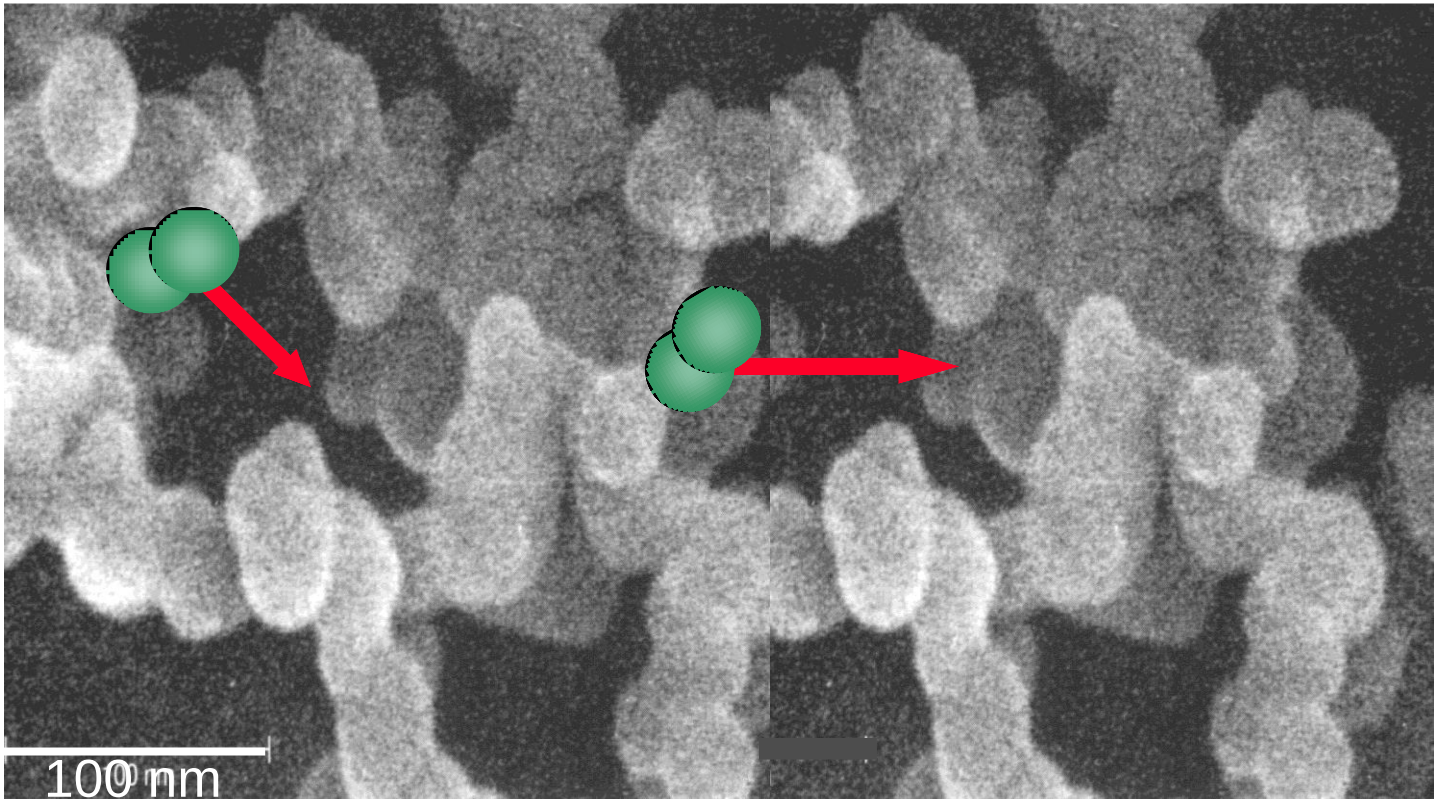

Wacker Chemie

pore size: 200-500 nm
mean free path (1 bar): 70 nm

COUPLING EFFECTS

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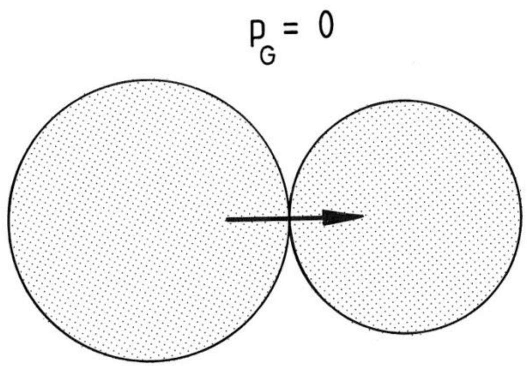
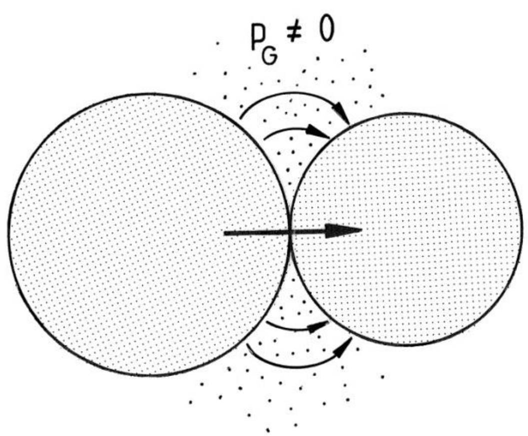


In vacuum the point contacts between adjacent beads provide high thermal resistances,



in air these more or less are shorted out.

The higher the conductivity of the solid beads, the stronger is the coupling effect.

MOISTURE ADSORPTION

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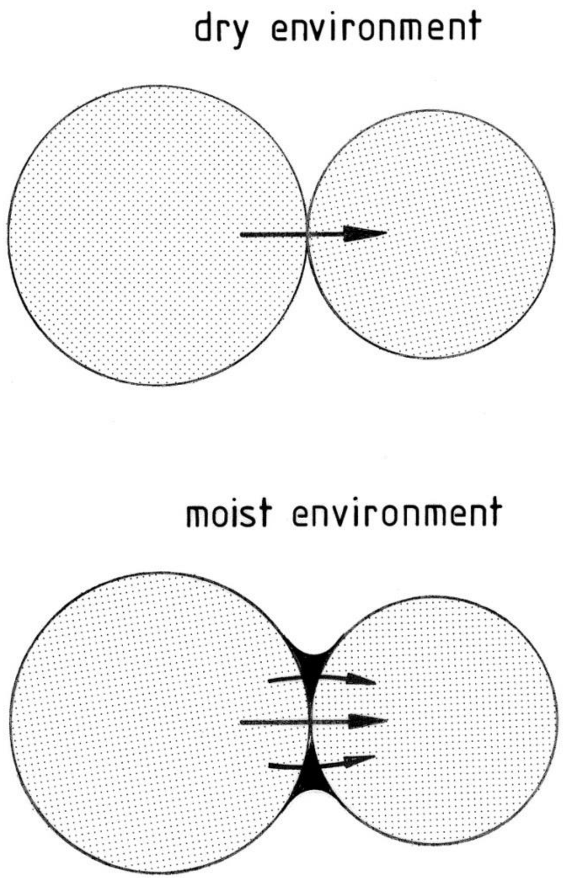
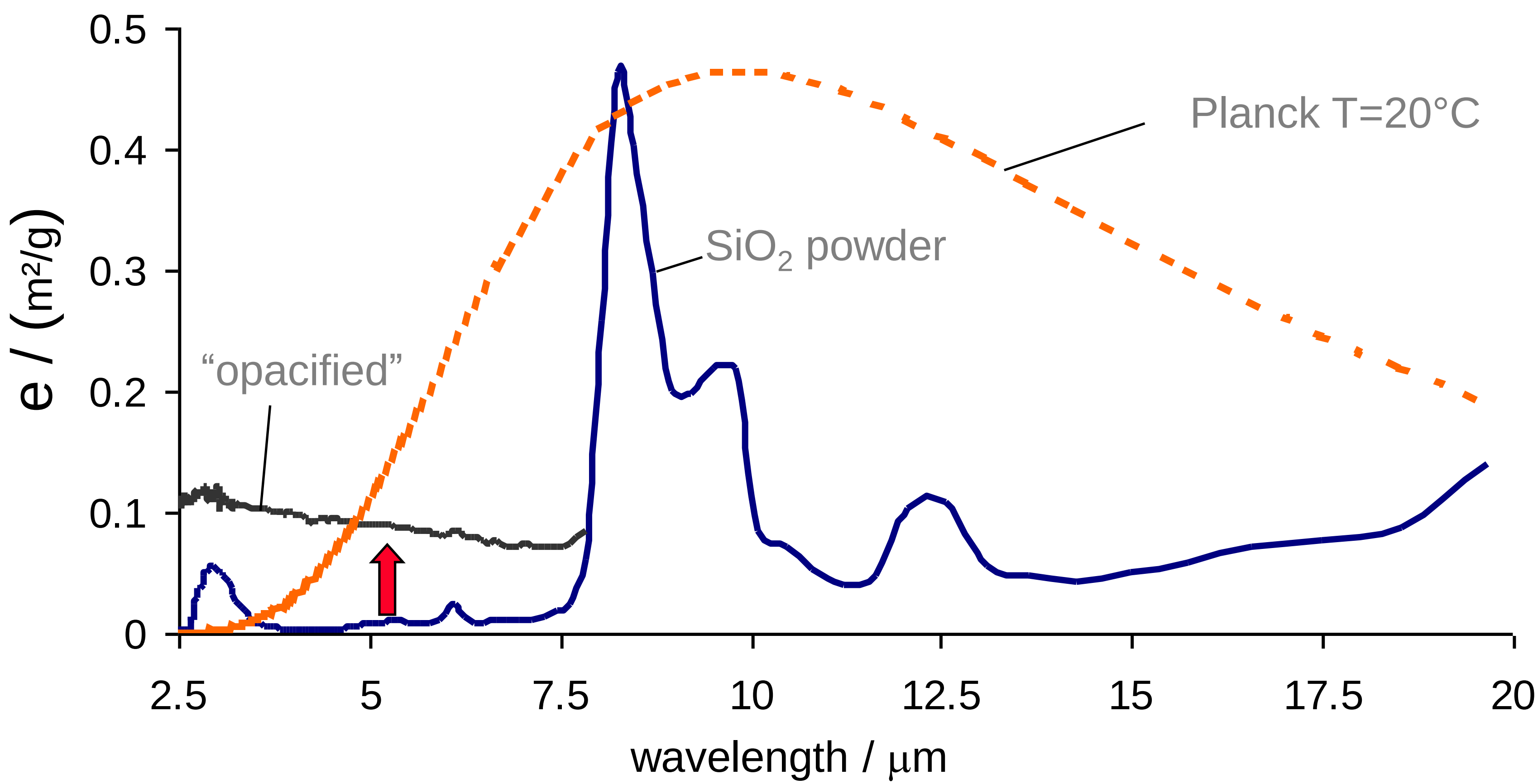


Water vapor preferentially is adsorbed at the concave necks;
this leads to an increase in “solid conductivity”.

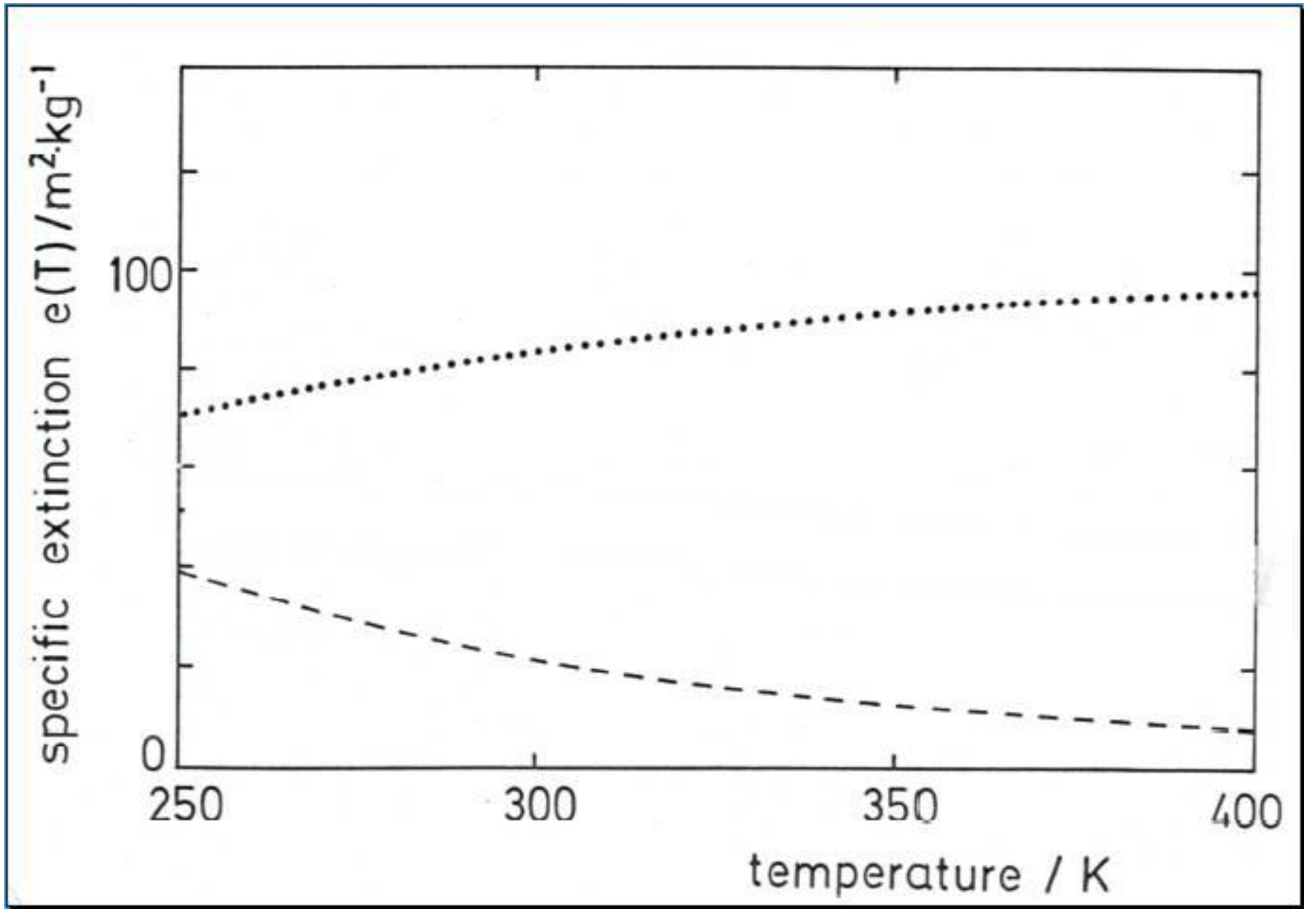
SPECTRAL EXTINCTION COEFFICIENT

$$\lambda_{rad} \propto \frac{T^3}{E(T)} \propto \frac{T^3}{e(T) \cdot \rho}$$

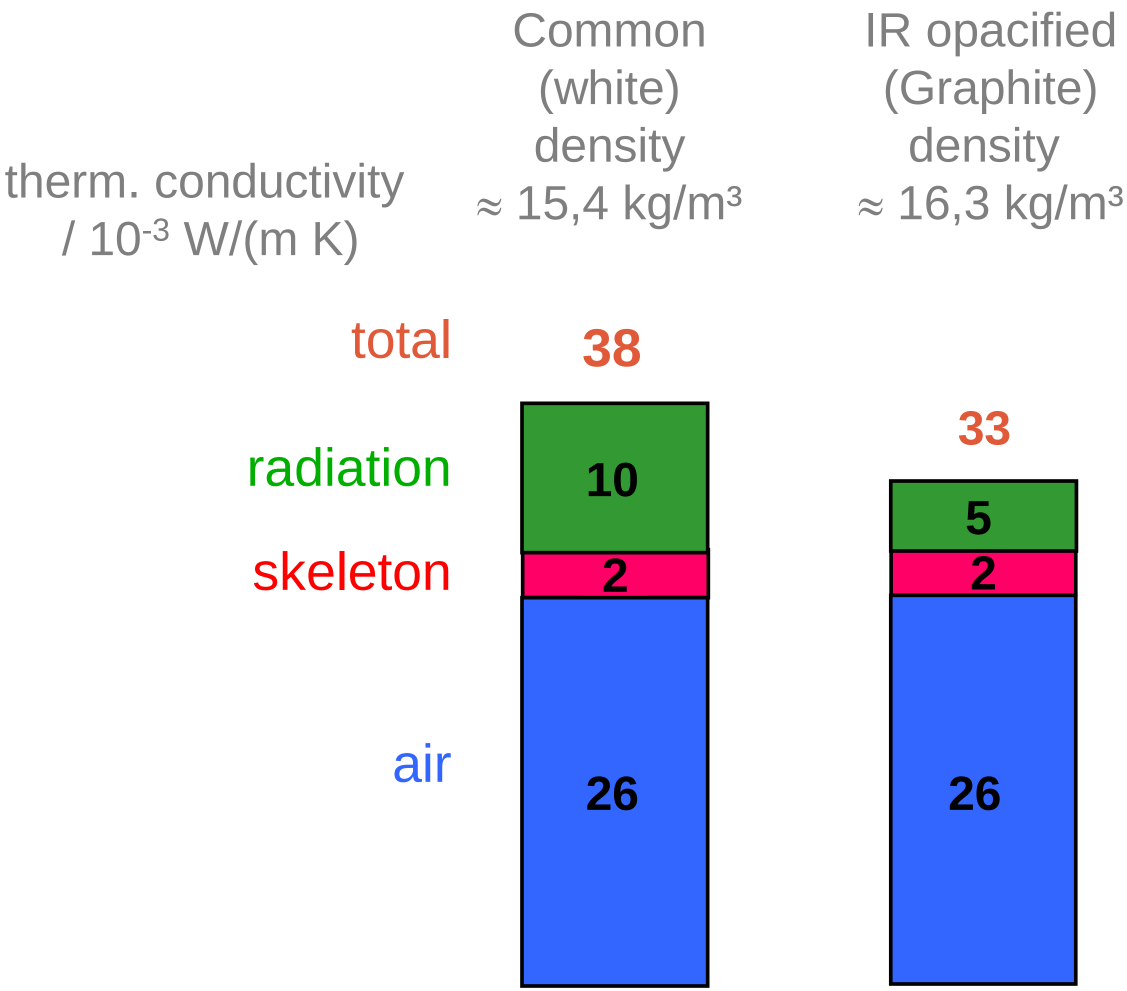


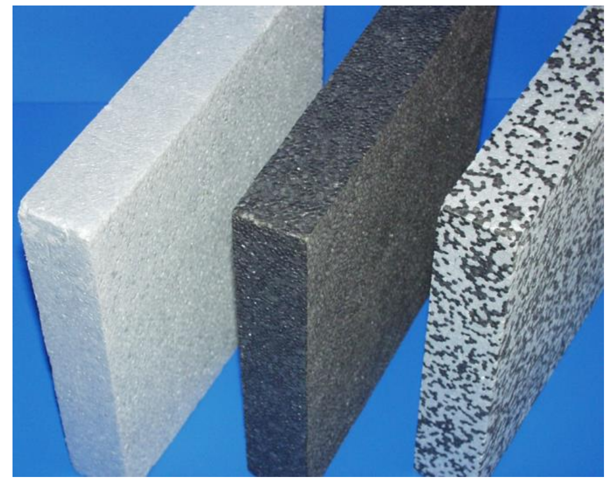
RADIATIVE CONDUCTIVITY

$$\lambda_{rad} \propto \frac{T^3}{e(T) \cdot \rho} \propto \frac{1}{\rho}$$



EXPANDED POLYSTYRENE (EPS)





COMPARISON OF THERMAL INSULATION MATERIALS

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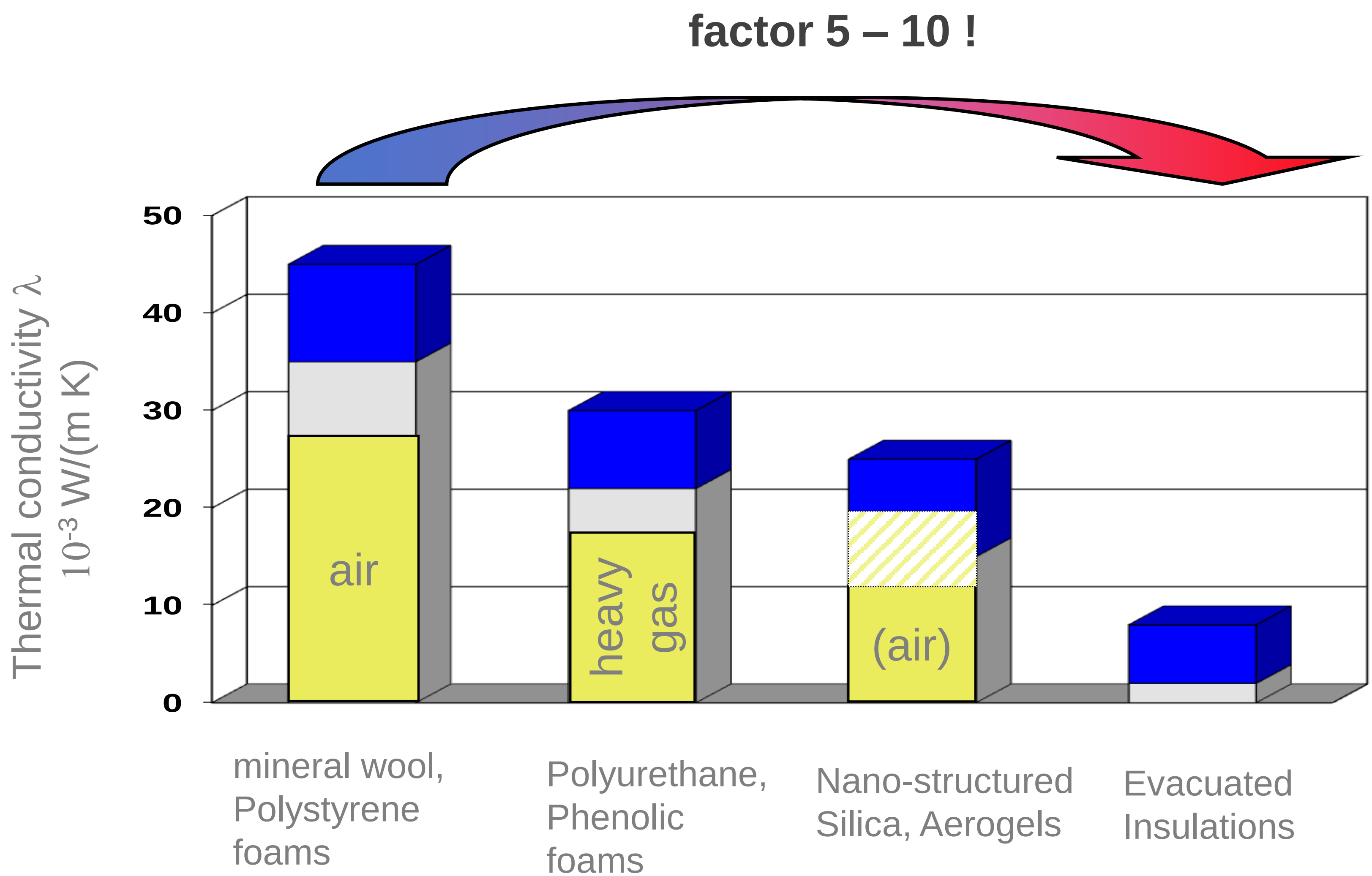

EVACUATED THERMAL INSULATIONS

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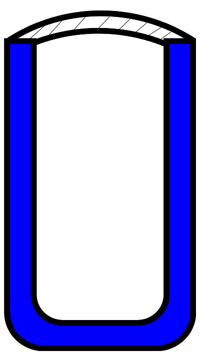
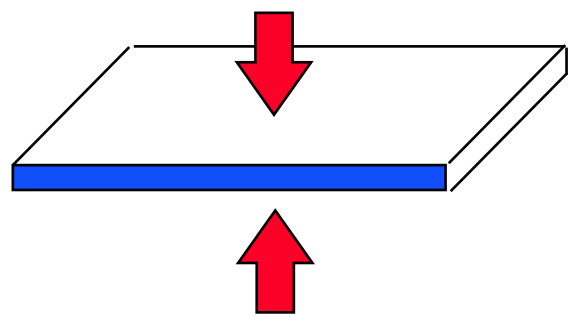
vacuum insulations

cylindrical vessels	flat panels
	load bearing filler materials
$\lambda^{*} = 0.01...5 \cdot 10^{-3} \frac{\mathrm{W}}{\mathrm{m} \cdot \mathrm{K}}$	$\lambda = 2...8 \cdot 10^{-3} \frac{\mathrm{W}}{\mathrm{m} \cdot \mathrm{K}}$



cryogenic,
dewars,
thermo cans



load:
"10 tons per square meter"

VACUUM INSULATION PANELS

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Insulation material ➔ insulation **elements**

In many aspects comparable to a window:

- effort for planning, standard sizes ⇔ customization
- sensitive against damage
- increased heat transfer at the edges

VIP	=	core material	+	envelope
requirements:		• to be evacuated (open pores) • resistant to compression • „clean“ (no degasing)		„vacuum tight“

DEGUSSA PANEL FROM THE 1990s

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Degussa/Hanau produced VIP for refrigerator applications with precipitated silica kernel

$\rho \approx 200$ kg/m³
$\lambda \approx 0.006\ldots0.007$ W/(m·K)
life expectancy 15 years

bottom: U-shaped organic laminate
top: Al-foil (12µm).

OWENS CORNING PANEL FROM THE 1990s

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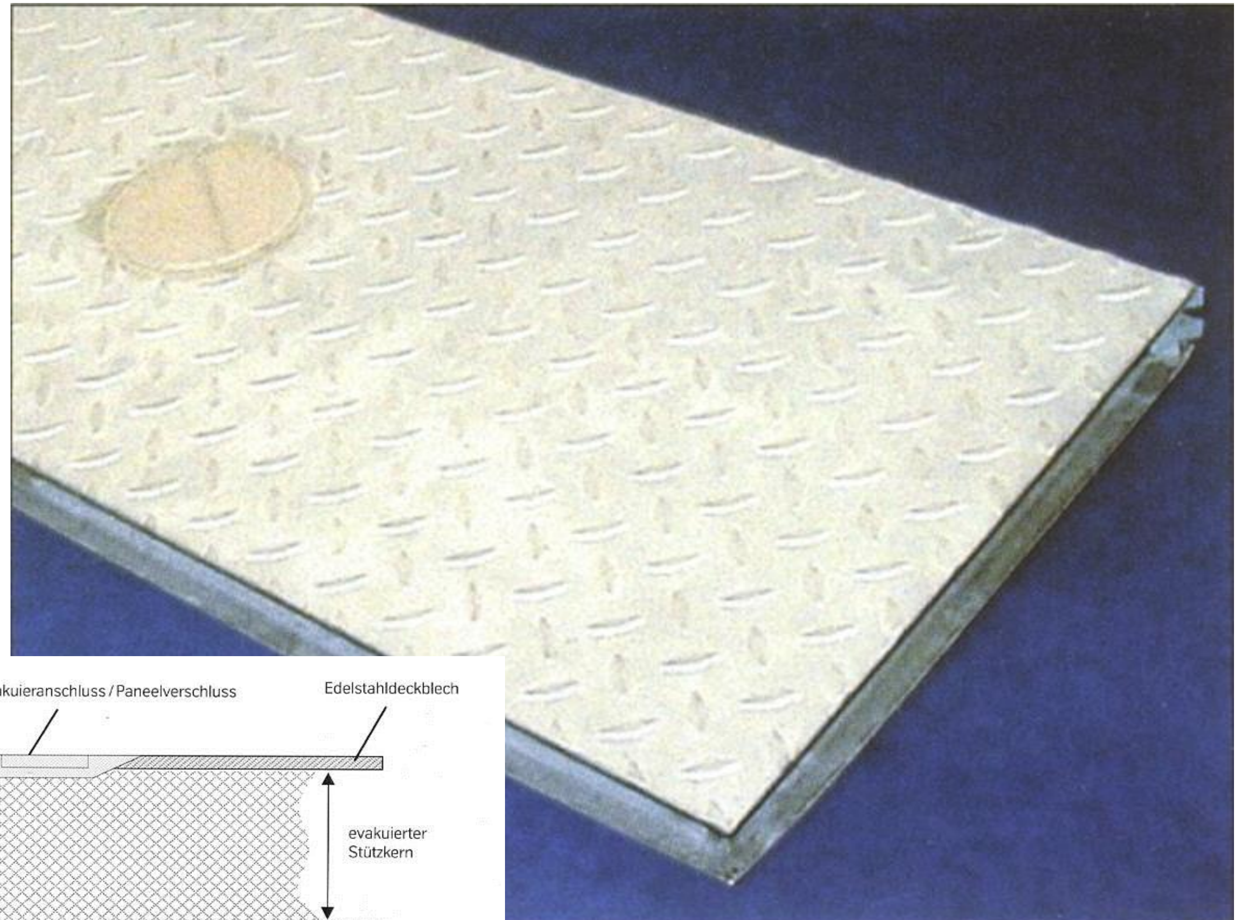
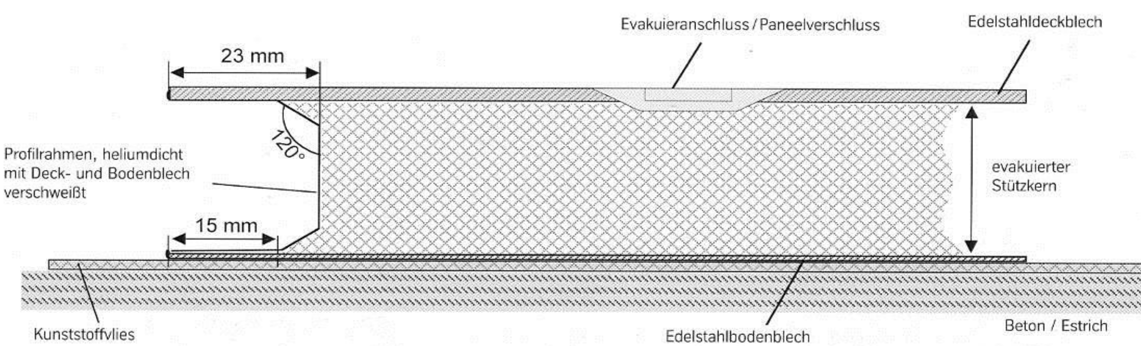
**Owens Corning produced fiber-filled VIP („Aura“)
with a density of 240 kg/m³,
75 µm e-beam welded sheet steel envelope,
center-λ ≈ 0.002 W/(m·K).**

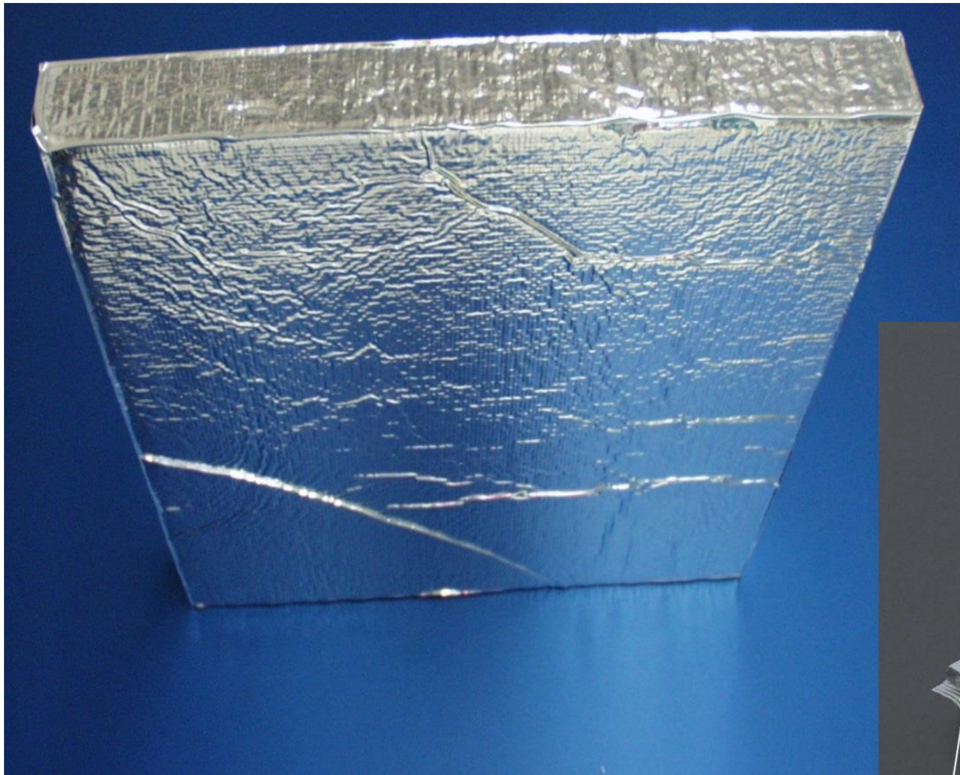
THYSSEN KRUPP PANEL

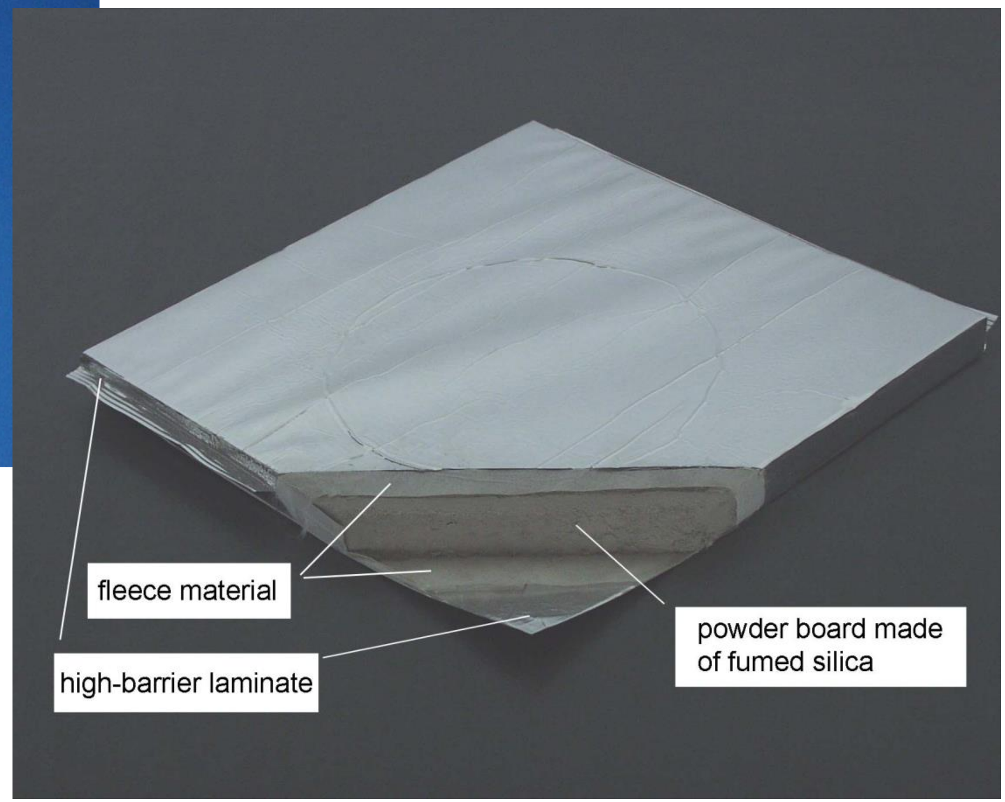
Thyssen Krupp / lambdasave
envelope: stainless steel, welded,
core: fumed silica,
used for the bottom of cold chambers.



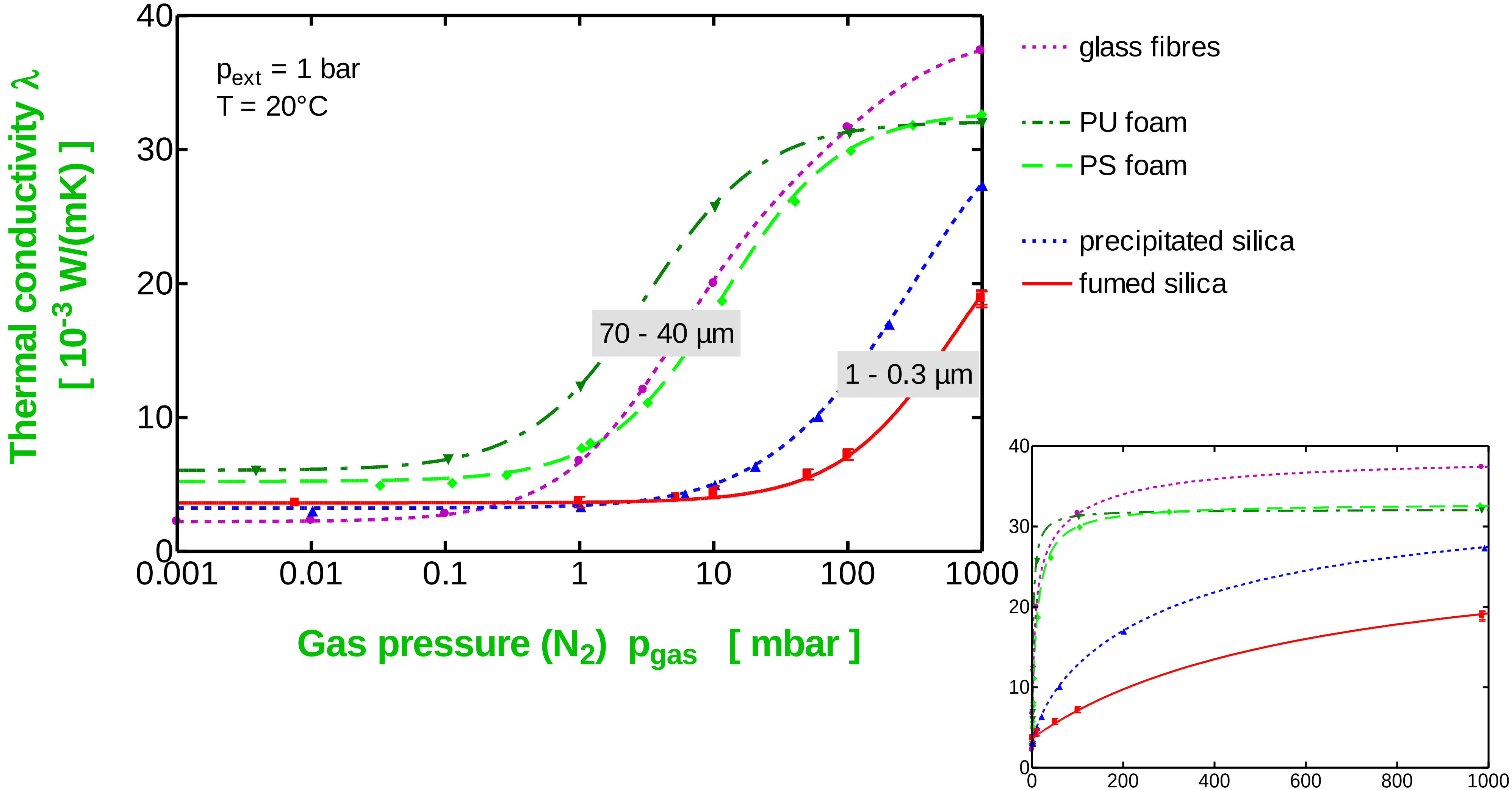


PANELS WITH HIGH BARRIER LAMINATE

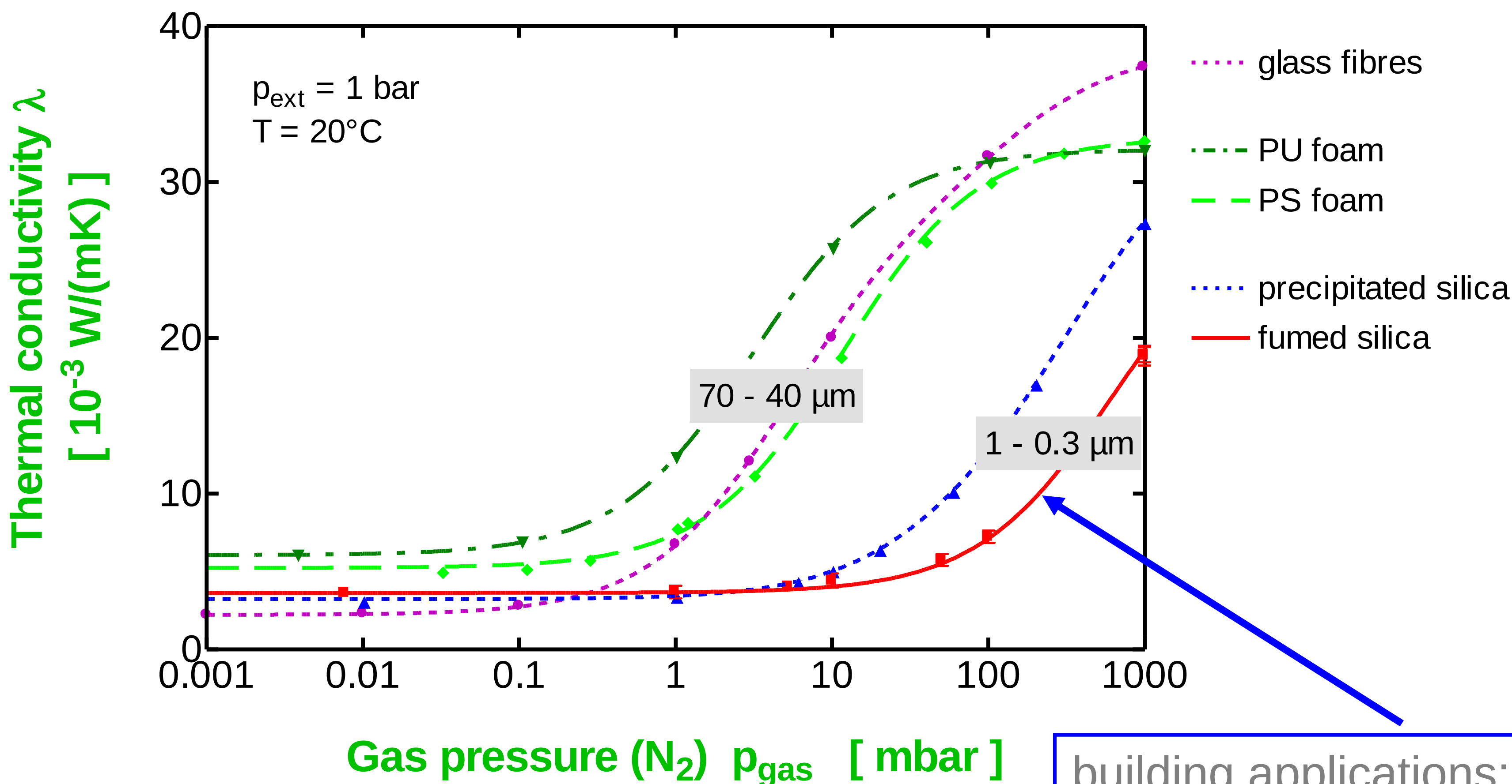




THERMAL CONDUCTIVITY



THERMAL CONDUCTIVITY



building applications:
fumed silica +
metallized high barrier laminate

ENVELOPE MADE OF GLASS OR METAL

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Envelope made of glass or metal:

+ sufficiently tight,
  applicable for all filler materials,

+ wide experience from vacuum technics
  and cylindrical „load bearing“ evacuated insulations
  thermos flasks and cryo vessels,

+ „relatively robust“

- manufacturing complex and costly

METALLIZED OR ALUMINUM HIGH BARRIER LAMINATES

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Envelope made of Aluminum laminates or metallized high barrier laminates:

- penetrating gases reduce the insulation performance
  Permeation:
  - through the laminate, through the seams,
  - „dry air“ and water vapor
  - depending on temperature und humidity

- higher risk of damage
- reliability / durability

+ flexible manufacturing
+ manufacturing less expensive

THERMAL BRIDGING, OVERALL U-VALUE

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- increased heat transfer at the edges, in gaps and at any disruption of the VIP layer

- compared to conventional insulation solutions cold bridges are much more critical when VIP are used

➔ **effective / overall U-value is larger than expected for the center of the VIP!!!**

(depending on the specific situation in application)

THERMAL BRIDGE EFFECTS (ENVELOPE AND GAPS)

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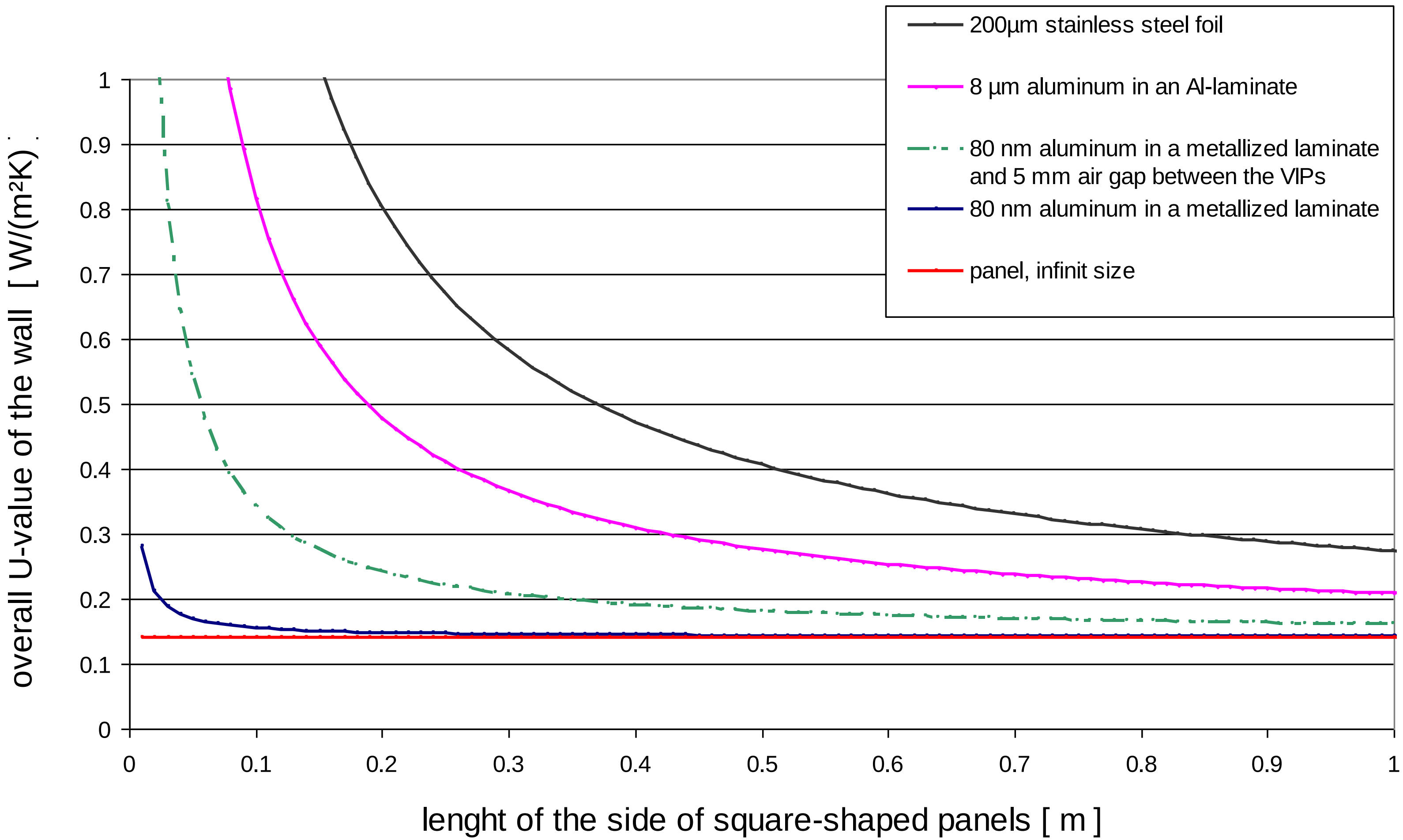

Wall: 17.5 cm sand-lime brick, 3cm VIP + 3 cm PS

THERMAL BRIDGE EFFECT (DEPENDING ON SITUATION)

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VIP: thickness 1 cm, thermal conductivity 0.005 W/(m K), width 1m, length infinite								
Thickness of Alu within the laminate	heat transfer resistance hot side	heat transfer resistance cold side	additional layers at both sides	overall U-value	R-value (total)	R-value adj. + add- layers	R-value center of panel	reduction of the R-value by the laminate
	m²K/W	m²K/W		W/m²K	m² K/W		m² K/W	
8µm	0	0		0.8196	1.22	0	2	-0.78
8µm	0.13	0.04	1mm Aluminum sheet	0.6860	1.46	0.17001	2	-0.71
8µm	0.13	0.04		0.5471	1.83	0.17	2	-0.34
8µm	0.13	0.04	5mm Polystyren 040	0.4649	2.15	0.42	2	-0.27
80 nm	0	0		0.5032	1.99	0	2	-0.01
80 nm	0.13	0.04	1mm Aluminum sheet	0.4635	2.16	0.17001	2	-0.01
80 nm	0.13	0.04		0.4632	2.16	0.17	2	-0.01
80 nm	0.13	0.04	5mm Polystyren 040	0.4151	2.41	0.42	2	-0.01

APPLICATIONS

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For the same thermal resistance an insulation using VIP is more expensive and somewhat challenging compared to a conventional insulation.
Thus VIP are used when space is limited, valuable or when a significant higher performance is required,
e.g.:

- refrigerators, freezers
- small transport boxes or containers
- buildings
  - for economical reasons: cities with high costs of the ground,
  - refurbishment, when additional costs can be avoided
  - technical reasons
  - architectural reasons
- …

EXAMPLE TRANSPORT BOX

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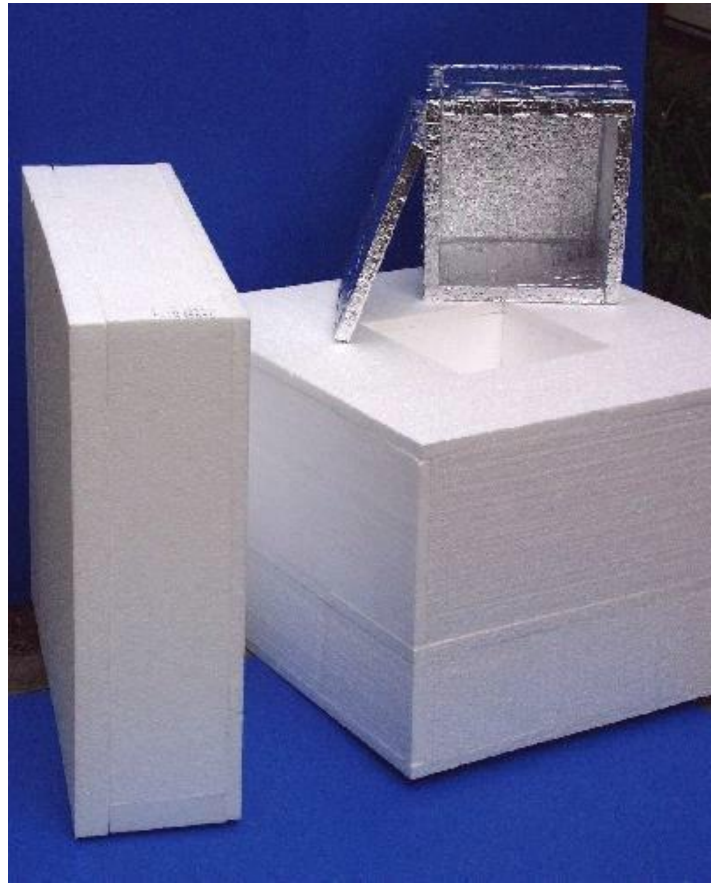
Transport boxes with similar insulation properties

here:
The volume of the VIP insulated box is about 1/20 of the standard PS-Box



BUILDING APPLICATION

Successful “self-trial” using VIP within a façade of the ZAE-building in 1999

BUILDING APPLICATION

Renovation of gable façade

Thank you for your kind attention!

Energy Efficiency Center
http://www.energy-efficiency-center.de/en/Home//