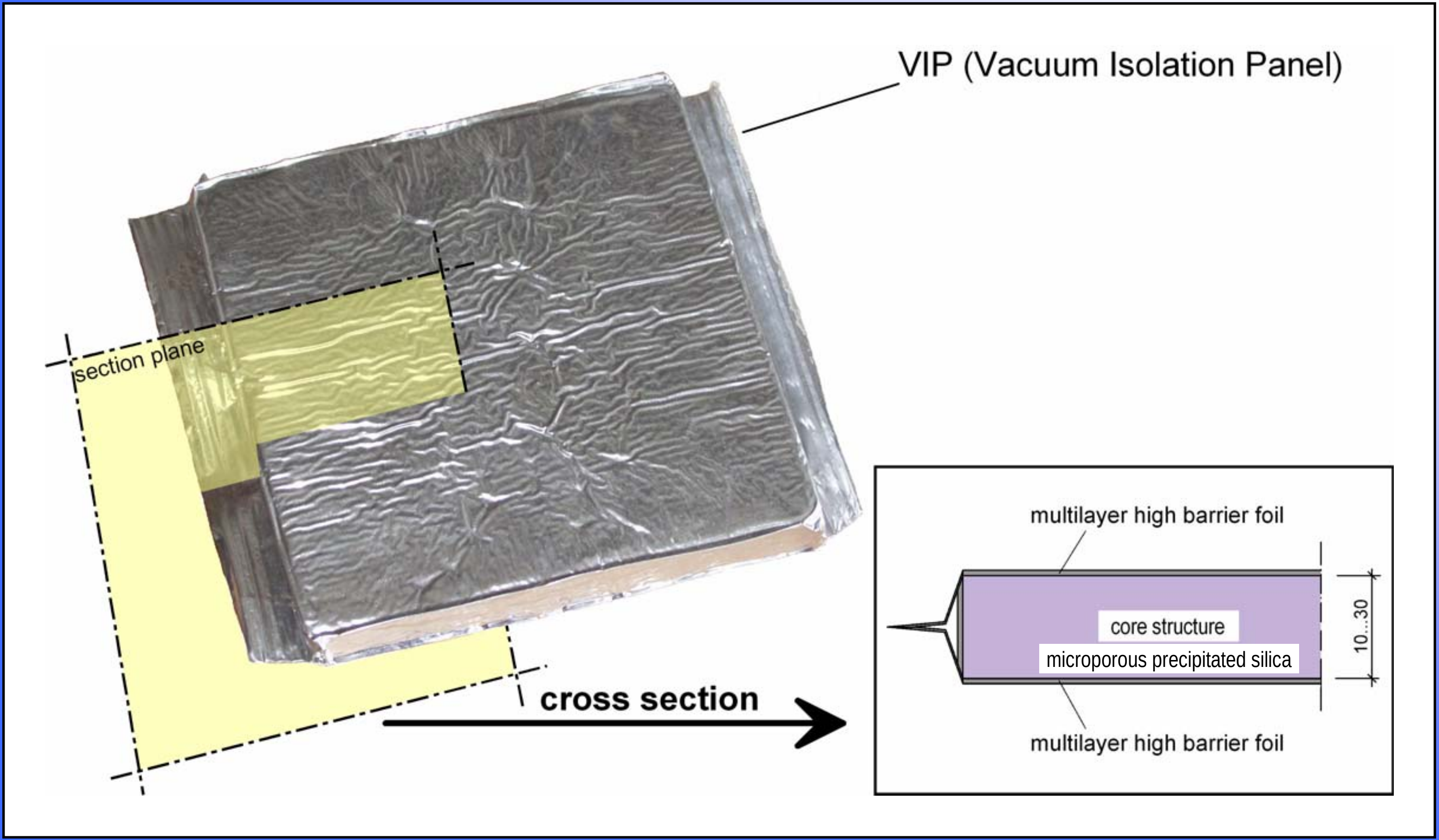
Numerical Investigations on Thermal Bridge Effects in Vacuum Insulating Elements

Dr.-Ing. Kai Schild

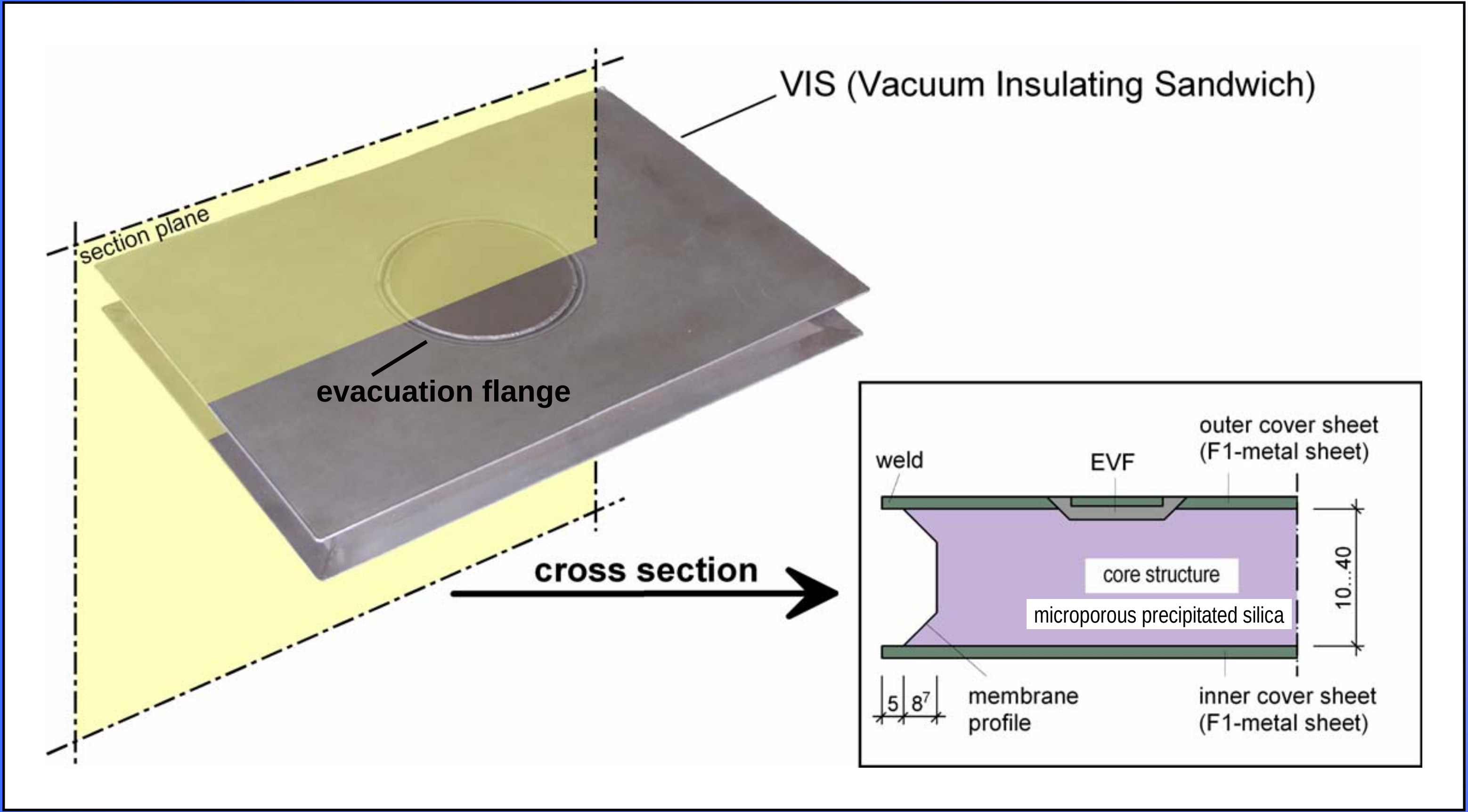
Ruhr-University Bochum, Germany

1. Physical structure of VIP and VIS elements
2. Heat transfer through vacuum insulated elements
3. Center-of-panel thermal conductivity
4. Thermal conductivity of the envelope material
5. Linear thermal transmittances of different edge designs
6. Obtaining an equivalent thermal conductivity
7. Examples for vacuum insulation in building applications
8. Conclusion

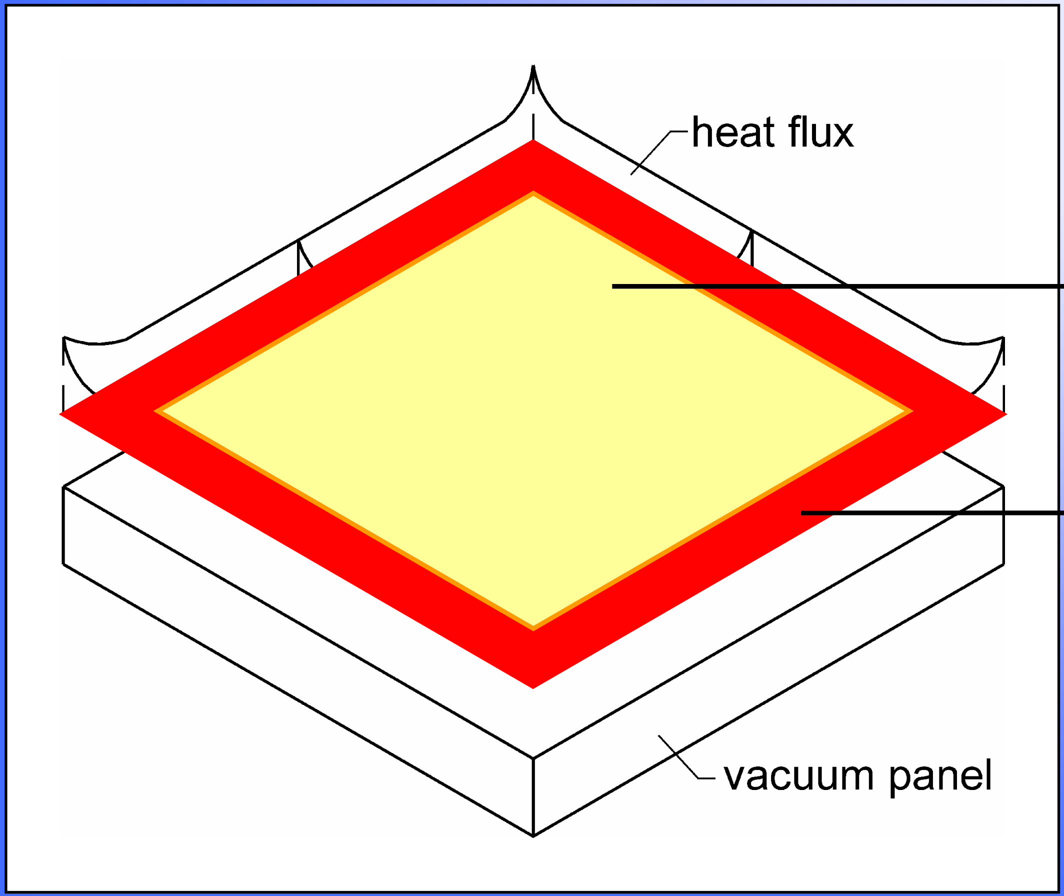
Vacuum isolation panels (VIP)



Vacuum insulating sandwiches (VIS)



Heat transfer through a vacuum insulated element



center-of-panel area
(heat flux normal to surfaces)

edge area
(w ~ 1 … 10·t)

A = 0,5 m²:
$\Phi_{edge} \sim \Phi_{cop}$

A = 9 m²:
$\Phi_{edge} \sim 0{,}5 \cdot \Phi_{cop}$

Center-of-panel thermal conductivity: Initial values

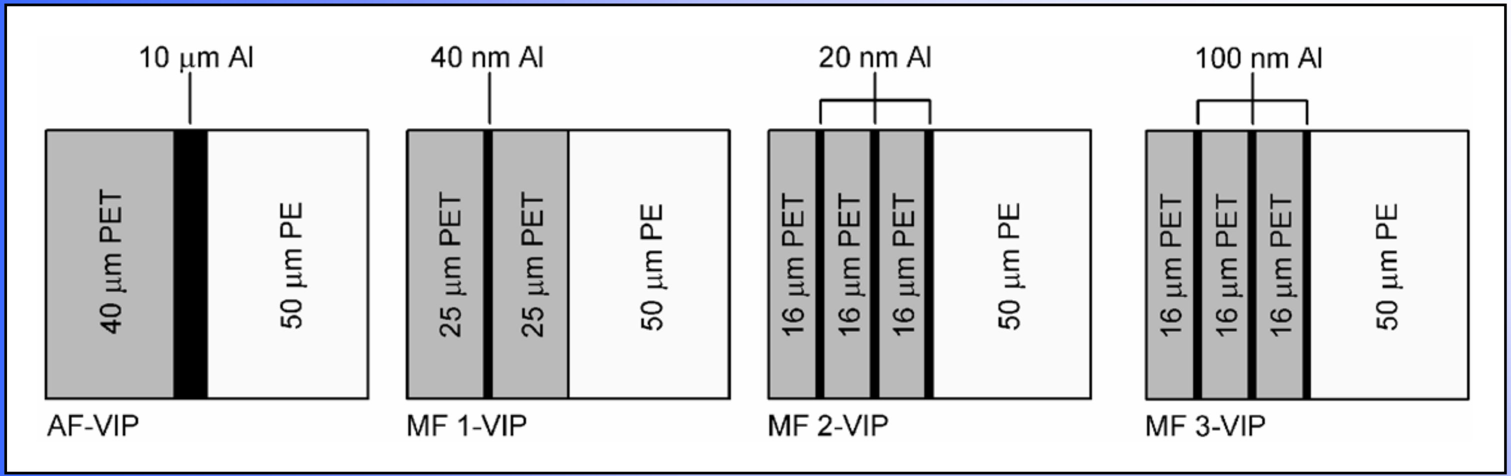
- VIP + VIS: ~ 4 ÷ 5 mW/(mK)

Center-of-panel thermal conductivity: Values after aging

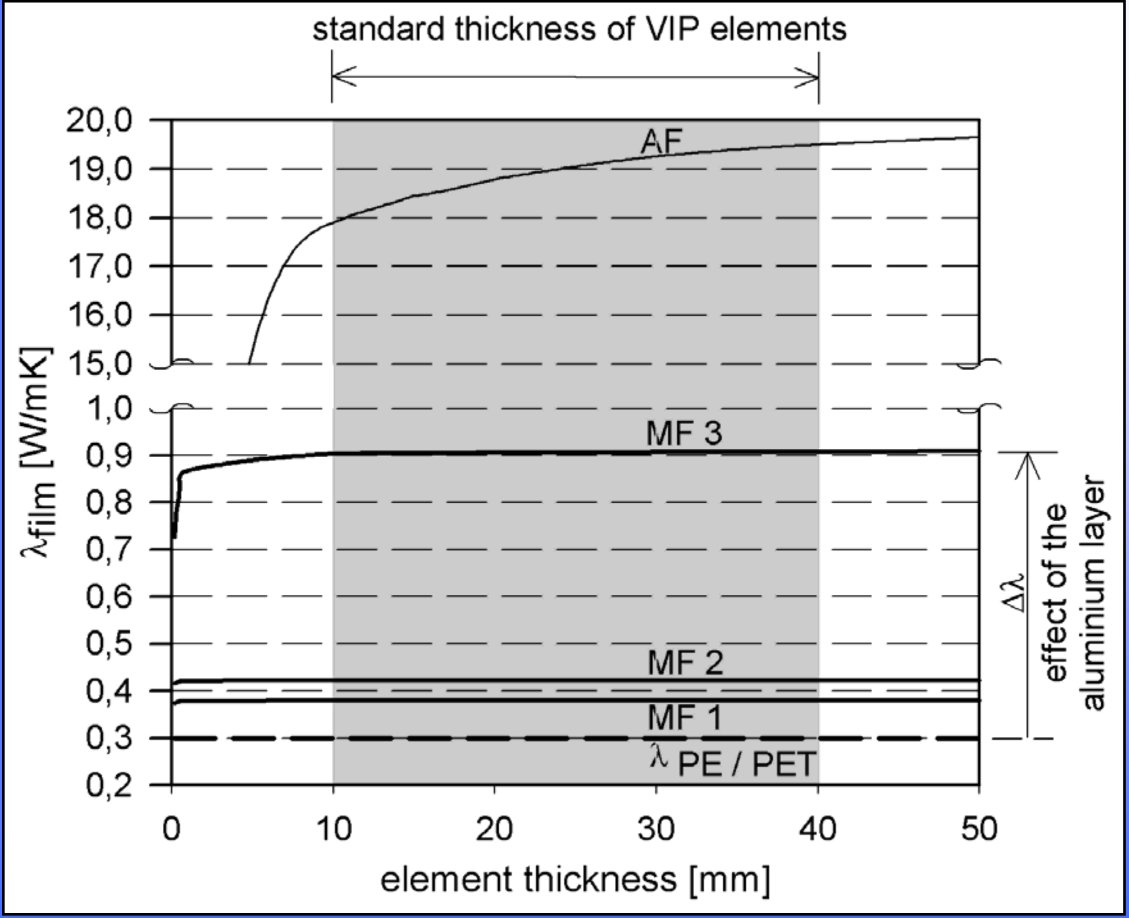
Type of vacuum element	λ_{cop} [mW/(m·K)]	Reference
MF-VIP	up to 10*	(Simmler & Brunner 2003)
AF-VIP	6**	(Simmler & Brunner 2004)
MF-VIP	8**	(Simmler & Brunner 2004)
all VIP	8**	(Erb 2004)
MF-VIP	8***	(va-q-tec 2004)
VIS	5.4 to 6.9****	(FIW 2004)

* assumed upper limit for moist conditions
** assumed values for a 25 year service life
*** value at an internal pressure of 100 mbar
**** values from experimental investigations

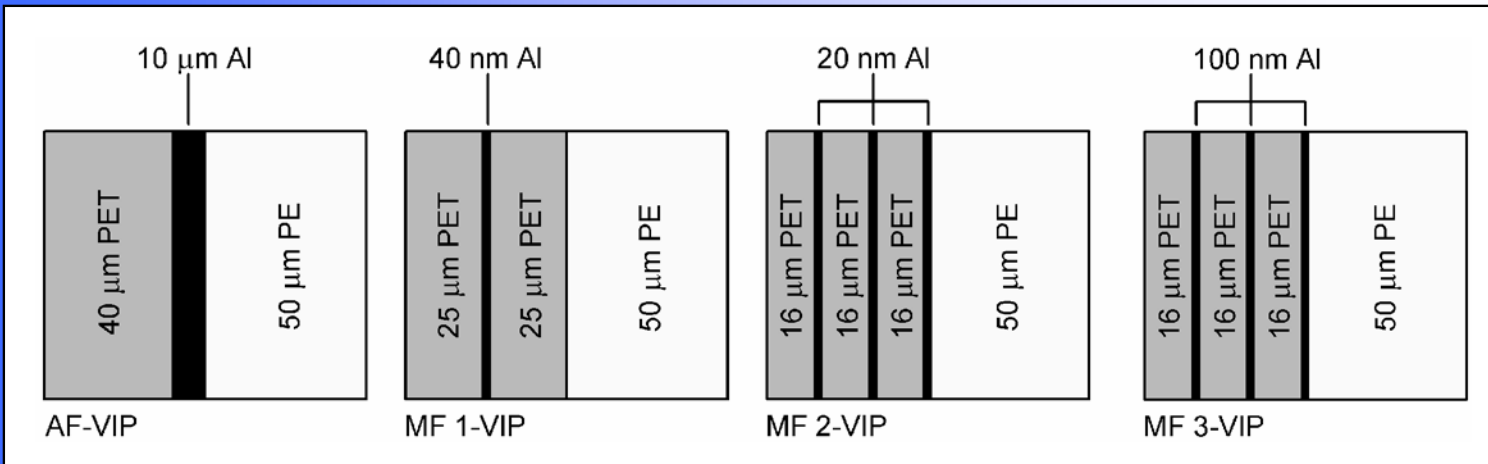
Different structures of barrier films for VIP elements



Average thermal conductivity of barrier films

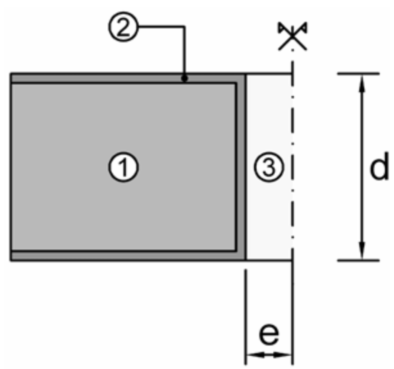


Edge losses of VIP elements for different barrier film



ψ [W/mK]	AF (λ_{film} = var.)	MF 1 (λ_{film} = 0,38)	MF 2 (λ_{film} = 0,42)	MF 3 (λ_{film} = 0,90)
d_{VIP} [mm]	No imperfections estimated			
10	0,049	0,011	0,011	0,020
20	0,047			0,017
30	0,042	0,010	0,010	0,014
40	0,038			0,013

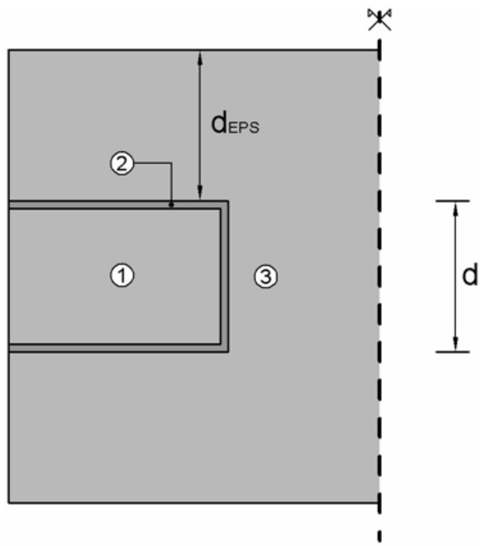
Influence of air gaps between VIP elements



① core material
② barrier film
③ air gap

ψ [W/mK]	AF (λ_{eff} = var.)		MF 1 (λ_{eff} = 0,38)		MF 2 (λ_{eff} = 0,42)		MF 3 (λ_{eff} = 0,90)	
	e_{air} [mm]							
d_{VIP} [mm]	2,5	5,0	2,5	5,0	2,5	5,0	2,5	5,0
10	0,054	0,058	0,016	0,021	0,016	0,021	0,025	0,027
20	0,053	0,058					0,021	0,024
30	0,047	0,052					0,019	0,022
40	0,043	0,049					0,017	0,020

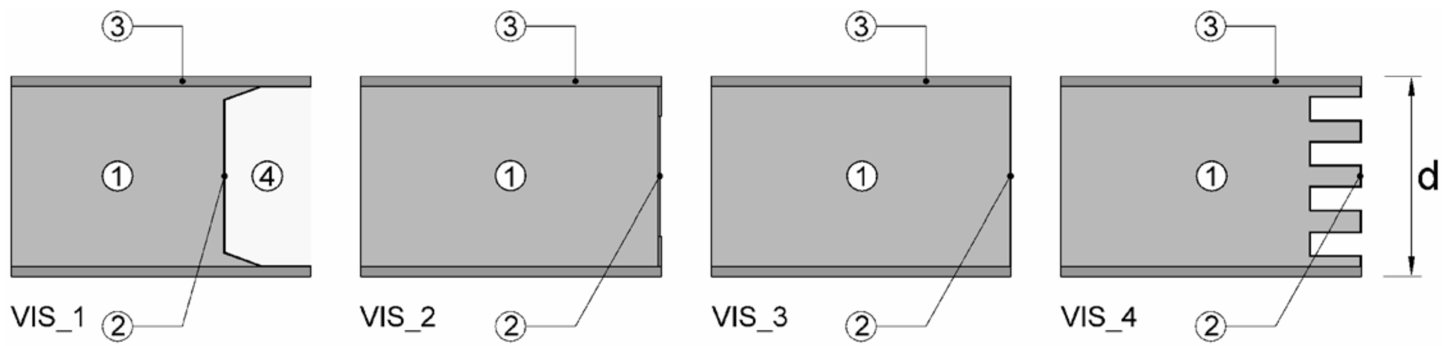
Linear thermal transmittance of EPS covered VIP elements



① core material
② barrier film
③ EPS covering

ψ [W/mK]	MF 1 (λ_{eff} =0,38)		
	d_{EPS} [mm]		
d_{VIP} [mm]	10	20	30
10	0,020	0,025	0,027
20	0,017	0,021	0,024
30	0,014	0,019	0,022
40	0,013	0,017	0,020

Edge losses for different edge designs of VIS elements



① core material ② edge membrane d = 0,1 - 0,3 mm ③ cover sheet d = 0,1 mm ④ air gap

ψ [W/mK]	VIS_1			VIS_2			VIS_3			VIS_4		
	$d_{membrane}$ [mm]											
d_{VIS} [mm]	0,10	0,20	0,30	0,10	0,20	0,30	0,10	0,20	0,30	0,10	0,20	0,30
10	0,069	0,085	0,096	0,085	0,102	0,109	0,079	0,099	0,109	0,043	0,061	0,074
20	0,069	0,090	0,105	0,067	0,095	0,112	0,064	0,093	0,112	0,044	0,065	0,082
30	0,066	0,084	0,099	0,053	0,079	0,097	0,051	0,078	0,097	0,042	0,062	0,079
40	0,063	0,079	0,093	0,044	0,067	0,084	0,043	0,043	0,084	0,040	0,058	0,074

Calculation of an equivalent thermal conductivity

$$\lambda_{equ} = \lambda_{cop} + \psi \cdot d \cdot \frac{P}{A}$$

λ_{equ} □ equivalent thermal conductivity

λ_{cop} □ center-of-panel thermal conductivity

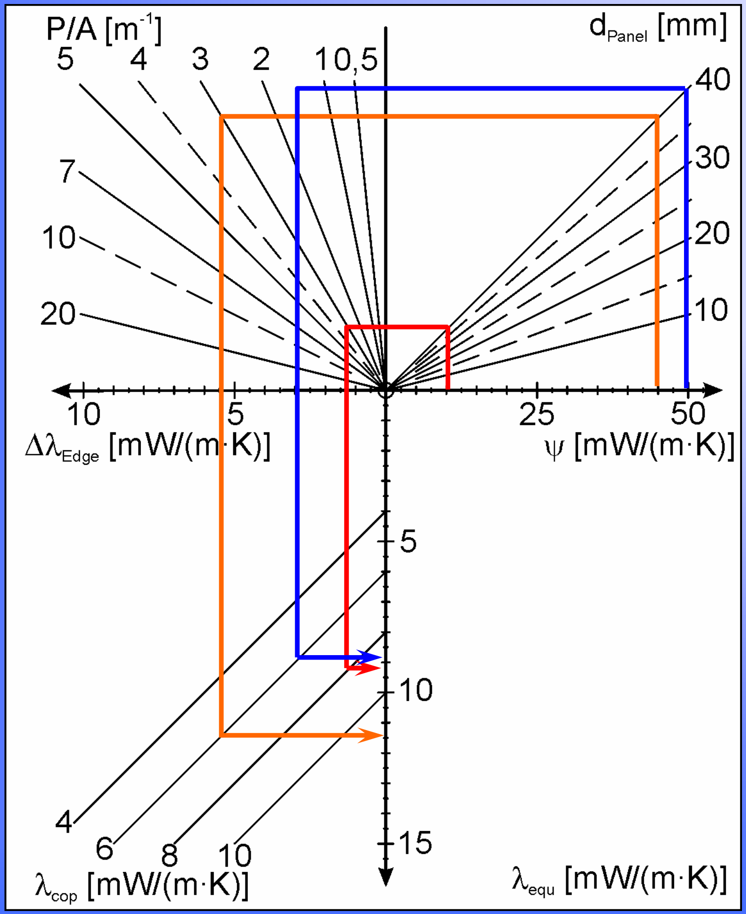
ψ □ linear thermal tranmittance

d □ element thickness

P □ perimeter lenght

A □ surface area

Nomographical solution

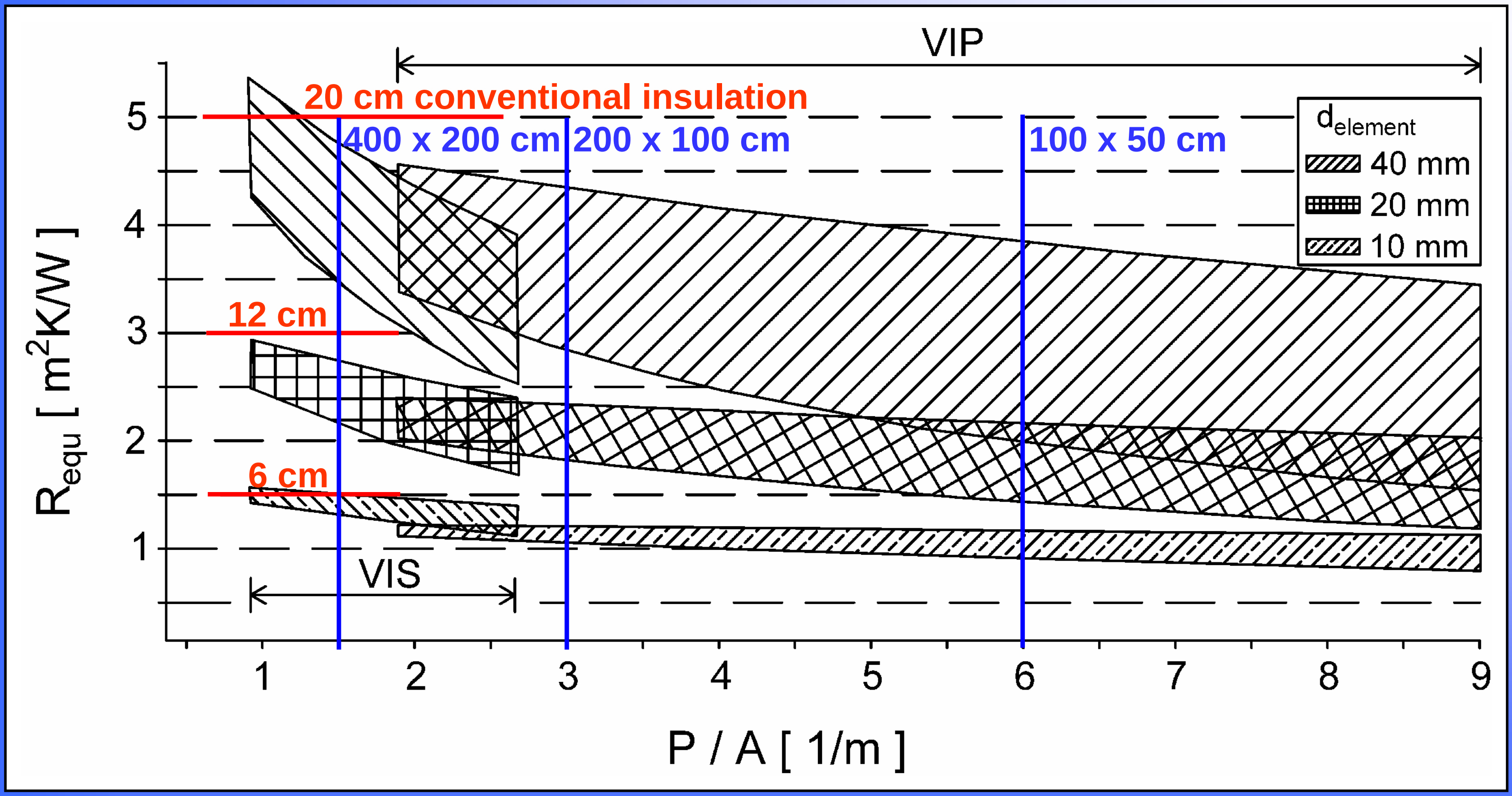


AF-VIP 100 x 200 cm

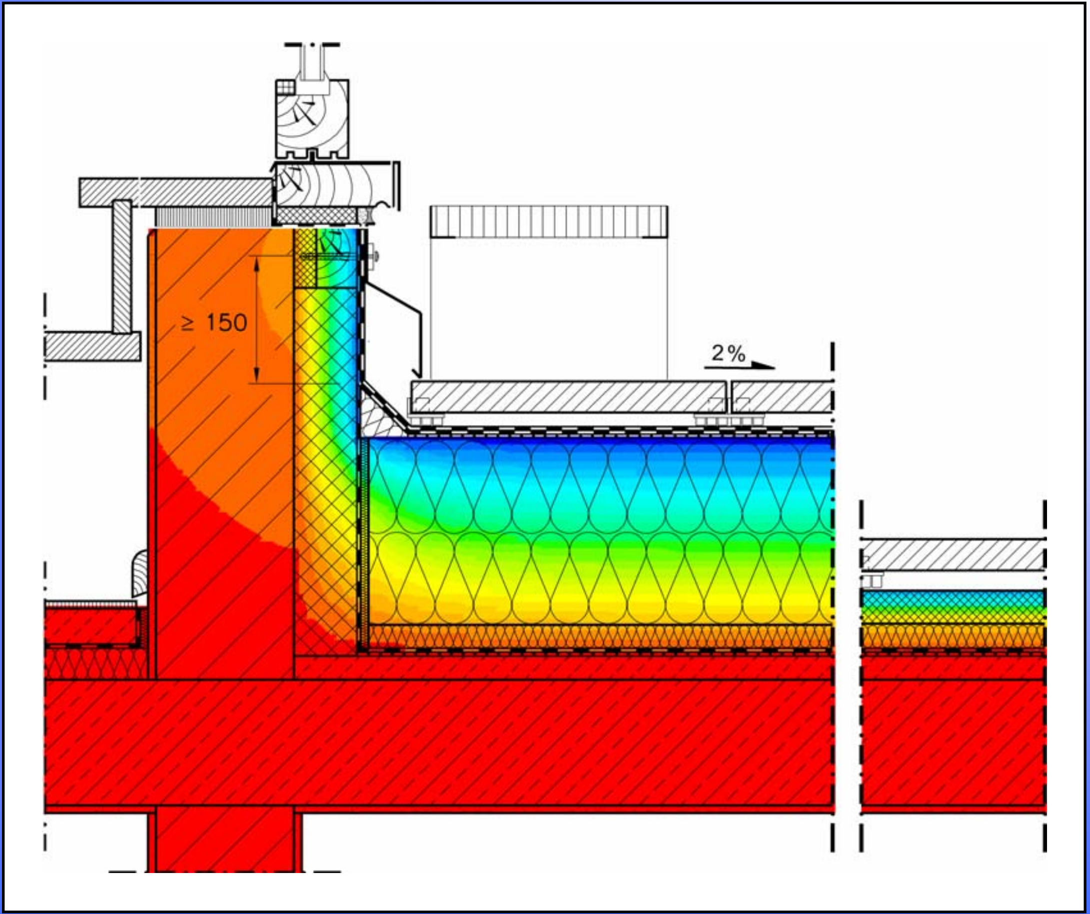
MF-VIP 100 x 200 cm

VIS 300 x 300 cm

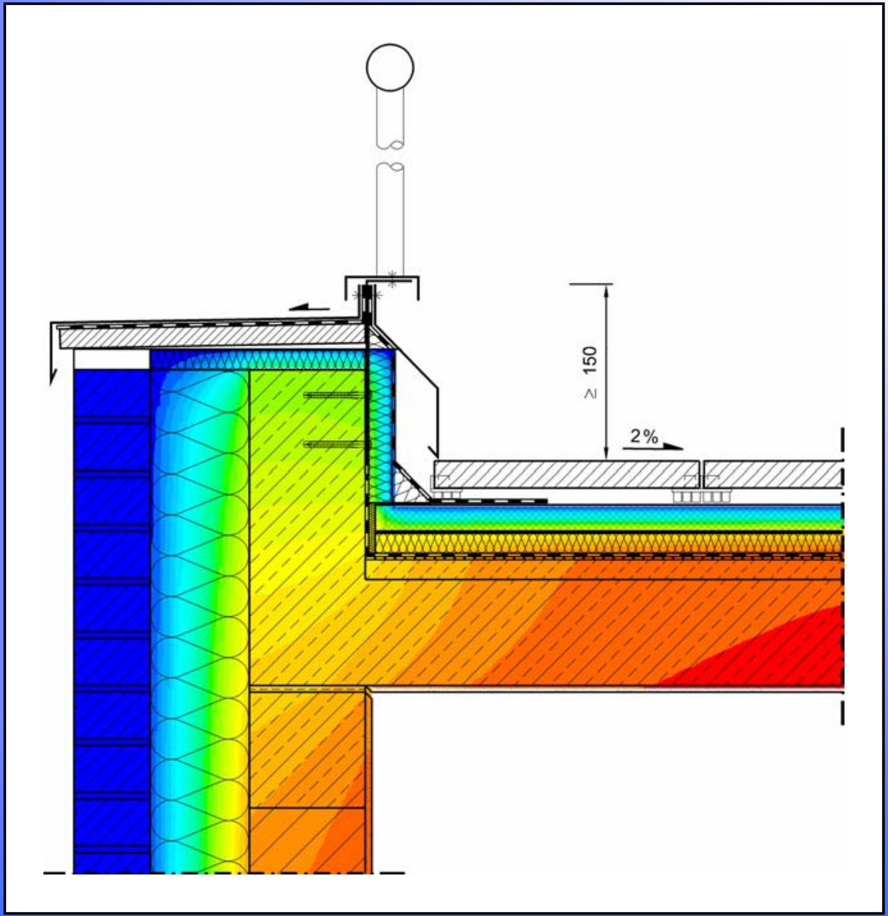
Obtainable thermal resistances for VIP and VIS elements



Connection of a terrace construction to a door (I)



Attica detail (I)



Conclusion

- Vacuum insulation is 4 to 6 times more effective than conventional insulation, even when considering aging effects
- With both MF-VIP and VIS elements, a low equivalent thermal conductivity of 8 to 10 mW/(m²·K) is obtainable for realistically sized elements
- For a thermal optimized element layout, element sizes above 2 m² are desirable
- The lowest reachable equivalent thermal conductivities are about 7,5 mW/(m²·K) for large scale VIS elements