Determination of linear thermal transmittance of VIP by measurement in a Guarded Hot-Plate- (GHP) or a Heat-Flow Meter (HFM) apparatus

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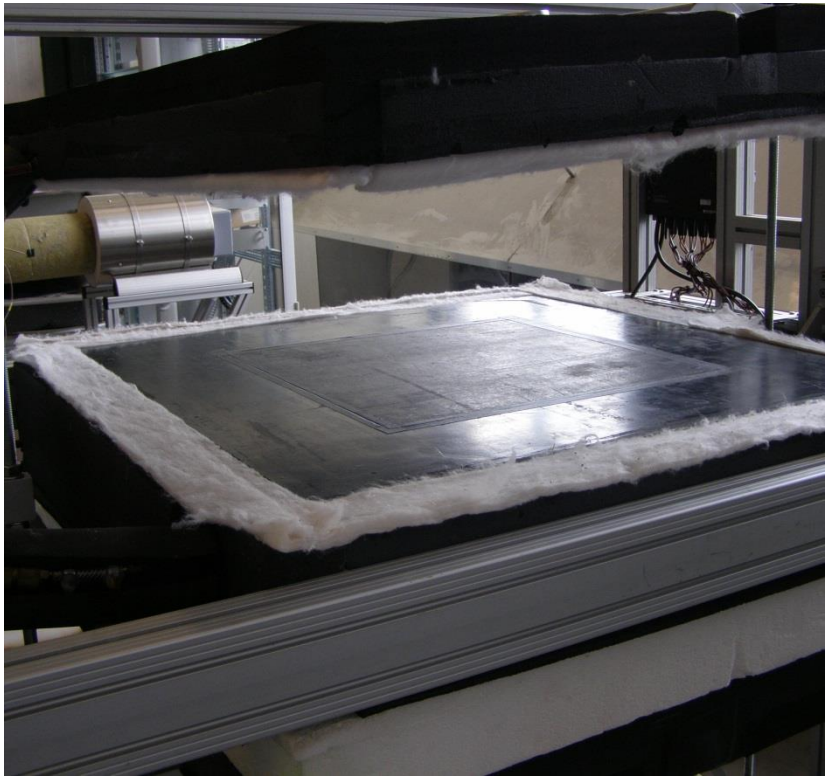
- Building kit: how to get from λ_{COP} to λ_{eff} to R to U
- Vice Versa: measure U or R and derive λ_{eff}
- Measurement procedure for linear thermal transmittance ψ
- Supporting FD-Simulations
- Results and Conclusions



Rotatable HFM apparatus of FIW

Influencing Factors on ψ

and order of magnitude

Influencing Factors

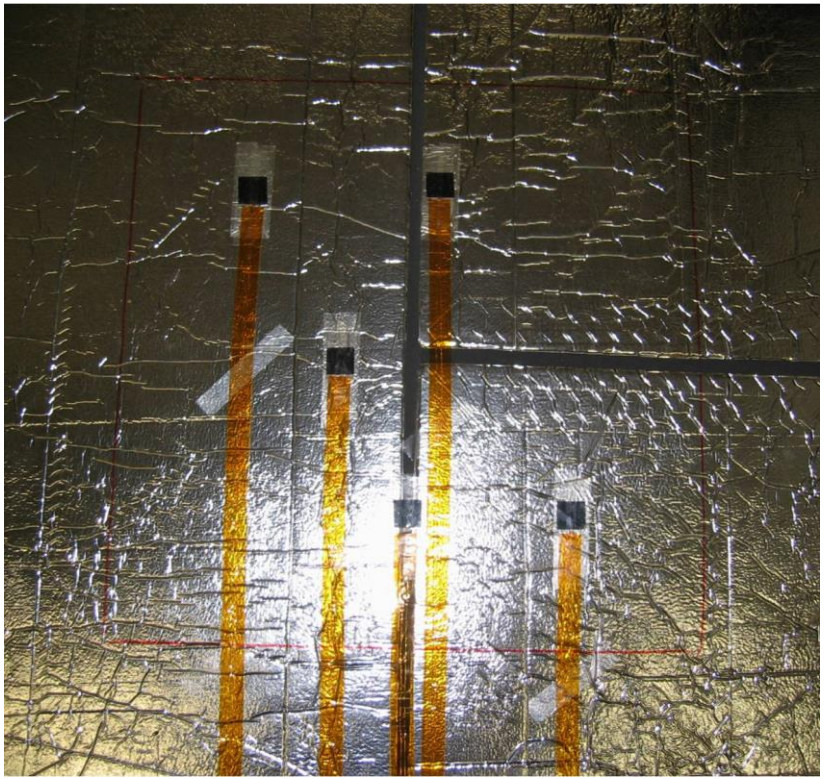
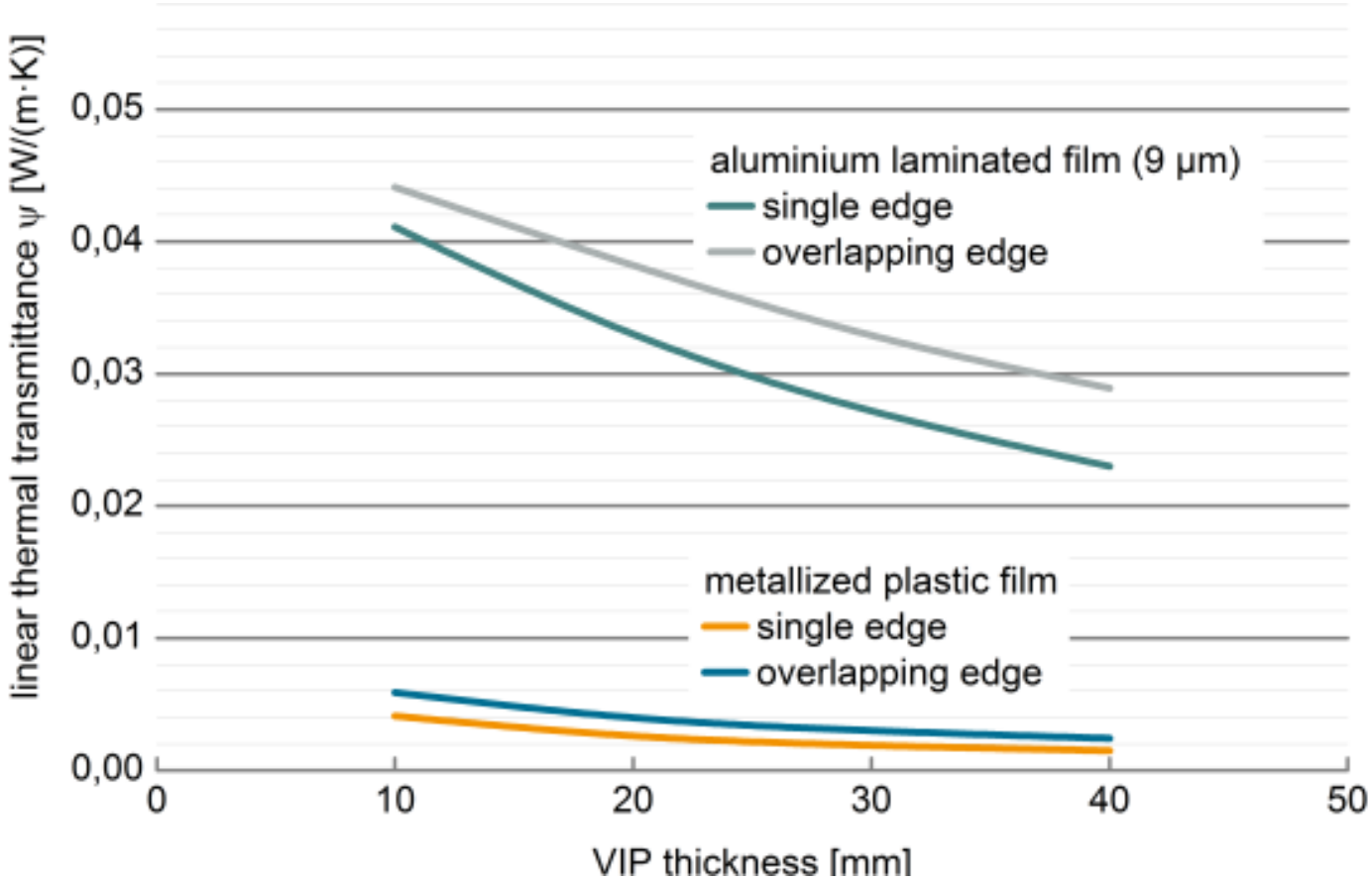


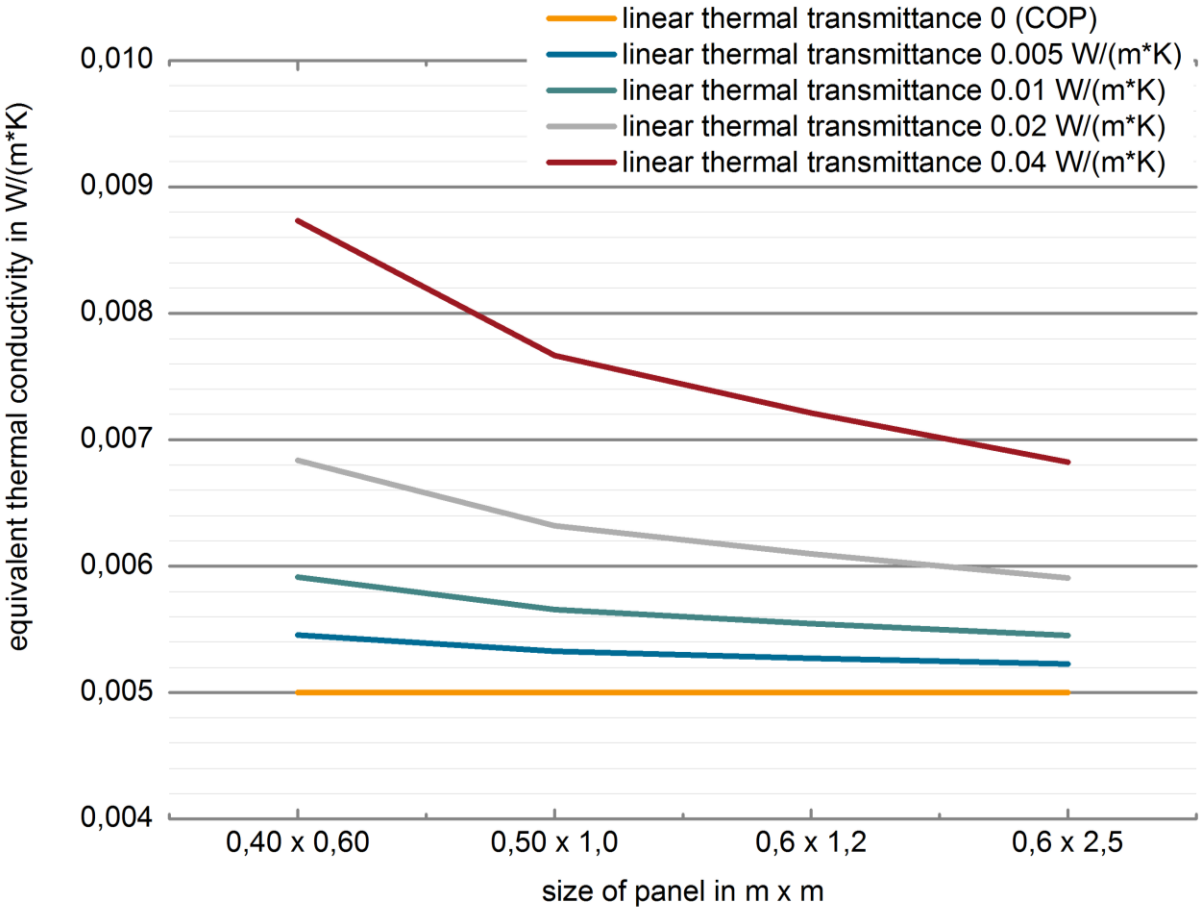
Photo: FIW

- Edge design
- Material and thickness of barrier layer
- Gap width between two panels and gap filler material
- Cover layer material
- Mounting and fixing
- 2-layered constructions

Edge design and thickness of barrier layer



Linear thermal transmittance vs. panel size



From λ_{COP} to U…

…and from U back to λ_{eff} for declaration

2-dim and 3-dim thermal bridges

$$U_{eff} = \frac{Q_{eff}}{A_{panel} \cdot \Delta\vartheta}$$

$$Q_{eff} = \Delta\vartheta \cdot (U_0 \cdot A_{panel} + \sum \psi_i \cdot l_i + \sum \chi_i \cdot n_i)$$

- Measure λ_{COP} in GHP or HFM apparatus and calculate U_0
- Add 2-dim effects for edges of panels (ψ and length)
- 3-dim effects need to be taken into account in constructions (χ and n)
- Effect easily exceeds the 3 % criterium in ISO 6946
- Calculate total heat flow
- Calculate U_{eff} depending on panel size and $\Delta\vartheta$

Derive λ_{eff} from U_{eff}

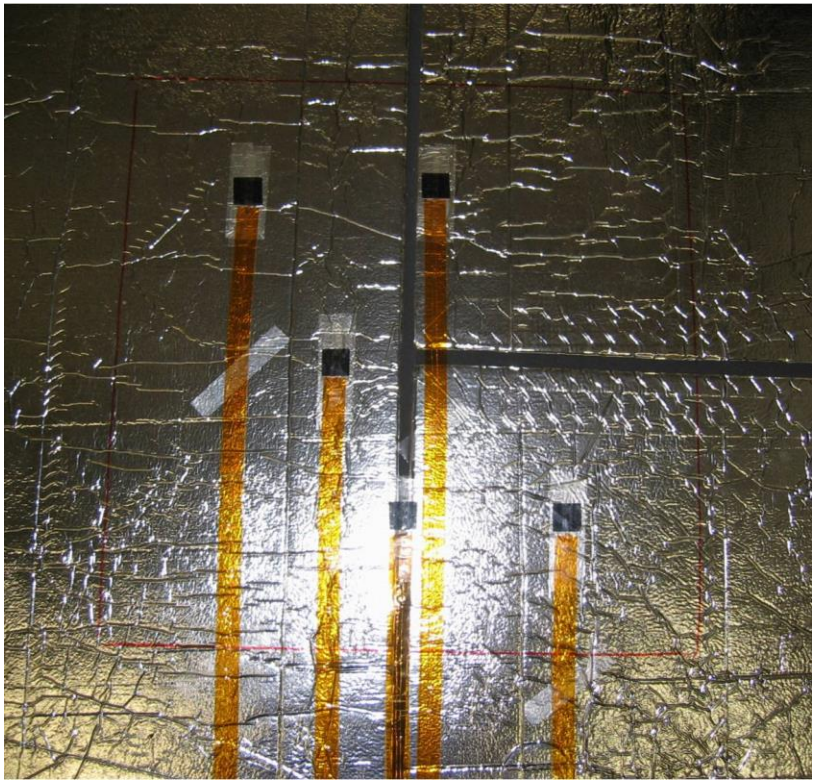
$$\lambda_{eff} = \frac{d_{panel}}{\frac{1}{U_{eff}} - R_s}$$

$$\lambda_{eff} = \frac{d_{panel}}{R_{eff}}$$

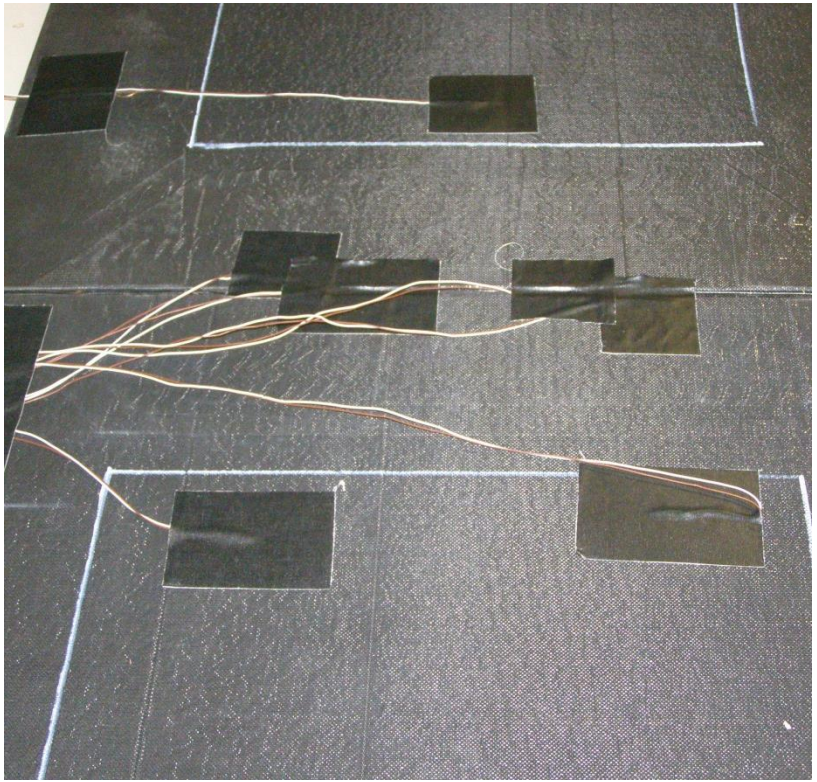
- Derive λ_{eff} from
  - U_{eff} from 2-/3-dim sim.+cal.
  - U_{eff} from Hot-Box measurement
  - R_{eff} from GHP or HFM measurement
- When calculating: all effects can be determined separately
- When using Hot-Box method: 2- and 3-dim effects can be considered (in sum!)
- When using GHP or HFM: only 2-dim effects can be measured (in sum!)

Measurement of ψ in GHP/HFM

Determination of ψ by measurement



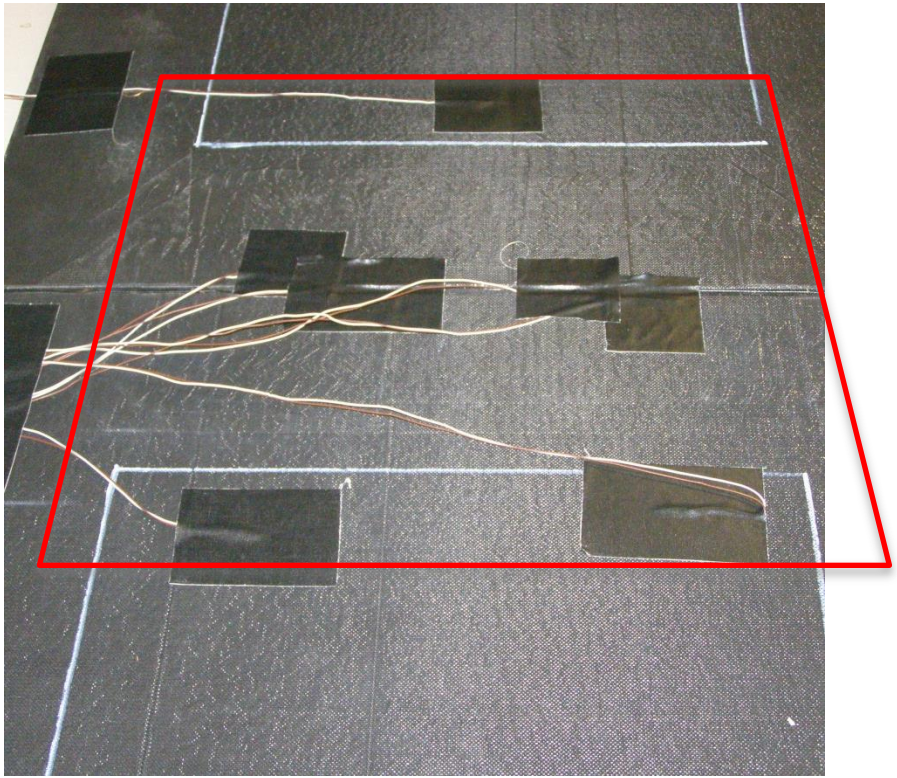
Thermal bridge measurement: T-joint



Thermal bridge measurement: single joint

Determination of ψ by measurement

- Significant joint length within the metering area
- Consideration of non-uniform temperature distribution
  - Sensors directly on the joint
  - Sensors in the slightly effected area
  - Sensors in the COP
- Temperature difference to be area weighted and averaged



Thermal bridge measurement: single joint

Area weighted temperature difference

$$\Delta\theta_m = \frac{A_{COP} \cdot \Delta\theta_{COP} + A_{SA} \cdot \Delta\theta_{SA} + A_{joint} \cdot \Delta\theta_{joint}}{A_{COP} + A_{SA} + A_{joint}}$$

$\Delta\theta_m$	Area weighted temperature difference for joint assembly in K
A_{COP}	Center of panel area in m²
A_{SA}	Area slightly affected in m²
A_{joint}	Joint area (strongly affected) in m²
$\Delta\theta_{COP}$	Temperature difference for COP area in K
$\Delta\theta_{SA}$	Temperature difference for SA area in K
$\Delta\theta_{joint}$	Temperature difference for Joint area in K

Equivalent thermal conductivity for joint ass.

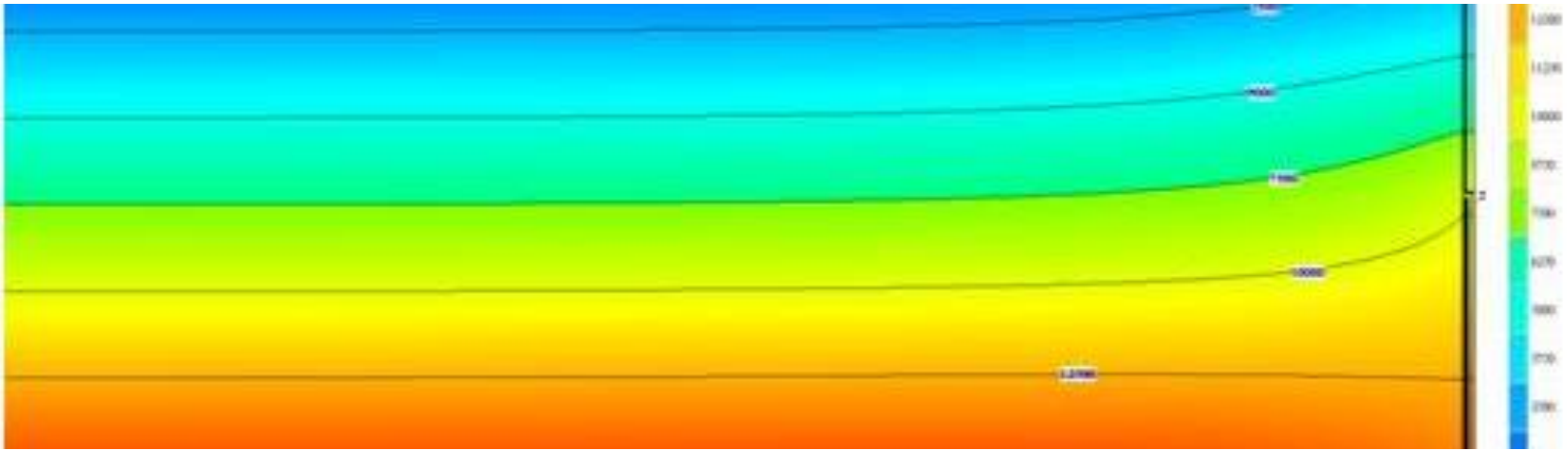
$$\lambda_{eq\ ja} = \frac{\Phi \cdot d_{panel}}{A \cdot \Delta\vartheta_m}$$

$\lambda_{eq\ ja}$	equivalent thermal conductivity for joint assembly in W/(m·K)
Φ	electrical power input for hot-plate metering area in W
d_{panel}	thickness of panel (equal thickness of joint assembly and COP specimens required for this method) in m
A	metering area in m²
$\Delta\theta_m$	area weighted temperature difference for Joint assembly in K

Determination of linear thermal transmittance

$$\psi = \frac{A}{d \cdot l_{\psi}} \cdot (\lambda_{eq\ ja} - \lambda_{COP})$$

ψ	linear thermal transmittance for the joints in the metering area in W/(m·K)
l_{ψ}	length of the joints within the metering area in m
$\lambda_{eq\ ja}$	equivalent thermal conductivity including edge effects for the specific joint assembly in W/(m·K)
λ_{COP}	thermal conductivity for center of panel in W/(m·K)



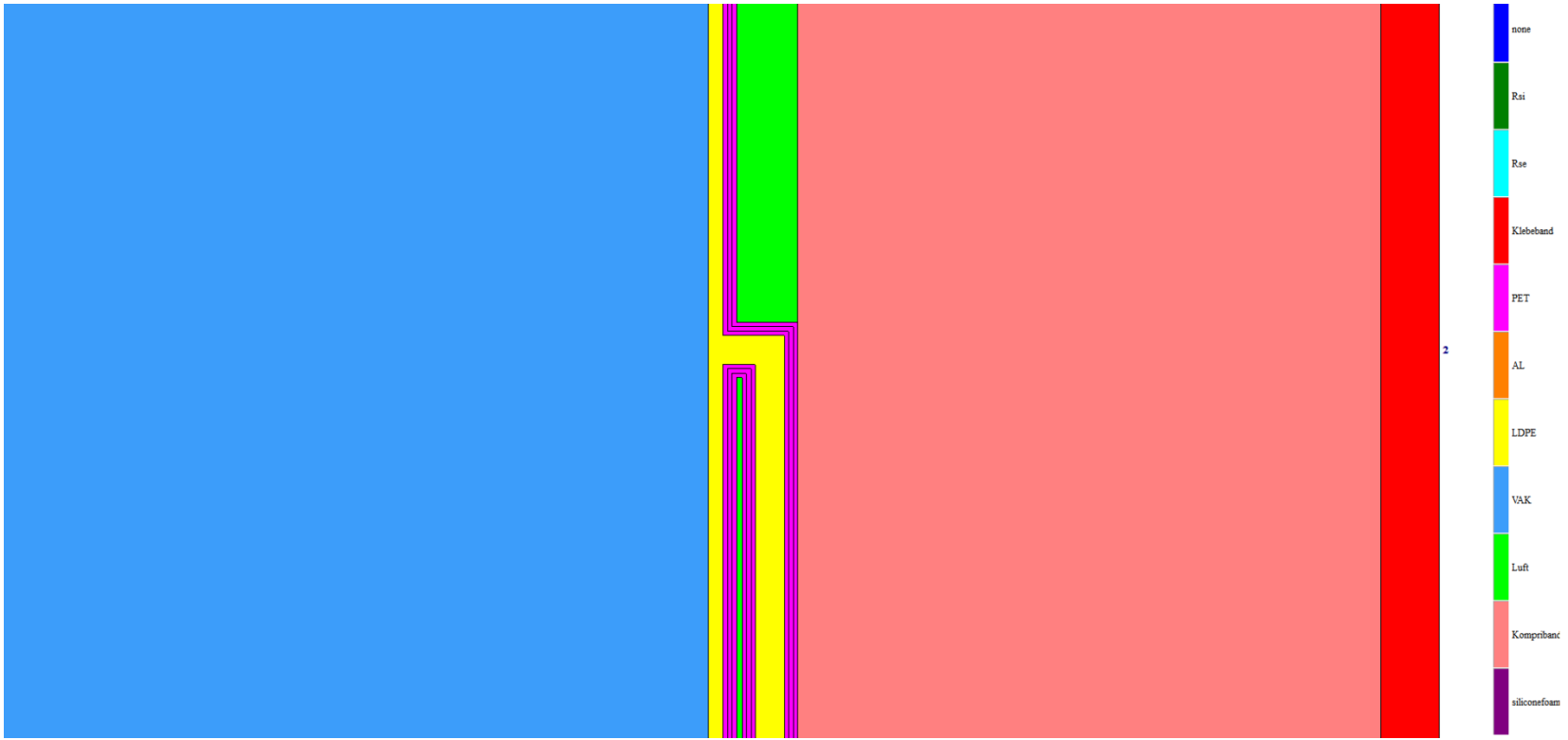
Supporting FD-simulations

Supporting FD-Simulations

- Width of influenced areas depend on
  - Cross conduction in
    - Barrier layers of foil
    - Cover layers of panel
    - Adjacent heating and cooling plates of apparatus
    - Joint filler material
    - Edge design etc.
- Dimensions of areas can be obtained by FD-Simulations

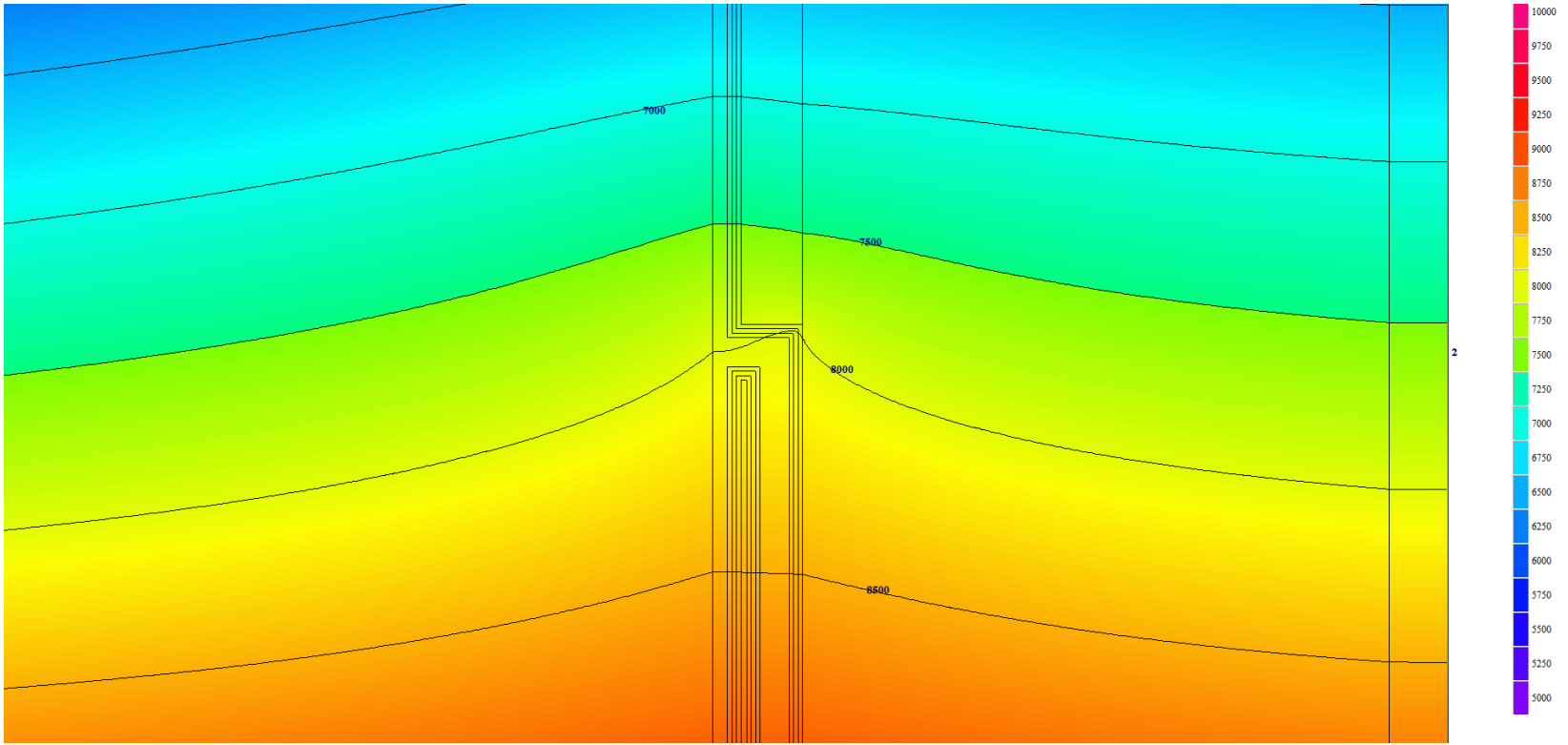
- Recommendations for assembly and panel size
  - Big enough to ensure significant COP area within metering area
  - Reasonable joint length
  - Ensure tight mounting
  - Ensure air-tightness
  - Ensure good contact of heating and cooling plates
  - Measure COP of both adjacent panels
  - Use contact layers in GHP or HFM measurement

Supporting FD-Simulations



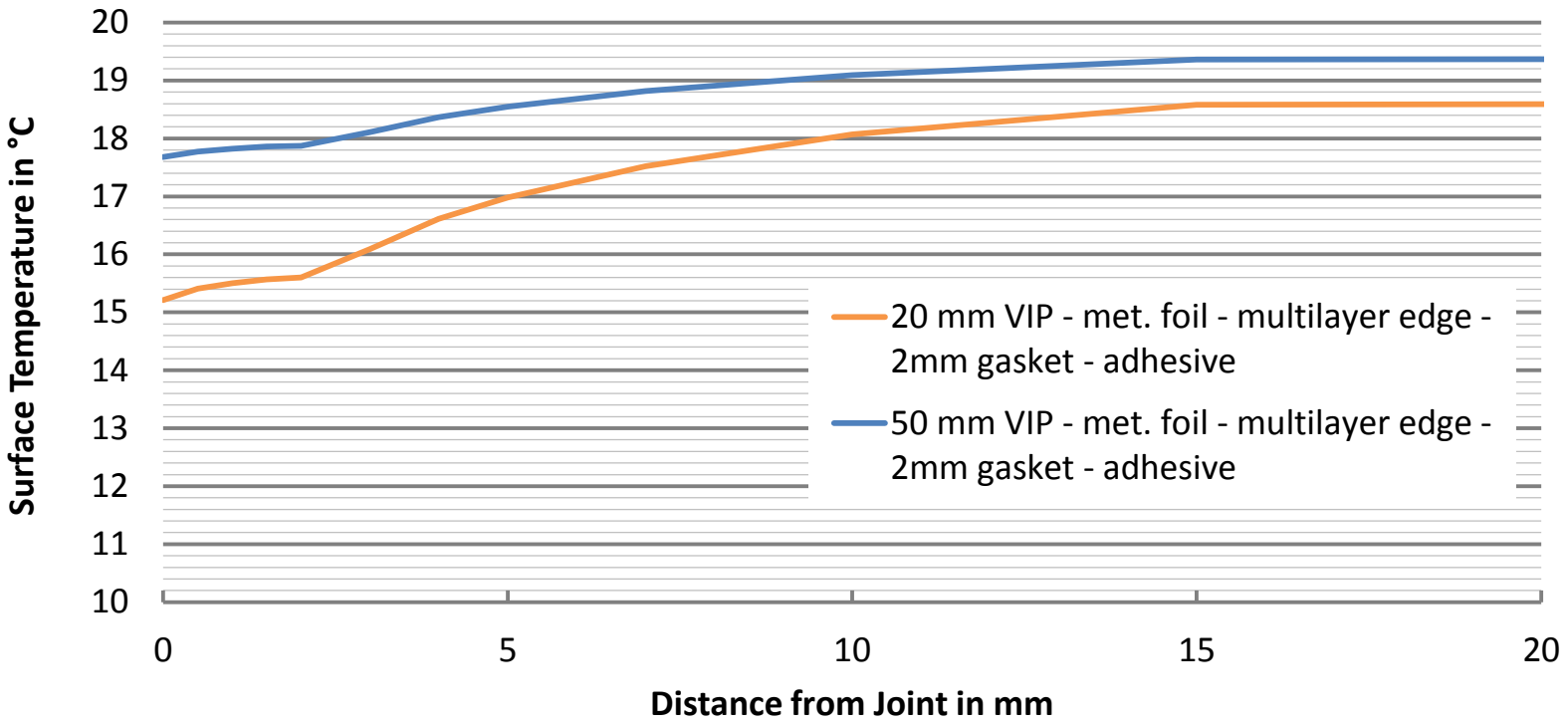
2D-Model for FD-Sim. of overlapping edge design with precompressed gasket strip and adhesive tape

Supporting FD-Simulations

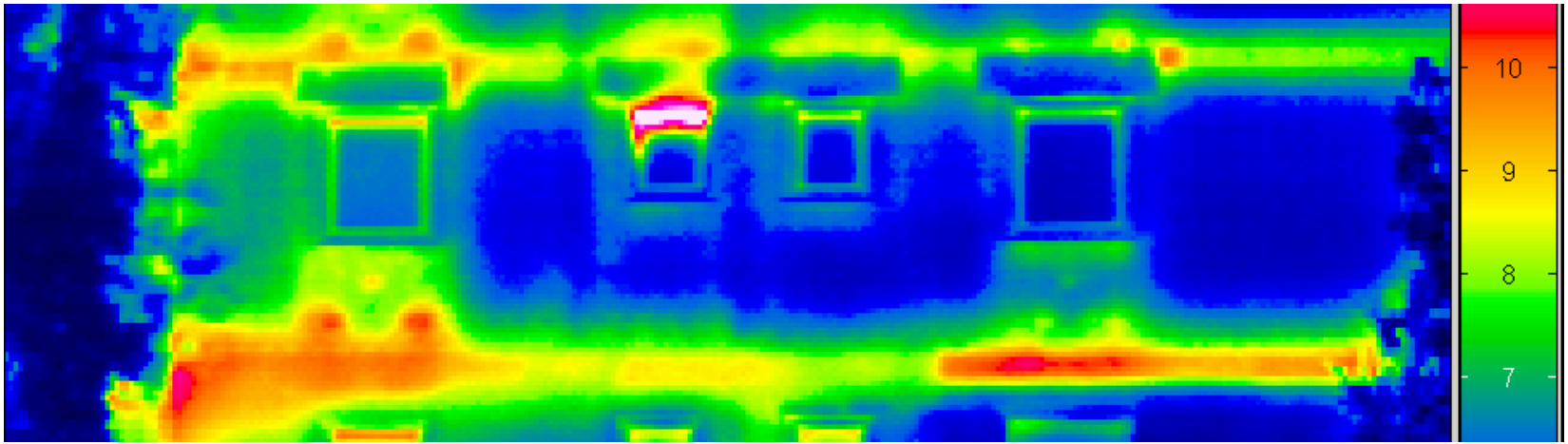


Temperature distribution (5 to 10°C) of overlapping edge design with precompressed gasket strip and adhesive tape

Temperature Gradient at panel edge



Simulated temperature gradient on the edge of the tested 20 mm and 50 mm VIP assemblies



Results and discussion

Comparison of FDM and HFM

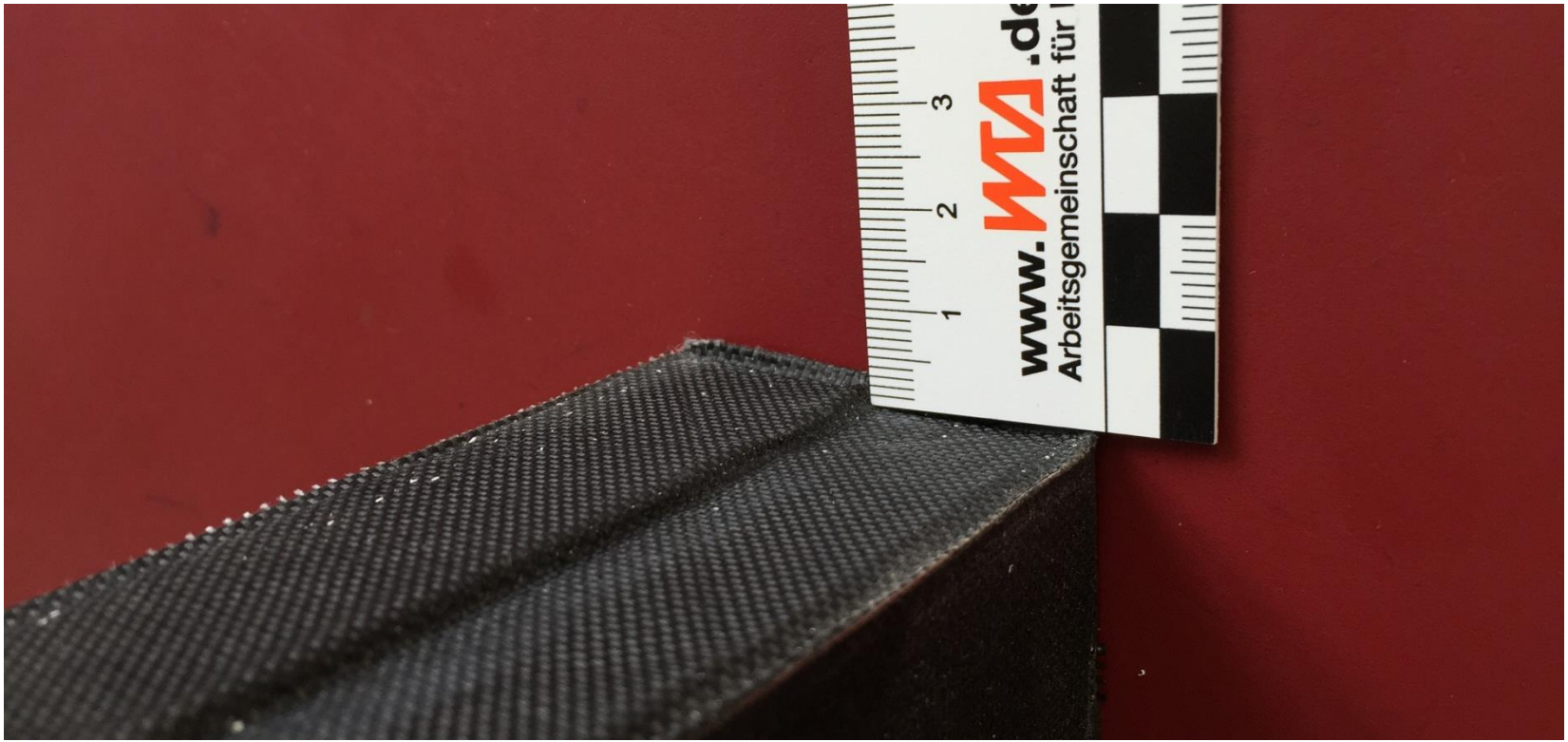
VIP Thickness	Linear thermal transmittance ψ in W/(m·K) obtained from…	
	numerical simulation with FDM	measurement in HFM apparatus
10 mm	0.0209	-
20 mm	0.0144	0.0151 ± 0.000755
30 mm	0.0109	-
40 mm	0.0088	-
50 mm	0.0073	0.0127 ± 0.00102

Comparison of results for ψ obtained from simulations and measurements – metallized foil – multilayered edge design – with silicone foam mats as contact layers

Results and Discussion

- Good agreement for 20 mm VIP under consideration of 5% uncertainty of HFM measurement
- Result for 50 mm VIP is significantly higher than ψ from numerical simulation
  - Even under consideration of increased uncertainty of 8%
  - Deviating results can – partly – be traced back to an increased λ_{COP} for one of the two adjacent VIPs
  - Width of the joint significantly bigger (force to compress gasket strip very high)
  - Edges of the panels uneven (core made from 2 core slabs: steps at edges leading to significantly wider joints! → compressed gasket strip partly expanded)

Results and Discussion



Uneven edge with additional 2 mm offset

Results and Discussion

- Accurate measurement of ψ is not easy
- Depending on a large variety of influencing factors
- Even small deviations in the measurement setup can lead to large uncertainties in the result
- Exact definition of boundary conditions needed, if measurement of ψ shall be used for the determination of thermal performance of VIP
  - Distance between panels
  - Joint filler material
  - Influence areas for temperature difference etc.
- More tests and more experience needed…e.g. common excercise for Annex 65!!!

Thank You!

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