Determination of linear thermal Transmittance of Vacuum-Insulation Panels by Measurement in a Guarded-Hot-Plate- (GHP) or a Heat-Flow-Meter- (HFM) Apparatus

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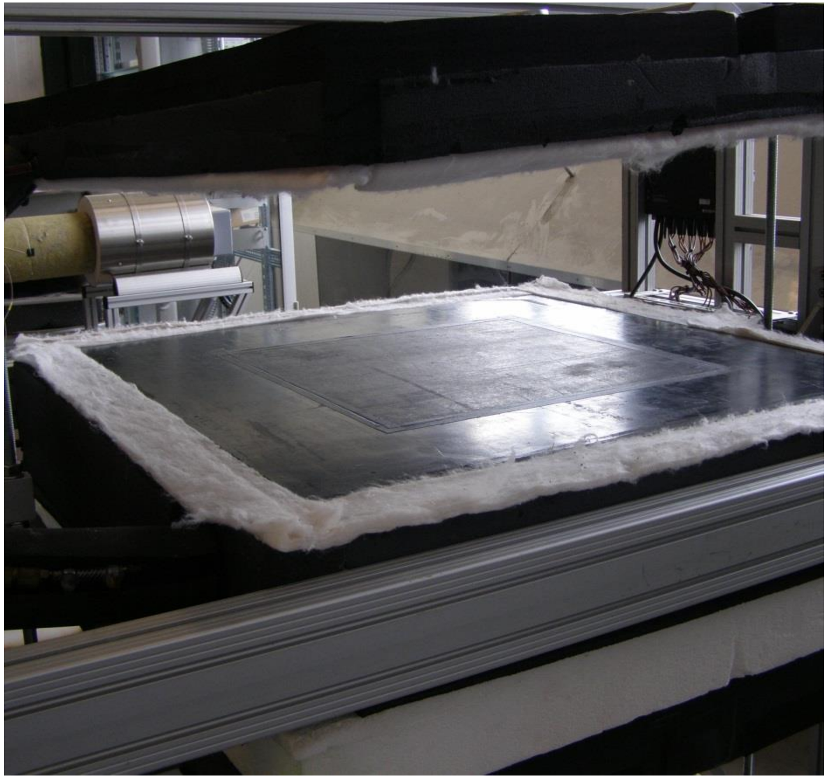
Content

- Brief introduction on linear thermal transmittance ψ
  - 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 Discussion



Rotatable HFM apparatus of FIW

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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 Δϑ

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!)

Influencing Factors on ψ

and order of magnitude

Influencing Factors

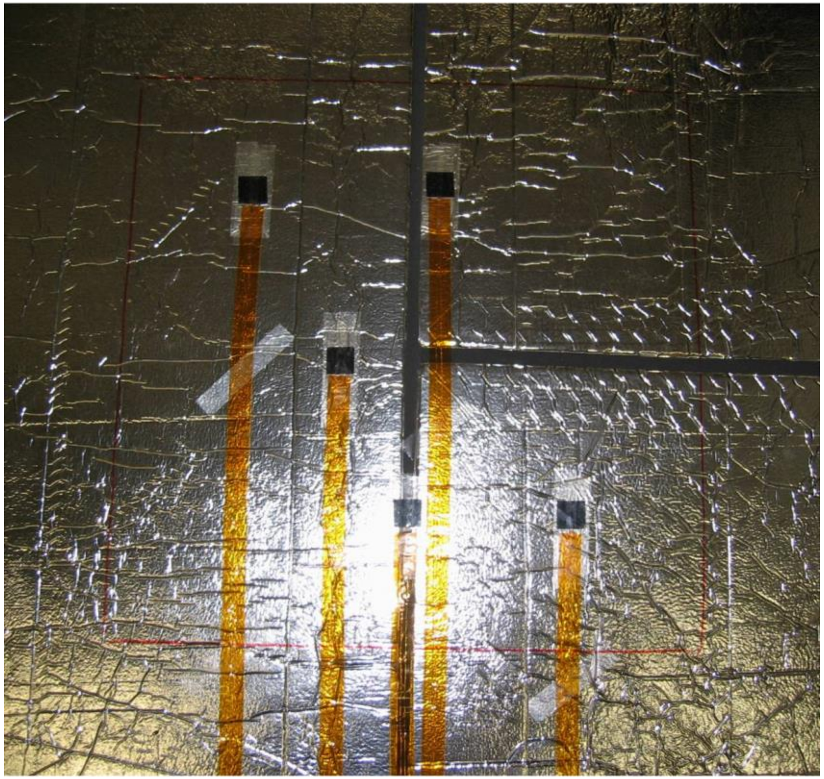
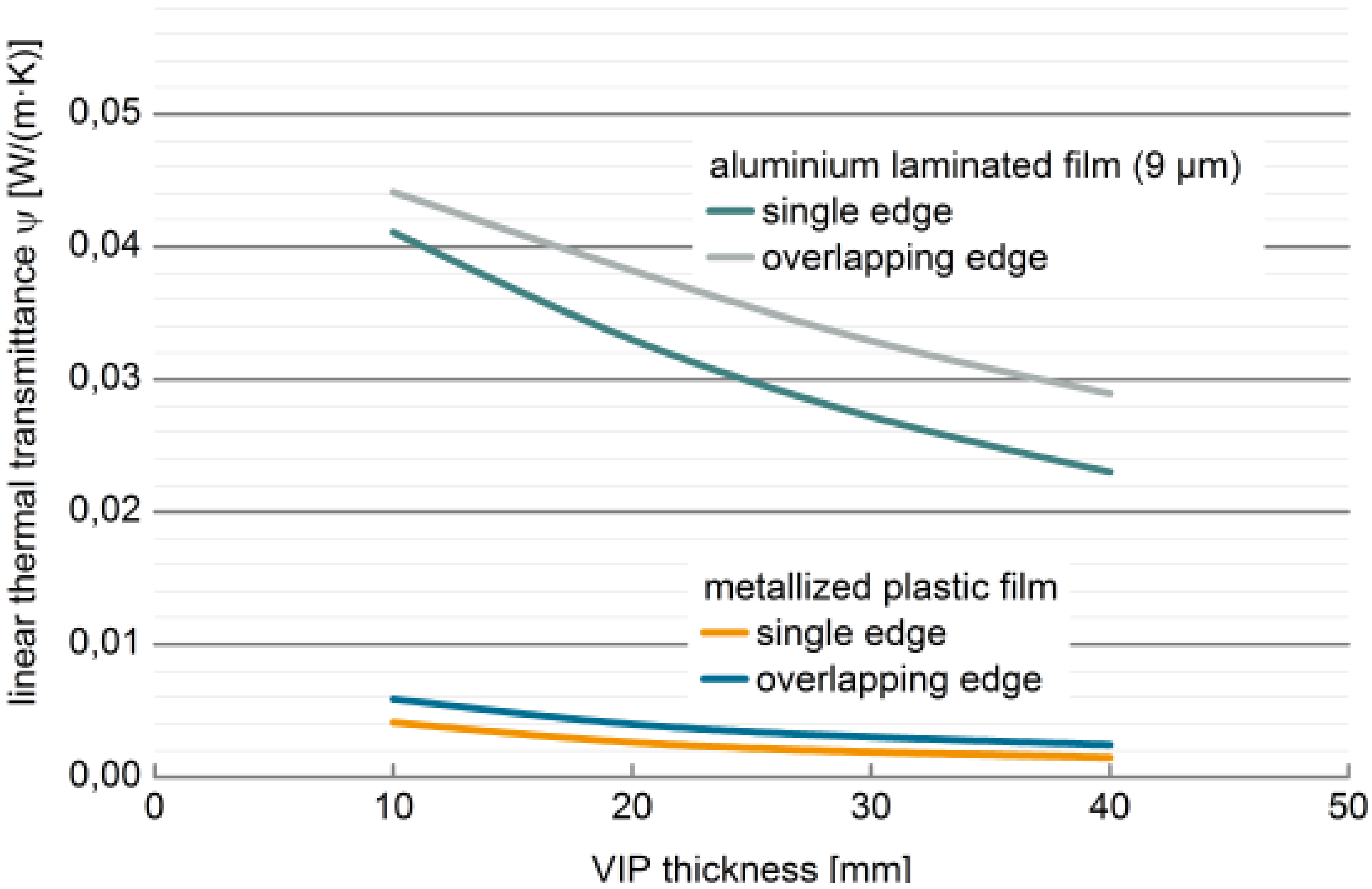


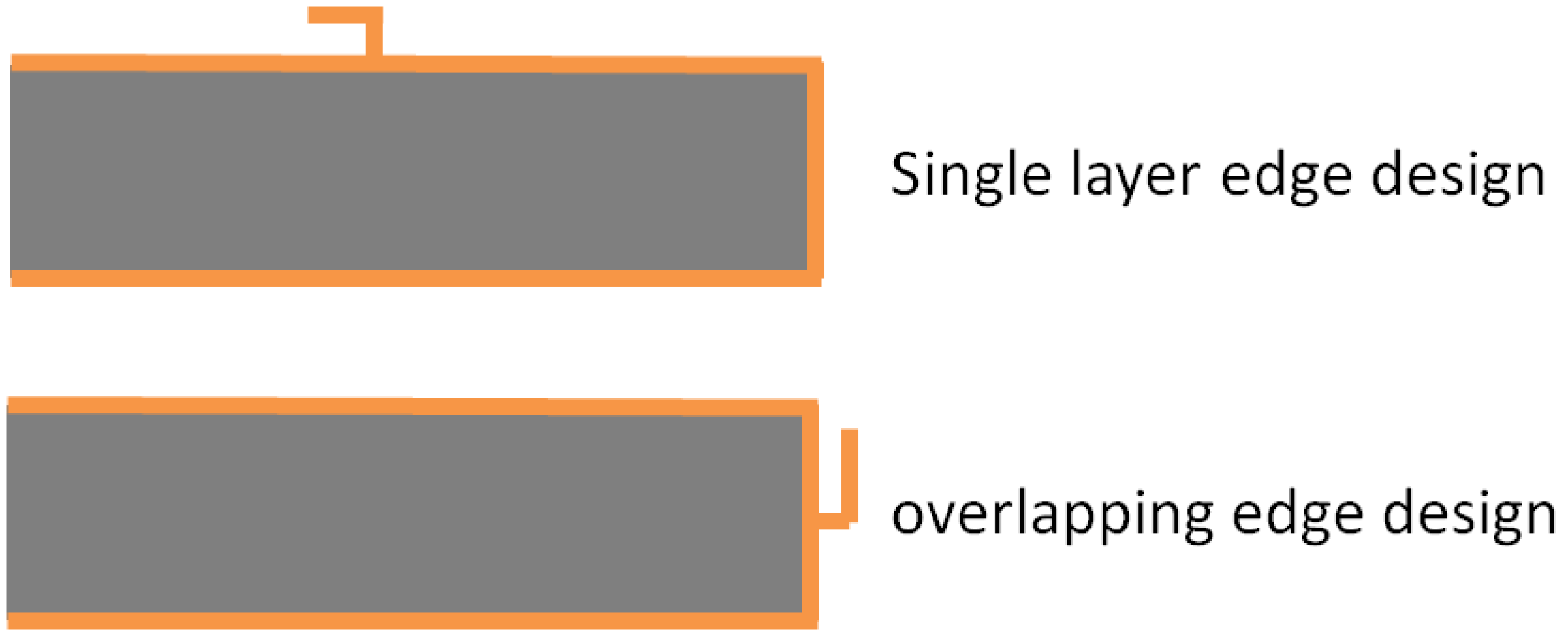
Photo: FIW

- 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



Edge Design



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How „severe“ is ψ?

- Depending on the ψ-value
  - Aluminium laminated foils

  vs.
  - Metallized plastic films

- Fluctuations in temperature difference

- Increased local heat-flux

- Lower R-value = higher efficient thermal conductivity

Photo: variotec

How „severe“ is ψ? Effect on Lambda...

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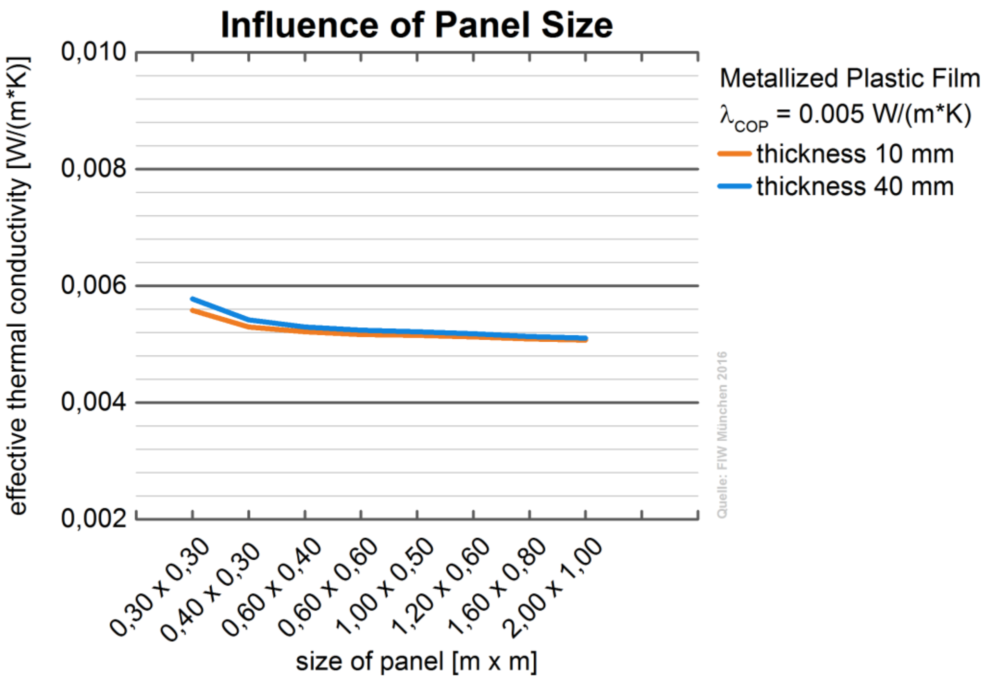
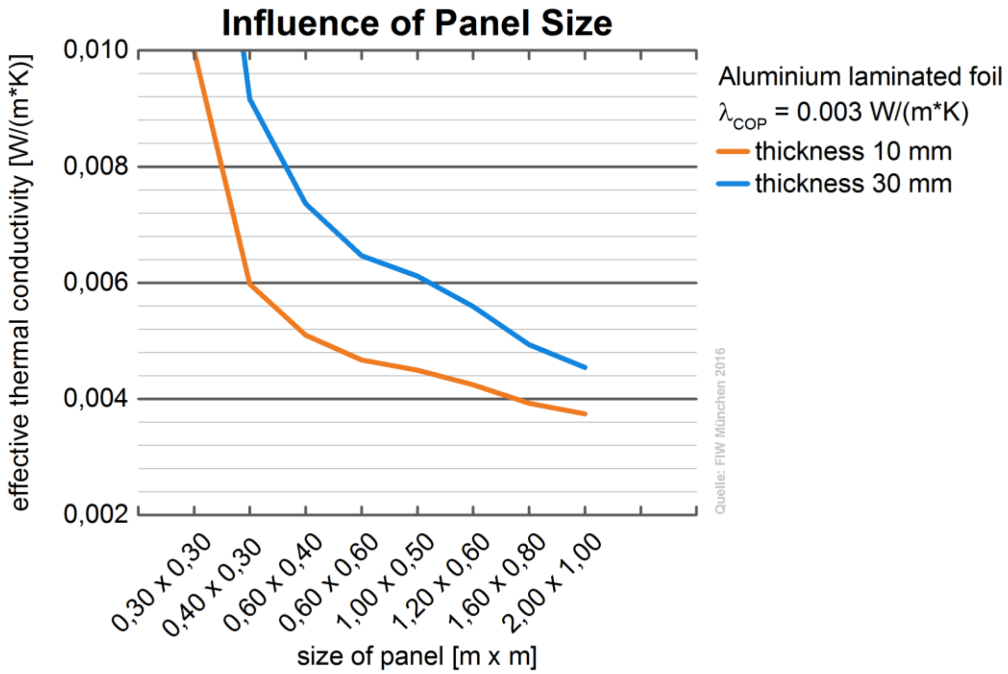
Metallized plastic film



How „severe“ is ψ? Effect on Lambda...

Aluminium laminated foil



How „severe“ is ψ? Effect on R-value…

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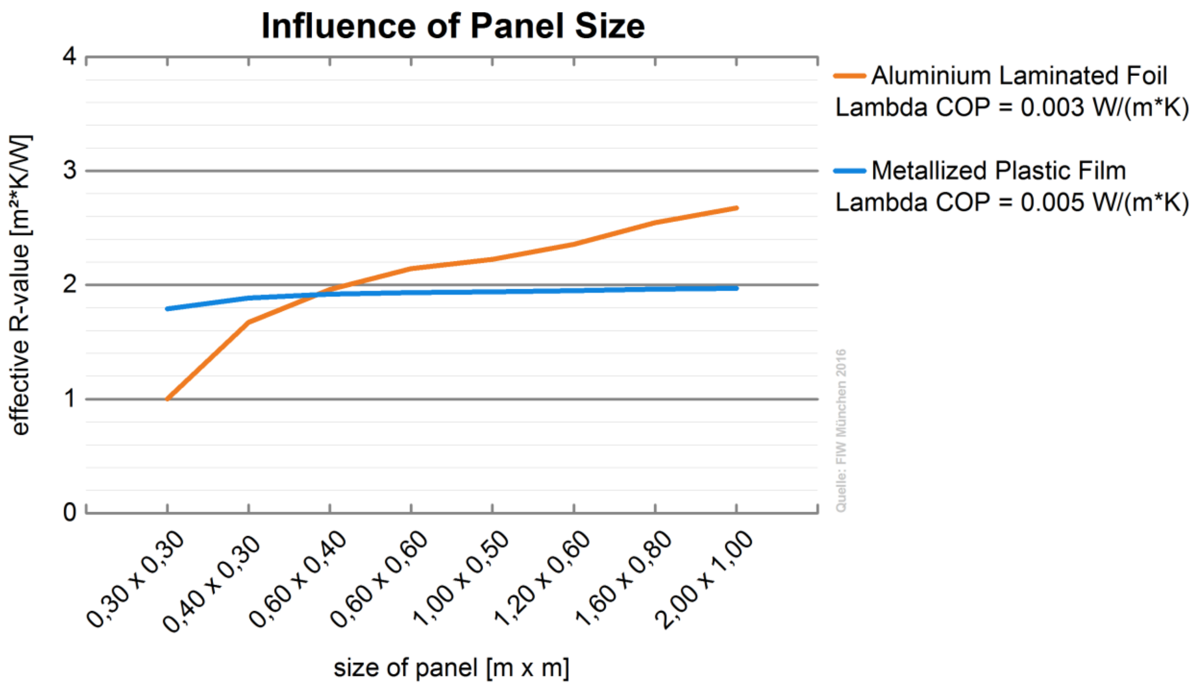
Comparison of 10 mm panels with silica and fiber glass cores



Hybrid Envelope

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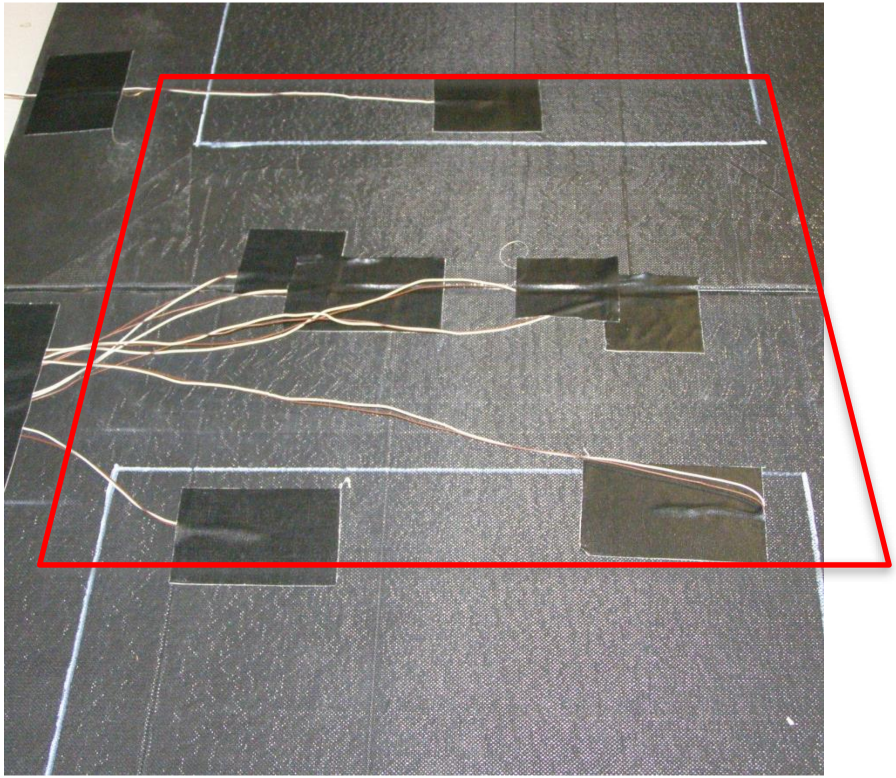
Measurement of ψ in GHP/HFM

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



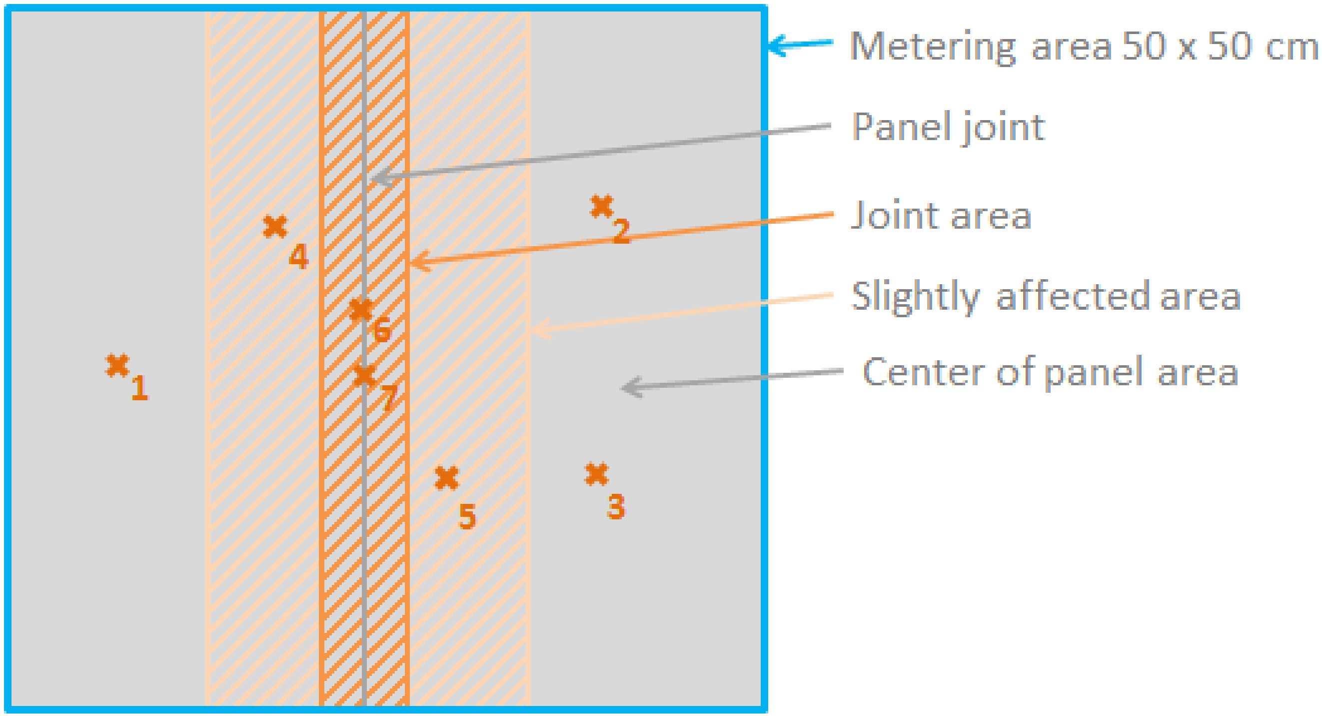
Thermal bridge measurement: single joint

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

Positioning of Thermocouples



GHP: Effect. Th. Cond. for joint assembly

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

$\lambda_{eq\ ja}$	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

HFM: Effect. Th. Cond. for joint assembly

$$\lambda_{eq\ ja} = \frac{d_{panel}}{R_{eq\ ja}} \qquad R_{eq\ ja} = \frac{\Delta\theta_m}{q}$$

$\lambda_{eq\ ja}$	equivalent thermal conductivity for joint assembly in W/(m·K)
q	heat-flux density from HFM in W/m²
d_{panel}	thickness of panel (equal thickness of joint assembly and COP specimens required for this method) in m
$R_{eq\ ja}$	Equivalent thermal resistance for joint assembly in m²·K/W
$\Delta\theta_m$	area weighted temperature difference for Joint assembly in K

Determination of linear thermal transmittance

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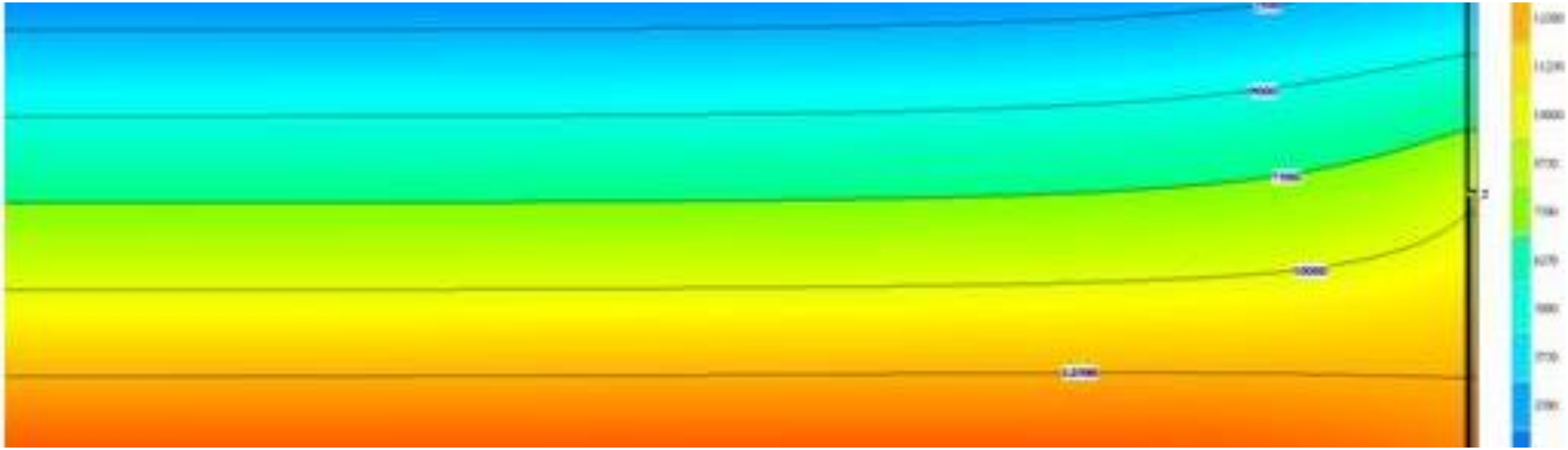
$$\psi = \frac{A}{d \cdot l_{\psi}} \cdot (\lambda_{eq\ ja} - \lambda_{COP})$$

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)



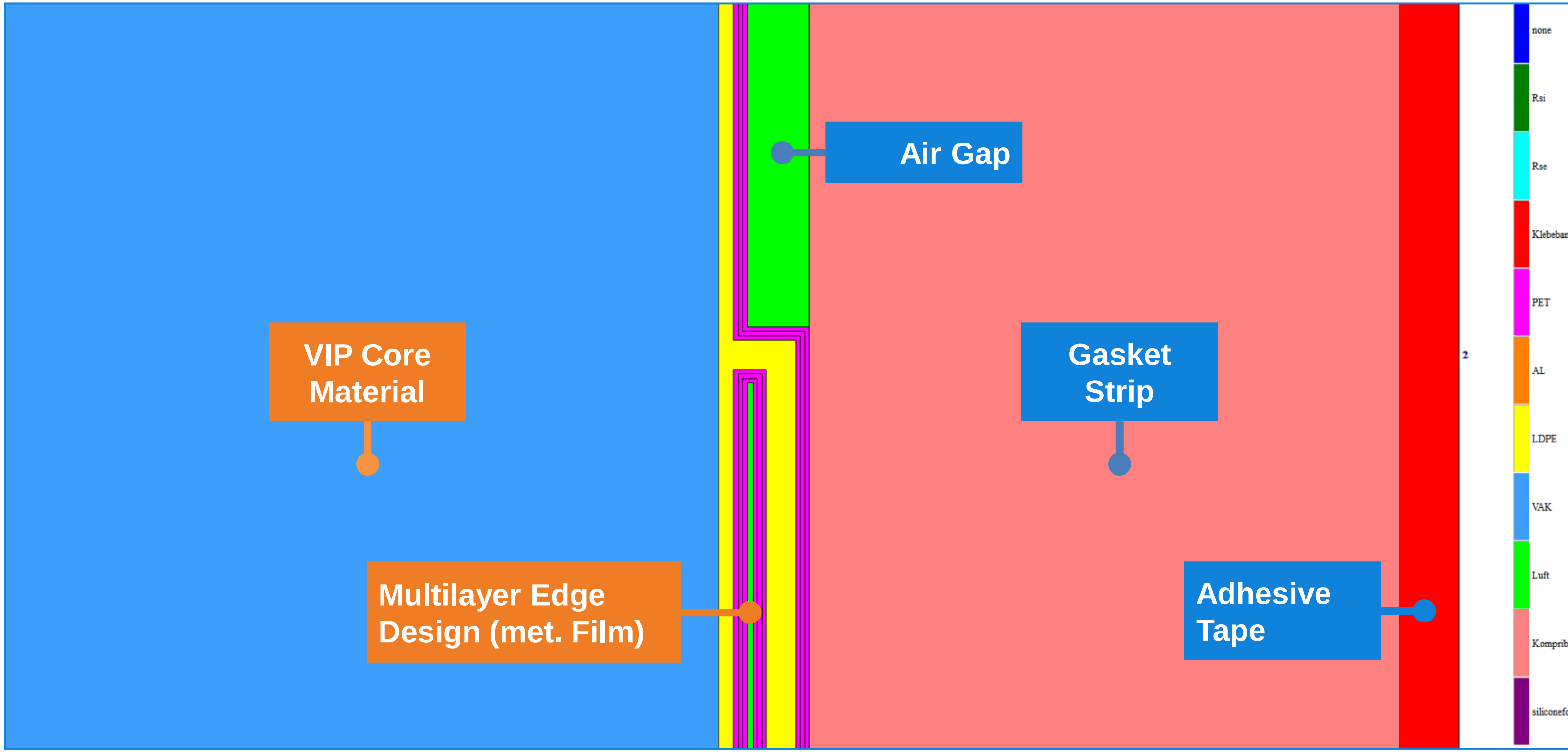
Supporting FD-simulations

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.

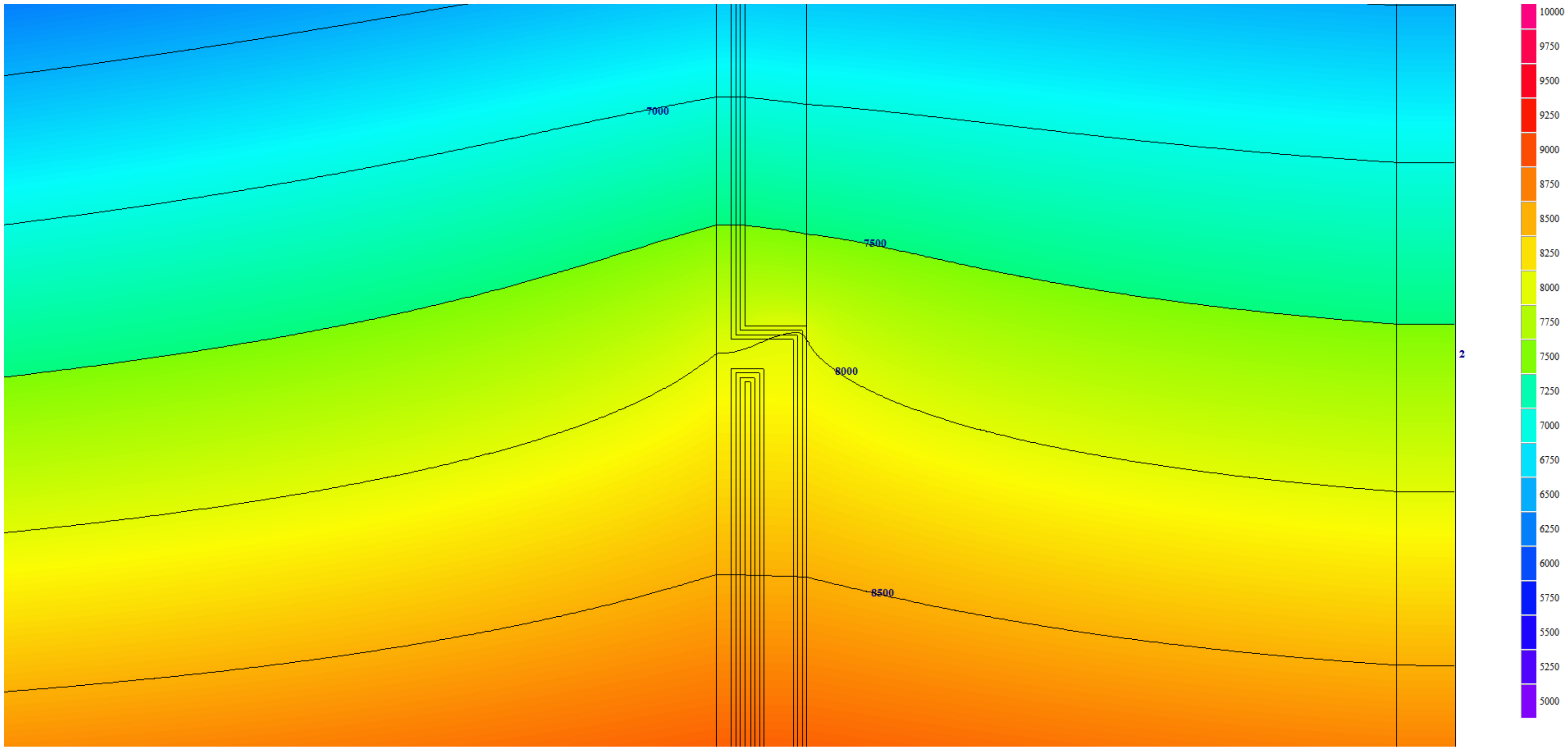
- Dimensions of areas can be obtained by FD-Simulations

Supporting FD-Simulations



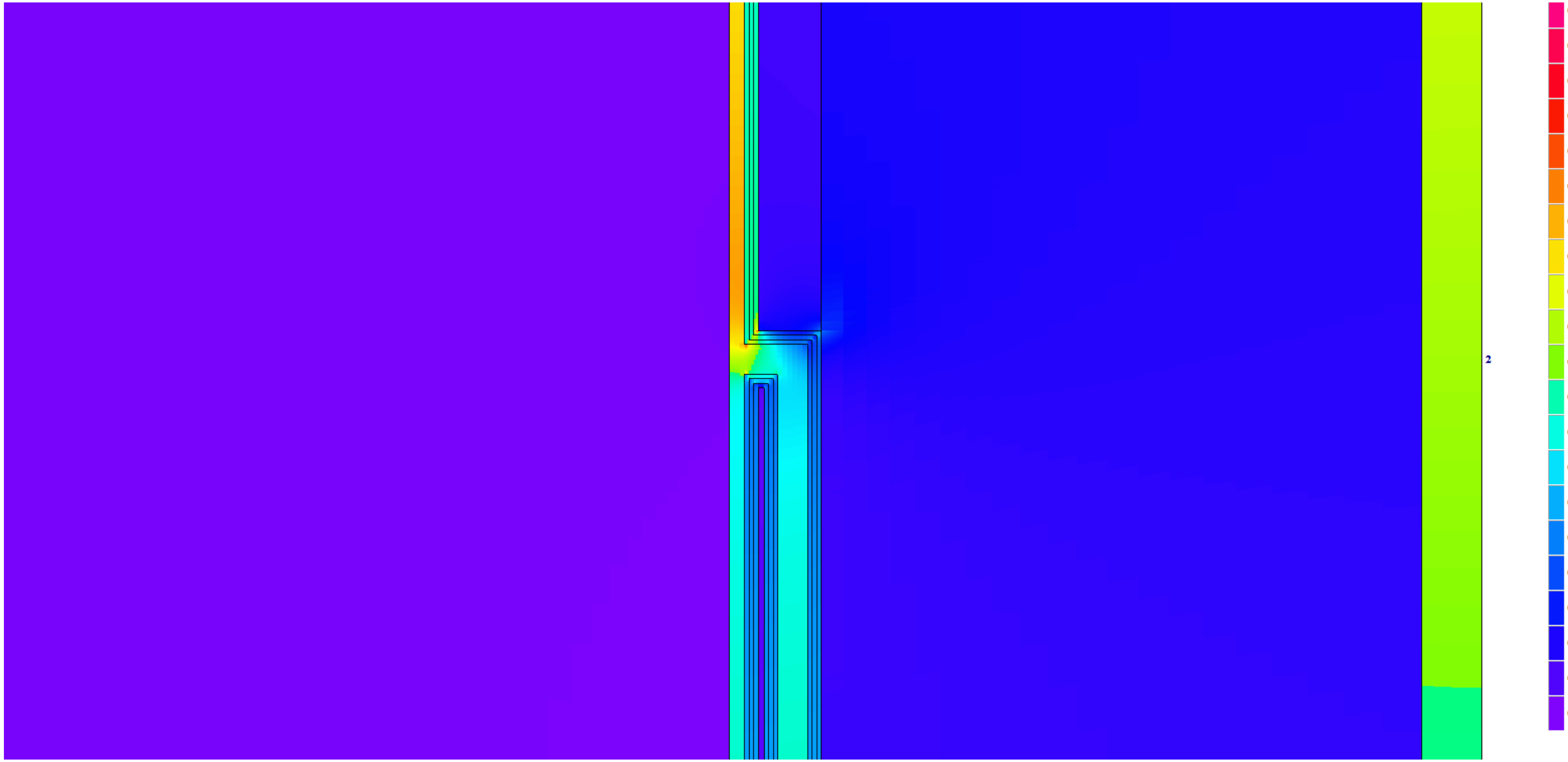
2D-Model for FD-Sim. of overlapping edge design with precompressed gasket strip and adhesive tape

Supporting FD-Simulations



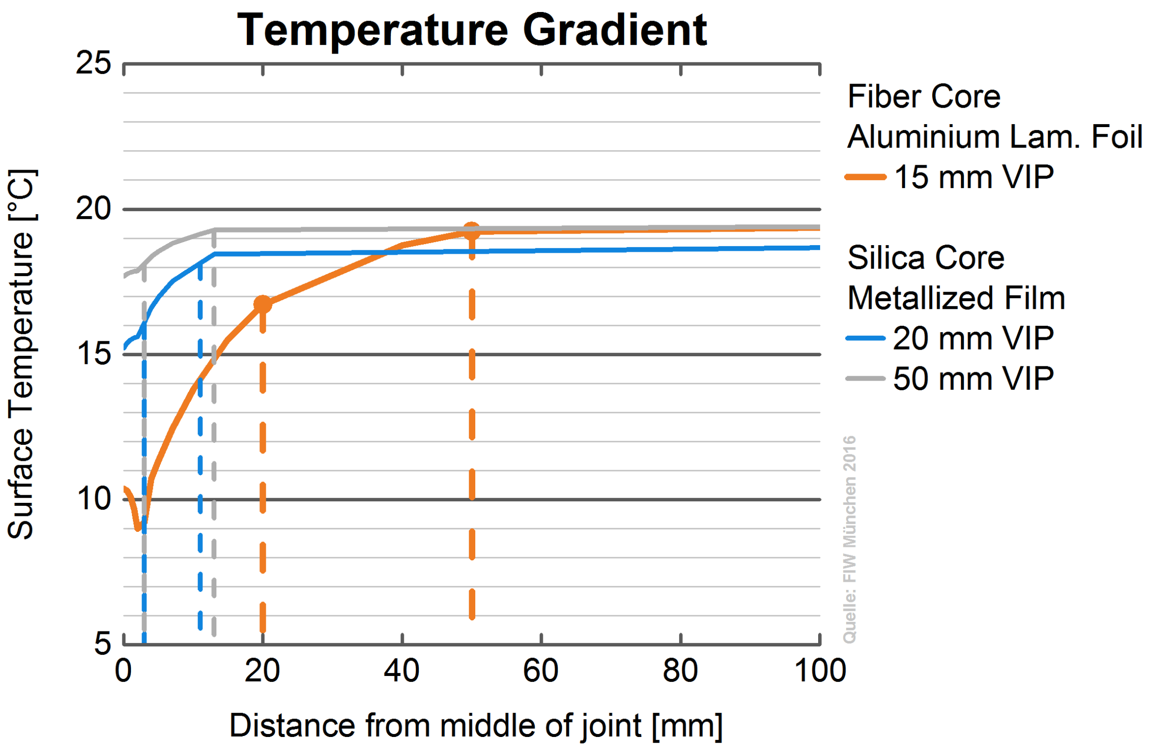
Temperature distribution (5 to 10°C) of overlapping edge design with precompressed gasket strip and adhesive tape

Supporting FD-Simulations



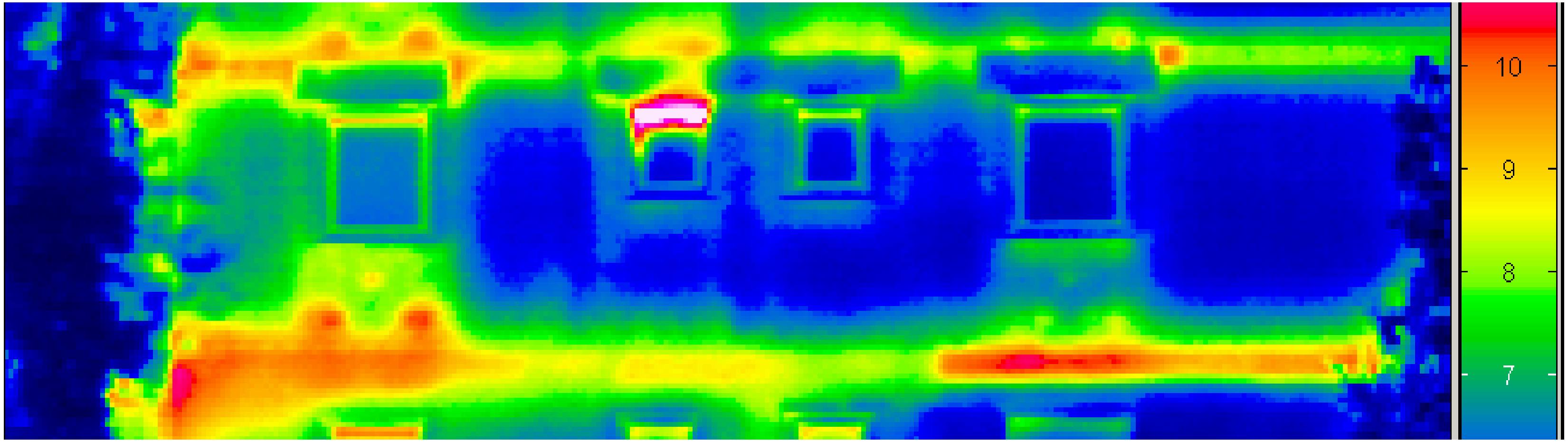
Total heat-flux density of overlapping edge design with precompressed gasket strip and adhesive tape

Temperature Gradient at Panel Edge



Area determination for 500 x 500 mm HFM

Panel	Joint Area	Slightly Affected Area	Center of Panel
FIB-AL.15	20 mm	30 mm	200 mm
FIB-MET.15	2 mm	15 mm	233 mm
FIB-HY.15	20 mm AL 2 mm MET	30 mm AL 15 mm MET	200 mm AL 233 mm MET
SIL-MET.20	2 mm	11 mm	237 mm
SIL-MET.50	2 mm	13 mm	235 mm



Results and discussion

Results

	FIB-AL	FIB-HY	FIB-MET	SIL-MET.20	SIL-MET.50
λ_{COP} [W/(m·K)]	0.0020 ± 0.00008	0.0021 ± 0.000084	0.0022 ± 0.000088	0.00435 ± 0.00014	0.0050 ± 0.00015
$\lambda_{eq\ ja}$ [W/(m·K)]	0.0056 ± 0.000448	0.0032 ± 0.000256	0.0027 ± 0.000216	0.00498 ± 0.00035	0.0062 ± 0.00043
$\Psi_{measured}$ [W/(m·K)]	0.117 ± 0.00937	0.037 ± 0.00296	0.016 ± 0.00128	0.015 ± 0.0012	0.013 ± 0.00104
$\Psi_{calculated}$ [W/(m·K)]	0.089	-	-	0.0144	0.0073
λ_{eff} panel size 1.0m x 0.5 m [W/(m·K)]	0.0079	0.0039	0.0030	0.0054	0.0070
λ increase from λ_{COP} to λeff [%]	293	85	35	23	39

Results and Discussion

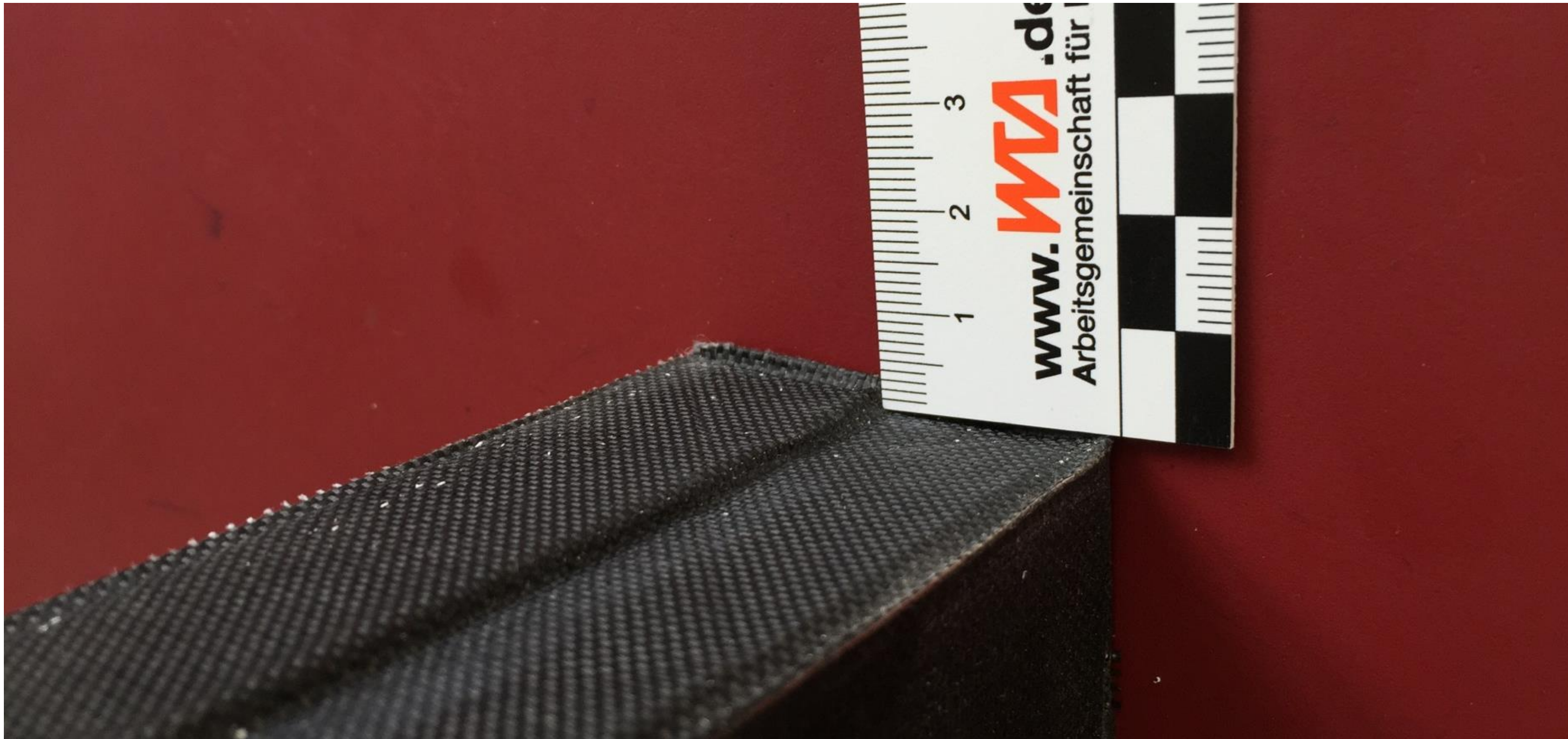
- Huge influence from thermal bridges on λ_{eff}!
  - Silica core with metallized film: 10 to 40 %
  - Fiber core
    - Aluminium foil: 20 to 300 %
    - Hybrid solution: 15 to 100 %
    - Metallized Film: 10 to 40 %
- Aluminium Foil recommend for „bigger“ panels
- Hybrid solutions with getters and/or desiccants

Results and Discussion

- Good agreement for 20 mm VIP
  - 5% - 8% uncertainty for HFM

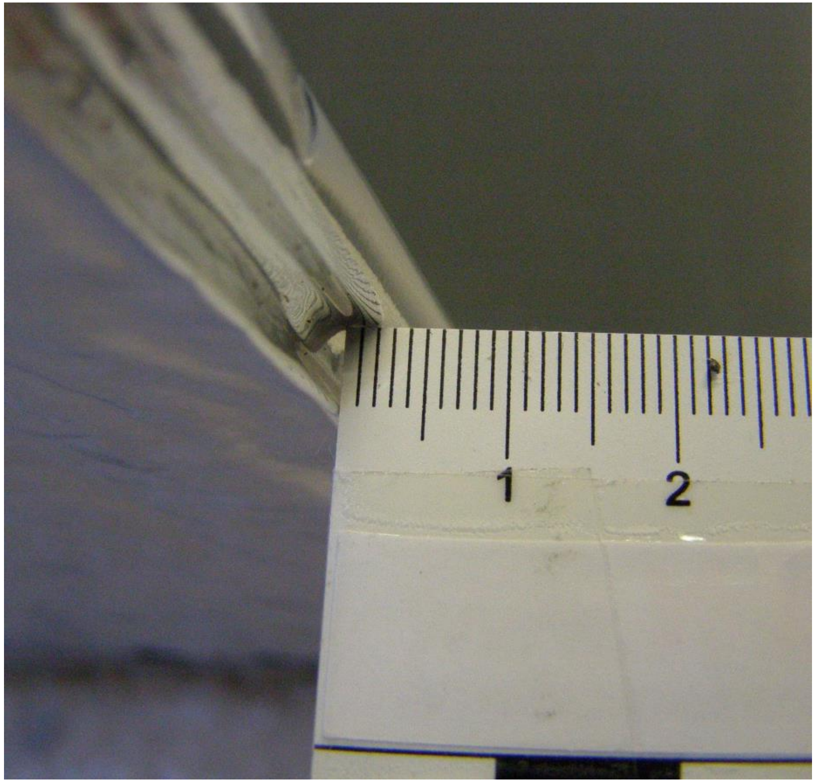
- Measurement for 50 mm VIP is significantly higher than ψ from numerical simulation
  - Even when considering extended uncertainty of 8% - 10%
  - Increased λ_{COP} for one VIP
  - Width of the joint significantly bigger
  - Edges of the panels uneven
  - Made from stacked core material slabs

Results and Discussion



Uneven edge with additional 2 mm offset

Results and Discussion



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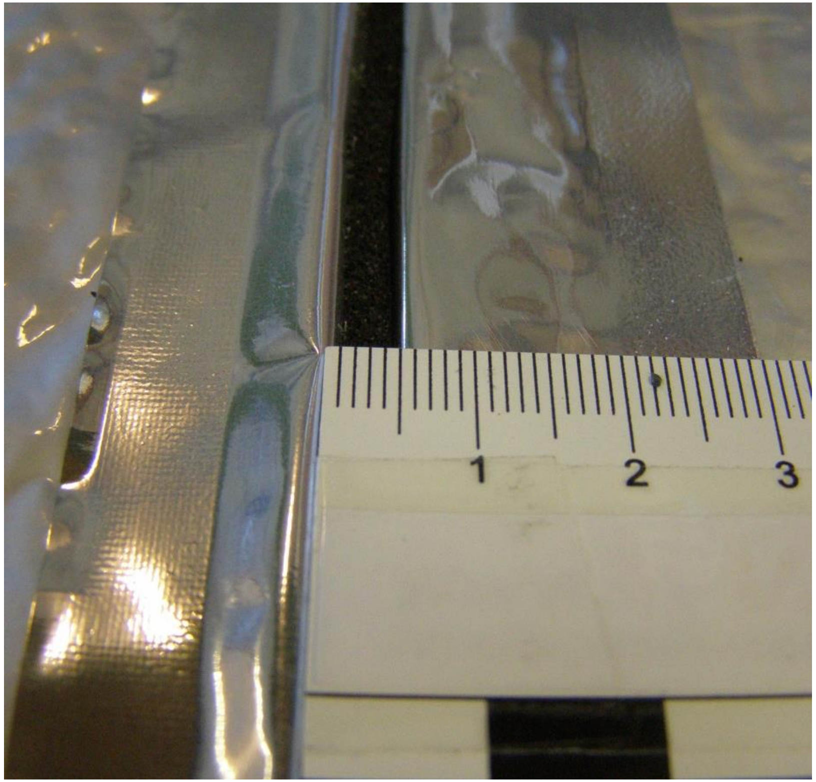

Photo: FIW München

Results and Discussion

- 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
  - When using GHP: make sure your regulation of the ring is o.k.

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 (differential measurement)
- 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.
- Recommend to use numerical simulations with FD-Method instead of measurements

Thank You!

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