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

Christoph Sprengard, FIW München
Content

- Brief introduction on linear thermal transmittance $\psi$
- Building kit: how to get from $\lambda_{\text{COP}}$ to $\lambda_{\text{eff}}$ to $R$ to $U$
- Vice Versa: measure $U$ or $R$ and derive $\lambda_{\text{eff}}$

- Measurement procedure for linear thermal transmittance $\psi$
- Supporting FD-Simulations
- Results and Discussion

Rotatable HFM apparatus of FIW
From $\lambda_{\text{COP}}$ to $U$...

...and from $U$ back to $\lambda_{\text{eff}}$ for declaration
2-dim and 3-dim thermal bridges

\[ U_{\text{eff}} = \frac{Q_{\text{eff}}}{A_{\text{panel}} \cdot \Delta \vartheta} \]

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

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

\[ \lambda_{eff} = \frac{d_{panel}}{U_{eff} - R_s} \]

\[ \lambda_{eff} = \frac{d_{panel}}{R_{eff}} \]

- Derive $\lambda_{eff}$ 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 $\psi$
and order of magnitude
Influencing Factors

- 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

Single layer edge design

overlapping edge design

Graphics: FIW München
How „severe“ is ψ?

- Depending on the ψ-value
  - Aluminium laminated foils
  - Metallized plastic films
- Fluctuations in temperature difference
- Increased local heat-flux
- Lower R-value = higher efficient thermal conductivity

Photo: variotec
How „severe“ is $\psi$? Effect on Lambda...

Metallized plastic film
How „severe“ is $\psi$? Effect on Lambda…

Aluminium laminated foil
How „severe“ is $\psi$? Effect on R-value...

Comparison of 10 mm panels with silica and fiber glass cores
Hybrid Envelope

Aluminum laminated film
Metallized plastic film

Graphics: FIW München
Measurement of $\psi$ in GHP/HFM
Determination of $\psi$ 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
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

- Metering area 50 x 50 cm
- Panel joint
- Joint area
- Slightly affected area
- Center of panel area
GHP: Effect. Th. Cond. for joint assembly

\[ \lambda_{eq\ ja} = \frac{\Phi \cdot d_{panel}}{A \cdot \Delta \theta_m} \]

\( \lambda_{eq\ ja} \) equivalent thermal conductivity for joint assembly in W/(m·K)
\( \Phi \) 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

\[ \lambda_{eq \ ja} = \frac{d_{panel}}{R_{eq \ ja}} \]

\[ R_{eq \ ja} = \frac{\Delta \theta_m}{q} \]

\( \lambda_{eq \ ja} \) 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

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

\( \psi \)  
linear thermal transmittance for the joints in the metering area in W/(m·K)

\( l_\psi \)  
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)

\( \lambda_{COP} \)  
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

VIP Core Material

Air Gap

Gasket Strip

Multilayer Edge Design (met. Film)

Adhesive Tape

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

Temperature Gradient

Surface Temperature [°C]

Distance from middle of joint [mm]

Fiber Core
Aluminium Lam. Foil
15 mm VIP

Silica Core
Metallized Film
20 mm VIP
50 mm VIP

Quelle: FIW München 2016
# Area determination for 500 x 500 mm HFM

<table>
<thead>
<tr>
<th>Panel</th>
<th>Joint Area</th>
<th>Slightly Affected Area</th>
<th>Center of Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIB-AL.15</td>
<td>20 mm</td>
<td>30 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>FIB-MET.15</td>
<td>2 mm</td>
<td>15 mm</td>
<td>233 mm</td>
</tr>
<tr>
<td>FIB-HY.15</td>
<td>20 mm AL</td>
<td>30 mm AL</td>
<td>200 mm AL</td>
</tr>
<tr>
<td></td>
<td>2 mm MET</td>
<td>15 mm MET</td>
<td>233 mm MET</td>
</tr>
<tr>
<td>SIL-MET.20</td>
<td>2 mm</td>
<td>11 mm</td>
<td>237 mm</td>
</tr>
<tr>
<td>SIL-MET.50</td>
<td>2 mm</td>
<td>13 mm</td>
<td>235 mm</td>
</tr>
</tbody>
</table>
Results and discussion
## Results

<table>
<thead>
<tr>
<th></th>
<th>FIB-AL</th>
<th>FIB-HY</th>
<th>FIB-MET</th>
<th>SIL-MET.20</th>
<th>SIL-MET.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{\text{COP}} ) [W/(m\cdot K)]</td>
<td>0.0020 ± 0.00008</td>
<td>0.0021 ± 0.000084</td>
<td>0.0022 ± 0.000088</td>
<td>0.00435 ± 0.00014</td>
<td>0.0050 ± 0.00015</td>
</tr>
<tr>
<td>( \lambda_{\text{eq ja}} ) [W/(m\cdot K)]</td>
<td>0.0056 ± 0.000448</td>
<td>0.0032 ± 0.000256</td>
<td>0.0027 ± 0.000216</td>
<td>0.00498 ± 0.00035</td>
<td>0.0062 ± 0.00043</td>
</tr>
<tr>
<td>( \psi_{\text{measured}} ) [W/(m\cdot K)]</td>
<td>0.117 ± 0.00937</td>
<td>0.037 ± 0.00296</td>
<td>0.016 ± 0.00128</td>
<td>0.015 ± 0.0012</td>
<td>0.013 ± 0.00104</td>
</tr>
<tr>
<td>( \psi_{\text{calculated}} ) [W/(m\cdot K)]</td>
<td>0.089</td>
<td>-</td>
<td>-</td>
<td>0.0144</td>
<td>0.0073</td>
</tr>
<tr>
<td>( \lambda_{\text{eff}} ) panel size 1.0m x 0.5 m [W/(m\cdot K)]</td>
<td>0.0079</td>
<td>0.0039</td>
<td>0.0030</td>
<td>0.0054</td>
<td>0.0070</td>
</tr>
<tr>
<td>( \lambda ) increase from ( \lambda_{\text{COP}} ) to ( \lambda_{\text{eff}} ) [%]</td>
<td>293</td>
<td>85</td>
<td>35</td>
<td>23</td>
<td>39</td>
</tr>
</tbody>
</table>
Results and Discussion

- Huge influence from thermal bridges on $\lambda_{\text{eff}}$!
  - 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 $\psi$ from numerical simulation
  - Even when considering extended uncertainty of 8% - 10%
  - Increased $\lambda_{COP}$ 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

Photo: FIW München

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 $\psi$ 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 $\psi$ 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!

Christoph Sprengard
FIW München
Lochhamer Schlag 4
82166 Gräfelfing
Phone +49 89 85800-58, Fax -40
sprengard@fiw-muenchen.de