Coupling Forced Convection in Air Gaps with Heat and Moisture Transfer inside Constructions

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Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan
Content

- Motivation
- Simulation Modell
- Results
Motivation

EU Projekt 3ENCULT (WP3): Hygrothermal Simulation of Beam-Ends

Source: Passiv Haus Institut, Protokollband Nr.32, Architekt Fingerling
Beam-End: Hygrothermal Simulation

- Heat and mass diffusion inside the solid domains
- Heat and mass convection through the air gap
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Heat and Mass Diffusion inside the Solid Domains

PDE, Coefficient Form

\[ \frac{\partial u}{\partial \varphi} \frac{\partial \varphi}{\partial t} + \nabla \cdot \left( -D_{m,\varphi} \nabla \varphi - D_{m,T} \nabla T \right) = 0 \]

\[ \frac{\partial h}{\partial T} \frac{\partial T}{\partial t} + \frac{\partial h}{\partial T} \frac{\partial \varphi}{\partial T} + \nabla \cdot \left( -D_{e,T} \nabla T - D_{e,\varphi} \nabla \varphi \right) = 0 \]

- Moisture distribution: \( \varphi(x,y,t) \) or \( a_w(x,y,t) \)
- Temperature distribution: \( T(x,y,t) \)

| \( \varphi \) | Relative humidity |
| \( T \) | Temperature |
| \( u \) | Water content |
| \( h \) | Specific enthalpy |
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Forced Convection in the Air Gap

Example: Energy Balance

\[ A v h_a - \alpha \frac{\partial h_a}{\partial t} A \Delta s + \alpha_k (T_b - T_a) L \Delta s \leq A v \left( h_a + \frac{\partial h_a}{\partial s} \Delta s \right) \]
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Forced Convection in the Air Gap: Governing Equations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_v )</td>
<td>Vapor density</td>
</tr>
<tr>
<td>( h )</td>
<td>Air enthalpy</td>
</tr>
<tr>
<td>( A )</td>
<td>Cross section area</td>
</tr>
<tr>
<td>( L )</td>
<td>Cross section perimeter</td>
</tr>
<tr>
<td>( \nu )</td>
<td>Air velocity</td>
</tr>
</tbody>
</table>

Inside\hspace{1cm}Outside

Beam

Wall

\[
A \left( \frac{\partial \rho_v}{\partial t} + \nu \frac{\partial \rho_v}{\partial s} \right) = L \beta_k \left( p_{v,b} - p_v \right)
\]

\[
A \left( \frac{\partial h}{\partial t} + \nu \frac{\partial h}{\partial s} \right) = L \alpha_k \left( T_b - T \right)
\]

Moisture balance

Energy balance
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**Weak Form on the Boundary**

\[
\int_0^S \left\{ \begin{array}{l}
w \left[ \frac{\partial \rho_v}{\partial t} - \frac{L \beta_k}{A} (p_{v,b} - p_v) \right] - \frac{\partial w}{\partial s} v\rho_v \end{array} \right\} ds + w v\rho_v,s - w v\rho_v,0 = 0
\]

\[
\int_0^S \left\{ \begin{array}{l}
w \left[ \frac{\partial h}{\partial t} - \frac{L \alpha_k}{A c_p \rho} (h_b - h) \right] - \frac{\partial w}{\partial s} v h \end{array} \right\} ds + w v h_s - w v h_0 = 0
\]
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Comparison with Delphin
2D Modell without Convection

Position 1

Position 2

Position 3

Mesh

\[ t=10[a] \]

\[ aw[\%] \]
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Forced Convection in the Air Gap: Air Velocity in the Gap

Development of the Air Velocity in the Gap

<table>
<thead>
<tr>
<th>t [d]</th>
<th>v [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>73</td>
<td>1.25</td>
</tr>
<tr>
<td>146</td>
<td>0</td>
</tr>
<tr>
<td>219</td>
<td>0</td>
</tr>
<tr>
<td>292</td>
<td>0</td>
</tr>
<tr>
<td>365</td>
<td>0</td>
</tr>
</tbody>
</table>
Forced Convection in the Air Gap: Results

325 [d]

345 [d]

365 [d]

Point 1

Point 2

Point 3

aw [-]

no convection

$v_{\text{max}}=0.6$ [m/s]

$v_{\text{max}}=1.25$ [m/s]

$v_{\text{max}}=1.8$ [m/s]
Outlook

Validation
- Numerical error analysis
- Experimental validation

Further development
- Free convection inside air cavities (CFD)
Thank you for your attention!

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