ETICS with vacuum insulation panels for retrofitting buildings from the great Swedish housing program “Miljonprogrammet”

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Robust and Durable Vacuum Insulation Technology for Buildings
KTH
Div. of Building technology

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Why the Swedish “Million program”? 

We have to deal with the existing building stock - to meet the “20-20-20” targets of the EU-commission related to climate and energy.

In Sweden, about 21% of the energy use can be related to the heat losses through the climatic envelopes of buildings.

The Swedish “Million Program” units built in the period between 1965 and 1974.

A U-value of about 0.6 Wm\(^{-2}\)K\(^{-1}\) on average for external walls.
Objectives

• To propose a new and robust VIP technical solution for the great Swedish Million dwelling program

• To investigate the influence of various design factors on the resulting U-value

• To simulate heat and moisture conditions.

• To compare theoretical assessments and in situ measurements of thermal performance

• To carry out a full scale measurement in a climatic chamber to investigate the influence of thermal bridges of a wall construction with exterior VIPs
Method

- A parametric study of the impact of the thermal conductivity of the joints of the panels and the adjacent insulation layer as well as the material of the fasteners.

- A 3-dimensional COMSOL simulation of heat transfer through the construction.

- A 2-dimensional transient modeling of vapor diffusion with COMSOL allowing for sorption in the material as well as enhanced moisture transport at high relative humidity.

Hovsjö, an example of a housing project in the “Million Program”
Parametric pre-study

- The material with a high thermal resistance at the VIP joints has a significant influence on the thermal bridges. Going from a value of 0.10 to 0.02 W m\(^{-1}\)K\(^{-1}\) will give a reduction that amounts to about 30% of the total density of heat loss.

- The influence of improving the outer insulation layer does also have a measurable effect on the heat flux, although somewhat smaller.
VIP technical solution

2D och 3D dynamic simulations with Comsol Multiphysics®

- The average hourly values for outdoor temperature and relative humidity are retrieved from an International weather for energy calculation (IWEC) climate file for Stockholm, 2012
- The indoor temperature and relative humidity are as defined by EN 15026

15 RENDERING
45 MINERAL WOOL
50 VIP, WITH A 10 MM JOINT BETWEEN PANELS
160 LIGHT AGGREGATE CONCRETE

ALL DIMENSIONS IN MM
Simulated heat transport
Moisture transport

The relative humidity distribution in wall construction in the long term, extreme conditions.
A new VIP mounting system

- Facade components are standard and available at market.

- The VIP sandwiches were glued to the outside of the wall structure, by the means of an adhesive (hydraulically setting mortar)

- A 3 mm thick L-profile plus a T-profile (stainless steel) provides a flexible ventilating air gap between the façade board and the structure
Full scale laboratory measurement
The heat flow meter (HFM) sensors were mounted in different positions on the interior surface.

80 temperature sensors, Copper/Constantan as well as Chromel/Alumel thermocouple were installed at various coordinates in the plane of the wall and at the material layer boundaries.
Calculated centre-of-panel U-value

The TPS technique (TPS 2500S-ISO/DIS 22007-2.2) used to evaluate the thermal properties of the materials used in the wall

<table>
<thead>
<tr>
<th>Material</th>
<th>d (mm)</th>
<th>$\lambda$ (W m$^{-1}$K$^{-1}$)</th>
<th>Standard deviations</th>
<th>Source</th>
<th>R (m$^2$K W$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerated concrete blocks</td>
<td>365</td>
<td>0.118</td>
<td>± 0.000223</td>
<td>TPS</td>
<td>3.09</td>
</tr>
<tr>
<td>Hydraulically setting mortar</td>
<td>2</td>
<td>0.959</td>
<td>± 0.000234</td>
<td>TPS</td>
<td>0.002</td>
</tr>
<tr>
<td>EPS</td>
<td>20</td>
<td>0.0329</td>
<td>± 0.000016</td>
<td>TPS</td>
<td>0.608</td>
</tr>
<tr>
<td>VIP$_{centre}$</td>
<td>20</td>
<td>0.0042</td>
<td>-</td>
<td>Manufacturer</td>
<td>4.76</td>
</tr>
<tr>
<td>EPS</td>
<td>10</td>
<td>0.0329</td>
<td>± 0.000016</td>
<td>TPS</td>
<td>0.304</td>
</tr>
<tr>
<td>$R_{si}$</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Standard value</td>
<td>0.14</td>
</tr>
<tr>
<td>$R_{se}$</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Standard value</td>
<td>0.04</td>
</tr>
<tr>
<td>$R_{wall}$</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>8.944</td>
</tr>
</tbody>
</table>

Calculated U-value (W m$^2$K$^{-1}$) 417

<table>
<thead>
<tr>
<th>Before retrofitting 0.305</th>
</tr>
</thead>
<tbody>
<tr>
<td>After retrofitting 0.112</td>
</tr>
</tbody>
</table>
Centre-of-Panels U-value using Thermocouples and reference material

\[ \frac{\lambda_{\text{Block}}}{d_{\text{Block}}} (T_{si} - T_{\text{Block-VIP}}) = U_{\text{wall}} (T_i - T_e) \]

Centre-of-Panels U-value by using Thermocouples and HFM sensors

\[ \frac{(T_i - T_{si})}{R_{si}} = q_{\text{HFM}} = U_{\text{wall}} (T_i - T_e) \]
Effective U-value by thermography investigations

\[ q_{tot} = U_{centre\text{-}of\text{-}panel} \cdot \Delta T + \Psi \cdot \frac{P}{A} \cdot \Delta T \]

\[ \frac{T_e - T_{se VIP center}}{R_{se}} = \frac{U_{centre\text{-}of\text{-}panel} \cdot (T_i - T_e)}{U_{effective} \cdot (T_i - T_e)} \]

- \( T_e \): Outside air temperature
- \( T_i \): Inside air temperature
- \( T_{se} \): Average outside wall surface temperature
- \( T_{se VIP center} \): Outside wall surface temperature at coordinate of the centre-of-panel
- \( R_{se} \): Wall surface thermal resistance at exterior side
- \( U_{centre\text{-}of\text{-}panel} \): Thermal transmittance of the wall at coordinate of the centre-of-panels
- \( U_{effective} \): Effective thermal transmittance of the wall
## Climatic Condition

<table>
<thead>
<tr>
<th>Climate sequences</th>
<th>Measuring time (Hours)</th>
<th>Colder side</th>
<th>Warmer side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$T_e$ (°C)</td>
<td>$T_i$ (°C)</td>
</tr>
<tr>
<td>Climatic time sequence No.1</td>
<td>410</td>
<td>-5</td>
<td>22-24</td>
</tr>
<tr>
<td>Climatic time sequence No.2</td>
<td>860</td>
<td>-15</td>
<td>23-28</td>
</tr>
<tr>
<td>Climatic time sequence No.3</td>
<td>2030</td>
<td>-20</td>
<td>23-28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R_{He}^a$ (%)</td>
<td>$R_{He}^a$ (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45 – 73</td>
<td>6.7–25.5</td>
</tr>
</tbody>
</table>

*Figures from Excel*
Measured temperatures

\[ T_i = +27.63°C \]

\[ T_e = -17.06°C \]

\[ T_{si} = +23.3°C \]

\[ T_{se} = -14.5°C \]

\[ +25.5°C \]

\[ +26.03°C \]

\[ +25.8°C \]

\[ 0.99°C \]

\[ +7.45°C \]

\[ +7.15°C \]

\[ -14.63°C \]

\[ -16.1°C \]

\[ -15.2°C \]
Centre-of- Panels U-values

Taking into account an addition standard thermal resistance of a ventilated air gap
**Effective U-value**

**Measured temperatures:**

<table>
<thead>
<tr>
<th>Placement</th>
<th>VIP No. 5-8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VIP&lt;sub&gt;centre&lt;/sub&gt; 1200×600 mm&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Inside air temperature (° C)</td>
<td>28.83</td>
</tr>
<tr>
<td>Interior surface temperature(° C)</td>
<td>25.62</td>
</tr>
<tr>
<td>Concrete blocks -VIP(° C)</td>
<td>6.89</td>
</tr>
<tr>
<td>Exterior surface temperature(° C)</td>
<td>-15.31</td>
</tr>
<tr>
<td>Outside air tempature (° C)</td>
<td>-16.87</td>
</tr>
</tbody>
</table>

**A comparison of the U-values and λ-values:**

<table>
<thead>
<tr>
<th></th>
<th>[W/(m&lt;sup&gt;2&lt;/sup&gt;·K)]</th>
<th>[mW/(m·K)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated U&lt;sub&gt;centre-of-panel&lt;/sub&gt;</td>
<td>0.112</td>
<td>According to manufacturer λ&lt;sub&gt;centre-of-panel&lt;/sub&gt; 4.2</td>
</tr>
<tr>
<td>Measured U&lt;sub&gt;centre-of-panel&lt;/sub&gt;</td>
<td>0.132</td>
<td>Measured λ&lt;sub&gt;centre-of-panel&lt;/sub&gt; ≈7</td>
</tr>
<tr>
<td>Measured U&lt;sub&gt;effective&lt;/sub&gt;</td>
<td>0.154</td>
<td>Measured λ&lt;sub&gt;effective&lt;/sub&gt; ≈10.9</td>
</tr>
</tbody>
</table>
Conclusions

• Use material with relatively low thermal conductivity at the joints have a significant impact on the resulting U value.

• Thermal conductivity of the adjacent insulation next to the VIP's have a measurable effect on the heat flow, while the choice of materials for the mounting (e.g. screws) have a smaller effect on the resulting U value compared to the effect of the material in the joints and adjacent insulation.

• Relative humidity calculation shows that the location of the VIP on the outside does not a moisture problem to the construction.

• There is no risk of high relative humidity at the joints.

• VIPs is a very competitive solution to renovate the construction of the Swedish “Million Program”.

• This study demonstrates a robust, effective, simple and fast system for external mounting of the VIPs, an improved centre-of-panels thermal transmittance of the wall, in the range of 0.118-0.132 W m\(^{-2}\)K\(^{-1}\) as well as a low effective thermal conductivity for the VIPs of 10.9 mW m\(^{-1}\)K\(^{-1}\), are reached.
Thanks for your kind attention!