HIGHLY INSULATING AEROGEL GLAZING

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Abstract – Granular silica aerogel offers the possibility to construct highly insulating translucent glazings. To avoid settlement of the granules upon atmospheric pressure changes, which occurred in earlier glazing concepts and even caused destruction of glazings, the granules are sandwiched between a double skin sheet made of PMMA. The sheet is mounted between two low-emissivity coated glass panes. This construction allows to achieve U-values of 0.4 W/(m²K), depending on pane emissivity and filling gas. A high solar transmittance of about 71% is obtained for a double skin sheet filled with a 14 mm thick layer of optimized silica aerogel. Thus, total solar energy transmittances of up to 0.45 for the whole glazing unit are achieved. The glazing has a thickness of about 50 mm. Such aerogel glazings can be used as light scattering daylighting elements with considerable energy gains if oriented towards the sun and vanishing energy losses even if mounted into north oriented facades.

1. INTRODUCTION
The energy performance of buildings is mainly determined by their facade construction. Transparent and translucent facade elements generally have heat transfer coefficients (U-values) above 0.7 W/(m²K). While opaquely insulated walls typical U-values are 0.3 W/(m²K). In extreme cases for ultra low energy buildings U = 0.1 W/(m²K) is required.

In residential buildings developments focus on the reduction of heat losses and increased solar gains in winter. In office buildings often daylighting aspects are of primary importance.

Various systems for daylighting and solar walls are commercially available or under investigation:
• fleeces between window panes [1]
• capillary and honeycomb structures [2]
• windows containing aerogel layers [3].

The development of highly insulating translucent glazings allows to introduce new daylighting and energy concepts which reduce the total energy demand of buildings and provide comfortable working and living conditions.

In the following a newly developed aerogel glazing is described. Problems due to settlement that occurred in earlier developments are overcome using a novel construction. The aerogel glazing has superior optical and thermal properties.

2. SYSTEM DESCRIPTION
2.1 Daylighting element
The translucent glazing contains a 16 mm thick double skin sheet filled with granular silica aerogel. The bars of the double skin sheet have a thickness of about 2.5 mm and a distance of 64 mm. In order to obtain very low U-values, low emissivity (.) coated glass panes as well as rare gas fillings (argon or krypton) are used. Depending on the situation, low-e coatings with a high solar gain coefficient (g-value) are used for daylighting facades in dwellings. For office buildings coatings with a small g-value are preferred in order to reduce solar gains. The pane-skin distance can be adapted to avoid convection of the gas filling. Using argon, a spacing of 16 mm is optimal; with krypton 10 to 12 mm are used.

Figure 1. Schematic cut view of the translucent aerogel glazing.

The aerogel-filled double skin sheet is not affected by "pumping" of the window panes upon atmospheric pressure changes which was the main reason for settlement of the aerogel granules in previous aerogel windows [3].

Figure 3 shows a photograph of a prototype of the translucent aerogel glazing with a size of about 0.5m x 0.5m. The whitish appearance of the aerogel layer separated by the bars of the double skin sheet with a distance of about 60 mm dominates the optical impression of the system.
2.2 Preparation and optimization of aerogel granules

The aerogel granules are prepared from waterglass in a sol-gel process. The hydro gel is silylated and dried at ambient pressure.

Two types of granular aerogels are available, one kind consisting of regular spheres (Fig. 4a) and the other of irregularly fractured pieces (Fig. 4b). The problem with irregular granules is the appearance of “clouds” in the filling. The regular granules show a much more homogenous distribution. There is a significant difference in the optical properties of the regular and the irregular granules, too.

3. MEASUREMENTS

3.1 Optical properties of granular aerogels

In order to characterize the optical quality of the aerogel granules normal-hemispherical transmission and reflection measurements in the solar spectral range (400 nm to 2000 nm) were performed. The measurements were carried out using an integrating sphere arrangement. In figure 5 the results for different aerogel samples are depicted.

Rayleigh and Mie scattering at structural inhomogeneities are responsible for the increase of transmission with increasing wavelength. Typical sizes are in the 10 nm to 100 nm range for the primary structures building by the SiO2 network while surface defects and cracks within the particles measure several microns[5]. In the near-infrared (NIR) spectral region absorption by the SiO2 molecules and adsorbed water and organic compounds occurs.

The investigated irregular aerogel samples show a higher transmittance than the more regular aerogels. By optimizing the
production process the transmittance of both aerogel types could be significantly increased.

To determine the absorption transmission and reflection measurements of a aerogel-filled double skin sheet were performed. Figure 6 shows the transmittance and reflectance as well as the derived absorptance. In the visible region absorption is negligible (below 5%), in the NIR region additional absorption of the PMMA double skin sheet occurs.

To give characteristic quantities for the optical performance of the systems the solar ($\tau_{\text{nh,solar}}$) and visible ($\tau_{\text{nh,vis}}$) normal-hemispherical transmittance was determined by weighting the spectral values $\tau(\lambda)$ with an AM 1.5 solar spectrum or with the product of the solar spectrum and the sensitivity of the human eye [6] in table 1 and 2 the achieved results are shown.

![Fig. 6. Spectral normal-hemispherical transmittance, reflectance and absorptance of a 14 mm thick irregular granular aerogel layer (type I) within a double skin sheet.](image)

**Table 1.** Solar- and visual-averaged values of the normal-hemispherical transmittance of a 20 mm thick granular aerogel layer.

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>$\tau_{\text{nh,solar}}$ $\pm$</th>
<th>$\tau_{\text{nh,vis}}$ $\pm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregular aerogel I - 20 mm</td>
<td>0.75 ± 0.04</td>
<td>0.72 ± 0.04</td>
</tr>
<tr>
<td>Irregular aerogel II - 20 mm</td>
<td>0.50 ± 0.03</td>
<td>0.43 ± 0.03</td>
</tr>
<tr>
<td>Regular aerogel I - 20 mm</td>
<td>0.37 ± 0.03</td>
<td>0.26 ± 0.03</td>
</tr>
<tr>
<td>Regular aerogel II - 20 mm</td>
<td>0.31 ± 0.03</td>
<td>0.25 ± 0.03</td>
</tr>
</tbody>
</table>

Using argon or krypton as filling gas the thermal conductivity further decreases.

### 3.3 System properties

To characterize the translucent system described in section 2.1 U-value, solar and visual transmittance as well as the $g$-value of a sample filled with aerogels were measured. In addition U- and $g$-values were calculated using [7] and the properties of the applied low-e coatings, gas filling and aerogel.

Table 3 shows that the measured and calculated values agree well. This allows us to predict the thermo-optical properties of a variety of system modifications.

**Table 3.** Measured and modeled U- and $g$-values for two glazings. Glazing I consists of two low-e coated glass panes with an emissivity of 0.08 and a gas fill of 80% Kr and 20% filled with regular aerogel type I air (photograph shown in fig. 3), while the second glazing consists of two low-e coated glass panes with an emissivity of 0.03 and a gas fill of 60% Kr and 40% air filled with irregular aerogel type II.

<table>
<thead>
<tr>
<th>Glazing</th>
<th>$U$-value / W/(m²K)</th>
<th>$\tau_{\text{nh,solar}}$</th>
<th>$\tau_{\text{nh,vis}}$</th>
<th>$g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured I</td>
<td>0.40 ± 0.04</td>
<td>0.22 ± 0.02</td>
<td>0.26 ± 0.02</td>
<td>0.31 ± 0.00</td>
</tr>
<tr>
<td>Modeled I</td>
<td>0.44</td>
<td>0.21</td>
<td>0.24</td>
<td>0.33</td>
</tr>
<tr>
<td>Measured II</td>
<td>0.45 ± 0.04</td>
<td>0.13 ± 0.02</td>
<td>0.27 ± 0.02</td>
<td>0.20 ± 0.00</td>
</tr>
<tr>
<td>Modeled II</td>
<td>0.46</td>
<td>0.12</td>
<td>0.23</td>
<td>0.22</td>
</tr>
</tbody>
</table>

In table 4 the calculated U-values are shown for different systems:

<table>
<thead>
<tr>
<th>Glazing construction</th>
<th>emissivity of used coatings</th>
<th>U-value / W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>application: daylighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 / 16 / 10 / 16 / 4</td>
<td>0.08 / 0.08</td>
<td>0.56</td>
</tr>
<tr>
<td>pane/Ar/aerogel/Ar/pane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 / 12 / 16 / 12 / 4</td>
<td>0.08 / 0.08</td>
<td>0.44</td>
</tr>
<tr>
<td>pane/Kr/ aerogel /Kr/pane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>application: sun protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 / 16 / 10 / 16 / 4</td>
<td>0.03 / 0.03</td>
<td>0.47</td>
</tr>
<tr>
<td>pane/Ar/ aerogel /Ar/pane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 / 12 / 16 / 12 / 4</td>
<td>0.03 / 0.03</td>
<td>0.37</td>
</tr>
<tr>
<td>pane/Kr/ aerogel /Kr/pane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5 shows the calculated visual transmittance and solar gain coefficient for the cases mentioned above. They show no significant dependence on the filling gas.

The translucent glazings split reach a high visible transmittance of about 0.4 while the total energy transmittance can be varied between about 0.2 and 0.4 by using different pane coatings. The visible properties are dominated by the properties of the aerogel granulate – using aerogel balls instead of the optimized aerogel split reduces the visible transmittance by more than 50%, while the solar gains show only a slight decrease.

<table>
<thead>
<tr>
<th>application:</th>
<th>irregular type I</th>
<th>regular type I</th>
</tr>
</thead>
<tbody>
<tr>
<td>daylighting</td>
<td>0.54 / 0.45</td>
<td>0.24 / 0.33</td>
</tr>
<tr>
<td>sun protection</td>
<td>0.38 / 0.23</td>
<td>0.19 / 0.17</td>
</tr>
</tbody>
</table>

4. DISCUSSION

To qualify the energetic behavior of the developed system the monthly balanced heat flux,

\[ q_{\text{m}} = g \cdot F_R \cdot I_m - U \cdot (\theta_i - \theta_{a,m}) \cdot \Delta t_m \]

is calculated depending on the facade orientation with

- \( F_R = 0.54 \): Reduction factor due to frames, dirt and not normal incidence of the monthly insolation \( I_m \).
- \( \theta_i = 20^\circ \text{C} \): Indoor temperature.
- \( \theta_{a,m} \): Monthly averaged outdoor temperature.
- \( \Delta t_m = 720 \text{ h} \): Time interval.

In fig. 7 the resulting heat fluxes are depicted for an aerogel glazing with \( U = 0.4 \text{ W/(m}^2\text{K)} \) and \( g = 0.3 \). To compare this glazing with available facade components, the heat fluxes for a “solar” triple glazing (\( U = 0.8 \text{ W/(m}^2\text{K)}, g = 0.6 \)) and for an opaque insulation (\( u = 0.2 \text{ W/(m}^2\text{K)} \)) are also shown.

To quantify the usability of the solar gains the typical heating period for low energy houses limited by an outdoor temperature of 12°C is marked. In Würzburg this period extends from October to April. Within this period the usability of solar gains is high (typically 80 to 100%). Outside this period the usable fraction drops rapidly due to increasing ambient temperatures and higher insolation.

In all considered cases the balanced heat flux of the aerogel glazing during the heating period is higher than that of an opaque insulation. Thus the aerogel glazing can be integrated into the facade independent of wall orientation and without any restrictions due to heat losses. Illumination via daylighting with aerogel glazings thus becomes an intriguing possibility. Attractive is also the small system thickness of 50 mm.
• On north facades the energetic balance of the aerogel glazing is significantly better than that of a triple glazing. Integrating the heat fluxes in the heating period yields –10 kWh/m²a for the aerogel glazing, –12 kWh/m²a for the triple glazing and –17 kWh/m²a for the opaque system, respectively.

• On east or west facades both systems perform nearly equal during the heating period. In summer the energy input through the aerogel window is reduced. The balanced energy fluxes are 18 kWh/m²a for the aerogel glazing and 35 kWh/m²a for the triple glazing, respectively.

• On south facades the energy flux of optimized triple glazings is always higher than for the aerogel glazing. During the heating period 92 kWh/m²a are balanced for the triple glazing and 46 kWh/m²a for the aerogel glazing, respectively.

In every case aerogel glazings offer the possibility to provide diffuse natural light. Due to the low U-value the inside temperature of the aerogel glazing is near the inside air temperature providing good thermal comfort. The diffusely back-scattered light is responsible for the whitish appearance of the aerogel glazing, which is important for architectural design.

5. CONCLUSIONS

The remarkable features of the new aerogel glazing presented in this paper are its outstanding insulation performance with a U-value below 0.5 W/(m²K), a thickness of only 50 mm, and its superior daylighting properties. If compared to the triple pane window and an opaque insulation the aerogel glazing mounted into a north oriented facade shows the lowest thermal losses.

ACKNOWLEDGEMENTS

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REFERENCES