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Highly Insulating and LIght Transmitting Aerogel Glazing for Super Insulating Windows

HILIT+

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Executive publishable summary

Objectives

The first main objective deals with "aerogel process optimisation". The general goal was to demonstrate that the elaboration process, developed during the recent HILIT project, permitted to obtain a significant amount of light transmitting, insulating and transparent 15-20 mm monolithic and crack-free nano-structured aerogel materials through a reasonably fast and reproducible process. The applicative part of this project aimed at elaborating, studying and optimising "state-of-the-art" (0.5 W/m2 K) aerogel glazings for windows. An important issue was the risk of outside condensation and rime and its avoidance. The final aerogel window is optimised with regard to its production and performance in view of the technical, economical and life cycle aspects.

Results

The aerogel production process has been optimised and tuned so monolithic silica aerogel sheets are produced with more than 85% crack free sheets per batch. Furthermore the production time has been reduced to 1/3 of the initial production time through detailed theoretical and experimental analyses of especially the supercritical washing step included in the drying phase. At the same time the production plant have been modified to recycle most of the chemicals involved in the production process. A large number of aerogel glazing prototypes have been made with partly e-vacuated aerogel in between two layers of low iron and anti reflection treated glass panes with an airtight edge seal solution based on multi-layered plastic foil developed for vacuum insulation purposes. The edge seal solution shows only a very limited thermal bridge effect. The final glazing has a total solar energy transmittance above 85% and a U-value of 0.7 W/m^2 K for about 14 mm aerogel thickness, which for a 20 mm thickness corresponds to a U-value of approximately 0.5 W/m^2K. No other known glazing exhibits such an excellent combination of solar transmittance and heat loss coefficient. The annual energy savings compared to triple low energy glazing is in the range of 10 – 20% depending on type of building.

Usefulness and possible applications

Beside the application in glazing production the HILIT+ aerogel material it self has a large variety of applications:

- Thermal insulation in various fields from cryogenic applications (spatial tankers, …) to high-temperature applications (ovens, …) passing by moderate temperatures (pipelines, risers, geothermal resources, …)
- Due to the large internal surface of aerogel (up to 1000 m^2/g), the material is proposed to serve as substrate for catalytic materials.
- The special pore structure of aerogel could be used for gas filters in the 20 to 100 nm region.
- The sound velocity within aerogel is in the range of 100 to 300 m / s, which should be one of the lowest for an inorganic material. Due to the low density, the acoustic impedance of aerogel could help boost the efficiency of piezoelectric transducers.
- Waste encapsulation, spacers for vacuum insulation panels, membranes, etc.

Plans for future use

The most forward application would be as daylight components, but also for insulation panels with or without vacuum. Contacts have been established for possible demonstration as normal skylight and as special large round skylight.

Publishable synthesis report

Objectives and strategic aspects.

The two main objectives are “aerogel process optimisation” and “glazing optimisation”. Concerning the process optimisation the general goal was to demonstrate that the elaboration process, developed during the recent HILIT project, permitted to obtain a significant amount of light transmitting, insulating and transparent 15-20 mm monolithic and crack-free nano-structured aerogel materials through a reasonably fast and reproducible process.

The applicative part aimed at elaborating, studying and optimising “state-of-the-art” (0.5 W/m^2 K) aerogel glazings for windows. An important issue was the risk of outside condensation and rime and its avoidance. The final aerogel window is optimised with regard to its production and performance in view of the technical, economical and life cycle aspects.

The project fulfils the intentions in the European Research Area (ERA) – integration of the European research efforts and capacities, the European White Paper on Energy for the Future COM-(97)599 final (26/11/97); “Promoting of high efficiency windows” is suggested as specific measure to reach the target of a total reduction of the energy consumption in the building sector by 50% in 2010. The project results have the capacity of improving the quality of life and health in terms of better indoor climate, which will improve the working conditions for many employees. Also the preserving and/or enhancing the environment policy will benefit from HILIT+ due to that primary fossil energy can partly be replaced by solar energy and thus CO_2 reduction is going to be obtained.

Scientific and technical description of the results.

<u>Precursor production</u>

An industrial pilot facility for production of precursors for the aerogel production has been established and proved to be able to deliver the required amount and quality of precursor for lab-, medium-, and large-scale production.

<u>Strengthening of wet gels</u>

Intensive studies of ageing possibilities for strengthening the wet gels to achieve a more robust gel and thus less risk of cracks in the final aerogel sheet have been carried out and an understanding of the connection between strength and other material properties have been elaborated. This work is used to optimise the process with respect to reproducibility, optical and thermal properties of the final monolithic aerogel sheet. Furthermore, the study has resulted in a reduction of the ageing time from 8 to 1 days – an important step in the overall manufacturing duration.

<u>Drying of the gels</u>

Theoretical studies by means of CFD simulations of the super critical CO_2 flow during the drying phase in the autoclave have been used for optimisation of the drying process. The simulations have been validated with mid-scale experiments carried out on an instrumented drying loop and showed good agreement. The conclusion of the study is that the governing factor in the drying process is the very low diffusion coefficient of the aerogel material.

Production of large size aerogels

The large-scale production of aerogel sheets (~ 55 × 55 cm^2) has been continuously optimised with respect to batch size, fraction of crack free sheets per batch, total manufacturing duration, recycling of chemicals and improved transparency (figure 1).

Figure 1. Example of aerogel sheet with high optical quality.

The capacity of the autoclave system has been doubled from previously 6 sheets per batch to 12 sheets per batch, and the fraction of crack free sheets per batch has been increased to above 85% primarily by adjustment of the different handling steps in the production line.

The overall production time per batch has been largely reduced by increasing the moulding capacity and optimising the pressure decrease rate of the autoclave but primarily by reducing the washing time (figure 2) thanks to the detailed studies at lab- and mid-scale and the proven possibility to remove residual chemicals from the dried aerogels by means of a fast heating of the aerogel to approximately 400 °C.

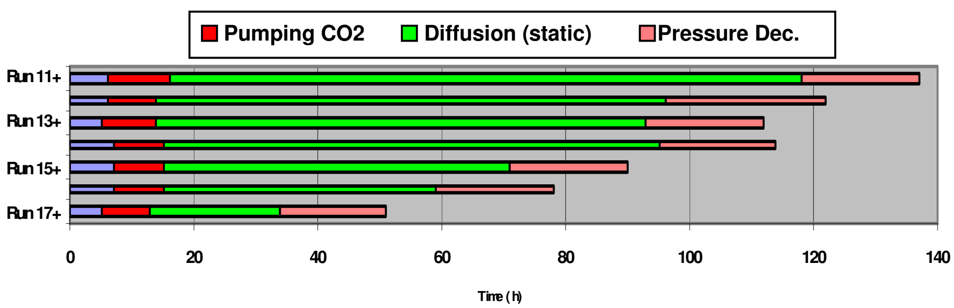

Figure 2. Reduction of the drying duration at large-scale through comparison between RUN11+ to RUN17+.

Optical properties of monolithic silica aerogel

The optical properties of the final optimised monolithic silica aerogel shows a very high transparency obtained as a result of the different optimisation steps in the production process and heat treatment for removal of the residual chemicals in the aerogel. The resulting transmittances are shown in table 1 below. The transparency ratio T.R. is a measure of the transparency of the material, i.e. how much of the light that passes direct through the material without being diffused. The extinction coefficient E is a measure independent of material thickness of the overall transmittance – the lower the better. The extinction coefficients in table 1 are very low and comparable to a glass pane of same thickness.

Table 1. Optical result in transmittance for RUN 18+ and 19+ aerogel samples.

Sample	τ_v^{nh}	$\tau_v^{ndirect}$	τ_e^{nh}	$\tau_e^{ndirect}$	**T.R.**	**E**(m^{-1})
Run 18+	86.2	74.0	85.7	75.4	0.858	9.12
Run 19+	86.5	76.5	84.9	76.9	0.884	8.24

Thermal properties of monolithic silica aerogel

The thermal conductivity has been measured at normal pressure as well as under different degrees of vacuum. Due to the very high porosity of the aerogel, the thermal conductivity of aerogel (17 mW/m K) at atmospheric pressure is below the air conductivity (23 mW/m K). Evacuation of the aerogel permits to reduce the conductivity further to 6-7 mW/m K (figure 3).

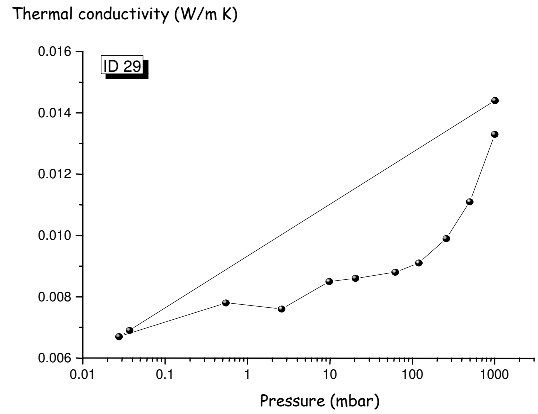

Figure 3. Thermal conductivity as function of pressure.

The glazing assembly

The application of the aerogel has in this project been focusing on the use in highly insulating glazing. The glazing is made up of a monolithic silica aerogel sheet in between two layers of glass. In order to achieve the low U-value in the range of 0.5 W/m^2K the aerogel is evacuated to a rough vacuum around 1 hPa where the thermal conductivity will be in the range of 0.01 W/mK. This requires an airtight rim seal and one part of the optimisation with respect to the glazing has been focused on development of an airtight edge rim seal solution with a minimum of thermal conduction and to prove the reproducibility of the assembly process. This has been done by the making of 34 small glazing prototypes with the size of approx. 28 cm x 28 cm with about 14 mm aerogel thickness as well as 17 aerogel glazings prototypes at a dimension of 55 cm x 55 cm. The glazing has been assembled in a vacuum chamber – the so-called AGEA. The evacuation time is approximately 15 minutes based on investigations of resulting pressure inside the aerogel material as function of evacuation time.

Optical properties of the glazing

The optical properties of the glazing have been improved by an optimised heat treatment of the aerogel sheets prior to assembly and evacuation. The heat treatment is done by a fast heating of the aerogel tile to approximately 400 °C at which temperature the residual chemicals from the production process is removed. Further increase of the optical properties is achieved by use of low iron glass and anti reflectance treatment of the glass panes. The result is a glazing with a visible and total solar energy transmittance above 85% (table 2).

Table 2. Measured transmittance of aerogel glazing as function of angle of incidence.

	Transmittance directional/directional		Transmittance directional/hemispherical	
Angle of incidence	Visible	Solar	Visible	Solar
0	80.9	78.9	87.5	85.4
15	82.7	80.6	86.6	83.7
30	79.3	77.2	86.1	82.8
45	72.8	71.2	82.7	79.1
60	65.1	64.7	71.6	68.6

Although the aerogel is slightly scattering, the colour rendering according to EN410 is very good with values of R_a > 90 for directly and hemispherical transmitted light.

Thermal properties of the glazing

The heat loss coefficient has been measured to approximately 0.7 W/m^2K for a glazing with about 14 mm aerogel thickness. This corresponds to a U-value of approximately 0.5 W/m^2K for a glazing with 20 mm aerogel. The edge sealing made up of polystyrene and a multi-layered plastic foil developed for vacuum insulation shows a very little thermal bridge effect and is in fact approximately 8 – 10 times more efficient than the best known warm edge solutions developed for conventional sealed glazing units.

Acoustical performance of aerogel glazing

The acoustical performance of a partly evacuated glazing with a total thickness of approximately 23 mm is similar to a single layer of glass of the same thickness. The noise reduction is measured to 33 dB. In a noisy environment it will be necessary to combine the aerogel glazing with an additional layer of glass with an air gap in between, which will increase the noise reduction to at least 37 dB.

Energetic performance of aerogel glazing

The yearly energetic performance has been calculated based on the measured values of solar energy transmittance and heat loss coefficient and compared to double and triple low energy glazing types on the market. The general conclusion is that the most benefit of the aerogel glazing is achieved in the northern European climates where the combination of high solar transmittance and low U-value allow for maximum exploitation of the limited solar radiation during the winter season. However, if the aerogel glazing is combined with efficient mobile solar shading devices and use of passive cooling strategies approximately 10% energy savings can be achieved for a flat with only one surface facing the ambient compared to the case with triple low energy glazing. In case of a single-family house, calculations for a Danish climate show an annual energy saving increase to approximately 20%.

Outside condensation on highly insulating glazing

Use of highly insulating glazing types leads to formation of condensation on the outside glazing surface on clear nights due the heat loss towards the sky by long wave radiation, which makes the outer glass surface become colder than the ambient dew point temperature due to the limited heat transfer through the glazing. This effect is judged by the glazing manufacturer as a serious marketing problem as the outlook through the advanced glazing types are reduced for several hours during the year. A simulation program has been evaluated against experiments carried out in this project and good

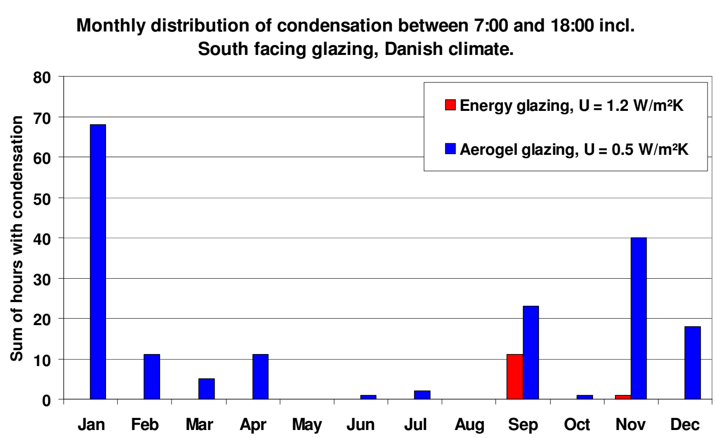

Figure 4. Calculated condensation pattern for a gas-filled energy glazing, U = 1.2 W/m^2 K, and an aerogel glazing, U = 0.5 W/m^2 K

agreement has been found. Figure 4 shows the number of hours per year with condensation appearing on an aerogel glazing and a double low energy glazing between 7.00 in the morning and 18.00 in the evening. Even for the double-glazing condensation occurs mostly during autumn, but for the super insulating glazing the effect is present all year round.

<u>Economic evaluation and forecast</u>

The actual production of both the monolithic silica aerogel sheets and the actual glazing assembling are at the moment a highly labour intensive process leading to an actual cost at this level of approximately 930 € per m^2 final glazing. However, if a large scale production is foreseen with a 10 m^3 autoclave and full automation the costs are evaluated to drop to approximately 277 € per m^2.

Assessment of Results and Conclusions

The developed aerogel glazing posses both low U-value and high solar transmittance, which is opposite to low-U glazings on the market – as shown in table 3. Increasing the aerogel thickness to e.g. 20 mm will decrease the centre U-value to around 0.5 W/m^2 K, but the solar transmittance will be beyond 75%.

Table 3. Aerogel glazing compared with commercial low-U glazings.

Property \ Glazing	**Aerogel "RUN 18+"**	**Three-layer**	**Two-layer**
	low iron content glass sheets and low reflectance coating	- with two low-e coatings	- with one low-e coating
Type (-) / thickness (mm)	4-13.5-4 / 21,5	4-12-4-12-4 /36	4-15-4 /23
Gas type	none	argon	argon
Centre U-value (W/m² K)	0.72	0.7	1.2
Solar transmittance, direct/hemispherical (%)	85	34	52
Total solar energy transmittance - g-value (%)	~ 87	46	63
Energy balance for a North facing glazing* (kWh/m^2)	25	-10	-35

*: Over the heating season for a Danish location.

This makes aerogel glazings an excellent option for improved daylight utilization combined with a fair outlook by placing large areas of aerogel glazing in north facades. Due to the very good insulation properties and the high solar/daylight transmittance this can be done even with energy gain, which cannot be obtained with any other known glazing or daylight component options. Furthermore, the daylight will be at a more constant as well as pleasant level during the daytime compared to a south orientation and the excess temperature problems will be reduced considerably. So the use of aerogel glazings in new buildings will offer the possibility of increase the north facing glazing area and decrease the south facing one and the capital cost for overheating prevention, e.g. shading devices, air conditioning, enhanced venting, etc., can be greatly reduced.

The optical quality of aerogel glazing is not yet at the same level as conventional glazing units. But the optical quality has been improved considerably - thanks to the research carried out within the HILIT+ project - to a level where almost no disturbance in the view through is present if shielded against direct radiation. A material model has been developed to include aerogel glazing units in a raytracing simulation. Photorealistic images has been created based on a physically correct simulation of a given scenery and environment. Figure 6 shows a situation in an office room equipped with aerogel glazing. For comparison, a room equipped with a standard double-glazing is also shown (figure 5).

Figure 5. Office room with standard glazing. Illumination by a diffuse overcast sky.

Figure 6. Office room with aerogel glazing. Illumination by a diffuse overcast sky.

It can also be noted that due to a) the monolithic aerogel acts as spacer over the whole aperture of the glazing, b) ultra-flat aerogel sheets and c) the atmospheric pressure on the unit; the glass panes of an aerogel glazing are always flat and hence the glazing will never exhibit the so-called Dallas effect.

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