Evacuated aerogel glazings
This paper describes the main characteristics of monolithic silica aerogel and its application in evacuated superinsulating aerogel glazing including the evacuation and assembling process. Furthermore, the energetic benefit of aerogel glazing is quantified. In evacuated aerogel glazing the space between the glass panes is filled with monolithic silica aerogel evacuated to a rough vacuum of approximately 1-10 hPa. The aerogel glazing does not depend on use of low emissive coatings that have the drawback of absorbing a relatively large part of the solar radiation that otherwise could reduce the space heating demand in residential buildings. The U-value of the glazing can be designed to meet the required value by increasing the monolithic silica aerogel thickness without the need for additional layers of glass. An aerogel glazing with 20 mm glass distance can reach a U-value below 0.5 W/(m² K) combined with a solar energy transmittance above 0.75.

Transparent aerogel Windows: results from an EU FP5 project
In a recent EU FP5 project, monolithic silica aerogel was further developed with respect to the production process at pilot-scale, its properties and the application as transparent insulation material in highly insulating and transparent windows. 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 (12 sheets of 55 cm x 55 cm 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 evacuated 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 about 87% and a U-value of 0.7 W/m²K for about 14 mm aerogel thickness, which for a 20 mm thickness corresponds to a U-value of approximately 0.5 W/m²K. No other known glazing exhibits such an excellent combination of solar transmittance and heat loss coefficient. At a Danish location and North facing, the energy balance for such a prototype glazing is calculated to be around 30 kWh/m² for the heating season whereas the best commercial available glazing has a energy balance of –10 kWh/m².

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 applicable 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. 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 evacuated aerogel in between two layers of low iron and anti-reflection coated 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/m2 K for about 14 mm aerogel thickness, which for a 20 mm thickness corresponds to a U-value of approximately 0.5 W/m2K. 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. 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 m²/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.
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. 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 evacuated 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/m² K for about 14 mm aerogel thickness, which for a 20 mm thickness corresponds to a U-value of approximately 0.5 W/m²K. 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.

Monolithic silica aerogel - material design on the nano-scale

By means of a production process in two major steps - a sol/gel process and a supercritical drying – open-cell, monolithic silica aerogel can be made. This material can have a density in the range of 30- to 300 kg/m³, corresponding to porosities between 86 and 98 %. The solid structure has characteristic dimensions of 2 – 5 nm and the typical pore diameter is about 20 nm. A number of different applications of aerogel have been proposed: • 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 m²/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.
range of 100 to 300 m/s, which should be one of lowest for an inorganic material. Due to the low density, low acoustic impedance of aerogel could help boost the efficiency of piezoelectric transducers. - Other applications could be; waste encapsulation, spacers for vacuum insulation panels, membranes, etc. Department of Civil Engineering is co-ordinator of a current EU FP5 research project1, which deals with the application of aerogel as transparent insulation materials in windows. Due to the excellent optical and thermal properties of aerogel, it is possible to develop windows with both high insulation and high transmittance, which is impossible applying the conventional window techniques, i.e. extra layers of glass, low-e coatings and gas fillings. It can be shown that an aerogel window, North facing and for a Danish location, will have a positive energy balance over the heating season, i.e. the aerogel window will contribute to the space heating, whereas a conventional super low-energy window cannot perform beyond a neutral energy balance for the same conditions2. Finally, it can be mentioned that one of the partners, the Swedish company Airglass AB, in the above-mentioned EU project, has produced the aerogel material used for a dust-analysers on the Stardust satellite, which collected dust from the comet “Wild 2” in January 2004. It is expected that Stardust will return to Earth on January 15, 2006 (more information on the NASA website: http://stardust.jpl.nasa.gov/).


This project is an example of applied nanotechnology, namely development of a smart window with three operating mode by means of Polymer Network Liquid Crystal (PNLC). The main objective is the implementation, owing to the conception and the realisation of a pre-industrial machine, of a smart window: 1) with sufficient area glazing to meet the market, 2) using a technology which supplies the glazing with three operating modes: 2a) a reflective mode limiting the glazing overheating, 2b) a transparent mode with an excellent transparency, 2c) a scattering mode having a grey scale, 3) for which the operating modes don’t require energy consumption and where the transition from one to the other mode is fast (10 ms) thanks to an applied voltage or voltage pulse, 4) allowing a high solar factor modulation; a Solar Heat Gain Factor (SHGS) between 0.3 and 0.8 and a high daylight modulation between 0.1 and 0.8, 5) with a good lifetime. The outcome of the project was: Several methods were developed and these allowed improving and realisation a number of lab-scale size (from 2 cm sq. up to 15 cm x 30 cm), active films with three optical states (clear, reflective or scattering state) to three original and complementary directions: - increased modulation magnitude of the light flux (reflective band broadening up to 240 nm), - obtain near perfect reflective state and - having a glazing with only one reflective face. A concept study – including simulations - of the optimal pattern and shape for SmartWin II windows as well as realisation and scaling-up of switch-able patterned glass samples for smart windows. A market assessment study of smart windows have been carried out and by taking into account e.g. the fenestration markets, functionality and cost of currently available daylight systems, and it shows a very large market potential for this technology. Conception and realisation of a pre-industrial machine for manufacturing smart windows were obtained. By means of this pre-industrial machine, the sample surface area was progressive increased from lab-scale (approx. 10 cm sq.) up to 60 cm x 80 cm at Mid-Term and up to 68 cm x 120 cm at the end of the project.

This project is an example of applied nanotechnology, namely development of a smart window with three operating modes by means of Polymer Network Liquid Crystal (PNLC). The main objective is the implementation, owing to the conception and the realisation of a pre-industrial machine, of a smart window: 1) with sufficient area glazing to meet the market, 2) using a technology which supplies the glazing with three operating modes: 2a) a reflective mode limiting the glazing overheating, 2b) a transparent mode with an excellent transparency, 2c) a scattering mode having a grey scale, 3) for which the operating modes don’t require energy consumption and where the transition from one to the other mode is fast (10 ms) thanks to an applied voltage or voltage pulse, 4) allowing a high solar factor modulation; a Solar Heat Gain Factor (SHGS) between 0.3 and 0.8 and a high daylight modulation between 0.1 and 0.8, 5) with a good lifetime. The outcome of the project was: Several methods were developed and these allowed improving and realisation a number of lab-scale size (from 2 cm sq. up to 15 cm x 30 cm), active films with three optical states (clear, reflective or scattering state) to three original and complementary directions: -increased modulation magnitude of the light flux (reflective band broadening up to 240 nm), -obtain near perfect reflective state and -having a glazing with only one reflective face. A concept study – including simulations – of the optimal pattern and shape for SmartWin II windows as well as realisation and scaling-up of switch-able patterned glass samples for smart windows. A market assessment study of smart windows have been carried out and by taking into account e.g. the fenestration markets, functionality and cost of currently available daylight systems, and it shows a very large market potential for this technology. Conception and realisation of a pre-industrial machine for manufacturing smart windows were obtained. By means of this pre-industrial machine, the sample surface area was progressive increased from lab-scale (approx. 10 cm sq.) up to 60 cm x 80 cm at Mid-Term and up to 68 cm x 120 cm at the end of the project.

Super insulating aerogel glazing
This paper describes the application results of a previous and current EU-project on super insulating glazing based on monolithic silica aerogel. Prototypes measuring approx. 55´55 cm² have been made with 15 mm evacuated aerogel between two layers of low-iron glass. Anti-reflective treatment of the glass and a heat-treatment of the aerogel increases the visible quality and the solar energy transmittance. A low-conductive rim seal solution with the required vacuum barrier properties has been developed along with a reliable assembly and evacuation process. The prototypes have a centre heat loss coefficient below 0.7 W/m²K and a solar transmittance of 76%.
Development of windows based on highly insulating aerogel glazings

Within a finished and a current EU project, research and development of monolithic silica aerogel as transparent insulation in windows are being carried out. On behalf of the partners of the two projects, results related to the window application will be presented here. At the thermal envelope of buildings, the window area is the weakest part with respect to the heat loss, but at the same time, it also provides e.g. solar energy gain. Glazing prototypes have been made of aerogel tiles of about 55 cm sq. (elaborated within the projects). Those tiles are quickly evacuated and easily sealed between two glass panes and a specific rim seal. A heat treatment phase (after the supercritical CO2 drying) of the aerogel is currently being developed in order to improve its optical quality. This step increases the solar transmittance about 6 percent points. For glazing prototypes with an aerogel thickness of approx. 15 mm, a centre heat loss coefficient of below 0.7 W/m² K and a solar transmittance of 76% have been obtained. The research is funded in part by the European Commission within the frameworks of the Non-Nuclear Energy Programme – JOULE III and the Energy, Environment and Sustainable Development Programme – EESD; the contracts JOR3-CT97-0187 (acronym: HILIT) and ENK6-CT-2002-00648 (acronym: HILIT+).

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Contributors: Jensen, K. I., Schultz, J. M., Kristiansen, F. H.
Pages: 351-357
Publication date: 2004
Peer-reviewed: Yes

Super insulating aerogel glazing

Monolithic silica aerogel offers the possibility of combining super insulation and high solar energy transmittance, which has been the background for a previous and a current EU project on research and development of monolithic silica aerogel as transparent insulation in windows. Generally, windows form the weakest part of the thermal envelope with respect to heat loss coefficient, but on the other hand also play an important role for passive solar energy utilisation. For window orientations other than south, the net energy balance will be close to or below zero. However, the properties of aerogel glazing will allow for a positive net energy gain even for north facing vertical windows in a Danish climate during the heating season. This means that high quality daylight can be obtained even with additional energy gain. On behalf of the partners of the two EU projects, results related to the window application will be presented here.

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Contributors: Schultz, J. M., Jensen, K. I., Kristiansen, F. H.
Pages: 867-874
Highly Insulating and Light Transmitting Aerogel Glazing for Window (HILIT Aerogel Window): Confidential final report

The HILIT AEROGEL WINDOW project with participants from Denmark (coordinator), France, Germany, Norway and Sweden, was formulated in order to develop a safe and clean production of monolithic silica aerogel based on supercritical CO2 drying of the gels, to study the process parameters and to transfer the results from lab- to mid- and finally to large-scale making of 60 by 60 cm² in a pre-industrial plant. The large samples forms the basis for assembly of evacuated aerogel glazings optimised with respect to thermal and optical properties. The production process development and transfer to pre-industrial fabrication of aerogels has succeeded in all details. A pilot plant for precursor elaboration has been established and precursors of required amount and quality has been delivered to all partners. Studies at lab-scale have identified the important parameters for optimising the mixing of the chemicals, which is the mixing rate and the HF (catalyst) flow rate. A mixing reactor have been designed and successfully transferred to large-scale application. A wet gel strengthening process has been developed and optimised at laboratory-scale and transferred at mid-scale with success (concerning monolithicity). A direct supercritical CO2 drying loop has been developed at mid-scale, successfully transferred and re-adapted at large-scale. At large scale a complete CO2 loop has been build including CO2 regaining by separation of CO2 from the solvent. The CO2 has been reused for several batch runs. The optical properties have been improved compared to previous aerogels thanks to the process and the smooth surfaces obtained and a heat treatment of the dried aerogel. A rim seal solution that offers the required air and moisture tightness without leading to severe thermal bridge effects has been developed as well as an assembly process including heat treatment and evacuation in a vacuum chamber. The centre U-value is measured for several prototype glazings to 0.68 W/m²K, which is somewhat higher than the targeted value of 0.4 W/m²K due to the thinner aerogel sheets available. The overall U-value including the thermal bridge effect of the rim seal solution is measured to 0.74 W/m²K. The solar energy transmittance is measured to 76% thanks to the use of low-iron glass with an anti reflective coating.

General information
Publication status: Published
Organisations: Department of Civil Engineering
Number of pages: 139
Publication date: 2001

Publication information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark, Department of Civil Engineering
Original language: English
Source: orbit
Source-ID: 63893
Research output: Book/Report › Report – Annual report year: 2001 › Research
thickness up to 15 mm have been produced with a good reproducibility. The thermal conductivity is approximately 0.015 W/mK at atmospheric pressure and 0.010 W/mK at 10 hPa. The optical properties have been improved compared to previous aerogels thanks to the process and the smooth surfaces obtained and a heat treatment of the dried aerogel. A rim seal solution that offers the required air and moisture tightness without leading to severe thermal bridge effects has been developed as well as an assembly process including heat treatment and evacuation in a vacuum chamber. The centre U-value is measured for several prototype glazings to 0.68 W/m2K, which is somewhat higher than the targeted value of 0.4 W/m2K due to the thinner aerogel sheets available. The overall U-value including the thermal bridge effect of the rim seal solution is measured to 0.74 W/m2K. The solar energy transmittance is measured to 76% thanks to the use of low-iron glass with an anti reflective coating.

General information
Publication status: Published
Organisations: Department of Civil Engineering
Number of pages: 24
Publication date: 2001

Publication information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark, Department of Civil Engineering
Original language: English
Source: orbit
Source-ID: 63895
Research output: Book/Report › Report – Annual report year: 2001 › Research › peer-review

Technology Implementation Plan: EU JOULE III Project nr. JOR3-CT97-0187
The Technology Implementation Plan (TIP) describes the main project results and the intended future use. The TIP is confidential.

General information
Publication status: Published
Organisations: Department of Civil Engineering
Contributors: Jensen, K. I., Schultz, J. M.
Publication date: 2001

Publication information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark, Department of Civil Engineering
Original language: English
Source: orbit
Source-ID: 63890
Research output: Book/Report › Report – Annual report year: 2001 › Research

Vurdering af de termiske forhold i vogn til transport af fødevarer og andet

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Buildings and Energy
Contributors: Jensen, K. I., Kristiansen, F. H., Madsen, T. L., Schultz, J. M.
Publication date: 2001

Publication information
Place of publication: Kgs. Lyngby
Publisher: Danmarks Tekniske Universitet (DTU)
Edition: 1
Original language: Danish
Source: orbit
Source-ID: 64306
Research output: Book/Report › Report – Annual report year: 2001 › Research

Evacuation and assembly of aerogel glazings

General information
Publication status: Published
Highly insulating and Light transmitting aerogel glazing for window - PPR1: First periodic report

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Jensen, K. I.
Number of pages: 12
Publication date: 1999

Highly insulating and light transmitting aerogel glazing for window - PPR2: First year assessment report

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Jensen, K. I., Schultz, J. M.
Number of pages: 141
Publication date: 1999

Conditions for industrial production

General information
Publication status: Published
Organisations: Department of Buildings and Energy, Glassolutions A/S
Contributors: Jensen, K. I., Schultz, J. M., Brauer, H.
Publication date: 1996

Host publication information
Title of host publication: Development and Investigation of Evacuated Windows Based on Monolithic Silica Aerogel Spacers
Place of publication: Brussels
Publisher: European Commission
Source: orbit
Source-ID: 165271
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1996 › Research › peer-review

Conditions for industrial production: Estimated sales volume and economy

General information
Publication status: Published
Development and Investigation of Evacuated Windows Based on Monolithic Silica Xerogel Spacers

Potential energy savings and thermal comfort

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Jensen, K. I., Rudbeck, C. C., Schultz, J. M.
Publication date: 1996

Host publication information
Title of host publication: Development and Investigation of Evacuated Windows Based on Monolithic Silica Aerogel Spacers
Place of publication: Brussels
Publisher: European Commission
Source: orbit
Source-ID: 165270
Potential energy savings and thermal comfort

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Jensen, K. I., Rudbeck, C. C., Schultz, J. M.
Publication date: 1996

Host publication information
Title of host publication: Development and Investigation of Evacuated Windows Based on Monolithic Silica Xerogel Spacers
Place of publication: Brussels
Publisher: European Commission
Source-ID: 165281

Window prototype investigations: Measurement of thermal parameters for aerogel/xerogel windows
Measurement techniques and equipment for measurement of heat loss coefficients and solar energy transmittance both on laboratory level and under real climatic conditions are described as well as the European PASSYS test method.

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Jensen, K. I., Schultz, J. M.
Publication date: 1996

Host publication information
Title of host publication: Development and Investigation of Evacuated Windows Based on Monolithic Silica Aerogel Spacers
Place of publication: Brussels
Publisher: European Commission
Source-ID: 165277

Vinduer og solvægge med monolitisk silica aerogel

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services
Contributors: Jensen, K. I., Svendsen, S.
Publication date: 1991

Publication information
Place of publication: Kgs. Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)
Original language: Danish
(Byg Rapport; No. LFV-220).
Electronic versions:
Karsten.pdf
Source-ID: 274954