Building and Environment 95 (2016) 405–413

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Perspective of aerogel glazings in energy efficient buildings

Tao Gao [a, b, *], Takeshi Ihara [a, c], Steinar Grynning [a, d], Bjørn Petter Jelle [b, d], Anne Gunnarshaug Lien [d]

[a] Department of Architectural Design, History and Technology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[b] Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[c] Takenaka Corporation, Osaka, Japan
[d] Department of Materials and Structures, SINTEF Building and Infrastructure, Trondheim, Norway

ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form
8 October 2015
Accepted 9 October 2015
Available online 22 October 2015

Keywords:
Silica aerogel
Window
Glazing
Energy efficient building
Environmental impact

ABSTRACT

The application perspective of aerogel glazings in energy efficient buildings has been discussed by evaluating their energy efficiency, process economics, and environmental impact. For such a purpose, prototype aerogel glazing units have been assembled by incorporating aerogel granules into the air cavity of corresponding double glazing units, which enables an experimental investigation on their physical properties and a subsequent numerical simulation on their energy performance. The results show that, compared to the double glazing counterparts, aerogel glazings can contribute to about 21% reduction in energy consumptions related to heating, cooling, and lighting; payback time calculations indicate that the return on investment of aerogel glazing is about 4.4 years in a cold climate (Oslo, Norway); moreover, the physical properties and energy performance of aerogel glazings can be controlled by modifying the employed aerogel granules, thus highlighting their potential over other glazing technologies for window retrofitting towards energy efficient buildings. The results also show that aerogel glazings may have a large environmental impact related to the use of silica aerogels with high embodied energies and potential health, safety and environment hazards, indicating the importance of developing guidelines to regulate the use of aerogel glazings.

1. Introduction

As an important building element in modern architecture, windows allow light, solar energy, and fresh air to promulgate the living area and offer an irreplaceable indoor–outdoor interaction, thus having a huge impact on the occupant comfort. However, the fact that windows are usually made of clear glass may bring with some drawbacks, such as glare and solar overheating, which may degrade the user comfort and increase the energy consumption of buildings [1]. Another issue associated with clear glass windows is their poor thermal insulation performance compared to other building envelope components such as walls or roofs. In general, windows represent a large thermal bridge and can constitute up to 45% of the total energy loss though the building envelope [2]. Consequently, improving the thermal insulation level of windows has without doubt been an important research topic [1–3]. Highly insulating glazing units or windows with *U*-values (heat transfer coefficient) lower than 0.7 W/(m^{2}K) have been under rapid development [2]; commercial products such as multilayered windows [4,5] and aerogel glazings [6–8] have been sold for a wide range of applications, i.e., for both new buildings and window renovations towards energy efficient buildings.

Aerogel glazings are an interesting glazing technology and may address simultaneously the energy efficiency and user comfort requirement placed on windows [6–9]. Aerogel glazings are architecturally similar to the conventional double glazings, where the air cavity between the two clear glass panes is filled with silica aerogels with low thermal conductivities (about 0.013 and 0.020 W/(mK) for monolithic and granular aerogels, respectively) [8,9]. Aerogel glazings have usually a high level of thermal insulation and a typical *U*-value of about 0.6 W/(m^{2}K) can readily be achieved [6–9]. In practice, due to the weak mechanical strength of monolithic aerogel panes [10], aerogel glazings are usually assembled with aerogel granules, which results in translucent glazing units with improved thermal insulation, enhanced light scattering, and reduced sound transmission [11–14]. Aerogel glazings are of

* Corresponding author. Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.
E-mail address: tao.gao@ntnu.no (T. Gao).

http://dx.doi.org/10.1016/j.buildenv.2015.10.001

interest in building applications where an unobstructed outside view is not essential [12].

The potential of aerogel glazings in buildings and related infrastructure industry has widely been addressed [6–9,11–17], mostly from an energy saving perspective. For example, Dowson et al. have recommended aerogel glazings as a potential solution for retrofitting single-glazed windows to reduce the heat loss without detrimental reduction in light transmission [15]. Using a thermal model in a German climate, Reim et al. have calculated the energetic benefit of aerogel glazings to be comparable to triple glazings [16]. More recently, by comparing the energy performance of an office building consisting of different glazing systems, Ihara et al. have revealed the application potential of aerogel glazings in different climates [17]. However, as any other emerging materials or technologies, how aerogel glazings are used in buildings depends on not only their energy saving potentials, but also other factors such as appearance, cost, service time, and maintenance requirement. As a translucent glazing technology, aerogel glazings are different for the normal transparent windows, which may challenge the architects in the design phase. More importantly, the use of silica aerogels – a manufactured nanomaterial – may lead to potential health, safety and environmental (HSE) concerns [18]. Hence, it is very important to evaluate the potential of aerogel glazings from different aspects, such as energy efficiency, process economics, and environmental impact, in order to strengthen the existing advantages while counteracting disadvantages of this emerging glazing technology. Nevertheless, there seems a lack of studies on such an important topic.

In this work, we discuss the application perspective of aerogel glazings in energy efficient buildings by evaluating their energy efficiency, process economics, and environmental impact. For such a purpose, we have assembled aerogel glazing units (AGUs) by incorporating silica aerogel granules into the air cavity of double glazing units (DGUs), which enables a detailed experimental characterization of their physical properties; thereafter, the energy performance of aerogel glazings has been evaluated by numerical simulations. Moreover, the process economics, building integration, and environmental impact of aerogel glazings have also been evaluated. The results reveal that aerogel glazings are promising in energy efficient buildings; however, developing guidelines to regulate the use of aerogel glazings is also very important.

2. Materials and methods

2.1. Assembly of AGUs

Hydrophobic silica aerogel granules were received from PCAS, France, with typical particle sizes of about 3–5 mm, as shown in Fig. 1a. Clear glass panels (float glass, 350 mm × 500 mm × 4 mm) were cleaned with acetone and ethanol to remove the surface contaminations before the assembly of the glazing units. Thermix® TX.N® plus spacer with a gap size of 14 mm was used. Silicon sealant was purchased from Jula AS, Norway, and used as received.

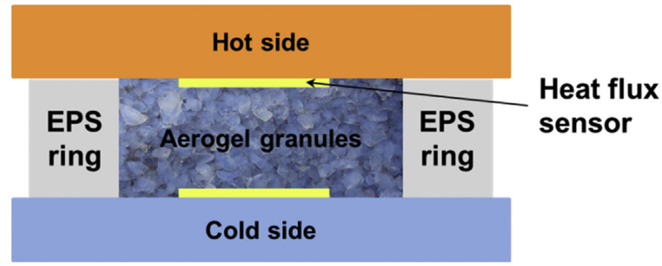

Fig. 2. Experimental setup for the heat flow meter measurements. An EPS (expanded polystyrene) ring is used to enclose the aerogel granules; the measureable dimensions are about 450 mm × 450 mm × 50 mm.

AGUs were assembled by incorporating aerogel granules into the cavity of a double glazing unit made of two clear glass panels (Fig. 1b) [9]. During the assembly process, the glazing unit was subject to mechanical vibration to ensure a compact packing of aerogel granules inside the cavity and thus reduce future subsiding of the aerogel particles, which might create visible air pockets in the top of the inter-pane cavity [9]. The dimension of the glazing aperture was about 475 mm × 325 mm. The as-prepared AGUs were thereafter aged in air at 25 °C for 2 weeks and followed by another 2 week aging at 50 °C to harden completely the silicon sealant. Small sized AGU samples (glazing area ~4 cm^2) were also prepared and used for the optical measurement purpose.

2.2. Characterization

Thermal conductivity of aerogel granules was measured by using a heat flow meter method, which was performed according to ISO 8301 [19] and EN 12667 [20]. As shown in Fig. 2, the sample was enclosed in an EPS (expanded polystyrene) ring and sandwiched between the two heat flux sensors. Preset temperature for the hot (top) and cold side (bottom) was 20 and 0 °C, respectively. Thermal properties (i.e., thermal resistance, conductivity, and transmittance) of the as-prepared AGUs were also evaluated by using the same experimental setup. Here, the AGUs were treated as a homogeneous material system with high thermal resistance, which is similar to that used for vacuum insulation panels [21].

Optical properties (transmittance and reflectance) of the as-prepared glazing units were evaluated from 290 to 2500 nm on a PerkinElmer Lambda 1050 UV/VIS/NIR spectrophotometer with a 150 mm Integrating Sphere Accessory, which operates in double

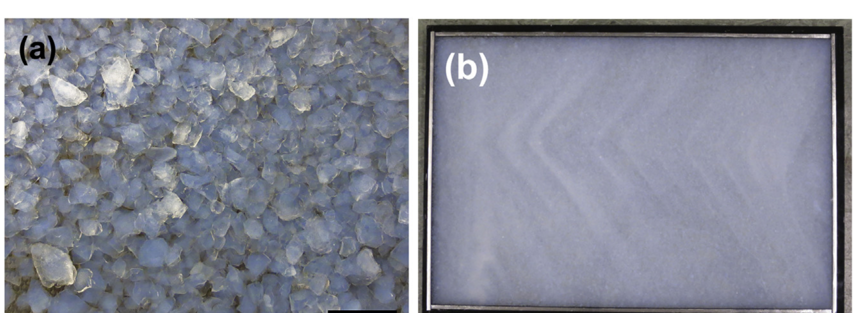

Fig. 1. Photograph of (a) silica aerogel granules and (b) the assembled aerogel glazing unit (dimensions 475 mm × 325 mm). Scale bar in panel a: 10 mm. The wrinkle pattern in the aerogel glazing unit results from the assembly process [9].