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Building integration of aerogel glazings

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Abstract

The recent building practices have shown that aerogel glazings can be used as a multifunctional building envelope component for different purposes. Nevertheless, the distinctive physical properties and energy performance of aerogel glazings suggest that building integration of aerogel glazings may create architectural challenges, aesthetic problems, as well as concerns on their durability and environmental impact, thus highlighting the importance of developing guidelines to regulate the use of aerogel glazings in the building sector. This study discusses various approaches for the building integration of aerogel glazings by presenting a number of successful examples; the advantages of integration are quantified and suggestions are given to address the possible challenges.

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Keywords: building integration; aerogel; glazing; energy efficiency; environmental impact

1. Introduction

In most European countries, the building sector consumes about 40% of the total energy and contributes to about 30% of greenhouse gas emissions; therefore, improving energy efficiency of buildings has been regarded as one important measure to reach the EU 2020 energy and climate targets [1]. Different technologies, however, may be required to improve the energy efficiency of buildings, since buildings usually consist of various structural and/or

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functional components, such as windows, walls, floors, and roofs – each of them has rather different energy features and plays different but important roles on the overall energy efficiency of buildings. For example, previous studies have shown that windows can constitute up to 45% of the total energy loss through the building envelope, and windows with a low thermal transmittance (i.e., *U*-value) can substantially reduce the energy loss and saving cost [2, 3]. Not surprisingly, highly insulating glazing units and windows have been under rapid development; commercial products, such as multi-glazed windows [4], vacuum glazings [5], and aerogel glazings [6], have been sold for a wide range of applications, i.e., for both new buildings and window renovations towards energy efficient buildings.

We are particularly interested in aerogel glazings [7-10], which represent an interesting glazing technology and show a promising potential in the building sector. Aerogel glazings are architecturally similar to the conventional double glazings, where the air cavity between two clear glass panes is filled with silica aerogels – a manufactured nanoporous material with low density, low thermal conductivity, good optical transmittance, and excellent fire and acoustic resistance [12]. Both specular (Fig. 1a) and diffuse glazing units (Fig. 1b) can be achieved by using monolithic and granular aerogel materials, respectively. In practice, due to the high manufacture cost and weak mechanical strength of monolithic aerogel panes [13], aerogel glazings are usually assembled with granules, which gives translucent glazing units with improved thermal insulation, enhanced light scattering, and reduced sound transmission [11, 12].

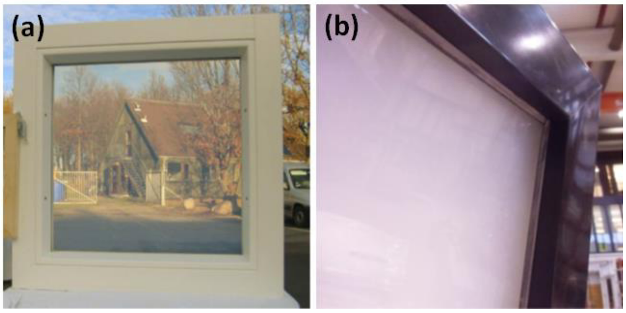

Fig. 1. (a) Specular [14] and (b) diffuse [10] aerogel glazings/windows.

The unique features of aerogel glazings not only make them an interesting building component for different applications, but also bring about challenges when integrating them into the building envelope. For example, replacing the traditional clear glass windows with aerogel glazings may change the user comfort, i.e., the loss of an unobstructed outside view. Aerogel glazings may be used to replace, partially or totally, the opaque building envelope component (e.g., walls or roofs) for daylight management purpose, which, however, may arise other concerns such as cost, energy performance, and safety of aerogel glazings [8]. Obviously, further studies are still necessary and important for the building related application of aerogel glazings. We discuss in this paper various approaches for the building integration of aerogel glazings by presenting a number of successful examples; the advantages of integration are quantified and suggestions are given to address the possible challenges. This work contributes to the development of guidelines to regulate the use of aerogel glazings in the building sector.

2. Properties of aerogel glazings

As any other building materials or components, how aerogel glazings are used in buildings depends mostly on their physical properties, especially the thermal and optical ones.

First of all, incorporating aerogel granules into the cavity of double glazings improves significantly the thermal insulation performance. As shown in Table 1, a double glazing with a 14-mm air cavity has usually a *U*-value of about 2.86 $W/(m^2K)$; applying low emissivity (low-e) coatings and argon (Ar) filling can reduce further its *U*-value down to ~ 1.20 $W/(m^2K)$. In contrast, a similar *U*-value of ~ 1.19 $W/(m^2K)$ can readily be achieved by filling the air cavity of the normal double glazing with aerogel granules. More importantly, the thermal performance of aerogel glazings can also be controlled by modifying the employed aerogel materials [7, 8]. For example, increasing the aerogel layer thickness from 14 mm to 30 mm, the corresponding *U*-values of aerogel glazings can be reduced further to about 0.60 W/(m^{2}K). Hence, the thermal performance of aerogel glazings can be predesigned, which is a promising feature over other glazing technologies and offers great flexibilities to meet different energy efficiency requirement in the building practice.

Table 1. Physical properties of aerogel glazings.

Glazing type*	*U*-value (W/(m^{2}K))	Visible transmittance	Solar factor	Reference
Double glazing (14 mm)	2.86	0.81	0.76	[8]
Double glazing (low-e/Ar/low-e)	1.20	0.74	0.52	[8, 15]
Aerogel glazing (14 mm)	1.19	0.50	0.57	[7, 8]
Aerogel glazing (30 mm)	0.60	0.17	0.34	[8]

* Calculation parameters: thickness of float glass is 4 mm; air gap is 14 mm; emissivity of glass and low-e coating is 0.836 and 0.071, respectively [15]; thermal conductivity of aerogel granules is 0.020 W/(mK) [7].

Aerogel glazings are typically a translucent (or diffuse) glazing technology and cannot provide an unobstructed outside view. However, aerogel glazings enable the visible solar radiation to propagate uniformly within the living area, thus minimizing the daylight problems such as glare and high contrast zones that are typically associated with clear glass glazings (see, for example, Fig. 2) [8]. High quality diffuse light is important to the user comfort; therefore, aerogel glazings are an interesting solution for daylight management in buildings. It is worth noting that, increasing the thickness of aerogel glazings may decrease their visible transmittance, as shown in Table 1. Apparently, the thermal and optical properties of aerogel glazings need to be optimized to meet the practical requirement.

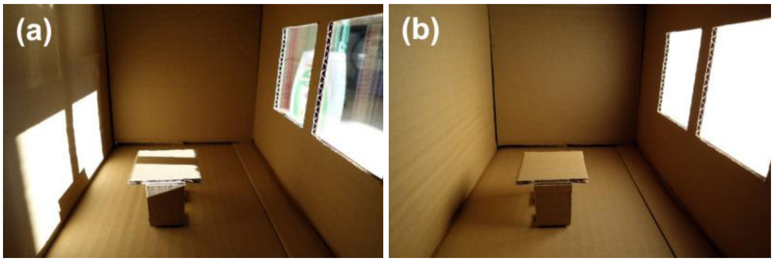

Fig. 2. Comparison between (a) specular double glazing and (b) diffuse aerogel glazing for daylight management by using a cardboard house model [8].

Aerogels are a nanoporous material with high manufacture cost and high environmental impact [8]; hence, the incorporation of aerogel materials into the glazing units may bring about other concerns such as cost, durability, lifetime, and safety of the resulting aerogel glazings, which are also important for their applications in buildings. For example, compared to double glazings, aerogel glazings usually have a higher manufacture cost due to the use of aerogel materials that are relatively expensive. However, aerogel glazings may still be a cost-effective solution since the increased cost of aerogel glazings can be compensated by their large energy savings during the service. For example, previous study has shown that, compared to the double glazing counterparts, aerogel glazings can contribute to about 21% reduction in energy consumptions (i.e., heating, cooling, and lighting), giving a short payback time of a few years [8]. In this regard, an improved design of aerogel glazings that enables a better durability and a longer lifetime is very important. In practice, alternative glazing materials such as polycarbonate and/or safety glass have been used to enhance the safety of aerogel glazings; other innovative designs such as honeycomb core container (see, for example, Fig. 3) have also been applied to reduce the settling effect of aerogel granules [16, 17]. These improvements are important for the practical application of aerogel glazings.

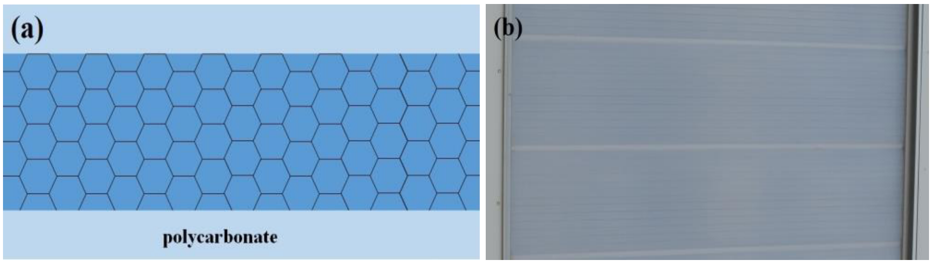

Fig. 3. (a) Schematic drawing of commercial aerogel glazing product shown in pane (b). Aerogel granules are contained in the honeycomb arrangement of cells.

3. Building integration

The unique feature of aerogel glazings make them a multifunctional building component for different purposes. For example, aerogel glazings can be used in the building envelope as windows, walls, and/or roofs. In this respect, an integrated design process must be applied so that aerogel glazings become an essential part of the building rather than an add-on feature. This is by now the case in many of the buildings integrated with aerogel glazings, including residential, commercial and public buildings.

Fig. 4 shows a single-family house built in 2013 in Holmenkollen, Oslo, Norway [18]. At the third floor, it has been designed to have the east-, south-, and west-facing walls integrated with aerogel glazing panels (65% of the wall area), which let light in while opaque enough to maintain privacy. The use of aerogel glazings in this project has turned to be very satisfactory. For example, it creates ~ 13 m^2 extra living space due to the thinner insulation thickness of aerogel glazings; the market value of these extra square meters compensates partly the initial investment of aerogel glazings. In addition, it saves greatly the lighting energy consumption, which pays back the investment during the service of aerogel glazings. Most importantly, the use of aerogel glazings provides a vivid living environment that greatly enhances the user comfort.

Fig. 4. Single-family house with aerogel glazings (Villa Holmenkollen, Oslo) [18].

In the commercial sector, reducing the energy budget of operating the building is very important. This in general requires the application of many different energy efficient technologies. A quite elegant example is the new supermarket Rama 1000 at Kroppanmarka, Trondheim, Norway (Fig. 5) [19]. In this project, the wall (also partially the roof) has been designed with integrated aerogel glazings, which spread daylight effectively into the store and at the same time make it unnecessary to install costly shading systems. An automatic lighting control system enables to turn off the fluorescent lights in the ceiling when there is sufficient daylight in the store. Together with a fully integrated system for heating, cooling, and ventilation, this project turns to be very energy efficient. Recent measurements have shown that it consumes 30% less energy than four other comparable stores [20].

Fig. 5. The Rama 1000 supermarket at Kroppanmarka with 220 m^2 aerogel glazing panels [19, 21].

In the public buildings where the lighting condition has priority, aerogel glazings can be a promising solution. There are probably many different ways of integrating aerogel glazings into the building envelope. For example, aerogel glazings can be used together with the clear glass glazings to optimize the visual comfort (including outside view and the access of diffuse light) of the users (Fig. 6) [21]. It is worth noting that aerogel glazings may have also glare problems, especially for those with a slim thickness, Hence, aerogel glazings can be used as roofs or roof windows for daylight management (Fig. 7) [21], which is by far the most successful application of aerogel glazings and similar projects can be found in other places [22].

Fig. 6. Levanger primary school, Norway. The entire second floor has built with two glazing systems: aerogel glazings for upper windows and normal clear glass glazings for low windows [21].

Fig. 7. Sandvika knowledge center, Oslo. The roof has been integrated with aerogel glazings [21].

4. Conclusion remarks

It can be seen from the above-mentioned examples that aerogel glazings are indeed a multifunctional building envelope component. Their capabilities of providing high quality of diffuse light while maintaining high level of thermal insulation indicate a promising potential in energy efficient buildings.

To promote further the application of aerogel glazings, some three general comments have been made:

(1) Architecturalization of aerogel glazings is important. Aerogel glazings are probably not the only but one of the technologies that can be used to meet the user's requirements (e.g., cost, appearance, indoor comfort, and

energy budget of the building). It is thus important for the architect to have enough information on this emerging glazing technology.

(2) An integrated design process must be applied. Aerogel glazings, as any other building component, are an integral part of the whole building; therefore, the overall building performance will correlate to aerogel glazings. It is important to note that the properties (e.g., optical and thermal) of aerogel glazings can be modified by controlling the incorporated aerogel materials. In this regard, the performance of the building should be evaluated and then optimized during the design phase.

(3) It is still necessary and important to conduct further research on aerogel glazings. It seems common for any newly developed technology that their novel property and promising potential have the priority in the earlier stage of the development; however, their potential disadvantages must be clarified for developing guidelines during the practice. For aerogel glazings, there is a lack of information on their environmental impact, which may require further efforts dedicated to this field.

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References

[1] The EU 2020 Climate and Energy Package: http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm (accessed on Jan. 9, 2016)
[2] A. Gustavsen, S. Grynning, D. Arasteh, B. P. Jelle, H. Goudey, Key elements of and material performance targets for highly insulating window frames, Energy and Buildings 43 (2011) 2583-2594.
[3] B. P. Jelle, A. Hynd, A. Gustavsen, D. Arasteh, H. Goudey, R. Hart, Fenestration of today and tomorrow: A state-of-the-art review and future research opportunities, Solar Energy Materials and Solar Cells 96 (2012) 1-28.
[4] A. Roos and B. Karlsson. Optical and thermal characterization of multiple glazed windows with low U-values. Solar Energy, 52 (1994) 315-325.
[5] R.E. Collins, T.M. Simko, Current status of the science and technology of vacuum glazing, Solar Energy 62 (1998) 189–213.
[6] K. I. Jensen, J. M. Schultz, and F. H. Kristiansen. Development of windows based on highly insulating aerogel glazings. Journal of Non-Crystalline Solids, 350 (2004) 351-357.
[7] T. Gao, B. P. Jelle, T. Ihara, and A. Gustavsen. Insulating glazing units with silica aerogel granules: The impact of particle size. Applied Energy, 128 (2014) 27–34.
[8] T. Gao, T. Ihara, S. Grynning, B. P. Jelle, A.G. Lien, Perspective of aerogel glazings in energy efficient buildings, Building and Environment 95 (2016) 405-413.
[9] T. Ihara, T. Gao, S. Grynning, B.P. Jelle, A. Gustavsen. Aerogel granulate glazing facades and their application potential from an energy saving perspective. Applied Energy, 142 (2015) 179-191.
[10] T. Ihara, S. Grynning, T. Gao, A. Gustavsen, B.P. Jelle. Impact of convection on thermal performance of aerogel granulate glazing systems. Energy and Buildings, 88 (2015) 165-173.
[11] C. Buratti, E. Moretti, Nanogel windows, in: F.P. Torgal, M. Mistretta, A. Kaklauskas, C.D. Granqvist, L.F. Cabeza (Eds.), Nearly Zero Energy Building Refurbishment - A multidisciplinary approach, Springer, London, 2013, pp. 555-582.
[12] F. Schneider, OKAGEL: High insulating day lighting systems, in: M.A. Aegerter, N. Leventis, M.M. Koebel (Eds.), Aerogels Handbook, Springer, New York, 2011, pp. 879-888.
[13] T. Woignier, J. Phalippou, and M. Pradhan. Glasses from aerogels. Part 2. The aerogel-glass transformation. Journal of Materials Science, 25 (1990) 3118-3126.
[14] J.M. Schultz , K.I. Jensen, Evacuated aerogel glazings, Vacuum 82 (2008) 723–729.
[15] B. P. Jelle. Solar radiation glazing factors for window panes, glass structures and electrochromic windows in buildings – Measurement and calculation. Solar Energy Materials & Solar Cells, 116 (2013) 291–323.
[16] M. Morphet, Glazing panels, US Patent 2005/0048231 A1, 2005.
[17] S.F. Rouanet, J.N. Litrun, Insulated panel and glazing system comprising the same, US Patent 2006/0144013 A1, 2006.
[18] L.Ø. Öberg, Supertynn isolasjon slipper lyset inn, Hus & Bolig 4 (2013) 74-79 (in Norwegian).
[19] T. Gao, B.P. Jelle, A.G. Lien, Heat and daylight management of buildings through aerogel windows, ZEB Annual Report 2013, 18-21.
[20] http://aerogelnorge.no/wp-content/uploads/2013/09/Energigjerrig-dagligvarebutikk-SINTEF.pdf (accessed on Jan. 9, 2016)
[21] http://aerogelnorge.no/category/presse (accessed on Jan. 9, 2016)
[22] http://www.cabotcorp.com/solutions/applications/construction/daylighting (accessed on Jan. 9, 2016)