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# Development of glazing systems with silica aerogel

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**Abstract**

The implementation of innovative materials for energy saving is among the most compelling topics in the building sector worldwide. In this regard, silica aerogels have received an increasing interest in the last years thanks to their exceptionally low thermal conductivity, generally around 0.01-0.02 W/(m·K). Aerogel panels laminated to drywall boards have started being adopted in highly energy-efficient buildings. However, the most promising application of silica aerogels seems to be in highly-insulating glazing systems. During the last years, double pane glazing systems with both granular and monolithic aerogel in the glass cavity have been developed and tested. Firstly, this paper reviews existing glazing systems designed with monolithic panels or granular aerogel and show their possible applications. Constrains of these systems, such as the low light transmissibility, cost, and fragility, are discussed. Then, the paper describes the development of a glazing system designed for the retrofitting of an educational building. Lighting and energy simulations allowed comparing window design options with different percentages of glazing area with aerogel. The analysis of the tradeoff between the goals of guaranteeing sufficient daylighting, clear perception of the external environment, and energy saving helps finalizing the design of the new monolithic aerogel glazing system.
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*Keywords:* aerogel; energy saving; glazing systems; trasparent thermal insulation

## 1. Introduction

The increase of building energy consumptions driven by the higher expectations for indoor comfort, together with concerns for the rise in GHG emissions, are pushing the research and design interest toward energy saving in buildings. In this context, the development of new insulating materials is among the most promising options [1-3]. This paper

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focuses on the development and characterization of new glazed units which incorporate aerogel monolithic panels and granules as replacement of the air-gap in double-pane windows.

The aerogels are considered one of the most promising family of materials for insulating purposes, given their high thermal insulation [2,3]. They are dried gels with such a high porosity that they have lower thermal conductivity than air [4]. Moreover, they are nontoxic, low flammable, lightweight, and air permeable. The synthesis of these materials was discovered in the early 1930s and since that time, several products have been developed, mainly using silica as a raw material [5]. The production process of silica aerogel aims to build sufficiently rigid materials with the same porous texture as that of the wet sol-gel stage. The aging of the gel and its drying are the two most risky phases of the production of aerogels, and are responsible of their high cost [6].

Due to the small pore sizes, aerogels have thermal conductivity in the range of 0.01-0.02 W/m·K, resulting from a well-balanced relationship among the low solid skeleton conductivity, the low gaseous conductivity, and the low radiative infrared transmission. This balanced relationship among the different heat transfer modes is hard to achieve because each heat transfer mode is tightly coupled with the others [7]. Although dense silica has relatively high thermal conductivity, silica aerogels have a small proportion of solid silica. Also, the inner skeleton structure of aerogels has many dead-ends, resulting in ineffective heat transfer paths. Finally, the Knudsen-effect which expresses the gaseous conduction in a porous media explains the low gaseous conductivity in aerogels.

The solid microstructure of the aerogels has been described as “beads on a string” or “pearls on a necklace” referring to the roughly spherical particles connected by small necks or thin strands. This structure is much less stiff than that of an open-cell foam (up to 30 to 50 times lower [8]). After cost, the main limitation that is preventing aerogels from becoming more widely used in the building sector is hence their high fragility. Their fragility has hence suggested the use of aerogels in protected compartments. Given their good light optical properties, aerogels have been considered for building fenestration systems since the 1980s. Products with aerogel in the interspace between the window panes have shown to provide high thermal resistance and light transmittance.

Two types of aerogel exist, the monolithic and the granular aerogels. Monolithic silica aerogels have higher solar transmittance than granular ones; for example, 10 mm monolith translucent silica aerogel windows have shown a solar transmittance up to 0.8, whereas the maximum solar transmittance of granular silica aerogel windows is around 0.5 [9-11]. However, cracks often occur when manufacturing large pieces of monolithic aerogels, so glazing systems with monolithic aerogel have not yet been used beyond research prototypes [12]. A monolithic aerogel window with vacuum glazing and a 13.5 mm thick aerogel panel was developed within the EU project HILIT; this project proved the possibility to realize windows with a thermal conductivity of 0.66 W/m$^2$K and a light transmissibility above 0.8. Since then, Airglass AB, the firm that provided the aerogel in the HILIT project, has continued refining the production process of monolithic panels.

After that preliminary experiences during the HILIT project, many more studies have been done to investigate the possibility to introduce aerogel in glazing systems. Buratti and Moretti compared several aerogel glazing systems according to their thermal and lighting performances [9,11]. Results showed that compared to double low-e glazing, monolith aerogel windows guaranteed 55% reduction in heat losses and 25% reduction in light transmittance, whereas granular aerogel windows showed 25% reduction in heat losses, and 66% reduction in light transmittance.

Other laboratories and companies currently active in the development of monolithic aerogel panels are Japan Fine Ceramics Center, Aerogel Technologies, Gyroscope, Guangdong Alison Aerogel, and Surnano Aerogel Inc. However, given the fragility of large monolithic aerogel, it remains difficult to produce reliable monolithic aerogel windows. Currently, the maximum size of a crack-free monolith silica aerogel panel is 0.6 m x 0.6 m [2,5].

Although monolithic aerogel panes show some higher performances, granular silica aerogels suffer less the fragility, and although they have a lower light transmissibility, they have been the only ones incorporated in glazing systems included in buildings. The size of most common translucent aerogel granules range between 1 mm and 4 mm. Most of the granular aerogel is manufactured by Cabot Corporation, a US company located in Boston, MA. The company produces two kinds of product: Enova, with a granule size of 2-1200 μm and a U-value of 0.012 W/m$^2$K, and Lumira, with granule size of 0.7-4 mm and a U-value of 0.018/0.023 W/m$^2$K. Nowadays, several window manufacturers produce granular aerogel window systems incorporating Lumira in the glass cavity. Table 1 reports some technical data for the aerogel window systems with the largest diffusion. First experiences have shown that fully aerogel systems are reasonable only in skylight windows, whereas for façade applications aerogel windows and traditional transparent windows are generally alternated in order to maintain a clear outside view in some portions of the window (Fig. 1).

Table 1. Technical data for currently commercialized aerogel window products (info obtained directly from the websites).

| Manufacturer | Thickness | U-value W/(m$^2$K) | $T_{vis}$ | website |
|---|---|---|---|---|
| Advanced Glazing Ltd (glazed windows) | 25.4 mm (1”)<br>44.45 mm (1.75”)<br>76.2 mm (3”) | 1.14<br>0.61<br>0.31 | 10% - 45%<br>9% - 40%<br>7% - 32% | http://www.advancedglazings.com/wp-content/uploads/products/solera-lumira-aerogel-r18-datasheet.pdf |
| Duo-Gard (polycarbonate) | 10 mm<br>16 mm<br>25 mm<br>40 mm | 0.26<br>0.17<br>0.11<br>0.09 | 72%<br>62%<br>59%<br>40% | http://www.duo-gard.com/lumira-aerogel/ |
| Kalwall (glazed windows) | 60 mm | 0.30 | 12% - 20% | http://kalwall.com/aerogel.htm |
| Okalux (glazed windows) | 4/30/4 (30 mm)<br>4/60/3 (60 mm) | 0.60<br>0.30 | 59%<br>45% | http://www.okalux.de/fileadmin/img/images/Produkte/Marken/Prospekte/OKAGEL_klein_2012.pdf |
| Pilkington (Profilit TGP) | 16 mm<br>25 mm | 0.21<br>0.19 | 50%<br>38% | http://www.tgpamerica.com/structural-glass/pilkington-profilit-insulation/ |
| Wasco (polycarbonate) | 16 mm | 0.22 | 48% | www.wascoskylights.com |

Fig. 1 – Two examples of built projects in which granular filled aerogel windows have been alternated to traditional transparent windows: Detroit School of Arts, MI, USA (left), and Nobel Halls at SUNY Stony Brook, NY, USA (right).

## 2. Development and characterization of an aerogel window

Airglass AB monolithic panels were selected for developing the window units described in this paper. The main reason for the selection of Airglass AB aerogel was the ability of the manufacturer to produce crack free 0.4 m x 0.3 m aerogel panels. The glazing system was composed of a 14 mm monolithic silica aerogel panel between two 4 mm glass panes. For this project, the aerogel windows were not evacuated, so a less than optimal thermal insulating performance was expected. However, thermal aspects are not the focus of the present paper.

The transmittance of the monolithic panel and of the panel between the glasses was measured using an Agilent Cary Series UV-Vis-NIR spectrophotometer between the 200nm and 2000 nm, with a 1 nm accuracy, without using an integrating sphere. Each measurement was repeated three times. Multiple tests were performed in order to consider the influence of different sample position. The results of light transmissibility were practically the same in every test. Fig. 2 shows the average values among the tests of the transmissibility of the monolithic panel alone or between two glass panels at each wavelength. The results show a remarkable light transmissibility, especially in the high spectrum range. The small discontinuity around 700 nm derives from a beam change in the equipment testing, whereas the drops around 1300 nm and 1800 nm are related to the light absorption of $CO_2$ (high absorption at 1437 and 1955 nm) and water vapor (high absorption at 1200, 1470, and 1900 nm). The lack of an integrating sphere was considered also responsible for the strong absorption in these bands.

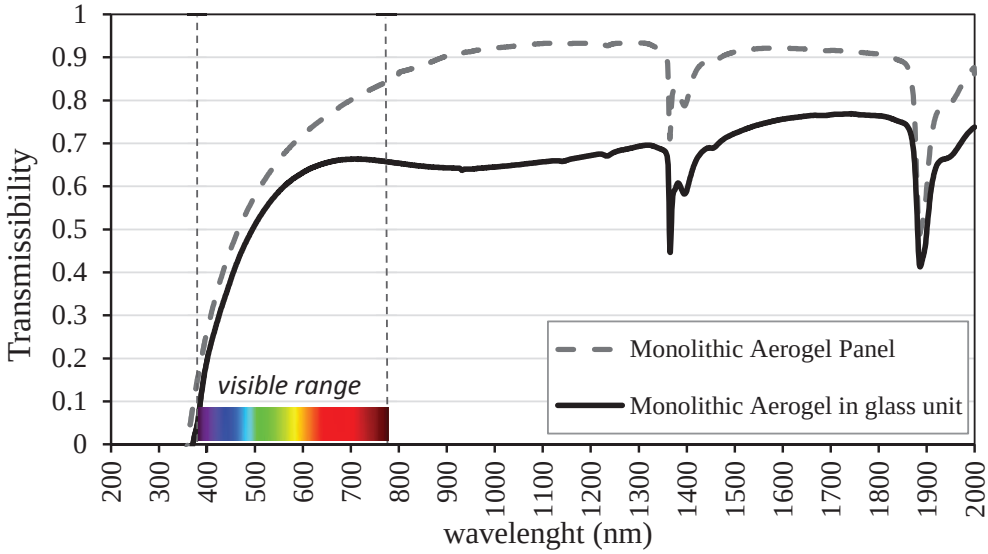


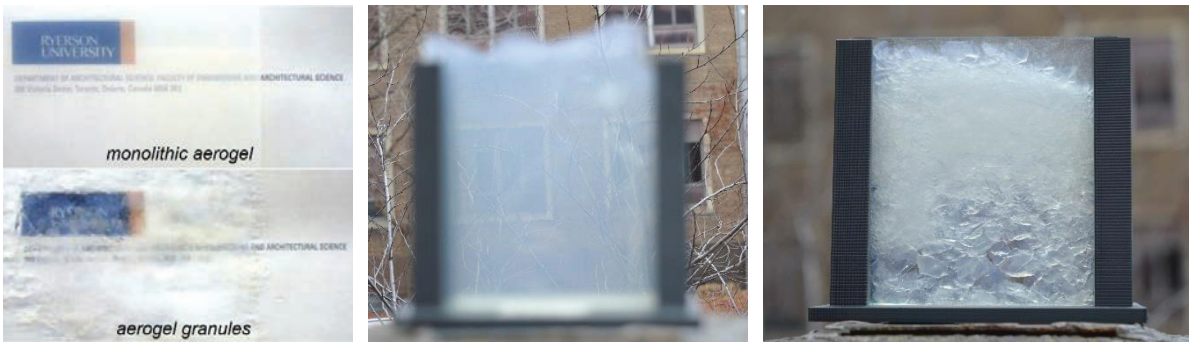

Fig. 2 – Light transmissibility of a 14mm aerogel pane alone (dotted line) or among two 4 mm thick clear float glasses (continuous line).

In order to evaluate the performance of the window units, light transmittance $\tau_v$ (in wavelength range from 380 nm to 780 nm) and solar direct transmittance $\tau_e$ (in the wavelength from 780 nm to 2500 nm) were calculated according to the ISO 9050 [13]. In particular, the light transmittance of a sample was calculated as:

$$\tau_v = \frac{\sum_{380}^{780} D_\lambda \tau(\lambda) V(\lambda)}{\sum_{380}^{780} D_\lambda V(\lambda)} \quad (1)$$

in which $D_\lambda$ is the relative spectral distribution as given by the standard, $V(\lambda)$ the spectral luminous efficiency for photopic vision defining the standard observer, and $\lambda$ the wavelength of analysis (in this case equal to each nm).

The light transmittance of the window with the monolithic aerogel was assessed to be 0.6. The test was also repeated for a window filled with 2mm granular aerogel and the result of the direct light transmissibility was equal to 0.3. This results confirms the higher transmissibility achievable with monolithic aerogel, respect to granular aerogel systems, as evident also in Fig. 3 which allows comparing the effect of the size of the aerogel granules. For the following simulations, it is important to mention that testing the double glass unit without the aerogel, a light transmittance of 0.7 was measured.




a) b) c)

Fig. 3 – View through a 14mm monolithic pane and granular aerogel (a); sample of a glazing system with a 14mm aerogel pane in the cavity (b) and with aerogel granules of different sizes, smaller than 2mm granules above and larger granules below (c).

## 3. Aerogel window in a retrofitting project

The possible use of the aerogel glazing system in an educational building located in Massachusetts (US) was analyzed. Although a change in the window systems is often considered not the best strategy for building retrofitting given the high cost of fenestrations, it was decided to act on these elements for the following reasons: the building envelope of this old building had a poor insulation performance, especially for the single clear glass windows (U-factor equal to 5.8 $W/m^2K$); the poor state of conservation of the windows also generated significant air drifts (a blower door fan test resulted in air infiltration values of 15 $cm^2/m^2$ at 50 Pa); the building was in use every day of the year, hosting many activities also during the summer, so it was unlikely to close it for long time for deep retrofitting interventions, and only a quick intervention was possible.

The solar transmission of the existing windows was estimated to be 0.82, so the adoption of glazing systems with monolithic aerogel would have reduced appreciably the daylight penetration into the building. The design of the new windows aimed to preserve the original design of the typical New-England windows, which consisted of 25 individual rectangular glasses, each with a dimension of 0.4 m by 0.3 m.

Figure 4 shows the four designs with the different rates of aerogel window replacements: 40%, 60%, 80%, and 100% of panels within aerogel in the double glass units. The design tried to preserve a clear view to the outside by having no aerogel filled the window at eye height and at the center of the window. Moreover, considering that only the central bottom part of the window is currently openable, the selection of the panes for aerogel inclusion tried to avoid movable parts of the window in order to limit the risk of cracks of the fragile aerogel panes.

*Original* *40% Aerogel* *60% Aerogel* *80% Aerogel* *100% Aerogel*

Fig. 4 – Possible New England window configurations with different percentages of window areas with monolithic aerogel in the cavity.

## 4. Daylight availability with aerogel windows

Daylight analysis were performed with the software DIVA (Design Iterate Validate Adapt) [14]. Among the possible indices for lighting assessment, the Useful Daylight Index (UDI) was selected. This index measures the percentage of time in which the daylight illuminance level is sufficient and useful for occupants. In literature, values below than 100 lux are considered ‘too little’, while values above 2000 lux are considered ‘too much’, with risk of visual discomfort or glare. So, the illuminance levels between 100 and 2000 lux are often considered useful in the evaluation of the UDI [15]. For the scope of this study, four corner rooms were considered in order to test the impact of the new windows for the different orientations. Square grids of 0.45 m were evaluated at 0.85 m off the floor.

Figure 5 reports the UDI with single pane windows (existing case) and double pane windows (possible retrofitting). In room 1 (facing south-east), with single clear windows, the average UDI over the year resulted 34.8%. In room 2 (facing south-west), the installation of double glass window would decrease the amount of excessive daylight in a year, as shown by the fact that the UDI is higher for double glasses than for a single pane. In room 3, which is mostly north facing, the installation of double window would decrease the UDI. Obviously, the overall daylight performance is affected also by the geometry of the room, as proven by the fact that the rooms that extends deep into the building, (room 3) have overall poorer UDI than small rooms, such as room 4. Figure 5 also shows the UDI in case of adoption of windows with 40% or 60% of aerogel. The overall trend of UDI in these cases was a small decrease with a higher amount of aerogel. However, the UDI reduction was relevant only far from the windows and only in the largest room (room 3). Comparing the results with double glasses and 40% of aerogel, it emerges a really similar daylight effect.

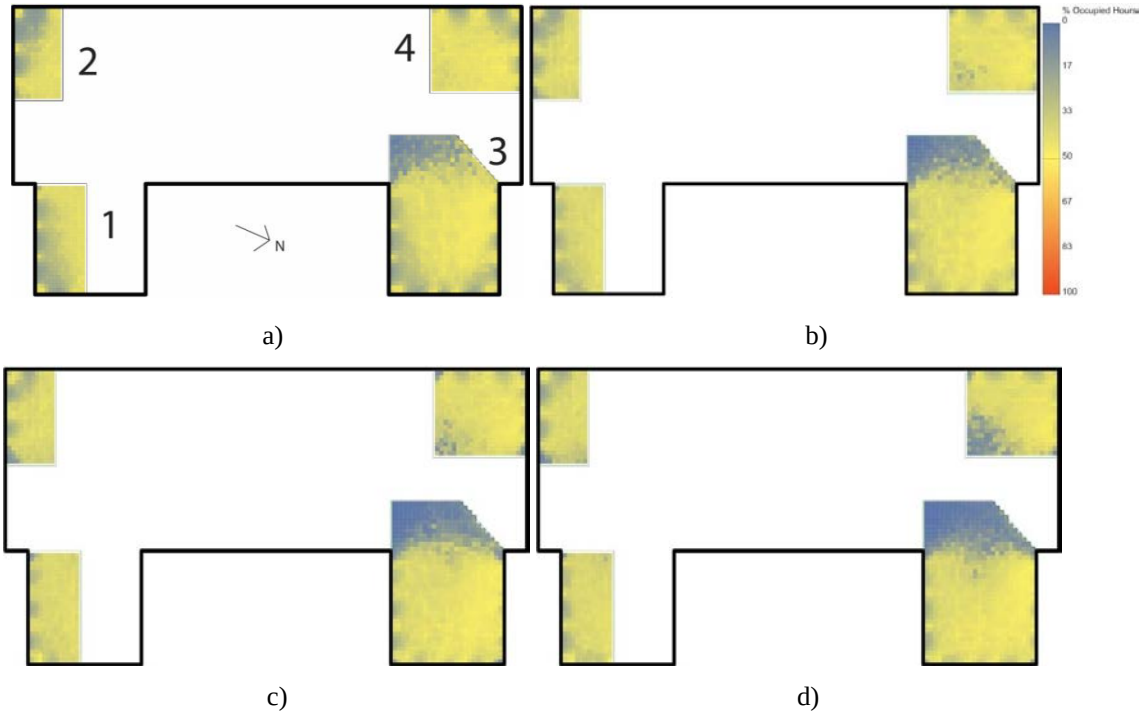



Fig. 5 – Useful Daylight Index with single pane windows (a), double pane windows (b), 40% aerogel windows (c), and 60% aerogel windows (d).

The results of this study prove that the windows with 40% of aerogel were a valid solution for this retrofitting project, being able to increase significantly the resistance value with advantages also for the daylight quality.

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