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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

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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).