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Super insulated aerogel windows: Impact on daylighting and thermal performance

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ABSTRACT

Window design plays an important role in achieving energy efficient buildings and in providing thermal comfort of building occupants. This paper investigates a newly developed aerogel window and the potential improvement on the comfort factors of an office in relation to daylighting. Improved comfort levels can impact on health and wellbeing of building occupants leading to knock on effects on absenteeism and productivity. A simulation tool was presently created that will easily enable comparison of different façade design and their impact on heat and light transmission and therefore enable optimisation. One of the most important aspects of the present work was comparing the performance of the newly developed aerogel window against the more traditional Argon-filled, coated double-glazing. Whereas the aerogel window provided an extremely low heat-loss index of 0.3 W/m^{2}K, the latter usually offered a centre-glazing U-value of 1.4 W/m^{2}K. On a like-with-like basis the daylight transmission of the aerogel window was significantly lower than double-glazing. However, in view of low thermal loss larger areas of the former can be deployed. This article presents the influence of three key parameters that may lead to an optimum design: daylight, thermal loss and solar gain.

1. Introduction

1.1. Daylight and thermal comfort

Health is defined by WHO as ‘a state of complete physical, mental and social well-being and thus not merely as the absence of disease and infirmity’ [1]. Recent medical and biological research has shown that daylight has an important non-visual effect on most of the body's biological processes [2]. Natural daylight in the workplace can positively influence the health of office personnel reducing unnecessary sick leave and has an important bearing on human brain chemistry, stimulating nerve centres which control daily rhythms and moods. Truly sustainable buildings need to foster health and well-being of their occupants so current lighting design criteria needs to be extended to include non-visual factors [3].

Daylight has also been seen to provide productivity benefits within the workplace. Since the majority of office costs are staff salaries (up to 84%) and in comparison energy costs are small, therefore small increases in staff productivity are equivalent to large savings in energy. It can positively influence the health of office personnel, improving efficiency and resulting in greater benefits for enhanced productivity [3]. Research has shown that the costs of employees is some 160 times that of energy. A 1% productivity (salaries) saving can nearly offset a company's entire annual energy cost [4].

The following studies have found improvements in productivity and energy saving as daylight levels increase; the Lockheed Building 157 in Sunnyvale California identified a 50% savings in lighting, cooling and ventilation energy and 15% reduced absenteeism due to the daylighting design [5]. A multiple building study identified an average 40% increase in sales in retail stores where skylights provide a significant portion of daytime lighting [6]. A field study identified a 15% increase in time dedicated to work tasks and a 35% decrease in electric lighting use for occupants of windowed offices, as compared to occupant in interiors offices with no access to daylight, with an increased performance of 3.75% [7]. A study at The VeriFone Company in Los Angeles, California, reported that after their employees moved to a newly designed distribution centre where extreme care was devoted to daylighting, productivity increased by 5% and total product output increased by 25% in just one and a half years after the move. The company also reported that absenteeism declined by 6.8 h per person per year [8].

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Despite current calls for energy conservation, daylighting is rarely used as a significant strategy to reduce energy consumption. Many buildings remain lit at night even when unoccupied and many offices and stores continue to be lit during the day when there is no need for additional illumination. However increased daylight in buildings can also create key energy saving benefits. Within the UK, lighting accounts for around 5% of the total primary energy consumption. However, in some types of buildings, such as office blocks, 10%–30% of the primary energy is used by lighting [9]. If carefully designed, daylight strategy can bring tangible energy savings, as long as it minimises energy use for artificial lighting and prevents glare and other visual discomfort [10]. Other studies by the UK based Building Research Establishment (BRE) indicated potential energy savings averaging 20%–40% in offices and factories if daylighting is used effectively. Most studies focus on strategies related to daylight harvesting such as daylight-linked lighting controlled systems [11–13]. Generally all methods of increasing internal daylight levels result in heat losses when compared to well insulated walls or building materials. A number of studies showed that daylight harvesting and reduction in energy consumption can be achieved with reasonable window-to-wall ratios (WWR) of no more than 30–40% and by considering carefully the thermal transmission properties and light transmission characteristics of windows [13–15].

The potential overheating of buildings due to excessively high solar gains if the conventional, opaque walls are replaced by super insulated 'walls' must however be considered. Thermal comfort is a result of a combination of parameters of both the environment and the human body itself. Since elevated temperatures in summer may have negative consequences for building users, it may be recommended that air temperature during summer should be set within the lower half of the summer thermal comfort range, to improve performance of office work and also avoid the negative health effects discussed above [16,17].

1.2. Aerogel material

Aerogel is a light and effective insulating material. Current façade options for building designers include transparent glass or opaque wall, but Aerogel windows now offer a third translucent option which enable provision of an abundance of daylight while offering very low U-values. Such glazing with light transmission control can manage the issues of both discomfort and disability glare without the need for other daylight blocking methods such as blinds, curtains, external shading and/or solar control glass types. The removal of these standard glare control methods will have a direct cost saving on the overall construction costs of a project. Aerogel has recently been used as thermal and acoustic transparent insulation material (TIM) in windows more commonly developed for application to building facades [18–22]. While each TIMs has a unique pattern of solar transmission and physical behaviour, they showed to consistently reduce heat losses, control indoor temperature while also allowing solar transmittance of more than 50% [22,23]. Aerogel windows were found to have the greatest potential for improving the thermal performance, daylight (high quality of diffused light) and solar properties (good solar heat gains) in the window sectors with centre of glass U-values reaching values as low as 0.3 W/m^{2}K while also having good sound insulation characteristics [18,24–31].

1.3. Present research

This research examines the feasibility of a newly developed super insulated aerogel glazing prototype into modern architecture and compares the concept's performance against the traditional Argon-filled, coated double-glazing technology widely available in the marketplace. Most studies on aerogel windows focus on the actual characteristics of the material rather than its daylight penetration ability and its impact on building performance related to occupants' comfort. Nowadays daylight illuminance distribution in any given building environment is analysed using numerical models. While a variety of simulation programmes have been developed over the years, few have integrated accurate simulation of the visual and solar radiation transmittance of aerogel windows. Using recently measured laboratory data this paper presents a visual transmission equation for aerogel windows and estimates by way of computer simulation the daylight illuminance distribution and penetration achieved in a building design scenario. A simulation tool was presently created that will easily enable comparison of different façade design and their impact on heat and light transmission and therefore enable optimisation. The potential added benefits of aerogel windows are also investigated. Finally general remarks for energy efficient buildings using aerogel windows are formulated with some recommendations.

2. Super insulated aerogel window system description

In this work the hydrophobic translucent Cabot's Lumira aerogel made of dry silica particulate was examined. This nanogel is a lattice network of glass strands with very small pores made up of 5% solids and 95% air. Each particle consists of air contained in a nanostructure with pore sizes less than the mean free path molecules. This nanoporous silica of average pore size of 20 nm severely inhibits heat transfer through the material, thus enabling very high standard of thermal performance to be achieved.

The prototype aerogel window under investigation is less than 50 mm thick containing a double skin sheet made of polymethylmethacrylate filled with 16 mm translucent granulated aerogel mounted between two low emissivity coated 4 mm glass panes filled with argon in order to obtain low U-values. Note that in view of the suppression of cavity convection made possible by the presence of Aerogel material it is worthwhile to use double, low-e coatings, i.e. one coating on each pane. Fig. 1 shows a schematic view of the aerogel window prototype.

In order to evaluate the performance of the system, four parameters were considered: a) visual light transmittance (τ_v), representing the capacity of the glazing system to diffuse natural light, b) shading coefficient (SC), representing the total amount of heat passing through the glazing compared with that through a single clear glass, c) solar heat gain coefficient (SHGC) and d) heat transfer coefficient (U-Value). The Lumira aerogel glazing's range of values for visual light transmittance, solar heat gain coefficient and the U-Value measured using the standards procedures [32,33] are presented in Table 1. The design of this product carefully optimises the improved thermal and optical performance. The range given indicates that the super-insulated window combines both low U-Value with a relatively modest level of visual transmittance. In the past, aerogel windows have not had such a high thermal performance.

To compare innovative and conventional solutions, the prototype was evaluated alongside a traditional Argon-filled, coated double-glazed window and a single glazed window. Whereas the super insulated aerogel windows provide an extremely low heat-loss index, the latter usually offer a centre-glazing U-value of 1.4 W/m^{2}K and 5.8 W/m^{2}K respectively. With such low U-values, large super-insulated windows may be deployed to good effect for harnessing daylight, particularly in winter time when gloomy interiors are not particularly welcome by the occupants. New high-performance windows have also made it possible to reduce solar heat gain with a reduction in visible transmittance as shown in section 3.