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OPTICAL AND THERMAL PERFORMANCE ANALYSIS OF AEROGEL GLAZING TECHNOLOGY IN A COMMERCIAL BUILDING OF HONG KONG

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ABSTRACT

Improving thermal insulation of glazing units is a common strategy of reducing building energy use for spacing cooling. This research paper newly examined the application of the aerogel glazing technology in Hong Kong by the means of laboratory testing and simulation. Nine prototypes of granular aerogel glazing will be examined of their optical properties. Optical properties of aerogel will be used to calculate the total window thermal performance indices. A 40-storey commercial office building with 2000 m^2 usable floor area is being modeled by simulation software EnergyPlus to compare the thermal performance of aerogel glazing with different glazing technologies. Simulation results had suggested that when comparing aerogel glazing to double glazing, a reduction of window heat gain by 57% and cooling energy by 8.5% could be achieved. The results depict that the insulation performance of aerogel glazing is even better than double glazing with Low-E coating. Aerogel glazing can be a choice of glazing to comply with the existing OTTV requirement and reduce the energy use for space cooling of a building.

Keywords: Granular aerogel glazing system, OTTV, energy consumption, heat insulation.

1. INTRODUCTION

In Hong Kong, Heating Ventilation and Air Conditioning (HVAC) system take up one-fourth of total building energy use for commercial sector. Thermal behavior of building envelope is very important since it is correlated to building energy use. Therefore, Overall Thermal Transfer Value (OTTV) regulation is developed to govern the heat transfer of a building envelope which aims to reduce building energy use. It is always a challenge for a commercial building with high Window to Wall Ratio (WWR) to comply with the statutory OTTV requirement. Window is the weakest component of the building envelope which draws a lot of solar radiation. Therefore, this paper proposed a new glazing technology namely Aerogel glazing technology in order to reduce the heat gain through the window with an aim to reduce the energy use for space cooling.

Y. Chen et al. (2018) showed that aerogel is one of the most promising insulating materials due to its ultra-low thermal conductivity (0.01-0.02 W/m.K). Since it is a porous material with 20nm average pore size which restricts the gas conduction and convection inside the particles. The thermal properties make them effective insulators against heat. Tao Gao et al. (2016) suggested that aerogel is also performed well in terms of sound insulation. Regarding visual performance, aerogel can optimize the visual comfort by reducing the glare and make the indoor illumination level more uniformly. With these characteristics, aerogel glazing is very attractive in the fenestration industry.

In this paper, a thorough study of granular silica aerogel in the perspective of optical and energy use will be presented. The study is carried out into three parts. Firstly, the visual performance of aerogel glazing technology will be examined by laboratory testing. Secondly, based on the optical properties of granular silica aerogel, the thermal performance indices will be further analyzed by computer program and energy simulation software. In the last step, aerogel glazing is compared to other glazing types. The results of this study will be helpful to the industries that are considering alternative heat insulation glazing technology in Hong Kong.

2. OBJECTIVES

This study will mainly focus on accessing the optical properties and energy performance of aerogel glazing. The objectives are listed as follows:

(i) examine the optical and thermal properties of granular aerogel glazing varies with wavelength

(ii) find out the optimum choice of aerogel glazing technology that can minimize energy consumption and maximize visible transmittance

(iii) compare the power consumption among the aerogel glazing system with different glazing technologies in a subtropical climate.

3. METHODOLOGY

In this paper, a methodology as shown in Figure 1 has been adopted. The methodology consists of five steps: Assessing the optical parameter of aerogel glazing samples; Computing the thermal performance indices of samples; Calculating the OTTV of the samples and other glazing technologies; Finding the baseline case and input data to simulation software EnergyPlus; Compare the performance with other glazing technologies in the perspective of energy use and solar heat gain through window.

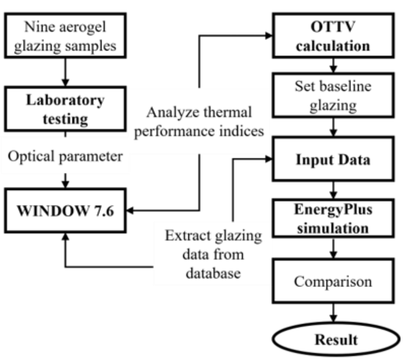

Fig 1 Flow chart of research methodology

3.1 Preparation of aerogel glazing samples

Table 1 shows the details of the aerogel glazing system samples filled with aerogel particles. In this study, nine samples of the aerogel glazing were prepared with various particle sizes and aerogel filling thickness. Figure 2 presents a schematic diagram of granular aerogel glazing. The structure of the aerogel glazing system is constructed by two 4 mm thick standard glass, while the aerogel particles were filled in between of two glasses. Regarding the appearance of the aerogel glazing sample, as can be noticed in Figure 2, it is a kind of semi-transparent glazing element which allows natural daylight passing through.

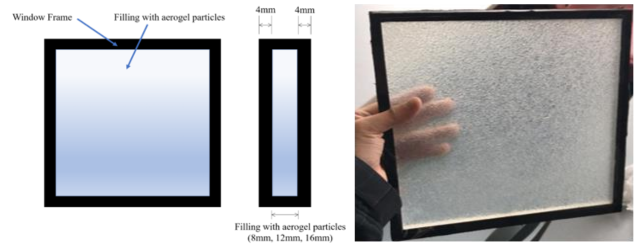

Fig 2 Structure and apperance of aerogel glazing sample

Table 1 Summary of aerogel glazing samples

1P8F	2.5P8F	4P8F
1P12F	2.5P12F	4P12F
1P16F	2.5P16F	4P16F

P: Particle size (mm) F: Filling thickness (mm)

3.2 Laboratory testing

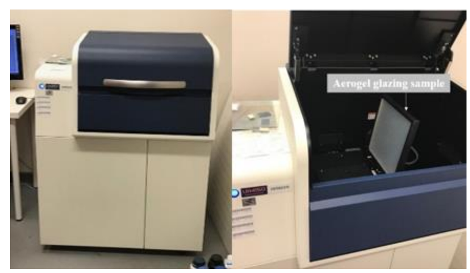

Fig 3 (UV/VIS/NIR) Spectrophotometer HITACHI UH4150

A spectrophotometer (UV/VIS/NIR HITACHI UH4150) as shown in Figure 3 was used to measure the optical properties of aerogel glazing at the laboratory of The Hong Kong Polytechnic University. Spectral solar radiation transmittance and reflectance of samples were measured. The wavelength interval was 2 nm. The visible, solar radiation transmittance, visible and solar radiation reflectance can be calculated by the following equations:

$$\tau_v = \frac{\int_{380}^{780} D_\lambda \, \tau(\lambda) V(\lambda) d\lambda}{\int_{380}^{780} D_\lambda \, V(\lambda) d\lambda} \quad \rho_v = \frac{\int_{380}^{780} D_\lambda \, \rho(\lambda) V(\lambda) d\lambda}{\int_{380}^{780} D_\lambda \, V(\lambda) d\lambda}$$

$$\tau_e = \frac{\int_{300}^{2500} \tau(\lambda) S_\lambda \, d\lambda}{\int_{300}^{2500} S_\lambda \, d\lambda} \quad \rho_e = \frac{\int_{300}^{2500} \rho(\lambda) S_\lambda \, d\lambda}{\int_{300}^{2500} S_\lambda \, d\lambda}$$

τ_v = visible transmittance
τ_e = solar radiation transmittance
ρ_v = visible reflectance
ρ_e = solar radiation transmittance
D_λ = relative spectral distribution of illuminant D65
$\tau(\lambda)$ = spectral transmittance of the glass
$\rho(\lambda)$ = spectral reflectance of the glass
$V(\lambda)$ = visual spectral luminous efficiency
S_λ = relative spectral distribution of solar radiation
$d\lambda$ = wavelength interval

3.3 Computing software

Berkeley Lab WINDOW 7.6 was used to evaluate the thermal performance indices of the glazing system including U-values, solar heat gain coefficient (SHGC) and visible transmittances. The algorithms adopted for the calculation of total fenestration product U-values and SHGC consistent with ASHRAE. i.e. (SHGC = TSOL+ASOL x N). The fenestration products in this report were simulated in accordance with the NFRC 100-2010. International Glazing Database (IGDB) is available in WINDOW 7.6 which is a collection of optical data for glazing products. In this paper, the thermal performance indices of different glazing technologies listed in IGDB will be used for comparison in the following sections.

3.4 Description of simulation model

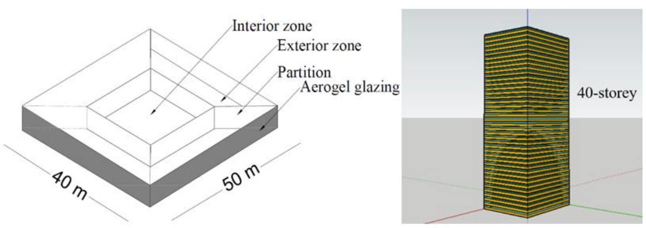

Fig 4 Schematic drawing of an office model building

A 40-storey commercial office building model with floor area 2,000 m^2 in Hong Kong was used to access the energy performance of different glazing technologies. The building model is presented in Figure 4. The design condition of the model is in accordance with the guidelines of the Hong Kong Government. The Window to wall ratio (WWR) was assumed to be 40%, and all the windows were equally distributed in 4 orientations. There are 5 air-conditioning zones including four symmetrically equal zones facing N, E, S, and W respectively and an interior zone. The floor to floor height was set to be 3.2 m.

3.5 OTTV calculation

Overall Thermal Transfer Value (OTTV) is a value that indicates the total heat being transfer into a building through building envelope. It is a performance-based building energy code which aims to reduce the building energy use. According to Code of Practice for OTTV in Buildings 1995, OTTV is used as a control measure for commercial buildings and hotels. Regarding a building tower, the OTTV should not exceed 24 W/m2. In this study, double glazing with a structure of 6-12(air)-6 will be used as a baseline which marginally fulfills the requirement of OTTV. The OTTV of the building can be calculated through the following equation: Apart from aerogel glazing, five types of glazing material extracted from WINDOW IGDB will be used as OTTV comparison along with different Window to Wall Ratio (WWR). The properties of glazing technologies are shown in Table 2.

Table 2 Thermal properties of glazing

Glazing type	U-value ($W/m^2.K$)	SHGC	T_{vis}	ρ
Double glazing (Baseline)	2.701	0.714	0.782	0.142
Single clear	5.8	0.87	0.86	0.08
Double Low-e Air	1.517	0.625	0.694	0.1799
Double Low-e Vacuum	0.639	0.578	0.751	0.1464
1P16F	2.065	0.346	0.058	0.1237
4P8F	2.401	0.576	0.491	0.1053
4P12F	2.22	0.52	0.373	0.1025

3.6 EnergyPlus simulation

In this study, EnergyPlus was used for building energy simulation. EnergyPlus is a well-known building energy simulation program which can calculate the energy consumption within the building and the heat gain through the envelope. Regarding the lighting, air-conditioning system, occupancy, and equipment schedule of the office model, all the schedule will be in accordance with BEC 2007. Occupancy density (13 m^2/person) according to the same reference was chosen to fit with the situation of Hong Kong. An office model building had been accessed from 1 Jan 2019 to 31 Dec 2019 with the weather typical year file for Hong Kong. Table 3 lists the design condition of the simulation.

Table 3 Air-conditioning system design condition

Outdoor condition	T_{DB} 35°C, T_{WB} 29°C
Indoor condition	T_{DB} 23°C, RH 50%
Lighting load	15 W/m^2
Equipment load	10 W/m^2
Infiltration	0.5 ACH
Ventilation rate	10 L/s/person
Usable floor area	2000 m^2
Window to wall ratio	0.4

4. RESULTS

Figure 5 shows the laboratory testing results of solar radiation transmittance and solar radiation reflectance of aerogel glazing with different filing thicknesses, and different filling particle sizes. From Figure 5, we can observe that the pattern of transmittance and reflectance against different wavelength are similar.

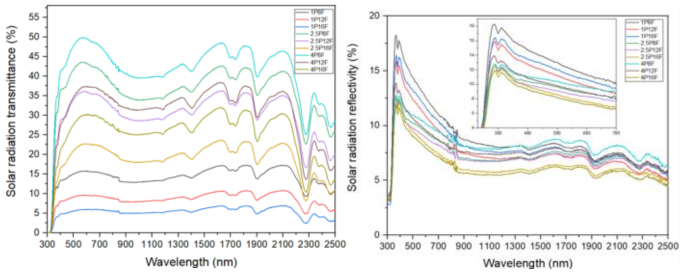

Fig 5 Transmittance and reflectance of glass

The results of the OTTV calculation considered cases with different WWR are presented in Figure 6. The figure identified the potential of aerogel glazing technologies in Hong Kong, 1P16F was the most effective in fulfilling the statutory requirement as it is the only one complying with the requirements when the WWR is increased to 0.6 and 0.8. From the perspective of heat transfer, it can be concluded that the thermal insulation performance of the aerogel glazing system is better than the double Low-E glass with an air gap in between.

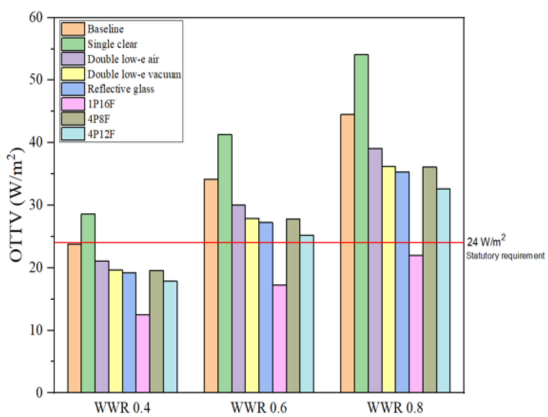

Fig 6 OTTV performance

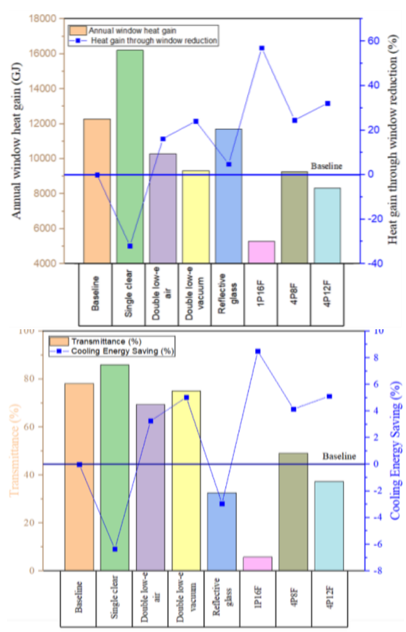

Fig 7 Heat insulation and energy performance

Figure 7 summarizes the insulation performance of glazing options. Among the glazing types, 1P16F obtained a better performance compared to other glazing types in which there is a 57% reduction of heat gain when compared with double glazing. From Figure 7, it can be observed that the annual energy consumption is relatively low when compared with another glazing. Since aerogel glazing application has the lowest window heat gain hence reduce the energy use for space cooling. In accordance with the heat gain pattern, the energy performance of aerogel glazing is better than double glazing with Low-E coating. Figure 7 illustrates the relationship between transmittance and energy saving of corresponding glazing technologies. It is noted that 1P16F has the best energy saving potential. The visible transmittance and energy saving are 5.8% and 8.5% respectively.

CONLUSION

This paper proposed the aerogel glazing technology as an insulating material to reduce cooling energy consumption. The work highlights the energy saving potential of aerogel glazing application on the modeled building. The following conclusions can be drawn.

(i) The envelope heat gain and cooling energy consumption were reduced by 57 % and 8.5% respectively by replacing double glazing with aerogel glazing.

(ii) Aerogel glazing has very high effectiveness in minimizing the heat flow with a low SHGC.

(iii) Low visible transmittance is one of the concerns in this technology. 4P12F has a balance between energy saving and visible transmittance which is the best option in this model building.

In the future, the development of monolithic silica aerogel can be significantly enhanced the solar transmittance with a better thermal insulation property like granular aerogel glazing

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