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Effect of sky clearness index on transmission of evacuated (vacuum) glazing

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ABSTRACT

Glazing transmittance variation with clearness index has higher influence than incident angle for soar energy application. This work presents variation of vacuum glazing transmittance with clearness index. Clearness index and transmittance was calculated from measured one year (2014) solar radiation and glazing transmittance data in Dublin, Ireland. Clearness index below 0.5 offer single value of transmittance whereas above 0.5 clearness index glazing transmittance varies with clearness index. For different azimuthal orientation, clearness index associated with vertical plane glazing transmittance has been proposed. In Dublin for south facing vertical plane, vacuum glazing has 35% transmittance below 0.5 clearness index. Yearly usable single transmitted solar energy and solar heat gain coefficient for vertical plane south facing vacuum glazing are 87 W/m^2 and 0.22 respectively.

1. Introduction

Reduction of building energy consumption can be possible by using advanced adaptive glazing technologies [1–4]. Solar heat gain control and low heat loss are the two major types of advanced glazings, which are gaining more importance in research due to their potential application in building cooling and heating energy demand reduction respectively. Solar heat gain control glazing such as electrochromic [5–7], suspended particle device [8–14], liquid crystal [15,16], thermochromic [17,18], gasochromic [19,20] and thermotropic [21,22] control the entering solar heat by changing their states from “transparent” to “opaque”. Thus, these types of glazing reduce the cooling load demand of building. These glazing are more suitable for hot climatic area and summer time in cold climatic area. Low heat loss glazing such as vacuum glazing [23,24], aerogel [25–27], and multiple pane glazing [28] reduce the heat passing from the room to outside thus reduce the heating load demand of building. These glazing are suitable for cold climatic area and wintertime in composite climate to reduce a building’s heating energy demand [24].

Low heat loss vacuum glazing is advantageous compared to aerogel glazing due to its high transparency. Vacuum glazing is also advantageous compared to other multiple panes glazing due to its low weight and elimination of convective heat transfer between two panes [24]. In vacuum glazing, two glass panes are separated by a vacuum. Small pillars between the two glass panes withstand the outside atmospheric pressure [29–33] as shown in Fig. 1. The overall heat transfer coefficient of vacuum glazing is low compared to double-glazing [24]. The idea of vacuum glazing was first introduced by Zoller in 1913 and was granted with a patent in 1914 [34]. A vacuum tight thermally insulating edge sealing process makes the fabrication of a vacuum glazing complicated compared to other glazing technologies. To avoid deformation from the high temperature, the sealing should be performed below the softening temperature of the glass, which is generally low (for example, the softening temperature of common soda-lime glass is lower than 600 °C [35].

Vacuum glazing was first fabricated successfully in the early 1980s [36]. Thermal performance of this glazing was poor as a vacuum pressure below 0.1 N/m^2 is required to eliminate the gaseous conduction [37]. A laser was used to fuse two sheets of glass together successfully within a vacuum chamber to form a periphery edge seal for the vacuum gap [36–38].

To manufacture successful vacuum glazing, a fabrication technique was developed by Robinson and Collins, which was commercialized in 2000 by Nippon Sheet Glass (NSG) under brand name of SPACIA [23]. High temperature solder glass (melting point

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Nomenclature

I	Incident global solar radiation on the vertical surface of glazing (W/m^2)
$I_{beam,h}$	Incident beam solar radiation on the horizontal surface (W/m^2)
$I_{dif,h}$	Incident diffuse solar radiation on the horizontal surface (W/m^2)
$I_{global,h}$	Incident global solar radiation on the horizontal surface of glazing (W/m^2)
I_0	Extraterrestrial solar radiation (W/m^2)
I_{sc}	Solar constant (W/m^2)
k_b	Anisotropy index
k_d	Diffuse fraction
k_T	Clearness index
N_g	Number of glass pane
n	Refractive index
n_d	Number of day
SHGC	Solar heat gain coefficient
TSE_{vacuum}	Transmitted solar energy through vacuum glazing (W/m^2)

Greek symbols

δ	Declination angle
ω	Hour angle
φ	Latitude
θ	Incidence angle

450 °C) edge sealing was employed to produce this product, which restricts the choice of inner pane low-e coating. Low temperature indium alloy edge sealing (melting point 200 °C) enable low-e coating [35] to be used. Details of vacuum glazing edge sealing process can be found elsewhere [39,40]. A finite volume model to calculate the thermal performance of vacuum glazing with various frames [41], low-e coatings [42,43], glazing size, glass thickness [44], and vacuum pressure inside glazing [45] were predicted and validated experimentally [46,47]. To obtain low heat loss switchable glazing, investigation was performed using vacuum electrochromic [42,48,49] and vacuum suspended particle device combinations have been employed [50].

Thermal characterisation of vacuum glazing has been conducted under outdoor weather conditions in Sydney, Australia [51] and in Dublin, Ireland [24] has also been performed. Building energy performance due to glazing is dependent on glazing transmittance. Available glazing transmittance value is only suitable for normal solar incidence. Due to diurnal variation of solar radiation, incident angle also changes. Thus, glazing transmission is not a constant parameter; it changes with incident angle [52–54]. For building energy calculation, clearness index is more influential than incident angle as clearness index directly related with incident solar radiation. Glazing transmission changes for clearness index has been theoretically calculated by Waide and Norton [55]. They observed that below a critical clearness index for particular locations the transmission was largely invariant as the diffuse component.

The clearness index (k_T) is defined as the ratio between total solar radiation and the corresponding extraterrestrial radiation (H_0) [56,57]. Clearness index is an effective parameter for solar energy application, as it requires only measured global solar radiation [58]. Knowledge of glazing parameter such as transmission, transmitted solar energy (TSE), and solar heat gain coefficients (SHGC) is essential for building designer and architecture. First time the correlation between vacuum glazing transmission, TSE through vacuum glazing, and SHGC of vacuum glazing has been investigated with clearness index. Results from this investigation are suitable for calculation of building energy using vacuum glazing with less error in northern latitude area.

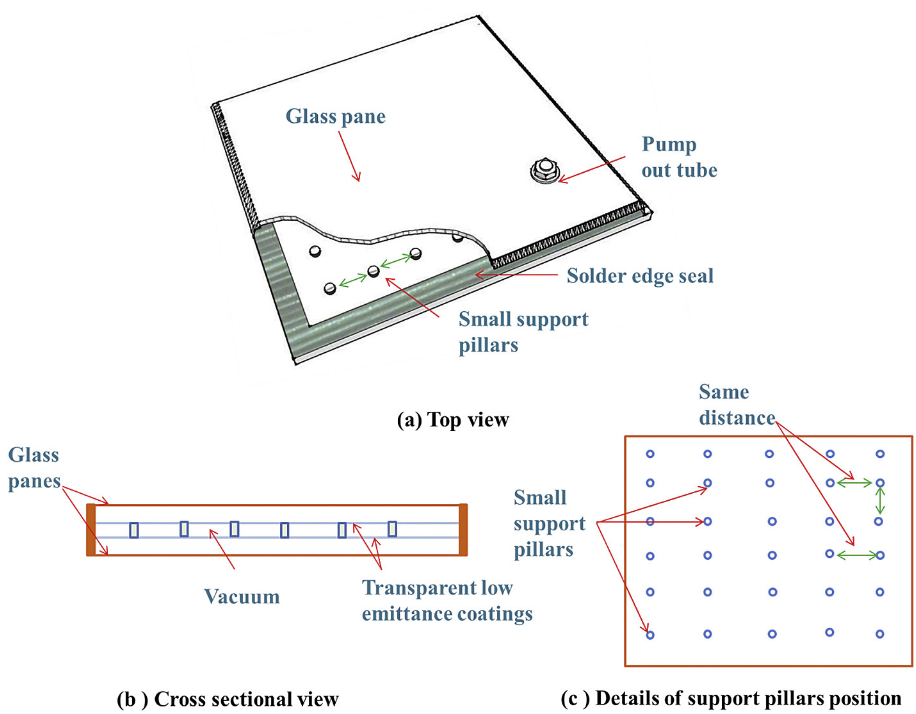

Fig. 1. Schematic details of vacuum glazing.