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Influence of atmospheric clearness on PDLC switchable glazing transmission

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ABSTRACT

Electrically activated switchable polymer dispersed liquid crystal (PDLC) is suitable for adaptive windows. A particular type requires 20 V to become 71% transparent while in the absence of power it is 27% transparent. Glazing transmission changes with light incident angle. As the clearness of a sky changes the fraction changes alter of direct insolation (that has an azimuthally changing incident) and diffuse insolation (that has a largely constant incident). Thus, the effective overall incident angle determining the glazing transmittance also changes. In this work for the first time, the variation of PDLC glazing transmission with clearness index has been investigated. For diffuse sky condition, single glazing transmittance value can be used below a particular clearness index for building energy calculation. This threshold clearness index changes with different azimuthal direction. In Dublin for south facing vertical plane PDLC glazing, yearly usable single transmittance (38% for transparent and 25% for translucent state), transmitted solar energy (TSE) (70 W/m^2 for transparent state and 20 W/m^2 for translucent state) and solar heat gain coefficient (SHGC) (0.17 for transparent state and 0.005 for translucent state) for transparent and translucent states were investigated.

1. Introduction

Large glazed façade building elements [1,2] enable commercial and residential buildings to exploit heating energy and daylight [3] from sun [4,5]. Electrically actuated switchable material filled double glazings in such large façade applications offer better control when compared with non-electrically activated switchable glazing. In additions, electrically actuated switchable glazings

- offer more than one transmittance and intermittence transmittance by applying variable power [6–9];
- can control glare [7–10];
- provide daylight where spectrum has a positive influence on occupant comfort [8–10];
- can be powered by connected with PV [11–15];
- addition with vacuum glazing [16–18] electrically activated glazing can form a low heat loss switchable glazing [19–25];

Electrically actuated glazings include electrochromic (EC) [26], suspended particle device (SPD) [27] and polymer dispersed liquid crystal (PDLC)[6] type. Electrically activated EC glazing is powered by direct current power supply. Tungsten trioxide (WO_3) based EC is the well-studied for glazing system [28] in which an ion-conducting polymer or inorganic material based transparent electrolyte is sandwiched between nanoporous W and Ni oxide films. These three layers are placed between two transparent electrical conductors. The functioning of an EC devices is very similar to an electrical battery [29–31]. A voltage applied between these two transparent conductors changes the color of EC material to absorb solar spectrum. In the absence of power, the EC is transparent (bleached). An EC material can control near infrared solar radiation. Modulation of NIR is also possible of EC glazing [26,32]. Colour changes of EC is gradual depending proportionally on the area of the device. An EC changes colour between 1 and 30 min, depends on the device area [33].

An SPD glazing consist of an SPD film, sandwiched between two glass panes, adhesive films, retaining films and a transparent conductor [34]. An SPD film is made of needle-shaped, rod-shaped, or lath-shaped dihydrocinchonidine bisulfite polyiodide or herapathite particles less than 1 μm in linear size [35,36]. These particles exhibit large optical anisotropy. In the presence of alternating current power supply, these particles become aligned to pass light through the film. In the absence of power, the particles exhibit Brownian movement. Thus, the light passing through the cell can be transmitted, absorbed or rejected, depending upon type and

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Nomenclature

A_i	Anisotropy index
$I_{global,h}$	Incident global solar radiation on the horizontal surface of glazing (W/m^2)
$I_{global,v}$	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_{extra}	Extra-terrestrial solar radiation (W/m^2)
I_{sc}	Solar constant (W/m^2)
k_d	Diffuse fraction
k_g	Extinction coefficient
k_T	Clearness index
N_g	Number of glass pane
n	Refractive index
SHGC	Solar heat gain coefficient
TSE_{PDLC}	Transmitted solar energy through PDLC glazing

Greek symbols

α	Absorptance
τ	Transmittance
τ_v	Vertical global transmittance
τ_{dir}	Direct transmittance
τ_{diff}	Diffuse transmittance
τ_g	Ground reflected transmittance
θ	Incidence angle

concentration of particles and the energy content of the light. The optical change of SPD glazing from transparent to opaque and from opaque to transparent both needs only few seconds [20,37,38]. However, particular example of this glazing needs high 110 V AC to become transparent. Long term durability of this technology is also not fully understood [38].

Alternative current (AC) powered electrically activated switchable liquid crystal (LC) is another switchable glazing technology [39]. Polymer dispersed liquid crystals (PDLC) are the best suited for glazing application as they do not need a polarizer to operate compared to twisted nematic, ferroelectric [40,41]. In a PDLC glazing, liquid crystal particles are dispersed into a matrix. The presence of a power supply, orients the particles to allow light pass through. In the absence of power, these particles are randomly oriented so lights is scattered. Droplets with radii smaller than the incident light wavelength allow light to pass through without scattering. For large size droplets mainly forward scattering ensues [42]. Reverse mode PDLC have also been investigated in which the glazing is unpowered when transparent and powered to be opaque [43,44]. Fig. 1 shows the working principle of PDLC glazing.

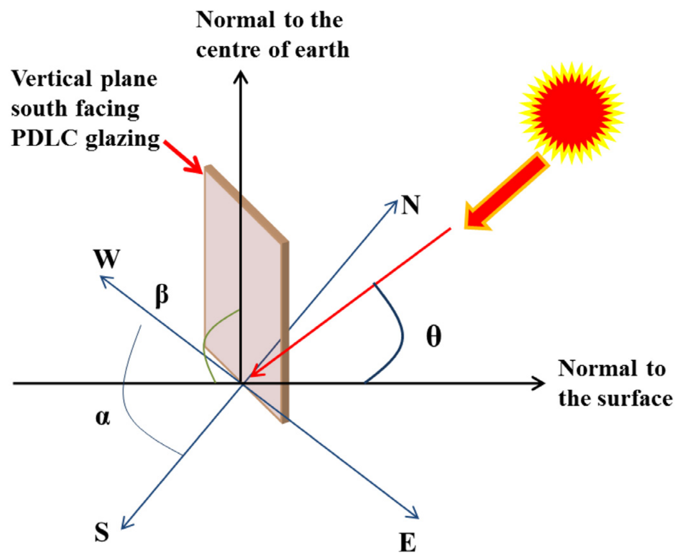

Fig. 2. Schematic diagram of a south facing vertical plane glazing with incident angle and solar elevation angle.

Transmitted incident solar radiation through a glazing system depends on the optical properties of the glazing and incident-angles of the direct, diffuse and ground reflected solar radiation components. Incident angle for a vertical glazing façade also changes with time of a day and season [45–49]. Thus, calculated solar energy for a building based on constant glazing transmittance often leads to an overestimated result. For building energy calculations, incident solar radiation and glazing transmittance are essential parameters. Horizontal global and horizontal diffuse solar radiation data are often available for a particular location. However, glazings are usually installed vertically to receive vertical solar radiation. Clearness index uses global horizontal solar radiation to determine how "clear" a sky is [50–52]. Theoretically, the relation between glazing transmission and clearness index was investigated for selected European locations and surface orientations by Waide and Norton [53]. Experimentally correlations between SPD glazing [54], vacuum glazing [17] and SPD-vacuum glazing [19] with clearness index had also been investigated.

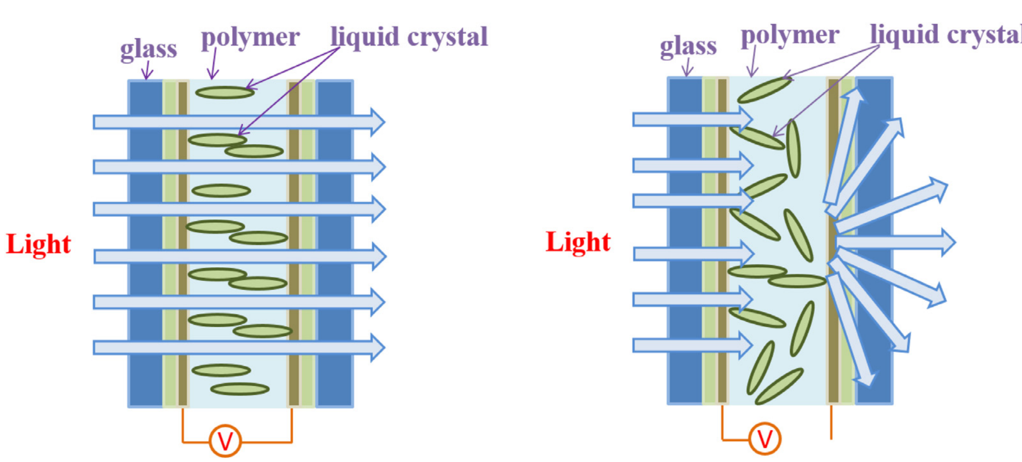

Fig. 1. Schematic working principle of PDLC glazing in its transparent and translucent states.