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Effect of sky conditions on light transmission through a suspended particle device switchable glazing

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ABSTRACT

A suspended particle device (SPD) switchable glazing changes its state from opaque to transparent in the presence of a power supply. SPD glazing's near normal transmission varies with incident angle and clearness index. Due to a lower diffuse component, higher glazing transmission ensues at higher clearness indices. Transmittance values for different azimuthal incident angle for a SPD glazing for its "transparent" and "opaque" states have been determined. In Dublin, below 0.5 clearness index, isotropic diffuse transmittance was prevailed while transmission of direct insolation was dominant above 0.5 clearness index. For south facing vertical plane SPD glazing transmittance in its transparent and opaque states are 0.25 and 0.025 respectively while clearness index is below 0.5.

1. Introduction

Solar energy transmitted through a glazing system is the consequence of the optical properties of the glazing producing distinct incident-angle dependencies applicable to the differing relative intensities of direct, diffuse and ground reflected solar radiation components. As sunlight is incident at a range of different incident angles changing with time of a day and season, glazing transmittances are therefore significantly different from their values at normal incidence. Thus, design calculations for glazing systems in buildings based on near-normal transmittance and reflectance values alone offer over-estimated results [1–5].

For the diffuse transmittance, an equivalent value of the direct transmittance for an average incidence angle of about 60° has been recommended for use in design calculations [6]. Hemispherical normal reflectance and transmittance properties of a variety of coated and uncoated plastics (teflon, tedlar, acrylic) and fiberglass composites (e.g., greenhouse coverings) are available as a function of wavelength, polarization and incident angle [7]. The composition, thickness, density, column shape, size, direction, and the spatial arrangement of column and voids all have an effect on the angular dependent optical properties of glazing [8]. The variation of glazing transmission with clearness index for selected European locations and surface orientations has been studied theoretically [9] as it has the effect on transmission due to presence of coatings [10,11].

1.1. Solar energy material for glazing technology

A wide variety of different advanced glazing technologies are available that (i) control heat and/or light gain, (ii) provide low heat loss (iii) control air-flow, (iv) deflect daylight deep into a room and/or (v) provide reduced noise transmission [12–14]. A switchable transparency glazing can be actuated electrically or non-electrically [15–20]. Electrically-actuated glazings include AC-powered suspended particle devices (SPD) and DC powered electrochromic (EC) devices [18]. Electrically-actuated SPD glazing can provide control of solar heat gain and glare in building fenestration applications [21–23]. SPD glazing is almost opaque without the application of power supply and transparent when, AC power supply is applied (in this example, an 100 V) as shown in Fig. 1. An SPD glazing will have intermediate transparency, for the particular example chosen, between 5–55% when the applied AC voltage is set between 0 and 100 V [24,25]. The daylighting and thermal performance of an SPD glazing showed that SPD glazing is superior over other glazing applications in building [23,24].

When a SPD glazing is to be considered for inclusion in either new or refurbished buildings, knowledge of solar energy transmission behaviour with clearness index provides a ready means of assessing annual glazing performance [9]. The clearness index has been shown to be useful for parameterising insolation conditions [26].

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Nomenclature

I	incident solar radiation on the vertical surface of glazing (W/m^2)
I_{global}	incident solar radiation on the horizontal 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
SE_{SPD}	transmitted solar energy through SPD 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

The variation for a particular SPD, of its glazing transmittance with clearness index is presented in this work.

For a vertical glazing as shown in Fig. 2, direct solar radiation is incident to a glazing surface at oblique incidence angles.

The transmittance of the vertical glazing is given by;

$$\tau_v = [k_d\{k_T R_b(1-k_d) + (1-\cos\beta)(1-k_T(1-k_d))\} + R_b(1-k_d) + R_g\frac{1-\cos\beta}{2}] \times$$
$$\tau_{dir}R_b(1-k_d)(1+k_d k_T) + \frac{\tau_{dif}k_d}{2}(1+\cos\beta)(1-k_T(1-k_d)) + \frac{\tau_g R_g(1-\cos\beta)}{2} \quad (1)$$

where

$$\tau = \frac{1}{2}\left[\frac{1-\left\{\frac{\sin(\theta-n)}{\sin(\theta+n)}\right\}^2}{1+(2n_g-1)\left\{\frac{\sin(\theta-n)}{\sin(\theta+n)}\right\}} + \frac{1-\left\{\frac{\tan(\theta-n)}{\tan(\theta+n)}\right\}^2}{1+(2n_g-1)\left[\frac{\tan(\theta-n)}{\tan(\theta+n)}\right]^2}\right] \times \exp\left(\frac{-k_g N_g t_g}{\cos\theta}\right) \quad (2)$$

and

$\tau = \tau_{dir}$ when $\theta = \theta_{dir}$

$\tau = \tau_{dif}$ when $\theta = \theta_{dif} = 59.68 - 0.1388\beta + 0.001497\beta^2$ [27]

$\tau = \tau_g$ when $\theta = \theta_g = 90 - 0.5788\beta + 0.002693\beta^2$ [27]

Simplified equation for angle dependent glazing transmissions are

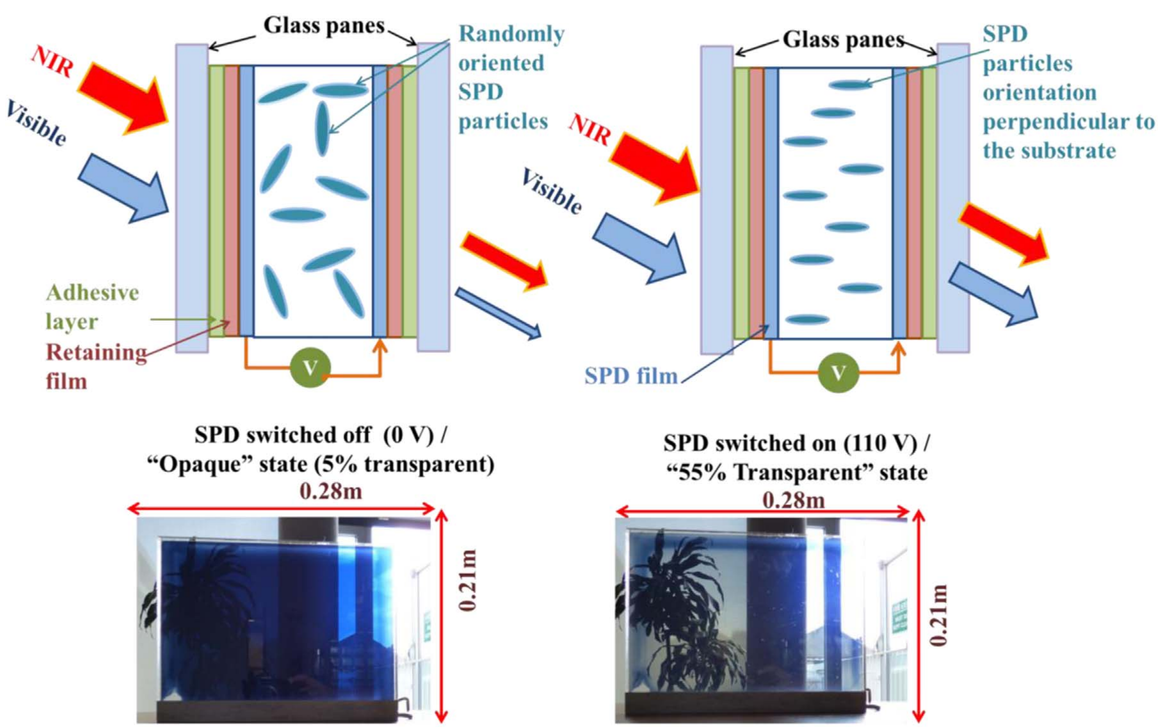

Fig. 1. : Operation and appearances a particular example of SPD glazing in its "opaque" and "transparent" states.