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Daylighting performance and glare calculation of a suspended particle device switchable glazing

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Abstract

The daylighting performance of a suspended particle device (SPD) switchable glazing has been evaluated using an unfurnished outdoor south facing test cell with glazing to wall ratio of 1:8. Interior illuminance levels were determined using useful daylight illuminance level (UDI) for clear sunny, intermittent cloudy and overcast cloudy days. Daylight provided by an SPD and a same area of double-glazing were compared. Daylight glare indexes (DGI_N) and daylight factor (DF) were calculated for SPD "opaque" and "transparent" states. An electrically actuated suspended particle device switchable glazing with transparency that varied between 5% and 55% was found to control daylight glare.

Keywords: SPD glazing; Liquid crystal; Electrochromic; UDI; DGI; DF

1. Introduction

Artificial lighting and air-conditioning buildings account for about 80% of total office building electricity consumption (Li and Lam, 2003). Appropriate daylight distribution (Smith, 2004) can reduces lighting energy consumption of residential and office building (Balaras et al., 2000; Bodart and Herde, 2002; Chel et al., 2009; Hunt, 1979; Krarti et al., 2005), hotels (Santamouris et al., 1996), large atrium spaces (Littlefair, 2002; Atif and Galasiu, 2003) and corridors (Li and Lam, 2003).

As comfortable daylight closely matches the human visual response, it has positive influences on occupant satisfaction, performance and productivity (Joshi et al., 2007; Littlefair, 1987, 1990; Muneer, 2004). However high illuminance from direct sunlight and bright skylight can create discomfort glare. The level of discomfort varies with glare source position, the part of sky seen and the size of glare sources (Galasiu et al., 2004; Hopkinson, 1972; Nazzal, 2005). A daylight control system should shade occupants from direct sunlight to mitigate daylighting glare (Littlefair et al., 1994). Shading devices can be

(i) External (Bellia et al., 2013; Freewan, 2014) such as overhangs (Ebrahimpour and Maerefat, 2011) and vertical fins;
(ii) Internal such as venetian blinds (Lee et al. 1999; Chan and Tzempelikos, 2013), horizontal blinds (Galasiu et al., 2004), louvres (Dutta, 2001; Marrero and Oliveira, 2010) and vertical blinds;
(iii) Tinted coated fixed- opacity windows;
(iv) Switchable transparency windows.

Switchable transparency window has the advantage over movable shading devices of requiring less cleaning and

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Nomenclature

A_w	aperture area of window (m^2)
A	total area of interior surface of test cell (m^2)
DF	daylight factor
DGI	daylight glare index
DGP	daylight glare probability
$E^{in}_{v,neag}$	vertical illuminance near the glazing (lux)
$E^{in}_{V,win}$	SPD glazing illuminance (lux)
$E^{in}_{V,adp}$	adaptation illuminance (lux)
GI	glare index
L_{adp}	adaptation luminance of the surroundings (cd/m^2)
L_{ext}	exterior luminance of the outdoor source (cd/m^2)
L_i	test cell interior horizontal luminance (cd/m^2)
L_o	test cell exterior horizontal luminance (cd/m^2)
L_{win}	SPD glazing luminance (cd/m^2)
M	maintenance factor
n	refractive index
N_g	number of glazing pane layers
R	internal reflectance
t_g	thickness of glazing (m)

Greek symbols

$\tau(\lambda)$	spectral transmittance of the SPD glazing
θ_{DF}	the solid angle from visible sky patch to the viewers
β	angle between plane of the surface and horizontal (deg)
θ	incident angle (deg)
ω_N	apparent solid angle (deg)
Ω_{pN}	solid angle subtended by source (deg)

maintenance. Switchable transparency windows can block both direct and diffuse solar radiation, unlike most passive shading devices and unlike fixed tinted glass, can become transparent during the early morning and afternoon hours to improve natural lighting conditions.

Electrically-actuated switchable windows can be categorized based on the required type of electrical supply. Electrochromic (EC) glazings use a DC supply whereas liquid crystal (LC) and suspended particle device (SPD) use an AC supply.

EC glazings have several disadvantages.

(i) Switching time

Slow switching time of EC glazing is a major drawback of EC. Sky condition changes from 20 to 40 klux within 1–2 s whereas EC glazing changes its color between 1 and 30 min, depends on the size. Switching speed decreases with increased glazing area (Ho, 1999; Lee and DiBartolomeo, 2002; Lee et al., 2006).

(ii) Durability

Durability is an issue with EC glazing. For intermittent cloudy skies, switching is required more often and more than 30–50 k cycles but most of the present available EC material has nearly 1000–5000 cycles.

(iii) Heat absorption

The electrochromic layer rejects heat by absorption, rather than reflection, and so can get quite hot when irradiated. For some devices, switching is not permitted if the maximum design temperature is exceeded (Lee and DiBartolomeo, 2002).

LC glazing has following disadvantages (Lampert, 1998; Papaefthimiou et al., 2006)

(i) LC glazings are hazy because they scatter rather than absorb light, so there is a fog factor even when the device is in the transparent state.
(ii) A LC glazing is either transparent or opaque with no in-between states.

SPD glazing has advantages over EC glazing.

(i) It can be directly connected to the main power supply whereas EC glazing needs inverter to power directly with main supply.
(ii) To maintain "opaque" state no power is required.

SPD glazing also has advantage over LC glazing

(i) In "transparent" state, there is no haze like LC (Papaefthimiou et al., 2006; Ghosh et al., 2015).
(ii) It has intermediate states between "opaque" and "transparent" state (Barrios et al., 2013).

An SPD is composed of suspended particles that become induced dipoles in the presence of an electric field. The active layer has particles of dihydrocinchonidine bisulfite polyiodide suspended in an organic fluid or gel (Barrios et al., 2013; Ghosh et al., 2015) laminated or filled between two electrical conductors. In the presence of electric power, transmission ranges of SPD window can be from 5% to 55% with switching speeds of 100–200 ms (Ghosh et al., 2015). An SPD glazing is shown in Fig. 1.

Daylight and glare data for SPD glazing are required for future architectural applications.

In this study