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Daylight characteristics of a polymer dispersed liquid crystal switchable glazing

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Abstract

The daylighting performance of a polymer dispersed liquid crystal (PDLC) switchable glazing has been evaluated using an unfurnished outdoor south-facing test cell with a glazing-to-wall ratio of 1:9. Useful daylight illuminance levels (UDI) were determined for clear sunny, intermittent cloudy and overcast cloudy days. Daylight glare indexes (DGI_N) was calculated for the PDLC glazing in its transparent and translucent states. An electrically-actuated adaptive PDLC switchable glazing with transparency that varied between 27% and 71% was able to control daylight glare.

Keywords: ~~adaptive~~Adaptive; PDLC; ~~glazing~~Glazing; ~~daylight~~Daylight; UDI; ~~glare~~Glare

1 Introduction

Replacing artificial light with daylight (i) reduces the building energy consumption [1] (ii) enhances visual comfort [2] (iii) prevents or reduces eyes tiredness and fatigue [3] and (iv) achieves natural daylight colour rendering [4,5]. Reducing artificial lighting energy demand in building during the day requires appropriate daylighting design [6–8]. Occupant visual comfort can be maintained via the use of curtains, blinds and adaptive glazings that actively or passively adjust their optical properties [9–11].

Acceptable illuminances for work and study inside a room can vary between 100 and 2000 lx as shown in Table 1 [12].

Table 1 Acceptability of illumination.

alt-text: Table 1

		Acceptability	Activity	Reference
Illuminance level (Lux)	≥ 150	Comfort	Working space	[13]
	500	Comfortable	Office work	[14]
	500	Comfortable	Office work	[15]
	840–2146 (morning)~~ 840–2146 (morning)~~	Comfortable	Office work	[4,5,15]
	782–1278 (afternoon)~~ 782–1278 (afternoon)~~	Comfortable		
	700–1800 ~~ 700–1800~~	Comfortable	Computer work	[16]
	100–2000 ~~ 100–2000~~	Useful Daylight Illuminance	Any types of work	[12]

Switchable glazing includes electrochromic (EC) [17–19], gasochromic [20], thermochromic [21], thermotropic [22,23], liquid crystal (LC) [24], suspended particle device (SPD) [25–28] and phase change materials (PCM) [29]. These glazing can be electrically, thermally, or chemically actuated. Electrical actuation of switchable glazings EC, SPD, and LC gives control of the switchability of glazing [30–34]. EC glazing changes its transparency from transparent to opaque state in the presence of direct current power supply. EC glazing can control NIR [35,36]. Higher switching time of EC glazing can be mitigated using suitable powering [37]. Degraded EC films (both based on W oxide and Ti oxide) can be rejuvenated by galvanostatic treatment [38–40]. Large scale (1.2 ~~m×0.8~~m × 0.8 m and 1.2 ~~m×0.5~~m × 0.5 m) EC device was also investigated using PASSYS test cell [41]. Daylight and glare performance of EC glazing has been evaluated theoretically in a hot climate in a west orientated wall [42–44] and evaluated experimentally performed for computer tasks [45]. Operated by an alternating current power supply, SPD glazing changes its state from opaque to transparent [46]. SPD glazing has a low switching time [47] intermediate transmission states between opaque and transparent state and high stability [48]. However controlling thermal comfort with SPD requires additional coated panes as the near infrared transmission is high [49]. Daylight and glare performance of SPD glazing has been evaluated [50]. In a liquid crystal (LC) glazing, LC films are sandwiched between two glass panes as shown in Fig. 1. Due to the anisotropic electrooptic properties of the LC material, transmitted light through the cell is controllable by applying appropriate voltages [51–54]. Polymer dispersed liquid crystals (PDLC) types are suitable compared to twisted nematic, ferroelectric and guest host type LC as they don't need polarizer to operate [55]. Liquid crystal droplets with diameters in the range of ~~1~~1–20 ~~to 20 μm~~ μm in a polymer matrix form a PDLC. In the presence of an electric field LC droplets are aligned with electric field so allowing light passes through it. In the absence of an electric field LC droplets orient isotropically, scattering incident beam so becoming white translucent.

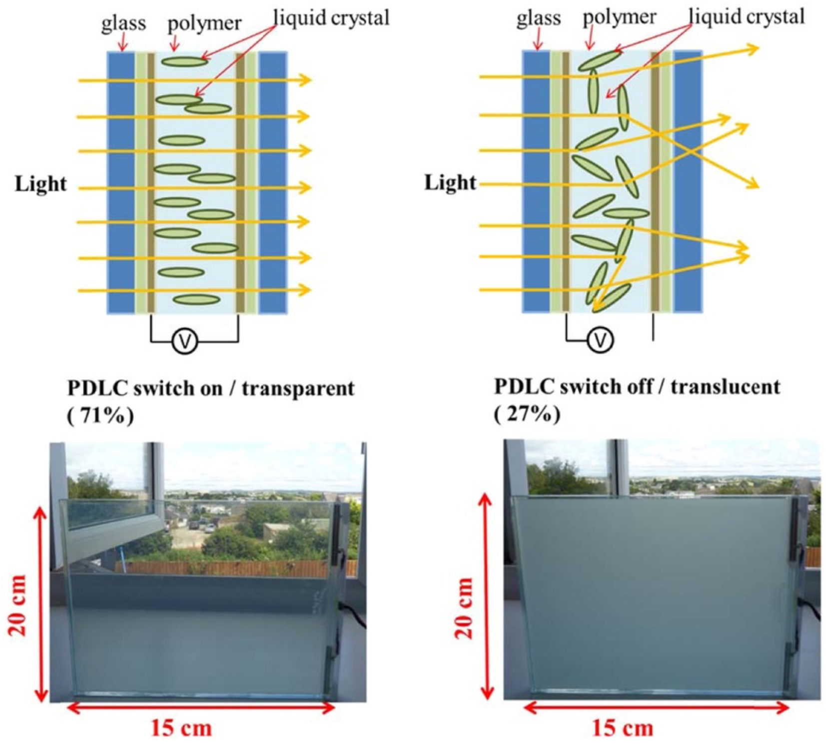

Fig. 1 The "transparent" and "translucent" states of a PDLC glazing. As PDLC glazings are intended for architectural applications, thus PDLC glazing daylight and glare results are essential information for building integrated PDLC switchable glazing. In this work first outdoor characterisation of PDLC glazing using test cell was performed to find out its glare and daylight control potential.

alt-text: Fig. 1

2 Methodology

Daylight glare index (DGI) [56,57] has been used to characterise EC glazing [42,43] and for SPD glazing [50] using data from a test cell. The DGI_N is given by

$$DGI_N = 10\log_{10} 0.478 \sum_{i=1}^{n} \frac{L_{ext}^{1.6}\Omega_{pN}^{0.8}}{L_{adp} + 0.07\omega_N^{0.5} L_{win}} \quad (1)$$

where L_{ext} is the exterior luminance of the outdoor source including direct sunlight, diffuse skylight and reflected light from the ground and other external surfaces (cd/m2), L_{win} is window luminance (cd/m2), L_{adp} is adaptation luminance of the surroundings including reflections from internal surface (cd/m2), ω_N is solid angle subtended by the window, Ω_N is solid angle subtended by the glare source. Schematic diagram showing DGI_N is given in Fig. 2. The luminance level 5 provided by glazing, adaptation and exterior are calculated from Eqs. (2)–(4).

$$L_{win} = \frac{E^{in}_{V,win}}{2\pi\phi} \tag{2}$$

$$L_{adp} = \frac{E^{in}_{V,adpt}}{\pi} \tag{3}$$

$$L_{neag} = \frac{E^{in}_{V,neag}}{2\left(\pi - 1\right)} \tag{4}$$

where

$$L_{ext} = L_{neag}$$

$$\omega_N = \frac{\left[ab\ \cos\left(\tan^{-1}X\right)\cos\left(\tan^{-1}Y\right)\right]}{d^2} \tag{5}$$

$$\Omega_N = 2\pi\phi \tag{6}$$

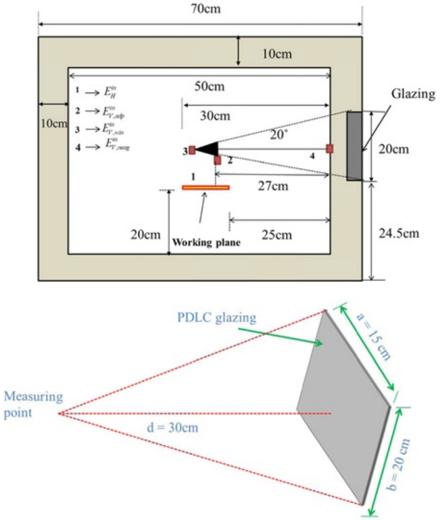

Fig. 2 Experimental set up used to obtain data for the calculation of DGI_N, with configuration factor calculation diagram.

alt-text: Fig. 2

The configuration factor ϕ was calculated from the Eq. (7) using (Fig. 2)

where

$$\phi = \frac{\left(A\tan^{-1}B + C\tan^{-1}D\right)}{\pi} \tag{7}$$

where

$$A = \frac{X}{\left[\sqrt{\left(1+X^2\right)}\right]},\quad B = \frac{Y}{\left[\sqrt{\left(1+X^2\right)}\right]},\quad C = \frac{Y}{\left[\sqrt{\left(1+Y^2\right)}\right]},\quad D = \frac{X}{\left[\sqrt{\left(1+Y^2\right)}\right]}$$

X and Y can be calculated from Eqs. (8) and (9).

$$X = \frac{a}{2d} \quad (8)$$

$$Y = \frac{b}{2d} \quad (9)$$

where

a is the width of PDLC glazing, b is the height of PDLC glazing and d is the perpendicular distance from the observation place of the centre of glazing as shown in Fig. 2.

A PDLC glazing dimension of 0.2 m × 0.15 m was investigated that unpowered becomes translucent and powered become transparent. The PDLC glazing was connected with a 0–200 V variable AC supply. PDLC spectral measurements were performed using a LAMBDA 1050 UV/Vis/NIR Spectrophotometer. Fig. 3 shows the variation of PDLC transmission when “transparent” with 71% average transmittance and “translucent” with 27% average transmittance.

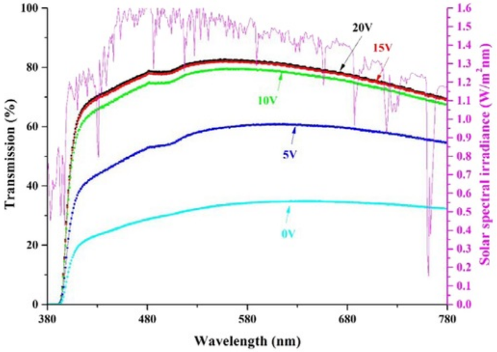

Fig. 3 Voltage dependant luminous transmission of a PDLC glazing in transparent, translucent and intermediate states.

alt-text: Fig. 3

A 0.7 × 0.7 m × 0.7 m test cell with unobstructed solar illuminance whose internal surfaces were painted with 0.8 reflectance matt white paint. The area of glazing on the test cell was in a ratio of 1:9. Six illuminance sensors were used. One on the vertical surface of the outside surface of the test cell and three inside the test cell. Horizontal measurements were made 27 cm distant from the glazing inner surface as shown in Fig. 2. All illuminance sensors had a ~~350~~ 350–820 nm sensitivity spectral range with a spectral response curve adapted to human eye sensitivity [25,26,50]. Data were recorded at 1 min intervals. Outdoor experimental test cell characterisations were performed as functions of time, different types of day (clear, intermittent cloudy, overcast cloudy), and test-cell orientation (south) for two switching states ‘transparent’ and ‘translucent’. Horizontal illuminances on a work plane inside the test cell and daylight glare index (DGI) were investigated using PDLC glazing transparent/switch on and translucent/ switch off conditions in the Dublin climate ~~(53.3478~~(53.3478°N latitude) for three days with different prevailing weather conditions.

3 Results and discussions

Internal illuminance into the test cell for PDLC glazing and exterior illuminance for clear sunny, intermittent cloudy and overcast cloudy days for Dublin are shown in Fig. 4. PDLC translucent perfectly achieved UDI level throughout the intermittent cloudy day. Due to higher diffuse transmission of PDLC translucent always offered higher UDI level.

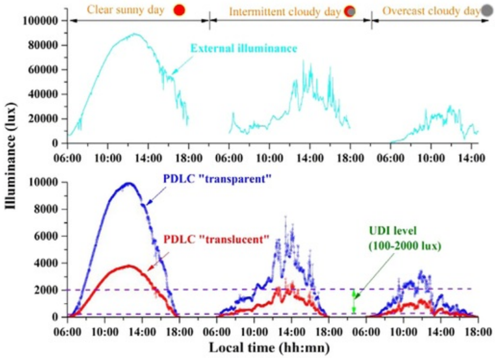

Fig. 4 External illuminance and internal illuminance for south facing PDLC transparent and translucent states for clear sunny, intermittent cloudy and overcast cloudy day in Dublin.

alt-text: Fig. 4

Figs. 5–7 show the daylight glare index (DGI_N) of PDLC glazing for its transparent and translucent state for clear sunny, intermittent cloudy and overcast cloudy sky conditions.

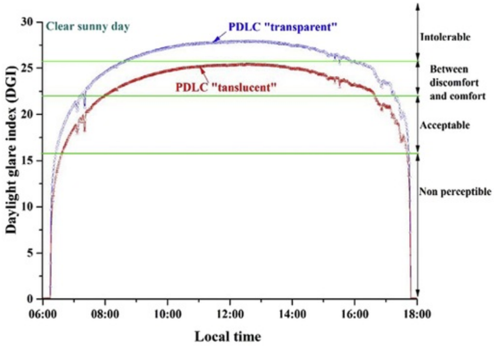

Fig. 5 DGI of PDLC glazing transparent and translucent states for a sunny day in Dublin.

alt-text: Fig. 5

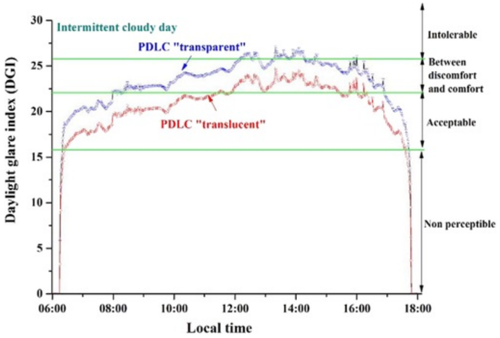

Fig. 6 DGI of PDLC glazing transparent and translucent states for an intermittent cloudy day in Dublin.

alt-text: Fig. 6

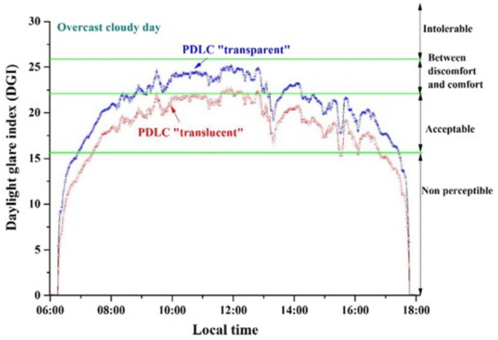

Fig. 7 DGI of PDLC glazing transparent and translucent states for an overcast cloudy day in Dublin.

alt-text: Fig. 7

The DGI represent the discomfort glare of occupant. DGI_N is the best method to evaluate as it deals with direct sunlight and vertical illuminance. In the equation L_{ext} was measured using illuminance sensor and shown in Fig. 4~~.The~~. The DGI of PDLC glazing in its transparent and translucent states was calculated using Eq. (1). The solid angles subtended by the glare source (Ω_N) and by the glazing (ω_N) were 0.057, 0.03 Sr and 0.35 Sr respectively.

For clear sunny day translucent PLDC always provided DGI level below the intolerable limit. For intermittent and overcast cloudy day translucent PDLC usually provided acceptable DGI level. PDLC glazing in its translucent state possess ~~83%~~ haze which offer high diffuse light and increase the transmission in the switched off state ~~[58].~~Due to low contrast ratio (contrast ratio=transmission ratio between PDLC transparent and translucent) of this PDLC glazing variation of DGI level is less between two states. For a clear sunny day PDLC transparent was above the discomfort level where as translucent was above the comfort level. For intermittent day PDLC translucent was able to provide glare control from morning to mid-day and afternoon period. PDLC translucent was completely capable to control glare on an overcast cloudy day where as transparent state offered discomfort for short time span.

4 Conclusion

First outdoor daylighting characterisation using PDLC glazing was investigated using small scale test cell. Useful daylight illuminance (UDI) of a PDLC switchable glazing in “transparent” and “translucent” states has been measured using test cell for clear sunny, intermittent cloudy and overcast cloudy skies. It was found that PDLC “translucent” condition achieved the UDI level under intermittent and overcast cloudy day. Daylight glare index (DGI) was calculated for clear sunny, intermittent cloudy and overcast cloudy day. For clear sunny day PDLC glazing was not able to offer comfortable glare. However for intermittent and overcast cloudy day PDLC glazing's performance was impressive. Higher diffuse transmission on translucent state helped PDLC to offer higher transmission. This is suitable for building façade application where daylight penetration get higher priority than viewing. For self-powered (PV) PDLC application, excess power generated from PV can be stored during day time and stored power will be utilised in the night or cloudy day to make glazing transparent.

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Highlights

- Daylight indices and factors have been calculated for a PDLC glazing “translucent” and “transparent” states.
- Voltage ~~dependent~~dependant transmission of a PDLC glazing is reported.

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Answer: All are correct

Query:

Highlights should consist of 3 – 5 bullet points. There are less bullet points provided. Please edit the highlights to meet the requirement.

Answer: Experiment was performed using outdoor test cell

Query:

Please complete and update the reference given here (preferably with a DOI if the publication data are not known): Ref. [58]. For references to articles that are to be included in the same (special) issue, please add the words ‘this issue’ wherever this occurs in the list and, if appropriate, in the text.

Answer: please delete this