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Evaluation of colour properties due to switching behaviour of a PDLC glazing for adaptive building integration

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ABSTRACT

In this study, intermediate transmissions, colour-rendering index (CRI) and correlated colour temperature (CCT) of an electrically actuated, switchable polymer dispersed liquid crystal (PDLC) glazing have been investigated. This 0.03 m^2 PDLC glazing changes its state from translucent to transparent in the presence of a 20 V AC power supply. Modulation of visible and NIR transmissions were observed for different applied voltages and no modulation was found in the UV range. For this particular type PDLC glazing, the CCT and CRI varied between 5430 K and 6100 K and 93 to 98, while luminous transmittance varied from 0.27 to 0.71 respectively. Low contrast ratio between the translucent and transparent states of this PDLC glazing offered a strong linear correlation between CCT and CRI.

1. Introduction

Buildings consume 40% of the global energy for heating, cooling and lighting energy demand. This high demand is also a root cause of high CO_2 emissions. In the UK, if residential houses and buildings reduce one third of their existing energy demand, then a 60% CO_2 reduction is possible by 2050 [1].

To achieve sustainable environment and society, energy efficient buildings are essential. Compared to the rest of the building envelope, fenestrations get higher attention as it is multi-functional allowing incoming daylight into the building's indoor space as well as offering visual amenity, privacy, solar heat gain, heat loss, and control of light and air [2,3]. Single and double glazing are the most widely available fenestration technology for building window applications [4,5]. To mitigate glare issues due to excessive daylight, shading devices are often used [6]. However, these have limitations due to cleaning and maintenance. Advanced smart glazing is a preferable replacement to single or double glazing as it possesses higher energy efficiency and is also aesthetically suitable [7,8]. These smart glazing systems include non-switchable types (static or constant transparency) such as aerogel [9], vacuum [10–12], and photovoltaic [13] and switchable types, which include thermally actuated phase-change materials [14], thermochromic [15], thermotropic [16], hydrogen actuated gasochromic [17], electrically actuated electrochromic (EC) [18,19], liquid crystal (LC) [20] and suspended particle devices (SPD) [21,22]. Except constant transparency vacuum (evacuated) glazing [12], other aforementioned non-switchable and switchable glazing systems have the potential to allow comfortable daylight and glare control for indoor spaces.

In general, buildings experience dynamic weather throughout both the year and the course of a day. Diurnal variation of ambient temperature and solar radiation causes changes to the indoor temperature and light levels [23]. Alleviation of these changes by using constant transparency smart glazing is not feasible. For buildings, adaptive glazing is required so that transparency can be altered in response to the internal environment and transient external conditions [23]. Thus, smart switchable glazing systems are gaining priority over non-switchable glazing.

Switchable glazing offers more than one transparency level and intermediate transmission states are possible. However, controlling of the intermediate transmission states of non-electrically switchable glazing requires complex processes. Thus, electrically actuated glazing can be more attractive than non-electrically actuated switchable glazing as they offer easily accessible user control.

EC glazing systems are activated by low (0–5 V) DC power supply [24,25]. It consumes power to become coloured and becomes opaque both in the absence of and in reversing the power supply. Direct coupling with photovoltaic (PV) devices is possible as EC glazing systems are actuated by direct current (DC) supplies and PV generates DC power [26–29]. In addition with vacuum glazing, it offers switchable-low heat-loss glazing [30–34]. Control of the NIR solar spectrum [35,36] and intermediate transmission [37,38]

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also makes it a viable glazing material for low-energy building applications. Low-cost manufacturing [18,39,40], large durability [41], large-scale (higher than 1 m^2) application [42], low-voltage requirement at higher-surface temperature [43,44] are all added advantages of EC glazing. However, EC glazing needs power converter to connect with mains supply.

SPD glazing is made using dihydrocinchonidine bisulfite polyiodide or herapathite-type particles suspended in a plastic film [45]. In the presence of a high, 100–110 V AC power supply, this SPD glazing becomes transparent. Absence of a power supply renders this glazing opaque [46]. SPD glazing integration needs an inverter to connect it with a PV [47]. The high contrast ratio between the opaque and transparent states [48], high durability [45], simpler connection with household mains [46] and low heat-loss switchable potential makes this glazing a potential candidate [23,49] for low-energy building applications. SPD glazing has a high NIR transmission [22], high-cost and high-voltage requirement to operate.

In liquid crystal (LC) glazing, LC films are sandwiched between two glass panes. The LC materials can be twisted nematic, ferroelectric, guest host, and polymer dispersed liquid crystal (PDLC) types [50–53]. Since they do not require polarizers to operate, PDLCs are the most suited for glazing applications [54]. For PDLC type glazing, micron sized liquid crystal droplets are contained in a polymer matrix. In the presence of an AC power supply, particle orientation becomes aligned, parallel to the applied electric field and they admit light [20]. In the absence of a power supply, the LC particles scatter the light as shown in Fig. 1. The power supply required to make PDLC glazing transparent depends on LC particle size, shape, dielectric and conductive anisotropy, molecular weight and chemical nature of the polymer and anchoring effects at the polymer boundary [50,51,55].

PDLC glazing having reverse mode operation transparent OFF state and opaque ON state, was also investigated [51]. Daylight characterisation using PDLC glazing was investigated using outdoor test cell for Dublin weather condition was investigated [20]. This particular type of PDLC glazing had 71% transmission in the transparent state 27% transmission in the translucent state. Presence of high 82% haze of this PDLC glazing allowed higher daylight transmission in the translucent state [56]. However, for clear sunny day, this PDLC glazing was not able to control glare. For intermittent cloudy and overcast cloudy day PDLC glazing performance was acceptable to control glare. To generate haze free and low driving voltage PDLC glazing, polymer was replaced by glass material. This type of LC glazing was introduced as glass dispersed liquid crystal (GDLC). One 5 × 5 cm2 GDLC device was fabricated which offered 10 times lower switching time, 85% low voltage (15 V) was required to achieve 80% transmission compared to similar type PDLC [57].

Daylight is classified as solar irradiance with a spectral power distribution in the visible range (380–780 nm), which depends on time of day, season, latitude, weather, dust and pollutants. Filtered daylight into an indoor space due to a PDLC window can affect the color rendering of interior objects. As PDLC glazing is potentially considered for adaptive, low-energy building envelopes, it should not distort the daylight spectrum significantly. Thus, investigation is required before marketing this glazing for building integration. Correlated color temperature (CCT) and colour rendering index (CRI) are the colour properties which quantify the quality of daylight [58].

In this work, intermediate transparency levels for 0.03 m^2 of PDLC glazing in the solar, visible and UV range were investigated. Solar factors for different solar transmission levels were calculated. Colour properties (CCT and CRI) of this PDLC glazing for its different visible (luminous) transmission states were also calculated to find out its suitability for adaptive building window integration. CCT and CRI results were also compared with those of an SPD glazing, vacuum glazing and air-filled double-glazing. Building engineers and architects can use these results to design an aesthetic, adaptive-low-energy building with PDLC glazing or façade.

2. Methodology

Building occupants spend a considerable amount of time at indoor workplaces and at home. However, they prefer daylight than artificial light in an indoor environment. Daylight has been shown to increase productivity at work, improve well-being and offer protection from health issues [59]. Thus, it is desirable, particularly for temperate and higher latitude countries that windows should have good-quality view and allow natural daylight to enter providing the primary source of light for more healthy indoor space environment. The quality and quantity of daylight should be controlled to ensure the physical and mental well-being of building occupants [59].

The transmitted daylight properties of a glazing are characterized by a correlated colour temperature (CCT) and colour-rendering index (CRI). The CCT of the sky varies mostly between 6000 K (overcast sky) and 10,000 K (light blue sky) [60]. The color temperature of dark blue sky can be higher than 20,000 K. A CCT needs to be equivalent to that of a blackbody source at temperatures between 3000 and 7500 K. CRI values of 90 or higher are considered acceptable whereas close to 100 indicates an excellent visual quality [61,62]. Good color rendering indicates no significant perceived color difference between objects illuminated by daylight and by the same illuminant transmitted through a glazing [63–65].

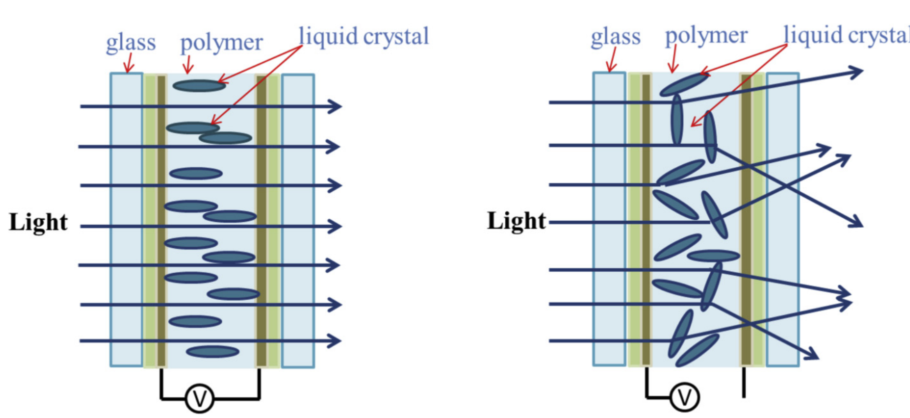

Fig. 1. Schematic presentation of PDLC glazing for switched-on transparent state and switched-off translucent state.