Thermal Performance Analysis of BIPV-PDLC Window

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Abstract

Electrically activated switchable glazing is potential to control excessive entering solar heat gain to an indoor space by altering its state from transparent to opaque or translucent. Electrically operated polymer dispersed liquid crystal (PDLC) glazing become transparent in the presence of power supply and become translucent without power supply. Addition of photovoltaic (PV) with PDLC will ease the external power supply and turn it into a self-sufficient autonomous switchable glazing. In this work, first thermal performance of BIPV – PDLC was conducted using indoor characterization. This combined 0.063 m^2 BIPV-PDLC glazing had a transmission of 46.5% in the transparent state and 31.5% in the translucent /opaque state. In the PDLC-OFF state, maximum PV cell temperature was 86.2°C which was 8% higher than PDLC-ON state condition.

Keywords: PDLC, PV, glazing, temperature, transmission, BIPV

1. Introduction

Building sector emits 39% carbon dioxide due to the consumption of 36% total global energy. Thus, to obtain less energy-hungry building, lowering the building energy consumption by using energy efficient building envelope is paramount. In a building through transparent façade, solar gain penetrates which enhances the building's cooling energy load demand. Solar gain is a key factor for buildings' which is the addition of penetrated direct and diffuse solar energy and associated with the reflected component of solar energy (Ghosh and Norton, 2018). Control of solar gain is feasible by using solar control window which includes power generating building-integrated (BI) photovoltaic (PV) (BIPV) window, thermally activated thermochromic, thermotropic window, electrically activated electrochromic (EC), suspended particle device (SPD) and polymer dispersed liquid crystal (PDLC) type windows (Ghosh and Norton, 2018). BIPV window has the potential to control solar gain by blocking the incoming solar energy, and it also controls daylight and generates benevolent electricity. In a BIPV window, PV devices include (Nayak et al., 2019) opaque crystalline silicon (Peng et al., 2019), thin-film semi-transparent amorphous silicon, cadmium telluride (Sun et al., 2018) and copper indium gallium selenide, semitransparent emerging dye-sensitized (Cornaro et al., 2018; Lee and Yoon, 2018), perovskite (Snaith, 2018), organic (Chemisana et al., 2019; Chen et al., 2012), and quantum dot (Zhang et al., 2018) types. However due to mature stability, and higher efficiency (Green et al., 2019), commercially available silicon still dominates the BIPV market. Crystalline silicon-based BIPV-window needs spaced type arrangement to enable visibility (Park et al., 2010). To render lower heat loss from solar control BIPV, vacuum glazing can be included (Ghosh et al., 2018b). Static transparent BIPV window can be replaced by a switchable type window because of their tunable transmission property, which can vary in response to the diurnal nature of the environment.

Electrically activated windows have positive attributes over the thermally activated window' of being operated based on occupant's demand criterion. PDLC glazing specifically has an advantage over EC and SPD due to the presence of scattering property which allows daylight but blocks the viewing (Ghosh et al., 2018a). PDLC is superior for glazing application compared to conventional super twist cells, twisted nematic, π-cell LC as it does not require polarizers to operate. At high-temperature polarizer often peel off or degrades. Absence of polarizer reduces the power loss (polarisers absorb ~ 50% incident light in LC cells) which increase the device efficiency. PDLC glazing consists of tiny liquid crystal (LC) droplets which are embedded in a polymer. In the presence of alternating current (AC) power supply, LC droplets orients in an orderly way and refractive index of particles and polymer matches which allows light to pass through and this become clear. In the absence of power supply, particle orients randomly and mismatch of refractive index between particle and polymer scatters light which makes PDLC translucent (Hu et al., 2018) as shown in Figure 1. At a clear state, PDLC allows solar heat gain, daylight whereas at the translucent state, PDLC blocks solar heat gain, viewing and allows diffuse daylight (Hakemi, 2017). Infrared control (Khandelwal et al., 2016), daylighting (Ghosh et al.,

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2018a), stability, and reverse mode operation (Cupelli et al., 2009) of PDLC was investigated in past. To reduce the accentuated haze created in PDLC under direct solar radiation, new glass dispersed LC was developed (Jung et al., 2017).

Switchable glazing needs external power to operate which can be diminished by using PV. PV powered switchable glazing includes side by side or tandem structure. Side by side structure reduces the chances of lowering the overall transmission of the system where PV can be included in building in the form of building integrated (BI) or building attached (BA) types. Previously switchable glazing powered by PV was investigated with EC where the structure was tandem (Cannavale et al., 2015; Shen et al., 2019) and side by side. AC powered switchable SPD glazing was powered in a real temperate climate where a 40 Wp PV device continuously powered a 0.07 W SPD glazing (Ghosh et al., 2016). Power conversion is critical for AC powered switchable glazing powered by PV.

In this work for the first time spaced type crystalline PV and PDLC combination was investigated. Thermal performance of this combined system was evaluated using an indoor test cell set up.

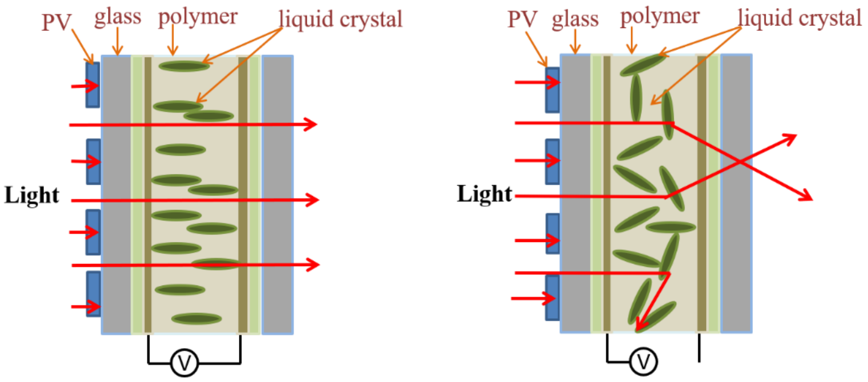


Fig. 1: Schematic of BIPV-PDLC glazing.

2. Experiment

Investigated BIPV-PDLC glazing had a dimension of 0.3 m × 0.21 m × 0.1 m which become transparent in the presence of 20 V AC and become translucent without power supply. Six polycrystalline PV cells, each had a dimension of 5.2 cm × 5.2 cm was placed on the top of the PDLC and electrically connected where three cells were in series and two parallel strings. After placing the PV cells, sylguard was poured and another single glazing (0.04 m) was placed on the system. Presence of PV covered 40% of exposed PDLC area. A small-scale test cell dimension of 0.37 m×0.22 m×0.26 m was fabricated using 10 mm thick polystyrene to perform indoor characterisation. The ratio of glazing and test cell was 1:3. The indoor characterisation was performed using continuous indoor sun simulator exposure. This simulator was AAA type and its spectrum matched with solar spectrum between 250 nm and 3000 nm. Five thermocouples were employed to measure external and internal glass surface, test cell ambient and indoor laboratory ambient and PV cell temperature. Temperature data of 5 min interval was recorded using Pico data logger. Photograph of full experimental set up is shown in Figure 2 and the location of the thermocouple is shown in Figure 3. Spectral performance of investigated BIPV-PDLC glazing was characterized by using Perkin Elmer® Lambda 1050 UV/vis/NIR.

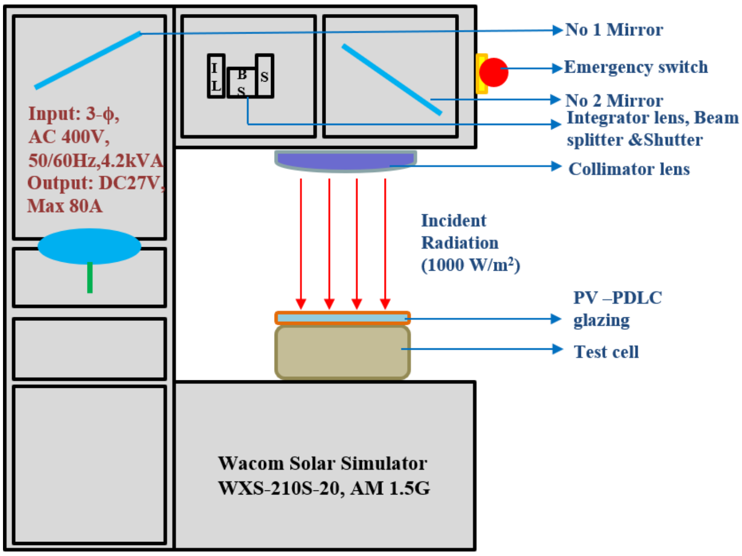
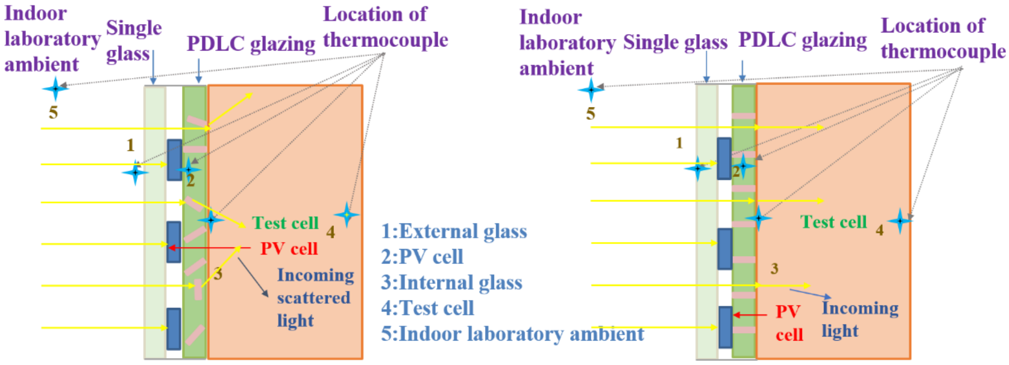


Fig. 2: Schematic of experimental set up for thermal performance.



BIPV -PDLC (OFF state) window

(a)

BIPV-PDLC (ON state) window

(b)

Fig. 3: Location of thermocouple for (a) BIPV-PDLC OFF state, (b) BIPV-PDLC ON state using test cell

3. Result and discussion

Figure 4 shows the transmission through the PDLC glazing. Average solar transmission (300 nm-2500 nm) of this system was 62% and 42% for transparent (ON) and translucent (OFF) state respectively. Contrast ratio (transmission in the translucent state: transmission in the transparent state) was close to 1:1.5. Variation was low due to high scattering behavior of PDLC glazing. Reflection was 18% and 17% for PDLC switched OFF and switched ON state. Due to absorption it is evident that this PDLC glazing offered only forward scattering which reduced the possibility of multiple scattering options. Six spaced type polycrystalline silicon PV covered a total area of 162.24 cm^2 ($5.2\times5.2\times6=162.24\ cm^2$) whereas glass pane had an area of ($30.5 \times 21=640.5\ cm^2$) 640 cm^2. Thus, 25% area was covered by these six PV cells. Due to this spaced type semitransparent BIPV, working transmission for BIPV-PDLC for the transparent state was 46.5% and translucent state was 31.5%.

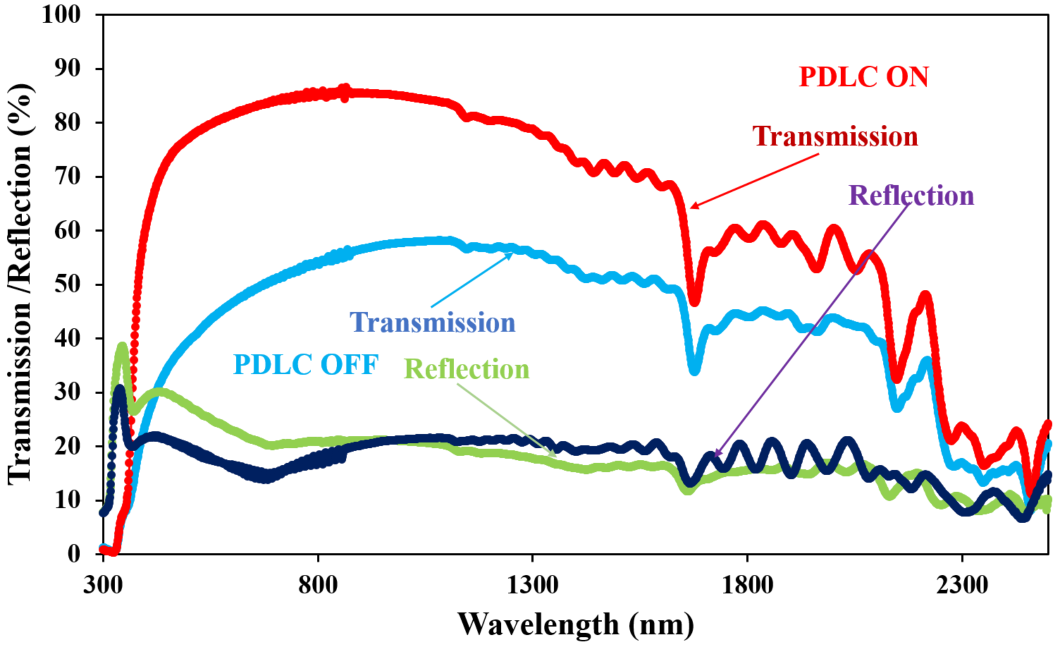


Fig. 4: Hemispherical total (direct+diffuse) transmission and reflection PDLC glazing for switched ON transparent and switched OFF translucent state.

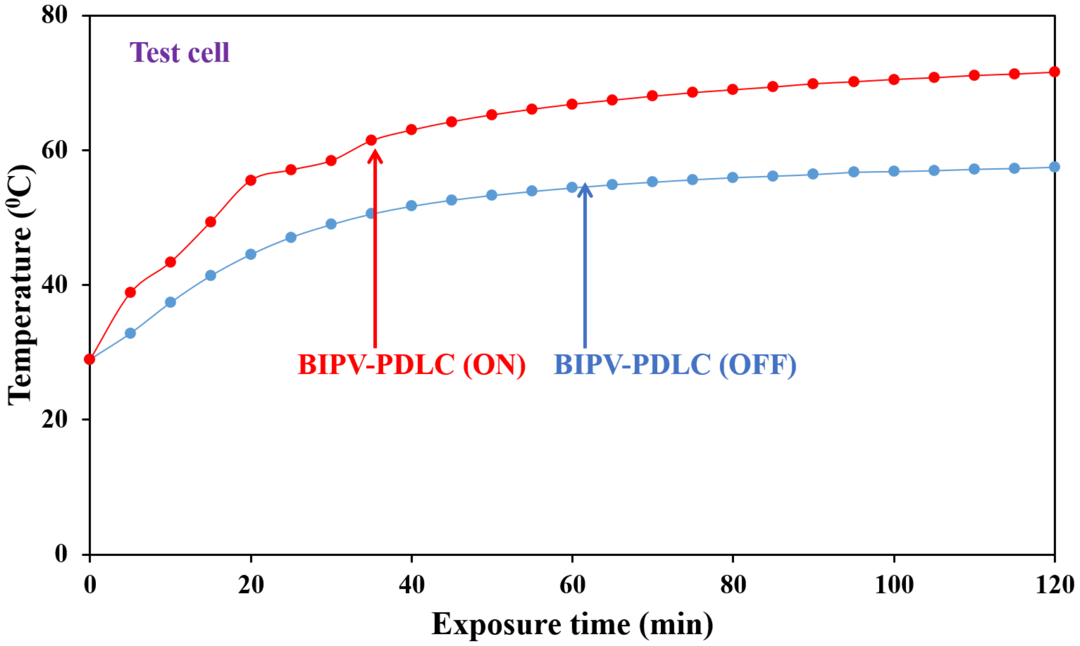


Fig. 5: Test cell temperature of BIPV-PDLC for ON (transparent) and OFF (translucent) state

Figure 5 shows the test cell indoor temperature for BIPV-PDLC combined system while PDLC was ON and OFF states. For combined system, PDLC ON state condition, test cell temperature showed 19% higher indoor temperature after 120 minutes continuous exposure from an indoor simulator. Presence of electrical actuation liquid crystal particle’s orientation was organized which allowed higher order incoming light intensity. Without power supply, particles orientation was random and incoming light was mostly scattered in nature which restricted to pass through an equal amount of incoming light compared to ON state. Thus, PDLC ON state exhibited higher indoor temperature, however, the difference was less as PDLC regulates the transmission by scattering not by reflecting or absorbing the light. Figure 6 shows the enhancement of PV cell temperature under the exposure of indoor simulator for 120 minutes. It was found that PV cell temperature was 8% higher in the PDLC OFF state. Variation of PV cell temperature for BIPV-PDLC ON state was 32°C to 79°C whilst for BIPV-PDLC OFF state it was 26°C to 86.2°C. PDLC OFF state condition blocks light to pass through, however it absorbs higher heat which has a contribution to the enhancement of PV cell temperature.

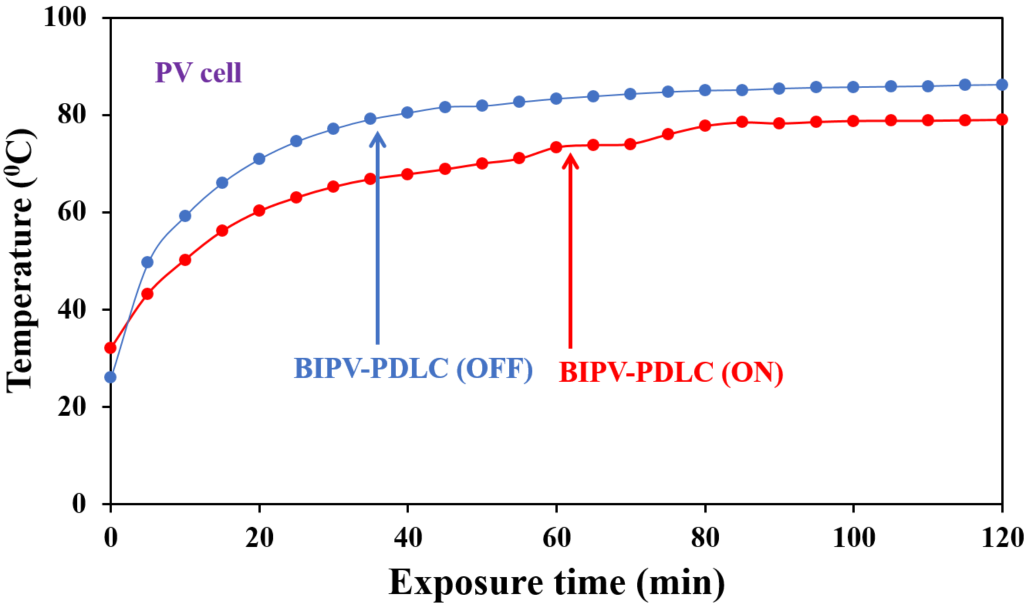


Fig. 6: PV cell temperature of BIPV-PDLC for ON (transparent) and OFF (translucent) state

4. Conclusions

In this work for the first time, combined BIPV-PDLC glazing’s thermal behavior was conducted using indoor characterization. Inclusion of photovoltaic (PV) in a building replaces the building construction material usage and cost, generates electricity, controls light and heat. Electrically activated switchable polymer dispersed liquid crystal (PDLC) in the presence of power supply become transparent and allow viewing and in the absence of power supply becomes a haze. Six polycrystalline PV cells were connected electrically maintaining sufficient gap between two cells to fabricate spaced type semitransparent BIPV. Each cell had a dimension of 5.2 cm × 5.2 cm. PDLC film was sandwiched between two glass panes. In this work, the total employed glass panes for combined BIPV-PDLC system was three. The spectral measurement showed BIPV–PDLC had 46.6% and 31.5% transmission in ON and OFF state respectively. PV cell temperature was 8% lower in the PDLC ON state than PDLC OFF state condition. In the future, glazing factors, overall heat loss and power requirement of this combined glazing to switch will be investigated.

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