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Durability of Switching Behaviour After Outdoor Exposure for a Suspended Particle Device Switchable Glazing

Aritra Ghosh
University of Exeter

Brian Norton
Technological University Dublin, brian.norton@tudublin.ie

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Durability of switching behaviour after outdoor exposure for a suspended particle device switchable glazing

Aritra Ghosh*

aritra.ghosh@mydit.ie

aritraghosh_9@yahoo.co.in

Brian Norton

Dublin Energy Lab, Dublin Institute of ~~Technology~~Technology, ~~Dublin~~Dublin, Ireland

*Corresponding author.

Abstract

Adaptive suspended particle device (SPD) switchable glazing is promising for low energy building application. SPD glazing allows light passes through it in the presence of applied voltage and block light in the absence of power supply. In this work SPD glazing performance after 3 years of outdoor exposure was evaluated. It was found that contrast ratio of SPD glazing before and after exposures changed from 1:11 to 1:10. SPD glazing surface temperature for any transparency level varies between ~~13-40°C~~ 13 and 40 °C under indoor and outdoor thermal exposure. SPD glazing's surface temperature variation occurs due to the incident radiation level, not for the transmission level of glazing. Voltage and power requirement of SPD glazing did not vary at elevated glazing surface temperature.

Keywords: ~~adaptive~~Adaptive glazing; ~~glazing~~Glazing; SPD; ~~temperature~~Temperature; ~~durability~~Durability; ~~voltage~~Voltage

1 Introduction

Admitted solar radiation through a glazing of a building enhances the temperature swing, which introduce thermal discomfort in summer and thermal comfort in winter. Thus, solar gain has positive effect in winter and reduces heating energy demand; on the other hand, it induces cooling load demand in summer. Glazing of a building also plays an important role for visual performance. Widely available glazings are double pane and single pane. Constant transparency single and double-glazing does not perform satisfactory to reduce building energy demand and thermal comfort [1] as admitted solar radiation is diurnal in nature. Due to sun position variation throughout the year, a vertical plane glazing often experiences variable transmittance of solar spectrum.

Thus glazing having more than one transmittance is beneficial for building application. Switchable glazings offer more than one optical transmittance enabling the glazing to adapt to different solar heat gain conditions [2–9].

Switchable adaptive glazings include electrochromic (EC) [10–13], liquid crystal (LC) [14,15], suspended particle device (SPD) [16,17], thermochromic [18,19], gasochromic [20,21], ~~thermtropic~~thermotropic [22,23], phase change material (PCM) [24–27] types. Thermochromic, thermotropic, gasochromic and PCM are non-electrically actuated glazing whilst EC, LC and SPD are electrically actuated glazing. These glazing act differently in their transparent and opaque state to control the transmitted solar radiation. Thermochromic material at higher temperature reflects infra-red (IR) solar radiation and absorbs ultraviolet (UV) during its transition from transparent to opaque state [18,19]. Thermotropic material at low temperature becomes “transparent” and above switching temperature, both transmitted and reflected lights are scattered and makes it “opaque” [22,23]. Solid PCM material inside PCM glazing, absorbs IR, become liquid, and passes visible solar radiation [27]. Electrically actuated glazing in contrast with non-electrically actuated can be controlled based on occupant criteria.

Electrically actuated EC glazing absorbs IR spectrum of solar radiation [28]. In addition, at higher glazing surface temperature this glazing requires less power to switch [29,30]. LC glazing at opaque state scatters the light, become haze, and provides no control of NIR [31]. SPD glazing can control only the visible solar spectrum and transmit IR spectrum [32].

EC glazing is the most investigated glazing device among all other electrically actuated glazing. However EC glazing can suffer from (i) its low durability (sensitive to UV) [33], (ii) high increased surface temperature, (iii) slow colouration process; and (iv) non uniform colouration process for large-scale glazing application [34–37]. Thus for building application SPD glazing can be considered potential over EC and LC glazing.

Suspended particle device (SPD) technology was patented by Dr Edwin Land in 1934 [38,39]. Dihydrocinchonidine bisulfite polyiodide or ~~heraphathite~~herapathite particles can be needle-shaped, rod-shaped, or lath-shaped. In the absence of an applied electrical field, the particles move randomly in a liquid suspension due to Brownian movement. In this state, light passing into the cell is rejected, transmitted or absorbed depending upon the cell structure, the nature of particles, concentration of the particles and the energy content of the light [40]. The presence of an electric field causes the particles become aligned so that most of the light can pass through the cell [41]. For glazing applications, plastic films rather than a liquid suspension are used. Plastic film avoids a liquid bulging effect due to hydrostatic pressure and leaking from the device. In a plastic film, the fewer number of particles do not noticeably agglomerate when the film is repeatedly activated with a voltage [42,43]. In current practical device, rotating particles are trapped inside a dual layer of plastic film as shown in Fig. 1. Presence of conducting layer makes it to behave like parallel plate capacitor.

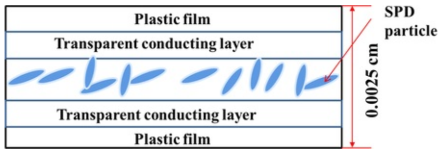

Fig. 1 Cross section of a SPD film manufactured by Research Frontiers.

alt-text: Fig. 1

The thermal [44], daylighting [45] and electrical [46] performance of a commercial SPD glazing as shown in Fig. 2 have been characterised using outdoor test cell. This 0.034 m^2 SPD glazing offered a contrast ratio (ratio of minimum and maximum transmittance) of 1:11 for opaque and transparent state [44]. SPD glazing offers switchable single glazing behaviour as it possess high over all heat transfer 5.9 W/m^2 K [44] while solar heat gain coefficient change from 0.05 to 0.38 [47]. A low heat loss SPD glazing was also examined using SPD and vacuum glazing together [48]. This system offered 72% improvement of overall heat losses compared to SPD glazing [48]. It was also reported that SPD glazing can be supplied by a PV device though appropriate inverter is required [46]. SPD glazing showed an impressive glare control and useful daylight illuminance control [45]. All these results make SPD glazing a viable device for use in commercial or residential building.

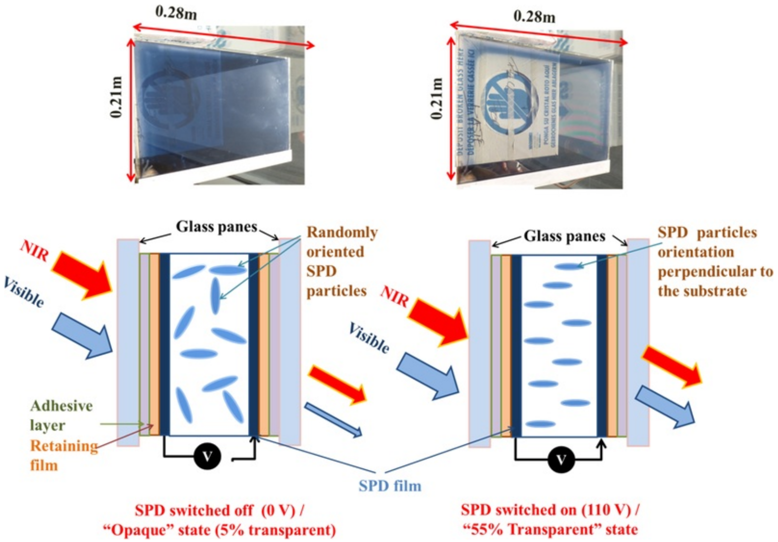

Fig. 2 Photographic view and details of SPD glazing in opaque and transparent state.

alt-text: Fig. 2

However, for building application durability data of SPD glazing is essential. For switchable glazing the durability of the switching speed, power requirement and transmittances are important. Till now no experiment has been reported about the long term switching durability of SPD glazing.

In this work two particular aspects has been investigated

(1) SPD glazing performance after long term outdoor exposure over 3 years;

(2) For switching SPD glazing voltage and power requirement at elevated temperature.

2 Methodology and experiment

Adaptive switchable SPD glazing can be a viable component for low energy building if it survives nearly 20 years without degradation of its performance. A glazing is a suitable building application component if it sustain against solar radiation exposure, operating temperature range, thermal shock, humidity, air, rain and pollutants [34]. Performance of a glazing in a building degrades due to the direct exposure of this material under solar radiation specially the UV portion of spectrum has negative impact on glazing longevity. Solar energy distribution for various wavelengths is shown in Fig. 3.

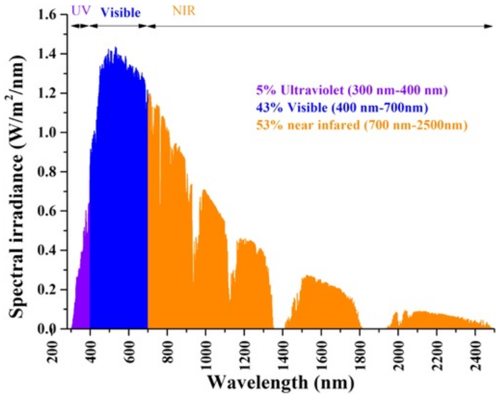

Fig. 3 Solar energy distribution.

alt-text: Fig. 3

To find out the durability/ degradation durability/degradation of SPD glazing and voltage requirement at elevated temperature two different experiments were performed. To find out degradation of SPD glazing, it was exposed extreme outdoor condition in Dublin (53.3°N, 6.2 6.2°W) climate from Jan 2013 to April 2016. From Jan 2012 to Dec 2012 it was used for indoor performance and kept only in indoor lab. Details of SPD glazing mounting on the roof of DIT Kevin Street using test cell has been reported before [44–49]. During this full period SPD glazing came across different types of weather. SPD glazing transmittance was measured before and after outdoor exposures.

The SPD switching voltage variation with temperature was investigated using indoor condition as shown in Fig. 4. SPD glazing was powered at 60 V and exposed under indoor simulator at constant 1000 W/m^2 radiation for 7 hours. h. Indoor simulator was Griven INSE 1200 MSR metal halide lamp. An avaSpec-ULS2048 spectrometer was employed to measure transmission of SPD glazing before and after thermal exposure. SPD glazing surface temperature was measured using K type thermocouple. Thermocouples were attached in the centre of SPD glazing facing simulator, surface of SPD glazing facing integrating sphere, corner of the SPD glazing facing simulator and ambient room temperature. For understanding SPD glazing before outdoor exposure can be expressed as SPDb and after exposure, it is SPDa.

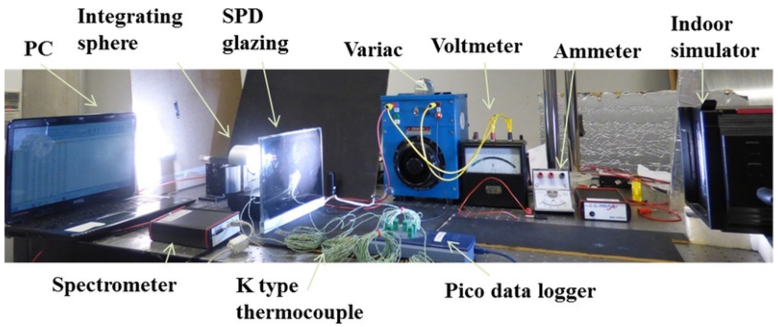

Fig. 4 Indoor experiment arrangement to determine SPD glazing voltage-transmission dependency at elevated temperature.

alt-text: Fig. 4

3 Results and discussions

3.1 Outdoor exposure of SPD

In Dublin, annual horizontal plane total global solar radiation was 3677.85, 3502.12, 3490.24 MJ/m^2 for year of 2013, 2014 and 2015 respectively as shown in Fig. 5. It reveals 9-fold differences between average solar radiation in the summer and winter at Dublin latitude. This result is very similar to the result reported by Gill ~~et.al.~~ et al. [50]. For Dublin maritime climate, most common types of days are generally clear sunny day, intermittent cloudy day and overcast cloudy day [44–49,51]. Fig. 6 shows that SPD glazing surface temperature increment varies between 40 ~~to 13°C~~and 13 °C for varieties of different days and its states. From solar energy distribution 5% solar energy remain in UV spectrum ~~(300~~ (300–400 nm) thus 183.8, 175.1 and 174.5 MJ/m^2 UV per year were exposed on SPD glazing. For 3 years of time this SPD glazing suffered from total 533.5 MJ/m^2 UV radiation.

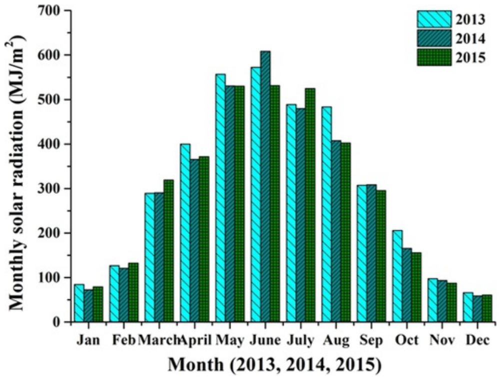

Fig. 5 Monthly average solar radiation for 2013, 2014, 2015 at Dublin, Ireland.

alt-text: Fig. 5

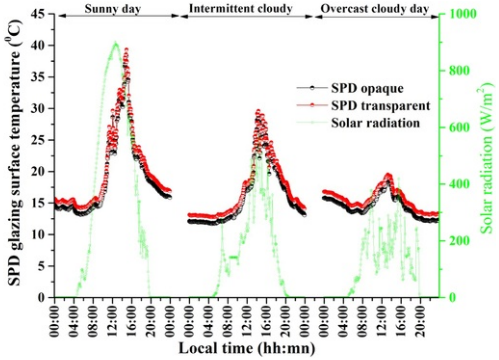

Fig. 6 SPD glazing surface temperature for typical Dublin sunny, intermittent cloudy and an overcast cloudy day for it opaque and transparent state.

alt-text: Fig. 6

SPD glazing transmission was measured before (denoted SPDb) and after (SPDa) outdoor exposure. Solar transmittance of SPDb and SPDa under 110 V for wavelength range between ~~278–1100~~278 and 1100 nm was 62% and 64% respectively as shown in Fig. 7. Change of solar transmittance is only 3% after 4 years of operations for SPD transparent state. Solar transmittance of SPDb and SPDa under 0 V for wavelength range between ~~278–1100~~278 and 1100 nm was 20% and 17% respectively as shown in Fig. 8. Transmission change in the visible range for SPDb and SPDa are 55% and 57% under 110 V power supply (SPD transparent state) as shown in Fig. 9. Transmission change in the visible range for SPDb and SPDa are 5% and 5.5% at SPD opaque state as shown in Fig. 10. Contrast ratio of SPD glazing before exposure was 1:11 and after exposure was 1:10 for SPD opaque and transparent state in visible region. It is evident that after 4 years of operation including 3 years outdoor conditions exposure, SPD glazing performance degradation was found to be negligible. Fig. 11 shows a photograph of SPD glazing opaque and transparent state before and after outdoor exposure. Degradation of SPD glazing transmission properties after real time UV exposure can be considered relatively less amount.

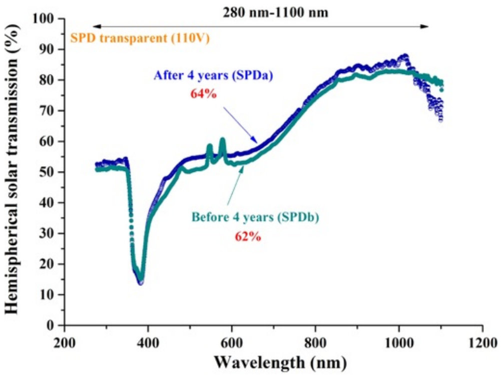

Fig. 7 Change of hemispherical solar transmittance of SPD glazing at 110 V before and after 4 years of operation (3 years outdoor conditions).

alt-text: Fig. 7

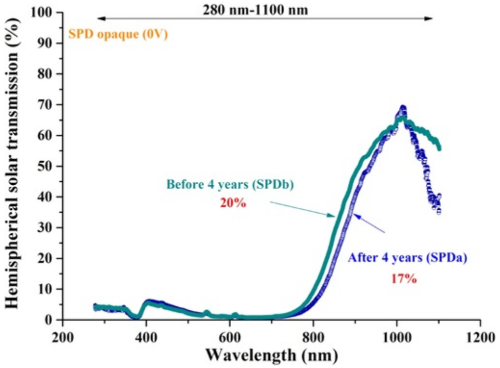

Fig. 8 Change of hemispherical solar transmittance of SPD at 0 V before and after 4 years of operation (3 years outdoor conditions).

alt-text: Fig. 8

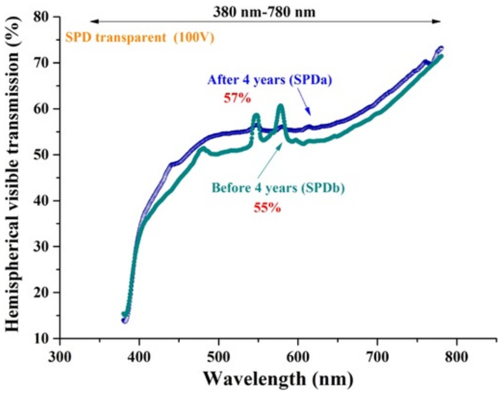

Fig. 9 Change of hemispherical visible transmittance of SPD at 110 V before and after 4 years of operation (3 years outdoor conditions).

alt-text: Fig. 9

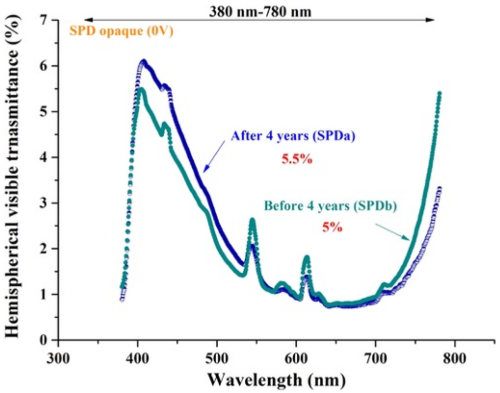

Fig. 10 Change of hemispherical visible transmittance of SPD at 0 V before and after 4 years of operation (3 years outdoor conditions).

alt-text: Fig. 10

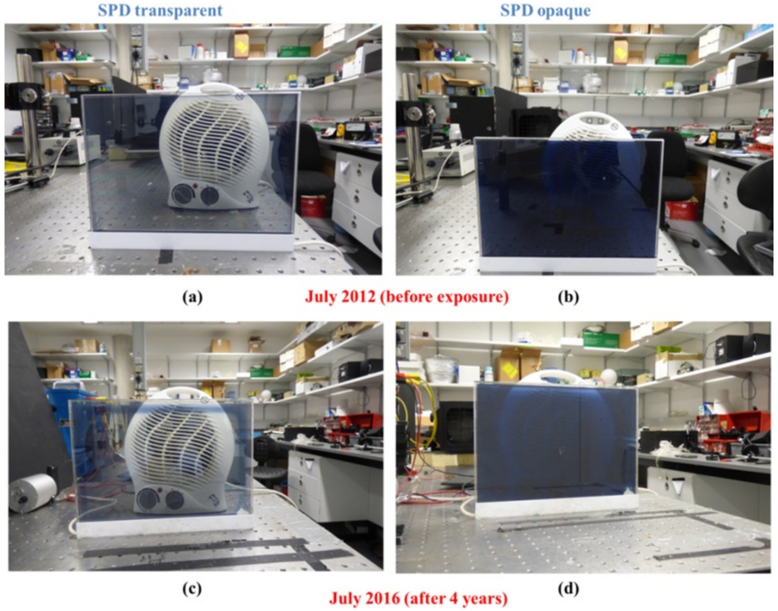

Fig. 11 Photographs of SPD glazing (a) transparent and (b) opaque state before environmental exposure. After environmental exposure SPD glazing transparent (c) and opaque (d) states.

alt-text: Fig. 11

3.2 Variation of solar transmittance for variable voltage

Fig. 12 indicates the solar transmittance of SPD glazing for its intermediate applied voltage between 0 and 110 V. In the visible range (380–780) SPD glazing transmission, varied in higher order for different applied voltage. Variation was less at higher wavelength. Table 1 listed the solar transmission for different applied voltage.

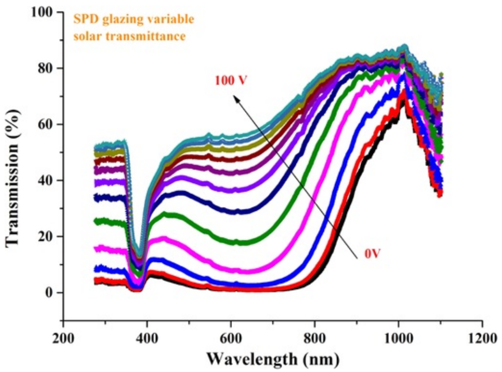

Fig. 12 Solar transmittance for SPD glazing after exposure at variable voltage.

alt-text: Fig. 12

Table 1 Average solar transmittance for different applied voltage.

alt-text: Table 1

Applied voltage (V)	Current (μA)	Power (W)	Solar transmittance (278–1100 nm)

0	0	0	18
10	72	0.00072	19
20	126	0.00252	25
30	193	0.00579	33
40	253	0.01012	42
50	313	0.01565	49
60	378	0.02268	54
70	442	0.03094	57
80	506	0.04048	60
90	569	0.05121	62
100	630	0.063	63
110	695	0.07645	64

3.3 Variation of voltage at elevated temperature

Fig. 13 shows the SPD glazing surfaces temperature and indoor ambient temperature while it was exposed at controlled indoor environment. Thermocouples placed on the centre of the SPD glazing showed higher temperature increment from ~~24°C~~24 °C to ~~38°C.~~38 °C. This position was directly illuminated by the simulator. Temperature increased at rate of ~~2°C/h~~2 °C/h while ambient temperature increased at ~~1°C/h.~~1 °C/h. Temperature recorded from the opposite side, which was facing spectrometer showed lower increment than the front surface. At indoor condition, SPD glazing surface temperature reached up to ~~38°C~~38 °C at 60 V power supply while its solar transmission was 54%. At outdoor condition, SPD glazing surface temperature also reached near ~~40°C~~40 °C for its opaque and transparent state. It is evident form the both indoor and outdoor experiment that this glazing surface temperature reaches between ~~38-42°C.~~ 38 and 42 °C. Less temperature was achieved in the indoor condition due to the solar simulator as it had only limited spectrum available. From our outdoor investigation [44] SPD glazing surface temperature increment was found ~~1-2°C~~1–2 °C higher than the indoor investigation. It is also confirmed that rise of SPD glazing surface temperature is independent of its transparent state.

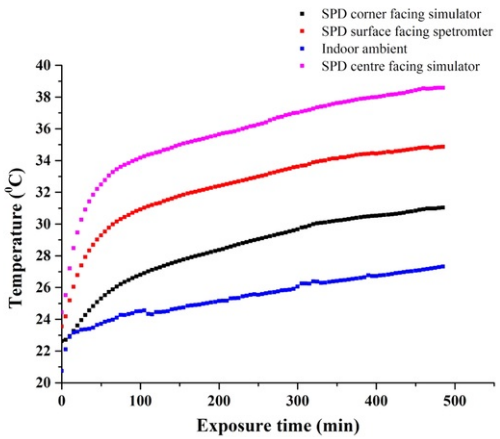

Fig. 13 SPD glazing surface temperature at controlled indoor environment.

alt-text: Fig. 13

Fig. 14 indicates the 54% and 49% transmission of SPD glazing at 60 V and 50 V applied voltage respectively. Measurements were made before and after thermal exposure (7 h). After thermal exposure SPD glazing achieved

54% transmittance at 60 V applied voltage. No voltage and power variation was observed before and after thermal exposure. From experimental studies, it is evident that SPD glazing at higher and lower surface temperatures consume equal amounts of power to achieve a transparent state.

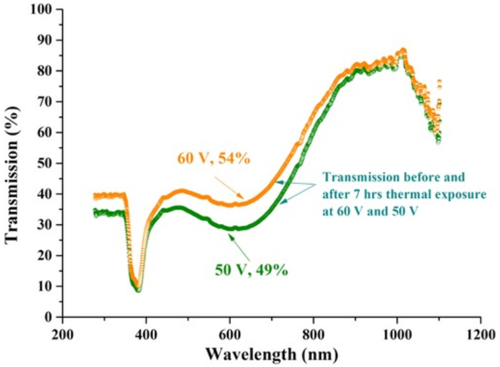

Fig. 14 SPD glazing transmission before and after 7 ~~hours~~h of thermal exposure at indoor environment at 60 V and 50 V applied voltage.

alt-text: Fig. 14

4 Conclusions

The effects of the environment on the properties of an SPD switchable glazing was evaluated using an outdoor exposure for three years at extreme Dublin climatic conditions. SPD glazing transmission behaviour changed very little during this period. Before and after exposure, the contrast ratio of SPD glazing changed from 1:11 to 1:10. SPD glazing visible transmission changes in higher order compare to ~~infrared~~infra-red transmission. From indoor characterising maximum SPD glazing surface temperature was found between ~~38-40°C.~~ 38 and 40 °C. This increment was similar to the result found from outdoor characterisation [44]. SPD glazing surface temperature increment is independent on the applied voltage and thus the transmission. It is also found that SPD glazing transmission and required power supply to achieve that transmission is also independent on the SPD glazing surface temperature.

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Highlights

- SPD glazing transmission was investigated after 3 years of outdoor exposures.
- SPD glazing switching voltage at elevated temperature was investigated.

Queries and Answers

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