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Field assessment of visual performance of a dynamic dual glazing assembly for occupants with lateral incident light

Etienne Magri^{1*}, Vincent Buhagiar¹, Mauro Overend²

¹ Department of Environmental Design, Faculty for the Built Environment, University of Malta, Malta.

² Department of Architectural Engineering & Technology, Faculty of Architecture & Built Environment, TU Delft, Netherlands.

*etienne.magri.99@um.edu.mt

Abstract. Switchable glazing has made great strides to increase its potential of being deployed in adaptive building facades. These can provide shading solutions in climates with high solar insolation without compromising outlook and views, while allowing for privacy on demand. This paper further builds on previous knowledge and investigates the potential of a novel switchable assembly, comprising a dual dynamic solar-PDLC (Polymer Dispersed Liquid Crystal) and SPD (Suspended Particle Device) films, deployed in a side-lit, scale model setup for field testing. Using a comparative approach with static glazing, luminance photometry is used to determine the Daylight Glare Probability (DGP) provided by the different states of the switchable glazing. The measurements obtained assess the ability of this novel assembly of switchable films, to provide for privacy and glare control through the conversion of windows into opaque elements.

1. Introduction

Visual privacy is a key aspect of building design, especially in environments where people live, work, or gather. It refers to the ability to shield occupants from being seen or exposed to unwanted views, both from outside the building and from within. The psychological need for privacy in humans is substantially acknowledged in literature and is defined as the need of an individual or group to regulate their visual, aural, and olfactory contact with others [1]. The increased use of glazing not only affects privacy, but in climates with high solar insolation is likely to cause overlit negatively affecting comfort, usability, and the overall performance of the space. Too much light, especially direct sunlight, often creates visual discomfort. Glare makes it hard to see screens, read, or concentrate and is particularly problematic in offices and classrooms. Workspaces near unshaded facades are often too bright to use a computer comfortably and the high contrast created between bright and dark zones makes the human eye struggle to adapt, causing eyestrain and visual fatigue.

2. A Novel Dynamic Glazing Assembly

Solar-PDLC and SPD switchable technologies are widely available and already in use in the automotive and aviation industries, both falling under the category of smart glazing. These technologies have distinctive properties: the provision of privacy and dispersion of incident solar radiation, and the ability to control the levels of daylight to potentially achieve a glare-free indoor environment. Since these films can effectively be embedded in any sort of glazing configuration, the potential of them being both



assembled within the same façade glazing element, leads to a potentially innovative combination to achieve a high degree of façade glazing adaptability. Previous research by the same authors [2] has already shown that in cases where the solar disc is in the field of view, the combination of technologies within the same assembly can give a wide dynamic range of privacy and glare control, potentially pushing away the use of conventional indoor blinds and shades.

Figure 1 illustrates a conceptual schematic detail of a dual dynamic insulated glazing unit intended to provide for privacy on demand (provided by the external laminate) and daylight control (provided by the internal laminate). For the scope of these experiments however, both laminates were overlaid onto each other to assess the visual performance of a side-lit indoor space when viewed by an occupant sitting parallel to the façade glazing (Figure 2). Since thermal performance was not of interest in this case, the assembly of the laminates into an IGU was not deemed necessary.



Figure 1. Conceptual schematic detail of a potential novel switchable IGU

Figure 2. Schematic detail of overlaid laminates for the scope of this experiment

3. Experimental Setup & Methodology

Prior to investigating the performance of the novel dynamic glazing assembly in a full-scale setup, a series of experiments on a scale model were conducted. Scale models under field test conditions for the analysis of visual and thermal properties of dynamic glazing have been adopted in other studies, primarily by [3, 4, 5] for their studies of glazing samples with SPD.

Using a sample set of static and dynamic glazing samples of dimensions 290 x 200mm provided by the switchable film manufacturer, a physical model of a room scaled 1 in 10 was constructed as shown in Figure 3, having an indoor dimension of 400mm in width; 500mm in depth; and 260mm in height. The model provided a glazing ratio of 56% and due consideration was given to allow for the placement of a luminance photometer within the test box to simulate an occupant seated parallel to the façade glazing. Due attention was given to both the choice of materials in relation to their albedo and the assembly method to prevent any stray lighting or reflections from penetrating the scaled indoor space other than that entering through the glazed aperture. An opaque blackout fabric was used to prevent stray lighting from entering the model from the back end with attention given to keeping the fabric in a secure position when images were shot. Similarly, appropriate sealing of the edges of all glass samples ensured a secure detail to prevent ingress of stray lighting from around the perimeter of the samples.

The different configurations of static and dynamic glazing and the various shading and switching states tested were as shown in Table 1.

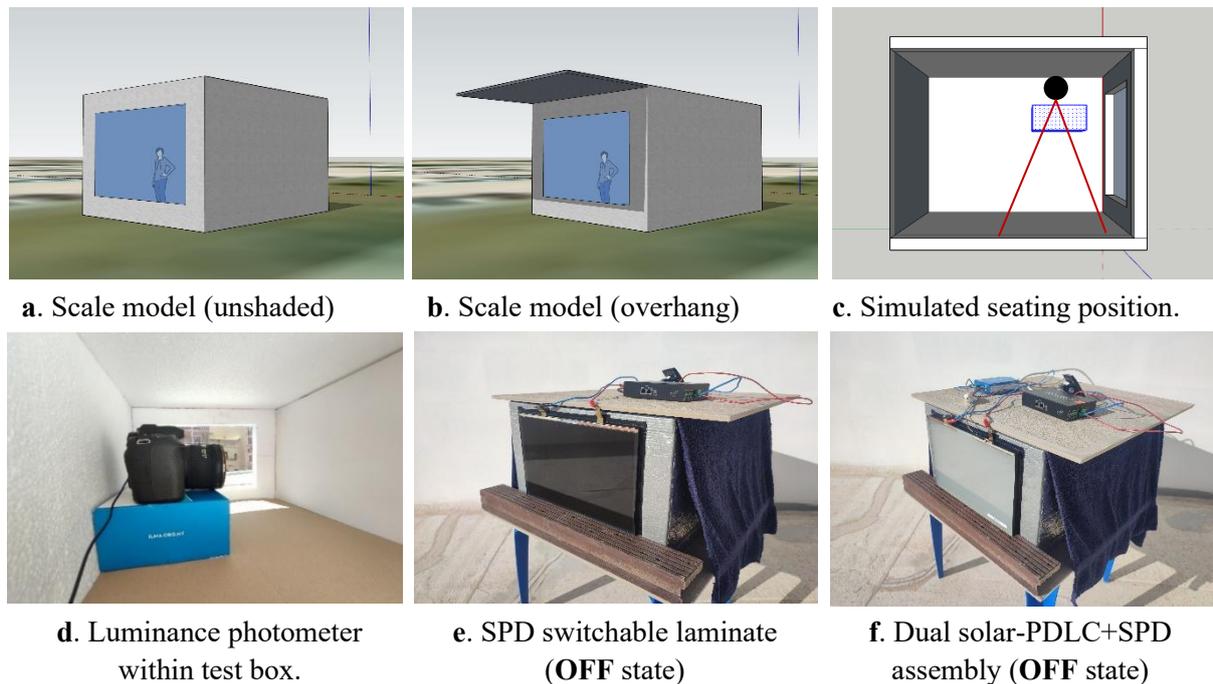


Figure 3. Schematic representation and actual scale model experimental setup.

Table 1. Different static and dynamic glazing configurations

Static Glass Samples	Assembly thickness	unshaded	with opaque overhang
• Guardian Solar Bronze 20	6 mm	U1	S1
• Guardian HP Bronze 40/27 IGU	6-10-4 mm	U2	S2
• Saint Gobain KN148	8 mm	U3	S3
• Guardian SunGuard SN70-35HT	8 mm	U4	S4
Dynamic Glass Samples		Switching state	
• Solar PDLC laminate (extra-clear)	9.62mm	D1a <input type="radio"/> OFF	D1b <input type="radio"/> ON
• SPD laminate (extra-clear glass)	9.79mm	D2a <input type="radio"/> OFF	D2b <input type="radio"/> ON
• Dual solar-PDLC+SPD assembly (extra-clear glass)	19.41mm	D3a <input type="radio"/> OFF <input type="radio"/> OFF	D3c <input type="radio"/> OFF <input type="radio"/> ON
		D3b <input type="radio"/> ON <input type="radio"/> OFF	D3d <input type="radio"/> ON <input type="radio"/> ON

Wienold and Christoffersen [6] had developed a new metric for the computation of glare, namely “the Daylight Glare Probability (DGP) which expresses the percentage of occupants disturbed by a daylighting glare situation” (Equation 1):

$$DGP = 5.87 \cdot 10^{-5} \cdot E_v + 9.18 \cdot 10^{-2} \cdot \log \left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1,87} \cdot p_i^2} \right) + 0.16 \quad (1)$$

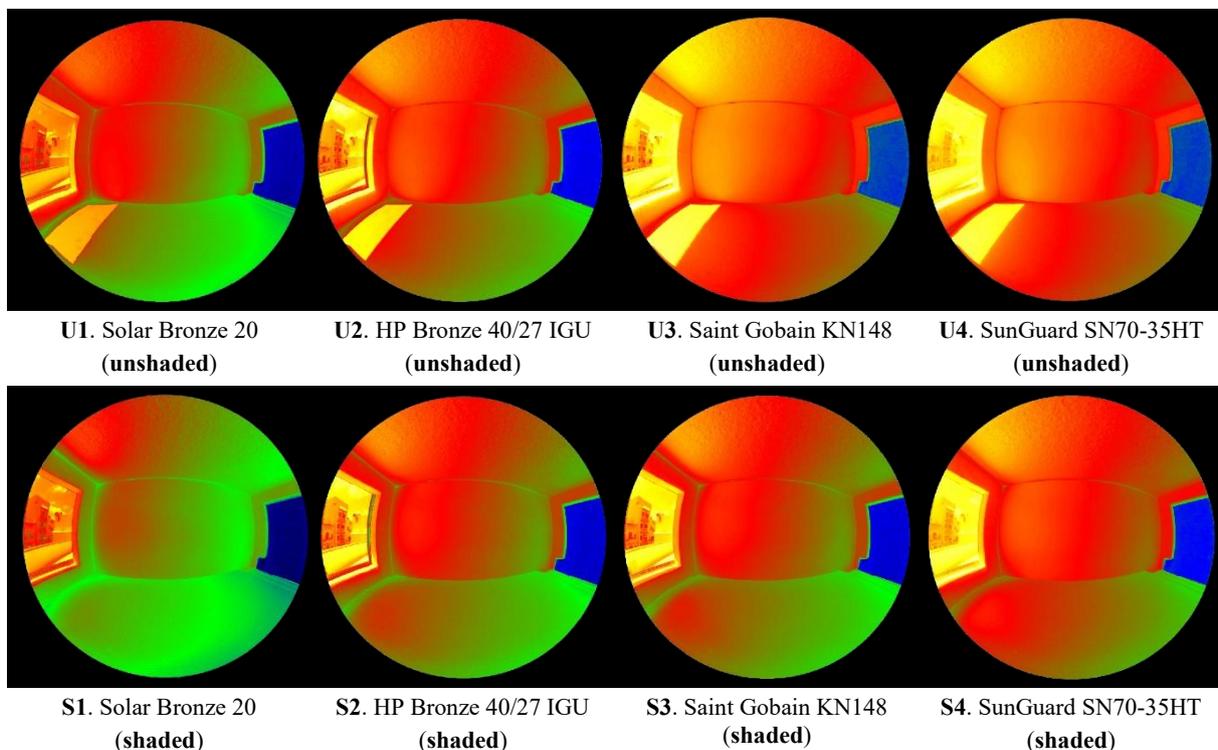
where $L_{s,i}$ is the source luminance (cd/m^2), $\omega_{s,i}$ is the solid angle, E_v is the vertical illuminance (lux), and p_i is the Guth position index for the field of view. DGP is primarily influenced by the first term (E_v) with the second term relating to the apparent contrast. This method for the assessment of glare now forms part of EN 17037:2018 [7] and is widely considered as being the standard approach for the computation of glare. Pierson *et al.* describe a methodology for the computation of point-in-time glare through the generation of luminance maps from high dynamic range photography using semi-professional equipment [8]. Pierson *et al.* further describe analytical methods for the simulation of glare using the *Evalglare* software [9].

The objective of these experiments was the generation of a dataset of luminance images taken from the simulated position of the occupant for the subsequent analysis of glare as perceived by the human eye. For this scope, a series of high-resolution images taken at different exposure times were taken using the TechnoTeam® LMK Mobile-R image-resolved luminance photo camera for field measurements, equipped with a SIGMA 4.5mm 1:2.8 circular fish-eye lens. Following the generation of a high dynamic range [HDR] photograph for each scene, luminance maps were created using the TechnoTeam® proprietary LMK LabSoft® suite. Following the identification of all light sources in the field of view of the observer, the DGP as described by Wienold and Christoffersen [6] was computed through software, this metric giving a reliable indication of the potential discomfort or otherwise to the observer with the solar disc outside the field of view. The luminance camera used in this study was designed for research use, and thus already calibrated by the manufacturer with detailed data sets and corrections for response curves, vignetting, and point source errors directly embedded in LabSoft® 14.3.6 software. This provided for accurate luminance readings, not requiring any further calibration, with the software handling the entire procedure of merging all photos into a single HDR image, the creation of the luminance maps and the calculation of the DGP.

4. Results & Discussions

A field test experiment was conducted on a clear sunny day in March 2025 on a roof top of an existing building in Malta ($35.89^{\circ}N$; $14.46^{\circ}E$; $11:30hrs - 12:30hrs$) to assess the visual performance of a side lit space fitted with different types of static and dynamic glazing. Glare as perceived by a building occupant, sitting at a desk, was assessed by computing the DGP of the scene using a calibrated luminance photometer. This was mounted at a position to simulate the view by a person at a desk located perpendicular to the glass, potentially susceptible to glare.

A graphical representation of all luminance maps and the ranges of luminous intensity in cd/m^2 for each scene is featured in this section (Figure 4). Results show the computed DGP for each scene following the identification of the light sources by the luminance photometer based on the selected luminance threshold.



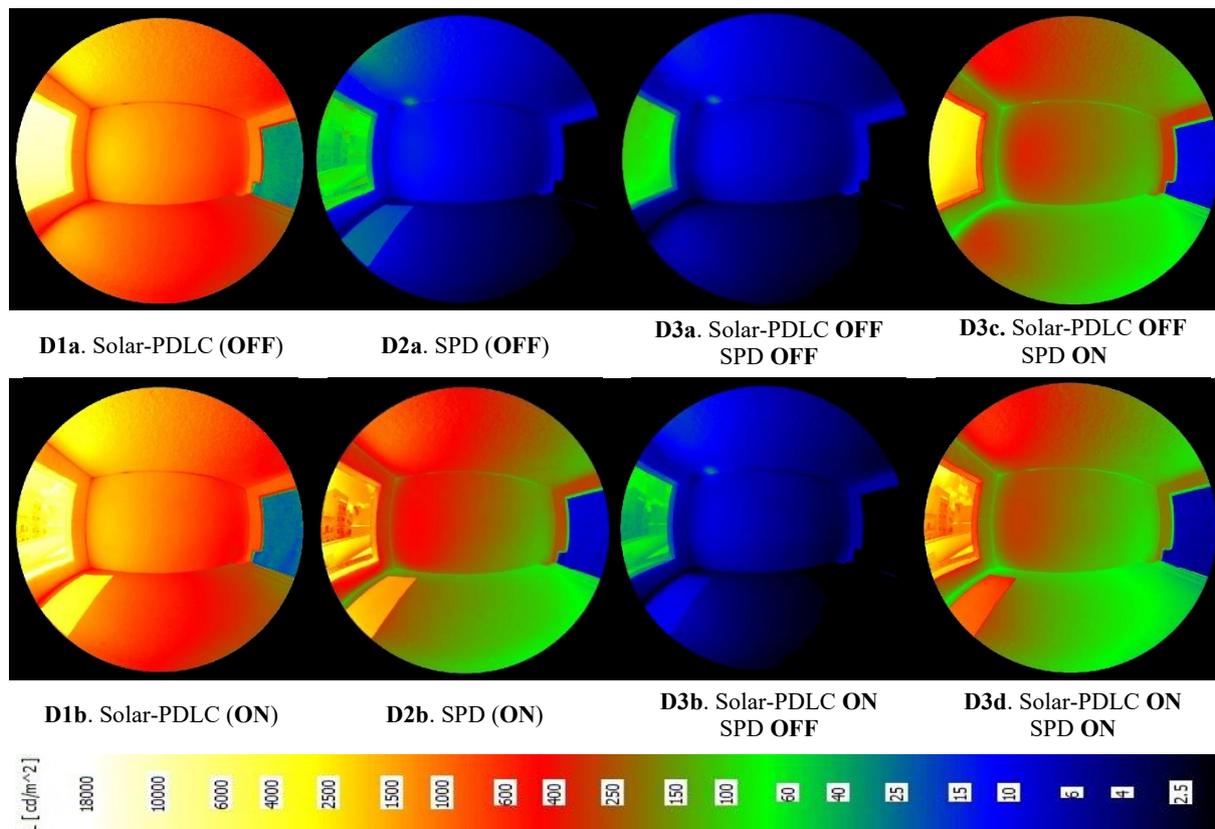


Figure 4. Luminance maps for all static and dynamic glazing samples. (all configurations)

All DGP readings taken for the sixteen experiments were plotted onto a histogram to summarize the findings (Figure 5). Results show that in the case of a space facing south-east, most of the glazing types tested provided for a glare-free environment to an occupant seated parallel to the glazed façade with the solar disc outside the field of view. This is particularly due to the size and brightness of the solar patch formed within the room in relation to the altitude of the sun. In the unshaded cases, all DGP values featured a direct relationship with the visible light transmittance of the glass with only the Guardian SunGuard SN70-35 (70% VLT) falling within the *perceptible* range with a value of 36%. In all cases where an opaque overhang was placed above the window, the solar patch within the room was prevented from forming, this influencing the lowering of the DGP values for all cases. Here again, the values of the DGP confirm a direct relationship to the visible light transmittance value of the static glass samples. All experiments featuring static glass (both unshaded and shaded), comprised full transparency between indoors and outdoors. The DGP values measured are valid for that timeframe when building occupants do not perceive privacy as being an issue.

When deployed as an electronic blind, solar PDLC technology was noted to be very effective at disconnecting the indoor-outdoor interface across the façade, thus particularly useful in providing full privacy to building occupants. The uniform dispersion of daylight into the indoor space prevented the solar patch from forming and allowed for a more uniform distribution of daylight. The level of DGP measured in its OFF (*translucent*) state fell however within the *disturbing* range of the DGP scale (44.32%). The entire window is perceived as a light source in itself, with a large solid angle subtended to the observer’s eye. This would thus have a mathematical influence on the DGP formula resulting in a higher level of DGP. In its ON (*transparent*) state, the DGP level still falls within the *disturbing* range, likely due to the sample film being laminated within extra clear glazing (VLT=72%).

SPD technology appears to have a greater potential for controlling glare, though not very effective at providing for complete privacy. The level of DGP measured in its OFF (*tinted*) state was noted to be

well within the *imperceptible* range of the DGP scale (16.85%) whereas in its ON (*bleached*) state, the DGP level attaining a value of 23.60% (*imperceptible*), thus slightly higher than that provided by the unshaded Guardian Solar Bronze 20 static glass.

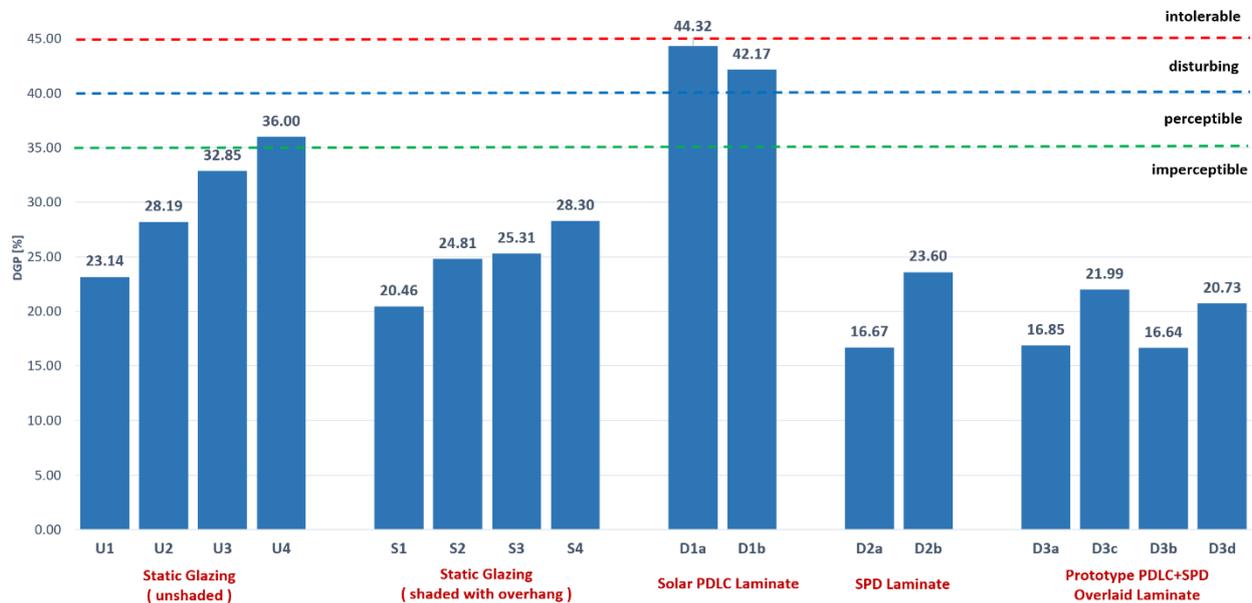


Figure 5. Graphical Distribution of the results of the DGP values for the entire experiment.

The experiments featuring the combination of both solar-PDLC and SPD technologies within the same assembly representative of a novel IGU provided the following observations. With both films switched OFF (*translucent and tinted*) the façade provided for maximum privacy and glare control, with the DGP level achieving a level of 16.85% (*imperceptible*). This means that in this state, the occupant would benefit from complete privacy while attaining the same level of indoor daylight. In the PDLC:OFF + SPD:ON state (*translucent and bleached*), the combined unit appeared visually similar to the solar-PDLC deployed individually, that is, a provision of complete privacy with a uniform dispersion of daylight. The level of DGP however was measured at 21.99% (*imperceptible*), thus featuring a remarkable improvement in the level of perceived glare. This result shows that the apparent amplification of the DGP level by the solar-PDLC film appears to become nullified when combined with SPD technology. In the PDLC:ON + SPD:OFF state (*transparent and tinted*), the combined unit appeared visually similar to the SPD film deployed individually with a DGP level measured at 16.64% (*imperceptible*). This result shows that the state of the solar-PDLC film, and thus the availability or otherwise of privacy, does not have an effect on the level of daylight and the perceived level of glare. With both films switched ON (*transparent and bleached*) the glass provided for a DGP value of 20.73% (*imperceptible*), and only slightly less than that provided by the unshaded Guardian Solar Bronze 20.

5. Conclusions

Visual privacy is about giving an occupant a choice to engage or retreat and is as important as the need for outlook and views. High glazing ratios in building façades provide for an increased connection between to the outside but in climates with high solar insolation, is likely to cause glare and visual discomfort. This paper confirms that in the case of side-lit spaces, solar-PDLC deployed on its own allows for full privacy but amplifies the perception of glare when compared to static glazing with an overhang. Results confirm that SPD film performs better at glare control but does not provide full privacy. The dynamic dual film combination, representative of a novel switchable IGU was found to provide for both privacy and glare control without the amplification of the DGP when solar-PDLC film is switched ON. This assembly can thus give an occupant, a wide dynamic range of visual properties.

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