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The book of proceedings

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Switchable Glazing in a Mediterranean Climate
Preliminary Investigation of a Novel Switchable Glazing Assembly

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ABSTRACT: The control of glare in office environments is often retrospectively improvised using shading devices, typically internal blinds. Despite the leap towards energy efficiency goals, visual comfort is still being compromised in climates with high solar insolation resulting in intolerable glare. This paper discusses the visual performance of a novel glazing assembly comprising of two, independently switchable (solar Polymer Dispersed Liquid Crystal and Suspended Particle Device) interlayers intended to control the visible light transmittance into an indoor space. Readings of DGP in a full-scale test cell are presented together with an analysis of the visual appearance of the glass.
KEYWORDS: Switchable Glazing, Adaptive Facades, Glare, Occupant well-being, DGP.

1. BACKGROUND

Excessive levels of daylighting in buildings having high glazing ratios in climates with high insolation levels is a matter that is frequently overlooked. The control of glare is often retrospectively improvised using shading devices, typically internal blinds. This means also blinding the view, with an unwarranted artificial lighting load during broad daylight. To address overheating issues, glazing technology of an insulated glazing unit (IGU) has evolved particularly through the use of static selective coatings on glass, thus delivering much of the expected performance in terms of low U-values, g-values, and visible light transmittance (VLT). However, despite the leap towards energy efficiency goals, visual comfort has often been compromised with lower daylight levels and partial blockage of external views. Internal shading devices, typically louvres or roller blinds are considered as cheap, quick-fix solutions for glare control and solar rejection of a façade. External shading devices are typically fixed and sometimes moveable to allow for their adjustment according to the external day-to-day climatic conditions.

1.2 The Research Gap: Problem defined.

In a cooling-oriented central Mediterranean climate, the main thrust in design trends is verging towards fully fletched glazed façades with a design 'overkill' in terms of daylighting requirements, while generating unwarranted cooling gains. Although yearning for unobstructed distant views, occupants often experience glare, distracting them from their daily tasks, while also impacting their overall health, well-being, and productivity.

This research has established gaps in the body of knowledge in that independent of how energy efficient they may be, static facades still have a limited degree of adaptability and tend to provide limited performance in adverse daytime conditions. The daylight and visual performance of a static façade is limited to basic control by blinds, often limiting views. This points to the need to reduce glare and the associated discomfort, without compromising the views which often come at a premium in real estate terms. This may be achieved by optimizing daylight levels and provide for appropriate shading while decreasing the need for daytime artificial lighting. The restrictions of conventional static facades therefore need to be overcome to avoid discomfort glare, protect views, and encourage productivity to prop up overall occupant well-being.

Figure 1: Buildings with a high glazing ratio in Malta, relying on indoor blinds for the control of glare.

2 ADAPTIVE GLAZING FOR VISUAL COMFORT

Buildings are naturally subjected to diurnal and seasonal changes. The concept of a responsive, adaptive building façade as opposed to spaces protected only by static enclosures, relying on active, climate-controlling systems for the attainment of comfort, makes more sense now than ever. Glazing appears to be following the trend and need, of adaptability as technology seeks to address the need to bridge the gap between transparency and opaqueness.

Chromogenic glass is a generic term that refers to glass that can change its optical properties. The main functions of chromogenic glass when applied to architectural glazing is to control the flow of light and heat into and out of a glazing, according to the requirements of building occupants. The change of optical properties in chromogenic glazing can be in the form of absorptance, reflectance or scattering. Thermotropic materials allow for a change in state of the polymeric material, which affects its refractive index turning it from a solar transmitting material to a solar absorbing one, thus from transparent to translucent (Compagno, 1999), whereas thermochromic materials are based on the features of transition metal oxides which transforms the material from a solar transmitting to a solar reflective one (Granqvist, 2007). Photochromic materials alter their properties through the UV radiation in the solar spectrum, whereas electrochromic materials can alter their optical properties when triggered by an electric current. The most common of the electrically activated types are phase dispersed liquid crystals (PDLC), dispersed particle system (DPS) and electrochromics.

The UV-resistant PDLC privacy film (solar-PDLC) and SPD tinting technologies are two of the most established, commercially available products on the market today. These have the added advantage of being assembled in conventional glass-assembly factories without the need of any specialized equipment. Switchable dynamic glass appears to have a great potential at achieving privacy and daylight control, where besides having the ability to be manually controlled by building occupants, can in turn be pre-set on the basis of an automated control strategy.

3. AN INNOVATIVE GLAZING ASSEMBLY

The diverse properties of both solar PDLC and SPD technologies has prompted the author with an idea of possibly an *innovative combination of technologies within a single laminate*. Having a glass laminate with both solar-PDLC and SPD interlayers potentially allows for the external laminated sheet of glass in an IGU to offer both privacy and tinting properties according to the requirements of the building occupants. The solar PDLC film can be maintained in two states (**ON** [transparent] and **OFF** [translucent]), whereas the SPD can retain a *variable* tint by means of its electronic controllers. Different applications of how this glazing assembly can be set within an external façade are substantial and is believed that this combination of technologies, if proven to be effective at reducing overheating and glare for facades in a cooling-dominated climate, may push away conventional indoor blinds and shades, and given time, may possibly render them obsolete. In addition, having this technology capable of being connected to smart systems of buildings and the IoT, the possibilities of integration and control of this form of switchable glass assembly are practically endless.

3.1 Experimental Setup

For the scope of this study, two twin full-scale test cells were set up within the grounds of the University of Malta to carry out a series of comparative experiments between the prototype switchable glazing assembly and other forms of conventional, static facades (Figure 2).

The test cells were installed on precast concrete foundations laid out to permit the rotation of the test cells to face different orientations as required. A comparative testing approach as described by (Cattarin et.al., 2015) is being adopted, wherein the performance of a component, in this case the prototype glazing assembly, is assessed in relative terms to a reference element being tested at the same time.

For the assessment of the visual suitability of the indoor environment, the Daylight Glare Probability (DGP) metric developed by (Wienold & Christoffersen, 2006) will be measured using a state-of-the-art, calibrated luminance photometer, TechnoTeam© LMK Mobile 6 equipped with a SIGMA fish-eye lens, coupled with the proprietary LMK Labsoft© glare analysis suite.

Figure 2: Photos the full-scale, twin test cells installed at the University of Malta grounds.

4. METHODOLOGY

For the scope of this research, two pairs of films, each having dimensions of approximately 1.0m x 2.0m were cut to fit an overall glazed area of approximately 2.0 x 2.0m, both laminated in between an 8mm glass with a low emissivity coating on surface two and a 6mm extra clear glass with EVA interlayers in between the films. This glass laminate intends to combine both solar-PDLC and SPD films into a single laminate, and since the scope of this study focused solely on the visual performance of these films, their assembly into an insulated glass unit (IGU) for the assessment of their thermal performance, fall beyond the scope of this study. (Figure 3).

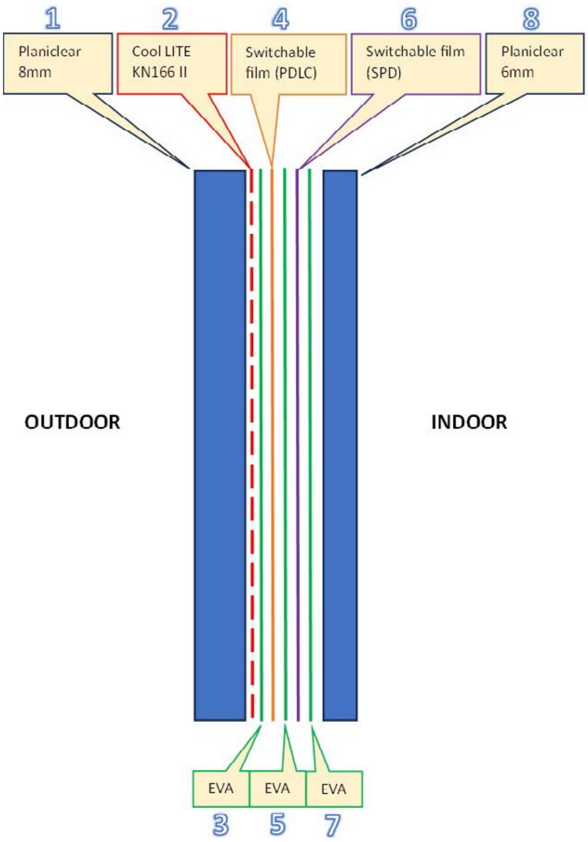


Figure 3: Schematic section of the novel switchable laminate.

Prior to lamination, both switchable films were prepared for the installation of the copper busbars through an edge deletion process, wherein the protective polyethylene terephthalate (PET) coating of the films and the actual formulation were carefully removed at two specific locations to expose the underlying conductive indium tin oxide (ITO). This allowed for the required space to attach the copper busbars to permit electric current to power-up the films. (Figure 4). Following the adhesion of the busbars with the ITO of the switchable films, two copper contact points for each film, of sufficient length to protrude from the edges of the laminate, were then soldered to the busbars themselves to provide for connecting the necessary wiring from the films to their proprietary electronic controllers (Figure 5). Two different controllers were required, one for each film, thus allowing for the control of each film independently.

Figure 4: Preparing films for busbar installation.

Figure 5: Preparing films for busbar installation.

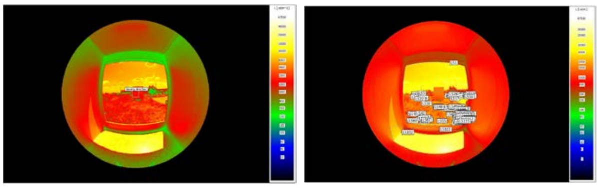
Figure 6: Placement of films in between the interlayers prior to lamination.

5. PILOT STUDY: PRELIMINARY RESULTS

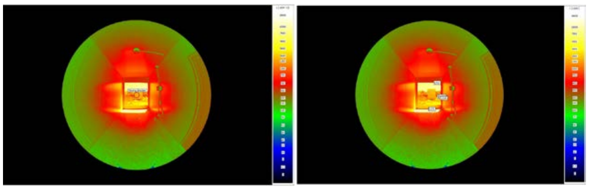
5.1 Suitability of the Testing Setup.

An initial DGP pilot study was conducted on a partly cloudy day in March 2023 to collect preliminary DGP readings inside the test cells without any glazing installed, this to assess the geometry and finishes of the test cells (Figure 7). The objective was to familiarize with the operation of the TechnoTeam© LMK mobile luminance photometer and its software for the analysis of the luminance maps generated by the camera itself and to obtain a preliminary indication of the DGP without any filtering provided by any of the glazing assemblies. The luminance photometer was mounted on a secure tripod and readings taken at three different positions within the cells: **1.5m**, **3.0m** and **4.5m** away from the opening. The luminance maps generated for the two extreme distances showed a *remarkable* difference in both the DGP readings and the number of light sources detected by the software. As expected, the closer the distance of the building occupant to the opening, the greater is the DGP (**79.38** at 1.5m; **34.39** at 4.5m) with a value in region of 30, being the threshold beyond which an occupant tends to perceive a scene as being too bright. It was also noted that the distance of a building occupant from the opening of the test cell had a substantial effect on the number of light sources in the field of view, perceived as being too bright (**115 light sources** at 1.5m; **5 light sources** at 4.5m). Figure 8 refers.

Figure 7: Placement of the luminance photometer within one of the test cells (no glazing installed)



Number	PosIdxType	Adaptation (lx)	Threshold (cd/m²)	Value	Summary
115	PosIdx Guth et. al. + PosIdx Iwata et. al.	10330	4357	L(mean) (cd/m²)	
				Omega (sr)	
				Theta (°)	
				PosIdx	
				DGP	79.38



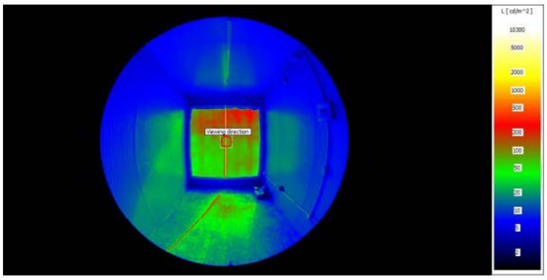
Number	PosIdxType	Adaptation (lx)	Threshold (cd/m²)	Value	Summary
5	PosIdx Guth et. al. + PosIdx Iwata et. al.	2293	5402	L(mean) (cd/m²)	
				Omega (sr)	
				Theta (°)	
				PosIdx	
				DGP	34.39

5.2 DGP Measurements for the switchable laminate.

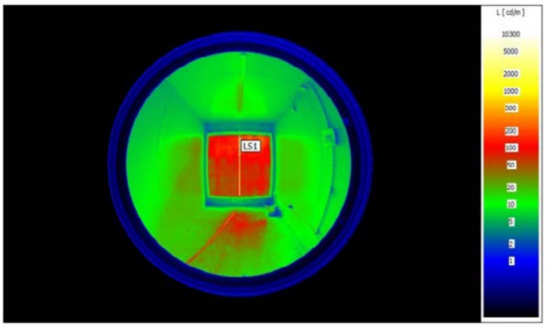
Following the installation of the switchable laminate within one of the test cells (Figure 9), readings were taken on a clear, sunny day in November 2023, with the position of the sun perpendicular to the laminate. The scope of these field tests was to measure take readings of the DGP under different states of the films and to assess the visual quality of the test façade and that of the indoor environment within the cell itself. The luminance photometer was mounted on a secure tripod and readings taken at the centre of the test cell - 3.0m away from the opening. The luminance maps generated for two switching states (solar-PDLC OFF; SPD OFF) and (solar-PDLC ON; SPD OFF) are as shown in Figure 10.

Figure 9: The prototype switchable laminate installed within a test cell.

Luminance image



Light sources

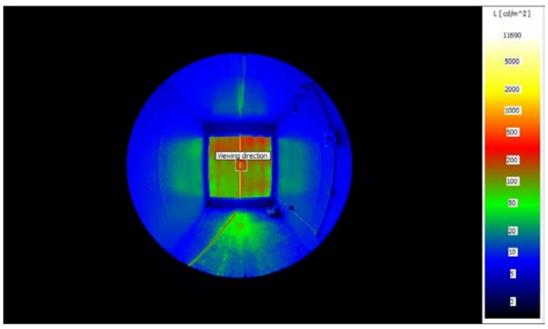


DGP table

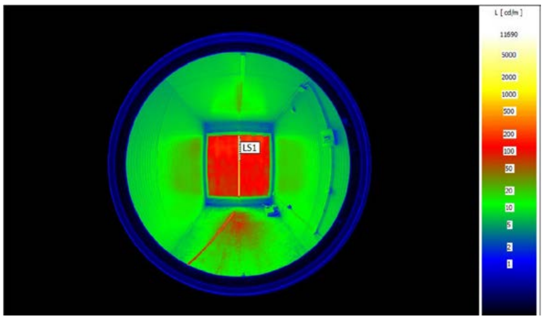
Number	PosIdxType	Adaptation (lx)	Threshold (cd/m²)	Value	Summary
1	PosIdx Guth et. al. + PosIdx Iwata et. al.	88.73	4357	L(mean) (cd/m²)	
				Omega (sr)	
				Theta (°)	
				PosIdx	
				DGP	22.74

*Figure 10: Readings for (solar-PDLC **OFF**; SPD **OFF**).*

Luminance image



Light sources



DGP table

Number	PosIdxType	Adaptation (lx)	Threshold (cd/m²)	Value	Summary
1	PosIdx Guth et. al. + PosIdx Iwata et. al.	96.8	4357	L(mean) (cd/m²)	
				Omega (sr)	
				Theta (°)	
				PosIdx	
				DGP	22.84

*Figure 11: Readings for (solar-PDLC **ON**; SPD **OFF**).*

When both films were switched off, the darkest state of the glazing was achieved. Measurements of the VLT through the laminate showed that in this state, the laminate blocked up to 99% of the visible light. The DGP reading of the scene taken from the viewing angle under consideration was 22.74, hence less than the recommended threshold of 30. The opacity of the glazing and its effectiveness at blocking visible light resulted in the photometer detecting the entire glazing areas as one light source (Figure 10). When the solar-PDLC was switched on to omit translucency of the file, the DGP reading showed a slight increase to read 22.84, with the glazing area still read as one light source by the luminance photometer (Figure 11).

Figure 12: View from the test cell (solar-PDLC **OFF**; SPD **OFF**).

*Figure 13: View from the test cell (solar-PDLC **ON**; SPD **OFF**).*

*Figure 14: Solar disc as seen with the naked eye. **LEFT**: solar-PDLC **OFF** - SPD **OFF**. **RIGHT**: solar-PDLC **ON** - SPD **OFF**.*

*Figure 15: View from the test cell (solar-PDLC **OFF**; SPD **ON**).*

*Figure 16: View from the test cell (solar-PDLC **ON**; SPD **ON**).*

*Figure 17: Solar disc as seen with the naked eye. **LEFT**: solar-PDLC - **OFF**; SPD - **ON**. **RIGHT**: solar-PDLC - **ON**; SPD - **ON**.*

6. DISCUSSION

When both films were switched off (State-1), a complete visual disconnection could be noted within the test cell to the outside (Figure 12). A feeling of complete enclosure was observed, resulting in a sense of total privacy. The solar disc could be comfortably looked at directly with the naked eye (Figure 14 - left). In a state where the solar-PDLC film was switched on (State-2), only a marginal visual connection to the outside could be achieved. Results show that the blue SPD film in its OFF state tends to visually overpower the solar-PDLC privacy film in its ON state (Figure 13). In this state, the solar disc could also be comfortably observed with the naked eye (Figure 14 – right).

When the solar-PDLC film was switched OFF and the SPD film switched on (State-3), the blue tint of the SPD film was noted to disappear completely, save for a slight tint along the edges of the films. The translucency provided by the solar-PDLC film again provided for a complete visual disconnection from the outside, hence providing privacy (Figure 53). When observed with the naked eye under this state, the solar disc could also be comfortably looked at directly with the naked eye (Figure 17 – left). With both films switched on (State-4), bright and direct sunlight penetrated the test cell allowing for direct internal illumination of the internal space.

A visual connection to the outside was now noted, albeit with a degree of visual haze comparable to that provided by a transparent sheer curtain behind a conventional glass pane. This visual effect is likely to be caused by internal reflection of incident light onto the formulation particles of the solar-PDLC film itself when oriented horizontally (film switched ON). Under this state, the solar disc was visually unbearable to be directly looked at. (Figure 17–right).

7. CONCLUSIONS

Switchable solar-PDLC and SPD films have the potential of being integrated for the control of daylight. A prototype glazing assembly comprising both solar-PDLC and a tinting SPD within a single laminate was assembled and installed within a full-scale test cell.

Measurements of the DGP showed promising results in achieving a value within acceptable limits with both films allowing for a high degree of protection from the adverse effects of the solar disc causing disability glare when falling within the field of view.

This study has shown that in its bleached (quasi-clear) state, the switchable laminate did not offer full clarity of the view normally associated with clear glazing, potentially creating a degree of human dissatisfaction. This merits further investigation by conducting occupant satisfaction studies on a select number of participants working from the test cell itself.

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