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RESEARCH PAPER

Preliminary assessment of visual performance of novel switchable glazing assemblies for glare control in a mediterranean climate

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Abstract The control of glare in office environments is often improvised retrospectively using shading devices, typically internal blinds. Consequently, views are blocked, and artificial lighting loads are increased. Today's glazing technology, particularly that of the IGU (insulated glazing unit) delivers much of the expected performance in terms of heat transfer and indoor natural lighting, but occupant glare discomfort is commonplace, particularly in climates with high solar insolation. This paper provides a preliminary assessment of the visual performance of a novel glazing assembly comprising of two, independently switchable solar-PDLC (solar Polymer Dispersed Liquid Crystal) and SPD (Suspended Particle Device). These switchable interlayer films are intended to control the visible light transmittance into an indoor space. The outcomes of this study will guide the order and assembly combination of a prototype IGU for future full-scale testing from both visual and thermal comfort perspectives. Using a novel scale model approach to

represent a typical indoor space with a high glazing ratio and a luminance photometer, the Daylight Glare Probability (DGP) provided by the different states and positioning of the switchable glazing are compared to that provided by conventional static glass under identical field test conditions. Comparisons of the visual appearance of the potential combinations of these technologies were also investigated relative to an unshaded glazing configuration, to assess the ability of switchable films to instantly convert transparent openings into opaque, wall-like elements. The results indicate that the scale-model approach was effective for such preliminary investigations and that more specifically, such a combined switchable glazing assembly does have the potential for reducing glare, and thus merits further investigation in a full-scale study.

Keywords Switchable glazing · Adaptive facades · Glare · Occupant well-being · DGP · VLT

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1 Background

Design trends across most office buildings even in a cooling-dominated climate such as that of the Central Mediterranean, still feature an aesthetic need of providing a façade design with the highest glazing ratio. Whereas this approach appears to satisfy the scope of developing buildings that look 'modern and transparent' to maximise on real estate value, the demand for

heating and cooling has invariably increased substantially. (Ben Bacha et al. 2016) Whereas research in the field of environmental performance still attempts to improve the properties of the building fabric for the reduction of energy consumption, substantial research has been carried out to assess the benefits of occupant comfort, particularly in relation to the quality of the indoor visual environment (Dhayal et al. 2023). Internal shading devices, primarily window blinds and shades are often installed, these being quick-fix and cheap after-thought solutions for the control and alteration of the properties of a façade. The control of glare using internal shading devices, however, often brings along the obliteration of views and an increased internal lighting load, while the overheating issue remains largely unresolved. Blinds installed too close to the glazing can trap heat, causing the temperature to rise significantly between the blind and the glass sometimes causing permanent deformation of window components.

2 Adaptive glazing for visual comfort

Glare is a “*negative sensation*”, caused by “*bright areas with sufficiently greater luminance that the luminance to which the eyes are adapted to, producing annoyance, discomfort or loss in visual performance and visibility.*” (EN 17037:2018). This standard specifically highlights the need to protect building occupants from glare using shading devices and to minimize direct view to the sun. The concept of responsive, adaptive architecture is based on the theory of interaction, and simple adaptive conditioning which defines a building as a self-adjusted system operated by feedback from occupants and the environment (Kolarevic & Parlac 2015). Switchable glazing is glass that can alter the visible light transmittance and g-values of a glazing assembly, with the U-value remaining largely unchanged. Dynamic glazing technologies are classified as ‘*passive*’ or ‘*active*’, with the latter having optical and thermal properties altered through voltage or electric current acting as the stimulus for change (Baetens et al. 2010; Michael et al. 2023). A key advantage of active technologies is the ability of the glazing to change its properties on demand, and if manually operable, giving full control to building occupants to address the specific requirements of their indoor environment at any moment in time. Electrically controllable dynamic glazing technologies

include electrochromic glazing (EC); suspended particle devices (SPD); liquid crystal devices (LC) besides other technologies. Electrochromic glazing operates by having lithium ions and electrons travelling from one electrochromic layer to another within the glazing assembly upon the application of a low voltage. (Casini, M., 2018) In its dark state the glazing limits the amount of light and heat that enters a space, with the opposite happening with the glazing set in a transparent state. Suspended Particle Devices (SPD) comprise of particles having optical properties suspended in an organic fluid in between two conductive layers (ITO), in turn embedded between two layers of PET (Polyethylene Terephthalate) film. In the OFF position, the particles are randomly arranged blocking most of the light. When voltage is applied, the particles align allowing increased light transmittance. To permit operation therefore, these devices need a continuous potential difference to operate, thus requiring continuous electrical energy consumption. (Granqvist 2007). Today’s advancement in this technology permits a very low power consumption of an average of 1.5W/m² (www.gauzy.com/spd-smart-glass), with SPD devices having typical visual transmittance ranges of 0.79–0.49 and 0.50–0.04; a switching time of 100–200 ms and require 65–220 V AC to operate. (Baetens et al. 2010). In their study, (Ghosh & Norton 2017) suggest that over a period of four years of physical testing, the transmittance behaviour of SPD switchable glazing changes very little, thus indicating the durability of the material, and the robustness of the technology.

Polymer dispersed liquid crystal devices (PDLC) comprise of two electrical conductors of thin transparent plastic with tiny liquid crystal spheres having a diameter of approximately 500 nm (Rezaei et al. 2017; Casini 2015). In its OFF state, the spheres are randomly aligned allowing the scattering of light, thus making the film completely translucent, (diffusing the light), obscuring view, and providing privacy. (Kim et al. 2015; Murray et. al., 2017). On application of a voltage, the crystals get aligned allowing light to be transmitted and making the film look transparent. Similarly to SPD technology, this film requires continuous voltage to retain a transparent state but unlike SPD, this film can only maintain too distinct states – OFF (translucent) and ON (transparent). One of the main benefits of PDLC is the ability to offer full privacy to building occupants, however the deployment of this

technology on its own within a façade still needs to be investigated.

A comparison of the main characteristics of these technologies are as shown in Table 1.

Smart window devices are nowadays increasingly being deployed within the automotive and luxury yacht industries as they can provide for a change in the indoor environment of passenger cabins. (www.gauzy.com/automotive-smart-glass-adas/). Similar potential exists in buildings wherein occupants spend a much greater amount of time. Moreover, the ability of PDLC materials to provide for privacy, gives added value to a façade which can completely disconnect its occupants from the external environment especially after sunset. 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. (Ibrahim et al. 2023).

The use of PDLC films within façades may have not yet been investigated enough. Current market applications of these types of films have been so far limited to internal partitions, primarily to provide for privacy screens. Manufacturers such as *Gauzy*; *Switch-film*; *Smartglass International*; and *Singyes* have been developing PDLC film suitable for use in facades and designed to withstand direct exposure to the sun. Gauzy offers an outdoor (solar and high-temp versions) PDLC (www.gauzy.com/outdoor-pdlc/) UV stabilised product designed to protect the film against long-term degradation from UV light. It is marketed as a product that can improve energy ratings by blocking the infra-red component of the electromagnetic spectrum without blocking natural light, while offering the benefits for building occupants to have a privacy screen on demand. Switchable glazing in general can indeed be easily integrated within building facades, provided that a source of low voltage is within reach. Factors such as durability and performance of the switchable films due to the long-term effects of climatic and thermal loads are subject areas that would merit further research, but which fall outside the scope of this paper.

3 Novel glazing assemblies

Solar-PDLC and SPD switchable technologies have clearly distinctive properties: privacy and dispersion of incident solar radiation; and the ability to control

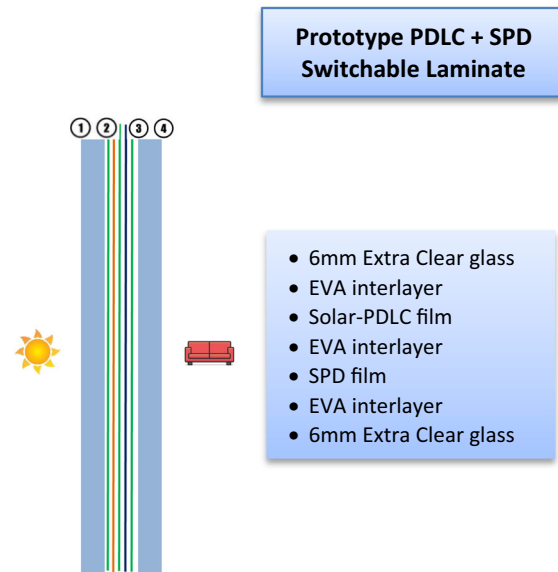


Fig. 1 Conceptual schematic detail of a potential novel switchable laminate

the levels of daylight to potentially achieve a glare-free indoor environment. Considering that these films can effectively be embedded in any sort of glazing configuration, the potential of them being both assembled within the same glazing element, leads to a potentially innovative combination for the benefit of the occupant.

Therefore, this combination can be effectively deployed in two distinct ways, namely:

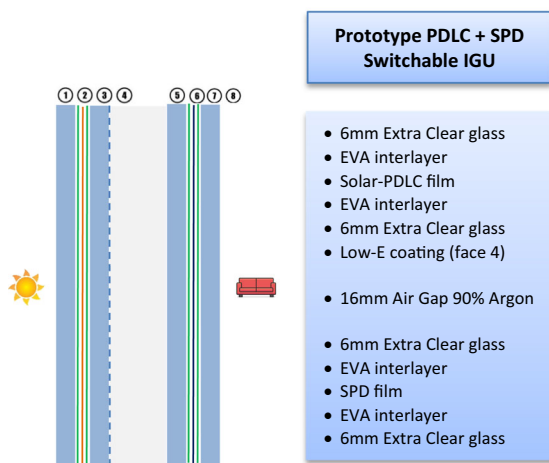
- The integration of both technologies into a single laminate, in the case where an insulated glazing unit is not required; or
- The deployment of both technologies within individually laminated elements, to be then assembled to form a switchable insulated glazing unit.

A schematic illustration of these configurations is as shown in Figs. 1 and 2.

To ensure durability, product specifications and manufacturer's instructions determined the order of placement of both switchable films. It was strongly recommended by the manufacturer to have the solar-PDLC film placed on the outermost face of the glazing assembly to protect the SPD film from potential degradation caused by the UV component of the electromagnetic spectrum. This order of placement applies to both prototypes.

Table 1 Technical characteristics of selected dynamic glazing technologies. *source Nundy et al. (2021). ** source www.gauzy.com

	Electrochromic glazing [EC] *	Solar polymer dispersed liquid crystal [solar-PDLC] **	Suspended particle device [SPD] **
Operating Voltage	0–5 V	42–70VAC	100VAC
Power Consumption	1.23 W/m ² (during switching times)	3 W/m ²	1.5 W/m ²
Switching Speed	Several minutes	10 ms	< 3 s
Dimmable [Y /N]	Y	N	Y
No Power State	bleached	translucent	tinted
Powered State	tinted	transparent	bleached
Privacy Application	No: Viewing is possible in tinted state	Yes: complete privacy is achievable	No: Viewing is possible in tinted state

**Fig. 2** Conceptual schematic detail of a potential novel switchable IGU

The recommended buildup for an IGU for use in a Mediterranean climate would require a thermal insulation (U) value in the order of less than 2 W/(m²K). To achieve this in normal practice, a low emissivity coating is recommended on the outer side of the cavity (face 4 in Fig. 2) in addition to having a cavity with 90% argon gas. The integration of both switchable films within each laminate would still allow for the assembly of an IGU having both the low emissivity coating and the argon cavity. Each individual laminate would be assembled using a vacuum bag lamination process followed by the assembly of both laminates in a single IGU. It can thus be confirmed that from a manufacturing perspective, the inclusion of switchable films is

practically achievable without compromising any of the benefits of a static IGU. The inclusion of the films will have a negligible effect on the mass of the unit, hence the U-value of such a unit is not expected to change. However, there may be a potential for an improvement on the overall thermal performance of the unit due to a better g-value, which potential would need to be investigated.

Having a glazing laminate with both solar-PDLC and SPD interlayers potentially allows for building occupants to have full control in terms of privacy, while having the control over the levels of daylighting within the room. Such a unit can therefore transform a static building element, often associated with overheating and visual discomfort in buildings with high glazing ratios into an interactive and responsive building element that can be adapted according to the transient diurnal and seasonal external environment. The common practice of installing shading devices in the form of internal blinds does not only fail to improve the quality of the indoor environment but in doing so, they obliterate all external views for which a building with a high glazing ratio would have had this design intent in the first place. Although a PDLC film in its OFF-state blocks outward views, the ability of both films to block most of the daylight if assembled within the same glazing assembly, would allow occupants to transform a window (the transparent building component) into an opaque element by operating an electronic switch. Moreover, a combined unit would give maximum flexibility for a building occupant to control daylight (to various degrees), privacy and view especially



Fig. 3 External and internal views of the scale model used for the luminance field experiments

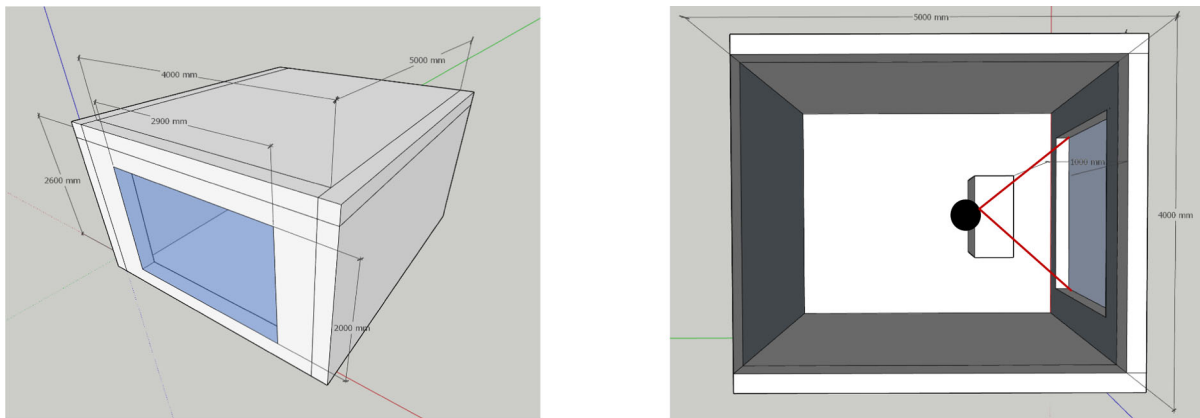


Fig. 4 Three-dimensional graphic and plan of the simulated real-life office showing the simulated seated location of an office worker

in those applications where the use of a conventional indoor blind is not desirable or not practical. If proven to be effective at reducing overheating and glare for facades, with further development of each individual technology, this makes it cheaper and thus more affordable. Hence the internal shading device may eventually be rendered obsolete. In addition, having these technologies capable of being connected to smart building systems and the IoT, combined with machine-learning and AI, the possibilities of integration and control of switchable glazing assemblies are practically endless.

4 Scale model experimental set-up

4.1 Scale model

The ultimate objective of this research study is to investigate the optimal glazing assembly through a full-scale

study. This will assess the long-term visual performance, including on-site monitoring experiments, as well as responses from human subjects, in full-scale test cells representative of offices. As a prelude to this study, a preliminary scaled-down assessment of the visual performance of various combinations of the switchable glazing assembly was deemed necessary, in order to compare to industry-grade static glass with solar control coatings. The principal two objectives of these field tests were to:

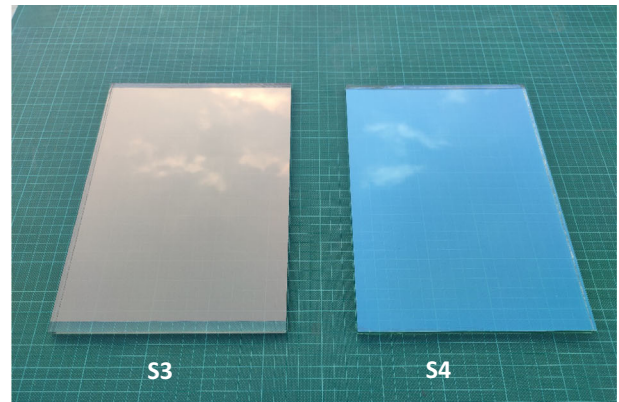
- shortlist the best comparable static glass assembly to be used as the reference model with the switchable glazing.
- assess the potential of the switchable films in their various assembly combinations under a challenging condition, being that of a façade facing west, with the sun at a low altitude angle directly in the field of view of a building occupant.



Test box mounting on a secure base



Luminance photometer within the test box.

Fig. 5 Photos of the experimental setup**Fig. 6** Photos of the static glazing samples featuring a solar control coating. *** ** Photos not taken on the same day as that of the experiment**Fig. 7** Photos of the switchable glazing samples – Solar-PDLC (Left); SPD (Right). *** ** Photos not taken on the same day as that of the experiment

Scale models under field test conditions for the analysis of visual and thermal properties of switchable glass have been adopted in other studies, primarily by (Ghosh & Norton 2018); (Ghosh et.al., 2016) and (Ghosh et.al., 2015) for their studies of glazing samples with SPD. In their research, tangible results were reported for the various metrics collected in their experiments, including the Daylight Factor (DF), Daylight Glare Index (DGI) and Useful Daylight Illuminance (UDI). Using an available sample set of static and switchable glazing samples of dimensions 290×200 mm provided by the switchable film manufacturer and considering the appropriateness on the use of a scale model to collect preliminary data, a physical model of a room scaled 1 in 10 was constructed as shown in Figs. 3, 4 and 5, having an indoor dimension of 400 mm in width; 500 mm in depth; and 260 mm in height. The size of the scale model provided a glazing ratio of 56% whereas due consideration was given to allow for the placement of a luminance photometer within the test box. Particular attention was given to both the choice of materials and the assembly method not to allow for any stray lighting or reflections to penetrate the scaled indoor space other than that entering through the glazed aperture. An opaque blackout fabric was installed 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. Due consideration was also given to ensure that the size of the test box was sufficient to ensure that the captured images are in focus and that the luminance maps generated would have a similar geometrical appearance as those normally take in a full-scale setup. (Figs. 6, 7, 8 and 9)

Due to the limited size of the test box, the luminance photometer could only be placed in one specific position, at the normal to the aperture, simulating a person sitting directly facing the window. This viewing position may not be fully representative of a typical seating position in a room and is a limitation for a scale model. However, a comparison of different DGP readings between different switchable glazing configurations, relative to the samples of static glass, would still be sufficient at giving an indication of which order and combination, switchable films would perform best. Cognizant of the fact that scale factors may affect results taken in absolute terms with experiments



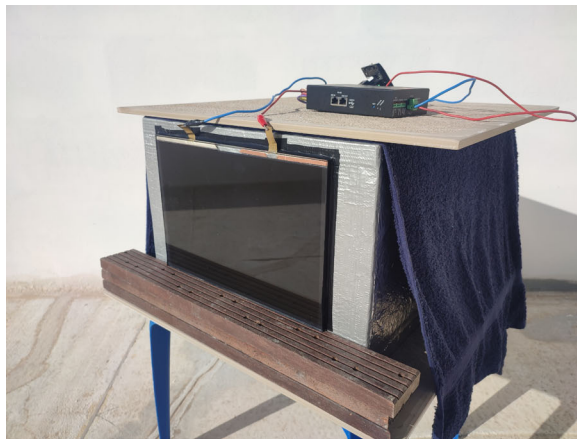
Fig. 8 View of the Gauzy-Hitachi prototype combined solar-PDLC & SPD laminate under investigation. **** Photos not taken on the same day as that of the experiment

involving scale models, it is believed that in the case of these experiments, the behaviour of incident light into a space is independent of the size of the testing chamber. Due to the extremely small size of light wavelengths (380–790 nm), the physical behaviour of light is identical for both a full-size room and its equivalent scale model. (Ruck et. al., 2000). Considering also that all readings were taken under identical conditions in relative comparison, any such factors ought not influence the outcome of the results.

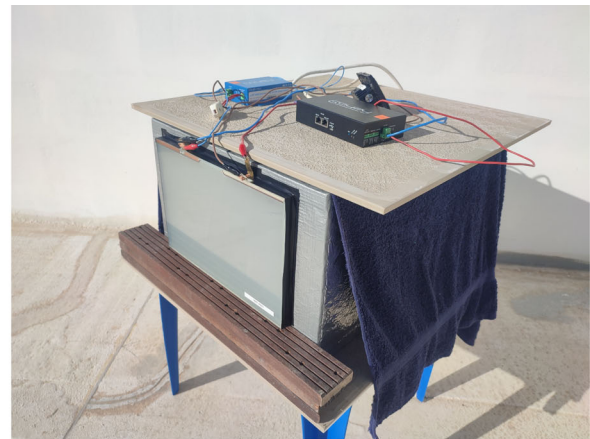
4.2 Selection of the glass samples for field testing

Market research was carried out in conjunction with a leading architectural glazing supplier in Malta to establish specific glazing products most often ordered for use in curtain walls. The scope of this exercise was to shortlist and test the most appropriate static reference glazing to be compared with the switchable samples. Four samples have been identified, the characteristics of which are listed in Table 2, with the parallel light transmittance of each of the samples measured by a calibrated WTM-1200 tint meter, having a resolution of 0.1 and an accuracy of $\leq 2\%$.

Different configurations of switchable glazing technologies were then established for testing. The configurations could be classified in four main categories (Table 3), namely:



SPD switchable laminate (OFF state)



Overlaid solar-PDLC and SPD laminates (OFF state)

Fig. 9 Photos showing typical placement of glazing samples onto the scale model**Table 2** Technical characteristics of static glazing samples featuring a solar control coating

Specimen ID (S: Static)	Brand name	Configuration	Thickness [mm]	Dimensions [mm]	Specified VLT [%]	Measured VLT ^{***} [%]
S1	Guardian SunGuard Solar Bronze 20	Single-glazed unit	6	300 × 210	20	19.0
S2	Guardian SunGuard HP Bronze 40/27	Insulated glazed unit	6–10-4	300 × 210	40	35.7
S3	Saint Gobain KN148	Single-glazed unit	8	300 × 210	48	39.5
S4	Guardian SunGuard SN70/35HT	Single-glazed unit	8	300 × 210	70	64.0

* Parallel light transmittance was measured using a calibrated WTM-1200 tint meter, having a resolution of 0.1 and an accuracy of $\leq 2\%$

** Total visible light transmittance assumed to be equal to the parallel light transmittance considering that samples consist of clear glass

- Switchable solar-PDLC film laminate. [4 mm clear glass + EVA interlayer + PDLC film + EVA interlayer + 4 mm clear glass]
- Dimmable SPD film laminate. [4 mm clear glass + EVA interlayer + SPD film + EVA interlayer + 4 mm clear glass]
- Switchable solar-PDLC film and dimmable SPD film laminated in a SINGLE LAMINATE. [4 mm clear glass + EVA interlayer + PDLC film + EVA interlayer + SPD film + EVA interlayer + 4 mm clear glass]
- Switchable solar-PDLC film laminate OVERLAID onto a dimmable SPD film laminate. [4 mm clear glass + EVA interlayer + PDLC film + EVA interlayer + 4 mm clear glass] + [4 mm clear glass + EVA interlayer + SPD film + EVA interlayer + 4 mm clear glass]

5 Testing approach

5.1 Visual appearance tests

A series of short-exposure ($1/250$ s) photos were taken with a TechnoTeam® LMK Mobile-R image-resolved luminance camera, comprising of a Canon EOS80D DSLR equipped with a SIGMA 4.5 mm 1:2.8 circular fish-eye lens between 1100 h and noon on 11th March under a clear blue sky to record the visual appearance of all the static and dynamic glazing samples, under all switching combinations. Each sample of glass was placed directly on the anti-reflection ring of the fish-eye lens, and images captured with the camera directly facing the sun. The objective was to visually assess the appearance of the solar disc through the different glazing samples while gauging the ability of a human

Table 3 Technical characteristics of the switchable glazing configurations under consideration

Specimen ID (D: Dynamic)	Configuration	Switching state	Thickness [mm]	Dimensions [mm]	Parallel light transmittance* [%]
D1a	Gauzy Solar-PDLC laminate	OFF (translucent)	9.62	340 × 235	< 1.1
D1b		ON (transparent)			72
D2a	Gauzy-Hitachi SPD laminate	OFF (tinted)	9.79	340 × 235	< 0.1
D2b		ON (bleached)			45
D3a	Prototype Gauzy-Hitachi Solar-PDLC + SPD combined laminate	PDLC (OFF) < SPD (OFF)	10.61	340 × 235	< 0.1
D3b		PDLC (OFF) < SPD (ON)			< 0.1
D3c		PDLC (ON) < SPD (OFF)			< 0.1
D3d		PDLC (ON) < SPD (ON)			35
D4a	Prototype Gauzy-Hitachi Solar-PDLC + SPD overlaid laminate	PDLC (OFF) < SPD (OFF)	19.41	340 × 235	< 0.1
D4b		PDLC (OFF) < SPD (ON)			< 0.1
D4c		PDLC (ON) < SPD (OFF)			< 0.1
D4d		PDLC (ON) < SPD (ON)			32**

*Parallel light transmittance was measured using a calibrated WTM-1200 tint meter, having a resolution of 0.1 and an accuracy of $\leq 2\%$

** Approximate value since thickness of glazing laminate exceeds the maximum specification of the tint meter (18 mm)

**Fig. 10** Photographic fish-eye shots of the solar disc as seen through the reference glass samples

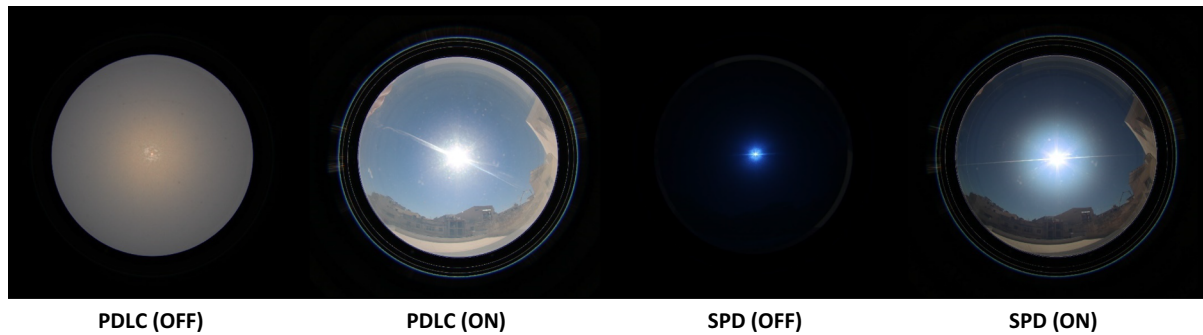


Fig. 11 The solar disc as seen by the naked eye through the separate PDLC and SPD laminates. (different states)

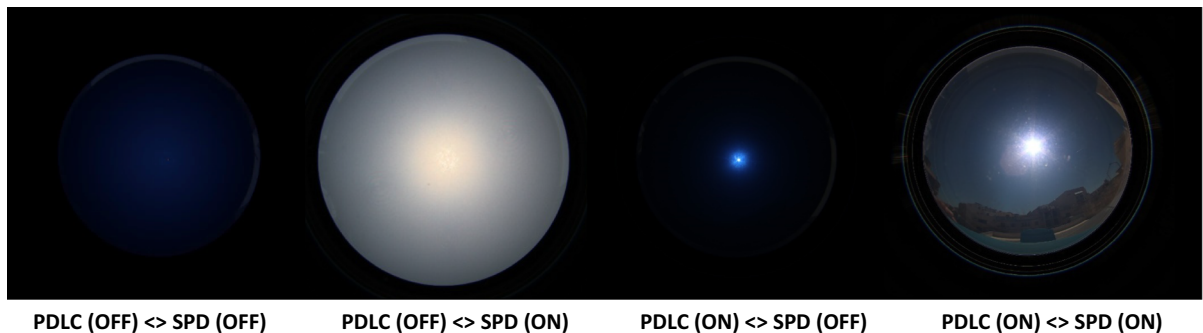


Fig. 12 The solar disc as seen by the naked eye through the prototype combined PDLC + SPD laminate (different states)

eye to look directly at the sun. The photographs featured in Figs. 10, 11 and 12 show a clear distinction in the appearance of the solar disc between the different categories of samples.

As expected, the intensity of the solar disc through the static glass varies according to the visible light transmittance. It was noted that in all four cases, a human subject could not withstand the intensity of light when looking directly at the solar disc. It could be also noted that the Guardian SunGuard SN70/35HT featured a slight degree of transmission haze with a slightly less clarity than the other three samples (Fig. 10).

The solar-PDLC was noted to offer good protection against incident solar radiation with the image showing evident dispersion of light across the entire fish-eye image. The SPD laminate performed better at blocking off solar radiation with the solar disc diameter reduced to a small, dimly illuminated circle with most of the surrounding pixels in the image appearing completely dark (Fig. 11). This was noted despite the reading taken by the tint meter, listed in Table 2 as having 0 parallel light transmittance, being likely related to the resolution of the instrument.

In their transparent/bleached state, the appearance of the solar disc was noted to be similar to that featured through the conventional, static samples. In its switched-on state, the PDLC film appeared to feature an element of transmission haze. Due to the nature of the PDLC formulation, the presence of haze appears to be at its lowest when the sample is viewed perpendicularly to the glass and tends to increase when the sample is viewed at a greater angle from the normal (Fig. 11).

The prototype solar-PDLC and SPD films combined within the same laminate appeared to provide exceptional protection in its PDLC (OFF) < > SPD (OFF) (*translucent and tinted*) state with the solar disc nearly completely blacked out. In its PDLC (ON) < > SPD (ON) (*transparent and bleached*) state, the view towards the solar disc featured a similar state to that of the conventional, static samples. In the PDLC (OFF) < > SPD (ON) (*translucent and bleached*) and PDLC (ON) < > SPD (OFF) (*transparent and tinted*) states, the images resembled closely to that of the same films with individual laminates (Fig. 12). In the case of PDLC(ON) < > SPD(OFF), the solar disc appeared as a very dim, slightly illuminated, and concentrated dot.

This was noted despite the reading taken by the tint meter and listed in Table 2 as having 0 parallel light transmittance, being likely related to the sensitivity of the instrument.

The prototype overlaid solar-PDLC and SPD laminates also showed excellent protection in its PDLC (OFF) < > SPD (OFF) (*translucent and tinted*) state, with the solar disc again nearly completely blacked out. In its PDLC (ON) < > SPD (ON) (*transparent and bleached*) state, the view towards the solar disc again featured a similar state to that of the conventional, static samples. In the PDLC (OFF) < > SPD (ON) (*translucent and bleached*) and PDLC (ON) < > SPD (OFF) (*transparent and tinted*) states, the image resembled closely to that of the same films laminated individually (Fig. 13).

5.2 Methodology for measuring glare

Various glare indices have been developed over the years. (Hopkinson 1972) first attempted to quantify glare from daylight through the establishment of the “Daylight Glare Index” (DGI), which “*had the merit to introduce in its equation all the main factors potentially concurring in the determination of a glare condition from daylight: luminance and solid angle of the light source, average luminance of the background, position of the light source relative to the observer’s field of view*”. (Iwata et al. 1992a; Iwata et al. 1992b; Waters et al., 1995) however show that “*DGI showed a low reliability as a glare predictor in presence of windows, especially when these occupy most of the observer’s field of view, or when the sun is in the occupant’s visual field*.” (Velds 1999) later simplified the calculation of daylight glare and attempted “*to estimate it by using the vertical illuminance at the observer’s eyes, in replacement of the background luminance*.” (Wienold & Christoffersen 2006) had introduced 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*”, as in.

$$DGP = 5,87 \cdot 10^{-5} \cdot E_v + 9,18 \cdot 10^{-2} \cdot \log \left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1,87} \cdot P_i^2} \right) + 0,16$$

where $L_{s,i}$ is the source luminance (cd/m²), $\omega_{s,i}$ 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 mainly 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 and is widely considered as being the standard approach for the computation of glare. (Pierson et al. 2021) 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. (Pierson et al. 2018) further describe analytical methods for the simulation of glare using the Evalglare software.

The primary objective of this part of this experiment was the generation of a dataset of luminance images taken under identical climatic considerations 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 4.5 mm 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 (TechnoTeam, n.d.). Apart from the identification of all light sources in the field of view of the observer, the Daylight Glare Probability [DGP] as described by (Wienold and Christoffersen 2006) was computed through software, this metric giving a reliable indication of the potential discomfort or otherwise to the observer when facing the glazing sample with sun in the direct 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 able to handle the entire procedure of merging all photos into a single HDR, the creation of the luminance maps and calculating the DGP.

All field measurements were taken in August 2024 on an unobstructed roof of a building within the central part of Malta, with a 50-min time period to minimize effects of transient weather and sky conditions that could have had a bearing on the results. Weather

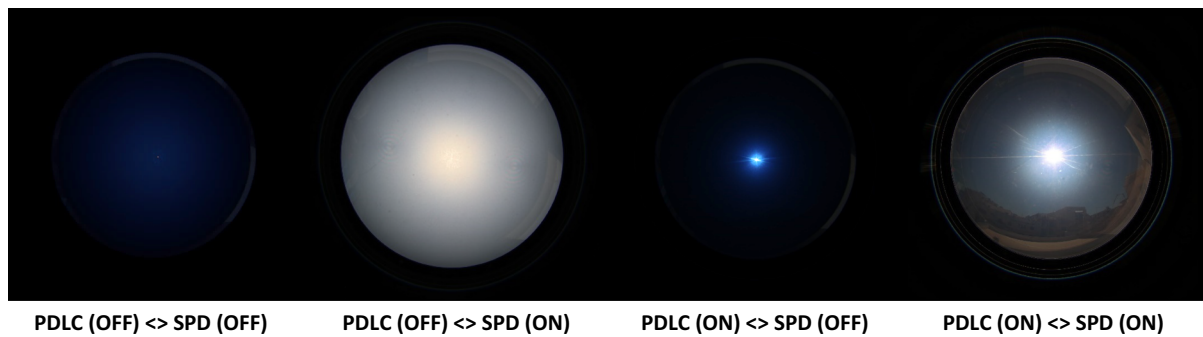


Fig.13 The solar disc as seen by the naked eye through the overlaid PDLC + SPD laminate (different states)

conditions at the time of the tests were an average temperature of 31 degrees Centigrade; with an average windspeed of 13 km/hr under a clear blue, cloudless sky, typical of a Mediterranean August day.

The luminance camera was positioned at a distance of 20 cm from the glazed opening within the model, representing an occupant in a seated position at distance of 2 m from the glazed façade. The camera was mounted on a secure base, with a series of 5 photographic shots, each taken at different exposure times [$1/250\text{ s}$, $1/200\text{ s}$, $1/160\text{ s}$, $1/125\text{ s}$ and $1/100\text{ s}$] to create an HDR image for the eventual processing through software.

The images collected were analysed using the LMK LabSoft® software suite, wherein a series of high dynamic range images were first created for each scene, followed by the generation of a dataset of high-resolution luminance images. For the analysis of glare, the threshold luminance for each scene was set at 3,000 cd/sq.m., this being the threshold for visual discomfort as suggested by (Bian & Luo 2017). This value of 3000 cd/sq m. is midway within a range specified by (Wienold & Christofferson 2005) with luminance values < 1,500 cd/sq.m. likely to be perceptible and > 4,500 cd/sq m. likely to be uncomfortable for a view direction perpendicular to a window.

Having the solar disc in the direct field of view, it was expected that some pixels within the luminance maps would experience luminous overflow considering that neutral density filters were not used for these experiments. Cognizant of the fact that ‘overdriven’ pixels may have an effect on the accuracy of the DGP calculation (Jakubiec et al. 2016), the number of overdriven pixels was, in each case, expressed as a ratio of the total number of pixels of the light source containing the solar

disc. This ratio has been reported in the results, as a statistical error, (Tables 4 5 and 6), to denote the accuracy of the contrast component of the DGP equation for the light source containing the solar disc.

6 Results & observations of DGP performance

A graphical representation of all luminance maps and the ranges of luminous intensity in cd/sq.m. for each scene is as featured below. Results show the computed Daylight Glare Probability [DGP], and the number of light sources picked up by the luminance photometer based on the selected luminance threshold as shown in the respective tables.

The classification of glare has been based on the four-point scale described by (Weinold, 2009) and adopted in similar studies, such as (Reinhart & Wienold, 2011), wherein glare discomfort is classified into classes, precisely: *imperceptible glare* ($DGP < 35\%$); *perceptible glare* ($35\% \leq DGP < 40\%$); *disturbing glare* ($40\% \leq DGP < 45\%$) and *intolerable glare* ($DGP \geq 45\%$). A graphical representation of this 4-point scale is as shown in Fig. 14. This categorization now also forms part of the normative standard EN 17037:2018. (Figs. 15, 16 and 17)

6.1 Static glass samples

Results for the samples featuring static solar control coatings are as shown in Table 4. The values of the DGP of the four samples tested appear to correlate with the visible light transmittance of the samples. It was

Table 4 Tabulated Results of the Static Glass Reference Samples

Specimen ID	Brand name	DGP [%]	DGP classification	Number of light sources identified	Luminance threshold [cd/sq.m.]	Statistical error [%]
S1	Guardian SunGuard Solar Bronze 20	41.51	<i>disturbing</i>	22	3,000	0.188
S2	Guardian SunGuard HP Bronze 40/27	60.76	<i>intolerable</i>	130	3,000	0.147
S3	Saint Gobain KN148	70.25	<i>intolerable</i>	134	3,000	0.157
S4	Guardian SunGuard SN70/35HT	$\geq 100^*$	<i>intolerable</i>	108	3,000	0.191

*DGP values measured as greater than 1 (100%) reported as being at the theoretical maximum level of 1 (100%)

Table 5 Tabulated Results of the Switchable Glass Laminates

Specimen ID	Brand name	DGP [%]	DGP classification	Number of light sources identified	Luminance threshold [cd/sq.m.]	Statistical error [%]
D1a	Gauzy PDLC off	$\geq 100^*$	<i>intolerable</i>	116	3,000	0.003
D1b	Gauzy PDLC on	$\geq 100^*$	<i>intolerable</i>	87	3,000	0.122
D2a	Gauzy-Hitachi SPD off	25.15	<i>imperceptible</i>	1	3,000	3.964
D2b	Gauzy-Hitachi SPD on	57.40	<i>intolerable</i>	134	3,000	0.124

*DGP values measured as greater than 1 (100%) reported as being at the theoretical maximum level of 1 (100%)

Table 6 Tabulated Results of the prototype Solar-PDLC + SPD combined laminate

Specimen ID	Brand name	Switching state	DGP [%]	DGP classification	Number of light sources identified	Luminance threshold [cd/sq.m.]	Statistical error [%]
D3a	Prototype Gauzy-Hitachi Solar-PDLC + SPD combined laminate	PDLC (OFF) < > SPD (OFF)	17.46	<i>imperceptible</i>	2	3,000	0.000*
D3b		PDLC (OFF) < > SPD (ON)	69.72	<i>intolerable</i>	12	3,000	0.004
D3c		PDLC (ON) < > SPD (OFF)	27.26	<i>imperceptible</i>	2	3,000	7.580
D3d		PDLC (ON) < > SPD (ON)	50.56	<i>intolerable</i>	92	3,000	0.111

*No overdriven pixels identified

0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	
imperceptible								intolerable											
				perceptible			disturbing												

Fig. 14 Graphical representation of the DGP four-point scale classification. (Weinold 2009)

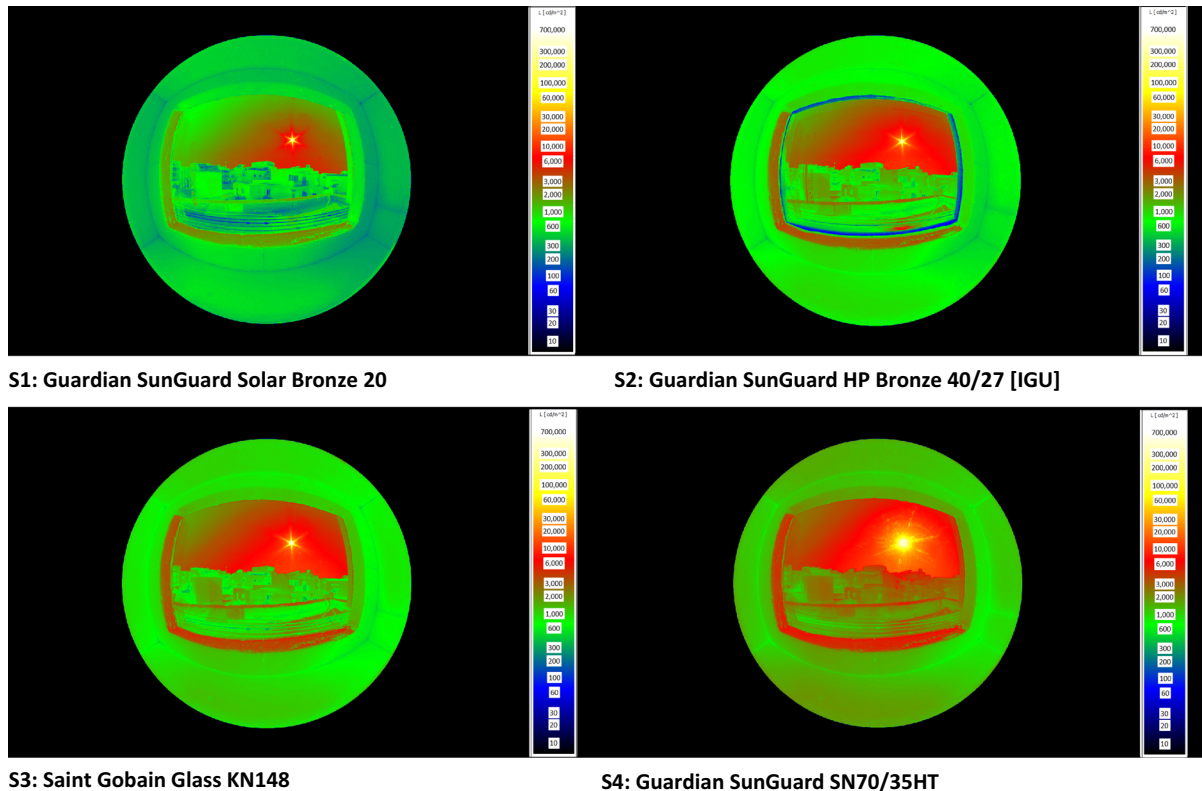


Fig. 15 Luminance maps for the four reference static glazing samples featuring a solar control coating

noted that sample S1 with the lowest VLT of 20% still achieved a value of 0.42 (42%) DGP—a reading falling within the bracket in which a building occupant would most likely experience glare categorised as ‘*disturbing*’. Samples S2, S3 and S4 achieved DGP readings within the ‘*intolerable*’ bracket with most of the light sources picked up by the luminance photometer being mainly the reflections within the space itself, along the perimeter of the aperture’s opening due to the slight unevenness of the model’s material. Statistical errors representative of the number of ‘overdriven’ pixels in relation to the size of the light source containing the solar disc were observed as being less than 0.2%.

6.2 Individual switchable PDLC and SPD laminates.

Results for the switchable laminates tested individually are as shown in Table 5. The DGP values of the two switchable laminates in each of their two states feature across two opposing ends of a rather wide range (25.15%— $\geq 100\%$). The readings with the solar PDLC film in both its switching states (*translucent*: D1a, *transparent*: D1b) feature exceptionally high values far above 0.45 (45%) DGP, beyond which glare would be considered ‘*intolerable*’. The physical composition of the formulation disperses incident solar radiation uniformly across the surface of the glass, making it behave

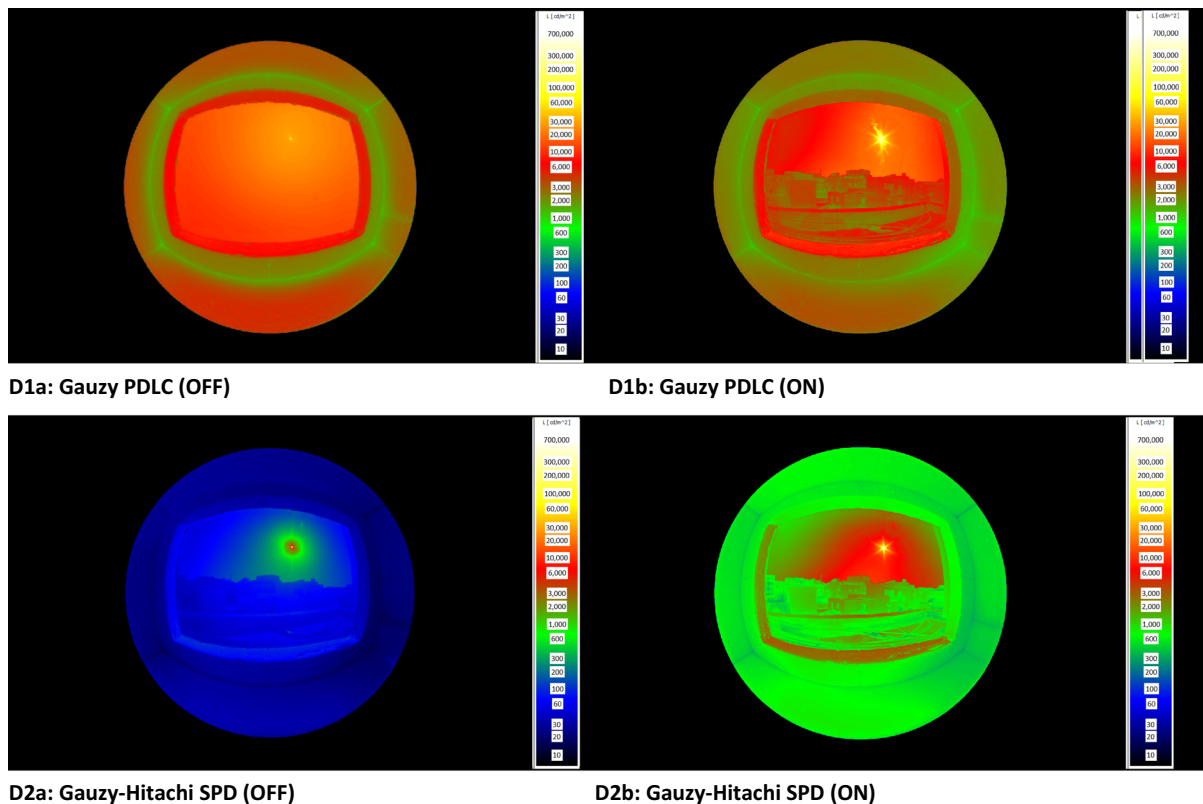


Fig. 16 Luminance maps for the two independent solar-PDLC and SPD laminates in their various switching states

as a translucent uniform light source in itself. The high value of this reading may have been unexpected considering its visual appearance and its apparent ability to offer visual protection when placed in front of the solar disc (Sect. 5.1). The substantial number of light sources read by the luminance photometer refer again to internal reflections off the material's texture of the scale model. Both components of the DGP formula affect the DGP value in that the value depends both on the vertical illuminance of a scene and on the intensity and size of the light source, contributing to a greater value of $L_{s,i}$ (the source luminance) and $W_{s,i}$ (the solid angle of the source subtended towards the point of observation). Having the entire glass acting as a light source, the effect of its intensity coupled by the size and hence the solid angle it subtends, contributes to a high value of the DGP.

The SPD film in its fully bleached state (D2b) exceeded a DGP of 0.45 (45%) ('intolerable'). This result was expected considering the visual similarity of the glass in this state when compared to a static

reference glass. In its fully tinted state (D2a), the reading confirms the ability of this technology to keep the DGP value of the scene, within the 'imperceptible' limits, that is less than 0.35 (35%), even with the sun in the direct field of view, on a cloudless, blue-sky day in August. The higher value of the statistical error is likely due to the small size of the light source containing the solar disc exceeding 3,000 cd/sq.m.

6.3 Prototype combined switchable laminate

Results for the prototype combined switchable laminate are as shown in Table 6. The DGP values of the prototype solar-PDLC + SPD laminated unit fall within a much narrow range than the readings observed for both films laminated individually. In their OFF (*translucent and tinted*) state (D3a), both films provide for a DGP value well below 0.3 (30%), thus within the 'imperceptible' range. In their fully ON (*transparent and bleached*) state (D3d) they achieved a visual appearance very close to that provided by the conventional

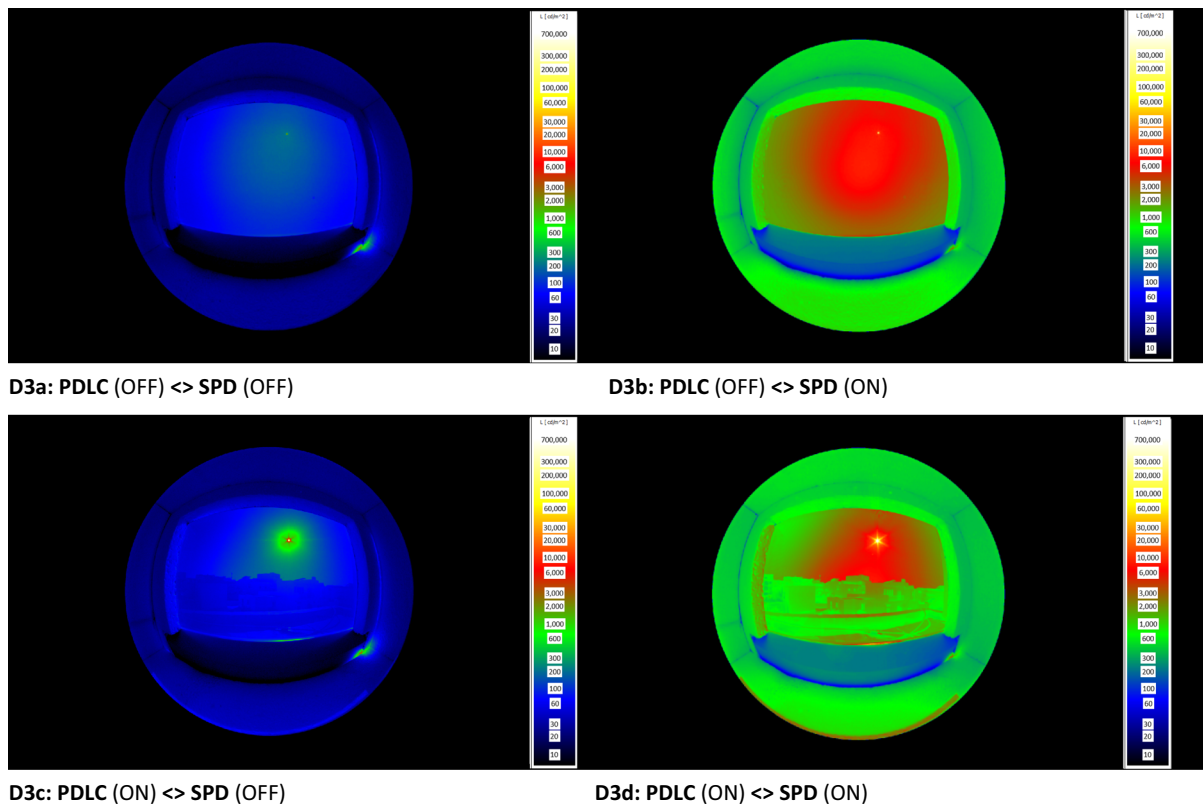


Fig. 17 Luminance maps for the prototype Solar-PDLC + SPD combined laminate

glazing samples, with the DGP value exceeding 0.45 (45%)—‘*intolerable*’, with the sun in the direct field of view.

With the PDLC:ON + SPD:OFF state (*transparent and tinted*) (D3c), the DGP value again falls within the ‘*imperceptible*’ range, whereas with the PDLC:OFF + SPD:ON state (*translucent and bleached*) (D3b), the internal scatter of the incoming solar radiation increased the overall DGP value substantially to 0.646 (64.62%) thus falling with the ‘*intolerable*’ range. This result shows that although the SPD film may be more suited for the control of indoor daylighting levels, its combination with the solar-PDLC within the same laminate, reduces further the maximum level of DGP that it could ever achieve if deployed on its own on a building façade. The substantial number of light sources observed, again refer to internal reflections around the perimeter of the model’s glazed opening, whereas the higher value of the statistical error in test case (D3c) being likely related to the very small size of the light

source containing the solar disc exceeding the luminance threshold of 3,000 cd/sq.m.

6.4 Prototype overlaid switchable laminates

Results for the prototype overlaid switchable laminate are as shown in Table 7. The DGP values of the prototype solar-PDLC + SPD overlaid unit, representative of a novel switchable IGU, again fall within a relatively narrow range than the readings observed for both films laminated individually. In their OFF (*translucent and tinted*) state (D4a), this assembly provides for the lowest DGP value of the entire dataset and well within the ‘*imperceptible*’ range. With both films in their fully ON (*transparent and bleached*) state (D4d), this prototype assembly performs nearly equal to the prototype combined laminate but still provides a maximum DGP value beyond 0.45 (45%), ‘*intolerable*’ thus very close to that provided by the conventional glazing samples. With the PDLC:ON + SPD:OFF state (*transparent and tinted*) (D4c), the DGP value again falls well

Table 7 Tabulated Results of the prototype Solar-PDLC + SPD overlaid laminate

Specimen ID	Brand name	Switching state	DGP [%]	DGP Classification	Number of light sources identified	Luminance threshold [cd/sq.m.]	statistical error [%]
D4a	Prototype Gauzy-Hitachi Solar-PDLC + SPD overlaid laminate	PDLC (OFF) < > SPD (OFF)	17.37	<i>imperceptible</i>	1	3,000	0.000*
D4b		PDLC (OFF) < > SPD (ON)	65.68	<i>disturbing</i>	4	3,000	0.004
D4c		PDLC (ON) < > SPD (OFF)	27.59	<i>imperceptible</i>	1	3,000	5.597
D4d		PDLC (ON) < > SPD (ON)	51.22	<i>intolerable</i>	28	3,000	0.112

*No overdriven pixels identified

within the '*imperceptible*' range, with a higher value of the statistical error again related to the very small size of the light source containing the solar disc exceeding the luminance threshold of 3,000 cd/sq.m. In the case of the PDLC:OFF + SPD:ON state (*translucent and bleached*) (D4b), the DGP value at 0.656 (65.68%) falls within the '*intolerable*' range thus slightly below the 0.697 (69.72%) observed with the prototype combined laminate ('*intolerable*'). These results show that there seems to be an equal potential in having an overlaid assembly of both films in a fashion usually adopted in the assembly of an IGU.

All DGP readings of the sixteen experiments were plotted onto a graph to summarize the findings (Fig. 18). Results show that in the case of a west-facing orientation with the sun in the field of view, static glazing with solar control coatings can never achieve the desired levels of glare control even with a visible light transmittance as low as 20%. SPD technology appears to have the greatest potential of controlling glare, whereas solar-PDLC when used on its own appears to have a magnification effect on the level of glare within an indoor space.

The prototype assembly comprising both films within a single laminate, on the contrary, appears to combine the benefits of both technologies in achieving a glare level well within the recommended limits when switched to its fully translucent and tinted state. Results clearly demonstrate that in its fully transparent and bleached state, the assembly can still reduce the level of glare when compared to static glazing with a visible light transmittance of 40% and above. The

prototype model for a novel switchable IGU further confirmed the performance of both switchable technologies within the same assembly by giving results within the '*imperceptible*' range with the SPD film in its fully tinted state.

7 Results & observations of luminous intensity

An assessment of the light sources identified by the luminance photometer was also carried out on all test samples. A light source is any region within the luminance map that exceeds the luminance threshold of the scene under study. In these experiments, the solar disc was always in the direct field of view, hence as expected, it acted as the brightest light source for each scene. What differed across the sixteen scenes analyzed was the size and mean luminance of the light source containing the solar disc, both parameters having a bearing on the perception of glare from the given viewing direction.

The size of the subtended angle (measured in steradians) of each of the sixteen experiments were recorded and plotted in the graphical representation shown in Fig. 19. The chart shows a wide range of sizes of subtended angles ranging from 2.6810sr to a negligible 0.0001sr. The static glazing samples featured a progressive increase in the size of the light source with sample S1 (*Guardian SunGuard Solar Bronze 20: 20% VLT*) being the smallest, to sample S4 (*Guardian SunGuard SN70/35HT: 70% VLT*) the largest.

The solar-PDLC samples featured the highest values of subtended angles both in their

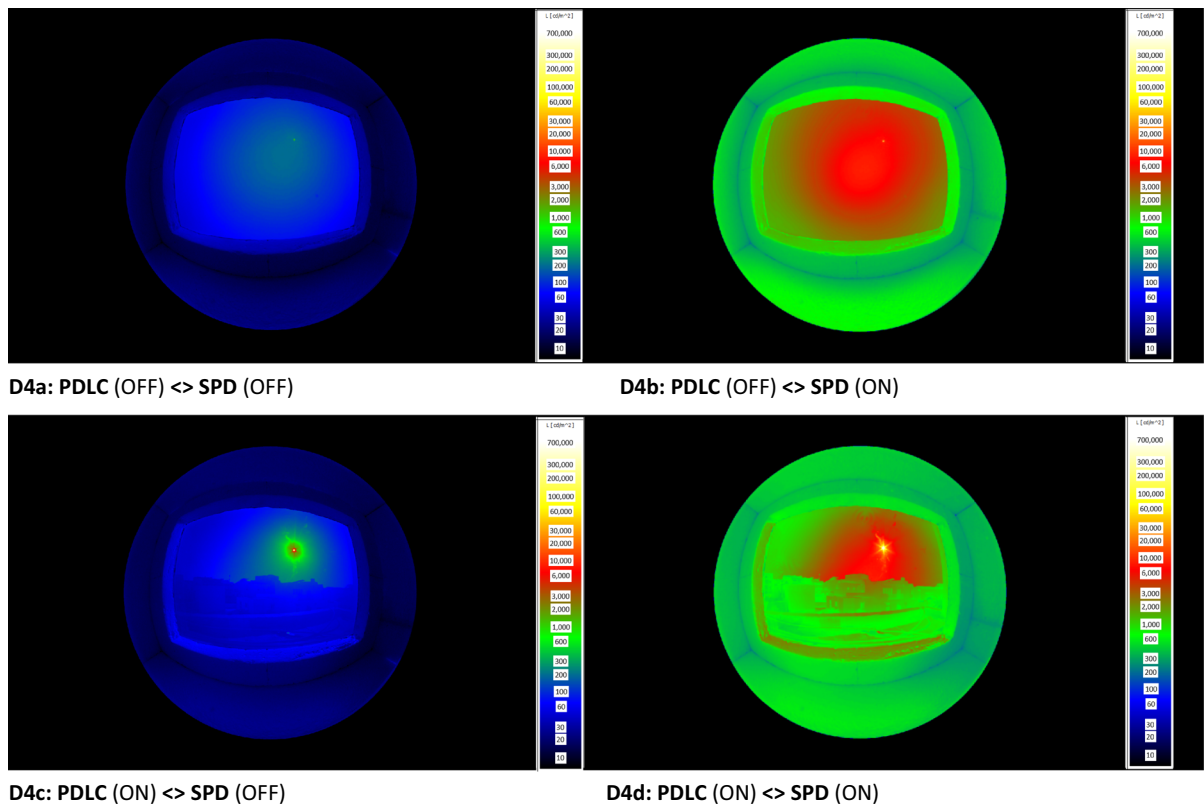


Fig. 18 Graphical distribution of the results of the DGP values for the entire testing experiment

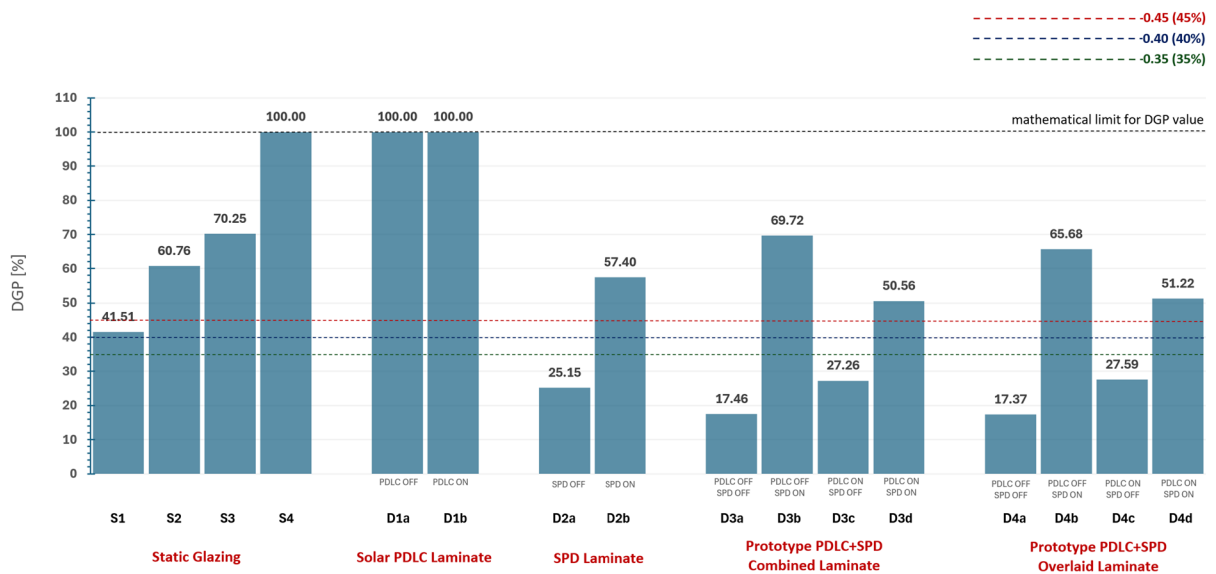


Fig. 19 Graphical representation of subtended angles of the light source containing the solar disc

OFF (D1a—*translucent*) and ON (D2b—*transparent*) states. The dispersion of light in its OFF state effectively converts the glass as a diffused light source in itself, hence the size of the subtended angle. The reason for the apparent amplification of the light source in its ON (*transparent*) state is still being investigated and may be due to the slight effect of the haze, typical of PDLC.

The SPD laminate in its OFF (*tinted*) state (D2a) featured an exceptional reduction of size of the solar disc to 0.0034, whereas in its ON (*bleached*) state (D2b), the performance of the glass was similar to that experienced by static samples with a VLT of 20–40% (samples S1 and S2).

The prototype combined switchable laminate featured a complete blackout effect when both films were switched OFF (D3A—*translucent* and *tinted*) but with a substantially large, subtended angle when the SPD was switched to its bleached state (D3b). This is again likely due to the dispersion of light by the solar-PDLC. With the solar-PDLC switched ON (*transparent*) and the SPD film in its OFF (*tinted*) state (D3c), the subtended angle by the solar disc was very low, whereas with both films in their ON state (*transparent* and *bleached*), the size of the light source was again similar to the that of the static samples with a VLT of 20–40%.

The prototype overlaid switchable laminate representative of an IGU again featured exceptionally low values of the subtended angle in both cases when the SPD was kept OFF (*tinted*) (D4a and D4c). With this combination of switchable technologies, however, there was a slight reduction in the size of the subtended angle in both conditions where the solar-PDLC was kept OFF (*translucent*) (D4b and D4d) when compared to the case with both technologies installed within the same laminate, possibly resulting from the presence of the additional thickness of glass within the overlaid assembly.

These results show that the combination of both switchable films within the *same laminate* or in an IGU can provide for a substantial improvement in glare control when compared to the same technologies *deployed individually* on a building façade. In addition, their combination can also provide the facility for a transparent glazing element to be instantly converted into a nearly opaque state.

An assessment of the mean luminance values within the light source containing the solar disc was carried

out on all sixteen experiments. Results were plotted in a histogram as shown in Fig. 20. In the case of the glass samples featuring static solar control coatings, the mean luminance values showed a progressive increase in the readings in relation to the visible light transmittance of each static sample: a range between 5,032 cd/m² for the glass sample with a 20% VLT (S1) to 7,679 cd/m² for the glass sample with a 70% VLT (S4).

The solar-PDLC laminate in its OFF (*translucent*) state (D1a) featured a substantially higher mean luminance value of 15,390 cd/m² which related to the film's ability at diffusing direct solar radiation. In its ON (*transparent*) state, (D1b), the maximum level of luminance achieves a mean of 8,646 cd/m², thus within the range of a conventional static glass with a VLT of over 70%.

The SPD laminate on the other hand, featured a much higher level of mean luminance, in its OFF (*tinted*) state (D2a) with a mean of 24,200 cd/m². This result is likely due to a high value of illuminance concentrated within a very small solid angle of 0.0034 steradians (Fig. 21), thus resulting in a high mean value within the light source containing the solar disc. In its ON, (*bleached*) state, the laminate still achieved a mean value of 6,886 cd/m², comparable to a static glass with a VLT of approximately 40%.

The prototype combined switchable laminate with both PDLC and SPD films switched OFF (*translucent* and *tinted*) (D3a) featured a mean luminance value comparable to that of a static glass with a VLT of between 48 and 70%, but within a negligible size of the solid angle of the light source containing the solar disc. With the SPD film switched ON and PDLC switched OFF (*translucent* and *bleached*), (D3b), the mean luminance value decreased to 5,452 cd/m², thus lower than achieved with the PDLC laminate by itself (D1b). With the PDLC (ON) and SPD (OFF) state (*transparent* and *tinted*), (D3c), the mean luminance value was at the highest of the entire dataset (47,170 cd/m²). This is possibly due to an amplification effect of the luminance value at the centre of the solar disc brought about by the presence of the PDLC film in its transparent state. The negligible size of the solid angle of the light source containing the solar disc appears to limit any negative visual effect of this high mean luminance value as could be confirmed by the low DGP value of 27.26% (Fig. 18). With both films in their ON state (*transparent* and *bleached*) (D3d), the mean luminance value was

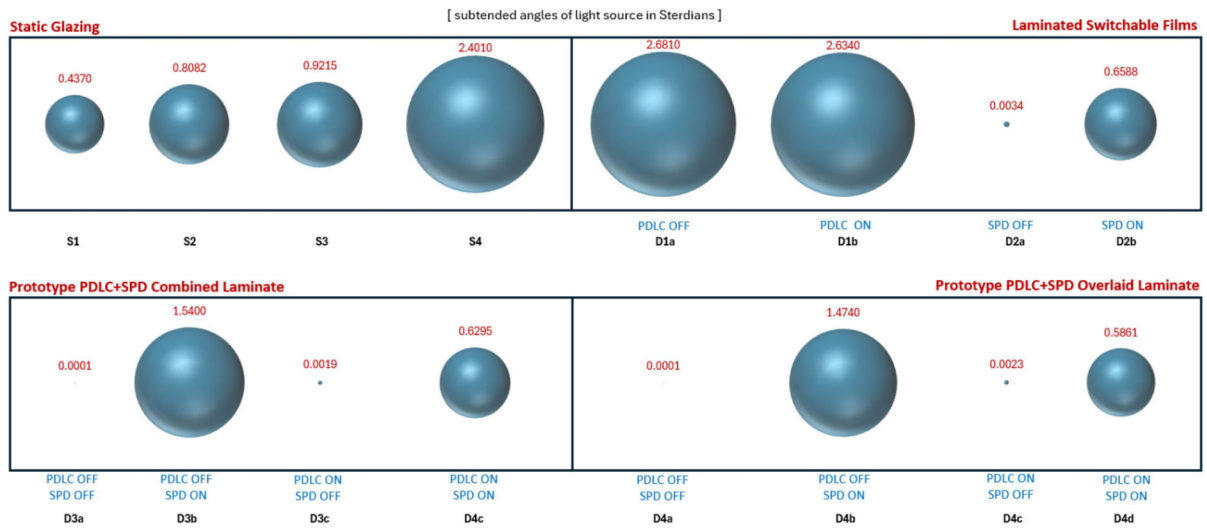


Fig. 20 Graphical representation of the mean luminance values of the light source containing the solar disc

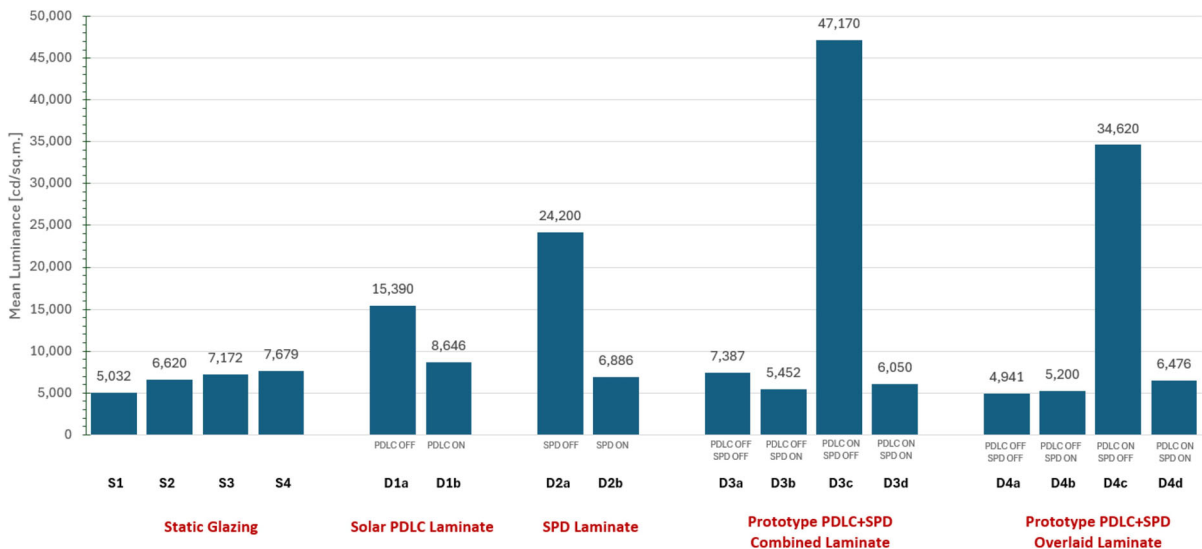


Fig. 21 Luminance maps for the prototype Solar-PDLC + SPD overlaid laminate

noted to be again comparable to that of a static glass with a VLT of between 20 and 40%.

The prototype overlaid switchable laminate representative of a novel switchable IGU showed an identical profile of mean luminance, but with lesser, improved values in three out of four switching states. The (*translucent and tinted*) (D4a); (*translucent and bleached*) (D4b) and (*transparent and tinted*) (D4c) states achieved lower mean luminance values than

those obtained with the combined switchable laminate, thus giving an indication of a potentially better performing glazing assembly. The (*transparent and bleached*) (D4d) state resulted in a mean luminance value slightly higher than that given by the combined laminate but comparable to a static glass with an approximate VLT of 40%.

8 Conclusions

This paper has presented an innovative combination of deploying both PDLC and SPD films into a single glazing assembly. The two options presented were either a single glazing laminate, or a distinctive switchable laminate within the same insulated glazing unit. The need for a visually comfortable indoor environment, particularly in an office space, is well documented in literature. Apart from the view, it is a well-known fact that we spend most of our workday looking at a computer screen. Switchable solar-PDLC and SPD films have distinctive properties that can help achieve this objective if deployed on a building's facade. Hence this experiment.

Field test results for the preliminary assessment of the quality of the visual environment using a scale model representing an office space were carried under real life conditions in Malta, considered a country with a typical representative central Mediterranean climate. Using a calibrated, high-end luminance photometer equipped with a fish-eye lens, a series of readings of the daylight glare probability and the visible light transmittance were taken and compared relatively to an unshaded glazing configuration. Tests were carried out on four categories of samples namely, conventional glazing with solar control properties, together with individually laminated solar-PDLC and SPD films. This paper then presented two prototype samples highlighting the authors' novelty of combining the established two technologies, namely the PDLC and SPD films, within a single glazed assembly. In addition, this paper presents a novel field-testing approach based on a scale model for a representative visualization of an indoor space.

Initial results from visual appearance tests confirmed that the human eye can never withstand a direct view towards the solar disc with conventional static glazing and only partially with PDLC and SPD films deployed individually. Having a solar PDLC and SPD film combined within the same laminate provided excellent protection to the human eye, whereas with both films laminated in an assembly representative of an IGU, the human eye was observed as being capable of comfortably tolerating a direct view towards the solar disc.

Results from calculations of the Daylight Glare Probability confirm that conventional, static glass with solar control coatings can never provide for the desired

levels of glare control even with a visible transmittance as low as 20%. With static glass, the use of external or internal shading devices is necessary to attain an acceptable level of glare control, with these devices resulting in a detrimental impact on outlook and view. SPD technology appears to have the greatest potential for controlling glare, whereas solar-PDLC when used on its own appears to have a 'magnification' effect on the level of glare within an indoor space. The prototype model for a novel switchable laminate combining both technologies certainly augurs well for an improved indoor visual environment. The prototype model representative of a switchable IGU appears to further improve on the performance of the laminate prototype by giving results well within the '*imperceptible*' range in selected switching states. This potential for improved glare control coupled with the ability of this novel glazing assembly, which also aims towards providing occupants with '*privacy on demand*', makes this switchable glazing combination merit further investigation.

The need for privacy and the control of glare are two distinct requirements in an indoor space. The use of an internal blind for instance, affects both the availability of views and indoor daylight levels simultaneously, without giving the building occupant a choice over the two. A blind, even with a very low openness factor, is often still insufficient at controlling glare when the sun is in the field of view since solar rays are still likely to penetrate through the blind's fabric. A solar-PDLC film deployed on its own allows for privacy and diffused daylight, with limited protection against glare for an occupant facing directly the window. An SPD film on its own allows for excellent glare protection but gives a limited degree of privacy, especially at night. A combined solar PDLC and SPD assembly would give an occupant different combinations of privacy, daylight, and glare control, and since the unit can be adjusted electronically, and possibly remote-operable, an occupant is not required to stand up from one's desk to manually alter the state of the glass. Moreover, a combination of both films has shown a remarkable potential of converting a transparent opening into nearly a fully opaque building element. With this capability, one can start looking at the concept of "switching off the windows" when a space is not in use, potentially shielding the space from excessive heat gain for which energy would be required to cool off the next time that space is used.

The benefits of a switchable IGU over a conventional indoor blind, including those featuring blackout fabrics, are various. While the use of blackout blinds is a common strategy for the control of glare, they obliterate completely outlook and views while disconnecting the human interface with the external environment. Although electrically operable motorised versions of indoor, integrated and external shading devices give a degree of adaptability, the presence of moving parts poses maintenance issues while their components tend to experience varying degrees of degradation particularly for external and integrated devices. Moreover, their kinetic movement may cause a degree of distraction whereas any blind system partially drawn down only alters the characteristics of that part of the window which it covers. Being a solid-state device, the switchable glazing unit under study has the potential of allowing for a high degree of adaptability without any moving parts, while altering the characteristics of the entire area of the window uniformly and instantly. In addition, this switchable unit would be appropriate in buildings where indoor blinds are discouraged such as in the case of healthcare-related buildings; public buildings where fabrics can pose a fire risk; and corporate office buildings whose developers often require having a uniform facade appearance.

9 Future work

The preliminary findings presented in this paper show that these novel switchable assemblies merit further investigation. Two full-scale mock-up offices setup are being installed on Campus (University of Malta: N 35° 54.05 E 14° 28.79). One of the testing chambers shall be fitted with the most promising switchable glazing prototype identified in this paper, to undergo a comprehensive testing regime under different orientations and with the sun, within and outside the field of view. Comparative tests of this switchable IGU in its various switching states will be compared to the reference mock-up testing chamber fitted with a conventional, low-E, solar control IGU having its visible light transmittance equal to that of the switchable glazing assembly in its fully bleached and clear state. This full-scale setup together with a software simulation approach is intended to confirm (or negate) the preliminary findings from a scale model presented in this paper. Further work is also necessary to refine the methodology

of data capture particularly related to the use of neutral density filters with the luminance photometer to perform illuminance-based correction for luminous overflow. Moreover, additional testing is required to assess performance for different orientations, different sun positions and varying dimming states of the SPD. A comparative assessment between this novel switchable glazing assembly and conventional static glass with dynamic shading would also be appropriate.

- o Since occupant satisfaction tests are crucial in studies of this nature, particularly to assess the level of satisfaction or otherwise of having a switchable glazed facade fitted in an office setup, human subjects will be invited to work from within the mockup offices and their level of satisfaction assessed through questionnaires and real-time voting devices. The quality of the indoor visual environment and the aforementioned '*privacy on demand*' will also be assessed as the 'human factor' to this scientific study.
- o Finally, the thermal performance of the prototype switchable IGU, when compared to a conventional IGU with a solar control coating is also a subject of great interest. The authors believe that this matter ought also to be investigated. Besides comfort at a visual level, further investigation is required to assess the potential of this façade to provide improved thermal comfort and energy efficiency. This should thus go a long way towards more sustainable buildings with today's technology.

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Data availability The datasets presented in this article are not readily available since they form part of an ongoing study. Requests to access the datasets should be directed to etiennemagri.99@um.edu.mt

Declarations

Conflict of Interest The authors are research-based academics and hereby declare that they have no conflict of interest.

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