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DOI
10.1088/1742-6596/2600/13/132005

Publication date
2023

Document Version
Final published version

Published in
Journal of Physics: Conference Series

Citation (APA)
Magri, E., Buhagiar, V., & Overend, M. (2023). The Potential of Switchable Glazing in Cooling Dominated Climates. *Journal of Physics: Conference Series*, *2600*(13), Article 132005. https://doi.org/10.1088/1742-6596/2600/13/132005

The Potential of Switchable Glazing in Cooling Dominated Climates

Etienne Magri[1], Vincent Buhagiar[1], Mauro Overend[2]

[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; vincent.buhagiar@um.edu.mt; m.overend@tudelft.nl

Abstract. The design trend of most commercial and office buildings over the past three decades focused on attaining a façade design with the highest possible window to wall ratio. Whereas this approach appears to satisfy the aesthetic scope of developing buildings that look 'modern and transparent' to maximise on real estate value, the demand for heating and cooling of these buildings tends to fall short of what one should expect. Literature review shows the possible benefits of switchable glass. This paper proposes a methodology for a novel switchable glazing assembly identified as having the potential of offering increased occupant comfort, particularly in providing sufficient daylight and glare control without diminishing the view quality. The hypothesis is that switchable glazing may have a substantial potential to achieve lower cooling loads and improved indoor visual comfort without compromising views and a positive outlook.

1. The Need for Occupant Wellbeing

The typical design approach for an office building in a central Mediterranean climate is the established trend of adopting a façade with large, glazed surfaces in excess of what would be required for daylighting within a cooling-dominated climate. The choice of such a facade configuration is often driven by market trends in that glazed buildings tend to appear more visually appealing and corporately sophisticated making them more 'sellable' or 'leasable'. Such a design approach leads to significant heat gains and losses together with substantial glare related issues resulting in a slow deep deleterious effect on occupant well-being.

External shading devices, typically fixed or adaptive, to allow for their adjustment according to the external climatic conditions, are being employed far less than ever, presumably but not solely, due to their obstruction of external views for which tenants pay a premium. Internal shading devices, primarily window blinds and shades are often installed, these being quick-fix and cheap solutions for the control and alteration of the properties of a façade. The control of glare using internal shading devices often comes along with the obliteration of views and an increased internal lighting load, while the overheating issue remains largely unresolved. The glass within a fixed or openable window or façade assembly has to date evolved towards better U-values, g-values, and visible light transmittance values. However, in spite of energy efficiency goals, visual comfort has often been compromised with lower daylight levels and partially blocking external views.

2. The Adaptive Building Envelope

The concept of responsive, adaptive architecture is based on the theory of interaction, and simple adaptive conditioning which define a building as a self-adjusted system operated by feedback from occupants and the environment (Kolarevic & Parlac, 2015). Energy-inefficient facades are characterized by a high rate of heat transmission through conduction, convention, and radiation, an increased rate of daylight admittance and a high rate of moisture ingress. Regardless of how energy efficient they may be, static facades still constitute a limited degree of adaptability and thus tend to provide limited performance in transient external environmental conditions. The daylight and visual performance of a static façade can only be improved by reducing window glare and the associated discomfort effect. This is achieved by decreasing the need for artificial lighting, by optimizing internal daylight levels, and by providing shading screens.

To overcome the restrictions of conventional static facades, concepts of adaptive façades which exploited potential benefits of improved technologies were proposed. An active façade is one which can manage internal environments by dynamically modifying the characteristics of a building skin and responding to external environmental parameters. (Millard, 2015). The building envelope characteristics are modified by using a building control system, which allows the building envelope to be capable of controlling, managing, and adjusting parameters such as light levels, glare discomfort effects, lighting energy efficiency, thermal resistance values, solar heat gain coefficients, heat energy efficiencies, response to solar patterns, occupant comfort level, and passive ventilation. Responsive façade systems are centered around the need to have a response to environmental stimuli so that building occupants are provided with thermal and visual comfort.

3. Switchable glazing as an adaptive material for facades.

Switchable glazing is glass that has the ability to alter the visible light transmittance and g-values of a sheet of glass, with the U-value remaining largely unchanged. *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). In *photochromic* materials the adaptation is triggered by the UV radiation in the solar spectrum and is the most widely known category and used in many applications. *Electrochromic* (EC) materials on the contrary, allow for a change in optical properties that is triggered by an external current. This is achieved by means of changing the amount of free electron density in a metal base oxide or polymer. The EC materials are metal based and show lower UV degradation problems than the polymeric ones. Different technologies make use of the EC feature of this materials in order to achieve an optically controllable window, among which are *all-solid state electrochromic, electrophoretic, or suspended particle devices (SPD) and polymer dispersed liquid crystal devices (PDLC)*. The latter technologies differ from EC materials in that they require an electrical field to align the suspended particles or the liquid crystal, which are otherwise randomly ordered, thus allowing light to pass through. Due to this feature, these devices need a continuous potential difference to operate, thus requiring continuous electrical energy consumption. (Granqvist, 2007). Today's advancement in this technology, however, permit a reduced power consumption of an average of 1.5W/m². (*www.gauzy.com/spd-smart-glass*). The slow switching times of EC glazing is however a substantial limitation with both SPD and LC technologies being able to alter their state in a matter of milliseconds and this perceived as instantly to the human eye.

4. Novel Glazing Assembly

UV-resistant PDLC privacy film (solar PDLC) and SPD tinting technologies appear to be two of the most established, commercially available products on the market. 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. The diverse properties of solar PDLC and SPD technologies has led to the identification of a possible innovative combination of technologies within a single IGU. Having a laminated glass 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. The possible combinations of how this glazing assembly can be set within an external façade are thus substantial. It 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 actually push away conventional indoor blinds and shades, and given time, may 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.

For the scope of this research, two pairs of films, each having dimensions of approximately 1.0m x 2.0m were cut to fit a 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 laminated sheets of glass were in turn assembled into an IGU with a 16mm argon-filled gap, with an additional 4+4mm extra clear glass to form the inner face of the IGU. (**Figure 1 refers**).

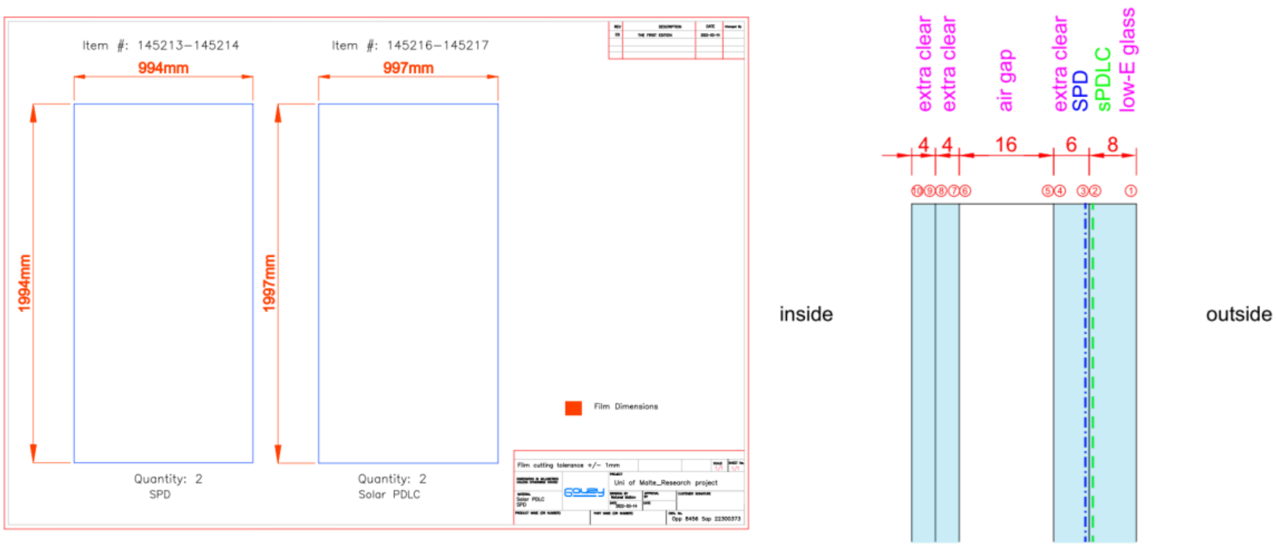

Figure 1. The proposed assembly of the novel switchable IGU

Prior to lamination, both switchable films were soldered to proprietary busbars permitting the provision of connection points protruding from the edges of the IGU (**Figure 2**). By connecting the panes to the two electronic controllers, one for each film, the assembly allowed for the control of the state of each film independently (**Figure 3**).

Figure 2.
Soldering of the connectors to the films (*top*) and the placement of the EVA in between the films prior to lamination. (*bottom*).

Figure 3.
The laminated sheet in a fully bleached state, transparent (*top*) and fully dark and opaque (*bottom*).

5. Proposed Methodology & Experimental Setup

An assessment of the performance of this glazing assembly is currently being carried out through live field tests. A comparative testing approach as described by (Cattarin *et.al.*, 2015) is being adopted, wherein the performance of a component, in this case the novel glazing assembly is assessed in relative terms to a reference element being tested at the same time. The reference benchmark element shall be a conventional, low-E, solar control IGU having a similar visible light transmittance equal to that of the switchable glazing assembly in its fully bleached and clear state and a U-value equal to that of the switchable glazing assembly.

The performance of the two spaces in all experiments shall be evaluated on the basis of the collection of empirical data within two identical, test cells in free-floating conditions installed in a central Mediterranean climate, namely in Malta. Readings of key performance indicators are planned be taken and shall include internal and external surface temperatures of the glass, the indoor ambient air temperature, indoor relative humidity, mean radiant temperature and illuminance on the horizontal working plane (Figure 4). This study will attempt to investigate whether switchable glazing can have a positive effect on the energy-saving potential of a space in terms of cooling and heating loads. Variant comparative studies will also be investigated including the inclusion of external shades and indoor blinds on the reference glazing to establish whether this advanced switchable glazing assembly can provide or otherwise improved thermal and visual characteristics of an indoor space.

Considering the potential of switchable glazing for the control of excessive natural daylight within an indoor space, comparative field test experiments of the quality of the visual environment will also be carried out. Although various glare indices have been developed over the years, a relatively new metric for the computation of glare developed by (Wienold & Christoffersen, 2006) is the Daylight Glare Probability (DGP)., nowadays considered as being the most accurate assessment of glare. For the scope of the experiments, DGP readings in both testing chambers shall be taken using a state-of-the-art, calibrated luminance photometer, LMK mobile 6 equipped with a SIGMA fish-eye lens, coupled with the proprietary LMK Labsoft© glare analysis suite.

Figure 4.
View of the rotatable environmental testing chambers (*top left, right*) and the view of the mounted luminance photometer during the DGP study. (*bottom left*)

6. Pilot Study: Preliminary Results

A DGP pilot study was conducted on a partly cloudy day in March 2023 to collect preliminary DGP readings without any glazing installed and to assess the suitability of the testing setup. The objective was to familiarize oneself with the operation of the 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: 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, 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 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 5**).

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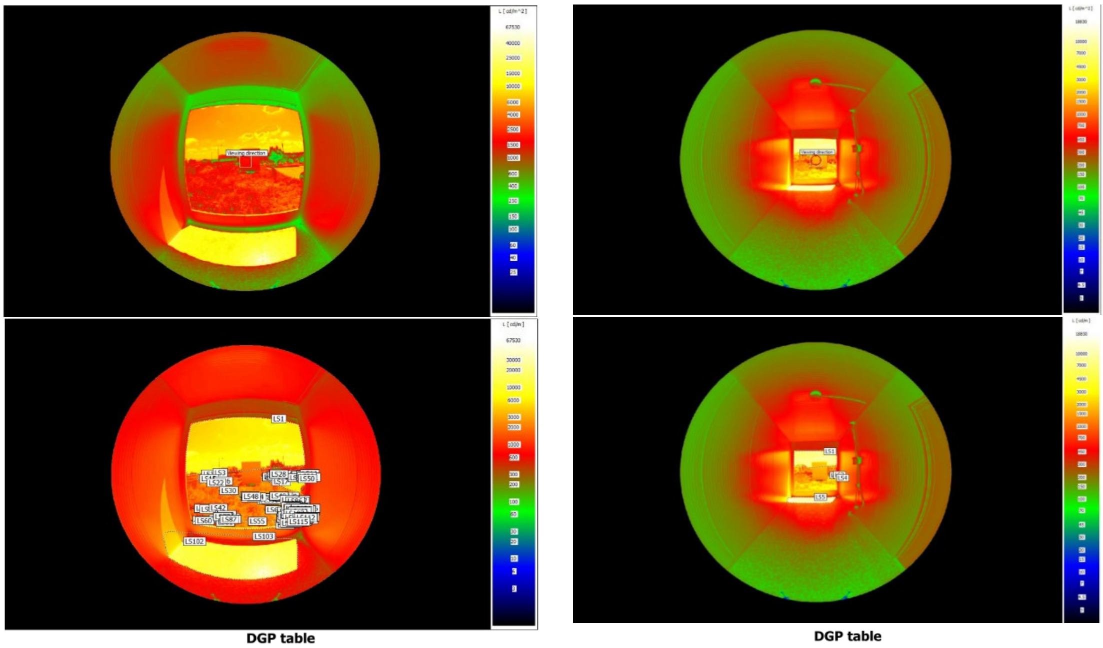
2600 (2023) 132005 doi:10.1088/1742-6596/2600/13/132005



DGP table

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

DGP table

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

Figure 5. DGP readings from different locations withing the testing chambers. (1.5m away from the opening (*left*) and at 4.5m away from the opening (*right*).

7. Conclusions

Overheating and glare contribute to substantial discomfort in buildings in the Mediterranean basin, with a predominant demand for cooling energy. A novel glazing assembly comprising of solar-PDLC and a tinting SPD within a single IGU has the potential of enhancing thermal and visual comfort to occupants. The pilot study was intended to assess the suitability of a field test setup for assessing the performance of a space fitted with this switchable assembly; data logging included the measurement of temperatures and glare, the latter using a highly accurate luminance photometer. This paper is the outcome of all this, which also derives 'lessons learnt', acting as the springboard for fine tuning the same methodology in time for the full scale survey, namely an office set up with occupants as subjects for qualitative feedback.

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