Building daylight control on work-plane illuminance and discomfort glare

Yujie Wu[1], Luoxi Hao[1], Jean-Louis Scartezzini[2]

[1]College of Architecture and Urban Planning, Tongji University, Shanghai (China)

[2]Solar Energy and Building Physics Laboratory (LESO-PB), EPFL, Lausanne (Switzerland)

Abstract

This study evaluated the effectiveness of an automated external Venetian blind (EVB) shading system in optimizing daylight conditions and enhancing visual comfort. The system utilizes external real-time High Dynamic Range (HDR) imaging and computational simulations to dynamically control slat angles based on monitored outdoor luminance. This approach avoids the privacy concerns associated with interior-facing cameras. Experiments conducted in autumn under clear and partly cloudy skies demonstrated the system's robustness. The system effectively maintained work-plane illuminance (WPI) within the optimal range of 500-2000 lux for 88% of working time under clear conditions and 83% under partly cloudy conditions. Concurrently, discomfort glare was consistently mitigated, keeping the Daylight Glare Probability (DGP) below the 0.35 threshold in all scenarios. The findings highlight the potential of advanced automated shading to effectively manage daylight, ensure visual comfort, and reduce energy consumption by preventing excessive solar heat gain.

Keywords: Daylight, Discomfort Glare, Automatic Control, Visual Comfort

1. Introduction

Daylight is a sustainable and cost-free resource that significantly contributes to energy efficiency (Strømann-Andersen and Sattrup 2011), occupant comfort, and overall well-being in built environments. Effectively harnessing daylight can substantially reduce dependence on artificial lighting, which can account for 15-30% of electricity consumption in commercial buildings, thereby lowering energy consumption and associated costs. Additionally, numerous studies (Andersen, Gochenour et al. 2013, Turley, Rafferty et al. 2024) have demonstrated positive impacts of daylight exposure on occupants, including via non-image forming effects of light that influence improved productivity, mood enhancement, and better general health.

However, the inherently variable nature of daylight poses considerable challenges. Excessive daylight introduction can contradict energy goals by increasing cooling loads in warm seasons and, critically, can cause severe discomfort glare for occupants (Tzempelikos and Athienitis 2007). Shading devices, particularly Venetian blinds, are widely used to manage daylight entry, reduce glare, and maintain visual comfort, offering a high degree of control via two degrees of freedom (vertical position and slat tilt). Despite their prevalence, manual shading systems often fail to perform effectively. Studies show that occupants interact with shades infrequently, often less than once per day, and commonly hesitate to reopen shades once they are closed (Mahdavi and Pröglhöf 2009). This leads to suboptimal daylight utilization, increased reliance on artificial lighting, and compromised comfort.

Automated shading systems have emerged as a solution to these limitations, optimizing daylight usage while ensuring comfort and energy efficiency. Early automation methods often relied on closed-loop controls using ceiling-mounted photo-sensors pointing at the task area to stabilize work-plane illuminance (Kuhn 2006).

10.18086/swc.2025.08.05 Available at http://proceedings.ises.org

While these systems achieved energy reductions, they suffered from complex calibration requirements and performance issues, as the sensor readings could be affected by slat angles, solar position, or even furniture rearrangement. Crucially, they fell short in effectively mitigating discomfort glare, a major source of occupant dissatisfaction, because a simple photo-diode cannot resolve the directional luminance of light sources that cause glare.

Recent technological advancements have facilitated more sophisticated control strategies. Some systems use the 'cut-off angle' strategy to block direct sun, but this often fails to address glare from specular inter-reflections between slats. Other methods use interior camera-based systems (Goovaerts, Descamps et al. 2017) to assess glare directly using metrics like Daylight Glare Probability (DGP). While these indoor camera setups can manage glare, they introduce significant practical barriers: they are prone to 'hunting' or 'oscillation' behavior, their field of view can be occluded by occupants, and they raise significant privacy concerns, hindering practical adoption.

Addressing these challenges, novel approaches using external High Dynamic Range (HDR) imaging have been proposed. These systems monitor outdoor luminance distribution, circumventing privacy issues and efficiently managing glare across multiple viewing directions. Building on prior research by Wu et al (Wu, Kämpf et al. 2019), this paper evaluates the performance of automated external Venetian blinds using HDR sky luminance mapping combined with real-time computational analysis. Conducted in Lausanne, Switzerland, during winter with low solar elevation angles, this study examines the ability of automated shading systems to maintain optimal illuminance (500-2000 lux) and mitigate discomfort glare under various sky conditions. The findings from these 'in-situ' experiments provide practical insights for improving daylight management strategies, offering significant benefits in energy efficiency, occupant comfort, and overall building sustainability.

2. Methods

The study was conducted using an automated shading control system integrated with external Venetian blinds (EVB) installed in a daylighting test module located in Lausanne, Switzerland. This test module, measuring 6.4 m × 2.9 m × 2.6 m, featured a south-facing, double-glazed unilateral façade with a 0.62 window-to-wall ratio. The EVB slats were 8 cm wide aluminum plates with a sinusoid profile.

The system was managed by a shading controller, technically an embedded photometric device (EPD), composed of a field-programmable gate-array (FPGA) processor and a calibrated High Dynamic Range (HDR) imaging system. Positioned externally, the HDR imaging device monitored the complete sky luminance distribution, including the sun, sky, clouds, and landscape features 6, across a dynamic range of 150 dB (up to 3.78×10^9 cd/m^2).

Figure 1 Set-up of the blinds and control systems

The shading controller utilized these HDR images to generate high-resolution luminance maps, as shown in

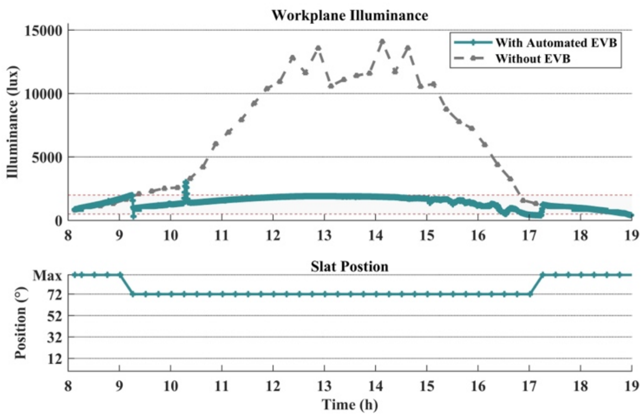
Figure 1. It performed real-time lighting simulations using a time-efficient five-phase matrix algebraic approach. This method relies on pre-characterized Bi-directional Transmittance Distribution Function (BTDF) data, generated using RADIANCE , to rapidly compute the daylight passing through the blinds at different angles. These simulations determined optimal shading positions based on two critical metrics: work-plane illuminance (WPI) and Daylight Glare Probability (DGP).

The system evaluated 15 distinct shading positions, ranging from fully retracted (maximum openness) to fully extended, with slat angles varying at 5° intervals between 72° (horizontal) and 0° (fully closed). The control strategy's primary goal was to maintain WPI within a comfort range of 500 to 2000 lux (per European standard EN 12464-1) while simultaneously ensuring the DGP remained below the 0.35 discomfort threshold. This DGP limit was assessed for two virtual occupant view positions (1.2 m height, oriented at 45° and 135° to the façade). A secondary objective was to maximize the blind's opening to preserve the occupants' view out. Evaluations and shading adjustments were conducted every 15 minutes to accommodate daylight variations.

To validate the controller's performance, an array of five lux meters was positioned at the task area (0.8 m height and centered 1.5 m from the façade). These sensors measured the actual WPI at 30-second intervals. Experiments were carried out on partly cloudy days in Autumn, specifically on Sept. 09 and Nov. 14th. The study aimed to evaluate system performance in maintaining visual comfort and optimal daylight utilization under varying sky conditions.

3. Results

The experimental results demonstrated the effectiveness of the automated shading system in maintaining the target comfort criteria under diverse sky conditions in Autumn. Under clear sky conditions (Sept. 5th, Figure 2), the system demonstrated stable and minimal intervention. The blinds were automatically extended and set to a 72° horizontal tilt angle in the morning (9:20) as WPI exceeded the 2000 lux limit. This single position was successfully maintained throughout the peak daylight hours, keeping the WPI within the target range. The blinds were only fully retracted late in the afternoon (16:40) when daylight levels fell below the 500 lux minimum. Critically, while the unprotected façade experienced intolerable glare (DGP > 0.45), the automated EVB kept the DGP consistently within the imperceptible range (below 0.35). This highlights the system's ability to maximize daylight and view with only two primary movements on a stable day.



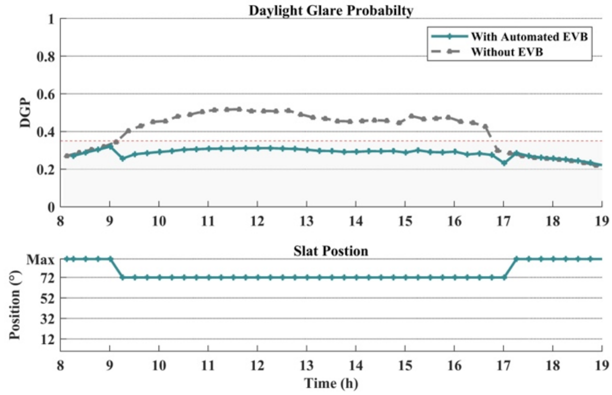


Figure 2 WPI and DGP with/without automated EVB (autumn, clear sky)

Performance under partly cloudy conditions posed a greater challenge due to rapid and significant changes in sky luminance. On one partly cloudy day (Sept. 7th, Figure 3), the system successfully maintained the WPI within the target [500, 2000] lux range for approximately 88% of the day. As shown in Figure 4, the system dynamically adjusted slat angles in response to these variations. It initially set slats to 52°, then proactively adjusted to mitigate increasing glare. When cloud cover reduced daylight in the afternoon, the controller promptly reopened the slats to 72° (horizontal) to ensure sufficient daylight ingress. Over ten adjustments were required on this day, but the system's slow tilt-angle motor (0.8°/s) was designed to make these changes smooth and unobtrusive.

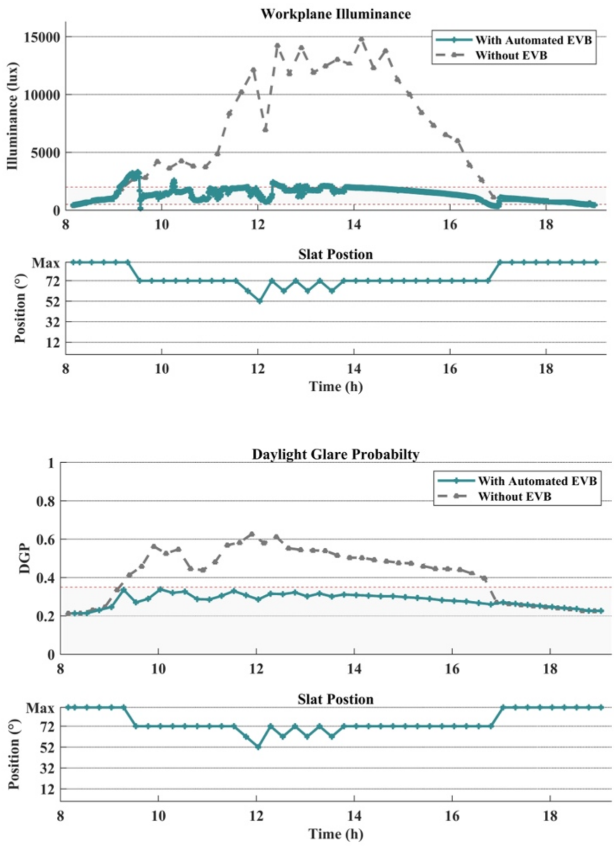


Figure 3 WPI and DGP with/without automated EVB (autumn, partly cloudy sky)

In another challenging day in late Autumn (Nov. 14th, Figure 4), characterized by a low solar elevation angle (approx. 25° at noon), the system kept the WPI within the target range for 83% of the working hours. Figure 4 illustrates the extreme conditions: without shading, the WPI (grey dashed line) was highly erratic, peaking above 25,000 lux. Upon activation, the EVB adjusted to 42°, immediately bringing the WPI (green line) within the comfort bounds. Concurrently, the DGP was reduced from intolerable peaks of 1.0 to below the 0.35 threshold.

Across all scenarios, the system consistently regulated WPI and successfully maintained the Daylight Glare Probability (DGP) below the discomfort threshold of 0.35. These results confirm the system's capability to provide consistent visual comfort by proactively managing both illumination levels and glare risk, demonstrating its effectiveness for dynamic daylight management.

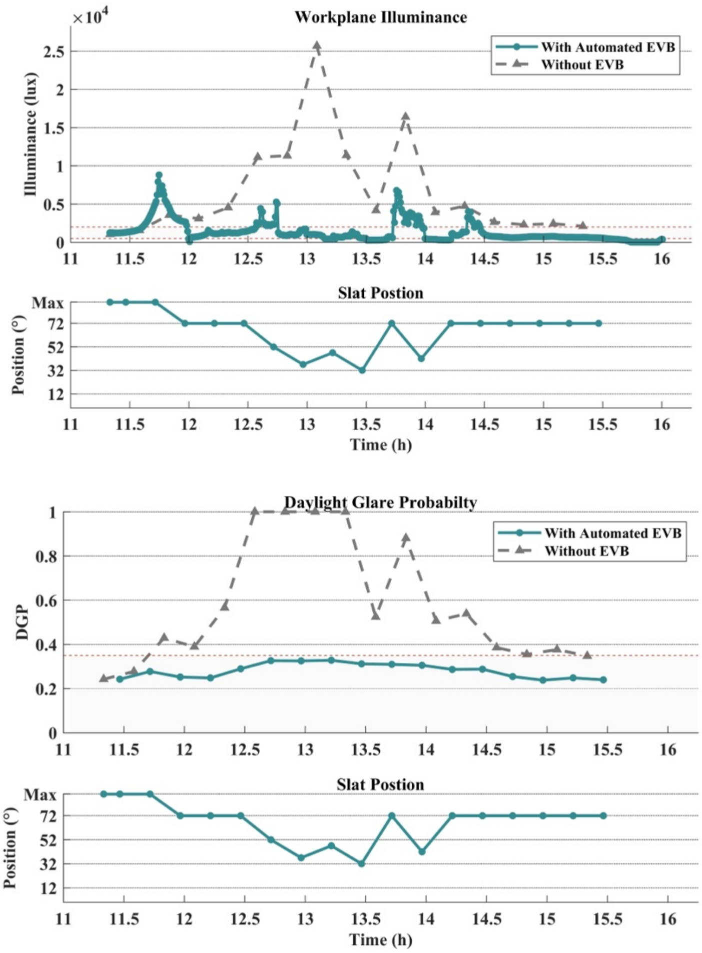


Figure 4 WPI and DGP with/without automated EVB (late autumn, partly cloudy sky)

4. Conclusion

The study demonstrated the practicality and effectiveness of the automated shading system in maintaining optimal daylight conditions and visual comfort. The system's control strategy, based on external High Dynamic Range (HDR) sky luminance monitoring and real-time computational simulation, proved highly successful. It effectively maintained work-plane illuminance within the target comfort range (500-2000 lux) for 88% of the time under clear skies and 83% under partly cloudy conditions.

In challenging partly cloudy conditions, despite frequent sky fluctuations, the system dynamically responded by adjusting slat angles—sometimes more than ten times per day —to ensure consistent visual comfort. A key finding was the system's ability to consistently mitigate discomfort glare, keeping the Daylight Glare Probability (DGP) below the 0.35 discomfort threshold in all tested scenarios.

Overall, the automated shading solution successfully managed daylighting performance. By preventing excessive solar gain, the system proves beneficial for reducing energy use, with potential projected cooling load mitigation. This approach, which points externally, avoids the privacy concerns and view obstructions of interior camera-based systems. As a decentralized, stand-alone system, it operates without needing external weather data, confirming its robust potential for enhancing occupant comfort and energy efficiency in real-world building environments.

5. Acknowledgement

This research project was financially supported by the Swiss Innovation Agency Innosuisse and was part of the Swiss Competence Center for Energy Research (SCCER FEEB&D).

5. Reference

Andersen, M., et al. (2013). "Modelling 'non-visual' effects of daylighting in a residential environment." Building and Environment **70**: 138-149.

Goovaerts, C., et al. (2017). "Shading control strategy to avoid visual discomfort by using a low-cost camera: A field study of two cases." Building and Environment **125**: 26-38.

Kuhn, T. E. (2006). "Solar control: A general evaluation method for facades with venetian blinds or other solar control systems." Energy and Buildings **38**(6): 648-660.

Mahdavi, A. and C. Pröglhöf (2009). "User behavior and energy performance in buildings." Wien, Austria: Internationalen Energiewirtschaftstagung an der TU Wien (IEWT): 1-13.

Strømann-Andersen, J. and P. A. Sattrup (2011). "The urban canyon and building energy use: Urban density versus daylight and passive solar gains." Energy and Buildings **43**(8).

Turley, K., et al. (2024). "Evaluating the Impact of a Daylight-Simulating Luminaire on Mood, Agitation, Rest-Activity Patterns, and Social Well-Being Parameters in a Care Home for People With Dementia: Cohort Study." JMIR mHealth and uHealth **12**: e56951-e56951.

Tzempelikos, A. and A. K. Athienitis (2007). "The impact of shading design and control on building cooling and lighting demand." Solar energy **81**(3): 369-382.

Wu, Y., et al. (2019). "Automated 'Eye-sight'Venetian blinds based on an embedded photometric device with real-time daylighting computing." Applied energy **252**: 113317.