

Article

Multi-Objective Optimization of Daylighting for an Office Space in a Very Hot Climate: A Comparison of Corrugated, Perforated, and Separated Shadings

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Abstract

Dynamic shading systems offer a promising approach to improving daylight and visual comfort in hot climates. The present work aims to enhance hourly daylighting performance by optimizing useful daylight illuminance ($UDI_{500\sim1000\text{ lx}}$), illuminance uniformity (U_o), and daylight glare probability (DGP). Radiance and SPEA-2 enable the identification of optimal solutions for corrugated, perforated, and separated trapezoid shading systems. The first multi-objective optimization selected a 15° slat angle, yielding an average illuminance of approximately 782.22 lx, a U_o of 0.7229, 100% coverage in the $UDI_{500\sim1000\text{ lx}}$ range, and a DGP of 0.3324. Fully automatic control of the upper, central, and lower facade sections addressed issues of $UDI_{300\sim500\text{ lx}}$ in June and $UDI_{1000\sim2000\text{ lx}}$ in December. Corrugated shadings achieved over 90% for $UDI_{500\sim1000\text{ lx}}$ during most investigated equinox and solstice conditions, with a minimum U_o of 0.79 in March and approximately 0.6 in December. Perforated inclined panels improved $UDI_{500\sim1000\text{ lx}}$ for morning and afternoon. The fully automated trapezoid-separated shading system increased $UDI_{500\sim1000\text{ lx}}$ coverage to at least 99.47% at 15:00 in March, 92.95% at 15:00 in June, and 92.06% at 12:00 in December, with DGP within imperceptible glare. The methodological scope was limited to a selected office space and point-in-time simulations from 10:00 to 15:00 on representative equinox and solstice days; therefore, the results should be interpreted as simulation-based design guidance rather than full annual or experimentally validated performance.

Keywords: corrugated slats; perforated shadings; separated louvers; multi-objective optimization; daylighting



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1. Introduction

The construction industry makes a substantial contribution to energy consumption and global warming, both of which are among the most urgent global environmental challenges [1,2]. The construction industry accounts for almost one-third of worldwide energy consumption and 40% of CO_2 emissions, contributing to resource shortages and increasing temperatures [3,4]. Design professionals increasingly acknowledge the need to optimize visual and thermal performance to reduce indirect greenhouse gas emissions and energy use. The optimization of the building envelope to regulate solar radiation and daylighting has emerged as a critical principle in response to the obstacles presented by

environmental changes [5]. The exterior facade system and its components are essential to the strategic design of carbon-neutral structures that meet sustainability objectives. External shadings have been widely used to reduce undesirable glare, control heat, and optimize useful daylight illuminance (UDI) [6].

1.1. Need for Visual Comfort

Optimal daylight significantly influences the psychological and physical health of those who spend extended periods indoors [7]. Shading is used in commercial structures to control daylight by blocking or redistributing it. Despite extensive research and numerous proposed architectural approaches, shading designers continue to face challenges in providing tailored solutions that enhance visual comfort for occupants across various built environments while adapting to changing natural illuminance conditions [8,9]. Furthermore, because existing building forms are often difficult to alter, adding external shading devices to the facade can enhance facade articulation and architectural integration.

Previous research frequently employs integrated approaches that concurrently combine parametric modeling, performance-based construction simulations, and optimization to investigate building performance potential in the initial stages [10]. Optimization is the systematic process of determining the lowest or highest possible values of objectives by selecting the most suitable values for the design variables [11]. According to Khidmat et al. [12], the use of multi-objective optimization (MOO) resulted in a substantial enhancement in $UDI_{300-500\text{ lx}}$ by 80% in Birmingham, 146.26% in Jakarta, and 79.48% in Sydney. Meanwhile, the cooling energy consumption decreased by 28%, 3.26%, and 2.99%, respectively. Mangkuto et al. [13] examined internal shading mechanisms, including horizontal and vertical blinds, highlighting that the slat angles of blinds have a greater impact on daylight performance than the reflective properties of the materials used. The optimal solutions varied with the sky conditions, resulting in notable improvements in building performance.

The effectiveness of shading types in regulating sunlight and reducing glare substantially affects visual comfort in building interiors. This encompasses vertical and horizontal louvers, light shelves, overhangs, and egg-crate structures [4]. Optimized horizontal shading devices, considering factors such as building orientation, number of shades, depth, angle, glazing material, window-to-wall ratio (WWR), and shading distance, markedly improved visual comfort [14]. Yao et al. [15] investigated egg-crate shadings and found that multi-objective optimization could reduce the discomfort glare index (DGI) by 55–100%, depending on the building's orientation. Khidmat et al. [16] optimized expanded-metal shading, demonstrating that the proposed design met LEED v4.1 daylighting standards by entirely avoiding annual sunlight exposure (ASE) and enhancing UDI by about 50% relative to the original model.

1.2. Importance of Design Control of Facade

The cut-off angle for slats is a predominant open-loop control approach in research [17]. However, numerous studies have indicated that a cut-off angle approach alone is inadequate for controlling glare because it ignores indirect daylight and sky conditions [18]. Origami-inspired facades [19,20] exhibit enhanced adaptability, enabling them to adjust to both indoor and outdoor conditions through several design options. The positions and the hourly openness level could improve illuminance while reducing glare. Tabadkani et al. [19] presented 1800 point-in-time results to demonstrate the feasibility of kinetic hexagonal shadings. Hourly openness behavior can meet the competing goals of reducing cooling demand and optimizing daylighting [21]. Subsequent performance improvements should be pursued to effectively broaden the range of dynamic operating conditions, enhance real-world applications, and improve the reliability of parametric behavior mapping.

The previous research works for different building envelopes focusing on the desired illuminance are presented in Table A1 (Appendix A).

With the rise of recent building designs, perforated solar screens have become increasingly common. However, only a few studies have examined the trade-off between maximizing daylighting and minimizing solar heat gains with perforated screens. Bustamante and Uribe [1] optimized the performance of perforated curved louvers for spatial daylight autonomy ($sDA_{300/50\%}$) and $ASE_{2000/400h}$ in accordance with standards set by the Illuminating Engineering Society (IES). Their work employed mkSchedule to generate schedules for the complex fenestration systems, with thermal modeling conducted in EnergyPlus and daylighting performance assessed using Radiance. It was strongly suggested that an efficient control system with appropriate parameters be established during the early design stages to optimize both daylighting and energy use. Chi et al. [22] investigated perforated solar facades in an office space in Seville, Spain, using orthogonal arrays to reduce computational effort. Optimizing shape, matrix, and perforation percentage can improve modified daylight availability by up to 50% and reduce annual energy use by 55%. The thermal and visual performance of office buildings can be improved using double-sided blinds. Previous studies [23] proposed using different reflectance for the front and back sides of the slat, combined with dimming control, to decrease the overall building load by 24.6% relative to the baseline scenario.

Recent investigations propose trapezoidal louvers [4] as a robust alternative to plane shading for effectively reducing cooling loads. These devices address overheating by achieving 42.40% energy savings compared to 34.27% for typical flat louvers. Additionally, split configurations significantly improve UDI to 92.60% while minimizing visual discomfort. Automated horizontal louvers further optimize performance, achieving 98% coverage of $UDI_{500\sim1000\text{ lx}}$ with a uniformity (U_o) of 0.6 [24]. This dynamic hourly openness mitigates morning and afternoon daylight deficits often found in fixed exterior shadings.

1.3. Research Objectives

Previous studies have examined corrugated shadings [4,24], perforated slats [1,22], separated shadings [23], and expandable louvers [16], but have not systematically investigated the combined effects of corrugation, perforation, and split-facade control with variable reflectance in trapezoid geometries. Therefore, a comprehensive evaluation of hybrid shadings necessitates an in-depth examination of the critical factors influencing daylight performance:

1. The illuminance coverage of $UDI_{500\sim1000\text{ lx}}$ within the overall illuminance range of $UDI_{100\sim1000\text{ lx}}$ should be examined thoroughly in terms of corrugations, perforations, and reflectance values of slats.
2. The hourly openness behavior can be explored in terms of daylighting assessment for different sections of the split facade, considering $UDI_{500\sim1000\text{ lx}}$.
3. The fully automated trapezoidal corrugated slats should be explored to increase daylighting in the morning and afternoon.
4. The effects of different slat reflectance for various sections of the facade should be considered for hybrid louver shading.

This work aims to maximize daylighting performance and reduce discomfort glare by implementing parametric modeling and optimization methods. To achieve this, Radiance (version 5.4a) was connected to Octopus (an evolutionary algorithm plugin), facilitating the identification of optimal solutions for $UDI_{500\sim1000\text{ lx}}$. The hourly openness levels of different facade sections were examined using split-controlled trapezoid louver shading systems. Issues of low work plane illuminance in June were addressed by employing fully automated slats. This study presents a Radiance-based simulation and a Strength Pareto

Evolutionary Algorithm 2 (SPEA-2) optimization workflow to compare trapezoid louver shading systems in a selected office space in Miami, addressing the limited evidence on how split-facade hourly openness, corrugation, perforation, and variable slat reflectance affect $UDI_{500-1000\text{ lx}}$ and illuminance uniformity.

2. Simulation and Optimization Methodology

2.1. Parametric Design Workflow

The integration of parametric design tools with optimization approaches enables a more seamless exploration of design alternatives [25]. The parametric design workflow, as illustrated in Figure 1, is intended to enhance daylighting in office environments. A south-oriented office room is chosen for the investigation [26]. Further details about Radiance parameters and Octopus optimization settings can be found in previous work [24]. This study simulates visual comfort using Radiance optimized by SPEA-2 [27]. In previous research, daylighting and energy models were compared with literature [4], supporting reliable design recommendations through parametric modeling using Radiance and EnergyPlus [24].

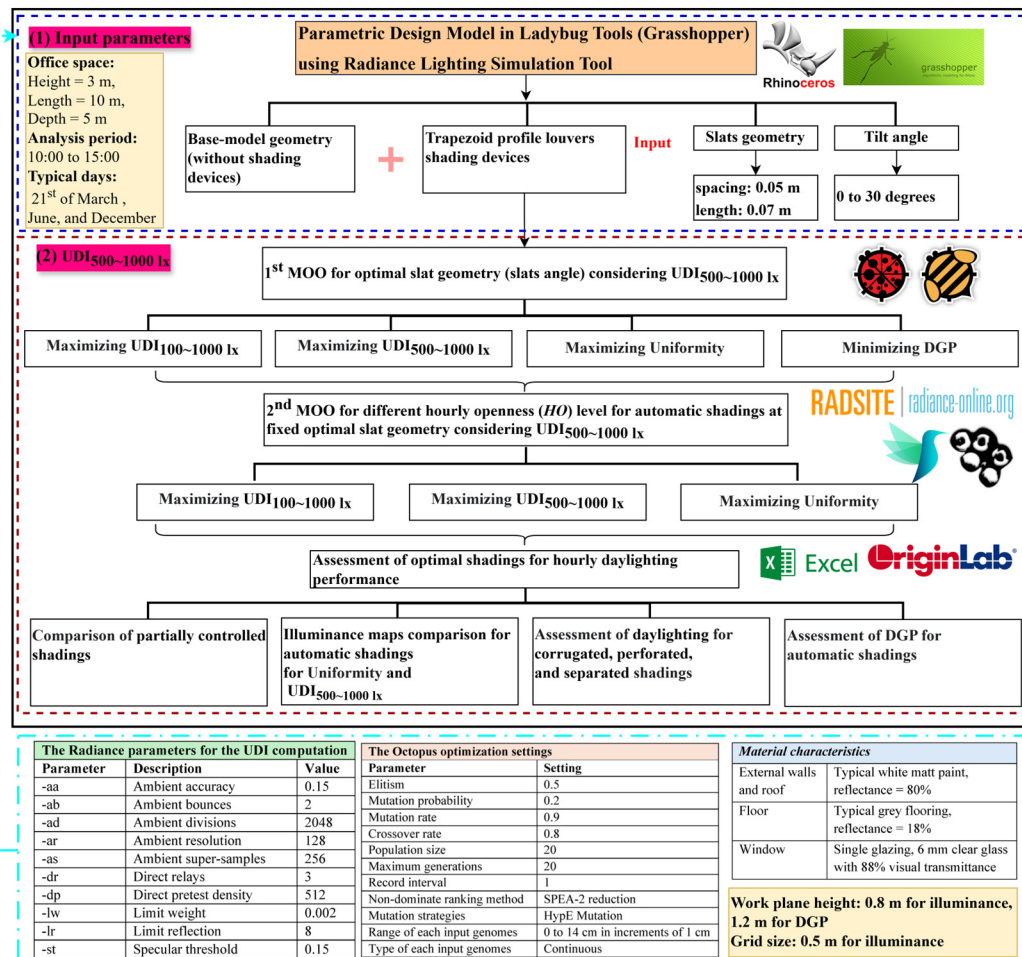


Figure 1. Parametric modeling workflow.

The studied office space extends 10 m in the longitudinal direction, 5 m in the lateral direction, and 3 m in the vertical direction [8]. The facade is divided functionally: the upper area ensures daylight entry, the middle area preserves external visibility, and the lower area manages heat transfer [28]. The climate of Miami (very hot and humid) is considered for investigating the performance of dynamic louvers regarding daylighting [24]. The shading consists of trapezoid-shaped slats (constructed from recycled corrugated panels)

positioned horizontally [4]. The literature commonly uses the equinoxes and solstices as representative seasonal days to sample daylight extremes in early-stage facade or shading studies, thereby approximating annual daylight performance and reducing computational effort [7,29,30]. Therefore, the daylight modeling was performed from 10:00 to 15:00 on typical days, considering the spring equinox (21 March), the summer solstice (21 June), and the winter solstice (21 December) [7].

The parametric louver systems were engineered to provide an optimal range of daylight illuminance for most of the day. Useful daylight illuminance represents the proportion of occupied hours during which indoor illuminance remains within the defined lower and upper limits [31]. The illuminance values of $UDI_{100\sim2000\text{ lx}}$ were studied in the current investigation. The UDI was evaluated by classifying the model's hourly illuminance at work plane height, focusing on the optimal range ($UDI_{500\sim1000\text{ lx}}$). The simulated illuminance values at each grid point are classified into different UDI ranges [4,24]. The proportion of a given bin, such as $UDI_{500\sim1000\text{ lx}}$, is calculated as the ratio of the cumulative illuminance values falling within the 500 to 1000 lx range to the cumulative illuminance values across all bins. A very high UDI value, for example, at least 90% of the occupied space within 500 to 1000 lx at a given hour, indicates that daylight provides adequate illuminance for visual tasks during most of the occupied period, thereby reducing the need for electric lighting at the work plane level within the office space [24,32]. Daylight glare probability (DGP) represents the proportion of individuals affected by glare, ranging from 0 (no disturbance) to 1 (everyone is disturbed) [33]. Radiance produces a fisheye HDR luminance image at the observer's position, which is passed to evalglare as input for glare analysis. Evalglare segments glare sources by applying a luminance threshold to group pixels into sources, then extracts source luminance, solid angle, and position. DGP is calculated from vertical eye illuminance together with the glare source terms defined by Wienold and Christoffersen [33], and the visual overlays only confirm detected sources.

2.2. The Control of Trapezoid Shadings

The parametric design is simplified by arranging the slats in successive fixed and movable units, as presented in previous research work [24]. In the facade configuration, the upper, central, and lower segments incorporate 18, 20, and 18 slats, with 50% of each segment fixed and the remaining 50% movable, depending on the control strategy. The spacing between adjacent slats is maintained at a constant 0.05 m [8,34–36]. Control of the desired illuminance is achieved by horizontally displacing dynamic slats.

2.2.1. The Control of Partially Automated Trapezoid Shadings

The hourly openness (HO) value is calculated as the ratio of the horizontal displacement of a slat relative to its neighboring slat (x) to half the pitch of the trapezoidal slat (y) [24]. Optimization of HO is carried out for the top (HO_t), middle (HO_m), and bottom (HO_b) sections across different trapezoidal shading configurations, as shown in Figure 2. In the parametric model, HO was implemented as discrete horizontal translations of the movable slats within a range of 0–0.14 m, using 0.01 m increments. Partially automated configurations were introduced as simplified control strategies, in which selected facade sections remain fixed in open or closed positions. In contrast, only one or two sections are optimized through movable slats for daylighting control. The fully automated configuration allows all facade sections to adjust hourly openness simultaneously to improve $UDI_{500\sim1000\text{ lx}}$ coverage and achieve a more uniform daylight distribution.

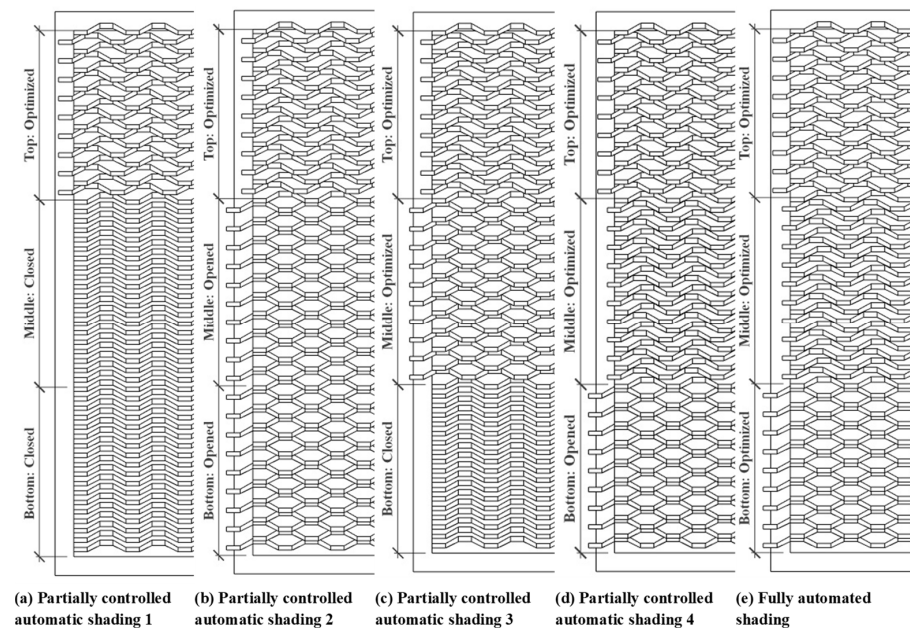


Figure 2. Partially and fully automated trapezoid shadings.

Partially controlled automatic shading 1 has only the top section movable and optimized, whereas the middle and bottom of the facade are kept fixed and closed at HO of 0%, as shown in Figure 2a. For partially controlled automatic shading 2, the central and lower portions of the facade are kept fixed and opened at HO of 100%, as shown in Figure 2b. This configuration gives less control over daylight. For partially controlled automatic shading 3 and 4, the upper and central sections are movable to optimize the slat positions. Fully automated shading has all sections adjust the position of HO to balance UDI and U_o , as shown in Figure 2e.

2.2.2. The Control of Fully Automated Trapezoid Shadings

The corrugated slats can be modified to increase daylight entering the space, particularly at noon and in the afternoon during the summer solstice. The inclined panels in Figure 2 for corrugated trapezoid shadings have no perforations. The perforated external shading panels [22,37] could improve lighting quality and daylight availability. The perforated curved louvers proposed by Uribe et al. [37] employed an overall perforation of 20%. However, the present work used 20% perforation only in the top section of the inclined panels. In contrast, the flat panels are not perforated, as shown in Figure 3. This enhancement can increase UDI illuminance coverage during early and late hours. In contrast, midday conditions are less affected because the flat panels lack perforations. The middle and bottom sections have all inclined and flat panels without perforations.

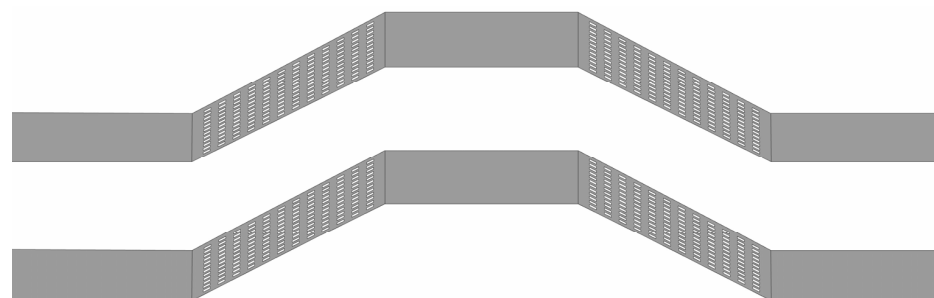


Figure 3. The cross-section of trapezoid corrugated slats for the top section of the facade.

The present work employed different types of shading based on their geometric characteristics and considered the performance improvements achieved by split shading. Table 1 presents details of corrugated shadings [4], perforated shadings [22,37], and separated shadings [23] used in the present work to evaluate daylighting and visual comfort in terms of $UDI_{100\sim1000\text{ lx}}$, $UDI_{500\sim1000\text{ lx}}$, uniformity, and DGP.

Table 1. The details of different fully automated trapezoid shadings.

Shade Type	Slat Properties	Top Section	Middle Section	Bottom Section
Corrugated shadings	Perforation	No	No	No
	Reflectance values	Front: 30% diffuse reflection Back: non-reflective	Front: 30% diffuse reflection Back: non-reflective	Front: 30% diffuse reflection Back: non-reflective
Perforated corrugated shadings	Perforation	20% on inclined panels	No	No
	Reflectance values	Front: 30% diffuse reflection Back: non-reflective	Front: 30% diffuse reflection Back: non-reflective	Front: 30% diffuse reflection Back: non-reflective
Separated/split corrugated shadings	Perforation	No	No	No
	Reflectance values	Front: 50% diffuse reflection Back: 10% diffuse reflection	Front: 30% diffuse reflection Back: 10% diffuse reflection	Front: 30% diffuse reflection Back: 10% diffuse reflection

2.3. Multi-Objective Optimization of Shadings

Significant progress in shading device optimization has occurred over the last decade, driven by the need to balance multiple performance objectives. The complexity of design scenarios, together with the variable characteristics of solar radiation and occupant behavior, requires the use of advanced multi-objective optimization methods. A multi-objective method concurrently optimizes two or more competing goals while considering the given constraints [38]. SPEA-2 is appropriate for multi-objective optimization because it can efficiently search complex parametric design spaces, maintain diverse Pareto-optimal solutions, and support the identification of balanced trade-off options among competing building-performance objectives, such as energy demand, daylight, glare control, and thermal comfort [2,10,26,27,39–42]. Therefore, the present work used SPEA-2 in conjunction with hypermutation to dynamically modify the design variables and continually seek the optimal solution [3,43].

2.3.1. The Optimal Slat Geometry

To maximize daylight for the required bins, an appropriate slat inclination angle is essential. The optimal slat configuration varies across regions due to climatic variations in temperature and daylight. The first round of MOO for daylight simulations is performed over the tilt-angle range of 0° to 30° . The spacing between adjacent slats is consistently maintained at 0.05 m [8,34–36], whereas the slat length is fixed at 0.07 m. These values were derived from prior research indicating a substantial decrease in energy consumption when using trapezoidal shading with slat lengths of 0.05 m and a tilt angle of approximately 30° [4]. For finding the optimal slat geometry, the slat inclination angle is taken as a genome, while $UDI_{500\sim1000\text{ lx}}$, U_o , DGP, and $UDI_{100\sim1000\text{ lx}}$ are taken as objectives on 21 December at 12:00, as shown in Figure 4. The following fitness function, which maximizes the $UDI_{500\sim1000\text{ lx}}$, U_o , and $UDI_{100\sim1000\text{ lx}}$ while minimizing DGP, was used to rank all Pareto-optimal solutions and identify the best trade-off solution [10,27,39–42].

$$FF_i = (UDI_{500\sim 1000 \text{ lux}_i} - UDI_{500\sim 1000 \text{ lux}_{min}})C_1 + (U_{o_i} - U_{o_{min}})C_2 - (DGP_i - DGP_{min})C_3 + (UDI_{100\sim 1000 \text{ lux}_i} - UDI_{100\sim 1000 \text{ lux}_{min}})C_4 \quad (1)$$

$$C_1 = \frac{100}{UDI_{500\sim 1000 \text{ lux}_{max}} - UDI_{500\sim 1000 \text{ lux}_{min}}}$$

$$C_2 = \frac{100}{U_{o_{max}} - U_{o_{min}}}$$

$$C_3 = \frac{100}{DGP_{max} - DGP_{min}}$$

$$C_4 = \frac{100}{UDI_{100\sim 1000 \text{ lux}_{max}} - UDI_{100\sim 1000 \text{ lux}_{min}}}$$

where i indicates the result of the iteration, min represents the lowest value of the optimization set, and max represents the maximum value of the optimization set.

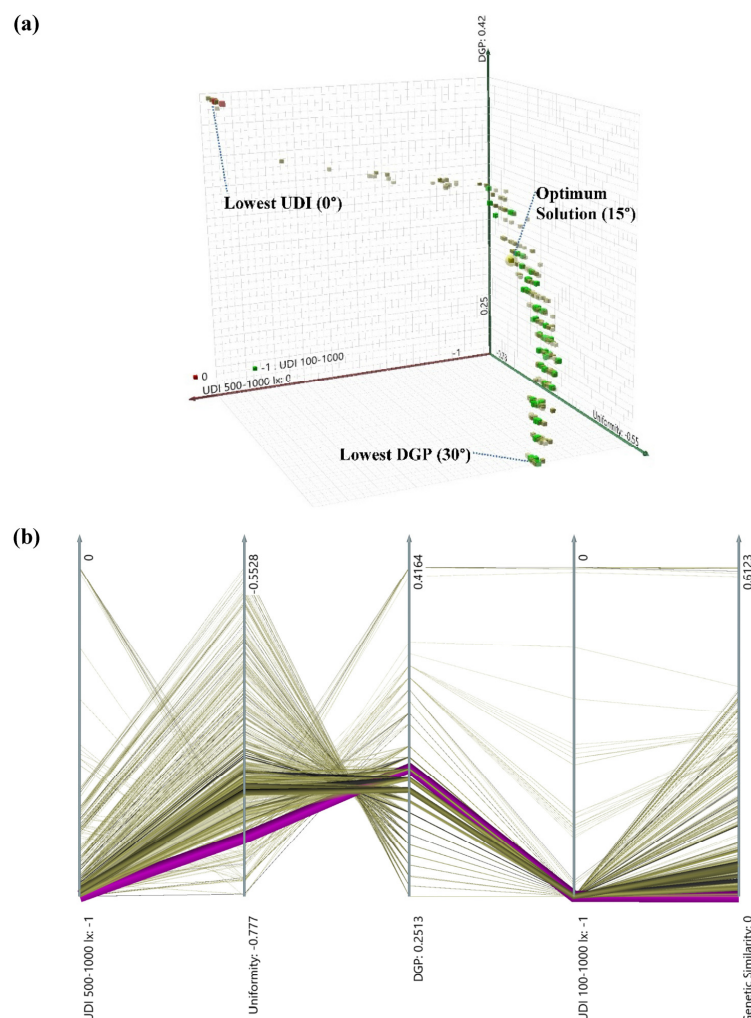


Figure 4. First set of multi-objective optimization for obtaining the inclination of the slats considering $UDI_{500-1000 \text{ lx}}$, DGP, U_o , and $UDI_{100-1000 \text{ lx}}$ based on 21 December for early-stage design calculations.

When daylighting systems attain 70% coverage within the target illuminance range and a uniformity ratio of 0.4, they are often deemed satisfactory [24]. Occupant comfort, in terms of thermal conditions and visual quality, is a fundamental consideration in the design of shading devices [19]. The criterion for visual comfort is satisfied when the DGP value lies within the imperceptible glare range ($DGP < 0.35$) [5]. 21 December marks the winter solstice, with the fewest daylight hours and the lowest solar altitude angles, creating critical

worst-case conditions for evaluating daylight sufficiency and the potential for low-angle glare from south-facing facades [44]. Optimizing the slat geometry, as shown in Figure 4a,b, for this extreme date ensures that the system effectively manages deep sunlight penetration and visual discomfort under the most challenging annual sky conditions. Consequently, simulations performed on this typical date provide a computationally efficient yet robust proxy for annual performance limits suitable for early-stage daylighting analysis and design decision-making.

At 0° , the average illuminance is around 1375.18 lx with a U_o of 0.7363 and 100% coverage in $UDI_{1000\sim 2000\text{ lx}}$, where the DGP value is 0.4165, as illustrated in Figure 4a. At 30° , the DGP value is 0.2510, which is much lower than that for slats without tilt, while the average illuminance is around 521.39 lx with a U_o of 0.5574. The illuminance coverage is 0.78% in $UDI_{100\sim 300\text{ lx}}$, 30.25% in $UDI_{300\sim 500\text{ lx}}$, and 68.97% in $UDI_{500\sim 1000\text{ lx}}$. At 15° , the average illuminance is approximately 782.22 lx, with a U_o of 0.7229 and 100% coverage in $UDI_{500\sim 1000\text{ lx}}$, and the DGP value is 0.3324. The multi-axis view, shown in Figure 4b, generated in Octopus Grasshopper, demonstrates the trade-offs among $UDI_{500\sim 1000\text{ lx}}$, U_o , DGP, $UDI_{100\sim 1000\text{ lx}}$, and genetic similarity, where lower genetic similarity values indicate a more diverse solution population and higher values reflect convergence toward similar design configurations during the optimization process. Under the aforementioned parameters, a slat angle of 15° was chosen for further daylighting investigation.

2.3.2. The Optimum Hourly Openness of Shadings

The hourly openness levels are further examined between 10:00 and 15:00 on the spring equinox, the summer solstice, and the winter solstice [7]. The DGP values are in the imperceptible glare range; therefore, it is more computationally efficient to exclude the glare computation from further analysis. For the second set of MOO (Figure 5), the slat inclination angle is fixed (at 15°), as obtained from the first set of optimizations (Figure 4). The input parameters include the horizontal motion of slats at different sections of the facade. The second set of optimizations includes $UDI_{100\sim 1000\text{ lx}}$, $UDI_{500\sim 1000\text{ lx}}$, and U_o to find the optimal HO values, as shown in Figure 5a. The optimal solution, which balanced the slat positions across all three sections of the split facade, exhibits the lowest genetic similarity, as shown in Figure 5b.

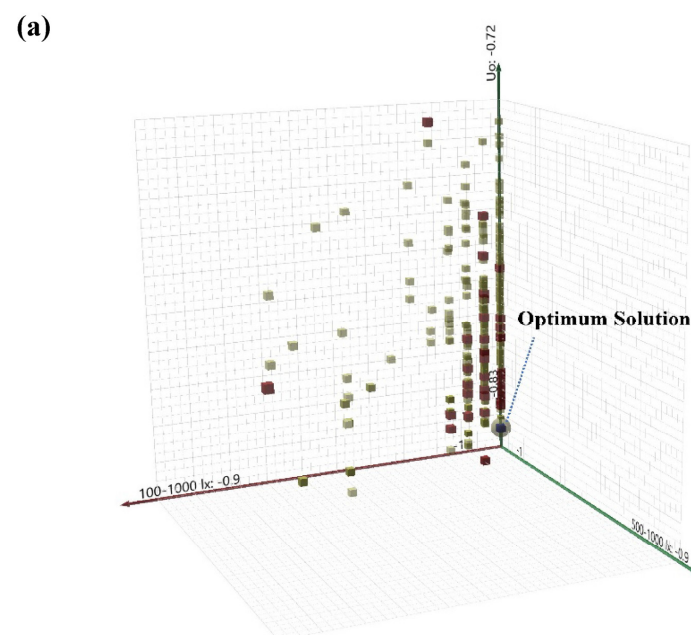


Figure 5. Cont.

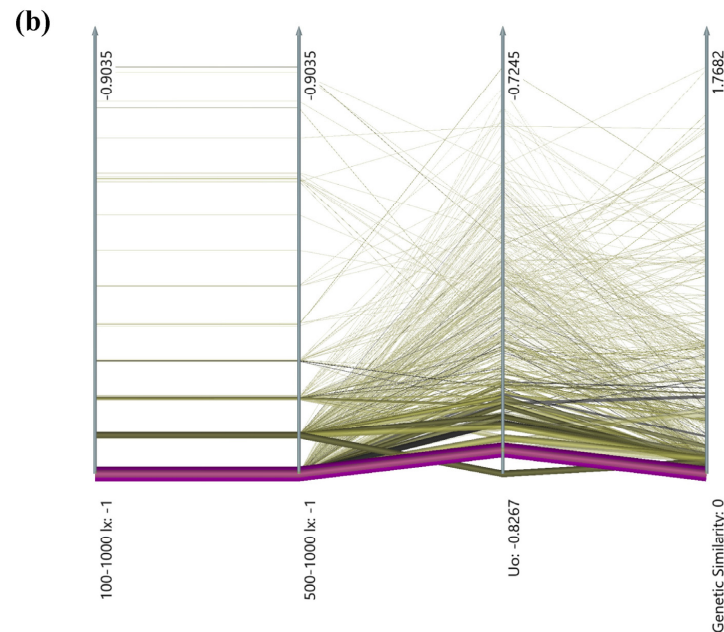


Figure 5. The second step of MOO, which can be used to obtain the hourly openness values from 10:00 to 15:00 for the typical days (considering the spring equinox, the summer solstice, and the winter solstice), consequently improving the desired $UDI_{500-1000\text{ lx}}$ and U_o by optimizing hourly openness.

3. Results

3.1. Partially Automated Trapezoid Shadings

The partially controlled shadings are compared in terms of horizontal automation across the facade's upper, central, and lower sections. Partially controlled automatic shading 1 could provide satisfactory daylighting in March and December, as shown in Figure 6a. However, this shading control resulted in lower illuminance of 39% and 47% for $UDI_{300-500\text{ lx}}$ coverage during June at 10:00 and 15:00, respectively. For optimizing the top section with fixed, open trapezoid middle and bottom sections, the $UDI_{300-500\text{ lx}}$ coverage during June can be reduced to 9% and 18%, respectively. However, the partially controlled automatic shading 2 design performed least effectively in December owing to excessive solar irradiance. $UDI_{1000-2000\text{ lx}}$ values reached approximately 83% at 12:00 in December, as shown in Figure 6b. This could increase the risk of glare and visual discomfort for occupants.

Optimizing the split facade improved daylighting compared to using only the top section. Partially controlled automatic shading 3 resulted in illuminance of 21% and 30% for $UDI_{300-500\text{ lx}}$ coverage during June at 10:00 and 15:00, respectively. This represents an improvement over the partially controlled automatic shading 1, as shown in Figure 6c. Meanwhile, $UDI_{1000-2000\text{ lx}}$ values reached around 15% in December at 13:00. This control option could provide 70% daylight space within $UDI_{500-1000\text{ lx}}$ and uniformity values above 0.4 for all times investigated. On the other hand, partially controlled automatic shading 4 is similar to shading control 3, but with open bottom sections. Opening the facade affected daylight performance in December, as shown in Figure 6d. The $UDI_{500-1000\text{ lx}}$ values dropped to 63% at 12:00 in December.

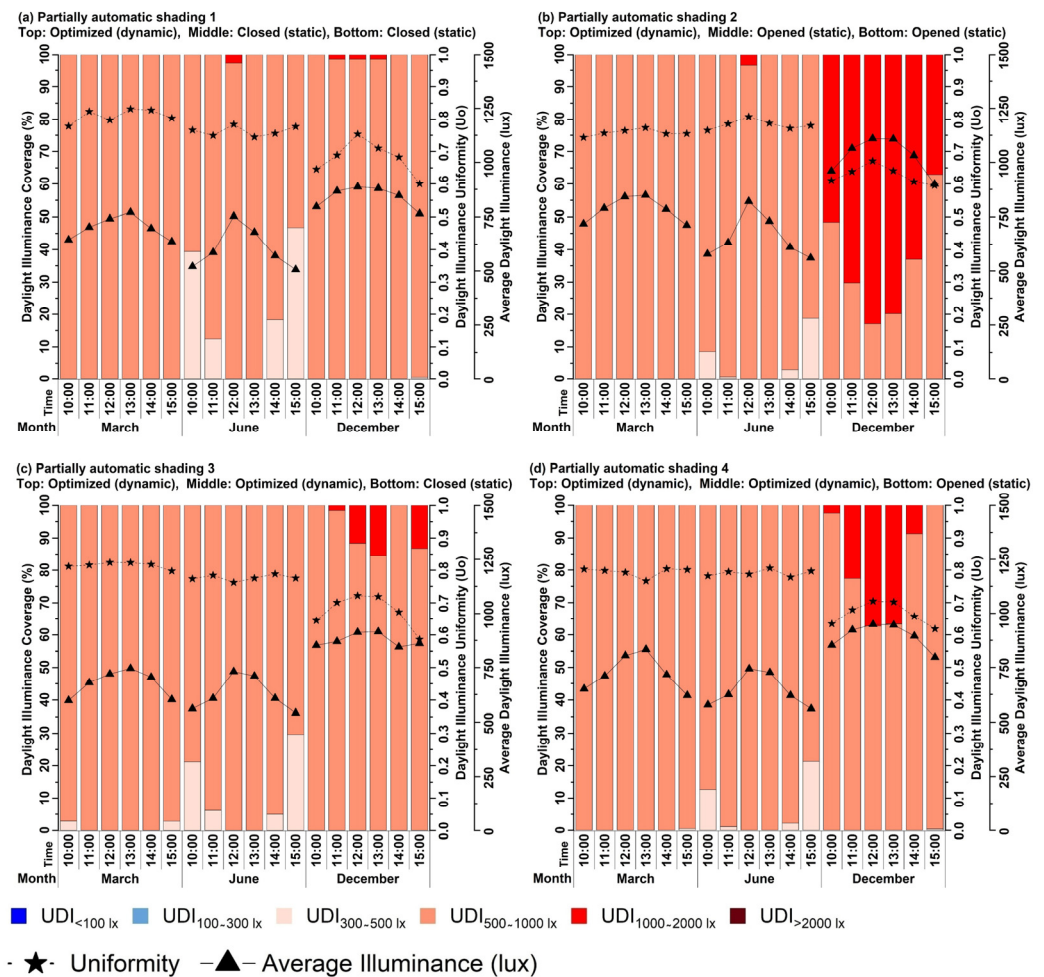


Figure 6. Comparisons of partially controlled shadings in terms of daylighting.

3.2. Fully Automated Trapezoid Shades

3.2.1. Corrugated Shadings

Further simulations are performed with fully automatic control of the facade, using optimized positions for the upper, central, and lower sections, as shown in Figure 2e. This control strategy could solve the issues of lower illuminance ($UDI_{300-500 \text{ lx}}$) in June and higher illuminance ($UDI_{1000-2000 \text{ lx}}$) in December. Illuminance maps focusing on $UDI_{500-1000 \text{ lx}}$ and uniformity are presented in Figure 7. Results indicate that the proposed automatic shadings maintain greater than 90% coverage for $UDI_{500-1000 \text{ lx}}$.

The minimum Uo is 0.79 in March and around 0.6 in December. For the June scenario, the noontime can provide illuminance greater than 90% for the $UDI_{500-1000 \text{ lx}}$ metric. The $UDI_{500-1000 \text{ lx}}$ metrics were deemed satisfactory for daylighting with coverage between 70% and 90% at 10:00 and 15:00 during June. There is 19% coverage for the $UDI_{300-500 \text{ lx}}$ range. However, the previous study [4,24] reported $UDI_{300-500 \text{ lx}}$ to be sufficient for office work visual tasks.

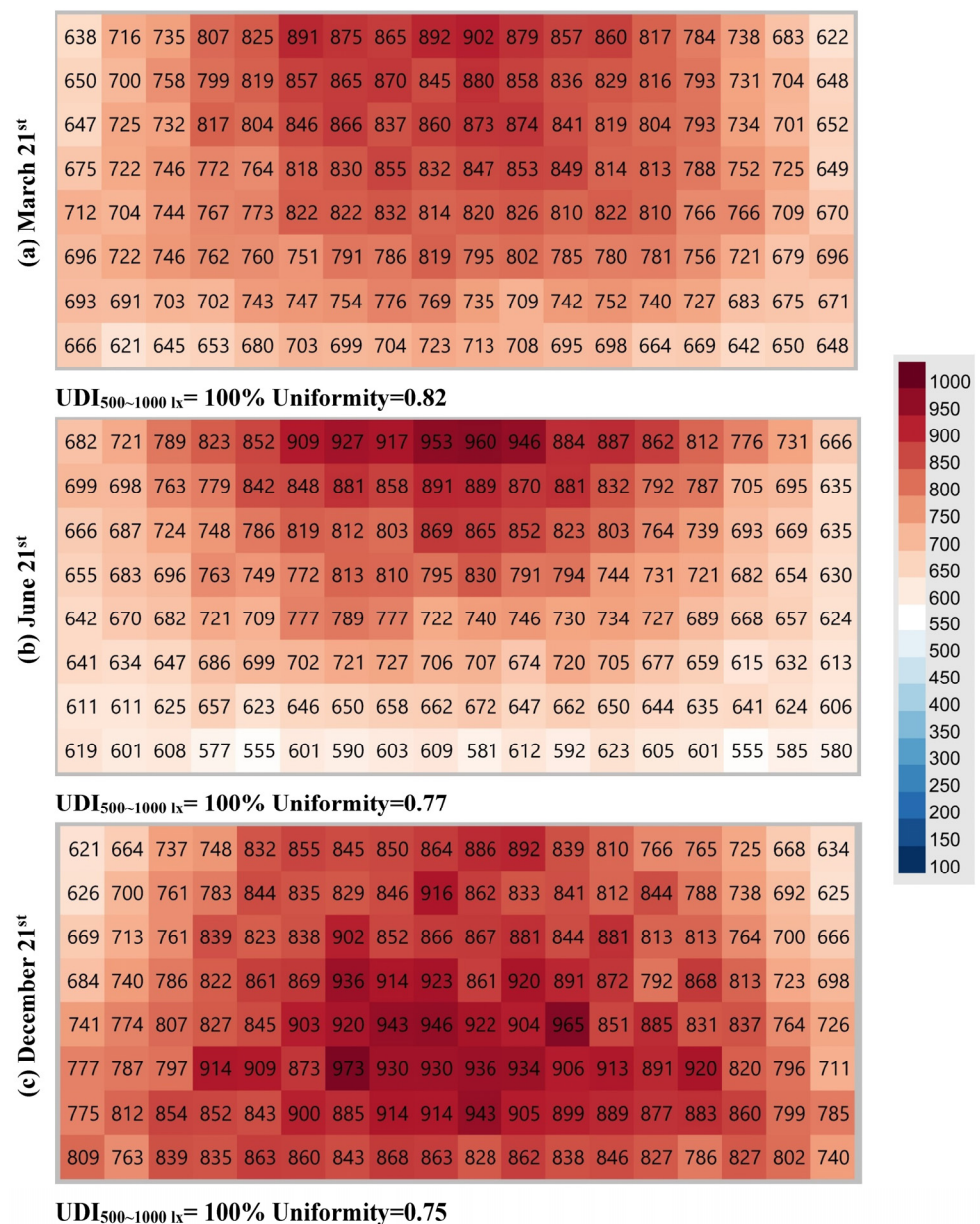


Figure 7. Illuminance maps for MOO of fully automated trapezoid corrugated slats for UDI_{500-1000 lx} metrics.

The hourly variations of daylight illuminance uniformity are plotted against UDI_{100-1000 lx} and UDI_{500-1000 lx} in Figure 8. UDI_{500-1000 lx} is shown using solid triangles, while UDI_{100-1000 lx} is presented using circles. The color of the symbol is based on the percentage coverage of the illuminance in the work plane. Most of the shading positions achieved almost 100% coverage of UDI_{500-1000 lx} within the range of UDI_{100-1000 lx} between 11:00 and 14:00 in March. However, the illuminance coverage is between 90% and 100% for UDI_{500-1000 lx}, while it is 100% for UDI_{100-1000 lx} at 10:00 and 15:00. A few shading positions resulted in satisfactory daylighting, with coverage between 70% and 90%. The daylight uniformity remains around 0.80, which is above the recommended criteria of 0.6.

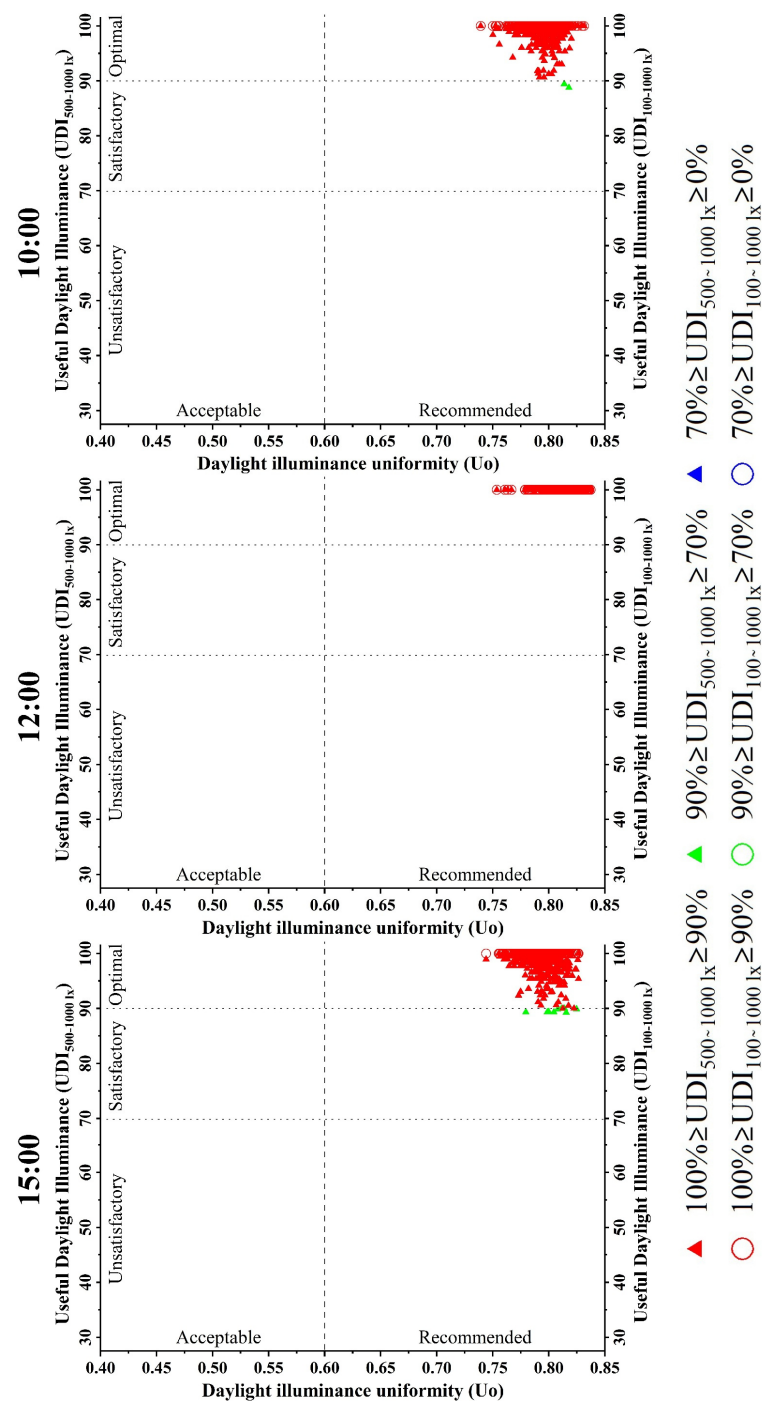


Figure 8. The variations in uniformity against $UDI_{500-1000\text{ lx}}$ and $UDI_{100-1000\text{ lx}}$ metrics on 21 March.

All the shading positions reached 100% coverage of $UDI_{100-1000\text{ lx}}$ from 10:00 to 15:00 in June, as shown in Figure 9. The illuminance coverage is less than 90% for $UDI_{500-1000\text{ lx}}$ at 10:00 and 14:00, while the majority of simulations covered above 90% of $UDI_{500-1000\text{ lx}}$ at 11:00. From 12:00 to 13:00, all the shading positions targeted almost 100% coverage of $UDI_{500-1000\text{ lx}}$. The shading positions marginally met the satisfactory illuminance range of $UDI_{500-1000\text{ lx}}$ within 70% to 90% at 15:00. A few shading positions result in satisfactory daylighting with coverage between 70% and 90%. At the same time, the majority of results remained below the satisfactory coverage threshold. During June, the daylight uniformity averages around 0.80, above the required threshold of 0.6.

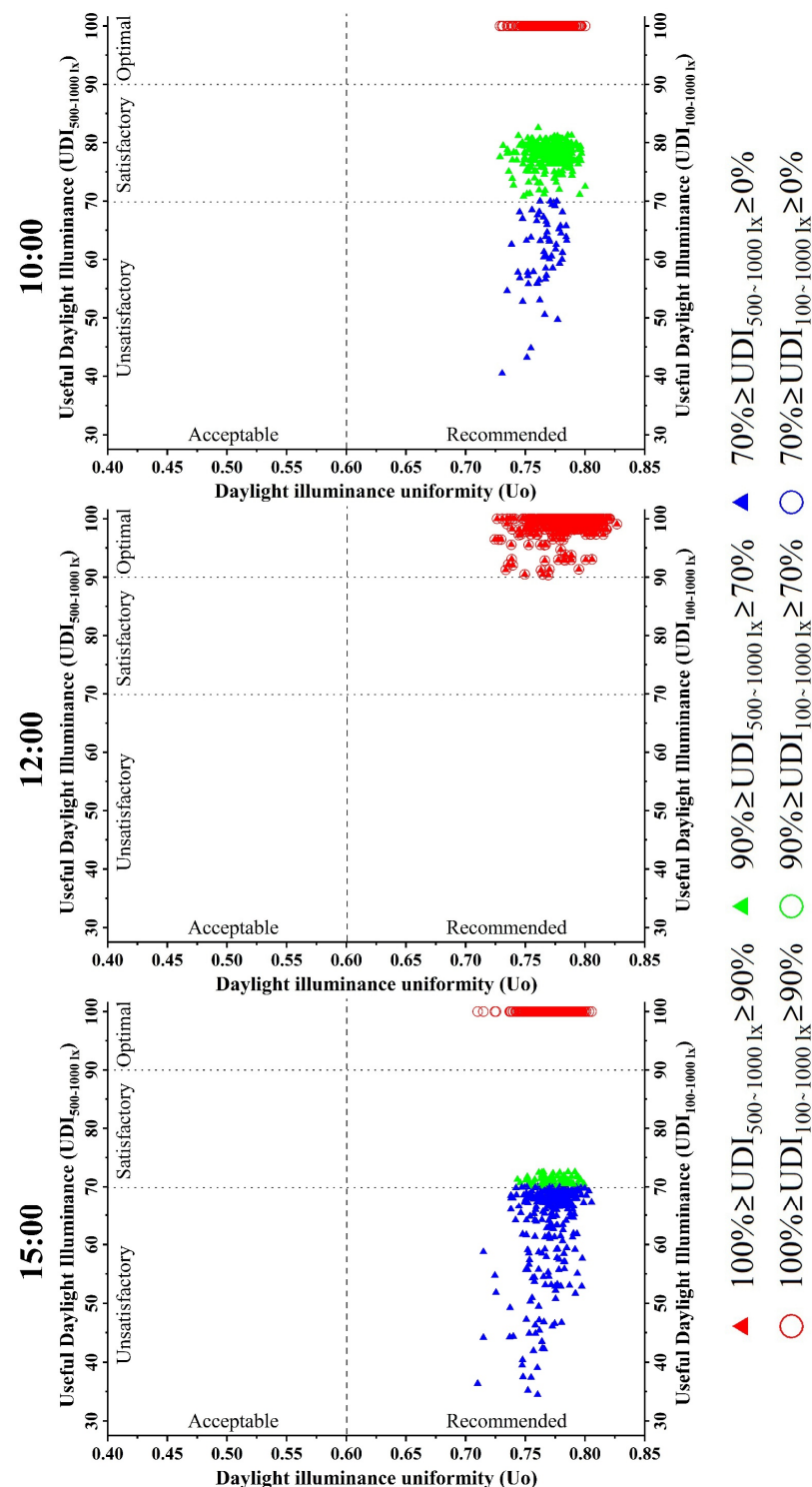


Figure 9. The variations in uniformity against $\text{UDI}_{500 \sim 1000 \text{ lx}}$ and $\text{UDI}_{100 \sim 1000 \text{ lx}}$ metrics on 21 June.

The variations in December differ from those observed in March and June. At Miami's latitude, the solar altitude is around 40° during December, rises to approximately 64° in March, and attains a near-vertical 90° in June. This increases the likelihood of $\text{UDI}_{1000 \sim 2000 \text{ lx}}$ coverage, particularly during the winter solstice. The shading position adjustment could provide an overall above 90% of $\text{UDI}_{500 \sim 1000 \text{ lx}}$ from 10:00 to 15:00 during December, as shown in Figure 10. From 11:00 to 14:00, the percentage coverage of $\text{UDI}_{500 \sim 1000 \text{ lx}}$ and $\text{UDI}_{100 \sim 1000 \text{ lx}}$ is the same, while the remaining coverage is under $\text{UDI}_{1000 \sim 2000 \text{ lx}}$.

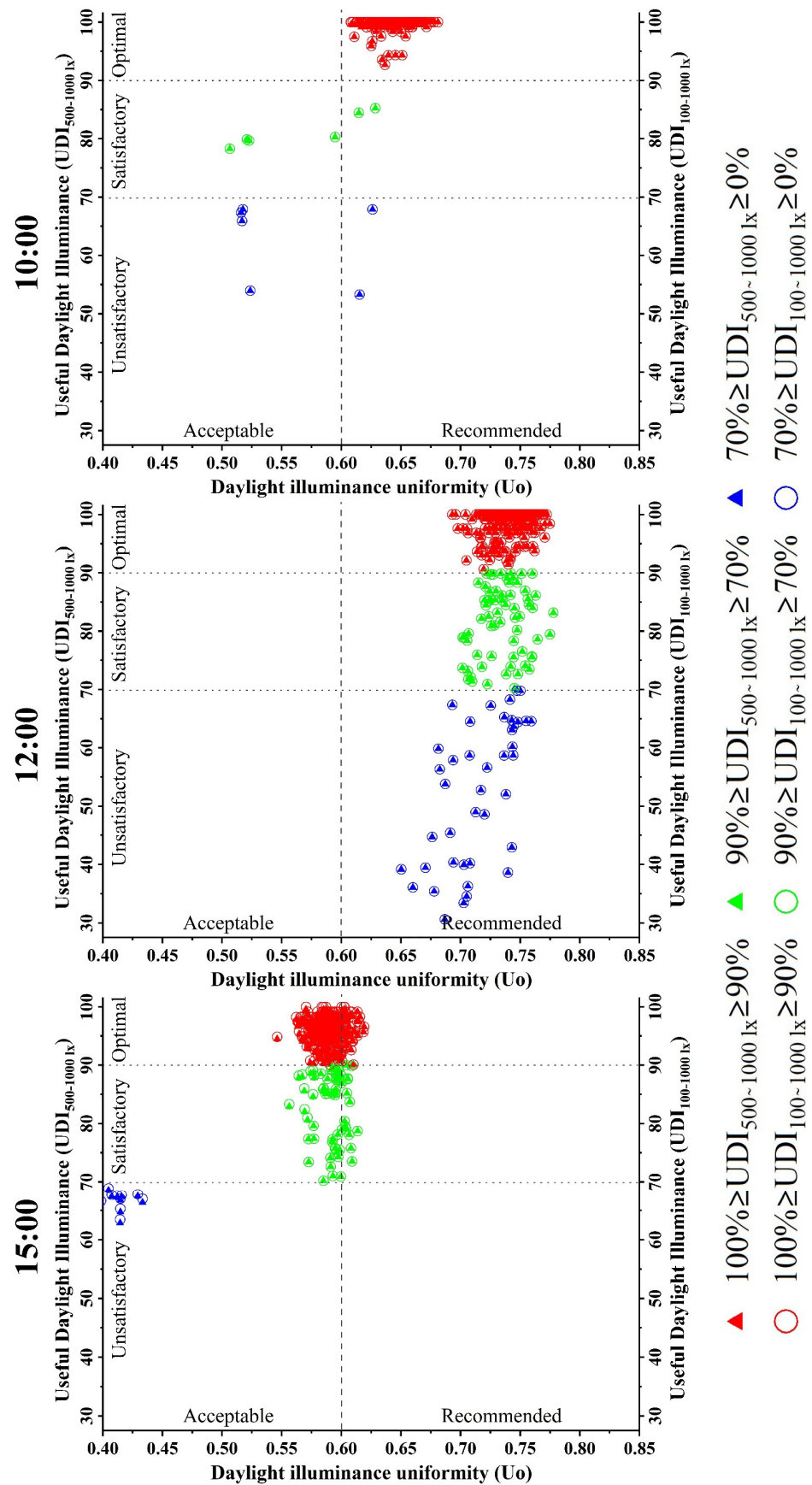


Figure 10. The variations in uniformity against $UDI_{500-1000\text{ lx}}$ and $UDI_{100-1000\text{ lx}}$ metrics on 21 December.

3.2.2. Corrugated-Perforated Shadings

The fully automated trapezoidal shadings could meet daylighting requirements of >90% coverage for $UDI_{500-1000\text{ lx}}$ metrics in most of the hours investigated in the present work. However, the control system was deemed satisfactory for daylighting, with coverage between 70% and 90% at 10:00 and 15:00 during June. The issues could be mitigated by perforating the inclined panel of the trapezoid slats while leaving the flat panel unperforated. The effectiveness of the proposed perforation is confined to the upper zone of the facade. On the other hand, perforated corrugated panels in the central and lower sections of the facade could increase $UDI_{1000-2000\text{ lx}}$ values and cause glare issues. Illuminance maps for the MOO of fully automated trapezoid-perforated corrugated slats for $UDI_{500-1000\text{ lx}}$ metrics are shown in Figure 11. The corrugated slats have a higher average illuminance than cases without corrugation. Specifically, the winter solstice makes corrugated slats vulnerable to illuminance exceeding 1000 lx at noon.

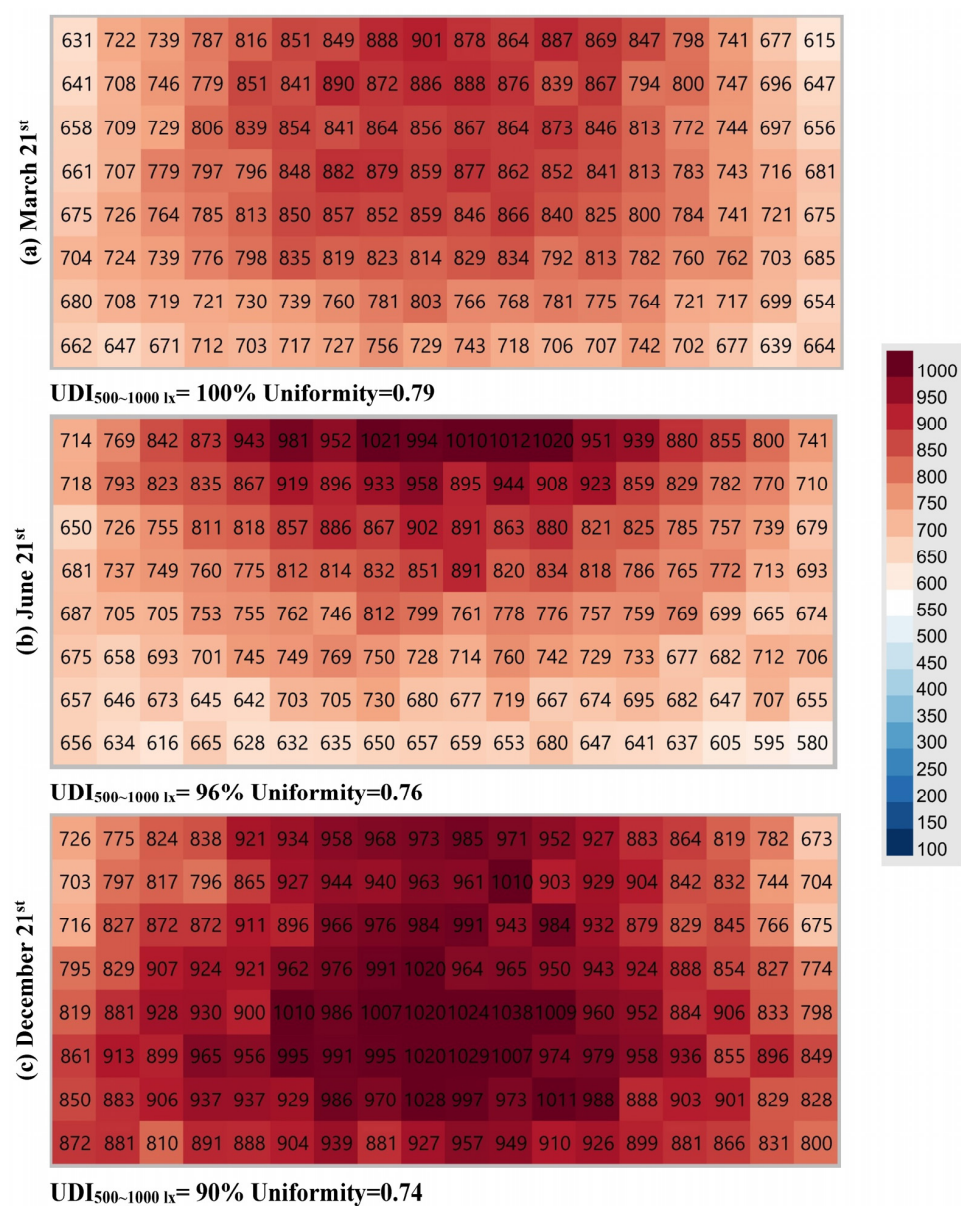


Figure 11. Illuminance maps for MOO of fully automated trapezoid perforated corrugated slats for $UDI_{500-1000\text{ lx}}$ metrics.

3.2.3. Corrugated-Separated Shadings

In the previous sections of the present work on trapezoidal shadings, including the partially automated and the fully automated (corrugated and perforated), 30% diffuse reflection is used on the front side, with non-reflective back sides for all facade sections. The split louvers perform better at slightly higher reflectance values in the upper portion, while the lower sections can be equipped with lower reflectivity [5]. Further assessment of slats is performed using separated slats with a front-side reflectance of 50% [23], applicable to the upper zone of the facade. The backsides of all sections have a reflectance of 10%. The front side of the slats in the middle and bottom sections of the facades has a reflectance of 30% [3], presented in Table 1.

The separated slats, considering variable reflectance under fully automatic control of the facade with optimized positions of top, middle, and bottom, are simulated for UDI illuminance coverage, as shown in Figure 12. This control technique may address the problems of lowered illuminance in June ($UDI_{300-500\text{ lx}}$) and increased illuminance ($UDI_{1000-2000\text{ lx}}$) in December. The recommended automated shading systems may achieve illuminance above 90% for the $UDI_{500-1000\text{ lx}}$ metric. Within this case study, coverage was found to be nonexistent for $UDI_{<100\text{ lx}}$, $UDI_{100-300\text{ lx}}$, and $UDI_{>2000\text{ lx}}$ for the specified time frames.

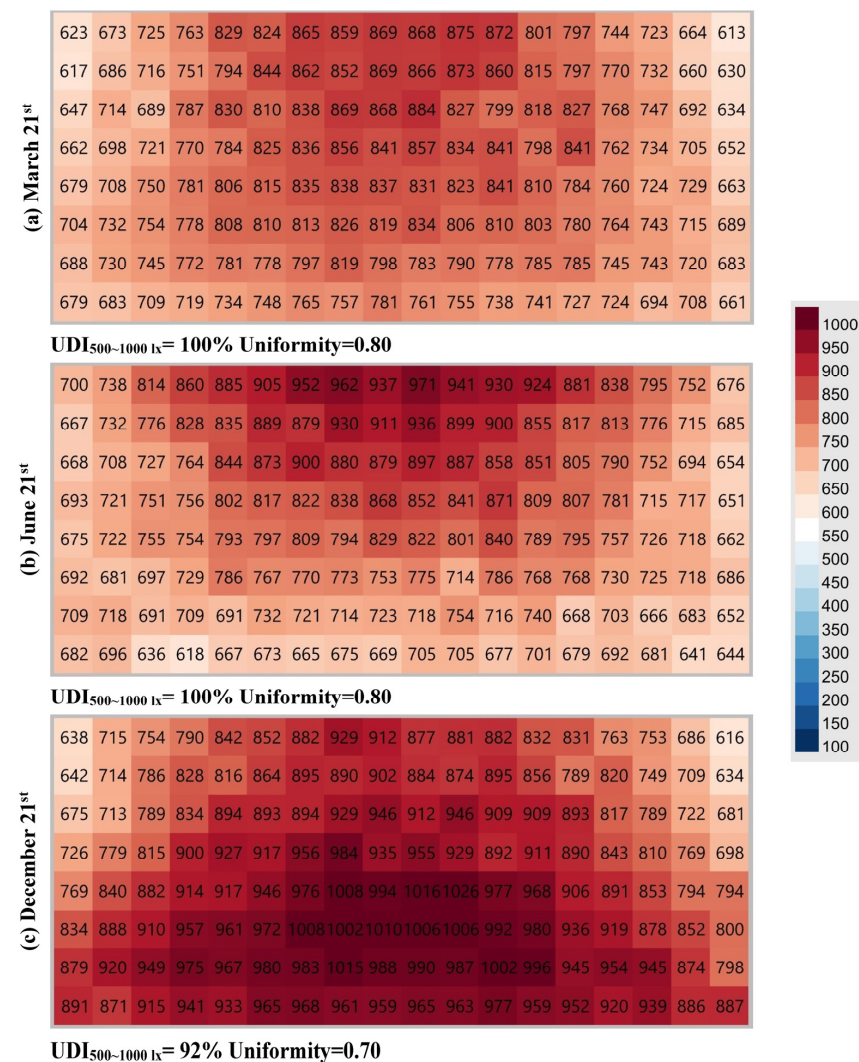


Figure 12. Illuminance maps for MOO of fully automated trapezoid separated corrugated slats for $UDI_{500-1000\text{ lx}}$ metrics.

Visual comfort, in terms of DGP, is assessed inside the office building [33]. DGP is measured in the center of the room near the sidewall by installing a camera at a height of 1.2 m [24]. The hourly DGP values on the typical dates during midday are illustrated in Figure 13. The computed results fall within the acceptable range corresponding to imperceptible glare (DGP < 0.35) [5]. Radiance falsecolor converts the luminance image to a pseudo-color map, where each color band corresponds to a luminance range shown in the cd/m^2 legend. Evalglare check images produce contour outlines to mark detected glare-source regions, while the remaining view is rendered in grey for verification. Different contour colors are used only to distinguish separate detected sources and do not represent glare magnitude, which is reported numerically via DGP.

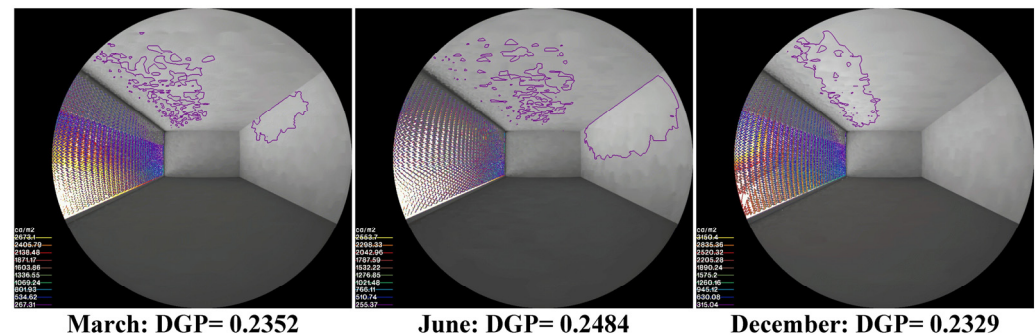


Figure 13. Daylight glare probability for fully automated trapezoid separated corrugated slats at 12:00.

4. Discussions

4.1. Comparison of Fully Automated Trapezoid Shades with Typical Flat Profile Slats

The commonly used plane profile fixed shading in the horizontal position [4] is selected to compare with the proposed automatic trapezoid shading. Therefore, this comparison evaluates the combined effect of trapezoid geometry, automated hourly openness, split-facade control, perforation, and variable slat reflectance. The UDI bin (ranging from 500 lx to 1000 lx) with greater than 90% is a favorable metric for preventing disruptive glare [45]. Figure 14 presents illuminance values at different times for plane, trapezoidal, and corrugated trapezoidal shading.

Plane/flat shading resulted in 100% $\text{UDI}_{500\sim1000\text{ lx}}$ on March 21st for the investigated hours; however, these slats had coverage issues of 18.30% and 20.82% for $\text{UDI}_{300\sim500\text{ lx}}$ across the morning and afternoon hours of June. The observed value was 9.85% for $\text{UDI}_{1000\sim2000\text{ lx}}$ at noon in June. Meanwhile, there is about 56.78% illuminance coverage of $\text{UDI}_{1000\sim2000\text{ lx}}$ during noon of December for the typically used plane shadings, as shown in Figure 14a. During the winter solstice, the low solar altitude angle causes excessive illuminance due to deep sunlight penetration at shallow angles [2,24]. Research indicates that fixed optimization configurations fail to intercept low-angle solar radiation as effectively as in summer, when the sun's position facilitates better shading control. Winter months exhibit reduced UDI performance because daylight illuminances frequently exceed 1000 lux near fenestration zones, creating non-uniformity. Implementing adaptive control approaches that respond to changes in solar position can reduce fluctuations in seasonal uniformity while maintaining optimal UDI ranges year-round.

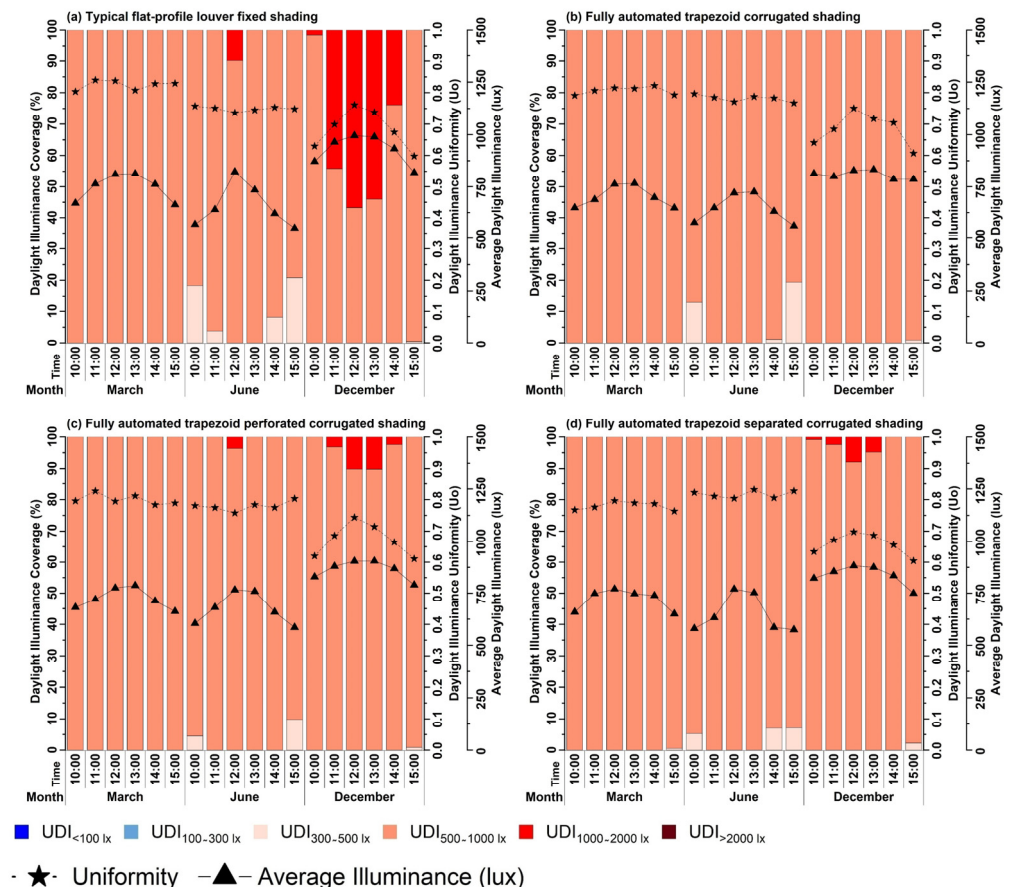


Figure 14. Performance comparisons of fully automatic shading configurations.

The hourly openness behavior using automated trapezoid corrugated shadings mitigated the above limitations for $UDI_{1000-2000\text{ lx}}$ during December, presented in Figure 14b. Corrugated slats still have lower illuminance issues of 12.79% and 19.40% at $UDI_{300-500\text{ lx}}$ across the morning and afternoon hours in June. Introducing perforated corrugated slats for the top section increased the $UDI_{500-1000\text{ lx}}$ for June. Fully automated trapezoidal shading with perforated slats achieved nearly 90% compliance with $UDI_{500-1000\text{ lx}}$ across the examined hours while attaining a Uo of 0.6, as illustrated in Figure 14c. In the meantime, there is about 10.15% coverage of $UDI_{1000-2000\text{ lx}}$ during noon of December. Trapezoid separated slats increased the $UDI_{500-1000\text{ lx}}$ with at least 99.47% in the afternoon during March, 92.95% in the afternoon during June, and 92.06% at noon during December, as illustrated in Figure 14d. Therefore, this work suggests applications of varying slat reflectance for split shading to balance daylighting effectively.

4.2. Limitations and Future Research Directions

To conduct a thorough assessment of future studies and recommendations identified in multi-objective optimization research on shading devices, it is essential to recognize key trends and priority areas. Future work in this field primarily focuses on expanding research to encompass diverse climates and building types, exploring dynamic shading systems, incorporating advanced technologies, and enhancing optimization methodologies. The gap between simulation-based results and real-world performance remains a significant challenge, as various environmental and operational factors influence the efficacy of shading devices. Several studies [21,25] underscore the importance of real-world case studies for validating MOO research findings. Future work should prioritize validation through field tests, experimentation, and post-occupancy evaluations. Early collaboration

with architects, building engineers, and developers during the design stages can further bridge the divide between theoretical models and practical applications.

The reported gains in energy savings, UDI, DA, and DGP support trapezoidal-profile louver shading as an alternative to plane or flat-shaped shading for highly glazed facades where integrated daylight and visual comfort targets are required [4,24,26]. Therefore, while the present study focuses on daylight and visual comfort optimization, prior work has already established the energy–daylight relationship for trapezoidal-profile louvers, and future studies should extend this framework by incorporating energy-intensity metrics, such as W/m^2 optimization. Future research should conduct annual occupied-hour analysis incorporating lighting schedules, dimming control, and occupant behavior to quantify potential electric-lighting savings resulting from $UDI_{500\sim1000\text{ lx}}$. This study is limited to a selected south-oriented office space in Miami and point-in-time daylight simulations on representative equinox and solstice days from 10:00 to 15:00. The results were not validated experimentally and do not include annual daylight analysis, lighting-energy modeling, lighting schedules, dimming control, occupant behavior, or an extended assessment of DGP across multiple view positions.

5. Conclusions

This study presents a simulation-based comparative workflow to assess how automated hourly openness, split-facade operation, perforation, and different slat reflectance values affect daylighting performance and visual comfort in trapezoidal louver shading systems under the selected Miami office-space conditions. A constant spacing of 0.05 m was maintained between adjacent slats, while the slat length was fixed at 0.07 m. The slat tilt angle was optimized from 0° to 30° to achieve optimal performance for $UDI_{500\sim1000\text{ lx}}$, U_o , and DGP.

1. The hourly openness in one or more sections of the facade was optimized under the partially controlled shading system. At the same time, the remaining sections were fixed in either open or closed positions. A higher percentage coverage of $UDI_{300\sim500\text{ lx}}$ was observed when the facade sections were fixed in the closed position. Conversely, fixing sections in the open position could lead to excessive $UDI_{1000\sim2000\text{ lx}}$ during winter. This control option achieved 70% coverage within the $UDI_{500\sim1000\text{ lx}}$ band and U_o above 0.4 throughout the investigated time periods.
2. The fully automated trapezoid corrugated shading system improved the balance between daylighting and uniformity; it can achieve over 90% illuminance within the $UDI_{500\sim1000\text{ lx}}$ range at the equinox and solstice. The minimum U_o is 0.79 in March and approximately 0.6 in December. In June, noontime conditions can provide over 90% illuminance within the $UDI_{500\sim1000\text{ lx}}$ range. The $UDI_{500\sim1000\text{ lx}}$ metrics were deemed satisfactory for daylighting, with coverage between 70% and 90% at 10:00 and 15:00 during June.
3. Perforated inclined panels improved $UDI_{500\sim1000\text{ lx}}$ in the morning and afternoon without significantly impacting noontime UDI values. However, significant penetration of direct sunlight was observed during December.
4. The fully automated trapezoid-separated shading system provided the most effective daylighting balance among the investigated systems. It achieved over 90% illuminance corresponding to the $UDI_{500\sim1000\text{ lx}}$ category. The lowest $UDI_{500\sim1000\text{ lx}}$ coverage is 99.47% in March at 15:00, 92.95% in June at 15:00, and 92.06% in December at 12:00. At most, 7.05% coverage was observed for $UDI_{300\sim500\text{ lx}}$ and 7.94% for $UDI_{1000\sim2000\text{ lx}}$ during the hours investigated. In the current case study, no coverage was observed for $UDI_{<100\text{ lx}}$, $UDI_{100\sim300\text{ lx}}$, and $UDI_{>2000\text{ lx}}$ within the specified time frames. Additionally, the hourly DGP values on selected dates representing seasonal transitions (21 March,

21 June, and 21 December) were within the accepted range for imperceptible glare ($DGP < 0.35$).

Compared with typical plane/flat-profile slats, automated trapezoid-separated shadings more effectively balance $UDI_{500\sim1000\text{ lx}}$, U_o , and DGP . Therefore, this work suggests the application of varying slat reflectance for split shadings to balance daylighting effectively. Future studies should expand the proposed optimization framework to different climates, orientations, and building types while integrating energy-intensity metrics, field validation, real-time control strategies, and computationally efficient techniques.

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Appendix A

Previous studies focusing on the desired illuminance within $UDI_{100\sim2000\text{ lx}}$ are presented in Table A1 for different building envelopes.

Table A1. Summary of previous research for useful illuminance coverage.

Author	Building Type, Location	Time	Illuminance	Louvers Design	Software	Contributions	Key Issues
Sun et al. (2017) [46]	Office buildings ($4.4 \times 2.9 \times 3.3\text{ m}$); Stockholm, London, Beijing, Hong Kong, and Singapore	Yearly data	Range: $100\sim2000\text{ lx}$ (79%); Targeted: $500\sim1000\text{ lx}$ (50%)	Parallel slat transparent insulation material	Radiance	- Translucent slats increase useful daylight by up to 79%. - PS-TIM improves daylight and reduces glare risks. - Smaller slat pitches optimize performance at higher latitudes.	- The study ignores PS-TIM effects on building views. - Radiance simulations exclude neighboring buildings or vegetation obstructions. - Overall, building energy performance requires further research validation.
Eltaweel et al. (2020) [47]	Deep-plan office ($12 \times 8 \times 4\text{ m}$); Cairo (Egypt)	9:00 to 17:00	Range: —; Targeted: $300\sim500\text{ lx}$ (90%)	One-axis, Bi-axis, and two-layer parametric louvers	Radiance and DAYSIM (Grasshopper)	- Advanced Bi-axis and Two-layer louvers achieve over 90% daylighting coverage within $300\sim500\text{ lx}$. - Parametrically shifted target points maintain steady illumination across deep-plan office rooms.	- Complex rotational structures in Bi-axis designs limit immediate practical application. - Fixed slats remain necessary to shade excessive scattered light and prevent glare. - Future feasibility requires investigating smaller, lighter slats and concave or convex shapes.

Table A1. Cont.

Khidmat et al. (2022) [12]	Deep-plan office (12 × 8 × 3.5 m); Birmingham, Jakarta, and Sydney	Yearly data	Range: 100~2000 lx; Targeted: 300~500 lx (80%, 146.26%, and 79.48%)	Optimized louver shading	Radiance and Octopus optimization	- MOO significantly increased UDI by 146.26% in Jakarta. - Framework maximized effective UDI range (300~500 lx).	- MOO search iterations were limited by computational time. - Simulations addressed only specific extreme hot-weather periods. - The study used a virtual office model and excluded site context.
Alsukkar et al. (2023) [5]	Deep-plan office (12 × 8 × 4 m); Amman (Jordan)	8:00 to 12:00	Range: 150~750 (Up to 100%); Targeted: 300~500 lx (71~100%)	Flat, concave, convex, and retro shadings	Radiance and DAYSIM (Grasshopper)	- Retro slats achieve UDI150~750 lx coverage across 90% work plane. - Design maintains 0.70 uniformity while minimizing daylight glare. - Parametric system eliminates common blinds through optimal sunlight redirection.	- Complex parametric designs responding to solar angles need further study. - The three-phase method requires high computational resources and Radiance expertise. - Simplified reflection assumptions might not accurately represent highly reflective surfaces.
Ibrahim et al. (2024) [4]	Prefabricated building (12.2 × 4.9 × 2.9 m); Miami (USA), Guangzhou (China), and San Diego (USA)	12:00	Range: 100~2000 (Up to 100%); Targeted: 500~1000 lx (97.22%)	Trapezoid shadings	Radiance (Grasshopper)	- Trapezoid shades improved annual UDI values to 92.60%. - Innovative split louvers reduced DGP levels. - Rectangular rib profiles achieved 97.22% UDI coverage. - Fixed shading effectively maximized visual comfort.	- Adjust tilt angles to redirect light in cold climates. - Integrate realistic occupancy schedules to refine energy data. - Explore dynamic control systems for further efficiency gains. - Analyze interactions between shading and variable glazing properties.
Ibrahim et al. (2025) [24]	Office buildings (10.0 × 5.0 × 3.0 m); Miami (USA), Guangzhou (China), and Amman (Jordan)	10:00 to 15:00	Range: 100~2000 (Up to 100%); Targeted: 500~1000 lx (Up to 90%)	Optimized trapezoid shading devices	Radiance and Octopus optimization	- Dynamic louvers achieved at least 98% UDI500~1000 lx. - Monthly variations showed uniformity above 0.6 with 90% UDI500~1000 lx.	- Automated louver performance requires investigation for a lower illuminance range. - Further geometry optimization is needed. - More investigation is needed for ASHRAE thermal zone 3.

Table A1. Cont.

Present work	Office buildings (10.0 × 5.0 × 3.0 m); Miami (USA)	10:00 to 15:00	Range: 100–2000 (Up to 100%); Targeted: 500–1000 lx (Up to 90%)	Optimized corrugated, perforated, and separated hybrid shadings	Radiance and Octopus optimization	- The effect of perforation and variable reflectance is investigated. - Optimized slats improved the UDI500–1000 lx to 90% above the value with lower DGP. - Introduced simple horizontal sliding to automatically balance visual comfort and DGP for most of the working hours. - Partially optimized shading was introduced and compared with fully automated slats.	- Need real-world applications to implement the feasibility. - Cold climates need further modifications for design variables. - The ratio of perforation and slat reflectance can be adjusted accordingly.
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References

- Bustamante, W.; Uribe, D.; Vera, S.; Molina, G. An integrated thermal and lighting simulation tool to support the design process of complex fenestration systems for office buildings. *Appl. Energy* **2017**, *198*, 36–48. [\[CrossRef\]](#)
- Alsukkar, M.; Ibrahim, A.; Eltaweel, A. Multi-Objective Optimization of Daylighting Systems for Energy Efficiency and Thermal-Visual Comfort in Buildings: A Review. *Build. Environ.* **2025**, *288*, 113921.
- Wu, H.; Zhang, T. Optimal design of complex dynamic shadings: Towards sustainable built environment. *Sustain. Cities Soc.* **2022**, *86*, 104109. [\[CrossRef\]](#)
- Ibrahim, A.; Alsukkar, M.; Dong, Y.; Hu, P. Improvements in energy savings and daylighting using trapezoid profile louver shading devices. *Energy Build.* **2024**, *321*, 114649. [\[CrossRef\]](#)
- Alsukkar, M.; Hu, M.; Alkhater, M.; Su, Y. Daylighting performance assessment of a split louver with parametrically incremental slat angles: Effect of slat shapes and PV glass transmittance. *Sol. Energy* **2023**, *264*, 112069. [\[CrossRef\]](#)
- Eltaweel, A.; Su, Y.; Mandour, M.A.; Elrawy, O.O. A novel automated louver with parametrically-angled reflective slats; design evaluation for better practicality and daylighting uniformity. *J. Build. Eng.* **2021**, *42*, 102438. [\[CrossRef\]](#)
- Fan, Y.; Xue, J.; Zheng, H.; Lai, D. Draw to shade: A personalized daylighting regulation method through user-involved paintings for enhanced indoor visual comfort and aesthetics experience. *J. Build. Eng.* **2023**, *80*, 108014. [\[CrossRef\]](#)
- Hakimazari, M.; Baghoolizadeh, M.; Sajadi, S.M.; Kheiri, P.; Moghaddam, M.Y.; Rostamzadeh-Renani, M.; Rostamzadeh-Renani, R.; Hamooleh, M.B. Multi-objective optimization of daylight illuminance indicators and energy usage intensity for office space in Tehran by genetic algorithm. *Energy Rep.* **2024**, *11*, 3283–3306. [\[CrossRef\]](#)
- Rezaei, F.; Sangin, H.; Heiranipour, M.; Attia, S. Multi-objective Optimization of Window and Light Shelf Design in Office Buildings to Improve Occupants' Thermal and Visual Comfort. *J. Daylight.* **2024**, *11*, 55–68. [\[CrossRef\]](#)
- Wu, H.; Zhang, T. Multi-objective optimization of energy, visual, and thermal performance for building envelopes in China's hot summer and cold winter climate zone. *J. Build. Eng.* **2022**, *59*, 105034.
- Machairas, V.; Tsangrassoulis, A.; Axarli, K. Algorithms for optimization of building design: A review. *Renew. Sustain. Energy Rev.* **2014**, *31*, 101–112. [\[CrossRef\]](#)
- Khidmat, R.P.; Fukuda, H.; Paramita, B.; Koerniawan, M.D. The optimization of louvers shading devices and room orientation under three different sky conditions. *J. Daylight.* **2022**, *9*, 137–149. [\[CrossRef\]](#)
- Mangkuto, R.A.; Dewi, D.K.; Herwandani, A.A.; Koerniawan, M.D. Design optimisation of internal shading device in multiple scenarios: Case study in Bandung, Indonesia. *J. Build. Eng.* **2019**, *24*, 100745. [\[CrossRef\]](#)
- Khani, A.; Khakzand, M.; Faizi, M. Multi-objective optimization for energy consumption, visual and thermal comfort performance of educational building (case study: Qeshm Island, Iran). *Sustain. Energy Technol. Assess.* **2022**, *54*, 102872. [\[CrossRef\]](#)
- Yao, B.; Salehi, A.; Baghoolizadeh, M.; Khairy, Y.; Baghaei, S. Multi-objective optimization of office egg shadings using NSGA-II to save energy consumption and enhance thermal and visual comfort. *Int. Commun. Heat Mass Transf.* **2024**, *157*, 107697.
- Khidmat, R.P.; Fukuda, H.; Paramita, B.; Qingsong, M.; Hariyadi, A. Investigation into the daylight performance of expanded-metal shading through parametric design and multi-objective optimisation in Japan. *J. Build. Eng.* **2022**, *51*, 104241.

17. Chan, Y.-C.; Tzempelikos, A. Efficient venetian blind control strategies considering daylight utilization and glare protection. *Sol. Energy* **2013**, *98*, 241–254. [\[CrossRef\]](#)
18. Tabadkani, A.; Roetzel, A.; Li, H.X.; Tsangrassoulis, A. A review of automatic control strategies based on simulations for adaptive facades. *Build. Environ.* **2020**, *175*, 106801. [\[CrossRef\]](#)
19. Tabadkani, A.; Shoubi, M.V.; Soflaei, F.; Banihashemi, S. Integrated parametric design of adaptive facades for user's visual comfort. *Autom. Constr.* **2019**, *106*, 102857.
20. Tabadkani, A.; Banihashemi, S.; Hosseini, M.R. Daylighting and visual comfort of oriental sun responsive skins: A parametric analysis. *Build. Simul.* **2018**, *11*, 663–676. [\[CrossRef\]](#)
21. Kim, H.; Clayton, M.J. A multi-objective optimization approach for climate-adaptive building envelope design using parametric behavior maps. *Build. Environ.* **2020**, *185*, 107292.
22. Chi, D.A.; Moreno, D.; Navarro, J. Design optimisation of perforated solar façades in order to balance daylighting with thermal performance. *Build. Environ.* **2017**, *125*, 383–400. [\[CrossRef\]](#)
23. Oh, M.H.; Lee, K.H.; Yoon, J.H. Automated control strategies of inside slat-type blind considering visual comfort and building energy performance. *Energy Build.* **2012**, *55*, 728–737. [\[CrossRef\]](#)
24. Ibrahim, A.; Alsukkar, M.; Dong, Y.; Hu, P. Investigations for the daylighting performance of trapezoid profile shadings using multi-objective optimization. *J. Build. Eng.* **2025**, *99*, 111645.
25. Taveres-Cachat, E.; Lobaccaro, G.; Goia, F.; Chaudhary, G. A methodology to improve the performance of PV integrated shading devices using multi-objective optimization. *Appl. Energy* **2019**, *247*, 731–744. [\[CrossRef\]](#)
26. Ibrahim, A.; Alsukkar, M.; Wang, L.; Hermaputi, R.L.; Dong, Y.; Yin, S.; Xiao, Y.; Hu, P. Targeting integrated daylighting comfort in deep office by multi-objective optimization using partial vertical deployment of adaptive corrugated shadings. *Energy Built Environ.* **2026**, *in press*. [\[CrossRef\]](#)
27. Fan, Z.; Liu, M.; Tang, S. A multi-objective optimization design method for gymnasium facade shading ratio integrating energy load and daylight comfort. *Build. Environ.* **2022**, *207*, 108527. [\[CrossRef\]](#)
28. Olbina, S.; Hu, J. Daylighting and thermal performance of automated split-controlled blinds. *Build. Environ.* **2012**, *56*, 127–138. [\[CrossRef\]](#)
29. Bahdad, A.A.S.; Fadzil, S.F.S.; Taib, N. Optimization of daylight performance based on controllable light-shelf parameters using genetic algorithms in the tropical climate of Malaysia. *J. Daylight.* **2020**, *7*, 122–136. [\[CrossRef\]](#)
30. Özdemir, H.; Çakmak, B.Y. Evaluation of daylight and glare quality of office spaces with flat and dynamic shading system facades in hot arid climate. *J. Daylight.* **2022**, *9*, 197–208. [\[CrossRef\]](#)
31. Nabil, A.; Mardaljevic, J. Useful daylight illuminance: A new paradigm for assessing daylight in buildings. *Light. Res. Technol.* **2005**, *37*, 41–57. [\[CrossRef\]](#)
32. Eisazadeh, N.; Allacker, K.; De Troyer, F. The Impact of Window Systems on Daylighting Performance, Visual Comfort and Energy Efficiency in Patient Rooms. In Proceedings of the Building Simulation 2019: 16th Conference of International Building Performance Simulation Association, Rome, Italy, 2–4 September 2019; pp. 1207–1215.
33. Wienold, J.; Christoffersen, J. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy Build.* **2006**, *38*, 743–757. [\[CrossRef\]](#)
34. Naderi, E.; Sajadi, B.; Behabadi, M.A.; Naderi, E. Multi-objective simulation-based optimization of controlled blind specifications to reduce energy consumption, and thermal and visual discomfort: Case studies in Iran. *Build. Environ.* **2020**, *169*, 106570.
35. Kim, J.-H.; Park, Y.-J.; Yeo, M.-S.; Kim, K.-W. An experimental study on the environmental performance of the automated blind in summer. *Build. Environ.* **2009**, *44*, 1517–1527. [\[CrossRef\]](#)
36. Freewan, A.A.; Shao, L.; Riffat, S. Interactions between louvers and ceiling geometry for maximum daylighting performance. *Renew. Energy* **2009**, *34*, 223–232. [\[CrossRef\]](#)
37. Uribe, D.; Vera, S.; Bustamante, W.; McNeil, A.; Flamant, G. Impact of different control strategies of perforated curved louvers on the visual comfort and energy consumption of office buildings in different climates. *Sol. Energy* **2019**, *190*, 495–510. [\[CrossRef\]](#)
38. Deb, K.; Pratap, A.; Agarwal, S.; Meyarivan, T. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Trans. Evol. Comput.* **2002**, *6*, 182–197. [\[CrossRef\]](#)
39. Konis, K.; Gamas, A.; Kensek, K. Passive performance and building form: An optimization framework for early-stage design support. *Sol. Energy* **2016**, *125*, 161–179. [\[CrossRef\]](#)
40. Lakhdari, K.; Sriti, L.; Painter, B. Parametric optimization of daylight, thermal and energy performance of middle school classrooms, case of hot and dry regions. *Build. Environ.* **2021**, *204*, 108173. [\[CrossRef\]](#)
41. Talaei, M.; Sangin, H. Multi-objective optimization of energy and daylight performance for school envelopes in desert, semi-arid, and mediterranean climates of Iran. *Build. Environ.* **2024**, *255*, 111424.
42. Talaei, M.; Sangin, H. Thermal comfort, daylight, and energy performance of envelope-integrated algae-based bioshading and static shading systems through multi-objective optimization. *J. Build. Eng.* **2024**, *90*, 109435.

43. Kirmat, A.; Manioğlu, G. A simulation-based performance evaluation of new generation dynamic shading devices with multi-objective optimization. *J. Build. Eng.* **2024**, *90*, 109322.
44. Omid, A.; Golchin, N.; Masoud, S.E. Evaluating the visual comfort of Orosi windows in hot and semi-arid climates through climate-based daylight metrics: A quantitative study. *J. Asian Archit. Build. Eng.* **2022**, *21*, 2114–2130.
45. Shen, H.; Tzempelikos, A. Daylighting and energy analysis of private offices with automated interior roller shades. *Sol. Energy* **2012**, *86*, 681–704. [[CrossRef](#)]
46. Sun, Y.; Wu, Y.; Wilson, R. Analysis of the daylight performance of a glazing system with Parallel Slat Transparent Insulation Material (PS-TIM). *Energy Build.* **2017**, *139*, 616–633. [[CrossRef](#)]
47. Eltaweel, A.; Su, Y.; Lv, Q.; Lv, H. Advanced parametric louver systems with bi-axis and two-layer designs for an extensive daylighting coverage in a deep-plan office room. *Sol. Energy* **2020**, *206*, 596–613. [[CrossRef](#)]

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