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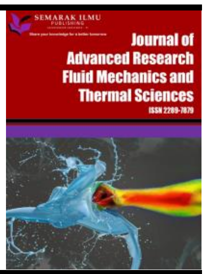

Design Optimization for Light-Shelves with Regard to Daylighting Performance Improvements in The Tropics

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ABSTRACT

Different daylight device systems and control strategies can be employed in different parts of a window system to perform different functions, particularly for fully glazed façades. A light-shelves with parametric control in both portions of the system were proposed in this study as an innovative daylighting device to improve daylighting distribution and glare probability. The aim of this article was to present a simulation study to investigate the influence of light shelves on daylighting performance improvements in buildings located in tropical climates. Multi-objective optimization method was proposed by classifying the results based on sky conditions. The metrics of Useful Daylight Illuminance and Daylight Glare Probability were used to evaluate the daylight performance and glare to compare the final solutions of the blight shelf parameters of the light shelf. The study concludes that daylight improvements by optimal solutions of light shelves can provide the best range of optimal daylighting for visual comfort in office spaces in the tropics. The idea of a light shelf system with parametric control in both portions (inner and outer) provides the most optimal options for achieving balanced daylighting levels in both the front and back of the room. This resulted in a glare-free environment with undetectable glare indices, and acceptable daylight is accomplished, as well as a high percentage coverage within UDI300-2000 lux between 63% and 73.8% at midday and no less than 55% during working hours.

1. Introduction

Daylighting is a critical component of architectural illumination, and its proper utilization may minimize total energy use. Furthermore, incorporating natural light into the indoor environment significantly impacts the health and well-being of the inhabitants [1]. To create optimal indoor daylight, it is necessary to balance many daylight factors, including suitable illumination, glare prevention, and visual access to the outside, as well as energy saving [2, 3]. Thus, it is critical to maintaining a sufficient light level that is safe and appropriate for work [4, 5]. Thus, to overcome and control these impediments, daylighting techniques have been implemented as part of a window system [6-9]. The Daylighting systems contribute to meeting these requirements by offering

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protection from direct sunshine and warming in the summer, reducing cooling loads, preventing glare, and providing privacy or even a view of the exterior [10]. Daylighting systems are integrated into buildings that provide high-quality illumination. Daylighting systems ought to be simple and cost-effective to follow the needs of the market. However, the correct design and determination of daylighting systems can fundamentally help in improving natural illuminance performance [11-13], as well as enhance the overall room performance [3]. Daylight techniques that do not include light redirection or light transmission solutions to promote daylighting within a place are regarded as a waste of natural resources. However, new techniques are being created and improved, and light redirection into spaces is one of the primary areas of daylighting research [14].

Various types of daylighting systems have been created. However, many are primarily useful for large locations where the device can be installed [5]. A light shelf is one of the most efficient daylight techniques for controlling the amount of sunlight that enters an indoor room [15-18]. Light shelf performs a crucial role in enhancing and regulating indoor daylight performance, hence enhancing the visual comfort of occupants [12, 19, 20]. A light shelf is a standard daylighting system that is put on a window to let in natural light. Light shelves usually bring natural light into indoor spaces by reflecting daylight to the ceiling surface of the room. This helps save energy on lighting because it lets natural light reach deeper into the room [21-23]. Light shelves can also fix lighting problems inside by acting as a shade to keep some of the excessive natural light from coming in through the window [24-26]. During the design phase of a daylight system, which in this case is a light shelf, trying to maximize daylight penetration and view while minimizing light's negative effects, like glare and energy use, can lead to conflicting goals. One of the key challenges with using light shelves to improve how well buildings use daylight is that engineers don't know enough about the most important parts of the system that affect how well daylight performance works by the system. One of the most important parts of making a light shelf is choosing the right parameters to make sure it works as well as possible [27]. As a result, optimum daylight efficiency of buildings can be attained by simplifying problems with a large number of characteristics and selecting appropriate system design parameters [12, 28]. However, these conflicting objectives frequently necessitate a multi-objective optimization strategy. The use of parametric modelling and multi-objective optimization via evolutionary genetic algorithms (GA) to discover the best solutions in building design is becoming more widespread in building performance analysis [5].

Multi-objective optimization differs from a single objective enhancement primarily in its increased complexity, a direct result of the complicated nature of simultaneously satisfying several goals, often with competing outcomes. In order to accurately optimize multiple objectives, a set of circumstances that define the optimal solutions must be defined, and a Pareto frontier generated [29]. Multi-objective optimization algorithms strive to produce solutions that are as close to the Pareto optimal front as possible while maintaining a uniform distribution. When the non-dominated alternatives are found, decision-makers select a final resolution from this group based on the specific problem and personal preferences. In most applications, including building design, decision-makers require only one best option. Each application has its own set of criteria for selecting the final point from the non-dominated points. The representations used to describe the various objectives under consideration can be tied to maximum or minimum functions. [5, 29, 30].

The genetic algorithm (GA) has become one of the most common methods for addressing problems with multiple objectives. It is motivated by the process of natural selection in order to obtain a high-quality solution that fits the optimization's need or objective [28]. By merging technology for parametric modelling platforms, GA has been used to optimize the daylight performance in a specific environment [12, 31, 32]. The GA optimization process is anticipated to be reasonably rapid, with results that satisfy the goal and are obtained in a methodical yet efficient manner [33]. In this study, the optimization process is a multi-objective optimization, which has been carried out using the GA embedded in the Octopus tool included in Grasshopper.

As a parametric and optimization control method to optimized daylight performance, Grasshopper and it is optimization tool Octopus was particularly utilized in previous studies to find the optimal parameters design of the light-shelve system configuration to guarantee a better daylight distribution inside the room. Where the investigation to find the optimum light-shelves parameters configuration and its impact on the daylight performance of the building has been conducted by many researchers [9, 28, 34-39], considering different objectives. For example, Mangkuto, Feradi [28] investigated the optimal light shelf for the east and west facades of an open-plan examination room in a dental institution in Bandung, Indonesia. This study analyzed the exterior and interior depths, external tilt angles, and specularity of the light-shelves using a genetic algorithm. Dogan and Stec [40] examined the rotation control of a reflective light shelf based on the incident angle of sunlight to increase daylighting performance in a New York office space. Ebrahimi-Moghadam, Ildarabadi [41] compared the most effective design choices for a light-shelf with respect to two objectives of energy consumption, including heating, cooling, and electrical energy. Based on the design of horizontal and vertical light shelves, optimization parameters comprise three design variables: angle, depth, and number of light shelves.

Despite the efforts made by past research on Light shelf to promote and create awareness of different aspects of the daylight performance of light shelf concerning multi-objectives is still of interest to many researchers, and some gaps still exist in the literature. Therefore, further research is yet to be carried out to increase daylight performance and improve visual comfort with this system. In optimizing the parameters of light shelf, the majority of prior studies analyzed the relevant values using a factorial design or one at a time. Another knowledge gap is the lack of a comprehensive understanding of the varying weights for all design characteristics of the external and interior components of the system to optimize daylighting in prior research. Most studies treated the system as one unit, assigning equal weight to all parameters for both the exterior and interior components, and presenting optimum values for a restricted number of parameters. While the optimal values of different parameters created for the tropics may have unequal weight and have not yet been proposed, it is possible that the optimal values of these parameters will be proposed in the future. To bridge this gap, this study aims to develop a protocol for optimizing office daylight design using light-shelves system by defining the optimum light-shelf parameters for typical office buildings in tropical, which targets the minimization of glare effects and the optimization of daylighting distribution for visual performance. In order to fulfil the aforementioned goals, this paper focuses on the design optimization of light shelves using the GA approach, utilizing an office unit as a case study. In this study, the application of GA permits the investigation of the co-influence of light shelf characteristics on the visual comfort of office environments. The primary novelty of this study is that it proposes, evaluates, and presents the optimal values of the light shelf design parameters for both the exterior and interior parts as a design strategy for the system by providing the optimal conditions for daylight distribution while simultaneously minimizing glare.

2. Research Methodology

2.1 Research Framework

This research paper applies a multi-objective optimization technique with the intention of maximizing daylighting performance and minimizing glare in an office environment, across various light-shelf parameter design scenarios. Advanced parametric processes and genetic algorithm (GA) optimization were used to enable the investigation of a wide range of design intentions and the development of alternative design configurations by addressing multiple conflicting objectives within a nearly infinite number of possible design solutions. In order to examine the daytime performance potential of light shelves, environmental plugins Ladybug and Honeybee are used to feed modelling inputs to a parametric interface named Grasshopper. These instruments are supported by verified engines, such as EnergyPlus for thermal calculations and Radiance and Daysim for daylighting simulations. This method enables the designer to simulate the total number of design choices, which would be a time-consuming process using conventional building simulation tools; nonetheless, it increases the study's robustness against uncertainty. The framework of the study consists of four steps, as can be seen in Figure 1. The first step is the modelling setup. In this step, the dimensional and construction properties of the hypothetical office module, with the parameters design variables obtained from the literature on the design of light-shelves systems detailed in Section 2.2, were determined and parametrically created using Grasshopper plugins for Rhino. The second step is the development of the daylight model with Radiance and EnergyPlus parameters via Ladybug and Honeybee plug-ins. After obtaining location climate data, were transferred to the Ladybug plugin, which is used to perform dynamic climate simulations, while the set of objectives was assigned using honeybee plugins. The optimization started at the third step, the GA optimization method using Octopus tool included in Grasshopper is applied for finding the optimum design parameters of light shelves that provide the best visual comfort and minimizing glare simultaneously. Finally, the best results based on objective targets for optimal design variables of light-shelf (optimum position height, external and internal angles, and external and internal depths) are introduced in the final phase.

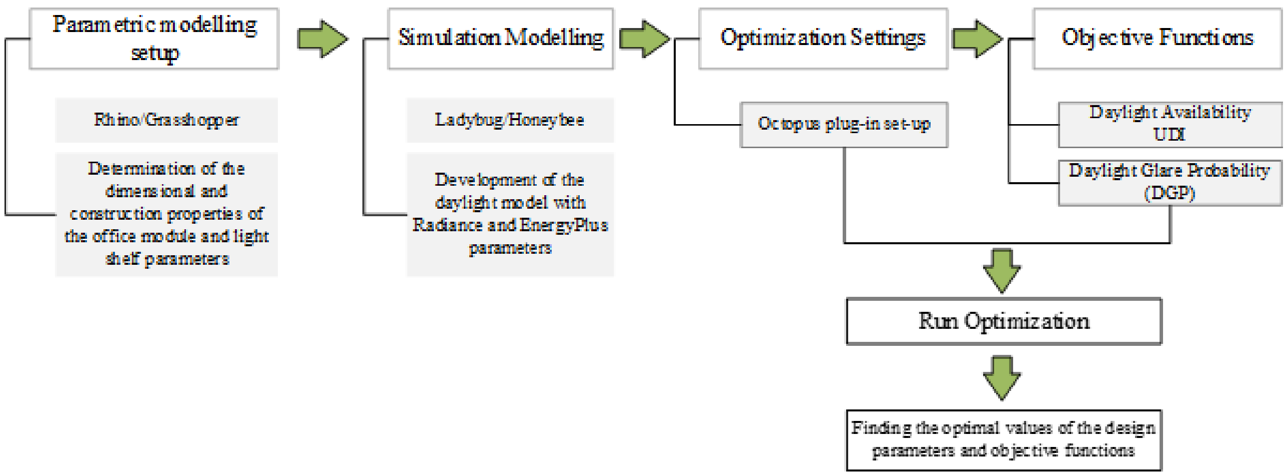


Fig. 1. Research Framework

2.2 Hypothetical Office Module and Parameters of Light Shelf

Based on parametric 3D environment of Grasshopper/Rhinoceros is a visual algorithmic programming language for parametric modelling that can be used as a scripting language to deal with various parameters and was used to build and control the different parameters of the model and light-shelf system in this work. As depicted in Figure 2, a hypothetical reference office module is adapted from a specification set out in a previous research paper, which comprises of a single-zone working space measuring 5.0 m x 8.0 m x 2.8 m (width x depth x height). The room is supposed to be placed on the middle floor of a building with multiple floors. It is surrounded by other office rooms, save for the south-facing facade (Figure 2). The south-facing office was completely glazed (WWR = 90%) with a transmittance of 60%; this transmittance was chosen based on earlier studies [26, 30, 42]. The south-facing surface was chosen for analysis because, according to the sun's position in

Malaysia, it receives more sunlight [15, 43, 44]. In accordance with earlier research, the reflectance of the surface material of the ceiling, internal walls, outside walls, floor, and light shelf was established for the reference model, which kept constant during optimization process. As shown in Figure 2, The surface reflectivity of the ceiling, inner walls, outside walls, floor, and light-shelf was set to 80%, 75%, 40%, 20%, and 90%, respectively. These surface materials were chosen because they are ideal for office environments [5, 35, 36].

The light-shelf system is mounted on the fully glazed southern façade of the office room model. Grasshopper was employed to parametrically controlled different parameters of the system. The effectiveness of light shelves is affected by several variables, including their depth, height, angle, and reflectance [28, 35, 38, 45]. Meresi [9] and Moazzeni and Ghiabaklou [38] advised that the light shelf consist of both external and interior components based on past research. As shown in Figure 2, the light shelf is therefore proposed to be a combination of external and internal light shelf installed on the south facade at a height of 1.80 m above the floor. In this study article, the parameters of light-shelf height, depth of external and interior sections, and pivot angle of both parts have been evaluated as choice factors for determining the optimal daylight performance. The range of values with minimum/maximum and interval values for each parameter is displayed in Table 1. Each light shelf parameters value was, therefore separately adjusted for both the exterior and interior sections of the system in order to provide a satisfactory daylighting availability in terms of quantity and quality while minimizing glare. These values were selected based on several studies [9, 37, 38, 46].

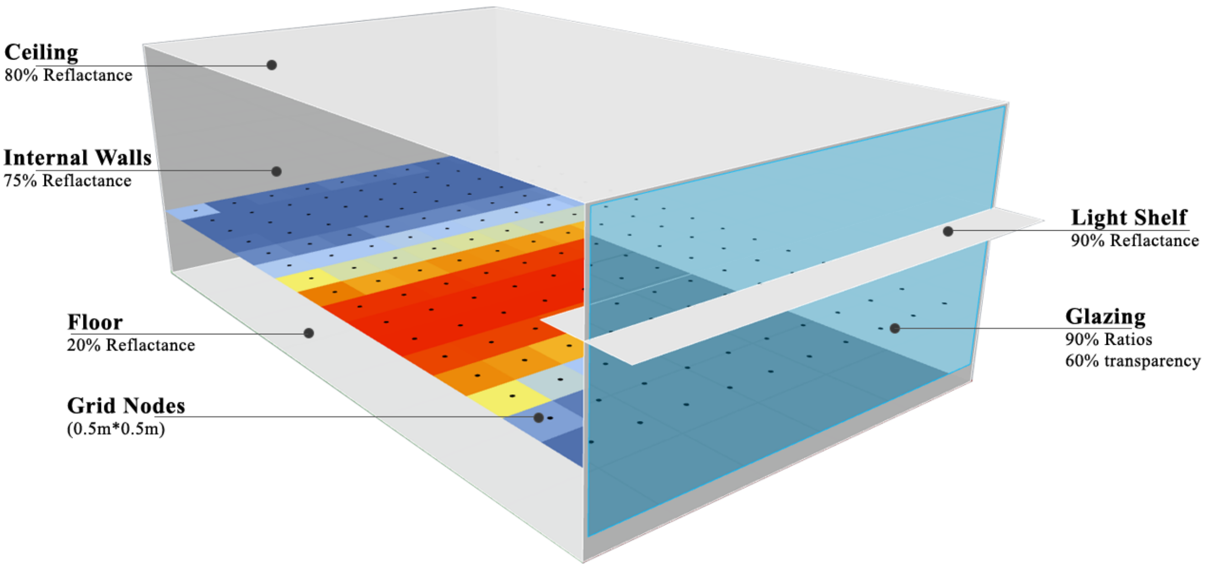


Fig. 2. The simulation reference model

Table 1
Selected parameters of the light-shelf design for optimising

Variable	Range (minimum/maximum)	Interval
Height	1.80/2.20 m	0.10 m
Depth of external and interior	0.50/1.50 m	0.25 m
Pivot angle of external and interior	-30°/+30° (0° is horizontally)	10°

2.3 Optimization Objectives and Metrics

In order to find the optimum specifications of light-shelf in each case, Useful Daylight Illuminance (UDI) is used as the desirable metric to be maximized, and the Daylight Glare Probability (DGP) is the metric to be minimized. UDI is as an annual daylighting metric showing the fraction of the area which receives enough daylight during standard operating hours. UDI is commonly used to analyze the availability of daytime light in order to assess how much space daylight provides and to check the frequency of current illuminance ranges. UDI is similar to Daylight autonomy (DA), with the exception that UDI specifies lower and upper illuminance thresholds. The UDI assesses how frequently daylight on the working plane falls within a specific illuminance range, with lower and upper thresholds of 100 and 2000 lux used for at least 50% of occupied hours. As a result, three different UDI ranges were used, as proposed by Nabil and Mardaljevic [47]. The upper range where UDI>2000lux is intended to reflect periods when an excess of daylight could cause visual and/or thermal discomfort, the lower range (UDI<100 lux) symbolizes times when there is 'too little' daylight, and the useful range (UDI100-2000lux) indicates 'useful' daylight [48]. According to Malaysian standard (MS 1525:2014) [49], the minimum recommended daylight illuminance of office spaces at the work-plane is equal or more than 300 lux, and the maximum acceptable UDI range as mentioned previously is 2000 lux, so the useful daylight illuminance in this study, is defined where all the illuminances are within the range 300 lux to 2000 lux. For this research, each range set of UDI values were sorted into one of these three categories: Under threshold UDI<300 lux, within threshold UDI300-2000 lux, and Over threshold UDI>2000 lux areas. These three thresholds of UDI values were used in this research to the performance comparison of different light shelf parameters to optimize the best light shelf parameters design for office spaces.

DGP is a glare index that has been widely used to assess visual comfort in illuminated environments. DGP is regarded as one of the most important climate-based daylight metrics for assessing daylight quality, though more research is required to develop appropriate standards for appropriate luminance ratios and to investigate cases with direct sunlight in the field [50]. The evaluation criteria in this study were based on study by Wienold [51] DGP evaluation method, and four DGP thresholds were used to conduct a dynamic analysis of DGP over a year: (a) DGP < 35%: 'imperceptible glare', (b) DGP in the range 35–40%:'perceptible glare', (c) DGP in the range 40–45%: 'disturbing glare', and (d) DGP > 45%: 'intolerable glare' [52].

2.4 Optimization Conditions and Setting

In the tropical region, particularly in locations nearby the equator, for a part of the year, the sun's apparent position is slightly at the north part of the sky hemisphere, while for the rest of the year it is at the south part of the sky [53]. As demonstrated in Figure 3, which depicts two separate solar solstices (21st of June and 21st of December) and two Equinoxes (21st of March and 21st of September), the sun is almost perpendicular to the horizontal surface, with a minor change over the year. At the time of the two equinoxes (about 21 March and 21 September), the altitude and azimuth angles are almost parallel to the horizontal plane, as seen in the diagram. On the 21st of June, the sun is very inclined to the north, whereas on the 21st of December, it is strongly inclined to the south [5, 12]. This study will concentrate on the four days between the equinox and the solstices. Parametric simulations and optimization for selected parameters were done on the 21st of June, March, and December during four crucial periods of daily office work; 09:00, 12:00, 15:00, and 17:00, which are depicted as four distinct sun angles in a day as shown in Figure 3. These dates were chosen to represent the most critical climatic factors of the Malaysian sky sun pat, and to cover all potential scenarios of daylight exposure.

For such cases, the GA optimization method utilizing the Pareto Front in the Octopus multi-objective optimization plug-in for Grasshopper is the optimal solution. The Pareto Front technique offers a series of solutions with fewer target conflicts than other alternatives [54]. The design parameters of light shelf are connected to Octopus's GA input, while the daylight simulation outputs are attached to Octopus's Fitness input. According to the recommendations of earlier studies [55-58], the appropriate GA parameters in the Octopus plug-in were allocated, as shown in Table 2, and the specifications of the Radiance daylight parameters were also provided. The objective to be maximized, which in this study was UDI, should be increased by 1 because Octopus can only tackle minimization problems. Therefore, the objective to be maximized, which in this study was UDI, should be multiplied by − 1.[55, 59]. The Ladybug plug-in is used to analyze the fundamental design process, such as weather, shade, sun, thermal comfort, etc. Honeybee Plug-in provides a robust interface for users and architects by integrating energy modelling (EnergyPlus) and daylighting simulation (Radiance and DAYSIM). Honeybee Plugin offers the option to simulate thermal energy, optimize energy consumption, analyze lighting and daylight, simulate thermal energy and building loads and so on. In the Honeybee plug-in, which was utilized for the Radiance simulation, analysis grid points (nodes)placed on the work-plane at height of 0.80 m were created in Honeybee plugin-in Grasshopper, which is used as an engine to stimulate Radiance simulation. The number of points is 160, and the size of the grid is 0.5 × 0.5 m (Figure 3), which is used as an engine to stimulate Radiance simulation.

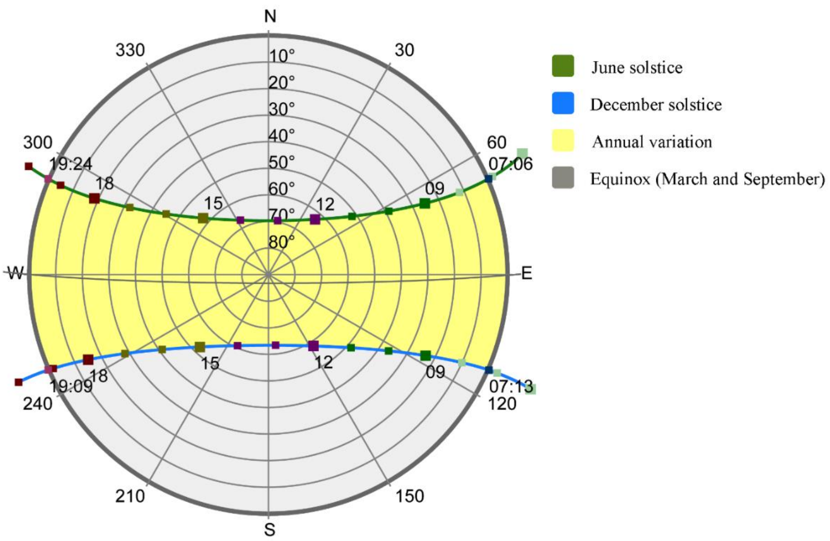


Fig. 3. Sun path diagram of Malaysia

Table 2
Octopus and Radiance's settings

Optimization Parameters	Elitism	Mutation rate	Crossover rate	Population size	No. of Generation
	0.5	0.1	0.6	50	20
Radiance Parameters	Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient resolution
	6	1000	20	0.1	300

3. Optimization Results

The parametric design and optimization provide numerous parameters designed for Light shelf parameters that are previously addressed. Utilizing a multi-objective technique scenario, the optimization processes were conducted. in this study, as mentioned previously, daylight optimization is performed for office models with and without light-shelf facing south. The effect of the light shelf on the selected daylight and glare metrics which in this case is UDI and DGP has been analyzed by comparing the results for the office without a light shelf, as the base models, and the office with optimum light-shelf. At this point of analysis, the optimization objective differs from the majority of multi-objective optimization problems, as the two objectives are inconsistent with each other. This means that good design choices appear to have good daylight availability (UDI) while minimizing glare effects (DGP) at the same time. The optimization process resulted in a range of successful solutions that better enhance the performance of light-shelf regarding daylight performance with keeping illuminance levels within the max accepted range for UDI during test hours compared to base case. To facilitate detailed analysis and interpretation, only the best options for selected dates and times were presented (12 options). the Details values of design parameters in all GA optimized process are generation are displayed in Table 3. Table 4, 5, 6 presented the geometries of optimal solutions and UDI thresholds, DGP, and illuminance distributions on the work-plane.

Table 3
The best parameter values of the light shelf in all optimal solutions result from optimization processes

Date	Time	Optimal Parameters values (Height, depth of external and interior, pivot angle of external and interior)
21 March	9	1.90 m, 0.75 m, 1.00 m, 20°, -20°
	12	1.90 m, 1.25 m, 0.50 m, 0°, 0°
	15	1.90 m, 0.75 m, 0.75 m, 10°, -10°
	17	1.90 m, 0.50 m, 0.50 m, 0°, -20°
21 June	9	1.90 m, 1.25 m, 0.75 m, 0°, -10°
	12	1.80 m, 1.00 m, 0.50 m, 10°, 0°
	15	1.90 m, 1.25 m, 0.75 m, -10°, -10°
	17	1.90 m, 0.75 m, 0.50 m, 10°, -30°
21 December	9	1.90 m, 0.50 m, 1.00 m, -30°, -20°
	12	2.00 m, 1.25 m, 1.00 m, 0°, -10°
	15	1.80 m, 0.75 m, 1.25 m, -20°, -10°
	17	1.80 m, 1.25 m, 1.25 m, -10°, -20°

Table 4
The GA Optimization outputs of multi-objective solutions on 21st March

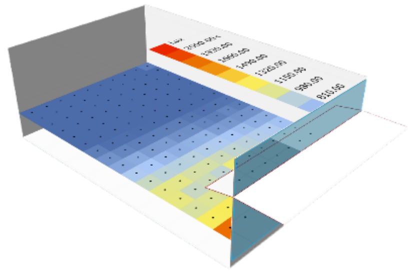
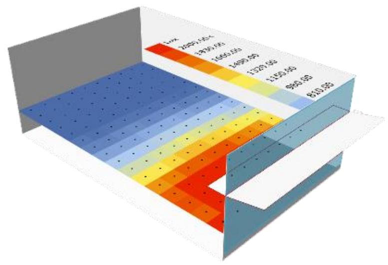
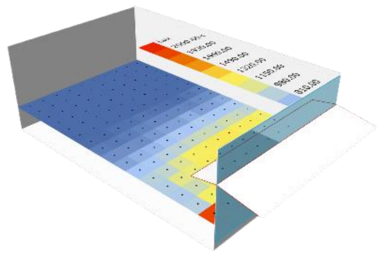
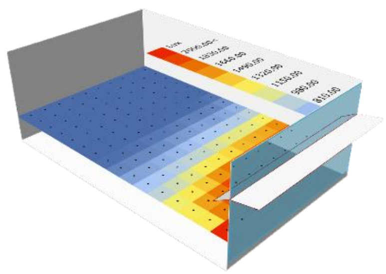
Date	Optimal Cases at different times	UDI thresholds	Avg. %	DGP thresholds	Avg. %	Visualization (UDI 300-2000 lux)
21st of March	9:00	UDI <300 lux (Under threshold)	43.8	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	55.0	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	1.2	DGP > 45% (intolerable)	-	
	12:00	UDI <300 lux (Under threshold)	34.4	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	63.1	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	2.5	DGP > 45% (intolerable)	-	
	15:00	UDI <300 lux (Under threshold)	37.5	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	60.6	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	1.9	DGP > 45% (intolerable)	-	
	17:00	UDI <300 lux (Under threshold)	44.4	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	55.6	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	0.0	DGP > 45% (intolerable)	-	

Table 5
The GA Optimization outputs of multi-objective solutions on 21st June

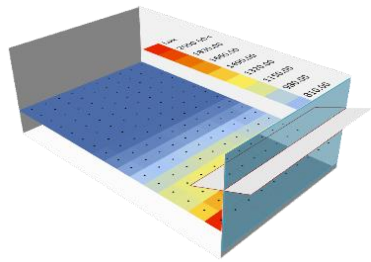
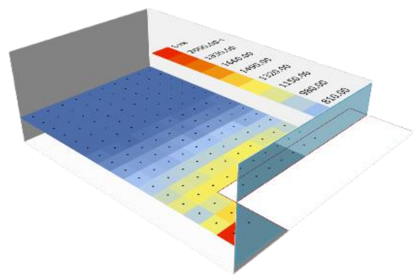
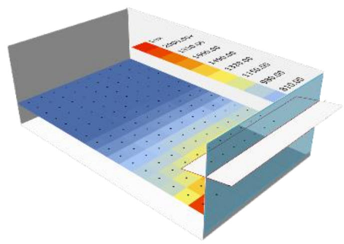
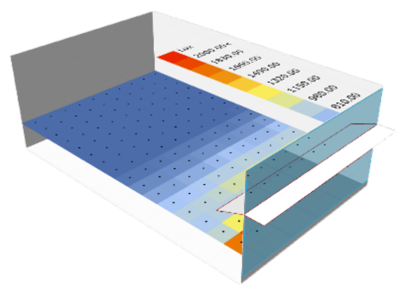
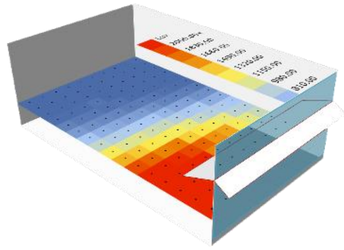
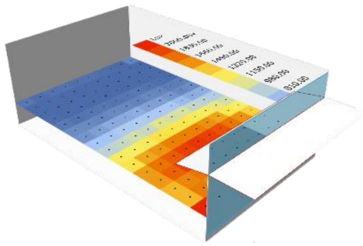
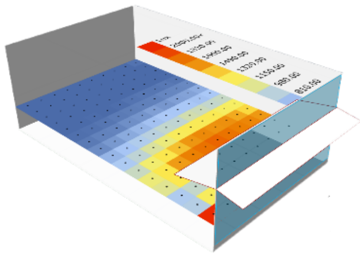
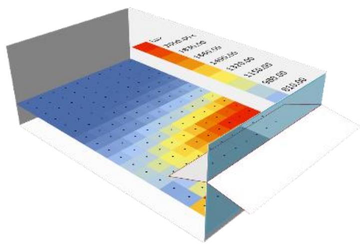
Date	Optimal Cases at different times	UDI thresholds	Avg. %	DGP thresholds	Avg. %	Visualization (UDI 300-2000 lux)
21st of June	9:00	UDI <300 lux (Under threshold)	38.8	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	60.6	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	0.6	DGP > 45% (intolerable)	-	
	12:00	UDI <300 lux (Under threshold)	27.5	DGP < 35% (imperceptible)	97.50	
		UDI 300-2000 lux (within threshold)	56.9	DGP 35–40% (perceptible)	2.50	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	15.6	DGP > 45% (intolerable)	-	
	15:00	UDI <300 lux (Under threshold)	33.8	DGP < 35% (imperceptible)	100	
		UDI 300-2000 lux (within threshold)	65.6	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	0.6	DGP > 45% (intolerable)	-	
	17:00	UDI <300 lux (Under threshold)	38.1	DGP < 35% (imperceptible)	94.38	
		UDI 300-2000 lux (within threshold)	55.0	DGP 35–40% (perceptible)	1.25	
				DGP 40–45% (disturbing)	1.25	
		UDI > 2000 lux (Over threshold)	6.9	DGP > 45% (intolerable)	3.13	

Table 6
The GA Optimization outputs of multi-objective solutions on 21st December

Date	Optimal Cases at different times	UDI thresholds	Avg. %	DGP thresholds	Avg. %	Visualization (UDI 300-2000 lux)
21st of December	9:00	UDI <300 lux (Under threshold)	20.6	DGP < 35% (imperceptible)	91.25	
		UDI 300-2000 lux (within threshold)	63.1	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	16.3	DGP > 45% (intolerable)	8.75	
	12:00	UDI <300 lux (Under threshold)	16.9	DGP < 35% (imperceptible)	99.38	
		UDI 300-2000 lux (within threshold)	78.8	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	4.4	DGP > 45% (intolerable)	0.63	
	15:00	UDI <300 lux (Under threshold)	25.6	DGP < 35% (imperceptible)	99.38	
		UDI 300-2000 lux (within threshold)	73.8	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	-	
		UDI > 2000 lux (Over threshold)	0.6	DGP > 45% (intolerable)	0.63	
	17:00	UDI <300 lux (Under threshold)	25.6	DGP < 35% (imperceptible)	96.88	
		UDI 300-2000 lux (within threshold)	61.9	DGP 35–40% (perceptible)	-	
				DGP 40–45% (disturbing)	0.63	
		UDI > 2000 lux (Over threshold)	12.5	DGP > 45% (intolerable)	2.50	

4. Discussion

A comparison was made between the optimization outcomes and base case with an average performance value. These average values can indicate the average daylight availability and glare effects during work hours. By comparing the efficiency of the improved solutions to the average values, it is straightforward to determine the improvement brought about by the optimization procedure. Table 4, 5, and 6 above compare objective function values for the base case and optimal solutions after optimizing light shelf characteristics at different hours (9 a.m., 12 p.m., 15 p.m., and 17 p.m.) on three typical days. As shown in Table 4, 5, and 6. The illuminance maps show that the optimal cases of light shelf offered sufficient daylighting in the front of the room with a more consistent and uniform distribution most of the time, compared to the base case as shown in Figure 4, 5, and 6, where daylight availability values of around UDI 300-2000 lux of above 55.0% to 78.8% are achieved at 12:00 pm on all three days. Similarly, at 15:00 pm, the optimal parameters of the proposed system perform efficiently to achieve at least 60% within UDI300-2000 lux, respectively. In the morning 9:00 am and 17:00pm, The optimal cases of the system perform efficiently to achieve at least 55% on March 21st and June 21st, while on December 21st, a higher daylight availability is achieved at least 61.0%; this is due to the penetration of the direct sun due to the low solar angle.

For the DGP analysis, Grasshopper's Honeybee plugin was utilized to measure the DGP at the desk level for the proposed light shelf. The DGP of the light shelf is presented in Table 4, 5, and 6 at 9:00 a.m., 12:00 p.m., 15:00 p.m., and 17:00 p.m. In general, the DGP values for the three typical dates, fall within an acceptable range below 0.35, which is regarded as imperceptible glare. On the 21st of March, the DGP levels at all daytime hours are deemed appropriate for visual comfort, with unnoticeable DGP values reaching 100%. On the 21st of March, however, the unbearable DGP values at 17:00 on the 21st of June are approximately 3.13. While On December 21, the glare intensifies to unacceptable levels at 8:00 a.m., 12:00 p.m., 3:00 p.m., and 17:00 p.m., reaching 8.75, 0.63, 0.63, and 2.50 respectively.

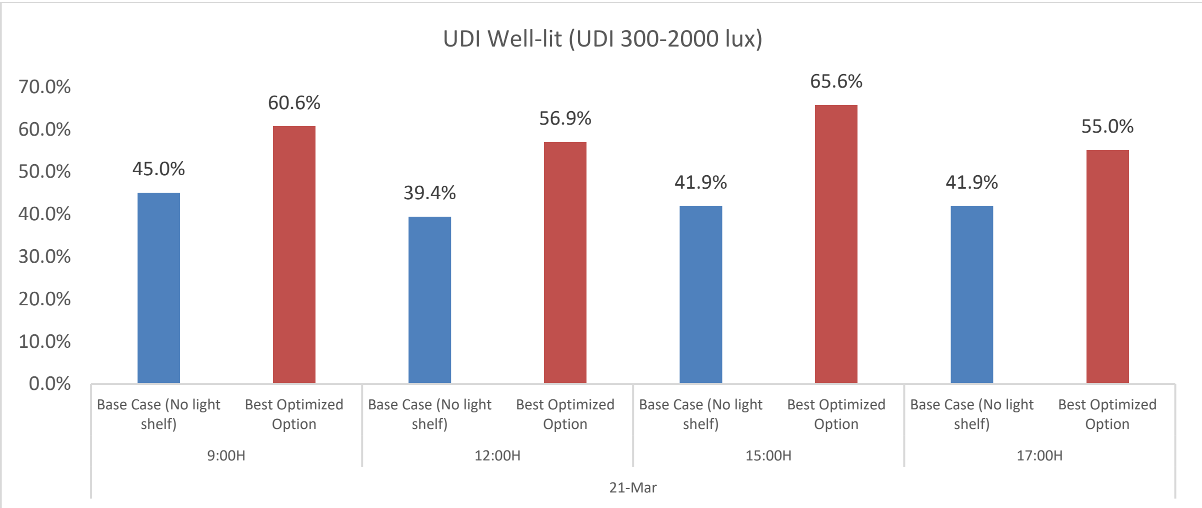


Fig. 4. Daylight performance of optimal design options of light shelf parameters on 21st March

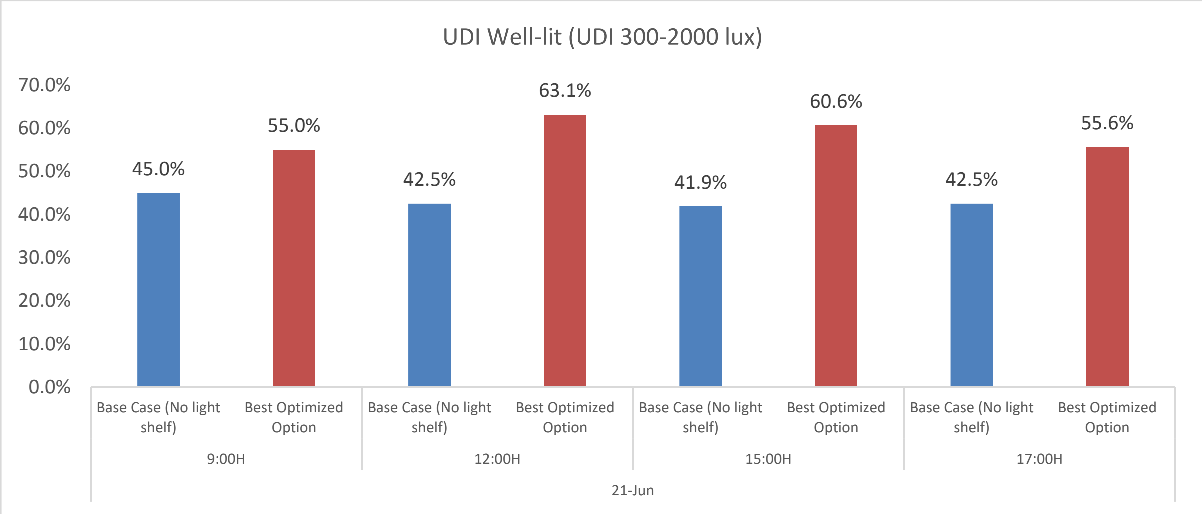


Fig. 5. Daylight performance of optimal design options of light shelf parameters on 21st June

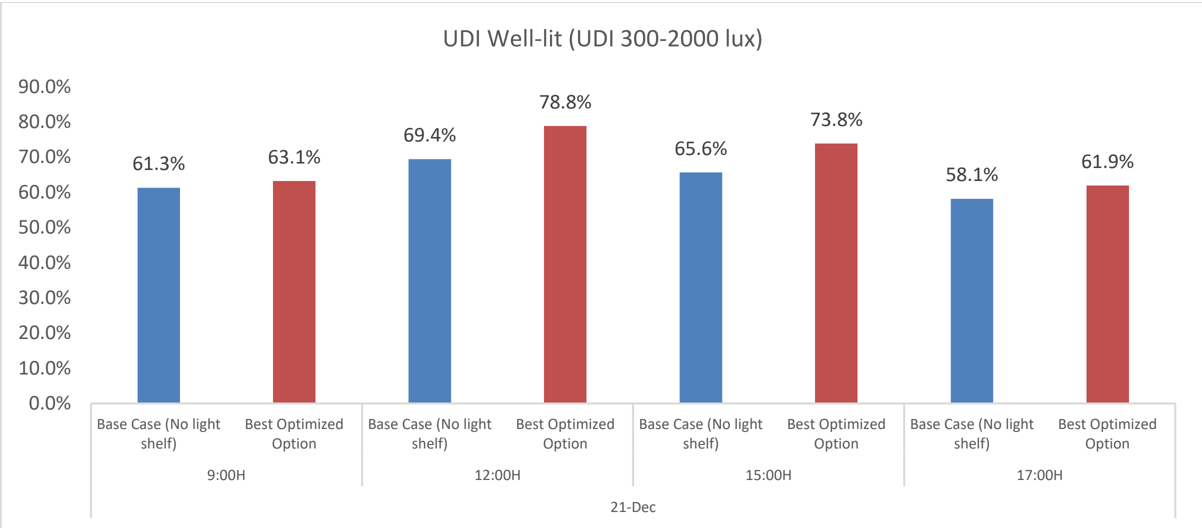


Fig. 6. Daylight performance of optimal design options of light shelf parameters on 21st December

5. Conclusion

Achieving design practicability and occupant visual comfort requires striking a compromise between variable characteristics, such as solar altitude and intensity, and daylight device design to provide the requisite uniform daylighting availability while minimizing glare effects at the desktop level. The light shelf is a crucial component of building window systems of high-glazing office buildings that enhances the performance of natural light. The current work proposes a light shelf system that can redirect sunlight to illuminate the ceiling while regulating daylight spatial distribution and visual comfort in the office. Using the parametric software "Grasshopper," the optimal design of the light shelf parameters, including (adjustment control of height, and depth of external and interior, pivot angle of external and interior) in its different sections (outer and inner), was determined to provide nearly optimal daylight performance. Overall, the light shelves with variable configurations that are controlled parametrically outperform the conventional shading system. The idea of a light shelf system with parametric control in both portions (inner and outer) provides the most optimal options for achieving balanced daylighting levels in both the front and back of the room. In addition to a glare-free environment with undetectable glare indices, acceptable daylight is accomplished, as well as a high percentage coverage within UDI300-2000 lux between 63% and 73.8% at midday and no less than 55% during the rest of the year's working hours. It may be deduced that a parametrically controlled light shelf offers improved overall daylighting performance and is considered practical and easy to implement in a real-world setting.

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