Journal of Advanced Research Design 138, Issue 1 (2026) 26-41

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Evaluation on Daylighting Performance of Integrated Light Diffuser Material and Shading System for Office Façade in Tropical Climate

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ARTICLE INFO

Article history:
Received 20 January 2025
Received in revised form 10 February 2025
Accepted 30 June 2025
Available online 20 July 2025

Keywords:
Architecture; daylighting; passive design; shading; facade

ABSTRACT

Daylighting is a passive design approach in architecture. It is abundant, free and has no negative environmental impact in tropical countries. It has a positive physiological and psychological effect on males, in addition to excellent colour rendering. Despite its broad availability and advantages, daylighting is often underutilized, particularly in the tropics. This study aims to see how light diffuser material and shading devices affect Malaysia's daylighting system. The investigation was carried out via the use of VELUX Daylight Visualizer for daylight simulations. From the series of parametric studies, the selected design of external shading devices to undergo comparison on their shading effect. Various variables were also taken into consideration including orientations, dates, & times. The simulation process is pursued in two phases. The first one was the daylight factor simulation under overcast sky condition, in which two out of four models with shading devices were selected based on their daylight factor results for further simulation. In the second phase, two selected models together with the base case model underwent illuminance simulation under intermediate sky condition. The results show that the integration of light diffuser material on shading device can increase the daylighting potential while reducing glare and hotspots. The findings of this study help the designer and architect in their design decision especially in the early design phase in term of daylighting performance.

1. Introduction

Buildings are responsible for 40% of global energy use [1-4]. Artificial lighting consumes 25 to 40% of the energy utilised on a worldwide scale [5]. When the amount of energy consumption is restricted to Asian nations, the trend of energy consumption remains consistent [1]. According to a study on energy consumption of commercial buildings in South Asia, the figure is 233 kWh/m^2/yr [6]. Malaysia as a country utilises 269 kWh/m^2/yr, the most among the countries surveyed, according to the same report. This discovery is similar to the one made by Ramli *et al.,* [7]. Energy usage of less than 135 kWh/m^2/yr is recommended per Malaysian standards. However, nearly 100% of energy use exceeds this requirement [6].

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https://doi.org/10.37934/ard.138.1.2641

According to a research, cooling and ventilation, lighting, office equipment and other uses account for 58, 20, 19 and 3% of energy usage in Malaysian government offices, respectively [8]. In office buildings, 57% of energy use is for cooling and heating, 19% is for lighting, 18% is for pumps and the remaining 6% is for other services [9]. These studies reveal that lighting in Malaysian office buildings consumes a significant amount of energy. Power consumption should be minimised to ensure sustainable development; hence, the 11th Malaysia Plan for 2016–2020 intends to encourage the use of green technology in the provision of electricity goods and services [10]. However, data show that the cooling and lighting loads in Malaysian structures would be the most difficult to overcome. According to Saidur [9], lighting accounts for almost 19% of overall energy usage in Malaysian office buildings.

Higher energy costs, excessive reliance on fossil fuels and awareness of the resulting environmental damage have led to demand for energy efficiency in buildings. Building shading to reduce energy consumption requires careful consideration. Many studies have focused on the use of shading devices. For example, an outdoor shading system can save 10% to 11.3% energy in hot and humid conditions [11]. On the other hand, most shading devices are designed for aesthetics rather than energy efficiency. Designers may ignore data about the importance of awnings because they conduct research later in the design development process. Solar shading devices need to be carefully considered early in the design, especially on façades with high windows to walls [12]. This article aims to investigate the effectiveness of shading devices for more energy-efficient buildings in the hot and humid environment of Malaysia. This study examines the effects of different configurations of sunshades on lighting.

2. Literature

2.1 Daylighting

According to Heerwagen *et al.,* [13], daylight is light from the sun that has diffused through the atmosphere, clouds and particles in the air. It is divided into three sections:

i. Sky component (SC)
ii. External reflected component (ERe)
iii. Internal reflected component (IRC)

2.1.1 Benefits and significant of daylighting

Malaysia receives a lot of sunlight every year, according to Sern *et al.,* [14]. As a result, it is advocated that sunshine be exploited as a source of indoor illumination. Furthermore, according to Ander [15], daylight is beneficial in the following areas:

i. <u>The flow of light and the modelling of things in the space:</u> In contrast to the normally downward luminous flux found in many lighting systems, a room illuminated from the side in daylight has an almost horizontal luminous flux near the window. Modelling of the resulting room objects is often considered better than what can be achieved with artificial downlights alone.
ii. <u>Colour variation in natural lighting:</u> The light from the sun is hotter than the light from an overcast sky, which is hotter than the light from a clear north sky. Because sunshine does not tend to falsify, the colour rendition will be as accurate as possible.

iii. Outsider's perspective: While any view from a structure is better than none, most people prefer to gaze out a window at natural components like trees or grass rather than closely neighbouring buildings. According to various studies, having a view of the sky is crucial and individuals who are further away from windows suffer from a loss of natural view and a lack of natural lighting.
iv. Certain building types may save money on their net fuel costs: Increased daylighting may save a lot of money on energy expenditures in commercial buildings, which is more important than any increases in heating costs from artificial lights and other sources.

2.1.2 Malaysia climate condition

Malaysia is a nation in Southeast Asia just north of the equator. Malaysia is completely tropical, with latitudes ranging from 1 to 7 degrees north and longitudes of 100 to 120 degrees east [16]. High heat and humidity characterize the environment throughout the year. Throughout the year, Malaysia is bathed with natural light. In Malaysia, the sky is defined as intermediate or average, with cloudy skies 85.7% of the time and overcast skies 14.0%.

2.1.3 Problems of daylight

The following elements raise the risk for daylight problems:

i. Limited light entry to a room: Whether or whether there is a view of the sky, electric lighting will almost certainly be needed throughout the day in spaces far from windows in large rooms.
ii. Availability of daylight: Depending on the time of day and month of the year, the quantity of daylight accessible varies. It also fluctuates during the day.
iii. Glare due to window: Windows with lots of light glare can be felt in places observed from a usually gloomy interior, especially if the view is of a bright sky.

2.1.4 Visual comfort and performance

The body structure of the attention is intently related to visible feature features, which can be used to evaluate whether or not a specific lighting fixtures circumstance allows sight or visibility. Enough quantity of mild for the predicted visible task, uniform illuminance and luminance distribution, enough directionality to version third-dimensional gadgets and surfaces (path of incident mild from the facet or from above), loss of glare and enough spectral content material to render shades as it should be while required are all traits of suitable visibility.

2.2 Shading System
2.2.1 Background of shading system research

There have been numerous studies on the use of daylighting systems and shading devices as strategies for reducing energy consumption in buildings. Table 1 categorizes research on daylight systems and shading devices by the types of shadings, energy analysis methodology, parameters and environment included in the study. The data was compiled using Science Direct, Web of Science, Scopus and Conference Proceedings. Keywords like daylighting, light shelf, office spaces, visual performance and tropical environment were used to achieve this. Table 1 lists a few notable research studies and their findings.

Table 1
Significant research study and result

Author	Date	Title	Result
Al-Tamimi *et al.,* [17]	2011	The Potential of Shading Devices for Temperature Reduction in High-Rise Residential Buildings in the Tropics.	The use of egg-crate shading reduces the number of hours spent in discomfort.
Aldawoud [18]	2013	Conventional fixed shading devices in comparison to an electrochromic glazing system in hot, dry climate.	When compared to other evaluated shading circumstances, electrochromic glazing delivers the highest performance in lowering solar heat gains.
Cho *et al.,* [19]	2014	Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis.	The horizontal overhang and the vertical panel would reduce cooling energy demand by 19.7% and 17.3%, respectively.
Esquivias *et al.,* [20]	2016	Climate-based daylight analysis of fixed shading devices in an open-plan office	Overhangs, as well as horizontal and vertical louvres, behave similarly.
Lau *et al.,* [21]	2016	Potential of Shading Devices and Glazing Configurations on Cooling Energy Savings for High-rise Office Buildings in Hot-humid Climates	The most yearly cooling energy savings are achieved with egg-crate shadings.
Qing *et al.,* [22]	2017	External Window Sunshade Device Simulation Analysis and Optimization Design	Designed a foot shading device that is more user-friendly for pupils.
Rashid *et al.,* [23]	2019	The Efficacy of Shading Design in Commercial Buildings in The Semi-arid Climate of Lahore	For a southern aspect, horizontal shadow is the most beneficial.
Sghiouri *et al.,* [24]	2020	Comparison of passive cooling techniques in reducing overheating of clay-straw building in semi-arid climate	The most efficient method is automated moveable shade.

2.2.2 External shading devices

External shading devices such as eaves, awnings and veranda are important for limiting undesired solar heat intake, especially in cooling-dominant regions and throughout the summer in temperate climates. Shading devices operate by preventing direct sun radiation from entering a room through windows. Second, they help by limiting the amount of heat that is transferred directly to the walls. The most effective technique to limit solar heat gain is to use external shade devices.

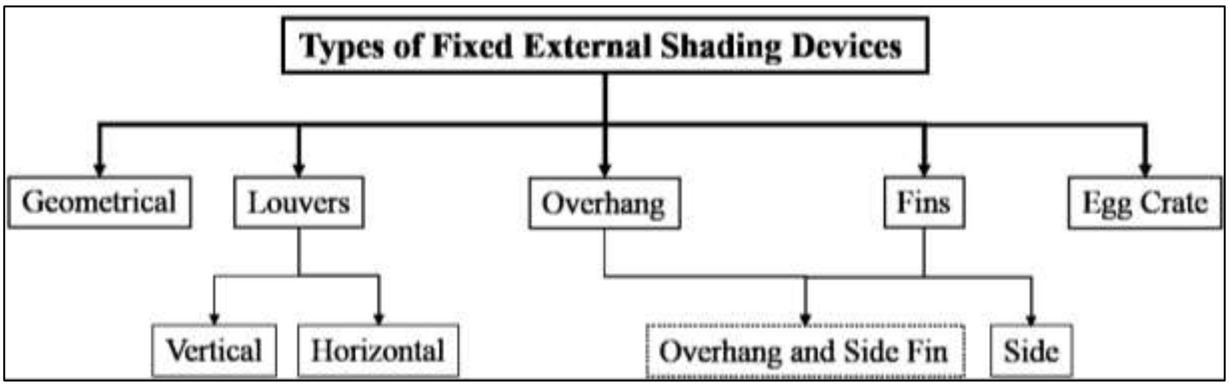


Fig. 1. Classification of different types of fixed external shading devices

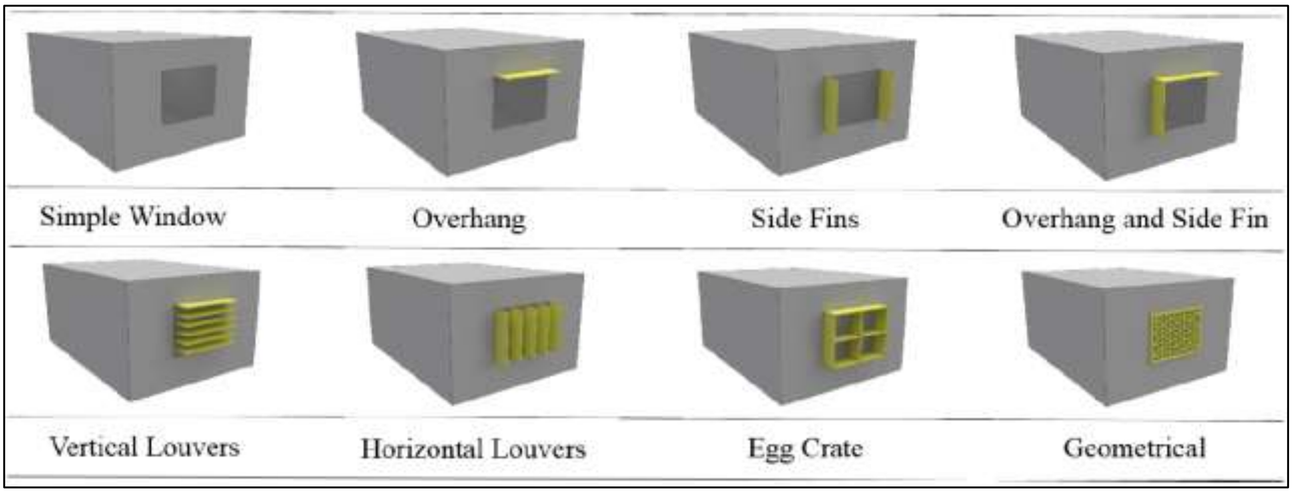


Fig. 2. Types of fixed external shading devices

3. Methods
3.1 Simulation Methods

The five suggested models were examined in this study using the VELUX Daylight Visualizer program. This simulation program has been demonstrated to properly estimate daylighting performance early in a building's design phase and display the effects of different design decisions on daylight performance. It uses both raytracing and radiosity techniques. It is based on a simulation with a physical foundation that offers photometric quantities (illuminance and luminance) in three-dimensional models. Numerous research studies have tested and validated this software [25-27].

3.2 Model Design and Simulations Procedure

A typical deep plan office space with dimensions of 6.0m (width) x 12.0m (depth) x 3.0m (height) was designed as a base model (Figure 3) in SketchUp and imported into Velux software for simulation in this study. Base model is then applied with 4 types of shading devices.

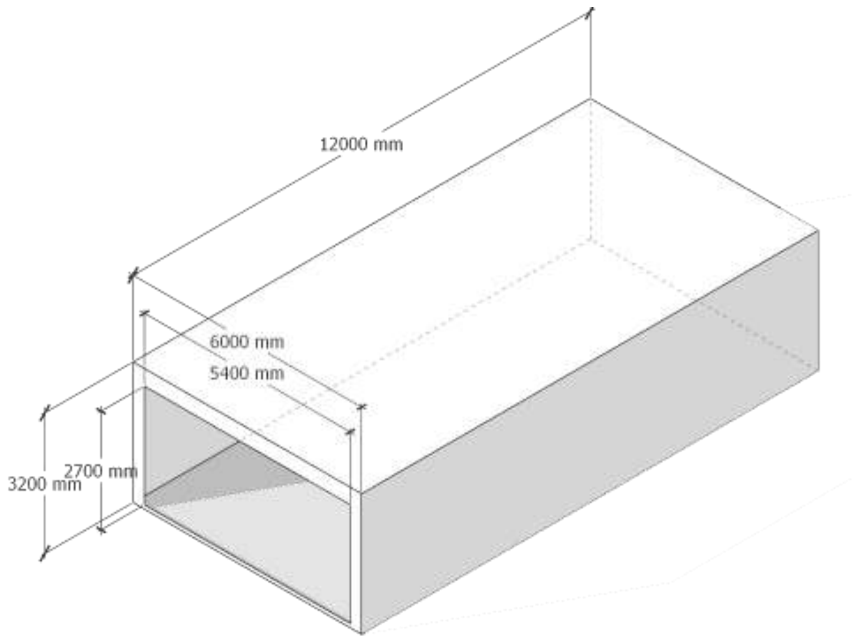


Fig. 3. A 6mx12m base case model with one side opening

Figure 4 shows the types of shading design from Type A to Type D which is window light shelf, overhand, horizontal louver blinds and folding form with light diffuse material respectively.

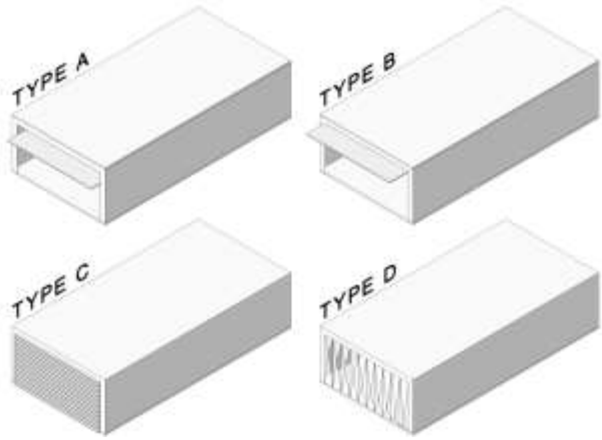


Fig. 4. Selected 4 types of shading designs

Table 2 shows the reflectance, light diffuser transmittance and roughness of the surface material values.

Table 2
Values for the surface properties in VELUX simulation

Components	Reflectance (%)	Light Diffuser Transmittance (%)	Roughness (%)
Internal Wall, Floor, & Ceiling	40	0	0.03
Shading Devices	40	0	0.03
Façade Diffuse Material	-	30	-

As shown in Figure 5, diffuse daylight enables the most productive use of the building floor plate because there are fewer "hot spots" or areas that are caused by direct sunlight near the building. Some daylight is transmitted directly, while the majority is diffused, to reduce the energy required for artificial lighting, reduce glare and promote user comfort.

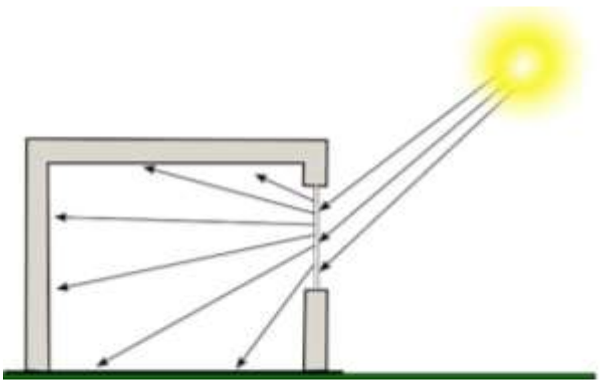


Fig. 5. Illustration of light diffuse through diffuse material

The simulation process is pursued in two phases. The first one was the daylight factor simulation, in which two out of four models with shading devices were selected based on their daylight factor results for further simulation. In the second phase, two selected models together with the base case model underwent illuminance simulation.

3.3 Criteria of Analysis
3.3.1 Estimated indoor illuminance (EII)

The daylight ratio (DR) is the ratio of interior illuminance to outside illuminance level. According to Dahlan *et al.,* [28], it is a feasible strategy that can only be used in places around the equator. Furthermore, it is used in tropical daylighting research since the absolute value of illuminance will alter over time. The daylight ratio was applied as a standard measurement for the illuminance simulation of five models.

The simulated outdoor global horizontal illuminance from the Velux simulation was significantly lower than the actual exterior global horizontal illuminance from a tropical sky. Thus, the simulated illuminance level was utilised to determine the DR, which was then converted to estimated indoor illuminance (EII) using the equation shown in Eq. (1). The EII values employed for this investigation at 09:00, 12:00 and 15:00 were 27,104 lx, 84,613 lx and 74,991 lx, respectively [29]. Results obtained were taken and went through comparison and analysis. The comparison was completed based on their percentage of comfort Lux reading based on the indoor floor area.

$$DR = \frac{Simulated\ Outdoor\ Illuminance}{Exterior\ Horizontal\ Global\ Illuminance}\ x\ 100\% \quad (1)$$

3.3.2 Illuminance

The models were oriented to face North, East, South and West in order to capture data from various angles during the day. Three design days were used, on the 21st of March, the 21st of June and the 21st of December, with three different hours of 09:00, 12:00 and 15:00. The amount of days-lighting within the room was identified using the Velux daylight visualizer to assess visual comfort. The illuminance level and daylight factor inside the room were calculated using this simulation tool. Because the room's purpose is an office space, the norm of visual comfort will be 300-500 lux according to Table 3.

Table 3
Recommended room illumination level

Location	IES Standards	MS 1525 Recommendation	Panduan Teknik JKR
General office with mainly clerical task	500	300-400	500
Executive office	500	300-400	300

3.3.3 Daylight factor (DF)

The daylight factor is a yearly simulation of the daylight ratio under overcast skies that provides the worst-case scenario of a design [30]. It also considers surface reflections, window transmittance and surface interreflections. In this simulation sky setting, an overcast condition is selected, which reflects the worst-case scenario to moderate with sun. Therefore, the direction of the structure and the time required have no effect on the outcomes of the computations.

The Green Building Index Non-Residential New Construction (GBI NRNC) Tools and MS1525: 2014 Implementation Standards for Energy Efficiency and Renewable Energy Use of Non-Residential Buildings are method to achieve green office buildings in Malaysia. Points are awarded under Daylight Credit EQ8 (for GBI NRNC) based on the percentage of net rentable area (NLA) that achieves a Daylight Factor (DF) of 1.0–3.5% measured at the work level [31].

Table 4
Recommended daylight factor according to Malaysia Standard 1525

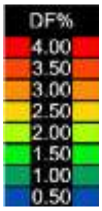
Daylight Factor	Lighting	Glare	Appearance and energy information
> 6.0	Intolerable	Intolerable	Room appears strongly daylit. At daytime artificial lighting is rarely needed but thermal problems due to solar heat gain and glare may occur.
3.5-6.0	Tolerable	Uncomfortable	
1.0-3.5	Acceptable	Acceptable	Room appears moderately daylit. Good balance between lighting and thermal aspects. Supplementary artificial lighting is needed at dark areas due to effect of layout or furniture arrangement.
< 1.0	Perceptible	Imperceptible	Room looks gloomy, artificial lighting is needed most of the time.

4. Result

4.1 Daylight Factor

In daylight performance, Table 5 shows the comparison of daylight factor between the base case model and selected 4 types of shading designs, from Type A to Type D. The area of comfort daylight factor is calculated and converted into a percentage ranging from 1% to 3.5%. The base case model has the highest daylight factor of greater than 3.5% which covered 24.22% of the indoor area. This is due to excessive direct sunlight entering the room without any shading device. The result showed that Type A and Type D both have the highest amount of comfort DF area, which is 26.51% and 34.51%, respectively. The reason for this result is that it is believed that Type A with light shelf shading design can bounce daylight into the inner area, which leads to an increase in indoor illumination. The use of a Type D folding shading design with light-diffused material results in less direct sunlight at the window area and some sunlight redirected to different angles. Both effects contributed to a reduction in the high daylight factor near the window area and an increase in the low daylight factor in the interior. The Type C horizontal louvre blinds design shows the highest 68.41% of indoor area covered with lower than 1% daylight factor. Even though horizontal louvre blinds shading can decrease the high amount of direct sunlight penetrating into space, it also leads to light being unable to transmit into the inner area.

Table 5
Daylight factor comparison between base case model and selected 4 types of shading designs

Model		Base	Type A	Type B	Type C	Type D
Result 						
Daylight Factor	<1%	290169 (52.49%)	354608 (64.21%)	322162 (58.27%)	377103 (68.41%)	270325 (49.99%)
	1%-3.5%	128745 (23.29%)	146401 (26.51%)	134116 (24.26%)	120792 (21.91%)	186621 (34.51%)
	>3.5	133918 (24.22%)	51291 (9.29%)	96573 (17.47%)	53355 (9.68%)	83802 (15.5%)

4.2 Estimated Indoor Illuminance

The illuminance simulation between selected model orientated facing north and south was performed and the results are shown in Figures 6 and 7. When compared to the base case model, both Type A and Type D have a greater shade effect and a bigger region of tolerable lux range. This proves that shading devices serve to increase the quality of daylight in the interior. According to previous study, Comfortable Lux Range (CLR) is from 300Lux – 500Lux. Figure 6 shows the percentage of area within CLR among 3 different models facing north. At 0900, the location of CLR remains the same throughout the year. Type A shows the highest level of area of CLR due to its design is able to reduce direct sunlight and confine a certain amount of light into the inner area. From 1200 until 1500 has the higher outdoor illumination level. A large amount of direct sunlight is diffused into the inner area for Type D, thus it shows the highest CLR compared to other models. Furthermore, the CLR for Type A and Type D appears to be located at the inner area of space due to high outdoor illuminance level at noon.

This phenomenon is more obvious especially during December solstices when the opening is facing north and June solstices according to Figure 7 when the opening is facing south. The sunlight is able to reach the end of the room and reflect from the inner wall, which results in CLR reaching up to 30%. During March 1200 until 1500, the equinox sun path provides a similar angle of light from the sun resulting the location of CLR remain the same for both north and south orientated opening.

The illuminance simulation between selected model orientated facing east and west was performed and the results area shown in Figures 8 and 9. Compared to the north-south orientated model, the east-west oriented model showed a significant difference at 0900. At 0900, morning sunlight penetrated all the models through openings facing east, resulting in a high amount of Lux level near the opening area. *Vice versa*, opening facing west at 0900, receives a slight amount of light into the space. Despite this, Type A with a light shelf can bounce the light into the inner area, which makes it have the highest amount of CLR compared to others for both east and west-oriented models. At 1200, the amount of light that penetrates into the space is similar for all the models, which remains the same throughout the year. At 1500, even though there is less direct sunlight for the east-oriented model, but high exterior illumination results in only a slight decrease in indoor illumination compared to 1200. From 1200 until 1500, Type D showed a significant increase in CLR compared to others. This is because light-diffused materials can redirect sunlight in different directions, allowing it to enter the interior. At 1500, models orientated west receive a high amount of lighting, which results in more than 60% of the inner space being provided with a higher than 500 Lux level despite shading devices being applied to the models.

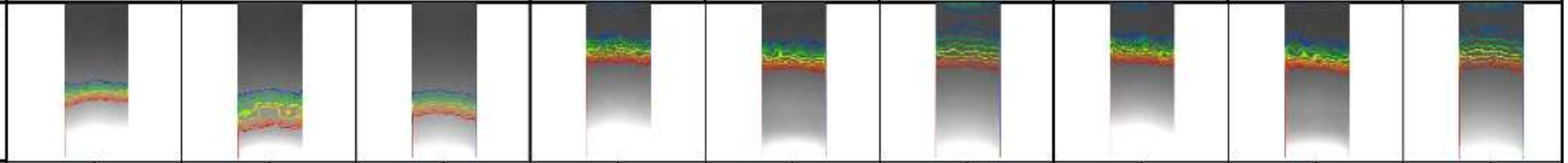
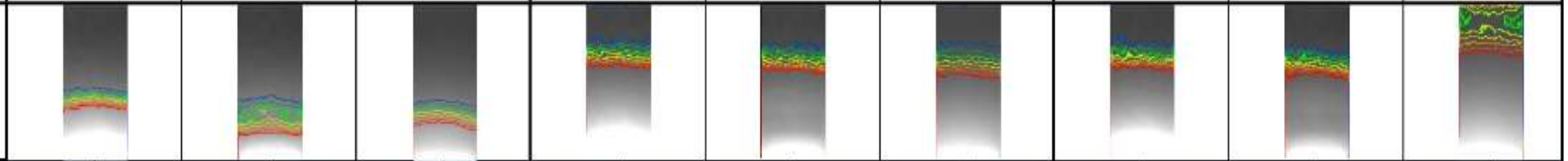
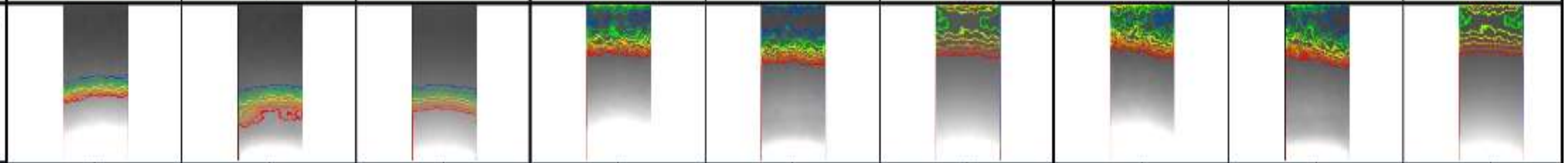
Orientation	Month	Time	900						1200						1500					
		Type	Base		A		D		Base		A		D		Base		A		D	
North	March	Result Lux 600 471 443 414 386 357 329 300																		
		<300	64452	51.4	71430	56.9	72473	57.7	25737	20.5	31696	25.3	17875	14.2	25300	20.2	30573	24.4	19025	15.2
		300-500	15311	12.2	29371	**23.4**	18719	14.9	22662	18.1	22326	17.8	34772	**27.7**	23515	18.7	23670	18.9	33651	**26.8**
		>500	45737	36.4	24699	19.7	34308	27.3	77101	61.4	71478	57.0	72853	58.1	76685	61.1	71257	56.8	72824	58.0
					✓								✓						✓	
	June	Result Lux 600 471 443 414 386 357 329 300																		
		<300	67678	53.9	75917	60.5	77850	62.0	29044	23.1	32611	26.0	31920	25.4	30632	24.4	36346	29.0	0	0.0
		300-500	15527	12.4	28417	**22.6**	18994	15.1	22066	17.6	21899	17.4	26748	**21.3**	21913	17.5	22372	17.8	39858	**31.8**
		>500	42295	33.7	21166	16.9	28656	22.8	74390	59.3	70990	56.6	66832	53.3	72955	58.1	66782	53.2	85642	68.2
					✓								✓						✓	
	December	Result Lux 600 471 443 414 386 357 329 300																		
		<300	58525	46.6	66041	52.6	65846	52.5	0	0.0	16729	13.3	0	0.0	0	0.0	4979	4.0	0	0.0
		300-500	16899	13.5	26644	**21.2**	19700	15.7	40796	32.5	30966	24.7	41579	**33.1**	39694	31.6	41535	33.1	39847	**31.8**
		>500	50076	39.9	32815	26.1	39954	31.8	84704	67.5	77805	62.0	83921	66.9	85806	68.4	78986	62.9	85653	68.2
					✓								✓				✓			

Fig. 6. Illuminance comparison between selected model facing north

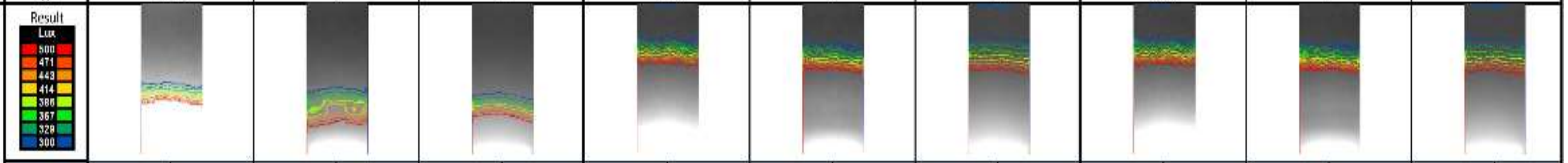
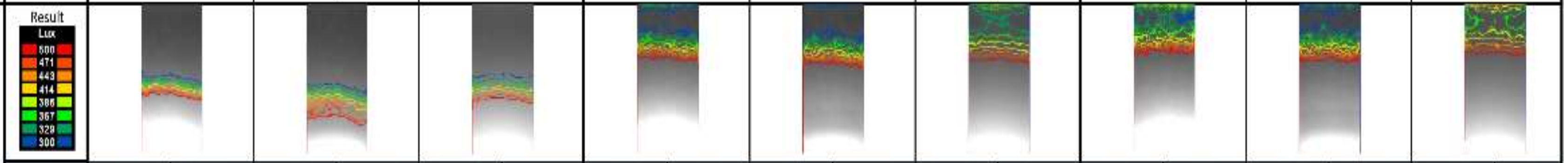
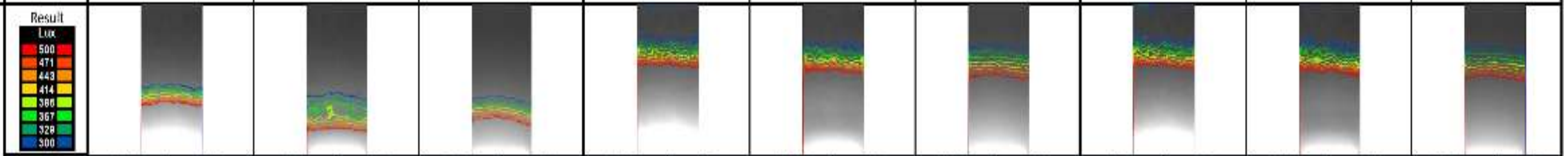
Orientation	Month	Time	900						1200						1500					
		Type	Base		A		D		Base		A		D		Base		A		D	
South	March																			
		<300	66883	53.3	74943	59.7	75860	60.4	29025	23.1	33982	27.1	27360	21.8	28940	23.1	33669	26.8	28252	22.5
		300-500	15413	12.3	28667	**22.8**	18307	14.6	21391	17.0	21425	17.1	28693	**22.9**	22017	17.5	22172	17.7	28642	**22.8**
		>500	43204	34.4	21890	17.4	31333	25.0	75084	59.8	70093	55.9	69447	55.3	74543	59.4	69659	55.5	68606	54.7
					✓								✓						✓	
	June																			
		<300	60464	48.2	68598	54.7	67264	53.6	16547	13.2	23848	19.0	0	0.0	0	0.0	14327	11.4	0	0.0
		300-500	16251	12.9	27943	**22.3**	18963	15.1	29465	23.5	26773	21.3	47598	**37.9**	40223	32.1	33102	26.4	41869	**33.4**
		>500	48785	38.9	28959	23.1	39273	31.3	79488	63.3	74879	59.7	77902	62.1	85277	67.9	78071	62.2	83631	66.6
					✓								✓						✓	
	December																			
		<300	67818	54.0	75453	60.1	78258	62.4	28458	22.7	33618	26.8	34853	27.8	28833	23.0	33575	26.8	36011	28.7
		300-500	15187	12.1	28958	**23.1**	18285	14.6	22482	17.9	22139	17.6	25222	**20.1**	22739	18.1	23138	18.4	25055	**20.0**
		>500	42495	33.9	21089	16.8	28957	23.1	74560	59.4	69743	55.6	65425	52.1	73928	58.9	68787	54.8	64434	51.3
					✓								✓						✓	

Fig. 7. Illuminance comparison between selected model facing south

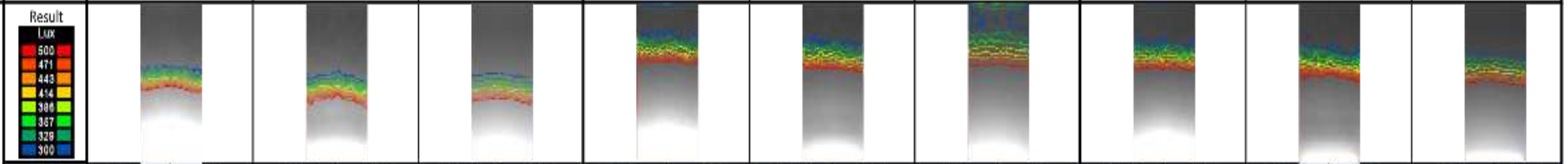
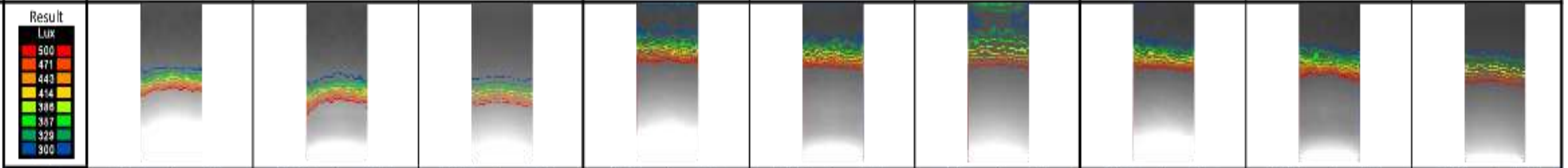
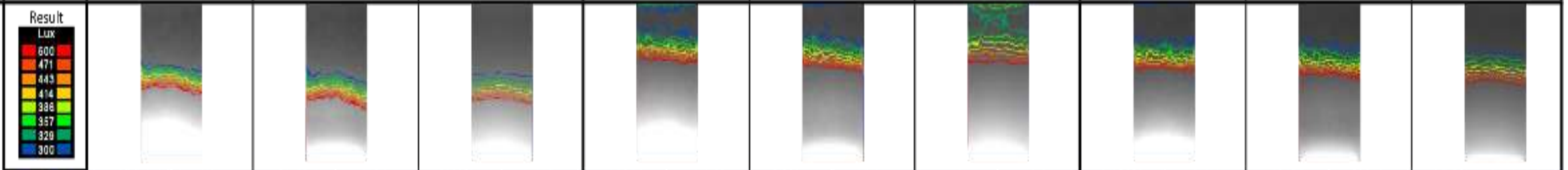
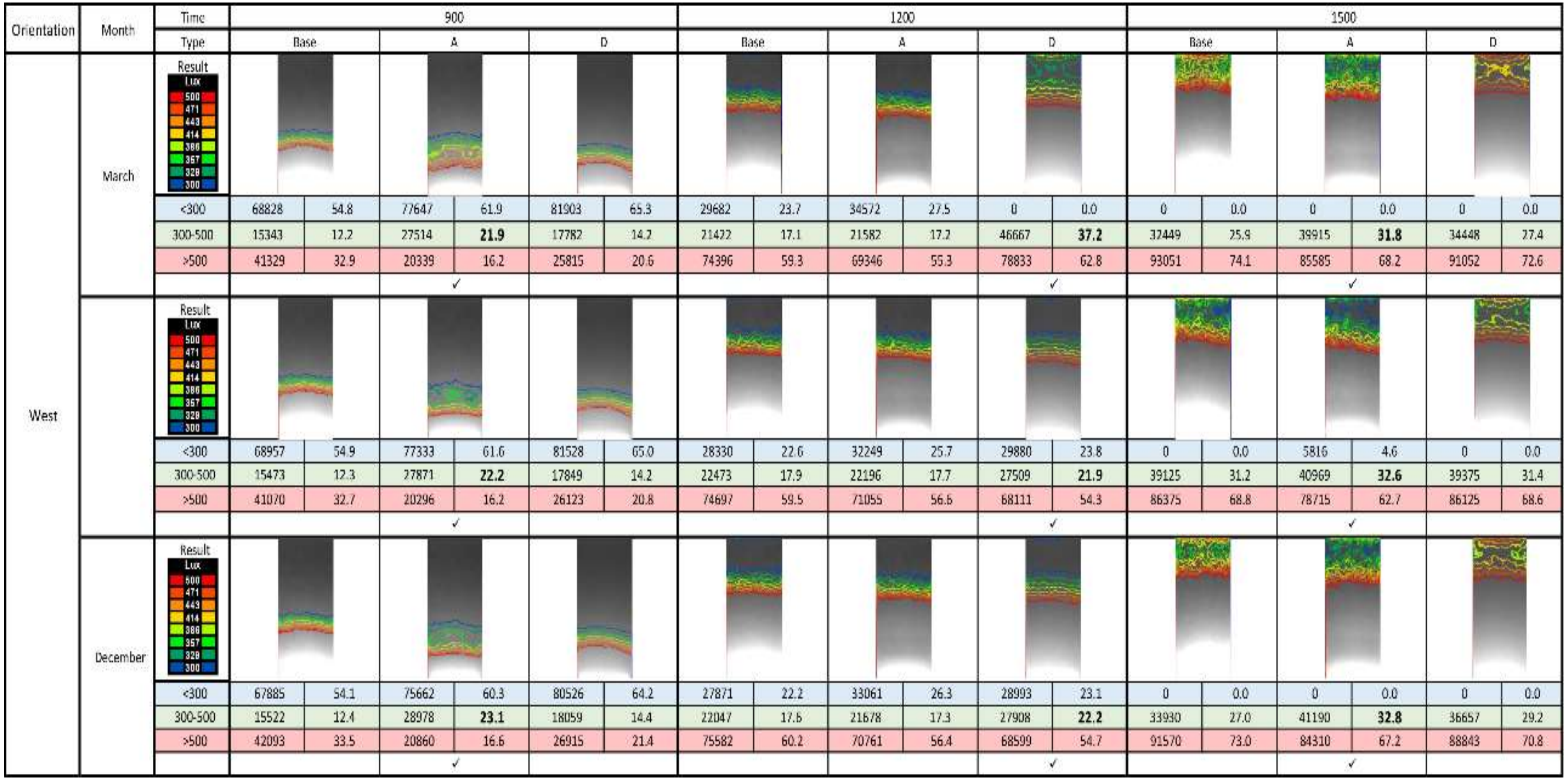
Orientation	Month	Time	900						1200						1500					
		Type	Base		A		D		Base		A		D		Base		A		D	
East	March	Result 																		
		<300	50587	40.3	58024	46.2	57400	45.7	23346	18.6	30354	24.2	6473	5.2	30328	24.2	35825	28.5	40809	32.5
		300-500	16945	13.5	20138	16.0	20573	**16.4**	23649	18.8	22921	18.3	43868	**35.0**	22557	18.0	22373	17.8	23510	**18.7**
		>500	57968	46.2	47338	37.7	47527	37.9	78505	62.6	72225	57.5	75159	59.9	72615	57.9	67302	53.6	61181	48.7
							✓						✓						✓	
	June	Result 																		
		<300	51474	41.0	59168	47.1	59200	47.2	18739	14.9	26846	21.4	3381	2.7	30788	24.5	36052	28.7	38790	30.9
		300-500	17888	14.3	20746	**16.5**	20544	16.4	28200	22.5	24979	19.9	46457	**37.0**	21676	17.3	22381	17.8	24063	**19.2**
		>500	56138	44.7	45586	36.3	45756	36.5	78561	62.6	73675	58.7	75662	60.3	73036	58.2	67067	53.4	62647	49.9
					✓								✓						✓	
	December	Result 																		
		<300	50321	40.1	56756	45.2	56139	44.7	15806	12.6	26438	21.1	0	0.0	28365	22.6	33415	26.6	38409	30.6
		300-500	17535	14.0	20577	**16.4**	20394	16.3	29714	23.7	24714	19.7	47001	**37.5**	23429	18.7	23558	18.8	24213	**19.3**
		>500	57644	45.9	48167	38.4	48967	39.0	79980	63.7	74348	59.2	78499	62.5	73706	58.7	68527	54.6	62878	50.1
					✓								✓						✓	

Fig. 8. Illuminance comparison between selected model facing east



Orientation	Month	Time	900						1200						1500					
		Type	Base		A		D		Base		A		D		Base		A		D	
West	March	<300	68828	54.8	77647	61.9	81903	65.3	29682	23.7	34572	27.5	0	0.0	0	0.0	0	0.0	0	0.0
		300-500	15343	12.2	27514	**21.9**	17782	14.2	21422	17.1	21582	17.2	46667	**37.2**	32449	25.9	39915	**31.8**	34448	27.4
		>500	41329	32.9	20339	16.2	25815	20.6	74396	59.3	69346	55.3	78833	62.8	93051	74.1	85585	68.2	91052	72.6
					✓								✓				✓			
		<300	68957	54.9	77333	61.6	81528	65.0	28330	22.6	32249	25.7	29880	23.8	0	0.0	5816	4.6	0	0.0
		300-500	15473	12.3	27871	**22.2**	17849	14.2	22473	17.9	22196	17.7	27509	**21.9**	39125	31.2	40969	**32.6**	39375	31.4
		>500	41070	32.7	20296	16.2	26123	20.8	74697	59.5	71055	56.6	68111	54.3	86375	68.8	78715	62.7	86125	68.6
					✓								✓				✓			
	December	<300	67885	54.1	75662	60.3	80526	64.2	27871	22.2	33061	26.3	28993	23.1	0	0.0	0	0.0	0	0.0
		300-500	15522	12.4	28978	**23.1**	18059	14.4	22047	17.6	21678	17.3	27908	**22.2**	33930	27.0	41190	**32.8**	36657	29.2
		>500	42093	33.5	20860	16.6	26915	21.4	75582	60.2	70761	56.4	68599	54.7	91570	73.0	84310	67.2	88843	70.8
					✓								✓				✓			

Fig. 9. Illuminance comparison between selected model facing west

4.3 Discussion

4.3.1 Daylight performance

In daylight factor simulation, Table 5 shows the significant daylight performance of models applied with shading devices compared to the base case model. Compared to the base case model, which has 24.22% of the indoor area with a daylight factor higher than 3.5%. Type A to Type D models with shading devices show a significant reduction from 24.22% to 9.29%, 17.47%, 9.68% and 15.5%, respectively. In this simulation, Type D showed the best performance compared to other models. It decreases the gloomy inner area where the daylight factor is less than 1%, from 52.49% to 49.99% compared to the base case model. Besides that, it also increases the area of the acceptable daylight factor (1%-3.5%) from 23.29% to 34.51% which is in accordance withto previous studies [12,14,18]. This proves that light diffuse material can redirect the incoming sunlight equally in all directions, which decreases the brightness at the periphery area and also directs light deeper into a space.

As shown from Figures 6 to 9, models with shading device shows improvement of daylight performance compared to base case model. From the simulation, Type A with light shelf shading device is seen to show the best shading effect and provide high quality of daylight performance during 0900. This is because the light shelf can bounce and redirect the direct sunlight into the inner area even though the EII is less compared to 1200 and 1500 [12]. This effect can clearly be seen when model from the simulation results under all four orientations.

At 1200 and 1500, high exterior illumination results in on average more than 50% of indoor space where lux level higher than 500 lux. According to this result, additional shading method is required in order to reduce the lux level near to periphery area.

4.3.2 Limitation and future research

This research used computer software simulation as a tool for obtaining the results. A scaled model study needs to be done to validate the selected computer software regarding the selected location, selected times and dates.

Besides that, another limitation of this study was that the room used was absolutely empty. The lack of furniture and the materials used did not represent the reality of a used office space, all of which would alter the light levels and outcomes.

Lastly, this study employed only one type of building opening. Though research on different numbers, sizes, shapes and positions of building opening areas are needed to provide a complete picture of daylight performance. It can help in determining which shading method corresponds to the respective type of building opening to maximize the potential of the shading device.

4. Conclusion

The simulation results of four proposed shading devices on daylighting performance for office space in Malaysia were evaluated in this study. The results show that the VELUX Daylight Visualizer can reasonably forecast interior illuminance. Even while the shading devices lower the depth of penetration, they can nevertheless allow illuminances that are somewhat greater than the permitted threshold to be achieved. As a result, the design of exterior shading devices needs a comprehensive solution that involves admitting enough daylight into the room, avoiding direct views of the sky and providing an appropriate architectural design. This research also proves that light shelf shading devices can reflect direct sunlight and direct it into the inner area, which increases overall indoor illumination.

Besides that, this research also showed the advantage of using light diffuse material for façade and shading system in architecture. Light diffuse material can evenly distribute incoming light in all directions. This means that as much light is focused within and upward as it is downward and toward the floor. The usable daylight is dispersed deeper into a place as a result of this redistribution. This increases daylight potential while reducing glare and hotspots.

In general, the research study provides a comprehensive picture of the hidden obstacles that restrict the use of skylight systems in Malaysia. Malaysia's climate is sunny all year, making it a great location for maximize the use of daylighting. Daylighting design is the need to control natural light entering a building to reduce the need for artificial lighting and save energy, while optimizing user comfort by reducing glare and direct sunlight.

Acknowledgement
The author would like to acknowledge research funding from Short Term Research Grant, Universiti Sains Malaysia (304/PPBGN/6315590).

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