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Enhancing Daylight Distribution in Deep-Plan Office Buildings in Malaysia through the Integration of Light-Shelves Techniques

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Abstract
Provision optimum daylight distribution in architectural spaces is a challenging task. This study aimed to critically assess the integration of light shelves with glazing façade to enhance the daylighting in rear areas of deep-plan office buildings in Malaysia. A scaled-model experiment was conducted to determine the illumination levels achieved by light shelves. Scaled model results were validated against computer simulation using radiance calculation, it found to be in good agreement, and the results indicated significant Pearson correlations at the 0.01 to 0.04 level. The maximum percentage of Daylight Ratio (DR) differences was 1.8% (≤10%) which is accepted. The results indicated that, there is no common Light Shelf Systems (LSSs) solution under tropics sky. Overall, can considered the best LSSs location and position in different orientations in most cases was found to be one that is L1 at P1 and P2. The results showed the optimum cases achieved a significant increase in illuminance levels in the back of space. Finally, the study confirmed the positive contribution of LSSs as a daylighting system under tropical region. The study proposed a LSSs with dynamic properties which could provide optimum daylighting performance for different sky conditions, times, months and orientations under tropical sky.

Keywords: *Day lighting, daylight strategy, light-shelves, Malaysia, office buildings, scale-model*

INTRODUCTION

The provision of optimum daylight distribution in architectural spaces is a challenging task for all architects and building designers. Optimal daylighting distribution requires maintaining the daylight level in the rear parts of interior spaces within a suitable range that does not negatively influence users' health and contributes positively to their productivity [1]. The recent design of most modern outer shells of office buildings has frequently shifted toward the use of a high ratio of glazing surfaces in exterior façades, which requires considerable attention to the building envelope design in terms of its effect on occupants' visual comfort and energy saving requirements [2]. Nowadays, environmental awareness assessments of building design are acknowledging the importance of daylight utilization in building design. Daylight utilization in interior workspaces of office buildings throughout the entire day or during most of the day may lead to considerable savings in energy consumption for electric lighting and may create a high-quality interior environment [3].

One remarkable benefit of daylight utilization in building interiors is that it replaces artificial lighting sources to reduce the amount of consumed electricity [4]. However, daylighting provision inside a building typically does not reduce energy consumption. Daylighting can only contribute to energy reduction when daylighting techniques are integrated to improve the overall lighting conditions [5]. The advantage of natural light in office workspaces is widely recognized. The utilization of natural lighting in offices leads to energy reduction, reduces maintenance costs, and improves the performance of employees. A wholesome environment workspace raises the efficiency of occupants [6]. A large amount of consumed energy for lighting in primary office workspaces constitutes one-third of energy consumption, and lighting energy consumption depends on the building's purpose and daylight use [7]. Artificial lighting alone consumes approximately 23% of total energy used in Malaysian offices [8].

Daylighting is an important strategy to achieve an efficient building that is integrated with ambient environmental conditions in which it is inserted. Thus, the surrounding daylight should be critically investigated. To conduct an efficient daylight study and its impact on interior spaces in buildings, daylight-related data of a site location in which the building stands should be collected [9].

In tropical areas, natural light is abundant due to the high intensity of sunlight and its long illumination duration throughout the day. In spite of this potential, insufficient understanding about sky conditions in this region may lead to the underutilization of most daytime illumination. The design of natural light utilization in tropical areas is challenging due to various sky changes [10]. Appropriate daylighting distribution requires design experience. Window-to-wall ratios and roof/ceiling apertures are two strategies used in daylight design utilization in buildings. The first strategy is side light (SL), and the second strategy is top lighting (TL), both of which enable daylight penetration inside the building. However, the amount of natural illuminance can deliver only a limited distance toward the back of a space through the window although no obstruction to the sky exists and the roof opening is a source of heat gains and glare [8]. In addition, side openings can occasionally be a source of glare, especially in areas near windows when direct sunshine travels toward the window surface.

In most Malaysian office buildings, SL is a widespread as a main daylighting design system, especially in high-rise buildings. TL is ignored by designers due to the excessive heat gains that are delivered to the inside spaces, although it enables more light distribution in a space than SL [11]. Several studies have provided different methods to guide natural light in deep-plan interior workspaces. However, the use of the SL strategy in hot-humid region buildings remains challenging due to direct sunlight, especially in office buildings. Studies have shown that Malaysian buildings are exposed to high grades of direct sunshine, which limit the adoption of conventional daylight strategies, especially on normal vertical windows. A study on several kinds of daylighting strategy determined that the SL system could be relatively valuable. However, harnessing SL for office buildings in tropical areas is challenging and requires composite adjustments to the dominant effects of light level and light intensity in indoor spaces, which can cause visual discomfort [10].

DAYLIGHTING SYSTEMS (DSS)

DSs are devices located close to or at the apertures of the building envelope, which can reflect and deliver direct daylight toward the deep part of spaces to enhance the overall lighting conditions [5]. DSs aim to meet the daylight requirements in the interior spaces of a building when a limited amount of natural light is provided [12]. DSs guide natural daylight to the back areas of spaces, improve daylight distribution, and minimize lighting problems in interior spaces. However, inaccurate design of daylighting techniques on the envelope may frequently lead to many light issues, such as glare, shadows, and high-energy lighting consumption in a building [13].

DSs have been developed recently to harness solar light in building design. Given the high proficiency obtainable by DSs, several studies have focused on the performance enhancement of these techniques [14]. The maximization of daylight grades at the back portions of interior spaces is a key goal by using DS devices on envelope apertures, thereby increasing the time when the interior portions of the building are above the target minimum illuminance grade. The required minimum illuminance grades are related to the intended use of the vacuum as shown in Figure 1. To achieve the maximum benefit of DSs, glare should be minimized by lowering unnecessary lighting grades near the window through shading capability, unobstructed view toward the external environment, light guidance toward the back part of the room, and enhancement of homogeneous daylight distribution [15].

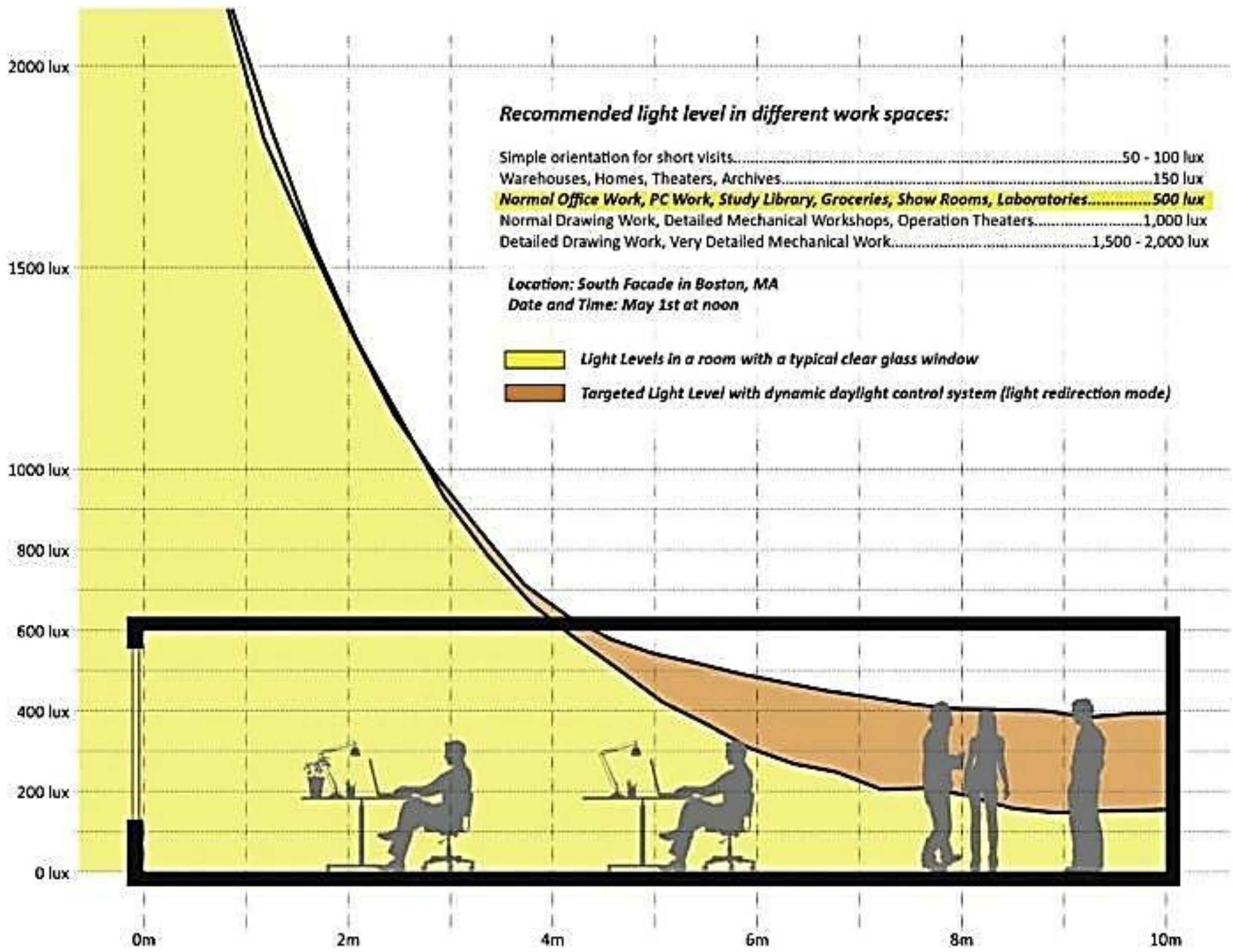

Figure 1: *Illuminance levels in the interior spaces depending on their function.*

Light Shelf Systems (LSSs) are a DS technique that can cause direct or diffuse natural illumination in the deep parts of a building. LSSs are widely used in modern buildings and are frequently recommended as an effective strategy that can enhance the daylighting quality of a space [16]. Previous studies showed that this technique has considerable capabilities in guiding daylight toward the deep portions of interior spaces. LSSs are commonly installed horizontally or tilted to an angle attached to the upper part of the façade opening with a reflective surface. LSSs act by redirecting sunlight to a specific point on the ceiling at which it is reflected to the rear portion of the space [17].

LSSs are passive systems used for daylight control and are placed in the upper part of windows above the human eye level. LSSs decrease the light density in the front part of a room under a window, increase light penetration to the back space, accurately distribute daylight in spaces, and reduce glare by redirecting daylight to the ceiling and reflecting it in the space. LSSs are mostly coupled with shading for better results [18].

OBJECTIVES

This study aims to determine the effect of light shelves in enhancing the daylighting performance in Malaysian deep-plan office spaces. This objective can be achieved by finding answers to the following questions:

- What is the difference in the improvement of daylight distribution in the back areas of space using light shelves compared with the reference case without any light shelves?
- What is the optimal design of light shelves in terms of good daylighting penetration in deep-plan office spaces under Malaysian sky conditions?

LITERATURE REVIEW ON LSSs

Various studies that focus on daylight and DSs have been published, including studies that emphasize the importance of utilizing light shelf techniques to improve the daylighting performance in the interior portions of office workspaces. Warrier and Raphael [17] conducted a performance evaluation on light shelves by experiment and simulation. Experimental results showed that interior lighting increases by an average of 21%. Simulation results are obtained by Radiance lighting software, thereby proving that light shelves enhance daylight in interior spaces at distances greater than the height of the window and reduce glare by providing shading near the window.

Lim and Ahmad [19] examined the performance of light shelves under real tropical sky condition, the examined carried out under direct solar radiation using physical scale models to evaluate several configurations of light shelves under the Malaysia climate. Their study concluded that employ of light shelves as daylight system at building facades in tropics region is more complicate than the use of window orientations and that light shelves perform better under overcast sky conditions than under other tropical sky conditions. Berardi and Anaraki [20] study evaluate the advantages of light shelves utilized to office facades design in Toronto for daylight illuminance using a simulation method. Their results showed that the use of light shelves increases the daylight illuminance values at the first 6 m from the windows and provides a homogeneous daylight distribution.

Other studies [14, 21, 22] have been conducted on the performance of light shelves and the factors that influence their daylighting performance. However, few studies have focused on the effect of light shelves on daylighting performance in Malaysian office buildings. Additional studies should be conducted to determine the role of light shelves as daylight guiding systems by performing experiments and simulations on such systems. These studies will be conducted to assess the performance of light shelves in Malaysian office buildings under a tropical climate with different configurations.

Day-lighting in Office Buildings in Malaysia

The design of DS in buildings in Malaysia under a tropical climate is difficult due to various sky conditions. A comprehensive understanding of all various sky conditions (clear/ overcast/ cloudy) is essential in obtaining appropriate daylighting. This approach is critical in tropical environments, where the sky is predominantly intermediate with inconsistent direct sunlight [19]. Consequently, the challenge in tropical daylighting is the control of daylight quality rather than daylight quantity [23].

The realization of allowable minimum/ maximum levels of daylight distribution in interior workspaces in office buildings is also crucial. Many standard guidelines and studies have provided various ranges of daylight levels (see Table 1). However, the optimum level that is must achieved is still under debate and evaluation [24]. In regions with tropics sky conditions, there is really plentiful quantity of illumination [25], natural illumination levels can vary from 5000 lux in a heavily overcast sky to over 40,000 lux in clear sky with direct sunlight. These amounts are significantly greater than what adequate inside daylighting requirements. Generally, typical indoor illuminance demands more than 500 lx for work-plan office spaces [26].

Malaysian standard 1525: 2014 recommends a lighting level between 300–500 lux and daylight factor (DF) between 1−3.5% is acceptable for light and glare, while 3.5%-6% is tolerable for light and uncomfortable for glare. Malaysia's Green Building Index suggests the same lighting level and 1.0%-3.5% DF for general offices [25]. However, many existing typical Malaysian office buildings do not utilize natural daylight due to designs that are inappropriate for intense sunshine in a tropical climate despite the abundant daylight diffusion in a tropical sky that is unutilized in buildings [25]. Existing daylight evaluation studies on office spaces indicated that most daylighting techniques are not commonly integrated in the envelope design of buildings [13].

A study on 41 spaces in five office buildings in Malaysia demonstrated that none of these office spaces provide more than 0.5% DF due to the utilization of interior window shading systems [14]. Hirning et al., conducted a survey in six office buildings in Malaysia, including three green-certified and three normal office buildings. Results indicated that high luminance in green buildings is obtained from windows that cause 35% glare to occupants compared with 7% in non-green office buildings [27].

Several studies have investigated the lighting conditions in five Malaysian government office buildings with various plan configurations. Their findings showed that all office buildings are not intended for natural light usage with DF lower than 1.5% and poor natural illumination distribution uniformity. The findings confirmed that all the selected buildings demonstrate full reliance on artificial lighting regardless of adequate external daylight accessibility in tropical areas [23]. Lim et al. thirteen different designs of Malaysian high-rise office buildings with open plan have been examined in Johor Bahru. Their result illustrated that the envelopes of buildings consist of large glazed façades without any daylighting techniques on outside surfaces. The interior illuminance is high with non-uniform distribution accompanied by glare issues [28].

***Table 1:** Recommended levels of illumination.*

Recommended Levels of Illumination	**Operation Class**	**Visual Performance [x]**		
		Minimum	**Standard**	**Maximum**
USA	General	500	750	1000
Japan		300	500	750
Republic of Korea		300	400	600

On the basis of previous studies, many researchers recommended that the minimum illumination level of DF should be at least 5% in assessing the daylighting performance in Malaysian office buildings [24]. Fadzil et al., [29] determined that the range of DF values is from 0.8% to 2.3%.

METHODOLOGICAL PROCEDURE

Methodology

The daylighting distributions of light shelf techniques under tropical sky conditions can be achieved by using two approaches, namely, real experimental measurements and computational simulations. Experimental measurements can be either set on fieldwork measurements in real buildings or scaled-model prototype tests. Experimental measurements record the real results that are analyzed based on daily climate data. Computer simulation tools evaluate many design solutions in the same model [30]. The use of scale-model is widely adopted as an efficacy approach for evaluate the daylight in an interior. It can be examined under real weather conditions or manufactured conditions at different types of artificial skies. Many researchers pointed out that the results gotten by scale model most of times leads to an overestimation of if it is compared to real scale test rooms. However, this overestimation commonly accepted among the most researchers [31]. Thus, the outcomes gotten from direct measurements of fieldwork physical scaled-model method are often preferred in the research community by validation as compared to those from computer simulations. Where some studies have indicated by authors that the average level percentage of illuminance differences between results of fieldwork studies and computer simulation tools must be with the range less or equal 20% [4, 32−34], and the differences in Daylight Factor (DF%)/ Daylight Ratio (DR%) ≤10% [8, 35].

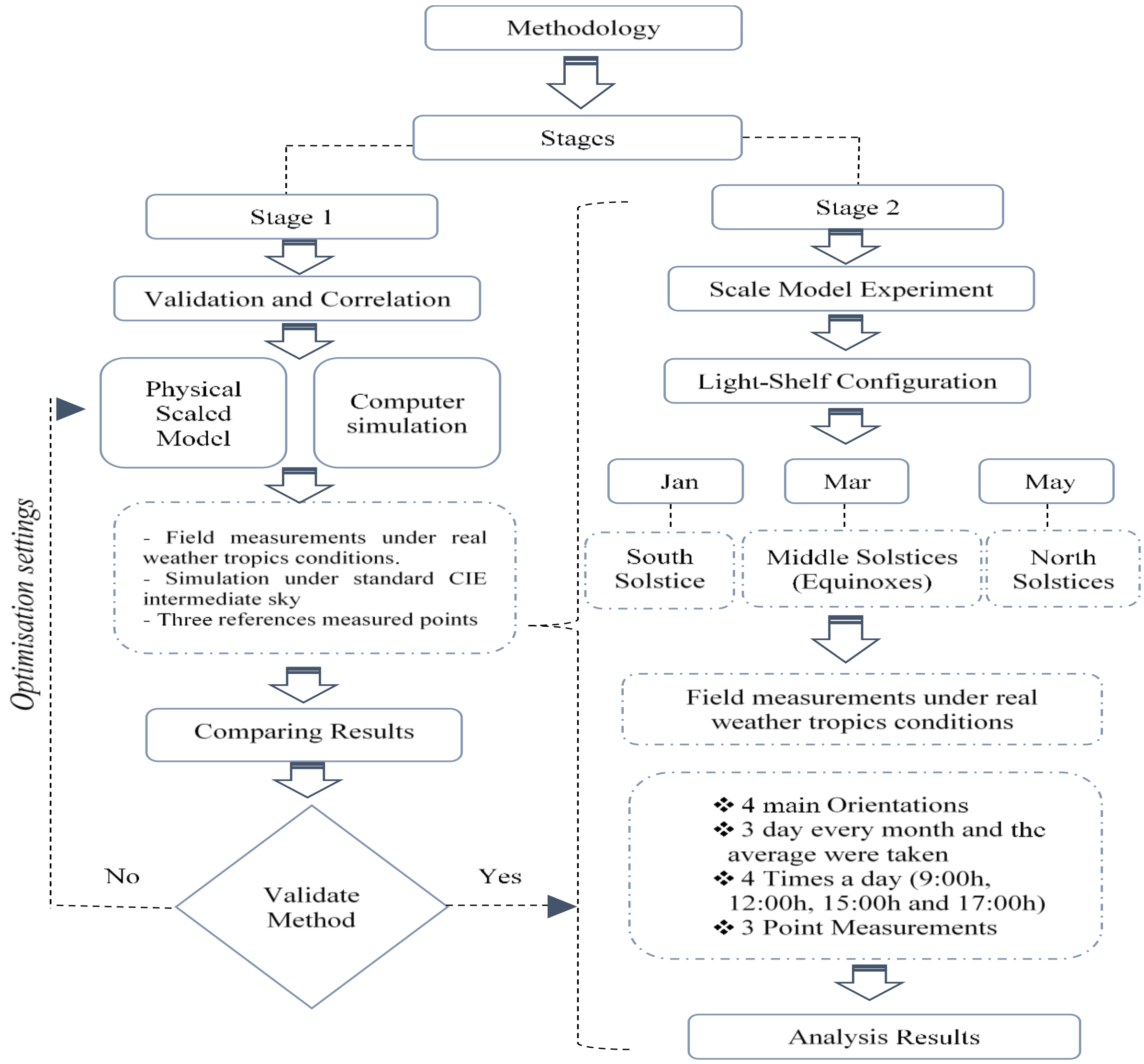

***Figure 2:** Methodology flowchart.*

Starting from this point, in this study, scaled-model method was used to experiment a model under real sky condition to prepare information on the daylighting performance of the LSSs. In order to achieve successful fieldwork measurements by scaled-model method, scaled-model method was validated by the simulation software's using Radiance daylight engine. In order to generalize the experimental findings. These two major processes of methodology were presented in detail in Error! Reference source not found.

The validation processes through comparing the illuminance performance in 1:10 physical scale model and computational simulation tool which utilized Radiance engine interface for illuminance computation as a first stage. To directly compare the results of physical tests that carried out under tropical sky conditions with simulation outcomes, the standard intermediate CIE sky was used via the simulation. Because, most of the literature researches demonstrate that tropical sky is classified as intermediate sky [19]. In the second stage after validating the method used, different configuration of light-shelves was examined. The experiment of light-shelves was carried out in two qualified scaled model (1:10) of typical unit with single

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side-lighting window. The measurements are conducted under real sky conditions in an open area on the top roof of the main building of the School of Housing, Building, and Planning at USM in Penang. However, the experimental data from the field measurement would affirm the usefulness, appropriateness and precision of the indoor daylight availability [4]. As well as the physical scaled-model provides information on the daylighting performance of the selected light shelves.

Light shelf design variables in the experiment

According to many design variables of light shelves can be effects on the performance of daylight, in this study only two basic variables were selected configurations of light-shelves; Location (L), and Position (P) were chosen as shown in Figure 3. Nine configurations of LSSs were proposed. The first three types were completely placed outside the window, and the second three types were placed in the middle of the window, which includes external and internal parts. The last three types were completely placed inside the window. Each light shelf was evaluated in a horizontal position. The width of all LSSs configurations was 1 m based on most studies on variables related to LSSs. Each light shelf was investigated at three proposed heights, namely, 1.80, 2.00, and 2.20 m from the floor. Those heights proposed based on study Joarder, Ahmed [36].

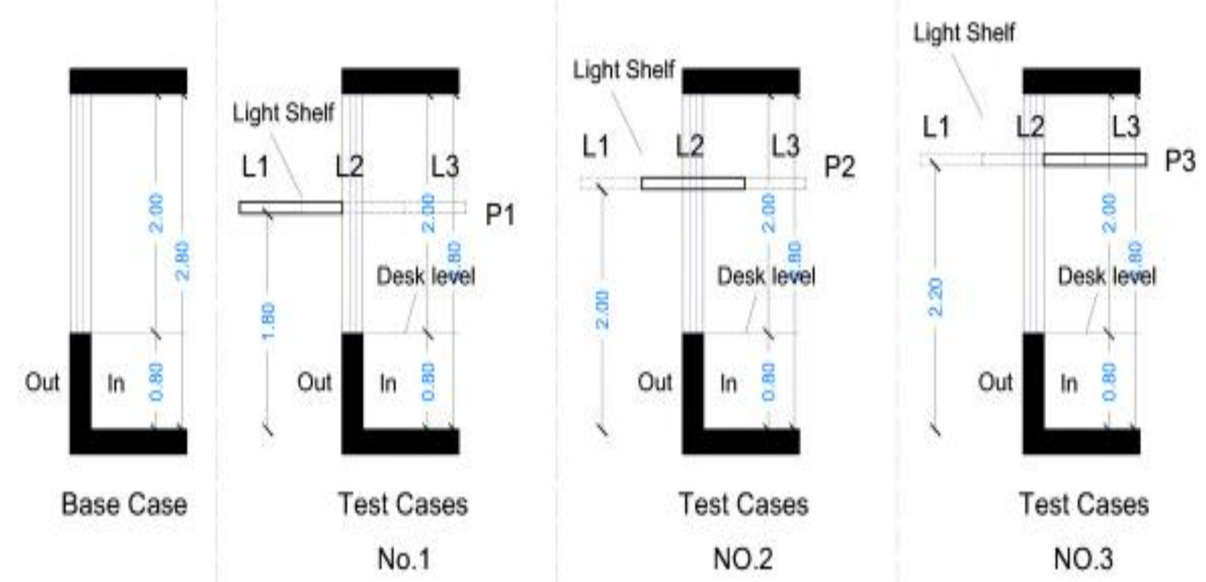

Figure 3: *Configuration of base case and 9 cases of light shelves design variables.*

Experimental Measurement Setup

The scaled model experiment method was used in this research to study the daylight penetration under real sky conditions. The experiment was carried out in a two (1:10) scaled-models of typical unit of Malaysian office spaces with one side-facing window which was located in turn toward four main orientations as illustrated in Fig. 1. The models were construction based on study Lim, Ahmad [25]. The models have same internal dimensions of 5.00 m width, by 8.00m depth, by 2.80 m height. The office unit model had a one sided-lit opening with dimensions 4.20m width by 2.20m height which resulted in a 40% window-to-wall ratio.

The first office unit model is a base case model without any LSSs on the side-lit window and was used as a reference to compare the performance of daylight

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distribution on the model with different combinations of light shelf configurations. The model was constructed with thin plywood. And all construction materials and interior surfaces (walls, floor, and ceiling) were painted white and had the same reflectance values in the two model spaces. The external envelope of the two models was painted black to block other sources of daylight apart from the single-sided external window.

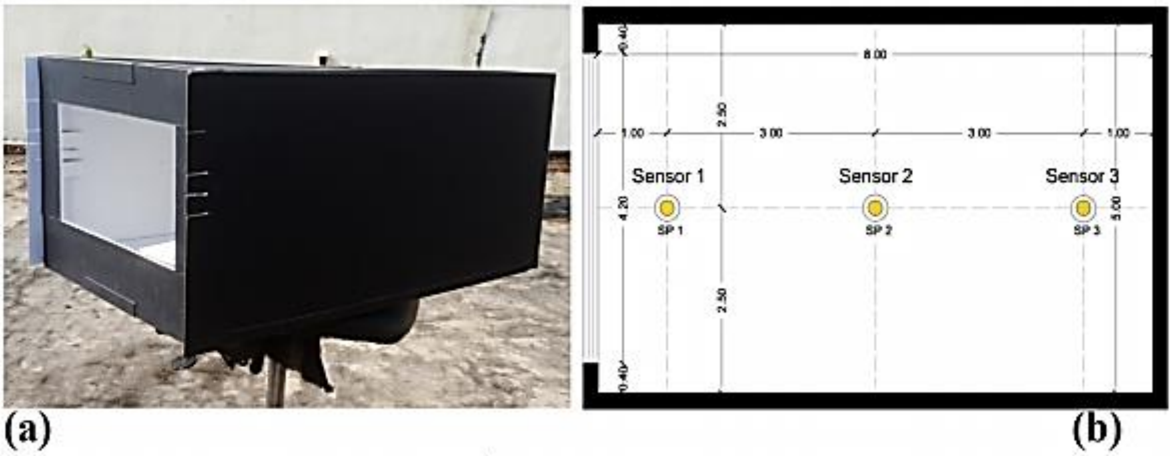

Figure 4: *Physical scaled model a) Perspective, and b) Layout of scaled-model.*

Table 2: *Experiments measurement details.*

Experimental Conditions	Place of Experimental	Type of Sky	Month of Measurements	Day	Orientation	Time	Intervals of Readings
Bright and sunny (real sky)	In an Open area on the top roof of main building of HBP school, USM	Intermediate sky	Jan Mar May	21st, 22nd 23rd	East South West North	9:00h 12:00h 15:00h 17:00h	5 min

Data Collection

Each physical scaled-model with three illuminance measurement points, namely, SP1, SP2, and SP3, was placed at the middle desk level in the reference and evaluated models. The position of these points inside each office model is illustrated in Figure 4(b). The measurements as presented in Table 2 were taken in during three months; January, March and May 2019, three days in very month 21st, 22nd, and 23rd and the average was taken at four period of time; 9:00h, 12:00h, 15:00h and 17:00h. With the scale model oriented in the four main directions, namely, East, South, West, and North respectively. Readings were taken with the light shelf with intervals of 5 min was used for every orientation. This selected period was presented by three Solar Solstice of Malaysian sky Model as shown in Figure 5, where, in the month of Jan., the sun is on the South Solstice the more directly on south orientation while, in the month of March the sun is on the equinoxes. As for the month of May, the sun is on the North Solstice the more directly on North orientation.

The measurements were conducted by using a lux meter data logger (TL-600 Digital Data Logging [accuracy reading ± 4% from 0 to 10.000 lux; ± 10 from 10.000 to 200.000 lux]). This data

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logger sensors were calibrated and validated against simulation using Radiance engine as explained in validation section below.

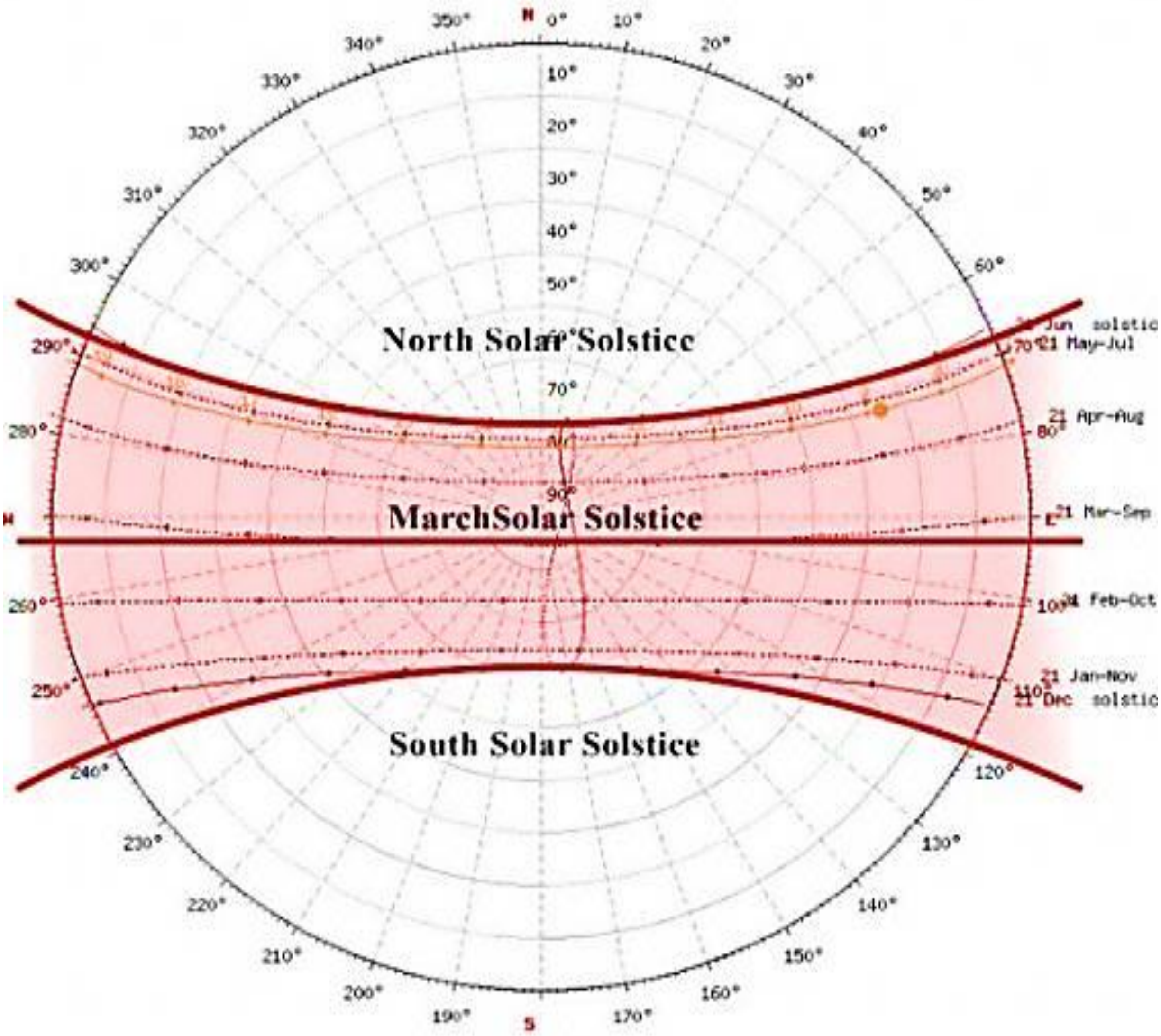

Figure 5: *Sun path diagram of Malaysian sky model.*

RESULTS AND DISCUSSION

Validation of Methodology to validate the scaled-model method under tropics sky, this study utilized Radiance daylight engine assessments to compare with the field scaled-model measurements outcomes as shown in Figure 6. Based on validation illuminance analysis of the scaled-model experimental and simulation, the external illuminance (Ei) was measured and compared to each other as shown in Figure 7, so as to have a better comprehension of the standard CIE sky and real tropical sky characteristics. Due to the huge variation between the external outdoor illuminance under tropical sky and CIE skies, previous researches [8, 23, 28, 37], pointed out that relative ratios be utilized for the tropical daylight assessments validation methods under tropics sky conditions.

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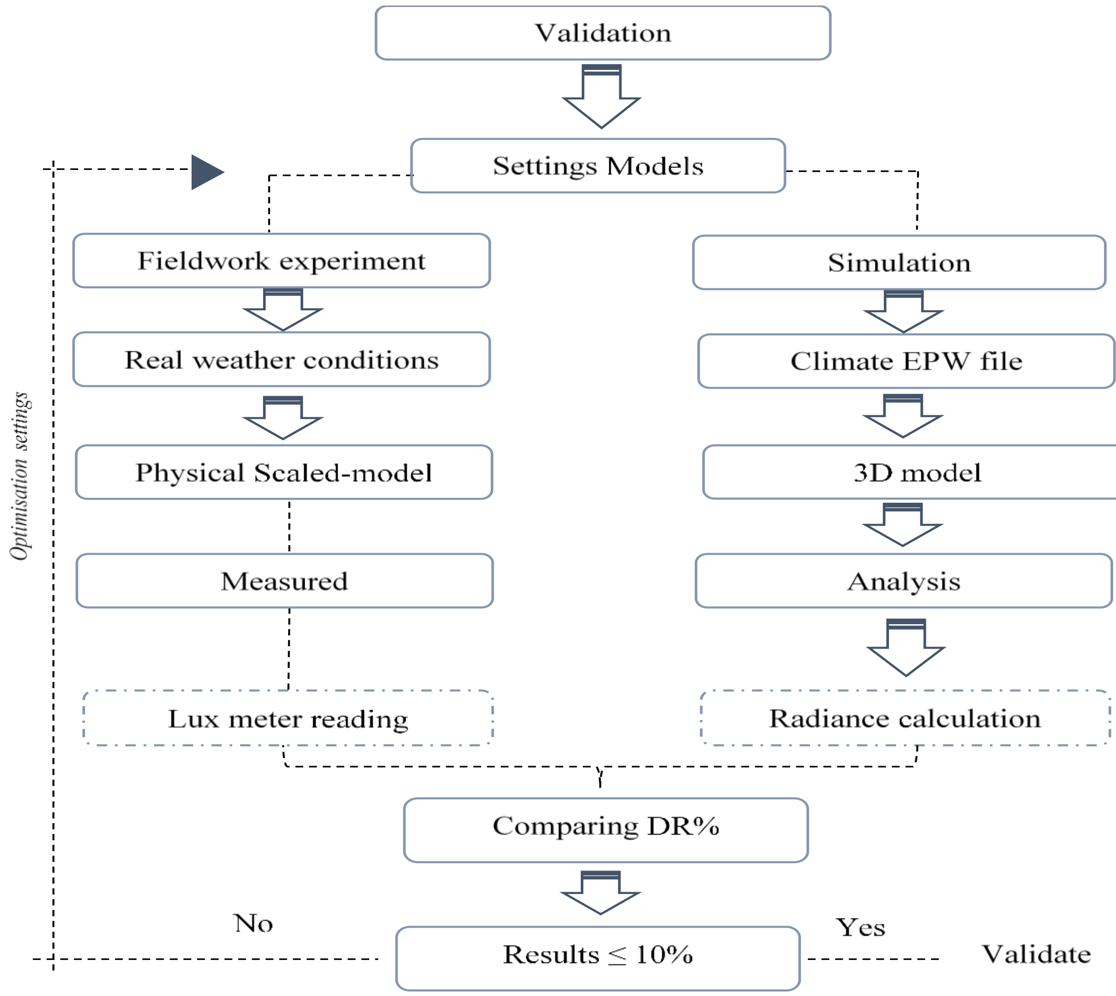


Figure 6: *Overall validation methodology used in this study.*

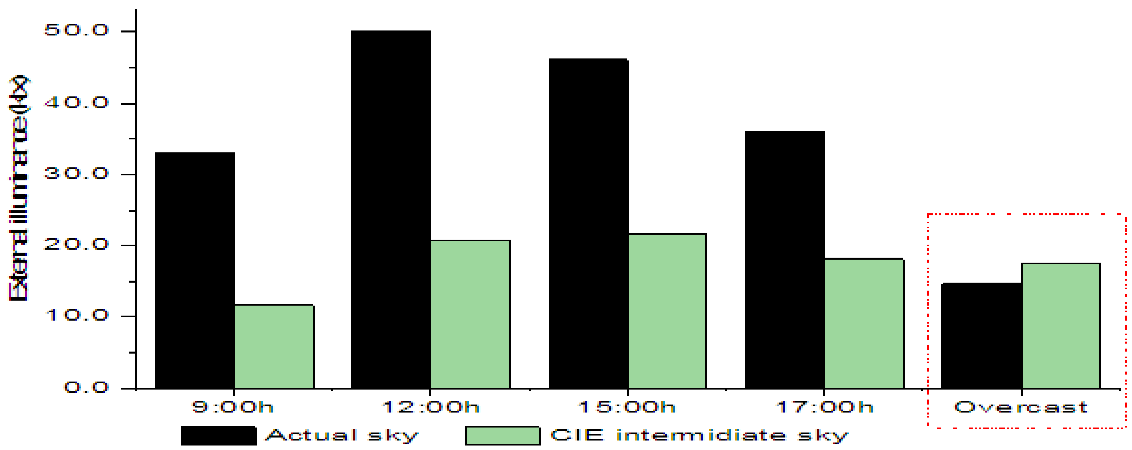


Figure 7: *External illuminance comparison of actual sky and CIE sky.*

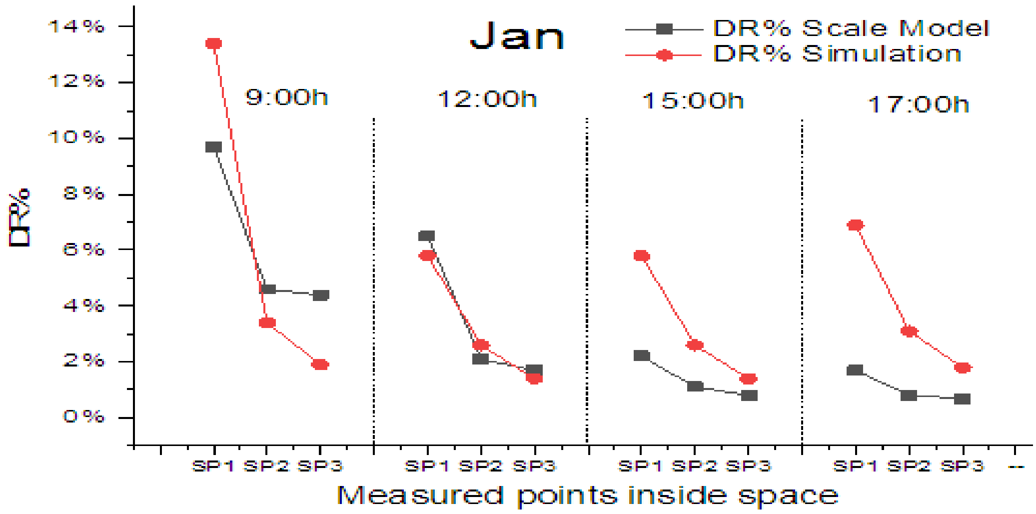
Concurrently, the internal illuminance of physical scaled-model and simulation model was measured and compared in points SP1, SP2 and SP3. The locations of the measurement points were exactly at the center of space at work plane height 0.80m (see Figure 4). Besides these points, physical scaled-model and simulation models were computed with performance indicator Daylight Ratio (DR) in tropics

skies. Many studies demonstrated that the use of DR calculation method which is more suitable for tropics regions using equation [23, 28, 38]:
DR% = (Indoor illuminance/Outdoor Illuminance) *100 (1) The dates and times selected for validation analyses were 21st Jan, 21 March and 21 May, at the same experiment time (9:00h, 12:00h, 15:00h and 17:00) with South orientation, these times indicate to the different solar angles of sun path throughout the day. As well as, these arrangements represented the intermediate sky with and without direct sunlight with three different solar solstices of Malaysian Model Year Climate, when the Sun is in south solstice, equinoxes and north solstices respectively.

A comparison was made by calculating the percentage of difference between the performance indicators DR in the physical scaled-model and simulation model were compared for various times in a day for south orientation and the results are presented in Figure 8.

Statistical analysis was employed to exam the relationship between prediction results from the physical scaled-model and simulation model using relative ratios of the performance indicators DR% was examined using Pearson correlation among the daylight ratio results are shown in Table 3.
Overall, the results showed the average DR% differences between simulation and scaled-model measurements are 1.2%, 1.8% and 1.3% (≤10%) [8, 35] on Jan, March and May respectively, which is an acceptable result, indicating the validity of the scaled model in terms of accuracy. In other words, the criteria used were reliable and acceptable for predicting internal illuminance. Therefore, the model is deemed valid and fit for further daylighting measurements.

The validation and correlation demonstrate the ability of scaled-model method to investigate daylighting for regions with constantly changing sky conditions such as Malaysian sky conditions. Therefore, it can be used confidently to perform further investigation to optimize the performance of the light-shelves. The following studies were conducted to examine the models of light shelves on three different Solar Solstice which were represents the Malaysian sky Model; South-Solstice (Jan), Middle Solstice/Equinoxes (March), and North Solstice (May) at four different times in a day; 9:00h, 12:00h, 15:00h and 17:00h to investigate how the systems work at different times of the day and year and the average of measurements were taken.



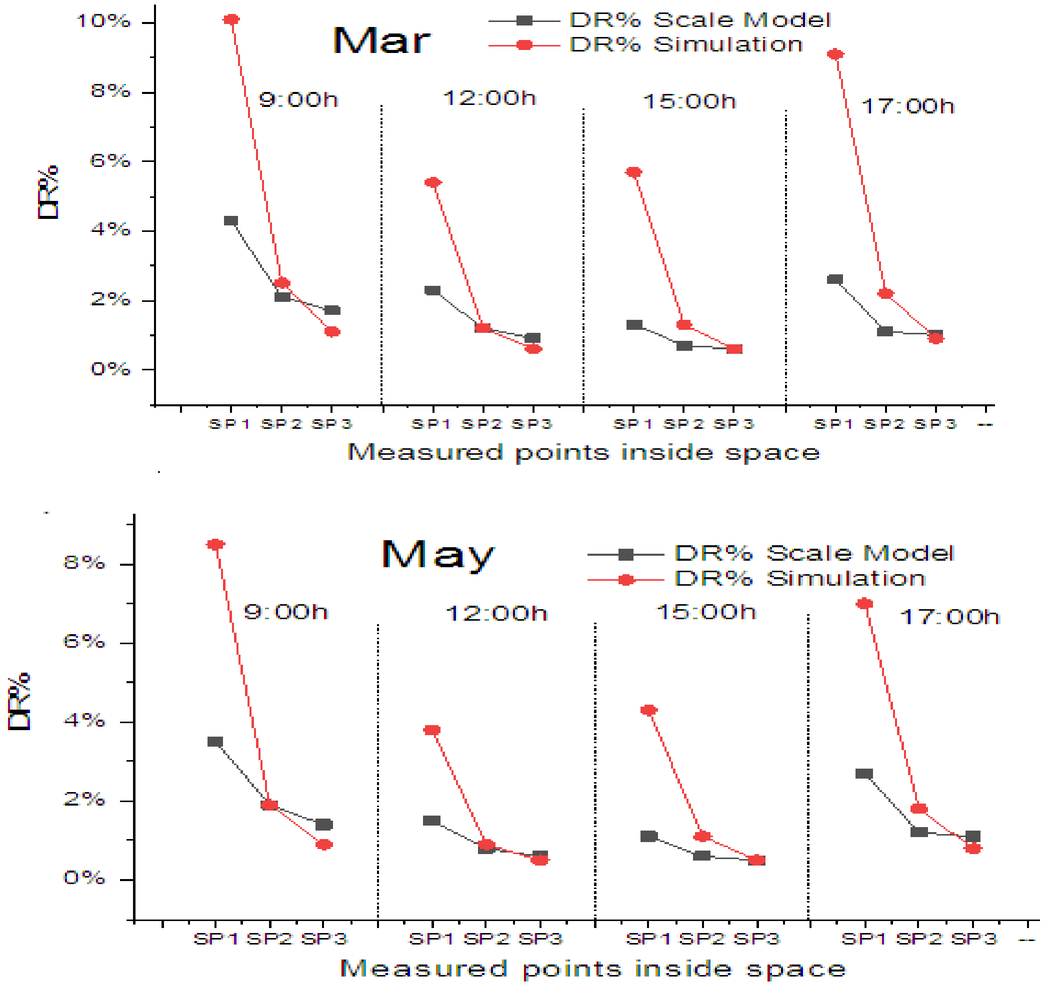


Figure 8: *Comparison between DR% in scaled- model and simulation.*

Table 3: *Statistical analysis of Pearson correlation analysis of base scale-model and base simulation model DR.*

Sky Condition	Sun Position	Pearson Correlation (R^2)				N
		9:00h	12:00h	15:00h	17:00h	
Actual tropics sky with direct sunlight (south)	South solstice	0.99*	0.98*	0.99*	0.98*	24
Actual tropics sky without direct sunlight (south)	Equinoxes	0.99*	0.99*	0.96*	0.99*	24
Actual tropics sky without direct sunlight (south)	North solstice	0.99*	0.99*	0.99*	0.99*	24
*****Correlation is significant at the 0.01 to 0.04 level (2-tailed).						

Fieldwork Experiment Measurements

The experiment was conducted on nine various cases of light shelf modifications (position and height) under the main orientations at three different times in a day. To achieve the research objective, an average increase in illuminance levels and Daylight Ratio (DR) is computed based on the measurement data for each combination of light shelves and window orientation. Daylight Ratio (DR), was used in this paper as a method to assess the daylight performance under intermediate skies. Because, In tropics sky conditions, it is very difficult to calculate Daylight Factor (DF) under real sky conditions as noted by other authors [28]. The performance of the varied light shelves configurations (locations and positions) were evaluated through the room at three defined SP1, SP2 and SP3 points with the criteria of daylight distribution, and comparisons with the East, West, South and North facing window were carried out. To examine the daylight performance of the LSSs system direct comparison of the value of calculated by sensors points and the results were compared to a reference-case.

The data analysis process conducted in this paper complied with LEED V4 daylighting requirement in which the three illumination evaluation levels for the floor area were used: ‘‘daylit”, ‘‘partially daylit” and ‘‘over-lit” areas. Where previous studies used LEED v4 daylighting as a design standard [39].

The illuminance level was set in this study between 300-500 lux, and daylight ratio range from 1% - 5% as a recommended levels of indoor illumination, The ‘‘Daylit” area achieves illuminance levels within the range of recommended levels, the ‘‘Overlit” area achieves illuminance greater than recommended levels and the ‘‘Partially lit” area achieves illuminance less than recommended levels.

As well as, the indoor daylight distribution analysis was divided into four orientations; North, South, East and West, where the light shelves for each period of time with the optimum and worst performance in illuminance performance (achieving the recommended minimum illuminance level and the highest improvement in daylight distribution) were chosen for comparison to the Base Case. For illuminance analysis, External illuminance (Ei), illuminance level and Daylight Ratio (DR) at points SP1, SP2, and SP3 in inside of room were measured.

Daylight Distribution Level
Calculations are performed on the exterior, middle, and interior positions of the light shelf at three heights, namely, 1.80, 2.00, and 2.20 m, by increasing the height to 20 cm from the floor level at three times from 9:00h., 12:00h, 15:00h and 17:00h. on Jan, Marc and May. For all cases, the light shelves improved the daylight distribution in the office room by minimizing the incoming sunlight near the window during daytime and maintaining or slightly maximizing it in the middle and back of spaces, for the East orientation at the period of time from 9:00h to 12:00h in all months, as for the South and North orientation only when the sun at South and North solstice, while at the West at the period of time from afternoon (12:00 h to 17:00 h) in all months.

LSSs Performance on East Orientation
Error! Reference source not found. illustrate how the light-shelves’ could change the daylighting performance regarding illuminance levels in the front and rear of the room in different times in a day and different solar solstices of Malaysian sky model. Based on minimized the illuminance density near the window and maximized at the rear areas of the space within the range of the recommended illuminance levels and DR%, the best illuminance distributions levels at 9:00h to 12:00h on all months, were obtained at the light shelf location L1 at position P1 and L1 at P2, while at time from 15:00h to 17:00h, the light shelf not worked well in all months. From the results achieved it can considered the optimal case of light shelf is at L1 at P1, where it gives the best results in reducing the illuminance level in the front (SP1) and increased it at the back of room (SP2 and SP3), but the illuminance level still is not within the range of recommended levels (see Error! Reference source not found and Error! Reference source not found.).

As also can noted that, light shelf at location L3 at all height positions did not work well regarding to the increased illuminance intensity at the middle and back of space (SP2, SP3), it can considered the worst cases of all light-shelves configurations.

At the period of time 9:00 am when the sun is at low altitude (Ei=29.6klux, 32.4klux and 23.9klux on January, March and May respectively), L1 at P1 managed the illuminance levels decreased by 15.3% (from 811 to 687 Lux) near the window at (SP1) and increased the illuminance by 5.9% (from 427 to 452 Lux) and by 5.6% (from 324 to 342 lux) respectively at the middle (SP2) and back (SP3) of the space in January. And it decreased by 15.3% (from 811 to 687 Lux) at (SP1) and increased the illuminance by 5.9% (from 427 to 452 Lux) and by 5.6% (from 324 to 342 lux) at (SP2) and (SP3) respectively on March. While on the month of May, L2 at P2 improved the illuminance performance, it managed the illuminance levels decreased by 20.2% (from 1884 to 1503 Lux) at (SP1) and increased the illuminance by 14.4% (from 1193 to 1365 Lux) and by 12.5% (from 939 to 1056 lux) at (SP2) and (SP3) respectively.

As for at the period of time 12:00 noon when the sun altitude was above the head and perpendicular to the building (Ei=45.5klux, 51.1klux and 48.3klux on January, March and May respectively), can considered L1 at P1 gives the best illuminance distributions levels for all months. It decreased illuminance levels by 4.5% (from 724 to 691 Lux) near the window at (SP1) and enhanced the illuminance by 22.1% (from 358 to 437 Lux) and by 19.1% (from 281 to 335 lux) respectively at the middle (SP2) and back (SP3) of the space in January. And it decreased by 2.6% (from 1185 to 1154 Lux) at (SP1) and increased the illuminance by 2.8% (from 601 to 618 Lux) and by 2.1% (from 469 to 459 lux) at (SP2) and (SP3) respectively on March. As for the month of May, it decreased by 2.9% (from 1532 to 1487 Lux) at (SP1) and increased the illuminance by 3.3% (from 1156 to 1195 Lux) and by 5.3% (from 886 to 933 lux) at (SP2) and (SP3) respectively.

Error! Reference source not found. Presented the daylight ratio were giving by with and without light shelves systems. DR was calculated for each set of variables selected in each case of light-shelves system at three points inside the space. DR is computed based on the measurement data for each combination of light shelf, hour and months on the East orientation, as shown in Error! Reference source not found which illustrate the effect of the change in light shelves' positions and heights on the daylighting performance in terms of illuminance levels in the office room.

In conclusion, for the east orientation the maximum illuminance occurred by Base Case at 9:00 h, while the minimum illuminance occurred at 17:00h. However, the illuminance levels at 9:00h to 12:00h is not within the recommended level was much higher than illuminance levels with light-shelves at all locations and positions. While the illuminance levels at 15:00 h is slightly increased than the recommended level at the front of space, while, at the middle and the back of space with and without light-shelf still is under or near the recommended level. Whereas, at the time 17:00h most of the space is not within recommended level of daylight.

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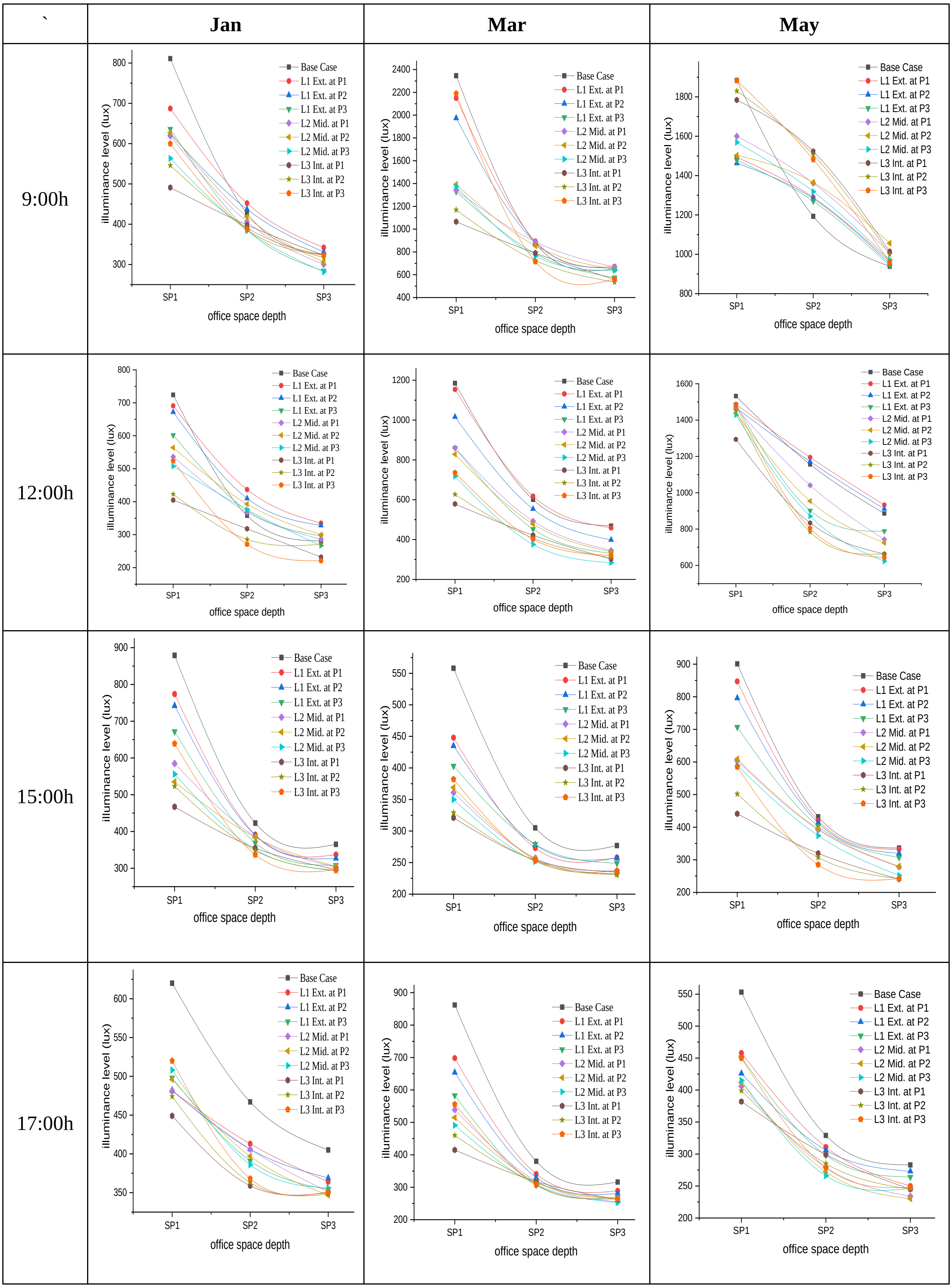

Figure 9: *Illuminance level computed by with and without light-shelf on East orientation.*

Table 4: *Daylight Ratio (DR%) in all measured points with and without LSSs for East orientation.*

	Model		9: 00 h			12:00 h			15:00 h			17:00 h		
			SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3
Jan	Base Case		2.7%	1.4%	1.1%	1.6%	0.8%	0.6%	1.9%	0.9%	0.8%	2.0%	1.5%	1.3%
	L1	P1	2.3%	2.1%	2.1%	1.5%	1.5%	1.3%	1.7%	1.6%	1.5%	1.6%	1.6%	1.6%
		P2	1.5%	1.5%	1.3%	1.0%	0.9%	0.8%	0.9%	0.9%	0.8%	1.4%	1.3%	1.3%
		P3	1.2%	1.1%	1.0%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	1.2%	1.2%	1.2%
	L2	P1	2.1%	2.1%	1.9%	1.2%	1.2%	1.1%	1.3%	1.2%	1.2%	1.6%	1.6%	1.7%
		P2	1.4%	1.4%	1.3%	0.8%	0.9%	0.8%	0.8%	0.8%	0.8%	1.3%	1.3%	1.3%
		P3	1.0%	1.0%	1.0%	0.6%	0.7%	0.6%	0.7%	0.7%	0.6%	1.2%	1.1%	1.2%
	L3	P1	1.7%	1.8%	2.0%	0.9%	0.9%	1.2%	1.0%	1.1%	1.4%	1.5%	1.6%	1.7%
		P2	1.3%	1.3%	1.3%	0.7%	0.6%	0.6%	0.8%	0.8%	0.7%	1.2%	1.2%	1.2%
		P3	1.1%	1.1%	1.1%	0.5%	0.6%	0.5%	0.7%	0.6%	0.6%	1.2%	1.1%	1.2%
Mar	Base Case		7.9%	5.0%	3.9%	2.3%	1.2%	0.9%	1.9%	0.9%	0.8%	2.6%	1.2%	1.0%
	L1	P1	6.2%	6.1%	6.2%	2.3%	2.0%	1.7%	1.7%	1.6%	1.5%	2.1%	2.0%	1.8%
		P2	5.4%	5.4%	5.3%	1.2%	1.1%	0.9%	0.9%	0.9%	0.8%	1.0%	1.0%	0.9%
		P3	4.0%	4.0%	3.9%	0.9%	0.8%	0.6%	0.7%	0.7%	0.7%	0.9%	0.9%	0.8%
	L2	P1	6.7%	6.3%	6.6%	1.7%	1.6%	1.4%	1.3%	1.2%	1.2%	1.6%	1.6%	1.5%
		P2	5.7%	5.7%	5.5%	1.0%	0.9%	0.7%	0.8%	0.8%	0.8%	1.0%	1.0%	0.9%
		P3	4.2%	4.4%	4.1%	0.7%	0.7%	0.6%	0.7%	0.7%	0.6%	0.8%	0.8%	0.8%
	L3	P1	7.5%	7.7%	7.9%	1.1%	1.2%	1.4%	1.0%	1.1%	1.4%	1.3%	1.4%	1.7%
		P2	6.4%	6.3%	6.2%	0.8%	0.8%	0.8%	0.8%	0.8%	0.7%	1.0%	1.0%	0.9%
		P3	4.2%	4.2%	4.0%	0.6%	0.6%	0.6%	0.7%	0.6%	0.6%	0.8%	0.8%	0.8%
May	Base Case		7.9%	5.0%	3.5%	3.2%	2.4%	1.8%	2.0%	1.0%	0.7%	2.2%	1.3%	1.1%
	L1	P1	6.2%	6.1%	6.2%	3.1%	3.0%	3.1%	1.9%	1.8%	1.6%	1.8%	1.7%	1.8%
		P2	5.4%	5.4%	5.3%	2.5%	2.4%	1.9%	0.9%	0.9%	0.9%	1.2%	1.2%	1.2%
		P3	4.0%	4.0%	3.9%	1.9%	1.9%	1.6%	0.7%	0.7%	0.7%	1.0%	1.1%	1.0%
	L2	P1	6.7%	6.3%	6.6%	3.0%	3.0%	3.0%	1.3%	1.4%	1.3%	1.6%	1.6%	1.6%
		P2	5.7%	5.7%	5.5%	2.2%	2.0%	1.8%	0.9%	0.9%	0.8%	1.1%	1.1%	1.0%
		P3	4.2%	4.4%	4.1%	1.5%	1.5%	1.3%	0.6%	0.6%	0.6%	0.9%	0.9%	1.0%
	L3	P1	7.5%	7.7%	7.9%	2.7%	3.0%	3.1%	1.0%	1.1%	1.3%	1.5%	1.6%	1.8%
		P2	6.4%	6.3%	6.2%	1.7%	1.6%	1.7%	0.7%	0.7%	0.6%	1.2%	1.1%	1.1%
		P3	4.2%	4.2%	4.0%	1.4%	1.4%	1.3%	0.5%	0.5%	0.5%	1.0%	1.0%	1.0%

Over-lit areas; partially daylight areas (DR recommended rangeT: 1%-5%)

LSSs Performance on South Orientation

The most critical illumination condition for south-facing orientation when the sun on South Solstice (January). When the sun is at low altitude at 9:00 h with (Ei= 31.1klux). For each of the nine light-shelves configurations comparing to the Base Case model, based on decreased and increased illuminance levels at in front and back of space, the best illuminance distributions levels on January at 9:00am were obtained when the L2 at P1, it can considered that the optimal case of light shelf as shown in fig, where it gives the best results in reducing the illuminance level in the front (SP1) and increased it at the back of room (SP2 and SP3) but the illuminance level still is not within the range of recommended levels. As well as can noted that on the months March and May, the light shelf not worked well under diffuse sunlight at this period of time. It decreased illuminance levels by 54.6% (from 3020 to 1370 Lux) near the window at (SP1) and enhanced the illuminance by 4.5% (from 1434 to 1498 Lux) and by 4.2% (from 1363 to 1420 lux) respectively at the middle (SP2) and back (SP3) of the space.

As for at the period of time 12:00 noon when the sun altitude was above the head and perpendicular to the building (Ei=49.9klux on January and 52.1klux on March), L2 at P1 gives the best illuminance distributions levels. It decreased illuminance levels by 19.4% (from 4230 to 3410Lux) near the window at (SP1) and enhanced the illuminance by 12.2% (from 1051 to 1180Lux) and by

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4.7% (from 825 to 864 lux) respectively at the middle (SP2) and back (SP3) of the space on January. While as, L1 at P1 and L1 at P2 managed to slightly decreased illuminance levels by 0.01% (from 1185 to 1154 Lux) at (SP1) and slightly increased the illuminance by 0.09% and by 0.07% at (SP2) and (SP3) respectively on March.

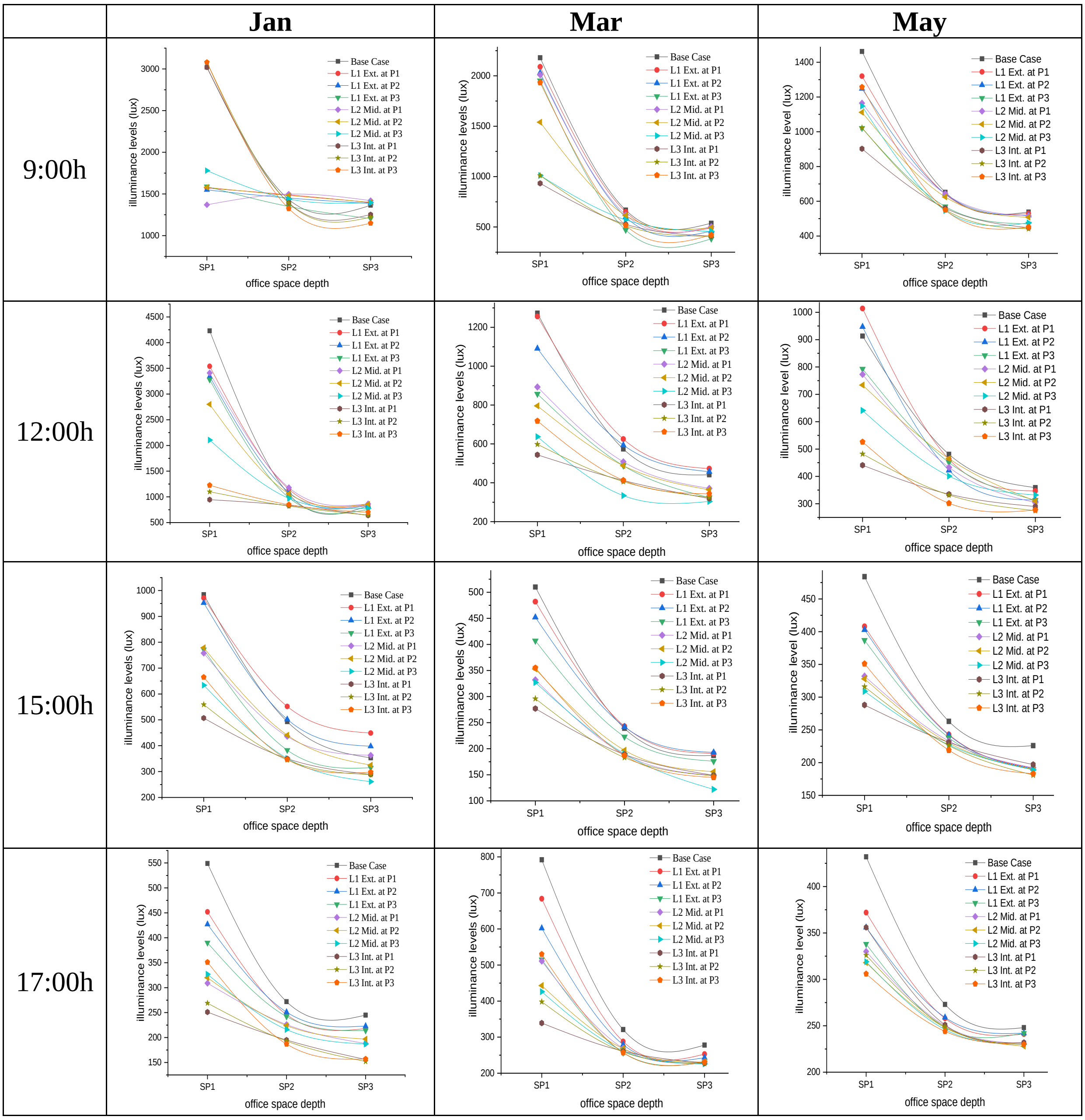

***Figure 10:** Illuminance level computed by with and without light-shelf on south orientation.*

At time 15:00h. with (Ei=43.8klux on January and 44.6klux on March), L1 at P1 managed to slightly decreased illuminance levels at (SP1) and slightly increased the illuminance at the middle (SP2) and back (SP3). As for at the period of time 17:00h, there is no improved effects of light-shelves can be noted on the illuminance levels inside the room.

From the Error! Reference source not found., it can also note that Light shelf at location L3 at height positions P2 and P3 did not work well regarding to the

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increased illuminance intensity at the middle and back of space (SP2, SP3), it can consider the worst cases of all light-shelves configurations. Error! Reference source not found. presented the DR calculated for each set of variables selected in each case of light-shelves system at three points inside the space.
In concluded, for the south orientation the maximum illuminance occurred when the sun at south solstice on January, the illuminance levels at 9:00h to 12:00h is not within the recommended level was much higher with and without light-shelves at all locations and positions. While the illuminance levels at 15:00h is slightly increased than the recommended level at the front of space, while, at the middle and the back of space with and without light-shelf still is under or near the recommended level. Whereas, at the time 17:00h most of the space is not within recommended level of daylight for all months

***Table 5:** Daylight Ratio (DR%) in all measured points with and without LSSs for South orientation.*

	Model		9: 00 h			12:00 h			15:00 h			17:00 h		
			SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3
Jan	Base Case		9.7%	4.6%	4.4%	8.5%	2.1%	1.7%	2.2%	1.1%	0.8%	1.7%	0.8%	0.7%
	L1	P1	5.0%	5.0%	5.1%	7.1%	6.7%	6.6%	2.2%	2.2%	1.8%	1.4%	1.3%	1.2%
		P2	4.8%	4.7%	4.3%	2.3%	2.2%	2.0%	1.3%	1.1%	0.9%	0.7%	0.8%	0.7%
		P3	4.5%	4.5%	3.9%	1.7%	1.7%	1.5%	1.0%	0.9%	0.7%	0.7%	0.7%	0.6%
	L2	P1	4.4%	5.1%	5.7%	6.8%	5.6%	4.2%	1.7%	1.8%	1.4%	0.9%	1.0%	1.0%
		P2	4.8%	4.8%	4.6%	2.4%	2.1%	1.9%	1.0%	1.0%	0.8%	0.7%	0.7%	0.7%
		P3	4.6%	4.5%	4.5%	1.7%	1.7%	1.6%	0.8%	0.7%	0.6%	0.6%	0.6%	0.6%
	L3	P1	9.7%	9.9%	9.9%	1.9%	2.2%	2.5%	1.2%	1.3%	1.5%	0.8%	0.8%	1.1%
		P2	4.5%	4.5%	4.3%	1.7%	1.6%	1.7%	0.8%	0.8%	0.8%	0.6%	0.6%	0.6%
		P3	4.0%	3.9%	3.7%	1.3%	1.3%	1.4%	0.7%	0.7%	0.7%	0.5%	0.5%	0.5%
Mar	Base Case		6.7%	2.1%	1.7%	2.4%	1.1%	0.8%	1.1%	0.5%	0.4%	2.4%	1.0%	0.8%
	L1	P1	6.5%	6.3%	6.0%	2.4%	2.1%	1.6%	1.1%	1.0%	0.9%	2.1%	1.8%	1.6%
		P2	2.0%	1.8%	1.5%	1.2%	1.1%	0.9%	0.5%	0.5%	0.5%	0.9%	0.8%	0.8%
		P3	1.5%	1.4%	1.2%	0.9%	0.9%	0.6%	0.4%	0.4%	0.4%	0.8%	0.7%	0.7%
	L2	P1	6.2%	4.8%	3.1%	1.7%	1.5%	1.2%	0.7%	0.8%	0.7%	1.5%	1.3%	1.3%
		P2	1.9%	1.9%	1.8%	1.0%	0.9%	0.6%	0.4%	0.4%	0.4%	0.8%	0.8%	0.8%
		P3	1.6%	1.5%	1.4%	0.7%	0.7%	0.6%	0.3%	0.3%	0.3%	0.7%	0.7%	0.7%
	L3	P1	2.9%	3.1%	6.0%	1.0%	1.1%	1.4%	0.6%	0.7%	0.8%	1.0%	1.2%	1.6%
		P2	1.6%	1.6%	1.6%	0.8%	0.8%	0.8%	0.4%	0.4%	0.4%	0.8%	0.8%	0.8%
		P3	1.3%	1.3%	1.3%	0.6%	0.6%	0.7%	0.3%	0.3%	0.3%	0.7%	0.7%	0.7%
May	Base Case		4.7%	2.1%	1.7%	1.6%	0.8%	0.6%	1.1%	0.6%	0.5%	1.7%	1.1%	1.0%
	L1	P1	4.2%	4.0%	3.3%	1.8%	1.7%	1.4%	0.9%	0.9%	0.9%	1.4%	1.4%	1.3%
		P2	2.1%	2.1%	1.8%	0.8%	0.7%	0.8%	0.6%	0.6%	0.6%	1.0%	1.0%	1.0%
		P3	1.7%	1.7%	1.5%	0.6%	0.6%	0.6%	0.4%	0.4%	0.4%	0.9%	0.9%	0.9%
	L2	P1	3.7%	3.6%	3.7%	1.4%	1.3%	1.1%	0.8%	0.8%	0.7%	1.3%	1.2%	1.2%
		P2	2.1%	2.0%	1.8%	0.8%	0.8%	0.7%	0.5%	0.5%	0.5%	1.0%	1.0%	1.0%
		P3	1.7%	1.6%	1.5%	0.5%	0.5%	0.6%	0.4%	0.4%	0.4%	0.9%	0.9%	0.9%
	L3	P1	2.9%	3.3%	4.0%	0.8%	0.8%	0.9%	0.7%	0.7%	0.8%	1.4%	1.3%	1.2%
		P2	1.8%	1.8%	1.8%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	1.0%	1.0%	0.9%
		P3	1.4%	1.4%	1.4%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.9%	0.9%	0.9%
Over-lit areas; partially daylit areas (DR recommended range: 1%-5%)														

LSSs Performance on West Orientation
From Error! Reference source not found., it can noted that the effects of light-shelves on illuminance distribution at the rear areas of the space begin when the sun exceed the middle of the day from time 15:00 to 17:00pm, whereas, the period of time from 9:00am to 112:00 noon, the light-shelves not worked well in all months. For all cases of light shelves under investigation. The best illuminance distributions levels at 15:00 to 17:00 pm all months were obtained at the light shelf location L1 at position P1 and L1 at P2,

whereas L3 at p3 can consider the worst cases of all light-shelves configuration. The optimal case of light shelf is at L1 at P1, where it gives the best results in reducing the illuminance level in the front and increased it at the back of space, nevertheless, the illuminance level near the window still is not within the range of recommended levels, while at the middle and back of the space still is under or near the recommended level (Error! Reference source not found. and Error! Reference source not found.).

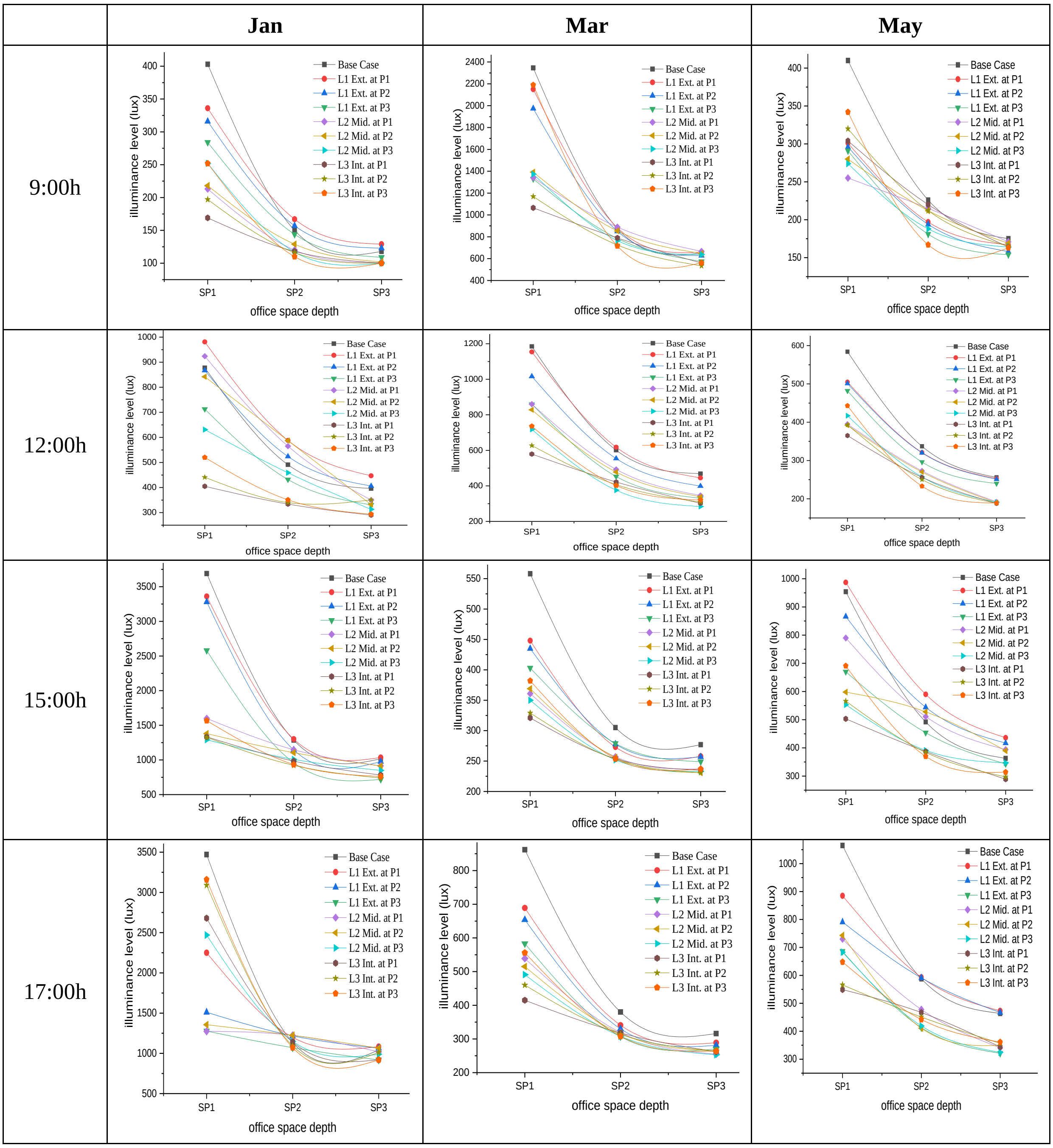

***Figure 11:** Illuminance level computed by with and without light-shelf on west orientation.*

At time 15:00h with (Ei=43.4klux, 45.1klux and 52.7klux on January, March and May respectively), L1 at P1 managed to slightly decreased illuminance levels by 8.9% (from 3690 to 3360Lux) near the window at (SP1) and enhanced the illuminance by 1.6% (from 1286 to 1301Lux) and by 1.9% (from 1016 to 1036 lux) respectively at the middle (SP2) and back (SP3) of the space on January, and it decreased illuminance levels by 19.7% (from 558 to 448Lux) at (SP1) and enhanced the illuminance by 5.3% (from 305 to 321Lux) and by 3.9% (from 277 to 288lux) at (SP2) and (SP3) on March. As for month of May, it decreased illuminance levels by 3.5% (from 954 to 987Lux) at (SP1) and enhanced the illuminance by 19.9% (from 492 to 590Lux) and by 20.1% (from 363 to 436 lux) at (SP2) (SP3). As time 17:00 pm, L1 at P1 managed to slightly decreased illuminance levels at (SP1) and slightly increased the illuminance at the middle (SP2) and back (SP3).

***Table 6:** Daylight Ratio (DR%) in all measured points with and without LSSs for West orientation.*

	Model		9: 00 h			12:00 h			15:00 h			17:00 h		
			SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3
Jan	Base Case		1.3%	0.5%	0.4%	1.6%	0.9%	0.7%	8.5%	3.0%	2.3%	10.3%	3.4%	3.%
	L1	P1	1.1%	1.0%	0.9%	1.8%	1.6%	1.3%	7.7%	7.6%	5.9%	6.7%	4.5%	3.8%
		P2	0.5%	0.5%	0.5%	0.9%	0.9%	0.8%	3.0%	2.6%	2.2%	3.6%	3.6%	3.2%
		P3	0.3%	0.3%	0.3%	0.7%	0.7%	0.6%	2.4%	2.2%	1.7%	3.2%	3.2%	2.7%
	L2	P1	0.7%	0.7%	0.8%	1.7%	1.6%	1.2%	3.7%	3.2%	3.0%	3.8%	4.0%	7.4%
		P2	0.4%	0.4%	0.4%	1.1%	1.1%	0.9%	2.6%	2.5%	2.3%	3.6%	3.6%	3.4%
		P3	0.3%	0.3%	0.3%	0.7%	0.6%	0.6%	2.1%	2.1%	2.0%	3.0%	3.2%	2.9%
	L3	P1	0.5%	0.6%	0.8%	0.8%	0.8%	1.0%	3.1%	3.1%	3.6%	8.0%	9.2%	9.4%
		P2	0.4%	0.4%	0.3%	0.6%	0.6%	0.7%	2.3%	2.1%	2.2%	3.4%	3.3%	3.2%
		P3	0.3%	0.3%	0.3%	0.5%	0.7%	0.5%	1.8%	1.7%	1.8%	2.7%	3.0%	2.7%
Mar	Base Case		7.2%	2.7%	2.0%	2.3%	1.2%	0.9%	1.2%	0.7%	0.6%	2.6%	1.2%	1.0%
	L1	P1	6.6%	6.1%	4.1%	2.3%	2.0%	1.7%	1.0%	1.0%	0.9%	2.1%	2.0%	1.8%
		P2	2.5%	2.6%	2.4%	1.2%	1.1%	0.9%	0.7%	0.6%	0.6%	1.3%	1.3%	0.9%
		P3	1.9%	1.9%	1.8%	0.9%	0.8%	0.6%	0.6%	0.6%	0.6%	1.5%	1.4%	0.8%
	L2	P1	4.1%	4.3%	4.2%	1.7%	1.6%	1.4%	0.8%	0.8%	0.8%	1.6%	1.6%	1.5%
		P2	2.7%	2.6%	2.4%	1.0%	0.9%	0.7%	0.6%	0.6%	0.6%	1.0%	1.0%	0.9%
		P3	2.1%	2.0%	2.0%	0.7%	0.7%	0.6%	0.5%	0.5%	0.5%	0.8%	0.8%	0.8%
	L3	P1	3.3%	3.6%	6.8%	1.1%	1.2%	1.4%	0.7%	0.7%	0.8%	1.3%	1.4%	1.7%
		P2	2.4%	2.2%	2.2%	0.8%	0.8%	0.8%	0.6%	0.6%	0.6%	1.0%	1.0%	0.9%
		P3	1.7%	1.6%	1.7%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.8%	0.8%	0.8%
May	Base Case		1.5%	0.8%	0.6%	1.1%	0.6%	0.5%	1.8%	0.9%	0.7%	3.6%	2.0%	1.6%
	L1	P1	1.1%	1.1%	1.1%	1.0%	1.0%	0.9%	1.9%	1.6%	1.3%	3.0%	2.7%	2.3%
		P2	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	1.1%	1.0%	0.9%	2.0%	2.0%	1.4%
		P3	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.8%	0.8%	0.7%	1.6%	1.6%	1.1%
	L2	P1	0.9%	1.0%	1.0%	0.8%	0.8%	0.8%	1.5%	1.1%	1.0%	2.5%	2.5%	2.3%
		P2	0.8%	0.8%	0.7%	0.5%	0.5%	0.5%	1.0%	1.0%	0.7%	1.6%	1.4%	1.4%
		P3	0.6%	0.6%	0.6%	0.4%	0.4%	0.4%	0.7%	0.7%	0.7%	1.2%	1.2%	1.1%
	L3	P1	1.1%	1.2%	1.2%	0.7%	0.8%	0.9%	1.0%	1.1%	1.3%	1.9%	1.9%	2.2%
		P2	0.8%	0.8%	0.6%	0.5%	0.5%	0.4%	0.7%	0.7%	0.7%	1.6%	1.5%	1.5%
		P3	0.6%	0.6%	0.6%	0.4%	0.4%	0.4%	0.5%	0.6%	0.6%	1.2%	1.2%	1.2%

Over-lit areas   partially daylit areas   (DR recommended range: 1%-5%)

Error! Reference source not found. Presented the DR calculated. In concluded, for the West orientation the maximum illuminance occurred when the sun at time from 15:00h to 17:00h, the illuminance levels at 9:00am to 12:00noon is not within the recommended level was much lower than illuminance levels with and without light-shelves at all locations and positions at the back of the space. While the illuminance levels at time from 15:00h to 17:00h is slightly increased than the recommended level at the front of space, while, at the middle and the back of space with and without light-shelf still is under or near the recommended levels.

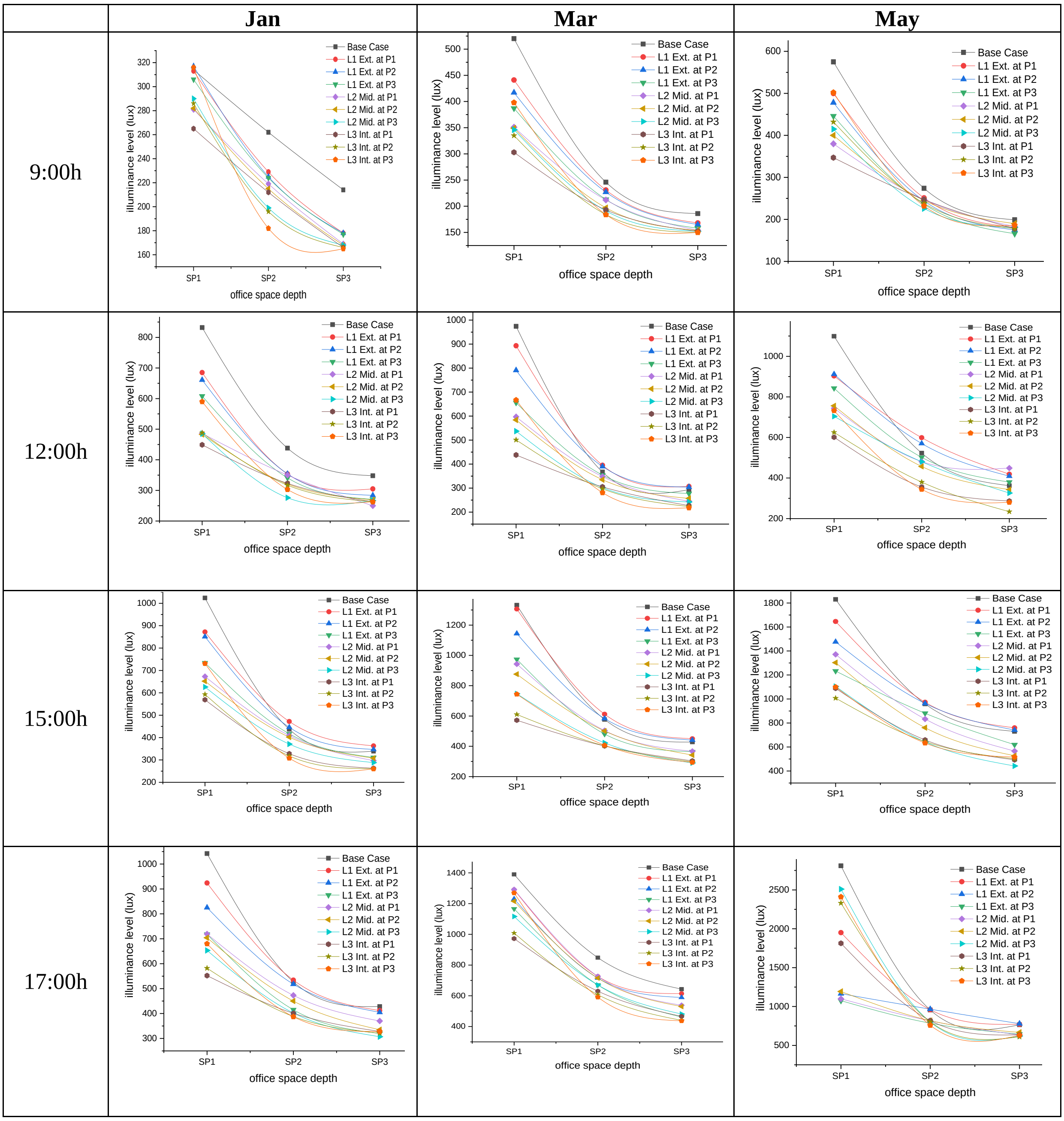

***Figure 12:** Illuminance level computed by with and without light-shelf on north orientation.*

LSSs Performance on North Orientation

For north-facing orientation, the most critical illumination condition when the sun on North Solstice (May). However, as shown in Error! Reference source not found., for each of the nine light-shelves configurations comparing to the Base Case model, based on decreased and increased illuminance levels at in front and back of space, the best illuminance distributions levels on all months at the period from 12:00noon to 17:00pm were obtained when the L1 at P1, it can considered that the optimal case of light shelf, where it gives the best results in reducing the illuminance level in the front (SP1) and increased it at the back of room (SP2 and SP3). While on the morning at 9:00h, the all light-shelves configuration not working good for enhanced illumination levels at the back areas of space. Nevertheless, the illuminance level near the window still is

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over the range of recommended levels, while at the middle and back of the space still is under or near the recommended level (see Error! Reference source not found. and Error! Reference source not found.).

Table 7: *Daylight Ratio (DR%) in all measured points with and without LSSs for north orientation.*

	Model		9: 00 h			12:00 h			15:00 h			17:00 h		
			SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3	SP1	SP2	SP3
Jan	Base Case		0.9%	0.8%	0.6%	1.6%	0.8%	0.7%	2.4%	1.0%	0.8%	3.4%	1.7%	1.4%
	L1	P1	0.9%	0.9%	0.9%	1.3%	1.3%	1.2%	2.1%	2.0%	1.7%	3.0%	2.7%	2.3%
		P2	0.7%	0.7%	0.6%	0.7%	0.7%	0.7%	1.1%	1.0%	1.0%	1.7%	1.7%	1.3%
		P3	0.5%	0.5%	0.5%	0.6%	0.5%	0.5%	0.9%	0.8%	0.7%	1.3%	1.3%	1.0%
	L2	P1	0.8%	0.8%	0.8%	0.9%	0.9%	0.9%	1.6%	1.5%	1.5%	2.3%	2.3%	2.1%
		P2	0.6%	0.6%	0.6%	0.7%	0.6%	0.5%	1.0%	0.9%	0.9%	1.5%	1.5%	1.3%
		P3	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.7%	0.7%	0.7%	1.2%	1.1%	1.0%
	L3	P1	0.8%	0.8%	0.9%	0.9%	0.9%	1.1%	1.3%	1.4%	1.7%	1.8%	1.9%	2.2%
		P2	0.6%	0.6%	0.5%	0.6%	0.6%	0.6%	0.8%	0.7%	0.7%	1.3%	1.3%	1.3%
		P3	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%	1.1%	1.0%	1.1%
Mar	Base Case		1.5%	0.7%	0.5%	1.9%	0.7%	0.6%	2.7%	1.2%	0.9%	4.2%	2.6%	2.0%
	L1	P1	1.3%	1.2%	1.1%	1.7%	1.5%	1.3%	2.7%	2.4%	2.0%	3.9%	3.7%	3.5%
		P2	0.7%	0.7%	0.6%	0.8%	0.8%	0.7%	1.3%	1.2%	1.0%	2.2%	2.2%	2.0%
		P3	0.5%	0.5%	0.5%	0.6%	0.6%	0.5%	0.9%	0.9%	0.8%	1.9%	1.8%	1.4%
	L2	P1	1.0%	1.0%	1.0%	1.2%	1.1%	1.0%	1.9%	1.8%	1.5%	3.9%	3.7%	3.4%
		P2	0.6%	0.6%	0.6%	0.7%	0.7%	0.6%	1.0%	1.0%	0.9%	2.2%	2.2%	2.0%
		P3	0.5%	0.5%	0.4%	0.5%	0.5%	0.5%	0.8%	0.7%	0.6%	1.6%	1.6%	1.5%
	L3	P1	0.9%	1.0%	1.2%	0.9%	1.0%	1.3%	1.2%	1.3%	1.5%	3.0%	3.1%	3.9%
		P2	0.6%	0.5%	0.5%	0.6%	0.6%	0.5%	0.8%	0.8%	0.8%	1.9%	1.8%	1.8%
		P3	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.6%	0.6%	0.6%	1.4%	1.3%	1.3%
May	Base Case		2.4%	1.1%	0.8%	2.1%	1.0%	0.7%	3.5%	1.8%	1.4%	9.5%	3.2%	2.6%
	L1	P1	2.1%	2.0%	1.9%	1.8%	1.8%	1.6%	3.1%	2.8%	2.3%	6.6%	3.9%	3.6%
		P2	1.0%	1.0%	1.0%	1.2%	1.1%	1.0%	1.9%	1.8%	1.7%	3.2%	3.3%	2.7%
		P3	0.8%	0.7%	0.7%	0.8%	0.8%	0.7%	1.4%	1.4%	1.2%	2.6%	2.6%	2.2%
	L2	P1	1.6%	1.7%	1.7%	1.4%	1.5%	1.4%	2.6%	2.5%	2.1%	3.7%	4.0%	8.5%
		P2	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	1.6%	1.4%	1.2%	2.8%	2.8%	2.7%
		P3	0.8%	0.8%	0.8%	0.9%	0.7%	0.6%	1.1%	1.0%	0.8%	2.1%	2.3%	2.1%
	L3	P1	1.4%	1.8%	2.1%	1.2%	1.2%	1.4%	2.1%	1.9%	2.1%	6.1%	7.9%	8.1%
		P2	1.0%	1.0%	1.0%	0.7%	0.7%	0.7%	1.3%	1.2%	1.2%	2.8%	2.7%	2.6%
		P3	0.7%	0.7%	0.8%	0.6%	0.5%	0.5%	0.9%	1.0%	1.0%	2.1%	2.1%	2.1%

Over-lit areas   partially daylit areas   (DR recommended range: 1%-5%)

As for at the time 12:00h (Ei=51.2klux on March and 51.4klux on May), L1 at P1 decreased illuminance levels by 8.3% near the window at (SP1) and enhanced the illuminance by 7.6% and by 4.8% respectively at the middle (SP2) and back (SP3) of the space on March. While as, managed to decreased illuminance levels by 17.8% at (SP1) and increased the illuminance by 14.5% and by 15.7% at (SP2) and (SP3) respectively on May. While on the month of January, light-shelves not worked well at this specific time.

For the time 15:00 pm with (Ei=42.5klux on January, 48.5klux on March and 52.5klux on May), L1 at P1 decreased illuminance levels by 14.8% near the window at (SP1) and enhanced the illuminance by 8.0% and by 7.1% respectively at the middle (SP2) and back (SP3) of the space on January. On March, it decreased illuminance levels by 1.9% near the window at (SP1) and enhanced the illuminance by 6.1% and by 5.1% respectively at the middle (SP2) and back (SP3). While as, it managed to decreased illuminance levels by 10.1% at (SP1) and increased the illuminance by 1.5% and by 4.1% at (SP2) and (SP3) respectively on May.

As for the time 17:00 pm with (Ei=29.6klux on May), L1 at P1 decreased illuminance levels by 30.6% near the window at (SP1) and slightly enhanced the illuminance by 0.3% and by 0.8% respectively at the middle (SP2) and back (SP3) of the space on May. While on the month of January and March, light-shelves not worked well at this specific time.

Error! Reference source not found. Presented the DR calculated for each set of variables selected in each case of light-shelves system at three points inside the space. In concluded, for the north orientation the maximum illuminance occurred when the sun at time from 15:00pm to 17:00pm. whereas, the illuminance levels at 9:00am to 12:00noon most of the areas of inside space is not within the recommended level, it was much lower than illuminance levels with and without light-shelves at all locations and positions at the back of the space. While the illuminance levels at time from 15:00pm to 17:00pm is increased than the recommended level at the front of space and at the middle and the back of space with and without light-shelf especially when the sun at north solstice in the month of May.

CONCLUSION

Results for the light shelf and its effects on daylighting performance are obtained through experiments. In general, the results showed the potential of several light shelf configurations for a building in Malaysia to improve the daylight in the back areas of a space and their limitations in improving daylight. The results indicated that external daylight availability in tropical sky varies remarkably throughout the day and affects the performance of the shelves considerably.

The only disadvantage of the use of light shelves as a daylight system is that the static design of light shelves occasionally caused low levels of daylight distribution in the back areas of interior spaces with the change in the sun's angle in the same orientation and over-lighting near the window, which contributes to glare due to excess brightness and highly non-uniform distribution. This paper demonstrates that simple modification of the location and positioning of light-shelf device could provide significant improvement in the indoor daylight quantity and quality. However, dynamic light-shelf device was necessary to control the direct sunlight patches to avoid glare problem.

This study determined the optimum design (position and height) of a light shelf on the glazing of an office building with all orientations in Malaysia to achieve optimal daylighting distribution at the back of spaces. Future studies should evaluate the different parameters (width, materials of light shelf, and angle) of a light shelf and the distance between the surface and the light shelf on the basis of the conclusions of this study. Furthermore, the possible energy reduction with the use of LSS integrated with a glazing façade should be assessed to improve daylighting.

Overall, some conclusions that can be drawn from this study include:

- It has been found that there is an agreement (Pearson Correlation is significant at the 0.01 to 0.04 level) between the scaled-model and the simulated results from the Radiance daylight engine under the Malaysia climate, and the average DR% differences between simulation and scaled-model at different solar solstices of Malaysian sky model were 1.2%, 1.8% and 1.3% (≤10%).
- That the LSs performed well for all orientations, but its performance in the East orientation was better than other orientations at the period of time from 9:00h to 12:00h, as for the South and

North orientation only when the sun at south and North solstice, while at the West at the period of time from afternoon (12:00h to 17:00h) in all months

- Can conclude there is no common fixed solution for all opening facade in all day under tropics climate due to the dynamic sky condition in a tropical region that changes from time to time. The most appropriate configurations of light shelf system which those located at L1 and at position P1 and P2 and L2 at P1 and P2 which are working well to enhance the daylight levels at the rear areas of the space for depending on the orientations and sun positions. Generally, can summarize the optimum design of light shelf is L1 at P1 for an intermediate sky in the all orientation. As also can noted that, light shelf at location L3 at all height positions did not work well regarding to the increased illuminance intensity, it can considered the worst cases of all light-shelves configurations.

REFERENCES

1. Alzoubi HH, AH Al-Zoubi (2010), "Assessment of building façade performance in terms of daylighting and the associated energy consumption in architectural spaces: Vertical and horizontal shading devices for southern exposure facades", *Energy Conversion and Management*, Volume 51, Issue 8, pp. 1592−1599.
2. Karlsen L et al. (2016), "Solar shading control strategy for office buildings in cold climate", *Energy and Buildings*, Volume 118, pp. 316−328.
3. Athienitis A, A Tzempelikos (2002), "A methodology for simulation of daylight room illuminance distribution and light dimming for a room with a controlled shading device", *Solar energy*, Volume 72, Issue 4, pp. 271−281.
4. Yu X, Y Su (2015), "Daylight availability assessment and its potential energy saving estimation–A literature review", *Renewable and Sustainable Energy Reviews*, Volume 52, pp. 494−503.
5. Wong L (2017), "A review of daylighting design and implementation in buildings", *Renewable and Sustainable Energy Reviews*, Volume 74, pp. 959−968.
6. Vázquez-Moliní D, et al. (2013), "Horizontal daylighting system for office buildings", *Energy and buildings*, Volume 67, pp. 525−530.
7. Shen H, A Tzempelikos (2013), "Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading", *Building and Environment*, Volume 59, pp. 303−314.
8. Roshan M, AS Barau (2016), "Assessing Anidolic Daylighting System for efficient daylight in open plan office in the tropics", *Journal of Building Engineering*, Volume 8, pp. 58−69.
9. Ramos G, E Ghisi (2010), "Analysis of daylight calculated using the EnergyPlus programme", *Renewable and Sustainable Energy Reviews*, Volume 14, Issue 7, pp. 1948−1958.
10. Al-Obaidi KM et al. (2017), "Designing an integrated daylighting system for deep-plan spaces in Malaysian low-rise buildings", *Solar Energy*, Volume 149, pp. 85−101.
11. Harntaweegonsa S, L Beltran (2017), "Daylighting Performance of Toplighting Systems in the Hot and Humid Climate of Thailand",
12. Mayhoub M (2014), "Innovative daylighting systems' challenges: A critical study", *Energy and Buildings*, Volume 80, pp. 394−405.
13. Alrubaih M et al. (2013), "Research and development on aspects of daylighting fundamentals", *Renewable and Sustainable Energy Reviews*, Volume 21, pp. 494−505.

14. Lee, H., et al. (2017), "Daylighting performance improvement of a light-shelf using diffused reflection", *Indoor and Built Environment*, Volume 26, Issue 5, pp. 717-726.
15. Park, D., et al. (2014), "Dynamic daylight control system implementing thin cast arrays of poly dimethyl siloxane-based millimeter-scale transparent louvers", *Building and Environment*, Volume 82, pp. 87-96.
16. Kontadakis, A., et al. (2017), A Review of Light Shelf Designs for Daylit Environments", *Sustainability*, Volume 10, Issue 1, pp. 71.
17. Warrier, G.A. and B. Raphael (2017), "Performance evaluation of light shelves", *Energy and Buildings*, Volume 140, pp. 19-27.
18. Moazzeni, M.H. and Z. Ghiabaklou (2016), "Investigating the influence of light shelf geometry parameters on daylight performance and visual comfort, cases study of educational space in Tehran, Iran", *Buildings*, Volume 6, Issue 3, pp. 26.
19. Lim, Y.-W. and M.H. Ahmad (2015), The effects of direct sunlight on light shelf performance under tropical sky. Indoor and Built Environment, Volume 24, Issue 6, pp. 788-802.
20. Berardi, U. and H.K. Anaraki (2016), "The benefits of light shelves over the daylight illuminance in office buildings in Toronto", *Indoor and Built Environment*, p. 1420326X16673413.
21. Freewan AA (2010), "Maximizing the lightshelf performance by interaction between lightshelf geometries and a curved ceiling", *Energy Conversion and Management*, Volume 51, Issue 8, pp. 1600−1604.
22. Meresi A (2016), "Evaluating daylight performance of light shelves combined with external blinds in south-facing classrooms in Athens, Greece", *Energy and Buildings*, Volume 116, pp. 190−205.
23. Lim YW et al. (2012), "Building façade design for daylighting quality in typical government office building", *Building and Environment*, Volume 57, pp. 194−204.
24. Al-Obaidi KM, MA Ismail, AM Abdul Rahman (2015), "Assessing the allowable daylight illuminance from skylights in single-storey buildings in Malaysia: a review", *International Journal of Sustainable Building Technology and Urban Development*, Volume 6, Issue 4, pp. 236−248.
25. Lim YW, MH Ahmad, DR Ossen (2013), "Internal shading for efficient tropical daylighting in Malaysian contemporary high-rise open plan office", *Indoor and Built Environment*, Volume 22, Issue 6, pp. 932−951.
26. Shameri M et al. (2013), "Daylighting characterstics of existing double-skin façade office buildings", *Energy and Buildings*, Volume 59, pp. 279−286.
27. Hirning MB, GL Isoardi, VR Garcia-Hansen (2017), "Prediction of discomfort glare from windows under tropical skies", *Building and Environment*, Volume 113, pp. 107−120.
28. Lim YW, C Heng (2016), "Dynamic internal light shelf for tropical daylighting in high-rise office buildings", *Building and Environment*, Volume 106, pp. 155−166.
29. Fadzil SFS, WMW Harun, A Abdullah (2015), "A method to determine a single point percentage daylight factor (% DF) value from field work data", *Advances in Environmental Biology*, pp. 39−43.
30. Chen Y et al. (2014), "Experimental and simulation study on the performance of daylighting in an industrial building and its energy saving potential", *Energy and Buildings*, Volume 73, pp. 184−191.
31. Boccia O, P Zazzini (2015), "Daylight in buildings equipped with traditional or innovative sources: A critical analysis on the use of the scale model

approach", *Energy and Buildings*, Volume 86, pp. 376−393.
32. Bian Y, Y Ma (2017), "Analysis of daylight metrics of side-lit room in Canton, south China: a comparison between daylight autonomy and daylight factor", *Energy and Buildings*, Volume 138, pp. 347−354.
33. Ochoa CE, MB Aries, JL Hensen (2012), "State of the art in lighting simulation for building science: a literature review", *Journal of Building Performance Simulation*, Volume 5, Issue 4, pp. 209−233.
34. Wienold J (2009), "Dynamic daylight glare evaluation", *Proceedings of Building Simulation*, pp. 944-951.
35. Ibarra D, CF Reinhart (2009), "Daylight factor simulations–how close do simulation beginners 'really'get?", *Building simulation*, pp. 196-203.
36. Joarder MAR et al. (2009), "A simulation assessment of the height of light shelves to enhance daylighting quality in tropical office buildings under overcast sky conditions in Dhaka, Bangladesh", *Building simulation*, pp. 1706-1713.
37. Lim YW, MH Ahmad, DR Ossen (2010), "Empirical validation of daylight simulation tool with physical model measurement", *American Journal of Applied Sciences*, Volume 7, Issue 10, pp. 14−26.
38. Dahlan ND et al. (2009), "Daylight ratio, luminance, and visual comfort assessments in typical Malaysian hostels", *Indoor and Built Environment*, Volume 18, Issue 4, pp. 319−335.
39. Mahmoud AHA, Y Elghazi (2016), "Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns", *Solar Energy*, Volume 126, pp. 111−127.

