Evaluating kinetic light-shelves and their impacts on daylighting performance

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ABSTRACT

This study aims to evaluate the natural illumination levels obtained using Light-Shelves Techniques (LST) under real tropical conditions in Malaysia. Two parameters of manually controllable of LST design have been examined; Location (L) and Position (P) which were placed on the south-façade window. A scaled-model experiment was applied to determine the illumination levels achieved by LST under real sky conditions. Computer simulation results using Radiance engine were used to validate the scaled-model method used indicators Daylight Ratio (DR%), and it observed to be in great concurrence with physical scaled-model data obtained under tropic sky which is mostly an intermediate sky. The maximum average level percentage of DR% differences between scaled-model and simulation was 1.8% (≤10%). The results showed the performance of the LST can be improved by controlling the location and position. The most optimal LST for south-facing orientation was found in different times at locations in the external L1 and L2 at P1 give the best illuminance near the window and the back. The best improvement in daylighting at deep office area (SP3) were 4.2% at 9:00h on Jan, 4.7% and 7.3% at 12:00h, and by 27% and 2.1% at 15:00h on Jan and March respectively.

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1. INTRODUCTION

Office buildings located in the changeable climate conditions region such as tropics have elicited the interest of researchers due to high consumption energy concerns and poor design for natural light usage in working spaces. Numerous researches pointed out that, many office buildings in tropical conditions, especially in Malaysia and Singapore, exceed the required level of the energy efficiency index. The usage of fixed shading devices in the tropics has been demonstrated to have restrictions regarding of controlling the amount and quality of received sunlight consistently throughout the year, particularly at various sun positions and angles with changing sky conditions [1]. Recent developments in building technologies all-over the world as in the modern Malaysian architectural, reflect the trend towards more intelligent and energy-efficient buildings through employ daylight, which is more advantageous in both economically and environmentally. Many studies have been done in the enhancement of indoor environments that use daylight as their essential source of illumination [2, 3].

Consequently, despite the abundance of solar radiation in tropics regions, daylighting design in an office spaces in the tropics face a critical challenge because to the dynamic illuminance condition in such region, in addition to overheating issues that plainly occur in large glazing areas and negative directions, for example, east and west. In Malaysia as an example, East and West orientation received a lot of direct sunshine during morning till sunset, as for the north orientation faces direct sunlight during May to August, and south orientation faces it during November to February [4].

Regardless of the numerous features of natural daylighting, auser's absence of capacity to control or control the sunshine inside their environment may lead to expanded energy usage from electric lighting and dispose positive results related to the presence of natural light and perspectives. Interior vacuums that are unsuccessfully daylit, regardless of whether they need client controls, permit unreasonable glare, or contribute to heat gain, can result in adverse impacts upon occupant performance and overall satisfaction [5]. Consequently, the adoption of daylight gathering techniques is a fundamental procedure so as to considerably reduce lighting energy consumption and improve the quality of visual comfort. In the plan process to design good interior daylighting environment, both the quantitative and the qualitative parameters must be met. because The introduction of daylight in a space adds unpredictability to the issue due to its dynamic nature, since shading demands have to counterbalance daylight adequacy [6]. In additional, the use of natural light in the tropics is challenging, due to sky conditions in this region inconstancy [7].

During the time there have been a few improvements in daylighting design, and it appears that there is a propensity to move away from static towards more dynamic methods. Still, the crucial difficulties stay consistent; how to admit appropriate natural light as deeply as possible into a space, making a high quality and productive environment for the users, while in the meantime achieving increased energy savings. Recently, an assortment of creative Daylighting Systems (DSs) solutions on building envelopes with dynamic features are being created by numerous researchers and architects. The main objective of daylight systems is to improve daylight autonomy by increasing the natural light levels at the back of the space, which maximizing the time where inside spaces of the building are over an objective least illuminance level [8].

The primary difference between dynamic and conventional ones is the capacity to change according to internal needs by the users to keep up indoor comfort and the outer loads placed on the building façade openings [9]. Dynamic system can be controlled by the occupants manually or with computerized devices. Albeit numerous of researchers looked into the employment of dynamic system as an efficient solution, automated system might cause the users losing their sense of control and influence the occupants fulfillment[10].

This study focused on manual control of daylighting systems in this case which are Light Shelves Techniques (LST). LST are a type of daylight guiding system, which were placed way up a window to control and redirect incoming sunshine, and can be external, internal, or both [11]. LST are a device meant to enhance daylight penetration into buildings. It works by reflecting falling natural light off to the ceiling from where it is further reflected to the rear areas of the space, As a general daylighting device for a room, the light shelf should optimal produce an enhanced illuminance levels at the back of a space for any sky condition [12].

LST are a daylight system that can enhance the quality of an inside space and reduce lighting energy by (a) reduce the direct effects of sunshine through prevent direct sunlight coming in from the outside and (b) enhancing the illuminace levels by bringing light further into inside space through reflection, which uniformly distributes the illumination indoors and resolves issues such as glare and uneven illumination that result from natural light entering directly from outside. The features of a LST that influence its daylighting performance comprise its type, angle, height, and width, and it may also be affected directly by factors of climate and weather [13]. LST are not usually a plain horizontal slab. It could be made of several kinds of shapes, sizes, materials, and mounted on different positions. Those variables interact with each other to decide the performance of LST. The performance of LST could also be influenced by windows, ceilings and room configuration [14].

Few researches have been carried out on the design and performance of dynamic type of devices especially, on tropics countries such as Malaysia in terms of visual comfort and their effect on daylight distribution. For example, Lim and Heng [15], in their study on dynamic internal light shelf for tropical daylighting in high-rise office buildings. They present a case study for the comparison of daylighting performance of 10 configurations of dynamic internal light shelves. However, the assessment of the efficiency of dynamic LST with respect to illuminance levels in an interiors has become a major research issue, particularly regarding how a kinetic type of light shelf system performs in terms of daylighting or what position and height or angle leads to get better illuminate the far areas from the slot as well as uniformity daylight distribution under tropics sky conditions. Such inquiries should be addressed during the very early stages of design by straightforward examination. Thus, LST with manually controlled adjustable features was developed to estimate the improve illuminance levels, and its effectiveness was assessed in this study.

2. RESEARCH AIM

This study aims to explore the effects of LST to achieve improved the quality of illuminance levels by using LST with manually controlled adjustable features that will exploit daylight in a typical Malaysian office space with south orientation, which can be adaptable to different sun and sky conditions. The purpose of this experiment is to explore the effects of various LST configurations in terms location and position on window on the performance of daylighting distribution and to determine the best LST location and position in terms of illuminance level at the back of space and illuminance distribution patterns on working planes.

3. RESEARCH METHODOLOGY

Physical models are considered a powerfull tool for studying daylighting, which widely adopted as an efficacy method for predicting the qualitative and quantitative effects of the daylighting design of interior areas of buildings [16]. Thus, physical scaled model is significant on the basis that it gives space for verifying the performance of light behavior in real world under various sky conditions that is not included in simulated and mathematical model. Literature studies have demonstrated the viability and exactness of scaled model to study daylighting performances under real sky conditions [17].

In order to fully verify the principle and characteristics of manually controlled kinetic light-shelves techniques and their abilities to improve daylighting distribution at the rear of space under tropical sky conditions, the methodology employed comprised two major processes; simulation and scaled-model experiment. Scaled model method provided an information on illumination performance of the selected LST. Whereas, the computer simulation method was used for comparison and validation the results of the scaled-model experiment to assure the reliability of results.

4. RESEARCH PROCEDURES

4.1. Scaled-model set-up and data collection

In this study, a qualified scaled model (1:10) of typical office unit with one side-lit opening with deep space plan. Penang, Malaysia was selected for daylight measurement and manually controlled light shelf designs were compared. This unit was derived based on the previous cases studies within the typical dimension as shown in Figure 1. It has a rectangular plan with net interior dimensions were 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 2.00m height without any glazing above the floor level, which resulted in a 40% window-to-wall ratio. The model was built with thin plywood, the interior walls, floor, and ceiling were painted by white colour, while the external surfaces were painted by black colour to block other sources of daylight apart from the single-sided external.

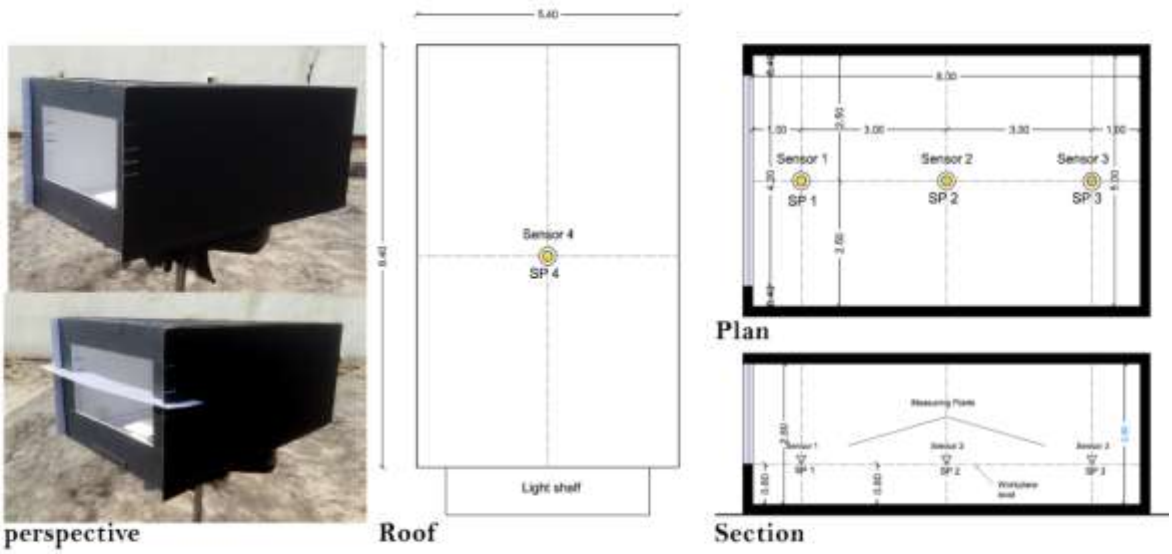

Figure 1. Physical scale model construction

The experiments took place at in an open area on the top roof of the main building of the School of Housing, Building, and Planning at USM (Universiti Sains Malaysia) in Penang, Malaysia as shown in Figure 2(a). The measurements period was taken for 3 days (21st January 21st March and 21st May 2019), during working day time at four period; 9:00h, 12:00h, 15:00h and 17:00h. with the scale model oriented in the south orientation. This selected period was presented the various Solar Solstice of Malaysian skies Models as shown in Figure 2(b), where, in the month of Jan the sun is on the South Solstice while, in the month of March the sun is approaching to more directly from East and West at the middle of sky. As for May the sun is on the North Solstice. Furthermore, these times were selected according to the different locations of the sun (morning, noon and afternoon) during office working hour, which the common public office working hours in Malaysia is start from morning at 9:00h. until 17:00h [18].

Data collection and analysis was done quantitatively by taking measurements of luminance level inside the space. Three illuminance Sensor Points (SP1, SP2, and SP3) were placed at the middle of the space above the work-plan level at height 0.80m to measure the internal illuminance level in the model, and SP4 placed at the roof of the model to measure the external illuminance (see Figure 1). SP1 and SP3 located at 1m from the wall aperture and wall at the back of space respectively, while the SP2 was placed at the middle of the space. The measurements were conducted by using a lux meter (TL-600 Digital Data Logging [accuracy reading ± 4% from 0 to 10.000 lux; ± 10 from 10.000 to 200.000 lux]). Lux meter sensors were validated and calibrated against simulation tools using Radiance calculation engine.

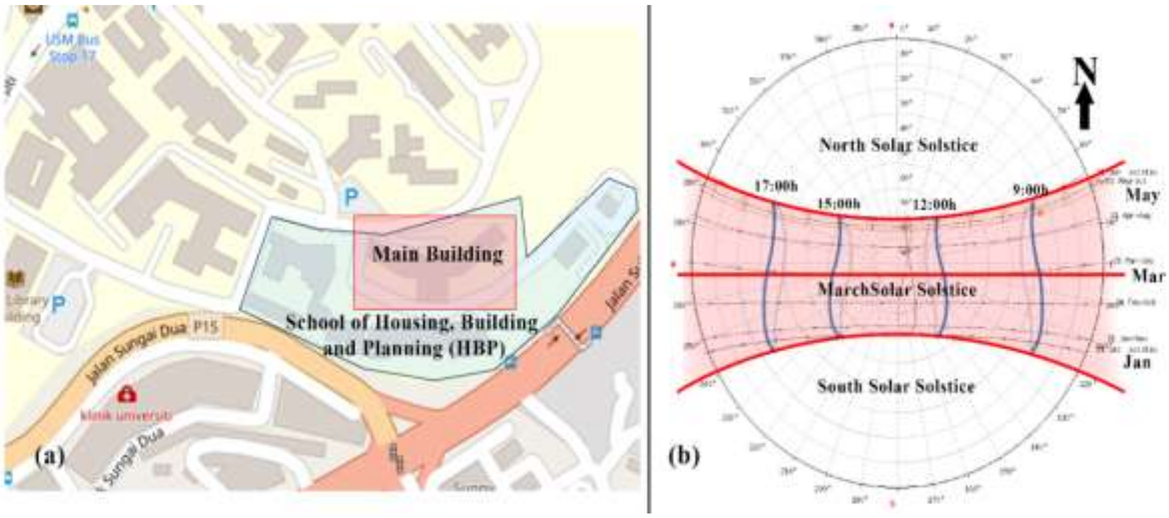

Figure 2. (a) Place of experiments and (b) Sun path diagram of Malaysian sky model

4.2. Manually controllable LST design variables

Recent research on light shelves have integrated various technologies to improve their efficiency. According to many design variables of light shelves can be effects on the performance of daylight which include light shelf postion height, location on window, geometry, building orientation, location, material and the climate conditions effect [19]. only two basic variables design of manually controllable of the light-shelves were selected in this study; Location (L), and Position (P) were chosen as shown in Figure 3.

The location movement means the location of light shelves which could be locate external or internal or on both sides of the window at the middle, while the position movement means: the height of light-shelves on the window. Three different location (L) and three different height positions (p) of light-shelves integrated with side-lit window facing to the south was manually controlled. L1, L2, and L3 indicated to external, middle, and internal respectively of the location of light-shelves on the window, whereas, the P1, P2, and P3 presented three different height of light-shelf configurations on the window at 1.8m, 2.00m, and 2.20m respectively. The width of all LST configurations was 1 m based on most studies on variables related to LST.

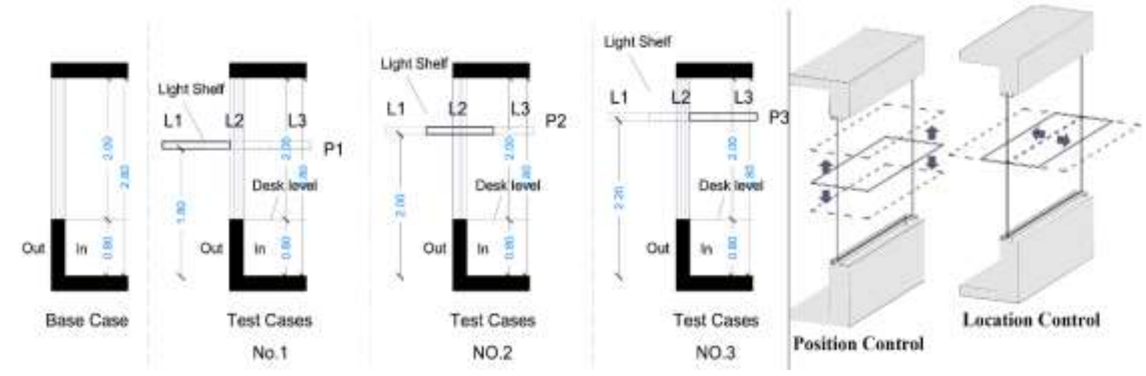

Figure 3. Configurations of manually controlling transforming of light shelf

5. RESULTS ANALYSIS AND DISCUSSION

5.1. Validation scaled-model method

In the research community of architectural field, the outcomes gotten from direct measurements of fieldwork physical scaled-model method are often preferred by calibration and validation as compared to those gotten from computer simulations. There are many software tools has been used to evaluate and analyse environmental performance [20]. Where previous studies pointed that the average level percentage of illuminance differences between results of fieldwork studies and computer simulation tools ≤20% [21-24], and the differences in Daylight Factor (DF%)/Daylight Ratio (DR%) ≤10% [18, 25]. So as to avoid sources of mistake and achieve reliable outcomes, the study utilized scaled model of least detail to compare with Radiance daylight engine. DR% was used in this stage to validate the method. Because, in tropics sky conditions, it is very difficult to calculate DF under real sky conditions as noted by other authors [26].

Based on validation illuminance analysis of the scaled-model experimental and simulation, the external illuminance (Ei) was measured for both methods, so as to have a better comprehension of the standered CIE sky and real tropical sky characteristics. Subsequently, the validation testing carried out on at the same time of scaled-model experiment under real intermediate sky condition (previous studies noted that tropical sky is predominantly intermediate), with South-facing window in the same scaled-mode. The internal illuminance of base scale model and base simulation model were measured and compared in points (SP1, SP2 and SP3) with performance indicators DR% using equation:

$$\text{Diff DR\%} = (\text{DR\% sim-DR\%s-model/DR\%s-model}) * 100 \quad (1)$$

The comparison of measurement results against the simulation results using Radiance calculation engine (CIE intermidate sky) on experiment months is shown in Figure 4, amd Table 1 summarized the average percent differences of DR% generated from the scale-model and Radiance calculation. The results showed the average DR% differences between simulation and scaled-model measurements are 1.2%, 1.8% and 1.3% (≤10%) 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.

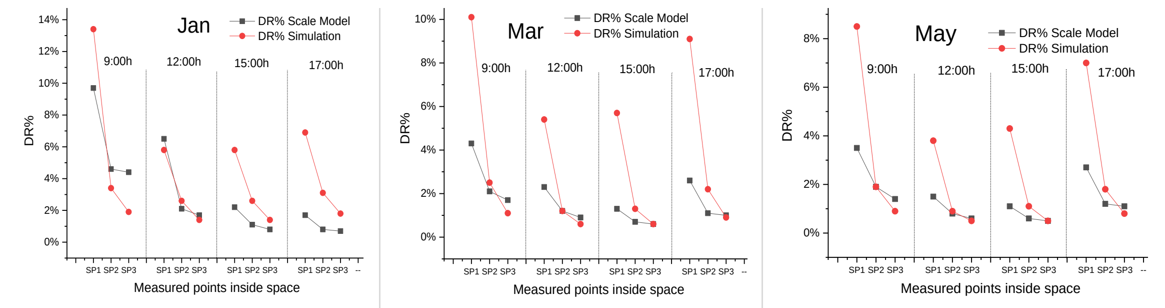

Figure 4. Comparison between DR% in scaled- model and simulation

Table 1. The average differences of DR% calculation

	9:00h	12:00h	15:00h	17:00h	Avg. DR%	Validate
21st Jan	0.0%	-0.1%	2%	3%	1.2%	
21st Mar	1.9%	0.9%	1.7%	2.5%	1.8%	≤10%
21st May	1.5%	0.8%	1.2%	1.5%	1.3%	

5.2. LST performance on south orientation

The results obtained from experiments on south facing orientation covering the different configurations of manually controlling of light-shelves outlined in the previous section. From the data collected and analysis results, the optimum light shelves for each period of time were selected for its luminance performance were chosen for comparison to the base case. For illuminance analysis, outdoor illuminance (Ei), and at work plan illuminance, at points SP1, SP2, and SP3 in inside of model were measured.

The most critical illumination condition for south-facing orientation when the sun on South Solstice. Figure 5-7 show the comparison illumination level in 21st of January, March and May at four periods of time. In the morning at 9:00h when the sun is at low altitude with outdoor illumanace was as high as 31.1klux on Jan, 32.4klux Mar, and 32.4klux May. light shelf system at L2 location with P1 was seen as a more balanced distribution, 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) on the month of Jan, and it can noted that on the months March and May, the light shelf not worked well under diffuse sunlight at this period of time.

Compared to the reference case, L2 at P1 on Jan decreased the illuminance levels by 54.6% near aperture, the illuminance levels decreased from 3020 to 1370 lx. and it recorded a slightly enhanced of illumination levels at the middle and back of the space, illumination levels increased by 4.5% from 1434 to 1498lx and by 4.2% from 1363 to 1420lx respectively. On the month of March and May, when the Sun is at the middle and North solstice with outdoor illuminance was as high as 32.4klx and 31.2lx, the light shelves not performed well, because the illuminance levels measured with light shelf system was less than those achieved from the Base Case, and all light shelves were slightly decreasing the illuminance levels at the middle and the back of space. 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 consider the worst cases of all light-shelves configurations.

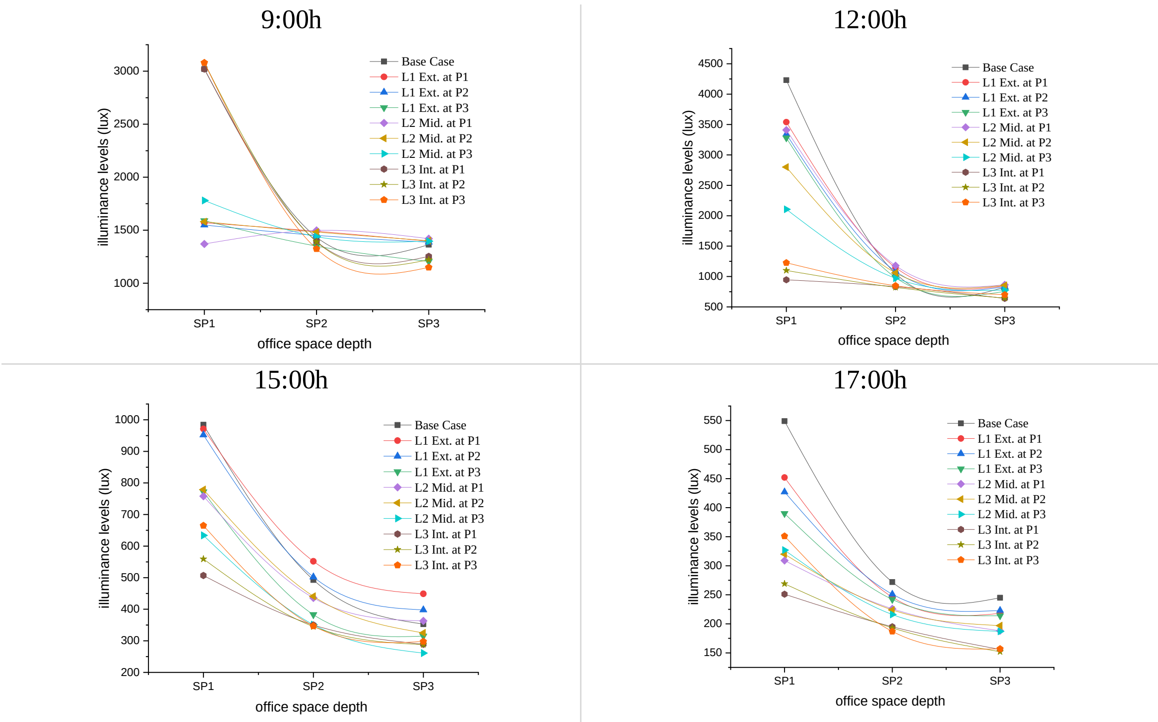

Figure 5. Illuminance level computed by with and without light-shelf on Jan

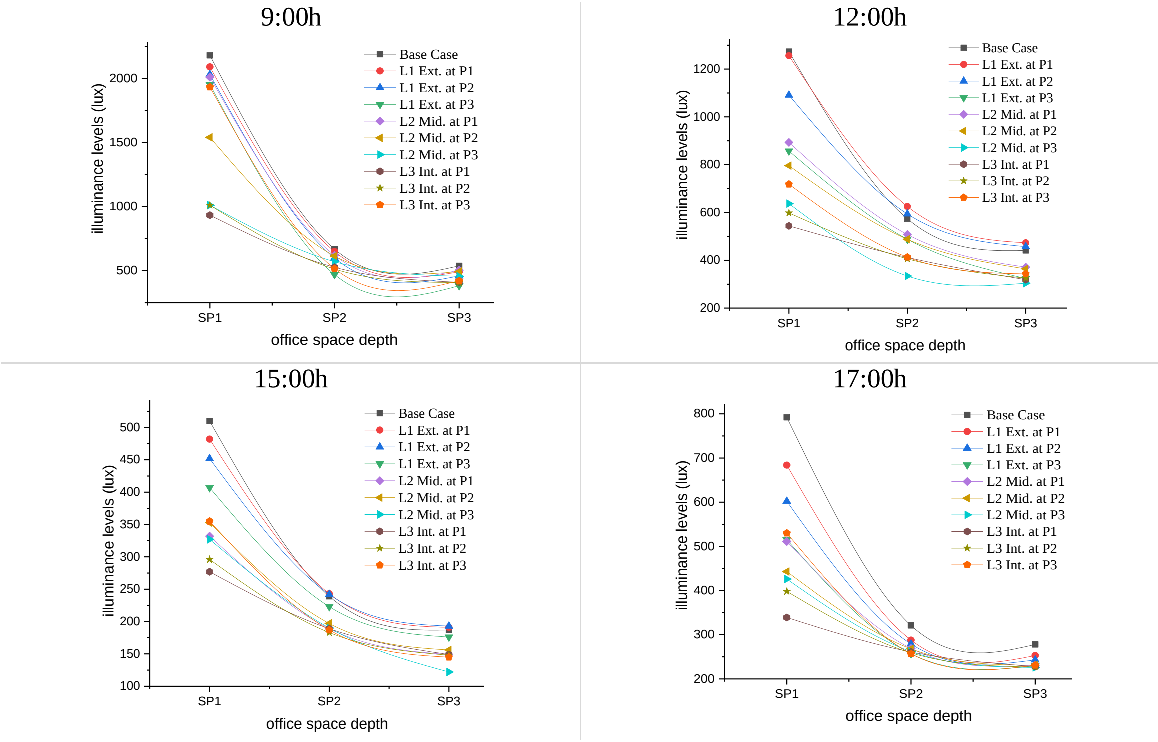

Figure 6. Illuminance level computed by with and without light-shelf on March

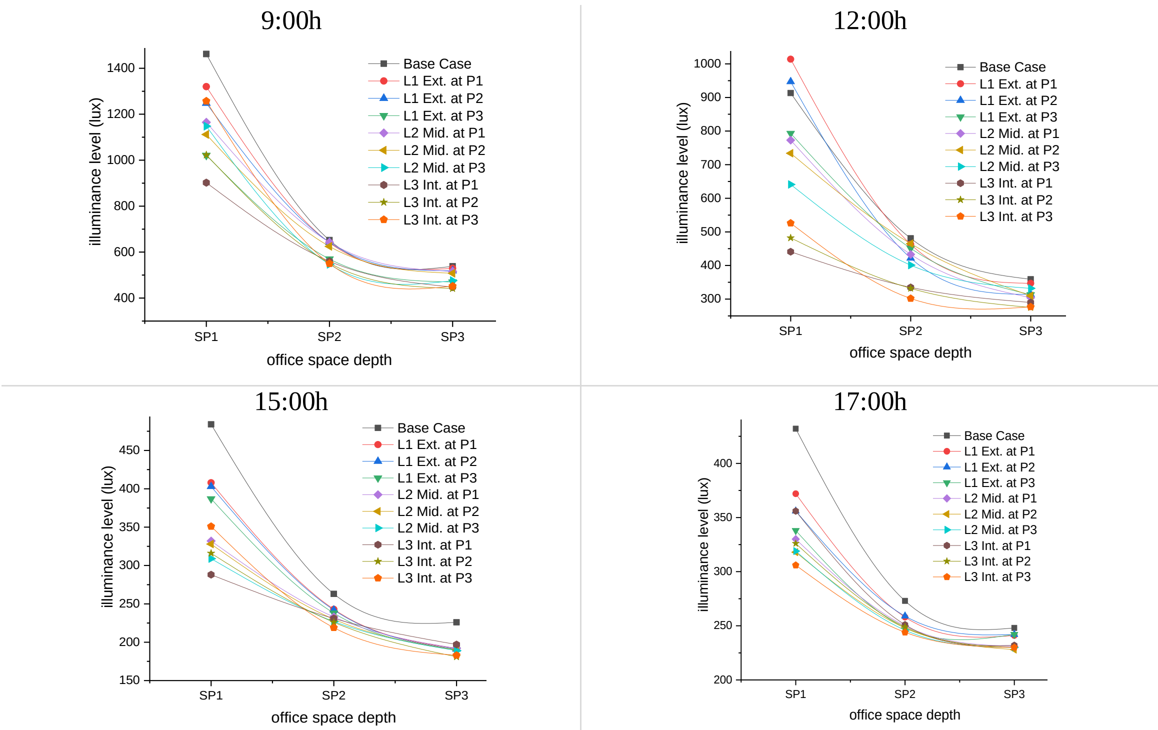

Figure 7. Illuminance level computed by with and without light-shelf on May

The most critical illuminance for south facade at the period of time 12:00h to 15:00h. when the sun at south solstice (on Jan) and sunshine falling directly and more concentrating on south facade. On this period of time when the sun altitude was above the head and perpendicular to the building with external illuminance was as high as 49.9klux, 51.2klux and 56.9klux at 12:00h and for Jan, Mar and May respectively. At 15:00h when the sun began to tilt toward the west with external illuminance was as high as 43.8klux, 44.6klux and 43.6klux respectively. On this period of time comparing to the Base Case without light-shelf, from the figures it can considered that the light shelf at location L2 at P1 is the optimal design in Jan to enhance the daylight in the middle and the back of space, While on Mar L1 at P1 performed well. As for May there is no effects to enhance the illuminance by the light shelves.

At 12:00h It was noted that the illuminance levels decreased by 24.1% from 4230 to 3210 lx near aperture, while enhancing the illuminance by increased illuminance levels by 12.3% from 1051 to 1180 lx and by 4.7% from 825 to 864 lx at the middle and back of the space on Jan. While on the month of Mar, it decreased by 1.3% from 1273 to 1256 lx near aperture, and increased illuminance levels by 8.9% from 574 to 625 lx and by 7.3% from 441 to 473 lx at the middle and back. As for the time 15:00 h. the illuminance levels decreased from 948 to 971 Lux by 1.3% on Jan near aperture, while enhancing the illuminance levels from 493 to 552 lx by 11.9% and from 353 to 449 lx by 27% at the middle and back of the space respectively on March decreased from 510 to 482 Lux by 5.5% near aperture, while slightly enhancing the illuminance levels from 239 to 243 lx by 1.7% and from 187 to 191 lx by 2.1% at the middle and back of the space respectively.

At the period time from17:00h when the sun at west with external illuminance was as high as 33.1klux. all light-shelves configuration not performed well, in terms to improving lighting levels at the back areas of the space, because the illuminance levels measured with light shelf system was less than those achieved from the Base Case in all months. All light shelves were improved the illuminance level near the window by decreasing the density of illuminance, at the same time decreasing the illuminance levels at the middle and the back of space.

6. CONCLUSION

This research study has discovered the impacts of two parameters controllable designing of light shelves namely; location and position on the performance of daylight distribution. These were examined using physical scaled model experiments. Experiments carried out on the south orientation under tropical sky conditions. The general idea of LST in the first place is to controlling the fallen and diffuse sunlight and delivered to the interior to get light to be more evenly distributed and more homogeneous throughout the space especially in areas of the middle of space (SP2) and the back (SP3), as well as to minimize the illuminance intensity on the areas nearest to the window at (SP1) so contrast can be minimized. In conclusion, can conclude there is no common fixed solution for south-facing orientation in all day-time 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 dutring working days for south facing 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 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 consider the worst cases of all light-shelves configurations. The highest improvement in daylighting near the window and at the back of space were 54.6% and 4.2% at 9:00h on Jan, and 24.1 and 4.7% at 12:00h on Jan, and 1.3% and 7.3% on March. And at 15:00h by 1.3% and 27% on Jan, and by 4.6% and 2.1% on March.

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