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Light Pipe Transporter for High-rise Office Building in Tropical Climate

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ABSTRACT

Daylight has known to bring benefits for human, psychologically and physiologically. It also provides better indoor environment quality and thus increase the performance and productivity of office workers as stated by Paevere (2009). However, due to economic reasons, the current practice of using deep open plan building has cause a dent to having daylight in the interior spaces, which cause a dependency on artificial lighting. Hence, to provide daylight in deep interior, light distribution system is needed. Although so, according to Hansen (2003), most of the systems can only illuminate up to 8m-10m depth. Therefore, light pipe (LP) plays an essential role where it can illuminate up to 20m depth. LP's efficiency depends on the 3 main components; collector, transporter and extractor. This research explores the effectiveness of horizontal LP through different type of transporter's shapes which includes rectangular, triangular, square and semi-circle. Previous studies have shown differences of efficiency on the shaped while using vertical LP. This research's analysis was done using a computer simulation, Integrated Environment Solution: Virtual Environment (IESVE), where DF of each shapes were compared to MS 1525:2007 benchmark. The viability of the software was also validated though an assessment with a physical scaled-model experiment that was conducted in an open car park in Universiti Teknologi Malaysia, Johor, Malaysia. The results from the simulation showed that semi-circle shaped transporter offered the same efficiency as rectangular shaped. These findings will promote the usage of LP in buildings as it decreases the costing for LP.

1. Introduction

The current rise of numbers in deep plan building has brought to an abandoning of daylighting which cause a dependency on artificial lighting. This is due to the profitable utilization of space in the office building where more usable area can be achieved by using open plan building. Though economically it brings revenue to the company, the negative impact of the absent of daylighting may dampen it. Paevere (2009) stated that daylight brings psychological and physiological benefits to human and thus, providing better indoor environment quality. Office workers under such surroundings will have better work performance and productivity that will boost the company's income.

Studies have been done on several system to bring in daylight to the interior through reflection, refraction or deflection. Such system are like louvres, blinds, holographic optical elements, light shelf, *anidolic* ceiling, *anidolic* zenithal opening and venetian blinds. However, Hansen et al. (2003) pointed out that these devices can only illuminate a room up to 8m to 10m depth, hence, unable to accommodate the deeper spaces. Therefore, light pipe (LP), which is able to bring daylight into more than 10m comes into the picture (Whitehead et al., 1987; Aizenburg et al., 1997; Hansen et al., 2001). The LP consists of 3 main parts, collector, transporter and extractor. These parts are essential to as they affect the ability of the LP to transport the light.

This research focuses on using LP as a mean to bring daylight into the interior. It emphasize on the performance of the LP in terms of quantity, rather than quality and is carried out using both scaled modelling and computer simulation method to acquire and evaluate the LP's performance in deep plan building.

2. Light Pipe

Reflectivity plays an essential role in designing a LP where a drop of 1% in reflectivity will cause the efficiency to decrease by 20% (3M, 2008). Hence, it is rational to use the best reflectivity rating of 99% in the LP. Due to this reason, there is a need to look at other aspect to develop the performance of LP; the surface area that reflects the light. The theory of reflection shows that, the larger the surface area is, the more light that can be bounced from the surface. Consequently, to achieve a larger area in a surface, modification of the LP has to be done at the largest percentage that reflects the light, which is the transporter (Figure 1).

Edmunds (2010) had done testing the effect of several shapes of transporter to LP. The shapes includes rectangular, rhombic, isosceles and equilateral triangular, circle. Although so, these research have only been conducted to a vertical LP. The difference in both type of LP are shown in Table 1.

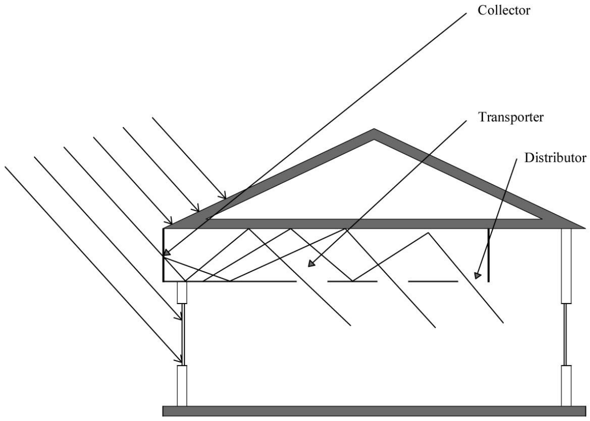

Figure 1: *Components of the light pipe*

Table 1: Comparison of horizontal and vertical LP.

Typology Criteria	Vertical Light Pipe	Horizontal Light Pipe
View of sunlight	Whole day long (in a clear sky condition)	Only a few hours of a day
Ways of extraction	Colored rings, dyes	Laser cut panels, openings
Footprint	Requires a large space penetrating through the interior.	Requires some space in the headroom.
Orientation dependability	No	Yes

Besides that, the collector and extraction point are also two of the main components in a LP. Previous studies have shown that Compound Parabolic Concentrator (CPC) performs the best at collimating daylight (Wittkopf et al., 2010). This was through a comparison of various collector design, ranging from flat baffle collectors to *anidolic* collector system. Other than that, the extractor of LP comprises of a simple opening at the end of the transporter. Both these components are kept constant throughout the research.

3. Methodology

There are several methods used in the study of LP; full scale modelling experiment, scaled model experiment, mathematical calculations and computer software simulation. Although so, there are several limitations with each of the methods. A usage of full scale modelling method requires a large compound for the room to be built. Moreover, the construction costs and expertise in building a LP require a high budget allocation for the research to commence. While a scaled model may offer an alternative to lower the costing, it has certain drawback as well. Thanachareonkit et al. (2005) suggested that the results from scale modelling were generally higher than the actual readings. The discrepancy may range from 20% to 105% as stated by Cannon-Brookes (1997) and Thanachareonkit et al. (2005). The error can be minimized by exerting consideration on the model's geometrical shape and the surface reflectance (Freewan et al., 2008; Thanachareonkit et al., 2010). Other than that, mathematical calculations has a disadvantage of having theoretical data where some may differ from the real results. It also needs a vast knowledge in the field of mathematics and physics. Another method often used in LP research is computer software simulation. There are a lot of software available which are suitable for different studies. Lim (2010) had made a comparison on various software and suggested that among those viable choices for daylighting study are Desktop Radiance, Velux Daylight Visualizer and Integrated Environmental Solutions: Virtual Environment (IESVE).

Therefore, this study employs computer simulation using Integrated Environmental Solutions: Virtual Environment (IESVE) as the main methodology in assessing the LP's performance. It uses Radiance-based engine to simulate an environment where ray-tracing calculation process will give the desired daylighting result. It also takes into consideration of distribution of emitted rays, reflection, transmission and refraction of surfaces. Moreover, based on IES Virtual Environment & Compliance with ASHRAE 90.1 (2014), rating authority has approved the climatic hourly data file of ASHRAE 90.1, which is used in IESVE.

Radiance, which is the running engine for daylighting module in IESVE, uses CIE skies model or local data input to generate the global and outdoor illuminance. Although so, these sky models behaves differently from the tropical sky (Lim et al., 2012; Shen et al., 2013). Therefore, simulating a tropical sky condition in computer software simulation is challenging due to its vast variety and ever-changing sky condition. Thus, to validate the results of the simulation, a physical scaled model experiment is carried out. Previous studies have shown that scaled mode has the ability to produce the daylight performance and accuracy of a full-scale building under actual sky condition after considering certain criteria (Ander, 2003; Baker et al., 1993; Cheng et al., 2007; Chou, 2004; Egan et al., 2002; Freewan et al., 2008; Freewan et al., 2009; Kim et al., 2011; Robbins, 1986). Furthermore, the validation process eliminates the results' inconsistency of scale modelling as explained by Thanachareonkit et al. (2005).

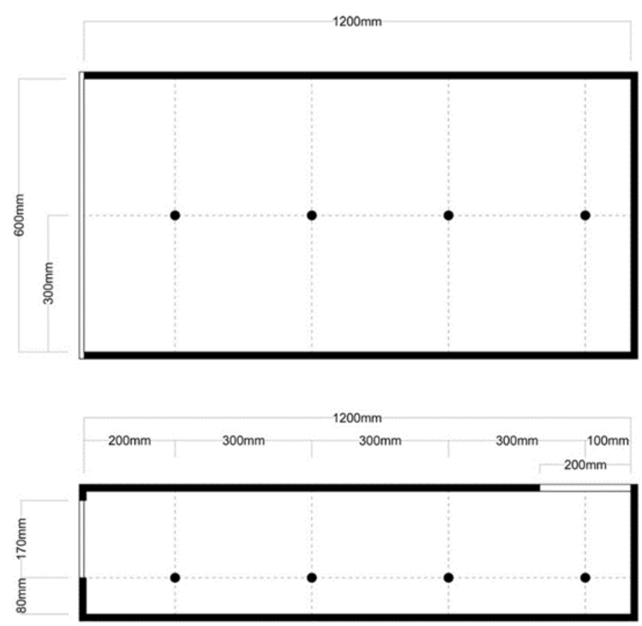

Figure 2: *Test model room configuration*

3.1 Validation

A scaled model room (Figure 2) comprising the size of 1200mm (depth) x 600mm (width) x 270mm (height) in the scale of 1:10 was used throughout the research. It has an opening with window to wall ratio (WWR) of 0.59, where an average WWR of office buildings in Malaysia is 0.5 – 0.6 as identified by Lim (2010) and Dahlan et al. (2009). The interior wall and ceiling surfaces for the room has a reflectance of 55% while the floor has a reflectance of 30%. Besides that, the interior surface for the LP, mainly the collector and the transporter, have been layered with an aluminum sheet that has 70% of reflectance.

The model was placed in an open car park in Universiti Teknologi Malaysia, Johor, Malaysia (latitude of 1o 3' N and longitude of 103o 37' E). The unobstructed area ensured no interference with shading from adjacent building or vegetation as that would interfere the result of the experiment. The opening of the model was orientated towards South due to the location of the site which is located above the Equator of the earth. This enabled the model to gather the most daylight throughout the whole day, which was from 9am until 3pm with regards to the typical office operating hours. The experiment was conducted for two days; 18th August 2015 and 31st August 2015 to ensure the feasibility of the experiment results.

Besides that, four probes (Delta Ohm's LP 471 PHOT) were placed inside the model to measure the illuminance level with a distance of 300mm from one another as shown in Figure 3. For measuring the outdoor illuminance, Delta Ohm's LP PHOT 02 was used. The readings were taken and recorded with a data logger (Delta Ohm's Data-Logger DO 9847) for every hour while interchanging between three variables; base case, rectangular LP and triangular LP.

Computer simulations were then done to validate the feasibility of the software using two statistical analysis; Pearson Correlation and paired T-test. All the configuration of the simulation used the same properties as the scaled model.

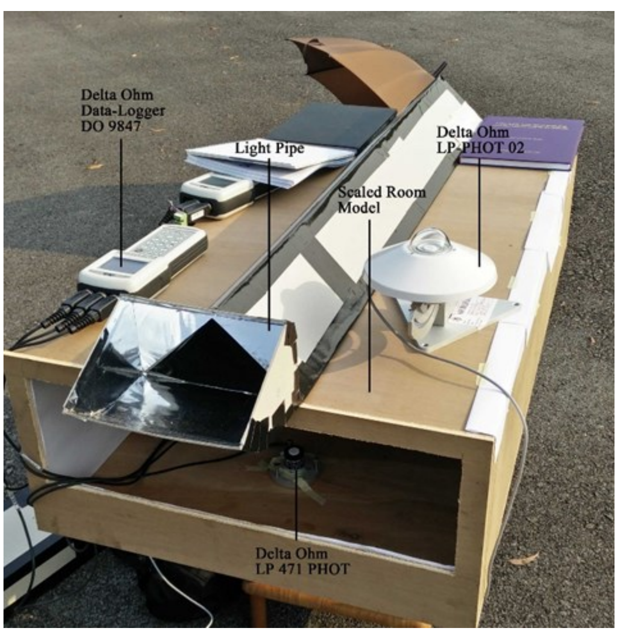

Figure 3: *Instrumentation of experiment on the LP and physical scaled model.*

$$Daylight\ Ratio\ (DR) = \frac{Indoor\ illuminance}{Outdoor\ illuminance} x100\%$$

(Equation 1)

3.2 Criteria of Analysis

The results from both the experiment and simulation were then converted into daylight ratio (DR) to assess the performance of the LP with Equation 1.

DR is used to determine the ratio between indoor Work Plane Illuminance and outdoor illuminance level. Based on the idea of Dahlan et al. (2009), it is a viable method that can be used only by the regions near the equator. Moreover, it is applied in tropical daylighting study as the absolute value of the illuminance will have constant changes in a short period of time. The DR was used as a measuring stick for both the validation process and the simulation of 5 different LP.

Other than that, daylight factor (DF) was used to determine the performance of the LP in the worst possible condition, which is the overcast sky. Equation 2 exhibits the formula used to obtain DF level where the indoor and outdoor illuminance will be attained in overcast sky condition setting. The DF were then being compared to the Malaysia Standard 1525: 2014 on the feasibility of the DF level for human's usage in the office as shown in Table 2. It proposed a range of 1.0-3.5% for an acceptable range for lighting, glare and thermal comfort. Readings above 6% is deemed as intolerable and uncomfortable for the three criteria. The DF was used only for assessing the IESVE's simulated results of the LP.

3.3 Computer Simulation Setup

For this study, 5 LP's transporter shapes were simulated using IESVE. These shapes are rectangular (LP1), triangular 45o (LP2), triangular 60o (LP3), square (LP4) and semi-circle (LP5) as shown in Figure 4.

$$Daylight\ Factor\ (DF) = \frac{Indoor\ illuminance}{Outdoor\ illuminance} x100\%$$

(Equation 2)

Table 2: *Performance indicators considered and interpretation.*

Performance indicator	Interpretation		
	Lighting	Glare	Thermal Comfort
Daylight Factor			
< 1.0	Perceptible	Imperceptible	Acceptable
1.0 - 3.5	Acceptable	Acceptable	Acceptable
3.5 – 6.0	Tolerable	Uncomfortable	Tolerable
> 6.0	Intolerable	Intolerable	Uncomfortable

Table 3: *Internal surfaces reflectance of simulation model in IESVE.*

Element	Reflectance	Specularity	Roughness	Visible Transmittance
Wall	0.70	0.03	0.03	N/A
Floor	0.20	0.03	0.20	N/A
Ceiling	0.80	0.03	0.03	N/A
Light Pipe	0.99	0.05	0.03	N/A
Glazing	N/A	N/A	N/A	0.75

The width of all the transporters are 2m except for the 60o triangle and the height are 1m. The length of the transporters spanned through the 12m depth of the office room. The room model has the same dimensions as the scaled model, which represented an office room. The reflectance, specularity and roughness of the wall, ceiling and floor used in IESVE are shown in Table 3. The glazing that occupied the opening of the room has a visible transmittance of 0.75%. All the properties of the components were constant throughout the simulation.

The simulation in IESVE consisted of three timing for each LP, as shown in Table 4, for the designated days throughout the year which are 21st March, 22nd June and 22nd December; 0900h, 1200h and 1500h. These represent the different critical angles of the Sun in tropical region. The results for 21st September was not simulated as the Sun angle was the same as 21st March where the Sun is directly on top at noon time. Besides that, an overcast sky condition which is set to 10k lux was used to assess the worst case scenario for the LP.

3.4 Validation Results

Table 5 shows the Pearson correlation and paired T-test between the results of simulation and both dates of experiments. For each sets of data, there were 84 readings taken. When compared to 18th August 2015, the Pearson correlation test gives a value of 0.9170, while for the later date, it was 0.9544. This shows the data obtained from the simulation software were reliable as the values were near to 1. Meanwhile, for the paired T-test, the results shows that the mean difference between both respective dates and IESVE are in between 0.2731 to 0.5591 for the former and the latter is 0.3991 to 0.6518.

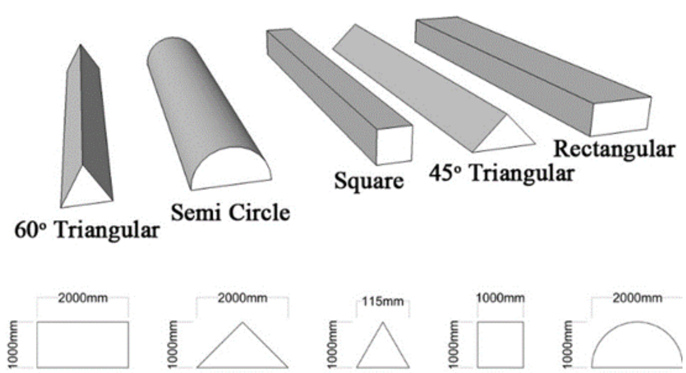

Figure 4*: LP transporter's shapes and dimensions. From the left: Rectangular (LP 1), Triangle 45^0 (LP 2), Triangle 60^0 (LP 3), Square (LP4) and Semi circle (LP5).*

Table 4: *Days and hours studies*

LP's Transporter Shape	CIE Intermediate Sky with Sun			CIE Overcast Sky
	21 March	22 June	22 December	
Base Case				
LP1 Rectangular	0900h			One Hour
LP2 Triangular 45°	1200h			(10 000
LP3 Triangular 60°	1500h			lux)
LP4 Square				
LP5 Semi Circle				

Hence, there's only slight deviation between the simulation and experiment data.

A comparison of DR of all the three sets of data are shown in Figure 5. The IESVE's results consistently showed the lowest among the three except for 0900 hours and 1000 hours. This outcome coincides with the study done by Thanachareonkit et al. (2005) where the scale modelling experiment's data will exceed the actual reading. Besides that, although there were larger differences between 1200 hours and 1400 hours, the DR values from IESVE were similar to both the experimental results. Therefore, IESVE is a viable simulation software for the conduction of this study.

4. Results and Analysis

4.1 Daylight ratio

Figure 6, 7 and 8 show the DR on 21 March, 22 June and 22 December for 0900 hours, 1200 hours and 1500 hours respectively for 6 cases of transporter shapes which were simulated thorough IESVE. The DR of all the cases at different dates hit the highest point at 0900 hours followed by 1500 hours and 1200 hours. Due to the sun path angle in the tropics, the readings in 22 June show the lowest DR among the three timing where the sun shines directly on top of the model. In contrast, the high angle of sun path in both the other two timing causes the sunlight to penetrate more into the room and thus, resulting in higher DR. All the results also demonstrate a drastic drop between the first meter which is the nearest to the window and the 4m region.

Besides that, out of all the 9 timing, Base Case generally showed the highest DR for all the three dates in the region of 1-4m and the use of LP lower the DR with the value at the first point of 21.36%, 6.19% and 9.68% on 21 March, 15.45%, 6.13% and 8.62% on 22 June and 14.38%, 17.20% and 21.34% on 22 December. The second and third highest DR is shown by LP 3 and LP 4. On the other hand, LP5 has the

Table 5: *Results of Pearson Correlation and paired T-test*

Date	N	Pearson Correlation	Paired T-Test	
			Lower Level	Upper Level
18th August 2015	84	0.9170	0.2731	0.5591
31st August 2015	84	0.9544	0.3991	0.6518

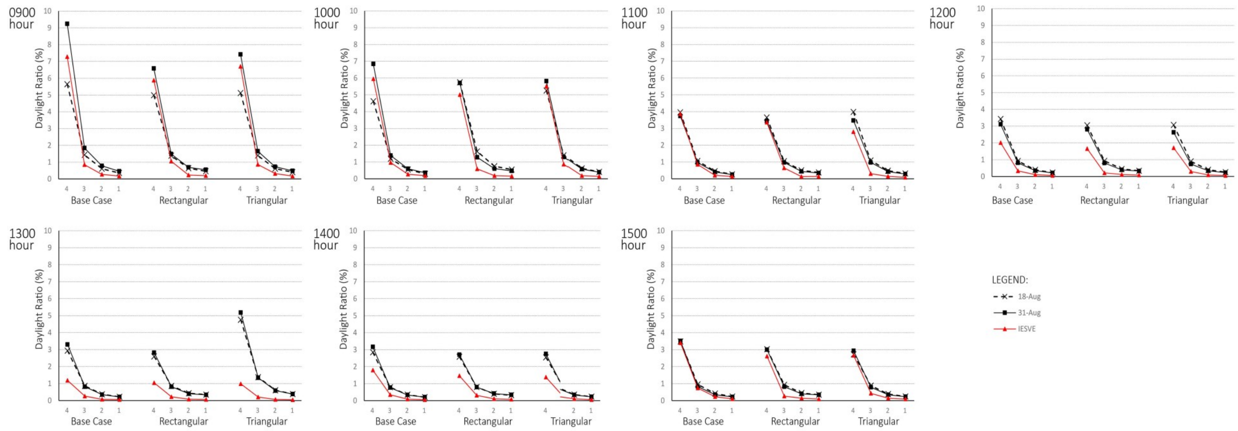

Figure 5: *Daylight Ratio comparison of experiment and simulation*

lowest DR in the stated region especially on 21 March (0900 and 1200 hours), 22 June (1500 hours) and 22 December (1200 hours) with the DR of 15.77%, 3.65%, 5.73% and 10.50% respectively. LP 2 has the lowest DR with 11.48% (0900 hours, 22 June), 68.31% (0900 hours, 22 December) while LP 1 has the lowest with 6.04% (1500 hours, 21 March), 3.95% (1200 hours, 22 June) and 14.91% (1500 hours, 22 December).

As for the 8m to 11m region which is located at the deepest end of the room, LP 5 is able to increase the DR of Base Case (at least two of the four deepest point in the room) for all the 9 timing except 1500 hours on 22 December. Furthermore, on 21 March (1200 hours), 22 June (0900, 1200 and 1500 hours) and 22 December (0900 hours), LP 5 has performed better for all the four points. Based on the three dates, the improvement of DR for the furthest point in the room (11m point) are 0.13%, 0.32%, 0.14, 0.20% and 0.61% compared to 0.10%, .027%, 0.11%, 0.15% and .051%. LP 2 on the other hand, is able to increase the DR for all the simulated timing. Therefore, it is one of the best performing LP. The third best performing LP is LP 1. With the same measuring stick used, it increases the DR of Base Case on 4 occasions throughout the simulation, where the DR achieved at 11m point are 0.11% (1200 hours, 21 March), 0.24% (0900 hours, 22 June), 0.11% (1200 hours, 22 June) and 0.14 (1500 hours, 22 June).

In the month of March, the highest DR at 0900 hours was produced by the Base Case and followed by LP 4 with the value of 21.36% and 19.16%. These values was the point nearest to the window. The lowest DR seen at the same time was LP 5 with 15.77%. As the values deteriorated across the room, LP 5 produced the highest DR at the 11m point with 0.56%. LP 4 and LP 1, however, had the lowest DR with the percentage of 0.29 and 0.35. Besides that, at 1200 and 1500 hours, the same pattern were exhibited on the 1m point where Base Case and LP 4 had the highest DR. However, LP 5 and LP 1 showed the lowest value at the respective timing with DR of 3.65% and 6.04%. At the depth of 11m in the room, LP 5 remained the highest DR percentage with 0.13% and 0.21%.

Moving on to the date of 22 June, both the Base Case and LP 4 showed the highest DR at the three period of time at 1m point with DR of 15.45% and 13.77% in the morning, 6.13% and 5.12% in the afternoon

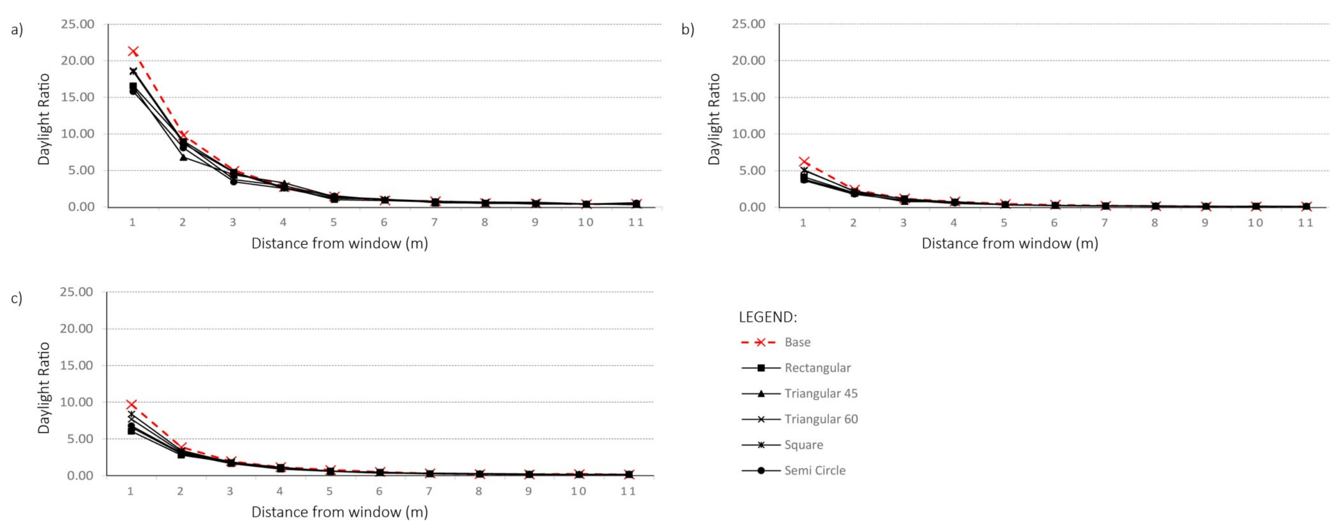

Figure 6: *DR for 21 March at 0900, 1200 and 1500 hours*

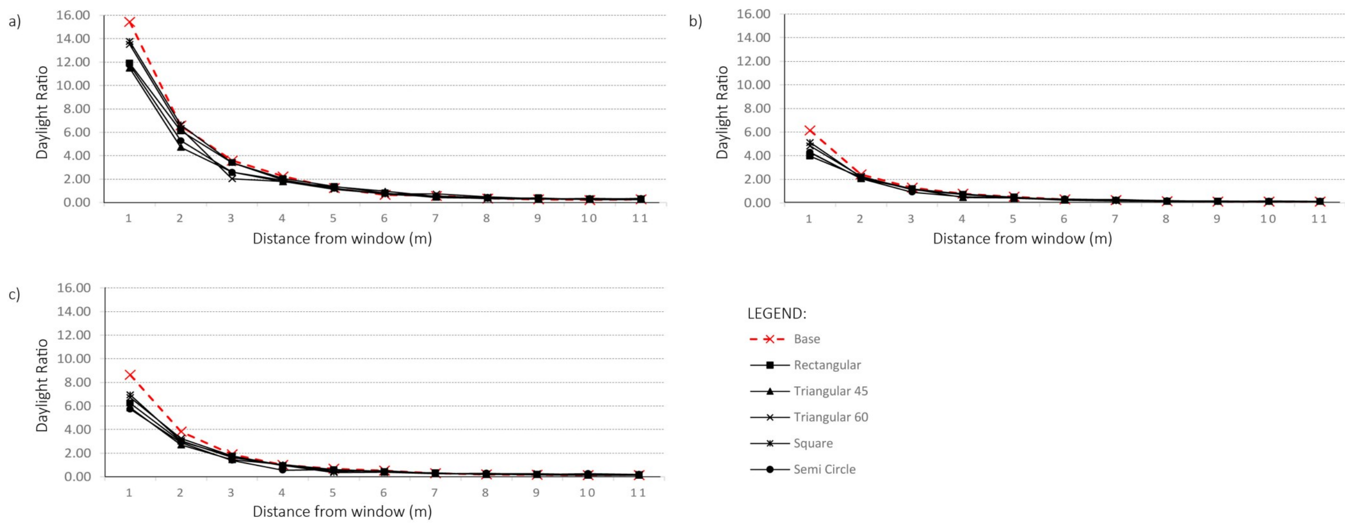

Figure 7: *DR for 22 Jun at 0900, 1200 and 1500 hours*

and 8.62% and 6.93% in the evening. As for the lowest DR, it was shown by LP 2 with 11.48% and trailed by LP 5 with 11.76% at 0900 hours. In the afternoon, LP 1 has the lowest DR with 3.95% whereas at 1500 hours, LP 5 had a DR of 5.73% while LP 2 came second with 5.85%. Meanwhile, the highest DR at the end of the room was displayed by LP 3 and LP 5 for all the three timing of the day with 0.35%, 0.14% and 0.20%. However, LP 4 had the same result in the afternoon with 0.14%.On the other hand, the lowest DR percentage were shown by LP 1 at all times.

Lastly, although there was a huge hike of DR value on 22 December, the highest DR at 1m point was shown by Base Case with 75.68% in the morning, 17.20% in the afternoon and 21.34% in the evening. The second highest DR were LP 3 at 0900 hours (72.32 %) and 1500 hours (18.28 %) and LP 4 at 1200 hours (14.84%). LP 2 has the lowest DR at 0900 hours with 68.31% while at 1200 and 1500 hours, LP 5 and LP 1 scored the lowest DR with 10.50% and 14.91%. LP 2 continued to possess the highest DR at the 11m point with 0.68% 0900 hours. The highest DR at 1200 and 1500 hours was LP 5 and LP 3 with 0.37% and 0.52%.

4.2 Daylight Factor

To take things to an extreme, an overcast sky condition was used in the simulation to evaluate the performance of the LP under the worst case scenario. The average DF for all the LP's transporter cases are shown in Figure 9. It also shows that in all the cases, the average DF falls under the category of tolerable lighting, uncomfortable glare and having tolerable thermal comfort, which is according to MS 1525:2014. LP 2 and LP 5 (DF 3.55% and 3.59%) came the closest case to comply with the standard level of DF that is in between 1.0% to 3.5%, followed by LP 1, LP 3 and LP 4 with DF of 3.67%, 3.98%

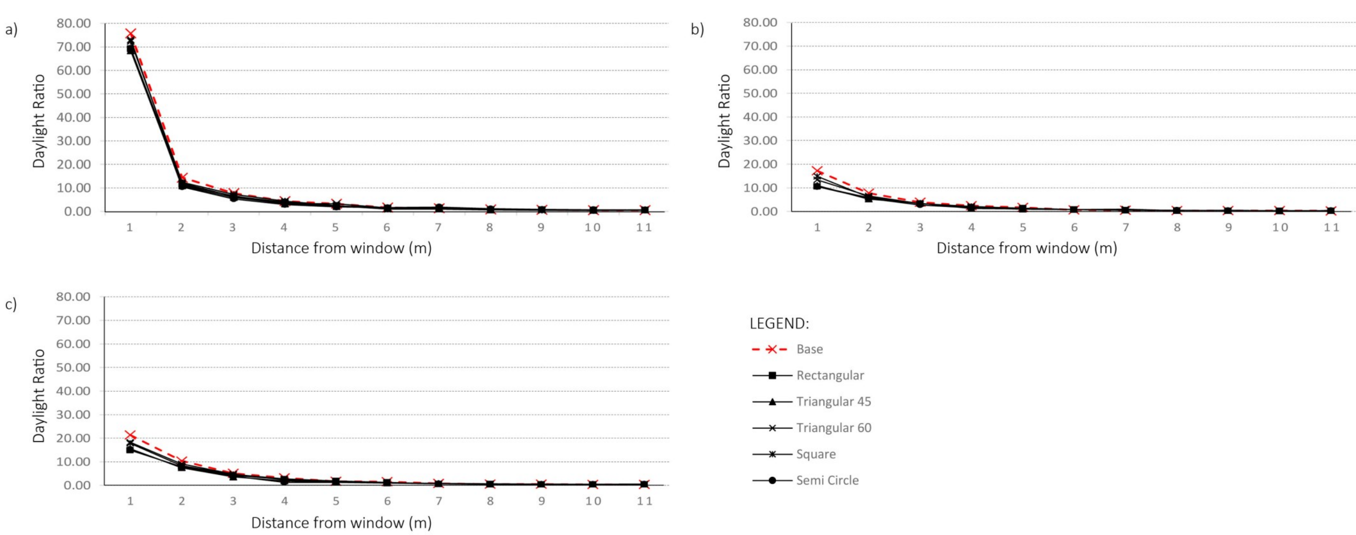

Figure 8: *DR for 22 Dec at 0900, 1200 and 1500 hours*

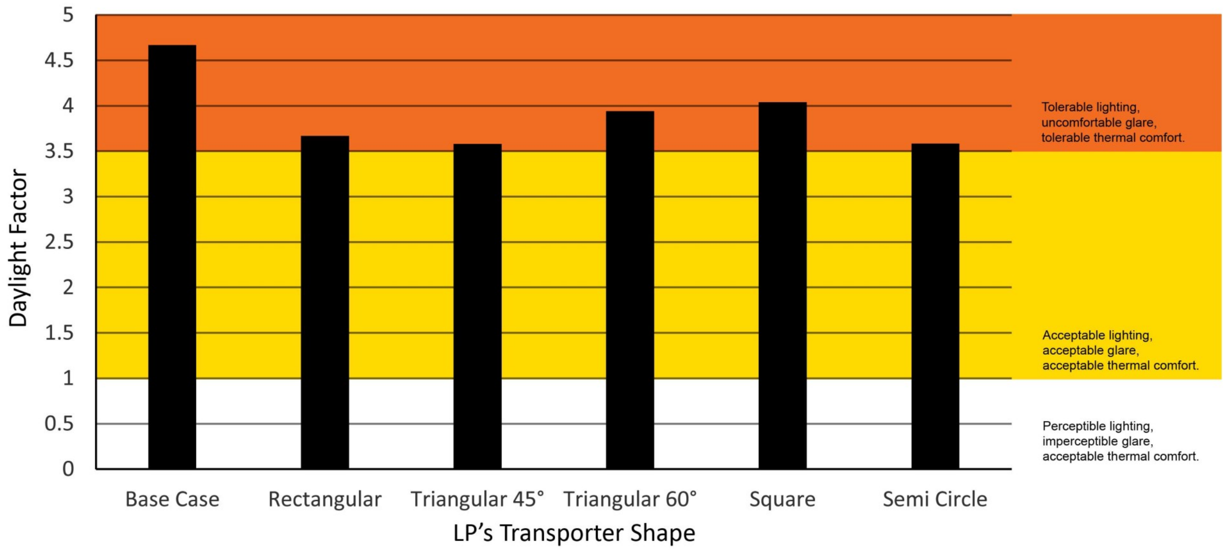

Figure 9: *Daylight Factor for different light pipe's transporter shape*

and 4.04% respectively. Therefore, all the cases with LP improves the DF of the base case (4.67%).

5. Discussion

Previous studies have been done on a number of shapes for vertical LP. However, it is not feasible to be implemented in a high-rise building due to the space limitation and the height of the building. Hence, this research focuses on the performance of horizontal LP when it is employed in a deep plan high-rise office. The impact of five shapes of LP's transporters was investigated using the simulation program IESVE.

As a general observation, the horizontal LP decreases the quantity of daylight in the area nearest to the window as the LP's collector provides shading for the room. This was more evident as the low Sun angle in 22 December caused bright sunlight patches on the work plane and walls. Moreover, in that period of time, the illumination in the room was significantly higher than the other two period of time where the difference in the morning was 72% when comparing to 21 March and 80% on 22 June. Furthermore, the illumination across the room was more uniform at the 1200 and 1500 hours compared to the morning. Hence, there is a need for shading to prevent an over illuminated area at the space nearer to the window especially in the morning.

To further discuss the LP's shape performance, the following sections are divided into two categories; daylight ratio performance and daylight factor performance.

5.1 Daylight Ratio Performance

From the result of DR analysis, the worst case scenario of all the simulated period is on 22 June where the Sun shines directly above the building. This decreases the overall DR level in the whole room as the daylight reflects more times in the transporter before entering the room, which caused the loss of light intensity. Films which has high reflective surface can be used in the transporter as to reflect the daylight to prevent this dampening effect.

The percentage difference of DR when comparing to Base Case ranged from -1% to -50%. Therefore, the LP helped in increasing the uniformity of the space. Furthermore, LP 1, LP 2 and LP 5 showed significant improvements to the Base Case as they increase the DR up to a maximum 42% at the innermost area of the 12m depth room. Therefore, the three shapes; rectangle, 45^{o} triangle and semi-circle, provided a potential reflection surfaces for the LP's transporter.

In a contrary, LP 3 and LP 4 showed low potential for a good LP shape. These cases failed to produce a good uniformity along the work plane as they unsuccessfully blocked the direct sunlight near the window and created low illuminance at the back of the room. Moreover, the acute angle of the 60^{o} triangle and small cross section of the squared shaped transporter caused the ineffectiveness of those particular LP.

5.2 Daylight Factor Performance

Daylight Factor was used to further discussed on the performance of the LP. Based on the performance of every LP shapes, all the average DF falls under the category of 3.5-6% where the lighting and thermal comfort are still tolerable while having glare problems. This shows that on an overcast sky condition, the room will have excessive lighting throughout the space. Though, it should be noted that the average DF was taken into consideration rather than the value of each point in the room. Hence, with the evaluation on the DF performance, there might be areas which adhere to the acceptable MS 1525:2014 range.

All the LP cases were able to lower the DF value of the Base Case. The first cause for this occurrence are the shading provided by the collector of the LP. The collector acts as an overhang above the opening that prevent high intensity daylight from penetrating into the room. This also helps with in providing a uniform distribution in the office itself.

Secondly, the lowering of DF is caused by the application of LP. A rectangular, 45o triangular and semi-circle shaped transporters provide the almost optimum DF result and therefore, shows that the lighting in the end of the room though the opening of the transporter elevates the illuminance of that area. Thus, this also lead to a more uniform distribution all over the room.

5.3 Limitation and future research

This research used a computer software simulation and scale modelling experiment as tools for obtaining the results. These tools may give a quantitative picture of how the illuminance level of the office room will look like but it bears the limitation of the quantitative aspect of daylight. Moreover, as claimed by Veitch et al., (1995), lighting quality can only be assessed though behavioral pattern studies. This implied the significant of having surveys in achieving the optimum data for the study. However, other methods such as study of uniformity on work plane illuminance and glare analysis may also help to provide the data needed to give an estimation of the LP's potential.

Besides that, another limitation of this research was the room used was completely empty. The absence of furniture did not represent the reality of a utilized office and it also significantly affected the light levels of the room. There would be a reduction of illuminance level if furniture were present during the simulation process and it will give a better result to the DF performance.

Finally, this study employed only the South elevation for the simulation. A more thorough research on four orientations are needed to provide a full picture of the LP's performance. It can also determine which LP's shape corresponds to respective orientation to maximize the potential of the LP.

6. Conclusions and Recommendations

In conclusion, LP 1, LP 2 and LP 5 give an optimum design on an intermediate while LP 3 and LP 5 edged the rest in overcast sky condition. Consequently, a set of two shapes, 45^o triangle (LP 2) and semi-circle (LP 5) provide alternatives to the conventional rectangular shaped transporter. The difference in surface area for each of the LP brings a potential of cost saving especially the usage of highly reflective films which are expensive in the market. This may encourage developers to incorporate the daylighting distribution system in their buildings as the current trend goes into the world of sustainability.

Besides that, the transporter shapes also give an opportunity to incorporate mechanical and electrical system into the negative space of the LP's transporter above the ceiling level and thus, promoting the usage of the daylight distribution system. Further studies are necessary to assess the qualitative performance, thermal and energy performance of the LP's shape to provide a clearer view on the feasibility of each shape as mentioned in the previous section. Moreover, studies on the daylight quality where glare and uniformity of the room can be improved by manipulating the extractor of the LP also can be done.

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