Model Study of Light Penetration Effects through Different Shadings on Window Surface

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***Abstract*—Direct sunlight penetration to the interior area in a hot and humid country like Malaysia creates high external daylight, glare, and thermal comfort problem. This problem is a significant risk factor for human health and human comfort to the occupants. This study aims to model the effects of light penetration on the window surface of the built environment. The study model used different % of cover filter on the clear surface perspex and a table lamp as the light sources from the sunlight. Three types of dotted size (i.e., 13, 19, and 25 mm) were used to measure the light penetration from three different angles (i.e., 45˚ from side 2, 45˚ from side 4, 180˚ from the centre) by using a light meter. Results show that the larger the size of the dotted filter has a high percentage of light reduction. The shading with 25 mm dotted diameter size can reduce the light penetration at the light source 45° from side 2, 45° from side 4, and 180° from the centre (top) by approximately 5.44%, 6.48%, and 4.18%, respectively, compared with 13 and 19 mm dotted diameter sizes. The high light reduction with the sizeable dotted size of the filter (i.e., 25 mm) through the window could lower the temperature inside the building and conserve the energy.**

Keywords—building; light penetration; solar energy; solar radiation; tropical country

I. INTRODUCTION

The built environment functions in controlling the direct penetration of daylight into indoor building spaces [1]. The health and productivity of people can be enhanced with excellent exposure of sunlight in indoor buildings (i.e., offices and homes) [2, 3] for comfortable living standards [4]. Hence, designing proper windows and openings is incredibly essential to create indoor light and appropriate thermal comfort, which is required for indoor activity [5]. However, the penetration of solar radiation and daylight into buildings through the windows and openings can increase the indoor heat gain and indoor air temperature. The sun radiation reaches the surface of the Earth or structures as direct radiation (27%), indirect radiation or diffuse radiation (23%), absorbed by the atmosphere (25%), reflected by the cloud (20.5%), and reflected by the ground surface (5 %) [8].

Indoor thermal comfort in a tropical region like Malaysia, which is hot and humid throughout the year, is challenging to achieve because the climate is above the comfort zone. Solar shading is a building energy efficiency measure used to overcome this problem; this measure has a vital role in saving energy within indoor buildings [8]. Many researchers have proposed ideas to solve this problem in their studies. Ahmed [9] found that a sloped shading device with a horizontal light shelf is the best shading device for the climate in Malaysia because it can reduce excess lighting. At least 10% of energy can be saved in Malaysian buildings while maintaining acceptable indoor thermal comfort. Yik and Bojić [10] suggested the switchable glazing glass window compared with the clear glass window because it can reduce the energy consumption of annual electricity for space cooling up to 6.6%.

Canadarma et al. [5] suggested the application of secondary skin or shading to achieve thermal and visual comfort. Lee et al. [6] recommended the light shelf with a width of 0.6 m and an angle of 30° that can reduce the lighting (0%–10.5%) and cooling energy consumption (6.9%–9.3%) during summer. Galagoda et al. [11] suggested the application of vertical greenery systems that can lower the indoor temperature by 2.4 °C with the averaged indoor temperature of 28 °C. The energy consumption can be reduced (10.97 MW) with financial benefits and protect the solar radiation with excessive brightness for sustainable energy development [5, 10]. Table 1 shows the recommended indoor illumination intensity standard (lux) with a different standard.

TABLE I. RECOMMENDED INDOOR ILLUMINATION INTENSITY STANDARD (LUX)

Standard	Minimum allowed illumination	Standard allowed illumination	Maximum allowed illumination
IES (USA) [12]	500	750	1000
JIS Z 9110-2010 (Japan) [13]	300	500	600
KS A 3011-2013 (Republic of Korea) [14]	300	400	600

Glare can be prevented by reducing the difference in luminance by using an external shading device and blocking the direction of solar radiation. The solar angle with the corresponding region and time, the angle of the shading device, and the orientation of the envelope should be considered when blocking the direct solar radiation, as shown in Figure 1 [15]. Choi et al., (2017) suggested the external movable shading devices prevent the overheating in indoor spaces by enhancing the thermal and lighting environment and can be used to avoid the glare. The external portable shading device is used as a shading device, as shown in Figure 2.

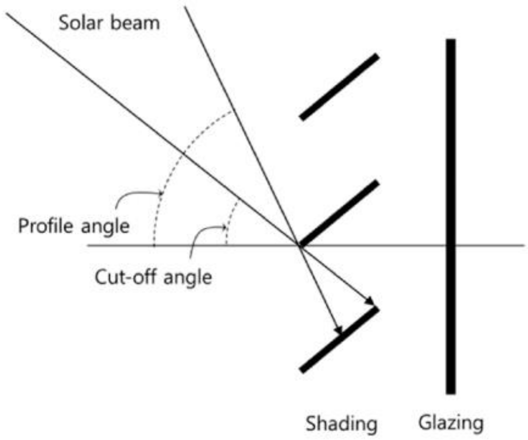

Fig. 1. *Control methods by calculating the solar angle to prevent glare at the slat angle [15].*

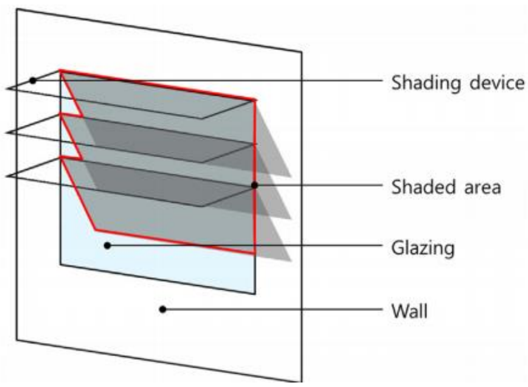

Fig. 2. *External movable shading device [16].*

II. MATERIALS AND METHOD

A. *Description of the Model Study*

The model study was conducted on a table in a research room at Universiti Sains Malaysia. The testing was performed on perspex as the transparent platform for the baseline. Overhead projector paper was used as a filter. A clear filter functions as a control to filter the light from the window. A dotted filter with diameter sizes of 13, 19, and 25 mm is used to study the effects of light penetration on the window surface. The illustration of the clear filter and dotted filter with diameter sizes of 13, 19, and 25 mm is shown in Figure 3.

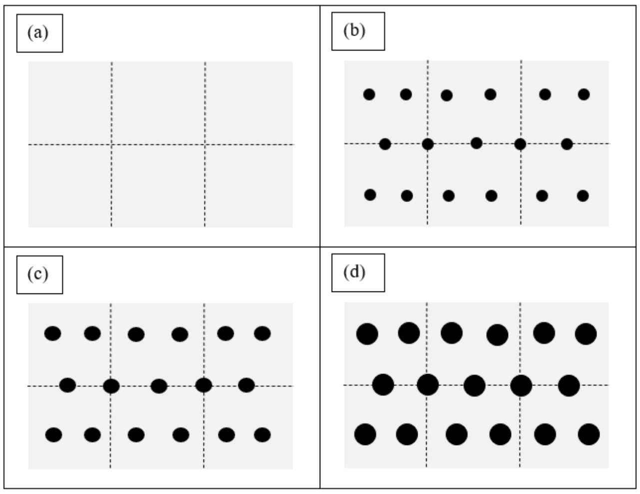

Fig. 3. *Clear filter and dotted filter with diameter sizes of (b) 13 mm dotted size, (c) 19 mm dotted size, and (d) 25 mm dotted size.*

A table lamp was used as the light source from the sunlight, as shown in Figure 4. The filter has 21 cm width and 29.5 cm length with the area of 619.5 cm2. The clear filter represents the window without shading. The filter with 13, 19, and 25 mm diameter sizes has a total number of 17 dots, representing 3.642%, 7.780%, and 13.470% of shading on the surface window, respectively.

Fig. 4. *Table lamp as the light source.*

B. *Light Penetration*

The clear filter was placed on the clear perspex as the window surface. The area below the perspex (i.e., on the table) was divided into six parts to measure light penetration. Light penetration was measured by using a light meter (Model: EXTECH instrument EasyViewTM 30 light meter), as shown in Figure 5. The light penetration was measured in three different sides, which are 45° from side 2, 45° from the side 4, 180° from the centre. This process was repeated for three times in each reading. The same procedure was then conducted for the filter with 13, 19, and 25 mm dotted diameter sizes. The top illustration of the model study 45° from side 2, 45° from side 4, and 180° from the centre is shown in Figure 6.

Fig. 5. *Light penetration is measured by using a light meter (Model: EXTECH instrument EasyViewTM 30 light meter).*

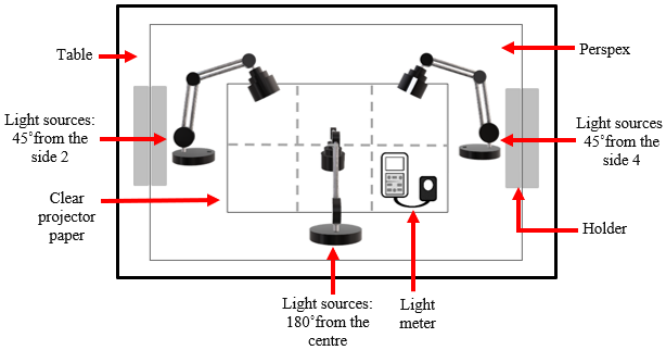

Fig. 6. *Top illustration of the model study (i.e., the light source at 45° from side 2, 45° from side 4, and 180° from the centre on a table).*

III. RESULTS AND DISCUSSIONS

The building envelope design involves many considerations, but the most important is the fenestrations, which are the windows and skylights. Table 2 shows the descriptive table of lux reading for the clear filter with 13, 19, and 25 mm diameter sizes. The results show the same pattern of light source reading at 45° from side 2, 45° from side 4, and 180° from the centre (top). The highest average lux reading of light source was dominated from the clear filter, followed by 13 mm diameter dotted size, 19 mm diameter dotted size, and 25 mm diameter dotted size. The average lux readings of light source at 45° from side 2 of the clear filter, 13 mm dots, 19 mm dots, and 25 mm dots filter are 655.220, 650.500, 632.440, and 620.890 lux, respectively, whereas from side 4 are 650.890, 647.000, 642.000, and 612.390 lux, respectively. The light sources at 180° from the centre (top) of clear filter, 13 mm diameter dots, 19 mm diameter dots, and 25 mm dots are 881.890, 878.000, 871.220, and 846.330 lux, respectively.

TABLE II. DESCRIPTIVE TABLE OF LUX READING FOR THE CLEAR FILTER, 13 MM, 19 MM, AND 25 MM DOTTED FILTER

	Clear FILTER	13 mm diameter dotted size (lux)	19 mm diameter dotted size (lux)	25 mm diameter dotted size (lux)
Light sources at 45º from Side 2				
Avg.	655.220	650.500	632.440	620.890
Min.	523.667	516.000	471.667	471.667
Max.	790.333	788.000	786.667	757.333
SD.	103.960	104.720	122.290	108.510
Light sources at 45º from Side 4				
Avg.	650.890	647.000	642.000	612.390
Min.	432.333	428.667	425.667	368.667
Max.	758.667	755.333	752.667	742.333
SD	151.270	152.510	151.980	158.250
Light sources at 180º from the centre (top)				
Avg.	881.890	878.000	871.220	846.330
Min.	814.333	800.000	772.000	721.333
Max.	964.333	961.667	967.333	947.667
SD	63.730	68.270	77.000	86.560

Figure 7 illustrates the average reading of light penetration (lux) for the clear filter and dotted filter (i.e., 13, 19, 25 mm) with (a) light source 45° from side 2, (b) light source 45° from side 4, and (c) light source 180° from the centre (top).

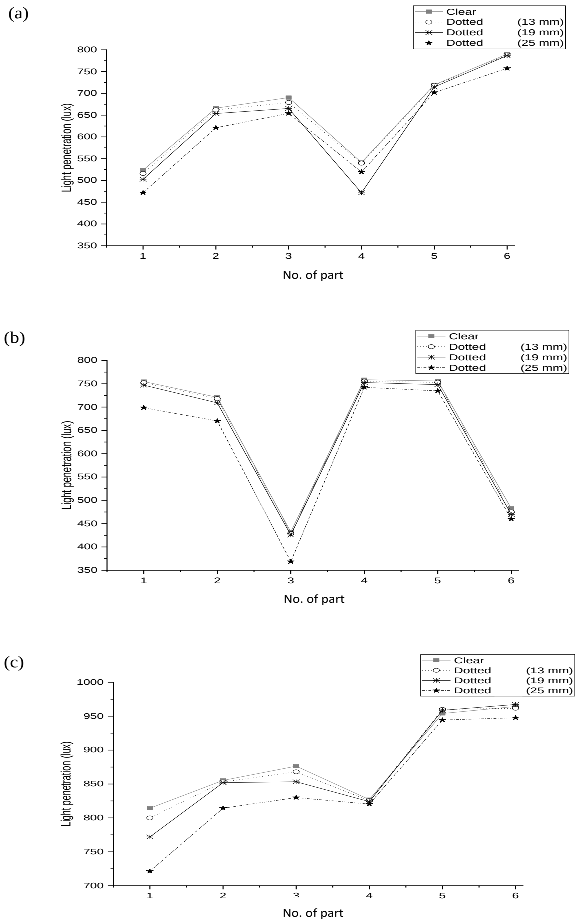

Fig. 7. *Average reading of light penetration (lux) for the clear filter and dotted filter (i.e., 13, 19, 25 mm) with (a) light source 45° from side 2, (b) light source 45° from side 4, and (c) light source 180° from the centre (top).*

Table 3 shows the percentage of light reduction for the dotted filter with 13, 19, and 25 mm diameter sizes. The results show that the highest rate of light decline is dominated by 25 mm, followed by 19 and 13 mm dots for all of the three positions of light sources (i.e., the light source 45° from side 2, the light source 45° from side 4, and light source 180° from the centre (top)). The average percentages of light reduction at the light source 45° from side 2 for 13, 19, and 25 mm diameter sizes are 0.75%, 3.92%, and 5.44%, respectively, whereas from side 4 are 0.68%, 1.46%, and 6.48%, respectively. The average percentages at the light source 180° from the centre (top) are 0.47%, 1.30%, and 4.18%.

TABLE III. PERCENTAGE OF LIGHT REDUCTION FOR THE DOTTED FILTER OF 13, 19, AND 25 MM DIAMETER SIZES WITH % COVERAGE OF 3.642%, 7.780%, AND 13.470%, RESPECTIVELY

Dotted FILTER with light source 45° from Side 2			
No.	13 mm (%)	19 mm (%)	25 mm (%)
1	1.46	4.01	9.93
2	0.60	1.85	6.76
3	1.64	3.62	5.26
4	0.31	12.87	4.06
5	0.19	0.69	2.45
6	0.30	0.46	4.18
Avg.	0.75	3.92	5.44
Dotted FILTER with light source 45° from Side 4			
No.	13 mm (%)	19 mm (%)	25 mm (%)
1	0.35	1.02	7.42
2	0.42	1.66	7.07
3	0.85	1.54	14.73
4	0.44	0.79	2.15
5	0.40	1.06	2.82
6	1.59	2.69	4.70
Avg.	0.68	1.46	6.48
Dotted FILTER with light source 180° from the centre (top)			
No.	13 mm (%)	19 mm (%)	25 mm (%)
1	1.76	5.20	11.42
2	0.27	0.39	4.79
3	0.95	2.62	5.29
4	0.20	0.36	0.81
5	-0.63	-0.49	1.01
6	0.28	-0.31	1.73
Avg.	0.47	1.30	4.18

The results show that a negative average percentage of light reduction is found for 13 mm diameter dotted size at box no. 5 (−0.63 %) and for 19 mm diameter dotted size at box nos. 5 (−0.49 %) and 6 (−0.31 %). This result indicates that no light reduction is found at the particular part when the light sources are at 180° from the centre (top) although shading is applied. The results show that the solar radiation is directed through the windows (light source angle of 180°) compared with the light source angle (45°) from sides 2 and 4. In the real situation, the results indicate that the temperature is lower before the occurrence of solar radiation, whereas it is high during solar radiation at 12 pm. Bakhlah and Hassan [17] recorded the lowest temperature on the south side of the mosque's building in the afternoon (1200 h) because the walls and roof surfaces are indirectly exposed to solar radiation.

IV. CONCLUSION

The high external daylight, glare, and indoor thermal comfort problems caused by direct sunlight penetration contributed to the occupants' discomfort. This study was conducted to model the effects of shading (i.e., filter) on the window panel to reduce the direct sunlight penetration to the interior area buildings. The study model was tested by using clear and dotted filters on the clear perspex and a table lamp as the light source from the sunlight. Three types of dotted size (i.e., 13, 19, and 25 mm) with % cover of 3.642%, 7.780%, and 13.470 %, respectively, were used to measure the light penetration by using a light meter. The light penetration reading was measured in three different angles (i.e. 45° from side 2, 45° from side 4, 180° from the centre). The results show that the larger the size of the dotted filter has a high percentage of light reduction. The shading with 25 mm dotted diameter size can reduce light penetration at the light source 45° from side 2, 45° from side 4, and 180° from the centre (top) by approximately 5.44%, 6.48%, and 4.18%, respectively, compared with the 13 and 19 mm dotted diameter sizes. The high light reduction with the large dotted size of the filter (i.e., 25 mm) through the window can lower the temperature inside the building and conserve the energy. Therefore, the dotted shade application improves indoor thermal comfort and reduces the energy consumption within interior buildings.

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