Impact of Adjustable External Horizontal Shading Slats on Indoor Visual Comfort in Tropical Climate

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Abstract

The main function of windows is to provide natural light and a view of the outdoor surroundings. Excessive direct sunlight penetrating into interior spaces through the windows poses glare and contrast problems in addition to excessive beam solar radiation which leads to high cooling loads. Shading slats are installed to block beam radiation and enhance the general visual environment for building occupants. Despite their proven energy saving potential, building designers tend to shun these shading devices for reasons such as maintenance costs, aesthetics, glare possibility and their interference of occupants' view of the outdoor surroundings. In this paper the impact of adjustable external horizontal shading slats on occupants' visual comfort and view was investigated. Full scale experiments were conducted under the dynamic tropical climate of Thailand. Annual simulations using full-year weather records were undertaken for a model room for cases of north and south facing windows to establish appropriate monthly slat adjustment angles that block undesired direct sunlight while guaranteeing the maximum possible view of exterior surroundings. Window luminance and work plane illuminance levels were examined and compared with proposed thresholds for comfortable working environments from previous studies. Lighting energy consumption and savings were also investigated in comparison to windows with heat reflective glass, commonly preferred by building designers. The study showed that it is possible to save 40% to 60% of energy consumed by electric lamps, avoid glare and achieve a comfortable workspace with a good view of exterior surroundings for most of the year by use of adjustable external horizontal shading slats.

Keywords: free view fraction, external horizontal slats, glare, energy savings

Introduction

Shading slats shield building occupants from adverse outdoor conditions such as undesired solar radiation and excessive daylight. The comfortability of the indoor environment determines energy consumption. Reduction of energy consumption by installation of shading slats remains a popular theme for many researchers. Studies by Chaiwiwatworakul, Chirarattananon, and Matuampunwong (2012), Chirarattananon, Chaiwiwatworakul, and Pattanasethanon (2002) and Chaiyapinunt and Nopparat (2013) extensively examined daylight availability, energy savings and solar radiation transmission through shading slats in tropical regions. However, precise studies on the impact of the adjustable external slats on the occupants' view and general visual comfort of workspaces remain scarce. A good outdoor view is difficult to quantify since occupants' preferences vary greatly. Some researchers analyze outdoor view by examining the free view fraction defined by Wirth and Gombert (1999) as 'the fraction of the window area that allows for unobstructed view between the slats in a given direction'. Tzempelikos (2008) presented a discussion on how slat geometry (curvature and thickness) impacts an occupant's view of the outdoor environment. A slat separation to slat width ratio of 1 was considered. It was also assumed that the occupant mostly looks outside in a horizontal direction. It was noted that the effect of slat thickness for thin slats is negligible. Likewise, the effect of slat curvature for slightly curved slats is also insignificant. Parmelee and Aubele (1952) also established that decreasing the slat separation to slat width ratio decreases the viewing potential of the slats. These studies did not examine the full year adjustment schemes and changes in free view fraction under real weather conditions.

Other important aspects of an occupant's visual environment that determine comfortability of indoor spaces include the glare and work plane illuminance levels (Da Silva, Leal, & Andersen, 2012). This study examines the monthly adjustment angles for manually controlled external horizontal shading slats to completely shade beam sunlight and ensure a maximum possible view of the outdoor surroundings. Glare possibility and work plane illuminance levels for office spaces with this shading device were also examined based on proposed limits that guarantee a comfortable working environment. Lighting energy consumption and savings were also estimated.

Methods and Materials

Calculation of slat angles that shade direct sunlight

Slat tilt angles that completely block beam daylight and radiation were determined using the proportion of the sunlit area to the total area on the glazing F_b discussed by Chaiwiwatworakul, Fathoni, and Mettanant (2016). Figure 1 shows the case where direct solar radiation is partly shaded by horizontal slats and Eq. (1), (2) and (3) are used to calculate the F_b values for various slat tilt angles. W_b represents the slat width, S_b is the slat separation distance, φ_b is the slat tilt angle and φ_s is the solar profile angle. For a given slat tilt angle to completely shade direct solar radiation in a given month the F_b value must remain zero for the entire month.

$$F_b = 1 - \frac{W_b - \sin\varphi_b}{S_b} - \frac{W_b \cos\varphi_b \tan\varphi_s}{S_b}, \text{ for } \varphi_b \geq 0^\circ \quad (1)$$

$$F_b = 1 - \frac{W_b - \sin|\varphi_b|}{S_b} + \frac{W_b \cos|\varphi_b| \tan\varphi_s}{S_b}, \text{ for } \varphi_b < 0^\circ \text{ and } \varphi_s < |\varphi_b| \quad (2)$$

$$F_b = 1 + \frac{W_b - \sin|\varphi_b|}{S_b} - \frac{W_b \cos|\varphi_b| \tan\varphi_s}{S_b}, \text{ for } \varphi_b < 0^\circ \text{ and } \varphi_s \geq |\varphi_b| \quad (3)$$

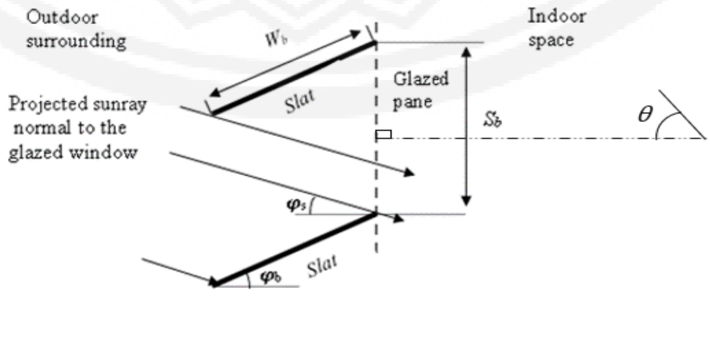


Figure 1 Incidence of direct sunlight on a window with shading slats

Calculation of free view fraction

Analysis of outward view was performed using the concept of free view fraction defined as the fraction of the window area that allows for unobstructed view in a given direction and is a function of the solar profile angle and the slat tilt angle. Tzempelikos (2008) observed that the effect of slat thickness on the free view fraction can be ignored for thin slats. The free view fraction is calculated using Eq. (4) and (5) (Kolas, 2013, p.74) which are modifications of the calculation procedure outlined by Wirth and Gombert (1999). Only downward slat tilting was examined in this study since the main focus was to block direct solar radiation.

$$f(\theta) = 1 + \frac{\cos\varphi_b \tan\theta + \sin\varphi_b}{S_b / W_b}, \quad \text{for slats tilted upwards} \qquad (4)$$

$$f(\theta) = 1 - \frac{\cos\varphi_b \tan\theta + \sin\varphi_b}{S_b / W_b}, \quad \text{for slats tilted downwards} \qquad (5)$$

where f is the free view fraction in a given viewing direction and θ is the viewing direction shown in Fig.1. An S_b / W_b ratio of 0.8 was considered. It was assumed that the occupant was looking outside through the window in a horizontal direction perpendicular to the vertical plane of the window ($\theta = 0$). Table 1 shows calculated free view fraction values of the angles considered in this study. $f(\theta)$ decreases gradually as the slats are tilted downwards from 0 degrees towards 50 degrees. A view fraction greater than 0.5 implies that more than half of the possible view of the exterior surroundings is achieved and is therefore considered to be desirable in this study.

Table 1 Free view fractions for different angles

φ_b	**Free view fraction** $f(\theta)$	**Description**
0	1	Full view
10	0.79	
20	0.58	↓
30	0.38	
40	0.20	
50	0	No view

Calculation of daylight illuminance through a window with shading slats

The daylight illuminance at an interior point consists of daylight emanating directly from the window and that from inter-surface reflection. A calculation algorithm described by Chaiwiwatworakul, Chirarattananon, and Rakkwamsuk (2009) was adopted since the predetermined slat angles completely shade beam sunlight for the whole year. The window and interior surfaces are subdivided into small segments. The illuminance E_{di} received directly from the window at a point i as shown in Figure 2 is contributed by the incremental light flux from an incremental patch da calculated using Eq. 6.

$$E_{di} = \int_{\gamma}\int_{\phi} L_w \cos\eta \sin\phi \, d\phi \, d\gamma \qquad (6)$$

L_w is the window luminance varying with line of sight from point i to the patch *da*, η is the incidence angle between the line of sight and the normal to the plane of the window, ϕ and γ are angles relating to the patch *da* and the point *i*. The ASRC-CIE sky model (1990) is used to determine the luminance of a sky patch. The radiocity method and configuration factors are used to account for inter-slat reflections. These calculation algorithms were integrated into a simulation program written in visual basic language and validated by comparison with experimental data.

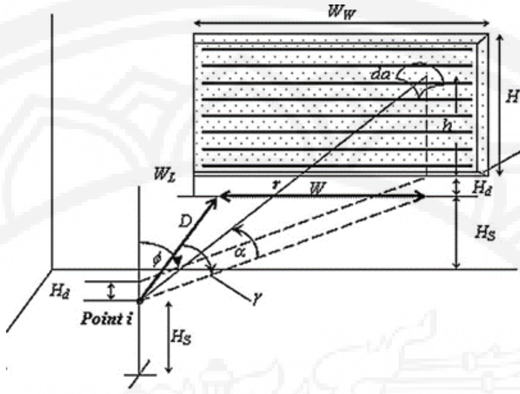


Figure 2 Light flux reaching a point i inside a room from a patch of window

Experimental set up

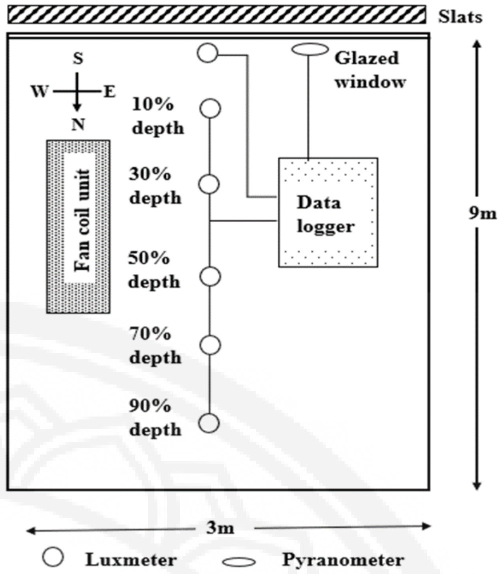
The experiment was conducted in a full-scale room located on the rooftop of the School of Bio-resources and Technology Building at the Bang Khun Tien campus of the King Mongkut's University of Technology Thonburi (latitude 13.7° N and longitude 100.44° E). The manually controlled external horizontal slat system is installed on the south facing window of the full-scale room. A data acquisition system and lux meters were installed to measure daylight illuminance along the work plane inside the experimental room. The global, beam, and diffuse exterior daylight illuminances and solar radiation in the south and north orientations were measured by a meteorological station located at the same campus.

The full-scale experimental room in Fig. 3 (a) was 9 m long and 3 m wide with a height of 2.66 m. The window was 3m wide and 1.8 m high with horizontal slats of width 0.125m and a slat separation distance of 0.1 installed on the exterior faÇ ade of the south facing window. Interior illuminance was measured at five points located on a line perpendicular to the windowed wall on the work plane level of 0.8 m above the floor along the center of the room. The five points were at room depths of 10%, 30%, 50%, 70% and 90%. Slat tilt angles of 0º and 30º were selected for the experiments.

Table 2 Properties of materials used in the study

	Slat	**Clear glass**	**Heat reflective glass**	**Opaque wall**
Material	Aluminum	Glass	Glass	Lightweight concrete
Thickness (m)	0.002	0.006	0.012	0.1
Visible transmittance	0	0.88	0.09	0
Visible reflectance	0.8	0.08	0.32	0.5
Solar transmittance	0	0.8	0.06	0
Solar reflectance	0.8	0.07	0.33	0.5

(a) Full-scale room



(b) Experimental set up

Figure 3 Experimental site and set up

Specific properties of the surface materials of the room are shown in Table 2. The complete setup is shown in Fig. 3 (b). A data logging system was used to record the measured data from the sensors every minute. The measured work plane illuminance and transmitted radiation were compared with the calculated values for validation of a developed simulation program. Photographs were also taken for each of the slat tilt angles for examination of free view fraction.

Results

Experiments were carried out for a south facing window on two different days to validate the daylight calculation algorithm. During the experiments, the outdoor daylight and solar irradiance varied during daytime hours. The first experiment was carried out for slats at 0° (fully open). The measured results are shown in Fig. 4 alongside the calculated result. It was observed that the sky was clear on the experimental day. The global illuminance (E_vg) reached 88 klux while the solar irradiance (E_eg) was 900 W/m^2 at noon (Fig. 4(a) and (b)). The sky diffuse components (E_vd and E_ed) were low throughout the day. In this experiment, the slats fully intercepted the direct incident beam sunlight. Despite the sun appearing in front of the window for the whole day, transmitted daylight (E_vT) was only 5-10 klux or 10-20% of the total vertical illuminance values (E_vS).

In the experimental room, the work plane daylight (E_vi) near the window (10%D and 30%D) was higher than 500 lux throughout the measured period as shown in Fig. 4(c). This illuminance level was sufficient for lighting, but it was quite high exceeding 2,000 lux. Near the rear wall (70%D and 90%D), the illuminance dropped to 100-250 lux, but it was still applicable for general lighting (Fig. 4 (d)). The transmitted daylight (E_vT) and transmitted radiation (E_eT) had a similar trend as shown in Fig. 4 (e) and (f). The incident vertical daylight (E_vS) and incident irradiance (E_eS) were about 4 times more than the corresponding transmitted values. It was observed that the measured and calculated values were comparable thus validating the daylight calculation algorithm.

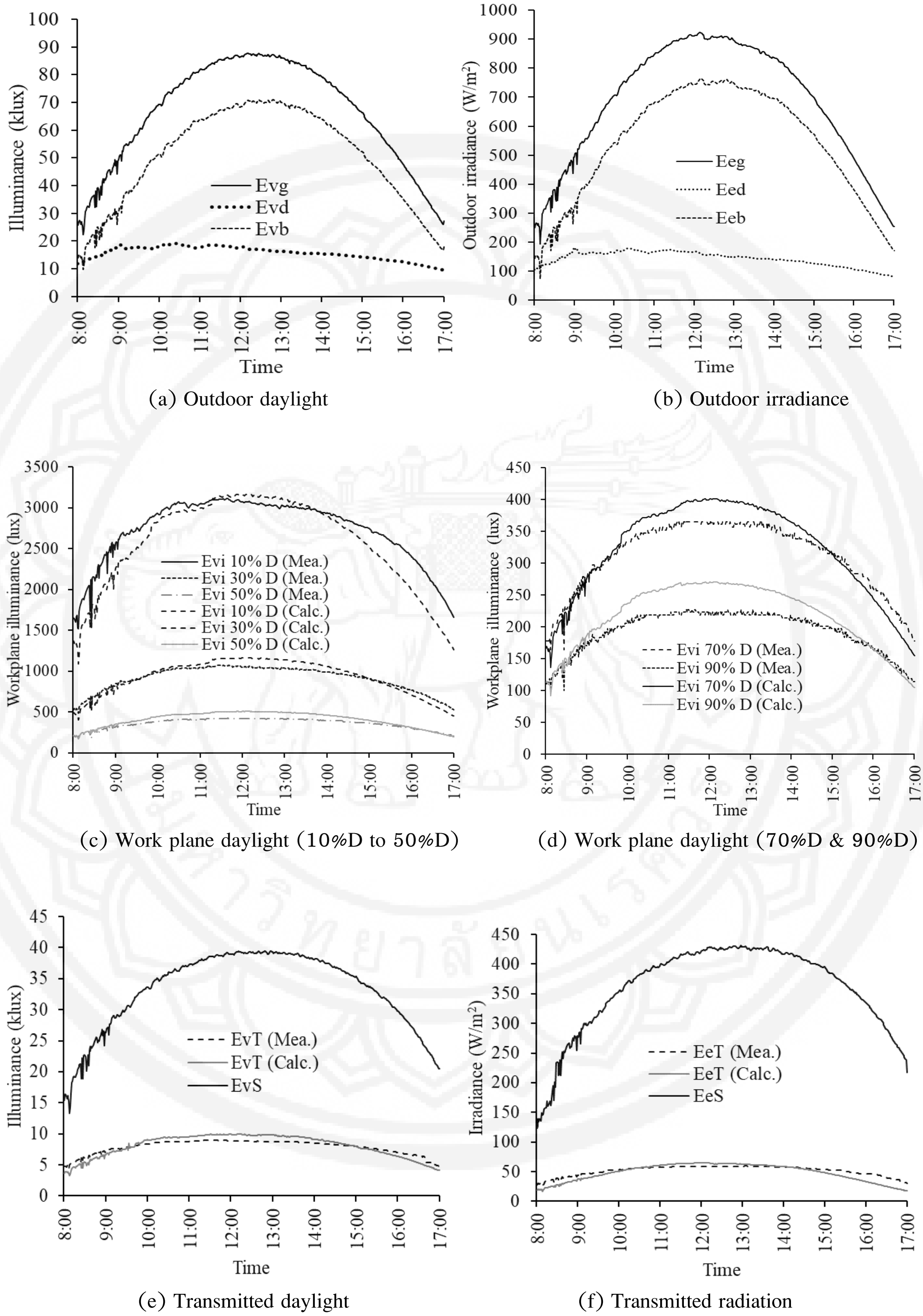
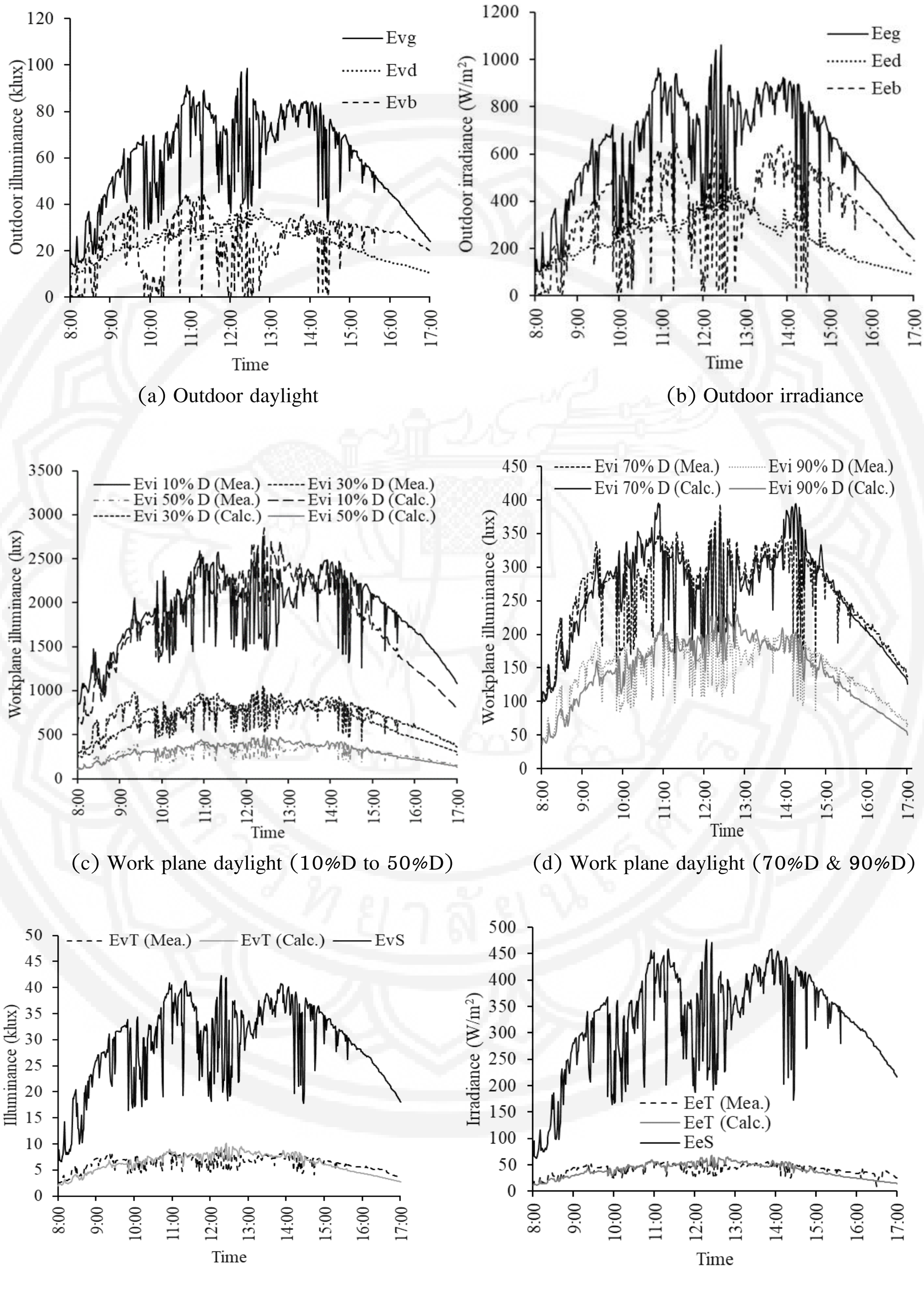


Figure 4 Experiment of the daylight from a south window with the slat angle 0°

Another experiment was carried out for slats tilted at 30°. On this day the sky was partly cloudy with largely variable outdoor daylight. However, the daylight was still excessive and the global illuminance reached 80-100 klux (Fig. 5(a)). The corresponding solar irradiances are given in Fig. 5(b).



(a) Outdoor daylight (b) Outdoor irradiance

(c) Work plane daylight (10%D to 50%D) (d) Work plane daylight (70%D & 90%D)

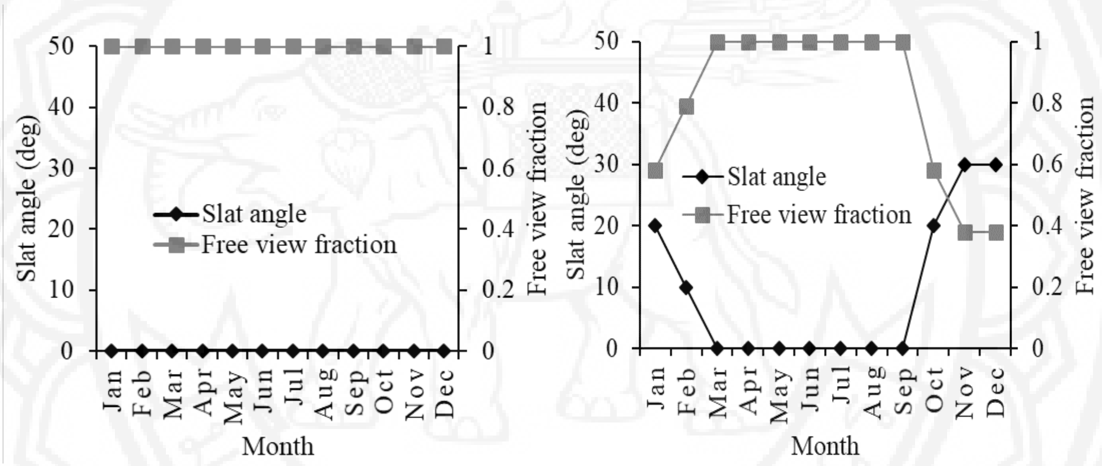
(e) Transmitted daylight (f) Transmitted radiation

Figure 5 Experiment of the daylight from a south window with the slat angle 30°

Tilting the slats to 30° intercepted more daylight and thus reduced its transmission into the room. However, the work plane daylight near the window was sufficient for lighting without any additional electric lighting. In this experiment, reducing the transmitted daylight improved the illumination quality as the excessive daylight was alleviated. Variation of the work plane illuminance was also alleviated by the slats despite the large and rapid fluctuation of outdoor daylight. Measured and calculated results were also comparable.

Monthly slat adjustment angles and free view fraction

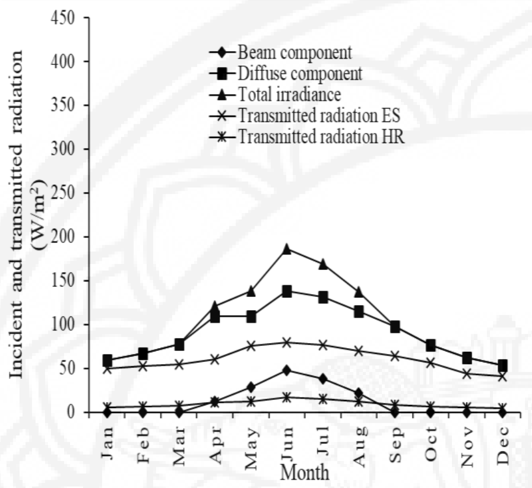
The validated program was used to simulate interior daylight through north and south facing windows equipped with external horizontal shading slats for a whole year. An hourly record of full year weather conditions in Thailand was used. A model room with similar dimensions and properties as the experimental room was selected for illustration. Simulations for slat tilt angles of 0°, 10°, 20°, 30°, 40° and 50° were performed to determine the Fb values for each angle during each month of the year. The smallest angle with a maximum Fb value of zero achieved during the month was selected implying that slats tilted at that angle blocked beam solar radiation for the whole month. The final monthly slat adjustment angles for each month are shown in Fig. 6(a) and (b).



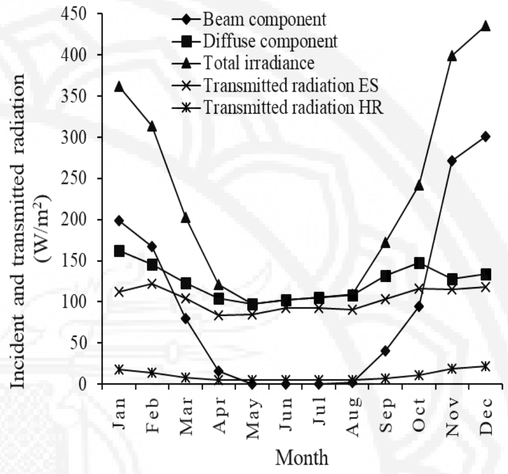
(a) North window (b) South window

Figure 6 Slat adjustment angles and free view fraction

Free view fractions were determined for each of the monthly slat adjustment angles in Table 1 as previously outlined. The resultant free view fractions are also shown in Fig. 6 (a) and (b) for north and south facing windows respectively. Full year simulations proved that the selected angles block undesired direct sunlight for the whole year as illustrated in Fig. 7(a) and (b). ES represents the window with adjustable external slats and HR represents the reference case of the window with heat reflective glass. For the north facing window with external slats, incident and transmitted radiation were highest in June (200 W/m^2) when the sun was directly in front of the window and decreased as the sun moved overhead and southwards. The south window exhibited an opposite trend with highest incident radiation in December (450 W/m^2). The transmitted radiation followed a similar trend to diffuse radiation but the values were quite close due to interreflection between the slats. The steeper slat angles during the sun facing months considerably reduced transmitted radiation. Figures 8 (a) to (f) show the photographs of the outward view from inside the full-scale room with the slats at 0°, 10°, 20°, 30°, 40° and 50° representing view fractions of 1, 0.79, 0.58, 0.38, 0.2 and 0 respectively. The photographs were taken by an occupant sitting on an office chair 3m from the window looking outside in a horizontal direction from the plane perpendicular to the window. Outdoor surrounding objects such as the sky, buildings, vegetation and the general horizon were clearly visible for angles of 0°, 10° and 20° translating to free view fractions above 0.5 hereby deemed to be desirable. However, the outdoor surrounding objects were barely visible at 30° and not visible at 40° and 50° which represent view fractions less than 0.5 hereby considered to be undesirable.



(a) North window



(b) South window

Figure 7 Incident and transmitted solar radiation

(a) $\varphi_b = 0, f(\theta) = 1$

(b) $\varphi_b = 10, f(\theta) = 0.79$

(c) $\varphi_b = 20, f(\theta) = 0.58$

(d) $\varphi_b = 30, f(\theta) = 0.38$

(e) $\varphi_b = 40, f(\theta) = 0.20$

(f) $\varphi_b = 50, f(\theta) = 0$

Figure 8 Outdoor view through slats at different angles

Figure 6 (a) shows that for north facing windows at the study location, a fixed slat angle of 0° can block beam radiation for the whole year and still achieve a free view fraction of 1 which indicates a complete unobstructed view of exterior surroundings for the whole year. This is because the sun is primarily either overhead or moving southwards for most of the year. A high sun position is maintained for the brief period when the sun moves northwards thus a fixed slat angle of 0° is sufficient to block beam solar radiation for the whole year.

For south facing windows, the sun moves southwards from October to February therefore slats were tilted downwards at larger angles to block beam radiation during periods of low sun position as shown in Fig. 6 (b). However, the free view fraction was higher than 0.5 for ten out of twelve months or 83% of the year. A full unobstructed view was achieved for seven out of twelve months or 58% of the year. The free view fraction was less than 0.5 only during the months of November and December with an outward view equivalent to Fig. 8 (d).

It was also noted that fixing the slats at an angle of 30° for south facing windows can block beam radiation for the whole year and achieve a constant free view fraction of 0.38 throughout the year. A full unobstructed view was not attainable for the south facing window hence adjusting the slats on a monthly basis is better than fixing the slats at one angle for the whole year.

Visual comfort

Lighting quality perception is influenced by numerous factors in human psychology such as mood of occupants, privacy and view of the outdoor surroundings. These factors are difficult to quantify objectively hence many researchers propose the study of visual comfort concurrently with other considerations such as energy efficiency and task performance conditions. Da Silva et al. (2012) reviewed a number of studies on evaluation of visual comfort in office buildings. It was noted that visual comfort evaluation is mainly based on illuminance levels. Recommendations have also been made by several studies on luminance-based assessment but proposed ranges vary greatly causing numerous discrepancies concerning energy consumption and design options. Table 3 shows a summary of recommended illuminance and luminance levels proposed by da Silva for assessment of task performance conditions for visual comfort in office spaces. Exceeding the recommended limits is likely cause glare.

The visual comfort from daylighting was evaluated against the recommended illuminance and luminance levels for office spaces proposed by da Silva. Figure 9(a) shows the maximum work plane illuminances for the same model room with a south facing window equipped with adjustable external horizontal slats as previously discussed. Recommended maximum work plane illuminance for comfortable office spaces should fall between 1,280 and 1,800 lux. Depth to window height (D/H) values of 0.5, 1.5, 2.5, 3.5 and 4.5 in the figure corresponded to points on the work plane at 10%, 30%, 50%, 70% and 90% of the room depth, respectively. The work plane illuminance at D/H>1 was within the proposed limits and daylight did not cause visual discomfort.

However, the work plane illuminance at D/H<1 often exceeded the proposed limits and could cause visual disturbance to the occupants. Based on the proposed limits, it is advisable for workstations used for paper-based tasks to be located at D/H = 3 to D/H = 5 and those for computer-based tasks at D/H=7 to D/H=9. This may be difficult to implement because of the dynamic nature of office space functions and preferences of occupants.

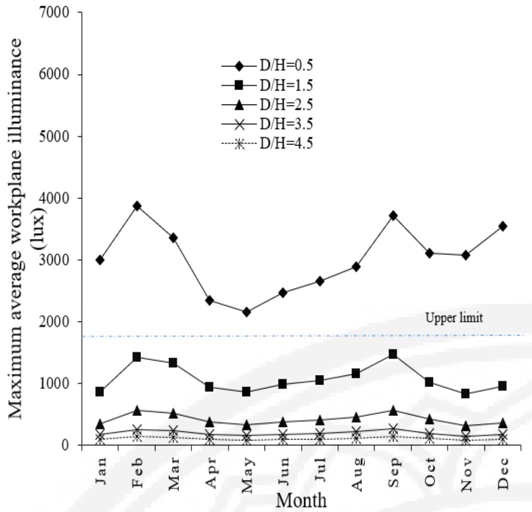
Table 3 Recommended illuminance and luminance levels for comfortable office spaces (Da Silva et al., 2012)

Parameter		Recommendation
Illuminance	Work plane illuminance (lux)	[100-300] - Computer based tasks
		[200-600] - Paper based tasks
		[1,280-1,800] - Max. values
	E_{min} / E_{max} work plane	[>0.5] - Acceptable
		[>0.8] - Recommended
	$E_{surrounding}$ / E_{task}	[0.2-0.8]
Luminance	Work plane luminance (cd/m^2)	[40-50]
	Window luminance (cd/m^2)	Max. values [4,000-6,000]
	Wall luminance (cd/m^2)	[5-179] Max. value: 1,000
	Glare source luminance (cd/m^2)	Max. value 2,500
	Ceiling luminance (cd/m^2)	Max. value [4,000-6,000]
	Average visual field illuminance (cd/m^2)	[20-75]
	L_{paper} / $L_{surrounding}$	[0.33-0.3]

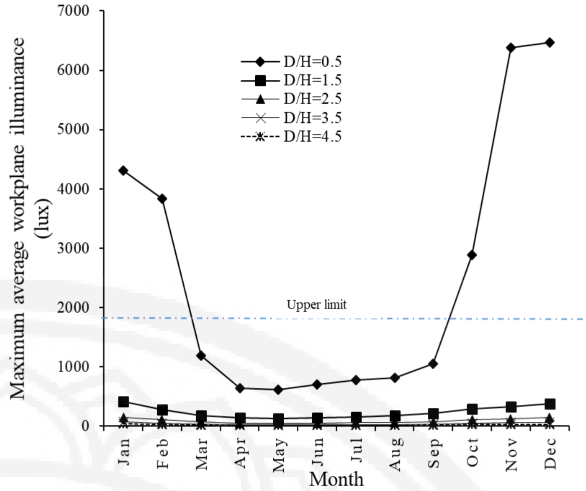
A similar analysis was performed for the model room with unshaded heat reflective glass, a common feature of commercial buildings in Thailand. In this case, the work plane illuminance level was within the recommended limits for D/H>1. It was also observed that beam daylight penetrated into the room during the sun facing months from November to February thus causing excessive work plane daylight at D/H<1 largely exceeding the recommended limit. Work plane daylight was also lower that the target illuminance of 500 lux between D/H = 3 to D/H = 5 indicating a necessity for supplementary electrical lighting, unlike the case of the window with external slats.

The possibility of glare occurrence was analyzed using window luminance levels. Da Silva proposed that the maximum window luminance should lie between 4000-6000 cd/m^2 and exceeding this can result in glare. Figure. 9(c) shows the maximum window luminance the two cases for a full year. It was observed that the window with heat reflective glass prevented glare for the whole year. The window with external slats also performed relatively well avoiding glare for most of the year except some instances in February, March and September. However, glare may still be quite rare because the luminance levels shown were based on averages of maximum values for each day and not the average mean window luminance.

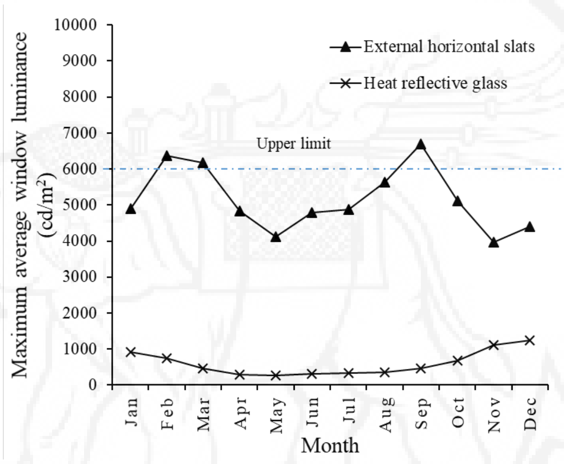
Similar results of maximum workplace illuminance were observed for the north window as shown in Fig. 10. The window luminance remained lower than the upper limit proposed for glare avoidance. This implied that glare was avoided for the whole year for both cases of the window with heat reflective glass and the window with adjustable external horizontal slats.



(a) Work plane illuminance (adjustable slats)

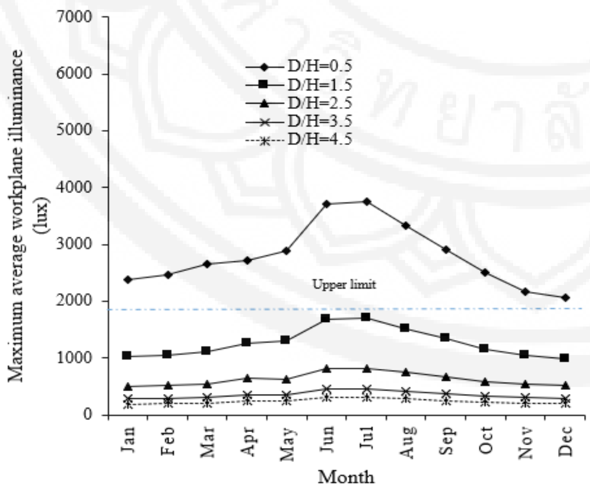


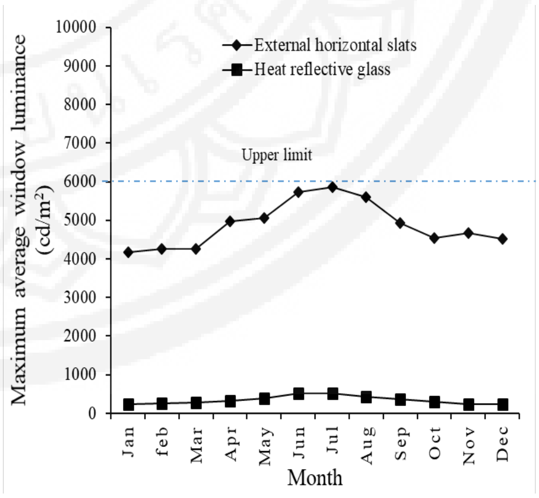
(b) Work plane illuminance (heat reflective glass)



(c) Window luminance

Figure 9 Maximum work plane illuminance and window luminance for south facing window





(a) Maximum work plane illuminance (b) Maximum window luminance

Figure 10 Maximum work plane illuminance and window luminance for north facing window

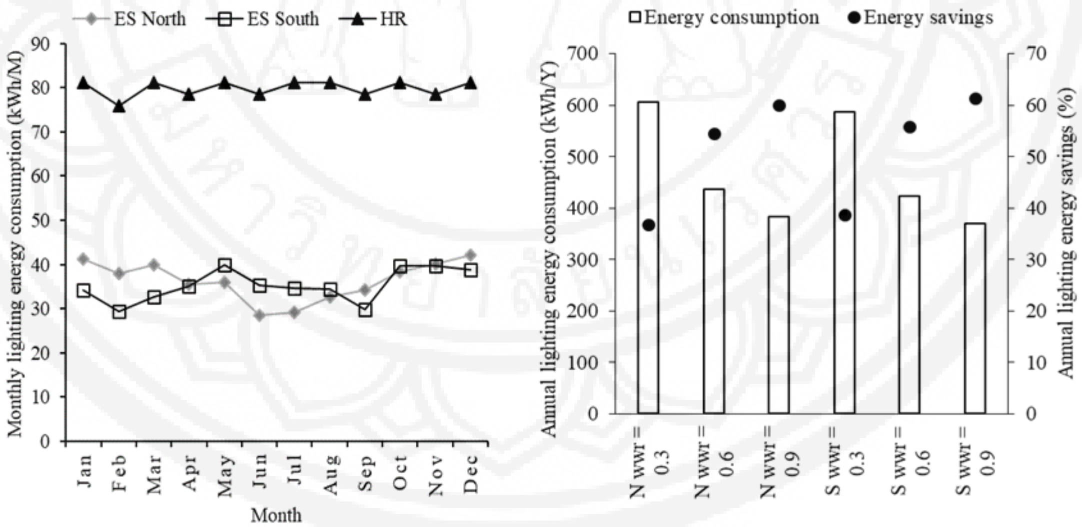
Lighting energy consumption and savings

A target work plane illuminance of 500 lux was selected and it was assumed that dimmable lamps of properties shown in Table 4 are installed uniformly on the ceiling of the model room to maintain 500 lux on the work plane and provide supplementary lighting in case the target illuminance was not achieved. Total lighting energy was calculated by multiplying the average value of the lighting power densities (LPD) at the five work plane points by the floor area and the total working hours during each month excluding weekends.

Working hours from 08:00 to 17:00 were considered for north and south facing windows. Annual simulations were performed for rooms with window to wall ratios (WWR) of 0.3, 0.6 and 0.9. For comparison, similar simulations were performed for the reference case of a window with heat reflective glass and all lamps turned on throughout the working hours, a common practice in commercial buildings in Thailand. The monthly lighting energy consumption for the model room of WWR = 0.6 is shown in Figure 11 (a). The lighting energy consumption for the room with heat reflective glass is rather constant at around 80kWh/month because the lamps are turned on throughout the working hours.

Table 4 Specific information of the luminaires

Number of lamps	2	$E_w = (LLF)\ (CU)\ (Lf/P)\ (P/A)$
Total light flux (lm)	5360	Where
Total power (W)	58.9	E_w=Target illuminance
Efficacy (lm/W)	90.9	LLF = Light loss factor (0.8)
Target work plane illuminance (lux)	500	CU=Coefficient of Utilization (0.65)
Lighting power density, LPD (W/m^2)	10.58	Lf/P = Efficacy
		P/A = Lighting Power density



(a) Monthly energy consumption (b) Energy savings

Figure 11 Energy consumption and savings

For the north facing windows the lighting energy consumption is highest during the months when the sun travels southwards, peaking at 42kWh/month in December. This is attributed to reduced daylight penetration necessitating more supplementary lighting. It reduces as the sun moves overhead and towards the north.

Lighting energy consumption is minimal when the sun is in front of the north facing window with the least observed at 28kWh/month in June due to increased daylight penetration. The reverse is observed for south facing windows. In the months of October, November and December the lighting energy consumption is almost similar for both north and south facing windows because despite the increase in daylight incident on the south window, the slats are tilted downwards to block beam solar radiation thus reducing the amount of daylight penetration.

Figure 11 (b) shows the annual lighting energy consumption and subsequent energy savings in relation to the reference case of heat reflective glass for both north and south facing windows and different window to wall ratios. Energy consumption is highest for WWR=0.3 and lowest for WWR=0.9 because work plane daylight illuminance increases with increasing WWR, hence energy savings also increase with increasing WWR. Savings of 40% to 60% for both north and south windows were estimated which were slightly lower than estimates of up to 80% by Chaiwiwatworakul, Chirarattananon, and Rakkwamsuk (2009). However, the aforementioned study used automated blinds thus achieved more savings. The difference between total annual lighting energy consumption and energy savings for north and south windows is very small.

Conclusion

The impact of the use of external horizontal shading slats on the occupant's visual environment was investigated under real full year climatic conditions of Thailand. Three aspects of indoor visual environment were examined namely glare occurrence, work plane illuminance level and view of outdoor surroundings. Experiments were conducted in a full-scale room and the measured results were compared to calculated results for validation of the daylight simulation program used. Slat tilt angles that completely shade direct sunlight for both north and south windows were determined for each month of the year and the changes in the free view fraction from adjusting the slats at the determined angles were analyzed. Indoor work plane illuminance and window luminance levels were compared to prescribed limits for comfortable workspaces from previous studies. Lighting energy consumption and savings in reference to the common case of windows with heat reflective glass were estimated.

The study established that adjustable external shading slats are not necessary for north facing windows and fully open fixed slats are preferable since they completely shade undesirable direct sunlight for the whole year, guarantee a full unobstructed view of the outdoor surroundings, avoid glare and allow for work plane illuminance levels within prescribed limits deemed to be comfortable. For south facing windows however, external horizontal shading slats adjusted monthly are necessary. The free view fraction was higher than 0.5 for ten out of twelve months indicating a desirable view for 83% of the year. A full unobstructed view was achieved for seven out of twelve months. An undesirable view was noted only during the months of November and December. Work plane illuminance levels were within proposed limits except for points closest to the window at room depth to window height ratio less than 1. Glare occurrence was possible for months of March, April and September. Lighting energy savings for both north and south orientations were estimated to range from 30% to 60%. Further analysis is required to examine the thermal comfort performance of adjustable external horizontal shading slats and establish possible correlations with visual comfort.

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