The Performance of External Vertical Slats for Shading West Windows in Office Buildings

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Abstract

In a hot climate region, the solar radiation transmitted into the building is very high throughout the year. This causes the consumption of electricity to be higher in terms of air-conditioning. The usages of shading devices are necessary to overcome the problem of glare and solar radiation. The uses of external vertical shading devices in west windows are more effective than horizontal shading devices because the sun is travelling overhead all the time.

In most office buildings, the heat reflective glasses (HR) are used to reduce the solar radiation. Therefore, this paper discusses the performance of external vertical slats with clear glass and compares the results obtained from the heat reflective glass window in west exposure. The daylighting performance was evaluated for both cases of using external vertical slats and HR in June and December to check variations. The results of the simulation showed that the application of external vertical slats always reduces energy consumption for three window to window ratio (0.3WWR, 0.6WWR and 0.9WWR) scenarios this is beneficial to the occupants. The results indicate that using the external vertical slats in the west faÇ ade achieving potential energy savings ranging between 16%- 52% less energy compared to heat reflective glass.

Keywords: Solar radiation, Shading devices, External vertical slats, Heat reflective glass and Energy saving

Introduction

Windows in the building are the most important part which can control solar gains, thermal losses and gives visual comfort. Window size should be large enough to allow daylight and at the same time reduces the solar radiation. According to Arifin (2015), external shading performs better in an office building in the tropics to reduce the amount of solar radiation entering the building compare to the internal shading. So for hot climate, solar radiation should be blocked to increase the energy savings in the space. The external vertical slats can be used to block solar radiation the east-west window. External shading devices are usually more effective than internal, it is very valuable to block the sun before it reaches the building (Ching & Shapiro, 2014).

Nabil & Mardaljevic (2006, proved that users prefer to work in offices with daylight and visual contact with the outside, and that environment with no glare and comfortable in terms of temperature. In some countries like Australia, office buildings use 69% of total energy consumption (air-cooling 43% and lighting 26%) (Australia building, 2012).

According to The International Energy Agency (IEA, 2012) most IEA countries consumed approximately 40% of the global energy. It is very important to reduce the energy consumption in the building. This can be achieved by the use of proper external shading devices.

Windows have a bigger impact on the quantity of daylight penetration. The glass used for windows in the building provides light and allow vision. Typical glazing windows that widely used are clear glass, obscure glass, and tinted glass. Clear single glazing is able to permit the highest daylight transmission and allows heat loss or heat gain depending on climate conditions. Carmody, Selkowitz, Arasteh, and Heschong (2000), they explained the main uses of these glasses are to reduce glare and solar energy transmitted to the interior, eventually, energy savings can be achieved.

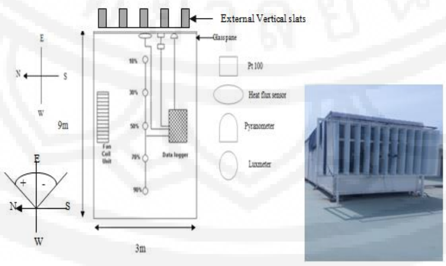
According to Illuminating Engineering Society of North America (IESNA, 1993) , explained the daylighting as a technique to bring natural light into a space by manipulating this free resource to achieve required illumination level in that room. Naturally, the human body needs fulfilled the requirements of comfort, both physically and psychologically. Daylight can save energy and ability to create a pleasant visual environment for occupants (Husin & Harith, 2012). As discussed by Lencher (2009), the daylight that enters through a window can have several sources like direct sunlight, clear sky, clouds or reflections from the ground and nearby buildings. The use of artificial lighting not only consumed energy but also produced waste heat inside the building that eventually contributed to the heating or cooling load (Zain, Sopian, Othman, & Abidin, 2002).

According to Kandilli & Ulgen (2008), Daylight provides about 110 lm/W of solar radiation, fluorescent lamps produce about 75 lm/ W of electrical input and incandescent lamps about 20 lm/ W. Therefore, daylighting generates only 1/ 2 to 1/ 5 of the heat. There important to implement shading devices in the window to overcome this situation of solar radiation. The main function of shading systems is to decrease overheating to improve thermal comfort for the users (Lencher, 2009).

This study analyzes the performance of windows with external vertical slats and window with heat reflective glass in the office buildings for tropical climate for the west window.

Methods and Materials

In the study, full-scale experiments were conducted to characterize the daylight from the shaded window. The measurements were also used to validate a computer program for computing the transmitted daylight, work plane daylight illuminance and the associated heat gain. In the last step, simulations using the program were performed with different window to wall ratio. Figure 1 shows the experimental setup in the room.



(a) Experimental setup (b) Exterior of the experimental room

Figure 1 Experimental room and setup

During the experiments, the vertical slats were set to a different angle, and the transmitted and the work plane daylight illuminances were measured at 10%, 30%, 50%, 70% and 90% of room depth (D).

The experimental site was an outdoor laboratory room. The room was situated on the roof of the School of Bio-resources and technology building, King Mongkut's University of Technology Thonburi (latitude

13.7° N and longitude 100.44° E). The external room dimension was 9m long and 3m wide with a height of 3m. The room length-side was laid along the east-west orientation. There were two glazed windows: the one situated on the east-facing faÇ ade and the other one on the west. A window has a single clear glass. The room was conditioned using a fan coil unit at 25. Table 1 summarizes the physical properties of the experimental room.

Table 1 Details on the experimental rooms and the surrounding environment.

Item	Internal Dimension (m)	Area (m^2)	Material	Reflectance	Transmittance
Interior Room Wall	2.85x2.65 (E and W walls) 8.8x2.65 (N and S walls)	61.75	Gypsum board	0.80	-
Ceiling	8.8x2.85	25.08	Gypsum board	0.8	-
Floor	8.8x2.85	25.08	Vinyl sheet	0.2	-
Window	2.85x1.9	5.42	Clear glass	0.08	0.88

A set of vertical slats was mounted outside the glass window to shade the incident beam irradiance. The slats were fabricated from aluminium sheet painted with white color. The slats had its width 0.3m, its separation 0.30m, and height of 2m.

A data acquisition system was used to record all measured data from all sensors at every minute. All measurements were started from 8:00 to 17:00 representing the typical office working hours.

During the experiments, a meteorological station located at the same campus near the experimental room recorded the global, diffuse horizontal and beam normal daylight illuminance and solar irradiant were measured together with the vertical daylight and irradiance on the four cardinal orientations: north, east, south, and wes

A calculation program called BESim was used to simulate the daylight in an office-like room with a window equipped with the external vertical slats. The program uses the recorded data from the station as the input (Chirarattananon, 2005; Rosa, 2004). The program performs daylight and thermal calculations based on the method outlined by Chirarattananon (2005).

Simulation study

After the validation, the program was used to simulate the daylight in a room of which window equipped with the external vertical slats and window with heat reflective glass. Analysis of the simulated results was made based on five working days (Monday to Friday), and the office hours 8:00-17:00.

To investigate the dependency of the interior daylight on the room configurations, the side-length of the windowed-wall was varied from 3.0m up to 15.0m. The depth from the windowed-wall to the opposite rear wall was also varied from 3.0m up to 15.0m. In all cases, the room height was 2.65m from the floor to the ceiling.

In each particular room shape, the window size was varied for three window-to-wall ratios: 0.3, 0.6, and 0.9, that corresponded with the window height of 0.8m, 1.6m, and 2.4m.

a) Electric lighting

LED lamps were assumed to be installed on the room ceiling to provide uniform illumination on the work plane. The lamp efficacy was approximated at 100lm/W. Based on the IESNA lumen method, the calculation indicated the lighting power density (LPD) was 10 W/m^2 for the required work plane illuminance 500 lux (see Table 2).

Table 2 Specific information of the light luminaire

Number of lamps	2	$E_w = (LLF)(CU)(L_f / P)(P / A)$
Total light flux (lm)	5360.0	where
Total power (W)	58.9	E_w =Target workplace illuminance
Efficacy (lm/W)	90.9	LLF=Light loss factor (0.8)
Work plane luminance (lux)	500	CU=Coefficient of Utilization (0.65)
Lighting power density (W/m^2)	10.5	P/A=Lighting Power density

b) Air-conditioning

The modeled room was conditioned to maintain the room air temperature at 25° C. The cooling load was calculated from the associated heat from the windowed-wall that were the transmitted solar radiation, and the convective heats from the window surface and from the opaque wall section. The electric LED lamps when turned on also contributed additional heat to the cooling load. In the calculation, the dissipated heat from the lamps was postulated equal to their supplied electrical energy. Equation 1 exhibits the calculation of the cooling energy of the modeled room (*En*) in a unit kWh/year.

$$En = \left(LPD + \frac{LPD + HG \cdot (A_w / A_f)}{COP} \right) \cdot A_f \cdot H , \qquad (1)$$

Where *LPD* stands for the average lighting power density (W/m$_{fl}^2$), *HG* stands for the total heat gain from the windowed-wall (W/m$_w^2$), A_w and A_f are the areas of the windowed wall and of the floor area (m^2), respectively. *COP* was the coefficient of performance of the air-conditioner assumed equal 2.7. *H* was the annual office hour, which was equal to 2340 hours.

The slat angles are -50° , -40° , -30° , -20° , -10° ,0° , 10° , 20° , 30° , 40° , and 50° were simulated to get angles that minimize the lighting and air-conditioning energy at the same time block beam.

Results

Experimental Study

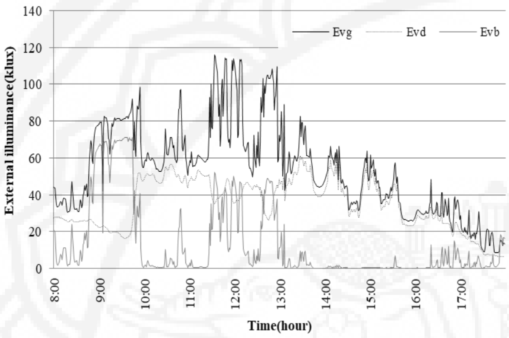
(a) Experiment of the slats at 10°

The experiment was carried out on 02/08/2018. Figure 2 shows the pictorial view of the experimental room. Figure 3 (a) shows the measured global (E_{vg}), beam normal (E_{vb}), and diffuse horizontal (E_{vd}) illuminances. This day, the beam illuminance reached 68klux at 9:07am and the maximum global illuminance was 115klux at 11:47am.

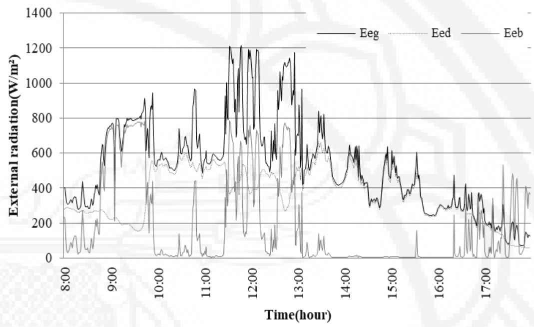
(a) Exterior view

(b) Interior view

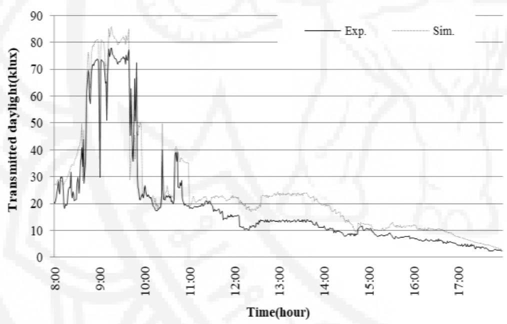
Figure 2 Pictorial view of the experiment:



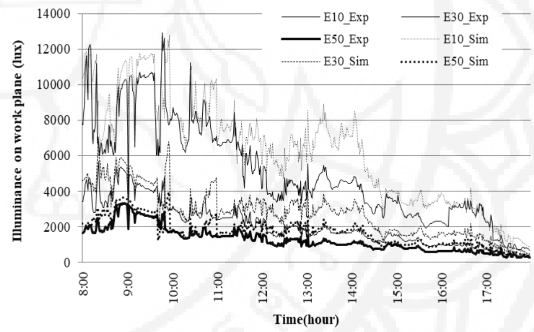
(a) Outdoor daylight



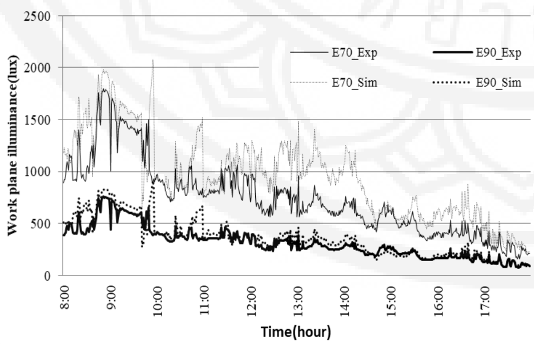
(b) Outdoor radiation



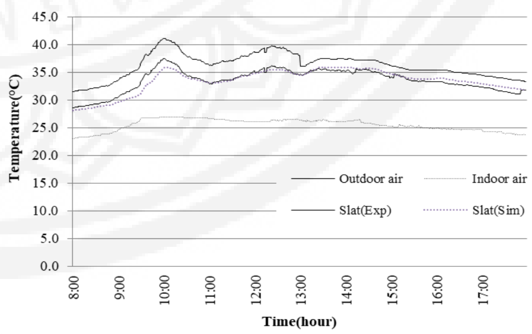
(c) Transmitted daylight



(d) Work plane daylight (10%D to 50%D)



(e) Work plane daylight (70%D &90%D)



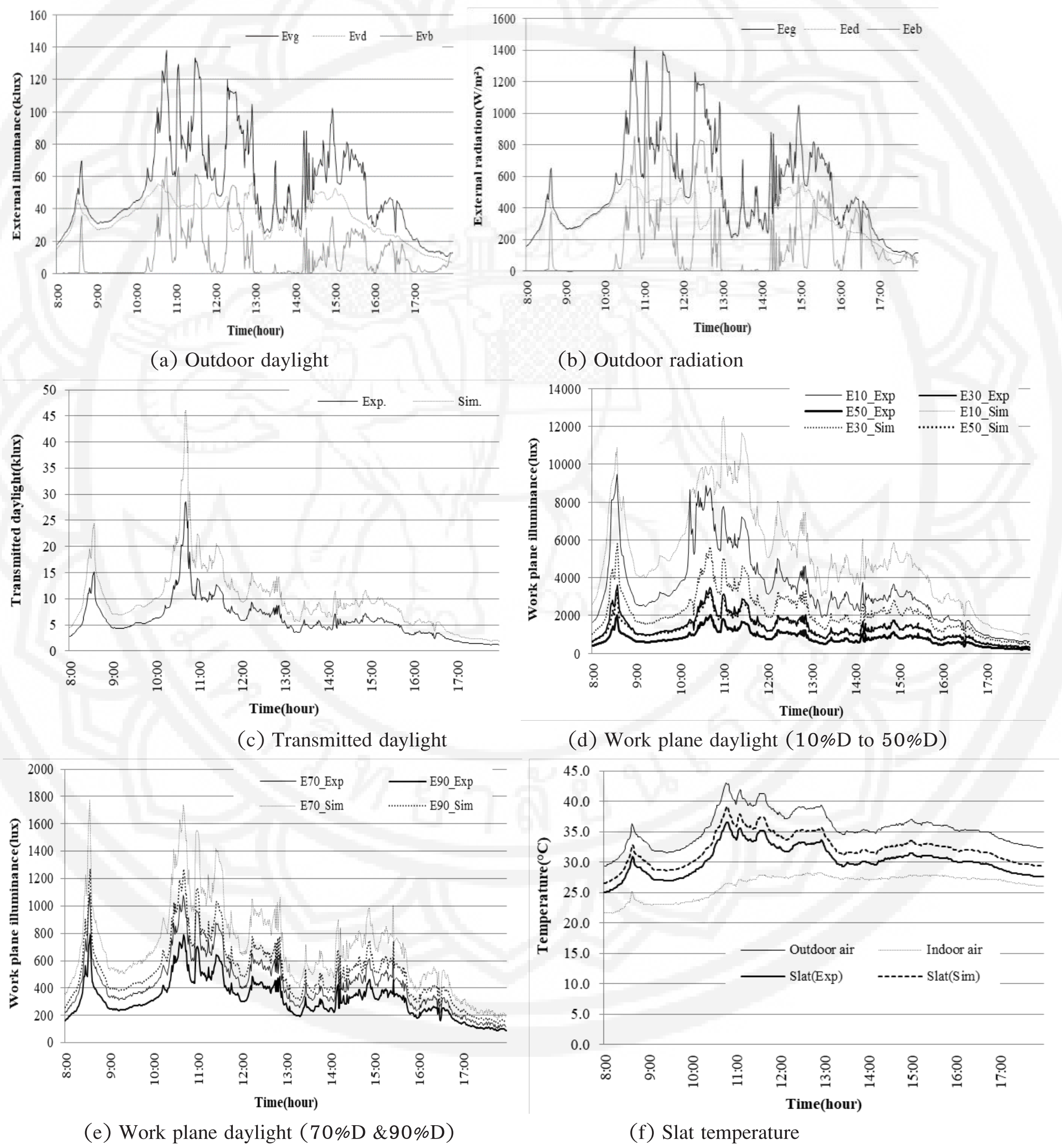
(f) Slat temperature

Figure 3 Experiment results of the slat angle at 10°

Figure 3 (b) shows the outdoor solar irradiance and Figure 3 (c) shows the amount of transmitted daylight through the window. Figures 3 (d) and (e) show the work plane daylight illuminance at the five measurement points. Close to the window (0.9m apart from the windowed-wall), the illuminance was excessively higher. Figure 3 (f) shows the surface temperature of the slats which varied around 28-33° C.

(b) Experiment of the slats at 50°

The slats were set at 50° in this experiment (1/08/2018). The slat angle was large enough to shade the sunray. As shown in Figure 4 (a), the daylight amount was abundant on this day with intermittent sunshine. The transmitted daylight was now limited to 26 klux (Fig. 4 (c)); however, the work plane daylight was still as high as 12,000 lux. Figures 4 (f) shows the surface temperature of the slats.



(a) Outdoor daylight

(b) Outdoor radiation

(c) Transmitted daylight

(d) Work plane daylight (10%D to 50%D)

(e) Work plane daylight (70%D &90%D)

(f) Slat temperature

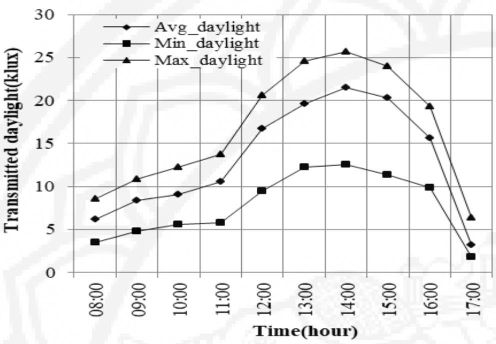
Figure 4 Experiment results of the slat angle at 50°

Simulation-based analysis

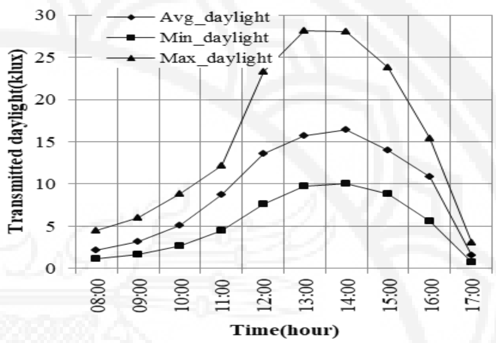
Annual simulations using the validated program were carried out to determine the interior daylight illuminance, the thermal gain through window, and the electric energy consumed for lighting and air-cooling of the rooms using the window equipped with the adjustable vertical slats. The comparison was made with the reference case of the same rooms using the heat reflective glass window.

(i) Transmitted Daylight

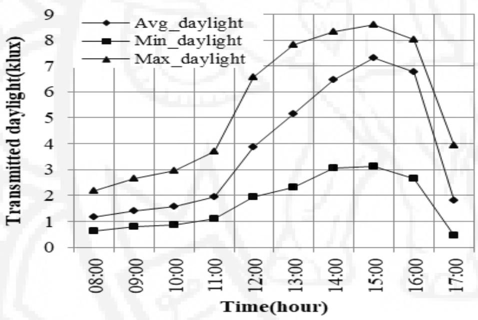
Figure 5 (a), (b), (c) and (d) shows the transmitted daylight for the selected months of June and December. Window with external vertical slats has more transmitted daylight compared with heat reflective glass.



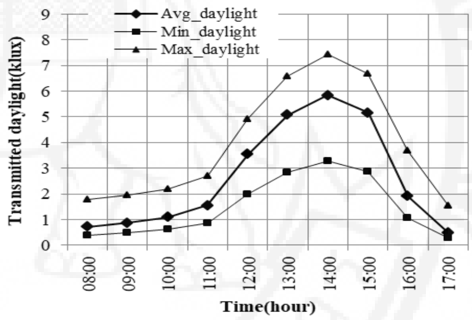
(a) Window with slat (June)



(b) Window with slat (December)



(c) Heat reflective glass window (June)

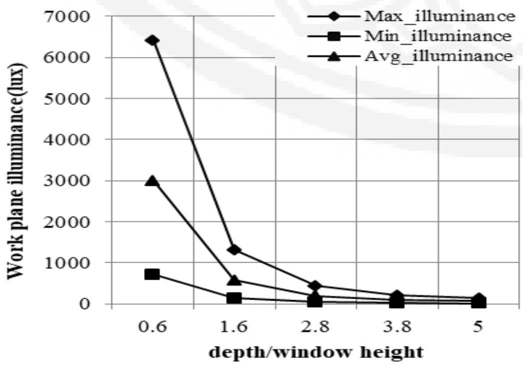


(d) Heat reflective glass window (December)

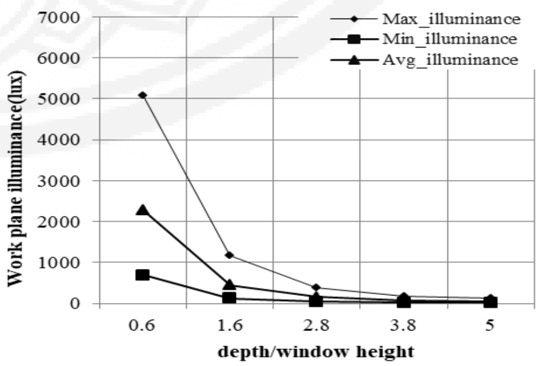
Figure 5 Transmitted daylight

(ii) Work plane daylight

Interior daylight on the work plane from the west window is presented in Figure 6 (a), (b) (c) and (d). The figure also exhibits the low work plane daylight from heat reflective glass window.

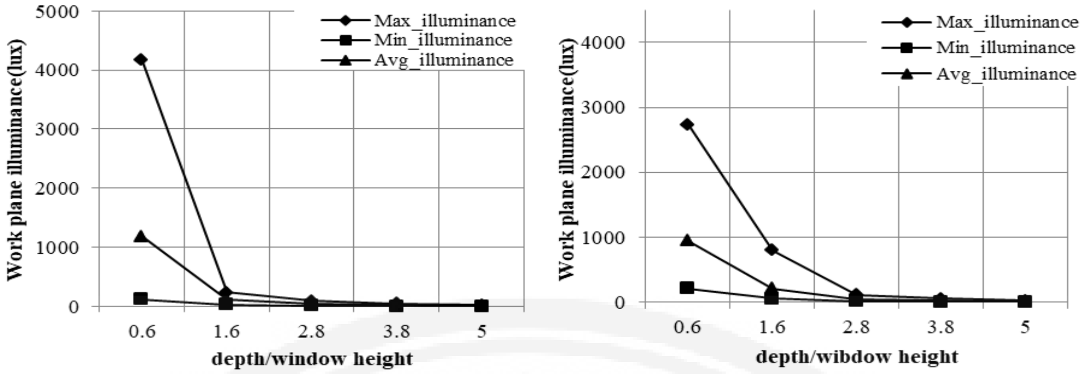


(a) Window with slat (June)



(b) Window with slat (December)

Figure 6 Work plane illuminance

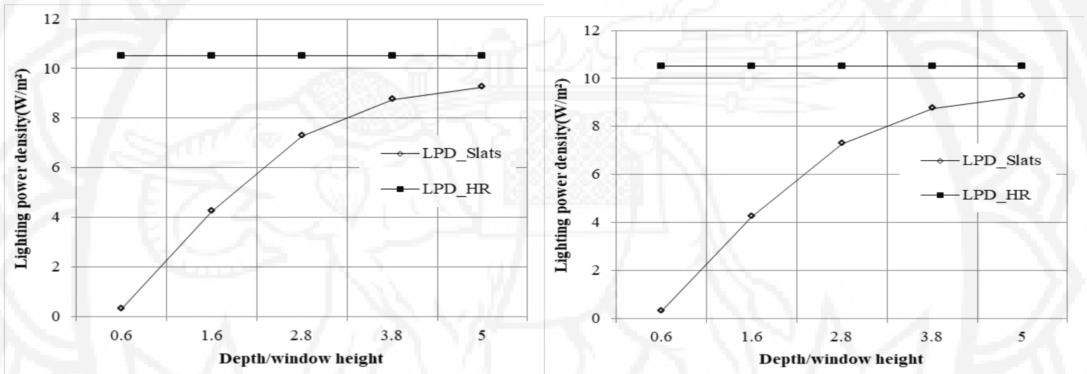


(c) Heat reflective glass window (June) (d) Heat reflective glass window (December)

Figure 6 (Cont).

(iii) Lighting Power Density (LPD)

The amounts of LPD were evaluated in June and December for slats and HR in figure 7 (a) and (b). The results show that the LPD increased with the room depth. Lighting power density for December is less compare to June due to high transmitted daylight in December which leads to use less artificial lighting.

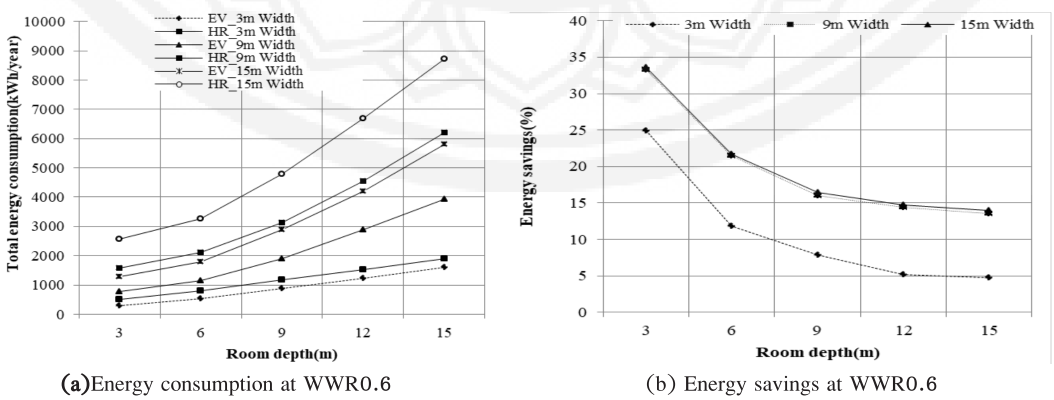


(a) LPD in June (b) LPD in December

Figure 7 Lighting Power Density

(iv) Energy consumption and Savings

The total energy consumption and energy savings for different WWR was evaluated. The WWR0.6 used to represents other results. The result shows that HR has higher energy consumption compared to window with the external slats (Figure 8(a)). The energy savings for vertical slats decreased when room depth increases (figures 8(b)).



(a) Energy consumption at WWR0.6 (b) Energy savings at WWR0.6

Figure 8 Energy consumption and savings at WWR0.6

Note: EV= External vertical slat HR= Heat reflective glass

Conclusion and Suggestions

This paper examined the typical performance of daylighting by comparing the window with external vertical slats with window with heat reflective glass for west exposure. In rooms with west windows, incoming daylight was the greatest in the afternoon.

The results show that the Heat reflective glass use more energy, especially in lighting because heat reflective glass has a low daylighting transmittance compared to clear glass. In addition, it was found that the higher the window-to-wall ratio, the larger the energy consumption. However, Energy consumption in the room with 9m and 15m width almost has the same energy consumption as well as savings compared to the room with 3m width.

The potential energy savings from external vertical slats is ranging between 16-52% less energy compared to heat reflective glass. Therefore, the simulation study suggests that for west orientation the appropriate angle block beam and gives minimum energy consumption is above 20^{o} (north-west) when sun travel in the south position and above 40^{o} (south-west) when sun travel in the north position. Also in the case of sun travel overhead, the slats can be tilted above 40^{o} either north or south.

Acknowledgments

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References

Arifin, N. A. (2015). An analysis of indoor air temperature and relative humidity in office room with various external shading devices in Malaysia. *Procedia-Social and behavioral Sciences*, *176*, 290-296.

Australia Building. (2012). *Council of Australian Governments.* Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia: Council of Australian Governments.

Carmody, J., Selkowitz, S., Arasteh, D., & Heschong, L. (2000). *Residential Windows: A Guide to New Technologies and Energy Performance.* New York: W.W Norton & Company.

Ching, F. D., & Shapiro, I. M. (2014). *Green Building Illustrated.* Hoboken, N.J.: Wiley.

Chirarattananon, S. (2005). *Building for Energy Efficiency.* Bangkok, Thailand: Asian Institute of Technology.

Husin, S. N. F., & Harith, Z.Y.H. (2012). The Performance of Daylight through Various Type of Fenestration in Residential Building. *Procedia - Social and Behavioral Sciences, 36*, 196 - 203.

IEA. (2012). *International Energy Agency, Energy Policies of IEA Countries.* Retrieved from http://www.iea.org/publications/freepublications/publication/Korea2012_free.pdf.

IESNA. (1993). *American National Standard Practice for Office Lighting.* Illuminating Engineering Society of North America: America.

Kandilli, C., & Ulgen, K. (2008). Solar Illumination and Estimating Daylight Availability of Global Solar Irradiance. *Energy Sources, 30,* 1127-1140.

Lencher, N. (2009). *Heating, Cooling, Lighting: Sustainable Design Methods for Architect.* Hoboken, NJ: John Wiley & Sons.

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings, 38*, 905-913.

Rosa, L. P., & Lomardo, L. L. B. (2004). The Brazilian energy crisis and a study to support building efficiency legislation. *Energy and Building, 36*, 89-95.

Zain, A. A., Sopian, K., Othman, M. Y. H., & Abidin, Z. Z. (2002). The Availability of Daylight from Tropical Skies: A Case Study of Malaysia. *Renewable Energy, 25*, 21-30.