Daylighting through external vertical slats on east windowed façade in a tropical climate

Akawat Suntudprom[1, 2], Pipat Chaiwiwatworakul[1,2,*]

[1]*The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand*
[2]*Center of Energy Technology and Environment, Ministry of Education, Thailand*

Abstract:
In the tropics, daylighting from a side window requires shading to intercept direct sunlight from the window whilst allowing penetration of daylight from sky. In this paper, daylighting from external vertical slats was investigated for which they are equipped on east-facing window of a room. Full-scale experiments and simulations were conducted to characterize distribution of the interior daylight from the slat window under a real tropical climate. Performance of the slat window was evaluated in terms of the "Useful daylight illuminance" (UDI), interior daylight availability and light power density (LPD) of an integrated dimmable lighting system. Using our tropical records of daylight illuminance, the simulation results show that altering properly the tilted angle of the vertical slats with the same configuration as that of the experimental room can improve the interior daylight illuminance and distribution and can save about 75% of electric energy from dimmable lighting.

Keywords: *Vertical slats; Daylighting; Illuminance; Useful daylight illuminance; Tropical climate*

**Corresponding author. Tel.: +662-872-9014 ext. 4107, Fax: +662-872-7978*
E-mail address: pipat_ch@jgsee.kmutt.ac.th

1. Introduction

In the tropics where the skylight is voluminous and the sun transverses in all directions, daylighting is quite challenge in the view of controlling the interior daylight illuminance within an acceptable range and preventing visual discomfort glare situation (Chirarattananon et al., 2002; Chirarattananon et al., 2007; Chaiwiwatworakul et al., 2009). For east facing windows, external multiple vertical slats are a simple device that effectively shade the direct sunlight and introduce diffuse skylight into building interior. Daylighting of glazed windows with shading slats has been studied in various configurations and under different climate conditions. In a high latitude region, a study conducted experiments in real offices to measure the workplane daylight illuminance from double glazed windows with horizontal slats and the resultant power consumption from dimmable light lamps (Galasiu et al., 2004). The results showed that the interior daylight is influenced largely by tilted angle of the slats, varying sky conditions, and sun position relating to window orientation. Energy savings from lighting depended on types of controls by which the continuous dimming offered in most cases higher savings than the automatic on/off. In another study, a light simulation software namely Lightscape was used to investigate the daylight distribution in a typical small office whose window was equipped with slats (Alzoubi et al., 2010). The study cautioned on excessive daylight on the area next to the non-slat windows and then demonstrated how slats can be used to attenuate the excessive daylight. Empirical equations were developed to predict the workplane daylight as a function of distance from the windowed-wall. Other studies conducted daylight simulations to achieve optimal configuration and tilted angle of the slats on window (Datta, 2001; Cheng et al., 2007). This paper aims to investigate on how to use properly the vertical shading slats equipped on a window of a room for daylighting in the tropical climate.

2. Methodology

A series of full scale experiments were conducted to measure the daylight transmitted through the external vertical slats and its distribution in an interior space. The experimental site was at a room of a single storey laboratory building in Bang Khun Tien campus of the King Mongkut's University of Technology, Thonburi (latitude 13.57°N and longitude 100.44°E). The experimental facilities, equipments and measurements can be described as follows.

2.1 The experimental room

The experimental room was a rectangular shape with floor dimensions of length 9 m. and width 3 m. The room height was 2.85 m. measured from the floor to the ceiling. A single pane glazed window was situated on east wall of the room. The window was 2.80 m. wide and 1.8 m. high and its sill was 0.85 m. above the floor. Slats were mounted vertically and externally over the front side of the existing 6 mm. green glass. Table 1 summarizes the specific information of the room and the environment. Fig. 1(a) exhibits a pictorial view of the test room.

Table 1 Specific information of the experimental room and its environment

Item	Internal Dimension (m)	Area (m^2)	Material	Reflectance	Transmittance
Experimental Room					
Opaque Wall	3.00 x 2.85 (E & W walls) 9.00 x 2.85 (N & S walls)	63.4	Gypsum board	0.80	-
Ceiling	9.00 x 3.00	27.0	Gypsum board	0.80	-
Floor	9.00 x 3.00	27.0	Vinyl sheet	0.20	-
Window	2.80 x 1.80	5.04	Green glass	0.06	0.74
Environment					
Ground	-	-	Concrete	0.40	-

(a) Test room

(b) Daylight measuring station

Fig. 1 Experimental facilities.

The vertical slats used in the experiments were 30.0 cm wide and painted white. Distance between two adjacent slats was 35.0 cm. As illustrated in Fig. 1(a), the daylight illuminance in the room were measured at five points located on a line perpendicular to the window wall across the center of the room on the work plane level (0.75m above floor). The points were positioned along the line at 10%, 30%, 50%, 70% and 90% depths of the room (*D*). A data logging system was used to acquire all measured data from the sensors every five minutes.

2.2 The daylight measurement station

During the experiments, the exterior global, diffuse horizontal and beam normal daylight were measured and recorded by a meteorological station. The station is located on the roof deck of a seven-story building of the school of bioresources and technology in the campus. The clock times of the data loggers at the station and at the experimental room were synchronized. Fig. 1(b) shows a photograph of the station. No tall building or structure offers obstruction.

Using the facilities above, the experiments were performed for different cases by tilting the slats to angles of 0°, 30° and 45° northward and southward. The experimental results were also used to validate the calculation algorithms to be described in Section 3.

2.3 Daylight Simulation

A computer program called AGI32 was used in the daylight calculation that utilized the measured data from the station. The program requires defining the configuration of the daylit room for its input. The software employs the fifteen CIE standard sky luminance distributions to describe the apparent sky [19]. According to the software, the interior daylight was calculated using forward ray-tracing method.

3. Experimental Results

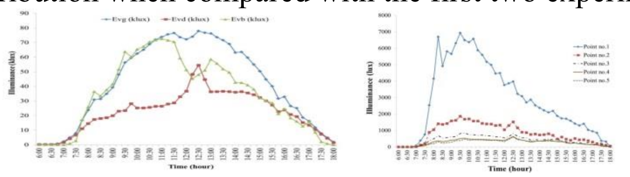
Results from the experiments were used to illustrate characteristics of the interior daylight from the slat window in the tropics and validate the daylight modeling using AGI32.

3.1 Experiment of the slat angle at 0°

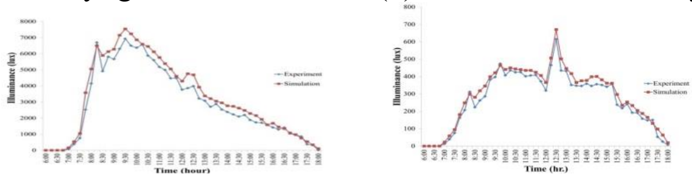
An experiment of the slat angle opened fully at 0° (see Fig. 1(a)) was conducted on 16th January 2014. Fig. 2(a) shows the global (E_{vg}) and the diffuse horizontal (E_{vd}) illuminances measured during the experiment. On this day, the sky was rather clear and the global illuminance reached 80 klux at noon. Fig. 2(b) shows a plot of the workplane illuminances at the five measurement points. It is observed that the illuminance values at 10%D were high upto 7,000 lux at 9:30, and its variation was closely related with the exterior sunlight. The illuminance values at 30%D and 50%D were still beyond 500 lux for most of the daytime; however, they varied closely to the diffuse skylight. Fig.s 2(c) and 2(d) shows the illuminance measured at 10%D and 90%D plotted against their corresponding values from the calculation. A good agreement is observed from the plots.

3.2 Experiments of the slat angles at -45° and 45°

Fig. 3 shows the experimental results of the slat angle at -45° made on 4th February 2014. The global illuminance on this day was slightly higher than that of the previous case. Although the slats were in the position that the window was almost completely closed; the illuminance at 10%D was still high in morning and not different from the previous. This is because the slats were turned toward south where the sun situated. Direct sunlight could penetrate into building interior at this slat position. From the noontime, the interior daylight sharply drop but its values are quite comparable with that of the first experiment (fully-opened slats). Fig. 4 shows the experimental results when the slats were turned 45° but in opposite direction. For this experiment, the slats shaded completely the sunlight, so the interior daylight improved significantly in term of illuminance level and distribution when compared with the first two experiments.

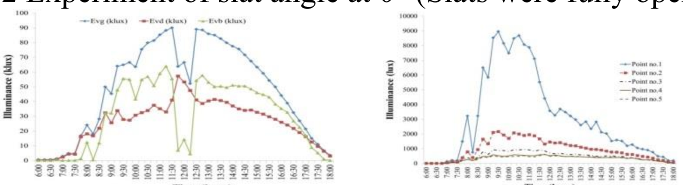


(a) Exterior daylight illuminance (b) Measured interior daylight illuminance



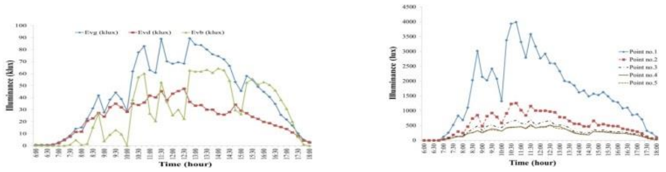
(c) Measured & calculated daylight at 10%D (d) Measured & calculated daylight at 90%D

Fig. 2 Experiment of slat angle at 0° (Slats were fully opened)



(a) Exterior daylight illuminance (b) Measured interior daylight illuminance

Fig. 3 Experiment of slat angle at -45° (the outer edge of slats toward south).



(a) Exterior daylight illuminance (b) Measured interior daylight illuminance

Fig. 4 Experiment of slat angle at 45° (the outer edge of slats toward north).

4. Simulation-based Analysis

The validated AGI32 model was used to simulate the daylight from the vertical slats for a whole year. In the simulation, a model room was set similar to the test room but values of the interior surface reflectance were defined to 0.7 for ceiling, 0.5 for walls and 0.3 for floor identical to those in the IES Lumen method for daylight calculation (Reas, 2000).

The simulation presumed that the light luminaires on the room ceiling provided uniformly a target illuminance on workplane level (0.75 m. above floor) regardless of daylight. Each luminaire was housed with two T8 fluorescent lamps (36W) and one electronic ballast (2W). One lamp produced the light flux of 2,680 lumens. By Lumen method calculation and a Coefficient of Utilization value (*CU*) of 0.50 for typical lighting design, the light power densities (*LPD*) of lighting to provide the illuminance at 500 lux were calculated at 17.5 W/m^2. The coverage area defined as the served area by a luminaire to meet a target workplane illuminance is 4.2 m_{fl}^2/set.

A dimming controller was integrated with the lighting system to regulate the light from lamps to supplement the daylight from the slat window. The lighting system however consumed electric power at 10% of its rated even when the daylight alone could illuminate the space at target illumination level or excess. Fig. 5 exhibits power consumption of dimmable lighting system for the workplane illuminance of 500 lux.

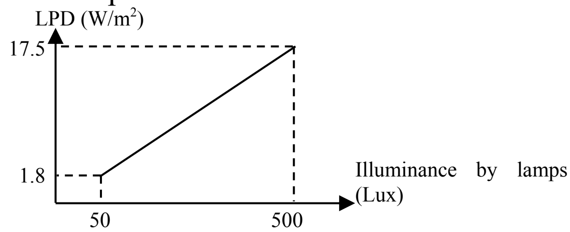
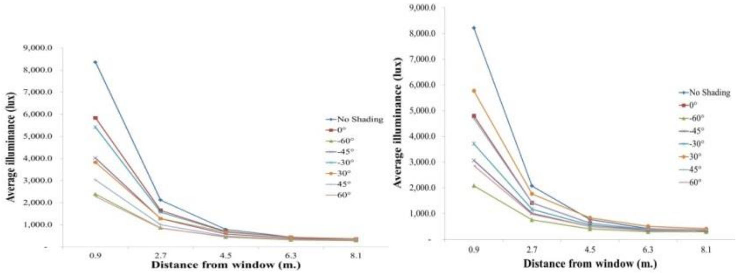


Fig. 5 Power consumption of the dimmable lighting system to provide the workplane illuminance of 500 lux.

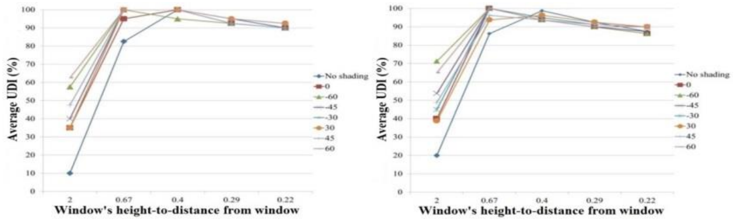
A series of the simulations was undertaken by varying slat angles from -60° to 60°. A complete one-year hourly record of the daylight and solar radiation measured in Thailand was used for the simulation. Fig. 6(a) exhibits the simulations results of annual average interior daylight illuminance in the room. The plots are separated for two periods of April-August when the sun is towards north and of September-March when the sun is towards south. A reference case of window with no shading is also included in the plots. The results show that the tilted angle of the slats influence significantly the interior daylight at points near the window but the effect is less near the rear walls of the room. Even the window equipped with vertical slats; the average interior daylight is still higher than 500 lux during daytime within the distance from the window upto 4.5 m (2.5 time of the window height).

The evaluation of the vertical slats was also made using "Useful daylight illuminance" or *UDI*. This index was proposed first time by Nabil and Mardaljevic (Nabil and Mardaljevic, 2006). The approach determines occurrences of daylight illuminances within a useful range of 100–2,000 lux, and outside the range i.e. less than 100 lux and greater than 2,000 lux. The approach can interpret better the climate-based analysis of daylight illuminance levels that are founded on hourly meteorological data for a period of a full year. It would lead to higher level of occupant satisfaction and energy savings. From Fig. 6(b), *UDI* values were plotted for the five measurement point in the room. According to the *UDI* definition, the vertical slats also improve the interior daylight in terms of *UDI* particularly the positions close to the slat window.

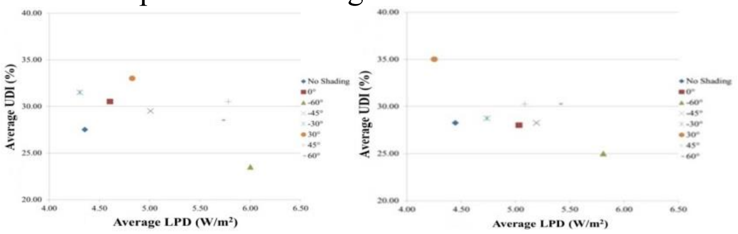
Fig. 6(c) exhibits the plots of average *UDI* against average *LPD*. From the plots, turning the vertical slat angle 30° towards south during April-August and 30° towards north during September-March will achieve the maximum *UDI* and the minimum *LPD*.



(a) Relationship between average illuminance and distance from window



(b) Relationship between average *UDI* and distance from window



(c) Relationship between average *UDI* and *LPD*

Fig. 6 Daylighting performance of external vertical shading slats.

5. Conclusion

The daylighting performance of the external vertical slats was investigated through the experiments and the simulations for east-facing windowed wall of a building under the tropical climate. The study showed that altering the vertical slat angle 30° towards south during April-August and 30° towards north during September-March maximizes the interior daylight illuminance and can save about 75% of electric energy from dimmable lighting. The study demonstrates on how to optimize the use of daylight from the vertical slat with an integrated dimmable lighting system.

6. Acknowledgement

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7. References

Alzoubi, H.H. and Al-Zoubi, A.H. 2010. Assessment of building facade performance in terms of daylighting and the associated energy consumption in architectural spaces: Vertical and horizontal shading devices for southern exposure facades. Energy Conversion and Management 51(8): 1592–1599.

Chaiwiwatworakul, P., Chirarattananon, S., and Rakkwamsuk, P. 2009 Application of automated blind for daylighting in tropical region. Energy Conversion and Management 50(12): 2927-2943.

Cheng, C.L., Chen, C.L., Chou, C.P., and Chan, C.Y. 2007. A mini-scale modeling approach to natural daylight utilization in building design. Building and Environment 42(1): 372-384.

Chirarattananon, S. and Chaiwiwatworakul, P. 2007. Distributions of sky luminance and radiance of north Bangkok under standard distributions. Renewable Energy 26(8): 1328-1345.

Chirarattananon, S., Chaiwiwatworakul, P., and Pattanasethanon, S. 2002. Daylight availability and models for global and diffuse horizontal illuminance and irradiance for Bangkok. Renewable Energy 26(1): 69-89.

Datta, G. 2001. Effect of fixed horizontal louver shading devices on thermal performance of building by TRNSYS simulation. Renewable Energy 23(3-4): 497-507.

Galasiu, A.D., Atif, M.R. and MacDonald, R.A. 2004. Impact of window blinds on daylight-linked dimming and automatic on/off lighting controls. Solar Energy 76(5): 523-544.

Nabil, A. and Mardaljevic, J. 2006. Useful daylight illuminances: A replacement for daylight factors. Energy and Buildings 38(7): 905–913.

Reas, M.S. 2000. Chapter 8: Daylighting. Lighting handbook: Reference and application, Illuminating Engineering Society of North America (IESNA).