An enhancement of the daylighting from side-window using two-section venetian blind

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Abstract:
In the tropics, daylighting from a side window requires shading to intercept direct sunlight from entering the window whilst allowing penetration of daylight from sky. Daylighting from a double-pane glazed window with enclosed horizontal slats has long been investigated under different climates and locations. In this paper, a double-pane window with the slats that were separated into two sections (lower and upper sections) was investigated for its daylight application in tropical climate. A series of full-scale experiments and simulations were conducted under real tropical skies and by which the slats in each section were tilted to different angles. Through the yearly simulations, performance of the two-section slat window was evaluated in terms of "useful daylight illuminance" (UDI), average interior daylight illuminance (ADI), and reduced light power density (LPD) of a dimmable lighting system. The results show that the two-section slat window can enhance the daylight use in the building by increasing more useful daylight illuminance, and providing better uniformity of the interior daylight distribution than the single-section slat window.

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

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1. Introduction

In tropical region, daylight from sky is voluminous (Chirarattananon et al., 2002), and the sun travels in all orientations over the sky vault. Nowadays, commercial buildings in Thailand are constructed with large glazed windows and no external shading. To avoid adverse effects of excessive solar gain, low optical transmittance glasses (heat reflective glasses) are suggested for the usage. This practice leads to loss of beneficial gain from the daylight use. Such buildings need full reliance on electric lighting even when the daylight is sufficient for the illumination (Kim et al., 2009).

The window with horizontal slats enclosed between two glass panes (slat window) is an interesting solution to the above traditional practice of the building envelope design. However, the daylight through the slat window is complicate. Optical properties of glass window and slats, tilted slat angle, sky condition influence largely on the daylight transmission and its interior distribution (Athienitis and Tzempelikos, 2002; Edmonds and greenup, 2002). Mathematical models have been developed to predict the interior workplane illuminance from the slat window (Chaiwiwatworakul et al., 2009; US-DOE, 2004). Some studies conducted daylight simulations to optimize configurations of the window and slats (Kim et al., 2009; Koo et al., 2010). Most studies focused on the slats that are tilted with same angle for the whole section. Recently, Hu and Obina (Olbina, 2012; Hu, 2011) introduced a double-pane window with multiple-section slats. The slats that each section can be adjusted to different tilted angles enhance the daylight use in building. This paper investigates such feature of a double-pane window unit with two-section slats for its application and performance in tropical climate.

2. Methodology

Full scale experiments were conducted to measure the daylight transmitted from a two-section slat window and its distribution in an interior space. The test room was a rectangular shape with interior dimensions of length 6.00 m. and width 3.00 m. The room height was 2.65 m. measured from the floor to the ceiling. In experiments, the interior daylight was measured at three 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%, 50%, and 90% depths of the room

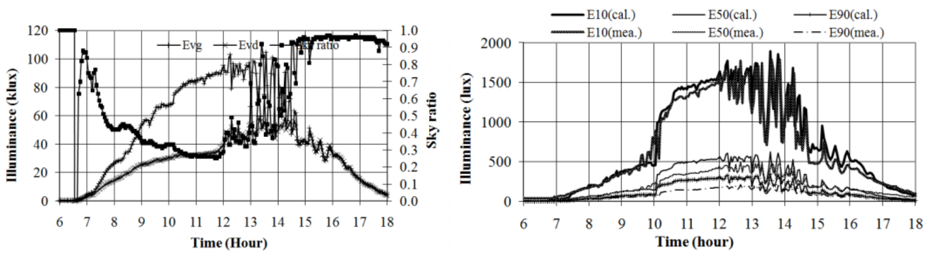
(D). A data logging system was used to acquire all measured data from the sensors every five minutes. During the experiments, exterior daylight illuminances were measured by a daylight station. At the station, daylight of global, diffuse horizontal and beam normal components have been measured. With the facilities above, a series of experiments were performed. The measurement results of daylight illuminance from the experiments were compared to those obtained using a daylight calculation algorithm described in (Chaiwiwatworakul et al., 2009).

3. Results and discussion

A series of experiments was conducted to measure the interior daylight from the two-section slat window. Two experiments made with two different proportions of the lower and upper slat sections are chosen for presentation. The experimental measurements were also compared with the calculations using the algorithms described in previous section.

3.1 Experiment with the Lower-to-upper Slat Section 80:20

This experiment was conducted on 23/2/2013. The angles of slats in the lower and the upper sections were set at 15° and -30°, respectively. Fig. 1(a) exhibits a plot of the global and the diffuse daylight illuminance on the experimental day. Variation of sky ratio, the ratio of the diffuse to global irradiance, was also presented in the plot. On this day, the sky was clear in the morning but partly cloudy in the afternoon.



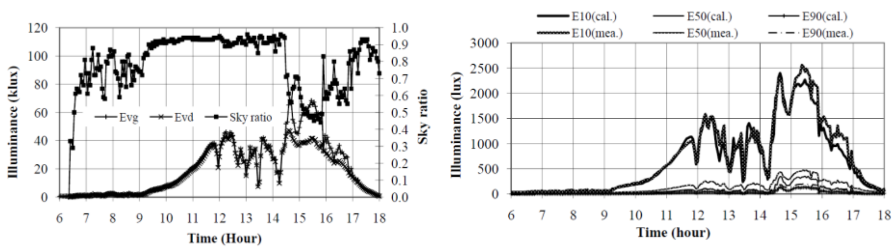
(a) Exterior daylight illuminance (b) Interior daylight illuminance

Fig. 1 Measurement of daylight illuminance on the experiment of 80:20 slat window (23/2/2013)

Fig. 1(b) exhibits results of the measurements of interior daylight at 10%, 50% and 90% depth of the room (D). It can be observed that the workplane daylight illuminance at 10%D is high upto 1800 lux during noon and drop rapidly to about 500 lux and 300 lux at 50%D and 90%D, respectively. It should be reminded that without the slats the beam daylight would penetrate into the room and caused highly non-uniform illuminance distribution and a serious glare problem. Fig. 1(b) also exhibits that the calculation algorithm can perform well the prediction of the interior daylight illuminance from the two-section slat window.

3.2 Experiment with the Lower-to-upper Slat Section 50:50

This experiment was conducted on 31/10/2012. In the experiment, the slat angle was at -30° for both lower and upper sections. On the experimental day, the sky was cloudy for most of the time. The sunlight appeared only from 14:30 to 16:30. From the plot in Fig. 2(b), it can be observed again a good agreement between the measurements and the calculations.



(a) Exterior daylight illuminance (b) Interior daylight illuminance

Fig. 2 Measurement of daylight illuminance on the experiment of 50:50 slat window (31/10/2012).

Comparing the results with those on 23/2/2013, the interior daylight near the window reaches 1500 lux (at 12:30), even though the exterior daylight is lower. The negative slat angle tends to increase the interior daylight in the near-window area.

3.3 Simulation-based Analysis

The algorithm in (Chaiwiwatworakul et al., 2009) was used to simulate the interior daylight from the two-section slat window facing south for a whole year. A complete one-year hourly record of the daylight measured in Thailand was used for the simulation. The ASRC-CIE sky model was adopted to calculate the resulting diffuse skylights on slat surfaces and the luminances of the sky patches viewed through the slats by points in the model room. In the simulation, a model room was set similar to the test room but its length was extended to 15 m allowing daylight to penetrate deep into the interior without the limit of room depth. 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). No modification was made for the blind properties and the window was due south. A series of the simulations was performed by varying the slat angle in upper and lower sections from -60° to 60° at 10° step size. The ratio of upper and lower slat sections is kept at 50:50.

3.4 Daylighting Performance

The two-section slat window was evaluated on its daylighting performance using two indicators (i) annual average interior daylight illuminance (*ADI*) and (ii) useful daylight illuminance (*UDI*). In Fig.3, *ADI* is shown. The labels in the plot are referred to angles of the upper slats. The values in the horizontal axis are angles of the lower slats. As reference case, The *ADI* values of a window using heat reflective glass without blinds is shown as horizontal line in the plot (at 201.32 lux). The *ADI* values of one-section slat window at various blind angles are included in the plot for comparison, as well. When lower blind angles are positive, most of the *ADI* values of window with two-section blinds are higher than that with one-section blinds, and vice versa. The maximum *ADI* value occurs when upper and lower blind angles of two-section slat window are set at -30 and -20 degree, respectively.

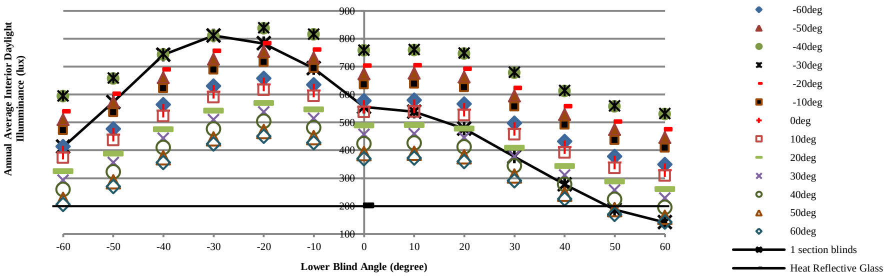
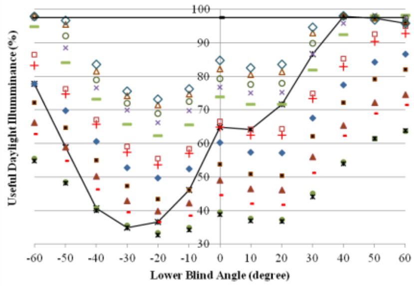


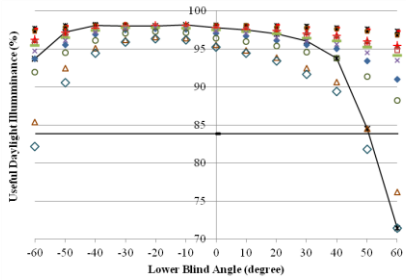
Fig. 3 ADI of the two-section slat window.

According to *UDI* definition, Fig. 4 (a) to (c) exhibit the occurrences of the workplane daylight illuminance within the useful range of 100-2000 lux from the slat window at different points inside the room. D/H values indicate the ratio of depth of the room measured from the window to height of the window. From Fig. 4(a), at D/H=1, the window with upper and lower blind angles at 20 and 60 degree, respectively, gives the maximum *UDI* values of 98%. At D/H=3, the *UDI* values are high for all cases. However, the two-section slat window with upper and lower blind angles at -10 and -30 degrees, respectively, gives the highest *UDI* values of 98%, as shown in Fig. 4(b). The trend of the results at D/H=1 is opposite to the results at the rest positions of the room. For all angles of the lower slats, the upper blind angle of -30 degree provides the lowest *UDI* at D/H=1 because the window introduces excessive daylight into the area, while the *UDI* values of the window at -30 degree upper blind angle are highest at other positions in the room.

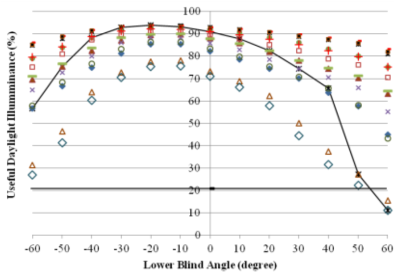
Excluding the position at D/H=1, the single-section slat window at -20 degree provides the highest *UDI* value in average because it gives maximum *UDI* values at D/H=5 and 7 as shown in Fig. 4(c) and (d). The daylight has no potential in the area deeper than the position of D/H=7 (room depth is seven times of the window height). In this area, the *UDI* values are 0 for most of the time for all window types so they are not plotted here. There is no single slat angle that can provide high daylight performance at all position in the room. However, when upper blinds are set at negative angles in the range of -30 to -10, a person in a room can view the sky at relatively higher portion. Therefore, more daylight can penetrate into a room. As a results, when the upper blind angles of -30, -20, and -10 are applied, high *UDI* values are obtained at the position of D/H = 3 and 5 while the lower blind angles do not affect much to the *UDI* values. At most of the slat positions, windows with blinds provide better daylight performance than window using heat reflective glass.



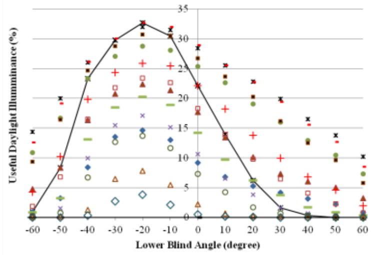
(a) Annual average UDI at D/H = 1



(b) Annual average UDI at D/H = 3



(c) Annual average UDI at D/H = 5



(d) Annual average UDI at D/H = 7

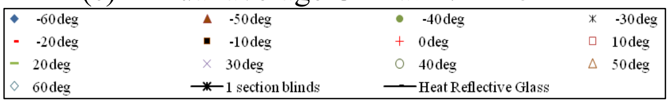


Fig. 4 Annual average UDI of the window.

3.5 Energy Saving

In this section, the energy savings from electric lighting is evaluated for the room model. It is assumed 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 17.26 W/m^2. For the base case, all the lamps were fully turned on during typical office hours 8:00-17:00 for five days a week (Monday-Friday).

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.

3.6 Lighting power density

According to the TIEA-DG003.2003 standard of the Illuminating Association of Thailand (TIEA), recommended illumination levels for office areas are in a range of 300 to 800 lux. The *LPD* values of the two-section slat window of the dimmable lighting system at three required illuminance levels which are 300, 500 and 800 lux are studied. By Lumen method calculation, the *LPD* of lighting to provide the illuminance at these three levels were calculated at 10.36, 17.26, and 17.26 W/m^2, respectively. The results show that at higher required illuminance level, the *LPD* requirement increases. However, the patterns of the *LPD* requirement at these three illuminance levels are similar because daylight potential is identical at the same outside conditions. As the consequence, the interior illuminance distributions of natural light are the same. Therefore, only the results at 500 lux required illuminance are shown here. The results of annual average *LPD* at 300 and 800 lux required illuminance levels are in the range of 4.63 to 7.22 and 15.38 to 22.94 W/m^2, respectively. The average *LPD* values per year of window with heat reflective glass are 6.79 and 21.66 W/m^2 for the cases of 300 and 800 lux required illuminance levels, respectively.

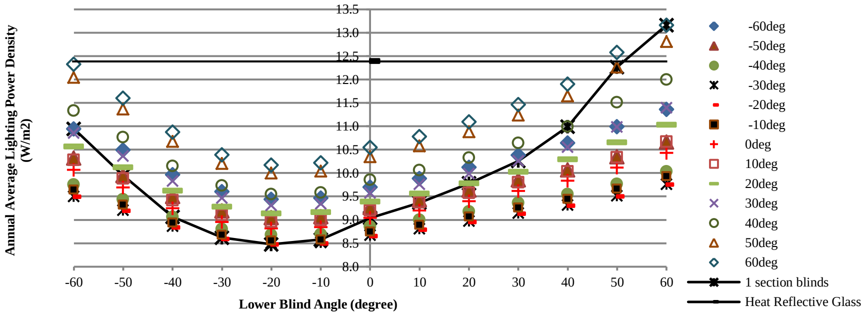


Fig. 5 Annual average *LPD* of the window at 500 lux required illuminance level.

Because of the high daylight potential of upper blinds when the upper blinds are set at negative angles in the range of -30 to -10, their *LPD* values are low. According to the same reason, single-section slat window at -20 degree provides the lowest *LPD* value at all illuminance level requirements and provides the maximum electricity saving from lighting system at 31% comparing to heat reflective glass window. As shown in Fig. 5, a room using window with blinds requires lower electricity from lighting system than that using window with heat reflective glass, except that tilt angles of both upper and lower blinds are high at 50 and 60 degree.

3.7 Thermal heat gain through window

For tropical region, cooling is dominant. Daylight penetrates through window along with heat which becomes cooling load of an air-conditioning system. When blind angles are negative, there are high chances that blind slats tilt parallel to beam solar radiation which enters the room. For this reason, the results of negative blinds angles show higher heat gain through window as shown in Fig. 6. At very high degrees of blind angles both in positive and negative directions such as -50, -60, 50, and 60 degree, heat gain through window reduces because the blind slats are almost close and beam radiation cannot penetrate through gaps between blind slats.

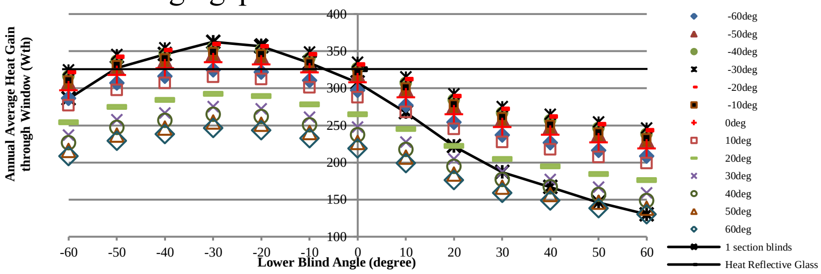
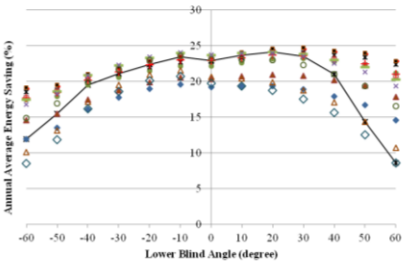


Fig. 6 Annual average heat gain through window (thermal Watt)

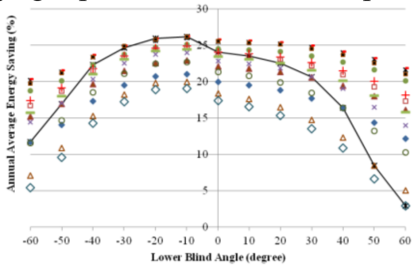
Examine again Fig. 4 and 6, for single-section slat window, when the blind angles provides high daylight potential, they also have high heat gain through window, and vice versa. Two-section slat window provides better flexibility for daylight use compared to single-section slat window because heat gains through window are the same for the same combination of slat angles. For example, see Fig. 6, the window with upper and lower sections at -30 and 30 degree blind angles has the same heat gain through window with the window with upper and lower sections at 30 and -30 degree blind angles. As shown in Fig. 4, the window with upper and lower sections at 30 and -30 degree blind angles provides higher *ADI* because higher portion of the sky can be seen from the occupancy.

Fig. 7 exhibits total electric energy savings of the room using two-section slat window based on the room using heat reflective glass window. The total electric energy saving composes of electric energy savings from the dimmable lighting system and the room's air-conditioning system. The electricity saving from lighting system depends on the *LPD* values as a consequence of daylight performance, while the energy saving of the air-conditioning system is an effect of cooling load due to lighting system and heat gain through window. Therefore, daylight performance has the major effect on the total energy saving because it influences both in lighting system and air-condition system.

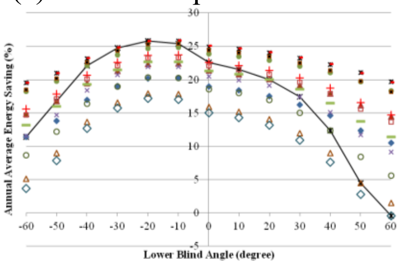
As show in Fig. 7 (b) and (c), window with upper blinds which are set at negative angles in the range of -30 to -10, provides high savings at all lower blinds angles due to their high daylight performances. Especially when the room is designed for high illuminance level (800 lux), high daylight level is required; consequently, the maximum saving occurs at the highest daylight performance window, -20 single-slat window. This is not the case when the room is designed for low illuminance level (300 lux). Heat gain through window plays more important low to the total energy requirement. High daylight level becomes excessive. As a result, two-section slat windows with positive angles at the lower section provide higher energy saving because less heat gains through window in these cases while their daylight performances are comparable.



(a) 300 lux required illuminance level



(b) 500 lux required illuminance level



(c) 800 lux required illuminance level

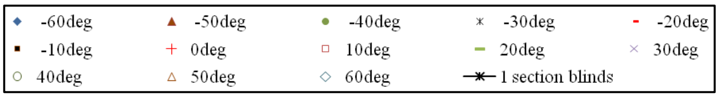


Fig. 7 Annual average electric energy savings.

4. Conclusion

Daylighting from a two-section slat window was investigated under tropical climate. A model was developed to simulate the interior daylight transmission through the window. The study results show that when the slats in the lower and the upper sections were tilted to proper angles, the two-section slat window can enhance the interior daylight use beyond the one-section slat window. It can also improve the uniformity of the interior daylight distribution. The two-section slat window and dimmable electric lighting system, when used in a room with the same configuration as that of the experimental room, can utilize daylight to save about 31% of electric lighting energy and 26% of the total electricity.

5. Acknowledgement

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