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Energy Analysis from Daylighting through Doublepane Window with Horizontal Slats in Thailand

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***Abstract*—This study evaluates the energy performance from the use of daylight through the window with horizontal slats installed between two glazing panes (slat window). Two mathematical models were validated with experiments and were adopted to determine the heat gain and the daylight transmission through the slat window under the tropical sky and climate. The results show that the daylight use from the slat window is energy efficient compared with the case of heat reflective glass that interior lighting is fully reliance on electric lamps. However, the daylighting through the slat window has to be implemented with care for shallow rooms with low values of required interior illuminance in order to avoid excessive heat gain to air-conditioning system.**

***Keywords*— Daylighting,Slat window, Heat transmission, Tropical climate.**

I. Introduction

Thailand is situated in the tropics where solar radiation is intense and daylight is abundant [1]. To avoid the adverse effect of thermal gain from solar radiation through glazed windows, low optical transmittance glasses are recommended for the usage for buildings. However, this practice leads to loss of beneficial gain from the daylight use including connectedness between the occupants and exterior scene. Buildings with such windows fully rely on electric lighting even when the daylight is sufficient for the illumination [2].

Among various technologies for windows, the glazing unit integrated with horizontal shading slats located between the two glass panes (slat window) is of particular interest as it offers a versatility to regulate daylight and heat transmission into buildings. From literatures, studies of thermal performance of the slat window have been conducted in different locations and conditions. Rheault and Bilgen [3, 4] evaluated the heat gain and loss through the slat window and then use to determine the slat angles that minimize the heating and cooling loads from the window under a typical Canadian climate.

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In USA, Lee et al. [5] conducted a full-scale experimental study on the performance of the slat window utilizing two experimental office-like rooms. The results showed that the slat window was capable of substantially reducing both the space cooling load and the energy for electric lighting.

In our previous works [6, 7], an analytical model was developed and used to calculate the interior daylight from the slat window and the resulting energy savings from electric lighting. In this paper, thermal performance of the slat window was investigated through experiments and simulations. The work aims to identify the appropriate angle of the slat that minimizes energy from both electric lighting and space air-conditioning for building in the tropical Thailand.

II. Heat Transfer Through Window Slat

In this study, a heat transfer model described in [3, 4] is adopted to determine the heat transfer through the slat window. As shown in Fig. 1, the heat transfer is analyzed based on radiative and convective heat exchange mechanisms.

The energy balance of the whole system components is performed to obtain the temperature of the glasses and the slats. The total heat gain from the slat window is finally derived from the known values of the transmitted solar radiation and the inner glass temperature

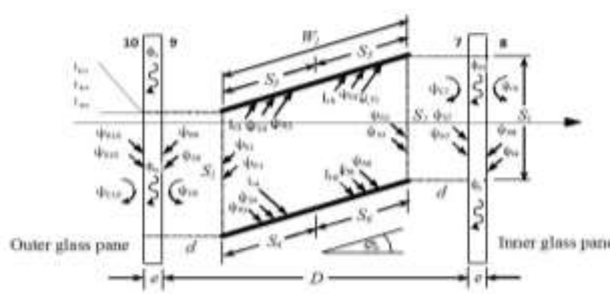

Figure 1. The heat transfer through the slat window

III. Daylight Through the Slat Window

This study adopts the model introduced by Chaiwiwatworakul and Chirarattananon [6, 7] for determining the daylight transmission through the slat window. The model separates the interior daylight into the direct component that is the light flux from the slat window, and the internally reflected component that is the light flux from internal reflecting room surfaces. Figure 2 depicts for the model the transmission of the direct daylight component to a point in interior space.

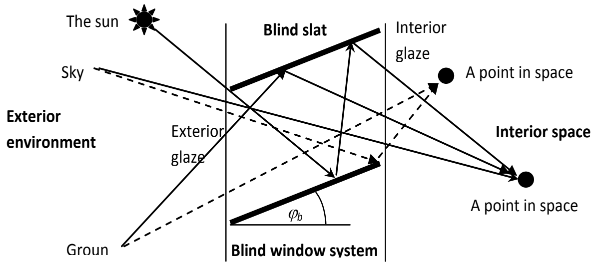

Figure 2. Paths of light transmitted through the slat window

IV. Experiment

A series of full scale experiments was conducted to measure temperatures of the glaze panes and the blinds of the slat window under the tropical solar radiation exposure. The transmitted daylight into interior room was also measured. The results were used to validate the heat transfer model and the daylight model in Section 2 and 3.

A. *Experiment facility*

The experimental site was 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). Figure 3 shows the experimental room. Table 1 exhibits the configuration of the room

A slat window was installed on the south wall of the room. The outer and inner glasses of the slat window were 6 mm. thick. The distance between the two glasses was 10 cm. The blind slats were 5.0 cm wide and white-painted aluminum. The distance between two adjacent slats was 4.2 cm. The thermal and optical properties of the glass and the blind were summarized in Table 2.

Figure 3. Experimental room

TABLE I. SPECIFIC INFORMATION OF THE EXPERIMENTAL ROOM AND ITS ENVIRONMENT

Item	Internal Dimension (m)	Area (m^2)	Reflectance
Wall	6.00 x 2.65 (E & W walls) 3.00 x 2.65 (N & S walls)	47.7	0.73
Ceiling	6.00 x 3.00	18.0	0.73
Floor	6.00 x 3.00	18.0	0.43
Ground	-	-	0.10

TABLE II. PROPERTIES OF LASS AND BLIND SLAT

Description		Clear glass	Slat
Solar range	Transmittance	0.80	0.00
	Reflectance	0.08	0.71
	Absorptance	0.12	0.29
Visible range	Transmittance	0.87	0.00
	Reflectance	0.08	0.75
Infrared range	Emittance	0.87	0.87

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B. *Experimental results*

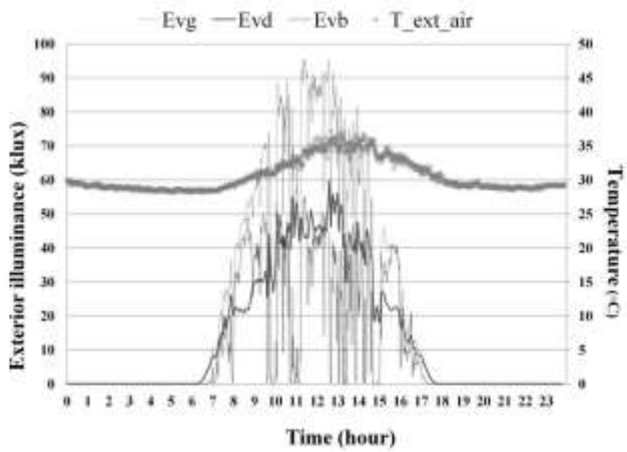
Only the experiment of the slat tilted at angle of 0 degree is chosen to present. The experiment was made on 11/11/2014. Figure 4(a) shows the global (E_{eg}) and the diffuse (E_{ed}) solar radiations on the date of experiment. Temperature of the ambient air is also shown in the plot. On this day, the sky was partly cloudy and the beam radiation was quite fluctuated. The maximum value of the global radiation was about 900 at noon time. Figure 4(b) shows the incident solar radiation on the outer glass pane from the measurement. As the sun stays in front of the window, the incident radiation was high up to 600 W/m^2. In the figure, the corresponding values of the incident radiation from the calculation using the radiation data together with the ASRC-CIE sky model were compared. A good agreement can be observed from the plot.

Figure 4(b) also shows the values of transmitted solar radiation. It could approximate that about 80% of the incident solar radiation can be shaded by the slat. With the model used, it can give a good prediction of the transmitted solar radiation. The temperatures of the glasses and the slats from measurement and from the calculation are compared in Fig. 4(c) and (d). It is found that the temperatures varied closely with the incident radiation of the outer glass. Again, the plots show that the calculated values from the model well agree with the measurement.

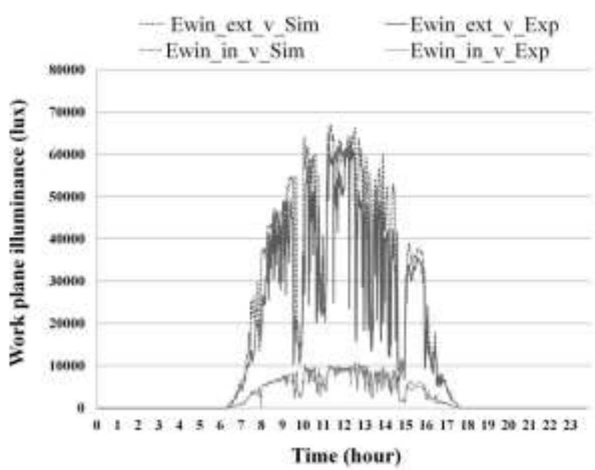
Other than the solar radiation measurement, the interior daylight illuminance at 10%, 50%, and 90% depth of the room was also measured. The results were shown in Fig. 4(e). It can be observed that, the illuminance on the work plane (80 cm. above floor) near the window can increase upto 2,800 lux at noon corresponding with the exterior daylight. The interior illuminance was found to exponentially drop from the window to the rear wall of the test room. The figure shows the predicted interior illuminance from the model used was quite agree with the measured ones.

Figure 4(f) shows the resulting heat transfer through the slat window calculated from the model. The heat transfer due to the solar radiation is also shown in the plot. The solar radiation influences significantly the heat gain through the slat window.

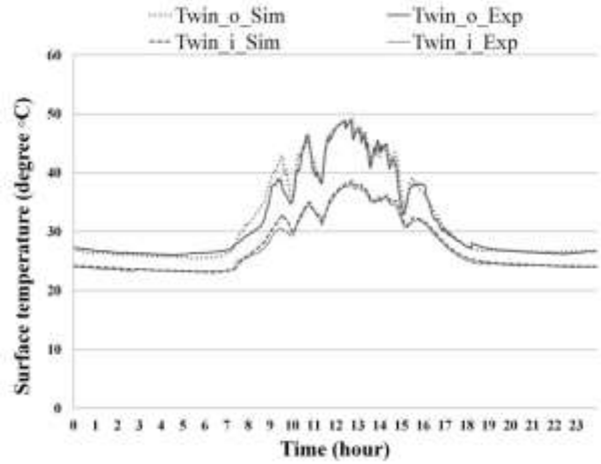
The temperatures of the glasses and the slats from measurement and from the calculation are compared in Fig. 4(c) and (d). It is found that the temperatures varied closely with the incident radiation of the outer glass. Again, the plots show that the calculated values from the model well agree with the measurement.



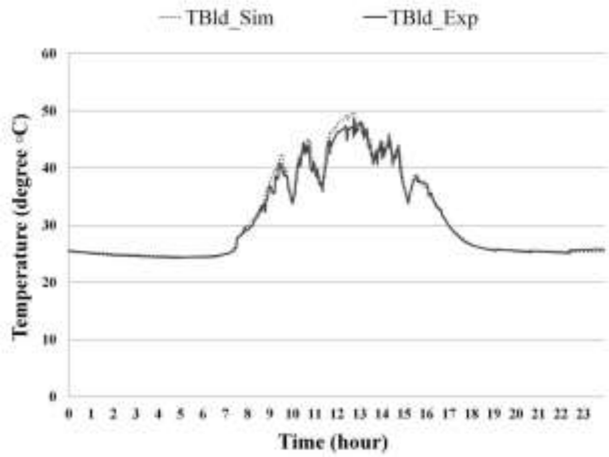
(a) Solar radiation and ambient air temperature



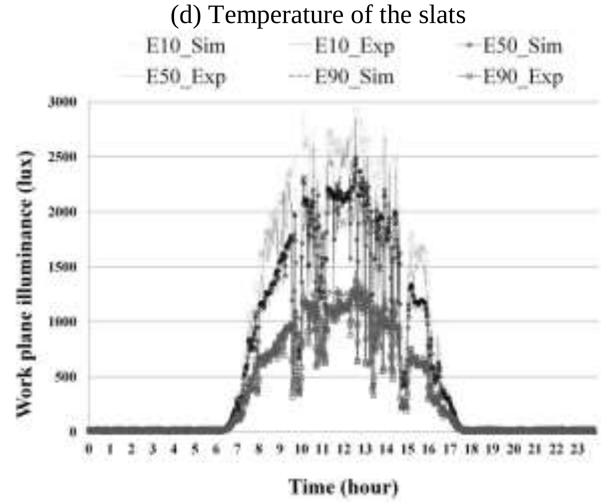
(b) Incident and transmitted solar radiation



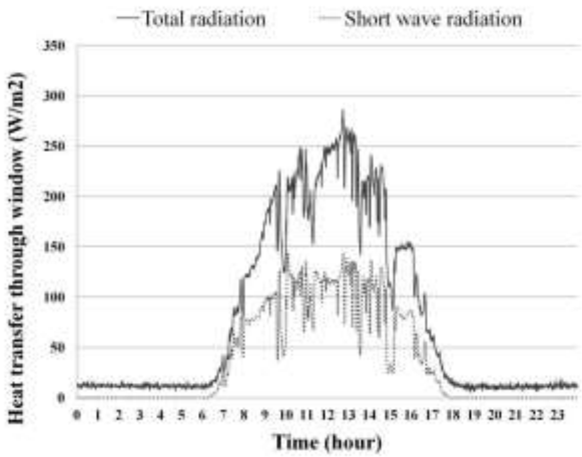
(c) Temperature of the outer and inner glasses



(d) Temperature of the slats



(e) The workplane daylight at 10%, 50% and 90% of the room depth



(f) The heat transfer through the slat window

Figure 4. Experimental results of the window with a slat angle 0° (11/11/2014)

V. Simulation-base Analysis

The validated algorithm in Section 3 is now used to investigate the thermal performance of the slat window. In the simulations, the model room was set similar to the test room but its length was varied to 3m, 6m, 9m, 12m, and 15 m. The required interior illuminance was also varied for 300 lux, 500 lux and 800 lux. This arrangement aims to identify the appropriate tilted angle of the slats in order to achieve the minimum energy consumption from both electric lighting and air-conditioning. 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 [8]. No modification was made for the blind properties.

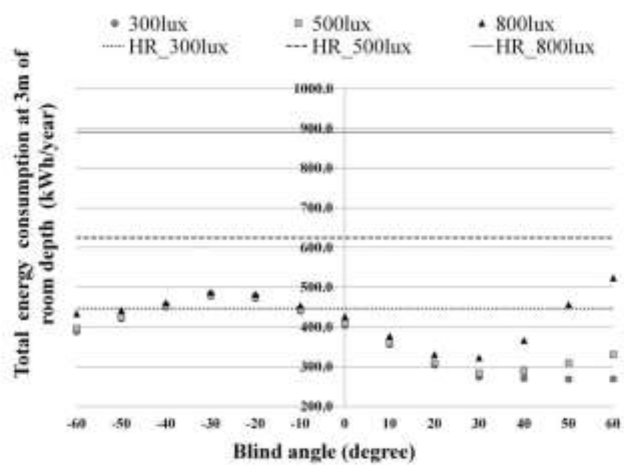
Equation 1 shows the energy equation established in this study for evaluating the performance of the slat window. In the equation, *HG* represents the total heat gain from the slat window in unit (W_{th}). Multiplying *HG* by a factor (A_w/A_f) converts the heat to be based on the unit of floor area. The lighting power density (*LPD*) represents the electric power demand from electric lighting. It is used to measure the electricity consumption by lighting. As the electrical energy for lighting itself finally becomes heat, it is included as a part of cooling load as shown in Equation (1). The power demand by air-conditioning can be derived by dividing the heat gain from the slat window with *COP*.

$$E_{ann} = \left(\frac{(A_w/A_f).HG+LPD}{COP}\right) \quad (1)$$

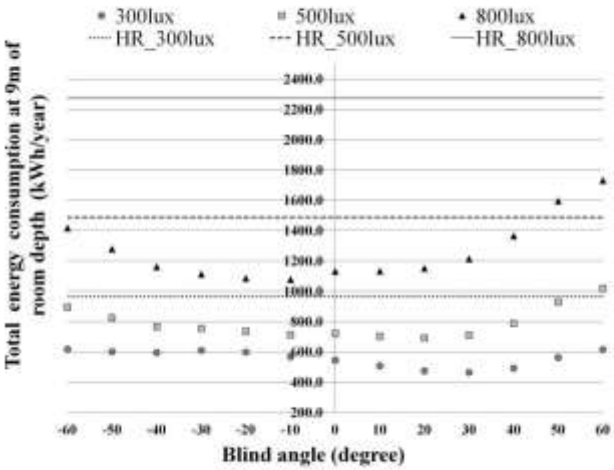
Figure 5(a) shows the simulation results for the room depth of 3m. The horizontal axis is the titled angle of the slat and the vertical axis is the annual energy consumption by lighting and air-conditioning influencing from the daylight use through the slat window. For the required interior illuminance of 300 lux, the energy consumption when the slat tilted at 60 deg is about 13.92 W/m^2. The consumption then decreases with the angle turned up to 30 degree. This would result from the introduced daylight to supplement light from electric lamp even though the associated heat gain increases. If the slats are still turned upward from 30 deg to -30 deg, the energy consumption now increases. This would result from excessive heat when the more incoming daylight cannot reduce the energy consumption for lighting. Figure 5(a) also shows the same plots for the required interior illuminance of 500 lux and 800 lux. It can be observed that when higher interior illuminance is required, the slats have to be turned more open.

Figure 5(a) also shows the annual energy consumption for a reference case of heat reflective glass. Comparing with the slat window integrated with dimmable electric lighting, the slat window consumes less energy from lighting and air-conditioning. Figure 5(b) shows a similar plot to Fig. 5(a) but for the room depth of 9m. This room has a longer depth from the window compared with the previous case. In order to achieve the same interior light level, lighting system requires higher power consumption per unit utilization floor area. For longer room depth, in order to achieve minimum energy consumption, the slats have to be turned upward to introduce more daylighting into deep interior.

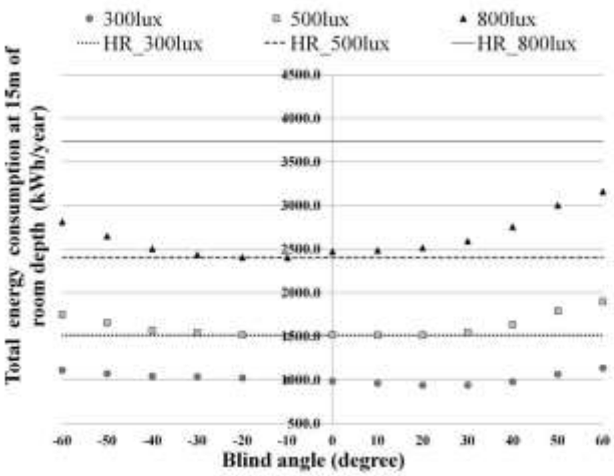
In the last Fig. 5(c), the results are presented for the room depth of 15m. The results show that the slat angles that minimize the energy consumption do not differ from the room depth of 9m. This would result from that daylight could not penetrate deeper than 9m.



(a) Room depth of 3m.



(b) Room depth of 9m.



(c) Room depth of 15m.

Figure 5. The resulting annual energy consumption of the slat window as functions of room depth and required interior illuminance level

VI. Conclusion

The energy analysis of the slat window was studied under tropical climate. The analysis demonstrates how to evaluate the energy performance of the slat window in terms of both lighting and air-conditioning.

The results show that under tropical climate, introducing daylight for interior illuminance is energy efficient for rooms with high room depth from the window. However, it has to be implemented with care to avoid excessive heat load to air-conditioning system for shallow room.

Acknowledgment

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