An application of automated slats for tropical daylighting

Vichuda Mettanant*, Pipat Chaiwiwatworakul

The Joint Graduate School of Energy and Environment, Center of Excellence on Energy Technology and Environment, King Mongkut’s University of Technology Thonburi, Bangkok, Thailand

Abstract:
The investigation of the application of an automated slat window was conducted. The sensor positions for controlling the automated slat window efficiently. The daylight illuminances from the slat window on a workplane were studied through the experimental and simulation studies. The flux transfer method was used to calculate the direct components and internally reflected components of daylight illuminance and solar radiation. The energy balances of the slat window were performed by considering the incident solar radiations, the net absorbed energy from the heat exchanges within the air gap, and the heat convection on the glass surfaces by the surrounding air. Three experiments are shown to examine the influences of the light control positions for various slats window areas. The results show that the positions of the light control sensor impacted the slat operation. However, the slats could adjust their angles effectively without beam penetration for maintaining the interior workplane illuminance. The transmitted solar irradiance can be reduced by 82% of the incident irradiance during the experimental days. The experimental results and the calculation results using the developed software exhibited an acceptable accuracy.

Keywords: Automated blind; Sun shading; Daylighting

*Corresponding author. Tel.: +66-085-952-6235
E-mail address: vichuda.mettanant@gmail.com

1. Introduction
Venetian blind is a device that offers an effective integration of natural daylight use with electric lighting particularly for tropical office buildings where require air-conditioning by cooling all year round. Appropriate control and setting of the slats can introduce sufficient daylight amount to illuminate interior space without excessive heat transmission; resulting in a great savings of energy from lighting and air-conditioning systems (Chaiwiwatworakul et al., 2009; Chaiwiwatworakul and Chiraratthananon, 2013; Chaiyapinunt and Khamporn, 2013; 2014; Chaiyapinunt and Worasinchai, 2009; Zanghirel et al., 2011). A co-benefit of the daylighting includes an improvement of occupant’s satisfaction and productivity through a better indoor environment. However, past studies reported that the slat manual-control always resulted in the slats to be fully shut-off to prevent entering beam irradiance, thus the daylight has never been employed even when it was sufficient for interior lighting for most office time (O’Brien et al., 2013). Automatic control is an alternative solution to improve the slat operation and utilization (Chaiwiwatworakul et al., 2009; Cheng et al., 2016; Iwata et al., 2017). However, many users still struggle to decide the sensor position that can integrate efficiently the daylight with artificial lighting system. Most studies located control sensor at the room center (Chaiwiwatworakul et al., 2009; Cheng et al., 2016; Gunay et al., 2017) or at the working position (Iwata et al., 2017). At the same setting of illuminance value, when the slat control sensor is located far from a window, more natural daylight can enter the room but thermal heat gain from a window will be high, and vice versa. This study aims to investigate the application of an automated slat window when it was used for daylighting in an office under Thailand tropical climate. The investigations were made through the experimental and simulation studies. In the study, the influences of the light control position for various window areas of the automated slats were examined.

2. Calculation of the daylight and heat gain from the slat window
The window with horizontal slats enclosed between two glass panes (slat window) is an interesting solution to the traditional practice of the building envelope design. In the present study the daylight illuminance from the window on a workplane is obtained by using a daylight calculation algorithm
described by Chaiwiwatworakul et al. (2009). Interior daylight illuminance composes of direct component and internally reflected component which uses the flux transfer method. The direct component includes light from the sun transmitted through gaps between slats, light flux from sky, light flux from ground, and light flux from luminous slat surface. The internally reflected component deals with the exchange of the light flux by multiple reflections between the small segments of the interior surfaces. A non-steady thermal model of the slat window explained by Fathoni et al. (2016) is used in the current study to determine the heat transfer through the slat window. The model can also determine the surface temperatures of the glasses and the slat. The heat transfer through the slat window is analyzed based on mechanisms of radiation exchanges and heat convections. As shown in Fig. 1, the energy balances of the whole window system are simultaneously performed in an iterative manner at the slats and the two glass panes by considering the incident solar radiations ($E_i$), the net absorbed energy from the heat exchanges within the air gap ($A'_{sw}$), and the heat convection on the glass surfaces by the surrounding air. In the energy balances, the effects of thermal storage and delay in the temperature and the heat transfer are taken into account.

![Fig. 1 The thermal resistance network of the slat window](image)

3. Experimental setup
A prototype of the automated slats was developed at the study site by equipping the manual-control slats with a stepping motor so the slats could be altered their angle according to signal from an indoor light sensor. The slat controller received the data from the meteorological station at Bang Khun Tein campus, King Mongkut’s University of Technology Thonburi, (latitude 14.7°N and longitude 100.5°E) via wireless network to calculate the sun position and define sky condition. From the calculation, the controller could define the limit angle for completely blocking the beam radiation while trying to provide workplane illuminance according to the user setting. A room of an outdoor single-story laboratory building was arranged for the experiments. The building situates 108 m from the meteorological station. This experimental room depth was 6.0 m. The room height was at 2.65 m. The room had a glass window on the south facing wall. The window was 2.8 m wide by 1.5 m high and its sill was 0.85 m above the floor. This room was conditioned by using a fan coil unit.

4. Results
Three experiments were chosen to present the operation of the automated slats, the resulting workplane daylight and the heat gains through the window system. In the first experiment (see Fig. 2), the light sensor was located to maintain the workplane illuminance at 0.6 m apart from the windowed wall (10% of the room depth). The daylight at the control position was maintained at the
desired level of 300 lux. In average, the slat window can reduced the transmitted solar irradiance by 82% of the incident irradiance over the experimental day. The temperatures varied correspondingly with the solar incidence. The resulting heat gain due to the temperature and the absorbed heat could be measured in a range of 8-23 W/m². This indicates the major portion of the heat gain from the slat window was in the form of the longwave heat.

The second experiment presents another setting of the light sensor close to the rear wall (90% of the room depth) (see Fig. 3). According to the sensor position, the slats turn upward to introduce more daylight to the rear wall. Even the daylight at the control position could not meet 300 lux, those at other points exceeded the required illumination level. This case would indicate the excessive daylight admission. The transmitted solar irradiance varied between 15-30W/m², accounting for 82% of the incident irradiance on the window. The thermal gain was averaged at 24 W/m² over the experimental period.

In Fig. 3, the third experiment was conducted to observe the slat operation when the window area was decreased by half. With the reduced window area, the slats could operate to convey daylight to the control position to achieve the workplane illuminance at the desired level. The slats were fully close for the whole period thus the transmitted irradiance was measured at 4-5 W/m². The longwave
heat gain was about 25-30 W/m². The mean bias difference (MBD) and the root mean square difference (RMSD) of the experiments are shown in Table 1.

![Graphs and diagrams showing experimental data](image)

**Fig. 3** Experiment #2 (9th October 2017)

**Fig. 4** Experiment #3 (30th December 2016)
Table 1 The mean bias difference (MBD) and the root mean square difference (RMSD) of the experiments

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameter</th>
<th>Exp. No.1</th>
<th>Exp. No.2</th>
<th>Exp. No.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illuminance at control sensor (lux)</td>
<td>MBD</td>
<td>50.1</td>
<td>-14.0</td>
<td>48.6</td>
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<td></td>
<td>RMSD</td>
<td>63.4</td>
<td>23.2</td>
<td>79.4</td>
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<tr>
<td>Solar radiation from window (W/m²)</td>
<td>MBD</td>
<td>1.1</td>
<td>-4.1</td>
<td>2.0</td>
</tr>
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<td></td>
<td>RMSD</td>
<td>1.5</td>
<td>8.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Heat transfer from window (W/m²)</td>
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<td>-4.6</td>
<td>-0.7</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>RMSD</td>
<td>5.6</td>
<td>-4.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Outside glass temperature (°C)</td>
<td>MBD</td>
<td>-1.1</td>
<td>-1.7</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>RMSD</td>
<td>1.7</td>
<td>2.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Slat temperature (°C)</td>
<td>MBD</td>
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<td>-2.0</td>
<td>-2.3</td>
</tr>
<tr>
<td></td>
<td>RMSD</td>
<td>1.7</td>
<td>3.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Inside glass temperature (°C)</td>
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<td>-1.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>RMSD</td>
<td>0.7</td>
<td>1.9</td>
<td>0.8</td>
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</table>

5. Conclusion
The experimental and simulation results exhibit a good potential of the automated slat windows for daylight application in tropical climate. The slats could effectively alter the angle to maintain the interior workplane illuminance under the dynamic change of the exterior daylight condition. During the low exterior daylight the slats tilted upward to maximize the entering daylight without beam penetration. However, the position of the light control sensor influenced the slat operation and the transmitted amount of the daylight and heat, and consequently the resultant energy consumption. The window size are also the important influencing factors to the slats performance. The comparison of the measurements from the experiments and the calculation using the developed software exhibited an acceptable accuracy of the calculation from the models.

References