

## Daylight Performance of an Automated Vertical Blinds System

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### Abstract

This paper describes the mathematical calculation of interior illuminance when vertical blinds are used. A computer program was developed and verified with the measurement data from an experiment. A prototype setup of an automated vertical blinds system was used in the experiment. The auto blinds were programmed to be able to adjust their angles according to the position of the sun in order to prevent direct illuminance which can cause visual discomfort. Only useful daylight from the sky can enter a room. The results of interior illuminance from the calculation were in agreement with the measurement data from the experiments. The computer program was used to calculate the interior illuminance level for rooms of which window are in the north, east, south, and west orientations. The results show that, when an automated vertical blinds system was used in rooms with window in the east and west directions, interior illuminance level was higher than when that was used in a room with the south or north windows. Useful daylight illuminance can supplement illuminance from electric light. Calculation results show that using automated vertical blinds could save electricity of lighting system up to 18%.

**Keywords:** Daylight, Vertical blinds, Automated blinds

### Introduction

Daylight is a useful source to illuminate an interior space. However, it needs to be careful when using natural light because direct sunlight can cause glare or visual discomfort. Diffuse sunlight is the part that is desirable. Use of an automated blinds was suggested as one of the solutions. Chaiwiwatworakul et al.<sup>1</sup> suggested the algorithm to calculate interior illuminance when venetian blinds are used. The vertical blinds are highly used in office buildings, and the study of this type of blinds is still limited. This paper presents the study of interior illuminance level when automatic vertical blinds are used by modifying the algorithm of Chaiwiwatworakul et al.<sup>1</sup>

### Calculation of Daylight Illuminance through Vertical Blinds System

The vertical blinds system includes a single glass pane and vertical blinds installed inside a room as shown in Figure 1.

#### Direct luminance

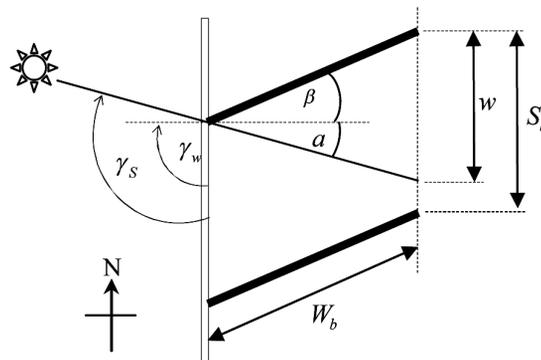
If the blinds angle is fixed or is not adjusted according to the position of the sun, direct sunlight can enter a room. This can cause visual discomfort. For

example, when the position of the sun is as shown in Figure 1, part of direct sunlight can enter a room.

The part of daylight going through the blinds system can be expressed as the difference between the length “ $w$ ” (in Figure 1) and the blinds separation ( $S_b$ ). The length  $w$  can be calculated as

$$w = W_b \frac{\sin(\beta + a)}{\cos(a)} \quad (1)$$

where  $a$  is the difference between solar azimuth angle ( $\gamma_s$ ), window azimuth angle ( $\gamma_w$ ),  $b$  is the tilt angle of blinds slats, and  $W_b$  is the width of a blinds slat.



**Figure 1** Top view of two adjacent slats and the line of incident sunlight.

**Diffuse Illuminance**

When an automatic blinds system is used, blinds slats are turned to prevent direct sunlight, and only diffuse light is able to pass into a room. Diffuse light from the window system is composed of light from the sky, reflected light from the ground, and reflected light from blinds slats.

**Sky luminance**

To calculate diffuse light from sky, the luminance distribution of the sky is treated as non-uniform sky. This means the luminance level at different patches of the sky is varied. The sky luminance is calculated based on Atmospheric Sciences Research Center-the Commission Internationale de l' Eclairage (ASRC-CIE) sky model.<sup>2</sup>

**Ground luminance**

The luminance of ground  $L_g$  can be determined from global illuminance and reflectance of ground using Equation 2.

$$L_g = \rho_g E_{vg} / \pi \tag{2}$$

where  $\rho_g$  is the ground reflectance, and  $E_{vg}$  is the global-horizontal illuminance on the ground.

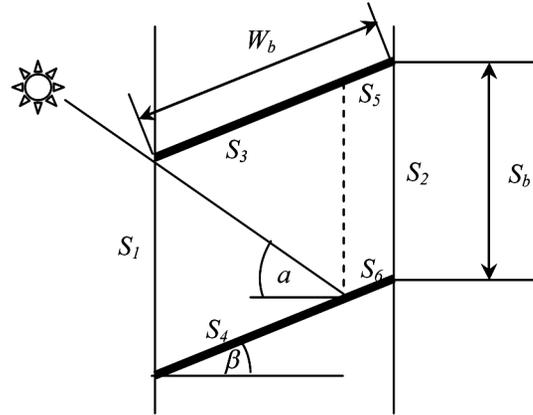
**Blinds luminance**

Blinds receive luminance on their surface from direct sunlight, diffuse sky light, and reflected light from the ground. This is initial light on blinds surfaces, then initial light reflects from one side to the other side of blinds slat. After inter-reflection of light between slats, the final luminance is a light source from window into interior space.

Figure 2 shows segments of a blinds system. Segments 1 and 2 ( $S_1$  and  $S_2$ ) are imaginary lines. Their lengths are equal to blinds separation. Segment 4 is the part that receives direct sun light. Its length is calculated as

$$S_4 = \frac{S_1}{\cos \beta \tan a + \sin \beta} \tag{3}$$

Segment 3 is an opposite side of Segment 4. The length of Segment 6 is equal to the subtraction of  $S_4$  from the blinds width. The lengths of Segments 3 and 5 are equal to those of Segments 4 and 6, respectively.



**Figure 2** Top view of a blinds system showing segments of blinds surfaces.

Only Segment 4 receives direct sunlight. The beam illuminance ( $E_{vb}$ ) that transmits through a glass pane strikes on a blinds slat and reflects off that slat. The initial exitance of Segment 4 due to direct light from the sun can be expressed by Equation 4.

$$M_{o4,b} = \tau_w(\eta_w) \rho_4 E_{vb} \cos \eta_b \tag{4}$$

where  $t_w(h_w)$  is the transmittance of the window as a function of the incident angle on window,  $r_w$  is the reflectance of Segment 4, and  $h_b$  is an incident angle on the blinds. The direct exitance due to direct light of other segments is zero.

The initial exitance of the segment due to diffuse light from the sky and the ground can be obtained by Equation 5

$$M_{oi,d} = \int_{\gamma_{ft}}^{\gamma_{rgt}} \int_{\theta_{low}}^{\theta_{up}} \tau_w(\eta_w) L \cos \eta_b d\theta d\phi \tag{5}$$

where  $L$  is sky or ground luminance level,  $q_{low}$  and  $q_{up}$  are the lower and upper limits of elevation angle of the segment, and  $g_{rgt}$  and  $g_{lft}$  are the right and left limits of azimuth angle of the segment.

The final exitance of each segment can be calculated by solving simultaneously a matrix of linear equation below

$$M_i = M_{oi} + \rho_i \sum_j M_j \cdot F_{ij} \tag{6}$$

where  $M_i$  is the final exitance of segment  $S_i$ ,  $M_{oi}$  is the initial exitance of segment  $S_i$ ,  $r_i$  is the reflectance of the segment  $S_i$ ,  $F_{ij}$  is the view factor from Segment  $i$  to Segment  $j$ .

The luminance on the surfaces of the right and the left blinds slat can be expressed by Equations 7 and 8.

$$L_{rt} = \frac{(S_3M_3 + S_5M_5)}{\pi(S_3 + S_5)} \quad (7)$$

$$L_{lt} = \frac{(S_4M_4 + S_6M_6)}{\pi(S_4 + S_6)} \quad (8)$$

**Window luminance**

As shown in Figure 3, at a particular blinds tilt angle  $b$ , a series of blinds slats can be divided into two main regions: right region and left region, and four sub-regions A to D.

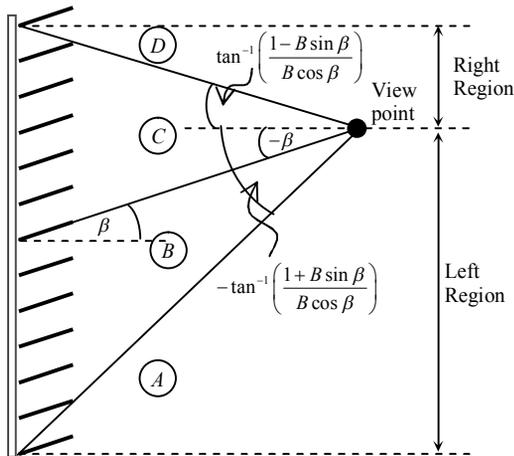


Figure 3 Top view of a series of blinds slats.

The right region represents the area where the surface of right slats is invisible while left region represents the area where the surface of left slats is invisible. The proportion of the exterior environment that is visible through the blinds slats from a point in the interior for the right region and the left region can be expressed by Equations 9 and 10, respectively.

$$V_R = \frac{S_b - x - y}{S_b} \quad (9)$$

$$V_L = \frac{S_b + x - y}{S_b} \quad (10)$$

where  $S_b$  is the blinds separation,  $x$  and  $y$  are distances as shown in Figures 4 and 5. The black dot in Figures 4 and 5 indicates a point of view inside a room, and the dash line represents the line of eye sight.

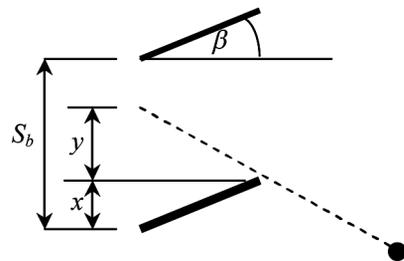


Figure 4 Top view of two slats showing visible ratio of the right region.

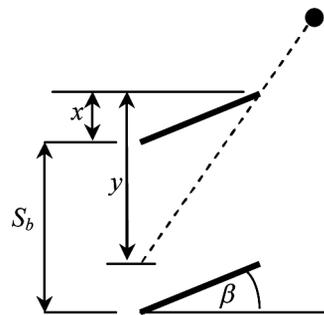


Figure 5 Top view of two slats showing visible ratio of the left region.

In sub-region A, only the surface of the left blinds can be seen. Therefore, the luminance of the window is equal to the luminance of the left blinds as calculated from Equation 8.

In sub-region B, both exterior environment and surface of the left blinds can be seen. The luminance of the window in sub-region B can be obtained from

$$L_w = V_L \left[ \int_{\theta_1}^0 L_g d\theta + \int_0^{\theta_2} L_k d\theta \right] + (1 - V_L) L_{lt} \quad (11)$$

For sub-region C, exterior environment and the surface of the right blinds can be seen. Equation 12 shows the luminance of window in sub-region C.

$$L_w = V_R \left[ \int_{\theta_1}^0 L_g d\theta + \int_0^{\theta_2} L_k d\theta \right] + (1 - V_R) L_{rt} \quad (12)$$

In sub-region *D*, only the surface of the right blinds can be seen. The luminance of the window is equal to the luminance of the right blinds. It can be calculated from Equation 7.

**Experimental Setup**

The experimental setup is located at latitude 13.49°N and longitude 100.2°E. It is a class room with the dimension of 3.85 m width, 6.36 m depth, and 3.50 m height. The window is oriented in the north-west direction with azimuth angle of 125 degree. The window is 1.88 m length and 1.45 m height. The window is located 0.94 m above the floor. There are twelve lamp fixtures in the experimental room as shown in Figure 6.

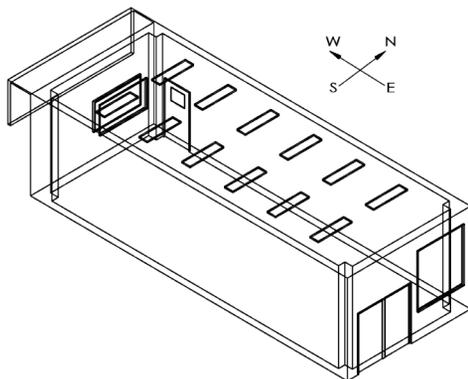


Figure 6 The experimental room

The window system consists of a clear-glass pane with 6 mm thickness and the automatic vertical blinds as shown in Figure 7. Transmittance of window pane is 0.87. The blinds slats are made of aluminum painted in white. Reflectance of the slats is 0.75.

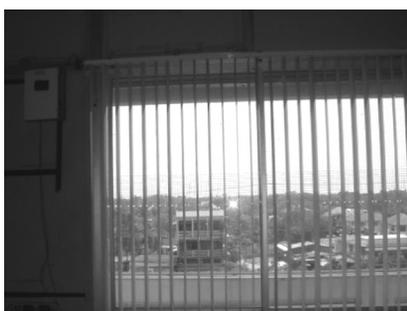


Figure 7 Installation of automated blinds in the experimental room

The controlling part of the automatic blinds system is composed of a stepping motor and a microcontroller module to drive the motor as shown in Figures 8 and 9. The stepping motor is connected to the shaft of the blinds system (see Figure 8).

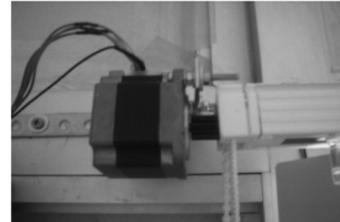


Figure 8 Stepping motor for blinds slat motion

The microcontroller module to control the motor and the blinds includes an interface board model AVR Mega 328, a real time clock circuit to input data of time for the microcontroller board, and a limit switch to check the blinds angle.

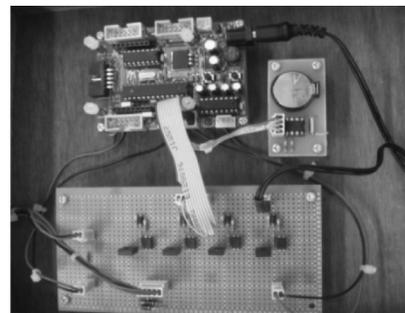


Figure 9 The microcontroller module for driving the motor

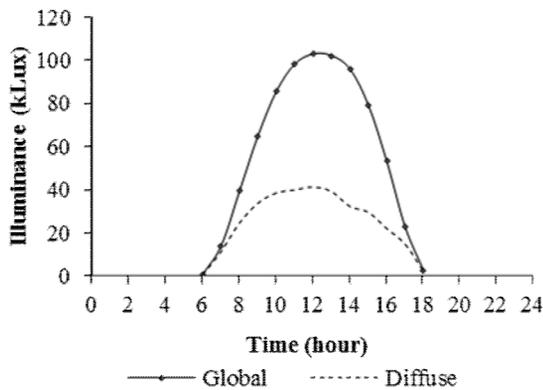
The blinds slats were programmed to tilt automatically according to position of the sun in order to fully shade direct sunlight. The measurement was conducted by using a lux meter model Testo 545.

**Results and Discussion**

**5.1 Comparison between simulation and experimental results**

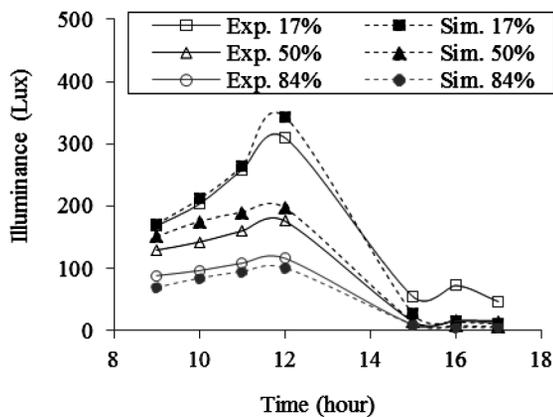
To verify the simulation program developed, the experiments were conducted for six days in March 2012. Figure 11 shows results on 22<sup>nd</sup> of March 2012. Global and diffuse horizontal illuminance data is acquired from department of physics, Faculty of Science, Silpakorn University, Nakhon Pathom, Thailand. The station is nearby

the experimental site. Figure 12 shows global and diffuse horizontal illuminance data on March 22<sup>nd</sup>, 2012 during 9:00-17:00 hr.



**Figure 10** Global and diffuse horizontal illuminance on 22<sup>nd</sup> March 2012

Inside the experimental room, Figure 11 shows the illuminance level on the floor at 17%, 50%, and 84% of the room depth when it is measured from the window. The solid lines present results measured from the experiment setup while the dash lines present results calculated from the simulation program.



**Figure 11** Interior illuminance on 22<sup>nd</sup> March 2012

Because the window is facing the north-west direction, the automatic vertical blinds adjusted their angles to prevent beam illuminance in the afternoon. As a result, the illuminance levels were low in the afternoon. The illuminance level decreases when the position away from the window increases.

The results from simulation are in the same trend with those from the experiment. The Root Mean Square Error (RMSE) and Mean Bias Difference (MBD) between the measuring and calculating results are showed in Table 1.

**Table 1** The Root Mean Square Error (RMSE) and Mean Bias Difference (MBD) between the measuring and calculating results

Position (% of room depth)	RMSE (%)	MBD (lux)
17	30.76	-9.92
50	20.96	12.74
84	4.54	-1.20

**Effects of window orientations**

To express the effects of using the automatic blinds for a window in other orientations on illuminance levels, illuminance was calculated by using the simulation program. The illuminance levels were calculated for the experimental room with window orientation of north, east, south and west on four reference days including 21<sup>st</sup> March, 21<sup>st</sup> June, 21<sup>st</sup> September, and 21<sup>st</sup> December. The average illuminance levels on the floor at 33% of room depth are 308.68, 306.32, 289.04, and 238.69 lux when the window is facing west, east, south and north, respectively.

**Electrical saving**

According to the Commission Internationale De L'Eclairage (CIE) standard, the illuminance level of a room for a general purpose should not be less than 300 lux. The calculation was evaluated for year 2011. The floor was separated into 35 sections. When the interior illuminance level was lower than 300 lux, the lamps above that area were turned on. Each fixture had two sets of 36-W-fluorescent lamps and a ballast of 14 W. The electricity charge was assumed as 2.78 Baht/kWh, the results showed that the electricity saving was 18% when and the payback period was 6 years.

## **Conclusion**

The simulation program was developed to calculate the interior illuminance level when a vertical blinds system was used. The program was verified with the experiments and the results were substantiated. The prototype of automatic vertical blinds was set. The blinds can adjust their angle automatically to fully prevent direct sunlight which cause glare or visual discomfort and allow only useful diffuse light into a room. The calculation also shows that use of the automatic blinds system can reduce electricity consumption of the lighting system.

## **References**

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