

Blind Control for Visual Comfort and Energy Savings in Buildings

So Young Koo¹ Hae Yeon Ku¹ Hyun Jung Lee¹
Myeong Seok Yeo² Kwang Woo Kim²

¹Department of Architecture, Seoul National University, Seoul, Korea,
soykoo@hotmail.com

²Department of Architecture, Seoul National University, Seoul, Korea,
msyeo@snu.ac.kr, snukkw@snu.ac.kr

ABSTRACT: The window blind is one of the most functional and widely used shading devices for reducing solar heat gain through windows by blocking direct solar penetration from entering the room. The objective of energy savings in buildings is to attain not only minimum energy consumption but also to provide maximum comfort for occupants. In a previous survey [8], it was shown that window blinds are usually rolled down most of the time and that they tend to be too low during some periods, resulting in the unnecessary blocking of daylight, solar heat, and view.

The purpose of this paper is to provide a control strategy for an automated blind that can achieve visual comfort and energy savings in buildings. Simulations were performed to investigate the environmental performance of control strategies. A thermal model was developed with Matlab/Simulink to implement various window blind controls. Also, RADIANCE software was used for daylight simulations. The results of the simulations show that the window blind vertical position is an important control variable and there is energy savings potential through taking maximum advantage of daylight in buildings. In order to validate the control system, a preliminary experiment was performed in a full-scale typical office space.

Keywords: automated blind, blind control, daylight, building energy

1. INTRODUCTION

Shading devices are usually used to minimize glare and overheating by blocking direct sunlight penetration, maximizing visual comfort and, in terms of environmental sustainability, minimizing building energy consumption. In recent years, a number of shading devices have been motorized and automated, rendering building fenestration more controllable and intelligent. The controllable shading device means that solar energy entering the room can be

controlled, thereby resulting in superior environmental performance.

Venetian blinds are used in many office buildings, since they have the advantage of simultaneous adjustment of both the slat angle and the vertical position. The vertical position is often called the occlusion value, which refers to the proportion of the window covered by a blind. In this paper, the focus lies in the optimal control of the automated venetian blind.

In terms of the control of window blinds, there are two effects of daylight: 1) thermal

effect, which is the heating and cooling loads of buildings in terms of solar gain as well as heat gain from artificial lighting [5], and 2) visual effects, which could substitute for artificial light and improve the quality of life in working environments, consequently reducing lighting energy consumption. The challenge of this study is to find a method of operating the blinds not only to block the direct solar penetration but also to take advantage of the daylight as a form of renewable energy from both thermal and visual considerations.

The previous survey conducted by Kim [8] on a motorized blind shows that when occupants pull down the blinds, they often do not open them up again. There was some relationship between the blind use by occupants and facade orientation. However, in most cases, the average frequency of a blind was moved was 0 to 1 times a day, confirming the earlier findings of surveys carried out by Rea [1] in US and Inoue [2] in Japan.

It was also found that most commercial automated venetian blinds are not able to be properly controlled in the vertical position and that only the slat angle is controlled. Consequently, most motorized and automated blinds are pulled down too low during some periods, which often cause the undesirable blocking of daylight.

2. METHODOLOGY

Firstly, the control objectives for the automated blind control were defined. Thermal and visual effects of daylight sometimes need to be traded off, especially during the cooling season. The control objectives need to be prioritized by considering the occupants preferences. The occupants preference is an important factor for window blind control [9]. Building geometry was defined for the calculation of solar geometry and the time line matrix.

For the purpose of investigating the impact of the vertical position of the blind on

the indoor thermal and visual environment, two building simulations were carried out. A thermal model was developed with Matlab/Simulink in order to implement the various blind controls, while RADIANCE software was used for daylight simulation.

For the preliminary validation of the thermal model, the calculation results obtained from the shading optical model were compared with those of EnergyPlus. Also, the experiment was performed in an environmental chamber and the window surface temperature was measured. The chamber was set to the fixed outdoor and indoor temperature with a sun simulator for simulating summer irradiance. The results of the measured temperatures were compared with the calculation results.

For the simulations, three cases were compared: 1) both slat angle and vertical positions were automatically controlled; 2) only the slat angle was automatically controlled; and 3) the blind was in a fixed position. Thermal simulations were carried out for one week and daylight simulations were performed for one day each during the summer and winter.

For the validation of the control system, the preliminary experiment was performed in a full-scale typical office space with an exterior venetian blind.

3. CONTROL ALGORITHMS

3.1 Control Objectives

Three control objectives were defined, those of visual comfort, energy savings and occupants preferences. Visual comfort includes daylight, glare and view, while cooling and heating energy should be considered for energy saving. Since control objectives often contradict each other, the objectives need to be prioritized to take into consideration the occupants preferences. Table 1 shows the priority matrix for the case where visual comfort has priority over energy savings.

Table I: Priority Matrix (The case where visual comfort has priority over energy)

		Priority High → Low		
Vertical Position	High ↓ Low	High		Low
		High	User preference	Lighting energy
			View	
			Daylight	
		Low	Glare	Cooling energy

4. SIMULATION

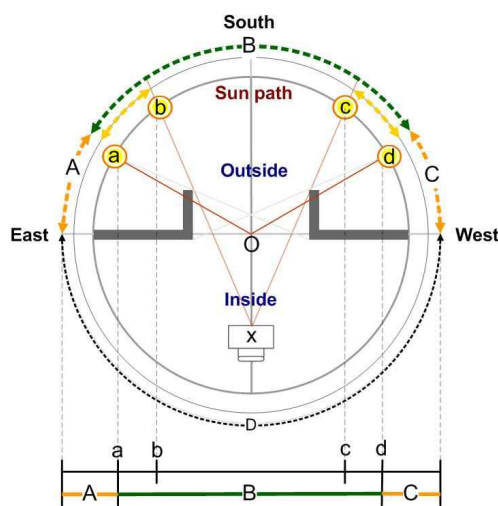
The optical model used for transmitted short-wave radiation and the thermal model used for absorbed solar radiation were implemented in the Matlab/Simulink module based on ISO 15099 [4] and EnergyPlus [7], which produces solar transmittance into the room and temperatures of the slats and glazing surfaces through the window/shading device.

4.1 Thermal Simulation

The simulations were carried out using the developed model to investigate the impact of controlling the vertical position on the indoor thermal environment. It is assumed that the window analysed in this study is facing south-west. Since the south-west shows a deeper depth of direct sunlight than that of the south, the solar heat gain in the afternoon is the major cooling load component.

A geometry model with the dimensions of 11.7m (W) x 6m (D) x 2.7m (H) was used, as shown in Figure 2. Weather data for Seoul (37°N) was used to define the boundary condition for the simulations. To investigate the effect of fenestration, symmetry conditions were assumed on the other side of the walls, with the exception of the window side. It was assumed that there was no mechanical heating and cooling in the room.

Simulations were performed for three cases, as presented in Table II. Three control strategies were applied for summer and winter. In case 1, both the vertical position and the slat angle of the blind are controlled. In case 2, only the slat angle is controlled. In case 3 the blind is not controlled and the vertical position is fixed to block 75% of the window area, which is the average value for a manual blind, as obtained from a previous survey [8]. The vertical position and the slat angle were controlled every 10 minutes, taking into account the position of the sun and the potential for the building orientation to block the direct sun penetration beyond the predetermined point. The predetermined

**Figure 1:** Diagram for Control Time

Since the focus of this paper is on the impact of the vertical position of the blind on the indoor environment, the goal is to block direct sun penetration beyond a predetermined point. A deeper predetermined point incurs a longer depth of direct sunlight from the window, resulting in more daylight and solar heat gain.

For the calculation of solar geometry, the basic geometry was defined as shown in Figure 1. In Figure 1, during time periods A and C, solar penetration is blocked beyond the predetermined point x. During time periods a to b and c to d, the length of time is affected by the position of the predetermined point x. Period D refers to the night time, when the blind may be controlled for energy saving rather than for visual comfort.

point was at a depth of 1.8m from the window, with a height of 0.86m, which were the closest work-planes in the room model.

Table II: Simulation Cases

Case	Summer (7/28~8/2)	
	Winter (1/24~1/29)	
	Vertical Position	Slat Angle
1 (VPSA)	Controlled	Controlled
2 (SA)	100%	Controlled
3 (Fixed)	75%	90°

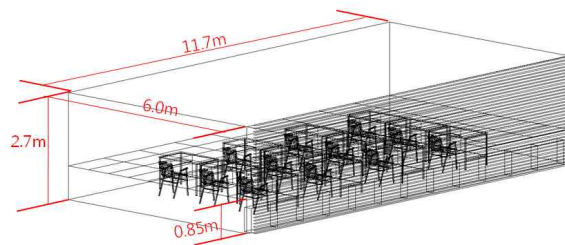


Figure 2: Geometry Model for Simulations

4.2 Daylight Simulation

Daylight simulation was carried out in order to investigate the effects of controlling the vertical position of the blind on the indoor visual environment. The same geometry model was used for daylight simulation and simulation condition is shown in Table III. The sky condition was assumed to be clear. The same simulation cases were used and the investigation was carried out on Jul. 30th and Jan. 29th for each summer and winter case.

4.3 Results and Discussion

The temperature fluctuations and transmitted solar irradiance on a surface during the summer period are shown in Figure 3 and Figure 4.

Table III: Conditions for RADIANCE Simulations

Date	Local Time	Vertical Position	Slat Angle
7/30	2:00pm	0.0	0.0
	3:00pm	10.3	0.0
	4:00pm	25.8	0.0
	5:00pm	36.0	9.7
	6:00pm	51.5	37.3
	7:00pm	67.0	73.3
	11:00am	5.0	0.0
1/29	12:00pm	20.6	0.0
	1:00pm	30.8	2.3
	2:00pm	40.9	17.4
	3:00pm	51.1	36.4
	4:00pm	56.2	47.3
	5:00pm	66.3	71.5

The outdoor temperature (T_{out} , Figure 3) corresponds to the typical summer temperature of Seoul within a range of 32°C. In case 2, no direct solar penetration is permitted and only diffused solar gain can enter into the room. Conversely, in case 3 no diffused solar gain is permitted between the slats and only direct or diffused solar gain through the lower 25% of the window is permitted to enter the room. The results demonstrate that case 2, where only the slat angle is controlled, has a similar thermal performance to case 3, where the blind is fixed. This implies that the total solar gain through the fenestration is almost the same between cases 2 and 3, as shown in Figure 4.

However, case 1 shows different room temperature fluctuations. The red line (Figure 3) shows the simulated room temperature for case 1, where both the vertical position and the slat angle were controlled. The temperature difference between case 1 and case 2 demonstrates the difference of solar gain between two control strategies and the impact of various solar gain values on the indoor thermal environment. The solar irradiance on a surface has a strong influence on the temperature differences, as shown in Figure 4.

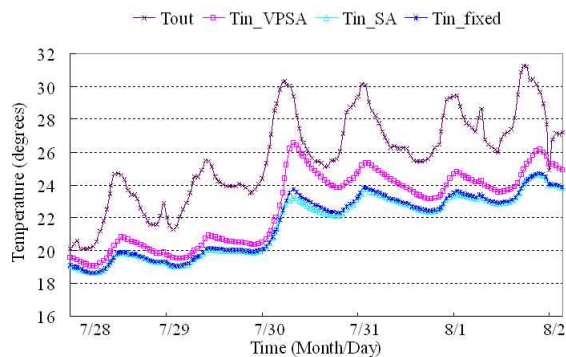


Figure 3: Temperature Fluctuation in Summer (7/28~8/2)

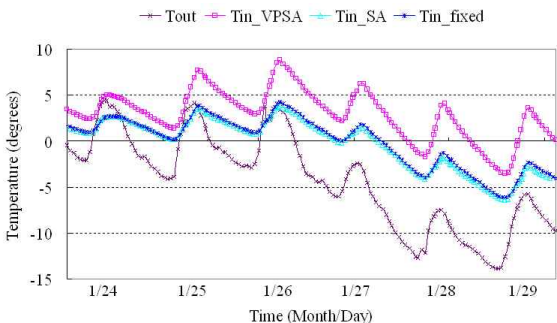


Figure 5: Temperature Fluctuation in Winter (1/24~1/29)

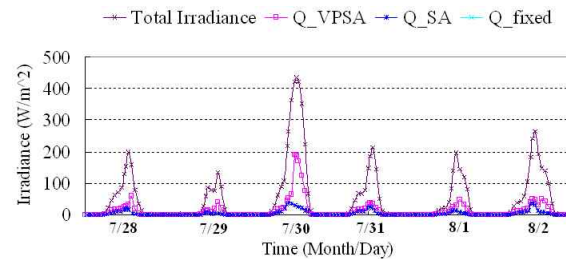


Figure 4: Solar Irradiance in Summer (7/28~8/2)

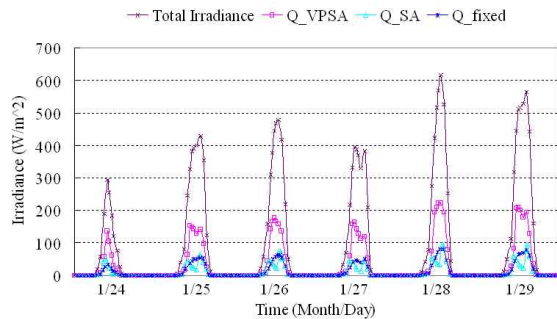


Figure 6: Solar Irradiance in Winter (1/24~1/29)

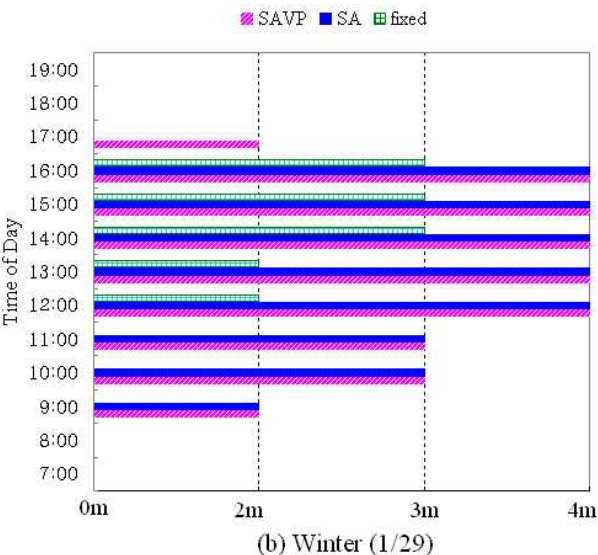
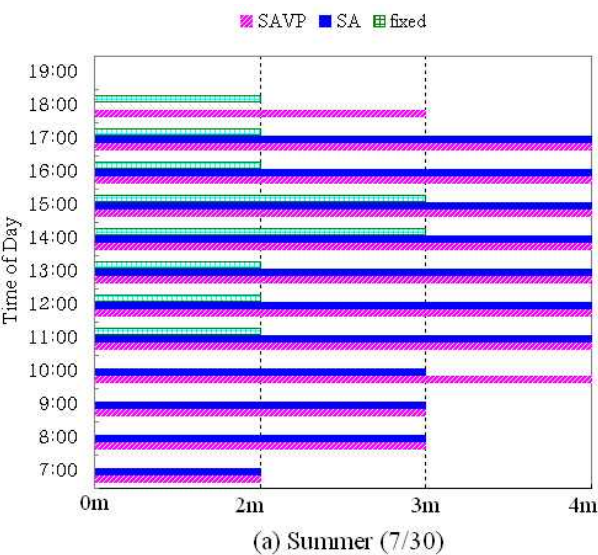


Figure 7: Room depth meeting the required illuminance

As solar irradiance increases, the transmitted solar gain entering into the room also increases, as shown in Figure 4, thereby increasing the temperature difference between cases 1 and 2, as shown in Figure 3. A similar approach can be taken in the case of winter, as presented in Figures 5 and 6.

In case 1, as shown in Figure 3, at times the room temperature is too high, resulting in a possible increase of the cooling load. However, in terms of heating load, this might result in a decrease of heating load, as shown in Figure 5.

Here, daylight simulations might provide somewhat different results. Figure 7 shows the comparisons between room depths in terms of providing the required indoor illuminance of 500lux [3]. Although cases 2 and 3 show a similar thermal performance, as mentioned previously, they show a different visual performance, as shown in Figure 7. The visual performance of case 3 is poorer than that of cases 1 and 2, which could be predictable. This demonstrates that an automatically controlled blind has a superior visual performance over a manual blind and that, in some cases, they have a similar thermal performance.

Case 1 and case 2 show a similar visual performance. This implies that the increase of solar energy by controlling the vertical position influences thermal performance more significantly than visual performance. However, in Figure 7 it can be seen that case 1 is slightly superior to case 2 in terms of visual comfort as well as lighting energy. It must also be considered that the quality of daylight cannot be determined only by the measurement of the required indoor illuminance.

5. EXPERIMENT

The preliminary experiment was performed in a full-scale typical office space. The goal was to block direct solar

penetration beyond the predetermined line. A web-camera was used to monitor and record the depth of solar penetration on the measurement surface. The remote PC could be accessed and the video files were downloaded. Figure 8 shows the calculated and measured depth of solar penetration. The still images were manually captured from the video files. Several errors occurred in the images for the early morning and the afternoon. These errors may have been caused by imprecise input data such as window surface azimuth and building geometry.

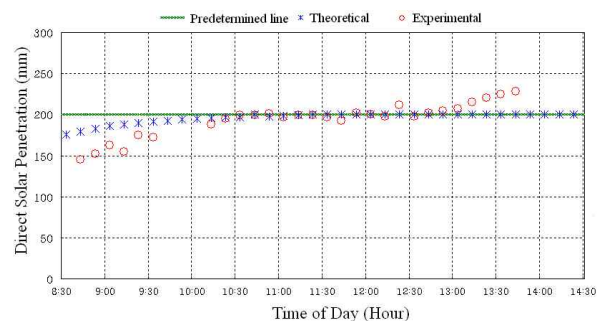


Figure 8: Comparison between the calculated and actual measurements (6/17)

6. CONCLUSION

This study investigated the simulation results of three cases of blind control strategies. The simulations were carried out using a developed model and RADIANCE software to investigate the impact of controlling the vertical position of a blind on the indoor thermal environment and the visual environment.

The results of thermal simulation show that the case where only the slat angle was controlled and the case where the blind was fixed have similar thermal performances. The case where the vertical position was controlled has a superior thermal performance during winter.



Figure 9: Full-scale office space for experiment

However, excessive solar gain during the summer could cause an increase in the cooling load. Also, the solar irradiance on a surface has a strong influence on the thermal performance of the blind. The results of daylight simulation show that the case where only the slat angle was controlled and the case where the vertical position and the slat angle were controlled have a similar visual performance. The case where the blind was fixed shows poor visual performance.

The above simulations demonstrate the possibility of controlling the vertical position of a blind in terms of thermal and visual environmental performance, consequently resulting in energy savings in buildings.

REFERENCES

- [1] M.S.Rea, 1984. Window blind occlusion: a pilot study, *Building and Environment* Vol 19. No 2. pp.133-137.
- [2] T. Inoue, T. Kawase, T. Ibamoto, S. Takakusa, Y. Matsuo, 1988. The development of an optimal control system for window shading devices based on investigations in office buildings, *ASHRAE Transactions* Vol 94. p.1049.
- [3] IESNA, 2001. *IESNA Lighting Handbook*, Illuminating Engineering Society of North America.
- [4] ISO, 2003. *ISO 15099-Thermal performance of windows, doors and shading devices-Detailed calculations*.
- [5] T. Miyazaki, A. Akisawa, T. Kashiwagi, 2005. Energy savings of office buildings by the use of semi-transparent solar cells for windows, *Renewable Energy* Vol 30. pp. 282-304.
- [6] F. Gugliermetti, F. Bisegna, 2006. Daylighting with external shading devices: design and simulation algorithms Vol 41. pp.136-149.
- [7] LBNL, 2006. *EnergyPlus Engineering Reference*.
- [8] Ji-Hyun Kim, M. S. Yeo, K.W. Kim, et al., 2007. An Experimental study for the evaluation of the environmental performance by the application of the automated venetian blind, *Proceedings of Clima 2007 WellBeing Indoors*, Helsinki, Finland, pp. 1678-1685.
- [9] H.Y. Ku, S. Y. Koo, M. S. Yeo, K. W. Kim, 2008. User preference based control strategy for an automated blind, *COBEE 2008, Proceedings of the 1st international conference on building energy and environment*, Dalian, China, pp.1132-1138.