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Analysis of The Thermal Load Variations Affected by Window Orientation, Transmitted Solar and Blind Parameters

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Abstract
Windows are the only part in buildings that can directly penetrate the solar radiation into the space and thus the shading devices are needed to control the solar penetration. Among different blind types in office buildings, optimized control strategies of slat-type blinds are suggested in the existing studies. Although many studies have been done, mostly the study focuses on window that is oriented towards the south. As it is obvious that in a real building windows can be facing any direction, in this study the effect of blinds on heating and cooling loads of a building has been done, when the design of blind is either horizontal or vertical, when it is placed either inside or outside and when the slat angle automatically changes based on either solar energy received on vertical wall or on horizontal surface (roof).

Keywords - EnergyPlus; internal blind; external blind; cooling load; heating load; orientation

1. Introduction

1.1 Background and purpose

Nowadays, building energy consumption covers 25% of whole energy consumption in Korea [1], and it is growing steadily. So reduction of building energy consumption is very important. But unfortunately many high-rise office buildings in Korea have recently adopted the curtain wall structure, due to aesthetic façade, openness, and light-weight construction [2]. As the curtain wall structure is made with glass, the curtain wall has higher U-value than masonry wall, which in turn increases cooling and heating load in the building [3].

There are many window types in the building with different solar transmission and U-values, but it is not easy that cope with the external environment. Thus, the shading system should be selected in order to reduce the energy consumption of buildings. Nowadays commonly used shading system is roll-shade blind. But roll-shade blind have the limited ability to control solar radiation, so a blind system with different shape was developed, that is slat blind. The angle of slats can be changed and controlled for different weather; this is the strong point of slat blind [3, 4].

Many studies have been previously done regarding the various blinds for window systems. G. Dutta [5] used TRNSYS to calculate the thermal performance of a building using external fixed horizontal louvers with different slat length and tilts. She found that properly designed louvers on the south window can reduce the cooling load in summer but optimum design depends on site location and weather condition. A. Tzempelikos et al. [6] suggested that to substantially reduce the cooling and lighting energy demand, it is better to take an integrated approach for automatic control of motorized shading in conjunction with controllable electric lighting systems. In case of Korea, Kim et al. [7] concluded on the basis of experimental results that using automated horizontal blinds can reduce cooling energy consumption as compared with motorized horizontal blinds. M.H Oh et al. [8] made a study on a double sided blind with different reflectance and by optimizing the control strategies, they were able to achieve 29.2% total energy saving with 0.1% chances of glare. Y.B. Yoon et al. [9] did a detailed heat balance analysis using EnergyPlus with horizontal blinds both inside and outside and with various glazing materials to find the different parameters that affect the different components of heat balance [3].

Although very detailed study have been carried out for different shading devices, most of the studies focus on horizontal slat type shading devices, like venetian blinds and roller-type blinds and almost all studies are done for windows/walls facing south orientation. As the western sun is known to cause more glare effect, study on the effect of blinds on other orientation is also relevant. Therefore, the objective of this study is to investigate the heating and cooling load variation caused by the change in slat angle of vertical and horizontal blinds when they are not present or placed either inside or outside the window. The most optimal slat angle for lowest cooling and heating load compromise is analyzed based on the amount of solar energy received on vertical and horizontal building surface like wall and roof [3].

1.2 Research scope

Two small-scale mock-up test units were used to obtain real time data for the validation purpose of the simulation model. The detailed validation process has been described in [10]. The validated EnergyPlus simulation model was rotated for the window to face south, east, west and north, and effect on the heating load and cooling load was investigated for blind location, blind type and slat reflectance. Thermal and visible properties of the window materials are based on the J and A glass manufacturing companies in South Korea [3].

2. Simulation outline

2.1 Simulation software

The simulation program used in this study was EnergyPlus developed by the United States Department of Energy (DOE). It is a relatively new building energy simulation program, which has greater capabilities than other programs [11]. EnergyPlus was selected because it is a heat balance based simulation program and the heat balance method is the current industry standard method for calculating space loads [12]. The blind optical model in EnergyPlus is based on Simmler's model [13].

2.2 Simulated modeling

The schematic overview of EnergyPlus simulation model is illustrated in Fig. 1, which is identical to the measurement. It is south-oriented and thermal properties of PVC and insulation material are based on ISO 10456-2007 [14]. The specifications of the modelled blind are summarized in Table 2. As discussed earlier, the validation process of the simulation model will not be discussed in this paper due to the fact that they are provided in [15] in detail [3].

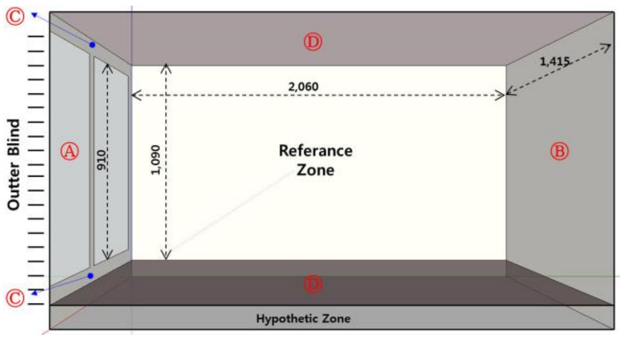

Fig. 1 Simulated Model [3]

Table 2. Specifications of simulated blind

	Contents	Value
Blind details	Front Reflectance	0.45
	Back Reflectance	0.45
	Slat Separation	0.025m
	Slat Width	0.025m
	Blind to Glass Distance	0.025m
	Slat Thickness	0.002m
	Slat Conductivity (W/m • K)	0.9

2.3 Simulation conditions

The weather data of Daejeon, South Korea used for the simulation was obtained from Meteonorm program. EnergyPlus recommends the use of Meteonorm weather data if it is not directly provided by EnergyPlus official webpage [16]. The weather in Daejeon is characterized as having four distinct seasons, with hot and humid summer and cold winter. The peak internal load levels are summarized in Table 3, which are based on ASHRAE Standard 90.1 2007b [17]. The indoor temperature set-points for heating and cooling were set at 22 ℃ and 26 ℃, respectively, based on the General Design Criteria of ASHRAE handbook HVAC Applications -2007a [18]. The thermal load profiles were calculated using the EnergyPlus function "ZoneHVAC:IdealLoadsAirSystem" [19] without modelling the heating and cooling systems [12][16][17]. This object provides the required supply air capacity to each zone at user specified temperature and humidity ratio to calculate the heating and cooling loads [3, 20].

Table 3. Input conditions of internal heat gain and indoor set-point [3]

	Input data		Reference
Internal Gain	People	1person (Sensible: 65W/person, Latent: 54W/person),	SI Unit Air conditioning equipment. (Author : Shin, Chi Woong)
	Lighting	10.8 W/㎡	ASHRAE handbook Fundamentals (2005)
	Equipment	11 W/㎡	ASHRAE Standard 90.1(2007b)
Set Temperature	Cooling	25 ℃ (May~Sep.)	ASHRAE handbook – HVAC Applications (2007a)
	Heating	22 ℃ (Oct.~Mar.)	

The simulation model was rotated so that the windows were facing south, east, west and north. The effect of vertical and horizontal slat type blinds on cooling and heating load inside the building was investigated where the blind was situated inside and outside the window. The control of slat angle according to zone transmitted solar [3].

3. Simulation analysis

3.1 Optimal slat angle for South

Table 4 shows optimum slat angles for different ranges of zone transmitted solar for lowest cooling and heating load in the south. Zone transmitted solar value was divided into 100 lux unit, cooling and heating marked as 'C' and 'H' respectively. The optimum slat angle for different ranges of zone transmitted solar is constant at 90° (close) for cooling purpose and but for heating purpose, during most of the time it is 0° (open) and changes as the ranges go over 800 lux but these angles are still quite small. This case is similar for both horizontal and vertical blinds [3].

Table 4. South orientation optimum slat angle for various ranges of zone transmitted solar for the lowest cooling and heating load [3].

	lux	Optimum Slat Angle							
		Ver_In		Ver_Out		Hor_In		Hor_Out	
		C	H	C	H	C	H	C	H
Zone Transmitted Solar	0-100	90	0	90	0	90	0	90	0
	100-200	90	0	90	0	90	0	90	0
	200-300	90	0	90	0	90	0	90	0
	300-400	90	0	90	0	90	0	90	0
	400-500	90	0	90	0	90	0	90	0
	500-600	90	0	90	0	90	0	90	0
	600-700	90	0	90	0	90	0	90	0
	700-800	90	0	90	0	90	0	90	0
	800-900	90	0	90	0	90	10	90	0
	900-1000	90	10	90	0	90	10	90	0
	1000-	90	20	90	0	90	20	90	0

3.2 Optimal slat angle for East

Table 5 shows optimum slat angles for different ranges of zone transmitted solar for lowest cooling and heating load in the east. Zone transmitted solar value was divided into 100 lux unit, cooling and heating marked as 'C' and 'H' respectively. In case of cooling load, for both horizontal and vertical blinds, for different ranges of zone transmitted solar, the slat angle is constant at 90°. But in case of heating load, the vertical blinds have a smaller slat angle when they are inside as compared to when they are positioned inside the window. But in case of horizontal blinds, the slats should be at 0°, i.e. fully open, except when the zone transmitted solar is over 700 lux in case of internal blinds [3].

Table 5. East orientation optimum slat angle for various ranges of zone transmitted solar for the lowest cooling and heating load [3].

	lux	Optimum Slat Angle							
		Ver_In		Ver_Out		Hor_In		Hor_Out	
		C	H	C	H	C	H	C	H
Zone Transmitted Solar	0-100	90	30	90	40	90	0	90	0
	100-200	90	30	90	35	90	0	90	0
	200-300	90	35	90	35	90	0	90	0
	300-400	90	35	90	35	90	0	90	0
	400-500	90	30	90	35	90	0	90	0
	500-600	90	20	90	40	90	0	90	0
	600-700	90	10	90	50	90	0	90	0
	700-800	90	0	90	45	90	20	90	0

	800-900	90	0	90	45	90	10	90	0
	900-1000	90	0	90	45	90	20	90	0
	1000-	90	0	90	35	90	30	90	0

3.3 Optimal slat angle for West

Table 6 shows the best slat angle for different ranges of zone transmitted solar for lowest cooling and heating load in the west. Zone transmitted solar value was divided into 100 lux unit, cooling and heating marked as ‘C’ and ‘H’ respectively. It is almost identical to the east orientation condition. In case of cooling load, for both horizontal and vertical blinds, for different ranges of zone transmitted solar, the slat angle is constant at 90°. But in case of heating load, the vertical blinds have a smaller slat angle when they are inside as compared to when they are positioned inside the window. But in case of horizontal blinds, the slats should be at 0° or fully open except when the zone transmitted solar goes over 500 lux in case of internal blinds. Here when the blinds are inside, comparing the vertical and horizontal, the cases flip at 500 lux [3].

Table 6. West orientation optimum slat angle for various ranges of zone transmitted solar for the lowest cooling and heating load [3].

lux		Optimum Slat Angle							
		Ver_In		Ver_Out		Hor_In		Hor_Out	
		C	H	C	H	C	H	C	H
Zone Transmitted Solar	0-100	90	30	90	40	90	0	90	0
	100-200	90	30	90	35	90	0	90	0
	200-300	90	30	90	30	90	0	90	0
	300-400	90	20	90	30	90	0	90	0
	400-500	90	10	90	30	90	0	90	0
	500-600	90	0	90	40	90	10	90	0
	600-700	90	0	90	45	90	20	90	0
	700-800	90	0	90	50	90	20	90	0
	800-900	90	0	90	45	90	20	90	0
	900-1000	90	0	90	45	90	20	90	0
	1000-	90	0	90	40	90	20	90	0

3.4 Optimal slat angle for North

Table 7 shows the best slat angle for different ranges of zone transmitted solar for lowest cooling and heating load for north orientated window. Zone transmitted solar value was divided into 100 lux unit, cooling and heating marked as ‘C’ and ‘H’ respectively. Here, for least cooling load the slats need to be completely closed and for least heating load, the slats need to be completely opened when the zone transmitted solar is taken into account [3].

Table 7. North orientation optimum slat angle for various ranges of zone transmitted solar for the lowest cooling and heating load [3].

lux		Optimum Slat Angle							
		Ver_In		Ver_Out		Hor_In		Hor_Out	
		C	H	C	H	C	H	C	H
Zone Transmitted Solar	0-100	90	0	90	0	90	0	90	0
	100-200	90	0	90	0	90	0	90	0
	200-300	90	0	90	0	90	0	90	0
	300-400	90	0	90	0	90	0	90	0
	400-500	90	0	90	0	90	0	90	0
	500-600	90	0	90	0	90	0	90	0
	600-700	90	0	90	0	90	0	90	0
	700-800	90	0	90	0	90	0	90	0
	800-900	90	0	90	0	90	0	90	0
	900-1000	90	0	90	0	90	0	90	0
	1000-	90	0	90	0	90	0	90	0

3.5 Optimal position of blind for minimized thermal loads

The following Fig. 2 shows cooling and heating energy inside the building when there is no blind and if there is blind, what is the effect of blind on the loads. Blind was controlled to be installed at an optimum angle for each of the value.

In case of South, the vertical blind located on the exterior is the best option for lowest thermal energy requirement. East case also, the best position is when the blind is on the outside. For the horizontal blind, the total energy demand is 1461.62 kWh and for the vertical blind is 1453.60 kWh. It is similar for west oriented window. The total energy demand difference between horizontal and vertical blind is 6.09 kWh, such that the vertical blind is better than horizontal one. North shows the cooling and heating energy different blind conditions for north oriented window, which is similar to the south oriented window. Surprisingly, the total energy demand for the north oriented window is higher than the south oriented window by about 200 kWh. In this case also the exterior vertical blind causes the least energy demand on the building.

In case of cooling load, for all cases – window orientation and blind location, the load is minimum when the slat angle is 90°, which means the blind is closed and there is no solar gain. For least amount of cooling load there should be no solar heat gain at all. But this also means that there will be no daylighting possible as well. In case of heating load, the slat angle is either 0° or very small, only up to 35° in case of vertical blinds. This means the blinds need to be either completely open or mostly open to decrease heating load [3].

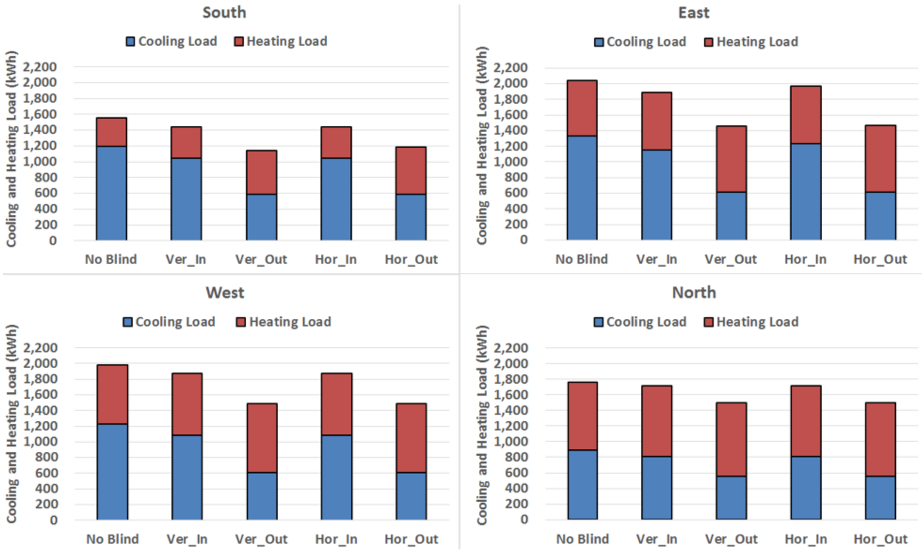

Fig. 2 Cooling and Heating energy for different blind locations [3]

4. Conclusions

In this study, the various slat angle for lowest heating and cooling load for horizontal and vertical blinds for inside and outside of south, east, west and north oriented windows as done. The heating and cooling loads were calculated for zone transmitted solar, i.e. the slat angle is controlled by the amount of solar angle received from the window. The following conclusions were drawn from this research.

- Without consideration of lighting, the results found here are very straightforward. For reduction of cooling load the slats needs to be closed, so that there is no solar gain and they need to be open, so there is maximum solar gain for lowest heating load [20].
- When the slat angle is controlled based on solar energy received on vertical surface, the lowest cooling load is observed when the blinds are positioned outside. And this also ultimately contributes to less overall load. For lowest total thermal load, horizontal blind is best for south, east and north but vertical blind is better for west [20].
- When the slat angle is controlled based on solar energy received on horizontal surface, the slat angle increases as the as the solar energy increases, but the drawback for this control type is that it is the same for all orientations. Since this strategy also considers dimming control, the total load in this system is higher. As the solar energy received on different orientation varies, this control cannot be very reliable [20].

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