European Journal of Sustainable Development (2017), **6**, 4, 302-308 ISSN: 2239-5938
Doi: 10.14207/ejsd.2017.v6n4p302

Analysis of Indoor Luminous Environment and Power Generation by Roll Screen and Venetian Blind with PV Modules

Seongkwan Hong, In-Tae Kim, An-Seop Choi*

Abstract
Venetian blind and roll screen are mainly used as a shading device because of the possibility of automatic control and simplicity of use. Venetian blind, in particular, can control the sunlight using slat rotation as well as up / down control. On the other hand, roll screen can control the direct sunlight inflow through up / down control. Such shading devices can also be used to generate electricity utilizing direct sunlight on them. This study aims to develop an optimal control method for generating electricity in terms of energy production while simultaneously blocking direct sunlight inflow in terms of occupant comfort using a shading device. In this study, we compare and analyze the change of the indoor luminous environment through appropriate control method for each shading device and power generation with attached PV modules.

Keywords: Photovoltaic, Luminous environment, Power Generation, Venetian blinds, Roll screens, Shading device

1. Introduction

Shading devices are devices that block direct sunlight to reduce the possibility of glare in indoor occupants. Shading devices are divided into indoor and outdoor shading devices according to installing location. Examples of indoor shading devices include venetian blind and roll screen, and examples of outdoor shading devices are louver, lightshelf and awning. In addition, shading devices are classified into fixed, manual and movable types according to operation method. Movable shading devices have lately become popular to achieve appropriate control. With the trend of auto control of such shading devices, interest in indoor luminous environment is increasing as well. Various studies are under way in the field of lighting to prevent overuse of lighting energy. Beyond studies on the use of energy-efficient light sources, studies on the introduction of natural daylight to reduce the use of light sources are very active. Some studies are attempting to save indoor lighting energy and maximize visual comfort of occupants through appropriate and efficient use of skylight [1-3]. Also, there is a study on a PV shading device that combines shading device and PV modules [4].

As mentioned earlier, recent studies are being conducted on energy saving in buildings through control of shading devices. However, most of studies are based on simulations, and there is lack of studies on the application in actual buildings. Accordingly, this study conducted an experiment in an actual space by selecting the venetian blind and roll screen, which are most widely used among indoor shading devices. After combining PV

[1]Department of Architectural Engineering, Sejong University, 209, Neungdong-ro, Gwangjin-gu, Seoul, Republic of Korea.
*corresponding author:

with commercial shading devices, indoor luminous environment and solar energy production were analyzed through auto control.

2. Shading device control

This study was conducted on indoor luminous environment and solar energy production using the venetian blind and roll screen attached with PV. The method of controlling shading devices can differ according to material and shape. As for the venetian blind and roll screen, the core element of the control method is slat and fabric, respectively. Accordingly, the two shading devices are to be controlled based on the following methodology. The venetian blind can be controlled by adjusting height and angle of slat. Height of the slat can be controlled to limit depth at which direct sunlight enters indoor, and angle of the slat allows to prevent glare, which shines direct sunlight entering through the gap between the slats onto indoor occupants to cause visual disability or discomfort. Accordingly, while maximizing the space between the slats of the venetian blind, the slat was adjusted to reflect direct sunlight. On the contrary, height of the roll screen is controlled to prevent entry of direct sunlight into indoor space, and the amount of skylight can be adjusted according to transmissivity of fabric. As shown in Fig. 1, the venetian blind adjusts angle of the slat to allow reflected skylight enter indoor and generates solar energy using PV modules of the slat. The roll screen allows skylight to enter indoor through transmissivity of the fabric and generates solar energy using PV modules on the bottom of the fabric.

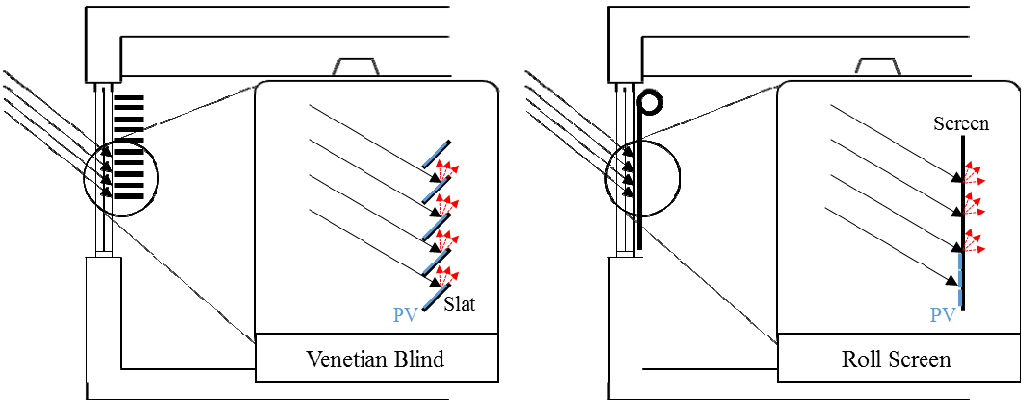

Fig. 1. Venetian blind and roll screen

The proposed method of controlling the shading device must consider changes of the Sun's orbit because it blocks direct sunlight and utilizes skylight. Here, the constant (displacement) used for position change of the Sun is profile angle. As shown in Fig. 2, it refers to altitude of the Sun on a plane perpendicular to façade of a building. Profile angle is used as a scale to find out the effect of direct sunlight on interior of a building. In the field of lighting, it is generally used to calculate depth of direct sunlight coming into a building. Especially, because the venetian blind used in this study can change angle of the slat unlike other shading devices, profile angle must be considered.

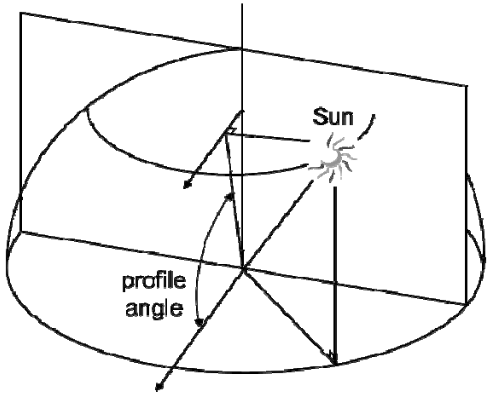

Fig. 2. Profile angle

3. Experiment

Fig. 3 and Table 1 show outline of the experimental space used during the experiment. The experimental space assumes an office space and is comprised of two rooms with identical setting. Experiment equipment are PV blind and PV roll screen shown in Fig. 4, and same quantity of PV modules is attached to the slat of the blind and the fabric of the roll screen. Measurement equipment include illuminance meters, battery, MPPT and power analyzer as shown in Fig. 5. Three illuminance meters were installed directly underneath and between the two lighting fixtures at height of 0.75m, which is height of ordinary work space.

.

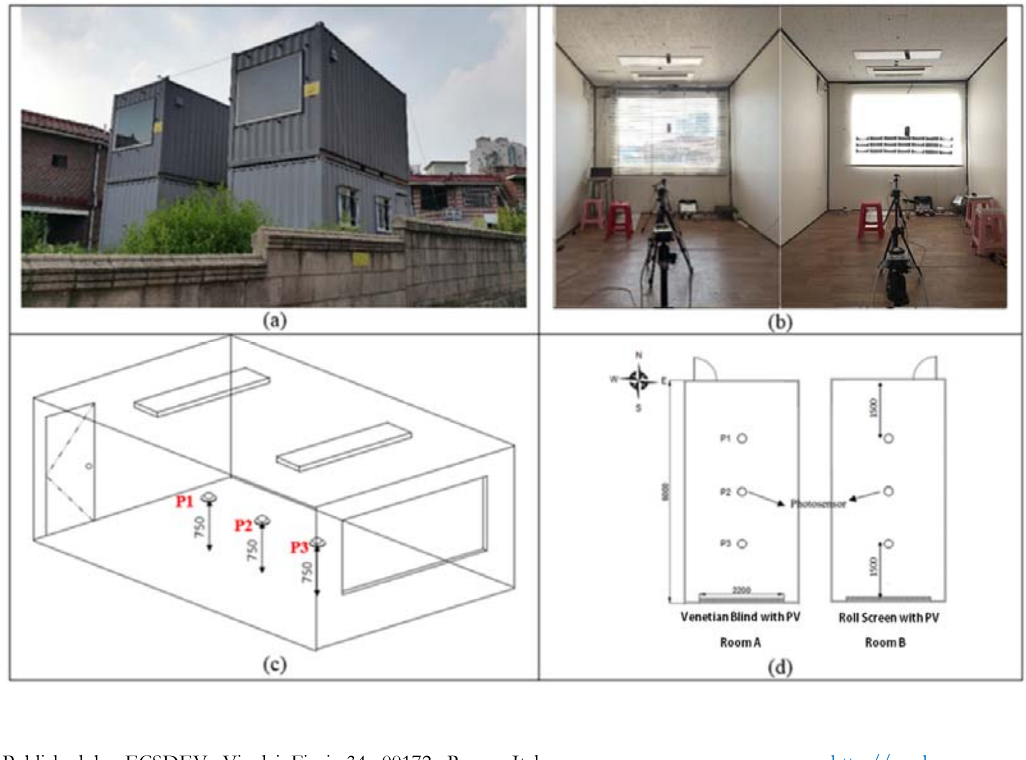

Fig. 3. The front view and interior of measurement space

Table 1. Outline of the measurement space

Location	Longitude	127.07 (degrees)
	Latitude	37.55 (degrees)
Size	Interior	6,000 × 3,000 × 3,000 (mm)
	Window	2,200 × 1,500 (mm)
Window Area Ratio		37 (%) – the south side
Building Elevation Angle		0 (degrees)

(a) *(b)*

Fig. 4. Experiment equipment
(a) PV Blind, (b) PV Roll screen

(a) *(b)* *(c)*

Fig. 5. Measurement equipment
(a) Illuminance meter, (b) Battery, MPPT, (c) Power analyser

The experiment was carried out according to the following process. First, profile angle of the space was calculated by considering geographical factors such as latitude and longitude of the experimental space. Height and angle of the shading devices were controlled based on calculated profile angle. Height of the venetian blind and roll screen was controlled by limiting incidence depth of direct sunlight to 1m. Height of the venetian blind and roll screen was 1.5m, identical to size of the windows, and was adjusted up and down according to size of the windows. For the venetian blind that requires additional angle control, the slat was adjusted on an hourly basis. Angle was adjusted by 10 degrees at a time. Since the amount of skylight reflected into indoor space becomes excessively low when slat angle of the venetian blind is orthogonal to profile angle of the Sun, slat angle was changed to allow for maximal inflow of skylight reflected off the slat into indoor space.

4. Results and Discussion

This study conducted an experiment on indoor luminous environment and solar energy production according to type of shading device combined with PV. The experiment was carried out for 9 days between June and July of 2017, and time of measurement was set to office hours from 9 AM to 6 PM. In order to rule out changes of indoor luminous environment caused by lighting fixtures, measurement was done at 5-minute interval with all lighting fixtures turned off. In addition, amount of solar energy generated was measured at 1-minute interval. Measured data were classified according to sky to analyze indoor luminous environment and solar energy generation.

To analyze quantitative data of indoor luminous environment, illuminance of each sky was analyzed. As expected, absolute value of illuminance increased closer to the windows. In addition, with clear sky, illuminance of the venetian blind was about 1.6 times higher than the roll screen. Then, power generation of the PV modules was analyzed to analyze solar energy production. The roll screen showed higher power generation compared to the venetian blind. In clear sky, power generation of the venetian blind was only 13.75% of the roll screen. For more detailed analysis, the ratio of indoor luminous environment and power generation of the PV modules according to sky condition was analyzed. The ratio of illuminance between the venetian blind and roll screen was not greatly affected by sky condition. On the contrary, the ratio of power generation of the PV modules between the two shading devices differed greatly in cloudy sky. Table 2 shows the ratios of illuminance and power generation according to shading device for different sky conditions. Fig. 6 is a sample graph that shows actual measurement values of the shading devices for partly cloudy.

Table 2. Results of the illuminance ratio and power generation ratio

Classification	Illuminance Ratio (Roll Screen / Blind) (%)			Power Generation Ratio (Blind/Roll Screen) (%)
	P1	P2	P3	
Clear	72.22	62.69	52.35	13.75
Partly Cloudy	66.78	56.24	45.93	14.32
Overcast	63.85	52.67	40.63	3.96

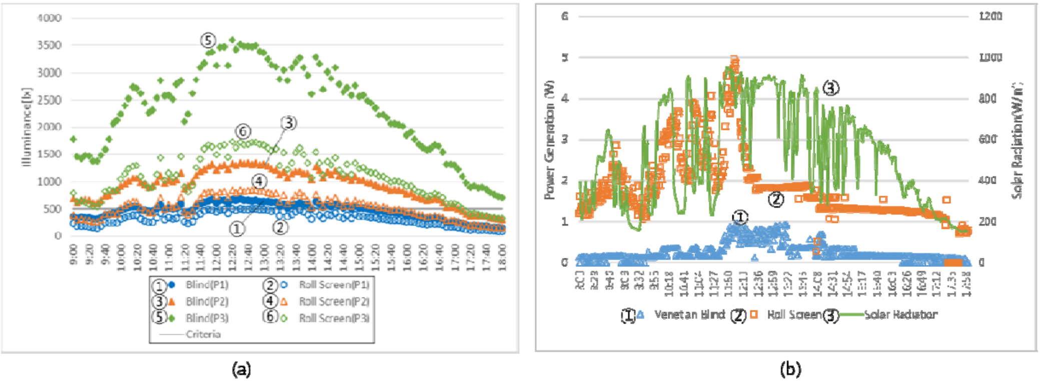

Fig. 6. Comparative analysis results: Venetian Blind vs. Roll Screen
(a) Measured illuminance, (b) PV power generation

This study attempted to find out the degree of incidence of skylight for different shading devices in order to save lighting energy of indoor luminous environment. Recommended illuminance for office space differs among nations. As presented in Table 3, IESNA has different illuminance standards according to age [5]. In general lighting design, target illuminance is 500lx. Therefore, potential saving of lighting energy can be estimated by referring to measurement data that excludes lighting fixtures. Of course, since measurement values can differ according to the ratio of long and short spans and size of windows, these factors need to be taken into consideration during actual application to lighting design.

Table 3. Office facilities illuminance recommendations

Applications and Tasks			Visual Ages of Observers (years)		
			<25	25-65	>65
VDT Screen and Keyboard	CSA/ISO Types Ⅰ and Ⅱ	Positive polarity	150lx	300lx	600lx
		Negative polarity	75lx	150lx	300lx
	CSA/ISO Types Ⅲ	Positive polarity	75lx	150lx	300lx
		Negative polarity	37.5lx	75lx	150lx

Conclusion

This study was conducted on indoor luminous environment and solar energy production by creating two identical spaces to test venetian blind and roll screen. To save lighting energy using skylight in indoor luminous environment, relative illuminance values were measured and comparatively analyzed while ruling out lighting fixtures. For solar energy production, power generation of the same quantity of PV modules attached to the venetian blind and roll screen were measured and comparatively analyzed. Here, in case of the venetian blind, angle of the slat was changed on an hourly basis according to profile angle, with the PV modules attached to the slat. On the contrary, angle of the PV modules does not change for the roll screen because the PV modules are attached to the fabric.

Summarizing the results of this study, illuminance from skylight was 1.6-1.9 times higher for the venetian blind compared to the roll screen. The venetian blind was found to be superior for indoor luminous environment. On the other hand, in terms of power generation of PV modules, the venetian blind was only about 3.96-14.32% of the roll screen. Such analysis implies that significant results were obtain in relation to indoor luminous environment and solar energy generation according to different types of shading devices.

As for indoor luminous environment, whereas skylight reflected off the slat was measured using illuminance meters for the venetian blind, skylight transmitting through the fabric was measured using illuminance meters for the roll screen. Therefore, the difference in indoor illuminance between the two shading devices is probably caused by the difference in characteristics between reflected skylight and transmitted skylight. In case of solar energy production, crossing angle between the Sun's profile angle and slat angle is low for the venetian blind because it is controlled by blocking direct sunlight with the slat and allowing maximal inflow of skylight based on reflection of the slat. On the contrary, incidence angle of the roll screen becomes higher than the venetian blind because the PV modules are attached to the fabric. The difference in power generation between the two shading devices probably resulted from such difference. Based on the results, the control method of shading devices can be further improved to maximize saving of lighting energy and production of solar energy. Accordingly, future studies will be conducted on the control methodology of shading devices and diversification of their materials.

Acknowledgments

"This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2017R1A2A1A05001170)"

References

[1] Li, D. H. W., Lam, J. C., & Wong, S. L. (2002). Daylighting and its implications to overall thermal transfer value (OTTV) determinations. Energy, 27(11), 991-1008.

[2] Li, D. H., Lam, J. C., & Wong, S. L. (2005). Daylighting and its effects on peak load determination. Energy, 30(10), 1817-1831.

[3] Bodart, M., & De Herde, A. (2002). Global energy savings in offices buildings by the use of daylighting. Energy and Buildings, 34(5), 421-429.

[4] Kim, S. H., Kim, I. T., Choi, A. S., & Sung, M. (2014). Evaluation of optimized PV power generation and electrical lighting energy savings from the PV blind-integrated daylight responsive dimming system using LED lighting. Solar Energy, 107, 746-757.

[5] DiLaura, D. L., Houser, K. W., Mistrick, R. G., & Steffy, G. R. (2011). The lighting handbook: Reference and application.