THE EFFECT OF EXTERIOR SHADING DESIGN ON VISUAL COMFORT AND ENERGY USE PATTERNS IN A BUILDING PERIMETER ZONE

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ABSTRACT

Daylighting is one of the most important factors to take into consideration during the schematic design stage, especially in modern office buildings. Introducing daylight with the proper quality and quantity can contribute to reducing the annual energy use as well as improving visual comfort. Moreover, because a comfortable visual environment could improve the workability of employees, building envelop (window and shading devices) design is very important for office buildings. Shading devices used in buildings usually have a large transparent area for several reasons: keep out the heat of the sun, block uncomfortable glare from direct sunlight and soften harsh daylight contrast. However, inappropriate shading devices might have the opposite effect, as well as cause visual discomfort, to what was intended: the increase in the heating and lighting energy consumption exceeds the decrease in the cooling energy use. For helping initiative understand both energy and comfort, the aim of this paper is to introduce the concept of the Facade Perimeter Distance (FPD) with excessive daylight illuminance levels and building energy use patterns according to the Projection Factor (PF) of shading. In this study, two exterior fixed shading types, a horizontal overhang and a vertical fin, were evaluated with various PFs, respectively. The FPD and heating, cooling, lighting and total energy use patterns were compared by shading types and window orientations.

KEYWORDS

Shading devices, Visual comfort, Energy consumption, Building perimeter zone

INTRODUCTION

In most designs for high performance buildings, energy consumption and occupant comfort are considered together. These cannot be considered separately from the design of a building; thus, integrated design approaches have gained much attention (DOE 2013, Atzeria. A et al. 2014, Chan Y. et al. 2015). In this context, the significance of adequate window and shading device design is highlighted. Daylight is one of the most important factors to take into consideration during the schematic design stage. Daylight

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can contribute to reducing the use of artificial lighting in a perimeter zone through an appropriate envelop design. Furthermore, it has a beneficial impact on occupant well-being and productivity (REHVA 2010, Grynning et al. 2014). However, excessive daylight causes both an increase in cooling demand during hot periods and a reduction in heating demand during cold periods. Moreover, it causes discomfort in a visual environment, such as glare and contrast between light and shadows. In office buildings, it is especially important to adjust daylight because cooling loads dominate the total energy demand. It also influences the workability of employees. For these reasons, shading devices are mainly used to control the quality and quantity of daylight (DOE 2013, Grynning et al. 2014, Kim et al. 2015). In Korea, the window and shading criteria for reducing solar gain were added to the Building Energy Conservation Code, recently (MOLIT 2015).

Due to the need for integrated approaches, a wide range of research has been done on how to design and control shading devices in terms of energy optimization and visual comfort. Many studies have focused on moveable shading control strategies incorporating the geometrical, thermal and visual properties of windows (or glazing) (Atzeria. A et al. 2014, Grynning S. et al. 2014, Kim H. et al. 2016). For assessments, Atzeria. A et al. (2014) used the spatial Daylight Autonomy (DA) and the Discomfort Glare Index (DGI) as indicators. In some cases, a systematic method for selecting shading design variables were investigated (Chan Y. et al. 2015). Other studies have been done with fixed shading devices. Kim M. et al. (2015) analyzed the effect of several fixed shading devices for reducing the cooling loads during a specific overheating period. They evaluated Daylight Factor (DF) and Useful Daylight Illuminances (UDI) together with cooling energy consumption. Alzoubi H. H. et al. (2010) assessed the illuminance profile in an architectural space and illuminance levels of a work plane with various shading designs. Esquivias P. et al. (2016) used indicators including DF, UDI and Daylight Autonomy (DA). Despite all these studies investigating both the overall energy demand and visual comfort, there has been a lack of indicators which could help architects intuitively understand shading design as well as apply them to building design.

Thus, the aim of this study was to introduce the concept of “FPD (Façade Perimeter Distance)” as an indicator that architects can use in office building design which includes artificial lighting in terms of energy and visual comfort. The FPD means the distance which has an excessive daylight illuminance level from the façade. This concept includes the UDI schema which defines the beneficial quantity range of daylight illuminances: 100-2000 lux (Nabil A. and Mardaljevic J. 2006). For this purpose, we investigated various cases of shading devices in an office building perimeter zone. Secondly, the energy use patterns were analyzed according to the FPD. Thus, the introduced concept of FPD can help to analyze the energy and visual environment simultaneously. Because exterior fixed shading devices are useful in restricting solar radiation and can be integrated with the building façade during the schematic design stage, we used two types fixed shading designs: a horizontal overhang and a vertical fin with various PFs. This study provides a guideline for fixed shading design in terms of energy use and visual comfort in the early stage of office building design.

METHOD

Numerical simulation was performed by COMFEN 4.1 which is useful to analyze the characteristics of a perimeter zone with different building envelop designs. This software can support integrated approaches including energy and daylight simulation of a single zone with fast performance. We used two simulation results: 1) the annual energy consumption with heating, cooling and lighting and 2) the seasonal daylight illuminance profile for calculating the FPD.

Table 1. *Description of the simulation zone*

Parameter		*Value*
Location		Incheon (37.5°N, 126°E)
Orientation		South and West
Dimension	Room depth	4.5 m
	Façade	6.0 x 2.7 m
	Window	4.2 x 2.3 m
	WWR	60 %
Internal gains	Lighting	10.76 W/m^2
	Equipment	9.34 W/m^2
	People	3 occupants
HVAC	System	Packaged Single Zone
	Outdoor air	0.0014 m3/s·m2
	Economizer	Enthalpy control
Lighting control		Stepped control

The descriptions of the simulation zone are shown in Table 1. Most of the details were set in a preliminary study (Kim H. et al. 2016) except for part of the internal gains and outdoor air flow rate condition. The equipment and outdoor air input value were taken from the Operating Regulations for Building Energy Efficiency Certification in Korea (MOLIT 2013). Lighting levels used were the COMFEN default value because the regulation does not mention it. The location was Incheon, a central district in Korea. The lowest monthly average outdoor dry-bulb temperature was -2.2℃ (January); the highest was 23.6℃ (July). According to the location condition and Korea building code, the U-value of the exterior wall was set as 0.25 W/m^{2}K (MOLIT 2016). COMFEN 4.1 supports individual window modeling including the frame and glazing system. Thus, an aluminum frame with a thermal break (U-value: 5.68 W/m^{2}K) and a glazing system (U-value: 0.85 W/m^{2}K, SHGC: 0.462, VT: 0.617) were selected from the International Glazing Database.

As shown in Figure 1, typically, daylight illuminances diminish with increasing distance from the façade. The criterion of 2000 lux was set as an excessive daylight illuminance level for the FPD from the UDI schema. We calculated the average annual daylight illuminance profile with the seasonal results of COMFEN, and then, the values of FPD were determined by the interpolation method.

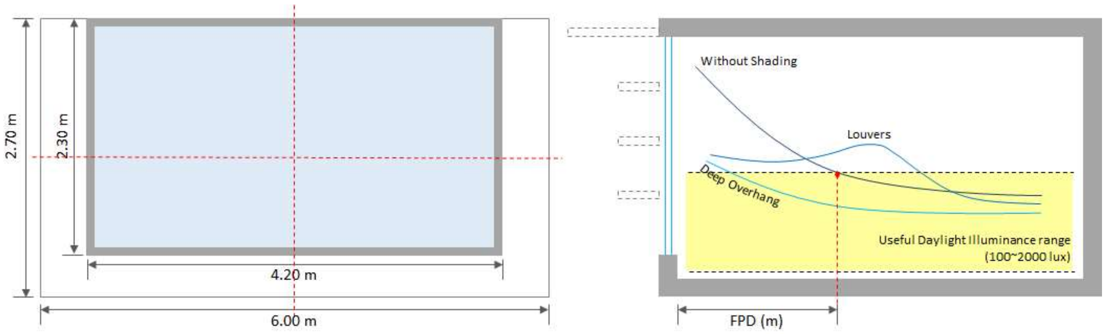

Figure 1. *Features of the simulation zone(left)&a concept diagram of the FPD(right)*

Because the features of the profile may change dependent on the envelop design (DOE 2013), it is necessary to investigate many shading design cases. Table 2 and Figure 2 show some details of the design variations in the shading devices. The investigated variations were set as follows: type, Overhang and Fin; PF, 0.1 to 0.7, and facing orientation, south and west.

Table 2. *Description of the shading device cases*

Type	*PF (m)*	*W (m)*	*Type*	*PF (m)*	*W (m)*
Horizontal Overhang	0.1	0.103	Vertical fin	0.1	0.128
	0.2	0.206		0.2	0.256
	0.3	0.309		0.3	0.384
	0.4	0.412		0.4	0.512
	0.5	0.515		0.5	0.640
	0.6	0.618		0.6	0.768
	0.7	0.721		0.7	0.896

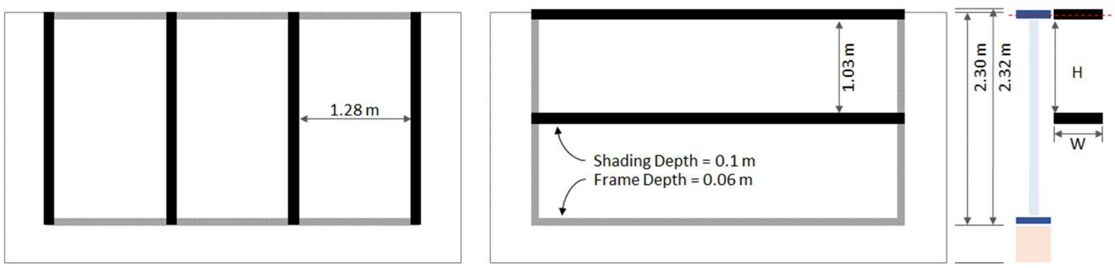

Figure 2. *Features of shading device cases: (left) Overhang, (right) Fin*

RESULTS & DISCUSSION

To confirm the relationship between the FPD and energy consumption, we first analyzed the illuminance profiles. Based on the simulation result, the average annual daylight illuminance profiles of each south case were calculated and are shown in Figure 3. The profile patterns of the west cases are similar with that of the south cases; however, the decreasing incline and entry illuminance are smaller than that of the south cases. In the cases of a south overhang, the profile patterns differ by 0.1-0.3 PF and 0.4-0.7 PF. It is understood that the horizontal overhang causes light reflection according to the increase in the width of shading. As mentioned in Figure 1, a louver provides illuminance distribution like a hill. This phenomenon is less effective for the western orientation compared to the southern orientation.

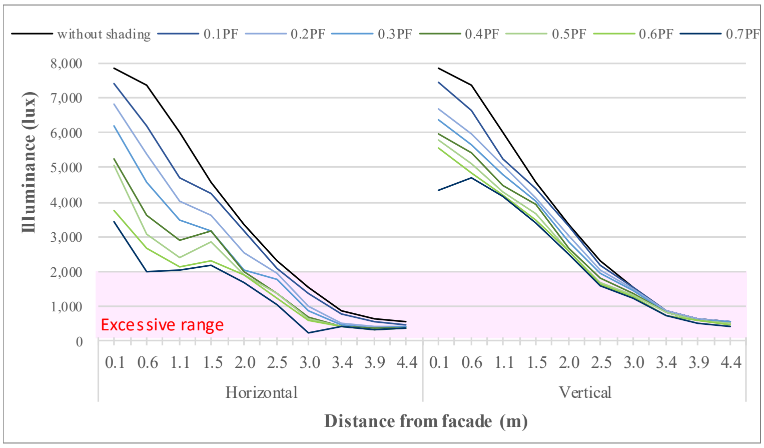

***Figure 3**. Avg. annual daylight illuminance profiles from different shading designs for the southern orientation*

The calculated results of the FPD for the various shading device cases are shown in Figure 4. The decreasing patterns of the FPD with increasing PF are different based on the shading device type and facing orientation. The FPD of the horizontal overhang type more rapidly decreases than that of the vertical fin regardless of the orientation. That means, in Korea, the overhang type with a 0.3 PF more efficiently blocks solar heat gain than that of the vertical fin with a 0.7 PF. It is also translated to economical issue. The reason for the decline in the profiles of the overhang due to the different orientations is the impact of light reflection as mentioned above. Architects can use the FPD to plan an office building perimeter zone which includes artificial lighting and a work space plan.

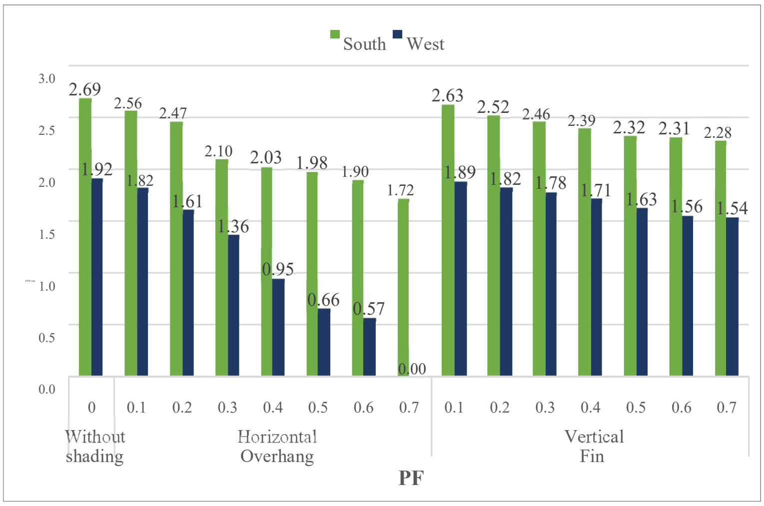

***Figure 4**. The results of the FPD according to varying design and facing orientation*

To verify the explanation ability of the FPD, we drew the scatter plots and calculated the correlation coefficients shown in Figure 5. The overall results show generally a high correlation between the FPD and the heating, cooling, lighting and total energy consumption, respectively. This means that the energy consumption patterns can be predicted with the FPD. However, the simulation cases are few, and we just confirmed the patterns here. The energy consumption optimization point is related with inflection point of the total energy consumption prediction line. The FPD value at that point can be useful to architects. When architects want to select several shading design alternatives, if the FPD values can be provided based on the shading deign, the architects can recognize the energy consumption patterns of each alternative with this graph.

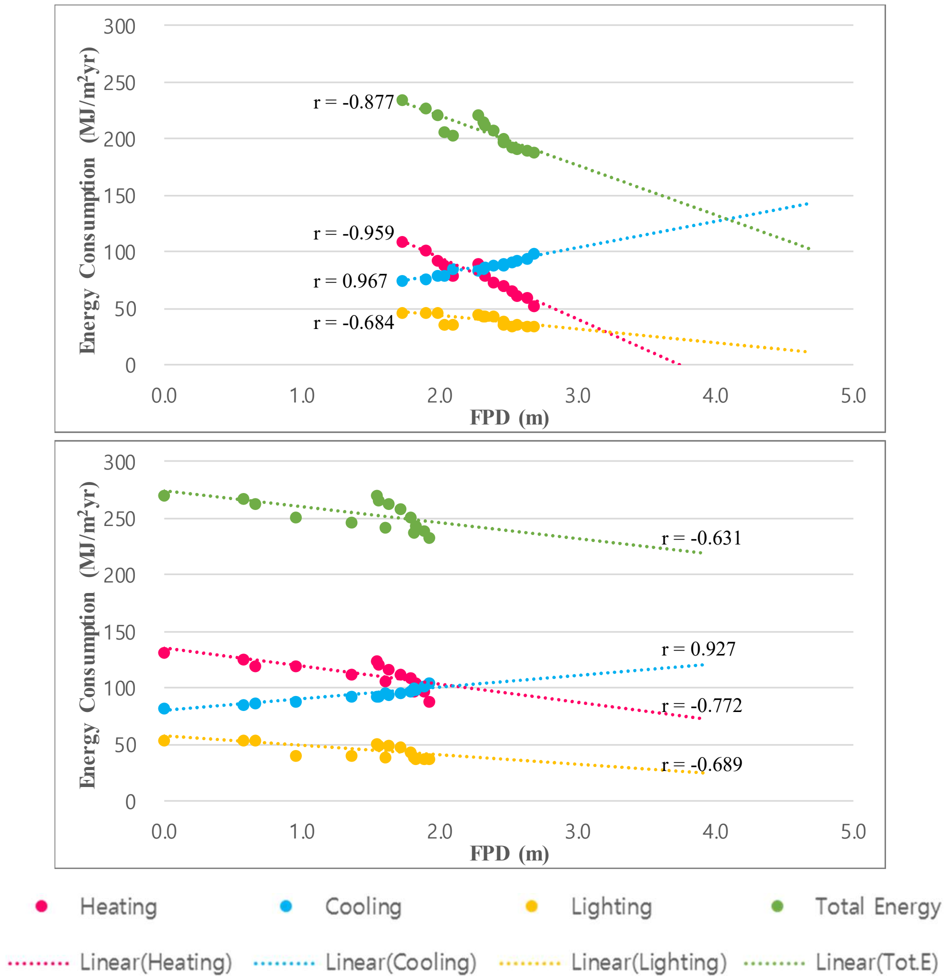

***Figure 5**. The scatter plots of the energy consumption results with correlation coefficients(r): (top) southern orientation, (bottom) western orientation*

CONCLUSION

This paper evaluated energy and daylight based on various exterior fixed shading device designs. With the introduction of the concept of FPD, we found several things as follows: 1) the FPD is dependent on the PF, orientation and number of shadings; 2) there is a high correlation between the FPD and energy consumption which includes heating, cooling, and lighting. Accordingly, the FPD concept is expected to be a useful indicator for architects. Further work should investigate energy consumption and FPD prediction models using more simulation cases. The cases should include more shading design variables with a wide range of input data.

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