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Article

A Study on the Variation of Heating and Cooling Load According to the Use of Horizontal Shading and Venetian Blinds in Office Buildings in Korea

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Abstract: The construction industry has made considerable energy-saving efforts in buildings, and studies of energy-savings are ongoing. Shading is used to control the solar radiation transferred through windows. Many studies have examined the position and type of shading in different countries, but few have investigated the effects of shading installation in Korea. In this study, the case of the shading installation according to the standard of Korea, and variations of the heating and cooling load in the unit area on the performance of the windows were examined. This study compared the variations of the heating and cooling load in the case of horizontal shading and the changing position of venetian blinds. This study confirmed that horizontal shading longer than the standard length in Korea saved a maximum of 13% energy consumption. This study confirmed the point of change of energy consumption by the Solar Heat Gain Coefficient (SHGC) variations. The exterior venetian blinds and those between glazing were unaffected by the SHGC. On the other hand, in the case of a south façade, the interior venetian blinds resulted in 24% higher energy consumption than the installation of horizontal shading in case of Window to Wall Ratio (WWR): 80%, U-value: 2.1 and SHGC: 0.4.

Keywords: Window to Wall Ratio (WWR); window; horizontal shading; venetian blind; office buildings

1. Introduction

The Window to Wall Ratio (WWR) of buildings has increased through the modern advances in architectural design. As the window area increases, the performance of windows becomes more important. Most efforts to improve this performance have been based on thermal insulation and air-tightness, when actually the cooling load is affected by the solar radiation transmitted through windows in buildings.

The thermal insulation performance and air-tightness performance help reduce the energy consumption in buildings. In addition, energy labeling, which is regulated in Korea, was proposed to grade the performance of thermal insulation (U-value, $W/m^2 \cdot K$) and air-tightness (flow rate, $m^3/h \cdot m^2$). As a result, the performance of windows has been improved by the manufacturers. On the other hand, solar heat gain increases the cooling load in summer and decreases the heating load in winter. This must be controlled appropriately. The Solar Heat Gain Coefficient (SHGC) and shading were used to consider solar control. Studies of the SHGC and shading are ongoing, and shading has been studied according to the material and method of installation to determine the most efficient shading effect. Despite this, few studies have examined energy consumption through a comprehensive examination of the window orientation and climate.

A range of studies have examined energy consumption in terms of windows. The complex application of window elements was confirmed [1], and the correlation between energy consumption and the impact of energy consumption was analyzed by simulation. On the other hand, they only confirmed energy consumption according to the variation of the window performance. Therefore, the present study confirmed the variation of the heating and cooling load by a similar review and a simulation of base modeling. In addition, the effects of heating and cooling energy consumption and lighting were confirmed by simulation of office buildings [2]. This study confirmed the variation of energy consumption according to the window performance. A study of the energy performance confirmed the correlation with glazing and windows [3]. The elements of this study were the U-value and G-value. Another study considered the elements of the windows for energy consumption and optical comfort [4]. The present study confirmed the importance of the WWR. A study of the change in energy consumption by the influence of WWR was published [5]. On the other hand, these studies did not consider the correlation between the elements of window performance and shading. Studies of a double-skin façade considered various shading factors. The intermediate space of the glass-skin is the installation position of shading, as the shading device is installed in this space. This study confirmed the effects of the shading device on the interior environment [6,7]. In addition, a study of the double skin façade design parameters confirmed that the design process changes according to the variations of the blind position and reflectance [8]. Studies of the external horizontal shading confirmed the variation of solar radiation incidence caused by six types of shading in tropical climates [9]. One study of the envelope design confirmed the effect of the various sunshields in Taiwan [10]. For sustainable design guidelines, a design parameter affecting the energy performance of shading was proposed, and its contribution of shading and reflective surfaces on the cooling load was confirmed [11]. Nevertheless, more studies of the variation of energy consumption according to the shading properties are needed.

The Korean government has provided guidelines and regulations for window installation. Shading is also defined by regulations in Korea. The guidelines and regulations for reducing the energy consumption in buildings are not perfect, and any study related to windows must adhere to the guidelines and regulations of the Korean government. The Building Energy Conservation in Korea defined shading as blocking solar radiation, and identified exterior shading, interior shading and between the glass shading as parameters [12]. In addition, the Energy Performance Indicator (EPI) checks the exterior shading and admits just the auto controlled interior shading. Green building certification is the proposed standard for decreasing the level of greenhouse gas emissions [13]. This standard proposes the minimum length of horizontal shading to decrease glare and provide environmental improvements. The minimum length of horizontal shading was determined using Equation (1):

$$P = \frac{H}{\tan A} \tag{1}$$

where P is the length of horizontal shading, H is the horizontal length to shading from the bottom of the window and A is the meridian altitude in summer (90-latitude + 23.5). Figure 1 presents the length of horizontal shading.

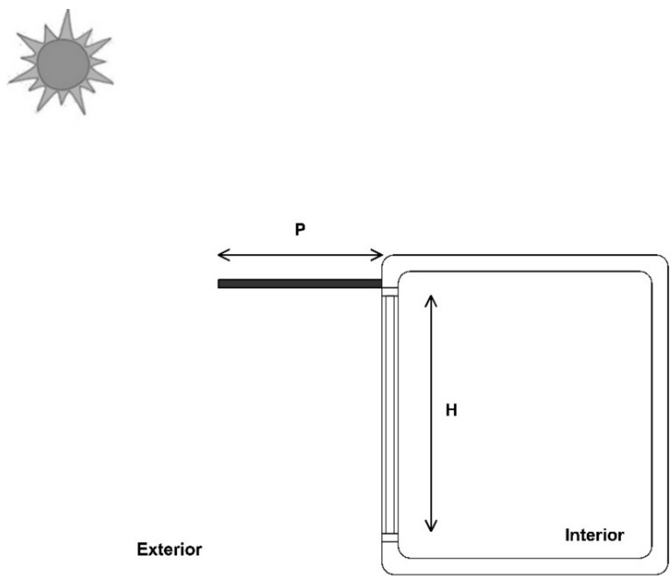


Figure 1. Length of horizontal shading.

"The Window Design Guidelines for Energy-saving of Buildings" were published the Ministry of Land, Transport and Maritime Affairs [14]. The purpose of these guidelines is to allow a variety of designs to consider the energy performance in building design. These guidelines confirmed the impact of the window design of office buildings on the energy consumption of buildings and proposed the orientation, WWR and types of windows in each region. In addition, these guidelines can be used to calculate the energy savings. The guidelines proposed the exterior shading for energy saving but it was just one case of a length of 600 mm. Table 1 lists the regulation and guidelines for windows in Korea.

Table 1. Regulation and guidelines for windows in Korea.

Title	Section	Contents
Building Energy Conservation Design Standards	Design performance	WWR/Orientation
	Window performance	Heat transmission coefficient (U-Value)/Air-tightness
	Shading	Position: Exterior/Between Glazing/Interior
Green Building Certification	Design performance	WWR
	Window performance	Heat transmission coefficient (U-Value)/Air-tightness
	Shading	Proposed minimum length (*P*) of shading
The Window Design Guideline for Energy-saving of Buildings	Design performance	WWR/Orientation
	Window performance	Heat transmission coefficient (U-Value)/Air-tightness/SHGC
	Shading	Optional Exterior shading (600 mm)

The aim of this study was to confirm the energy saving effect of shading installation. Because the remodeling or new buildings in Korea needs to install shading using the renewed Korean regulations, this study confirmed the energy saving effects and proposed basic research guidelines for shading design. In addition, this study referenced the regulations and guidelines in Korea. This study also confirmed the horizontal shading installation effect. The variation of heating and cooling load was confirmed by changing the length of horizontal shading. The results were compared according to the variation of SHGC. In addition, this study confirmed the correlation between the horizontal shading and the various venetian blind types through the variations of the heating and cooling load. This study confirmed the energy saving ratio of the various venetian blinds than the horizontal shading.

2. Standard Building Modeling and Simulation Condition

Standard buildings are needed to confirm the variation of energy consumption of a building according to the variation of shading. The standard building was not defined in Korea but this study referenced the standard building in previous research results. The standard building in this study references "The Window Design Guideline for Energy-saving of Buildings" and uses "unit area" as defined in the guideline. This method revealed the energy demand and the best way according to the variation of the window elements at each orientation. The unit space in the standard buildings was selected; the size of this unit space was 6 m × 4.5 m × 2.7 m. This size is the result of research that considered the average commercial building by an analysis of various buildings. The gap between the columns of the building was 6 m, the depth to the considered environment of light was 4.5 m, and the height of the room was 2.7 m [2]. Figure 2 presents a model of the standard building.

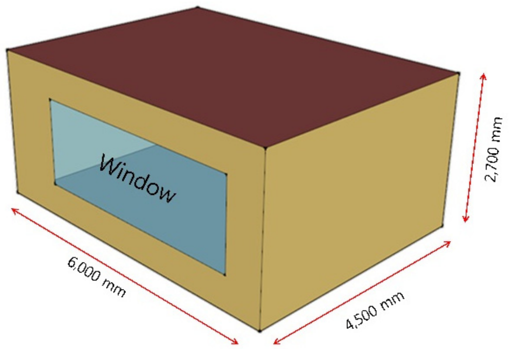


Figure 2. Schematic diagram of standard building modeling.

This study used the simulation tool, COMFEN 4.1, by the Lawrence Berkeley National Laboratory (LBNL, Berkeley, CA, USA) and simulated standard modeling. This tool is a façade design tool based on the Energy Plus engine and provides a systematic evaluation of various elevations. The Energy Plus engine is normally used to confirm the heating and cooling load in buildings. Many studies confirmed the accuracy of the algorithm for the daylighting analysis method [15,16]. COMFEN 4.1 can model the fenestration façade according to the number of windows, size, location, glazing, frame, and outside shading. The façade can select the daylight controls and has the option of orientating the buildings. The annual energy consumption (heating, cooling, fan, and lighting) and peak energy were analyzed by comparing the charts [17]. Table 2 lists the simulation conditions and Figure 3 presents the schedule.

Table 2. Simulation conditions.

Section	Contents
Heating, Ventilation, Air Conditioning	Packaged Single Zone
Temperature Set point	Cooling: 24 °C, Heating: 21 °C
Lighting/Equipment Load	16 W/m^2/10 W/m^2
People	3 people
U-Value of façade wall	0.4 W/m^2·K
Simulation period	Annual

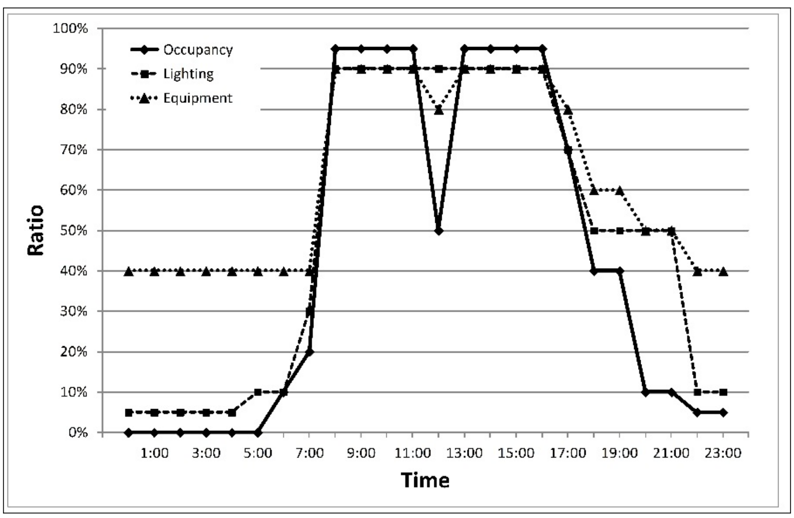


Figure 3. Simulation schedule.

3. Analysis of the Heating and Cooling Load with Horizontal Shading

3.1. Variation of Heating and Cooling Load with the Installation of Horizontal Shading

This study examined the heating and cooling load of buildings according to the horizontal exterior shading installation. The annual heating and cooling load of a building with non-shading and horizontal exterior shading were compared. The performance of the window was the level of regulation. The SHGC, WWR and shading length were not proposed standards in the regulation, therefore, this study referenced previous studies [2]. Table 3 lists the simulation parameters. Figure 4 shows the window area and position according to each WWR. This study used the weather data for Seoul in Korea. Seoul is located in the Northern Hemisphere, altitude 37.3° and longitude 127°. The weather data was provided from the Korean Solar Energy Society [18]. In addition, the data from previous research was used. The length of horizontal shading was calculated using Equation (1), which used latitude 37.3° for Seoul.

Table 3. Simulation parameter.

Section		**Contents**			
Orientation		**East/West/South/North**			
WWR		**20%/40%/60%/80%**			
Window Type	–	Type 1	Type 2	Type 3	Type 4
	U-Value (W/m^2·K)	1.8	1.8	2.1	2.1
	SHGC	0.4	0.6	0.4	0.6
Shading	WWR	20%	40%	60%	80%
	P = Length (m)	0.35	0.5	0.55	0.6

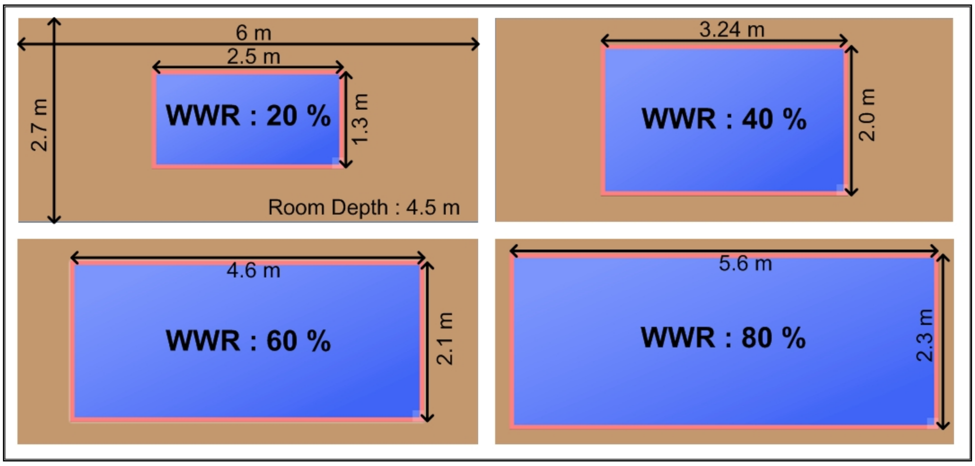


Figure 4. Simulation modeling by WWR.

This study confirmed the simulation result of the south façade according to the horizontal shading installation. In the case of WWR 20%, the energy consumption of non-shading was 79–87 kWh/m^2·y and the energy consumption by horizontal shading installation was 78–80 kWh/m^2·y. In the case of 40%, the energy consumption of non-shading was 93–111 kWh/m^2·y and the energy consumption by horizontal shading installation was 86–96 kWh/m^2·y. In the case of 60%, the energy consumption of non-shading was 106–137 kWh/m^2·y and the energy consumption by horizontal shading installation was 94–112 kWh/m^2·y. Finally, in the case of 80%, the energy consumption of non-shading was 122–165 kWh/m^2·y and the energy consumption by horizontal shading installation was 104–129 kWh/m^2·y. From the results, this study confirmed an energy saving of 9% by the installation of horizontal shading in the case of WWR = 40%. The energy saving was 22% by the installation of horizontal shading in the case of WWR = 80%. Figure 5 shows the variation of the heating and cooling load by shading installation on the south façade.

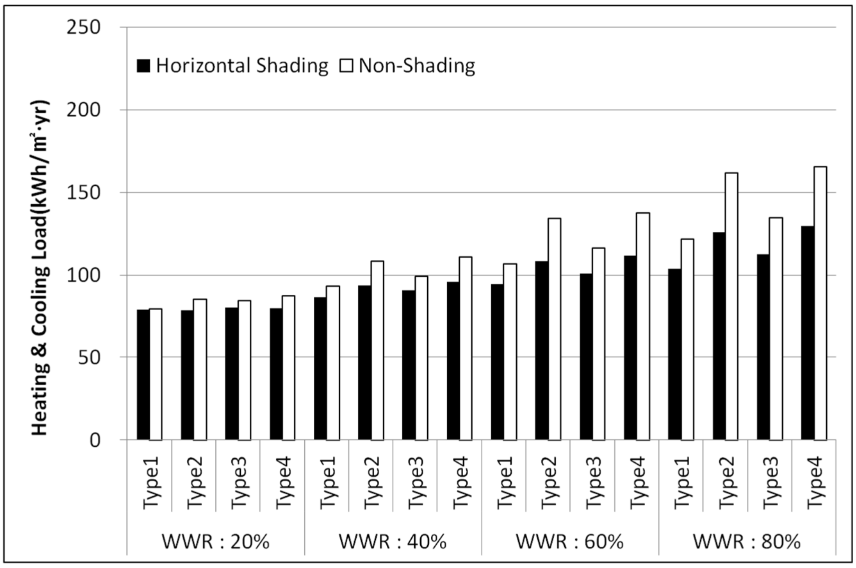


Figure 5. Variation of the heating & cooling load according to the shading installation (south façade).

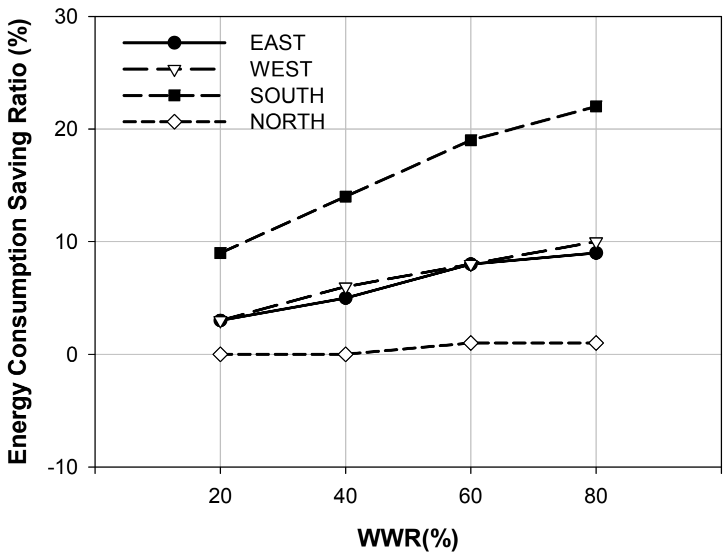


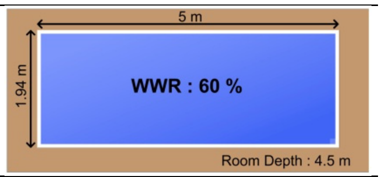
Figure 6. Energy consumption saving ratio by WWR and orientation.

This study confirmed the saving ratio for all orientation façades using type 4 glazing, and installation of horizontal shading. The length of horizontal shading was regulation level (0.6 m). In the case of the south façade, the energy consumption savings increased steadily with increasing WWR. The maximum saving was 22% at WWR = 80%. In case of the west and east façades, this study confirmed the maximum 10% energy saving at WWR = 80%. On the other hand, in the case of the north façade, there were no energy consumption savings at WWR < 40%. In addition, in the case of WWR = 60% and 80%, the energy consumption saving was only 1%. This means that to reduce energy consumption, the installation of horizontal shading on the south façade is recommended. Figure 6 shows the energy consumption saving ratio according to the WWR and orientation.

3.2. Variation of the Heating and Cooling Load by the Length of Horizontal Shading

The regulations of Korea propose a minimum length (*P*) of horizontal shading. The length of horizontal shading in the exterior was calculated using Equation (1). The length was affected by the window height (*H*) and the latitude of Seoul, but the regulation does not explain the reference of the length of shading. This study confirmed the variation of the heating and cooling load by changing the length of horizontal shading, as listed in Table 4. The length of horizontal shading was changed to 50% from 200%, WWR = 60%, the performance of window was U-value = 2.1 (W/m^2·K) and SHGC = 0.6. Figure 7 shows the energy consumption ratio variation of the heating and cooling load by the orientation and length.

Table 4. Simulation parameter and case.

Section			**Contents**			
Orientation			**East/West/South/North**			
WWR			**60% (*W*:5 m, *H*:1.94 m)**			
Window Performance	U-Value (W/m^2·K)		2.1			
	SHGC		0.6			
Shading	*P* (m)		$H/\tan A = 1.94/\tan(90 - 37.3 + 23.5) = 0.48 \approx 0.5$			
	CASE	Ratio (%)	50	100	150	200
		Length (m)	0.25	0.5	0.75	1

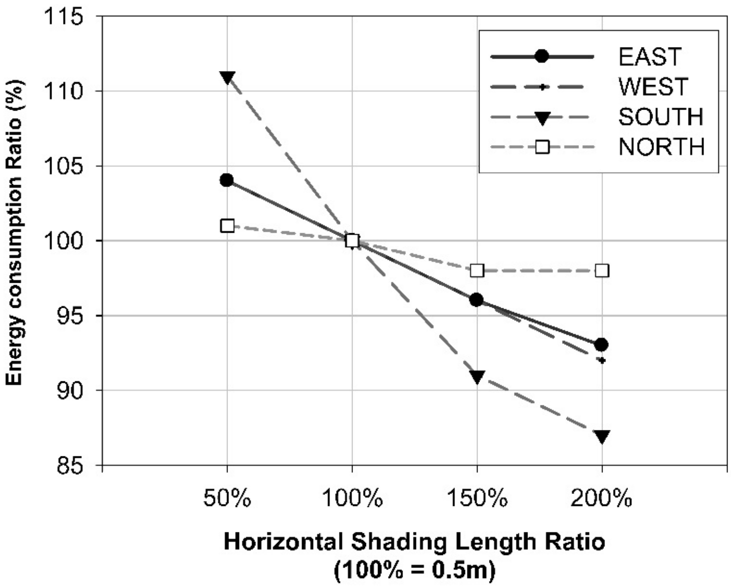


Figure 7. Ratio variation of the heating and cooling load with shading length.

The results of WWR = 60% and various lengths of shading confirmed the heating and cooling load dependence on the orientation and length of shading. The energy consumption ratio is all the orientation façades based on the installation of horizontal shading of 0.5 m. In the case of the east façade, the energy consumption was 150 kWh/m^2·y after the installation of horizontal shading. That length of shading was 0.5 m, which is the level of the regulation. The energy consumption was 139 kWh/m^2·y when the length was 200% (1 m). The energy consumption savings in that case is 7%. In the case of the west façade, the energy consumption was 142 kWh/m^2·y with a length of 100% (0.5 m). The energy consumption was 154 kWh/m^2·y at a length of 200% (1 m). That case saved 8% energy consumption. In the case of the south façade, the energy consumption was 112 kWh/m^2·y at a length of 100% (0.5 m). The energy consumption was 97 kWh/m^2·y for a length of 200% (1 m). That case saved 13% of energy consumption. In the case of the north façade, the energy consumption was 111 kWh/m^2·y at a length of 100% (0.5 m). The energy consumption was 109 kWh/m^2·y for a length of 200% (1 m). That case saved 2% of energy consumption. This means that the length of shading needs to be longer than the proposed regulation length to improve the energy savings. When the length of shading was less than 100% (0.5 m), the energy consumption ratio increased in all cases. This study confirmed that the heating and cooling load decreased with a length longer than the length of the regulation. The South façade showed the most effective energy savings for an extended shading length.

3.3. Analysis of the Heating and Cooling Load Variation with the SHGC and Shading

From the amount of heat gain from the window, the SHGC of the window affects the heating and cooling load. This study confirmed the variation of the heating and cooling loads according to various SHGC values and horizontal shading. In addition, this study found a correlation between the SHGC and shading. For the analysis, the WWR was fixed at 60%, the U-value of the glazing was 2.1 W/m^2·K and the length of horizontal shading was 0.5 m. Those conditions are the same as those listed in Table 3.

From the results of the simulation, in the case of the east façade, the use of the regulation horizontal shading length and changing SHGC from 0.2 to 0.75 resulted in an increase in energy consumption from 109 to 150 kWh/m^2·y. In the case of the west façade, the energy consumption was increased from a 107 to 149 kWh/m^2·y after changing the SHGC from 0.2 to 0.75. A 37% (east) 39% (west) increase in the heating and cooling load was observed by increasing SHGC. Figure 8 shows the variation of heating and cooling load with SHGC. This means that horizontal shading does not affect the energy consumption in the case of the east and west façades. In the case of the south façade, however, the energy consumption was not increased by changing the SHGC from 0.2 to 0.75. From 0.2 to 0.4 SHGC, the energy consumption showed a tendency to increase from 97 to 109 kWh/m^2·y, which is approximately a 12% increase. On the other hand, from 0.4 to 0.75 SHGC, the energy consumption showed a tendency to decrease from 109 to 105 kWh/m^2·y, which is approximately a 3% decrease. This shows that a high SHGC and horizontal shading resulted in less energy consumption than at a low SHGC. This study confirmed the correlation between the horizontal shading and SHGC. In the case of the north façade, energy consumption was increased from 103 to 125 kWh/m^2·y by changing the SHGC from 0.2 to 0.4. On the other hand, from 0.4 to 0.75 SHGC, the energy consumption changed only slightly, 124–125 kWh/m^2·y. At SHGC > 0.4, in the case of the north façade, the horizontal shading had a slight effect on the energy consumption.

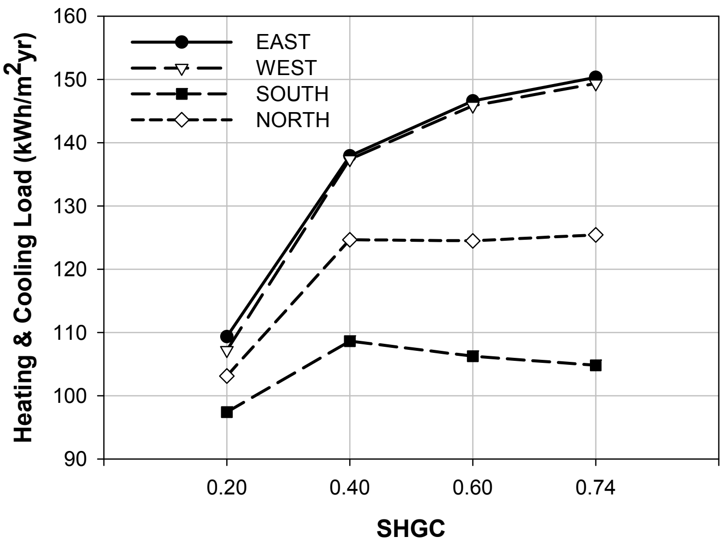
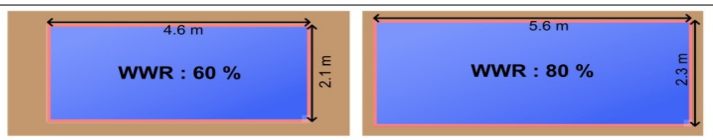


Figure 8. Variation of heating and cooling load with the SHGC.

4. Analysis of the Heating and Cooling Load According to the Type of Venetian Blind

The Building Energy Conservation in Korea has proposed the position of shading. The guidelines for the venetian blind position vary. To confirm the variation of the heating and cooling load with venetian blinds, this study compared the case of horizontal shading with the case of the various venetian blind positions. The angle of the venetian blind was 45°. This study used the venetian blind types of the interior position/between glazing position/exterior position. Table 5 lists the simulation case and venetian blind type. Figure 9 shows the type of shading. In the case of WWR 60% and 80%, and SHGC 0.4 and 0.6 of the window, this study confirmed the heating and cooling load of a standard building. Table 6 lists the results of the simulation.

Table 5. Simulation parameter and details of various shading.

Section			Contents			
Orientation			East/West/South/North			
WWR						
Window Performance		U-Value	2.1			
		SHGC	0.4/0.6			
CASE	Horizontal Shading	WWR (%)	60		80	
		Length (m)	0.55		0.6	
	Venetian Blind	Position	Angle (°)	Width of slat (mm)	Spacing (mm)	Thickness (mm)
		Exterior		76.96	70.1	
		Between glazing	45	4	7.62	1.02
		Interior		25.4	20.07	

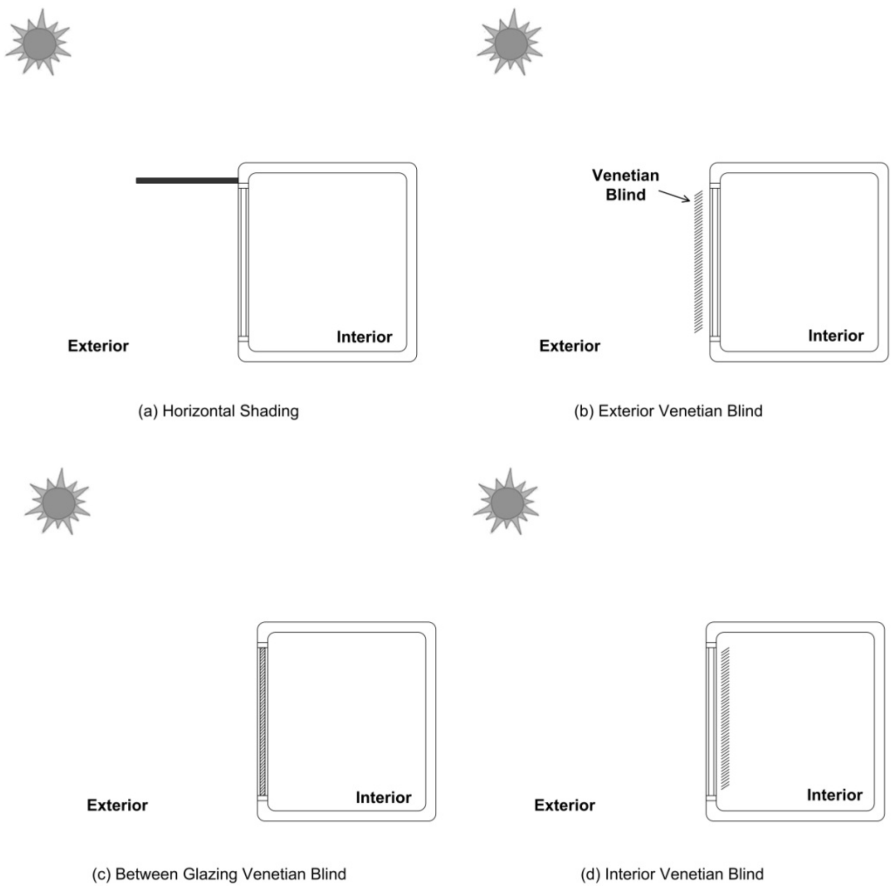


Figure 9. Type of shading and venetian blinds.

Table 6. Heating and cooling load variation with horizontal shading and venetian blinds.

WWR	Window Performance	Shading Type	Position	Period	Heating and Cooling load (kWh/m^2)			
					East	West	South	North
60%	U-Value: 2.1 (W/m^2·K) SHGC: 0.4	Horizontal shading	Exterior	May–Oct	57.5	58.2	40.7	59.5
				Nov–Apr	74.3	76.2	60.0	48.8
		Venetian blind	Exterior	May–Oct	55.7	55.5	50.1	57.9
				Nov–Apr	49.5	49.5	48.6	44.4
			Between glazing	May–Oct	51.2	51.7	45.4	54.7
				Nov–Apr	59.9	58.9	60.7	54.1
			Interior	May–Oct	58.6	60.1	47.0	57.9
				Nov–Apr	83.4	85.1	72.3	50.4
	U-value: 2.1 (W/m^2·K) SHGC: 0.6	Horizontal shading	Exterior	May–Oct	57.9	59.6	41.6	55.9
				Nov–Apr	91.8	94.6	69.9	54.8
		Venetian blind	Exterior	May–Oct	54.4	54.2	47.7	56.8
				Nov–Apr	52.2	52.6	51.4	45.7
			Between glazing	May–Oct	51.5	52.0	45.6	55.0
				Nov–Apr	59.6	58.7	60.4	53.9
			Interior	May–Oct	58.3	60.3	47.2	56.4
				Nov–Apr	89.2	91.4	76.7	54.0

Table 6. *Cont.*

WWR	Window Performance	Shading Type	Position	Period	Heating and Cooling load (kWh/m^2)			
					East	West	South	North
80%	U-value: 2.1 (W/m^2·K) SHGC: 0.4	Horizontal shading	Exterior	May–Oct	66.1	67.5	46.6	68.8
				Nov–Apr	85.7	88.2	66.0	51.7
		Venetian blind	Exterior	May–Oct	64.0	63.8	57.1	66.9
				Nov–Apr	51.7	52.2	50.7	44.4
			Between glazing	May–Oct	58.0	58.9	51.0	62.4
				Nov–Apr	65.1	64.4	66.4	58.3
			Interior	May–Oct	68.6	71.1	56.3	67.1
				Nov–Apr	98.2	100.4	82.9	54.3
	U-value: 2.1 (W/m^2·K) SHGC: 0.6	Horizontal shading	Exterior	May–Oct	68.1	70.9	50.3	64.1
				Nov–Apr	109.3	113.2	79.1	59.1
		Venetian blind	Exterior	May–Oct	62.1	62.0	53.9	65.3
				Nov–Apr	55.3	56.2	54.4	46.1
			Between glazing	May–Oct	58.4	59.2	51.4	62.8
				Nov–Apr	64.7	64.0	66.1	58.0
			Interior	May–Oct	68.9	72.0	57.7	65.1
				Nov–Apr	105.8	109.2	88.8	58.3

In case of WWR = 60% and SHGC = 0.4, the case of south façade, the energy consumption was decreased by 2% using the exterior venetian blind installation compared to horizontal shading installation. The energy consumption was increased 5% and 18% by between glazing and interior venetian blind installation, respectively, compared to horizontal shading installation. In the case of the east façade, the energy consumption was decreased 20% and 16% by exterior venetian blinds and between glazing venetian blind installation, respectively, compared to horizontal shading installation. The energy consumption was increased 8% by interior venetian blind installation compared to horizontal shading installation. In addition, in the case of the west façade, the energy consumption was decreased 22% and 18% by exterior venetian blinds and between glazing venetian blind installation, respectively, compared to horizontal shading installation. The energy consumption was increased 8% by interior venetian blind installation compared to horizontal shading installation. In the case of the north façade, the energy consumption was decreased 6% by exterior venetian blind installation compared to horizontal shading installation. The energy consumption was increased 1% by between glazing venetian blind installation compared to horizontal shading installation. In the case of interior venetian blind installation, the energy consumption was the same as case of horizontal shading installation.

At WWR = 60% and SHGC = 0.6, in the case of the south façade, the energy consumption was decreased 11% and 5% by exterior venetian blind and between glazing venetian blind installation compared to horizontal shading installation. The energy consumption was increased 11% by interior venetian blind installation compared to horizontal shading installation. In the case of the east façade, the energy consumption was decreased 29%, 26% and 1% by exterior venetian blind, between glazing venetian blind and interior venetian blind installation, respectively, compared to horizontal shading installation. In addition, in the case of the west façade, the energy consumption was decreased 31%, 28% and 2% by exterior venetian blind, between glazing venetian blind and interior venetian blind installation, respectively, compared to horizontal shading installation. In the case of the north façade, the energy consumption was decreased 7% and 2% by exterior venetian blind and between glazing venetian blind installation, respectively, compared to horizontal shading installation. In the case of interior venetian blind installation, the energy consumption was the same as that of horizontal shading installation.

At WWR = 80% and SHGC = 0.4, in the case of the south façade, the energy consumption was decreased 4% by exterior venetian blind installation compared to the case of horizontal shading installation. The energy consumption was increased 4% and 24% by between glazing and interior venetian blind installation, respectively, compared to horizontal shading installation. In the case of the east façade, the energy consumption was decreased 24% and 19% by exterior venetian blind and between glazing venetian blind installation, respectively, compared to horizontal shading installation. The energy consumption was increased 10% by interior venetian blind installation compared to horizontal shading installation. In the case of the west façade, the energy consumption was decreased 26% and 21% by exterior venetian blind and between glazing venetian blind installation, respectively, compared to horizontal shading installation. The energy consumption was increased 10% by interior venetian blind installation compared to horizontal shading installation. In the case of the north façade, the energy consumption was decreased 8% by exterior venetian blind installation compared to horizontal shading installation. In the case of between glazing venetian blind installation, the energy consumption was the same as that of horizontal shading installation. On the other hand, the energy consumption was increased 1% by interior venetian blind installation compared to horizontal shading installation.

At WWR = 80% and SHGC = 0.6, in the case of the south façade, the energy consumption was decreased 16% and 9% by exterior venetian blind and between glazing venetian blind installation, respectively, compared to horizontal shading installation. The energy consumption was increased 13% by interior venetian blind installation compared to horizontal shading installation. In the case of the east façade, the energy consumption was decreased 34%, 31% and 2% by exterior venetian blind, between glazing venetian blind and interior venetian blind installation, respectively, compared to horizontal shading installation. In the case of the west façade, the energy consumption was decreased 36%, 33% and 2% by exterior venetian blind, between glazing venetian blind and interior venetian blind installation, respectively, compared to horizontal shading installation. In the case of the north façade, the energy consumption was decreased 10% and 2% by exterior venetian blind and between glazing venetian blind installation, respectively compared to horizontal shading installation. In the case of interior venetian blind installation, the energy consumption was the same as that of horizontal shading installation. Figures 10–13 shows the saving ratio of heating and cooling energy consumption according to the type of shading. The result of the simulation showed generally low energy consumption in the case of the south façade. In the case of the north façade, the simulation showed little change. At WWR = 80% and SHGC = 0.6, the heating energy consumption was increased 11%–170% by exterior venetian blinds compared to horizontal shading. At WWR = 60% and SHGC = 0.4, the heating energy consumption was increased 8%–161% by exterior venetian blinds compared to horizontal shading. That reason for this is that venetian blinds tended to block more solar radiation in the winter season than horizontal shading.

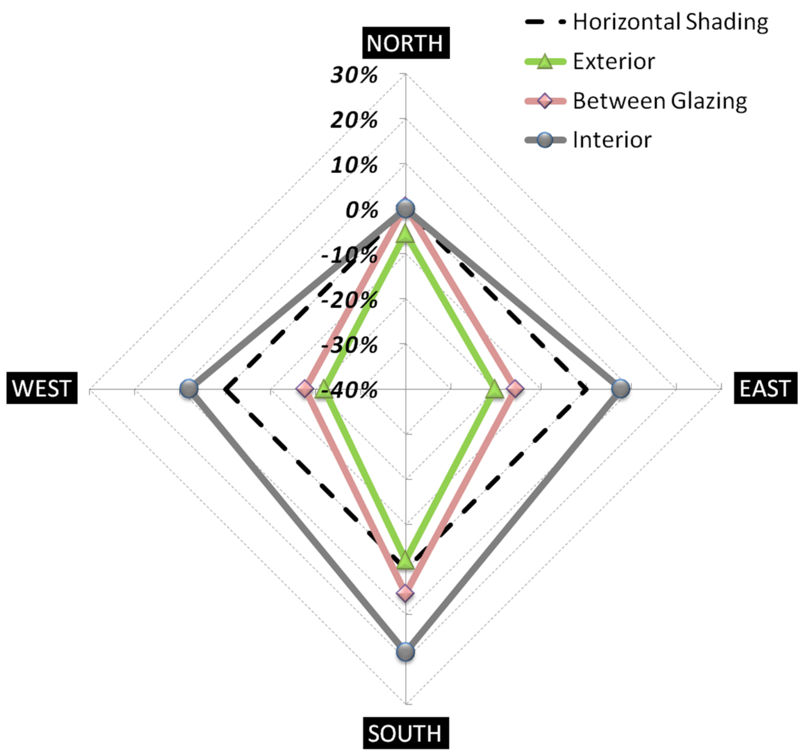


Figure 10. Saving ratio of heating and cooling load according to the type of shading (WWR 60%, U-value: 2.1, SHGC: 0.4).

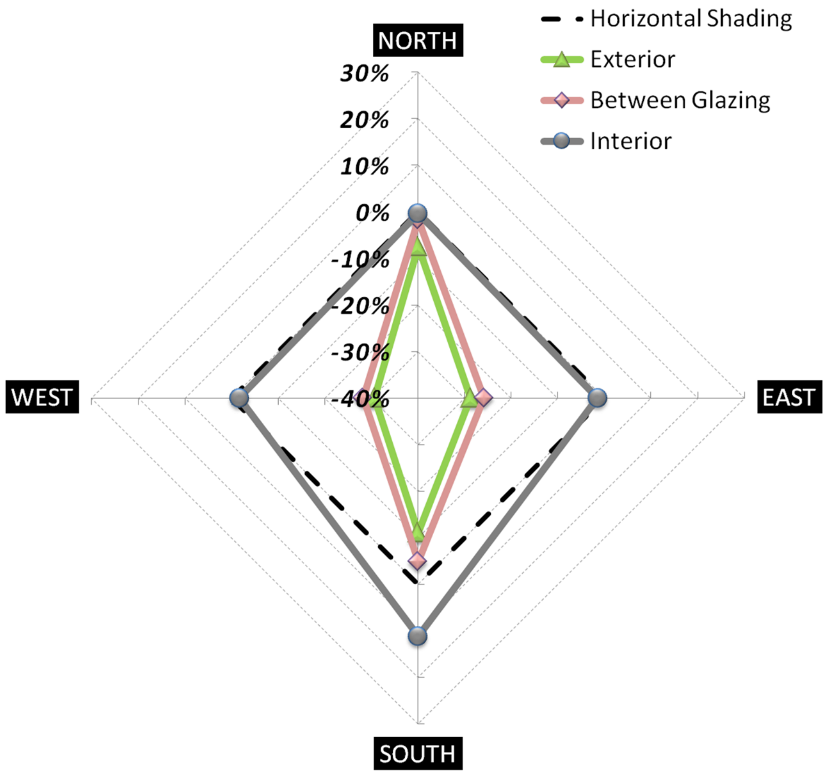


Figure 11. Saving ratio of heating and cooling load according to the type of shading (WWR 60%, U-value: 2.1, SHGC: 0.6).

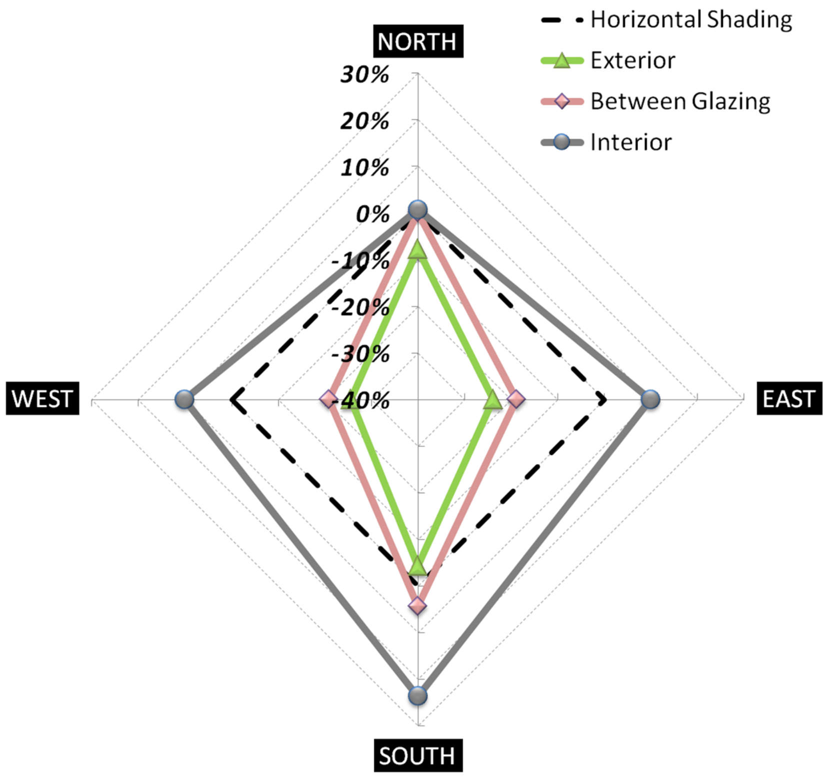


Figure 12. Saving ratio of the heating and cooling load according to the type of shading (WWR 80%, U-value: 2.1, SHGC: 0.4).

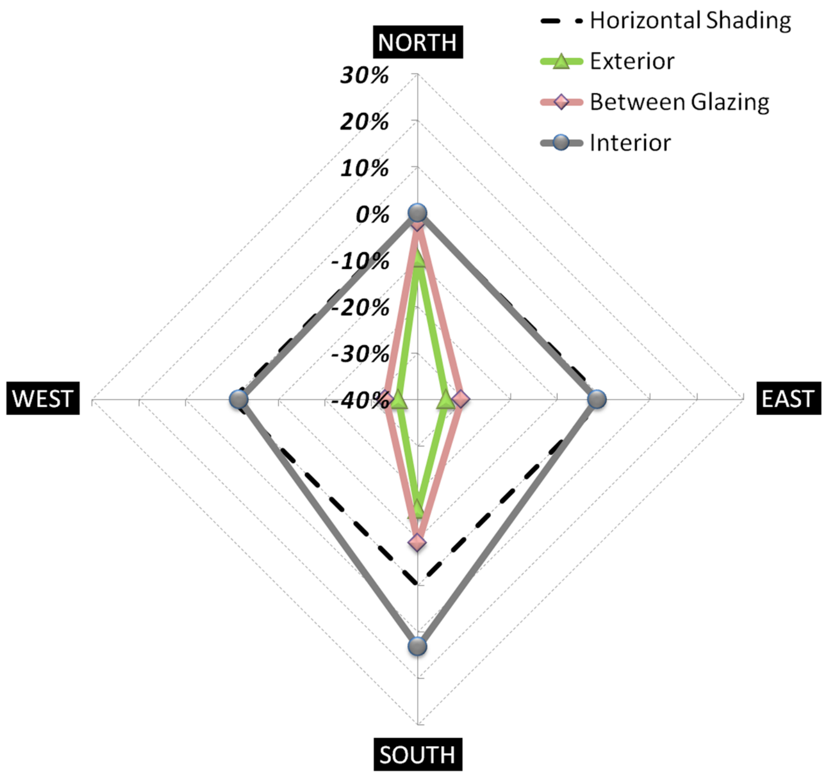


Figure 13. Saving ratio of the heating and cooling load according to the type of shading (WWR 80%, U-value: 2.1, SHGC: 0.6).

In the case of the south façade, the interior venetian blind resulted in higher heating and cooling energy consumption because the heating load was increased by blocked solar radiation in winter. At WWR = 80%, the exterior venetian blind saved 4%–36% of the heating and cooling load than the horizontal shading. This means that the exterior venetian blind was more efficient at saving energy than horizontal shading in a large WWR. In the case of the east and west façades, the exterior venetian blinds and between glazing venetian blinds improved energy consumption compared to horizontal shading. The maximum saving ratio was 36% at WWR = 80%, exterior venetian blind and west façade. In the case of the east and west façades, the exterior venetian blind and between glazing venetian blind is more efficient than horizontal shading. Shading the north façade had little or no effect on heating and cooling load regardless of the type of shading.

5. Conclusions

This study confirmed the annual heating and cooling load of a standard building by simulation modeling. The results of this study are as follows:

(1) In the case of horizontal shading installation, the heating and cooling load was lower than the case of no shading. The decrease in the heating and cooling load was most efficient in the south façade. Horizontal shading installation reduced the heating and cooling load by a maximum of 22% in the case of type 4 and WWR = 80%.

(2) Extended horizontal shading (1 m) compared to the regulation level (0.5 m) reduced the heating and cooling load. In the case of extending the length of horizontal shading, the south façade showed a maximum 13% decrease in heating and cooling load.

(3) This study confirmed the variation of heating and cooling load by the variation of the SHGC. In case of the south and north façades, the heating and cooling load was decreased at SHGC = 0.4. This means that the high SHGC and horizontal shading is more efficient in energy savings than the case of a low SHGC and horizontal shading.

(4) A comparison of horizontal shading with various venetian blind types showed that in the case of the west façade, the energy consumption was decreased 36% by exterior venetian blind installation compared to the case of horizontal shading installation.

The exterior venetian blinds and between glazing were unaffected by the SHGC. The exterior venetian blind was more effective in reducing the heating and cooling load than horizontal shading. In addition, the heating and cooling load of the interior venetian blind was higher than that of horizontal shading. From the results of this study, our next study will develop indicators and guidelines for the shading choice. These indicators or the guidelines for the shading design will be proposed to a designer.

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Author Contributions

All authors contributed to this work. Seok-Hyun Kim performed the result analysis of simulation and wrote the major part of this article. Kyung-Ju Shin and Bo-Eun Choi conducted the energy simulation. Jae-Hun Jo proposed the case of the energy simulation and conducted data analysis. Soo Cho performed the result discussion and gave technical support. Young-Hum Cho was responsible for this article and gave conceptual advice.

Conflicts of Interest

The authors declare no conflict of interest.

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