A Study on the Energy Consumption of Office Buildings with Variation Fenestration Design

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ABSTRACT

Windows characterize usage and visual comfort patterns in buildings. Especially for an office building, more buildings have increased window-to-wall ratio (WWR), such as through the use of curtain wall, for a sense of openness and a façade design, though excessive building energy consumption is widely criticized. Therefore, this study seeks to identify the energy consumption characteristics of buildings facing in four orientations (east, west, south and north) with differently designed windows by changing the WWR and considering the component of glazing. The paper showcases diverse measures available to valorise energy consumption. A series of energy criteria were selected and acceptance thresholds were defined for dynamic evaluations. Single zone computer simulations were performed on a standardized office located in Seoul. The results showed that the energy consumption amounts of buildings facing four orientations are affected by the glazing characteristics and the WWR. The detailed results of this study are as follows: 1) Regardless of whether a building faces east or west, when the SHGC increases, the total energy consumption level tends to increase with the same U-value. However, when the U-value increases, the total energy consumption slightly increases. 2) For buildings facing south, the total amounts of energy consumed by buildings with the lower U-value are decreased. However, when WWR increases, the total energy consumption decreases with lower SHGC. 3) As a building facing north has a lower insolation level compared to other orientations, the U-value, related to the thermal capacity influences the energy consumption level of these buildings more than the SHGC.

KEYWORDS

Energy consumption, Window- to-wall ratio (WWR), SHGC, U-value, Orientation

1. INTRODUCTION

In Korea, buildings account for 25% of all energy consumption. Therefore, it is necessary to improve the envelope capability to ensure higher energy efficiency in buildings. Compared to a wall, a window has a lower insulation effect of about seven times, and the heat loss through windows accounts for 10~40% of a building total heat loss. However, current window size has increased due to the view preferences. Especially for an office building, more buildings are being constructed with increased WWR such as a curtain wall, for a sense of openness and an envelope performance. The excessive energy consumption by these buildings, however, has been criticized.

Most of building codes seek to reduce their average WWR through different methods, by reinforcing the average thermal transmittance of an outer wall for instance, but this can become problematic in that these methods do not consider the window performance. In the case of a building with a large window area ratio, the U-value is directly related to the type of glazing, but the SHGC or VLT has much more influence on the building energy consumption. Given that air-conditioning in summer vastly increases the energy used by office buildings, the importance of fenestration factors cannot be stressed enough. Hence, a building energy consumption is not simply a matter related to its windows, but is influenced by complex factors related to a window glazing characteristics. Therefore, this study aims to identify the energy consumption characteristics of buildings facing 4 way all orientations (east, west, south and north) with windows of variation designs. It does this by changing the WWR and the components of the glazing.

2. RESEARCH METHODS

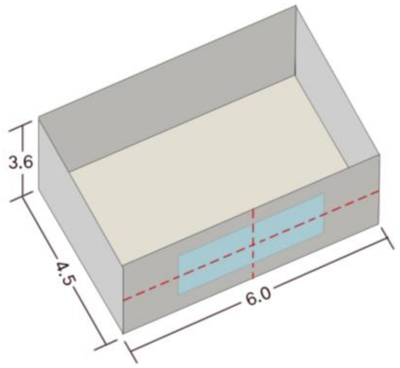
In previous studies, the building energy consumption has been associated with WWR (Xing su et al. 2010, Woo Ram Jeong et al. 2011, Carlos E. Ochoa et al. 2012). However, the impact of the orientation and thermophysical characteristics of window on the energy demand of buildings under different conditions has not yet been thoroughly analysed. In this study, the energy consumption that is used for the simulation is estimated for variation fenestration design (various combination of U-value and SHGC) and different conditions (orientation, WWR) by means of a dynamic simulation tool with regard to a reference room with specific thermophysical and optical properties, operation profiles and schedules of usage, defined by COMFEN manual.

2.1 Location and climate characteristics

A computer model was used for the climate of Seoul, Korea (37°N, 127°E) using a Korea typical meteorological data. It characterizes the hot summer and cold winter of this region, as well as the precipitation throughout the year.

2.2 Reference room description

To highlight how different optimization criteria affect the reference room used in this study, an actual office building module was used as the basis for the assessments. The module consists



of an office building unit (dimensions 6 x 4.5 x 3.6m) with a single external wall (Fig 1). Description of the simulation conditions is given in Table 2, respectively.

Figure 1. *Perspective plan of the reference room*

Table 1. *Simulation condition*

Parameter	*Condition*	*Parameter*	*Condition*
Building Type	Office	Equipment Load	10W/m²
Floor Area	27m² (6m×4.5m)	Lighting Load	16W/m²
facade height	3.6m (ceiling height 2.7m)	HVAC	Packaged single zone (PSZ)
Simulation Period	Annual	Wall U-factor	0.3985W/m² • k
		People	0.1 person/m²

2.3 Simulation case and tool description

Because this study focuses on evaluating optimization criteria, the glazing in all windows was double-pane glass without any shading device. And this study also presented the variation fenestration factors, and then established their ranges by Korea building code and passive house design guideline (with U-values ranging from 1.4 to 2.4 and SHGC values ranging from 0.3 to 0.7, and with a VLT value of 0.7). The WWR of the opening varied from 10% to 90% in discrete 10% steps. We used COMFEN to evaluate the building energy consumption.

Table 2. *Simulation case*

Location	Seoul
Orientation	East-West, South, North
WWR	From 10% to 90%
Lighting control	Continuous
Shading	No shading

Table 3. *Glazing Specification*

Case		*U-factor(W/m²k)*	*SHGC*	*VLT*
Case 1	Basis of Korea building codes	2.43	0.45	0.70
Case 2	-	2.43	0.37	0.64
Case 3	-	1.89	0.63	0.73
Case 4	-	1.88	0.49	0.66
Case 5	-	1.89	0.35	0.62
Case 6	Basis of passive house guidelines	1.41	0.47	0.70

3. RESULTS

3.1 Analysis of annual energy consumption: East , West

Buildings facing east-west have higher Insolation in those facing in other orientations. The total energy consumption level of buildings facing east-west, whose Insolation patterns are similar, ranged from 500 to 900MJ/m² • yr. This range is higher than the range of 450~700MJ/m² • yr for buildings facing south or north. In particular, when the SHGC value is higher than the U-value, the total energy consumption tends to be higher. The most likely reason for this difference is Insolation, which influences the building energy consumption more than the differences in the insulation performance. Especially for buildings facing east or west in summer, when insolation level is highest, as the SHGC increases, the Insolation also increases, leading to an increase in the cooling load. The increased cooling load increases the fan load, resulting in an increase in the building total energy consumption. Regardless of the WWR for buildings facing east or west, as the U-value decreases, the total energy consumption tends to decrease. However, when WWR facing the east is 30% or more, the total energy consumption decreases with lower SHGC. In case of WWR facing the west is 40% or more, the energy consumption decreases with lower SHGC, too.

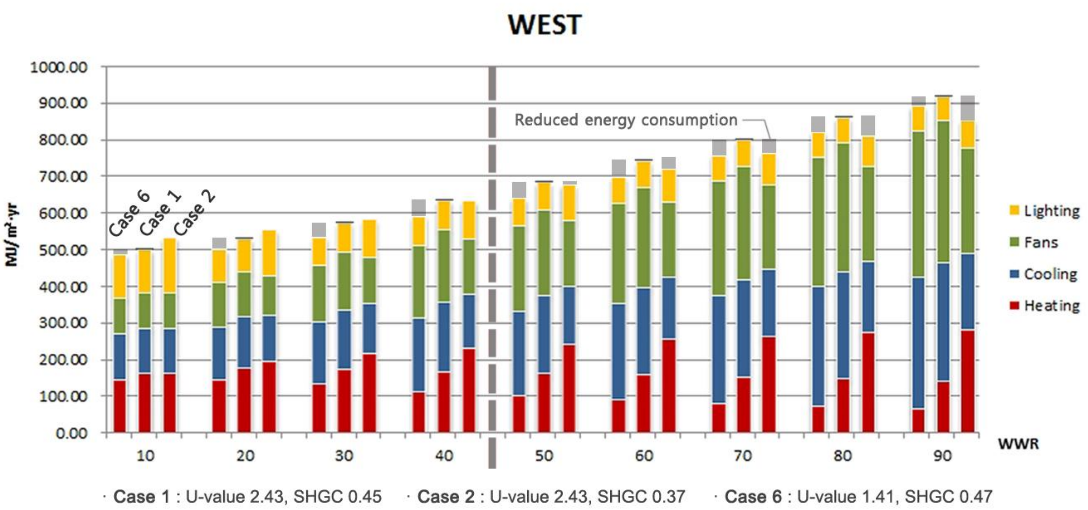


Figure 2. *Annual energy consumption of west orientation*

For cases in which the U-values of buildings facing east are identical to those of buildings facing west, as the SHGC values become lower, the total energy consumption declines. In summer, buildings facing to the east-west orientations have more Insolation. Therefore, as the SHGC increases, the cooling load increases as well. In contrast, as the SHGC decreases, the Insolation also decreases, causing less energy to be consumed. As a result, a lower SHGC value is more effective than other parameters in terms of saving energy. In particular, when the WWR increases, the total energy consumption decreases with lower SHGC.

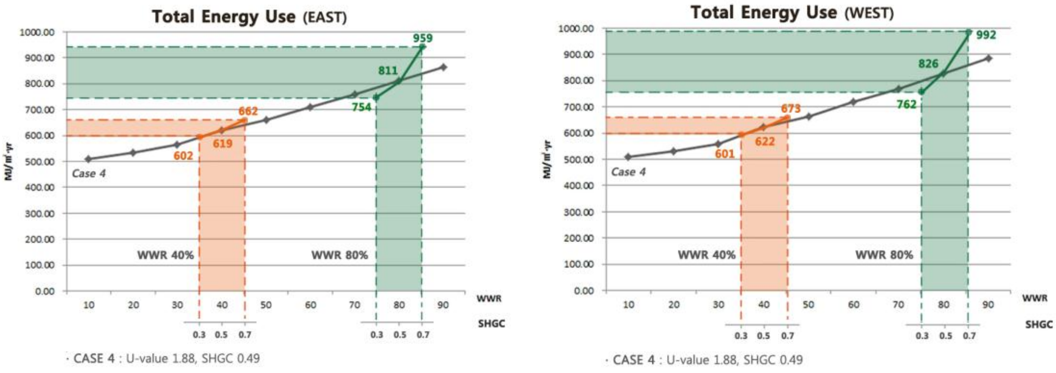


Figure 3. *Annual energy consumption with different WWR and SHGC (same U-value)*

Regarding the SHGC values of buildings facing east-west, the difference in the energy consumption depending on the insulation performance of the glazing is small. As the SHGC increases, the building total energy consumption increases, but the difference in terms of how the insulation performance affects the energy consumption level is small. This means that Insolation has a greater effect on the energy consumption level of a building facing east-west in summer, when the Insolation dominates the influence of the glazing insulation performance. When the SHGC value increases, the cooling load rate differs from the heating load rate depending on the insulation performance, but the energy consumption results are similar.

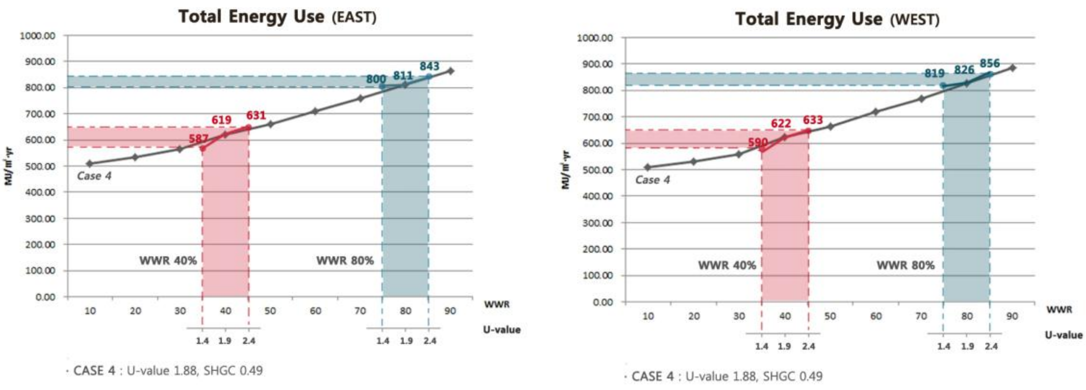


Figure 4. *Annual energy consumption with different WWR and U-value (same SHGC)*

3.2 Analysis of annual energy consumption: South

For buildings facing south, whose insolation levels in winter are the highest, the total amounts of energy consumed by buildings with the lower U-value are decreased, as opposed to buildings with the lower SHGC. However, when WWR facing the south is 60% or more, the total energy consumption decreases with lower SHGC. Especially when the SHGC decreases, the Insolation also decreases, leading to a decrease in the cooling load.

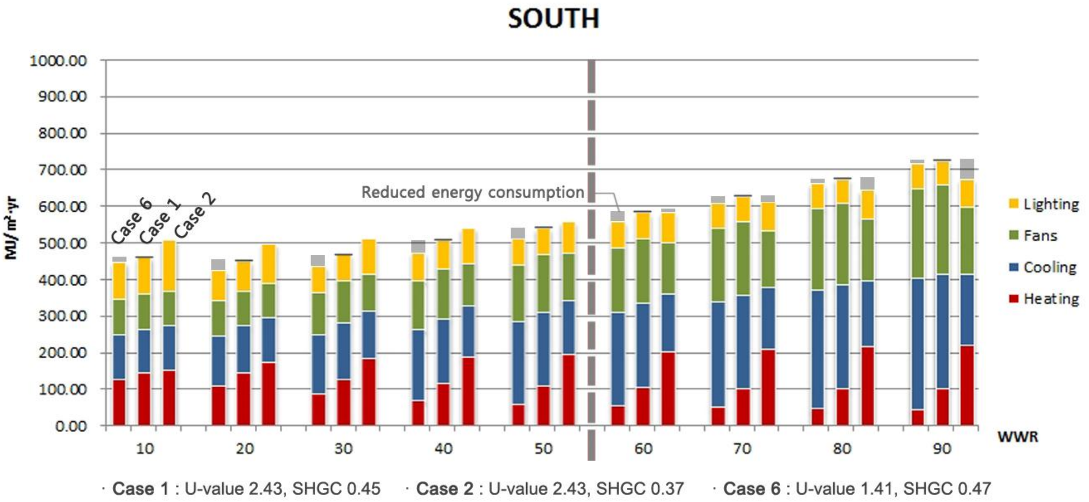


Figure 5. *Annual energy consumption of south orientation*

For buildings facing south with the same WWR, although the U-value is same, the both buildings total energy consumption may be different depending on SHGC. As the SHGC increases, the Insolation increases. Insolation can reduce the heating and lighting load, but it increases the cooling load in summer. Consequently, it increases the total amount of energy consumed. For cases involving a building facing to the south with the same SHGC, the total energy consumption levels are different depending on the U-value. In particular, when WWR is 40% or more, the gap between total energy consumption levels is widening greatly. For cases with the same SHGC, a lower U-value tends to decreases the heating load due to the improved insulation performance of windows.

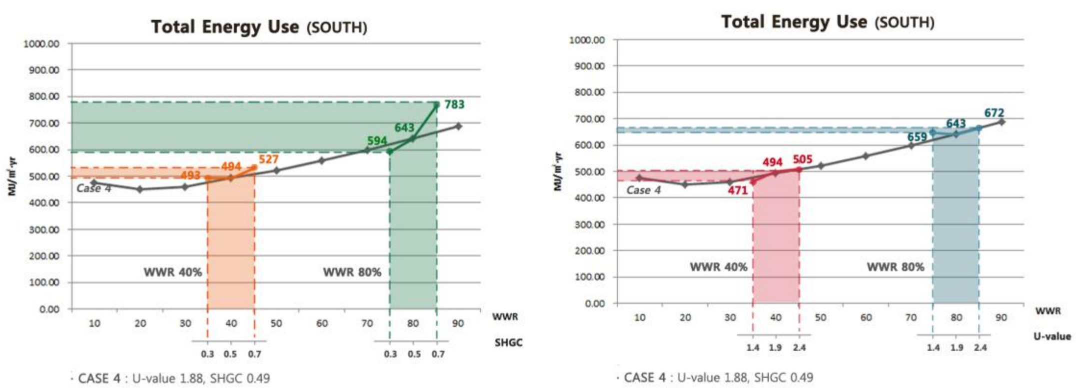


Figure 6. *Annual energy consumption with different U-value and SHGC*

3.3 Analysis of annual energy consumption: North

The total energy consumed by a building facing north is significantly lower than buildings facing other orientations. This difference arises because the insolation level is the lowest out of all other orientations and the cooling load is lower. In particular, when the WWR increases, the total energy consumption gap between cases increases depending on the U-value. As a building facing north has a lower insolation level compared to other orientations, the U-value, related to the thermal capacity influences the energy consumption level of these buildings more than the SHGC.

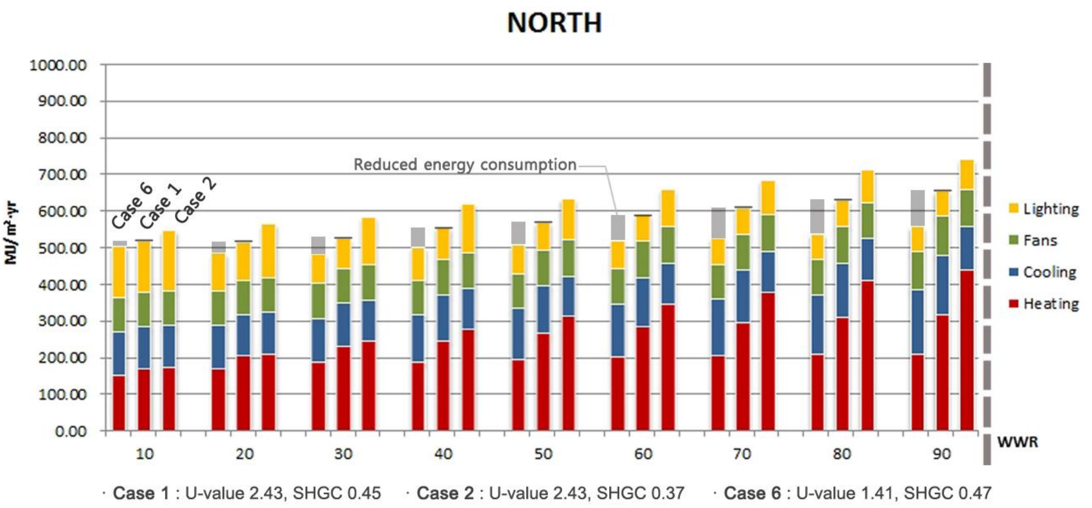


***Figure 7**. Annual energy consumption of north orientation*

When the U-value is certain in buildings facing the north, the patterns of total energy consumption of different buildings are similar regardless of the SHGC values. As the U-value becomes lower, the total energy consumption level is decreased, as a lower U-value of the glazing blocks the heat transfer from the outside. The solar radiation which flows in reduces the heating load and the radiant heat flows in again and does not escape to the outside. As a result, a lower U-value has the effect of reducing the heating load and the building total energy consumption level.

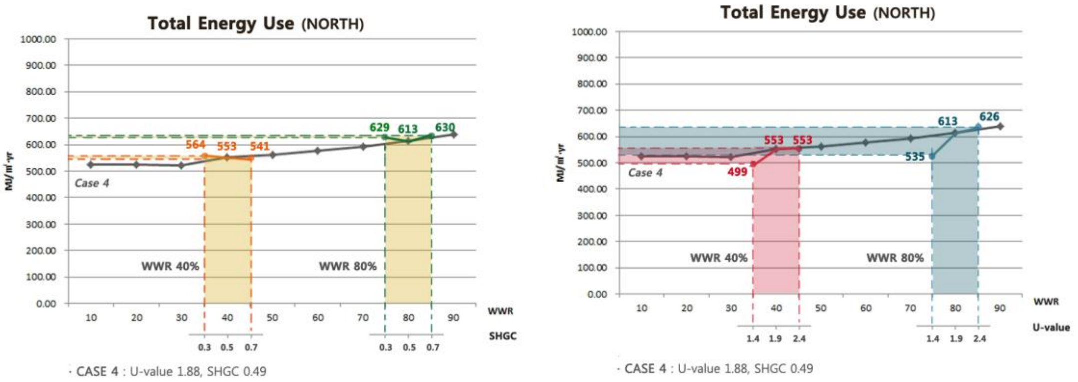


***Figure 8**. Annual energy consumption with different U-value and SHGC*

4. CONCLUSION AND DISCUSSION

The paper analyses energy consumption patterns according to different WWR value and material changes in the glazing through the simulation program COMFEN. The results showed that the amounts of energy consumed by buildings facing in four orientations (east, west, south and north) differ significantly due to the glazing characteristics and the WWR. The detailed results of this study are given below.

1) Regardless of whether a building faces east or west, when the SHGC increases, the total energy consumption level tends to increase with the same U-value. However, when the U-value increases, the total energy consumption slightly increases. The reason for this difference is solar heat gain, which influences the building energy consumption more than the differences in the insulation performance.

2) For buildings facing south, the total amounts of energy consumed by buildings with the lower U-value are decreased. However, when WWR is 60% or more, the total energy consumption decreases with lower SHGC. The result shows that when the WWR increases, the difference in total energy consumption is more the result of SHGC than the U-value.

3) For building facing north, when the WWR increases, the total energy consumption gap between cases increases depending on the U-value. As a building facing north has a lower insolation level compared to other orientations, the U-value, related to the thermal capacity influences the energy consumption level of these buildings more than the SHGC.

Our research has brought questions that need to be solved through further research. These include the window performance (U-value, SHGC, VLT and etc.) and the total energy consumption in a dynamic evaluation context. We are planning further studies to measure the relationship between window performance and the total building energy consumption.

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