Energy Impact of the Window Area in Residential Buildings

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ABSTRACT

Since windows are thermally vulnerable compared to exterior walls, special attention is required in building design. Windows are composed of frames, glass and spacers, and the overall performance is determined by area proportion and the performance of each part. Nevertheless, in most studies, changes in performance due to area changes have not been taken into account.

In this study, we examined the problems that might arise in the application of u-value and g-value by reflecting changes in the u-value and the g-value (Solar Heat Gain Coefficient) of the window, depending on the area changes in energy demand analysis. Research results showed that if the u-value differences between frames and glasses are greater, the u-value changes due to the increase in window area. In addition, it was analysed that in case changes in the u-value and the g-value due to changes in the area are reflected in the energy demand analysis, heating energy demand increases, and cooling energy demand decreases when compared to other cases.

Accordingly, changes in the u-value and the g-value due to changes in the window area must be reflected so a more accurate energy simulation analysis can be conducted.

KEYWORDS

Window Area, U-value, G-value, Energy Demand, Residential Buildings

INTRODUCTION

Energy savings in the building sector has become a global issue, and countermeasures have been prepared and executed by countries (EPBD 2010, US DOE 2008). The Korean government announced a road map to enforce zero-energy design on residential buildings by 2025 (PCGG 2009). In a related move, energy-saving design criteria have been strengthened since 2009, and the insulation performance of exterior walls and windows was enhanced by 24% and 45%, respectively, compared to that of 2008, and is expected to be strengthened even more in the future (MLTM 1992~2012). To dissemination zero-energy buildings, thermal performance must be enhanced by building parts as well as devise optimum design plans to minimize energy demand.

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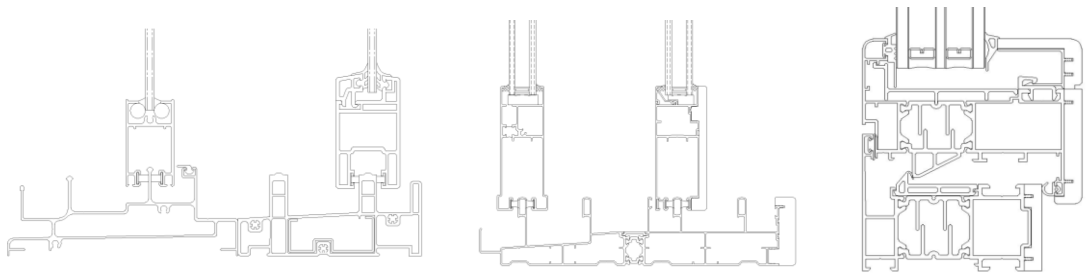
In particular, since the insulation performance of windows is inferior compared to that of walls, the window area by direction should be considered carefully in the design phase. There have been many studies on the relationship between windows and building energy. They can be divided further into studies on the component materials of the window, and studies in terms of architectural design (size, direction, etc.).
In addition, the impact of windows on the building energy varies, depending not only upon the area, but also on detailed factors that determine the overall performance of the window (window and frame u-value, g-value, etc.) (K.Tsikaloudaki et al. 2012, Enedir Ghisi 2005, Pyeongchan Ihm et al. 2012, Xing Su 2010, M.K. Urbikain 2009, Samar Jaber 2011).
This study was designed to analyse the impact of the window area on the building energy demand by reflecting changes in the thermal performance of the window (u-value and g-value) due to changes in the window area of residential buildings.

ANALYSIS TARGETS

(1)WINDOW

So far, a double window has been mainly applied to residential buildings. However, as insulation and air-tightness performance required for windows increase, the application of a system window is expected to be inevitable.
In this study, analysis targets were divided into the existing (A), present (B), and future (C) windows in consideration of the increased performance required for window systems. The insulation performance of windows required in residential buildings was 3.4 W/㎡•K in 2008. Window A is a double window in which 5-mm single glass and aluminium frames. With strengthened insulation performance requirements for windows in 2009, window B adopted low-e glass and applied polystyrene to some parts of the interior of aluminium double-window frames. Lastly, window C is a triple-glass system window with PVC frame. Figure 1 shows cross-sectional planes by analysis targets.



(a) Window A *(b) Window B* *(c) Window C*

Figure 1. *Windows*

(2) BUILDING

As a target building, a unit with 84 ㎡ of exclusive area on the middle floor of an apartment building in Seoul was selected. Table 1 and Figure 2 show an overview and a ground plan, respectively. An analysis was carried out, targeting a heating area measuring 100.13 ㎡ with a legalized balcony extension after December 2005. It was established that the balcony, toilet, shelter space, elevator shaft, and staircase were not air-conditioned.

Table 1. *Unit Information*

	Information
Orientation	South
Plans	BR3+LR+DK+WR2+Extra
Heating Area	101.13 ㎡(extended balcony)
Height	2.8m (Ceil. 2.38m)

Figure 2. *Unit Plan*

The envelope and window insulation levels were equally divided into three stages: designed from 2001 to 2008, designed before and after 2010 and meet the passive house design criteria. For exterior wall, the configuration and the thickness of the wall that meet the insulation standards presented in Table 2 was selected. Lighting load was 8 W/㎡, and the equipment load of 0.64 W/㎡ and 5.4 W/㎡ was applied to the bedroom and the dining room/kitchen, respectively.
To reduce the energy demand of the building, the ideal load system was applied, and the period beginning April 1st to September 30th was set as cooling (set-point at 26℃), and the rest as heating (set-point at 20℃) period. As ventilation level, 0.35 ach was applied. [Ministry of Environment 2008]

Table 2. *Building Elements U-value (W/m^2 • K)*

Level	*Exterior Wall*	*Core Wall*	*Floor*	*Window*
A	0.45	0.61	0.79	A window
B	0.33	0.49	0.79	B window
C	0.15	0.49	0.79	C window

CHANGE of U-value and G-value with WINDOW AREA

(1) Segmentation of performance by configuration

The segmentation of performance by configuration of the window was conducted by methods presented in ISO (EN ISO 10077-1&2, THERM, WINDOW).
Table 3 shows the results of WINDOW and THERM to calculate the insulation performance of each window frame, and the overall u-value of window was deduced from the case where window area is 2m×2m, the certified sample size of domestic windows.
In comparison with window A, the u-value of window B has significantly improved from 3.4 W/㎡ K to 1.9 W/㎡ K, which is attributed to the improved performance of the glass rather than the frame. In the case of window C, the u-values of the glass and the frame have significantly improved, and it is due to the increase in the number of compartments of the frame section.

Table 3. *Window u-value*

Segment			*A*		*B*		*C*
			Single - Window1	*Single – Window2*	*Single - Window1*	*Single – Window2*	
Frame	U_f	W/m²·K	9.33	13.55	11.57	12.73	1.269
	A_f	m²	0.496	0.945	0.496	0.945	0.496
Spacer	ψ_g	W/m·K	0.24	0.177	0.04	0	0.05
	l_g	m	3.488	3.496	3.488	3.496	3.488
Glass	U_g	W/m²·K	5.824		2.145		1.023
	A_g	m²	3.504		3.504		3.504
Single-Window	U	W/m²·K	6.468	7.80	3.348	4.645	1.09
Total Window	U	W/m²·K	3.4		1.9		

(2)Change of U-value and G-value by Window Area

Changes in u-value due to changes in the window area can be deduced by applying previously calculated values to the following equation.

$$U_{win} = \frac{U_g A_g + U_f A_f + l_g \psi_g}{A_{win}} \quad (1)$$

Here, U and A signify the coefficient of heat transmission and area, while win, g, and f signify window, glass, and frame, respectively. Moreover, l represents the tangent length of the glass and the frame, while Ψ thermal bridges the parts.

Like the u-value, if the total area of the window increases, the overall G-value was reduced by as much as the window area occupied by the frame in the g-value of the glass (K.Tsikaloudaki et al., 2012).

$$G_{win} = G_g \times (1 - f_f) \quad (2)$$

Here, G signifies SHGC, and f represents the proportion of the frame in the entire window area. Table 4 shows changes in the window area after the analysis. To identify changes in the window area, the south window was targeted, and its width varied by 0.6 m with its height fixed.

The area of the glass and the frame, as well as the length of the spacer portion, varies, depending on the changes in the width of the window, which was reflected to deduce u-value, while the g-value of the windows, due to changes in window area, was calculated in case the g-values of the windows are 0.3, 0.5, and 0.7, respectively.

The results were summarized in Table 5, and they were utilized as input values in the analysis of building energy demand. Here, bf represents the width of the window frames. To compare energy demand, the performance of the 2m×2m window was applied in the case of the u-value, while the g-values of the glass were collectively applied in the case of the g-value.

Table 4. *Change of Window Area*

Segment	*case1*	*case2*	*case3*	*case4*	*case5*	*case6*
Configuration of window area	①×8ea	②×8ea	③×8ea	③×2ea ④×6ea	③×2ea ④×2ea ⑤×4ea	③×2ea ④×2ea ⑤×2ea ⑥×2ea
Window Area (㎡)	10.56	21.12	31.68	39.60	44.88	47.52
Window to Wall Ratio (%)	14.10	28.21	42.31	52.88	59.94	63.46

Table 5. *Change of u-value and g-value by Window Area*

			Window g-value									*u-value (W/㎡K)*		
			Window A (bf=0.102m)			*Window B (bf=0.148m)*			*Window C (bf=0.236m)*			*A*	*B*	*C*
south	①	1.32	0.24	0.40	0.55	0.21	0.35	0.49	0.16	0.27	0.38	4.04	3.77	1.37
	②	2.64	0.26	0.44	0.61	0.25	0.41	0.57	0.22	0.36	0.50	3.59	2.76	1.24
	③	3.96	0.27	0.45	0.63	0.26	0.43	0.60	0.23	0.39	0.54	3.44	2.42	1.2
	④	5.28	0.27	0.46	0.64	0.26	0.44	0.61	0.24	0.40	0.56	3.36	2.24	1.18
	⑤	6.6	0.28	0.46	0.64	0.27	0.44	0.62	0.25	0.41	0.58	3.31	2.14	1.17
	⑥	7.92	0.28	0.46	0.65	0.27	0.45	0.63	0.25	0.42	0.58	3.28	2.07	1.16
	2.7		0.26	0.44	0.61	0.25	0.41	0.58	0.22	0.36	0.51	4.34	4	1.3
fixed case			0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	3.4	1.9	1.09

ENERGY ANALYSIS

(1)Net Window Energy

To identify the effect of changes in thermal performance on the energy demand of buildings, an analysis was conducted for heat gain and loss on the window's surface (M.K. Urbikain 2009, EnergyPlus 7.0). Figure 3 and 4 show the net window energy (= heat gain – heat loss) of windows due to changes in u-value and g-value. In consideration of the window size by case, higher u-values and lower g-values were applied in case of u-value and g-value adjustments, compared to the case with fixed values.

Generally, as g-values increase, heat gains through the window also increase. However, since heat losses undergo few changes, net window energy increases. The increase in net window energy acts as a plus factor for the reduction of heating load in the winter, but it serves as the cause of the increase in cooling load in the summer.

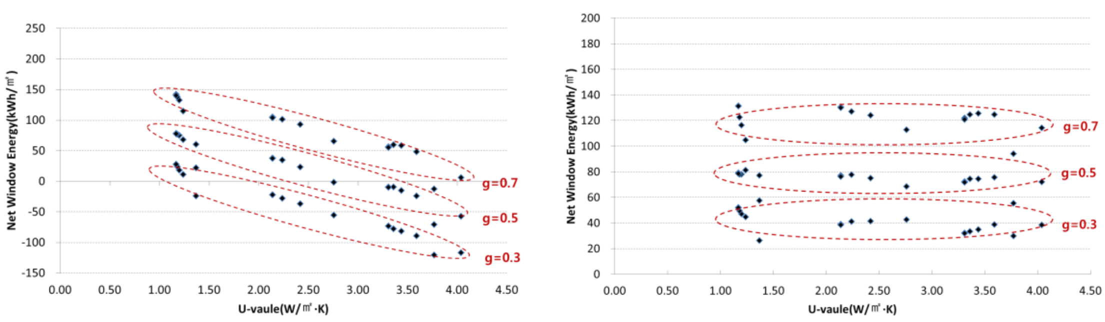


Figure 3. *u & g-value changed : heating(left), cooling(right)*

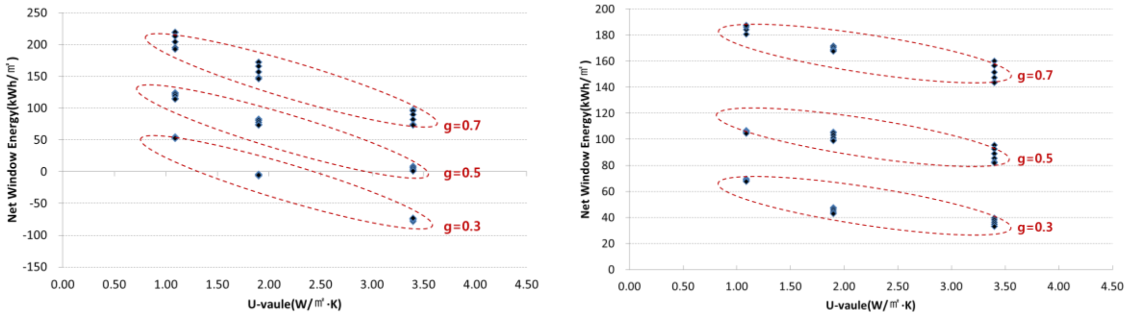


Figure 4. *u & g-value fixed: heating(left), cooling(right)*

(2) Energy Demand

Figure 5 shows the effect of the changes in u-values and g-values according to changes in the window area on the building energy demand. The differences in energy demand are the largest in the case of B with large differences in performance of windows and frames. In addition, as g-value varies, the impact of changes in the window area on the building energy demand changes (T.R. NIELSEN et al. 2001). That is, the window area ratio with the minimum energy demand has changed. Table 6 shows the optimal window area ratio with the minimum building energy demand by insulation performance. In case the g-value is 0.3, the effect of the insulation performance of buildings on the optimal window area ratio is expected to be large, but it is predicted that the effect of the insulation performance of buildings on the optimal window area will be greater in case g-values are 0.5 and 0.7.

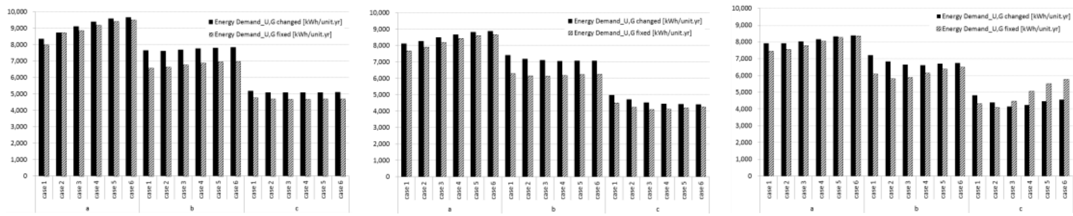


Figure 5. *Total Energy Demand (g=0.3(left), 0.5, 0.7(right))*

Table 6. *Optimal window area ratio*

	a		b		c	
	changed	fixed	changed	fixed	changed	fixed
g = 0.3	14 %	14 %	28 %	14 %	28 %	53 %
g = 0.5	14 %	14 %	53 %	42 %	63 %	42 %
g = 0.7	14 %	14 %	53 %	28 %	42 %	28 %

Figure 6 and 7 show heating and cooling energy demand due to the reflection of changes in the u-values and g-values, as window area increases from case 1 to case 6 in case the thermal performance of building envelopes is based on A, B and C.

The proportion of changes in the u-value and the g-value due to the improvement in building thermal performance (A→C) was 84% in B standard compared to A standard, and 55% in the case of the C standard, and the proportion was 76% and 55%, respectively, in the case with fixed u-values and g-values. It was analysed that the total energy demand was reduced, and these energy savings result from the fact that the amount of heating energy savings is relatively larger than that of cooling energy savings.

Next, it was found that as window area increased (case 1→case 6), heating energy demand decreased, but cooling energy demand increased in general. In case the building' s thermal performance is vulnerable (A), heating energy demand increased, which led to the conclusion that the impact of window area on the energy demand of buildings must be reviewed along with the thermal performance of building envelopes. In addition, it turned out that changing aspects become larger as g-values increase.

It turned out that in the case with fixed u-values and g-values, as window area increased, differences in thermal performance of buildings increased, while differences in thermal performance of buildings with changed u-values and g-values remained very small. There was little correlation between changes in cooling energy demand due to changes in window area and insulation performance of buildings. However, in case the window area is small, as thermal performance of buildings increased, cooling energy demand remained small. However, as thermal performance was enhanced, cooling energy demand increased from a certain point. That is, the analysis showed that in case the thermal performance of building envelopes is excellent, the impact of window area on cooling energy demand increases.

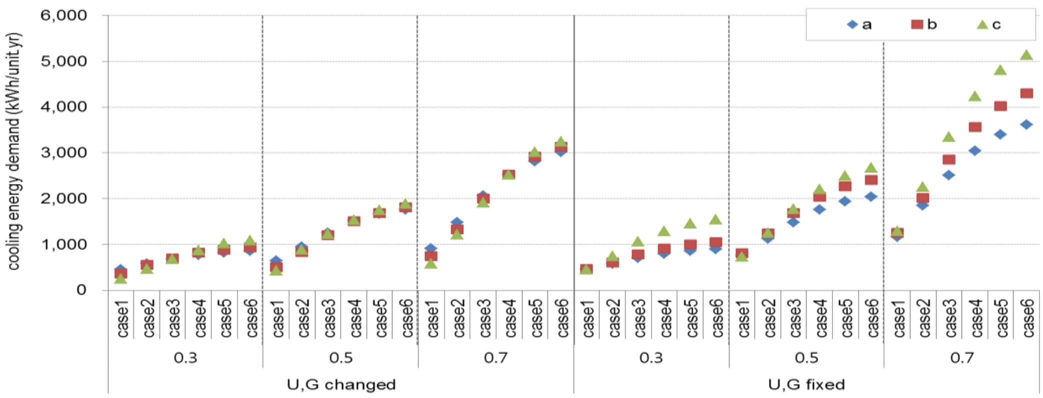


Figure 6. *Cooling Energy Demand*

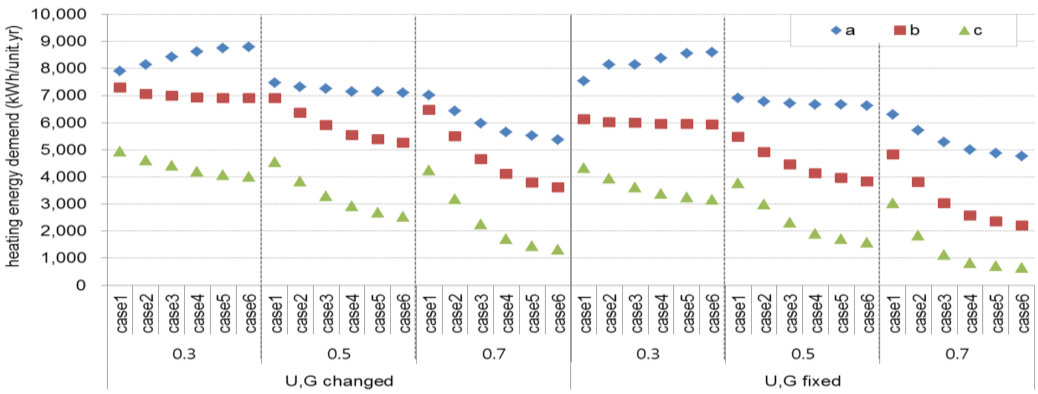


Figure 7. *Heating Energy Demand*

CONCLUSION AND IMPLICATIONS

In this study, we deduced changes in u-values and g-values due to changes in window area in case the thermal performance of envelopes, including windows in residential buildings, gradually increased, and investigated changes in cooling energy demand by using the deduced results as input values. From its results, it was found that differences in performance of the glass and the frame increased, as the impact of changes in window area on changed u-values increased. On the other hand, in case the performance of the glass and the frame was excellent, the impact was small. In addition, it was analysed that depending on window area, heating energy demand increased, but cooling energy demand decreased. That is, it was possible changes in u-values and g-values were not considered, and the impact of windows on the energy demand of buildings could be distorted. It is expected that, based on the research results, a more accurate building energy analysis will be carried out by reflecting u-values and g-values that were obtained in consideration of window area.

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