Energy Performance Analysis to Implement the Low-Energy Office Building in Korea

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ABSTRACT

These days, according to spreading the cognition and effort to decrease the energy consumption and enforcing the regulations in building energy fields, it is required to phase in the developed design methods and to develop the related technologies to cope with the tendency for the energy saving. Korean government announced the Carbon Reduction Target in 2020 which reduces 30% energy consumption compared to BAU (Business As Usual) on August, 2009. Also Korean government suggested "Low Carbon Green Growth". It is not only the passive concept that reduces carbon but active concept that advances new growth power. In building area, energy conservation roadmap was suggested as like regulation of total energy consumption in 2010, to reduce 30% of residential buildings' energy consumption in 2012, 60% in 2017, 60% of non-residential buildings' in 2020 and obligation of zero energy building in 2025.

Korean construction companies compete for hegemony in related industry. We have been doing a research project "The demonstration project for convergence and integration technologies to implement the low-energy building" funded by Korean government since 2010. Our objective is to demonstrate the energy saving within the reasonable cost rising in a real office building. To do this, we planned 19th floor office building and are constructing now. Our energy conservation technologies will be installed from 15th to 19th floor, and compared to other reference floor (1st – 14th). Energy performance analysis was conducted to verify that our technologies can satisfy our objective. In this project, we installed various technologies. So, most efficient alternatives (combination of conservation technologies) must be deduced by energy performance analysis.

This study proposes a new analysis approach to understand the effect of factors relevant to energy consumption and to predict the energy performance of buildings by Design of Experiments. As a result, this study derived a relationship which predicts the energy consumption of a building according to changes of various factors

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(insulation, solar shading, infiltration, and ventilation performance). Using this means of reduction, this study formulates an envelope design for existing building in the construction stage. This will also be verified through a comparison of the analysis results and actual measurements.

KEYWORDS
Low-Energy Building, Performance Rating Method, Design of Experiments, Optimization for building envelope

INTRODUCTION

In the case of Seoul, Korea, the glazing performance in particular accounts for large portion of the annual energy consumption of a building due to the four distinct seasons. The effects of ventilation and infiltration are extremely different according to the season. Therefore, a trade-off is necessary regarding the thermal and solar shading performances of glazing considering the four seasons.

It is an important issue to analyse the annual energy consumption according to the envelope plan and to determine an optimum plan during the design process.

This study conducts an energy analysis using dynamic thermal load estimations to derive the optimum envelope design to reduce the energy used by existing office buildings during the construction stage. However, it is difficult to analyse the many combinations of various pertinent factors. For this reason, the selection of a minimum case and the results of an analysis are utilized in the Design of Experiments (DOE).

The basic information (e.g., shape, scale, use) related to the selected office building is determined by Korean building codes. The main factors are the envelope performance factors (insulation, solar shading, air-tightness, ventilation, exterior shading performance) excluding the previously determined building information.

The selected office building is a 19-story building, and five upper stories are selected as the target space (15～19F) for applying the energy reduction alternatives. The envelope of the fourteenth story excluding the target space is designed according to the current building code. The selected optimum alternatives are applied to the target space. Then, this study analyses the energy consumption of the optimum alternative and the original alternative. These results are used to verify the energy reduction effect of the optimum alternative. This approach can make it possible to analyse building performances effectively to realize energy savings.

RESEARCH METHODS

Table 1 and Figure 1 ～ 2 show basic information of the selected building.

Table 1. *Basic information of the selected building*

Location	Seoul, Korea (Latitude 39°29‘07“, longitude 127°02’11”)
Scale of Building	6F underground, 19F above ground
Gross area	39,353.17 ㎡
Typical floor area	1,299.3 ㎡
Usage	Office

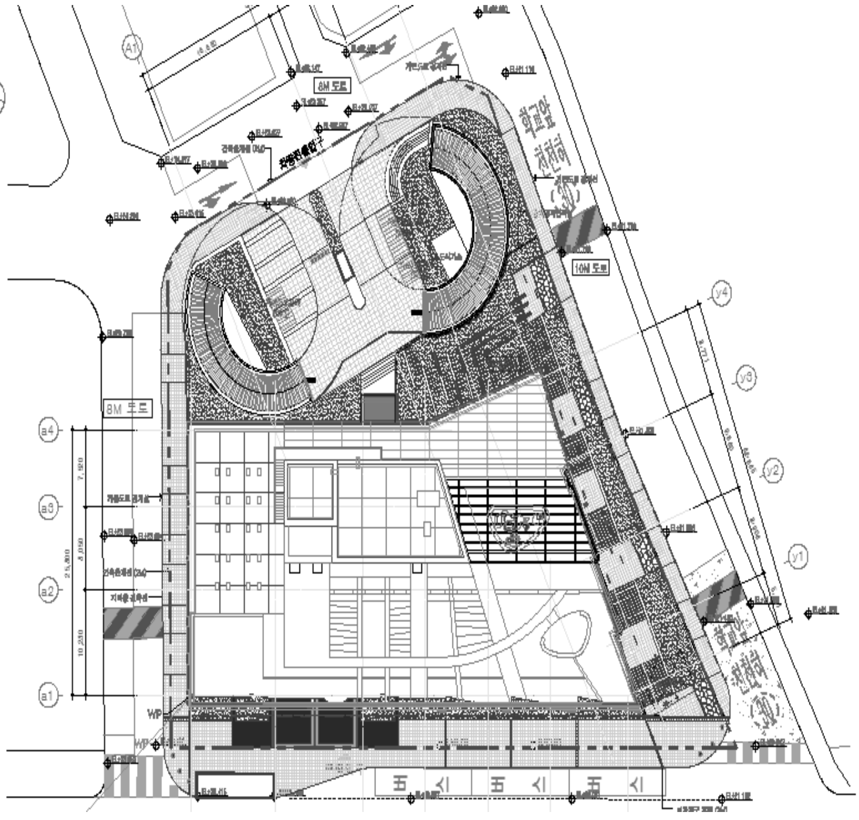

Figure 1. *Site plan of the selected building*

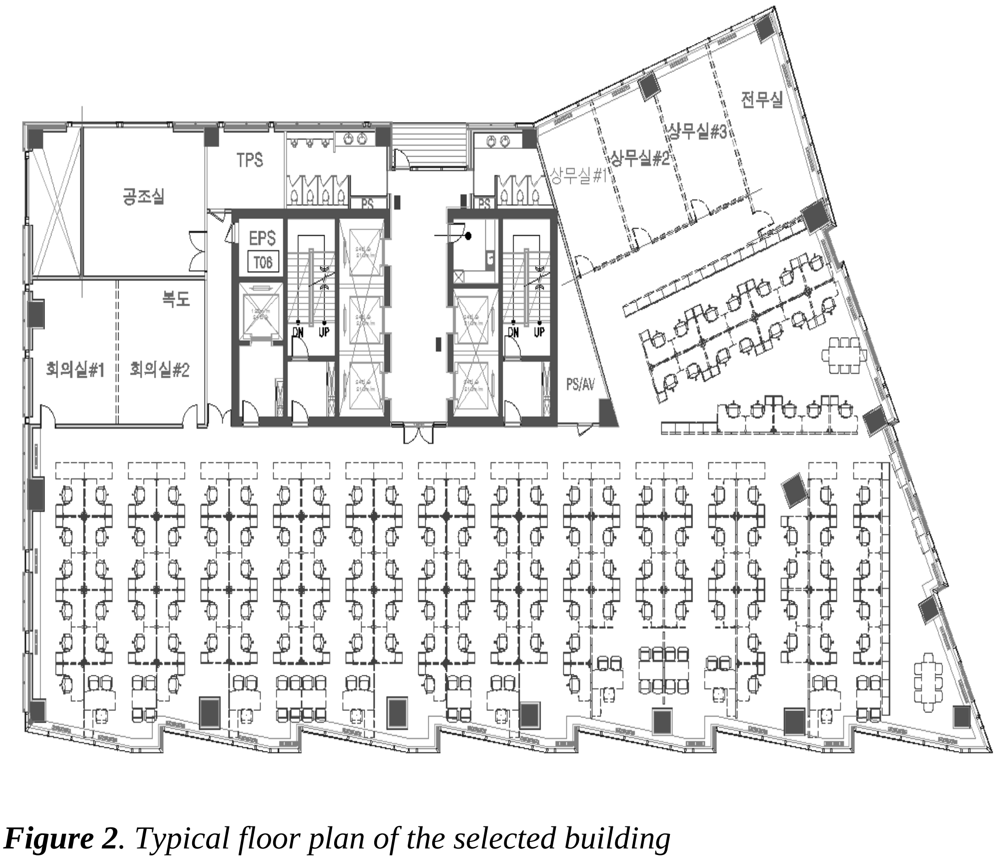

Figure 2. *Typical floor plan of the selected building*

Table 2. *Envelope specification of the selected building*

Specification		*Values*
Spandrel	U-value	0.28 $W/m^2 K$
Vision	U_g-value	2.1 $W/m^2 K$
	U_f-value	4.0 $W/m^2 K$
	SHGC	0.7

Table 3. *The factors and level of the envelope*

Factors	*Level*	*Reference*
Thermal performance of glazing(U_w)	U-value($W/m^2 K$) 0.7 ~ 2.5	4 Orientations (S,N,NE,W)
Solar shading performance of glazing	SHGC 0.2 ~ 0.6	4 Orientations (S,N,NE,W)
Thermal performance of frame(U_f)	U-value($W/m^2 K$) 1.5 ~ 4.0	4 Orientations (S,N,NE,W)
Exterior shading	Shading Coefficient 0.0 ~ 0.8	2 Orientations (S,NE)
Insulation filling	Infiltration(ACH) 0.1 ~ 0.5	-
Outdoor air cooling	Ventilation(ACH) 0.0 ~ 3.0	Cooling system Natural Ventilation
Total factors	16	
Total case	49 Run	48 Run + 1(center)

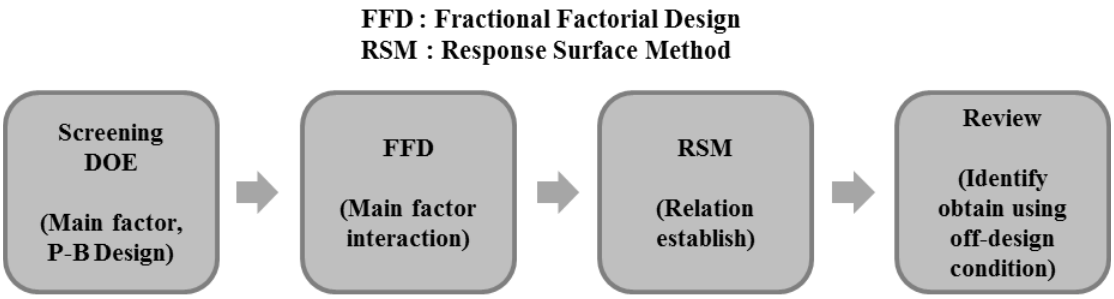

Figure 3*. DOE conduction process*

The west envelope of the selected building is adjacent to a similar scaled building doing a role of solar shading, while other orientations are not seen in adjacent buildings. Table 2 shows the existing specifications of the envelope design.

This study undertakes an experiment arrangement and analysis using DOE to derive the optimum envelope design. To do this, it utilizes Minitap v.14, which is a statistics analysis program. Table 3 and Figure 3 show the set factors and DOE conduction process.

A total of 49 cases were analysed by the experiment plan. This analysis resulted in five responses (the annual cooling load, the annual heating load, the annual heating and cooling load, the maximum cooling load, and the maximum heating load) according to the set factors. In this study, TRNSYS v.17 is used for the dynamic thermal analysis. Table 4 shows the basic condition for the analysis of the selected building.

Table 4. Basic condition of the selected building for analysis

Specification		*Values*
Set temperature	Cooling	26℃
	Heating	20℃
Internal loads	People	0.2 people/m²
	Lighting	20 W/m²
	Equipment	10 W/m²
Ventilation		27 ACH
Operation time		AM 08 ~ PM 18 (Five-day workweek)

RESULTS and DISCUSSION

Main Effect Analysis

Figure 4 shows the residual distribution of the annual heating and cooling loads as analysed by the experimental arrangement.

Through this analysis, the effective factors are extracted from among various factors in the selected building.

As a result of the analysis of the main effects, there were nine factors affecting the annual heating loads. These are the U-value of the glazing facing four orientations, the U-value of the frame facing south, the SHGC of the glazing facing three orientations (S, N, and NE) and airtightness. The factors affecting the annual cooling load numbered eight, as follows: the U-value of the glazing facing three orientations (S, N, and NE), the SHGC of the glazing facing three orientations(S, N, and NE), airtightness, and outdoor air cooling. There are six factors affecting the annual cooling and heating load: the U-value of the glazing facing south, and the SHGC of the glazing facing three orientations (S, N, and NE), airtightness and outdoor air cooling.

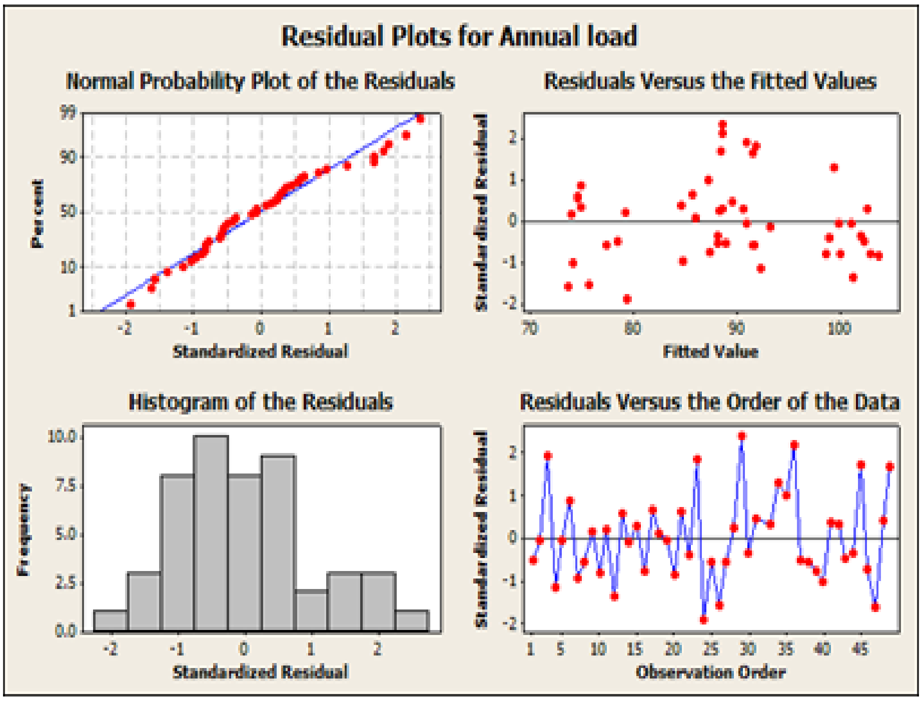

Figure 4. Residual distribution of annual heating and cooling load

In the case of the annual load, the exterior shading and curtain wall performance are not main factors. The main factors are the airtightness performance and the outdoor air cooling related to ventilation.

The envelope performance according to the orientations shows that the southern direction has the greatest effect, followed by northeast and north. In case of heating, U-value has the greatest effect and in case of cooling SHGC has the greatest effect.

Figure 5 and Figure 6 show the changes in the cooling and heating load according to the glazing performance of the south and northeast directions.

In case of west, solar shading performance of glazing is less effective due to adjacent building. Figure 6 shows that low values of U-value and SHGC is effect to reduce annual load.

However, in case of the southern direction, if the U-value is higher than 1.7, a lower SHGC is not effective for reducing the annual load. On the other hand, if U-value is lower than 1.7, a lower SHGC is effective for reducing the annual load (Figure 5).

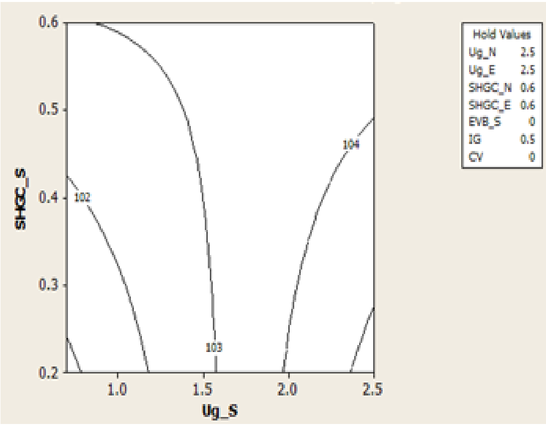

Figure 5. *Annual load and glazing performance of south*

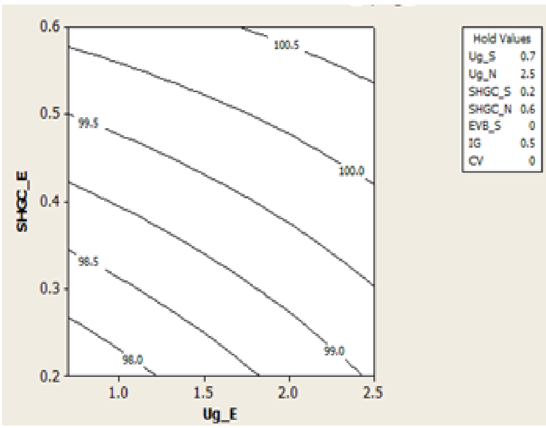

Figure 6. *Annual load and glazing performance of northeast*

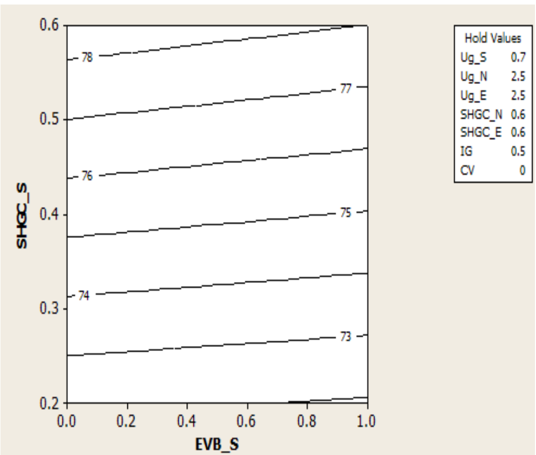

Figure 7. *Maximum cooling load, SHGC of southern glazing and exterior shading*

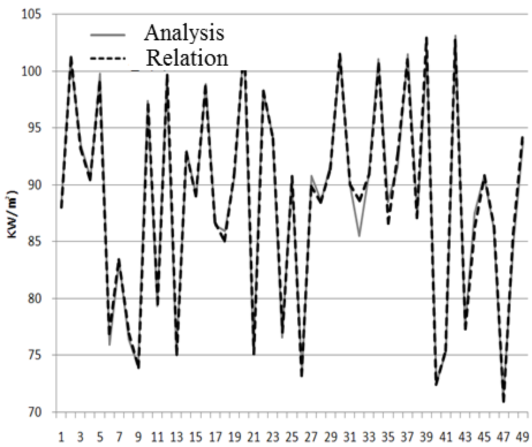

Figure 8. *Result comparison of the analysis and the relation for annual load*

This indicates that the U-value is the main effective factor which causes a change in the annual heating and cooling. It is a proper plan to apply glazing of a low U-value that is lower than 1.7 considering the effects of a low U-value and SHGC.

Regarding the maximum cooling and heating load, the main factors are similar to the results of the annual load analysis. Figure 7 shows the change in the maximum cooling load according to the SHGC of the glazing and the exterior shading of the southern direction. As a result, exterior shading of the southern direction has the great effect on reducing the maximum cooling load.

Deduction of the Optimum Envelope Design

Based on the analysis results, this study derives the relationship regarding the annual cooling and heating load using a response surface method (RSM). This relationship is reflected in the interaction among the main effective factors. The relationship between the annual cooling and the heating load is as follows (S = 0.8684, R-Sq = 99.7%).

Annual cooling and the heating load =71.5842+2.4741*U_s+0.307678*U_n+0.954074*U_ne+23.2856*S_s+4.17303*S_n+9.95479*S_ne+0.663076*E_s+32.9884*I-15.1541*C-0.0911076*U_s*U_n+0.188086**U_s*U_ne-5.59645*U_s*S_s-0.158402*U_s*S_n-0.788173*U_s*S_ne+0.348024*U_s*E_s+3.02220*U_s*I+0.524108*U_s*C-0.847656*U_ne*S_s-0.690738*U_ne*S_n-1.19052*U_ne*S_ne-0.134339*U_ne*E_s+1.12846*U_ne*I+0.187614*U_ne*C+1.25084*S_s*S_n-0.908153*S_s*S_ne-1.59545*S_s*E_s-24.0363*S_s*I-2.00107*S_s*C-0.940035*S_ne*E_s-3.89505*S_ne*I+0.0108046*S_ne*C-0.835196*E_s*I-0.382442*E_s*C+5.66123*I*C (1)

where U is the U-value of glazing, S is SHGC of glazing, E is exterior shading, I is insulation filling application, C is Outdoor air cooling application and n, s, e, w are orientation.

Figure 8 shows a comparison of the analytical results and the relationship results.

The derived relationship result is similar to the result of the analytical. Also, this study derives other relationships pertaining to the response.

Table 5 shows alternatives for energy savings for the selected building.

In this study, the proposed method is shown to be efficient for analysing the cost and energy consumption amounts of various alternatives. It is also possible to utilize economic analyses through lifecycle cost (LCC) analyses as an optimum alternative.

__Table 5.__ Alternatives for energy saving of the selected building

	Factors					Annual load		Cost (envelope)
	Glazing		Exterior Shading (South)	Insulation Filling	Outdoor Air Cooling	/㎡	Saving for Code (%)	Rising for Ref. (%)
	U-value (W/㎡ K)	SHGC						
Code	2.8	0.7	×	×	×	103.52	-	-
Ref.	2.1	0.7	×	×	×	91.44	11.70	-
Alt.1	1.34	0.27	○	○	○	75.85	26.70	49.00
Alt.2			×	○	○	76.13	26.50	26.90
Alt.3			×	×	○	87.13	15.80	21.80
Alt.4			×	○	○	76.13	26.50	26.40
Alt.5			×	×	○	87.13	15.80	21.30
Alt.6	0.67	0.23	○	○	○	72.87	29.60	69.90
Alt.7			×	○	○	73.19	29.30	47.80
Alt.8			×	×	○	83.69	19.20	42.70
Alt.9			×	○	○	73.19	29.30	47.30
Alt.10			×	×	○	83.69	19.20	42.20

* Our recommendation is Alt.4

CONCLUSION AND IMPLICATIONS

The energy analysis approach using DOE is able to analyse effective factors related to energy consumption. This study conducted a quantifiable comparison analysis of various alternatives through this relationship.

Specifically, it is possible to reduce the building load and understand the effects of building design changes while considering the interaction of effective factors. Thus, this study introduces an effective evaluation tool for a comprehensive analysis of various factors.

This study applies this process to several target floors of a selected building to derive the optimum alternative through an economic analysis. In the future, this approach will be verified in terms of the accuracy of its energy consumption predictions based on the real energy consumption as measured in the operation stage.

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