A CASE STUDY OF THE ENERGY PERFORMANCE OF AN OFFICE BUILDING WITH DOUBLE-ENVELOPE AND ATRIUM

Gook-Sup Song
Bucheon College, Bucheon City + 421-735 - Rep of Korea
Hyun-Woo Lee
KwangWoon University, Seoul City +139-701 - Rep of Korea
Won-Ryong Choi
DongWoo Architects Engineering Co., Ltd.
Seoul City +135-010 - Rep of Korea

ABSTRACT

This paper presents an investigation of the energy performance in an office building in Daejeon, Korea. The office building has a south-facing glazed double-envelope and a rectangular atrium. During the preliminary design of the building, a study was conducted by the research team in order to achieve the annual energy consumption per unit area of the building under 240 Mcal/m^2-yr. A number of building designs and HVAC system variables were analyzed in terms of energy performance. Based on the results of the analysis, the important building design issues including HVAC system specifications were identified for the building. Finally, the energy performance of the building was evaluated by comparing with a typical office building.

INTRODUCTION

The commercial energy consumption in Korea has risen very rapidly over 35 years since 1960s due to high growth of economy, cultural needs, and the energy policy of low fuel cost. The recent IMF shock in Korea caused an economic crisis and required a serious mental switch over imprudent energy use. Aside from this domestic problem, there are other global environmental problems related to the continued consumption of fossil fuel, which will inevitably increase emissions of carbon dioxide, CO_2 and resource depletion of the earth. In 1997 the Kyoto Protocol established an international agreement that CO_2 emissions should be cut to 94.8% of 1990 levels by 2012. Increased concern about the environmental problems has influenced once more the need for energy conservation of buildings.

This study aims to meet that need. The objective of this study is to evaluate the energy performance of an office building with a south-facing glazed double-envelope and an atrium, which are the most effective technology in reducing energy consumption. In addition to those two important designs, ten other design issues were examined to determine their most optimal values for the building. This includes air space width of a double-envelope, thickness of insulation of an exterior wall, coefficient of overall heat transmission of a window, shading coefficient of shading devices, use of task/ambient lighting, type of HVAC system, reset control of baseboard, method of varying fan volume, minimum outdoor air ratio, type of cooling refrigeration machine. A number of detailed hourly simulations using DOE-2.1E were conducted to evaluate the energy performance of the alternative designs and to achieve the annual energy consumption of the building under 240 Mcal/m^2-yr. Then, the energy performance of the office building equipped with the above design features including a double-envelope and an atrium was analyzed by comparing with a typical office building in Korea.

METHODOLOGY

An office building is presently under construction on a flat site of Korea Institute of Energy Research center in Daejeon, Korea. The building is a 5-story square building with the first basement, 32.4 m long, 32.4 m wide, and 20.6 m high with total gross volume of 25,500 m^3. A summary of the building is given in Table 1.

Table 1. Summary of the Building

Section	Content	
Location	Deajeon Chungnam, Korea	
Gross Area	6,184.62 m^2	
Floor Area	Floor	Area (m^2)
	B 1	1,227.95
	1 F	1,086.75
	2 F	967.48
	3 F	967.48
	4 F	967.48
	5 F	967.48

An exterior view from south-west is illustrated in Figure 1 and a typical floor plan of the building is shown in Figure 2.

Figure 1 Exterior View

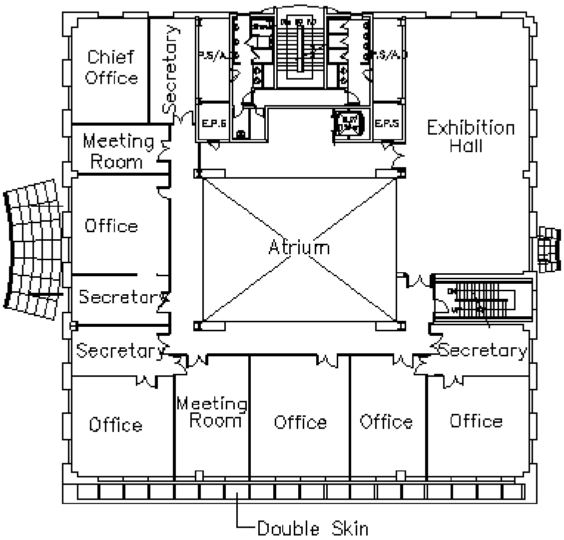

Figure 2 Typical Floor Plan

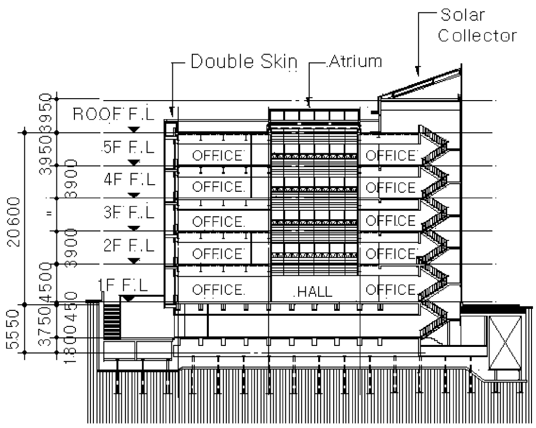

Figure 3 Major Section

The most distinguished feature of the building is a south-facing glazed double-envelope, in which two glazings are separated by a fairly wide air space. It is also worth noting the presence of a rectangular central atrium, where daylight through top skylight penetrates into office spaces. Major sections of the building are shown in Figure 3.

Although a double-envelope and an atrium are known as being excellent design concepts from the thermal and luminous standpoint, there are still remained questions concerning the energy performance of the whole building. Consequently, a study was needed to assess the energy performance of design alternatives related to building envelope and HVAC system. Basically, this study consisted of two stages:

First, a preliminary evaluation of alternative building designs and HVAC designs for the building was conducted. This stage led to the determination of the office building design of this case study to be evaluated in the next stage of the analysis.

Secondly, a comparison evaluation between the case office building and the typical office building was performed, which led to the conclusion of the energy performance for the office building with a double-envelope and an atrium in Daejeon , Korea.

A detailed hourly simulation program, DOE-2.1E was used for evaluation of the energy performance. Several assumptions for the simulation were made such as indoor air quality, thermal conditions, occupancy-related data, etc. The assumptions are summarized as shown in Table 2.

Table 2. Assumption of Simulation

Condition		Set Point Value
Heating Season	Indoor Temp./Humidity	Temp. : 20°C Humidity : 30%
	Nighttime Setback Temp.	Temp. : 12°C
Cooling Season	Indoor Temp./Humidity	Temp. : 26°C Humidity : 60%
	Nighttime Setback Temp.	Temp. : 33 °C
HVAC	Start Time	AM 7 – AM 8

ANALYSIS

The adoption of a double-envelope incorporating an atrium was the main design issue requested by the client, KIER at the preliminary stage of the design. The external envelope of the double-envelope of the case office building consists a single, blue tinted glass of 8 mm thickness. The internal envelope partly opaque consists of a double glazing made of two 6 mm clear glasses separated by 12 mm air gap. One of the objectives of this study was to verify advantages of the key design features in terms of the thermal and luminous environment and the energy performance. From thermal comfort standpoint, the advantage of a double-envelope is that a solar-induced ventilated cavity acts as a dynamic insulation system, which in turn reduces the heat losses through the envelope. The energy performance of the double-envelope solution was evaluated to see how the double-envelope performs better compared to the single-envelope. The comparison informed that the peak load reduction occurred greater in case of cooling but the annual energy saving was larger for heating when the double-envelope was adopted. This means the double-envelope is more efficient to reduce heating energy rather than cooling energy. The energy effect of variations in the air space width of the double-envelope was also examined. However, the results of the energy performance of six widths presented in Table 3 did not show significant differences among them. Therefore, the solar altitude in the summer season became a determinant factor for the air space width of double-envelope which was fixed as 1.5m.

Table 3. Energy Consumption of Double Envelope Width

Double Envelope Width (mm)	Peak Cooling Load (Kcal/h)	Peak Heating Load (Kcal/h)	Annual Cooling Consum-ption (Mcal)	Annual Heating Consum-ption (Mcal)
Single-Envelope	191,547.8	-365,009	270,630.8	-190,272
600	164,581.6	-353,714	251,982.6	-146,592
1200	164,533.5	-353,798	251,676.4	-146,627
1500	164,512.0	-353,838	251,534.5	-146,643
1800	164,490.5	-353,876	251,396.9	-146,658
2400	164,450.1	-353,947	251,140.6	-146,688
3000	164,413.9	-354,013	250,905.0	-146,714

Preliminary Evaluation of Alternative Building Designs and HVAC Designs

As a further step of the analysis, nine important design issues were identified and analyzed to decide the case office building.

Insulation of an exterior wall can greatly affect the energy performance of buildings. If a building is well insulated, little heat is transported through exterior walls. The effect of different thickness of insulation on the building loads is shown in Table 4.

Table 4. Energy Consumption of Insulation Thickness of Exterior Wall

Insulation Thickness (mm)	Peak Cooling Load (Kcal/h)	Peak Heating Load (Kcal/h)	Annual Cooling Consum-ption (Mcal)	Annual Heating Consum-ption (Mcal)
40	164,512.0	-353,838	251,534.5	-146,643
50	163,494.6	-351,630	252,749.7	-141,424
60	162,742.1	-350,000	253,743.9	-137,589
70	162,170.2	-348,761	252,565.2	-134,691
80	161,717.0	-347,781	255,257.5	-132,415
90	161,341.2	-346,969	255,862.9	-130,543
100	161,030.7	-346,297	256,387.5	-129,864

The figure illustrates the thickness increase of insulation reduces the peak load, which in turn can reduce the mechanical system size. However, it should be noted that there is no substantial load reduction beyond 80 mm of thickness of insulation. Therefore, the optimal thickness of insulation of the case building was found to be 80 mm.

The ability of glass to conduct heat is measured by its coefficient of overall heat transfer and by the magnitude of the temperature difference between the air on either side. According to the building regulations in Korea, the required "k" value for window should be 2.7Kcal/m^{2}h^{o}C or less. Four alternatives of the exterior glazing were examined. Among the four glazings, low-e glass with 1.8 Kcal/m^{2}h^{o}C was selected based on the result of the simulation as shown in Table 5.

Table 5. Energy Consumption of Coefficient of Overall Heat Transfer

K-Values (Kcal/m^{2}h°C)	Peak Cooling Load (Kcal/h)	Peak Heating Load (Kcal/h)	Annual Cooling Consum-ption (Mcal)	Annual Heating Consum-ption (Mcal)
1.8	169,940.3	-348,395	264,627.2	-146,971
2.0	170,550.9	-350,408	262,844.4	-150,594
2.4	171,734.3	-354,370	259,626.3	-157,574
2.7	172,573.6	-357,228	257,518.4	-162,545

The presence of sun-shading devices can greatly reduce the solar heat gain through windows. Their relative effectiveness in controlling solar heat gain is known by their shading coefficient values. Thus, deciding an appropriate device for shading needs enough information about shading device shapes and sun's position. Movable internal shading devices like venetian blinds are less efficient than external devices in reducing solar heat gain but are more reliable. Movable external devices tend to be costly and because of exposure to the weather require significant maintenance. A disadvantage of external fixed shadings is that it loses some permanent solar gain and daylight when needed. The energy performances of several shading devices were examined and summarized in Table 6. Exterior fixed louvers were selected for the east and west windows of the case building. Movable internal shads, venetian blinds were used in the south windows. Internal shads, shutters were placed underneath skylights of the atrium.

Table 6. Energy Consumption of Shading Device Strategy

Shading Strategy	Peak Cooling Load (Kcal/h)	Peak Heating Load (Kcal/h)	Annual Cooling Consum-ption (Mcal)	Annual Heating Consum-ption (Mcal)
Shading for All	169,032.1	549,681	233,115.0	-147,534
Shading Only for Atrium	169,032.1	561,617	245,328.8	-147,256
External Louver for East / West	169,032.1	563,386	247,532.9	-146,821
Venetian Blind	169,032.1	559,082.6	243,315.5	-146,735
No Shading	169,032.1	567,209.6	251,534.5	-146,643

Proper use of daylight for illuminating an interior office space can reduce the energy use in two ways, by minimizing the use of electricity for lighting and by cutting electric energy use and demand for cooling. Two lighting systems were compared to see the effect of daylight on the energy consumption. One is the general lighting and the other is the general lighting incorporating task/ambient lighting which takes account for daylighting benefit. For the case of general lighting only, the electric lighting power density was 25 W/m^2. On the other hand, for the case of general lighting with task/ambient lighting, the electric lighting power density was 7.754 W/m^2, which considered daylighting effect. Table 7 shows daylight asset gives much less cooling consumption but slightly more heating consumption.

Table 7. Energy Consumption of Lighting Power Density

Lighting Power Density	Peak Cooling Load (Kcal/h)	Peak Heating Load (Kcal/h)	Annual Cooling Consum-ption (Mcal)	Annual Heating Consum-ption (Mcal)
25W/m^2	**241,803.6**	**-324,879**	**465,363.2**	**-132,056**
7W/m^2+Task Light 0.754W/m^2	**191,547.8**	**-367,589**	**270,630.8**	**-190,272**

Variable air volume system is usually known as an energy saving system for office buildings. Variable air volume system can save 20 to 30 % in building energy consumption over conventional constant air volume system. Furthermore, VAV system can provide beautiful comfort when designed and operated properly. The energy performance of variable air volume system was compared with constant air volume system as shown in Table 8.

Table 8. Energy Consumption of HVAC System Type

	VAV (Mcal)	CAV (Mcal)
Electric	391,386	460,186
Gas	209,840	227,040

Reset control strategy of convector was examined for the study. Since equipment size is often oversized, the reduced convector peak output according to outdoor temperature can reduce the energy consumption. Table 9 shows the performance of different reset control ratios. Use of 70% of the peak output gave the best performance in terms of energy consumption and comfort.

Table 9. Energy Consumption of Reset Control of Baseboard

	Reset-07, 70% of Minimum (Mcal)	Reset-08, 80% of Minimum (Mcal)	Reset-09, 90% of Minimum (Mcal)	Reset-10, 100% of Minimum (Mcal)	No Reset Control (Mcal)
Electric	392,160	391,300	391,300	391,300	391,300
Gas	183,180	192,640	201,240	209,840	297,560

There are four different methods of varing fan volume in order to be proportional to the demand of the VAV terminals. These are variable speed motor, inlet vane, discharge damper, and cycling. This study examined variable speed motor, inlet vane, discharge damper methods. Variable speed motor resulted in the most efficient method of fan air volume control and highest energy savings of all volume control methods. Table 10 shows the result of energy performance of each method.

Table 10. Energy Consumption of Fan Volume Control Method

	SPEED (Mcal)	INLET (Mcal)	CONSTANT (Mcal)
Electric	359,480	396,460	460,960
Gas	303,580	297,560	299,280

Since VAV unit controls supply air volume, humidity control is difficult during heating season. To avoid this, minimum CFM ratio was applied for the case building. Four values for the minimum CFM ratio were examined. As shown in Table 11, 20 % of minimum CFM was the most efficient ratio, which was used as the input value for the case building.

Table 11. Energy Consumption of Minimum CFM Ratio

	15% (Mcal)	20% (Mcal)	25% (Mcal)	30% (Mcal)
Electric	393,880	396,460	399,040	401,620
Gas	297,560	297,560	298,420	299,280

There are three refrigeration methods, which are usually used in Korea: vapor compression, absorption, thermal energy storage. The energy performance of each method is presented in Table 12. Since cheaper electricity cost is charged for nighttime, thermal energy storage system was chosen for the case building simulation although the compressive refrigeration machine, a turbo chiller consumed the least gas.

Table 12. Energy Consumption of Refrigeration Machines

	TURBO (Mcal)	ICE (Mcal)	ABSOR (Mcal)
Electric	396,460	418,820	363,780
Gas	297,560	342,280	770,560

<u>Comparison Evaluation of the Case Building and the Typical Building</u>

Based on the previous preliminary analysis, various design issues of the case office building were analyzed and decided. Table 13 shows the synopsis of the building together with the summary of the typical office building.

A detailed hour-by-hour simulation were performed in order to assess the energy performance of the case building. Subsequently, the case office building was compared with the typical office building in Korea in terms of BEPS. The result of this analysis is presented as shown in Table 14.

Table 13. Comparison of Typical Building with Case Building

Section	Item	Typical Building	Case Building
Building	Insulation of Exterior Wall	Exterior Wall : 4cm Roof : 6cm	Exterior Wall : 8cm Roof : 8cm
	Double Envelop Width	Single Envelop	1.5m
	Shading Device	No	Exterior Louver for East / West, Venetian Blind for South Window and Sun Shade for Atrium
	Lighting Power	25W/m^2	7W/ m^2
	Task Light	No	0.754W/ m^2
	Coefficient of Overall Heat Transfer	2.7Kcal/ m^2.h.C	1.8 Kcal/ m^2.h.C
HVAC	System Type	CAV	VAV
	Thermal Energy System	No	Yes
	Reset Control	No	70%
	Minimum CFM	No	20%
	Fan Control	Constant	Speed Control
Lighting	Day-lighting	No	Yes

Table 14. Comparison of BEPS

Total Source Energy	Total Energy Consumption (Mcal)	Energy Consumption Per Unit Area Gross Area Mcal/m^2-yr
BEPS of Typical Building	2,654,180	424.5
BEPS of Case Building	1,301,180	209.6

ACKNOWLEDGEMENTS

This study was supported by Dongwoo Architects-Engineers Co., Ltd. and Korea Institute of Energy Research.

CONCLUSIONS

The energy performance of the case study office building with a double-envelope and an atrium was analyzed. The case office building shows an annual energy consumption of 209.6 Mcal/m^2-yr, which is much less than the target value, 240 Mcal/m^2-yr. It also shows the annual energy consumption of the case office building is less than the typical office building of same size in Korea. The results of the analyses in the previous sections indicate that the double-envelope and the atrium can be an energy saving solution for an office building compared with a typical design. The key advantage of the double-envelope design is that winter envelope heat losses are greatly reduced, and better control of summer solar gains can be achieved. The atrium is a successful solution for daylighting of the interior office space. It contributes not only to the reduction of lighting electricity but to the reduction of cooling electricity requirement. The overall performance of the case office building has been deeply satisfied with the research members.

REFERENCES

LBL, “DOE-2 Reference Manual Version 2.1“, May 1981

Burt Hill Kosar Rittlemann Associates/Min Kantrowitz Associates, “Commercial Building Design: Integrating Climate, Comfort, and Cost“, Van Nostrand Reinhold Company, New York, 1985

Gook-Sup Song ,“A Survey Study on the Actual Energy Consumption in the Office Buildings“, Journal of the Architectural Institute of Korea Volume14, Number2, Feb, 1988..

Ho-Tai Seok, “A Study on the Development of Load Prediction Equation and Design Guidelines for the Energy Conservation of Office Buildings“, Seoul National University, 1995

Nam-Ho Kyong, “A Study on the Development of Design Technique of Double Skins“, KIER-953220, 1996.

ASHRAE, ASHRAE Handbook 1997 Fundamentals, 1997

Gook-Sup Song and Hyun-Woo Lee, “An Analysis of Environmental Performance and Energy Consumption Evaluation of the Green Building“, Bucheon College, 1998.