AN EVALUATION OF ENERGY PERFORMANCE IN SUPER HIGH-RISE APARTMENT HOUSING WITH EXTERIOR WINDOW TYPES

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ABSTRACT: This study evaluates the energy performance of super high-rise residential buildings with e-QUEST simulation and calculates the annual cooling and heating load. The result of this study have concluded that the most influential factor is the characteristics of the window and also suggest the most efficient window system from the result of calculation of different glasses' cooling and heating load. The result of this study shows that The most efficient method to enhance the energy performance is to use low reflective 3 pairs Low-E glass and Low-E coating(inside of outer glass) pair glass.

Keywords: Super High-Rise Apartment Housing; Building Energy; Low-E Glass; e-Quest Simulation

1. INTRODUCTION

The building type of residential use in the city had been dramatically transformed through continuous industrialization. The issue of inner city problem, meaning that large population of inner city residence abruptly moved to the outskirts of the city, had been addressed since the industrial sectors of the inner city had been relocated to the satellite cities. This new phenomenon was aggravated and needed social attentions but recently found its solution with elegant super high-rise residential building type[1].

Super high-rise residential building is very efficient in respect to land-use but has a disadvantage of cooling and heating inequality because of excessive daylights and wind loads[2]. The glass double-skin of this building type, derived from the structural idiosyncrasy, is the main reason for increment of excessive air-conditioning and heating. Compared with low-rise residential building, super high-rise residential building, therefore, has more energy consumption[3].

The objective of this study is to enhance the energy-efficiency of super high-rise residential building with proposition of efficient building skin alternatives, which is based on the analysis of heat-oriented characteristics of the building skins.

This study, furthermore, will propose the most efficient building skins for energy-saving though analyzing the building energy performance of different glass-type in super high-rise residential buildings and the scope and process of study is as below.

- The examples of super high-rise buildings for this study are located in Ttukseom 3 district and general conditions and related data will be collected.
- Energy performance variables of super high-rise residential will be extracted from through the review of related literature regarding energy performance of the super high-rise residential buildings
- Energy analysis model of examples will be generated. e-Quest simulation will be used for the calculation of building cooling and heating loads and the amount of building cooling and heating in peak load will be also calculated with consideration of the characteristics of heat environment of each window type, heat generation from the inside, and building operation schedules.
- The factors, which have an influence on the building energy performance, will be estimated and air-conditioning and heating load of each factor will be calculated to decide the absolute cause of heat generation.
- The factors, described above, will be classified to various types and annual average cooling and heating

load will be extracted to decide the most energy-saving glass type.

- With the result of previous analysis, the priority of energy performance variables will be extracted to propose the enhanced methodology for building energy saving.

2. CASE STUDIES

This study object building is located in Ttukseom 3 district, Seoul and general summery of the building is described in Table 1.

Table 1. Building Summary

Categories	Building Summary
Location	685Sungsoo1 Ga, Seongdong-Gu, Seoul, KOREA
Site	18,315 ㎡
Size	51 Stories, underground 7 Stories, 2 Towers
Units	196 Units
Floor Area	A Type 330.833 ㎡, B Type 330.799 ㎡
Parking	1,534

The exterior of the building can be seen in Figure 1 and left side is Type A tower and right side is Type b tower. Typical plan can be seen on Figure 2 and there are 2 units on each floor.

Figure 1. Exterior Perspective

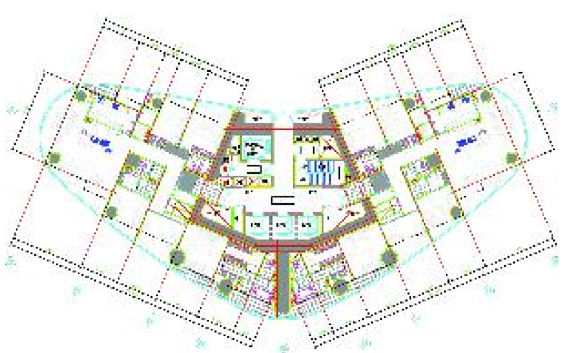

Figure 2. Typical Floor Plan

3. THE EVALUATION OF ENERGY EFFICIENCY BY E-QUEST SIMULATION

3.1 General Summary

The building energy performance analysis is defined to set up an efficient alternative for energy saving with the understanding of energy performance. To extract the most influential factors for building energy performance, he related variables should be set and then generate the energy analysis model of the specific building for simulation.

Based on the results of the analysis, described above, the priority of building energy performance variables will be extracted and the most efficient way for energy saving for specific building will be proposed.

To calculate the cooling and heating load of specific building, DOE-2.1E and e-Quest, dynamic energy analysis programs, will be used.

e-Quest program is basically simulation tool for building energy usage analysis, and the input data sets such as climate data, average inside temperature, building usage schedule, heating types, and insulation performance of structure are needed[4].

The detail system of energy sources like cooling and heating, lighting, and electricity are used to evaluate more accurate and more reliable dynamic heat load.

3.2 Boundary Condition and Modeling

The study objects for e-Quest simulation analysis are Tower A (330.833㎡) and digitally modeled for analysis. All the floors and units were analyzed for optimized result.

To achieve the best result, each unit should be divided by several rooms but units were regarded as a zone for cooling and heating load simulation. This building modeling can be seen on the figure 3 and 2 units of typical floor and core of Tower A were modeled as a unit zone.

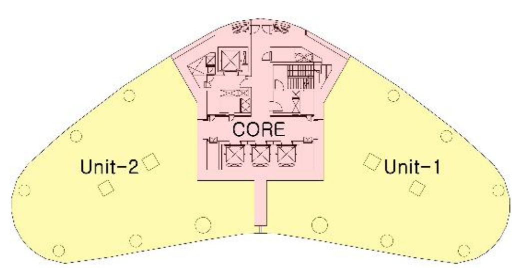

Figure 3. Unit Zone in Base Floor

The floor area of each unit were input as a Table 2 from the construction drawing sets

Table 2. The Size of Each Unit

Categories	Unit 1	Unit 2
Floor Area	325 ㎡	325 ㎡
Ceiling Height	2.9 m	2.9 m
Volume	942.4 ㎥	942.4 ㎥

Based on the result of Figure 3 and Table 2, the study object building was modeled as Figure 4.

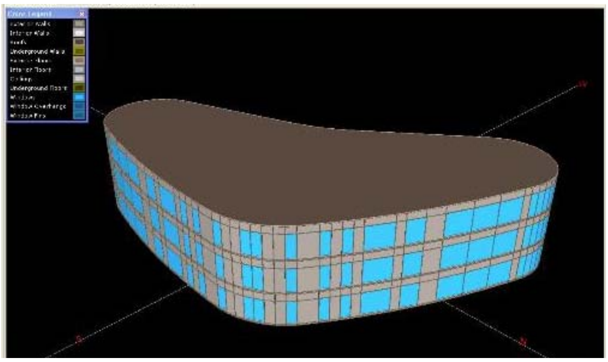

Figure 4. Modeling

3.3 The Data Input for Energy Performance Evaluation

To evaluate the energy performance of the building, influential factors for building cooling and heating loads were categorized as Table 3.

Table 3. Building Cooling Load Influential Factors

Categories	Contents
Glass Type	Cooling load by the characteristics of glass type
Inside Heat Generation	Cooling load by body heat, lighting heat, and electronics heat
B/D Operation	The operation plan of user, lighting, and electronics

(1) The Characteristics of Glass Window

Super high-rise residential building types are generally designed to have more generous floor area and more wide windows. The tectonic value of these windows is very crucial for cooling load and heating load.

This building, especially, have more façade ratio of window, compared to similar buildings, and the thermal characteristics of the buildings such as thermal conduction ratio, overall thermal transmission coefficient, and shading coefficient are very influential to the air-conditioning and heating load.

Therefore this study will evaluate the energy performance by the categorization of Low-E glass and reflective Low-E glass(Table 4) with the consideration of thermal performance.

Table 4. The Glass Types

Case	Glass Type	Component
1	Reflective Glass	6TE-15 +12A + 6CL
2	Low Reflective Glass	6PTS-30 +12A +6CL
3	2 Pairs Low-E Glass (Air)	6GN + 12A + 5LT-85
4	Low Reflective 2 Pairs Low-E Glass(Arg)	6KSN70 H/S + 12A + 6CL H/S
5	Low Reflective 2 Pairs Low-E Glass(Arg)	6KSN70 H/S + 12Ar + 6CL H/S
6	Low Reflective 3 Pairs Low-E Glass(Air)	6KSN70 + 17.5A + 5CL + 17.5A + 6LE-79

In case of 2 pairs Low-E glass window, 24mm Low-E glass window with the characteristics of green color, 2 sided coating, and visible ray (13% reflective ratio) were applied except living room and master bedroom balcony. In case of spandrel column, furthermore, 2 pairs Low-E glass window were applied with inside-air layer.

(2) Heat Generation of the Inside of the Building

The ASHRAE (The American Society of Heating Refrigerating and Air-conditioning Engineer) values, which are quoted from ASHRAE STANDARD 90.1, were used for inside heat generation value of the residential building as in Table 5[5].

Table 5. Categorization of Inside Heat Generation

Categories	Components
Body Heat	- Sensible Heat Load 131W/person (250BTU/h-person) - Latent Heat Load 45W/person (155BTU/h-person) - 4 People/Room - ASHRAE STANDARD 90.1 Residential B/D Scale Applied
Lighting Heat	- 5.43W/m^2(0.5W/ft^2)
Electronics Heat	- 7.01W/m^2(0.645W/ft^2)

The schedule of body heat, lighting heat, and electronics heat can be seen from Figure 5 to Figure 10 and X axis is representing time and Y axis is representing thermal load.

(3) The Schedule of B/D Operation

The schedule of building operation is as below. The air-conditioning period is set from June/1 to September 30 (4 months) and heating period is set from November/1 to February 28 (4 months).

The cooling temperature is set to 26℃ and heating temperature is set to 23℃. The operation schedule of the system is summarized in Table 6.

Table 6. Building Operation Schedule

Daily	Weekend and Holiday
PM 5:00 ~ AM 7:00	PM 4:00 ~ AM 9:00

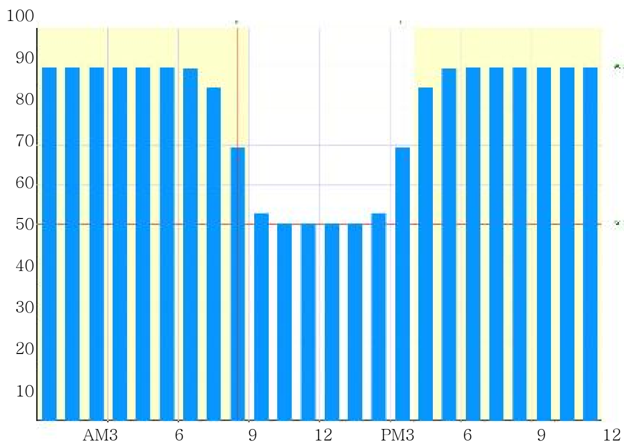

Figure 5. Body Heat Weekday Schedule

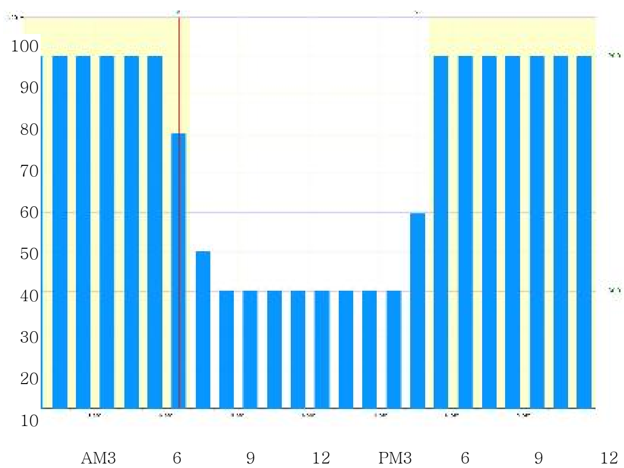

Figure 6. Body Heat Weekend Schedule

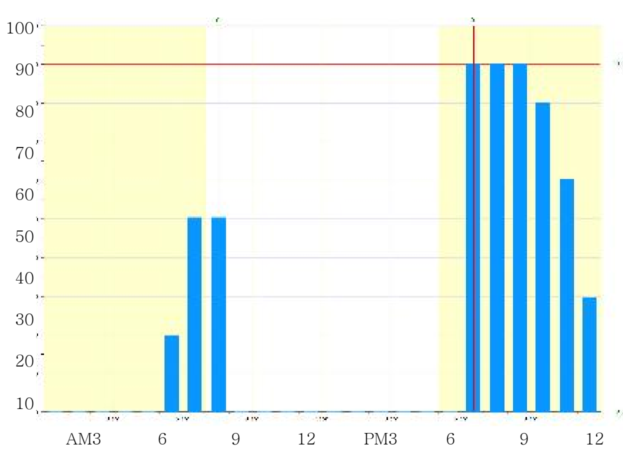

Figure 7. Lighting Heat Weekday Schedule

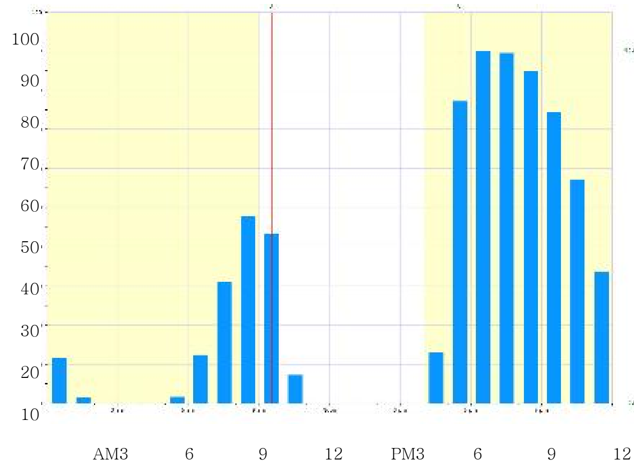

Figure 8. Lighting Heat Weekend Schedule

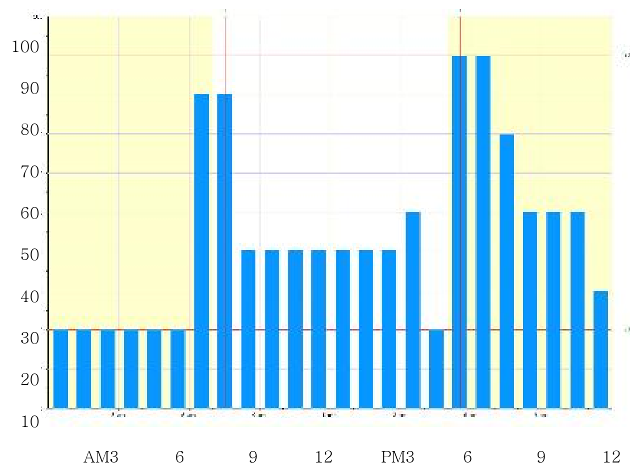

Figure 9. Electronics Heat Weekday Schedule

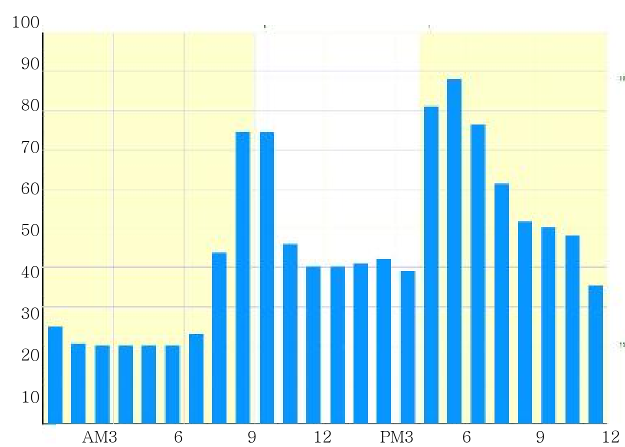

Figure 10. Electronics Heat Weekend Schedule

3.4 Building Cooling Load and Heating Load Calculation

This building has two towers and each tower is covered with curtain-wall system. Each floor is composed of 2 units. This study was focused on Tower A for energy performance, and air-conditioning load is 1.5 times than heating load as you can see on Table 7 and Figure 11.

Table 7. The Result of Annual Cooling Load and Heating Load Calculation

Categories	Cooling Load	Heating Load
Jan	24.7	-326.8
Feb.	39.0	-245.7
Mar.	78.1	-165.0
Apr.	158.5	-66.2
May.	238.8	-21.3
Jun.	289.0	-3.8
Jul.	331.7	-0.4
Aug.	349.7	-0.2
Sep.	259.3	-6.3
Oct.	155.9	-45.7
Nov.	47.0	-151.9
Dec.	20.1	-283.9
SUM	**1991.8**	**-1317.1**

The result of an analysis of peak load and load factors of the building with e-Quest simulation can be seen on Table 8. The peak cooling load was happened in Aug./27 18:00 and that of heating was happened in Feb./15 11:00.

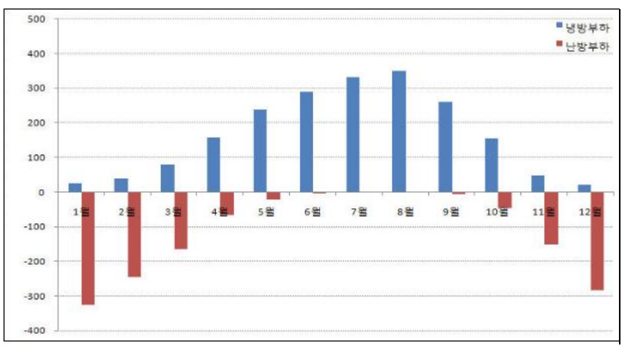

Figure 11. Chart of Annual Cooling Load and Heating Load

Table 8. Cooling load and Heating Load Peak Value

Categories	Cooling Load	Heating Load
Date/Time	8/27 PM 6	2/15 AM 11
Dry Bulb Temperature	33 ℃	-4 ℃
Wet Bulb Temperature	26 ℃	-6 ℃
Total Solar Radiation	482 W/㎡	85 W/㎡
Wind Velocity	3.2 m/s	11.1 m/s
Status 0(CLERA)~10	O	O

The summary of influential factors for peak load of cooling and heating is on Table 9.

Table 9. Cooling and Heating Peak Load Factor

Categories	Cooling Load(KW)		Heating Load(KW)
	Sensible Heat	Latent Heat	Sensible Heat
Wall Conduction	80.146	0	-123.594
Roof Conduction	0	0	0
Window Glass+ Frm Conduction	708.784	0	-602.537
Window Glass Solar	331.172	0	41.955
Occupancy to Space	21.951	16.676	9.662
Light to Space	1.257	0	5.462
Equipment to Space	171.017	0	88.642
Infiltration	230.812	460.252	-1325.385
Total	1545.139	476.929	-1905.796
Total Load	2022.068		-1905.796
Total Load / Area	60.983 W/m²^2		57.477 W/㎡

As seen in Table 9, the cooling peak load of this building is 2,022 kW and heating peak load is 1,905 kW. cooling load and heating load per unit area is 60.9W/m^2 and 57.4W/m^2

The most influential factors for cooling load are conduction and daylight by window glass and those for heating are conduction and infiltration by window glass.

4. COOLING LOAD AND HEATING LOAD CALCULATION ANALYSIS FOR WINDOW TYPES

The window type was proved as the most influential factor among the energy performance evaluation factors for super high-rise residential building. As for the next phase of the study, current market products of windows were selected for evaluation and the results were sum up in Table 10 and Table 11.

Table 10. Cooling Peak Load by Cases

Cases	Annual Cooling Load (kWh/yr)	Annual Cooling Load / Unit Area (kWh/m^{2}yr)	Average Load (kWh/㎡)
Case-1	24,080.2	74.1	67.2
Case-2	28,716.6	88.4	80.2
Case-3	33,949.0	104.4	94.7
Case-4	31,684.4	97.5	88.4
Case-5	31,572.5	97.1	88.0
Case-6	28,433.9	87.5	79.1

The cooling load of case-1 and case-2 in Table 10, which applied reflective glass and low reflective glass, were 67.2kWh/㎡ and 80.2kWh/㎡. Compared to this results, the cooling load of case-3, which applied 2 pair transparent Low-E glass, was 94.7kWh/㎡.

It was the highest value within 6 different types of window. The cooling load of case-4, which applied low reflective Low-E glass with air layer, was 88.4kWh/㎡ and case-5, which applied low reflective Low-E glass with argon layer instead of air layer, was 88.0kWh/㎡. These results showed that different gas layer could not make much difference.

Table 11. Heating Peak Load by Cases

Cases	Annual A/C Load (kWh/yr)	Annual A/C Load / Unit Area (kWh/m^{2}yr)	Average Load (kWh/㎡)
Case-1	-12,118.5	-37.3	-39.5
Case-2	-12,040.2	-37.0	-39.1
Case-3	-8,789.4	-27.0	-8.6
Case-4	-8,876.1	-27.3	-28.9
Case-5	-7,891.1	-24.3	-25.7
Case-6	-6,583.4	-20.3	-21.5

The heating load of case-1 and case-2 in Table 11, which applied reflective glass and low reflective glass, were -39.5kWh/㎡ and -39.1kWh/㎡. It meant that there was no distinctive difference. Compared to this results, the heating load of case-3, which applied 2 pair transparent Low-E glass, was -8.6kWh/㎡. It was the lowest value within 6 different types of window. Furthermore, heating load of case-4, which applied low reflective Low-E glass with air layer, was 38.9kWh/㎡ and case-5, which applied low reflective Low-E glass with argon layer instead of air layer, was 25.7kWh/㎡. This meant that different gas layer had similar results.

5. THE PROPOSITION FOR ENERGY PERFORMANCE ENHANCEMENT

In terms of cooling and heating aspects for super high-rise residential building, the most efficient glass type was low reflective 3 pairs Low-E glass, which was the combination of outside low reflective glass and inside Low-E glass. The cooling load was 79.1kWh/㎡ in second rank and heating load was 21.5kWh/㎡ in second rank.

In Figure 12, the study result showed that low reflective 3 pairs Low-E glass, the combination of outside low reflective glass and inside Low-E glass, was the most efficient method with the considerations of cooling load in summertime and dew condensation and interior excessive heat environment.

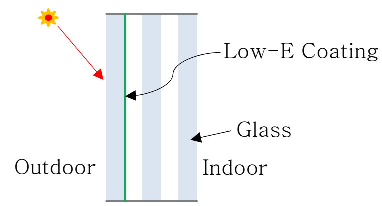

Figure 12. Triple Low-e Coating Glass

It is quite economical, as a matter of fact, to use low reflective 2 pairs Low-E glass since building code of Korea restrict the use of reflective glass and the system window is very expensive.

6. CONCLUSION

This study had reached three conclusions for the most efficient energy saving methodology from the energy performance analysis of super high-rise residential buildings, located in Ttukseom 3 district

(1) The cooling and heating peak load is 2,022kW in Aug. 27 18:00 and -1,905kW in Feb.15 11:00

(2) From the estimation with only sensible heat load, the most influential factors for cooling load of the building are conduction and daylight and the most influential factors for heating load are conduction and infiltration by windows. This means that annual total cooling and heating load is 2,022.068KW. The cooling and heating load including conduction and daylight load by pair glass window are 51.4% and 33.8%.

(3) The most efficient method to minimize cooling and heating load by the window system simultaneously is to use low reflective 3 pairs Low-E glass and Low-E coating(inside of outer glass) pair glass.

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