A Study on Thermal Environment and the Design Methods to Save Energy in Small Glass-Skin Commercial Buildings

Byungseon Sean Kim¹ and Kwangho Kim*²

¹ Professor, Department of Architectural Engineering, Yonsei University, Korea
² Doctoral Candidate, Department of Architectural Engineering, Yonsei University, Korea

Abstract

To represent the expansion and mutual insertion of spaces by the innate transparency of glass and express new possibility of high technology, some architects apply glass to the outer skin of a building. Though glass-skin buildings economize in the lighting and heating energy in winter, these buildings which are often designed without considering solar gain in the summer and glass conduction in winter, there are many problems such as poor built environment, energy waste and so on.

This study aims to provide architects with useful information by comparing with several alternatives, including double skin system etc., to save the energy as well as increase the quality of indoor environment without interfering with the expressed intention which an architect shows to the public by applying glass to the outer skin of building.

As results of this study, 1) in the temperature measurements, the surface temperature of glass skin increase by 50°C in small glass-skin buildings. Therefore it makes occupants feel serious discomfort by MRT and cause the increase of cooling load. 2) It is difficult to reduce the cooling load in small glass-skin buildings with considering indoor environment and energy problems rather than heating load. To solve that problem, double skin system is applied to design method with enough intermediate space and shading devices.

Keywords: thermal comfort; indoor environment; glass skin; commercial building; simulation

Introduction

The types of buildings in Korea have become high-rise, large-scale, and transparent since the 1990s. They spend a lot of energy in maintaining comfortable conditions for occupants because of internal gains from OA & communication equipments, and solar gains and heat loss from glass skin (J. Kim, 1993).

To represent the expansion and mutual insertion of spaces by the innate transparency of glass and express new possibility of high technology, some architects have applied glass to the outer skins of small office buildings (Y. Seo, 2002). Though these small glass-skin buildings economize in the lighting and heating energy in winter, the cooling loads and heating loads of their perimeter zones increase because they are often designed without considering solar gain in the summer and glass conduction in winter (Y. Kim, 2000).

Unlike large-scale glass-skin buildings with large core zones, the core zones of small office buildings are smaller than their perimeter zones. The small core zone can not absorb all of solar gains and conduction gains from the perimeter zone, the excess gains lead to poor built environment, energy waste and so on.

The percentage of energy loss from the glazing system was not reported in domestic research, but DOE(Department of Energy USA) reported that the loss accounted five percent of the whole energy use in the United States. Besides IAQ and energy problems, the discomfort glare and displeasure radiation from glass wall make office workers have trouble working especially in small glass-skin buildings. In that case, office workers make use of shading devices such as blinds and attach something like sheets of newspapers on the glass-skin (D. Kang, 1990), which interfere with architects’ objectives (ex. the expansion and mutual insertion of spaces).

This study aims to provide architects with useful information by comparing several alternatives, including double skin system etc., to save energy as well as increase the quality of indoor environment without interfering with the expressed objectives architects show to the public through glass application on the outer skin of a building.

The research procedures were; 1) The previous studies were closely scrutinized. 2) Two glass-skin buildings were selected in Seoul, Korea. 3) The questionnaires on thermal environment were administered to the occupants. 4) The indoor and outdoor temperature measurements including glass surface temperatures, and intensity of illumination were processed. 5) The results of the
questionnaires and the measurements were carefully analyzed by Paired-Samples T-Test, ANOVA and Duncan-Test, and Chi-Squared Test using SPSS, Energy-Shading-Glare Simulations using VE. Several alternatives were made to solve the above problems and carefully analyzed by Energy-Shading-Glare Simulations using VE(Virtual Environment; APACHE-SUNCAST-RADIANCE).

Indoor Environment Problems in Small Glass-Skin Buildings

Recently as architects prefer glass as a building material to any other material, they think glass is suitable to express the expansion and mutual insertion of spaces, transparency and reflection, smooth and light weight, and the image of high technology (S. Lee, 1995). Especially the prosperity of glass technology makes the usage limit of glass expand into media and structural materials, architects contribute for popularizing glass by applying it to building envelopes.

On the contrary, the thoughtless usage of glass as building envelopes without considering internal and external environmental problems results in depreciating city landscape and making built environment worse including energy problems. Besides energy problems, residents can feel discomfort to built environment in poor designed glass-skin buildings.

As you see in figure 1 and 2, The causes of which are 1) thermal discomfort from increasing indoor temperature by sunlight in the summer, 2) thermal discomfort from inequality of temperature distribution by difference between surface & indoor temperature in the winter, 3) discomfort glare from brightness difference (S. Yim, 2002), and 4) inattention from invasion of privacy. To prevent these problems, residents consume many energy resources such as gas and electricity. The tenants also use internal shading device in extreme means against discomfort glare. As these devices remarkably impair architects’ objectives (ex. the expansion & mutual insertion of spaces), they spoil the beauty of external appearance of building and then have a minus effect on the city landscape. According to the results of the precedent research, productivity increases by 15% when office workers are satisfied with built environment (Lomonaco & Miller, 1997).

On next section there are two buildings; typical small glass-skin office buildings in Korea were representatively selected to objectively approach the built-environment problems. Indoor temperatures including glass-surface temperatures were measured in building (A). The questionnaires on thermal comfort were conducted to office workers in buildings (A)(B).

Questionnaires in Two Subject Buildings

To inquire workers’ responses and determine the causes to built environment problems, questionnaires to office workers were conducted in (A) & (B) buildings.

In a personal organization, there is 71% male and 29% female. The subjects’ average age is 30.58 and the average length of their services is 20 months. Furthermore, most of them are distributed at the 3rd or 4th floor 42% on the west side and 29% on the east side of buildings. As a whole, they are good for health. In case of building (A) major business hours are between 9 AM and 12 PM.

Table 1. Questionnaires Outline

| Selected Buildings | Building(A)-Office, Gye-Dong, Seoul |
|--------------------|-----------------------------------|
| Withdrawn          | 48%                               |
| Rate               | 40 copies out of 100 copies       |
| Method             | distributing & collecting questionnaire copies under office worker in charge |
| Content            | General questions (sex, age, working place..) Cognition/satisfaction degree by 5-point scale |

1) Thermal and Humidity Environment

As hot degree is more than 3 at approximately 4.2 by 5-point scale in figure 3, office workers feel unbearable heat in the summer. In the winter, most of them point out that it’s freezing because the cold degree is less than 3 at about 1.5. Office workers are discontented with thermal environment in that the satisfaction degree of thermal environment has a 1.2 average. In the summer, the degree of humidity has an average of 3.0 that means equivalent but in the winter office workers feel very dry because the average is 1.8 by 5-point scale. The satisfaction degree of humidity environment has an average of 2.0 only resulting to humidity environment dissatisfaction.

2) Thermal Environment and Discomfort Radiance

As the satisfaction degree of discomfort radiation from
(1: Very Cold(Dry)~5: Very Hot(Humid))
(a) Thermal & Humid Recognition

(b) Thermal & Humid Satisfaction Degree

Fig. 3. The Cognition of Thermal & Humid Environment

glass wall has an average of 1.5 in figure 4, office workers are disgruntled at radiant heat from glass wall because the surface temperature of glass wall is increased by the sun in the summer. Like in the summer, they feel so cold due to a cold wave from glass wall in winter.

As you can see in figure 5, radiation satisfaction from glass wall has an effect on the cognition of thermal environment. Most of the office workers, dissatisfied with discomfort radiation from glass wall, feel unbearable heat in the summer and coldness in the winter.

Fig. 4. The Cognition of Discomfort Radiance From Glass Wall

3) Light Environment and etc.

Although office workers think it is a little bright, they think there is low desk lighting on their working area in figure 6. On the contrary, there is a discomfort glare by direct sunlight through glass-skin.

As the result of Radiance Simulation to building (A) is shown in figure 7, the line of vision is from north to southwestern in the 4th floor of building (A) at the basis time 15:00.

Intensity of glare is expressed as a size of circle and numerical value in figure 7(a), and the size of circle is big. The glare index exceeds 28 to approximately 60 in figure 7(c). It means that glare is serious problem and office workers feel so dazzled not to do their jobs.

To prevent this glare, more than 50% of them make use of internal shading devices such as blinds, curtains and panels, etc during the day. The transparency of the building is invaded by these devices.

Fig. 5. Correlation Between Thermal Environment & Discomfort Radiance

Fig. 6. The Cognition of Light Environment

Fig. 7. The Result of Radiance Simulation to Building (A)

Fig. 8. The Cognition of Indoor Air Quality
Office workers are conscious of high impurities in the air with a foul odor on the account of impurity degree (average 1.4) in figure 8. With this, they are dissatisfied with indoor air freshness.

Office workers come up with the problems that must be settled without delay. These problems are indoor temperature, discomfort glare and IAQ.

Measurement to the Subject Building(A)

To trace the changes of indoor temperature by hour and find the causes of these changes, temperature measurements were carried out on September 8~15, 2002. The outline of the measurements is illustrated in table 2 and figure 9.

Measurement data about outdoor temperature were generally precise. The difference was less than 1˚C in comparison with the meteorological agency’s data.

Taking into consideration the outdoor and indoor temperature, cloud quality, sunshine duration and weather condition, the analysis days were categorized into four groups as in table 3.

Though the outdoor temperature on September 9 is nearly equal to those of September 10-11, its indoor temperature differs among them because of cloud quantity. Therefore September 9 is exempted. September 14 is also exempted because it’s a Saturday.

In case of ②(September 10 (Tuesday), September 11 (Wednesday)), there are the results of the ANOVA analysis and the Duncan test in figure 10 after the measurement data were analyzed when the sun is on east side of the building (8:00 AM-12 NOON). The P-Value of ANOVA is 0.000 meaning that there are significant differences among the temperatures.

According to the Duncan test results in figure 10(a-1)(a-2), the average temperature in the east side is higher than that of the west by about 4.1˚C and higher than the average outdoor temperature of about 6.4˚C.

By analyzing the data of each measured point in the east side of the building, surface temperature on the glass is more than the temperature of the intermediate space between the internal shading device and the surface by about 1.9˚C and higher than indoor temperature by about 4.7˚C due to solar gain.

Figure 11 shows the results of the ANOVA analysis and the DUNCAN test to measurement data when the sun is in the west side of the building (12:30 PM- 7:00 PM). As you can see in figure 11(b-1)(b-2), there are significant differences among the temperatures because the P-Value of ANOVA is 0.000. The average temperature in the west side statistically differs from that of the east side by about 4.1˚C. It is higher than the average outdoor temperature by about 4.0˚C according to the DUNCAN test results.

In particular, though there is statistically no significant
At this chapter, the original form of building (A) is compared with 12 models on floating temperatures and loads. The basic structural condition of building (A) is presented in table 4. Also there are input data of 13 models in table 5.

Table 4. The Basic Structural Condition of Building (A)

| Side     | N | Subset for alpha = 0.05 |
|----------|----|------------------------|
| Outdoor  | 18 | 26.178                 |
| West Side| 162| 28.469                 |
| East Side| 162| 32.529                 |
| Sig      | 1.000|1.000                   |

The difference between the average temperature of the east side and the outdoor temperature, the outdoor temperature is a little more than that of the east side because of air-conditioning. As the above results are thought out collectively, it is known that solar gain has a great effect on thermal environment in building (A). In the west side of the building, the glass surface temperature is more than that of the intermediate space by about 5.4˚C and higher than indoor temperature by about 8.4˚C. Considering the differences on both sides, the differences of the west side are more than that of the east. As figure 11(b-1) and figure 11(b-2) of the west side is compared with figure 10(a-1) and figure 10(a-2) in the east side, the west side of the building has a weak condition. The temperatures in the east side don’t go over 40˚C but the temperatures in the west side exceed 45˚C in figure 11(b-3). The reason is thought that the solar intensity is bigger and the period that the sun is on the west side of building (A) is longer than that on the east side.

Development of Models to Improve Indoor Environment in Small Glass-Skin Building (A)

1) Models based on building (A)

It is difficult to decrease the cooling load and solve the problems about indoor environment in small glass-skin buildings. Figure 12 shows the causes and results of environment problems in the glass-skin space and enumerates several methods to solve them. Each method has a different degree of disturbance to the transparency.

Thirteen alternatives, based on the methods applied to building (A) in figure 12, were developed including the original form, double-skin system and concrete wall etc.

At this chapter, the original form of building (A) is compared with 12 models on floating temperatures and loads. The basic structural condition of building (A) is presented in table 4. Also there are input data of 13 models in table 5.

Table 4. The Basic Structural Condition of Building (A)

| Area of Building (A) | 1st Floor: 30.24 m², 2–5th Floor: 99 m² |
|----------------------|----------------------------------------|
| Total Area Of Floors | 456.24 m²                              |
| Set Point Temperature| Cooling Set Point: 26°C, Heating Set Point: 19°C |
| ACH                  | 0.5 ACH                                 |
| Internal Condition   | Sensible Heat: 90W/p, Latent Heat: 60W/p |
| Residential Density  | 10 m³/p                                 |
| Light                | 20 W/m², Equipment: 25W/m²             |

This study comes up with the external shading device and the shading device in the intermediate space of double skin system in figure 13, based on the design of the building, RMJM-Glaxo Wellcome HQ.

Especially, double skin system has three ventilation openings which are controlled by the condition between indoor temperature and outdoor temperature. The control algorithm is presented in figure 14.

2) Introduction of VE Simulation Program

The computer simulations were performed by using VE (Virtual Environment by IES4D). VE, an energy simulation program, has the engine
120  JAABE vol.3 no.1 May. 2004  Byungseon Sean Kim

based by esp-r which made by Strathclyde university in UK. Unlike DOE, VE is operated with MacroFlo which is a simulation Module for the design and appraisal of naturally ventilated and mixed-mode buildings. Therefore VE runs as an adjunct to MacroFlo, exchanging data at run-time to achieve a fully integrated simulation of air and thermal exchanges and outputting floating temperatures and loads etc.

There is no officially-recognized weather data of Seoul in Korea. The weather data used by VE is that of Seoul, Korea in 1983.

Comparison of Models

1) Case Analysis (1) as a comparison standard

The energy status of building (A) as a Case (1) is shown in figure 15. In case of the cooling load, the annual
Table 5. Input Data of Models

| Model   | Input Data |
|---------|------------|
| Case(1) | 1. Constitution: Single-Glazing Glass  
2. Glazing Type: 6.4mm acrylic/polycarb  
3. U-Factor = 5.00 W/m² K |
| Case(2) | 1. Constitution: Single-Glazing Glass+  
Internal Shading Device  
2. Glazing Type: 6.4mm acrylic/polycarb  
3. U-Factor = 5.00 W/m² K  
4. Transmission Coefficient = 0.05 |
| Case(3) | 1. Constitution: Single-Glazing Glass+  
External Shading Device  
2. Glazing Type: 6.4mm acrylic/polycarb  
3. U-Factor = 5.00 W/m² K  
4. External Shading Device In Figure 13 |
| Case(4) | 1. Constitution: Single-Glazing Glass 30%+  
Concrete 70%  
2. Glazing Type: 6.4mm acrylic/polycarb  
3. Glass U-Factor = 5.00 W/m² K  
4. Concrete U-Factor = 0.38 W/m² K |
| Case(5) | 1. Constitution: Double-Glazing Glass  
2. Glazing Type: 6.4mm airspace  
3. U-Factor = 3.12 W/m² K |
| Case(6) | 1. Constitution: Double-Glazing Glass+  
Internal Shading Device  
2. Glazing Type: 6.4mm airspace  
3. U-Factor = 3.12 W/m² K  
4. Transmission Coefficient = 0.05 |
| Case(7) | 1. Constitution: Double-Glazing Glass+  
External Shading Device  
2. Glazing Type: 6.4mm airspace  
3. U-Factor = 3.12 W/m² K  
4. External Shading Device In Figure 13 |
| Case(8) | 1. Constitution: Double-Skin System  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 350mm  
6. Transmission Coefficient = 0.05 |
| Case(9) | 1. Constitution: Double-Skin System+ Internal Shading Device In Intermediate Space  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 350mm  
6. Transmission Coefficient = 0.05 |
| Case(10) | 1. Constitution: Double-Skin System+ Shading Device In Intermediate Space  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 350mm  
6. Shading Device In Figure 13 |
| Case(11) | 1. Constitution: Double-Skin System  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 600mm |
| Case(12) | 1. Constitution: Double-Skin System+ Internal Shading Device In Intermediate Space  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 600mm  
6. Transmission Coefficient = 0.05 |
| Case(13) | 1. Constitution: Double-Skin System+ Shading Device In Intermediate Space  
2. Internal Glazing Type: 6.4mm acrylic/polycarb  
3. External Glazing Type: 6.4mm acrylic/polycarb  
4. U-Factor = 5.00 W/m² K  
5. Intermediate Space: 600mm  
6. Transmission Coefficient = 0.05 |

Fig. 15. Loads of Case (1)

(a-1) Summer Solstice, Non Air-conditioning

(a-2) Summer Solstice, Air-conditioning

Fig. 16. The Change of Indoor Temperature in Summer
total cooling load is 7722KW. The cooling load in August is higher than that of any other month. As you can see the heating load, the annual heating load is -8330KW and the heating load of January is at the peak.

There is something abnormal in Figure 15(b). The solar gain makes the cooling load abnormally higher and the conduction loss largely comes out in the summer solstice. As figure 15(b) is seen, it was found that heat is conducted from indoor to outdoor through the glazing system because the indoor temperature is much higher than that of outdoor by internal solar gain.

Consequently, the reason of energy problem and built environment problems in the whole-glass small building is the solar gain in the summer and the conduction loss through glass in the winter.

2) Comparison of Case (1) with Other Cases
The alternatives are analyzed and compared by VE (Virtual Environment). The results are shown in figure 16, 17 and 18. As the results of comparisons with indoor temperature of alternatives under non air-conditioning in the summer solstice in figure 16(a-1), the temperatures of Case (3), Case (4), and Case (13) are lower than outdoor temperature, but the others are higher than outdoor temperature.

In figure 18, Case (1) only has a single glazing glass without internal and external shading devices set as a standard to compare with other alternatives. Case (2) has an internal shading device with the characteristics of Case (1). Internal shading device blocks the sunlight that cause discomfort glare, but it cannot reduce the cooling load. The sunlight has already entered the building and then blocked by an internal shading device inside rather than outside the building. Case (3) has an external shading device and decreases cooling load because the sunlight is blocked, but heating load in the winter slightly increases.

In Case (5) with double-glazing glass, though the conduction loss in the winter decreases more than Case (1), it can increase cooling load in the summer because the temperature between the glasses is high. Internal heat is exhausted out of the building by conduction in summer because of the effect of thermal insulation.

Especially in figure 16(a-1), Case (5), a double glazing, goes up to 50Åé. It makes the cooling loads increase rapidly. The reason is that double-glazing has a high insulation performance that prevents heat conduction by solar gains from indoor to outdoor.

Case (12) and Case (13) to which applies double skin with the depth of intermediate space 60cm are best. These cases have shading devices in intermediate spaces. To be contrary, the preliminary result of the double skin systems, which has the depth of intermediate space less than 30cm with the same characteristics of Case (12) and Case (13), cannot reduce the cooling load because the temperature in intermediate space increases like the effect of double glazing glass.

Conclusion
Recently, the usage of glass in architecture is on the increase. But if glass is applied to buildings as a means only to exhibit the architects’ objectives without considering built environment and energy problem in
design process, it can bring about many of the above problems. Moreover, undesirable design worsens into a lawsuit between the architect and the building owner.

A brief summary of the results is given as follows;

1) In the questionnaire analysis about the satisfaction degree of built environment, occupants are discontented with indoor temperature, IAQ, discomfort radiant heat from glass wall and discomfort glare. To block sunlight, occupants used internal shading devices that interfere with architects’ objectives (ex. the expansion and mutual insertion of spaces).

2) In the temperature measurements, the surface temperature of glass skin increase by 50˚C in small glass-skin buildings. Therefore it makes occupants feel serious discomfort by radiant heat from glass wall and cause the increase of cooling load.

3) It is difficult to reduce the cooling load in small glass-skin buildings considering indoor environment and energy problems rather than heating load. To solve that problem, double skin system is applied to design methods with enough intermediate space and shading devices.

In conclusion, many problems caused by sufficiently not taking account of the cooling load by sunlight in summer, the heating load by conduction in the winter, and the discomfort glare in design process, have an effect on occupants’ behaviors in the building usage that lead to interfere with the architects’ expression objectives. Before architects apply glass to buildings, they need to make efforts to solve the built environment problems in keeping their design objectives.

References

1) Jongyoun Kim, ‘The Effect of Exterior Glass Wall on the Energy Consumption of Office Buildings’, Proceedings of Architectural institute of Korea, v.13 n.2, 1993.10
2) Daeho Kang, ‘Thermal Performance Analysis of Movable Shading System of Building’, Journal of Architectural Institute of Korea, v.6 n.5, 1990.10
3) Yongmin Seo, ‘A study on the characteristics and meanings of glass expressed on the outer skin of a building, Master’s Thesis, Yonsei University, 2002
4) Sokhee Lee, ‘A study on the Characteristic of Gloss Expression in the Contemporary Architecture’, Proceedings of Architectural institute of Korea, v.15 n.2, 1995.10.
5) Seungho Yoo, ‘The Thermal comfort simulation of a human body model in a radiant cooling enclosure’, Proceedings of Architectural institute of Korea, v.21 n.1, 2001. 4
6) Youngsup Kim, ‘Evaluation of Daylighting and Thermal Performance for the Optimization of Glazing and Shading Device in an Office Building’, v.16 n.12, 2000.12
7) C. Lomonaco and D. Miller, ‘Workstation Comfort and Control’, ASHRAE Journal Vol 38 No 9, 1997. 9.
8) Sangjoon Yim, The study about thermal environment of transparent glass building which apply with a proper external shading device, Proceedings of Korean Solar Energy Society, p209-218, 2002.11