Thermal Performance Evaluation of Curtain Wall Frame Types

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Abstract
This study is an evaluation of thermal performance according to curtain wall frame types. Heat transfer simulations were conducted on the currently preferred aluminum, steel and scagliola frames, which improved thermal performance and actual frames were produced for thermal performance experiments. The results of this study can be summarized as follows: when heat transfer simulation was conducted to compare the thermal performance of the three frames for summer and winter, scagliola showed the lowest temperature difference, both inside and outside with excellent thermal performance compared to the aluminum/steel frame. Also, as a result of a mock-up test based on the simulation results, for both night and day, the temperature difference was found to be lowest for the scagliola frame. Therefore, it was found that by applying the scagliola frame which improves on the thermal performance of the aluminum/steel frame, the heat loss from frames can be reduced.

Keywords: curtain wall frame; steel frame; aluminum frame; scagliola frame; frame simulation(Therm6.3, Window6.3)

1. Introduction
Facades are the elements that complete the overall form of buildings, and can express their character, while they are also an important factor in energy savings (Lam et al., 2005; Sozer, 2010; Sadinen et al., 2011). Recently, full size curtain walls have been used for the exteriors of buildings (Cho et al., 2010). Overall curtain wall thermal performance is a function of the glazing infill panel, frame, construction behind opaque areas, and perimeter details (Clarke et al. 1998; Ganguli and Quirouette 1987; Richmana and Pressnailb, 2010; Ge, 2002). In particular, curtain wall frame conductance is one of the important parameters for thermal performance, because of heat loss through the wall. Curtain walls can have differences in thermal performance depending on the materials used for the frames(Ge and Fazio, 2004). Aluminum frames are the most often used, as they can be produced in any form the designer wants and the material enables the construction of lightweight curtain walls. Steel frames are widely used alongside aluminum frames, and they have less deflection than aluminum, so they can handle a larger size of glass. However, both aluminum frames and steel frames have a very high thermal conductivity. This translates into high heat loss through aluminum or steel curtain wall mullions. On the other hand, scagliola has lower thermal conductivity, which improves thermal performance. Scagliola frames are based on steel frames, and are attached on the interior to reduce heat conductivity, and improve aesthetics and performance.

In this study, simulation and mock-up tests were conducted on the thermal performance according to the type of frame, which is an element of a curtain wall. The performances of curtain wall frames were analyzed through simulation and mock-up tests. The details of this study are as follows.
1) Existing curtain wall frame-related studies were reviewed.
2) A heat transfer simulation for curtain wall frames was executed, and the thermal performance for each type of curtain wall frame was found.
3) Each type of curtain wall frame was produced and a mock-up test was executed to measure and analyze the thermal performance of the frames.

This paper is intended to be utilized as an elementary resource for the performance enhancement of curtain wall frames.

2. Literature Review
2.1 Curtain Wall and Frame
There are diverse studies of curtain walls and frames. Kim et al. (2005) introduced a new prediction method regarding condensation, using a numerical simulation program. Song et al. (2006) evaluated...
energy and surface dew condensation prevention, using low-e coating and insulation spacers. Lee et al. (2009) executed an artificial solar laboratory (A.S.L), for performance evaluation of 24mm transparent glass applied to a typical curtain wall. Yoon et al. (2009) executed an artificial solar laboratory (A.S.L), for performance evaluation of 24mm transparent glass applied to a typical curtain wall. Yoon et al. (2009), used WEPT tools to quickly identify the most cost-effective and selected algorithm, by applying the energy analysis Trnsys program. Cho et al. (2010), conducted a survey on the characteristics of prospective consumers for super-high-rise curtain walls, by surveying market trends and types of steel curtain wall.

Lee et al. (2011) studied steel and aluminum frames, in order to enhance the fireproof performance of curtain walls.

Koo and Oh (2011) explored the use of fireproof, lightweight inorganic foam board, as an improvement for lightweight curtain wall systems made of aluminum and glass materials.

As a result of analyzing the existing Korean curtain wall studies, it can be seen that there have been numerous recent studies on the fireproof performance of curtain walls, but there has been a lack of studies comparing the thermal performance of different frames. Overseas, Miloslav and Martin (2011) dealt with a theoretical design of the contact between a frame and the window/door system. Also, there were studies on aspects of bonding, heat bridging, dew condensation prevention with glass, and sealant of diverse curtain walls. However, studies on the characteristics of materials applied to curtain wall frames and the execution of cross comparisons were inadequate just as in like the Korean situation.

2.2 Thermal Performance Evaluation of Curtain Wall Frames

No and Kim (2005) verified the conduction state of curtain wall materials through simulation, as well as evaluating the insulation efficiency and moisture condensation. However the air flow in the curtain wall frame was not considered and only a comparison and evaluation of aluminum and metal frames was conducted. Also, another study by No and Jeong (2011) compared general curtain walls commonly used in Korea, through both simulation and a life-size experiment. Here, however, the same material was used for the curtain wall frame, and there were no comparisons on the application of different curtain wall frame materials.

Therefore, as a result of the resource analysis on the precedent studies, it was found that most of the currently used curtain walls are metallic or aluminum frames, and the heat bridge phenomenon is a weakness, thus, studies to improve on these are required.

3. Simulation According to the Type of Curtain Wall Frame

3.1 Methodology

A thermal performance simulation according to the curtain wall frame was conducted on three frames from the preceding section. Simulation results for the types of curtain wall frames were generated using THERM6.3 and WINDOW 6.3 which have been developed by the Lawrence Berkeley National Laboratory (LBNL), THERM 6.3 is a two-dimensional effective conductivity heat transfer analysis program, while WINDOW6.3 is a publicly available computer program for calculating total window thermal performance indices. The boundary values and physical properties of each window/door were calculated, as shown in Table 1.

<table>
<thead>
<tr>
<th>Frame Types</th>
<th>Outdoor Frame</th>
<th>Indoor Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal transmittance coefficient (W/m²)</td>
<td>Area (m²)</td>
</tr>
<tr>
<td>Aluminum</td>
<td>5.45</td>
<td>0.56</td>
</tr>
<tr>
<td>Steel</td>
<td>5.12</td>
<td>0.56</td>
</tr>
<tr>
<td>Scagliola</td>
<td>5.20</td>
<td>0.51</td>
</tr>
</tbody>
</table>

The simulation was divided into summer and winter. Summer was set to an external temperature of 32°C and an internal temperature of 26°C. Winter was set to an external temperature of -10°C and an internal temperature of 22°C.

3.2 Results and discussion

(1) Summer

The summer simulation results are shown in Figs.1-3. and Table 2.

For summer, the temperature difference for scagliola was found to be the smallest (1.6°C). For steel and aluminum, the temperature difference was very large with 3 and 2°C, respectively. The temperature difference means the temperature difference between inner and outer frames.

(2) Winter

The winter simulation results are shown in Figs.4-6. and Table 3.

For winter, the temperature difference was large compared to summer. Steel showed the largest difference. For scagliola, the temperature difference
was smaller than that of aluminum (10°C) and steel (12.7°C). This means that the scagliola frame has less heat loss from inside to outside.

As a result of analyzing the three frames of aluminum, steel, and scagliola using the heat transfer simulation, it can be seen that the scagliola frame has little heat loss, both for summer and winter.

### Table 2. Simulation Temperature Results (Summer)(°C)

<table>
<thead>
<tr>
<th>Frame types</th>
<th>Aluminum</th>
<th>Steel</th>
<th>Scagliola</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Outdoor)</td>
<td>29.2</td>
<td>29.8</td>
<td>29.2</td>
</tr>
<tr>
<td>Temperature (Indoor)</td>
<td>27.2</td>
<td>26.8</td>
<td>27.6</td>
</tr>
<tr>
<td>Δt</td>
<td>2.0</td>
<td>3.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

### Table 3. Simulation Temperature Results (Winter)(°C)

<table>
<thead>
<tr>
<th>Frame types</th>
<th>Aluminum</th>
<th>Steel</th>
<th>Scagliola</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Outdoor)</td>
<td>5.5</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Temperature (Indoor)</td>
<td>15.5</td>
<td>17.7</td>
<td>13.7</td>
</tr>
<tr>
<td>Δt</td>
<td>10.0</td>
<td>12.7</td>
<td>8.7</td>
</tr>
</tbody>
</table>

### 4. Mock-up Test

#### 4.1 Methodology

In order to verify the thermal performance according to the types of curtain wall frame found in the previous simulation, a mock-up experiment building was constructed.

For the mock-up test, three different test rooms were constructed per frame material Room A (aluminum frame), Room B (steel frame), and Room C (scagliola frame), as shown in Figs.7.-12.

Each room was finished with and had the same size and panel material. Also, the frame and glazing were installed on the south side among the four vertical walls, as shown in Fig.13.

The temperature was measured by installing T-type sensors in four locations of the room indoors and outdoors of the frame and glass for each room. Indoor sensors were installed in the middle of each room, at heights of FL+200, 1,500, 2,000mm, as shown in Fig.14.

Because the measurement period was summer, air-conditioning was applied, and the temperature changes...
at the indoor/outdoor and frames were measured according to the change in external air temperature over a certain period of time.

4.2 Mock-up Test result and discussion

The experiment was divided into night and day.

In the daytime, the influence of the daylight and the external temperature was considered. In the nighttime, only the external air temperature was considered without the influence of sunlight. The experiment
results were compared and analyzed against the following items.

- Temperature change of indoor frame (Aug. 1st-18th)
- Temperature change of outdoor frame (Aug. 19th-25th)

Table 4. shows the mean for each temperature type.

Table 4. Definition of Each Temperature Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Temperature mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start temp.</td>
<td>The Initial temperature of each frame and structure, before using the cooling device.</td>
</tr>
<tr>
<td>Desired temp.</td>
<td>Indoor set temperature using the cooling device</td>
</tr>
<tr>
<td>A/C off</td>
<td>Temperature (Stop cooling device)</td>
</tr>
<tr>
<td>Off temp.</td>
<td>After the cooling system was operated, the final temperature for the experiment that exposed the room to external influences during a certain period (time of exposure to the outside after A/C was turned off: 1~3 hours)</td>
</tr>
<tr>
<td></td>
<td>Each Frame Temperature difference</td>
</tr>
</tbody>
</table>

(A) Daytime Indoor Frame Temperature Distribution

The temperatures of the frames measured indoor during the daytime are shown in Table 5. and Fig.15.

Table 5. Indoor Frame Temperature (Daytime) (°C)

| Room name | Start temp. | Desired temp. | A/C off temp. | Off temp. | |Δt| |
|-----------|-------------|---------------|---------------|-----------|--|----|
| Room A    | 38.8        | 21.7          | 25.7          | 42.2      | 16.5 |
| Room B    | 403         | 21.7          | 28.0          | 45.6      | 17.6 |
| Room C    | 384         | 21.7          | 30.2          | 40.1      | 9.9  |

Room A : Aluminum, Room B : Steel, Room C : Scagliola

The daytime outdoor frames' initial temperatures were 39.5°C, 41.5°C, and 40.2°C for the aluminum, steel, and scagliola frame, respectively. When the indoor average temperature reached 21.7°C after air-conditioning, the outdoor frame temperature was found to be 36.5°C for aluminum, 37.7°C for steel, and 40.8°C for scagliola.

Therefore, it was found that the scagliola frame showed the smallest temperature change.

(B) Daytime Outdoor Frame Temperature Distribution

The temperatures measured during the daytime and outdoors are shown in Table 6. and Fig.16.

Table 6. Outdoor Frame Temperature (Daytime) (°C)

| Room name | Start temp. | Desired temp. | A/C off temp. | Off temp. | |Δt| |
|-----------|-------------|---------------|---------------|-----------|--|----|
| Room A    | 39.5        | 21.7          | 36.5          | 41.4      | 4.9  |
| Room B    | 41.5        | 21.7          | 37.7          | 43.9      | 6.2  |
| Room C    | 40.2        | 21.7          | 40.8          | 41.3      | 0.5  |

Room A : Aluminum, Room B : Steel, Room C : Scagliola

The indoor temperature of each frame when the air-conditioning stopped at night was 22.2°C for scagliola, and 18.6°C for aluminum, and 19.1°C for steel.

(C) Nighttime Indoor Frame Temperature Distribution

The temperatures of the frames measured indoors and at night, without daylight, are shown in Table 7. and Fig.17.

Table 7. Indoor Frame Temperature (Nighttime) (°C)

| Room name | Start temp. | Desired temp. | A/C off temp. | Off temp. | |Δt| |
|-----------|-------------|---------------|---------------|-----------|--|----|
| Room A    | 27.7        | 18.1          | 18.6          | 25.7      | 7.1  |
| Room B    | 27.5        | 18.1          | 19.1          | 26.0      | 6.9  |
| Room C    | 29.4        | 18.1          | 22.2          | 26.7      | 4.5  |

Room A : Aluminum, Room B : Steel, Room C : Scagliola

In the temperature change results for the daytime indoor frame, the internal temperature of the scagliola-applied frame was found to be about 30.2°C. The aluminum and steel frames were 25.7°C and 28.0°C, respectively, which was about 2-5°C lower than that of the scagliola-applied frame.

It can be seen that the coldness was conducted through the frame due to the higher heat conductivity of aluminum and steel, as compared to that of the scagliola-applied frame.

Due to the influence of the external air temperature and daylight after termination of the air-conditioning, the temperature rose rapidly for the steel and aluminum frames.

Fig.16. Outdoor Frame Temperature (Day)

Fig.17. Indoor Frame Temperature (Night)


**5. Conclusion**

The purpose of this study was to evaluate the thermal performance by types of curtain wall frame. The thermal performance of curtain wall frames was analyzed through simulation and mock-up tests. The results of this study can be summarized as follows.

1) Through precedent study analysis, it was found that the most commonly used curtain walls are of metallic and aluminum frames, which cause the heat bridge phenomenon, and improvement studies are thus needed.

2) By using the heat transfer simulation with three frames of aluminum, steel, and scagliola, it showed that all three had little heat loss during both the summer and winter seasons.

3) The results from comparing frame temperature differences in the mock-up test experiment, show that scagliola had the lowest temperature difference for both night and day.

4) In comparing the frame thermal performance through the simulation and mock-up test, scagliola was found to be superior to aluminum and steel.

Therefore, it was found that the heat loss from frames can be reduced by applying the scagliola frame which improves the thermal performance over the aluminum and steel frames currently used in curtain wall structures.

**Acknowledgments**

This research was supported by the Chung-Ang University Excellent Student Scholarship.

**References**


