A Study on the Evaluation of the Heat Transmission Performance and Improvement of Thermal Insulation of Stone Finished Curtain Wall System

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ABSTRACT

With the recent trend in building tall, light-weight structures, stone is often used as the finishing material. The stone curtain wall is widely used not only in commercial buildings but also in the outer wall of residential buildings due to its economic efficiency and easy installation requirements. Moreover, using stone adds beauty and luxury to the structure and provides excellent durability, which are requirements of high-rise structures.

This study aims to evaluate the performance of heat transmission and to present a proposal for the improvement of thermal insulation using a mock-up test and two models: the stone curtain wall and the stone panel curtain wall. This study analyzed the heat transmission performance of each model and application. It was determined that thermal insulation can still be further improved. As for the stone curtain wall, the heat bridge occurs along the main structure as the continuous construction of the insulating material is not feasible because the construction should be done inside the steel frame, which causes a difference in temperature between materials in the wall. To intercept the heat bridge, the insulating paint coating method, the hard urethane pad insertion method and the urethane form coating method were suggested for fastening the unit that connects the wall and slab. The result shows that the insulating paint coating method and the hard urethane pad insertion method improve the thermal insulation performance of the fastening unit.

KEYWORDS: Curtain Wall, Fastener, Heat transmission, Stone panel

1. INTRODUCTION

In recently constructed buildings, the light curtain wall skin system is being favored more than masonry and heavy external walls for the RC structure. The new skin system presents many changes in the interior environment of structures.

With the growing trend in building taller and lighter structures, there is also an accompanying increase in the use of finish materials made of stone.

However, a number of metal fastening units that connect the wall and structure in stone-finished curtain wall have been installed. Accordingly, the phenomenon call “heat bridge” is formed through such units, thus increasing the energy consumption of air-conditioning and heating systems and causing environmental problems such as condensation on the surface and the fibrous insulation materials.

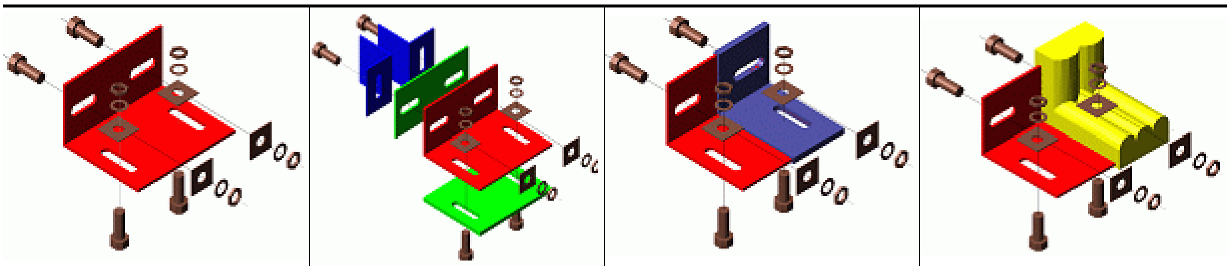
Considering such matters, this study seeks to evaluate the heat transmission performance of stone-finished curtain wall and to present a better alternative to fastening units of the wall and slab joint to improve its thermal insulation. This study aims to analyze the thermal insulation performance of the proposed alternative method in comparison to the existing curtain wall.

2. SETTING UP THE ALTERNATIVE METHODS TO IMPROVE THE THERMAL INSULATION PERFORMANCE OF STONE FINISHED CURTAIN WALL

Regarding improving thermal insulation, stone finished curtain walls (a general term for both stone curtain wall and stone panel curtain wall) suffer from most primarily condensation in the surface and inner insulations and thermal bridge attributed to the junction between stone and structure. Especially, in the light that condensation appearing in structures and insulations may lead directly to thermal bridge, it seems required to solve such the problem by combining closely the two factors.
Thus, this study aims to suggest unconventional methods to improve the thermal insulation performance of stone finished curtain wall skin system, focused on condensation and thermal bridge.

2.1 Target and method of evaluating the performance of stone finished curtain wall fastening unit system

In order to improve the thermal insulation and anti-condensation performance of stone finished curtain wall, improvement methods are suggested as shown in Figures 1.
Suggested for better performance, the improvement methods include the method to prevent thermal bridge in stone-structure joint and heat transfer between stones for the sake of its performance improvement; the method to use insulations; and the method to adopt insulation coating.



Using the existing	The hard urethane pad	The insulating paint coating	The urethane form coating

Figures 1. Methods to Improve Thermal Insulation Performance

① Insulation Padding Method
Hard urethane pad was selected as a type of insulation pad imbedded in the fastening unit. In the vertical direction, the thickness was set to 5 ㎜ equivalent to the maximum thickness to avoid interference with gypsum board, and the horizontal length (fastener-slab) set to 10 ㎜ in consideration for structural effects. The area of installation for hard urethane pad imbedded in the vertical (fastener-mullion) and horizontal (fastener -slab) directions were set same as the dimensions of the fastener. Accordingly, the three final alternatives were set up: hard urethane insulation padding into the vertical joint between fastener and mullion; hard urethane insulation padding into the horizontal joint between fastener and slab; and finally hard urethane insulation padding into both the vertical and horizontal joints. However, based on the results of the previous study, this study analyzed heat transmission performance centered on vertical/horizontal insulation padding method which is deemed the most effective in the aspect of thermal insulation performance.

② Insulation Coating Method
For insulating paints, the thickness coated once is very thin, about 0.1 ㎜, while for urethane foams, the thickness sprayed once is relatively as thick as approx. 30 ㎜. For the reason, the two alternatives are suggested as follows: coating with insulating paint the entire outer surface of the fastener jointing

slab and curtain wall mullion (coating thickness 0.3 ㎜); and coating with urethane foam the top and sides of the fastener (contacting floor finishing layer)(coating thickness 30 ㎜).

3. SIMULATION FOR PERFORMANCE EVALUATION OF THE WALL OF STONE FINISHED CURTAIN WALL

In this study, for the purpose of evaluating the performance of curtain walls, the several potential alternatives suggested were evaluated through computer simulation, and then mock-up experiments were performed for the sake of simulation verification.

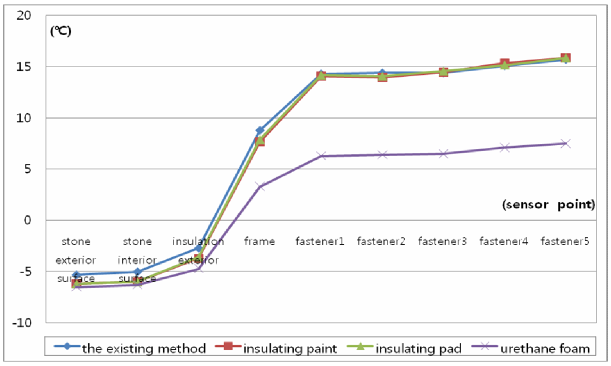
3.1 Simulation program for performance evaluation

In this study, THERM 5 program was employed, which was developed by U.S. LBNL (Lawrence Berkeley National Laboratory) and has been widely used to simulate the thermal insulation performance of windows and curtain walls across the world. THERM 5 program is available of analyzing windows, walls, footings, roofs, doors and any other regions where thermal bridge may occur by means of two-dimensional FDM (finite difference method) and calculating their energy efficiency and temperature distribution to enable to analyze any damage caused by condensation and moisture. The secondary conduction heat transfer analysis of THERM 5 is based on FDM and is available of modeling the complex forms of building elements.

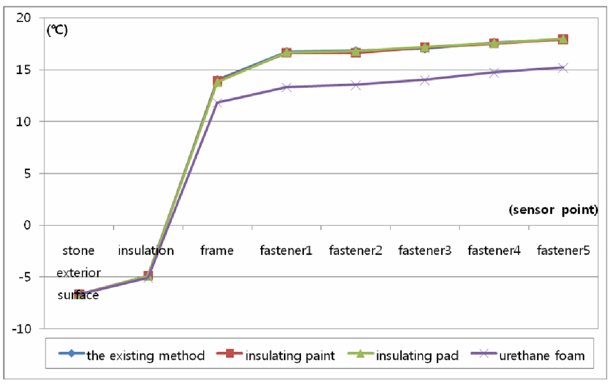
3.2 Analysis of simulation results

①Stone curtain wall

As a result of examining closely the simulation results of stone curtain wall, the outdoor surface temperature of stone was the highest with the existing method, followed by insulating paint, insulating pad and urethane foam coating in sequence. This tendency was same in the outdoor surface of stone as well as the indoor surface of stone and even the outdoor of insulation. On the other hand, the surface temperature of interior fasteners showed similar distribution in both the existing method and the methods to improve thermal insulation performance, suggesting that there are slight differences in the temperature.



Figures 2. Temperature Distribution of Stone Curtain Wall



Figures 3. Temperature Distribution of Stone Panel Curtain Wall

② Stone panel curtain wall

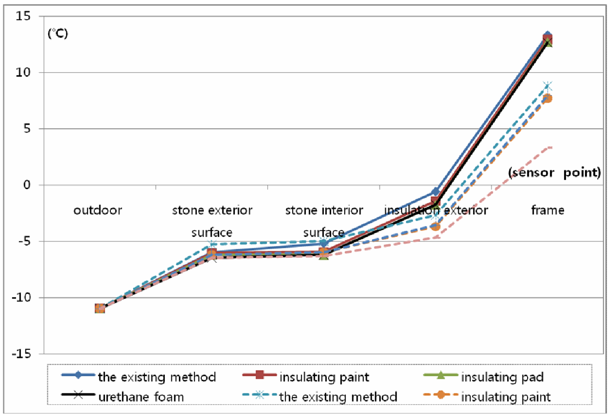
As a result of investigating into the temperature of stone panel curtain wall, almost similar temperature distribution was seen throughout the target materials ranging from the exterior surface temperature of stone to the interior surface temperature of fasteners, between the existing method and the methods to improve thermal insulation performance.

This finding suggests that compared with stone curtain wall, stone panel wall has less heat loss via fastening units in the curtain wall section, by virtue of sealing construction of insulation with double exterior insulation technique as a pre-fabricated type. Additionally, as compared with the heat transmission of stone curtain wall constructed with interior insulating technique using the inside space of steel frame, stone panel curtain wall exhibited better thermal insulation performance, and thus the effect of applying the methods to improve thermal insulation performance to fastening units was also less than that of stone curtain wall.

4. VERIFICATION AND COMPARATIVE ANALYSIS OF THE THERMAL INSULATION PERFORMANCE OF STONE FINISHED CURTAIN WALL

Mock up experiments were conducted with the intention of verifying the improvements in the thermal insulation performance of curtain wall as shown in the simulation applying the methods to improve the heat transmission performance of curtain wall.
To understand the heat transmission phenomenon depending on the kind of curtain wall finishing material, curtain walls were installed in the Environment Laboratory of University Y, and the existing method and the suggested methods to improve the thermal insulation performance of fastening unit were implemented between December, 2005 and March, 2006.

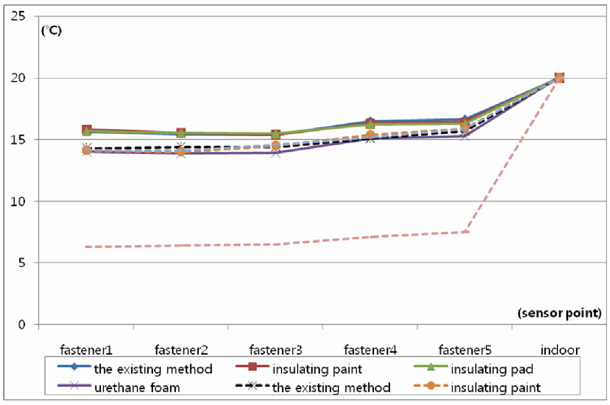
4.1 Comparative analysis of the results of simulation vs. experiment with stone curtain wall



Figures 4. Surface temperature comparison of stone curtain wall
(solid line: Mock-up, dotted line: simulation)

① The wall of curtain wall
In simulation, as a two-dimensional model was used for heat transmission analysis, there was some difference in the temperature of curtain wall's internal elements, however the temperature of exterior stone surface and interior fastener surface was similar between actual mock-up experiment and simulation. Accordingly, as seen in Figure 4, it is considered that the simulation enables the comparative analysis of heat transmission performance.

② Fastener surface
It is thought that the significant difference in the temperature of urethane foam coating method between mock-up experiment and simulation was attributed to different construction practices – that is, urethane coating seals tightly the structure and perfectly blocks heat transfer to the outside in simulation, whereas there are numerous pores in the surface of urethane foam and thus it is impossible to achieve perfectly tight sealing in the actual mock-up experiment, leading to heat transfer via fasteners.
Moreover, about 1.0℃ of overall difference was seen between simulation and mock-up experiment, however the tendency of temperature gradient was almost similar between the twos. Therefore, it is concluded that the simulation enables the comparative analysis of heat transmission performance.



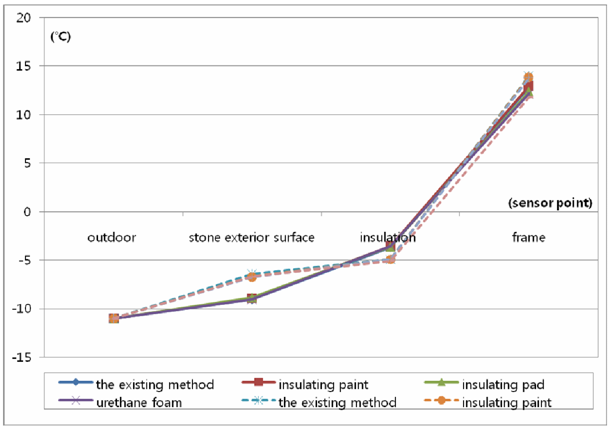
Figures 5. Surface temperature comparison of stone curtain wall fastener

4.2 Comparative analysis of the results of simulation vs. experiment with stone panel curtain wall

① The wall of curtain wall

As a result of examining closely the temperature of the surface of stone panel curtain wall's exterior wall finishing material (stone), in mock-up experiment, the existing method and the suggested methods to improve thermal insulation performance showed the temperature distribution ranging from -9.0℃ to -8.8℃, while according to the results of simulation, the existing method, the insulating paint coating method and insulating padding method exhibited the temperature distribution of -6.4℃~6.8℃, which indicates about 3℃ of difference.

Similarly for stone panel curtain wall, the urethane foam coating method led to somewhat significant difference in temperature in both mock-up experiment and simulation, compared to the other suggested methods

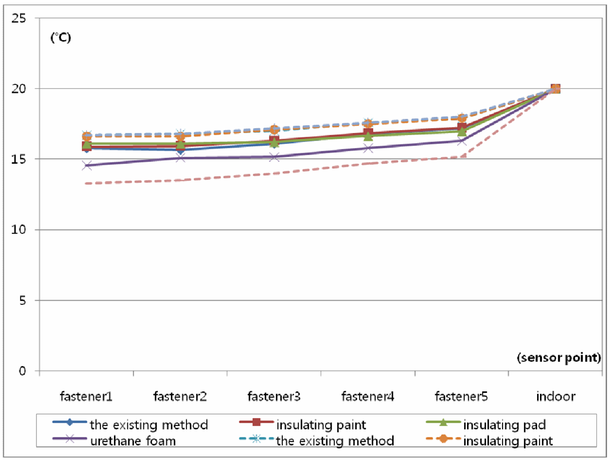


Figures 6. Surface temperature comparison of stone panel curtain wall
(solied line:Mock-up, dotted line: simulation)

Similarly to stone curtain wall, it is considered that these findings are attributed to the integrity of sealing with urethane foam spray in actual construction.

② Fastener surface

As a result of examining closely the temperature of fastener surface, similarly to stone curtain wall, the temperature of the fastener's horizontal portion was about 2℃ higher than that of the vertical portion, and the temperature of fastener surface ranged from 15.7℃ to17.2℃ in mock-up experiment. In the case of the urethane foam coating method, the temperature distribution corresponded to 14℃ to16℃, which is approx. 1℃ lower. In simulation, the temperature of fastener surface ranged approximately from 15.2℃ to 17.8℃, and the urethane foam coating method showed 13℃~14℃ of temperature distribution – about 3℃ lower.



Figures 7. Surface temperature comparison of stone panel curtain wall fastener

These findings suggest that the heat transmission results of applying the suggested methods to improve thermal insulation performance to stone curtain wall and stone panel curtain wall are similar between simulation mock-up experiment. Thus, since the results of using a heat transmission analysis program are similar in the aspect of thermal performance including temperature distribution (isothermal curve), portion-specific temperature and heat flow in mock-up experiment, the evaluation of heat transmission performance with the said program is deemed valid

5. CONCLUSION

In this study, with targeting two typical types of stone finished curtain wall, i.e., stone curtain wall and stone panel curtain wall, heat transmission performance was evaluated by means of a heat transmission analysis program called THERM 5 and some methods to improve thermal insulation performance were suggested.

Following application of the suggested methods, heat transmission performance was analyzed to predict the potential to improve the thermal insulation performance of stone finished curtain wall, and to verify the results of simulation, full-scale curtain walls were constructed and mock-up experiment was performed under the same outdoor/indoor environmental conditions.

1) Stone curtain wall

For stone curtain wall, as insulation is constructed using the interior space of steel frame installed to support heavy stone finishes and thus it is difficult to construct insulation successively, thermal bridge occurs along with the main structural elements, leading to different temperature among internal elements. In order to reduce conductive heat transfer via structure and prevent thermal bridge, it was suggested to apply the insulating paint coating method, the hard urethane pad method and the urethane foam coating method to fastening units jointing wall and slab.

As a result of evaluating the thermal insulation performance derived from the suggested methods, the insulating paint coating method, the hard urethane pad method and the urethane foam coating method were associated with the improved thermal insulation performance of fastening units. However, the urethane foam coating method was the most excellent in the aspect of thermal performance of curtain wall, while it showed lower temperature in the wall frame of curtain wall due to the effect of the coating of fastening unit's upper part, compared with the other suggested methods. Thus, it has the potential for condensation in the frame and internal condensation between fastening units and the wall of curtain wall. Therefore, it is concluded that the insulating paint coating method and insulation padding method are the most effective in improving the thermal insulation performance of the wall of stone curtain wall.

2) Stone panel curtain wall

Similarly to stone curtain wall, the thermal insulation performance of stone panel curtain wall was also evaluated after applying the existing method, insulation padding method, insulating paint coating method, urethane foam coating method.

In result, as for the wall of stone panel curtain wall, its interior elements are less affected by open air temperature by virtue of double exterior insulation construction technique, it was found that the effects of the methods to improve thermal insulation performance applied to interior fastening units were relatively insignificant compared with stone curtain wall, however slight improvement in the thermal insulation performance of the wall was observed.

Like stone curtain wall, it is thought that the thermal performance of stone panel curtain wall is most remarkably improved by the urethane foam coating method, however it has the potential for condensation attributed to urethane foam coating in the wall frame of stone panel curtain wall as well. Therefore, it is considered that the insulating paint coating method and insulating padding method are the most effective in improving the thermal insulation performance of the wall of stone panel curtain wall.

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