Appropriate technology to improve thermal performance of existing window

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Abstract. Technological development for reduction of CO2 emissions has been actively carried out globally. In buildings, windows and envelops are the parts that generate the greatest heat loss. Therefore, it is the target to improve primarily for the energy efficiency. Various techniques such as vacuum glass and heat-insulating reinforced frame have been developed to improve the thermal performance of windows, however, these techniques can be applied only for new windows. To apply these technologies, it is necessary to install them in a building on construction or to replace all of windows of existing building. In this paper, we developed the technology to improve the thermal performance of existing windows. This technology can be applied without any movement of occupants or furniture. Moreover, it is affordable, durable and available for everyone without any special expertise or tools. Another benefit of this technology is that it does not affect daylighting and view since it has a high transmittance. In order to verify the performance of it in terms of the thermal aspect, the mock-up experiment and the field test were conducted. Thermal transmittance of windows was measured and analyzed before and after improving their thermal performance with the technology. The result shows that the values of the thermal transmittance of windows have improved by 20% after application of the technology.

1. Introduction
The window is an essential element of a building and provides outside views, light, solar heat gain and ventilation. However, it is relatively weak in thermal performance, compared to the envelope which includes materials specializing in it. Therefore, many countries have been enacting or strengthening window insulation standards, taking into account its impact on the energy efficiency. In the case of Republic of Korea, Building Energy Conservation Design Standard has established and managed the thermal performance of windows applied to apartment buildings, and this standard has been considerably strengthened in last 10 years. (M.H. Kim, 2017)

Although, many technologies for high thermal insulation windows such as the vacuum glass, reinforced frames for thermal insulation have been actively developed, the study on the technology to improve the thermal performance of existing windows is deficient. In order to improve the thermal performance of a window, whole parts of it need to be replaced with new ones. However, there are difficulties such as structural safety, construction period, and cost which may be generated in the process of replacement and increase depending on state of buildings.

In this research, we suggests the technology to enhance the thermal performance of the glass part of windows without replacing the existing windows. In order to analyze the quantitative effect of this technology, mock-up experiments and field tests were conducted.
2. The technology to improve the thermal performance of existing windows (Attached Glazing)

The Attached Glazing is a technology designed to improve the thermal performance of windows without removing existing windows. The principle is not complicated. The attached glazing is installed in a space of about 10 mm between a window glass and its frame. The attached glazing and the air layer created between them generate a heat insulating effect. The characteristic of windows such as the view, the solar radiation and light can be maintained regardless of if the attached glazing is installed. As solar heat can be acquired, the glazing surface temperature on the inside glass is increased, and the energy loss is minimized.

The attached glazing is made of polycarbonate (PC) because it is transparent and has a low coefficient of thermal expansion, making it suitable for window glazings. Also, PC has durability in flame retardancy and corrosion resistance. Moreover, it is 150 times stronger than glass and it has more easier process. And, the solar heat gain coefficient and shielding factor of the attached glazing can be designed by considering heating and cooling load upon the technology applied building. The attached glazing is a low cost technology that can be used semi-permanently and constructed even by non-experts.

The thickness of the attached glazing is decided by the thickness of glazing and the gap between the window glass and the frame, but it is approximately 3mm which is suitable for a general sliding double window.(Korea's representative window type) Figure 1 shows the location of the attached glazing, and Figure 2 shows the appearance of the attached glazing.

3. Mock-up experiment

3.1. Methods of Mock-up Experiment

Mock-up experiments were conducted to quantitatively analyze the effect of improvement of the thermal performance when the attached glazing is installed on windows. Before and after applying the glazing, the thermal performance of windows was measured. The performance improvement was analyzed through comparison with two measurement values.

The measurement of thermal performance of windows was implemented based on KS F2278. This is the Korea industrial standard that specifies a method to measure the thermal resistance of windows and doors. A hot box with a warm chamber is attached to the cold chamber where the test body is installed. And the amount of heat transferred through the specimen is measured.

The test specimens (the window) of 2.0 m (w) x 2.0 m (l) size were placed in the test specimen frames.

Then, one of them was placed between the cold chamber and the warm chamber. The air temperature of the heating box and the warm chamber was set to (20.0 ± 1.0) °C, and then the cold chamber was set to (0.0 ± 1.0) °C. After the temperature of each chamber reached the set temperature and a steady state, the quantity of heat in each chamber and the surface temperatures of the specimen were measured. It was done by dividing the specimen into nine equal parts and using 18 points (9 indoor points, 9 outdoor points) attached to the center of the 9 parts. Figure 3 shows the measuring instrument of thermal transmittance of window, and Figure 4 shows the points for measuring temperature of the specimen.
The PVC sliding window which is $2,000(W) \times 2,000(H)$ mm was selected as the test specimen. The attached glazing applied to the specimen was a polycarbonate of 3 mm, and the air layer between the attached glazing and the window was 5 mm. Because of the large area of the glass, 5 mm of polycarbonates was cut and used as a spacer to maintain the space between the attached glazing and the glass. The description of the specimens is shown in Table 1.

### Table 1. The information of the test specimen

| Window type          | Frame material | Glass composition       | Filled gas |
|----------------------|----------------|-------------------------|------------|
| Window A             | Sliding / Duplex window | PVC                      | 41mm Low-e triple glass | Argon |
| Window B             | Sliding / Duplex window | PVC                      | 24m clear pair glass       | Air    |

#### 3.2. Results of Mock-up Experiment

The result values of the thermal performance which was measured before and after applying the attached glazing is shown in Table 2. The result of window A case was $1.225 \text{ W/m}^2 \text{ K}$ and $0.983 \text{ W/m}^2 \text{ K}$, improved by $19.8\%$. The result of Window B case was $2.673 \text{ W/m}^2 \text{ K}$ and $2.127 \text{ W/m}^2 \text{ K}$, indicating improvement of $20.4\%$. The thermal performance of window was improved by about $20\%$ averagely by applying the attached glazing. The effect of the attached glazing can be changed according to the insulation performance of the existing windows. In the case of a window with a large gap between its glass and frame, the air layer can be formed thicker with the same thickness of attached glazing so that the higher heat insulation performance can be expected.

### Table 2. Results of Mock-up Experimental

|                  | Thermal transmittance(\text{W/m}^2 \text{ K}) | (a)-(b)/(c)-(d) | Reduction ratio(\%) |
|------------------|-----------------------------------------------|-----------------|---------------------|
| Window A (a)     | 1.225                                         |                 | -                   |
| Window A+Attached glazing (b) | 0.983                                         | 0.242           | 19.76               |
| Window B (c)     | 2.673                                         | -               | -                   |
| Window B+Attached glazing(d) | 2.127                                         | 0.546           | 20.39               |
4. Filed test

4.1. Methods of field test

In order to analyze effect of applying the attached glazing, field tests were conducted in actual old buildings. The test method is as follows. The surface temperatures of the inside window glass and the attached glazing were measured and compared after the attached glazing was installed on the window facing the indoor air. It is impossible to perfectly control variables affecting the room temperature because the building is used by an actual resident. Therefore, we try to determine the heat loss by measuring the surface temperature of the inside glass and the attached glazing. The tests were conducted during nighttime (18:00 ~ 6:00) because it is not influenced by solar radiation in winter season. The locations on window to measure the surface temperature are shown in Figure 5. Figure 6 shows the circumstance of the field tests. The subjects of experiments are old buildings (Table 4) which is more than 20 years old in South Korea.

![Measurement location of the surface temperature](image1.png)

![Circumstance of field tests](image2.png)

**Figure 5.** Measurement location of the surface temperature  
**Figure 6.** Circumstance of field tests

### Table 3. The information of test subject

| Construction year | Building type       | Window type (Frame material) | Heater setting temperature(°C) |
|-------------------|---------------------|------------------------------|--------------------------------|
| CASE 1            | 1995                | Multi-family house           | Duplex window (AL+WOOD)        | 22                |
| CASE 2            | 1941                | Detached house               | Duplex window (PVC)            | 15                |
| CASE 3            | 1985                | Multi-family house           | Duplex window (PVC)            | 23                |

4.2. Results of filed test

Table 4 and Figure 8 shows the measured surface temperature of the inside glass and the attached glazing. The average surface temperatures of the inside glass were measured as 7.28 °C for CASE 1, 9.55 °C for CASE 2, and 18.81 °C for CASE 3. The average surface temperatures of the glazing glass were measured as 10.35 °C for CASE 1, 12.42 °C for CASE 2, and 20.95 °C for CASE 3. The average surface temperatures of the glass contacting room air (or attached glazing) were increased to 3.07 °C for CASE 1, 3.13 °C for CASE 2, and 22.14 °C for CASE 3. Therefore, the surface temperature of the window glass decreased by 2.78 °C on average after applying the attached glazing, which leads the heat loss to decrease and contributes to the reduction of building energy. The increase of the surface temperature of the window is affected by outdoor and indoor temperatures, and the outside air may influence it when existing windows are not airtight. In addition, an increase of surface temperature can reduce the problem of cold radiation which makes an occupant near the window lose radiant heat and feel the thermal discomfort.
Table 4. The Result of field test

| Case | Temperature(℃) | 18 | 19 | 20 | 21 | 22 | 23 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | Average |
|------|----------------|----|----|----|----|----|----|----|----|----|----|----|----|----|---------|
|      | Outdoor        | 6  | 5.6| 5.4| 5.4| 5.4| 4.7| 4.1| 4  | 3.5| 3.2| 2.9| 2.7| 2.3| 4.25    |
|      | O-S            | 8  | 7.5| 7.5| 7.6| 7.3| 6.6| 6  | 6  | 5.6| 5.2| 4.9| 4.7| 4.4| 6.25    |
|      | I-S            | 8.8| 8.2| 8.3| 8.4| 8.3| 7.6| 7.1| 7.1| 6.7| 6.4| 6.2| 5.9| 5.6| 7.28    |
|      | I-AG.S         | 11.3| 10.7| 11| 11.2| 11.2| 10.7| 10.3| 10.3| 10| 9.8| 9.6| 9.4| 9.1| 10.35   |
|      | Indoor         | 21 | 21.2| 22.3| 21.5| 22.4| 22.3| 22.3| 22.5| 22.4| 22.2| 22.4| 22.4| 22.4| 22.10   |
|      | Outdoor        | 0 | -0.6| -1| -1.4| -2| -2.4| -3.1| -3.8| -3.4| -3.8| -3.9| -4.2| -4.1| -2.59   |
|      | O-S            | 7.5| 7.3| 7.2| 7.3| 6.8| 6.3| 5.7| 5.5| 5.9| 5.6| 5.7| 5.3| 6.4|        |
|      | I-S            | 10.1| 10.1| 9.8| 10.5| 10.5| 10| 9.4| 8.7| 8.8| 9.4| 9.4| 9 | 8.4| 9.55    |
|      | I-AG.S         | 12.4| 12.5| 12.5| 14| 13.5| 12.8| 12.1| 11.3| 12.8| 12.6| 12.6| 11.9| 11.1| 12.42   |
|      | Indoor         | 14.3| 14.5| 14.8| 16.7| 16.1| 15.1| 14.3| 13.7| 14.9| 16| 15.4| 14.2| 13.5| 14.88   |
|      | Outdoor        | 11.3| 10.9| 9.8| 9.1| 8.7| 8.6| 7.7| 6.6| 6.3| 5.6| 5.4| 6.2| 5.4| 7.82    |
|      | O-S            | 17.4| 15.7| 14.8| 14.2| 13.8| 13.6| 13.2| 12.7| 12.2| 11.7| 11.4| 11.4| 11.4| 13.35   |
|      | I-S            | 21.3| 20.2| 19.6| 19.3| 19| 19| 18.8| 18.5| 18.3| 17.9| 17.7| 17.4| 17.5| 18.81   |
|      | I-AG.S         | 21.9| 21.5| 21.4| 21.3| 21.3| 21.1| 21.1| 20.9| 20.7| 20.6| 20.3| 20.2| 20.1| 20.95   |
|      | Indoor         | 23.4| 23.8| 23.7| 23.7| 24| 23.5| 24.1| 24| 23.8| 23.7| 23.6| 23.3| 22.9| 23.65   |

Figure 7. The Result of field test
5. Conclusion
In this study, we evaluated the performance of the attached glazing which is a technology to improve the thermal performance of the window. The mock-up experiments were conducted to measure the quantitative performance of the glazing, and the results showed that it improved the performance of a specimen window by about 20% on average. As a result of the field experiment conducted in an actual old building, surface temperature of the inside glass (or the attached glazing) was reduced by approximately 2.78 °C after applying the attached glazing. Therefore, it can be proved that the application of attached glazing significantly contributes to a reduction of heating energy and an improvement of indoor thermal environment.

In this study, two kinds of sliding window were applied for mock-up experiment, and the number of buildings was limited to three for field tests to analyze effect of the attached glazing. In future research, additional experiments need to be conducted on various types of old houses and windows to increase the reliability of the improvement in thermal insulation performance which the attached glazing makes.

Acknowledgements
This research was supported by a grant (19RERP-B082204-06) from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

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