Influence of Drainage Holes on Condensation Risk and Air-tightness of Windows
An Experimental Case Study of Triple Glazing PVC Windows

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Abstract
Triple glazing windows incorporate drainage holes on glazing beads or gaskets to provide a path for condensed water from the inside to the outside. These holes are considered to be effective for draining condensed water but may decrease the air-tightness and increase the condensation risk due to the drop in surface temperature resulting from the intake of cold outside air. In this study, the related specifications and documents on the application of drainage holes and previous studies were reviewed. For the triple glazing windows with and without drainage holes, the condensation resistance and air-tightness were evaluated and compared. Condensation resistance and air-tightness were tested in accordance with KS F 2295 and KS F 2292, respectively. The results showed that the use of drainage holes did not have a significant negative impact on the condensation resistance and air-tightness.

Keywords: triple glazing; window; condensation; air-tightness; condensed water drainage hole

1. Introduction
According to the data from the Office of Apartment Defect Dispute Mediation Committee under the Ministry of Land, Infrastructure, and Transport, the number of defect dispute cases has continued to rise, with 72% in the building and construction sector, 16% in the mechanical sector, 6% in the electrical sector, and 6% in the civil engineering or landscaping sector. Thus, the building and construction sector accounts for the largest share of such cases. In the building and construction sector, at 16%, condensation-related defects account for a significant percentage of cases (MOLIT, 2015). Windows are a major factor in condensation defect disputes, especially in apartment buildings, due to their relatively weak thermal performance compared to the opaque building envelope. At the same time, the area covered by the windows is also gradually increasing, due to the demand for a view. Condensation, which occurs on the inside surface of a window, drips down and stagnates in the lower part of the frame. Occasionally, if there is a large amount of condensation, the condensed water can even spill into the room and damage the floor and wall finishing. If this situation is neglected, it can cause several negative impacts, such as mildew and floor and wall finishing decay (refer to Fig.1.). As a solution to this condensation treatment, drainage holes and weep holes are punched in the sill or the track. These drainage holes or weep holes are punched through the empty sills or glazing beads or gaskets to provide an unblocked path for condensation from the inside to the outside.

Drainage holes or weep holes are definitely effective in terms of discharging condensation during winter and removing indoor vapor. However, as a channel connecting the inside and outside, they can allow cold outside air into the living area, and this cold air may lower the inside surface temperature of windows and cause heat loss due to the reduced air-tightness. In addition, such channels can act as a path for rainwater from the outside during heavy rain seasons, such as summer in Korea. Due to this aspect, drainage holes or weep holes are regarded as one of the possible reasons for window condensation problems by occupants when disputes over construction defects occur. Reflecting this situation, this study aimed to evaluate the extent of influence of drainage holes on the actual condensation risks and air-tightness of windows.

First, the related specifications and documents on the application of drainage holes as well as previous studies were reviewed. For the triple glazing windows with and without drainage holes, the condensation resistance and air-tightness were evaluated and
compared. Condensation resistance and air-tightness were tested in accordance with KS F 2295 (KATS, 2009) and KS F 2292 (KATS, 2013), respectively.

2. Related Specifications on the Application of Drainage Holes and Previous Studies

2.1 Application of Drainage Holes

In the case of sliding windows, the weep holes are usually bored into the track on the lower part of the window. In the case of tilt and turn triple glazing windows, the drainage holes are punched into the glazing bead supporting the glass on the interior side of the window, or they are bored into the gasket fastened to the glazing bead, as shown in Figs. 2. and 3. They are installed such that the condensed water from the inside surface of the windows does not spill into the living area. Instead, it flows into the drainage holes and through an unblocked channel to weep holes on the outside of the window frame, where it drains out. In the case of sliding windows, the extensive space between the tracks at the bottom of the window frame acts as a channel providing a wide drain for the condensed water. In tilt and turn windows, the inside of the window frame sill acts as the channel, which means that the space available for the condensation is relatively narrow.

2.2 Related Specifications on Drainage Holes

The Korean Standard Specification for Building Construction (MLTMA, 2016) states that the weep holes should not be blocked, and water or condensation on the inside surface of windows or doors should be immediately expelled through the weep holes. Generally, there should be at least two weep holes with a minimum diameter of 5 mm. Additionally, in the case of multi-layered glass, laminated glass, wired sheet glass, etc., the ends of the glass should not be exposed to moisture or seeping water for a long time.

The North American Fenestration Standard/Specification for windows, doors, and skylights (NAFS, 2011), which presents provisions addressing fenestration product requirements, requires the comprehensive description of test reports including the drainage system, indicating location and size of all active and passive weep holes, sloped sills, glazing drainage, etc. for condensation resistance and thermal transmittance tests. Similarly, the Information Handbook: Condensation in Buildings in Australia (ABCB, 2011) states that it is important to take preventative measures such as keeping surfaces above the dew point, improving ventilation or introducing drainage to discharge the moisture. Excessive condensate running on the inside surface of glazing that is not removed by drainage or drying can lead to deterioration of the window frame and floor surfaces. A major window manufacturer in the US (Pella, 2016) explains the role of weep holes in window systems: it
is normal for water to accumulate in the sill and track, and the water is intended to drain to the outside via the drainage or weep holes. For the drainage to work, it needs to be maintained such that the weep holes are clear of obstructions such as dirt, sand or building materials. Weep holes are located both inside and outside the window in the bottom of the frame. If the window is stacked, as in double horizontal window systems, there may be weep holes between the units to provide a path for water to run out of the window.

Even though there are specific instructions about the drainage holes and weep holes in windows, the condensation problem is often caused because of a blocked water channel or a lack of drainage holes or weep holes in practice. According to the report by the Office of Apartment Defect Dispute Mediation Committee (MOLIT, 2015), which analyzed apartments defect cases from 2013 to 2014, 16 of the 100 cases were related to window surface condensation defects. Of these 16, 11 cases were mainly due to window condensation defects such as water stagnation and mildew on the sealant, indicating a lack of drainage holes. Thus, in the windows installed in these apartments, the drainage holes either were not installed or were blocked. Ten of the cases occurred because there were no drainage holes in the triple glazing window system. According to the investigation of an ‘A’ window manufacturer, drainage holes were made during the manufacturing process of both sliding and tilt and turn windows; however, in the case of tilt and turn window systems, the drainage holes were often blocked when the windows were installed on site.

2.3 Previous Studies on Window Condensation

Many studies related to condensation on windows have been performed. Song et al. (Song et al., 2007) evaluated the inside surface condensation on windows with conventional aluminum spacer and insulation spacers made of thermally broken aluminum and thick-walled plastic, respectively. They reported that the application of an insulation spacer could substantially increase the lowest inside surface temperature, temperature factor and inside air humidity for preventing inside surface condensation and satisfy the required minimum temperature factor. Also, another research (Glaser and Ulrich, 2013) addressed dew and frost on the outdoor surface of triple glazing units. The results showed that with low-e coatings having a maximum emissivity of 0.2, frost could be prevented on the outdoor surface of all vertically installed glazed with a thermal transmittance $U_g \geq 0.47$ W/m²K.

Choe et al. (Choe et al., 2013) conducted various air-tightness tests to determine how much air infiltration occurs through different window types and how it affects window condensation. Comparing a casement window and a fixed window in a sliding window system, more condensation occurred on the fixed window. Kang and Kim (Kang and Kim, 2010) tested the condensation resistance in relation to wind speed and concluded that the triple glazing window resulted in a 5~10°C lower outside surface temperature when a wind speed of 6~8 m/s blew in front of the window compared to when there was no wind.

However, upon analyzing the previous studies on window condensation, many studies were found to consider a systematic approach to a whole window system’s condensation problem, but the effects of drainage holes or weep holes on condensation and air-tightness have not been considered or reported extensively in the literature.

3. Test Methods for Condensation Resistance and Air-tightness

A triple glazing window system was selected for testing because there were many condensation defect disputes related to the drainage holes. A mock-up test was performed using two cases: a window without drainage holes (CNH, the case with no drainage holes) and a window with condensed water drainage holes in the glazing beads (CWH, the case with drainage holes). The condensation resistance of each case was tested and compared based on the inside surface temperature ($T_{si}$) and the temperature difference ratio (TDR, refer to Equation (1)), while the air-tightness was tested and compared based on the air infiltration rate and the air-tightness level.

3.1 Overview of Window Specimen

The triple glazing window system specimen was manufactured according to the current Code for Energy-efficient Building Design (MOLIT, 2016), which requires the thermal transmittance (U-value) of less than 1.5 W/m²K for windows that are directly in contact with the outside in apartment buildings. The tilt and turn casement window was on the left side, and the fixed window was to the right. The specifications of the tested triple glazing window are listed in Table 1., and their cross sections are shown in Fig.4.

| Table 1. Specifications of Tested Triple Glazing Windows |
|---------------------------------------------------------|
| **Glazing** | **Spacer** | **Frame** |
| SLE+12Ar+5CL+12Ar+5LE | Thermoplastic | PVC with Steel Reinforcement |
| (Low-E coatings, Ar Gas) | | |
| SLE+12Ar+5CL+12Ar+5LE | Thermoplastic | PVC with Steel Reinforcement |
| (Low-E coatings, Ar Gas) | | |

Fig.4. Sections of Tested Triple Glazing Window
3.2 Condensation Resistance Test Methods

Based on the KS F 2295 (KATS, 2009), the condensation resistance test was conducted under conditions of steady-state heat transfer at a facility accredited by the Korea Laboratory Accreditation Scheme (KOLAS). The first purpose of this procedure is to measure the Tsi (inside surface temperature) at the measurement points to calculate the TDR (temperature difference ratio), and the second is to determine the formation of condensation of the product under the test conditions. This test method is similar to the AAMA 1503-09 (AAMA, 2009) in North America, which is for determining thermal transmittance and condensation resistance of windows, doors and glazed wall sections.

The test specimen was made to a size of 2,000 (width) x 2,000 (height) mm, which is the standard test size prescribed in the KS F 2295. Table 2. shows the test conditions for condensation resistance in accordance with the Korean Design Standard for Preventing Condensation in Apartment Buildings (MOLIT, 2016). Air temperature of the hot chamber was set to 25°C, and air temperature of the cold chamber was set to -15°C, corresponding to the Region II outside air temperature of the Design Standard. Fig.5. shows the required Tsi measurement points prescribed in the Design Standard. There are a total of 26 points, with 2 points in the center of the glazing (C-1, C-2), 8 points along the edge of the glazing (E-1~8), 7 points on the tilt & turn casement window frame (T-1~7), and 9 points on the fixed window frame (F-1~9) (MOLIT, 2016).

Table 2. Test Conditions for Condensation Resistance

| Location          | Hot Chamber       | Cold Chamber     |
|-------------------|-------------------|------------------|
| Temperature (°C)  | 25.0±1.0          | -15±1.0          |
| Relative Humidity (%) | 50±1         | -                |

Table 3. TDR (Temperature Difference Ratio) Requirements for PVC Windows in Region II

| Location     | Maximum Allowed TDR |
|--------------|----------------------|
| Glazing Center | 0.18                 |
| Glazing Edge  | 0.24                 |
| Frame         | 0.28                 |

Fig.5. Locations of Tsi (Inside Surface Temperature) Measurements
After the test specimen was attached to the apparatus, the environmental conditions were maintained as steady-state in the hot chamber at 25°C and 50% relative humidity and -15°C for the cold chamber, and then Tsi (inside surface temperature) was measured.

The test procedure, from mounting the test specimens to measuring the Tsi on each measured location of the case with no drainage holes (CNH) and the case with drainage holes (CWH), is shown in Fig.6. The measurements were first performed on the CNH specimen by installing the glazing beads without drainage holes, as shown in Fig.6., ⑦. The existing glazing bead was then replaced by the one with two drainage holes, and Tsi measurements of the CWH were performed, as shown in Fig.6., ⑧.

The drainage holes in the glazing bead of the CWH specimen had a width of 6 mm and a height of 18 mm punched through a PVC glazing bead itself as shown in Fig.6. Top and bottom round ended rectangular shaped drainage holes in a glazing bead and their locations are shown in Fig.7. Opening area of one drainage hole is 0.14x10^-3 m^2. Other than the glazing beads, all of the general conditions for the test specimens were identical.

Condensation resistance was evaluated by comparing the Tsi at each location as well as the TDR, as obtained from Equation (1). In a steady-state condition, this index remains the same even when the inside and outside air temperature changes. Therefore, this value can determine the occurrence of condensation under various inside and outside air temperature and humidity conditions. The temperature difference ratio has a value between 0 and 1. The closer to 0, the better the performance. Table 3. shows the required TDR of a polyvinylchloride (PVC) framed window for the Region II of the Design Standard.

\[ \text{TDR}_x = \frac{T_{Hx} - T_{X}}{T_{H} - T_{C}} \]  

\( T_{DR_x} \): Temperature difference ratio on x
\( T_{H} \): Hot chamber air temperature (°C)
\( T_{C} \): Cold chamber air temperature (°C)
\( T_{X} \): Surface temperature on x in hot chamber (°C)

3.3 Air-tightness Test Methods
The Code for Energy-efficient Building Design (MOLIT, 2016) requires air-tight window installation in apartment buildings, of which the infiltration rate is less than 5 m³/h·m², tested in accordance with the KS F 2292. For this reason, the air-tightness was tested according to the KS F 2292 at the same test institution accredited by KOLAS. This test method is similar to the ASTM E 283 (ASTM, 2012) in North America, which is for determining the rate of air leakage through exterior windows, curtain walls, and doors under specified pressure differences across the specimen.

Before the test, a test specimen was pre-pressurized for one minute at 250 Pa of pressure difference. After pre-pressurization, each air leakage amount at the standard pressure difference at 10, 30, 50, and 100 Pa, respectively, was measured and air infiltration rate was derived at each. Air infiltration rate represents the air leakage amount per hourly rate for the 1m² of the test specimen area (m³/h·m²) at each pressure difference level.

The test specimen size had a width of 1,500 mm and a height of 1,500 mm due to the limitations of the test facility. Fig.8. shows a picture of the mounted test specimen. Except that the distance between the drainage holes was reduced due to the smaller test specimen size than that for the condensation resistance test, all other specifications for the test specimens were the same as for the condensation resistance test. The installation of the CNH and CWH test specimens and the test procedures (refer to Fig.6., ⑦ and ⑧) were the same as for the condensation resistance test.

4. Test Results of Condensation Resistance and Air-tightness
4.1 Condensation Resistance Test Results
Table 4. shows the condensation resistance test results for the glazing. In the CWH window, the inside surface temperatures at all points were lower than those in the CNH by 0.1 to 0.3°C, with the exception of the center of the glazing (C-2) in the fixed window. This can be attributed to the partial heat loss due to the cold air intake through the drainage holes. However, TDR, which is a condensation resistance index, was the same or slightly increased by 0.01 at all of the points in the CWH other than C-2, showing that the drainage holes did not have a significant negative impact on the condensation resistance.

Table 5. shows the test results for the frame. The overall results were similar to the results of the glazing. In the CWH window, the inside surface temperatures at all points were 0.1 to 0.3°C lower than those in the CNH, with the exception of the bottom of the tilt and turn window (T-7, F-7). However, in the case of TDR,
Table 4. Condensation Resistance Test Results: Glazing

| Edge of Glazing (Top) | CNH | CWH |
|-----------------------|-----|-----|
| E-1                   |     |     |
| Tsi° (°C)             | 20.4| 20.2|
| TDR                   | 0.12| 0.12|

| Center of Glazing     | CNH | CWH |
|-----------------------|-----|-----|
| E-1                   |     |     |
| Tsi° (°C)             | 23.2| 23.1|
| TDR                   | 0.05| 0.05|

| Edge of Glazing (Bottom) | CNH | CWH |
|--------------------------|-----|-----|
| E-5                      |     |     |
| Tsi° (°C)                | 14.3| 14.0|
| TDR                      | 0.27| 0.28|

Table 5. Condensation Resistance Test Results: Frame

| Top Section of Frame    | CNH | CWH |
|-------------------------|-----|-----|
| E-1                     |     |     |
| Tsi° (°C)               | 22.4| 22.1|
| TDR                     | 0.07| 0.07|

| Middle Section of Frame | CNH | CWH |
|-------------------------|-----|-----|
| E-1                     |     |     |
| Tsi° (°C)               | 20.6| 20.4|
| TDR                     | 0.11| 0.12|

| Bottom Section of Frame | CNH | CWH |
|-------------------------|-----|-----|
| E-5                     |     |     |
| Tsi° (°C)               | 17.3| 17.1|
| TDR                     | 0.19| 0.20|

there was either no difference between the CNH and the CWH, or a slight increase of 0.01 in the CWH. This result also showed that the drainage holes did not have a significant negative impact on the condensation resistance of the frame.

Based on the test results, it can be concluded that the level of drainage holes in the specimens is not a major concern in terms of condensation. However, if some of the TDR values of the glazing and frame are very close to the required values of the Design Standard, even a small increase in the TDR, such as by 0.01, can lead to the failure of satisfying the Design Standard (refer to the required TDR values in Table 3. and the TDR values of E-6, E-8 and F-7 points in Table 4. and Table 5.). Hence, it is necessary to perform the test with the drainage holes unsealed in the case for determining whether the Design Standard is satisfied.

4.2 Air-tightness Test Results

Table 6. shows the air-tightness test results. In the case of CWH, when the pressure difference was 10, 30, 50 and 100 Pa, the measured air infiltration rate was 0.63, 1.22, 1.62 and 2.66 m³/h·m² respectively, which was increased by 0.14, 0.08, 0.06 and 0.13 m³/h·m² compared to the CNH. This result describes the airflow...
through the drainage holes. However, both the CNH and CWH comfortably satisfied the 1st grade of airtightness level prescribed in the KS F 2292, showing that the use of drainage holes did not have a significant negative impact on the airtightness.

Table 6. Air-tightness Test Results

| Infiltration rate (m³/h·m²) | CNH | CWH |
|----------------------------|-----|-----|
| 10 Pa                      | 0.49| 0.63 (+29%)  |
| 30 Pa                      | 1.14| 1.22 (+7%)   |
| 50 Pa                      | 1.56| 1.62 (+4%)   |
| 100 Pa                     | 2.53| 2.66 (+5%)   |

*Infiltration rate variations compared to the CNH

5. Conclusion

In this study, the influence of drainage holes on the condensation resistance and airtightness of the triple glazing window was evaluated and analyzed. The results of this study are as follows.

1. The inside surface temperatures (Tsi) at most of the measurement points of the glazing and frame were 0.1 to 0.3°C lower for the window with drainage holes (CWH) than for the window without them (CNH). However, in the case of temperature difference ratio (TDR), there was no difference between the CNH and the CWH, or a slight increase of 0.01 in the CWH, which showed that the level of drainage holes used in the specimen had no significant negative impact on the condensation.

2. When some of the TDR values of the glazing and frame are very close to the required values of the Design Standard, even a small increase in the TDR, such as by 0.01, can lead to the failure of satisfying the Design Standard. Hence, it is necessary to perform the test with the drainage holes unsealed in the case for determining whether the Design Standard is satisfied.

3. The infiltration rates of CWH were 0.06 to 0.14 m³/h·m² larger than those of the CNH. However, both the CNH and CWH comfortably satisfied the 1st grade of airtightness level, showing that the use of drainage holes did not have a significant negative impact on the air-tightness.

This case study presents the mock-up test results of a triple glazing window which has a turn and tilt part and a fixed part with and without two punched drainage holes on each bottom glazing bead. Consequently, the results may vary depending on the opening areas and locations of drainage holes as well as the window type, size and configuration. For further study, it is necessary to perform tests to evaluate the various types of window with various opening areas and locations of drainage holes.

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