Predicting Potential Condensation at the Inside Surface of the Glazed Curtain Wall of High-Rise Residential Buildings

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Abstract
Condensation on the inside surface of the curtain walls of high-rise residential buildings is an important environmental problem in Korea. The purpose of this study is to introduce a new prediction method that can analyze the occurrence hours (days) of inside-surface condensation and compare with several design alternatives under a design stage, utilizing software codes developed by the authors according to the Korean standard, and numerical simulation models such as DOE, esp-r and so on.

The method consists of three parts; the first part is on a numerical simulation program that supplies the third part with input data such as weather data, indoor temperature, relative humidity and etc for 8,760 hours (8,760 hours = 1 year). Moreover, it can control building component, air-conditioning system, internal element like people, equipment and so on. The second part is on accurate U-values of the glass center and the glass edge that are received to the third part. The third part is on a software code to 1) determine the occurrence of condensation by the precedent procedure that calculates the inside-surface temperature and the dew-point temperature at the specific time and condition, and 2) sum up the occurrence hours (days) of inside-surface condensation. The application of the method is illustrated with an example of a high-rise residential building.

Keywords: surface condensation; humidity; curtain wall; high-rise apartment; numerical simulation

1. Introduction

A curtain wall in modern architecture is not a simple exterior material for decoration but it is brought into relief as a main structural element. According to the authentic source, there is the ratio of buildings reaches 45%-50%, the façades of which are constructed as a curtain wall in United States [Samsung, 2002]. In Korea, a curtain wall has been mainly used for high-rise office buildings until 1990s, but lately, it shows a tendency to be expanded to residential buildings as well as middle-storied buildings.

Since the latter half of the 1990s in Seoul, Korea, many construction companies have supplied high-class customers with deluxe residential apartments which are mostly high-rise. Curtain wall systems are applied to window systems of these buildings in that they require high thermal insulation, air-tightness, and few window openings which are at liberty to open for energy savings and safety [Sehyun Kim, 2002].

By the above-mentioned reasons, they depends on mechanical ventilation like a commercial building rather than natural ventilation [Samwoo, 2003] and they are not good at adequately controlling airflow and humidity for IAQ unlike a commercial buildings because of the thermal characteristics of housing. In addition to these inadequate controls, the remarkable difference between indoor and outdoor temperatures during the heating season causes inside-surface condensation to come out on a curtain wall [Henderson CW, 2000]. If the condensation water is not handled and removed without delay, it encourages mold and bacteria to be diffused around housing and lead to deteriorate IAQ.

Although a large number of studies have been made on evaluation and prediction of inside-surface condensation, they generally have made conditions such as under a special indoor environment (a fixed temperature & humidity), on a specific inside-building element, in a space specified, at the appointed time, and so on. The reality is not microscopic-and-specific. It is unreasonable to collectively evaluate and predict a degree of condensation in a building by the results of these studies, because a indoor environment of building is actually changed in a series of time by weather, a type of building, building component, air-conditioning system, internal element like people and equipment, and others.

A new approach method is needed for collective prediction of inside-surface condensation under a design stage. What do architect and engineer want? They want to know a degree of condensation in his building under a stage of design and compare a basic design with several alternatives by the degree. If they can predict that it is serious, they can take a step to prevent it and change the
design.

The purpose of this study is to introduce a new prediction method that can analyze a degree of inside-surface condensation in a building under a design stage and compare a basic design with design alternatives which are made by controlling building component, air-conditioning system, internal element like people, equipment and etc. This method are executed by mean of a software code developed by the authors according to the Korean Standard, THERM (made by Lawrence Berkeley National Laboratory), and a numerical simulation program based on esp-r.

In this paper, a high-rise residential building with more than 40floors was selected as a subject of application, whose outer skin was made from a curtain wall with few opening windows. The occurrence hours (days) of inside-surface condensation on the curtain wall was analyzed in respective floors. Floors with serious condensation were improved by finding appropriate airflow rate.

2. Theoretical approach & methodology

Figure 1 shows that the new method consists of three parts. The first part is on a numerical simulation program that supplies the third part with information about indoor conditions and etc for 8,760 hours (= 1 year). The second part is on correct U-values of a curtain-wall glass that are calculated by THERM. And the third part is on a software code to determine the occurrence of inside surface condensation by the precedent procedure that calculates the inside-surface temperature and the dew-point temperature by receiving hourly data from the first part and correct U-values of glass from the second part, and sum up the occurrence hours (days) of condensation.

2.1 Input data acquisition by a numerical simulation program: the first part of the method

To predict the occurrence hours (days) of inside surface condensation in a residential building during the winter, the third part requires physical values of building components, hourly weather data, and hourly indoor thermal environment data.

A numerical simulation program like DOE and esp-r supplies us these data. It can have an existed-or-planning building transformed into a computational model with input data such as physical values of building components, mechanical system, internal elements like people and equipment, and etc which can be easily controlled by a user. It produces output data.

Physical values of building components are obtained from drawings. Weather data such as TMY, TRY and etc are offered as modified data from meteorological observatory by public institutions, which represent hourly climatic characteristics of a region including outdoor temperature and humidity, wind speed and direction, sunshine duration and amount of clouds, and so on. The output data, obtained from execution of a numerical simulation program, are made up all kinds of loads, hourly indoor temperature with mean radiant temperature, hourly indoor relative humidity, air exchange rate and etc coping with hourly weather data.

These output data are passed into the third part with physical values of building components and weather data to calculate the dew-point temperature and the inside-surface temperature and determine the hourly occurrence of condensation.
occurs when the surface temperature is lower than the dew-point temperature, and summing up the occurrence hours (days) of condensation for 8,760 hours (=1 year).

The two temperatures are calculated by using following equations (1-6) because they are affected by the resistances of materials, indoor temperature and humidity, outdoor temperature and etc.

2.3.1 Dew-point temperature
The dew-point temperature \( t_d \) of moist air can be calculated directly by one of following equations (1) and (2) [Peppers, 1988]:

\[
t_d = C_1 + C_2 \alpha + C_3 \alpha^2 + C_4 \alpha^3 + C_5 (p_w)^{0.1984}
\]

for the dew-point temperature range of 0 to 93˚C:

\[
t_d = 0.09 + 12.608 \alpha + 0.4959 \alpha^2
\]

where \( t_d \) is the dew-point temperature (˚C), \( p_w \) is the water vapor partial pressure (kPa), \( \alpha \) is defined as \( \ln(p_w) \), \( C_1 \) is 6.54, \( C_2 \) is 14.426, \( C_3 \) is 0.7389, \( C_4 \) is 0.09486, and \( C_5 \) is 4.569.

To calculate the dew-point temperature, the water vapor partial pressure \( p_w \) is required in the equation (1) or (2) and it can be calculated if the relative humidity and the water vapor saturation pressure are known. The indoor temperature \( t_i \) and the relative humidity \( \varnothing \) are given as input, therefore the physical relationship between the water vapor saturation pressure \( p_{ws} \) and the water vapor partial pressure \( p_w \) is reduced to:

\[
\phi = \frac{p_w}{p_{ws}} \times 100
\]

Finally, the water vapor saturation pressure \( p_{ws} \), still not known, may be obtained by the equation (4) or (5) [Hyland & Wexler, 1983].

The saturation pressure over ice for the temperature range of -100 to 0˚C is given by:

\[
\ln(p_{ws}) = C_6 T + C_7 T^2 + C_8 T^3 + C_9 T^4 + C_{10} T^5 + C_{11} \ln T
\]

where \( C_6 \) is -5.674359E+03, \( C_7 \) is 6.3925247E+00, \( C_8 \) is -9.6778430E+03, \( C_9 \) is 6.2215701E-07, \( C_{10} \) is 2.0748725E-09, \( C_{11} \) is -9.4840240E-13, and \( C_{12} \) is 4.1635019E+00.

The saturation pressure over liquid water for the temperature range of 0 to 200˚C is given by:

\[
\ln(p_{ws}) = C_{13} T + C_{14} T^2 + C_{15} T^3 + C_{16} T^4 + C_{17} \ln T
\]

where \( C_{13} \) is -5.8002260E+03, \( C_{14} \) is 1.3914993E+00, \( C_{15} \) is -4.8640239E-02, \( C_{16} \) is 4.1764768E-05, \( C_{17} \) is -1.44520932E-08, and \( C_{18} \) is 6.5459673E+00.

In both equations (4) and (5), \( p_{ws} \) is the saturation pressure (Pa), \( T \) is the absolute temperature (K = °C + 273.15), and \( C_{6-18} \) are the coefficients that have been derived from the Hyland-Wexler equations.

2.3.2 Surface temperature
Since the temperature drop through and component of the wall is proportional to its resistance, the indoor surface temperature of wall and window etc can be calculated by the equation (6) [JASS 14]:

\[
t_d = t_i - \frac{U}{k_{is}} (t_i - t_o) = t_i - \frac{r_{is}}{R} (t_i - t_o)
\]

in which \( t_d \) is the dew-point temperature, \( t_i \) is the temperature of indoor surface, \( U \) is the overall heat transfer coefficient, \( k_{is} \) is the thermal conductivity of indoor surface material, \( t_i \) is the indoor temperature, to is the outdoor temperature, \( R \) is the thermal resistance (\( R=1/K \)), and \( r_{is} \) is the indoor surface resistance.

3. Practical application of the new method
3.1 Case for application
To illustrate how to apply the method, the building (1), a high-rise residential building with 42 floors at Samsung-Dong in Seoul Korea, was selected as a real case. The plane of the standard floor had three units with three different unit areas and it was simplified for numerical simulation as in figure 2.

This study chose the apartment unit, with an area of 210m², as a subject unit of analysis and predicted a degree of inside-surface condensation on its curtain-wall glass, expressed by the thick line.

3.2 Building description of case for the first part of the method
3.2.1 Numerical program & weather data
At the first part of the method, a numerical simulation program was used for input data acquisition of the third part. It has an engine based on esp-r which was made by Strathclyde university in UK.

Unlike DOE, it can run as an adjunct to Macroflo, a Module for an appraisal of naturally-ventilated and mixed-mode buildings, and they can exchange output data on indoor environment at run-time to achieve a fully integrated simulation. There is no officially-recognized weather data of Seoul in Korea. In this study, the weather data, used by the numerical simulation program was that of Seoul, Korea in 1983.

3.2.2 Physical properties of curtain wall
Thermal properties of the curtain wall as an input factor for numerical simulation are described as follows;

- Double-glazing glass: Clear glass(6mm) + Air gap(12mm) + Low-e glass(6mm)
- U-value of double-glazing glass: 1.750 W/m²K (furnished by a manufacturer)
- Overall heat transfer coefficient of the frame: 1.21 W/m²K
- Crack flow coefficients (1s⁻¹ m⁻³ Pa⁻⁰.⁶): 0.15
- Length of crack: 8.6 m

3.2.3 Physical properties of wall & floor
Physical values of wall and floor properties are summarized in table 1.
3.2.4 Internal gains & schedules [S. Park, 2002]

There are several internal gains in housing, such as human beings, lightings, TV, computer, refrigerator, and something like that. Two major gains of them are human beings and lighting. Human beings give off heat and moisture in different states of activity and also lighting is a major space load component. These sensible and latent heat gains constitute a large fraction of the total load. In this study, sensible and latent heat gains from human beings were established with their schedule as in Table 2. And Table 3 shows sensible heat gain from lighting and its schedule.

3.2.5 Set-point temperature

Although the set point temperature for heating is set up 20˚C by the design standard of heating system [KIER, 1984], according to the precedent field studies on indoor temperature of apartment unit in winter, it generally maintained about 23-26˚C [Song, 1998].

In this study, the set-point temperature of heating season was established 25˚C.

3.2.6 Humidity generated from latent heat load

General simulation programs such as DOE and esp-r generally have no module to calculate generated moisture. However, it is possible to calculate relative humidity by controlling the latent heat load while the sensible heat load is 0 W.

Although there were no accurate data about a latent heat load of housing, they were adjacently obtained by using measurement data on thermal environment of the building that has suffered from surface condensation. Fortunately, the building (I) has actually suffered from inside-surface condensation. Its measurement on indoor environment was conducted and recorded as in table 4. Iterative numerical simulation was needed to find the latent heat load for humidity. It was repeatedly conducted with phasing up the latent heat load and fixing the airflow rate (0.5 ACH) until its simulation result was approximately equal to measurement data.

Absolute humidity became a subject of comparison in that it was not affected by the variations of temperature while relative humidity was influenced by them. In Table 4, the absolute humidity of the lower floors was approximately from 0.0033 to 0.0059 kg/kg and that of the upper floors was from 0.0082 to 0.0114 kg/kg.

According to the result of several iterations, as the latent heat load was 4.5 W/m^2, the average absolute humidity was found to be 0.005 kg/kg in the lower and 0.011 kg/kg in the upper under 0.5 ACH. This result was similar with the measurement data. Therefore, The latent heat load was established as 4.5 W/m^2.

3.3 U-values of glass center & edge from the second part of method

3.3.1 Input data for THERM

As a curtain-wall glass was divided into the glass center and the glass edge, their accurate U-values were calculated by THERM for precise prediction. All kinds of the curtain-wall materials and their properties were described as an input of THERM in Table 5.

Table 6 shows weather conditions including outdoor temperature, wind speed and etc which were made by NFRC (National Federation of Roofing Contractors, USA).

3.3.2 U-value of the glass center

According to the analysis result by THERM, the glass center U-value was calculated at 1.737 W/m^2K in summer and 1.755 W/m^2K in winter. Its values were tested by comparing with those of the laboratory measurement and other calculations. Their differentials were no more than 4%.

3.3.3 U-value of the glass edge

In figure 3, there were two locations of the curtain wall chosen for analysis of U-value, which were called mullion (1) and mullion (2).

To find the difference between the glass center U-value and the glass edge U-value, two points were selected in each mullion. One point was 60 mm far from the frame and another was 150 mm far from it.

Figure 3(a)(c) shows temperature contour graphs of two mullions. Under the weather condition with -18˚C of outdoor temperature and 21˚C of indoor temperature, based on NFRC, the lowest frame temperatures of mullion (1) and mullion (2) were decreased to -3.1˚C and -2.1˚C respectively.

Also this frame temperature, easily influenced by climate changes, have affected glass temperatures in that a part of glass had lower temperature as it was closer to the frame. The glass U-value at P1-2 (see figure 3) was calculated at 1.76 W/m2K in table 7, which was similar to the glass center U-value, 1.755 W/m2K. But the glass U-value at P1-1 was calculated at 2.34 W/m2K, increased by 30% in comparison with the glass center U-value because of the influence of the frame. In this study, 1.755 W/m2K of the glass center U-value and 2.34 W/m2K of the glass edge U-value were taken as an input of the third part.
Table 2. Occupation Schedule (%) Of Human beings With Sensible And Latent Heat Load

| Day     | Time | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  |
|---------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weekdays|      | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50  | 25  | 25  | 25  | 25  | 0   | 0   | 25  | 25  | 50  | 50  | 75  | 75  | 75  | 100 | 100 | 100 | 100 |
| Saturday|      | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50  | 25  | 25  | 25  | 25  | 25  | 25  | 50  | 50  | 75  | 75  | 75  | 75  | 100 | 100 | 100 | 100 |
| Sunday  |      | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 75  | 75  | 50  | 50  | 50  | 50  | 25  | 25  | 50  | 50  | 75  | 75  | 75  | 100 | 100 | 100 | 100 |

1) The size of a family is set up at 4 persons. 2) Sensible Heat Load: 90 W/person, Latent Heat Load: 60 W/person

Table 3. Internal Heat Load Of Lighting And Schedule (%)

| Type                  | Item   | Unit Power (W) | Num | Caloric Power/W (kcal/h) | Caloric Power (kcal/h) | Schedule (%) |
|-----------------------|--------|----------------|-----|--------------------------|------------------------|--------------|
| Fluorescent Lamp      | 40     | 60             | 0.66| 211.2                    | 0                      | 1-4          |
| Incandescent Bulb     | 60     | 3              | 0.62| 111.6                    | 0                      | 5            |
| Fluorescent Bulb      | 20     | 8              | 0.41| 65.6                     | 0                      | 6-7          |
| Total                 |        |                |     | 388.4                    | 0                      | 8-17         |

Table 4. Measurement Data On Thermal Environment Of The Building (I)

| Floor & Unit          | Item         | Temperature (°C) | Relative humidity (%) | Absolute humidity (kg/kg)* | Conden | 1 | 2 | Ave. |
|-----------------------|--------------|------------------|-----------------------|-----------------------------|--------|---|---|------|
| 11th Floor, Unit A (East) | Min. | Max.  | Ave. | Min. | Max. | Ave. | 1 | 2 | Ave. | 1 | 2 | Ave. |
| 19.5                  | 21.0         | 20.0             | 8.0                    | 5.0                         | X      | 0.0042 | 0.0056 | 0.0045 |
| 12th Floor, Unit A (North) | 12.0      | 20.0             | 20.0                   | 20.0                        |        | 0.0073 | 0.0049 | 0.0059 |
| 12th Floor, Unit B (West) | 15.0      | 20.0             | 20.0                   | 20.0                        |        | 0.0024 | 0.0033 | 0.0033 |
| 18.5                  | 20.0         | 20.0             | 20.0                   | 20.0                        |        | 0.0037 | 0.0062 | 0.0048 |
| 23rd Floor, Unit A (East) | 20.0     | 25.0             | 25.0                   | 25.0                        | O      | 0.0099 | 0.0115 | 0.0110 |
| 22nd Floor, Unit A (South) | 14.0     | 21.5             | 17.8                   | 17.8                        |        | 0.0075 | 0.0080 | 0.0082 |
| 23rd Floor, Unit B (North) | 22.0     | 25.0             | 23.9                   | 23.9                        |        | 0.0083 | 0.0114 | 0.0114 |
| 23rd Floor, Unit C (South) | 15.0     | 30.0             | 20.2                   | 20.2                        |        | 0.0092 | 0.0111 | 0.0109 |

1) Absolute humidity is in Minimum humidity, 2) Absolute humidity is in Maximum humidity

Table 5. Climate Condition Of THERM

| Outdoor Temperature (°C) | Thermal Conductivity (W/m²K) | Indoor Temperature (°C) | Thermal Conductivity (W/m²K) |
|--------------------------|-------------------------------|-------------------------|-------------------------------|
| NFRC100-2002 Winter     | -18                           | ASHRAE/NFRC              | 21                            |
| NFRC100-2002 Summer     | 32                            | ASHRAE/NFRC              | 24                            |

1) ASHRAE/NFRC Outside: 25.4 W/ m²K (Wind Speed 5.5%), 2) ASHRAE/NFRC Inside: 8.12 W/ m²K(Wind Speed -3%)
improved by reducing the sources of moisture and increasing the removal rate by ventilation or dehumidification. But in case of residential buildings, it is more difficult to reduce the moisture sources than to increase the removal rate. Therefore, it is necessary to analyze the variations of relative humidity by regulating airflow rate.

3.4.1 Analysis day

In table 4 as summarizing measurement data, it was reported that the apartment unit (b) in the 23rd floor had 0.114 kg/kg of absolute humidity under -8°C of outdoor temperature, 23.9°C of indoor temperature, and about 60% of relative humidity. These climatic conditions were similar to those of January 17 in the Seoul weather data of the year 1983. Therefore, January 17 was selected as an analysis day and its weather conditions were summarized as the following: -4°C of average outdoor temperature (-10°C of the lowest, -2°C of the highest), 2.1 m/s of the highest wind speed and etc.

3.4.2 Relative humidity under 0.5 ACH as minimum air exchange rate

First of all, it is necessary to analyze air exchange rate of each floor that influences humidity. And also it must be considered that air exchange can be divided into internal air exchange from a core, a stair case and etc, and external air exchange. In figure 4, average air exchange rate declined from 0.46 ACH of the 1st floor to 0.25 ACH of the 19th floor and then it again rose to 0.51 ACH of the 38th floor. Although the 19th floor had 0.25 ACH as the lowest, its external air exchange rate was more than those of the floors above it.

Figure 4 also shows that external air exchange rate decreased as it went up higher floor but internal air exchange rate came out from 0.01 ACH of the 19th floor and rose to 0.44 ACH of the 38th floor. These phases influenced relative humidity of each floor.

Relative humidity was rapidly increased before the 19th floor in accordance with the declaration of external air exchange rate and then, it fell gently after the 19th floor due to the rise of internal exchange rate. Relative humidity of the 1st floor was less than that of the 19th floor by 26%. It means that higher floors are more affected by the occurrence of discomfort condensation than the lower floors.

3.4.3 Relative humidity under 0.5 ACH+20m³/ hour person(h p)

The analysis of relative humidity in section 3.4.2 was conducted on the assumption that there was no air-handling unit under 0.5 ACH by infiltration. As a result of the analysis, high relative humidity of the 19th floor, one of middle floors, was caused by its low air exchange rate.

Air-handling unit, that conditions airflow rate for a building, is needed to reduce relative humidity. Figure 5 shows the variations of air exchange rate and relative humidity in the 1st floor and the 2nd floor under four conditions. Air exchange rate of the 19th floor with air-handling unit of 20m³/h p, represented by the white-circle line, shows an improvement by +0.28 ACH as compared against that of the 19th floor without air-handling unit, represented by the black-circle line. Due to the improvement of air exchange rate, relative humidity of the 19th floor with air-handling unit was reduced by +26%. In this way, an appropriate level of ventilation can be found to prevent discomfort condensation of a building.

3.5 Calculation of condensation hours from the third part of the method

The third part can determine whether inside-surface condensation occurs or not by calculating the dew-point temperature and the inside-surface temperature of the curtain wall and comparing with them. It receives essential input data for its calculations from the first and the second part.

Two 210m² apartment units of the 1st floor and the 19th floor, having the lowest relative humidity and the highest relative humidity respectively, were selected as a subject to calculate condensation hours (days) on two inside surfaces of the curtain wall which was divided into the glass center (1.755 W/m²K) and the glass edge.
3.5.1 Condensation hours (days) under 0.5 ACH in winter (December 1-February 28)

In case of the 1st floor, even if there was no air-handling unit, inside-surface condensation didn't occur. But in case of the 19th floor, table 8 shows that inside-surface condensation occurred during 341 hours in 42 days at the glass center and 839 hours in 44 days at the glass edge due to high relative humidity by low air exchange rate.

The variations of relative humidity in the 19th floor were presented in figure 6. The line, representing the variations of relative humidity in the 19th floor during the winter, widely fluctuates from 20% to 80%, but that of the 1st fluctuated small by the axis of 40%. It supports that surface condensation may occur when indoor relative humidity is higher than 80% for long periods [ASHRAE, 1997].

3.5.2 Condensation hours (days) under 0.5 ACH+20 m³/h

In case of installing air-handling unit with 20 m³/h person to reduce the surface condensation of the 19th floor, inside-surface condensation did not occur during the winter.

Table 8. Condensation Hours & Days Of Each Point(19th)

| Condensation Hours(1) | 341 | 839 |
|-----------------------|-----|-----|
| Condensation Hours(2) | 324 | 795 |
| Condensation Days     | 42  | 44  |

(1): without consideration of radiation 
(2): no condensation between 10am & 4pm due to radiation
4. Conclusion

In Korea, curtain wall systems are applied to the window systems of high-rise apartment buildings because of high thermal insulation and air-tightness for energy savings and safety. These residential buildings depend on mechanical ventilation like a commercial building. Their occupants have suffered from discomfort condensation on curtain walls caused by inadequate controls of ventilation and humidity, and remarkable difference between indoor and outdoor temperatures. Therefore, it is necessary for designers and engineers to know how many hours (days) there will be condensation on a curtain wall under a stage of design. If they know a degree of condensation under a design stage, they take a step to prevent it and change their designs.

This study comes up with a new method to predict inside-surface condensation of a curtain wall. This method consists of three parts: The first part is on a numerical simulation program that supplies the third part with information about indoor conditions for 8,760 hours. The second part is on correct U-values of a curtain-wall glass that are calculated by THERM. The third part is on a software code to determine the occurrence of inside-surface condensation and sum up the occurrence hours (days) of condensation by receiving hourly data from the first part and correct U-values from the second part.

A brief summary of the application results is given as follows;

First, the apartment unit with an area of 210m² was chosen as a subject unit in the building (I) with 42 floors at Samsung-Dong in Seoul Korea.

Secondly, the glass center U-value was 1.755 W/m²K and the U-value at 60 mm from the frame was 2.32 W/m²K and the U-value at 150 mm from the frame was 1.756 W/m²K. The glass edge has a higher U-value than the glass center by 30%.

Thirdly, relative humidity was rapidly increased before the 19th floor in accordance with the declination of external air exchange rate, and it fell gently after the 19th floor due to the rise of internal exchange rate. Relative humidity of the 1st floor was less than that of the 19th floor by about 26%. It means that higher floors are more affected by the occurrence of discomfort condensation than the lower floors. Installing air-handling unit (20m²/h person) made the unit’s relative humidity reduced to a meanly 40%.

Lastly, in case of the 1st floor, even if there was no air-handling unit, inside-surface condensation didn’t occur. But in case of the 19th floor, inside-surface condensation occurred during 341 hours in 42 days at the glass center and 839 hours in 44 days at the glass edge due to high relative humidity by low air exchange rate.

In case of installing air-handling unit with 20m²/hour person to reduce inside-surface condensation of the 19th floor, inside-surface condensation did not occur during the winter.

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