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Evaluation of the Insulation Performance of Curtain Walls in High-rise Residential Buildings

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Abstract

A curtain wall is presently being adopted widely in high-rise buildings because of its several merits in many aspects. Curtain walls, however, also have some problems, such as thermal efficiency and moisture condensation, especially in countries where there are four seasons like Korea, because of wide, glazing windows and metal frames that have high thermal conductivity. Furthermore, insulation efficiency is more important in high-rise buildings than in low-rise buildings when outdoor conditions worsen.

There are two main objectives in this research; first, to perform steady state conduction simulations for curtain wall materials in high-rise outdoor conditions, and second, to evaluate insulation efficiency and moisture condensation on curtain wall surfaces based on the results of the simulations.

Keywords: high-rise residential buildings, curtain walls, insulation efficiency, moisture condensation

1. Introduction

Construction technology has changed the form of residential structures. Furthermore, the restriction in residential areas, and the increase of building expenses have resulted in high-rise and highly dense residential buildings. Eventually, many Korean cities have high-rise residential buildings along with apartments and commercial stores. Most of these residential buildings have curtain walls as exterior envelopes. A curtain wall is presently being adopted widely in high-rise buildings because of their several merits in many aspects. Curtain walls, however, also have some problems, such as thermal efficiency and moisture condensation, especially in countries like Korea, where there are four seasons, because of their wide, glazing windows and metal frames that have high thermal conductivity. Moreover, insulation efficiency is more important in high-rise buildings than in low-rise buildings when outdoor conditions worsen. The cold bridge seeps through the metal frames whose high thermal conductivity deteriorates energy efficiency, and during winter, interior moisture condensation causes low durability in building materials.

To avoid cold bridge and moisture condensation, mock-up thermal tests must be performed during the designing process. Mock-up tests, however, require too much labor and expense. Therefore, a heat conduction simulation can be a very useful tool in curtain wall design because computer simulation has no limits, and needs less time and expense. Accordingly, there is a need to study the computer simulation of outdoor climate conditions with respect to high-rise buildings.

There are two main objectives in this study; first, to perform steady state conduction simulations for curtain wall materials in high-rise outdoor conditions, and second, to evaluate insulation efficiency and moisture condensation on curtain wall surfaces based on the results of the simulations.

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2. Methods

2.1 Hypotheses regarding insulation efficiency simulations

In this study, Fluent 6 (FVM) was used as a simulation tool.

In simulating curtain walls, the following hypotheses were made to simplify calculation:

- two dimensional steady-state conditions,
- the properties of building materials do not vary with changes in temperature,
- isotropic materials,
- the following effects are neglected:
  - airflow through building components, and
  - the effects of solar and long-wave radiation on the walls.

2.2 Heat transfer coefficients in high-rise conditions

The heat transfer coefficient number of exterior air is very important, especially in high-rise buildings. At the external surfaces of buildings, the transfer of heat to the natural environment is a complex and variable process with respect to the height of the buildings. The work of CIBS(Chartered Institute of Building Services) gave rise to the following design rule[1]:

$$h_c = 4.1V + 5.8 \qquad (1)$$

for h_c in W/㎡ K and wind speed V in m/s.

Wind speed varies with height because of the atmospheric boundary layer from the ground to 1Km. Winds aloft generally have a higher velocity than the winds at ground level. In other words, at any given time and place, wind speed usually increases with altitude. The effect of altitude on wind speed involves two factors:

◦ the degree of mixing turbulent flow prevailing in the atmosphere at the given time and place as characterized by the Pasquill stability class, and

◦ the terrain's surface area roughness which induces surface friction at the given location.

It has generally been agreed upon that the effect of altitude on wind speed is logarithmic, and can be expressed as[2]:

$$\frac{U_z}{U_g} = \left(\frac{H_z}{H_g}\right)^n, \qquad (2)$$

where :

U_z is the wind speed at height z (meter),

U_g is the wind speed at ground-station height,

H_z is the height z,

H_g is the ground-station height (10 meters), and

n is a function of the Pasquill stability class and the terrain type

Table 1. Exponent n for use in urban terrain

Stability	Exponent n
A	0.15
B	0.15
C	0.20
D	0.25
E	0.40
F	0.60

Table 1 shows various Pasquill stability types and the exponent number n. Fig. 1 shows the variation of wind speed with altitude and Pasquill stability[3]. In this study, Pasquill stability E(exponent n = 0.4) was used to simulate an adverse exterior climate condition.

By the above equations (1) and (2), the calculated wind speed value of exterior air at a height of 400m during winter was 9.8 m/s, and the heat transfer coefficient number was 45.98 W/㎡ K. As for the interior heat transfer coefficient number, 8.29 W/㎡ K was adopted with ASHRAE Fundamentals.[4]

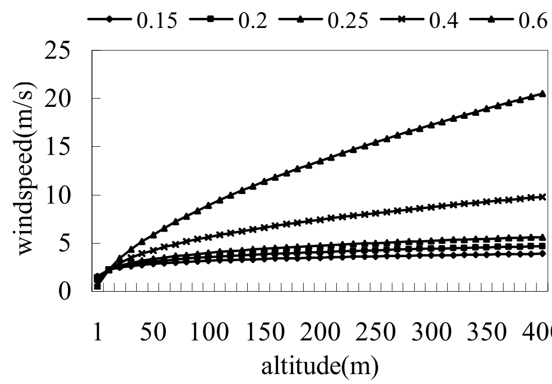

Fig. 1. Uz with various stability and altitude

Table 2 shows the values of the various boundary conditions used for simulation. The interior and exterior temperatures were established, considering heating conditions during winter.

Table 2. Boundary conditions for simulation

	Heat transfer coefficient	Temperature
Interior	8.29W/㎡ K	293K(20℃)
Exterior	45.98 W/㎡ K	258K(-15℃)

2.3 Structure of curtain wall frame

There are many types of curtain wall frames, and their shapes and materials vary. The simulation models are selected at random among the existing curtain wall frames of high- rise residential buildings constructed within the last five years.

Fig. 2 shows the details of each curtain wall type. Generally, the curtain wall frame consists of a mullion (vertical frame) and a transom (horizontal frame) as well as aluminum frame, a double glazed window with an air cavity, a gasket, a sealant and a thermal break.

They all have thermal breaks except type C.

Type A has a double thermal break in the mullion, and the height of the building is about 170m. Type B has a complicated section detail in the mullion, and the height of the building is about 256m. Type C has no thermal breaks and a simple section detail in the mullion, but is complicated with many gaskets in the transom, and the height of the building is about 70m. Type D has large frames and triple glazings with argon gas, and the height of the building is about 100m.

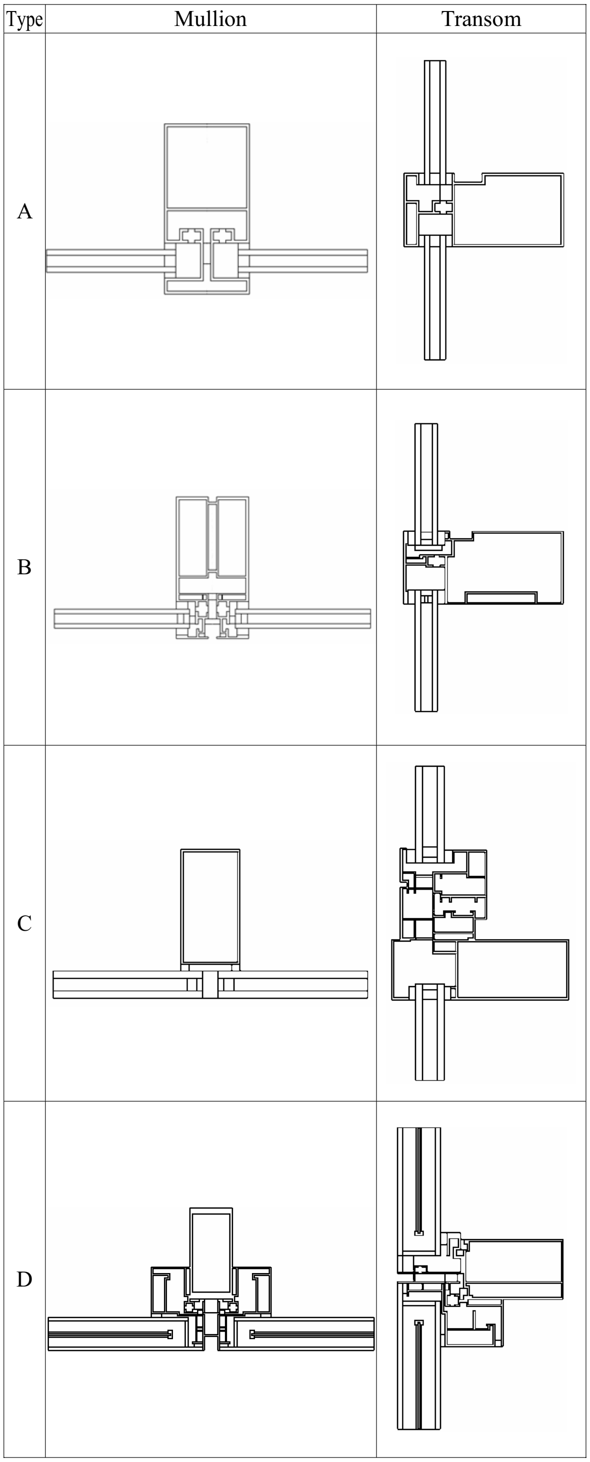

Fig. 2. Mullions and transoms for various curtain wall frames

Table 3 shows heat conductivity in curtain wall materials.[5)]

Table 3. Heat conductivity in curtain wall materials

Material	Heat conductivity(W/mK)
Aluminum frame	227.4
Sealant	0.032
Spacer(aluminum)	227.4
Thermal Break	0.03
Gasket	0.032
Glass	0.8

Table 4 shows the KSF 2295 condition. KSF is the Korean Industrial Standard for engineering and construction and, KSF 2295 defines the method in testing the efficiency of condensation prevention in windows and doors. Therefore, if the interior surface temperature of the curtain wall frame is below the dew point temperature (282.3K), condensation would likely occur[6)].

Table 4. Interior temperatures and humidity conditions of KSF2295

Interior temperature	Relative humidity	Absolute humidity	Vapor pressure	Dew point
293K	50%	7.34 g/kg	8.765mmHg	282.3K

2.3 Result of the simulations

Fig. 3 shows the temperature profiles, condensation lengths, and locations of curtain walls in normal and high-rise conditions using the same curtain wall frames. Temperature profile changes at the aluminum frame were more severe than at the glazing because of high thermal conductivity. The mullion of Type A was affected by the exterior climate more than the other types were because the exterior aluminum frame penetrated the wall and had no proper breaks. The low temperature of the exteriors was transmitted to the interiors through the aluminum frame. Type B showed more complicated section details. Both the mullion and the transom in Type B had the proper breaks designed to cut the exterior and interior aluminum frames by thermal break, the gasket, and the sealant. Since the transom of Type C had a large aluminum frame, the transom showed more temperature changes in high-rise conditions, compared to the mullion.

Because Type D also had large aluminum frames, the temperature at the aluminum frame was remarkably lower than that at the glazings, compared to the other types.

Fig. 4 compares the temperature distribution in normal and high-rise conditions at the interior surface. In all the given types, the aluminum frame and the

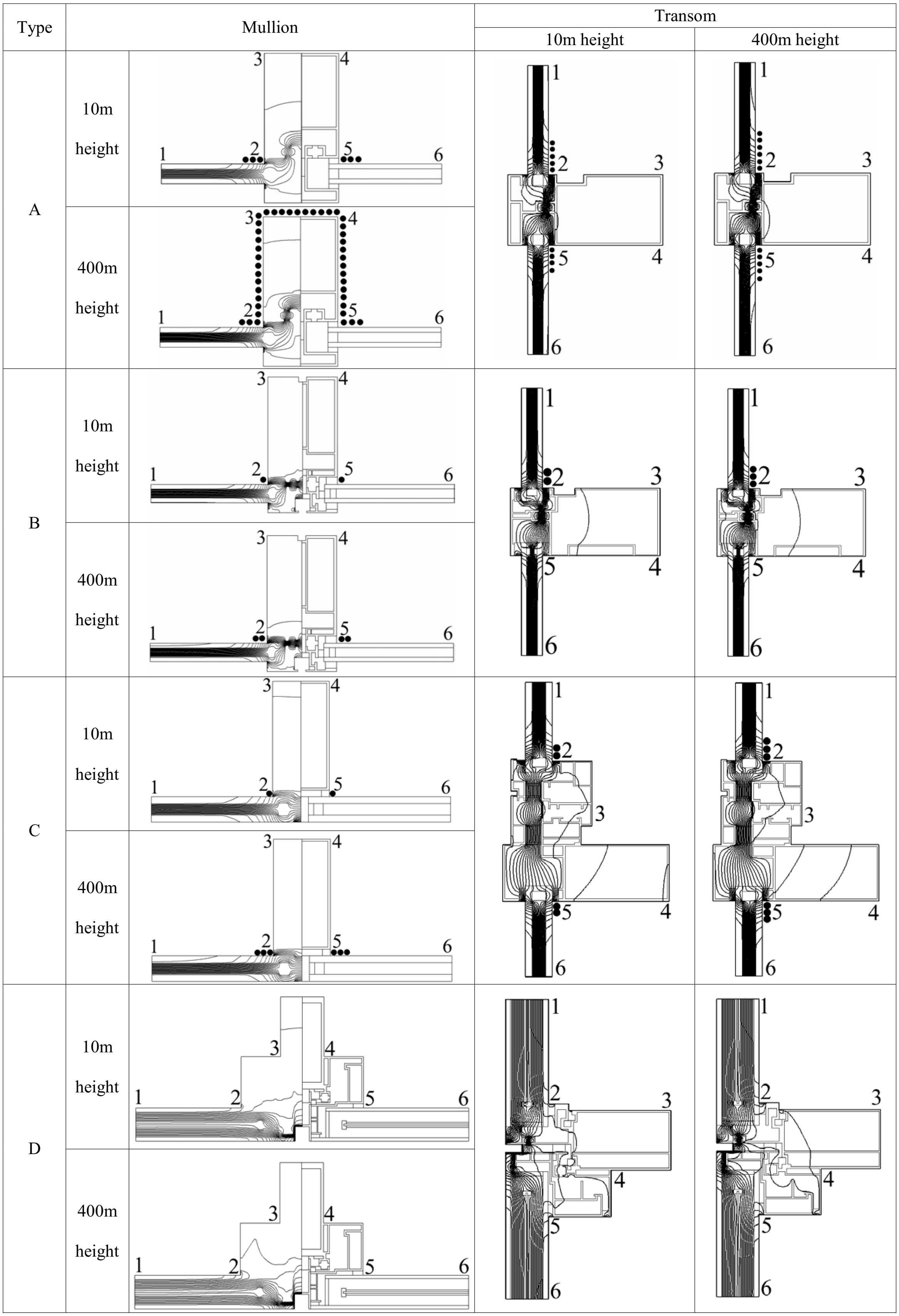

Fig. 3. Temperature profiles, condensation lengths, and locations of curtain wall in normal and high-rise condition

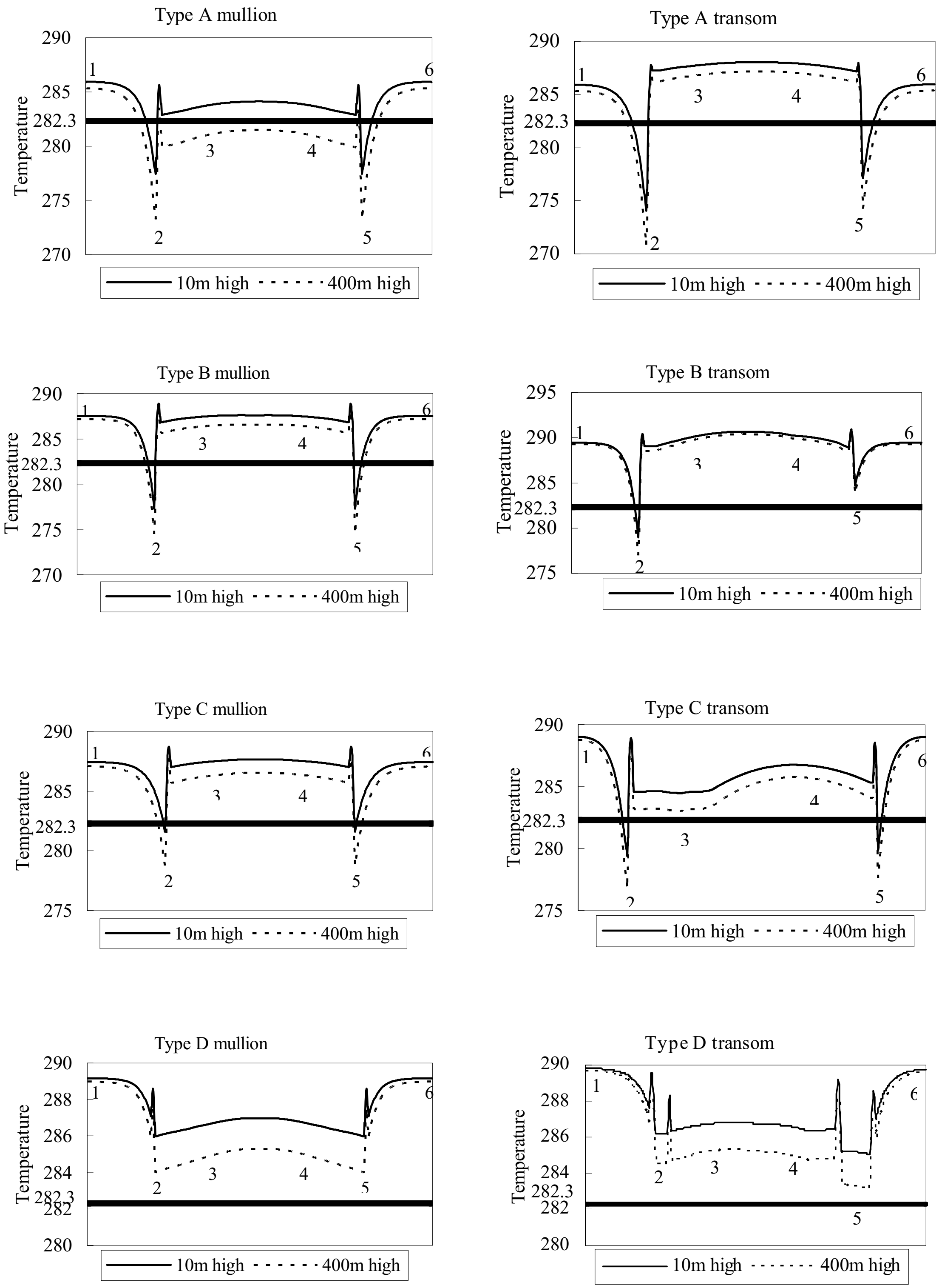

Fig. 4. Comparison of temperature distribution in normal and high-rise condition

glazings showed the lowest temperatures. Except in the case of Type D, the simulation on all the types of mullions and transoms resulted in moisture condensation at the interior surface, where the lowest temperature was below the dew point temperature of 282.3K. The changes of temperature at the mullions were greater than at the transoms because the interior and exterior aluminum frames of the mullion were not clearly separated as in the transoms. The mullion and the transom of Type B showed less changes in the temperature of glazings and the aluminum frame compared to other types. So Type B could be considered the most stable among the three types with the exception of type D. Though Type D had a large aluminum frame, the triple glazings with argon gas and the effective design of the joint aluminum frame and glazings did not resulted in moisture condensation.

Table 5. Comparison of condensation lengths in normal and high-rise conditions

	Mullion		Transom	
	10 m	400 m	10 m	400 m
Type A	40(mm)	414	49	69
Type B	40	56	9	13
Type C	8	36	31	50
Type D	0	0	0	0

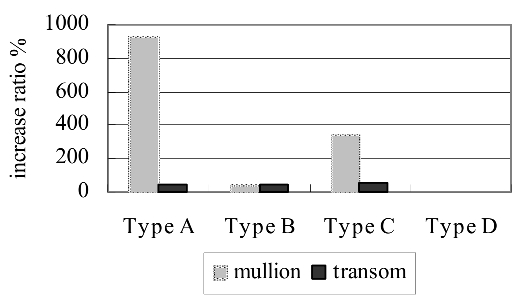

Fig. 5. Comparison of condensation length increase ratio in normal and high-rise conditions

To study the insulation efficiency of all types, the length of moisture condensation and its increase ratio were calculated.

Table 5 and Fig. 5 show more detailed results on the increase of moisture condensation by comparing condensation lengths in normal and high-rise conditions through the interior surfaces of the curtain walls.

The simulation results of moisture condensation length showed that high-rise conditions affected the insulation efficiency of curtain walls significantly because of the change in heat transfer coefficient number by height was equal in the all the types, but the increase ratio of moisture condensation length varied. The increase ratio of the condensation length of mullion Type A was 935%, the highest among all other types. As mentioned above, the insulation efficiency of mullion Type A was poor due to the penetrating aluminum frame. This result assumed that curtain walls with ineffective insulation would be worse in high-rise conditions. On the contrary, the condensation increase ratio of Type B was 40% (mullion), and 40.4% (transom), respectively, as Type B showed stable insulation efficiency against the changes in exterior conditions.

3. Conclusions

In this study, steady state conduction simulations for curtain wall materials were performed in normal and high-rise outdoor conditions, and insulation efficiency and moisture condensation on curtain wall surfaces were evaluated according to the results of the simulations.

Based on these results, the following conclusions were drawn.

- To simulate the insulation efficiency of curtain walls in high-rise conditions, this study established the heat coefficient number with the building's height.

Considering adverse conditions during winter, by the above equations (1) and (2), the calculated wind speed value of the exterior air at a height of 400m was 9.8 m/s, and heat transfer coefficient number was 45.98 W/㎡ K.

- The simulation results of the temperature profile for four curtain wall types showed that it is very important to separate exterior and interior aluminum frames appropriately through thermal breaks, gaskets and sealants.

In all types, the joint aluminum frame and glazings showed the lowest temperature. The joint frame and glazings have an effect on the insulation efficiency of the curtain walls. The Type D, with triple glazings and argon gas, showed the best insulation efficiency, as it showed no moisture condensation in normal and high-rise conditions.

- The simulation results with regard to moisture condensation lengths showed that high-rise condition affected the insulation efficiency of curtain walls because the change in the heat transfer coefficient number by height was equal in the all the types, but the increase ratio of moisture condensation length varied.

- The curtain wall with ineffective insulation would worsen in high-rise conditions. The increase ratio of the condensation length of mullion Type A was 935%, the highest value among all the types. The insulation efficiency of mullion Type A was poor because of the penetrating aluminum frame. On the contrary, the condensation increase ratio of Type B was 40% (mullion), and 40.4% (transom), respectively as Type B showed stable insulation efficiency against changes in exterior conditions.

Acknowledgments

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