INDOOR HUMIDITY INFLUENCED BY THE STACK EFFECT IN HIGH-RISE RESIDENTIAL BUILDINGS

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ABSTRACT

Interior-surface condensation on the glazed curtain wall of high-rise residential buildings is an important environmental issue in Korea. There are three causes of the surface condensation. One is the curtain wall frame materials, another is the generated moisture from residents' behaviors such as cooking and drying the laundry, the other is inadequate ventilation caused by stack effect. The purpose of this study is to analyze the hourly occurrence of interior-surface condensation on the glazed curtain wall for the comparison to design alternatives at the design stage of high-rise residential buildings by using numerical models. The results can be summarized as follows; The possibility of condensation occurrence in the upper floors is higher than that in the lower floorsdue to the stack effect.

KEYWORDS

Stack effect, Humidity, High-rise residential building, Condensation, Indoor humidity

INTRODUCTION

Recently, the number of high-rise residential buildings, which can supply full-sized units for the high-income bracket in large quantities, has been increased in Korea. These residential buildings have the following physical characteristics: (1) curtain-wall envelope having high insulation and air-tightness due to energy savings and safety against strong winds (2) central core connecting residential units to elevator shafts/stair halls (3) residential unit depending on mechanical ventilation rather than natural ventilation due to limited number of openable windows(SAMOO, 2003)

These physical characteristics with the high-rise structure give rise to the stack effect through the vertical elevator shaft/stair hall in the building, causing stack pressure difference which determines the amount and direction of airflow between two spaces as followings: between curtain wall envelope and unit, between unit and core, between core and elevator shaft/stair hall. This stack effect is generally reported to raise severe problems such as sticking elevator doors, difficulty in opening doors, and noise resulting from air flowing through cracks(Jo et al. 2007). However, new stack effect problems are reported in high-rise residential buildings in Korea. One of the problems is that condensation frequently occurs on the interior curtain-wall surface in the upper floors. The stack effect is spotted as a suspicious factor on this excessive indoor humidity of the upper floors, caused by an improper balance between moisture generation and removal due to the poor ventilation performance.

This study aims to analyze the influence of the stack effect on the indoor humidity of the high-rise residential building, and to suggest several methods that can relieve the excessive indoor humidity at the upper floors. This research procedure was as follows: (1) To predict the amount and schedule of moisture generation in the typical residential unit, air temperature and humidity were measured in the selected apartment units during the winter. (2) The I-Park building, a high-rise residential building with 42 basic floors in Seoul, Korea, which was verified on the stack effect from the study of Jo et al. (2007) was selected as a case building. (3) Energy simulations (VE) with the natural ventialtion module(Macroflo) were conducted to predict the pressure differences among the spaces for the influence analysis of the stack effect on the indoor humidity in the building.

METHOD

Building selection

To illustrate how to apply the approach method, figure 3 shows the I-PARK Building, a high-rise residential building with 42 floors at Samsung-Dong in Seoul, Korea, is selected as a real case. Each floor has three units with different areas, and its plan is simplified for energy and ventilation models as shown in Figure 1. The apartment unit with an area of 210 ㎡ is chosen as a subject unit for prediction in the degree of interior-surface condensation on the glazed curtain wall using the approach method of this study.

Input data for the energy and ventilation models

The energy simulation program VE (Virtual Environment) is used for the comparison analyses. Unlike DOE, VE can run as an adjunct to Macroflo, a ventilation module used for the appraisal of naturally-ventilated and mixed-mode buildings. They both can exchange output data on indoor environment at run-time to achieve a fully integrated simulation (IES, 2003).

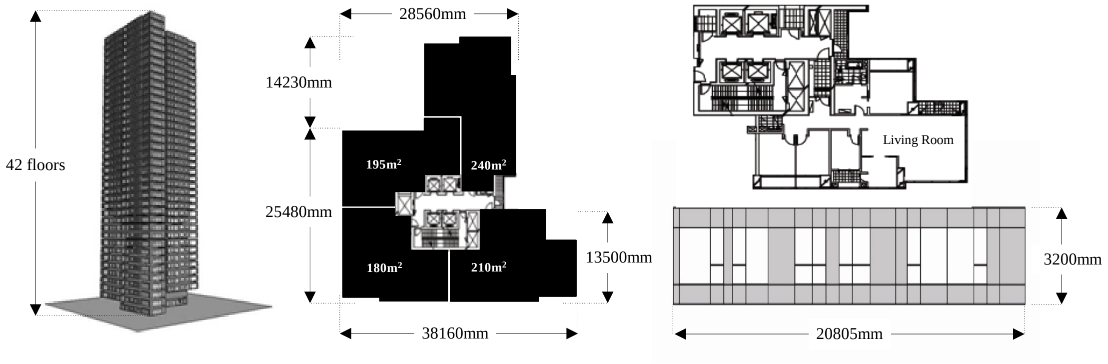


Figure 1 Simulated model of the selected building

Table 1 Occupation schedule of human beings with sensible and latent heat loads

DAY	SCHEDULE (%)														FAMILY & LOADS
	8	9	10	11	12	13	14	15	16	17	18	19	20	21-7	
Weekdays	50	25	25	25	25	0	0	0	25	25	50	50	75	100	4 persons in each unit
Saturday	50	25	25	25	25	25	25	25	50	50	75	75	75	100	Sensible heat 90W/p
Sunday	75	75	50	50	50	50	25	25	50	50	75	75	75	100	Latent heat 60W/p

Table 2 Internal heat load of lighting and schedule

ITEM / TYPE	W	NUM	KCAL/HW	KCAL/H	SCHEDULE (%)							
					1-4	5	6-7	8-17	18-19	20-21	22	23-24
Fluorescent Lamp	40	8	0.66	211.2	0	34	67	0	67	100	67	34
Incandescent Bulb	60	3	0.62	111.6	0	33	67	0	67	100	67	33
Fluorescent Bulb	20	8	0.41	65.6	0	33	67	0	67	100	67	33
Total				388.4	0	33	67	0	67	100	67	33

Table 3 Measured data of the selected building

	TEMPERATURE (℃)			RELATIVE HUMIDITY (%)			ABSOLUTE HUMIDITY (kg/kg)			YES/NO[1]
	MIN.	MAX.	AVE.	MIN.	MAX.	AVE.	MIN.	MAX.	AVE.	
11th Floor (Unit A,E)[2]	19.5	21.0	20.0	27.0	40.0	30.8	0.0042	0.0056	0.0045	No
11th Floor (Unit B, S)	12.0	31.0	21.1	26.0	56.0	37.8	0.0048	0.0073	0.0059	
12th Floor (Unit A, N)	15.0	20.0	18.6	23.0	28.0	25.1	0.0024	0.0043	0.0033	
12th Floor (Unit B, W)	18.5	27.0	20.5	28.0	36.0	32.0	0.0037	0.0062	0.0048	
23rd Floor (Unit A, E)	20.0	25.0	23.5	58.0	68.0	61.0	0.0099	0.0115	0.0110	Yes
22nd Floor (Unit A, S)	14.0	21.5	17.8	50.0	76.0	64.5	0.0075	0.0082	0.0080	
23rd Floor (Unit B, N)	22.0	25.0	23.9	42.0	69.0	61.7	0.0083	0.0114	0.0110	
23rd Floor (Unit C, S)	15.0	30.0	20.2	42.0	87.0	73.8	0.0092	0.0111	0.0109	

1) Yes/No: Yes is when there is condensation, No is when there is no condensation
2) (Unit, Direction)

Weather data of Seoul on September 8, 2002 obtained from the meteorological agency are used for the analyses including the comparison of measured data with predicted data.

1) Weather

There is no current officially-recognized weather data for Seoul in Korea. Historical weather data of Seoul, Korea in 1983 is used for this study.

2) Building description data

① Physical properties of walls, floors and glazed curtain walls

The thermal properties of the glazed curtain wall are described as follows:

- Double-glazing glass: Clear glass(6 ㎜) + Air gap(12 ㎜) + Low-e glass(6 ㎜)

Table 4. Crack flow coefficients $(1s^{-1}m^{-1}Pa^{-0.6})$

			WINDOWS			**DOORS**		
			LOWER QUART.	**MEDIAN**	**UPPER QUART.**	**LOWER QUART.**	**MEDIAN**	**UPPER QUART.**
External	Weatherstripped	Hinged	0.086	0.130	0.410	0.082	0.270	0.410
		Sliding	0.079	0.150	0.210	1.000	1.500	2.000
	Non-weatherstripped	Hinged	0.390	0.740	1.100	1.100	1.200	1.400
		Sliding	0.180	0.230	0.370	-	0.200	2.000
Internal	Non-westherstripped	Doors	-	-	-	1.100	1.300	0.750

- U-value of double-glazing glass: 1.755 W/㎡ K (furnished by the manufacturer)
- Overall heat transfer coefficient of the frame: 1.21 W/㎡ K

② Internal gains and schedules (Park, 2002)

There are several internal gains, such as human beings, lighting, TV, computer, refrigerator, and others in a residential situation. Human beings give off heat and moisture in different states of activity, and lighting is also a major internal load component. These two constitute a large fraction of the total internal load. In this study, the sensible and latent heat gains from human beings are established using a schedule as described in Table 1. Table 2 shows the sensible heat gain and schedule of lighting.

③ Set-point temperature

In this study, the set point temperature is set at 25℃.

④ Latent heat load for humidity

In Table 3, the absolute humidity ranges from 0.0033 to 0.0059 kg/kg in the lower floors and from 0.0028 to 0.0114 kg/kg in the upper floors. The absolute humidity is found to be 0.005 kg/kg on average in the lower floors and 0.011 kg/kg on average in the upper floors when the latent heat load is 4.5 W/㎡.

3) Input data and assumption for the ventilation model

The crack flow coefficient of the glazed curtain wall is set up at 0.08. The crack flow coefficient of the main, elevator and staircase doors is established to be 1.3 as shown in Table 4 by Technical Note AIVC 44 (1994). The front door is assumed to be open all day.

ANALYSIS OF RELATIVE HUMIDITY

A common cause of moisture problems during the heating season is excessive indoor humidity, caused by an improper balance between moisture generation and moisture removal. This improper balance can be improved by three methods. One is to reduce the sources of moisture, another is to increase the removal rate by ventilation or dehumidification, and the other is to enhance the level of insulation. In the case of residential buildings, it is more difficult to reduce moisture origins, related to residents' behaviors, than to increase the removal rate. Also, the enhanced insulation level would lead to an unwelcome increase in cost. Therefore, it is necessary to control variations in relative humidity by regulating airflow.

Analysis day; January 17

Table 3 as summarizes the data measured. The unit (b) in the 23rd floor has the indoor temperature of 24.5℃, the relative humidity of 60% and the absolute humidity of 0.114 kg/kg responding to the outdoor temperature of -8℃. These climatic conditions are similar to those of January 17 in the historical Seoul weather data of the year 1983. January 17 is selected as an analysis day and its weather conditions are summarized as following; average outdoor temperature of -4℃(-10℃ in minimum, -2℃ in maximum), the highest wind speed of 2.1 m/s, etc.

Relative humidity under infiltration

The air-exchange rate of each floor influences humidity. It must be considered that air exchange can be divided into internal air exchange from a core or a stairwell, for example, and external air exchange from the outside.

Figure 2 shows that the average air-exchange rate declines from 0.45 ACH on the 1st floor to 0.24 ACH on the 19th floor and increases to 0.51 ACH on the 38th floor. The 19th floor has the lowest rate since its internal air-exchange rate is less than that of floors above. The external air-exchange rate decreases on the higher floors while the internal air-exchange rate increases from 0.01 ACH on the 19th floor to 0.44 ACH on the 38th floor. These phases of airflow rate, called the stack effect, influences the relative humidity of each floor.

Relative humidity rapidly increases up to the 19th floor in accordance with the declination of external air-exchange rate and then decreases gently after the 19th floor due to an increase in internal air-exchange rate. The relative humidity of the 1st floor is less than that of the 19th floor by about 25%. This suggests that the higher floors are more likely to be affected by the occurrence of condensation than the lower floors.

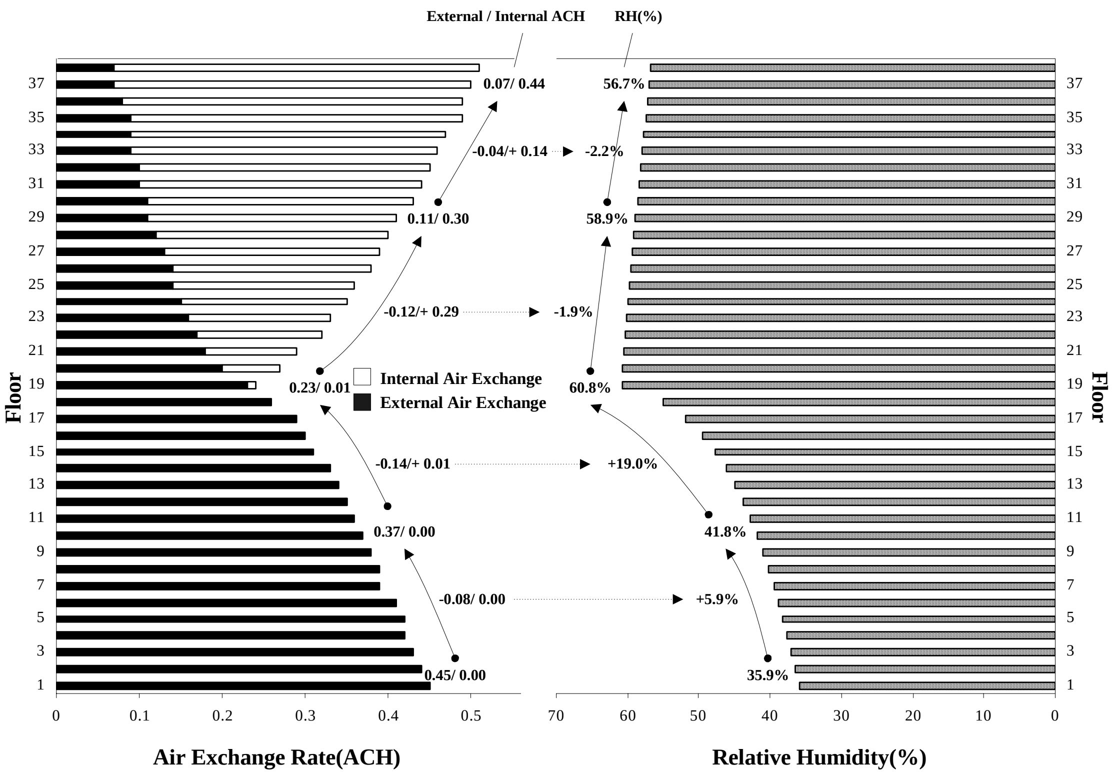


Figure 2 Variations of air-exchange rate with relative humidity

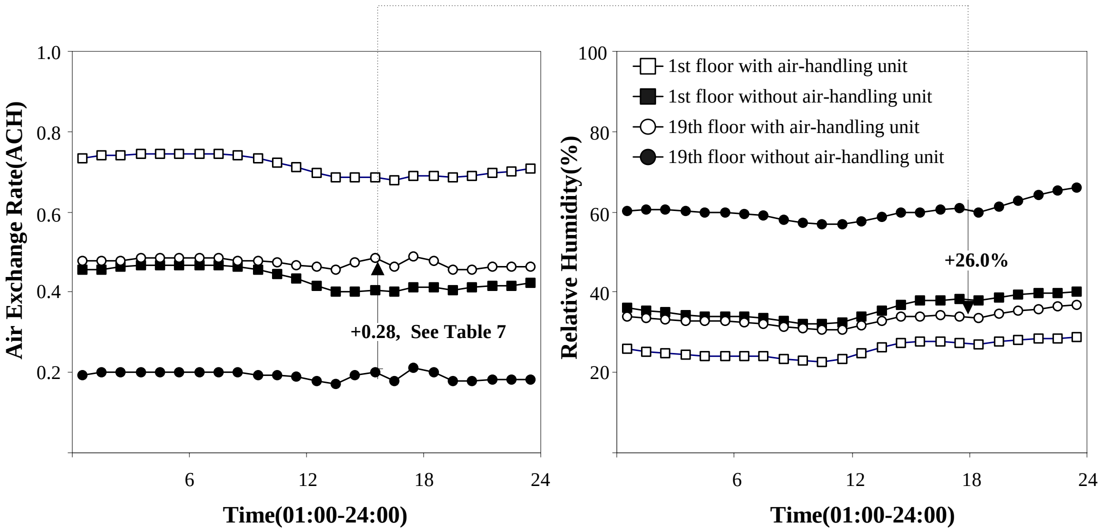
Table 5. Air-exchange rate of a 210 ㎡ unit with 20 ㎥/h·p

ROOM	SUPPLY AIR (㎥/H)	EXHAUST AIR (㎥/H)	AIR-HANDLING UNIT WITH 20 ㎥/H·P		
			ROOM'S VOLUME (㎥/H)	AIRFLOW (㎥/H)	AIR EXCHANGE RATE
Living room	80	-	646.9	180	**+0.28**
Main bedroom	40	-			
Bedroom-1	20	-			
Bedroom-2	20	-			
Bedroom-3	20	-			
Kitchen	-	140			
Dress room	-	40			
Total	180	180			

Relative humidity with air-handling unit

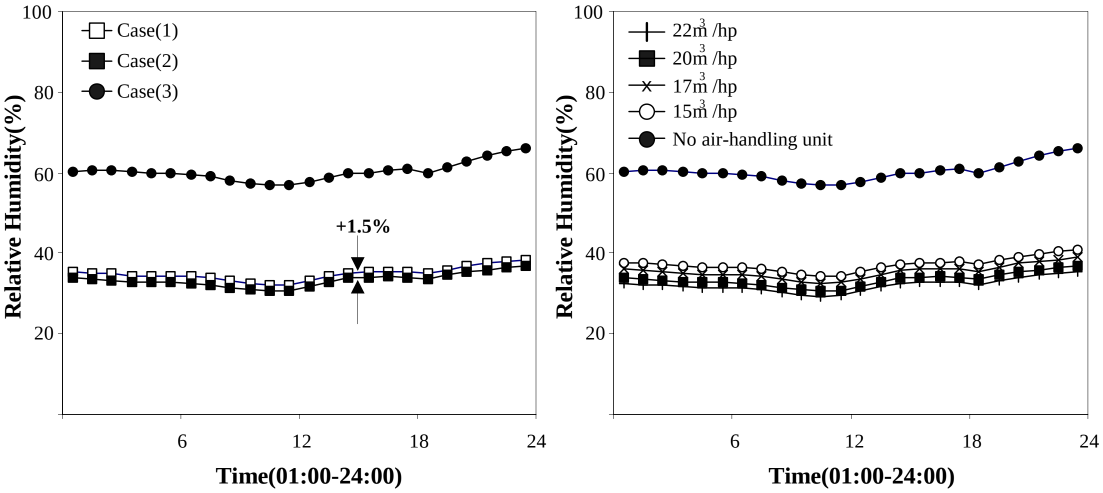
An air-handling unit is needed to reduce relative humidity by regulating airflow. Table 5 indicates that an increment of +0.28 ACH in air-exchange rate is calculated when the air-handling unit of an apartment unit is operated at 20 ㎥/h·p. Also figure 3, presenting the variations of air-exchange rate and relative humidity over time, illustrates that the air-exchange rate of the 19th floor shows an improvement of +0.28 ACH with air-handling unit in the simulated model. Due to the improvement of the air-exchange rate, the relative humidity is reduced by about +26%. There are two possibilities for the considerable drop in relative humidity on the 19th floor. One is that there is a decrease in the moisture that is risen up from the lower floors to the higher floors, and another is that there is an increase in the removal rate of moisture from the lower floors due to the high ventilation performance of the air-handling unit. Figure 4(a) showing the variations in relative humidity in three cases, supports the latter possibility.

Three cases are as following; Case (1) without any air-handling unit, Case (2) with the unit of the only 19th floor operating 20 ㎥/h·p air-handling unit and Case (3) with all units of all floors operating 20 ㎥/h·p air-handling unit. The relative humidity of Case (2) is higher than that of Case (3) by +1.5%. This means that the amount of removed moisture is greater than that of moisture generated from indoor origins due to the +0.28 ACH increment.



(a) air-exchange rate *(b) relative humidity*

Figure 3 Variations of air-exchange rate with relative humidity by air-handling unit



(a) operating cases of air-handling unit *(b) capacity of air-handling unit*

Figure 4 Variations of relative humidity by operating cases and capacity of air-handling unit

An appropriate level of air-handling unit operation can therefore prevent discomfort condensation of the selected building. This could be the 15 ㎥/h·p shown in Figure 4(b), if a standard requires less than 40% relative humidity.

CONCLUSEION

This study aims to analyze the influence of the stack effect on the indoor humidity of the high-rise residential building, and to suggest several methods that can relieve the excessive indoor humidity at the upper floors.

The results can be summarized as follows;

In case of the selected building, there was the neutral pressure level formed in the middle floors. This pressure level made the ventilation performance of the middle floors' units decreased. Also, during the winter, the stack pressure difference between the core and unit appeared to be positive at the upper floors and negative at the lower floors according to the neutral pressure level. The warm and humid airflow from the units of the lower floors rise through the elevator shaft/stair hall and come to the units of the upper floors. On this account, the possibility of condensation occurrence in the upper floors is higher than that in the lower floors. To relieve the excessive indoor humidity of the upper floors, the optimal ventilation system of the unit was suggested.

ACKNOWLEDGEMENT

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