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A Study on the Heat, Vapor and Pollutants Movement owing to the Airflow in High-rise Residential Buildings

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Abstract

High-rise residential buildings are popular in Korea owing to the overpopulation in urban areas in Korea. High-rise buildings increase stack effect that comes from air temperature and density difference between indoor and outdoor air and it makes many problems such as elevator breakdown, difficulty to open the door, noise, draught and others. Many researches were reported for these problems and proposed the countermeasures to reduce the stack effect related problems. When the air flows in buildings driven by stack effect, heat, vapor and pollutants are moved together. This phenomenon affects the residents' health and quality of life which is mainly issued in these days. In this study, the characteristics of air flow, heat, vapor and pollutant's movement in high-rise building were analyzed by long-term measurement in winter. The results indicated that the heat, vapor and pollutants were moved accompanied with the airflow in high-rise residential buildings. There were difference of the temperature, humidity and CO_2 concentration on each floor, and the difference was due to the stack effect in the analyzed building.

Keywords – High-rise residential building, Air flow, Pollutants diffusion, heat &vapor diffusion, Stack effect

1. Introduction

High-rise residential buildings are popular in Korea in these days, and previously unreported problems are aroused in high-rise buildings. The stack effect is a problem of the high-rise building and provokes a number of problems such as strong drafts, unpleasant noise, malfunction of elevators and doors, loss of conditioned air, etc. The stack effect is attributed to the large indoor and outdoor temperature and density difference. Previous studies focused on the investigation of the cause of stack effect and its countermeasures [1,2]. Stack effect is the vertical air movement and accompanies the movement of heat, moisture and contamination. Some researches were reported for the contaminant movement with the air movement in high-rise building [3, 4]. Few studies

have been conducted about the contaminant movement in high-rise buildings by measurement over long a period of time [5, 6].

In this study, the characteristic of heat, vapor and pollutant's movement in high-rise building was analyzed by long-term field measurement.

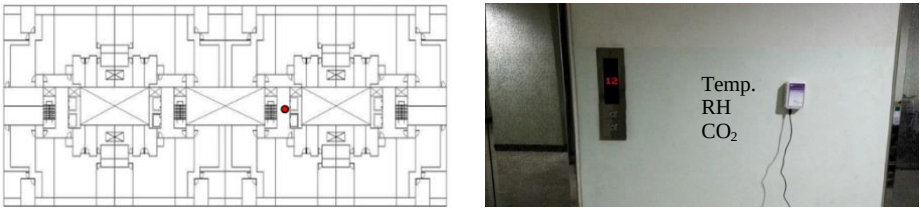
2. Method

2.1 Analyzed building

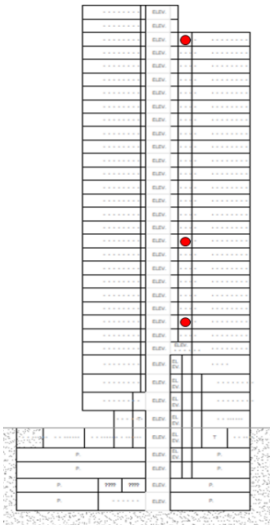
The analyzed building for long-term measurement was a high-rise residential building in Seoul, South Korea. The specifications of the building are shown in Table 1. Typical floor plan and section of the building and measurement points are shown in Fig 1

Table 1 Analyzed building information

Building information	Location	Seoul, Korea
	Building Type	Residential and commercial complex
	The number of floors	31 floors above ground and 5 floors underground -parking lot : B5 – B2 -shop : B1 – 4F -residential : 5F – 31F
	Building Height	107.5m
	Main horizontal airflow path	Envelope, household entrance door, elevator door, staircase door
	Main vertical airflow path	E/V shaft, staircases
	Building service system	Individual household ventilation systems, kitchen exhaust hood and exhaust fan in toilet, Radiant floor heating system



(a) Floor plan and measurement point



(b) Section

Fig.1 Measurement items and locations in the analyzed building

2.2 Long-term measurement

The outlines of the measurement are shown in Table 3. Field measurements were carried out for 60 days from January to February, 2014 (winter season in Korea). The aims of the long-term field measurements were investigating the characteristics of heat, humidity and contamination movement in high-rise residential building. Even though, there are several types of contaminations in buildings, but carbon dioxide was measured for the convenient of the long-term measurement. The determination of the measurement location is very important to gather the meaningful data in field measurement under occupied condition. Also, there are lots of limitations in field measurement in occupied condition. Before conducting the field measurement in this study, the airflow simulation was accomplished by network simulation method (CONTAMW) to analyze the airflow characteristics in the analyzed building. The input data for simulation were based on the prior study [7]. Fig. 2 indicates the simulation results for pressure difference at the elevator door on each floors.

Table 2. Measurement outlines

Period	2014.1 ~ 2014. 2 (60 days)	
Instruments	Temperature	Resol. : 0.10 °C
		Range : -100 to 300 °C
		Accuracy : ±0.1 °C

	Relative Humidity	Resol. : 0.10%
		Range : 0 to 100% RH
		Accuracy : ± 0.5%
	CO_2	Resol. : 1.0ppm
		Range : 10 to 20000ppm
		Accuracy : ± 10ppm
Locations		E/V hall 7F, 13F, 29F, outdoor
Intervals		one minute
Wireless communications	Frequency range	2.4 GHz
	Communication distance	50m
	Output	Maximum 8dBm
	Network	Wi-Fi
	Antenna	Ceramic antenna

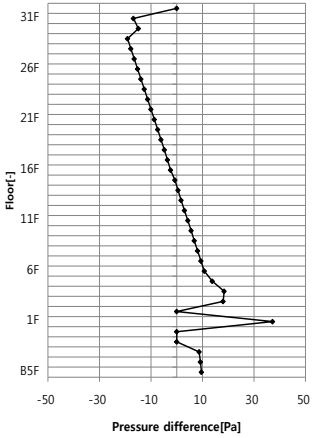


Fig. 2 Pressure difference at E/V door of the analyzed building by simulation

The highest pressure difference of the elevator door was occurred at lobby floor (1F), it means that a lot of air introduced through the lobby floor. The neutral pressure level, the pressure difference is nearly zero, was formed at 13 floors. Based on the airflow simulation of the analyzed building, the measurement locations were determined at 7th floor, 13th floor, 29th floor, and it represented the lower floor, neutral floor and top floor in terms of air flow in building. The measurement point was the mid-point of elevator hall (about 1.6m height) at the measured floor s.

3. Results and discussion

3.1 Vertical air temperature distribution

The heat, humidity and contaminant (CO_2) concentration in high-rise buildings are related to the air movement in building [8]. Therefore, the measurement results were analyzed considering the air movement in building, and the air movement in building are affected by thermal buoyancy (i.e. stack effect), wind pressure of envelope (velocity, direction), and door opening caused by people's movement. The characteristics of these parameters can be classified by the time that is daytime and night as like Table 3. The classification of the daytime and night was based on the elevator movement, and the time was classified as night when the elevator movement frequency was under 5 times per hour.

Table 3 Major factors affecting the airflow in analyzed building

	Temp. difference between indoor and outdoor	Wind velocity	Wind direction	People's movement	E/V operation
Daytime (06:00~22:00)	High	Fast	Not constant	frequent	frequent
Night (22:00~06:00)	Low	Slow	Constant (NW)	little	little

Fig. 3 shows the temperature distribution of the each measurement points according to the outdoor temperature changes in daytime. The outdoor temperature was fluctuated between -8 ^{o}C to 9 ^{o}C during measurement periods. Indoor temperature was changed about 5 ^{o}C to 24 ^{o}C with the changes of outdoor temperature. The difference of the temperature between the measurement points was not much when the outdoor air temperature was below zero temperature, while the temperature difference was grew and grew with the outdoor temperature was risen. In case of the outdoor temperature was -7 ^{o}C, the elevator hall temperature was about 9.05 ^{o}C at 7th floor, 9.65 ^{o}C at 13th floor and 9.67 ^{o}C at 29th floor. And the temperature was 19.5 ^{o}C at 7th floor, 21.5 ^{o}C at 29th floor and 22 ^{o}C at 13th floor when outdoor temperature was 8.8 ^{o}C. The highest temperature was found at 13th floor, and the lowest temperature was found at 7th floor in the measurement points in this study.

The results indicated that the temperature difference according to the building height was remarkable when the outdoor temperature was high and the temperature difference between indoor and outdoor was not much. This is because the vertical air movement and air mixing is not active when the temperature difference between indoor and outdoor is little. In contrast, the temperature difference according to the building height was little when the outdoor temperature was low and the temperature difference between indoor

and outdoor was great. This is because the vertical air movement and air mixing is active when the temperature difference between indoor and outdoor is great.

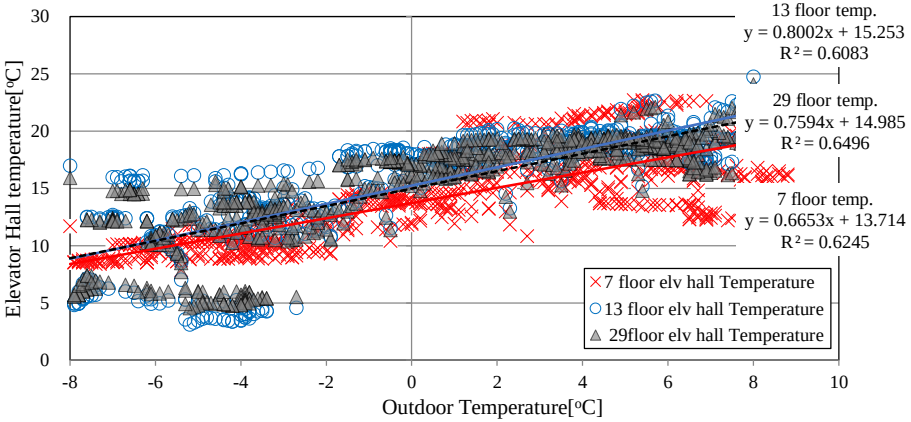


Fig. 3 Vertical air temp. distribution according to the outdoor air temp. changes in daytime

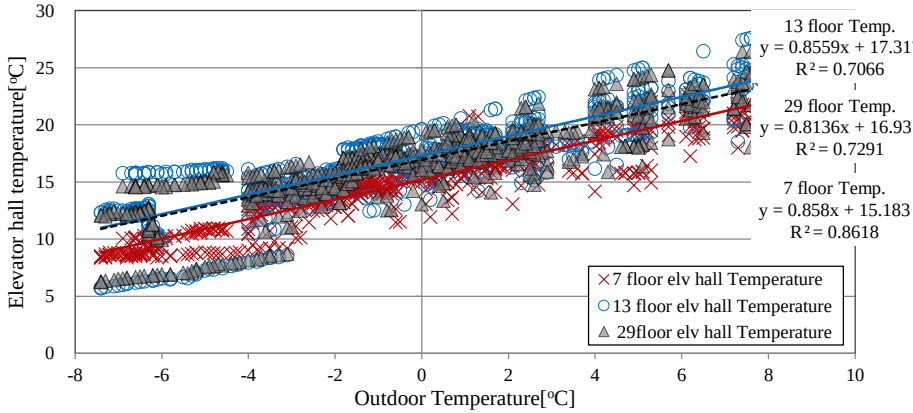


Fig.4 Vertical air temp. distribution according to the outdoor air temp. changes in night

The temperature differences according to the building height were remarkable in night than daytime (Fig. 4). Even though, the temperature differences between measurement points were little when outdoor temperature was low in daytime, however the temperature differences were kept constant in night. This is because the indoor temperatures were kept constant and the air movements in building were affected by thermal buoyancy and the influences of the other factors such as elevator operation and door opening were little in night. The temperature of the elevator hall at 13th floor was higher than other measurement points. It means that the air in 13th floor didn't move and stagnated because the 13th floor was a neutral pressure level of the analyzed building.

3.2 Vertical moisture distribution

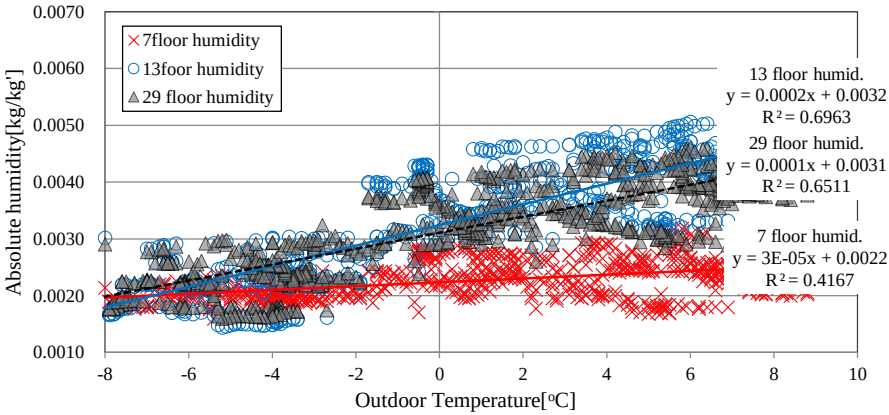


Fig.5 Vertical humidity distribution according to the outdoor air temp. changes in daytime

Fig. 5 shows the vertical humidity distribution according to the outdoor air temperature changes in daytime. The trends were very similar to the temperature distribution, but the differences according to the height were more clear and certain than temperature. The 13th floor showed the highest humidity level than 29th floor, and it indicated that the air in 13th floor didn't mix and stagnated

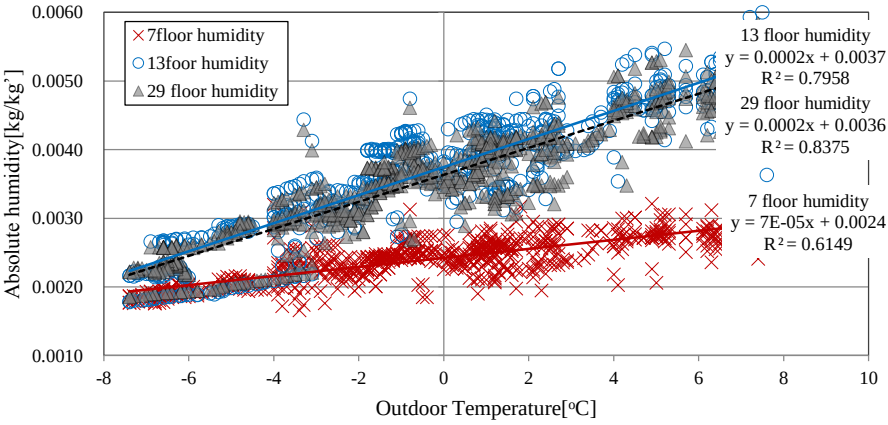


Fig.6 Vertical humidity distribution according to the outdoor air temp. changes in night

The humidity distributions in night in the analyzed building were more clear than daytime as similar to the temperature distribution. The humidity level of each

measurement points were quickly changed according to outdoor temperature compared to temperature changes as shown in Fig. 3 and 4. The humidity levels were high in night compared to the daytime and this is because of the increased indoor humidity level in night due to the increased number of people and the activities such as shower and bath.

3.3 Vertical contaminant (CO_2) level

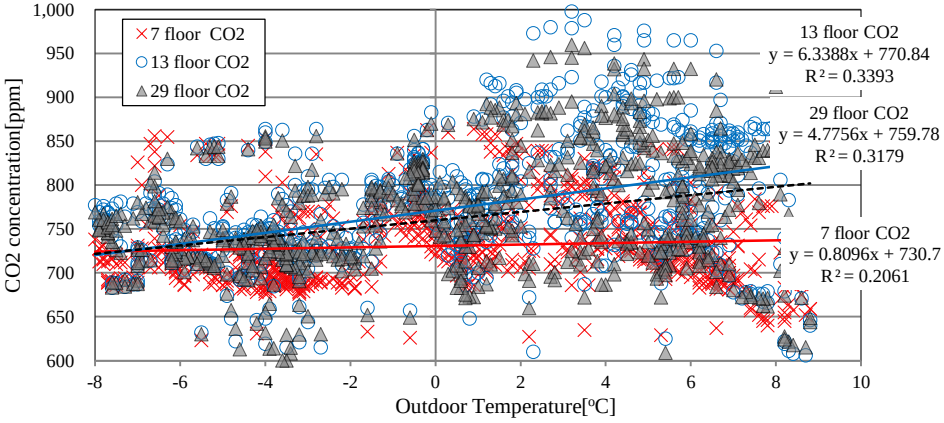


Fig.7 CO_2 distribution according to the outdoor air temp. changes in daytime

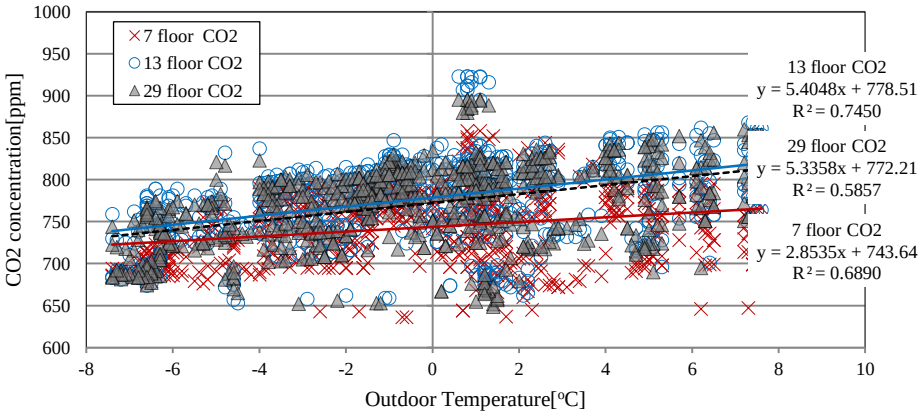


Fig.8 CO_2 distribution according to the outdoor air temp. changes in night

The CO_2 concentration was ranged from 600 to 1050 ppm according to the outdoor temperature in daytime. The CO_2 concentrations, in order of highest, were 13th floor, 29th floor and 7th floor. The tendency was same as temperature and humidity distribution. The highest CO_2 concentration was found at 13th floor because the 13th floor was in a neutral pressure level and the ventilation performance was poor. The distribution of CO_2

concentrations were scattered in daytime compared to the night. In case of the night, the CO_2 concentration was high compared to daytime because the increased number of people in night.

4. Discussion

The concentrations of heat, humidity and CO_2 in high-rise residential building were high at the neutral pressure level of the analyzed building that was 13th floor in this study. This is attributed to the poor ventilation performance at the neutral pressure level(NRL) in high-rise buildings. As results, heat, moisture, contaminant were stagnated at NRL. Also, the concentration of heat, humidity and contaminant (CO_2) at the upper floors were all high compared to the lower floors. This is because the outdoor air flows into lower floors and moves upward through vertical shaft such as elevator core and staircase and flows into the upper floors. The air moved in high-rise building caused by thermal buoyancy (i.e. stack effect) and heat, moisture and contaminants were moves together in high-rise buildings.

As result, the people who live at upper floors could be exposed to the high temperature, humidity and contaminant in high-rise residential buildings because of the stack effect in winter. The magnitude of the stack effect is proportional to the temperature difference between indoors and outdoors and building height, the building designer should pay a lot of attention to the stack effect and its related problems at design stage. Also, the NRL floor was the worst place in terms of IAQ, careful examination and consideration should be required in high-rise building design and construction.

Acknowledgement

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