A Study on Incomplete Ventilation in High-Rise Residential Buildings

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Abstract
Guideline for ventilation to improve indoor air quality in apartment housings in Korea was recently enacted and natural or mechanical ventilation system has become mandatory. Meanwhile, as the height of residential buildings goes up, the performance of ventilation system is influenced by stack effect especially in winter. This study is to review how stack effect influences ventilation system in high-rise residential buildings through simulations.

Keywords: High-rise Residential Buildings, Stack Effect, Ventilation System

Introduction

As global warming recently drew attention as an international problem, there is a growing interest in reduction of energy consumption and CO2 emission in Korea. In these social trends, there are growing efforts to reduce energy consumption in buildings. Similarly, there have been a lot of efforts to use natural power rather than mechanical power in ventilating buildings. But, as the height of apartment housings goes up, the effect by stack effect on buildings is growing in winter. Stack effect has effect on ventilation systems of high-rise residential buildings as well and there is a difficulty in securing enough performance of ventilation systems. For instance, due to stack effect, there is a difficulty in air supply and exhaust at part of building respectively above and below neutral pressure level.

Therefore, the aim in this study is to verify the influence and characteristics of stack effect on existing ventilation system in high-rise residential buildings and it will be used as reference data for improving the problem.

The research method in this study is to investigate existing ventilation systems used in apartment buildings in Korea and to quantitatively examine the influence of stack effect on the ventilation in high-rise residential buildings using simulation.

Target Building and Ventilation System Overview

1) Target building overview

Figure 1 shows a floor plan of the target building which is typical residential building plan in Korea. The target building of 58m high has 20 stories with 2.9m of floor height. Each floor has two apartments sharing a hall and stairways and elevator are across the hall.

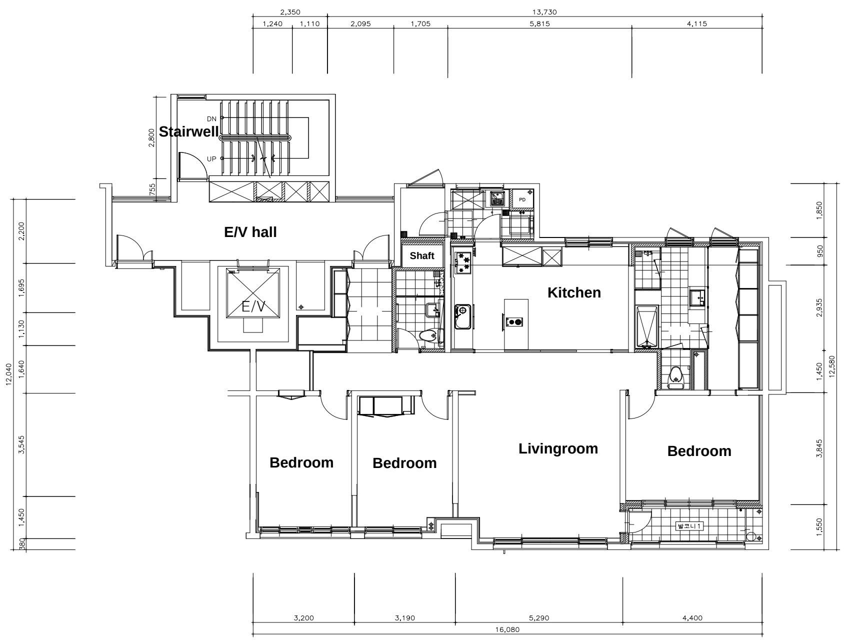


Fig. 1 Floor plan of the target building

2) Ventilation method and ventilation system overview

a) Natural ventilation system

Figure 2 shows a natural ventilation system installed in the balcony window frame. This kind of window is being additionally installed because the laws exclude doors and windows from a natural ventilation system and thus. The natural ventilation system has a natural ventilating opening, which manually or automatically opens, and a filter to remove outdoor dust.

The laws require that a natural ventilation system shall satisfy the ventilation rate of 0.7 times per hour by passing tests such as simulation, mock-up test or real-size test [1]. However, natural ventilation systems have difficulty in stably securing enough ventilation rates due to unstable outdoor wind speed or stack effect.

There are studies being conducted for the guidelines on performance test of natural ventilation systems [5].

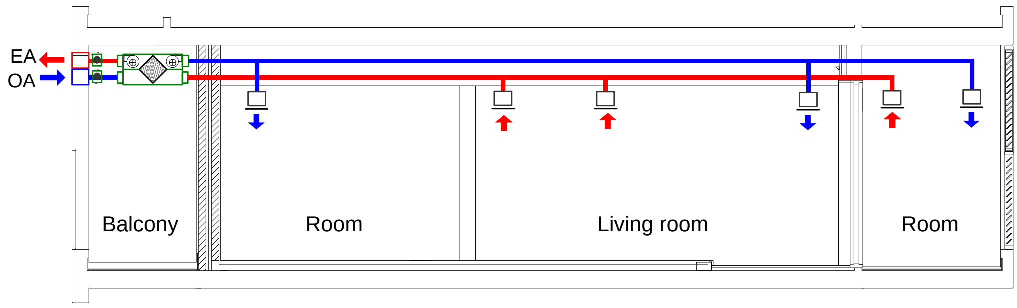
Fig. 2 Natural ventilation system

b) Mechanical ventilation systems

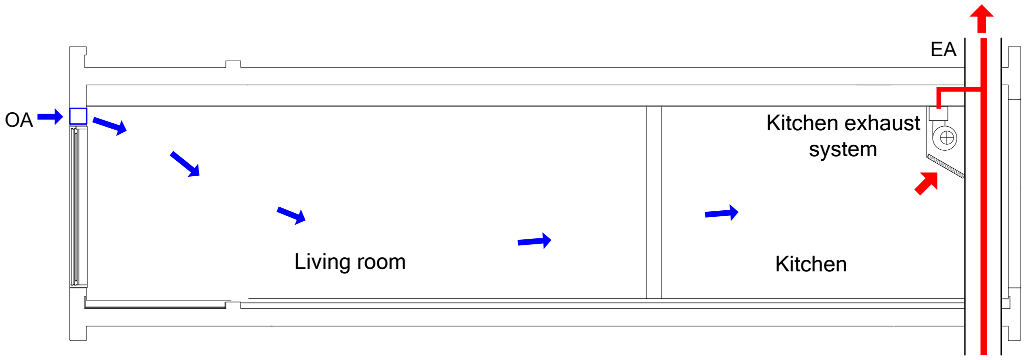
Figure 3-a) shows a heat recovery ventilation system. The heat recovery ventilation system is installed on the wall of balcony and outdoor air supply duct and indoor air exhaust duct are installed there. Air supply and exhaust distribution lines of heat recovery ventilation system are installed inside. The heat recovery ventilation system performs air supply and exhaust at the same time. Jang (2008) [2] measured the performance of heat recovery ventilation system installed in Korea for each brand.

Figure 3-b) shows a kitchen exhaust system. This ventilator emits indoor air exhaust by a kitchen exhaust system apparatus and natural or mechanical ventilator on the wall of balcony

is operated as well. Air exhaust from the kitchen exhaust system goes into a vertical air shaft and gets out of the building through air exhaust duct on the top of the building. However, there are reported problems that food smell from an apartment flowed back into another apartment through a kitchen exhaust system, causing displeasure.



a) Heat recovery ventilation system



b) Kitchen exhaust system

Fig. 3 Concept of mechanical ventilation systems

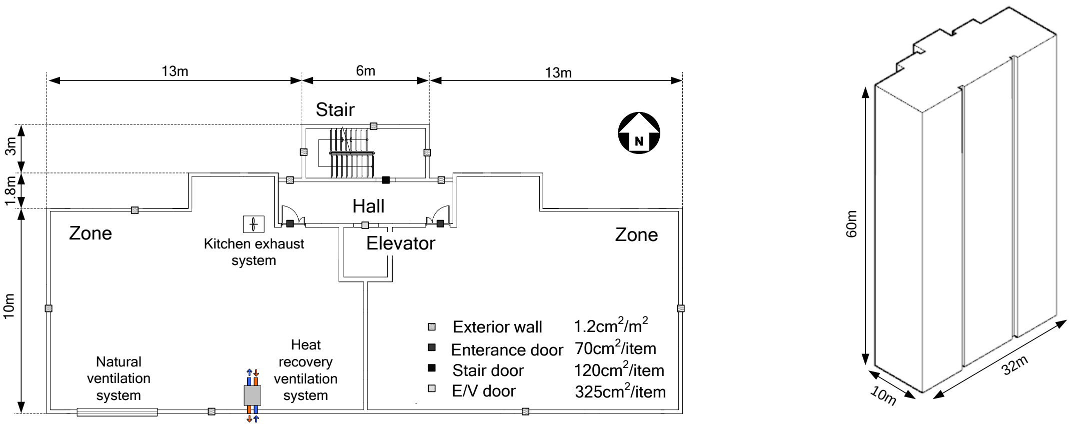
Review of Ventilation Rates and Airflow Characteristics for High-rise Residential Buildings through Network Simulations

This chapter covers airflow network simulations to quantitatively examine the influence of stack effect on the performance of ventilation systems.

1) Simulation overview

a) Simulation model overview

Figure 4 shows a simulation model for high-rise residential buildings. Two apartments, hall, stairways and elevator were modelled for each floor and partitions inside an apartment were ignored. ASHRAE data [4] and measurement data [3] in Korea were referred to for leakage area. Modelling for each ventilation system was conducted for each case.



a) A plane figure b) 3D view

Fig. 4 Simulation model overview

b) Simulation case and input conditions

Table 1 shows a simulation case. Case 1, 2 and 3 are respectively for natural ventilation system, heat recovery ventilation system and kitchen exhaust system. Table 2 shows simulation input conditions. Outdoor temperature condition examined is the temperature of the coldest day according to weather data. Indoor temperature was assumed at 22℃ due to heating. The temperature of stairways and elevator hall was assumed at 15℃ because they are not air-conditioned. Measurement data [3] and ASHRAE data [4] were referred to for leakage area of exterior walls. Leakage area was inputted as 0m, 1.5m and 3m to consider the variation in infiltration rate according to indoor and outdoor pressure difference for each height on the wall.

Indoor air pollutant is assumed as CO_2 generated by residents' breathing and each residence was assumed to have four adult residents. Discharge coefficient of natural ventilation system was assumed at 0.05 m^3/s/Pa to satisfy the ventilation rate of 252 CMH under the pressure difference of 2 Pa based on the research result by Kim (2008) [5]. Kim (2008) [5]'s research shows that even if there were differences among natural ventilation system products, discharge coefficient of natural ventilation system was in the range of 10~25 m^3/h/Pa for the length of 500 mm.

For heat recovery ventilation systems the one showing the best result of fan performance curve as a result of Jang (2008) [2] research was selected. For the kitchen exhaust system, fan performance according to company catalogue was used.

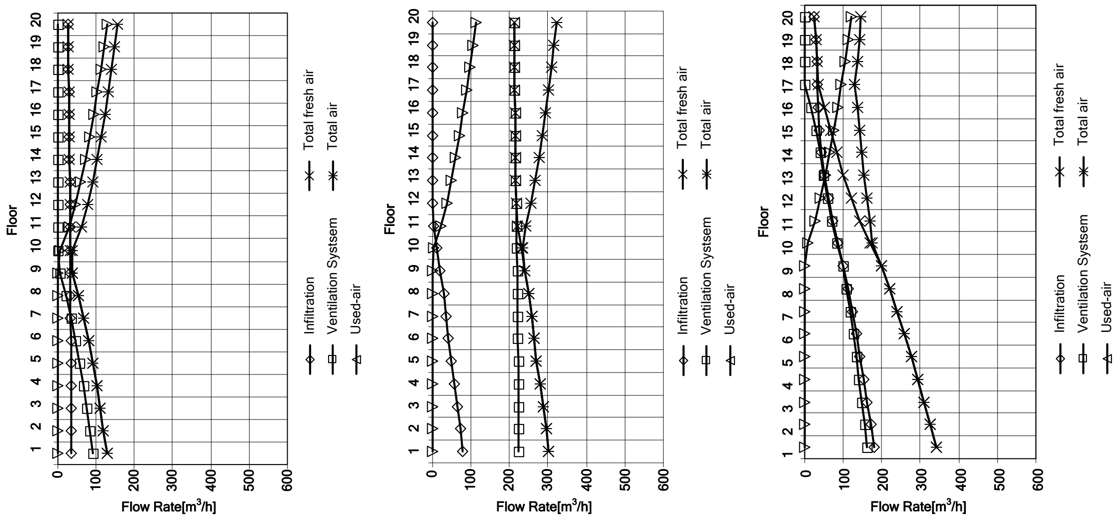
Table 1 Simulation case

	Ventilation system type	Ventilation type
Case1	Natural ventilation system	Natural ventilation
Case2	Heat recovery ventilation system, air supply and exhaust	Mechanical ventilation
Case3	Natural air supply + Kitchen exhaust system	Mechanical ventilation

Table 2 Simulation conditions

Items	Conditions		Remarks
Temperature	Outdoor temperature: -11.3℃ Indoor temperature: 22℃ Non-air conditioned (stairwell, elevator hall): 15℃		Suwon region Weather data
Leakage area	Outer wall(including windows)	1.2 ㎠/㎡	Jo (2007) [3]
	Entrance on the first floor	70 ㎠/item	ASHRAE[4]
	Entrance of each apartment	70 ㎠/item	ASHRAE[4]
	Elevator door	325 ㎠/item	Jo (2007) [3]
	Stairwell door	120 ㎠/item	Jo (2007) [3]
Air pollutant	CO_2 incurring location : all apartments from first floor to twentieth floor Number of residents: assumed as 4 CO_2 emission per person: 0.31[L/min] O_2 consumption per person: 0.373[L/min] Outdoor CO_2 concentration: 0.0005[kg/kg]		ASHRAE Standard 62-1999[6]
Natural ventilation system	$Q=C(\Delta P)^n$, 252 $m^3/h=C(2Pa)^{0.5}$, C= 0.05 m^3/s@1Pa, n=0.5 Front: 0.04 m^3/s@1Pa, Rear 0.01 m^3/s@1Pa, Installed height: 2.3 m		Kim (2008) [5] 13.9~35.78 m^3/h @2Pa, 0.5 m
Mechanical ventilation systems(Fig 3-a))	Heat recovery ventilation system, design capacity 250 m^3/h, pressure loss 150 Pa, Installed height : 2.3 m		Jang (2008) [2]
Mechanical ventilation systems(Fig 3-b))	Natural air supply device: 30 m^3/h@10Pa, 4 item Installed location: 2.3 m kitchen exhaust system catalogue referred to for fan performance data, Installed height: 1.5 m		Performance data provided by a company is referred to

2) Simulation results



a)Case1 b)Case2 c)Case3

Fig. 5 Flow rate for each ventilation method

a) Variation in airflow rate for each ventilation system

Figure 5 shows airflow rate for each apartment. Air supply and exhaust inside an apartment include infiltration through exterior walls, fresh air inflow from ventilation systems and used-air inflow through stairways or elevator halls. Air supply by infiltration and ventilation systems is called fresh air supply and if used-air is also added, it is called total air.

Case1 of natural ventilation system shows that the first and twentieth floors have 128.4 m^3/h and 156.1 m^3/h of total air, respectively, and the eleventh floor has 62.2 m^3/h of it, resulting in mid level having relatively smaller total air than lower or higher level. The first, eleventh and twentieth floors have 128.4 m^3/h, 26.2 m^3/h and 32.5 m^3/h of fresh air, respectively, resulting in relatively insufficient fresh air for mid and higher levels.

Outdoor air supply by natural ventilation systems is greater at lower level, but tends to go down towards higher level.

Case2 of heat recovery ventilation system shows that the first and twentieth floors have 302.6 m^3/h and 323 m^3/h of total air and the eleventh floor has 241.6 m^3/h of it, resulting in lower and higher levels having greater amount of total air than mid level. The first, eleventh and twentieth floors have 302.6 m^3/h, 211.3 m^3/h and 219.8 m^3/h of fresh air, respectively, tending to go down towards higher level. Outdoor air supply by heat recovery ventilation systems a little goes down towards higher level, but it is relatively consistent compared to natural ventilation system.

Case3 of kitchen exhaust system shows that the first, twentieth and eleventh floors have 342 m^3/h, 145.9 m^3/h and 168.3 m^3/h of total air, tending to decrease towards higher level. The first, twentieth and eleventh floors have 342 m^3/h, 24.6 m^3/h and 142.1 m^3/h, showing insufficient fresh air supply at higher level.

Figure 6 shows CO2 concentration variation for each ventilation method. Case1 of natural ventilation system shows the highest CO2 concentration of 3,709ppm at the tenth floor. This is because air supply is insufficient at mid level as shown in Fig. 5-a). Furthermore, due to absolutely insufficient fresh air supply as shown in Fig. 6-a), higher level shows higher CO2 concentration than lower level. However, higher level having lower CO2 concentration than mid level seems to be because CO2 concentration was diluted by used-air from stairwell or E/V halls.

Case2 of heat recovery ventilation system shows small variation in CO2 concentration. This seems to be because air supply by ventilation systems is consistent and CO2 concentration of used-air went down by indoor air supply and exhaust.

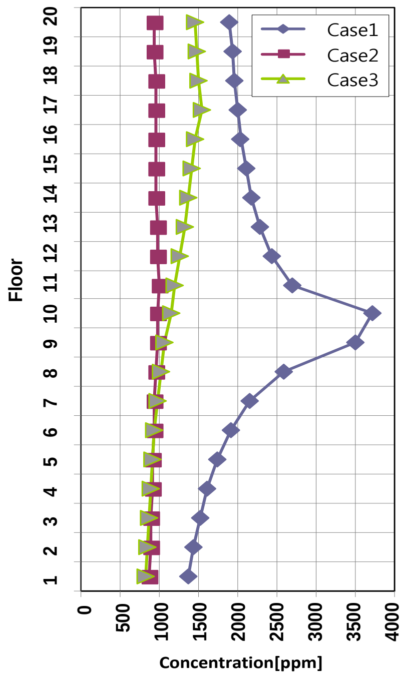


Fig. 6 CO_2 concentrations for each ventilation system

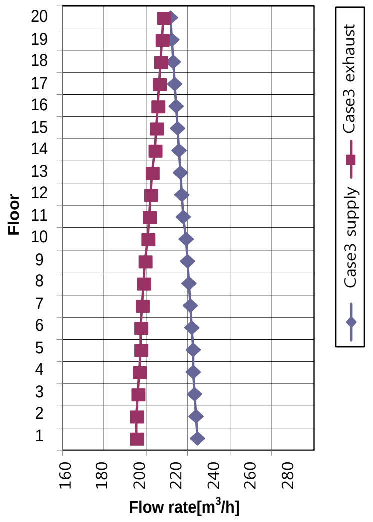
Case3 of kitchen exhaust system shows higher CO2 concentration at higher level than lower level. This is because fresh air supply goes down and used-air goes up towards higher level.

b) Change in fan performance of mechanical ventilation systems

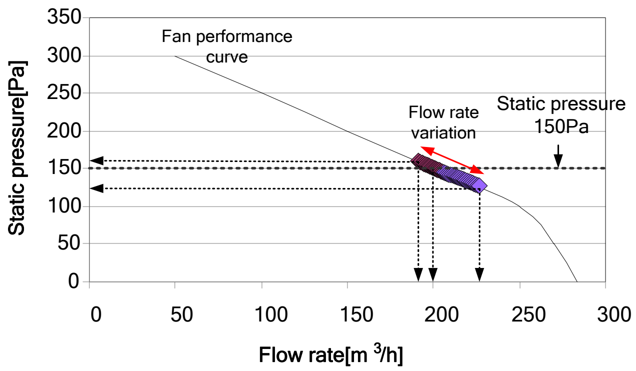
Figure 7-a) shows air supply and exhaust of heat recovery ventilation system for each level.

Case3 shows that air supply goes down and air exhaust goes up towards higher level. This is because due to stack effect, static pressure is applied to indoor from outdoor to help air supply below the neutral pressure level and it is applied to outdoor from indoor above the level to help air exhaust.

Figure 7-b) shows fan performance curves based on the results of Fig. 7-a). When duct static pressure loss was assumed at 150Pa, air supply should be 200 m^3/h in theory, but it was in the range of 195~224 m^3/h due to stack effect from the simulation result.



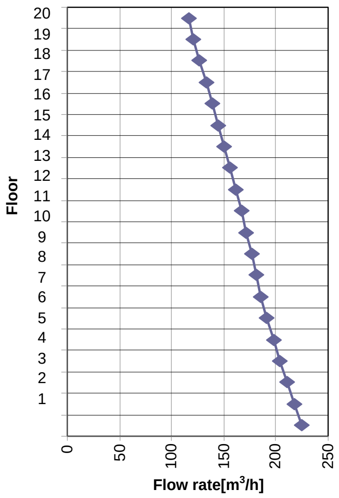
a) Supply and exhaust



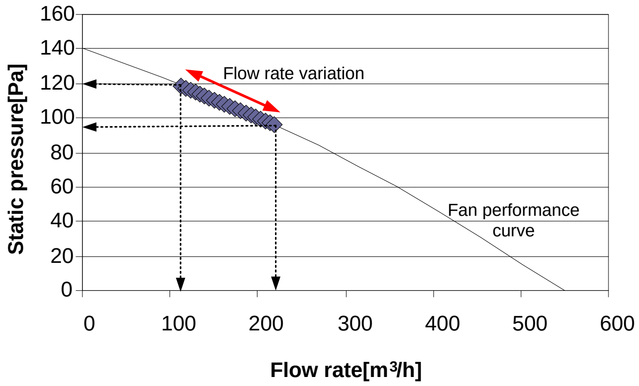
b) Change in fan performance

Fig. 7 Heat recovery ventilation system

Figure 8-a) shows air exhaust of kitchen exhaust system for each level. The first and twentieth floors have 224.1 m^3/h and 116.3 m^3/h of air exhaust, respectively, showing a great difference. Fig. 8-b) shows change in fan performance. Fig. 8-b) shows fan performance decrease towards higher level and it is because of the static pressure increase.



a) Air exhaust



b) Change in fan performance

Fig. 8 Kitchen exhaust system

Conclusions

Due to growing concern for energy saving at buildings, there will be growing importance in using natural ventilation. In case of natural ventilation system, ventilation is different for each apartment if it is uniformly applied without considering stack effect.

Mechanical ventilation system showed relatively stable fan performance compared to natural ventilation system, but it is likely to be influenced by stack effect in greater degree as the height of buildings goes up.

Therefore, to secure enough fan performance for high-rise buildings, it is critical to figure out the characteristics of airflow occurring inside the high-rise buildings.

In this study ventilation rates and indoor pollutant concentration distribution were examined for high-rise residential buildings in Korea and then, the problems of existing ventilation systems were reviewed under stack effect in the winter. The results are as follows.

1) Natural ventilation system

Introduction of fresh air in the natural ventilation system is not enough in winter due to stack effect above the neutral pressure level in the building and indoor air pollution or dilution occurs due to used-air introduced into the indoor from the stairwell or E/V shaft as well. Indoor air quality may go poorer due to insufficient ventilation at mid level, and higher level is disadvantageous in securing sufficient fresh air because air supply is not sufficient and used-air constantly flows in through vertical shafts.

2) Mechanical ventilation system

Despite the use of mechanical ventilation systems in winter at high-rise residential buildings, fan performance changes for each level due to stack effect and resulting air pressure. Stack effect goes up towards higher level. Due to stack effect, air exhaust goes down towards higher level in case of kitchen exhaust system. In addition, indoor CO2 concentration increased due to decrease in fresh air supply at higher level.

Acknowledgments

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