INFLUENCE ANALYSIS OF STACK EFFECT ON ODOR DISPERSION FROM UNIT TO CORE IN THE HIGH-RISE RESIDENTIAL BUILDINGS

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ABSTRACT

Food odor dispersion from residential unit to core is one of problems in high-rise residential building. In this study, it was analyzed in terms of stack effect, and the method how optimal air inflow of core was estimated and how the location of air in/outlet were decided were suggested to solve it. A combined CFD (Computational Fluid Dynamics) and CONTAMW analysis was used for stack effect of building, dispersion of food odor, optimal air inflow of core, and the location of air in/outlet in the method.

KEYWORDS

High-rise residential building, Stack effect, Odor dispersion, Optimal Airflow, Air inlet

INTRODUCTION

Recently, the number of high-rise residential building is increasing in Korea. In the building, the opening/closing function of window for natural ventilation is not flexible because the upper part of the building has to be safe from strong wind and energy has to be conserved by strong insulation and airtightness. Moreover, curtain wall systems which usually have small area of openable window are used for it. Accordingly, the mechanical ventilation system is used more than natural one in it (Lee et al. 2005). The factors that affect on ventilation performance are indoor air flow by envelop airtightness, backward flow of exhaust due to less of ventilation for upper stories, and stack effect by pressure difference between spaces (Kim et al. 2004, Kim et al. 2005, Kim et al. 2003, Jo et al. 2007). If the amount of ventilation and the location of air in/outlet are decided to exhaust pollutants without considering the factors, the pollutants can be rather dispersed to non-polluted area. Especially, food odor is used for this study. Residents have direct sense of it, so it can be a good sample among pollutants. Korean food usually generates a lot of odors during cooking, so the odors are dispersed to dining room and core area. Ultimately, the residential unit which generates the odors gives discomfort to neighbors which are another residential unit (Donga daily newspaper 2002).

The purpose of this study is to control the food odor that is dispersed from a residential unit to core and to show a method how the optimal amount of ventilation and optimal position of air in/outlet are decided. For this study, ventilation performance according to stack effect in high-rise residential building is analyzed by CFD and CONTAMW.

METHOD

In this study, the combined CFD and CONTAMW analysis were suggested to decide the optimal amount of ventilation and optimal position of air in/outlet. There are 5 steps for it, and Figure 1 is a summary (diagram) about it.

First of all, Step 1 is about building descriptions. A boundary condition is explained in the step for combined analysis such as building data, operating schedule of air in/outlet in a residential unit, type and density of a food odor, air leakage data, and weather data etc.

Second, Step 2 is to calculate pressure difference of stack effect by CONTAMW and the amount of airflow shifting between spaces. Third, Step 3 is to analyze density distribution of food odor that is dispersed from the residential unit by CFD with the boundary conditions that are result of Step 2 and generated intensity of food odor. Forth, Step 4 is to calculate the optimal amount of ventilation to dilute inflow food odor from the residential unit when air in/outlets are applied in core. For this step, CONTAMW is used, and the result of food odor density that is the result of Step 3 around front door area is used as a boundary condition. Finally, Step 5 is to evaluate the location scheme of air in/outlet that can restrict and isolate the dispersion of food odor by CFD with the boundary condition that is from result of Step 4.

Step 1. building description

In this study, a building is selected for combined CFD and CONTAMW analysis. It has thirty-seven stories above and six under the ground with a core system.

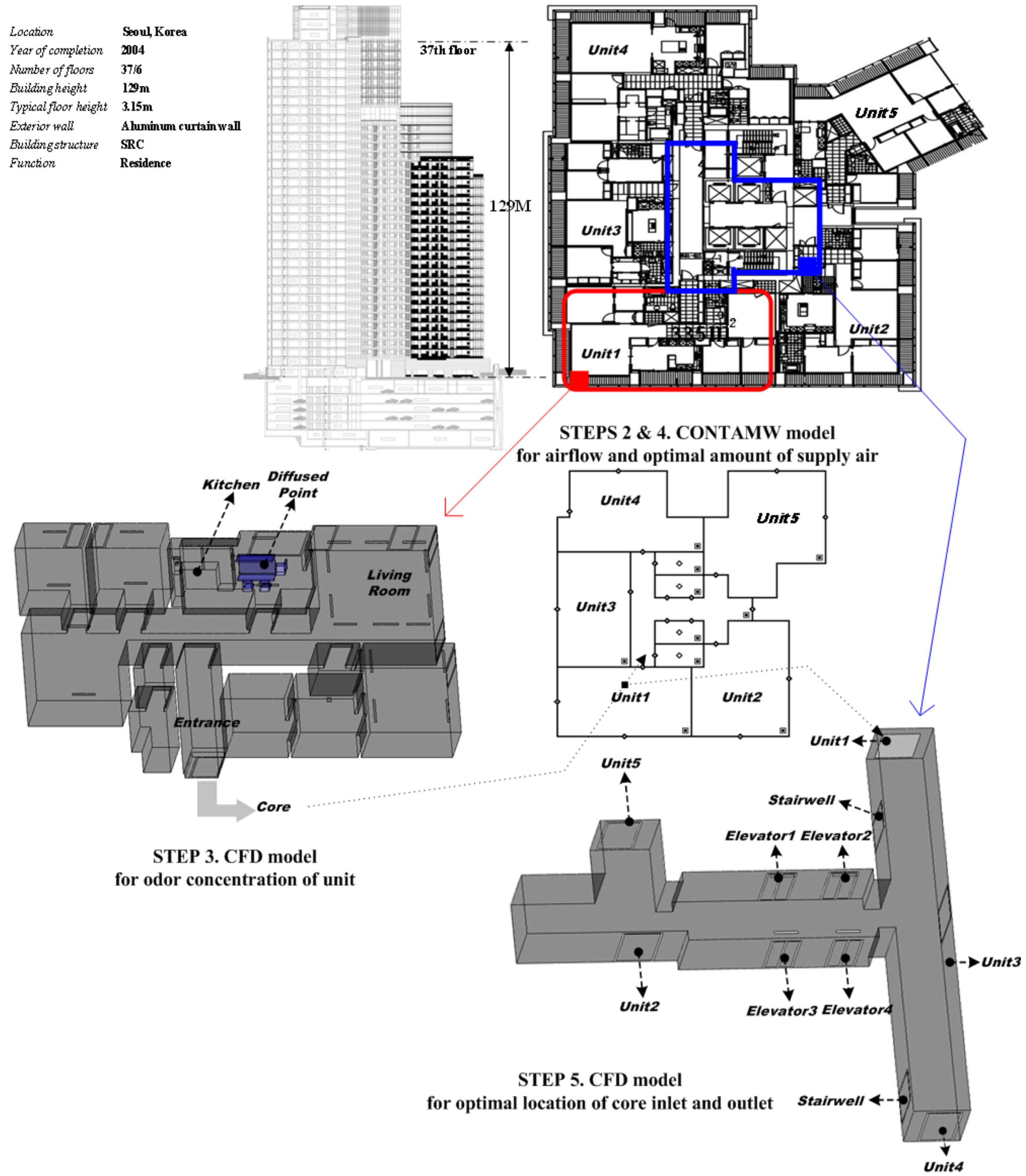

Figure 1 Summary diagram of combined CFD and CONTAMW analysis

Figure 1 shows summary, cross-sectional view, and standard floor plan of it. During cooking, generated food odor is collected by force of kitchen hood and outlet, and line inlet supplies air to prevent dispersion of food odor. However, during meal time, residents are usually turn kitchen hood and outlet off for comfortable meal time even though food odor keeps generating. In brief, food odor during meal time is going to be dispersed a lot more than during cooking because food odor can't be collected by kitchen hood or outlet. There is unusual case in Korea when dispersion of food odor is worst; residents set up table in dining room and have meal rather than they have meal time in kitchen that have good air outlet system. In this study, meal time was set as a boundary condition for CFD analysis for food odor dispersion of a unit, and food odor generating point during meal time was set as dining room which was the worst case.

The type of odor and density. Table 1 is about stench intensity according to type and density odor during food production (Jung 2004). It is from measurement method of chemical analysis. There are three main causes of food odor that are meat odor, Kim-Chi odor, and fish odor in Korean household.

Table 1 Odor elements and intensity

	FOOD TYPE[A]					SMELL	INTENSITY SCALE (UNIT: PPM)[B]				
	LIVESTOCK	FISH	KIM-CHI	STARCHY	FLAVORS		1	2	3	4	5
Hydrogen sulfide	◐	●	◐	●		rotten egg	0.0005	0.0056	0.063	0.72	8.1
Methyl merchaptan	○	○	○	○		onion	0.0001	0.00065	0.0041	0.026	0.16
Ammonia	○	○			○	urine	0.15	0.59	2.3	9.2	37
Tri-methyl amine		●	◐			fishy	0.00011	0.0014	0.019	0.24	3.0
Acetic aldehyde					○	mold	0.0015	0.015	0.15	1.4	14

[A] ●Major, ◐detected, ○Possible
[B] Intensity scale : 0 None, 1 Threshold, 2 Moderate, 3 Strong, 4 Very Strong, 5 Over Strong

Table 2 Air leakage data

BUILDING COMPONENTS		AIR LEAKAGE DATA
Exterior wall	At lobby	$EqLA_{75}$ 2.1 ㎠/㎡ [a]
	At typical floors	$EqLA_{10}$ 1.51 ㎠/㎡
Door	Residential entrance door	$EqLA_{10}$ 70 ㎠/item
	Elevator door	$EqLA_{10}$ 325 ㎠/item
	Stairwell door	$EqLA_{10}$ 120 ㎠/item
	Door for condensing room	$EqLA_{10}$ 23 ㎠/item
	Swing door located on lobby and basement floor	430 CMH at 50 Pa
	Revolving door located on lobby floor	73 CMH at 50 Pa
Etc.	Top of elevator shaft	Equivalent orifice area of 1.0 ㎡

[a] $EqLA_{75}$: Equivalent leakage area at 75 Pa, $EqLA_{10}$: Equivalent leakage area at 10 Pa

The factors of meat odor are Hydrogen sulfide(H_2S) and Ammonia(NH_3), the factors of Kim-Chi are Hydrogen sulfide(H_2S) and Methyl Merchaptan (CH_3SH), and the factors of fish odor are Hydrogen sulfide(H_2S) and Tri-methyl amine ($(CH_3)_3N$) etc.

In this study, fish odor was selected for dispersion of food odor and dilution of it in core was analyzed. In case of fish odor, the main causes of odor are Hydrogen sulfide (H_2S) and Tri-methyl amine ($(CH_3)_3N$). Accordingly, the hypothesis was set; Tri-methyl amine($(CH_3)_3N$) of 3ppm which is 5 of stench intensity is generating on diffused point in residential unit in terms of STEP 3. Also, 0.00011ppm of it was set as sensible stench intensity of STEP 4 to decide the optimal amount of air supply that satisfies under sensible stench density.

Air leakage data and weather data. Table 2 is about the air leakage data of exterior wall, the front door, elevator door, a stair hall door, and lobby door etc from the study of Jo et al (2007) which analyzed stack effect of high-rise residential building. Stack effect is proportional to difference between indoor temperature and outdoor temperature, so stack effect is going to be bigger as outdoor temperature is decreased. Accordingly, 22℃ and -11.9℃ of TAC 2.5 which are standard temperature of heating design in Seoul area were set as indoor and outdoor temperatures, respectively (SAREK 2001). Also, it is assumed that there was no wind for this study.

Step 2: airflow q

The amount of air in/outflow of residential unit and core, elevator shaft, a stair hall in entire of building that has a standard floor plan as shown in Figure 1, was calculated by CONTAMW. According to Figure 2, the air pressure of core which is above floor from middle floors (17^{th} and 18^{th} floor) is higher than other area, so the air flows from core to residential unit. Also, in case of the floors which are under middle floors, the air flows from residential unit to core because the pressure in residential unit is higher than core.

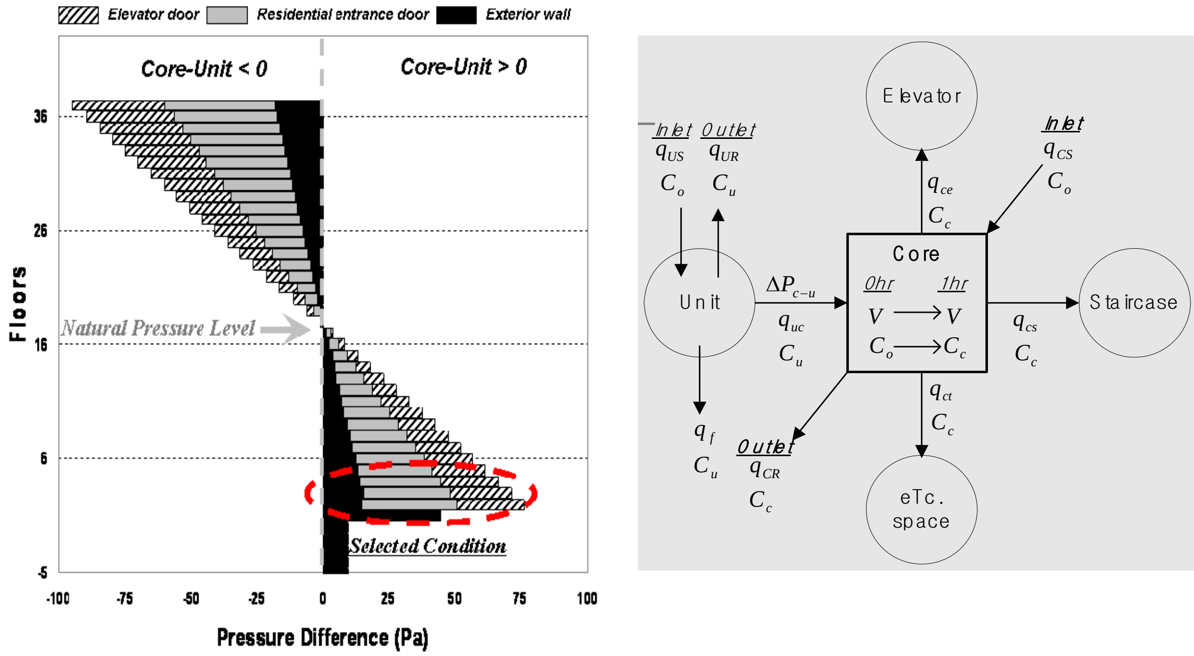

Figure 2 Pressure difference and airflow direction

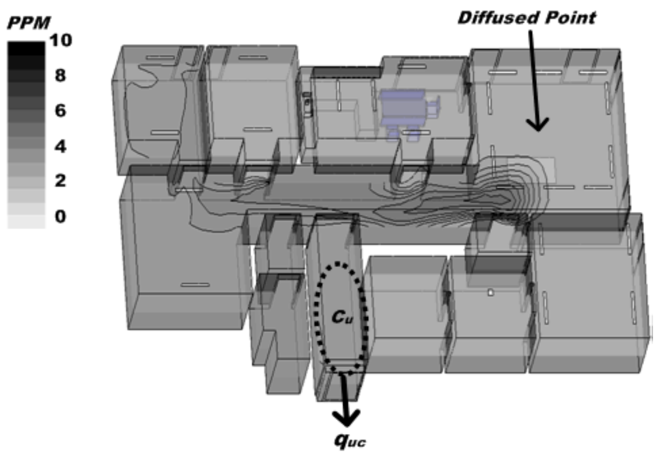

Figure 3 Concentration distribution of the unit

Table 3. Calculation condition of Steps 3 and 5

	STEP 3	STEP 5
Model	Standard k- ε High Reynolds	Standard k- ε High Reynolds
Mesh	700,000	300,000
Wall	Wall function	Wall function

In brief, the dispersion of food odor is happened in the floors that are under the middle floors. In this study, 3 floors which have big difference of the air pressure were selected, and the amount of air in/outflow of residential unit, core, elevator shaft, and a stair hall were calculated. Under the condition that air inflow(q_{US}) is 1369 m^2/h and air outflow(q_{UR}) is 1269 m^2/h, 1761 m^2/h of air flows from residential unit to exterior wall(q_f), 654 m^2/h of air flows from residential unit to core(q_{uc}), 1535 m^2/h of air flows from core to elevator shaft(q_{ce}), 105 m^2/h of air flows from core to a stair hall, and 120 m^2/h of air flows to other places(q_{ct}). There is no information of density of food odor (C_u) which is included in airflows from residential unit to core (q_{uc}) yet.

Step 3: odor concentration C_u

Dispersion of food odor was analyzed by CFD simulation with residential unit model of Step 3 in Figure 1. In this case, the odor density of the front door area according to dispersion of food odor can be set as C_u. The air inflow of 1369 m^2/h and the air outflow of 1269 m^2/h in residential unit were used as boundary conditions. Also, another boundary condition which were result of Step 2 were used; the amount of airflow of 1761 m^2/h from residential unit to exterior wall and the amount of airflow of 654 m^2/h from residential unit to core. Table 3 is calculating condition. Figure 3 is the result of density dispersion of food odor, and Cu around the front door is 0.495ppm in case of regular ventilation.

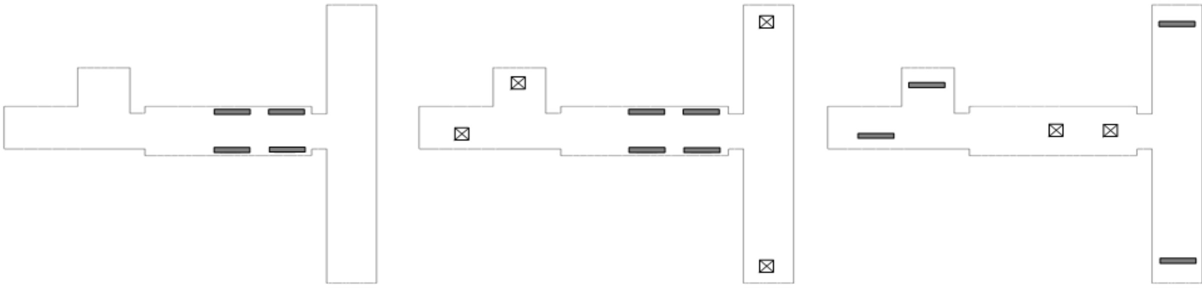

Figure 4 Cases according to the location of air in/outlet

Accordingly, 89 m^2/h air that has 0.495ppm density flows from residential unit to core. Even though the amount of air and density is small, the stench intensity is very high, so residents can be uncomfortable when they get in or out of the building.

Step 4: Optimal amount of ventilation q_{cs}

Minimum inflow(q_{CS}) that dilutes stench intensity from 1 to 0.00011ppm for each floor can be calculated by CONTAMW with maximum density C_u of a front door area which is the result of Step 3 when Tri-methyl amine($(CH_3)_3N$) is dispersed from residential unit to core. For example, in case of third floor of which pressure difference between residential unit and core were the biggest, the density of Tri-methyl amine ($(CH_3)_3N$) could be kept under the 0.00011ppm when 1000CMH air inflow (q_{CS}) and outflow (q_{CR}) were applied.

However, density of Tri-methyl amine ($(CH_3)_3N$) can be kept under the 0.00011with less than 1000CMH because the pressure difference is decreased as floor get higher until middle floor and the amount of airflow from residential unit to core is getting small.

With the same way, analyzing air inflows (0, 200, 400, 600, 800CMH) were applied for each floor. After all, to keep the density of Tri-methyl amine($(CH_3)_3N$) under 0.00011ppm, the minimum air inflow were analyzed as 800CMH from 3th floor to 17th floor, 300CMH from 19th floor to 20th floor, 500CMH from 21th floor to 27th floor, and 800CMH from 28th to 37th .

Step 5: location of inlet and outlet

To maximize the efficiency with calculated air inflow (q_{CS}) and air outflow (q_{CR}), the location of in/outlet has to be decided. First of all, Figure 4 is the schemes of ventilating system according to the location of air in/outlet. Four kinds of cases were analyzed: Case1 was about existing scheme, Case 2 was about Case1 with optimal amount of ventilation, Case 3 was about Case1 with air inflow in front of elevator, and Case 4 was about Case1 with air outflow in front of elevator. Figure 5 is about the result of CFD simulation. Case1 shows that the food odor from residential unit was dispersed not only to elevator area but also to stairwell area.

Case2 shows that the pollutants were not diluted and dispersed to central core area even though an optimal amount of ventilation was applied. However, Case3 shows the pollutants were diluted by air outlet that is in front of residential, and then the food odor was blocked by airflow which was generated by line air inlet in front of elevator. Finally, Case4 shows that the rest of food odor was dispersed to the core area due to airflow that was made by the air inflow even though the pollutants were diluted by air inflow in front of the residential unit. As a result, the optimal ventilating system was that ventilating system that had air inflow in front of elevator and air outflow in front of residential unit.

Results

This study was about dispersion analysis of food odor which was a serious problem in high-rise residential building in terms of stack effect. Moreover, it was showed the method how to calculate the optimal amount of air inflow and to decide the location of air in/outlet.

As a result of object building, the pressure difference between residential unit and core was big during winter. In case of the floors which were under middle floors, the air flew from residential unit to core because the pressure in residential unit is higher than core. Even though the density of food odor that goes to core area is very small, other residents can be uncomfortable because the stench intensity is very high. Furthermore, the food odor can be dispersed according to the location of air in/outlet even though the amount of ventilation is enough to dilute the food odor.

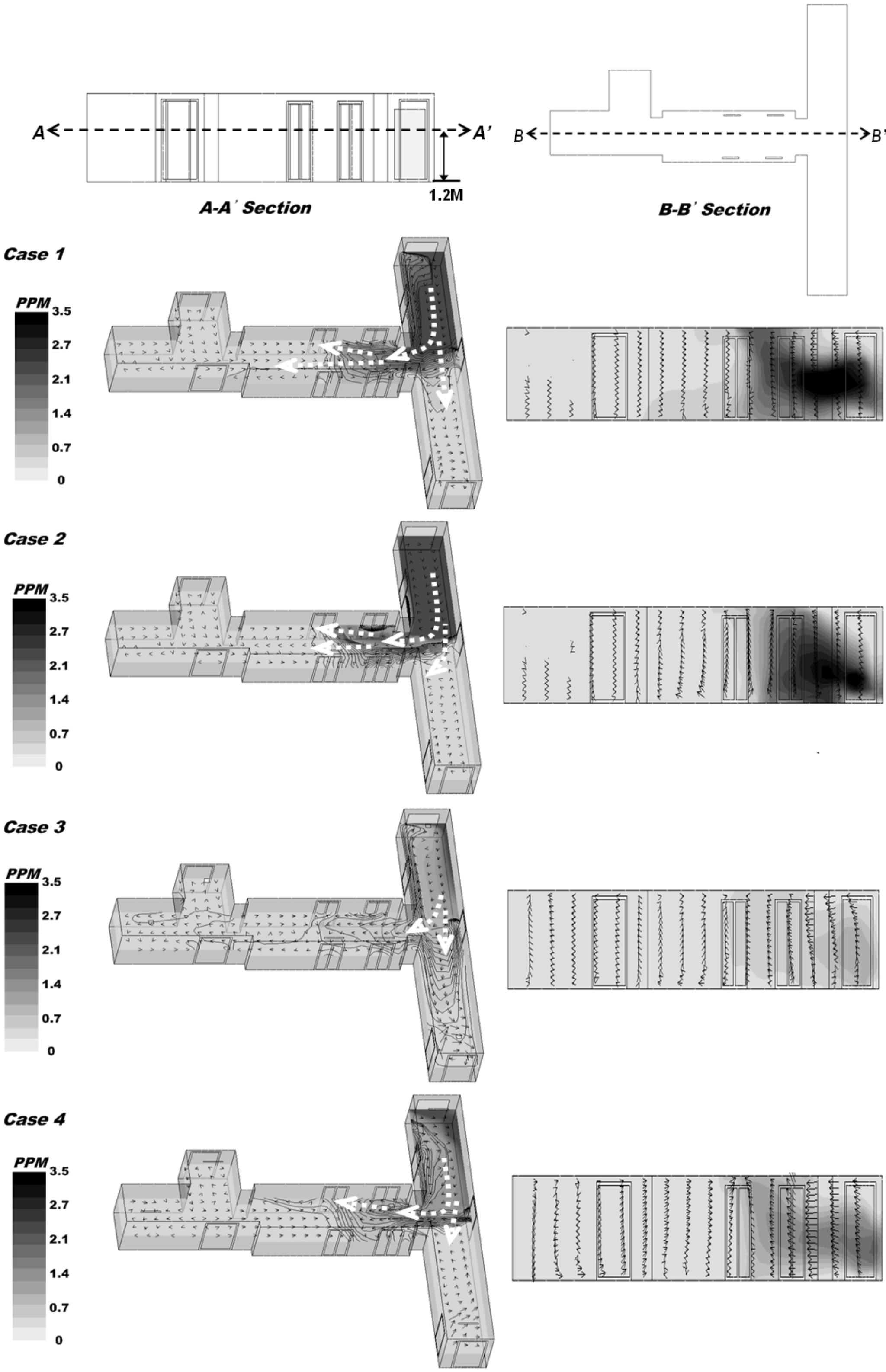

Figure 5 Concentration distribution of each case

DISCUSSION

This study brings the stack effect during winter into focus because the winter has the great difference between indoor and outdoor temperatures in South Korea. This difference increases the influence of the stack effect on the airflow between spaces. Also, a phase of stack effect during summer appears in different way from that of the stack effect during winter. In case of summer, the influence decrease because of the small difference between indoor and outdoor temperatures. The air pressure of core, which is above floor from middle floors-neutral pressure level, is lower than residential unit, so the air flows from residential unit to core. Also, in the floors under middle floors, the air flows from core to residential unit because the pressure in residential unit is lower than core. Unlike winter, the dispersion of food odor is happened in the floors that are above the middle floors. Therefore, in hot climate region, this odor problem is less likely to occur because of the small stack effect. Also, intensity of food odor is carefully studied with relation to the human behavior in the residential buildings.

ACKNOWLEDGEMENT

This work was supported (in part) by Yonsei Univers ity Research Fund of 2005

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