THE EVALUATION OF MULTI-ZONE AIR FLOW PATTERN AND VENTILATION RATES WITH TRACER GAS METHODS IN APARTMENT HOUSE

DW Yoon1*, JY Sohn2, SD Kim3 and HS Kim4

1Dept. of Building Equipment and System Engineering, Kyungwon University, Kyunggi, Korea
2School of Architectural Engineering, Hanyang University, Seoul, Korea
3School of Environmental Engineering, University of City of Seoul, Seoul, Korea
4Dept. of Architectural Engineering, Dankook University, Seoul, Korea

ABSTRACT
The air change rates of ventilation system and inter-zone airflow rates were investigated at the apartment house. The fully developed ventilation systems are designed to supply outside air at each room and gas range hoods are installed with makeup air to remove pollutants effectively from cooking processes. The airflow patterns and air balance could be changed due to the different operating conditions of the ventilation systems. Detailed testing of multi-zone airflow and ventilation rates were conducted using two different types of tracer gas method. The results of measurement and airflow pattern were compared with those of the design strategies. Air changes per hour were ranged from 0.38–1.33[h⁻¹] at individual rooms. In the dining room and kitchen area, air change rates are varied from 4.69–10.59[h⁻¹] with various operating conditions of range hoods.

INDEX TERMS
Inter-zone airflow, Ventilation, Tracer gas methods, Apartment house

INTRODUCTION
Ventilation has been concerned with HVAC system, but most of the effort has focused in the area of commercial buildings in Korea. Traditionally, ventilation of the residential building was not a major concern because people think that it was enough to get the fresh air through the operable windows and infiltration from the envelope leakage(Yoon.2001). Since the energy crisis, building technology has been developed and houses have become much more energy efficient and air- tight. Poor indoor air quality is related to new building technology, new materials, and ventilation and energy management system. All of these factors have contributed to an increasing public concerns about indoor air quality and ventilation. Sick house and sick building symptom is newly issued with increasing chemicals at the newly constructed buildings.

Apartment house air tightened and insulated has advantages to conserve energy but cause the indoor air quality problem. Due to the lack of the natural ventilation, poor indoor air quality and insufficient ventilation rate have resulted high risk of indoor environments from contaminants driven by finishing materials and residential activities such as cooking, cleaning and house keeping. It is urgent to apply the mechanical ventilation design systematically in apartment houses. The aim of this study is to chaise the airflow patterns at the apartment house where the mechanical ventilation system is fully developed with both of general

* Contact author email: dwyoon@kyungwon.ac.kr
ventilation and spot ventilation. The kitchen ventilation above the gas range is designed to exhaust the fume directly without spreading the contaminants to other indoor space during the cooking process. It is important not to be contaminated the living area for healthy indoor environment.

**METHODS**

**Selected Building**

All experiments are carried out in a real scaled model house as a show room constructed with exactly the same ventilation systems applied to a high-rise apartment house. The model house is located at the inside of the exhibition building of the show room. Ventilation system was designed to introduce proper amount of outside air to individual room with duct working, and the exhaust was installed at the kitchen and bathroom. It is important to remove the pollutants from the cooking process exactly before spreading to other indoor spaces. The ventilation system was designed to control the supply air volume properly and positive pressure was appeared at the individual room. The air balance is designed to lead the airflow to the kitchen ventilation hood when the ventilation is operating.

**Experimental Measurements**

Two types of tracer gas methods (Doi, Satoshi.1996), such as constant concentration method and step-down method, were applied to measure the multi-room airflow patterns using SF₆ gas [Multi-Gas Monitor, 1302, INNOVA Denmark]. Ventilation rate and airflow patterns were evaluated for various operating conditions of kitchen ventilation. At each case of operation, air volumes of the spot ventilation and HVAC system were measured directly using airflow meter [Air Capture Hood, Model 8373 and Air Flow Meter 8360-M, TSI USA]. And then pressure differences were measured to know the airflow pattern between two adjacent rooms using manometer [Microprocessor Manometer MEDM 5k, Dwyer USA]. Also two types of tracer gas methods were applied to figure out the air volumes from infiltration and inter-zone cross flow.

Constant concentration method, which releases SF₆ gas as tracer continuously and keeps the concentration of the tracer gas constant at whole area of the unit plan, is applied for determining airflow rate of outdoor air volume supplied to a individual room quantitatively. This air volume could be counted on both of infiltration and mechanical ventilation. As the constant concentration method should be kept tracer gas concentration constant at all rooms, the gas concentration was not effected by airflow from other rooms and it could be to measure the outside airflow rates entered individual room as infiltration. This method is possible to deal with variable conditions such as ventilation driving force change. The tracer gas concentration was constantly made 5ppm as set point. And the next step, the measurement of the step-down method as concentration decay was performed to determine the inter-zonal flow at each room quantitatively. Finally it is possible to calculate the air volumes both infiltration from the window and inter-zone flow to adjacent room.

Air change rate per hour is given by equation (1) using the constant concentration method.

Discharge rate of tracer gas, which is varied with outside air volume introduced, is proportionally adjusted by measurement device automatically.

\[
N(\tau) = \frac{F(\tau)}{V \times C} \left[ h^{-1} \right]
\]  

(1)

Where \(N(t)\) and \(F(t)\) are the air change rate and tracer gas dosing rate at time \(t\), \(V\) and \(C\) are...
the air volume of the room and tracer gas concentration at a room.

In step-down method, tracer gas concentration is measured with a gas analyzer at every point after releasing tracer gas into the room air. Air change per hour in step-down method is given by equation (2):

\[ N = \frac{1}{\Delta T} \cdot \ln \frac{C_1}{C} \]  

(2)

where \( C_1 \) and \( C \) are the tracer gas concentration at time \( t_1 \) and \( t \), and \( \Delta T \) means the time interval \((t-t_1)\) of measurement.

Table 1 shows the operating condition of the ventilation system in experiments. Airflow patterns were measured according to the various operating conditions. Case #1 shows the operating condition as a general ventilation concepts and Case #2 shows the fully operating condition of various kitchen ventilation.

### Table 1. The operating condition of the ventilation system in experimental design

<table>
<thead>
<tr>
<th>Location of Exhausts</th>
<th>Case.#1</th>
<th>Case.#2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen Hood</td>
<td>✗</td>
<td>☀</td>
</tr>
<tr>
<td>Extra exhaust grill</td>
<td>✗</td>
<td>☀</td>
</tr>
<tr>
<td>Constant exhaust on ceiling</td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td>Make-up air supply</td>
<td>✗</td>
<td>☀</td>
</tr>
<tr>
<td>Multiuse room hood</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Extra exhaust grill</td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td>Make-up air supply</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

( ☀ : operating , ✗ : stop operating)

### RESULTS AND DISCUSSION

**Airflow with the Ventilation Strategies**

Ventilation system is designed to supply outside air only at the individual room, which could be maintaining positive pressure to prevent spreading the pollutants and odor emitted during cooking process. The exhaust grills are located in the kitchen area only in order to make the air stream for the kitchen direction. Outside air volume was decided according to the number of occupants as 20m³/h - 80m³/h. Also, It is the design strategies that 400 m³/h of outside air is introduced at the kitchen and 350 m³/h is introduced at the multiuse room as a make-up air when the range hoods are operating.

Air change rates and air airflow patterns between rooms were measured for all cases of experiments. Airflow patterns were chased using smoke test and static pressure differences. In the case of general ventilation, individual room indicated slightly positive pressure due to the supply of outside air. And the negative pressure appeared in the kitchen, which is resulted from the constant exhaust without any supplying the make-up air.

Outside air volume at the kitchen was measured about 440 m³/h. Also supply air volume at the multi-use room was measured from 325 m³/h to 331 m³/h. It shows that the make-up air is maintained within 10% of the designed. Inter-zonal airflow rates among rooms were varied
with system operating conditions. Pressure differences between rooms measured with low values 0 ±1Pa during the general ventilation. But it is enough to find the airflow pattern in the whole area. Owing to the intensive exhaust in kitchen, the pressure difference between kitchen and living room were indicated to 5 ~ 6Pa.

**Evaluation of the Inter-zone Airflow Rate**

Two types of the tracer method and direct measurement of the supply air in ventilation system have realized to figure out the airflow rate via infiltration and inter-zone airflow between the adjacent rooms. At entrance hall and veranda areas where were affected by infiltration, the concentration was largely deviated but finally approached to set point of tracer gas when applying the constant concentration method.

Figure 1 shows the outside airflow rate resulted from the constant concentration method. Air change rate is measured similar to the designed air volume of the mechanical ventilation system. Several areas such as an entrance hall and two verandas appear highly deviated profiles of airflow rates. Table 2 shows the averages of the air change rates measured by constant concentration method. Air volumes evaluated indicate very similar to those of the measured directly in rooms.

![Figure 1](image_url)

**Table 2. The average of air change rates measured by constant concentration method(m³/h)**

<table>
<thead>
<tr>
<th>Items</th>
<th>Air change rate (m³/h)</th>
<th>Air change per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main room</td>
<td>34.2</td>
<td>0.69</td>
</tr>
<tr>
<td>Room(1)</td>
<td>20.6</td>
<td>0.61</td>
</tr>
<tr>
<td>Room(2)</td>
<td>16.3</td>
<td>0.59</td>
</tr>
<tr>
<td>Room(3)</td>
<td>15.8</td>
<td>0.51</td>
</tr>
<tr>
<td>Family room</td>
<td>24.1</td>
<td>1.34</td>
</tr>
<tr>
<td>Living room</td>
<td>68.3</td>
<td>0.67</td>
</tr>
<tr>
<td>Entrance room</td>
<td>25</td>
<td>3.90</td>
</tr>
<tr>
<td>Veranda(1)</td>
<td>59.4</td>
<td>2.32</td>
</tr>
<tr>
<td>Veranda(2)</td>
<td>23.2</td>
<td>1.69</td>
</tr>
</tbody>
</table>
Individual room has zonal airflow between adjacent rooms and the outside air volume supplied by mechanical ventilation system. After measurement of constant concentration method, the concentration decay (step-down) method was applied to find the total airflow rate in the individual room. Total airflow rate is ranged over 20–30 m³/h more comparing to air volume measured by the constant concentration method. Those air volumes are assured that of which caused by inter-zone airflow between adjacent individual rooms.

Table 3 shows the total airflow rates and inter-zone airflow between individual rooms. Hereby the total air change rates indicate the air volume combined both of the outside air by ventilation system and the cross airflow rates between rooms. It was found that total airflow in the rooms was decreased when the kitchen ventilation was "off" condition. The inter-zonal flow was decreased too with the same situation. Even though the driven force for the exhaust in the kitchen was increased, inter-zonal flow was relatively decreased. It seems that the range hood operating with the make-up air makes smoother for the inter-zone airflow and maintains the air balance effectively in the unit of the apartment house.

Table 3 – the airflow rates between rooms in each case of measurements(m³/h)

<table>
<thead>
<tr>
<th>Items</th>
<th>Room(1)</th>
<th>Room(2)</th>
<th>Room(3)</th>
<th>Family room</th>
<th>Main room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Air Volume with Mechanical Ventilation System</td>
<td>20.6</td>
<td>16.3</td>
<td>15.8</td>
<td>24.1</td>
<td>34.2</td>
</tr>
<tr>
<td>Case #1 Total Airflow Rate</td>
<td>44.5</td>
<td>36.9</td>
<td>48.3</td>
<td>46.1</td>
<td>45.6</td>
</tr>
<tr>
<td>Airflow Rate moved to other Rooms</td>
<td>23.9</td>
<td>20.6</td>
<td>32.5</td>
<td>22.0</td>
<td>11.4</td>
</tr>
<tr>
<td>Case #2 Total Airflow Rate</td>
<td>42.5</td>
<td>31.4</td>
<td>38.8</td>
<td>45.7</td>
<td>43.6</td>
</tr>
<tr>
<td>Airflow Rate moved to other Rooms</td>
<td>21.9</td>
<td>15.1</td>
<td>23.0</td>
<td>21.6</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Figure 2. Example of the airflow patterns and airflow rates.(Case #1 and Case #2).
Airflow Patterns in the apartment house
From the measurement of static pressure and the smoke test, airflow pattern was chased in whole unit of the model house. The airflow patterns and the air volumes introduced are shown in Figure 2. Because the model house is located at the inside of the covered building, the model house is not affected directly by the outdoor weather condition. Air infiltration is occurred at the veranda area and the rooms faced on the outside. In every case of measurement, the inter-zone airflow patterns are well matched to the design strategies for the mechanical ventilation system. It is found that the polluted matter emitted from the cooking process could be exhausted directly without spreading to the other areas.

The room air introduced by mechanical ventilation has finally moved to the kitchen and multi-use room for exhausts through bedroom and living room in turns. And the outside air volumes introduced by the ventilation system and air infiltration into veranda and entrance hall have been pretty much well balanced in apartment as total air volumes intakes.

CONCLUSION
The airflow patterns and the performance of the mechanical ventilation system were measured in the fully developed model house of apartment complex. According to the operating conditions of ventilation system, the air change rates and the airflow routes were investigated quantitatively using tracer gas techniques. The conclusions of this study were as follows.

1) Inter-zonal airflow patterns are well matched with the design strategies of the ventilation system. Airflow routes are as follows; “Bedroom ⇔ Living room ⇔ Dining room ⇔ Kitchen ⇔ Multiuse room” for exhausts.

2) The performance of the ventilation system and the cross inter-zonal flows between rooms were evaluated quantitatively. Especially using two types of tracer gas methods and pressure differences between rooms, it could be figure out the air change rate for inter-zonal flow between rooms. Also the overall performance of the ventilation system in rooms was evaluated with the various operating situation of the local ventilation system.

3) When supplying additional outside air as make-up at the kitchen, total air balance in the apartment house could be assured the more effective performance of the exhaust system. The variation of the exhaust air volume in the kitchen area didn’t have an influence on the air balance in living room or other rooms at the selected house.

REFERENCES
Doi, Satoshi. 1996. Measurement of Multi-zone Airflow in Experiment House, ROOMVENT ’96, pp55–60