Measurement of Indoor Air Quality for Ventilation with the Existence of Occupants in Schools

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This paper evaluates the performance of ventilation for the removal of indoor pollutants as a function of ventilation rate and the number of occupants in a test room and school classroom. An experimental apparatus consists of a test room, a tracer gas supply system, a gas detector, and a fan for ventilation air supply with a controller. The ventilation performance is evaluated in a step-down method based on ASTM Standard E741-83 using CO_2 gas as a tracer gas in the test room of 35 m^3. For the ventilation air flow rate of 1.0 ACH, a recommended ventilation flow rate of Korea school standard for acceptable indoor air quality in the case of one person, CO_2 gas concentration decreases up to 55% within 50 minutes without occupancy and increases up to 75% in the case of one occupant. Also indoor air quality at the school classroom is investigated experimentally.

Key Words : Indoor Air Quality, Ventilation, School Ventilation

1. Introduction

Air inside office buildings and residences is contaminated by a large variety of toxic contaminants. Ventilation has become well-recognized part of environmental control for human comfort and is a positive control method to improve the indoor air quality. Insufficient ventilation results in poor indoor air quality and can be harmful to the occupants of the building under extreme conditions which can cause problems associated with the sick building syndrome (SBS), Therefore, adequate ventilation is essential for achieving and maintaining indoor comfort.

All schools need ventilation, which is the process of supplying outdoor fresh air to the occupied areas in the school. As outdoor air is drawn into the school, indoor air is exhausted by fans or allowed to escape through openings, thus removing indoor air pollutants. The modern schools generally use mechanical ventilation systems to introduce outdoor air during occupied periods, but some schools use only natural ventilation or exhaust fans to remove odors and contaminants. In naturally ventilated buildings, unacceptable indoor air quality is particularly likely when occupants keep the windows closed because of extreme hot or cold outdoor temperatures (EPA, 2000).

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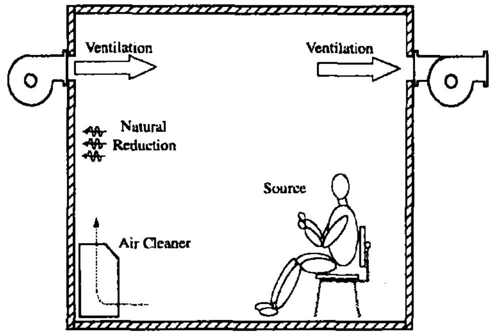

Fig. 1 Schematic diagram for analyzing indoor air quality used in mass balance of pollutants

Aerosol dynamics in the environmental chamber are investigated to determine factors that can influence the air exchange rate on the concentrations of pollutants. Fig. 1 shows a schematic diagram of the variation of indoor pollution concentration used in mass balance of pollutants.

Lee and Chang (1999) investigated the temperature, relative humidity, CO_2, SO_2, NO and air pollution level at five schools in Hong Kong. The indoor and outdoor average PM_{10} concentrations exceeded the Hong Kong standards (180 $\mu g/m^3$, 24 hour average), and the maximum indoor PM_{10} level was even at 472 $\mu g/m^3$. Indoor CO_2 concentration often exceeded 1,000 ppm indicating inadequate ventilation. Lee et al.(2000) studied ventilation effectiveness of three types of mechanical ventilation systems without occupants using a tracer gas technique for indoor air quality control and management as a function of air exchange rate and supply/extract location.

This paper evaluates the ventilation performance for the removal of indoor pollutants as a function of ventilation rate and the number of occupants in a test room. Also indoor air quality at the school classroom is investigated experimentally to evaluate ventilation performance based on Korea school standard with the test condition taking into account the ventilator and students.

2. Experimental Apparatus and Test Procedure

The experimental apparatus for testing ventilation performance consists of the test chamber, the humidifier, the electric heater, the supply fan to provide the clean air into the chamber, the tracer gas supply system to generate the tracer gas, and the tracer gas analyzer to measure the concentration of tracer gas with operating hours. The test chamber has the volume of 35 m^3, and is made of 3-layer panel sheet. Its middle layer is filled with insulating material, contains isothermal conditions between the inner and outer stainless sheet wall. There is no leakage of air from indoor side to outdoor side through the door and the wall clearance.

Table 1 Experimental conditions for ventilation efficiency

Parameters		Specifications
Test chamber (Fully closed and insulated)	Size	35 m^3
	Control temperature	15~45℃
	Control humidity	10~90% RH
Supply ventilation air (ACH*)		None, 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0
Human occupancy		None, One, Two
Temperature	Outdoor	25℃
	Indoor	20℃
Relative humidity	Outdoor	51% RH
	Indoor	45% RH

*ACH : air changes per hour.

Table 1 shows the test conditions for evaluating the ventilation performance. Supply ventilation air ranges up to 1.0 air change per hour (ACH) equivalent to the supply ventilation air up to 500 lpm, a recommended ventilation flow rate of the Korea school standard for acceptable indoor air quality in the case of one person.

The simplest tracer gas technique used in evaluating ventilation performance is the decay method known as the step-down method of ASTM E741-83. The mixing fans are installed in the chamber. The supply and exhaust fans are switched on and the chamber is filled with tracer gas to a suitable concentration level. After a period of mixing, the fans are switched off and the ventilation test starts. The concentration is then allowed to decay to a base level before the test is stopped. The CO_2 gas is selected as the tracer gas in this study. An ideal tracer gas should not be a normal constituent of the environment to be investigated, be easily measurable, non-toxic and non-allergenic to permit its use in occupied spaces, be non-reactive and non-flammable so that its movement is easily traced, and be economical to use. No single tracer gas fulfills all the requirements mentioned. A wide variety of gases have been employed and chosen to exploit a specific characteristic. CO_2 gas has proven useful as a tracer gas when its outdoor concentration is 350~600 ppm. The mixing fan makes CO_2 concentration uniform in the test room. Variations of the gas concentration as a function of time are measured at the center point of the test chamber wherein a mixing fan is operating for steady-state CO_2 concentration. The air exchange rates with the CO_2 gas monitor (CASELLA, ICS-500, 0~3000 ppm, and Kanomax, CMCD 10P) using a principle of nondispersive infrared absorption which also can analyze indoor airflow velocity change, CO_2 concentration, temperature and relative humidity (Lee et al., 2000; Han, 1999; Lee et al., 2001; Kim et al., 2003).

3. Results and Discussion

3.1 Ventilation performance in a test chamber

Figure 2 shows the CO_2 concentration decay as a function of the ventilation rate of 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, and 1.0 air changes per hour (ACH) in the test chamber of 35 m^3 with the air temperature of 20℃ and the relative humidity of 45% with no occupancy. The initial indoor and outdoor concentrations are 1,000 ppm, and 500 ppm, respectively. The ACH can be defined as the ratio of the supply ventilation air to the chamber volume, and the supply ventilation air of 50, 100, 150, 250, 400, 450, and 500 lpm can be calculated as the ACH of 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, and 1.0, respectively. The results show that the ventilation performance increases with increasing the supply ventilation air, and the CO_2 concentration decay are 2, 20, 32, and 55% for the ventilation rate of 0, 0.2, 0.4, and 1.0 ACH, respectively. The reduction constant can be obtained from the results, and it is found that the natural reduction constant is 0.0005 (min^{-1}) and the ventilation reduction constant with the natural reduction is 0.0110 (min^{-1}) for the ventilation rate of 1.0 ACH. The mechanism of natural reduction of CO_2 is the natural ventilation due to the infiltration.

Figure 3 shows the CO_2 concentration ratio in the test chamber as a function of the occupants and the ventilation rate (ACH) with the initial indoor concentration of 650 ppm and the outdoor concentration of 500 ppm. As shown in this figure, the CO_2 gas concentration increases with increasing period as a function of the occupants for the respiration in the test room. For the case of the initial CO_2 concentration of 650 ppm

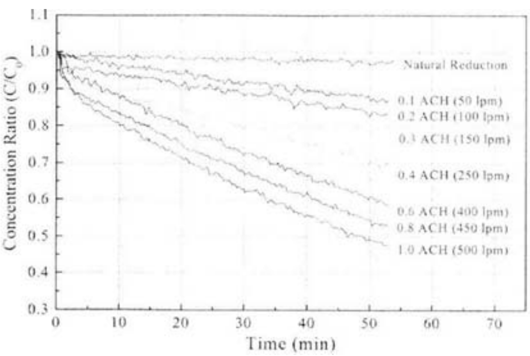

Fig. 2 CO_2 concentration decay as a function of air change per hour (ACH) in the test chamber with no occupancy

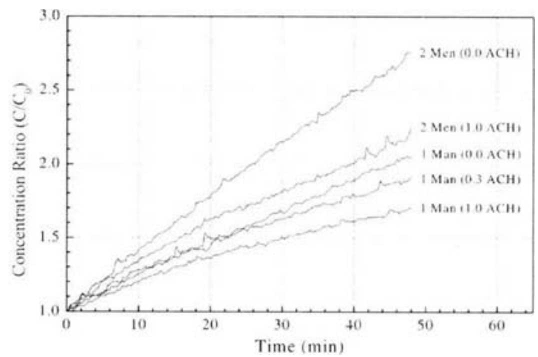

Fig. 3 CO_2 concentration ratio in the test chamber as a function of the occupants and the ventilation rate

without the ventilation, the CO_2 concentration increases gradually to 1,300 ppm with one occupant, and to 1,700 ppm with two occupants within 50 minutes. For the case of the ventilation rate of 1.0 ACH, the CO_2 concentration increases to 1,050 ppm with one occupant, and to 1,350 ppm with two occupants during the same testing time. The CO_2 concentration increases gradually due to CO_2 emission of an occupant in spite of the recommended ventilation rate of 1.0 ACH, and the ventilation flow rate of 1.0 ACH seems to be insufficient under the condition of one occupant. In this study, the test chamber has no leakage of air through the door and the wall clearance unlike general residence. It is believed that the ventilation performance becomes better due to the leakage of air through the doors and the windows in the real situation.

3.2 Ventilation performance in school classrooms

Table 2 shows the test results of the ventilation performance at the high school classroom (178.2 m^3) with the existence of 35 students, Changwon in Korea. The airflow rate of ventilators installed in the ceiling is ranged from 500 CMH (Cubic Meter per Hour) through 800 CMH. The Korea school standard specifies the average CO_2 concentration of below 1,000 ppm and the ventilation airflow rate of 21.6 CMH/person. The ventilation airflow rate more than 756 CMH is required for the 35 students. The maximum CO_2 concentration without ventilation of the classroom is 2,190 ppm. For the ventilation air of 500 and 600 CMH using the ventilator, the average CO_2 concentration exceeds 1,000 ppm, while for 800 CMH ventilation air, the average CO_2 concentration is 913 ppm. It is believed that the ventilator of 800 CMH is sufficient to meet acceptable indoor air quality in the classroom of 35 students.

Figure 4 shows the variation of indoor CO_2 concentration with the ventilator of 800 CMH airflow rate installed in the ceiling during 5 hours. The high school classroom (178.2 m^3) with the existence of 35 students is located in Changwon, Korea. The variation of outdoor CO_2 concentration ranges from 420 to 443 ppm during the testing period. It is important to measure the outdoor CO_2 concentration. The ventilation is the process of supplying outdoor air to the indoor air. If the outdoor CO_2 concentration is higher, the effectiveness of ventilation is lower. The variation of indoor CO_2 concentration ranges from 750 ppm to 1,000 ppm. Therefore, the ventilator of 800 CMH meets an acceptable indoor air quality requirement for the classroom of 35 students, a maximum number of students based on the Korea school standard.

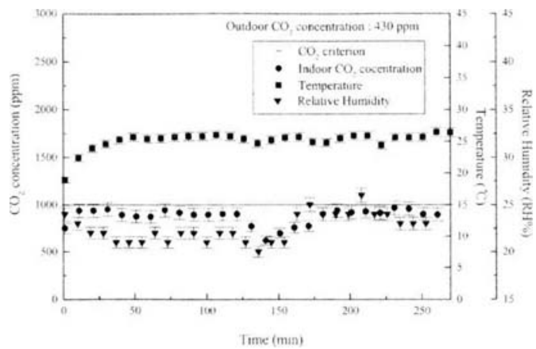

Fig. 4 Variation of indoor CO_2 concentration with the ventilator of 800 CMH airflow rate installed in the ceiling during 5 hours and in the high school classroom, in Changwon

Table 2 Test results of the ventilation performance at the high school classroom (178.2 m^3) with the existence of 35 students

Ventilation Air Rate (CMH)	Average Outdoor CO_2 Concentration (ppm)	Indoor CO_2 Concentration (ppm)			
		Ventilator OFF		Ventilator ON	
		Average	Maximum	Average	Maximum
–	400	1791	2190	–	–
500	410	–	–	1260	1536
600	401	–	–	1032	1145

4. Conclusions

This paper evaluates the ventilation performance as a function of ventilation rate and the number of occupants in a test room and a real classroom. For the test room and the ventilation air flow rate of 1.0 ACH, a recommended ventilation flow rate for acceptable indoor air quality in the case of one person, CO_2 gas concentration decreases up to 55% within 50 minutes without occupancy and increases up to 75% in the case of one occupant. For the ventilator of 800 CMH in the classroom with the existence of 35 students at the outdoor CO_2 concentration of 430 ppm, the average indoor CO_2 concentration is 913 ppm and the ventilator of 800 CMH is sufficient to meet an acceptable requirement of indoor air quality for the classroom of 35 students, a maximum number of students based on the Korea school standard.

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