Journal of the Korean Society of Marine Engineering, Vol.29, No.7, pp.736~743, 2005(ISSN 1226-9549)

Analysis of Ventilation Performance Using a Model Chamber

Tae-Wook Kang† · Tae-Hyeon Chang*

(Manuscript : Revised AUG 31, 2005 ; Revised OCT 4, 2005.)

Abstract : In this study, three different types of mechanical ventilation systems are compared based on their ventilation characteristics: tracer gas concentration decay characteristics, and ventilation effectiveness by calculating actual ventilation air flow rate. The experiments are performed by using a step-down method for measuring tracer gas, CO_2 gas, concentration in the model chamber. Application of a mixing factor, k, was used and measured values ranged from 0.68 to 0.77. The Type 2 ventilation system was found to have the highest ventilation effectiveness rather than the Types 1 and 3.

Key words : Ventilation Type, Ventilation Effectiveness, Mixing factor, Step-down method, Air change per hour(ACH)*

Nomenclature

ACH : Air changes per hour (hr_)
C : Concentration (ppm)
Cin : Concentration of tracer gas at supply duct (ppm)
Cout : Concentration of tracer gas at exhaust duct (ppm)
C(0) : Initial concentration (ppm)
k : Mixing factor
Q : Air flow rate (m^3/h)
Qcal : Actual ventilation air flow rate (m^3/h)
Qcon : Controled air flow rate (m^3/h)
t : Time (sec)
V : Room volume (m^3)
ε : Ventilation effectiveness
τ : Room mean age (sec)

1. Introduction

The fact is that a significant portion of a person's life is spent indoors and ventilation equipment is installed in most of their buildings[3]. But the data to maintain indoor air quality is not sufficient[10].

Outdoor air that flows through building for ventilation is used to dilute and remove indoor air contaminants. However, the energy required to condition outdoor air can be a significant portion of the total space-conditioning load. The magnitude of the outdoor air flow into the

† Corresponding Author(LG Electronics Inc.) E-mail : twkang@lge.com, Tel : 010)2288-3492
* Kyeongnam University

building must be understood for proper sizing of the HVAC equipment and evaluation of energy consumption.

There are three types of forced ventilation systems: the mechanical inlet and mechanical extract system, the mechanical inlet and the natural extract system, and natural inlet and mechanical extract system.

The objective of this study is to analyze the ventilation effectiveness of all three types of mechanical ventilation systems for evaluating the effective use of supplied air. The ventilation effectiveness and indoor pollutant concentration decay as a function of air exchange rate and supply/extract location is evaluated in the simplified model chamber using a tracer gas technique of CO_2 gas injected into a supply duct.

2. Theory

2.1 Mechanical ventilation systems

Where air movement is induced either by wind or by the effect of temperature difference, ventilation is termed natural. On the other hand, when air movement is resulted from power drive applied by fans, the arrangement is described as mechanical. The mechanical ventilation system is usually used to get a steady air flow rate.

Since the inlet and extract of air have to be considered separately, there are three possible combinations[5].

The first combination is a mechanical inlet and extract system. It can be applied to all types of spaces and is more preferred as compared to other two systems. In application, the ratio between the air volume duties of the inlet and extract systems must be selected with care in order to suit this particular application. The second one is a mechanical inlet and natural extract system. Outdoor air supply in this ventilation system is provided by mechanical means in order to maintain a positive pressure. This type of ventilation system is usually applied to an operating theater and a cleanroom to prevent pollutants from entering. The third is a natural inlet and mechanical extract system. Since the air is extracted from a space by fan, the space would maintain a negative pressure. This system is usually adapted to kitchen ventilation or a restroom ventilation to avoid odor or pollutants being released. There has been lots of research on the ventilation performance with mechanical inlet and extract ventilation system. But the comparative study of the ventilation performance in the three types of mechanical ventilation systems has not been conducted.

This study is to analyze the ventilation effectiveness of three types of mechanical ventilation systems for indoor air quality, and control and management as a function of air exchange rate and supply/extract location. The ventilation effectiveness is evaluated using a tracer gas technique with step-down method based on ASTM standard E741-83 in the simplified model chamber.

2.2 Concentration decay characteristics

Probably the most useful method of characterizing the effectiveness of room ventilation is the mixing factor guide reported by Constance(1970). If the room under consideration is ideally well-mixed, the concentration will decrease due to purging as indicated by the equation:

$$C(t) = C(0)\, e^{-(\frac{Q}{V})t} \qquad (1)$$

If the room is not well-mixed, then the rates of decay will not necessarily be logarithmic and hence the decay rates will be same in every part of the room.(Lidwell and Lovelock, 1946). This idea is identical to that used by Constance in the use of mixing factor k:

$$C(t) = C(0)\, e^{-k(\frac{Q}{V})t} \qquad (2)$$

Using the tracer gas technique, the value of k can be experimentally measured and thus accurately characterize room ventilation.

2.3 Calculation of actual air flow rate by variation of concentration

Variation of pollutant concentration according to time in a specific space have been used to assume actual ventilation air flow rate by mass balance of pollutant.

Measuring Cin, Cout, actual ventilation air flow rate which is can be calculated:

$$Qcal = -2.303\frac{R}{t}\log\frac{Cin - Cout}{C(0) - Cout} \qquad (3)$$

2.3 Ventilation Effectiveness

The ventilation effectiveness is defined using the actual air flow and the ventilation air flow rate controled.

$$\varepsilon = \frac{Qcal}{Qcon} X\, 100(\%) \qquad (4)$$

3. Experimental Apparatus and Test Procedure

Fig. 1 is a schematic diagram of the ventilation test system. It consists of the supply fan (DongKun, DB-118) to provide the clean air into the chamber, the exhaust fan (DongKun, DB-118) to extract the air out of the chamber, a tracer gas supply system to generate the tracer gas, the tracer gas analyzer to measure the concentration of tracer gas with time, and a model chamber. The model chamber has the dimension of $0.84 \times 0.68 \times 0.7m^3$, and has circular openings of 40mm in diameter. Four holes, 2 for supply and 2 for exhaust, are located at 90mm distance from top and bottom. Another hole for supply is located at the center of top. A tracer gas technique is used to evaluate ventilation effectiveness. The simplest tracer gas technique is the decay method known as the step-down method. The mixing fans are switched on and the chamber is filled with tracer gas for a suitable concentration level. After a period of mixing, the mixing fans are switched off and the test starts. The concentration is then allowed to decay to base level before the test is stopped.

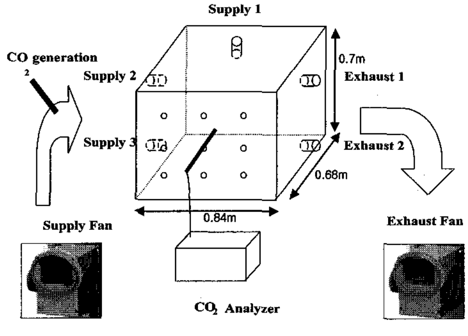


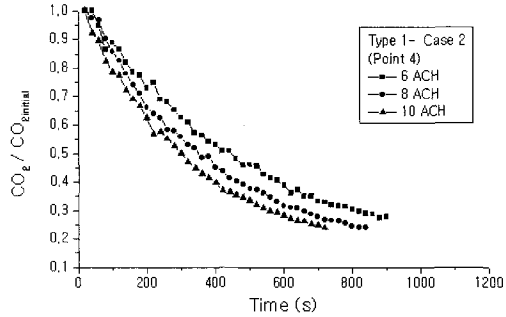
Fig. 1 A schematic diagram of the ventilation test system.

Variations of the gas concentration as a function of time are measured at various supply/extract locations and air exchange rates with the CO_2 gas monitor (CMCD 10P, Kanomax, Japan) using a principle of nondispersive infrared absorption. The tracer gas concentration is measured at 9 locations at the front side of chamber and they have same distance each other. One more measuring point is in the exhaust duct. Table 1 shows the test conditions for the measurements of the ventilation effectiveness as a function of ventilation type, supply/extract locations and air exchange rates. Since the inlet and extract have to be considered separately, there are three possible ventilation types such as mechanical inlet and extract system, mechanical inlet and natural extract system, and natural inlet and mechanical extract.

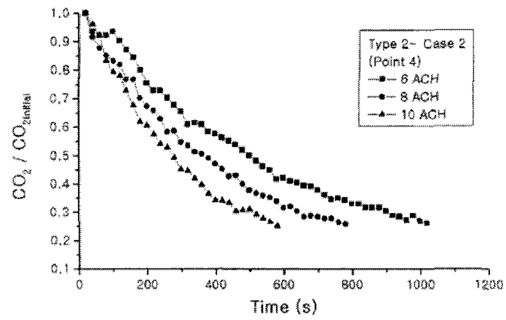
Table 1 Test conditions for the measurements of ventilation effectiveness

Parameters		Conditions
Chamber Dimension		0.84 × 0.68 × 0.7m³ (L× W× H)
Ventilation Type	Type 1	mechanical inlet and extract
	Type 2	mechanical inlet and natural extract
	Type 3	natural inlet and mechanical extract
Supply and Extract Locations	Case 1	upper supply and upper extract
	Case 2	down supply and down extract
	Case 3	ceiling supply and upper extract
	Case 4	upper supply and down extract
	Case 5	down supply and upper extract
	Case 6	ceiling supply and down extract
Air Changes per Hour	6 ACH	6(=2.4m³/hr)
	8 ACH	8(=3.2m³/hr)
	10 ACH	10(=4m³/hr)
Tracer Gas		CO_2
CO_2 Gas Analyzer		CMCD 10P(Kanomax, Japan)

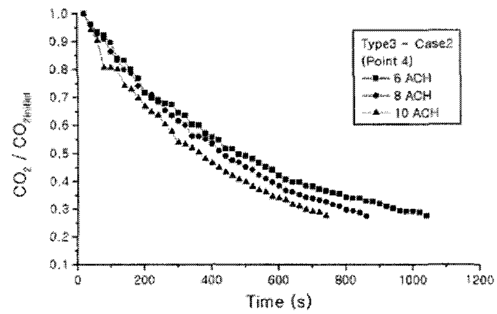
4. Result and Discussion



Type 1



Type 2

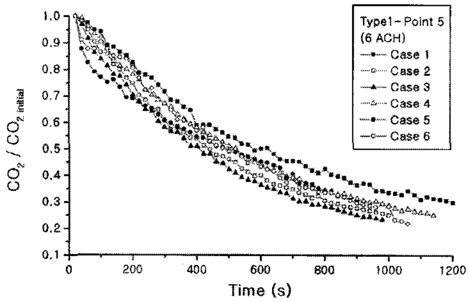


Type 3

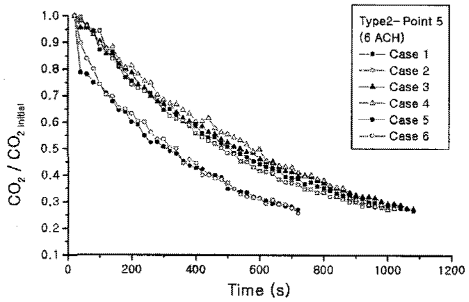
Fig. 2 Concentration variation of tracer gas with different air exchange rates in case 2.

Fig 2 shows variation of concentration with time in case 2 with air change rate 6 ACH, 8 ACH and 10 ACH each. The measurements are performed at point 4. The ventilation performance is increased in the high air change rate condition. On the other hand, ventilation performances have orders Type〉Type2〉Type3 and Type

2 is most effective and have the fastest decay of concentration in this experiment. The reason for this is as follows: the variation of supply air in Type 2 is considerably effective for the whole ventilation performance. On the contrary in case of Type 3 the effect of air change rate is comparatively low because outdoor air entered inside and spread and then exhausted to the outside.



Type 1



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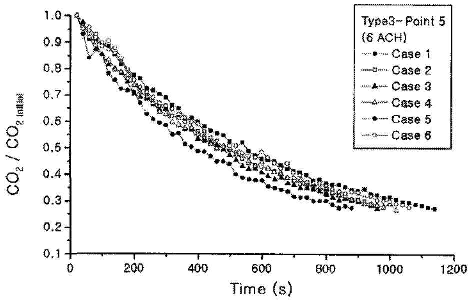


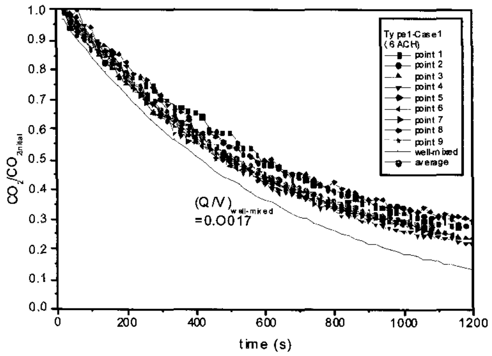
Type 3

Fig. 3 Concentration variation of tracer gas with different cases (Case1 ~ Case6)

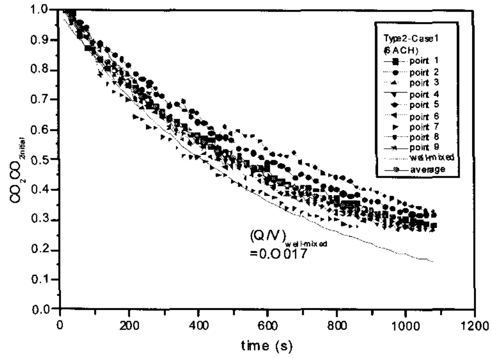
Fig. 3 shows variation of concentration at point 5 from Case 1 to Case 6 in each ventilation type. In case of Type 1, variation of concentration is relatively slow in Case 1(upper supply, upper extract) and Case 4(lower supply, lower extract). It means that air flows across the model chamber and the effect of supply air can be increased in Case 2, Case 3, Case 5 and Case 6 while the air flows in Case 1 and Case 4 is concentrated at the upper and lower part of the model chamber.

On the other hand, in case of Type 2 and Type 3, the effect of supply and extract location is relatively not high enough, especially in the case of Type 3 where concentration decay is similar in each case. Thus, outdoor air coming into the room is diffused into the space of the whole room.

Fig. 4 shows variation of tracer gas concentration with time at 6 ACH. These measurements are performed at 9 point of each case and air flows in the chamber can find indirectly. As described above, the concentration varies in the order of Type2 > Type1 > Type3. Concentrations on the 9 measuring point in Type 2 has big difference between each points and Type 3 is the smallest one. The reason for this is the flow patterns inside the chamber are different for each type: in case of Type 1 there is small difference in each point because of simultaneous operating of supply fan and exhaust fan. In the contrast of Type 1, concentration decay speed in Type 2 has bigger difference in decay speed of each point. In case of Type 3, relatively small differences at each point are shown due to uniform movement of air in the model which is supplied in the model by natural supply.



Type 1



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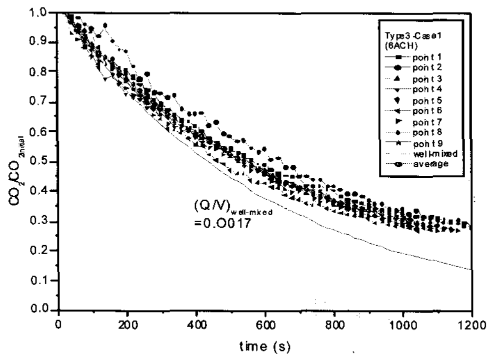

Type 3

Fig. 4 Concentration variation of tracer gas at different locations

Table 2 shows average mixing factors of each ventilation type. Type 1 and 2 have higher value of k comparing to Type 3.

Table 2 Mixing factor of each case at 6 ACH

	Type1	Type2	Type3
k	0.74	0.77	0.68

Ventilation effectiveness shown in Table 3 get the order type 2〉 type1〉 type 3 and these values are decreased according to increasing air change rate in each case. These results also agreed with the tendency from Table 2 and Fig. 4.

Table 3 Ventilation Effectiveness with different ventilation system types and air exchange rates (Case 1)

ACH	Ventilation Effectiveness(%)		
	Type1	Type2	Type3
6	91	94	89
8	85	90	78
10	79	88	72

5. Conclusions

The mixing factors and ventilation effectiveness is evaluated as a function of air exchange rate and supply/extract location in the simplified model chamber using a tracer gas technique based on ASTM standard E741-83. The conclusions can be summarized as follows.

(1) The ventilation performance decrease with increase in the air exchange rate from 6 ACH to 10 ACH. Type 2 shows the highest ventilation performance and is also influenced by the air change rate comparing to Type 1 and Type 3.

(2) The differences of the flow patterns with supply and extract locations affect the ventilation performance of the ventilation system. This has resulted from the difference of flow patterns mixing and displacement flow and short circuiting flow

(3) The concentration decay in Type 1 and Type 3 is relatively uniform at each 9 point. On the contrary there are bigger differences of decay in Type 2 by the change of flow patterns inside.

(4) The ventilation effectiveness, evaluating the ratio of actual air change rate and controlled air change rate, shows the best in Type 2 and this result is agreed with the result of mixing factor, k from 0.68 to 0.77.

Acknowledgement

This work is supported by Kyungnam University research fund, 2005

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Author Profile

Tae-Wook Kang

Tae-Wook Kang, Ph.D., P.E., is working as a chief engineer in air-conditioning division, LG Electronics. He is also leading LG's 25 global education centers for commercial-use air-conditioning systems. He has worked in air-conditioning laboratory of LG for 16 years and has been carrying on researches in the field of HVAC systems and heat exchangers for air-conditioners and heat recovery ventilators. His thesis of Ph.D. in Pusan National University and M.D. were also in the same field as his carrier research works.

Till now, more than 120 patents including 42 in overseas and 55 research papers were published by him or in collaboration with his research co-workers. He was awarded by prime minister of Korea for the development of competitive technology and core parts of air-conditioning system.

Tae-Hyeon Chang

He was educated at Dong-A University(B.E, 1969, M.E. 1971) in Korea. After obtaining his B.E. he was worked at Busan Thermal Power Plant(Korea Electric Company) for 10 years as a mechanical engineer. He obtained his Ph.D. at the department of mechanical engineering of the University of Wales(Swansea, UK) in 1991. He has been working for Kyungnam University since 1978 at the division of mechanical and automation engineering. He was promoted to a professor and appointed the dean of evening school for two years in 1998. He worked as a chairman of ASV'6 at Korea on May 28-31 2001. His major research fields are convection heat transfer with and without swirl in a tube. He has published five text books and more than 90 research papers.