Performance test of natural ventilators by field experiment

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ABSTRACT

Recently, a law securing 0.7ACH ventilation rates was enacted in South Korea. As a consequence, various ventilators have been installed in apartments. Of the different types of ventilators that have been installed, natural ventilators are able to minimize energy consumption and reduce environmental load by using natural energy. However, the disadvantage of natural ventilators is that they cannot supply continuous outdoor air, and the residents do not know how to use natural ventilators to achieve accurate ventilation rate. Therefore, it is necessary for residents to understand how the ventilation rate of natural ventilators installed in their house changes the condition of the indoor air. The purpose of this study is to measure the ventilation rate of various experiment cases and to compare their ventilation performance characteristics. In this study, in order to understand the ventilation rate of natural ventilators according to various variables, a range of situations were set for experiment cases, such as the position and ventilation ratios of natural ventilators, and the open or closed position of interior doors. Natural ventilators were installed in residential units of an apartment building. The ventilation rates were then measured by the tracer gas method and fan pressurization method.

1. INTRODUCTION

Recently, there has been an increased domestic interest in indoor air pollution. Consequently, a standard for installing ventilation facilities was established in order to secure an acceptable and safe indoor air environment by rapidly discharging indoor pollution materials to the outdoors.

Natural ventilators are widely applied in technologically advanced countries such as Europe since they are considered to be a successful way to reduce the environmental load by maximizing the utilization of natural energy and by minimizing the energy required to adjust the indoor environment of residential spaces. In particular, considering the domestic context, where a significant number of apartment houses are supplied, the installation of natural ventilators can help to increase the number of floors allowed. However, the disadvantage of natural ventilators is that ventilation performance retains a constant ventilation volume due to the influence of various environmental factors such as the peripheral environment and outdoor weather conditions. Accordingly, when applying natural ventilators, in order to secure an acceptable indoor air quality and prevent the unnecessary consumption of energy, it is essential to provide an efficient optimum volume for the natural ventilator through an exact evaluation of ventilation rate. Therefore, tests of various cases on site are carried out in this study in order to test the performance of natural ventilators according to indoor conditions and installation conditions.

2. OVERVIEW OF TEST

In this study, in order to evaluate the ventilation rate of a parallel-type natural ventilator, we installed a natural ventilator in a unit of an apartment house and evaluated the ventilation volume using the fan pressurization method and tracer method. The purpose of this study is to determine the characteristics of ventilation rate of a natural ventilator according to various factors.

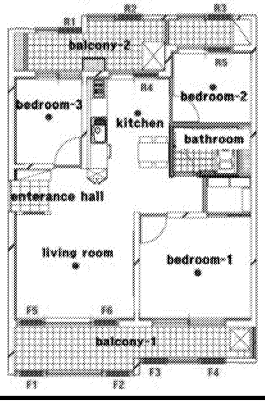
2.1 Overview of test product

The natural ventilator used for this test is the glass window installation-type Trickle ventilator which can be opened and closed manually. This ventilator is equipped with a free filter capable of filtering polluted materials that flow into the interior from the outside.

2.2 Overview of test household

The test on site was conducted in an apartment complex located in Gyeonggi-do. The apartment is located on the 7th floor, has a measured area of 59.57㎡, and consists of 3 rooms. Natural ventilators were installed at the front and the back of the apartment. The installed position, size and measured point of each natural ventilator are provided in Table 1 below.

Table 1 : Installation position of natural ventilator and measured point

Installation position and measured point	Size of natural ventilator		
	Location	W(mm)	H(mm)
	F1,F2	900	90
	F3,F4	600	
	F5,F6	755	
	R1	584	
	R2,R3	730	
	R4	650	
	R5	747	
	Front	4510	
	Back	3,441	
	Total	7,951	

2.3 Test method

2.3.1 Fan pressurization method

The fan pressurization method (ASTM E779-03) creates a pressure difference between indoor and outdoor pressure by reducing the indoor pressure using a blower door installed at the front door. We tested the air flow volume at each difference of pressure. For the test, the waterway, electric outlet, kitchen hood and bathroom ventilation fan were switched off. By selecting 5 points with indoor and outdoor pressure differences in the range of 10~60Pa, we measured the air flow volume (m^3/h) at corresponding pressure differences. Based on these results, we derived a related formula characteristic for pressure and airflow volume. By using the derived formula, we then calculated the ventilation volume and frequency at pressure differences of 1, 2, 4, 8, and 10Pa.

$$Q = K(\Delta p)^n \quad (1)$$

Where:

Q : airflow volume [m^3/h]

K : airflow coefficient

n : airflow exponent of the ventilator,
0.5 (turbulent flow) ≤n≤1 (laminar flow)

$\triangle p$: indoor and outdoor pressure difference

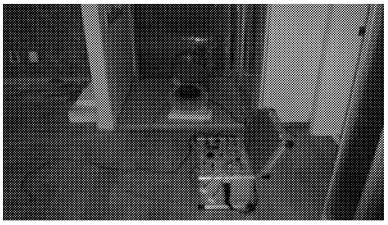


Figure 1: Field test by fan pressurization method

2.3.2 Tracer gas method

A tracer gas method test (ASTM E741-83) was conducted by applying the concentration decay method. CO_2 was used as the tracer gas. After slowly ejecting the tracer gas into the indoors for each test case, the indoor gas was stirred well to achieve the best mixture, and the initial concentration of indoor CO_2 was adjusted to be 5000ppm. As shown in Fig.2, the concentration change at the height of 1.1m in the center of the living room, the kitchen and dining room, and in the bedroom was measured for about 2 hours at intervals of 3~4 minutes, while the exit and entrance of people was controlled during the test. The measured value was substituted in formula 2 and the ventilation rate per hour (ACH) was calculated.

$$Q(m^3/h) = 2.303 \frac{V}{t} \log_{10} \frac{C_1 - C_0}{C_2 - C_0} \quad (2)$$

Where:

Q: airflow volume [m^3/h]

V : volume of object indoor air [m3]

t : elapsed time from initial measurement time to present time [h]

C_1 : CO2 concentration [m^3/m^3] of indoor air at initial measurement time (t=0)
C_t : CO2 concentration [m^3/m^3] of indoor air after time t
C_0 : CO2 concentration [m^3/m^3] of the air flowing into the interior from the outside

The concentration of CO_2 was measured using Innova Air Tech Instruments and the outdoor weather condition (temperature, airflow speed) was measured using Testo 350-XL.

kitchen bedroom living room

Figure 2 : CO2 measurement in each room

3. TEST RESULT ANALYSIS

3.1 Test by fan pressurization method

The detailed conditions for this test, as shown in Table 2, were categorized according to the length of the opened area supplied by the natural ventilator, whether or not the door of each bedroom and the glass door on the side of the interior were open, and the rate of opened ventilator area of the front and back sides. For cases 1~4, the natural ventilator was opened at the front and back sides. Accordingly, though the overall length of the opened area and the rate of natural ventilation supplied to the opened area at the front and back sides is the same, the conditions differ for the open/closed bedroom door and for the open/closed glass door at the balcony on the side of the interior. In the case where the glass door at the balcony on the side of the interior is closed, the outdoor air directly flows into the interior, passing the natural ventilator installed on the side of the chassis (Cases 3 and 5). For Cases 5 and 6, the rate of natural ventilation supplied to the opened area in the front and back sides is varied by closing part of the natural ventilator.

The difference in indoor and outdoor temperatures at the time of measurement was 0.0℃~0.4℃, which is an acceptable environmental condition for measuring ventilation volume when using the fan pressurization method. The results obtained of the evaluation of ventilation rate are provided in Table 3.

3.2 Test by tracer gas method

The detailed conditions for this test, as shown in Table 4, were categorized according to the length of the opened area supplied by the natural ventilator, and whether or not the door of the bedroom was open. In Case 1, the persisting air in the apartment was measured by closing all natural ventilators, while in Cases 2 and 3 the conditions for the open/closed bedroom door differ. In Cases 4, 5 and 6, the opening ratios of the front side to the back side are 1:2, 1:1, and 3:1, respectively. For all test cases, the glass door on the side of the interior was kept closed so that outdoor air could flow into the interior through the natural ventilator installed on the glass door on the side of the interior.

The results for the evaluation of ventilation rate according to the tracer gas method are shown in Table 6. When all natural ventilators were closed (Case 1), the air change rate was 0.14ACH, demonstrating that the ventilation in the tested apartment is very tight.

Table 2 : Detailed condition of test for CASE P

CASE P	Door of each room	Glass door on the side of the interior	Natural ventilator		Opened length (mm) (on the side of chassis)		
			open	closed	front	back	whole
1	open	closed	whole	-	3000	2044	5044
2	closed	closed	whole	-	3000	2044	5044
3	open	open	whole	-	3000	2044	5044
4	open	closed	F1~6	R1~5	3000	0	3000
5	open	open	F1,3,5/R2~5	F2,4,6/R1	1500	1460	2960
6	open	closed	F1,3,5/R2~5	F2,4,6/R1	1500	1460	2960
7	open	closed	R1~5	F1~6	0	2044	2044

Table 3 : Results of Ventilation rate [CASE P]

CASE P	Ventilation volume according to pressure difference(m^3/h)					Ventilation rate according to pressure difference(ACH)				
	1Pa	2Pa	4Pa	8Pa	10Pa	1Pa	2Pa	4Pa	8Pa	10Pa
1	101.5	156.5	241.4	372.3	428.0	0.50	0.76	1.18	1.82	2.09
2	92.9	141.4	215.2	327.6	375.0	0.45	0.69	1.05	1.60	1.83
3	148.3	231.9	362.7	567.3	655.1	0.72	1.13	1.77	2.77	3.20
4	85.3	130.5	199.7	305.5	350.3	0.42	0.64	0.97	1.49	1.71
5	120.2	182.5	277.1	420.7	481.2	0.59	0.89	1.35	2.05	2.35
6	82.2	128.2	199.9	311.7	359.7	0.40	0.63	0.98	1.52	1.75
7	97.7	141.3	204.2	295.3	332.5	0.48	0.69	1.00	1.44	1.62

Table 4 : Detailed condition of test for CASE G

CASE G	Door of each room	Glass door on the side of the interior	Natural ventilator		Opened length (mm) (on the side of chassis)		
			open	closed	front	back	whole
1	open	closed	-	whole	0	0	0
2	open	closed	whole	-	3000	2044	5044
3	closed	closed	whole	-	3000	2044	5044
4	open	closed	F2,6/R1 ~ 5	F1,3,4,5	900	2044	2944
5	open	closed	F1,3,5/R2 ~ 5	F2,4,6 / R1	1500	1460	2960
6	open	closed	F1 ~ 3,5,6/R2,4	F4 / R1,3,5	2400	730	3130

Table 5 : Outdoor air condition for CASE G

CASE G	Measured value		
	Average temperature (℃)	Average airflow speed(m/s)	Main airflow direction
1	31.55	0.60	west-southwest
2	31.71	0.45	west-southwest
3	30.07	0.42	west-southwest
4	35.31	0.12	northeast/west-northwest
5	36.83	0.16	northwest/west
6	36.44	0.15	west-southwest/west-northwest

Table 6 : Results of Ventilation rate [CASE G]

CASE G	Ventilation rate of each room(ACH)					Average ventilation rate (ACH)	Average ventilation volume (m^3/h)
	living room	Kitchen	bedroom1	bedroom2	bedroom3		
1	0.14	0.14	0.14	0.13	0.14	0.14	27.90
2	0.36	0.38	0.43	0.38	0.36	0.38	78.01
3	0.41	0.41	0.38	0.39	0.37	0.39	80.62
4	0.28	0.225	0.26	0.27	0.27	0.27	54.50
5	0.25	0.23	0.27	0.23	0.22	0.24	49.28
6	0.12	0.13	0.13	0.12	0.13	0.13	25.64

3.3 Results analysis

3.3.1 Comparison according to whether or not the bedroom door was open

- CASE P1 and CASE P2
- CASE G2 and CASE G3

In the above two test cases, where the installation

conditions for the natural ventilator were the same, the total ventilation volume and total ventilation rate were compared according to whether or not the bedroom door was open. For the results of the test using the fan pressurization method, the ventilation volume (141.4m^3/h@2Pa) when the bedroom door was closed was slightly less than the ventilation volume (156.5m^3/h@2Pa) when the bedroom was open, though the difference was not significant. For the fan pressurization method, the measurements are mostly conducted with a considerable difference of pressure, in the range of 20~50Pa. It is therefore assumed that if the lengths of the natural ventilators are the same, only the moving path of air changes according to whether or not the bedroom door is open, resulting in an insignificant difference in airflow volume.

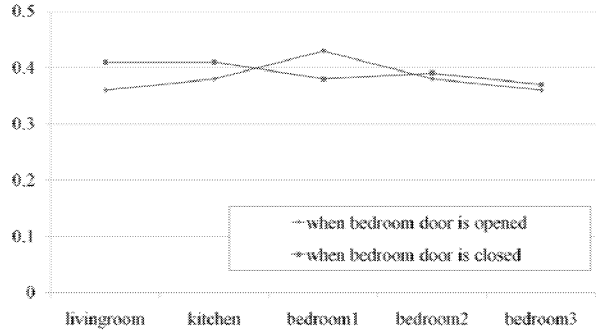


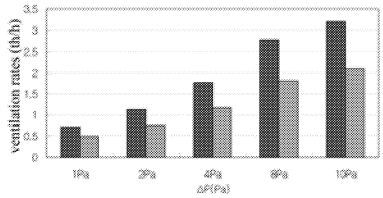
Figure 3 : Ventilation volume according to whether or not the bedroom door is open

In the measurement results obtained using the tracer gas method, as shown in Figure 3, the average ventilation rates were similar (0.38 ACH and 0.39 ACH). However, for the case where the bedroom door was closed, the ventilation rate of the bedroom was somewhat lower than the ventilation rate of the living room or the kitchen/dining room, where ventilation was supplied from both sides. The difference of ventilation rates between each test case were considerable, indicating that even if the bedroom door was closed and the natural ventilator was opened, ventilation from one side was provided and there was airflow through the door crevice of the bedroom.

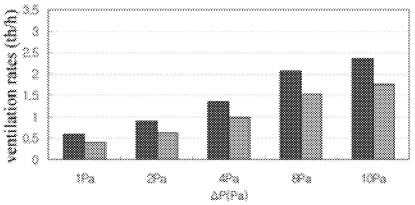
3.3.2 Comparison according to whether or not the natural ventilator is installed on the glass door on the side of the interior

• CASE P1 and CASE P3
• CASE P5 and CASE P6

The test cases above represent two different cases. In one case, the natural ventilator was installed on the glass door on the side of the interior so that the outdoor air can flow into the interior through the two natural ventilators. In the second case, the glass door on the side of the interior was kept open so that outdoor air can flow into the interior through only one natural ventilator. A comparison was made of the results obtained for these cases. Reviewing the test results, for the case where air flows into the interior through 2 ventilators, as shown in Figure 4, the resistance against airflow relatively increased, producing a ventilation volume that was 2/3 that of the case where airflow enters the interior through only one ventilator.



(a) CASES P1 and P3



(b) CASES P5 and P6

Figure 4 : Ventilation volume of each room according to whether or not a natural ventilator was installed on the glass door on the side of the interior (■ when natural ventilator was not installed ■ when natural ventilator was installed)

3.3.3 Comparison according to opening ratio of the front side and back sides

• CASE P4 and CASE P6 and CASE P7
• CASE G4 and CASE G5 and CASE G6

Through each test case shown above, a comparison was made of ventilation volume between the case where the opening ratios of the front and back sides of the natural ventilator were similar and the case where only the front side or the back side was open. The ventilation volume at the time of measurement obtained by

the fan pressurization method was in proportion to the installation length of the natural ventilator. In the results of measurements obtained by the tracer gas method, the ventilation rates differed, even when the installation lengths of the natural ventilator were similar. While there was not a significant difference in the overall installation length of natural ventilators for Cases G4, G5 and G6 (2944, 2960 and 3130mm, respectively), the ratio of the opening rate of the front side to that of the back side was 1 : 2, 1 : 1 and 3 : 1, respectively, indicating a significant difference.
Respective ventilation rates were shown as 0.27 ACH, 0.24 ACH, and 0.13 ACH. Case G4, in which the back side was opened to a greater extent, showed the lowest average airflow speed, yet the ventilation was relatively high at 0.27 ACH. This result was estimated when the wind direction at the time of measurement was mainly north-northeast, when the outdoor air sufficiently flowed into the interior through the natural ventilator installed on the back side. In Case G6, the opening ratio of the back side showed a ventilation rate at 0.13 ACH, which is close to the measured value of tightness of G1. It is assumed that smooth ventilation was not possible because the wind direction at the time of measurement was north-northwest and the opening ratio of the natural ventilator on the back side was low. Case G5, in which the front and back sides were opened at a similar ratio, showed results similar to those of Case G4, even though the wind direction at the time of measurement was west-southwest, which is a disadvantageous condition.
Accordingly, it is assumed that, while ventilation rate obtained by a natural ventilator is determined by the overall installation length, in order to flexibly respond to various conditions of wind direction, it is more efficient to maintain a similar opening ratio for the front and the back sides.

4. CONCLUSIONS

In this study, the performance of a natural ventilator was measured through a field test.
In order to measure the change in ventilation rate under various conditions, the conditions were categorized into various cases before carrying out the field test. The fan pressurization method and the tracer gas method were used to measure ventilation rate. The results of the test were derived as follows.
1. Whether or not the bedroom door is open does not significantly affect the overall ventilation volume. 2. In the case where the natural ventilator is installed on the glass windows both inside and outside the balcony, about 2/3 of the ventilation is reduced compared to the case where the natural ventilator is installed only on the glass window outside the balcony. 3. When the opening ratio of the front and back sides is similar, the response to various conditions of wind direction can be flexibly made. If this test result is applied to the installation of natural ventilators and to the setting of indoor conditions, more effective ventilation can be developed. It is intended that the characteristics of performance of a natural ventilator will be analyzed more accurately in future research by conducting a mock-up test and a simulation test based on the results of the field test for a natural ventilator.

ACKNOWLEDGEMENT

This research was supported by a grant (06-CIT-A02: Standardization Research for Construction Materials) from Construction Infrastructure Technology Program funded by the Korea Ministry of Land, Transport, and Maritime Affairs.

REFERENCES

Awbi, H. B.(2002), Ventilation of Buildings, Spon Press, pp.318-324, 2002.
British Standard EN 13141-1:2004 『Ventilation for buildings - Performance testing of components/products for residential ventilation, Part 1 : Externally and internally mounted air transfer devices』, 2004.
Emmerich, S. J., W. S. Dols, and J. W. Axley(2001), Natural Ventilation Review and Plan for Design and Analysis Tools, National Institute of Standards and Technology, 2001.
Fisk, W. J. and A. H. Rosenfeld(1997), Estimates of Improved Productivity and Health from Better Indoor Environments, Indoor Air, Vol. 7, pp. 158-172, 1997.
Francis, A.(1998), Natural Ventilation in Buildings, James&James(Science Publishers)Ltd., UK London, 1998.