# Performance assessment of a natural ventilator by different test methods

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ABSTRACT

Natural ventilation systems in multi-family residential buildings should meet the needs of reducing ventilation heat loss as well as providing good indoor air quality. Therefore, it is important to estimate the adequate area of natural ventilation systems based on reasonable performance data. The purpose of this study is to measure the air flow rates of a natural ventilator by different test methods and to find out its performance in a full-scale test house. First, air flow rates of a natural ventilator were measured by fan pressurization method using the ventilation performance test rig in the laboratory. Secondly, air flow rates were also measured using an orifice blower door in the mock-up test room. Finally, the air change rates of a residential unit with natural ventilators were measured under different opening conditions. By comparing the measurement results from the different tests, several considerations and recommendations were also discussed for evaluating the performance of natural ventilators.

## 1. INTRODUCTION

To create healthy indoor environment in new buildings, it is necessary to keep good indoor air quality with sufficient ventilation as well as pollution source control. In common with many other countries, occupants' concern over the poor indoor air quality in new residential buildings has led to establishment of the new ventilation standard in Korea. It specifies that newly built or remodeled residential buildings should be ventilated 0.7 times per hour by mechanical or natural ventilation systems. Before the enactment, most residential buildings had not been equipped with ventilation systems, excluding exhaust fans in bathrooms and kitchens. Building ventilation was usually achieved by opening windows and doors.

However, since Korean government enacted the indoor air quality and ventilation standard, various types of ventilation systems have been adopted to meet the mandatory ventilation requirements. Although mechanical ventilation systems with heat recovery have a predominant share in the market, natural ventilation devices have also been developed and supplied for various potential benefits. Because natural ventilation was driven by wind pressures and temperature differences, natural ventilators have the potential to save energy cost for operating mechanical ventilation systems. Additional ceiling space for ducts and diffusers is not required for residential buildings with natural ventilators. Also, some studies have indicated that occupants reported fewer symptoms in buildings with natural ventilation compared to buildings with mechanical ventilation (Mendell 1996, Emmerich 2001).

While the natural ventilator has these advantages, some questions still exits in its application to residential buildings. These questions include the reliability of the outdoor air change rates, control of condensation within the ventilators, building pressurization concerns, and the entry of polluted air from outdoors without an opportunity to filter or clean it (Emmerich 2001). Natural ventilation depends on natural conditions such as temperature, wind speed, and wind pressure while mechanical ventilation is made by fan operation which is adjusted by automatic control. It is not easy to secure proper ventilation rates continuously or adjust ventilation rates intentionally.

In addition, additional heating or cooling energy must be consumed to condition the induced outdoor air in naturally ventilated buildings. Natural ventilation systems in multi-family residential buildings are required to meet the need of reducing ventilation heat loss as well as providing good indoor air quality, From this point of view, prediction of the air flow rate is very important for analyzing the building thermal performance, as well as for ensuring appropriate air change rates for a healthy building environment(Karava, 2003). Therefore, it is very important to estimate the adequate area of natural ventilation systems based on reasonable performance data.

The purpose of this study is to measure the performance of a natural ventilator by different test methods ; laboratory test by air-flow test rig, mock-up test by blower-door, and field test by tracer gas method. Several considerations and recommendations were also discussed for evaluating performance of natural ventilators.

## 2. OVERVIEW

### *2.1 Natural ventilators*

Natural ventilation can be achieved by passing fresh air through building envelopes and openings. In recent years, there have been considerable developments in air inlet openings for natural ventilation application(Awbi, 2003) Besides conventional windows and stacks, advanced natural ventilation devices have been developed to provide background ventilation for buildings.

Natural ventilator can be expressed as a device that is incorporated into a window, door, and wall, allowing fresh air to induce into the room by wind or buoyancy. It can provide natural ventilation without opening windows or doors, which ensure inhabitants security as well as comfort. Natural ventilator is widely applied to the residential and office buildings in European countries as the role of 'background ventilators' to provide minimum ventilation rates. It also has become the main part of the building regulation in U.K.(ODPM 2006, SBDA 2007) and Korea. Basically, natural ventilators can be classified into three categories : fixed, manually adjustable, and pressure, humidity, temperature, and pollutant -controlled ventilator (Awbi 2003, Santamouris 2006). Natural ventilators can be mounted through openings in window glazing unit, window frame, or external wall. Products with filters have been developed to meet the needs of consumers who are sensitive to outdoor air pollution. Automatic controllable ventilators have also been introduced to the market.

The main purpose for using natural ventilators in Korean apartment buildings has been to solve condensation problems in balconies during winter. Since the application of ventilation systems has been legislated, the purpose has shifted to meet the required ventilation rates. The performance criteria and installation standards for natural ventilators have not been definitely described yet. Therefore, various products have been usually developed in order to meet the basic performance and requirements for windows. In order to improve the performance of natural ventilators, it is necessary to establish the performance criteria and test methods.

### *2.2 Ventilation performance test methods*

According to the EN 13141-1, aerodynamic performance of a natural ventilator should be measured by fan pressurization method using the air-flow test rig. The basic principle of the measurement is to measure the volume flow rates($m^3/h$) across the ventilator at static pressure differences(Pa) between 1Pa to 100Pa and to express the data with the power-law equation (1).

$$Q = K\Delta P^n \qquad (1)$$

where :

$Q$ : Volume flow rate across the ventilator($m^3/h$)
$K$ : Flow coefficient
$\Delta P$ : Static pressure difference (Pa)
$n$ : Flow exponent of the opening,
0.5(turbulent flow)≤n≤1(laminar flow)

To measure the performance of a ventilation system, tracer gas method is the most common way and it has been practiced for a long time(C.Y.Chao). Tracer gas method is used to measure the air change rates in the building by investigating the time variation in concentration after injecting specific tracer gas such as $CO_2$ and $SF_6$. This method is classified into transient increase, transient decay, and steady flow techniques according to the injection of tracer gas. Tracer gas method is available for measuring ventilation rates of the real building by field test. The measured results are considerably affected by external weather conditions in test periods.

## 3. METHODS

### *3.1 Test specimen*

Figure 1 shows the manually adjustable natural ventilator considered in this study, mounting on the upper side of window glazing. The ventilator can be equipped with filter in order to prevent outdoor pollutants from introducing into the room. Air-flow characteristic of the ventilator was evaluated by laboratory test and mock-up test. Ventilation performance of a residential unit with this natural ventilator was also measured under different opening conditions.

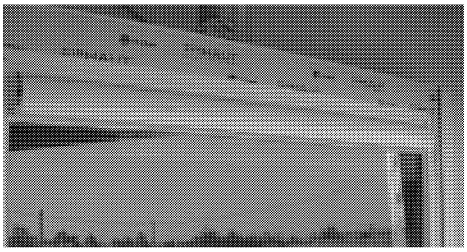

Figure 1. Tested natural ventilator

### *3.2 Laboratory test by air-flow test rig*

The air flow test rig in Figure 2 consists of air-tight test box, variable speed centrifugal fan, duct, air-flow meter, and manometer. The background leakage of the test rig was lower than $3.6m^3/h$ at 100Pa, which satisfies the specified requirements of EN 13141-1. The test rig has an opening of about 900mm x 600mm on one face of the test box, into which a wood board with the test specimen(500mm) was clamped. The air pressure difference was gradually increased by operating the fan, and the volume flow rate was measured at five values between 1 and 10Pa using a calibrated air-flow meter. The air flow across the ventilator was expressed as equation (1).

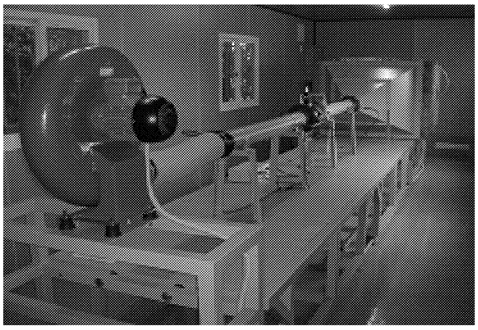

Figure 2. Air-flow test rig

### *3.3 Mock-up test by blower-door*

Mock-up test were carried out at an outdoor test room of a 2 story mock-up building located in the Korea Institute of Construction Technology. Floor area of the test room is $14.19m^2$, and the volume is $32.64m^3$. The ventilator(800m) was installed in the upper part of the glazed unit of the south-facing balcony sash.

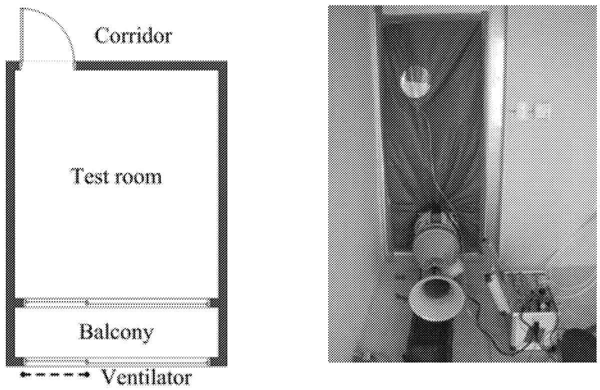


Figure 3. Test room and depressurization equipment

To minimize air leakage through the building envelope, air leakage paths around the windows and doors were sealed with PVC tapes. A blower door system was installed in the door for extracting air from the room to create negative pressure condition. The air pressure difference was gradually increased by operating the valve, and the volume flow rate was measured at five values of pressure difference and expressed as equation (1) automatically with the blower door. Two sets of tests were carried out ; with filter and without filter, in order to study the influence of the filter on the performance of the ventilator. Figure 3 shows the plan of the mock-up test room and the depressurization equipment.

### *3.4 Field test by tracer-gas method*

Full-scale field test was conducted on January 2007 to evaluate air change rates of a full-scale house equipped with the natural ventilators. The purpose of the test is to find out the proper locations and opening ratio of the ventilators. The test house, with the volume of 264m$^3$, is located at 17th floor of an apartment building in Yangju, Korea. The measured air leakage rate of the housing unit was 0.16h$^{-1}$ while all the doors and windows were closed. The ventilators were installed in the upper part of the windows in the front side and the rear side of the housing unit. The location of natural ventilators is shown in Figure 4. Air leakage path including water pipes, electric outlets, and exhaust fans in kitchen and bathroom were sealed to minimize the influence of other openings.

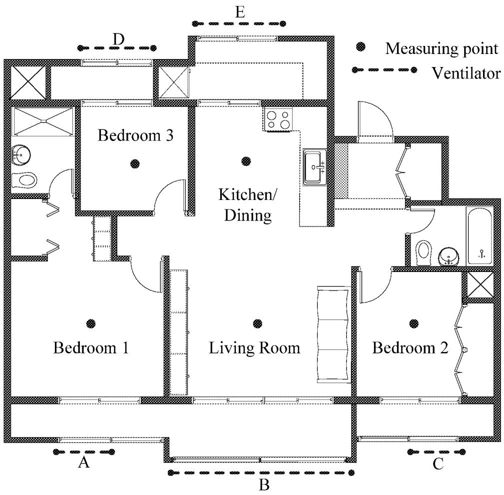

Figure 4. Test room and depressurization equipment

$CO_2$ was injected at the center of each zone and mixed by a fan. A gas monitoring system(Innova Air Tech) with air sampling systems was used to measure the tracer gas concentration. The sampling channels were connected to tubes reaching five sampling points in Figure 4. Each sampling tube inlets were installed at a height of 1.1m above the floor of each zone. Concentration data for each channel were collected every five minutes for 2 hours. Air change rates of each zone were calculated with the equation (2), respectively. Indoor and outdoor temperature and wind speed were also measured periodically.

$$N = 2.303\frac{1}{t}\log_{10}\frac{C_1 - C_0}{C_t - C_0} \qquad (2)$$

where :
$N$ : Air change rate (h$^{-1}$)
$t$ : Elapsed time from initial measurement (h)
$C_1$ : $CO_2$ concentration at initial measurement (t=0) (m$^3$/m$^3$)
$C_t$ : $CO_2$ concentration after time t (m$^3$/m$^3$)
$C_0$ : Outdoor $CO_2$ concentration (m$^3$/m$^3$)

Three sets of experiments were conducted as shown in Table 1 to investigate the ventilation rates under different opening conditions.

Table 1. Experimental cases for the field test

| Ventilator | | Case 1 | Case 2 | Case 3 |
|---|---|---|---|---|
| Status | Open | A,B,C | B,D,E | A,B,C,D,E |
| | Close | D,E | A,C | - |
| Length (m) | South | 6.17 | 3.93 | 6.17 |
| | North | 0.00 | 3.24 | 3.24 |
| | Total | 6.17 | 7.17 | 9.41 |

## 4. RESULTS AND DISCUSSION

Figure 5 shows the measured results and regression curve of the air flow through the ventilator by the laboratory test. The air flow characteristics can be described by

$$Q = 21.7\Delta P^{0.51} \qquad (3)$$

The flow exponent for the ventilator is 0.51, which indicates almost turbulent flow.

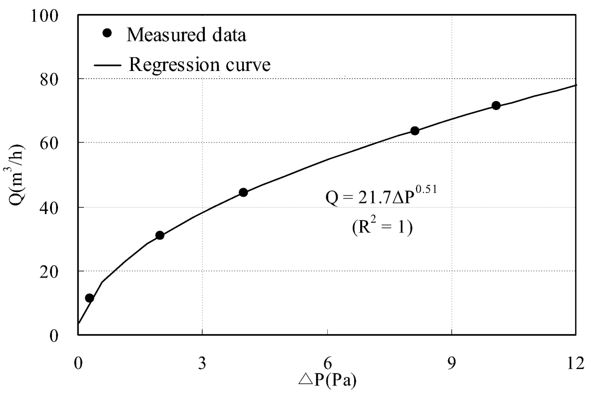


Figure 5. Air flow data from the laboratory test (Opening length = 500mm)

Figure 6 presents the measured results of the air flow through the ventilator with and without filter by the mock-up test. The airflow characteristics were also determined from a regression analysis. The air flow through the ventilator with filter decreases compared to the ventilator without filter. The flow exponent is 0.61 and 0.55 for with and without filter, respectively. The filter within the ventilator may create more laminar airflow.

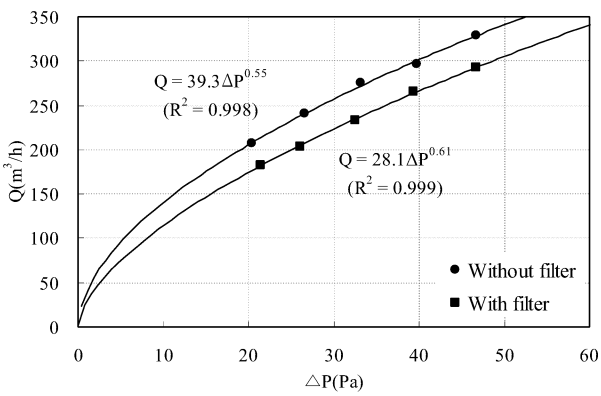


Figure 6. Air flow data from the mock-up test (Opening length = 800mm)

Then, we compare the air flow characteristics estimated from the laboratory test and the mock-up test. The air flow data from the laboratory test were converted considering the 800mm of opening length. As shown in figure 7, the air flow difference between the two tests might be associated with the air-tightness of the mock-up test room. Although we tried to control the air leakage through the windows and walls of the mock-up test room as much as possible, additional air flow might be induced through the leakage path of the test room. Therefore, for more reliable performance data of the ventilator based on the mock-up test, the correction value should be indicated considering the air-tightness of the test room. The two results might be different since the air flows were measured at different range of pressure differences ; under 10Pa and between 20 and 50Pa. Laboratory test seems to have a merit to be able to produce minute pressure differences through ventilators, which can be seen in real-scale wind pressure situation.

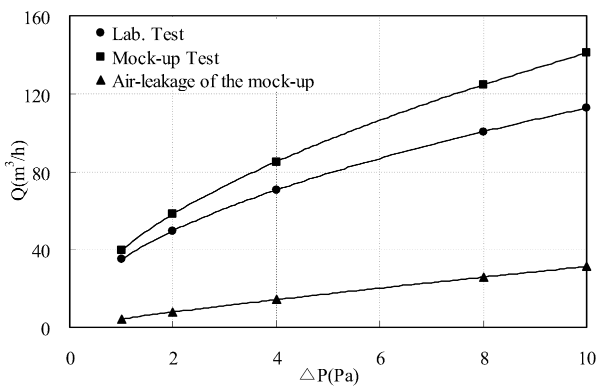


Figure 7. Comparison of the air flow rates (Opening length = 800mm)

The average outdoor wind speed near the house was 0.24m/s, which was much lower than the average wind speed data (0.4 ~2.6m/s) of the circumference area measured by the national meteorological office. The indoor and outdoor temperature differences ranged from 10 to 15°C.

Figure 8 shows the calculated air change rates using the equation (2) with the measured $CO_2$ concentration data. Ventilation rates in case 3 exceeded the ventilation requirements in Korea, since the conditions of ventilators allowed cross ventilation and opening length is longer than other cases. In case 1 where the ventilators were located at one side of the unit, relatively low air change rates were appeared in the kitchen/ dining room and BR 2 near the other side of the unit. Despite the location in the house, the air change rates of BR 1 were also lower than living room and BR 3. It seemed that the opening length of the BR 3 was very sufficient for one-side ventilation because of the recessed bathroom and closets in the room. Although the air change rates would be varied with the outdoor climate conditions, the test results will be useful to decide the locations and opening ratio of ventilators in the Korean houses.

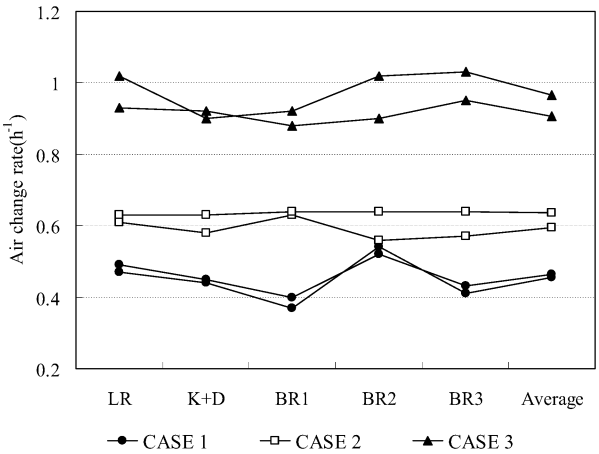


Figure 8. Air change rates of the housing unit

## 5. CONCLUSION

In this study, three kinds of experimental study were carried out to evaluate the performance of a natural ventilator in the laboratory, the mock-up test room, and the full-scale housing unit. We compared the air flow characteristics of a ventilator by different test method, fan pressurization and tracer gas method. Several considerations were also discussed for evaluating performance of natural ventilators. Since the filter within the ventilator can cause some variation in air flow characteristics, performance data of a ventilator should be supplied for two cases, with or without filter. Compared to the mock-up test, laboratory test seems to have a merit to be able to produce minute pressure differences through ventilators, which can be seen in real-scale wind pressure situation. For more reliable performance data of the ventilator based on the mock-up test, the correction value should be indicated considering the air-tightness of the test room. Since the required opening length and equivalent area is related with the indoor and outdoor pressure differences, the most valid pressure difference criteria should be suggested for the accurate performance evaluation of the natural ventilators.

## ACKNOWLEDGEMENT

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