Investigation of On-site Measurement of Air Flow Rate on Compact Air Terminal Devices

Takamasa Inomae
Topre Corp

Masaki Tajima
National Institute for Land and Infrastructure Management

Takao Sawachi
Building Research Institute, Japan

ABSTRACT

On-site air flow measurements of domestic ventilation systems with using funnel type air flow measurement instrument which is generally used in Japan, has been reported the measurement difficulties due to the terminal devices' installed location, the existence of furniture in the vicinity or skill of the measurer. Hence investigations on the measurement method, which has lesser influences of the disturbance, have been needed. Therefore, this study compares on-site air flow measurement with funnel method and pressure difference method which is considered as on of the solution. From the on-site measurement results, the pressure difference method approximately accords with the funnel method with less than ±5% relative errors on exhaust only ventilation systems employing flexible ducts, whose diameter is 50mm. Moreover, laboratory tests with pilot air terminal devices, which apply to the pressure difference method and can be connected to 50mm, 75mm and 100mm diameters duct, were operated under supply and extract conditions in order to obtain the air flow characteristics data under diverse conditions. The experimental results indicate that air flow rate measured with every terminal devices show approximately same as reference air flow rate under the extract conditions and the air flow rate measured with the terminal device connected to 100mm diameters duct shows relatively same as reference air flow rate under the supply conditions.

1. INTRODUCTION

In Japan, flexible duct, whose diameter is narrow like as 50mm or 75mm, is commonly employed for domestic ventilation systems, because it provides easier installation compared with larger diameter duct or solid duct. However it is difficult to estimate the pressure drops of the flexible ducts, which can be bent easily. Therefore air flow rate difference between designed value and on-site measured value is often observed. This indicates that both the validation of air flow rate and the precise design are important for the higher reliability of ventilation systems. For the on-site air flow measurements, air flow measurement instrument with funnel (hereafter funnel method) is generally used in Japan. However, it has been reported on the measurement difficulties due to the terminal devices' installed location, the existence of furniture in the vicinity or skill of the measurer. On the other hands, the pressure difference method (hereafter k-factor method) is considered as lesser influences of the disturbance and lesser human error. However this method has not been used for small terminal devices connected to narrow ducts.

2. METHOD

The following two steps were executed for this investigation.

1) On-site measurements with Existing air terminal devices

Comparison of air flow rates obtained by the funnel method and k-factor method were executed in order to evaluate the measurement accuracy of k-factor method with existing terminal devices, which were added pressure measurement point and were employed in domestic exhaust ventilation system.

2) Laboratory tests with Pilot air terminal devices

Laboratory tests with using three pilot terminal devices applying to the k-factor method were operated in order to estimate the accuracy of air flow rate measurement. The tests were conducted with extract and supply conditions.

3. ON-SITE MEASURMENT ON SMALL AIR TERMINAL DEVICES

3.1 Purpose of the on-site measurement

The k-factor method applying to domestic ventilation system has not been popular in Japan. Only few examples can be seen. Therefore on-site measurements with k-factor method and funnel method were operated in order to assess the accuracy of air flow measurement of k-factor method with small air terminal devices, which were connected to 50mm flexible duct.

3.2 Outline of the on-site measurement

The on-site measurements were executed by well trained person for the measurement method in five sites and fifteen air flow rate settings. Figure 1 illustrates a typical house employing the target exhaust ventilation system. The air flow rate measurement was done on air terminal devices (see Photo 1) with funnel method and k-factor method (see Photo 2, 3). The obtained data were compared to examine the accuracy of on-site measurement using the k-factor method. The measurement accuracy of the funnel method was checked in laboratory with the terminal device. The laboratory check confirmed that the measurement method was free of errors under the extract conditions. The terminal devices were added pressure measurement tubes for applying to the k-factor method as shown in Figure 2. The airflow rate is given by using formula (1). The terminal devices' *k* value and the *n* value are shown in Table 1.

$$Q = k\,(\Delta P)^{n} \qquad (1)$$

where:
Q: air flow rate [m^3/h]
k: k-factor
n: exponent
ΔP: pressure difference [Pa]

Table 1: Characteristics values of the terminal device

k	11.6
n	0.51

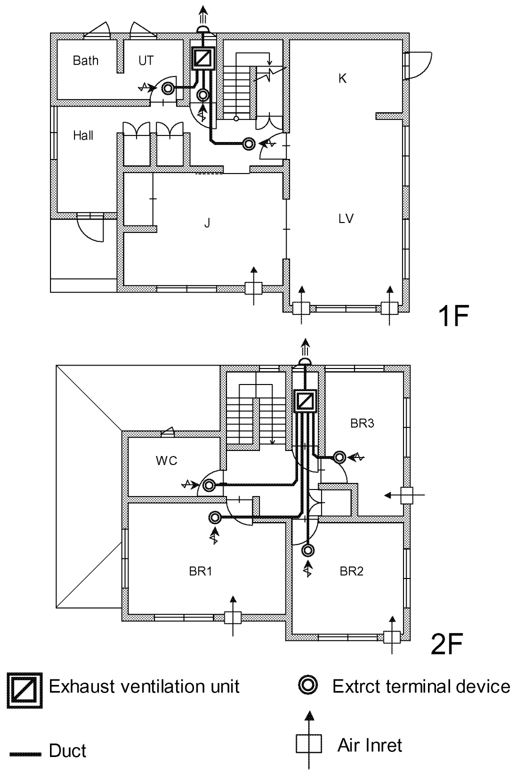


Figure 1: Example of typical 2-storey house employing Exhaust ventilation system

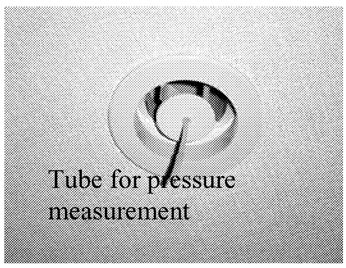
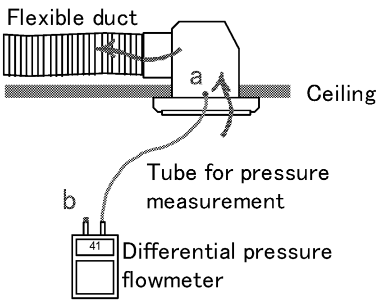


Photo 1: Target terminal device connected to 50mm flexible duct for on-site measurements

Photo 2: Air flow rate measurement (funnel method)

Photo 3: Airflow rate measurement (k-factor method)



The pressure difference between *a* (inside the terminal device) and *b* (room pressure) was measured and converted into an airflow rate.

Figure 2: k-factor method for the on-site measurement

3.3 Results of the on-site measurements

Figure3 shows the scatter graph of the air flow rates measured by each method on the each air terminal devices. Figure 4 shows the scatter graph of the system airflow rate, i.e., the total air flow rates measured by each method. Table 1 provides the summary of the standard error and standard deviation represent for the differences between the air flow rate measured by the funnel method as the reference and that measured by the k-factor method.

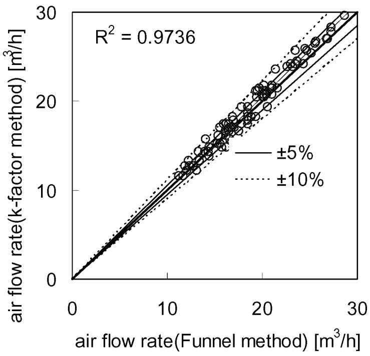


Figure 3: Air flow rate measured on terminal devices

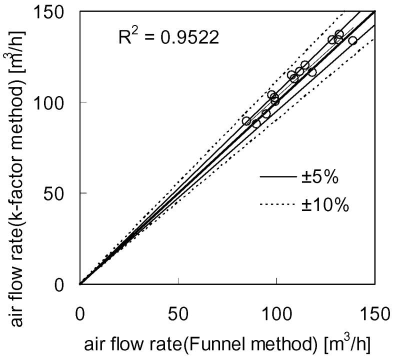


Figure 4: system air flow rate

Table 1: Standard error and standard deviation of air flow rate (m^3/h)

	On terminal devices	system airflow rate (total rate)
SD_m: Standard error	0.08	0.95
SD: Standard deviation	0.80	3.67
R^2 : Determination coefficient	0.974	0.952

3.4 Discussion

The two methods exhibited a relative error less than ± 10% of the air flow rate of the each air terminal devices and less than ± 5% of the system air flow rate. The standard error on each terminal device was small as $0.08m^3/h$ and that of system air flow rate was also small as $0.95m^3/h$. Therefore, it is concluded that the air flow rate by using the k-factor method approximately accords with the result of funnel method for this terminal device under exhaust condition.

4. LABORATORY TESTS WITH PILOT AIR TERNINAL DEVICES

4.1 Purpose of the laboratory tests

Three terminal devices apply to the k-factor method were trial manufactured in order to obtain the air flow characteristics data under diverse conditions.

4.2 Pilot air terminal devices

The air terminal devices were tested both under exhaust and supply conditions. The pilot terminal devices can be connected to a duct whose diameter is 50mm (hereafter TD50, see Photo 4: Revised version of the terminal device used in the on-site measurement), 75mm (hereafter TD75, shown in Photo 5) and 100mm (hereafter TD100, shown in Photo 6). The TD75 is shaped as similar as the TD50. At the same time the TD100 is shaped a sort of chamber type. All pilot terminal devices have dumper for adjusting air flow rate.

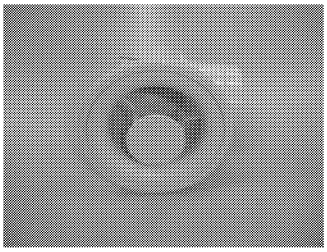


Photo 4: TD50 (connected to 50mm duct)

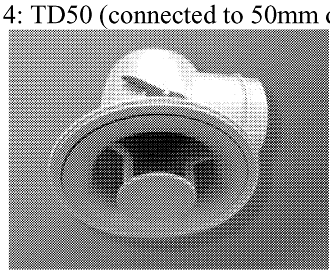


Photo 5: TD75 (connected to 75mm duct)

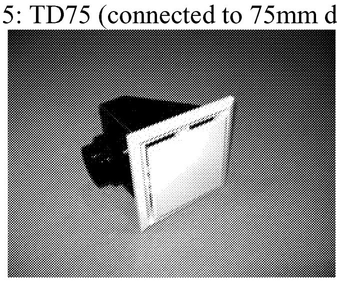


Photo 6: TD100 (connected to 100mm duct)

4.3 Outline of the Laboratory tests

Figure 5 shows the measurement system used for the laboratory tests to obtain the air flow characteristics of each terminal device. The tests were executed within various reference air flow rate (shown in Table 2) and various dumper's position (shown in Table 3). The reference air flow rate was measured on the reference that measured by the ultrasonic air flow meter.

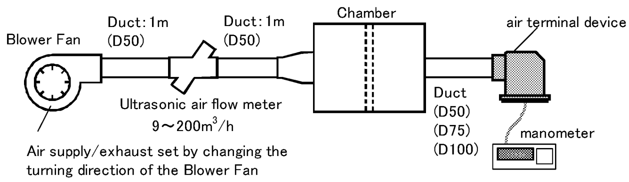


Figure 5 Laboratory test system

Table 2: Air flow rate for the laboratory tests

Pilot terminal device	Reference air flow rate [m^3/h]
TD50	10 – 50 (5 conditions)
TD75	10 – 75 (5 conditions)
TD100	20 – 100 (5 conditions)

Table3: Damper's position for the laboratory tests

Pilot terminal device	Damper's position
TD50	Open, 3/4, 1/2, 1/4
TD75	Open, 3/4, 1/2, 1/4
TD100	Open, 3/4

4.4 Results and Discussion of Laboratory tests

Figure 6 and 7 show the measured k values of the each air terminal devices. The centre values of the box plots in the Figure 6 and 7 are the k_S value, which means the mean k values derived by using all measured data. The ±Standard Deviation, Max and Min values were derived by the difference between the k_S value and the every single measured data. Under exhaust conditions, as shown in the Figure 6 and 7, only negligibly small differences in k_S value were shown by various damper's position or various air flow rate. Thus, the k_S value can be used to calculate the air flow rate regardless of the damper position. On the other hands, under supply conditions, changes in the damper position or air flow rate showed certain differences in k values, except for the TD100. When employing the TD50 and the TD75, it is practical to set the k values for each damper position to determine the air flow rate with further accuracy. Figure 8 to 13 show a scatter graph of the air flow rate calculated by using the k_S value for the formula (1). These air flow rate suggest the same conclusion as the Figure 6 and 7. Under exhaust conditions, the differences from the test air flow rates are small. Under the supply conditions, only the TD100 shows a narrower error range and the TD50 and TD75 show errors larger than 10%.

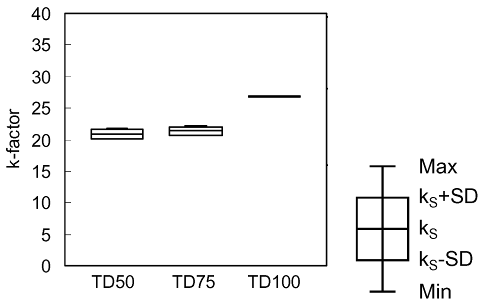


Figure 6: Differences in *k* value under exhaust conditions

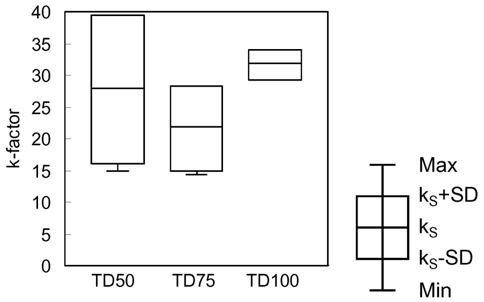


Figure 7: Differences in *k* value under supply conditions

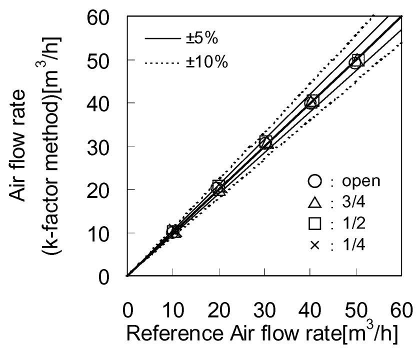


Figure 8: Comparison of air flow rate (Exhaust, TD50)

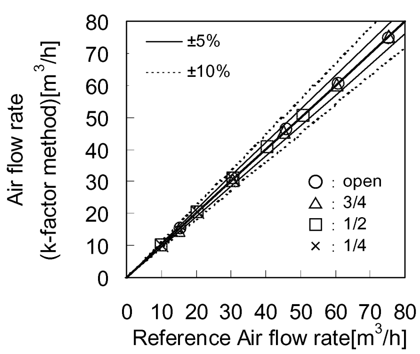


Figure 9: Comparison of air flow rate (Exhaust, TD75)

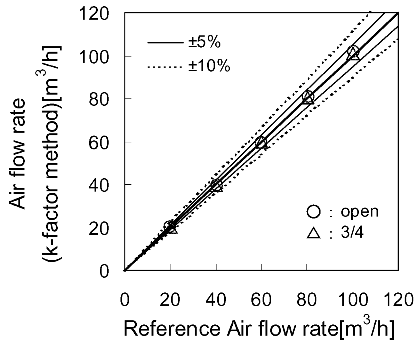


Figure 10: Comparison of air flow rate (Exhaust, TD100)

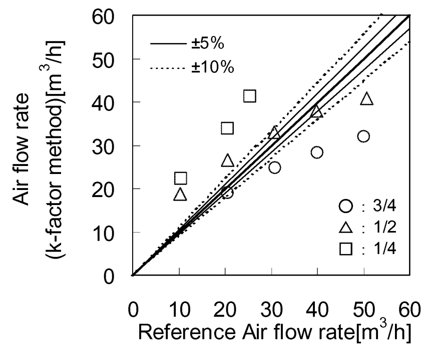


Figure 11: Comparison of air flow rate (Supply, TD50)

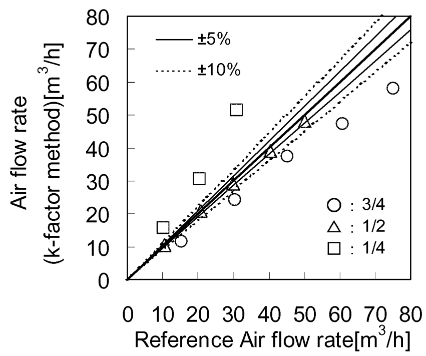


Figure 12: Comparison of air flow rate (Supply, TD75)

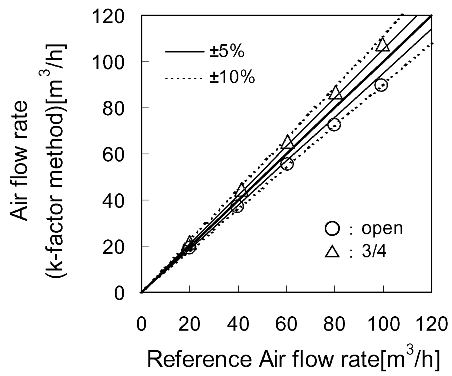


Figure13: Comparison of air flow rate (Supply, TD100)

However, Figure 14 to 16 show scatter graphs of the air flow rate under supply conditions derived by using the k_S' value which is k_S value determined by due to the each dumper's position.

Therefore, even for the TD50 and the TD75 under supply conditions, the air flow rate derived by k-factor method show the more accurate value compared with using k_S value (shown in the Figure 11, 12 and 13).

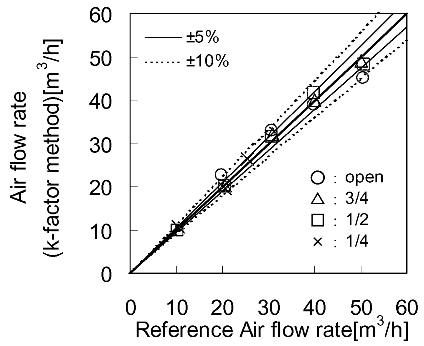


Figure 14: Comparison of air flow rate calculated by using k_S' value determined by due to the dumper's position (Supply, TD50)

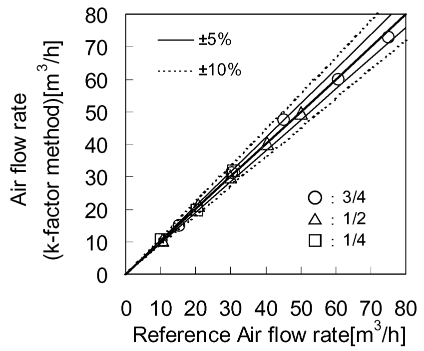


Figure 15: Comparison of air flow rate calculated by using k_S' value determined by due to the dumper's position (Supply, TD75)

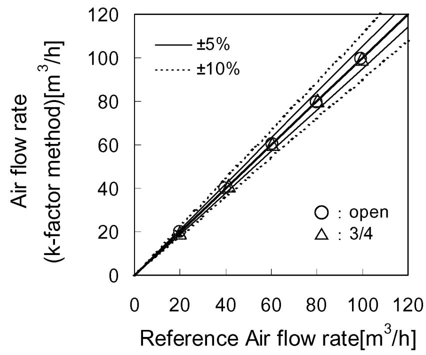


Figure 16: Comparison of air flow rate calculated by using k_S' value determined by due to the dumper's position (Supply, TD100)

5. CONCLUSION

This study investigated air flow rate measured on small terminal devices by using k-factor method and funnel method under the on-site exhaust condition and investigated the air flow characteristics of three small terminal devices applying to k-factor method with laboratory conditions. From the on-site measurement results, there was negligible deference on measured result between using funnel method and k-factor method under extract conditions. Therefore even for the narrow flexible duct like as 50mm diameter and the connected terminal device can be applied to k-factor method. From the laboratory experimental results, air flow rate measured with every terminal devices show approximately same as reference air flow rate under the extract conditions and the air flow rate measured with the terminal device connected to 100mm diameters duct shows relatively same as reference air flow rate under the supply conditions when only one k value is given for each terminal devices. On the other hands, further accuracy can be derived when k values are given by due to dumper position even under supply conditions.

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