An experimental study on how the difference between the test setups specified in JIS B 8628 and JIS B 8639 affects the performance values of energy recovery ventilators

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Abstract

JIS B 8628, "Air-to-air heat and energy exchanger and ventilators" provides standards for evaluating the performance of the energy recovery ventilators. JIS B 8628 was established in 2000, and revised in 2003. In 2017, JIS B 8628 was revised furthermore to ensure consistency with ISO 16494, which was established in 2014. For that purpose, the two room setup and the ducted setup, which are prescribed in ISO 16494 with specified pressure conditions at inlet and outlet of energy recovery ventilators for the airflow test, the tracer gas test and the thermal performance test, were added in JIS B 8628 (2017). In Japan, either the two room setup or the ducted setup is being used by manufacturers to determine the performance values, which are referred to when the compliance of total building energy performance to the Building Energy Efficiency Act is claimed. However, no studies have yet focused on the difference of the test results between the two room setup and the ducted setup. In this study, authors applied those setups and the test setup prescribed in JIS B 8628 (2003) to four energy recovery ventilators and compared their results. As for the airflow-static pressure characteristics, the curves obtained by the three test setups generally correspond to each other, except for the curves for the air exhaust line obtained by JIS B 8628 (2003). The unit exhaust air transfer ratio values obtained by the ducted setup and JIS B 8628 (2003) tend to be greater than those by the two room setup. As for the thermal performance represented by the total effectiveness, differences among the three test setups can be observed when there is a difference of the unit exhaust air transfer ratio and/or the ratio of the supply airflow rate to the return airflow rate.

Keywords: Energy recovery ventilator, Airflow-static pressure characteristics curve, Unit exhaust air transfer ratio, Total effectiveness, Gross effectiveness, Test setup, JIS B 8628, JIS B 8639, ISO 16494

1. Introduction

Indoor air in buildings is always contaminated such as by the metabolic chemistry of the individuals who perform activities indoors and chemicals released from interior building materials. Ventilation must be provided to supply fresh outdoor air and exhaust tainted indoor air. Recent improvements in building insulation and airtightness have led to increasing calls for measures to address indoor air contamination. In response to these calls, in 2003, the Building Standards Act was amended to require installation of mechanical ventilation systems. However, direct supply of outdoor air during seasons that require cooling or heating leads to an increased air-conditioning load and larger energy consumption. Energy recovery ventilators that are capable of supplying and exhausting air and exchanging heat and moisture between the supplied air and the exhausted air are known for their effectiveness in reducing air-conditioning load, and are increasingly widely adopted.

In Japan, JIS B 8628, "Air-to-air heat and energy exchanger and ventilators" has provided standards of the airflow test, the tracer gas test and the thermal performance test to obtain the air flow-static pressure characteristics curves, the

unit exhaust air transfer ratio (UEATR) and the gross effectiveness of energy recovery ventilators, respectively. JIS B 8628 was established in 2000, based on the Japan Refrigeration and Air-Conditioning Industry Association's JRA 4038, "Air-to-air heat exchanger" standard, which was formulated in 1992. JIS B 8628 was revised in 2003. Subsequently, ISO 16494, "Heat recovery ventilators and energy recovery ventilators – Method of test for performance" was formulated as an international standard for testing energy recovery ventilators. Since ISO 16494 prescribes test setups with conditions that were not specified in JIS B 8628 (2003), the latter required revision: this took place in 2017. Changes were made chiefly to the conditions of the tests. JIS B 8639 (2017), "Heat and energy recovery ventilators - Methods of tests for performance of flowrate, net supply airflow and gross effectiveness" was additionally established to provide detailed conditions of test setups and to support JIS B 8628 (2017).

In JIS B 8628 (2017), two different setups, "two room setup" and "ducted setup" are prescribed, and the different requirements for static pressures at inlets and outlets are specified for the two kinds of setup in compliance with ISO 16494. It is noteworthy that the static pressure requirements were newly introduced in JIS B 8628. It seems reasonable to approve different setups, which give test results similar to each other and are supported by the consensus of the industry. However, it is necessary to grasp the difference of the test results and characteristics of the test setups, so that users of the products and their performance information can avoid any confusion caused by the difference. The test results based on JIS B 8628 (2017) are being utilized in the calculation of energy use for air-conditioning in buildings, which has been a part of the mandatory requirements for new buildings not smaller than 2000 m^2 as of 2020 by the law, the Building Energy Efficiency Act established in July 2015.

In this study, authors developed a measurement apparatus for performing the tests in accordance with JIS B 8628 (2017), and carried out the tests on four types of the medium size energy recovery ventilator available on the Japanese market to evaluate how the difference between the two room setup and the ducted setup in JIS B 8628 (2017) affects the performance values of the energy recovery ventilators. We also performed the tests according to the previous standard, JIS B 8628 (2003) and compared the results with those by the new standard, JIS B 8628 (2017).

2. Comparison and description of the test setups

Figure 1 shows the airflow directions in energy recovery ventilators and the symbols for the static pressure at inlets (Outdoor air; OA and Return air; RA) and outlets (Supply air; SA and Exhaust air; EA). The static pressure at inlets and outlets is relative to the atmospheric pressure in the test room. Table 1 shows a comparison of static pressure and airflow rate requirements in JIS B 8628 (2017) and JIS B 8628 (2003) for the energy recovery ventilators which designed for duct connection.

As shown in Table 1, the condition for static pressure at inlets and outlets is different for the two room setup and the ducted setup. When the static pressure is different, the air leakage inside the energy recovery ventilator (for example, leakage through the gap between the internal space on the RA side and that on the SA side) may be different and performance values may be affected. External air leakage through the housing (for example, leakage through the gap

Fig.1   Airflow directions in energy recovery ventilators and the symbols for the static pressure at inlets and outlets.

Table 1   Comparison of static pressure and airflow rate requirements in JIS B 8628 (2017) and JIS B 8628 (2003).

Test setup	Test item	Static pressure and airflow rate measurement requirements
Two room setup JIS B 8628 (2017)	Airflow test	$Ps1 < 0$ Pa, $Ps3 < 0$ Pa $\|(\|Ps1\| - \|Ps3\|)\| \le$ Max (10 Pa, Max $(\|Ps1\|, \|Ps3\|) \times 5\%$) $\|(\|Ps2\| - \|Ps4\|)\| \le$ Max (10 Pa, Max $(\|Ps2\|, \|Ps4\|) \times 5\%$)
	Tracer gas test	
	Thermal performance test	
Ducted setup JIS B 8628 (2017)	Airflow test	For the maximum and minum airflow rate $\| (\|Ps1\| - \|Ps2\|) \| \le$ Max (10 Pa, Max $(\|Ps1\|, \|Ps2\|) \times 5\%$) $\| (\|Ps3\| - \|Ps4\|) \| \le$ Max (10 Pa, Max $(\|Ps3\|, \|Ps4\|) \times 5\%$) For each intermediate test point Max $(\|Ps1\|, \|Ps2\|, \|Ps3\|, \|Ps4\|)$ - Min $(\|Ps1\|, \|Ps2\|, \|Ps3\|, \|Ps4\|) \le$ Max (10 Pa, Max $(\|Ps1\|, \|Ps2\|, \|Ps3\|, \|Ps4\|) \times 5\%$)
	Tracer gas test	
	Thermal performance test	
JIS B 8628 (2003)	Airflow test	For supply airflow rate -10 Pa$< Ps1 < 0$ Pa, -10 Pa$< Ps3 < 0$ Pa, 0 Pa$< Ps4 < 10$ Pa For return airflow rate -10 Pa$< Ps1 < 0$ Pa, 0 Pa$< Ps2 < 10$ Pa, 0 Pa$< Ps4 < 10$ Pa
	Tracer gas test	-10 Pa$< Ps1 < 0$ Pa, -10 Pa$< Ps3 < 0$ Pa Return airflow rate : Same as supply airflow rate
	Thermal performance test	

between the internal space on the SA side and the test room space) may also vary depending on the airtightness of the energy recovery ventilator housing. The air leakage may also affect the performance values such as the airflow-static pressure characteristics, the UEATR and the gross effectiveness.

For energy recovery ventilators with different airflow-static pressure characteristics for the air supply line (OA-SA line) and the air exhaust line (RA-EA line), the difference in airflow rate under the symmetrical static pressure conditions for those two lines may affect the thermal performance, while JIS B 8628 (2003) required the equality of the airflow rates for those two lines.

In the tracer gas test according to the original JIS B 8628 (2003), only internal air leakage is measured and external air leakage is not measured. However, most manufacturers in Japan have applied JRA 4056 (2006) as the test requirement for the tracer gas test in place of the relevant part in JIS B 8628 (2003) to be able to consider the external air leakage. In this study, the same procedure and the requirement for the tracer gas test is applied instead of the original requirement in JIS B 8628 (2003).

3. Description of the tests
3.1 Measurement apparatus

Figure 2 shows a schematic diagram of measurement apparatus commonly used for the three kinds of test setup. In this measurement apparatus, to counteract the effect of turbulence in the auxiliary ducts on static pressure measurement, the static pressure measurement points are positioned in a distance of 1.0 m (5 times of the duct diameter) from the outlet of the energy recovery ventilator and the orifice plate on the upstream side, and in a distance of 0.5 m from the damper on the downstream side. The dry-bulb temperature measurement point and the tracer gas concentration measurement point are located in a distance of 0.25 m from the inlet and outlet of the energy recovery ventilator. The wet-bulb temperature at the inlet or outlet is obtained by the following procedure. First, the dry-bulb and wet-bulb temperatures are measured at the inlet or outlet of the auxiliary fan at the end of each auxiliary duct. Second, the humidity ratio of the air is calculated. Third, wet-bulb temperature at the inlet or outlet is calculated from the humidity ratio of the air and the dry-bulb temperature at the inlet or outlet of the energy recovery ventilator.
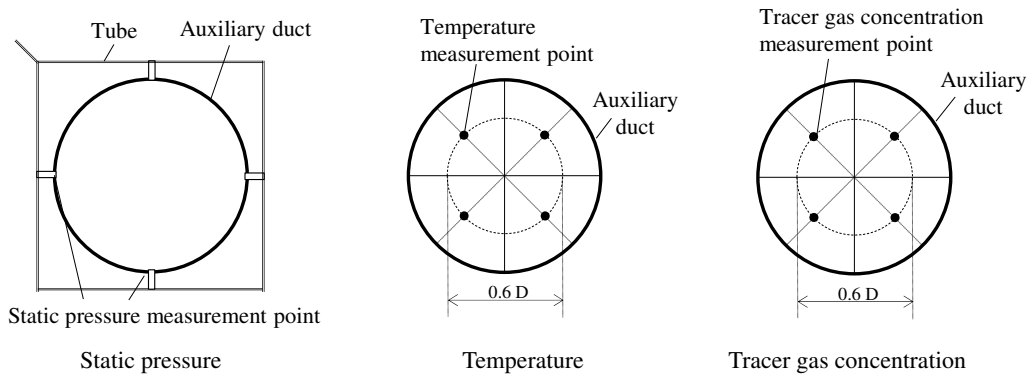
Figure 3 shows the measurement point of static pressure, temperature, and tracer gas concentration in the cross

section of the auxiliary duct. The average static pressure is obtained for four points across the auxiliary duct in accordance with JIS B 8330 (2000). Four platinum resistance thermometers to measure the dry-bulb temperatures are positioned as shown in Figure 3. The average of the four temperature measurement points is used as the dry-bulb temperature at the location. To measure the tracer gas concentration, four sampling tubes are inserted as shown in the cross-sectional view of the auxiliary duct in Figure 3. The air sampled at the four points is mixed and sent to the infrared gas analyzer.
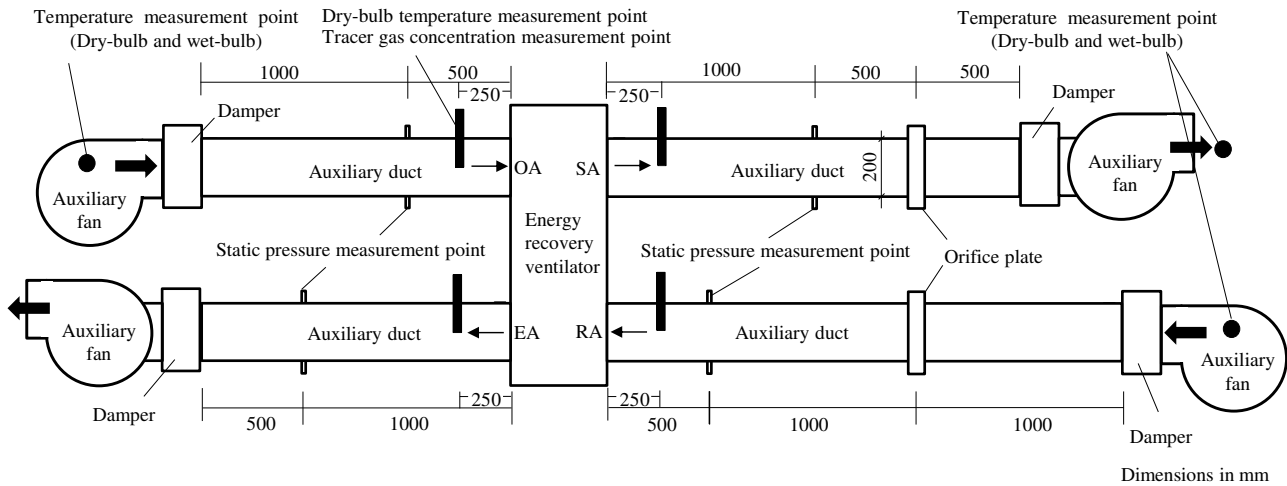
Fig.2   Schematic diagram of measurement apparatus.

Fig.3   Explanation of measurement point of static pressure, temperature and tracer gas concentration in the cross section of the auxiliary duct.

3.2 Energy recovery ventilators tested

Table 2 shows the description of the energy recovery ventilators. Figure 4 shows the diagram of the energy recovery ventilators. Four types of the medium size energy recovery ventilators, which are commonly used in non-residential buildings, were tested.

Table 2   Description of the energy recovery ventilators.

	Sample A	Sample B	Sample C	Sample D
Heat exchange element type	Plate type			
Constitution	Energy recovery ventilator			
Shape of inlet and outlet	Designed for duct connection			
Classification by air volume	Medium size (500m^3/h)			
Instalation	Ceiling hanging type			
Application	Non-residential buildings			
Motor and fan	Built-in (two motors and fans)			

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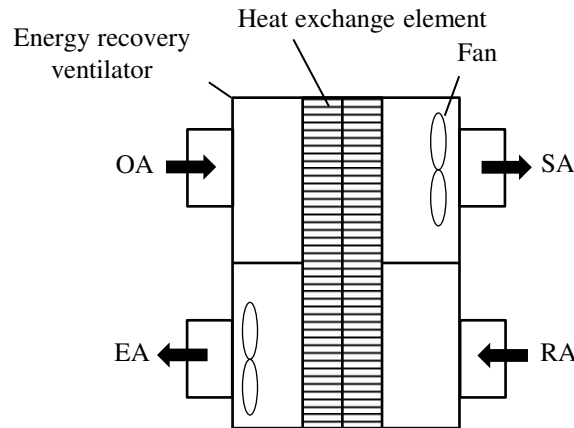
Fig.4   Diagram of the energy recovery ventilators (For Sample A, Sample B, Sample C, Sample D).

The energy recovery ventilators were provided by major three ventilator manufacturers. The JIS B 8628 (2017) classifies the energy recovery ventilators into three categories: large size, medium size, and small size. The medium size energy recovery ventilators, which are designed for duct connection and include two motors and fans, are most frequently used in the non-residential buildings in the Japanese market. The manufacturers, which provided the energy recovery ventilators, obtain the majority shares in the market. Therefore, the selected energy recovery ventilators are considered to be the representative products of energy recovery ventilator for non-residential buildings in Japan.

3.3 Test conditions

In the airflow test, the range of airflow rate measurement was between 200 m^3/h and 500 m^3/h, and the airflow rate was measured at more than 10 points to obtain the airflow-static pressure characteristics curves. In the tracer gas test and the thermal performance test, the airflow rates were set at around 200 m^3/h, 300 m^3/h, 400 m^3/h, and 500 m^3/h. Table 3, 4 and 5 show the exemplified test conditions for airflow rate and static pressure for Sample D as an example. The airflow test was performed first to determine the airflow-static pressure characteristics curves. The conditions for the tracer gas test and the thermal performance test were determined based on the results of the airflow test.

Table 3   Test conditions of the airflow rate and static pressure for the two room setup in JIS B 8628 (2017) for Sample D as an example.

Test setup	Test item	Measurement point	Supply airflow rate Q	Return airflow rate Q	Static pressure Ps1 (OA)	Static pressure Ps2 (SA)	Static pressure differential Ps2-Ps1	Static pressure Ps3 (RA)	Static pressure Ps4 (EA)	Static pressure differential Ps4-Ps3
			m^3/h	m^3/h	Pa	Pa	Pa	Pa	Pa	Pa
Two room setup JIS B 8628 (2017)	Airflow test	point 1	140.3	210.6	-0.4	261.4	261.8	-3.6	269.3	272.9
		point 2	237.1	303.8	-1.1	233.0	234.1	-4.0	239.9	243.9
		point 3	303.8	348.5	-1.6	216.8	218.4	-3.6	225.1	228.7
		point 4	334.0	374.1	-1.8	206.7	208.5	-3.2	215.6	218.8
		point 5	379.0	426.0	-2.5	186.5	189.0	-0.8	189.5	190.3
		point 6	435.7	468.3	-2.1	158.2	160.3	-1.2	156.4	157.6
		point 7	468.9	491.8	-1.1	125.5	126.6	-0.4	131.9	132.3
		point 8	484.1	530.2	-0.7	68.1	68.8	-1.6	77.4	79.0
		point 9	498.5	544.6	-2.6	36.6	39.2	-2.5	40.2	42.7
		point 10	511.3	555.3	-3.2	7.5	10.6	-3.3	14.9	18.2
	Tracer gas test	point 1	200.3	278.2	-1.6	246.6	248.2	-2.2	251.6	253.7
		point 2	301.0	354.9	-1.1	219.7	220.8	-3.2	224.5	227.7
		point 3	400.9	437.9	-1.6	176.8	178.5	-2.9	178.9	181.7
		point 4	505.0	538.2	-2.2	38.5	40.7	-3.2	38.0	41.1
	Thermal performance test (Heating conditions)	point 1	197.5	303.8	-1.8	243.3	245.1	-1.9	238.0	240.0
		point 2	298.7	348.6	-2.7	214.6	217.4	-1.7	223.8	225.5
		point 3	399.6	445.1	-3.2	172.6	175.8	-2.4	166.1	168.6
		point 4	501.7	549.3	-3.4	26.3	29.7	-1.2	22.6	23.8

Table 4 Test conditions of the airflow rate and static pressure for the ducted setup in JIS B 8628 (2017) for Sample D as an example.

Test setup	Test item	Measurement point	Supply airflow rate Q	Return airflow rate Q	Static pressure Ps1 (OA)	Static pressure Ps2 (SA)	Static pressure differential Ps2-Ps1	Static pressure Ps3 (RA)	Static pressure Ps4 (EA)	Static pressure differential Ps4-Ps3
			m³/h	m³/h	Pa	Pa	Pa	Pa	Pa	Pa
Ducted setup JIS B 8628 (2017)	Airflow test	point 1	141.3	170.7	-135.4	133.2	268.6	-137.9	139.6	277.4
		point 2	200.6	220.0	-127.8	127.0	254.8	-133.5	134.6	268.1
		point 3	276.7	288.8	-118.7	118.8	237.5	-123.4	124.3	247.7
		point 4	361.5	381.1	-101.0	101.6	202.6	-105.7	108.0	213.7
		point 5	402.5	443.4	-90.6	93.5	184.1	-86.7	93.2	179.8
		point 6	457.6	469.4	-76.2	78.7	154.9	-77.1	80.3	157.3
		point 7	472.6	477.9	-68.4	68.3	136.8	-72.5	72.5	145.1
		point 8	489.1	524.8	-38.0	42.8	80.9	-44.3	45.4	89.6
		point 9	502.8	545.9	-23.7	21.9	45.7	-26.1	17.3	43.4
		point 10	516.2	554.4	-7.7	10.6	18.3	-11.1	14.6	25.7
	Tracer gas test	point 1	201.5	269.8	-128.0	124.2	252.2	-126.6	126.7	253.2
		point 2	298.9	357.0	-110.4	111.5	221.9	-111.0	108.6	219.6
		point 3	401.8	438.5	-87.3	89.2	176.5	-85.2	86.1	171.2
		point 4	502.6	539.4	-18.0	14.5	32.4	-19.5	15.1	34.6
	Thermal performance test (Heating conditions)	point 1	200.7	220.2	-125.3	126.7	252.0	-131.4	131.4	262.8
		point 2	300.2	322.9	-111.6	109.6	221.2	-118.6	117.5	236.0
		point 3	400.9	435.9	-88.7	90.5	179.1	-87.3	87.9	175.2
		point 4	502.6	538.8	-11.7	17.8	29.4	-19.3	18.7	38.0

Table 5 Test conditions of the airflow rate and static pressure for the setup in JIS B 8628 (2003) for Sample D as an example.

Test setup	Test item	Measurement point	Supply airflow rate Q	Return airflow rate Q	Static pressure Ps1 (OA)	Static pressure Ps2 (SA)	Static pressure differential Ps2-Ps1	Static pressure Ps3 (RA)	Static pressure Ps4 (EA)	Static pressure differential Ps4-Ps3
			m³/h	m³/h	Pa	Pa	Pa	Pa	Pa	Pa
JIS B 8628 (2003)	Airflow test (For OA-SA line)	point 1	143.2	533.3	-0.9	257.5	258.5	-2.0	3.1	5.0
		point 2	276.0	541.1	-1.1	228.8	229.9	-1.1	1.5	2.5
		point 3	333.4	542.4	-1.5	205.6	207.1	-3.1	3.1	6.2
		point 4	383.0	546.6	-3.4	184.2	187.6	-3.1	2.2	5.3
		point 5	422.2	548.5	-1.4	167.9	169.3	-2.9	0.9	3.8
		point 6	456.9	550.5	-2.0	148.3	150.3	-3.4	2.1	5.5
		point 7	472.3	553.4	-2.1	127.1	129.2	-2.8	1.9	4.7
		point 8	488.7	556.0	-1.3	76.5	77.8	-3.2	2.5	5.7
		point 9	502.5	559.5	-2.9	42.4	45.3	-2.8	1.5	4.4
		point 10	516.1	560.4	-1.1	14.5	15.6	-2.6	1.8	4.3
	Airflow test (For RA-EA line)	point 1	523.5	141.0	-2.9	2.9	5.8	-268.6	3.5	272.1
		point 2	519.3	279.2	-0.9	2.7	3.6	-226.2	3.7	229.9
		point 3	518.7	335.9	-1.0	3.0	4.0	-203.4	1.2	204.5
		point 4	517.5	383.2	-3.2	2.7	5.9	-177.5	2.4	180.0
		point 5	518.8	422.2	-1.2	3.8	4.9	-146.5	2.4	148.9
		point 6	518.0	440.2	-1.9	3.9	5.8	-129.9	2.2	132.0
		point 7	518.8	474.8	-4.2	3.4	7.5	-104.8	2.9	107.7
		point 8	521.6	504.1	-0.8	2.2	3.1	-68.7	3.4	72.1
		point 9	515.8	530.7	-3.0	1.4	4.3	-36.6	1.7	38.2
		point 10	516.7	543.6	-2.5	1.4	4.0	-21.5	3.2	24.7
	Tracer gas test	point 1	203.0	202.3	-2.6	247.0	249.6	-3.6	270.5	274.1
		point 2	297.6	297.3	-2.4	219.8	222.2	-3.3	244.0	247.3
		point 3	400.7	399.2	-3.1	174.4	177.5	-3.0	202.5	205.5
		point 4	502.1	499.0	-0.9	32.0	32.9	-2.3	113.6	115.8
	Thermal performance test (Heating conditions)	point 1	202.3	201.6	-2.1	250.9	253.1	-1.4	268.0	269.4
		point 2	301.3	301.9	-0.7	223.2	223.9	-1.5	241.2	242.7
		point 3	401.7	399.1	-1.8	179.5	181.4	-1.7	203.8	205.5
		point 4	504.5	499.0	-1.8	32.4	34.1	-1.9	129.1	131.0

Table 6   Temperature condition of thermal performance tests.

Parameter		Heating	Cooling
Temperature of outdoor air (°C)	Dry-bulb	5.0	35.0
	Wet-bulb	3.0	31.0
Temperature of return air (°C)	Dry-bulb	20.0	27.0
	Wet-bulb	15.0	20.0

Table 6 shows the temperature condition of the thermal performance tests. In the test, the power supply voltage was set at the rated voltage (100 V or 200 V), and the frequency was 50 Hz. The fan speed of all ventilators was set to "High".

3.4 Measurement methods
3.4.1 Measurement method for airflow test
Figure 5 shows the steps to obtain the airflow-static pressure characteristics curves from the airflow test. The static pressure differential (ΔP) at more than ten airflow rate (Q) measurement points was obtained with a nearly equal interval of the airflow rate between the maximum and minimum airflow rates, and the change of the static pressure differential was approximated with a fourth or higher order polynomial, using the airflow rate as the independent variable. The test was repeated three times as shown in the center diagram of Figure 5. Before reaching the final curve, it was confirmed that the relative discrepancy from the average static pressure differential for each data of the three test runs was within ±5%. The average static pressure differential was calculated by using the static pressure differential obtained by substituting the representative airflow rate into each polynomial for the three test runs. The final airflow-static pressure characteristics curve was obtained by approximating the change the average static pressure differential with a fourth or higher order polynomial, using the representative airflow rate as the independent variable.
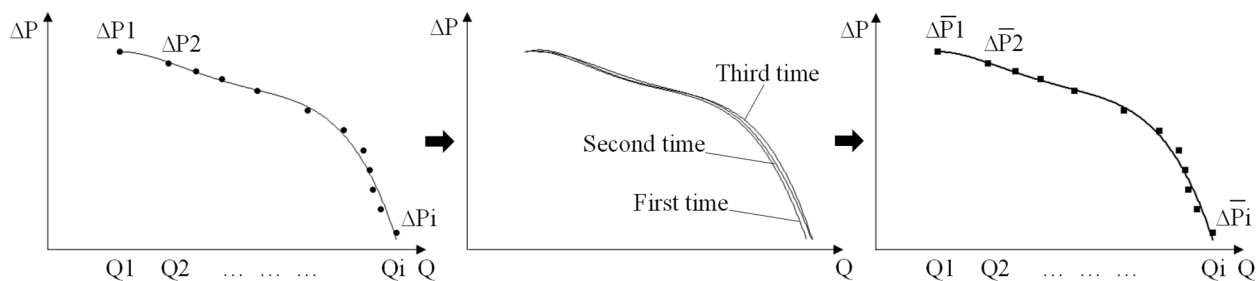
Fig.5   The steps to obtain the airflow-static pressure characteristics curve.

3.4.2 Measurement method for tracer gas test
A single infrared gas analyzer is used for the tracer gas test, and the air is sucked from the inlet and outlet auxiliary ducts to be measured of its gas concentration. Prior to measurement, it was confirmed that the tracer gas concentration of the air at RA was stable. First, the air at RA was sampled, followed by the air at OA, SA, and RA, again. It was checked that the difference in tracer gas concentration of the air at RA between the first and the last measurements was below 5%. This procedure was repeated three times. The UEATR was obtained using the average of the three-time measurements.

3.5 Measurement instruments
Table 7 shows the main measurement instruments and their performance. The platinum resistance thermometers used to measure the dry-bulb temperature and wet-bulb temperature were calibrated against the quartz thermometer PTR-111 digital temperature indicator, which was calibrated and certified by the JCSS (Japan Calibration Service System). The resistance thermometers are labelled as the tolerance class AA in JIS C 1604.

Table 7 Measurement instruments and their performance.

Measurement quantity	Measurement instrument	Uncertainty (JSCC calibration results)	Note
Temperature	Quartz thermometer PTR-111 (TOKYO DENPA CO.,LTD)	0.01°C (at 0 °C)	
Dry-bulb temperature Wet-bulb temperature	Platinum resistance thermometer (Yashimasokki.co,.ltd AAClass)	-	0.12°C (at 0°C)[1]
Static pressure	MKS Baratron 220DD	3Pa (at 100kPa)	
Atmospheric pressure	Digital barometer R-30 (SANOH CO.,LTD)	0.5hPa (at 1000hPa)	
Tracer gas concentration	Infrared gas analyzer IR400 （Yokogawa Electric Corporation)	-	±0.025% (at 5%)[2]
Airflow rate	Orifice plate (OHNISHI NETSUGAKU CO.,LTD)	-	

Note

(1):Uncertainty due to comparative calibration with PTR-111

(2):Repeatability shown in the specifications

4. Test results and discussion
4.1 Results and discussion of airflow test

Figure 6 shows the comparison of the airflow-static pressure characteristics curves for the OA-SA line and Table 8 shows the comparison of supply airflow rate at static pressure differential of 100 Pa and 225 Pa for the OA-SA line. Figure 7 shows the comparison of the airflow-static pressure characteristics curves for the RA-EA line and Table 9 shows the comparison of return airflow rate at static pressure differential of 100 Pa and 225 Pa for the RA-EA line. In Figure 7 for the RA-EA line, it is noticed that there is a difference between the results of the airflow test in JIS B 8628 (2003) and in JIS B 8628 (2017), especially for Samples B, C, and D.

As for the OA-SA line, the airflow-static pressure characteristics curves of the two room setup, the ducted setup and JIS B 8628 (2003) correspond to each other well at higher supply airflow rates (at lower pressure differentials) and the difference tends to be slightly greater at lower supply airflow rates (at higher static pressure differentials). According to Table 8, the largest difference is 13.4% (Sample C), which was observed for between the two room setup and the ducted setup at the static pressure differential of 225 Pa. A large negative static pressure in the OA-SA line in the ducted setup, which is due to the requirement for the ducted setup as shown in Table 1 and in the example of Sample D (e.g., negative values for Ps1 ranging from -7.7 Pa to -135.4 Pa), induces the air infiltration into the OA-SA line mainly from outside the ventilators and the increased supply airflow as a consequence. This interpretation coincides with the test results of the UEATR, which are shown in Figure 8. The UEATR for the ducted setup is generally larger than that for the two room setup.

As for the RA-EA line, there is also correspondence between the airflow-static pressure characteristics curves of the two room setup and the ducted setup. The largest difference is -7.8%, which was observed for Sample C at the static pressure of 225 Pa (Table 9). This difference is caused by a large negative static pressure in the RA-EA line in the ducted setup and the infiltration from outside the ventilators. This additional amount of the airflow into the RA-EA line is not measured by the orifice plate located upstream of the energy recovery ventilator (the location of the orifice plate is shown in Figure 2). For the curves of JIS B 8628 (2003), there is much larger difference compared to the curves of the two room setup and the ducted setup. The main reason for this difference is a large negative static pressure of the RA-EA line, which corresponds to the requirement for Ps3, the static pressure for return airflow as described in Table 1. In the example of Sample D shown in Table 5, Ps3 values range from -21.5 Pa to -268.6 Pa. The large negative static pressure induces air infiltration into the RA-EA line mainly from outside the ventilators, but the infiltrated airflow is not measured by the airflow measurement device located upstream in the RA-EA line.
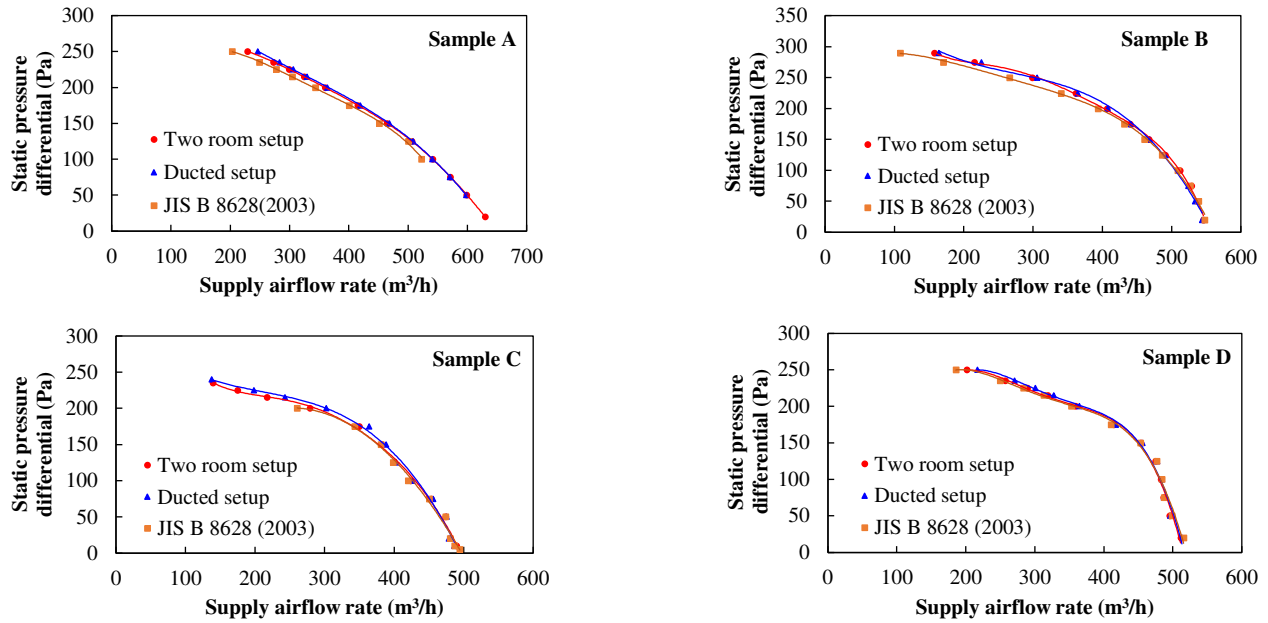
Fig.6   Comparison of the airflow-static pressure characteristics curves for the OA-SA line.

Table 8   Comparison of supply airflow rate at static pressure differential of 100 Pa and 225 Pa for the OA-SA line.

Sample A									Sample B								
Static pressure differential		Supply airflow rate			Increase-decrease ratio				Static pressure differential		Supply airflow rate			Increase-decrease ratio			
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)				Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)	
Pa	-	m^3/h	m^3/h	m^3/h	%	%	%		Pa	-	m^3/h	m^3/h	m^3/h	%	%	%	
100	1st	542.0	541.4	523.1	0.0	-0.1	-3.5		100	1st	509.9	510.3	509.0	0.0	-0.4	-0.7	
	2nd	541.8	541.1	523.5						2nd	515.5	509.9	505.8				
	3rd	541.6	541.3	523.0						3rd	511.4	510.3	511.7				
	Avg	541.8	541.3	523.1						Avg	512.2	510.2	508.8				
225	1st	299.2	306.6	278.0	0.0	2.3	-7.3		225	1st	359.5	365.0	341.6	0.0	0.7	-5.9	
	2nd	299.7	306.8	277.6						2nd	363.3	364.3	335.9				
	3rd	299.9	306.7	277.8						3rd	362.8	364.4	344.5				
	Avg	299.7	306.6	277.8						Avg	361.8	364.5	340.7				

Sample C									Sample D								
Static pressure differential		Supply airflow rate			Increase-decrease ratio				Static pressure differential		Supply airflow rate			Increase-decrease ratio			
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)				Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)	
Pa	-	m^3/h	m^3/h	m^3/h	%	%	%		Pa	-	m^3/h	m^3/h	m^3/h	%	%	%	
100	1st	426.0	426.8	418.2	0.0	0.6	-0.8		100	1st	478.0	488.0	480.7	0.0	0.3	0.3	
	2nd	422.7	427.5	422.7						2nd	490.0	483.7	485.4				
	3rd	423.3	425.6	420.4						3rd	480.6	480.6	486.1				
	Avg	424.0	426.6	420.4						Avg	482.9	484.1	484.1				
225	1st	186.0	198.1	-	0.0	13.4	-		225	1st	273.6	305.3	280.8	0.0	3.9	-2.1	
	2nd	170.7	196.1	-						2nd	303.9	300.0	284.8				
	3rd	167.7	200.6	-						3rd	289.9	295.9	283.8				
	Avg	174.8	198.3	-						Avg	289.1	300.4	283.1				

* Increase-decrease ratio was calculated based on two room setup   * Increase-decrease ratio was calculated based on two room setup
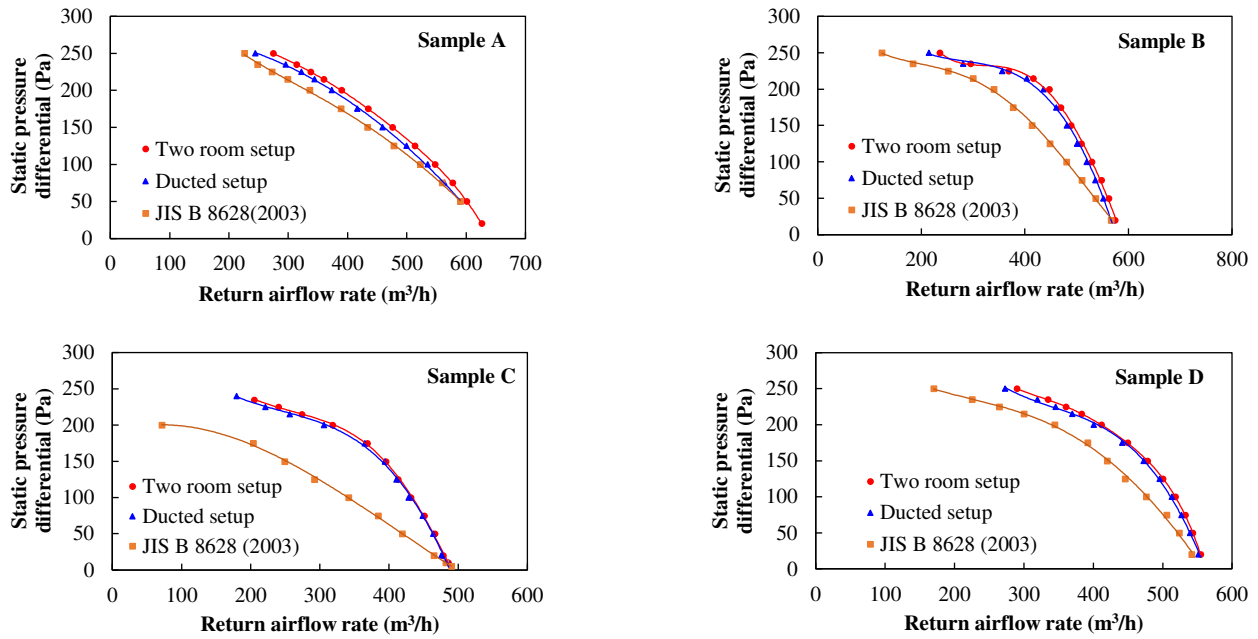
Fig.7   Comparison of the airflow-static pressure characteristics curves for the RA-EA line.

Table 9   Comparison of return airflow rate at static pressure differential of 100 Pa and 225 Pa for the RA-EA line.

Sample A								Sample B							
Static pressure differential		Return airflow rate			Increase-decrease ratio			Static pressure differential		Return airflow rate			Increase-decrease ratio		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)			Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
Pa	-	m^3/h	m^3/h	m^3/h	%	%	%	Pa	-	m^3/h	m^3/h	m^3/h	%	%	%
100	1st	547.7	534.8	522.5	0.0	-2.3	-4.6	100	1st	532.4	519.1	481.3	0.0	-1.9	-9.2
	2nd	547.5	534.6	522.3					2nd	529.0	519.7	480.5			
	3rd	547.8	534.9	522.2					3rd	527.0	519.8	480.4			
	Avg	547.7	534.8	522.3					Avg	529.5	519.5	480.7			
225	1st	313.6	296.0	248.4	0.0	-5.8	-21.0	225	1st	370.1	356.4	252.4	0.0	-3.4	-31.6
	2nd	314.0	295.5	248.3					2nd	370.9	355.7	252.6			
	3rd	313.8	295.7	248.2					3rd	365.6	356.6	251.5			
	Avg	313.8	295.6	248.0					Avg	368.9	356.3	252.2			
Sample C								Sample D							
Static pressure differential		Return airflow rate			Increase-decrease ratio			Static pressure differential		Return airflow rate			Increase-decrease ratio		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)			Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
Pa	-	m^3/h	m^3/h	m^3/h	%	%	%	Pa	-	m^3/h	m^3/h	m^3/h	%	%	%
100	1st	432.9	429.1	340.9	0.0	-0.8	-20.8	100	1st	517.0	516.6	477.5	0.0	-1.0	-8.1
	2nd	430.9	428.7	341.9					2nd	524.6	513.0	475.0			
	3rd	430.7	427.0	342.3					3rd	513.0	509.4	476.3			
	Avg	431.5	428.3	341.7					Avg	518.2	513.0	476.2			
225	1st	248.5	221.1	-	0.0	-7.8	-	225	1st	358.0	355.0	265.8	0.0	-4.0	-26.6
	2nd	235.1	219.2	-					2nd	370.0	349.6	263.4			
	3rd	236.7	224.2	-					3rd	352.7	332.9	263.7			
	Avg	240.1	221.5	-					Avg	360.2	345.8	264.3			

* Increase-decrease ratio was calculated based on two room setup   * Increase-decrease ratio was calculated based on two room setup

4.2 Results and discussion of tracer gas test

The tracer gas test is carried out to measure the air leakage characteristics of the energy recovery ventilators, for which the unit exhaust air transfer ratio is defined by the following equation:

$$UEATR = \frac{C_2 - C_1}{C_3 - C_1} \times 100 \qquad\qquad (1)$$

where

$UEATR$ is the unit exhaust air transfer ratio (%),
C_1 is the tracer gas concentration at outdoor air inlet,
C_2 is the tracer gas concentration at supply air outlet,
C_3 is the tracer gas concentration at return air inlet.

Figure 8 shows the comparison of the relationship between the UEATR and the supply airflow rate, and Table 10 shows the comparison of the UEATR at the supply airflow rate of 500 m³/h and 300 m³/h in each test setup, which are estimated by using approximation curves. The more the return air and/or the air of the test room surrounding the tested ventilators infiltrates into the OA-SA line, the larger the UEATR becomes. The infiltration makes the thermal performance (the gross effectiveness including the total effectiveness) of energy recovery ventilators look better than their actual one.

The UEATR tends to increase, when the supply airflow decreases and the static pressure differential across the ventilators increases (Figure 8). At the rated airflow rate for samples (i.e., 500 m³/h), the UEATR value ranges from 5.2% to 11.8% according to the results of the two room setup (Table 10).

The UEATR values obtained by the ducted setup tend to be greater than those by the two room setup, when the static pressure differentials increase, as already mentioned in 4.1. As shown in Table 1, for the ducted setup, Ps1 and Ps3 at entering points are required to be kept negative pressure of large magnitude, of which examples are shown in Table 4 (e.g., Ps1=-128.0 Pa and Ps3=-126.6 Pa for "point 1") as well as in Table 10. Due to this requirement, only in the ducted setup, the static pressure inside the ventilation becomes negative in large magnitude, while there is no such large negative static pressure condition for the two room setup and JIS B 8628 (2003). As a result, in the ducted setup, the air in the test room with indoor conditions infiltrates into the ventilator more easily than other setups.

For JIS B 8628 (2003), conditions for Ps1 and Ps3 are similar to the two room setup, but the return airflow entering into RA must be controlled equal to the supply airflow leaving from SA (Table 1). Due to this additional requirement,
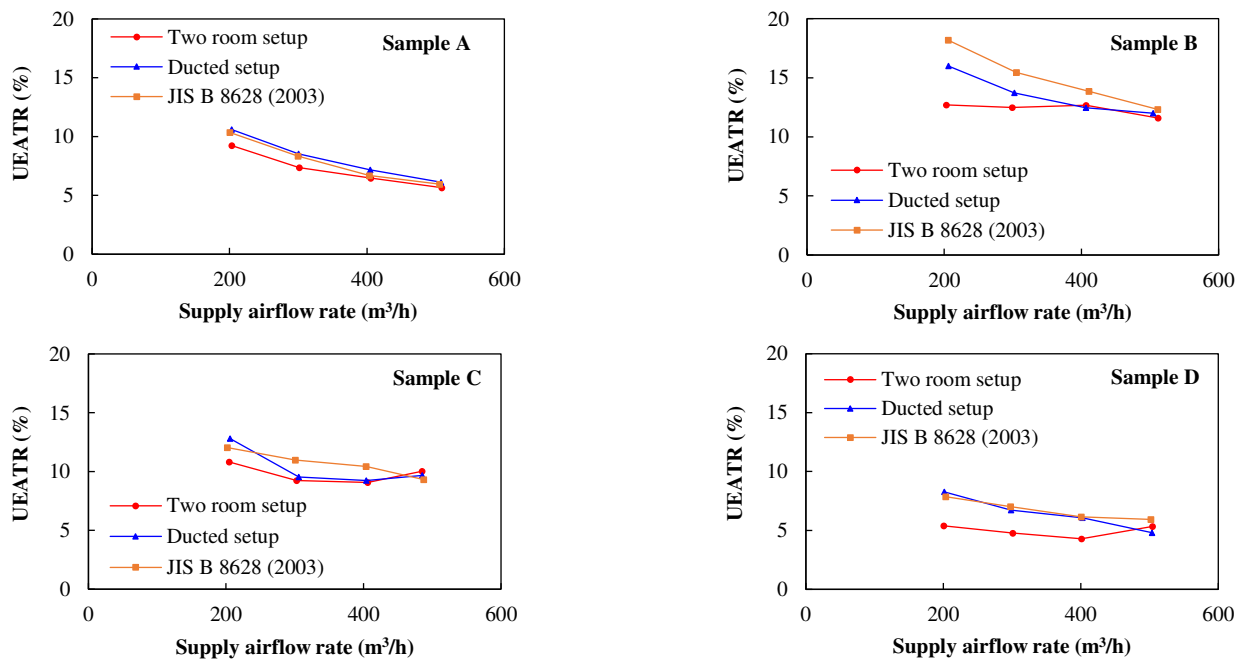

Fig.8　Comparison of the relationship between the UEATR and the supply airflow rate.

Table 10   Comparison of the UEATR at the supply airflow rate of 500 m³/h and 300 m³/h.

Sample A

Supply airflow rate		UEATR			Static pressure		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	-	%	%	%	Pa	Pa	Pa
500	1st	4.8	6.2	5.7	Ps1=-1.0	Ps1=-73.5	Ps1=-1.4
	2nd	5.3	6.2	6.0	Ps2=134.7	Ps2=68.0	Ps2=134.5
	3rd	6.7	5.8	6.0	Ps3=-2.9	Ps3=-68.1	Ps3=-1.5
	Avg	5.7	6.2	5.9	Ps4=136.0	Ps4=72.7	Ps4=143.9
300	1st	7.3	9.0	8.5	Ps1=-2.5	Ps1=-121.9	Ps1=-1.4
	2nd	7.3	8.1	8.0	Ps2=233.8	Ps2=117.4	Ps2=231.1
	3rd	7.5	8.5	8.5	Ps3=-2.1	Ps3=-125.3	Ps3=-1.2
	Avg	7.4	8.5	8.3	Ps4=232.5	Ps4=123.5	Ps4=248.7

Sample B

Supply airflow rate		UEATR			Static pressure		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	-	%	%	%	Pa	Pa	Pa
500	1st	11.2	12.2	12.1	Ps1=-1.4	Ps1=-57.3	Ps1=-2.6
	2nd	11.8	12.0	12.4	Ps2=107.6	Ps2=59.5	Ps2=115.8
	3rd	11.8	11.8	12.5	Ps3=-3.1	Ps3=-57.3	Ps3=-2.6
	Avg	11.8	12.0	12.5	Ps4=111.4	Ps4=55.6	Ps4=147
300	1st	12.5	13.9	15.5	Ps1=-2.0	Ps1=-128.9	Ps1=-3.0
	2nd	12.6	13.8	15.3	Ps2=253.4	Ps2=132.2	Ps2=258.2
	3rd	12.4	13.5	15.6	Ps3=-3.6	Ps3=-133.0	Ps3=-2.9
	Avg	12.5	13.8	15.5	Ps4=250.9	Ps4=132.6	Ps4=280.0

Sample C

Supply airflow rate		UEATR			Static pressure		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	-	%	%	%	Pa	Pa	Pa
500	1st	9.6	9.8	9.4	Ps1=-2.8	Ps1=-11.6	Ps1=-3.4
	2nd	10.1	9.3	9.3	Ps2=21.5	Ps2=10.9	Ps2=19.3
	3rd	10.4	9.9	9.3	Ps3=-3.6	Ps3=-13.0	Ps3=-2.7
	Avg	10.3	9.7	9.0	Ps4=27.7	Ps4=11.5	Ps4=6.9
300	1st	9.2	9.9	11.0	Ps1=-1.2	Ps1=-98.1	Ps1=-2.3
	2nd	9.1	9.5	10.9	Ps2=194.1	Ps2=104.5	Ps2=195.9
	3rd	9.4	9.3	11.1	Ps3=-4.1	Ps3=-102.1	Ps3=-3.0
	Avg	9.3	9.6	11.0	Ps4=199.1	Ps4=99.4	Ps4=221.5

Sample D

Supply airflow rate		UEATR			Static pressure		
		Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	-	%	%	%	Pa	Pa	Pa
500	1st	4.7	4.5	5.9	Ps1=-2.2	Ps1=-18.0	Ps1=-0.9
	2nd	5.4	5.6	6.0	Ps2=38.5	Ps2=14.5	Ps2=32.0
	3rd	5.9	4.3	5.9	Ps3=-3.2	Ps3=-19.5	Ps3=-2.3
	Avg	5.2	4.9	5.9	Ps4=38.0	Ps4=15.1	Ps4=113.6
300	1st	4.8	7.1	7.2	Ps1=-1.1	Ps1=-110.4	Ps1=-2.4
	2nd	4.8	6.5	6.7	Ps2=219.7	Ps2=111.5	Ps2=219.8
	3rd	4.8	6.6	7.1	Ps3=-3.2	Ps3=-110.0	Ps3=-3.3
	Avg	4.8	6.7	7.0	Ps4=224.5	Ps4=108.6	Ps4=244.0

* Ps1 is static pressure at outdoor air inlet, Ps2 is static pressure at supply air outlet,
Ps3 is static pressure at return air inlet, Ps4 is static pressure exhaust air outlet.

which is not applied in JIS B 8628 (2017), it seems that the static pressure in the RA-EA line becomes slightly higher than that in the OA-SA line, and the infiltration from the RA-EA line to the OA-SA line is enhanced.

In the tracer gas test for JIS B 8628 (2003) in this study, the method prescribed in JIS B 8628 (2017) for ventilators installed inside buildings is applied, so that air leakage into the ventilators from a surrounding space is treated as polluted indoor air as the return air. It is because if the method prescribed in JIS B 8628 (2003) was applied as it was for the tracer gas test in this study, the comparison with other test setups would be less meaningful.

4.3 Results and discussion of thermal performance test

In JIS B 8628 (2017) and JIS B 8628 (2003), the thermal performance of energy recovery ventilators is evaluated by the gross effectiveness. The gross effectiveness means the effectiveness of recovery ratio of thermal factors, which are dry-bulb temperature, humidity ratio or enthalpy, as defined by the following equation:

$$\varepsilon = \frac{x_1 - x_2}{x_1 - x_3} \qquad (2)$$

where

the subscript numbers 1, 2 and 3 mean the OA, SA and RA, respectively; ε is generally called the gross effectiveness, and is the sensible effectiveness when x is the dry-bulb temperature (°C), the latent effectiveness when x is the humidity ratio (kg water/kg dry air), or the total effectiveness when x is the enthalpy (J/kg).

In this paper, the thermal performance of energy recovery ventilators is represented by the total effectiveness, which is most frequently referred to in non-residential application with a large amount of cooling load.

Figure 9 shows the comparison of the relationship between the total effectiveness and the supply airflow rate for heating condition, and Table 11 shows the comparison of the total effectiveness at the supply airflow rate of 500 m³/h and 300 m³/h for heating condition. Figure 10 shows the comparison of the relationship between the total effectiveness
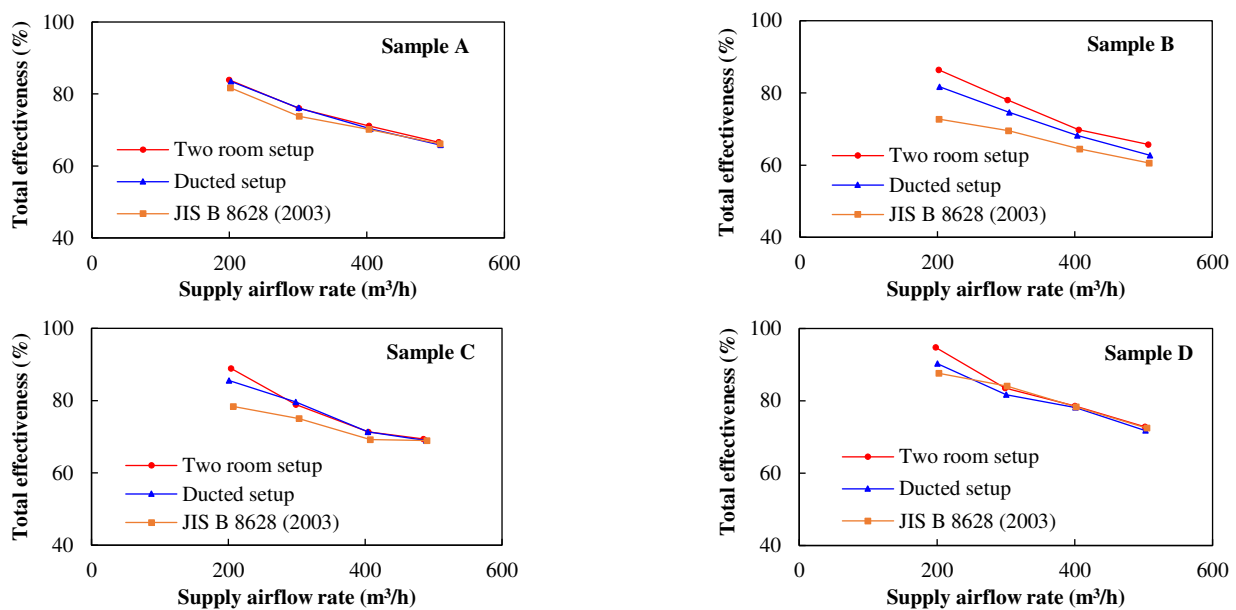
and the supply airflow rate for cooling condition, and Table 12 shows the comparisons of the total effectiveness at the supply airflow rate of 500 m³/h and 300 m³/h for cooling condition. The total effectiveness at the airflow rates was approximated by using polynomials. In Table 11 and 12, the ratios of supply airflow rate to the return airflow rate are also described.

As for the total effectiveness at a supply airflow rate of 500 m³/h (the rated airflow rate for tested products), there is less difference between the two room setup, the ducted setup and JIS B 8628 (2003) than at a smaller supply airflow rate such as 200 m³/h and 300 m³/h. As exemplified in Table 3, 4 and 5, at "point 4" of thermal performance test, neither the OA-SA line nor the RA-EA line has a large negative static pressure in those three test setups, and the difference between the supply airflow rates of the lines is less than 10% of the supply airflow rates (Table 11).

On the contrary, as for the total effectiveness at a supply airflow rate of 300 m³/h, the difference between the test setups becomes larger than at a supply airflow rate of 500 m³/h. One factor for this difference is clearly a larger amount of return airflow rate in the two room setup and the ducted setup, while in JIS B 8628 (2003) the return airflow rate is required to be kept equal to the supply airflow rate as described in Table 1. It is exemplified by the supply airflow rate

Fig.9   Comparison of the relationship between the total effectiveness and the supply airflow rate for heating condition.

Table 11   Comparison of the total effectiveness at the supply airflow rate of 500 m³/h and 300 m³/h for heating condition.

Sample A						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-
500	66.9	66.1	66.5	1.00	1.02	1.01
300	76.1	76.2	73.8	0.93	0.95	1.00

Sample B						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-
500	65.9	63.2	60.8	0.97	0.98	1.01
300	78.3	75.0	69.7	0.77	0.84	1.01

Sample C						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-
500	69.5	69.1	69.4	0.97	0.98	1.01
300	78.8	79.5	75.3	0.77	0.84	1.01

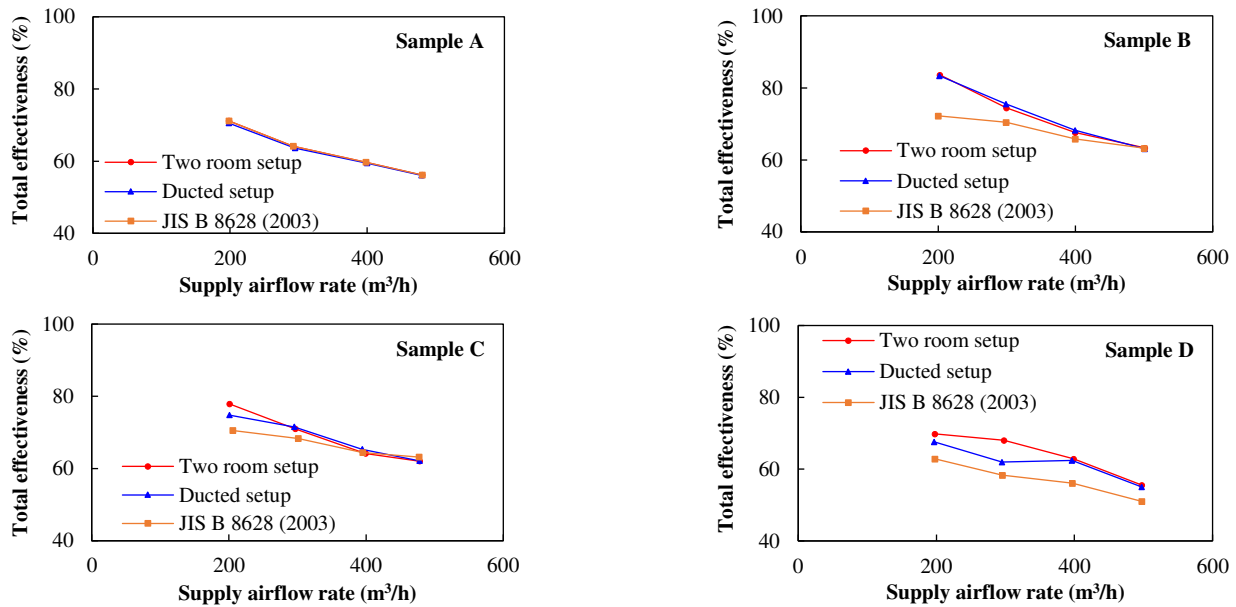| Sample D						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-
500	72.9	72.0	72.7	0.91	0.93	1.01
300	83.4	81.7	84.1	0.86	0.93	1.00

Fig.10   Comparison of the relationship between the total effectiveness and the supply airflow rate for cooling condition.

Table 12   Comparison of the total effectiveness at the supply airflow rate of 500 m³/h and 300 m³/h for cooling condition.

Sample A								Sample B						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate				Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)			Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-		m³/h	%	%	%	-	-	-
500	55.0	54.9	55.0	1.01	1.03	1.01		500	63.4	63.1	63.2	0.98	0.98	1.00
300	63.8	63.4	63.8	0.97	0.98	0.97		300	74.4	75.5	70.4	0.86	0.88	1.00

Sample C								Sample D						
Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate				Supply airflow rate	Total effecteveness			Ratio of supply airflow rate to return airflow rate		
	Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)			Two room setup	Ducted setup	JIS B 8628 (2003)	Two room setup	Ducted setup	JIS B 8628 (2003)
m³/h	%	%	%	-	-	-		m³/h	%	%	%	-	-	-
500	62.2	62.1	63.6	0.98	0.98	1.00		500	55.4	54.7	50.8	0.94	0.94	1.00
300	70.7	71.3	68.4	0.86	0.88	1.00		300	68.0	62.0*	58.3	0.84	1.11*	0.99

* These two values are uncertain and should be carefully referred to, because it has been found that the return airflow rate in this test condition was unnaturally smaller than the expected value. It is probable that tubes for pressure transmission were blocked by condensed water in the cooling condition and an error was contained in the static pressure measurement, which is monitored when adjusting the return airflow rate.

and return airflow rates at "point 1" and "point 2" for the thermal performance test in Table 3, 4 and 5. In the tables 11 and 12, the ratios of the supply airflow rate to the return airflow rate for the test setups for all four samples are shown. Not only for Sample D, but also for Samples B and C, the airflow ratios less than 0.9 were observed under the condition of the supply airflow rate of 300 m³/h. The smallest airflow ratio was 0.77, which was observed in the two room setup for Samples B and C in the heating condition. The inexistence of requirement for the equality between the supply and return airflow rates in the test setups in JIS B 8628 (2017) and ISO 16494 (2014) demands attention especially when evaluating the rated gross effectiveness, since the airflow ratio is one of the dominant factors of the gross effectiveness including the total effectiveness. Another factor influencing the measured total effectiveness is the negative static pressure

in the OA-SA and the RA-EA lines especially at the supply airflow rate of 300 m³/h in the ducted setup. The infiltration into those lines from outside the ventilator increases the measured total effectiveness.

5. Conclusions

In this study, the airflow test, the tracer gas test and the thermal performance test are performed for four commercially available products of the energy recovery ventilator, in order to characterize three different test setups and methods, which are the two room setup, the ducted setup, both of which are prescribed in JIS B 8628 (2017) and the test setup prescribed in JIS B 8628 (2003). The followings are the findings from this study:

1) As for the airflow-static pressure characteristics (Figure 6 and 7), the curves obtained by the three test setups generally correspond to each other, except for the characteristic curves for the RA-EA line obtained by JIS B 8628 (2003).

2) As for the UEATR (Figure 8), it tends to increase when the supply airflow decreases and the static pressure differential increases. Under the requirement to the ducted setup, which is prescribed in JIS B 8628 (2017), the static pressure inside the ventilators becomes negative in the largest magnitude compared with other test setups, and the air in the test room surrounding the ventilator infiltrates into the ventilator more easily than other test setups.

3) As for the thermal performance represented by the total effectiveness (Figure 9 and 10), there is less difference among the three test setups when neither the OA-SA line nor the RA-EA line is in a large negative static pressure. On the contrary, when there is a large negative static pressure in those lines in the ducted setup, the measured total effectiveness can be influenced by the infiltration into those lines from outside the ventilator and by the difference between the airflow rates of supply and return.

Referring to the results presented in this paper, it may not be possible to choose the technically best test setup among the test setups prescribed in JIS B 8628 (2017) and JIS B 8628 (2003). Instead, it is revealed that the results from different test setups should be examined carefully by taking the characteristics of the test setup into consideration. The characteristics of each test setup is represented by the static pressure inside the ventilators, the ratio between the supply airflow rate and the return airflow rate, and the location of airflow measurement devices with or without ability to measure whole airflow rate passing through the energy recovery ventilators.

Since the gross effectiveness including the total effectiveness depends on the airflow ratio, the airflow ratio when the measurement is done for the gross effectiveness should be recorded and presented upon request from users of the test results, who need to know the adjusted gross effectiveness under other airflow ratios by using any programs or diagrams for the adjustment. The diagrams are usually provided by manufacturers. Suppose that the supply airflow rate is maintained the same, the larger the return airflow rate is, the larger the gross effectiveness becomes.

The use of the test setups in JIS B 8628 (2017) has recently started by manufacturers, and more efforts are demanded to improve reliability and transparency of the test results to be able to estimate more accurately the actual performance of the energy recovery ventilators when they are installed in buildings.

Acknowledgements

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