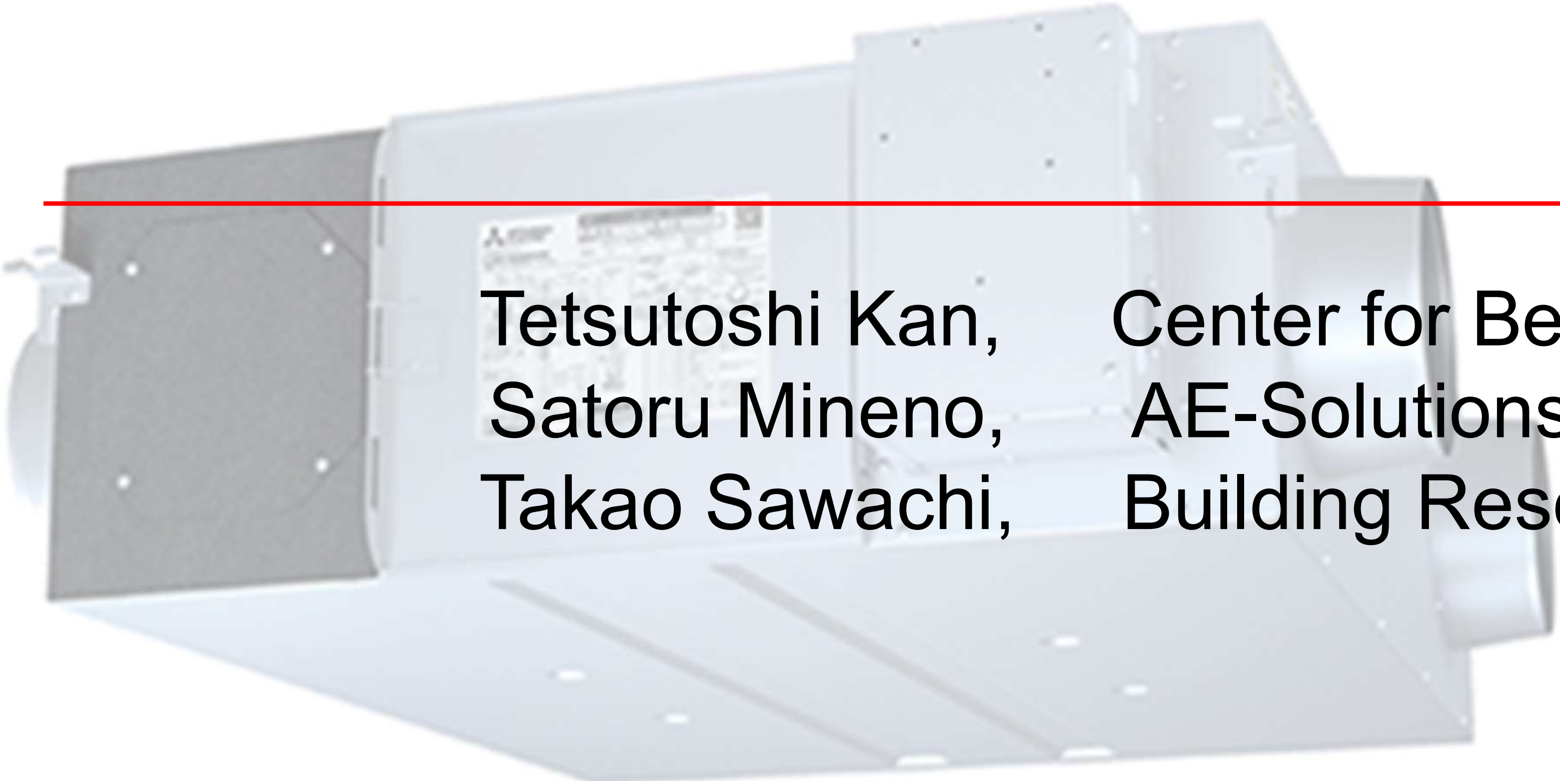
Actual effectiveness of energy/heat recovery ventilators in buildings: how is it influenced by key design factors and testing results(airflow, airflow ratio, unit exhaust air transfer ratio)?



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Agenda

1. Introduction

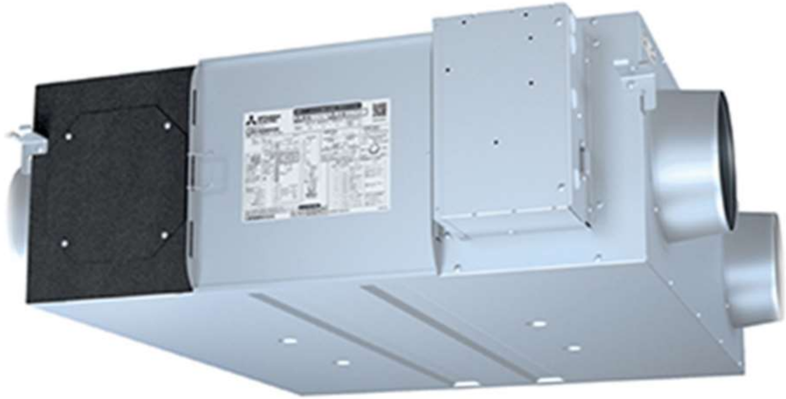
2. Test results and discussion

3. Correction formula for total effectiveness of energy recovery ventilator and accuracy verification

4. Confirmation of energy saving performance of energy recovery ventilator in HVAC system

5. Conclusions

Introduction



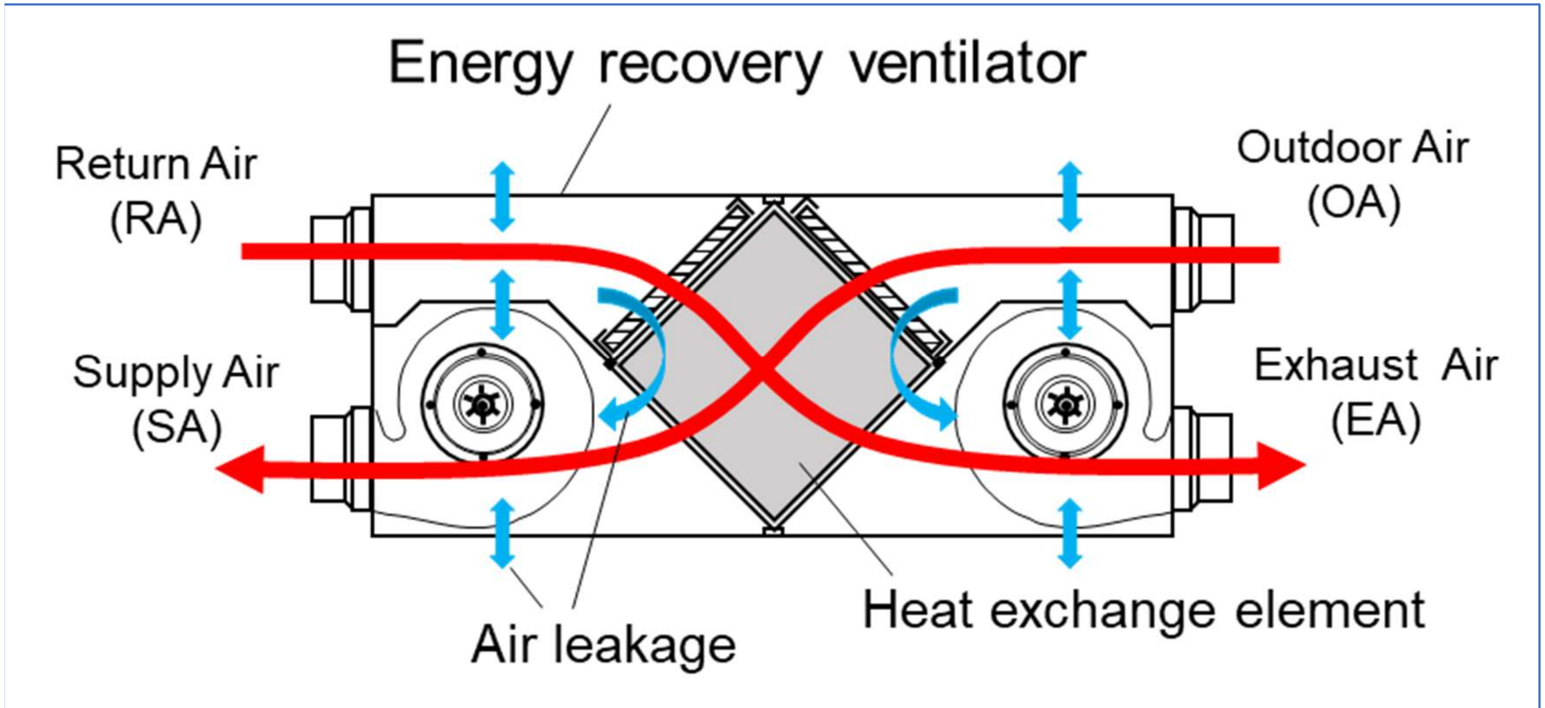
Energy recovery ventilator (ERV) :

> Supply outdoor air to indoor

> Exhaust indoor air to outdoor

> Supply air and Exhaust air exchange heat and moisture via heat exchange element

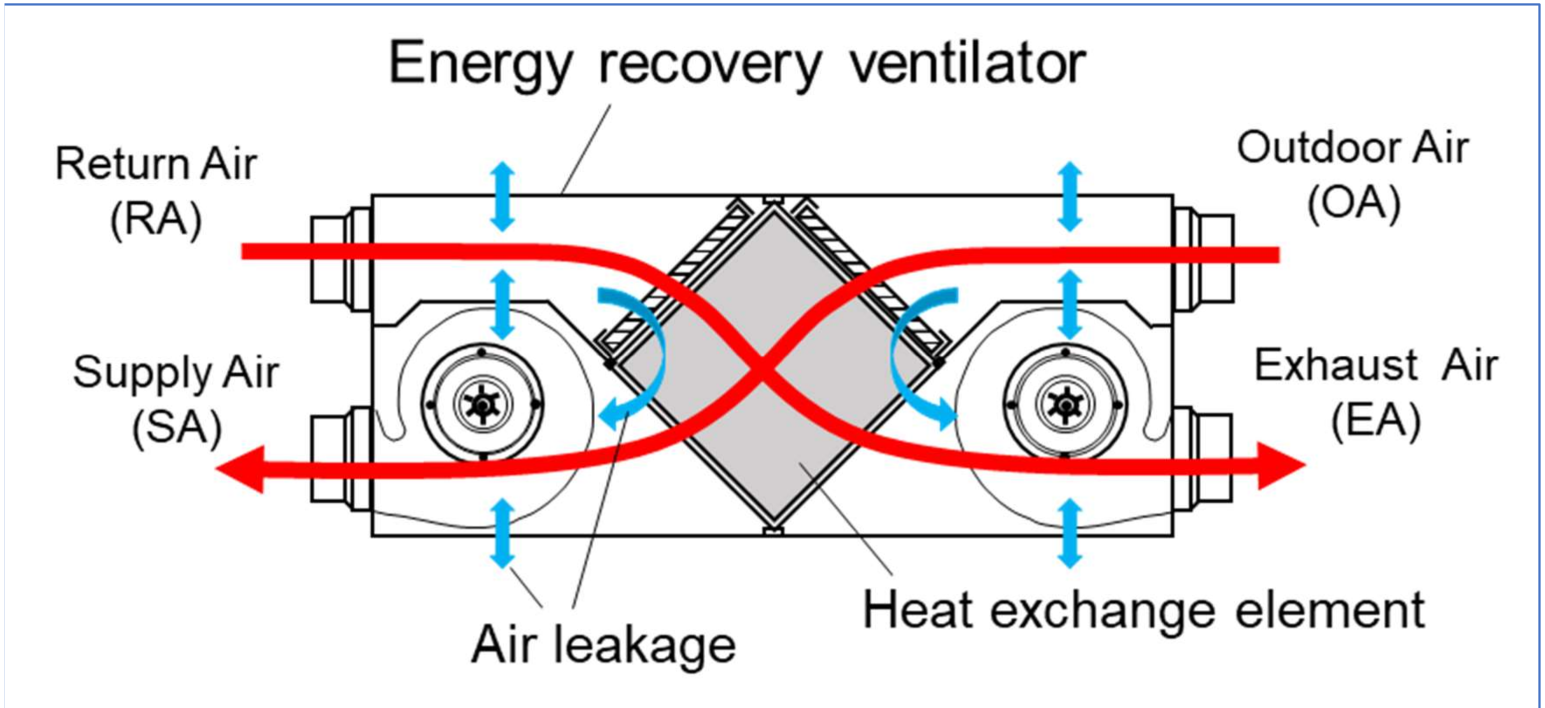
Reducing air-conditioning load (Energy- saving)



Introduction

Performance values of
Energy recovery ventilator (ERV) :

1. Airflow - static pressure characteristics
2. Gross effectiveness (Total effectiveness etc.)
3. Unit exhaust air transfer ratio (UEATR)
   or Net supply airflow ratio (NSAR)
   NSAR = 100-UEATR



Air leakage:

Depend on airtightness
>Throw the housing gap
> Throw the inside gap

Introduction

The performance value (The total effectiveness etc.) is not a constant value, but influenced by airflow rate, airflow ratio, unit exhaust air transfer ratio (UEATR).

Airflow, airflow ratio, UEATR are affected by ventilation equipment system in building and condition of operating.

In the design of heat recovery ventilation system in buildings, It is important to design airflow rate, airflow ratio, and UEATR to be appropriate in order to maximize the energy saving effect of the energy recovery ventilation systems.

Introduction

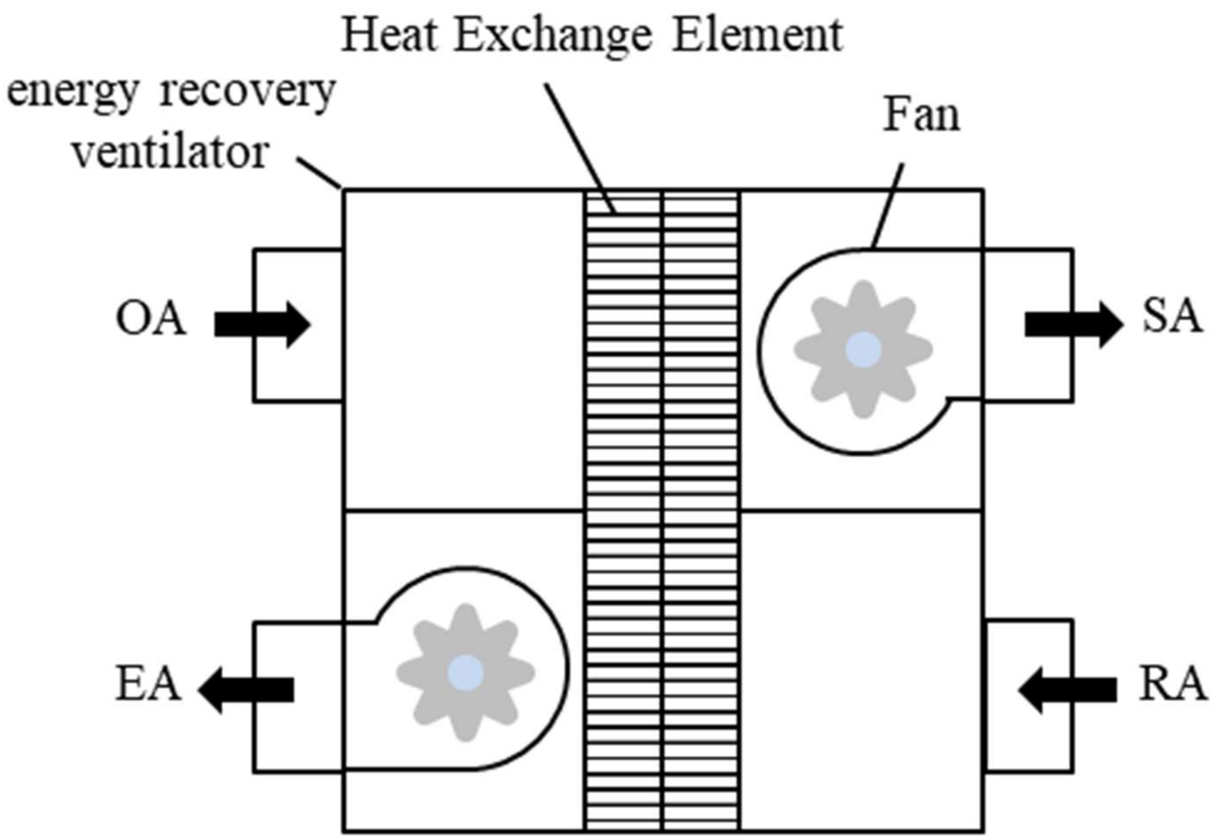
We conducted an experimental study to confirm how the total effectiveness of energy recovery ventilator is influenced by airflow rate, airflow ratio, and UEATR.

Purpose of experiment

2. Test results and discussion

Test method：JIS B 8628:2017 (ISO16494:2014)

Specimens: Plate type energy recovery ventilators



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2. Test results and discussion

Specimens: Sample A (for non-residential buildings)

Sample B (for residential buildings)

Table Description of the energy recovery ventilators

	Sample A	Sample B
Heat exchange element type	Plate type	
Constitution	Energy recovery ventilator	
Shape of inlet and outlet	Designed for duct connection	
Classification by airvolume	Medium size ($500m^3/h$)	Small size ($250m^3/h$)
Instalation	Ceiling hanging type	
Appliction	Non-residential buildings	residential buildings
Motor and fan	Built-in (two motors and fans)	

2. Test results and discussion

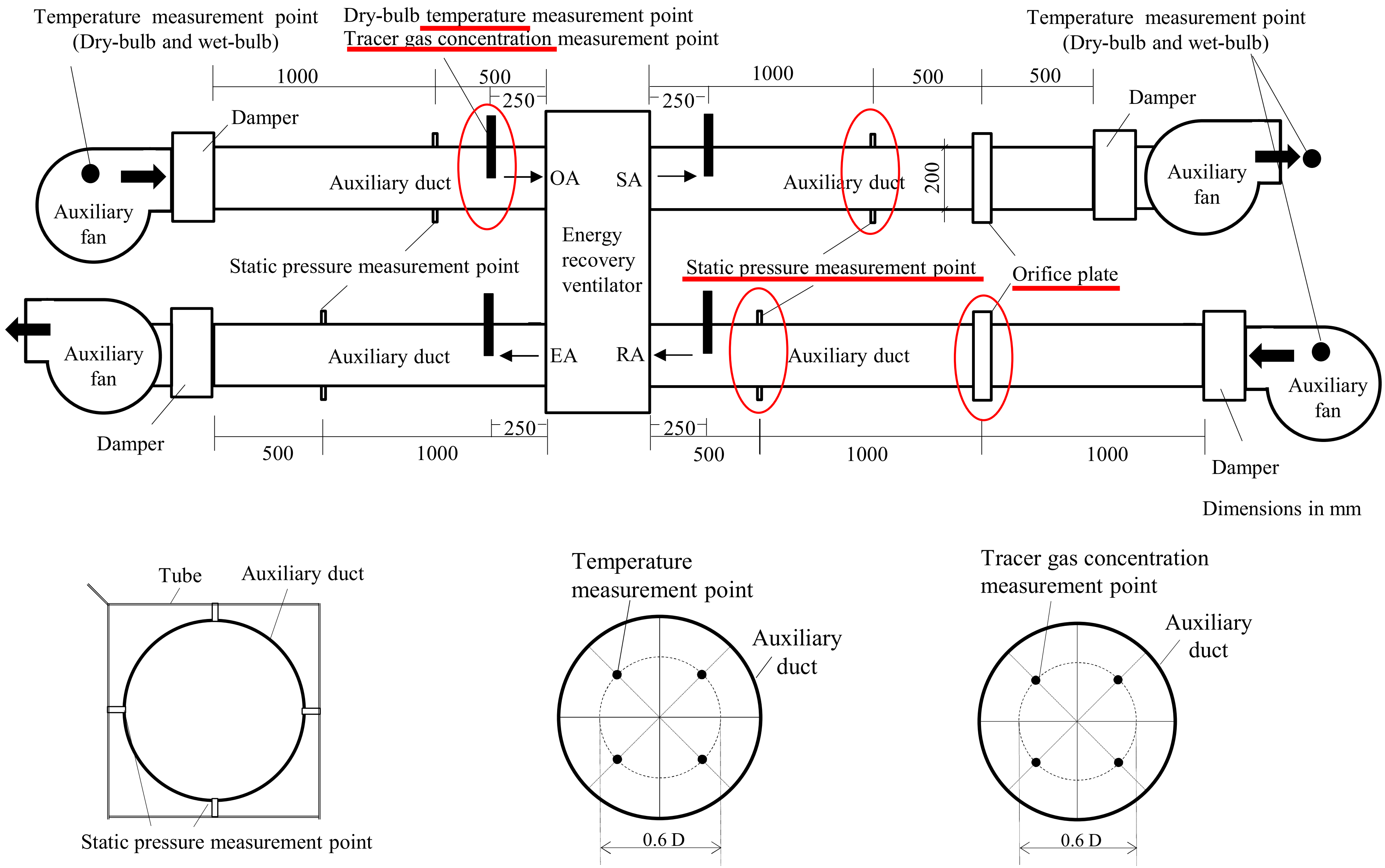


Fig　Schematic diagram of measurement apparatus

2. Test results and discussion

2. Test results and discussion

Table Measurement instruments and their performance

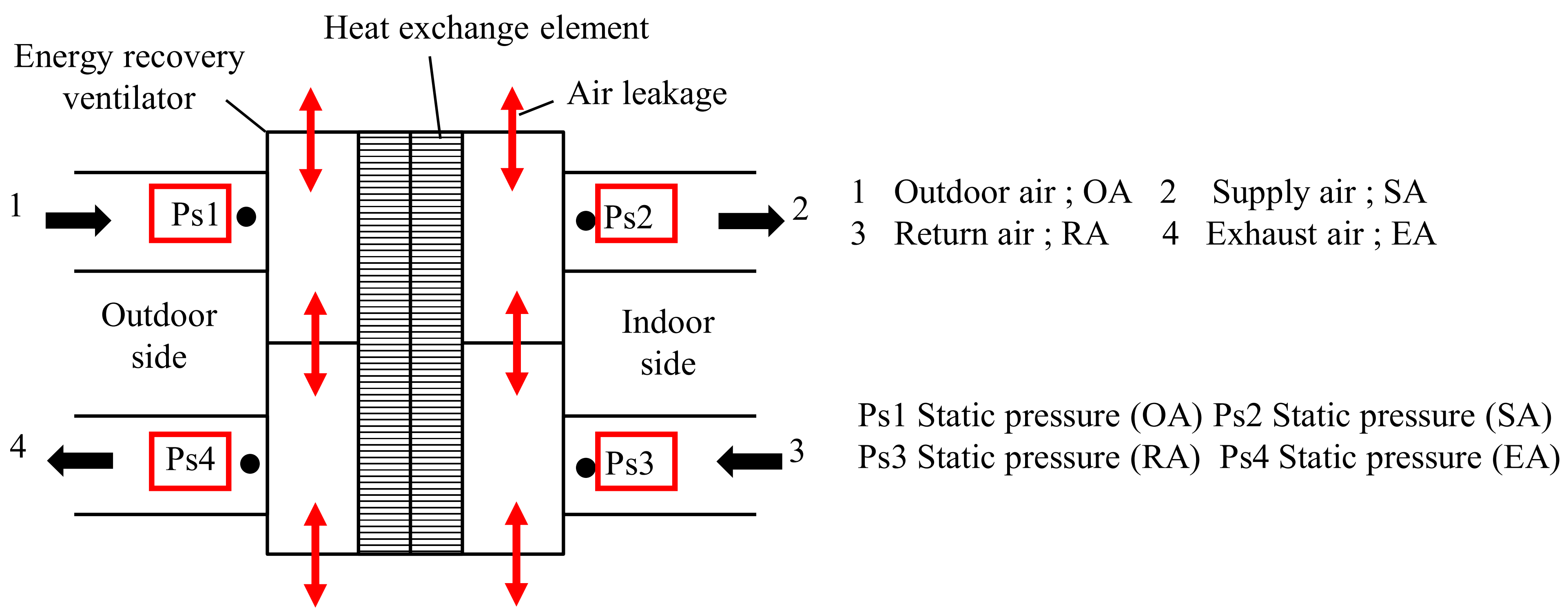
Measurement quantity	Measurement instrument	Uncertainty (JSCC calibration results)	Note
Temperature	Quartz thermometer PTR-111 (TOKYO DENPA CO.,LTD)	0.01˚C (at 0 ˚C)	
Dry-bulb temperature Wet-bulb temperature	Platinum resistance thermometer (Yashimasokki.co,.ltd AAClass)	-	0.12˚C (at 0˚C)(1)
Static pressure	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

2. Test results and discussion



Symbols for the static pressure at inlets and outlets.

2. Test results and discussion

Table Static pressure measurement requirements and Airflow rate measurement points

Test setup	Test item	Static pressure measurement requirements	Airflow rate measurement points
Two room setup	Thermal performance test	Ps1 < 0Pa, Ps3 < 0Pa |(|Ps1|-|Ps3|)| <= Max (10Pa, Max(|Ps1|,|Ps3|)×5%) |(|Ps2|-|Ps4|)| <= Max (10Pa, Max(|Ps2|,|Ps4|)×5%)	200, 300, 400, 500m^3/h
Ducted setup	Thermal performance test	For the maximum and minum airflow rate |(|Ps1|-|Ps3|)| <= Max (10Pa, Max(|Ps1|,|Ps3|)×5%) |(|Ps2|-|Ps4|)| <= Max (10Pa, Max(|Ps2|,|Ps4|)×5%) For each intermediate test point Max(|Ps1|, |Ps2|, |Ps3|, |Ps4|) - Min(|Ps1|, |Ps2|, |Ps3|, |Ps4|) <= Max(10Pa, Max(|Ps1|,|Ps2|, |Ps3|, |Ps4|)×5%)	200, 300, 400, 500m^3/h

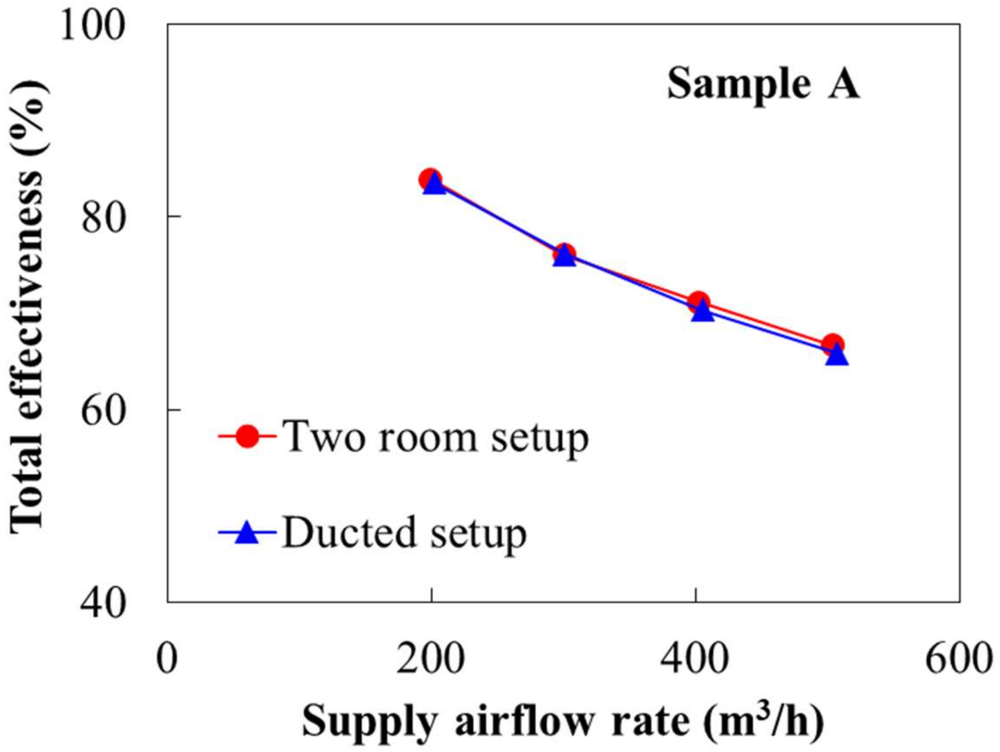
2. Test results and discussion

Table 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

2. Test results and discussion (Sample A)

Influence of airflow rate (supply ≒ return)



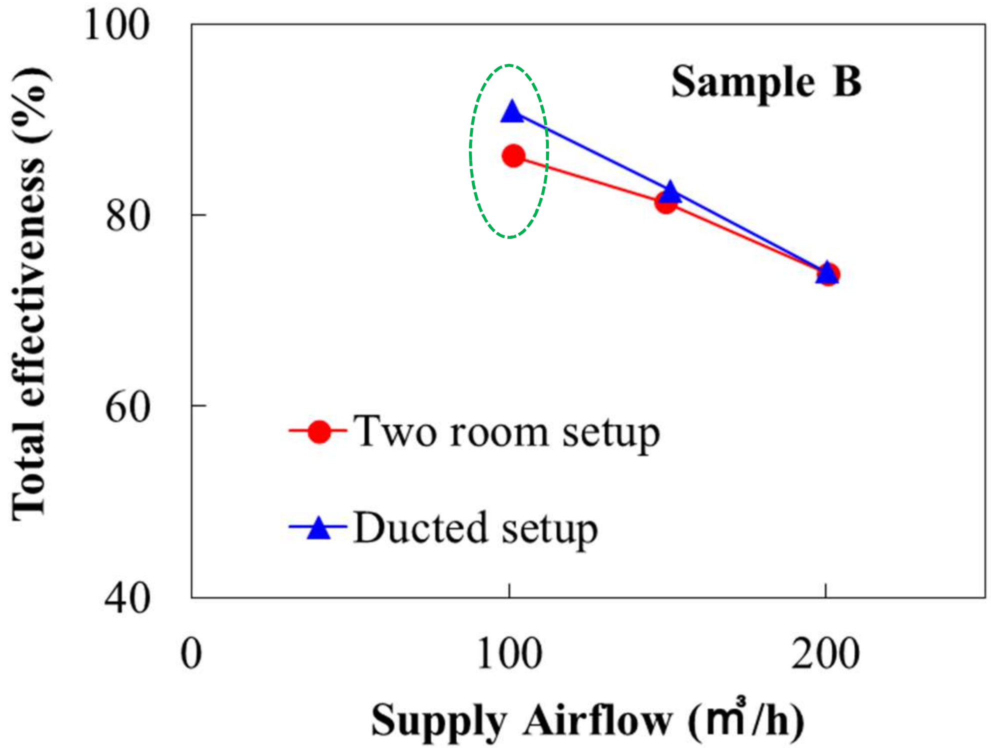
	Supply airflow rate	Return airflow rate	Airflow ratio	Total effecteveness
	m^3/h	m^3/h	-	%
Two room setup	199.5	212.4	0.94	83.9
	300.6	321.6	0.93	76.0
	403.0	412.3	0.98	71.1
	504.2	504.3	1.00	66.7
Ducted setup	202.1	203.9	0.99	83.5
	301.0	317.8	0.95	76.1
	405.2	407.3	1.00	70.3
	507.2	498.1	1.02	65.8

Sample A had relatively good air leakage performance, and there was no significant difference between the Two room setup and Ducted setup. The airflow ratio is approximately 1.0.

This result shows, if the airflow rate is small, the total effectiveness will be higher. At the supply airflow rate of 200m^3/h, the total effectiveness is about 84%. At the supply airflow rate of 500m^3/h, the total effectiveness is about 65%.

2. Test results and discussion (Sample B)

Influence of airflow rate



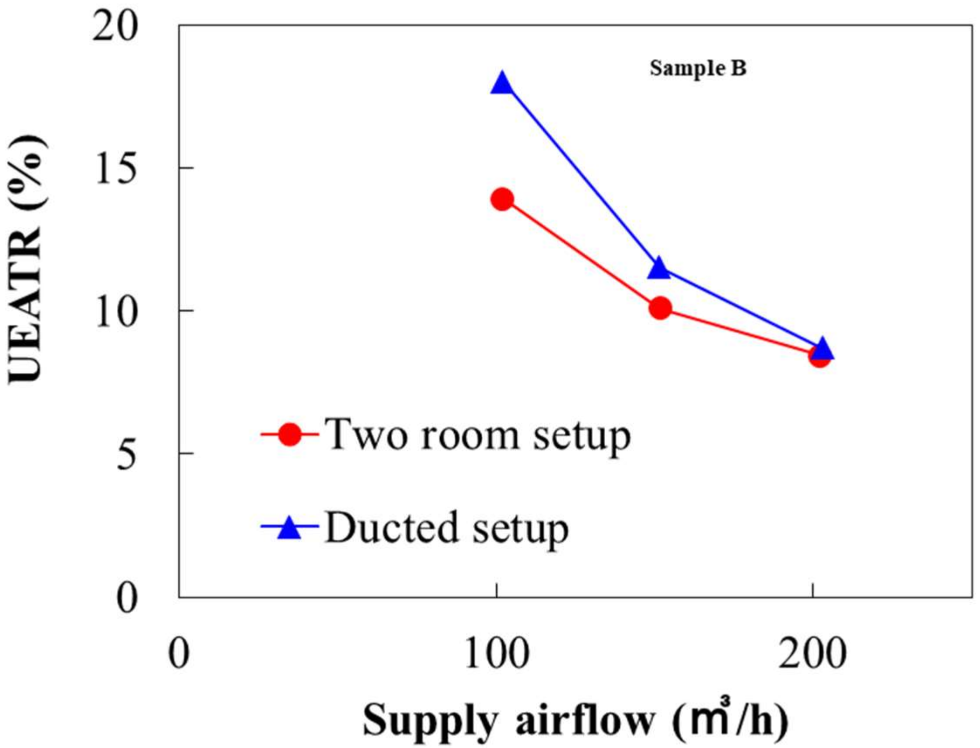
	Supply airflow rate	Return airflow rate	Airflow ratio	Total effecteveness
	m^3/h	m^3/h	-	%
Two room setup	101.3	108.3	0.94	86.2
	149.8	162.1	0.92	81.3
	200.6	207.2	0.97	73.8
Ducted setup	101.1	130.0	0.78	90.9
	151.1	170.1	0.89	82.6
	200.2	207.5	0.96	74.1

This is test result of Sample B.
Same with A, if the airflow rate is small, the total effectiveness will be higher.
But at the airflow rate about 100m^3/h, the total effectiveness is different between Two room setup and Ducted setup. This is due to the difference in the airflow ratio. Airflow ratio of two room setup is 0.94, compare to this the airflow ratio of ducted setup is 0.78. In the ducted setup, the return airflow rate lager than the supply airflow rate. We suppose another reason to cause such results is the difference in air leakage.

$$\text{Airflow ratio} = \frac{\text{Supply airflow rate}}{\text{Return airflow rate}}$$

2. Test results and discussion

Trace gas test result (Sample B)



	Supply airflow rate	Return airflow rate	Airflow ratio	UEATR
	m^3/h	m^3/h	-	%
Two room setup	102.0	119.0	0.86	13.9
	151.7	165.5	0.92	10.1
	202.2	211.0	0.96	8.4
Ducted setup	102.1	129.8	0.79	18.0
	151.6	172.5	0.88	11.5
	203.0	210.7	0.96	8.7

This is trace gas test result of Sample B.
At the airflow rate about 100m^3/h, the UEATR of Ducted setup is 18.0%, larger than UEATR of Two room setup (13.9%).
The reason of causing this difference is when the airflow rate small (the static pressure is large), the air leakage rate of each part of the energy recovery ventilator is different.
Similarly, it causes the difference of airflow ratio.

3.Correction formula and verification of accuracy

In order to properly evaluate the energy saving effect of energy recovery ventilator installed in a building for ventilation system design, the correction formula for total effectiveness of energy recovery ventilator was reviewed and proposed.

The total effectiveness values of energy recovery ventilator In the catalog were corrected by airflow rate, airflow ratio, and NSAR (NSAR =100-UEATR).

3.Correction formula and verification of accuracy

$$\eta_t' = \eta_t \times C_{tol} \times C_{eff} \times C_{bal}$$

η_t' : $is\ the\ corrected\ total\ effectiveness$ [%]

η_t : $is\ the\ total\ effectiveness\ listed\ in\ the\ catalog$ [%]

C_{tol} : $is\ the\ correction\ coefficent\ considering\ the\ total\ effectiveness\ tolerance\ listed\ in\ the\ catalog$ [−]. The default value is 0.95.

C_{eff} : $is\ the\ correction\ coefficent\ considering\ the\ net\ supply\ air\ flow\ ratio(NSAR)$ [

$\mathrm{NSAR} = 100 - \mathrm{UEATR}$

C_{bal} : $is\ the\ corrected\ coefficent\ due\ to\ the\ airflow\ ratio$ [−].

3.Correction formula and verification of accuracy

$$C_{eff} = 1 - \frac{\left(\frac{1}{\varphi} - 1\right)(1 - \eta_t)}{\eta_t}$$

C_{eff} : *is the corrected coefficent considering the net supply air flow ratio(NSAR*

$\mathrm{NSAR} = 100 - \mathrm{UEATR}$

η_t : *is the total effectiveness listed in the catalog* [%]

φ: *is the net supply airflow ratio* (*NSAR*) [%].

3.Correction formula and verification of accuracy

$$C_{bal} = \frac{\eta_{t,d}}{\eta_t}$$

C_{bal} : $is\ the\ corrected\ coefficent\ due\ to\ the\ airflor\ ratio$ $[-]$.

$\eta_{t,d}$: $is\ the\ corrected\ total\ effectiveness\ considering\ the\ airflow\ ratio$ $in\ the\ building$ $[\%]$

η_t : $is\ the\ total\ effectiveness\ listed\ in\ the\ catalogue$ $[\%]$

3.Correction formula and verification of accuracy

$$\eta_{\mathrm{t},d} = 1 - e^{\left[\frac{e^{\left(-N_d{}^{0.78} \cdot R_{vnt,d}\right)} - 1}{N_d{}^{-0.22} \cdot R_{vnt,d}}\right]}$$

$$R_{vnt} = \begin{cases} \dfrac{V_{d,SA}}{V_{d,RA}} & \left(V_{d,RA} > V_{d,SA}\right) \\ \dfrac{V_{d,RA}}{V_{d,SA}} & \left(V_{d,RA} \leq V_{d,SA}\right) \end{cases}$$

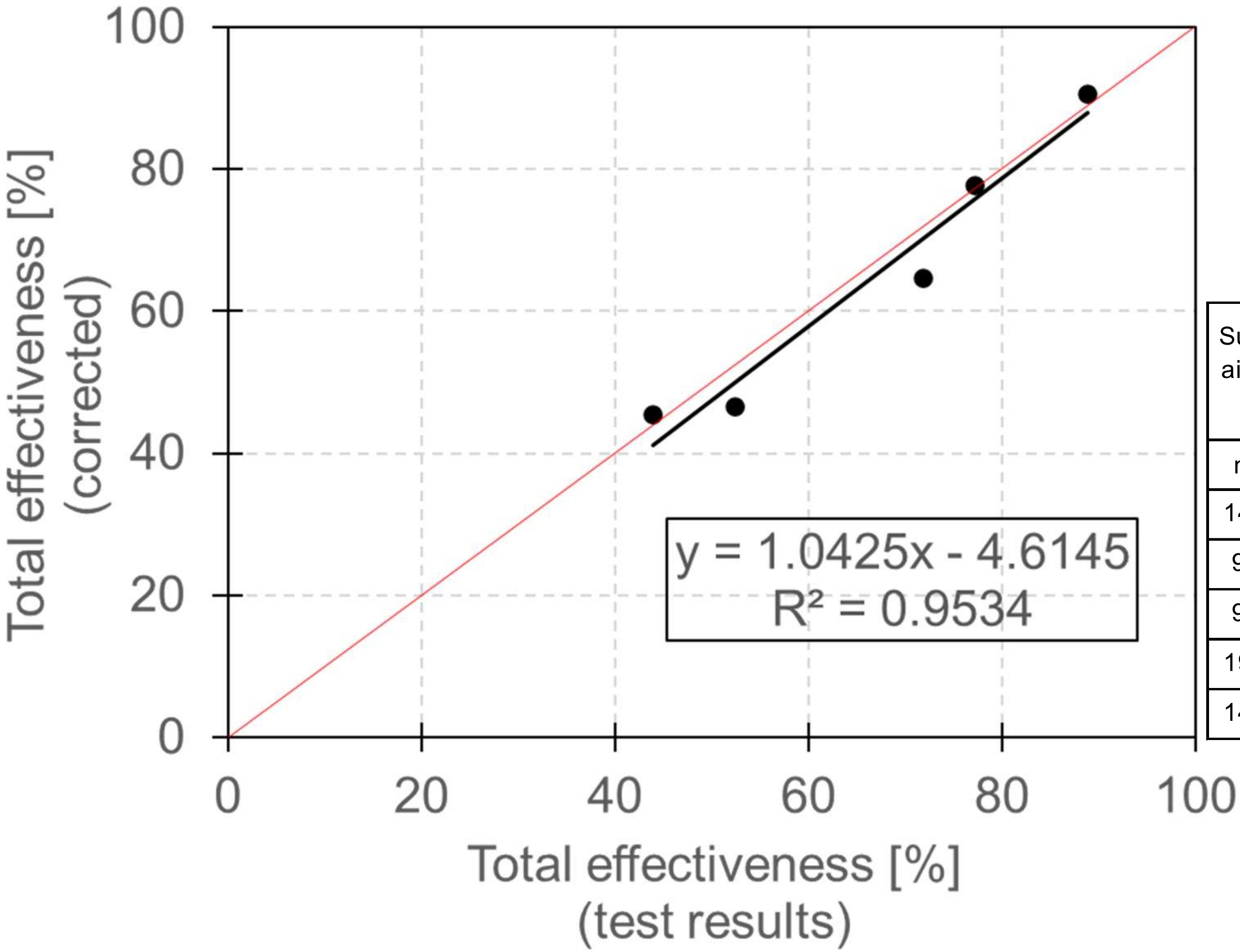
$\eta_{t,d}$: *is the corrected total effectiveness considering the airflow ratio in the building design* [%]

$V_{d,SA}$: *is the supply airflow rate in the building design* $[m^3/h]$

$V_{d,\mathrm{RA}}$: *is the return airflow rate in the building design* $[m^3/h]$

N_d : *is the heat transfer unit number in the energy recovery ventilator* $[-]$

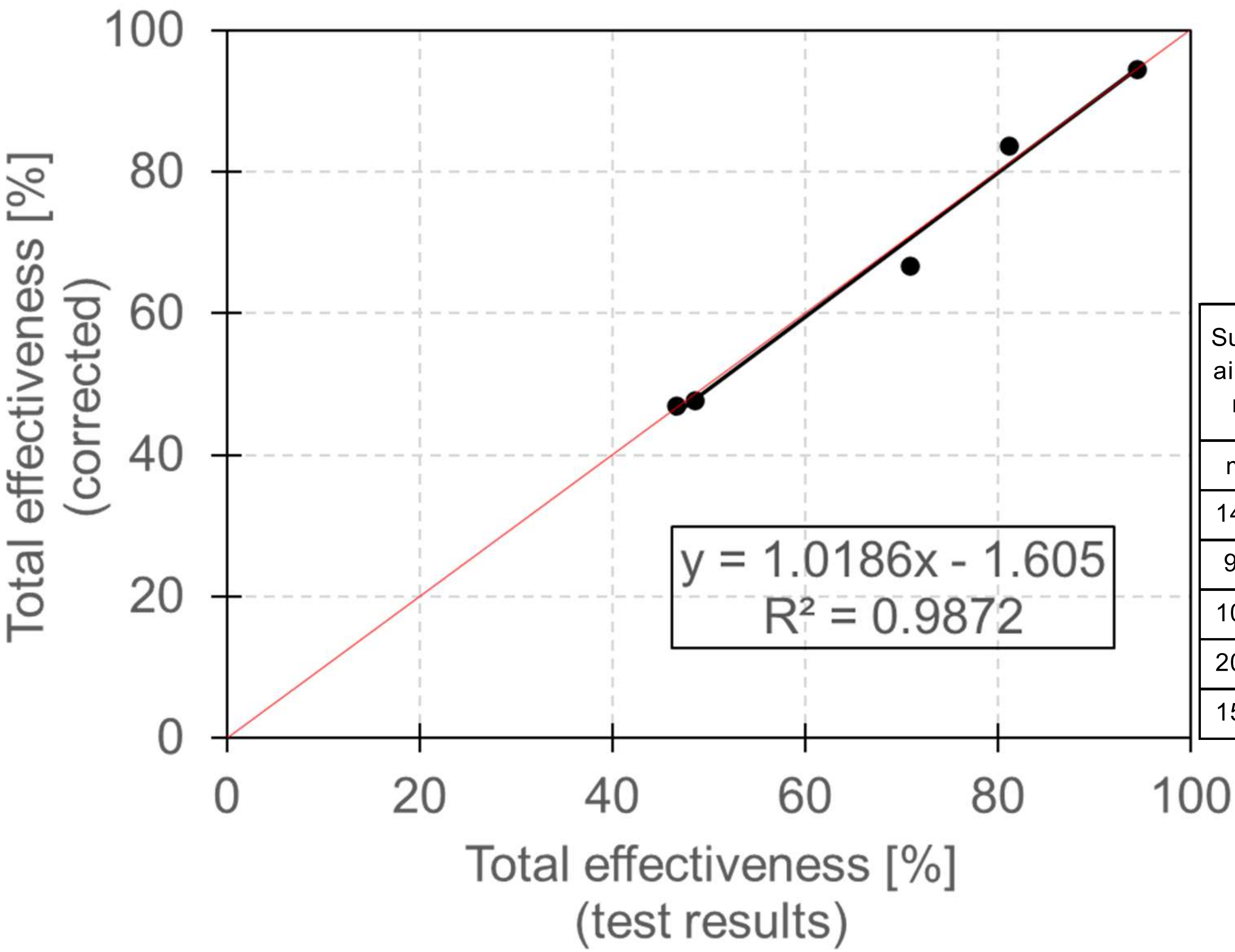
3.Correction formula and verification of accuracy



Supply airflow rate	Return airflow rate	NSAR	Airflow ratio	Total effectivenees (corrected)	Total effectiveness (test results)
m^3/h	m^3/h	%	-	%	%
147.7	197.6	88.0	0.75	77.1	77.7
99.7	198.6	82.3	0.50	88.8	90.6
98.7	74.5	83.3	1.32	71.8	64.7
197.1	99.0	90.9	1.99	43.9	45.5
147.4	73.4	88.2	2.01	52.4	46.6

Comparison of test results and corrected total effectiveness (Cooling condition)

3.Correction formula and verification of accuracy



Supply airflow rate	Return airflow rate	NSAR	Airflow ratio	Total effectivenees (corrected)	Total effectiveness (test results)
m^3/h	m^3/h	%	-	%	%
149.9	200.5	88.0	0.75	81.2	83.7
99.9	199.6	82.3	0.50	94.4	94.6
101.1	75.6	83.3	1.34	70.8	66.7
201.6	100.2	90.9	2.01	46.6	47.1
150.3	74.8	88.2	2.01	48.5	47.8

Comparison of test results corrected total effectiveness (Heating condition)

4. Energy saving performance in HVAC system

In Japan, there are calculation programs to estimate energy consumption performance at the design stage. The program runs on the website and is available through the website of Building Research Institute.

Energy Consumption Performance Calculation Program
https://building.lowenergy.jp/

Until 2023, the total effectiveness of energy recovery ventilator for non-residential buildings was calculated <u>using fixed values</u> for "Airflow rate" and "NSAR";
from 2024, the calculation method was changed to use the correction formula for total effectiveness of energy recovery ventilator.

As described in this presentation, we examined the energy saving performance of energy recovery ventilator when the total effectiveness is calculated by correction coefficient proposed.

4. Energy saving performance in HVAC system

Comparison of old and new calculation methods

	Airflow ratio	NSAR
Present calculation method	0.50	0.85
New calculation method (using correction formular)	Variable	Variable

Case study

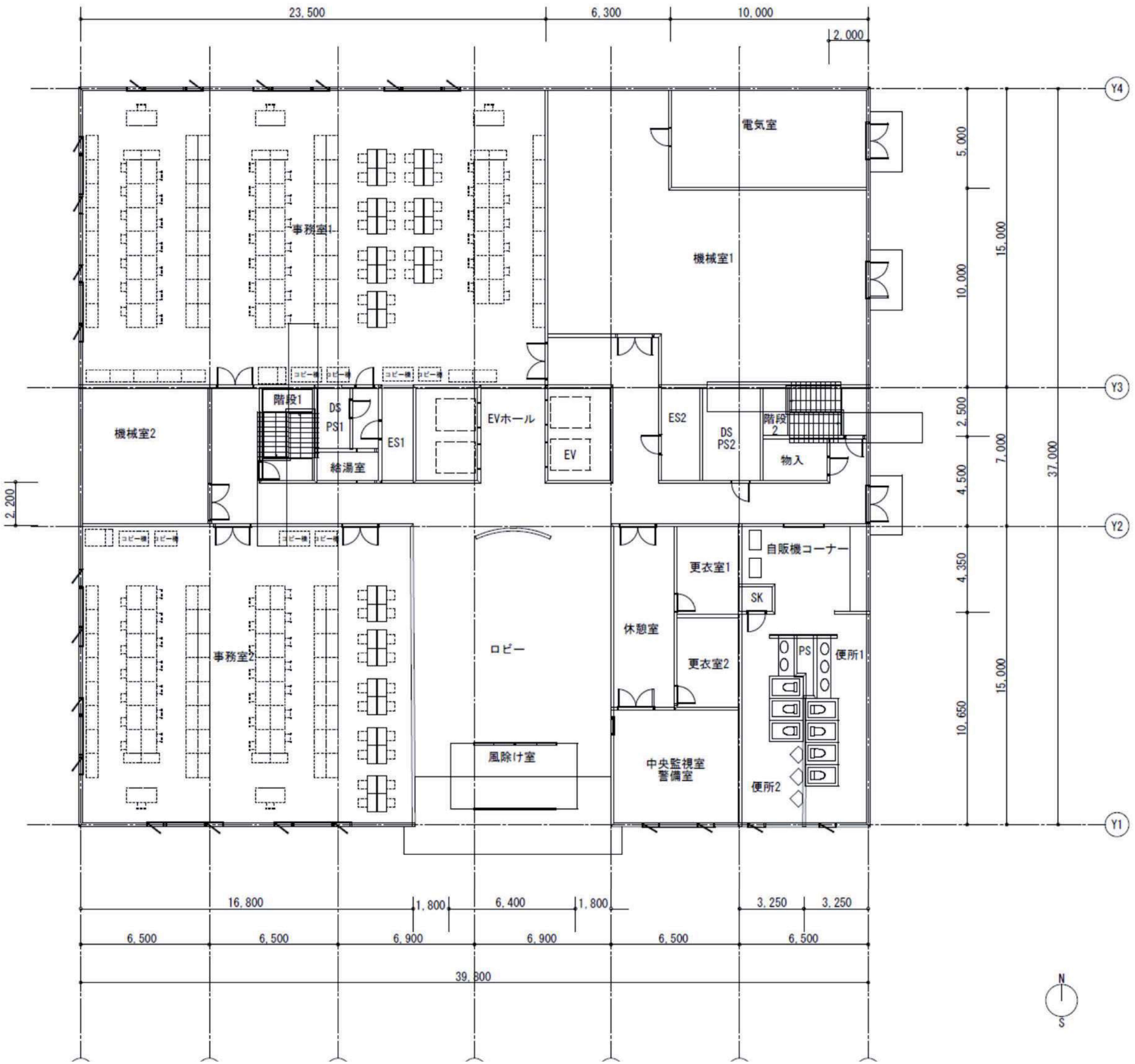
	Package air conditioner + Energy recovery ventilator
Present calculation method	Case A
New calculation method (using correction fomular)	Case A'

4. Energy saving performance in HVAC system

Building outline

Building location	Tokyo
Number of floors	7
Building use	office
Building strcture	steel reinforced concrete construction
Total floor area	10,358.3 m^2

4. Energy saving performance in HVAC system

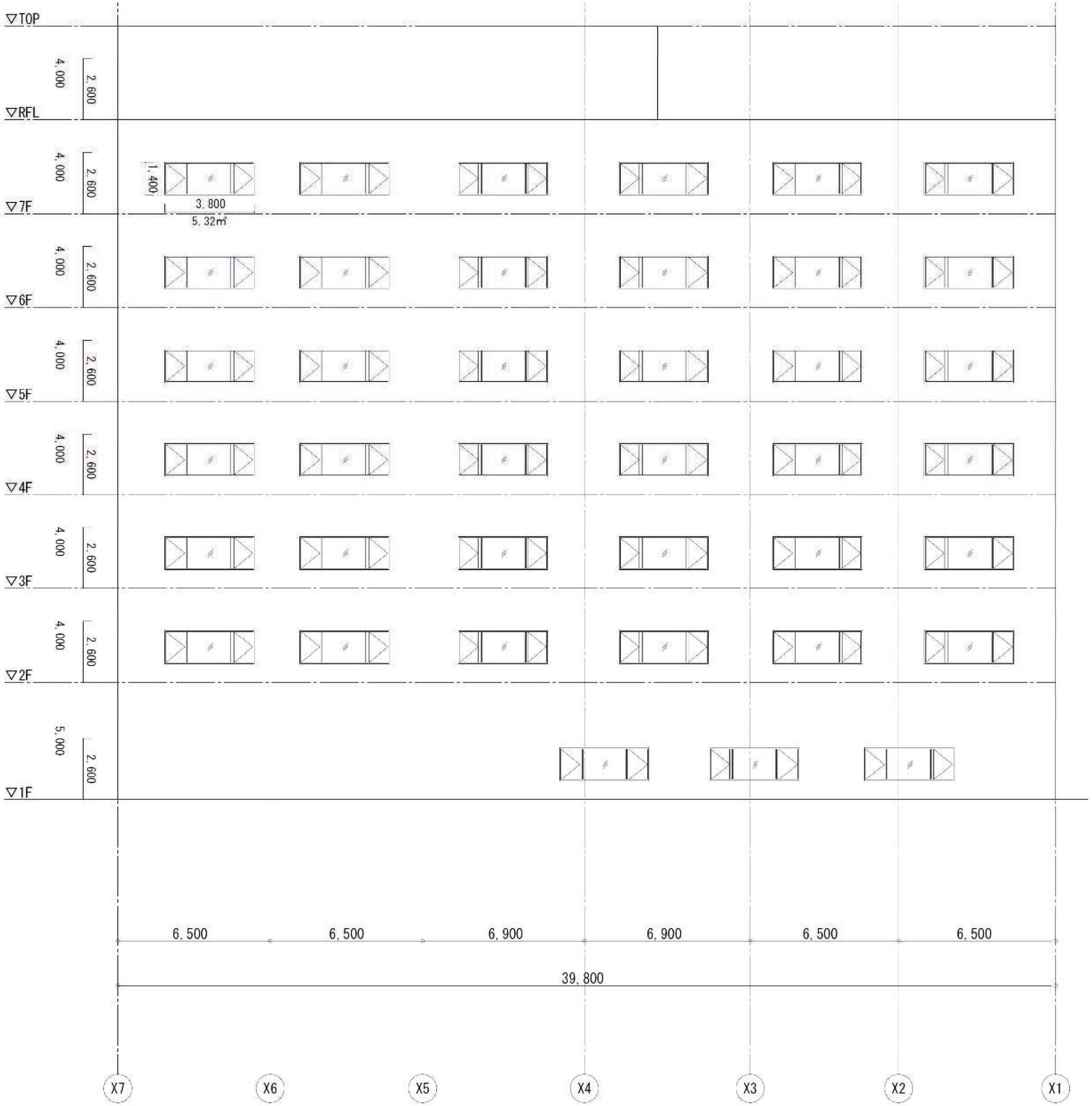


1st floor plan

4. Energy saving performance in HVAC system

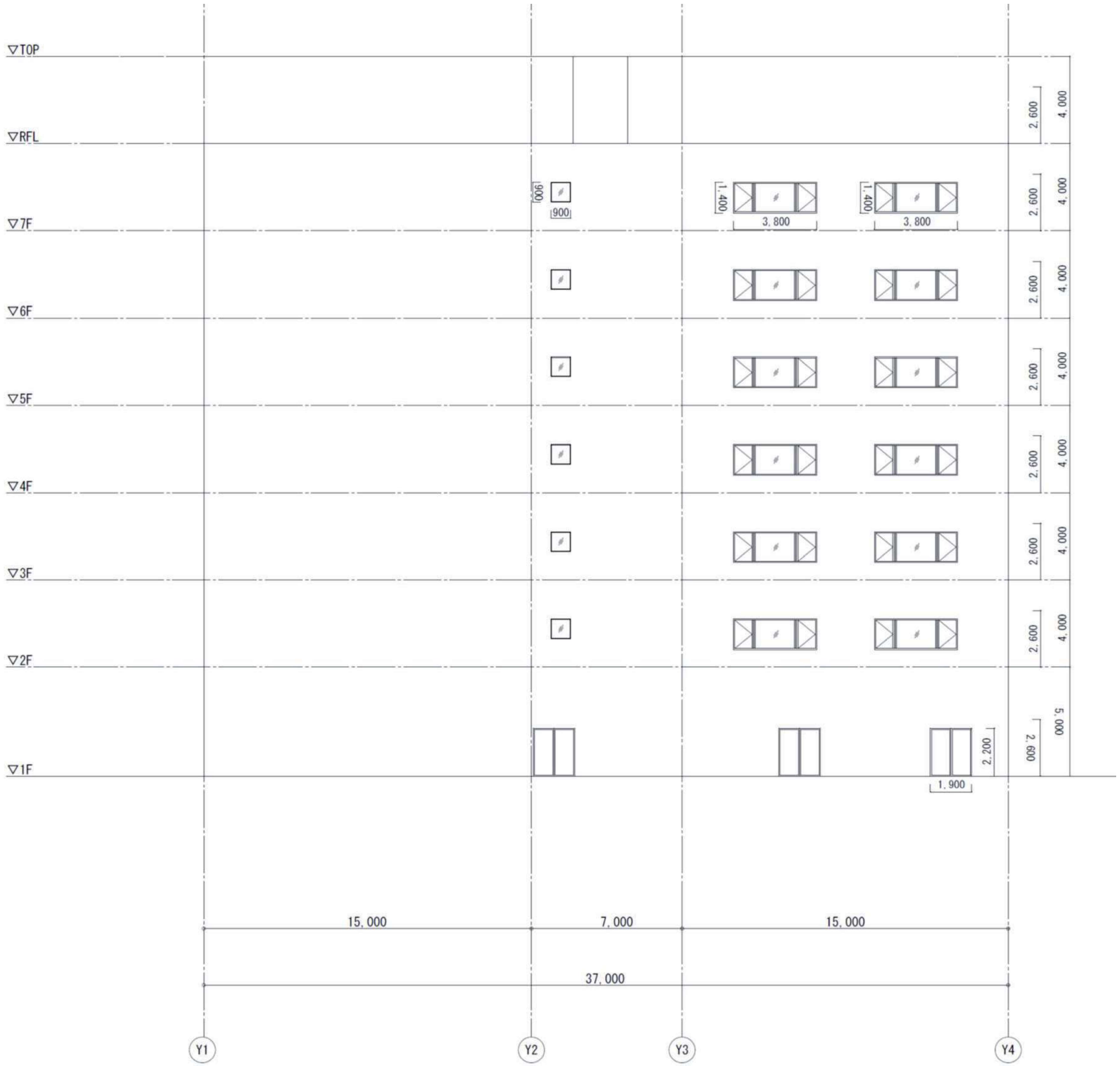
2nd to 7th floor plan

4. Energy saving performance in HVAC system



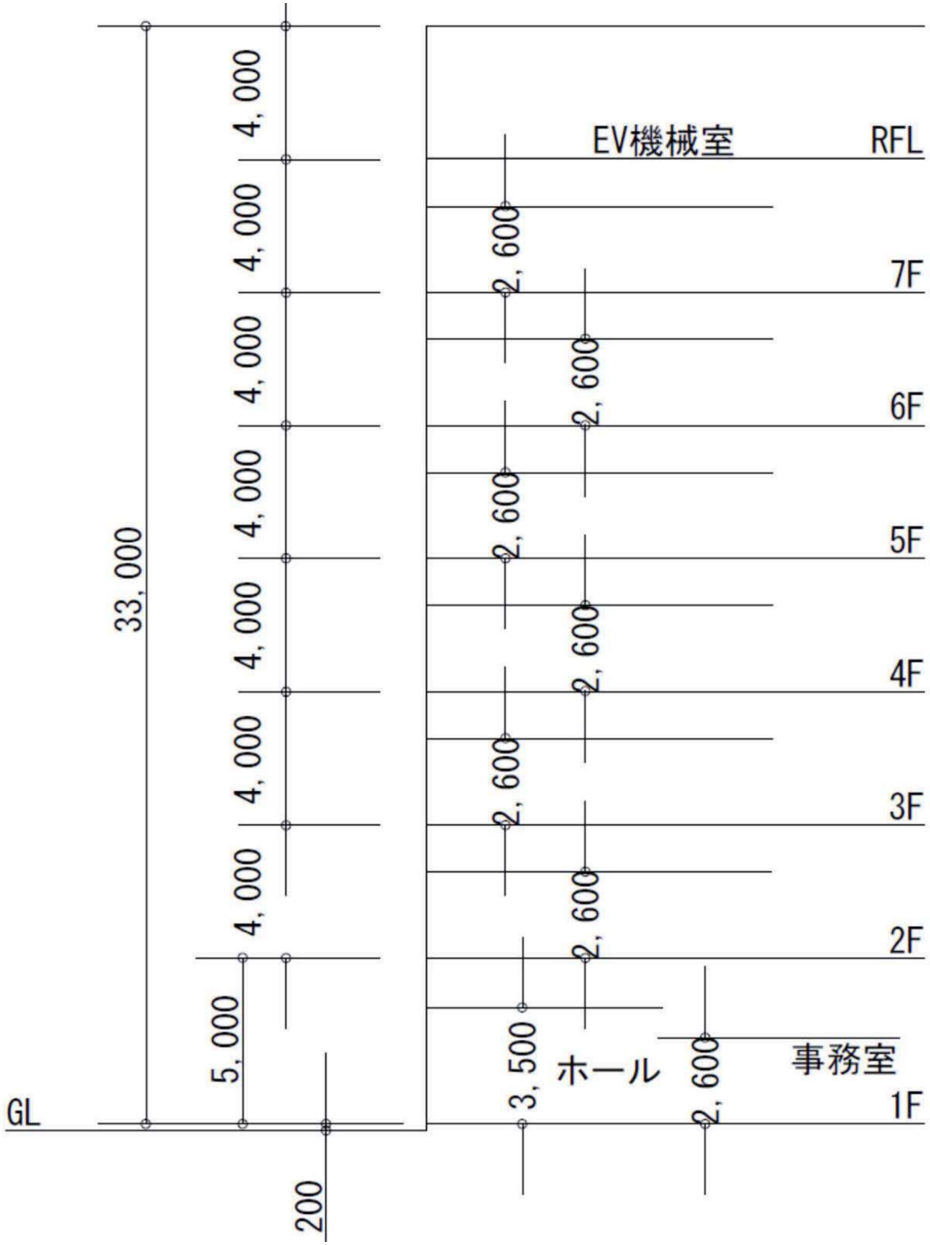
North side elevation

4. Energy saving performance in HVAC system



East side elevation

4. Energy saving performance in HVAC system



RF	63.5㎡
7F	1,472.60㎡
6F	1,472.60㎡
5F	1,472.60㎡
4F	1,472.60㎡
3F	1,472.60㎡
2F	1,472.60㎡
1F	1,459.16㎡
延べ床面積	10,358.26㎡

Cross section and floor space

4. Energy saving performance in HVAC system

Building skin insulation performance

	Thermal convection rate W/m^2K
Outer wall	0.59
Rooftop	0.32
Ground floor	0.80
Window	1.60

4. Energy saving performance in HVAC system

Dry and wet bulb temperature conditions

	Summer		Winter	
	Dry-bulb (°C)	Relative humidity (%)	Dry-bulb (°C)	Relative humidity (%)
Outside air condition	34.7	53.5	1.8	40.1
Office room air condition	26.0	50.0	22.0	40.0

4. Energy saving performance in HVAC system

Internal heat gains

	Lighting (W/m^2)	Office equipment (W/m^2)	Large office equipment (W)	People	Heat gain / Person (W/Person)	
					SHG	LHG
Office room 1	34.7	18.8	53.5	120	1.7	40.1
Office room 2	26.0	10.5	50.0	100	6.6	40.0

4. Energy saving performance in HVAC system

Air conditioning performance (Case A, Case A')

	Heating capacity (kW/m^2)	Cooling capacity (kW/m^2)	COP (Heating condition)	COP (Cooling condition)
Package air conditioner	0.118	0.133	3.39	2.96

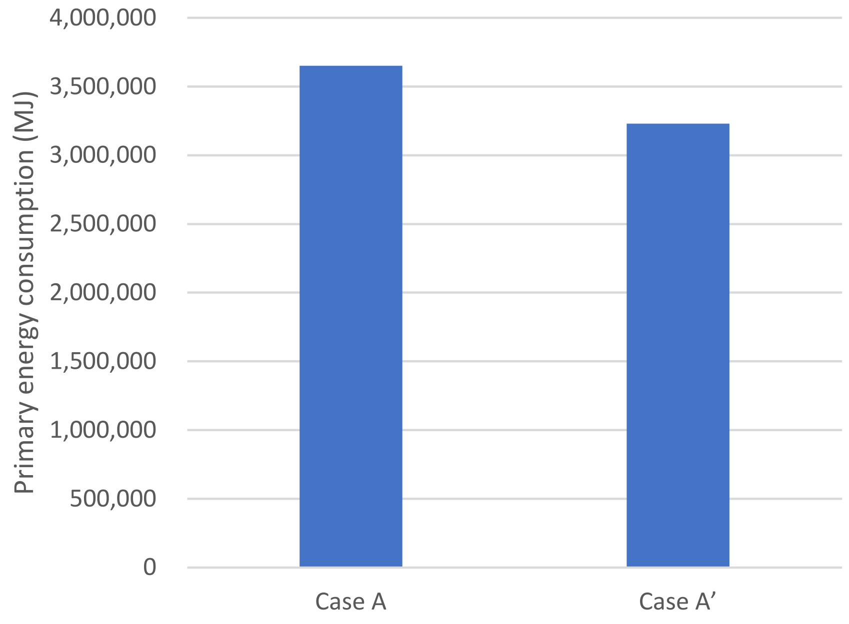
Performance values of Energy recovery ventilators (Case A, Case A')

	Total effectiveness (%)	NSAR (%)	Ratio of supply airflow rate to return airflow rate	Specific fan power
Eenergy recovery ventilator	70	92	1.25	0.51

4. Energy saving performance in HVAC system

Case	Primary energy consumption of the entire air conditioning system (MJ)
Case A	3,650,298
Case A′	3,228,859

Reduction (MJ)	421,439
Reduction rate	11.5%

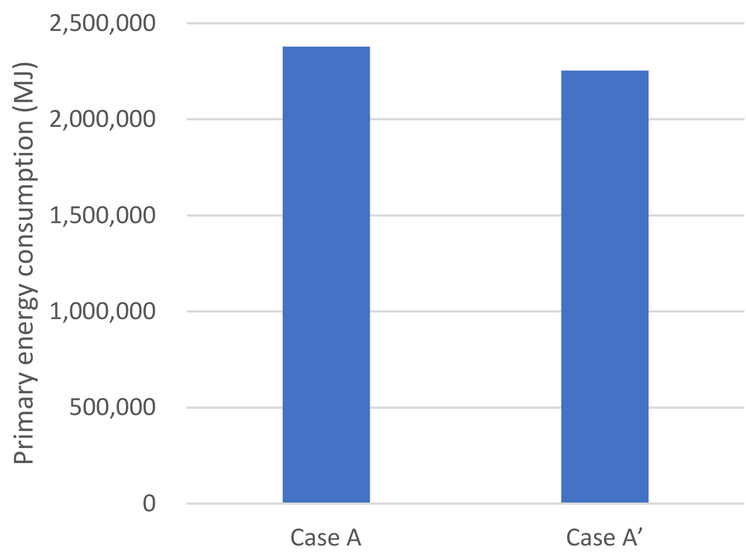


Comparison of Case A and Case A’

4. Energy saving performance in HVAC system

Case	Primary energy consumption of the entire air conditioning system (MJ)
Case A	2,378,448
Case A’	2,254,092

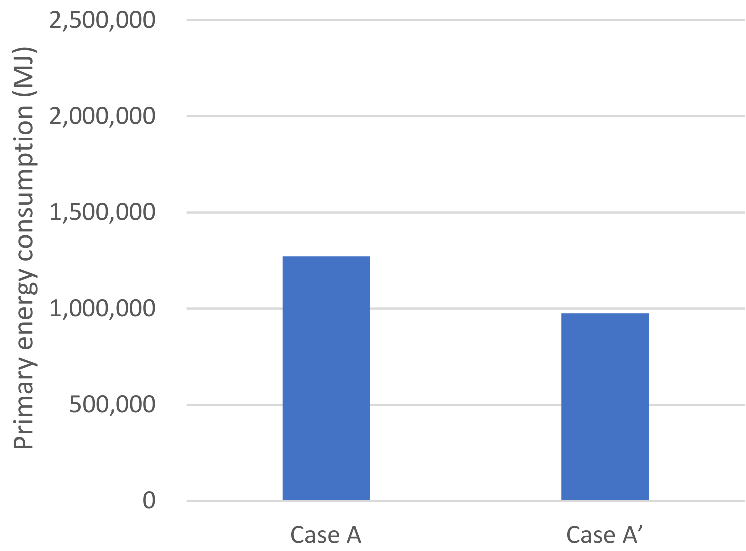
Reduction (MJ)	124,356
Reduction rate	5.2%



Comparison of Case A and Case A’ (Cooling condition)

Case	Primary energy consumption of the entire air conditioning system (MJ)
Case A	1,271,850
Case A’	974,768

Reduction (MJ)	297,082
Reduction rate	23.4%



Comparison of Case A and Case A’ (Heating condition)

5. Conclusions

1.Total effectiveness depends on the airflow, the airflow ratio, and the UEATR. And UEATR depends on the static pressure differential across the ventilators.

2.The total effectiveness of energy recovery ventilator operating in the building often differs from the total effectiveness in the energy recovery ventilator catalogs.

3. In order to properly evaluate the energy saving effect of energy recovery ventilator installed in a building for ventilation system design, it is necessary to correct the total effectiveness of energy recovery ventilator in the catalogs.

4.We proposed a correction formula that corrects the total effectiveness of energy recovery ventilator in the catalogs according to the airflow rate, airflow ratio, and NSAR. And using the correction formula was examined the energy saving performance of energy recovery ventilator in an office building.

5.The total effectiveness of energy recovery ventilator in the catalogs are also useful for product comparisons.