Development of an onsite performance evaluation method for variable refrigerant flow systems and approach to energy conservation

Master's thesis

DEVELOPMENT OF AN ONSITE PERFORMANCE EVALUATION METHOD FOR VARIABLE REFRIGERANT FLOW SYSTEMS AND APPROACH TO ENERGY CONSERVATION

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Master's Course of Marine System Engineering

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Contents

1 Introduction

1.1 Background of the study

Greenhouse gas emissions reached 49 billion tons in 2010 according to the IPCC Fifth Assessment Report(1) and the emissions from the building sector exceeded 19%. Specifically, energy consumption from air conditioning systems is an important issue and its reduction potential is quite considerable as shown in Figure 1.1-1.

Variable refrigerant flow (VRF) systems have gradually expanded their market share over the past several decades as shown in Figure 1.1-2 according to The Japan Refrigeration and Air Conditioning Industry Association(2). The systems have been installed not only in small-sized buildings but also in large-sized buildings instead of central air conditioning systems because of their high energy efficiency, flexible design, easy installation and low initial costs(3)(4). As refrigerants directly exchange heat with the ambient air in the systems(5), it is generally difficult to evaluate their performance accurately. Also, because it requires a large-scale environmental test chamber to examine, it is impossible for users to evaluate the performance of the systems. Also, it is an issue that installed capacities are designed excessively for avoiding complaints and unnecessary operations are being carried out.

Bruce D. Hunn et al. state that, "Although many buildings in the U.S., Canada, U.K., and elsewhere claim to be "green," "low energy," or "high performance," it is rarely clear on what evidence or data these claims are based. Such claims cannot be credible without standardized performance measurement protocols that are applied consistently. If claims of superior building performance are to be believed, it is essential that a common set of measurements be used and the results reported against meaningful benchmarks. Such protocols are also needed to give usable feedback to building designers and operators when measured performance does not match design intent"(6).

Therefore, it is important to obtain actual operating data for understanding the precise performance of VRF systems and encourage users to take action for energy-saving to be "green".

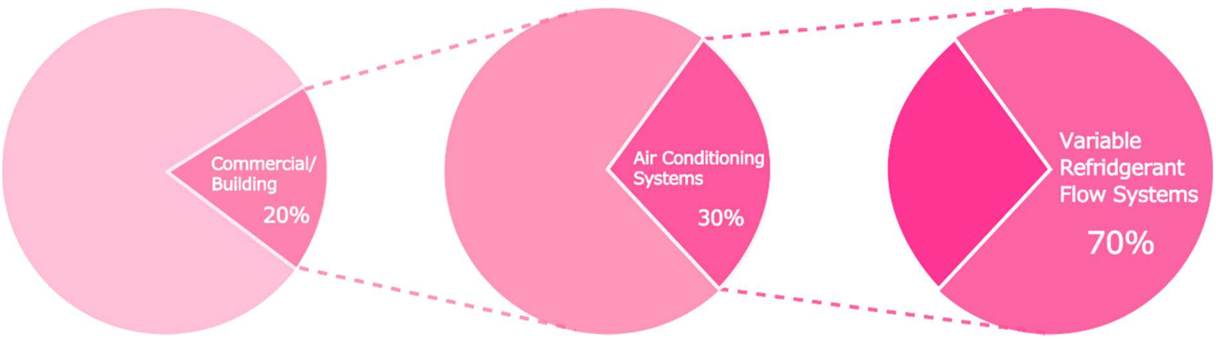

Figure 1.1-1 Percentage of energy consumption

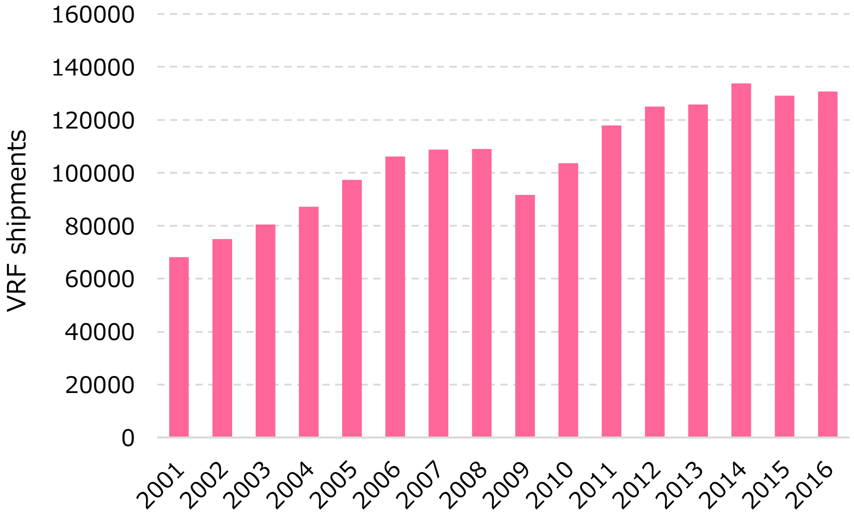

Figure 1.1-2 VRF shipments

1.2 Outline of the study

In the present study, we built an onsite performance evaluation method that reveals the operational performance of VRF systems. We succeeded in calculating the performance in real-time and with high accuracy within 10% on a low-cost and high-performance microcomputer board and sending data to the cloud server via the Internet. We installed this system nationwide in various buildings with different uses and weather conditions, performed measurements and analysed obtained data. As a result, actual conditions including unnecessary operations and performance degradation causes were clarified. We also examined an information providing method. Advice and messages based on the Nudge theory are sent to mobile devices and computers of users after data analysis to suggest better operational methods. Finally, an automatic control operation was carried out for energy-saving control operations and estimation of CO_2 reduction amount. According to the estimation, the reduction will be over 1 million tons by 2030 and the spread of this method will lead to energy conservation in the building sector.

The present study was carried out under the title of "Low Carbon Technology Research and Development Energy Program" with the support of the Ministry of the Environment.

1.3 Importance of the present study

This paper discusses the accuracy improvement of the performance evaluation method, the development of the onsite performance evaluation system and the actual conditions of operations, and the thermal comfort evaluation on energy-saving controls of VRF systems. Previous studies are clarified as follows to present the importance of the present study.

Takahashi et al.(7) and Wakahara(8) proposed the Compressor Curve method (hereafter referred to as CC method) as a performance evaluation method for VRF systems. The CC method is an approach of calculating the refrigerant flow rate and the air conditioning capacity using regression equations using physical properties of refrigerants of compressors. They claimed that the performance could be evaluated within an error of 15% under actual operations. However, as compressor characteristics are not available to the public, a volumetric efficiency value which is one of the physical properties of compressors has been fixed. Nobe et al.(9)(10) proposed a probe insertion method which performance evaluation was carried out by inserting a temperature probe into outdoor unit heat exchangers and measuring the amount of heat exchange. As a result, the error of performance evaluation was 19% which is relatively large.

Daikin Industries, Ltd. supplies a preventive maintenance service by remote monitoring(11). The service includes the collection and analysis of air conditioning operation data. When deterioration and abnormalities are detected, users will be informed. However, it is limited to air conditioners made by Daikin.

In recent years, papers related to operation controls aiming at high efficiency and energy-saving of air conditioners have come to be noticeable. Sawamura et al.(12) confirmed the reduction of gas consumption by energy-saving controls. In addition, they installed temperature and humidity meters inside the room to compare indoor environments with energy-saving controls. They confirmed the improvement of indoor environment, however, they didn’t carry out a thermal comfort survey. Sekine(13) conducted a thermal comfort survey of office workers but did not consider the evaluation with the Predicted Mean Vote (hereafter referred to as PMV) or the analysis with wind speed.

In the present study, we obtained volumetric efficiency values using an environmental test unit and examined the accuracy improvement of the CC method compared with the conventionally fixed value. Also, we have developed a performance evaluation system capable of revealing performance information of VRF systems, which has been difficult conventionally. The system calculates in real time and with high accuracy on a microcomputer board via the Internet. With this system, users and building designers will be informed actual operations including energy consumption due to differences in operation methods and installed capacities, and be encouraged to save energy. Furthermore, we estimated the effect of CO_2 reduction amount when spreading this system. Finally, we conducted a thermal comfort survey during the energy-saving operation controls, with the PMV and wind speeds evaluations.

1.4 Organization of the study

This paper consists of 6 chapters. Chapter 1 describes the current state and various problems of VRF systems, the background and the purpose of the study. And then it discusses comparison with relevant previous studies and clarifies the position of the present study. Chapter 2 gives an outline of the performance evaluation method of VRF systems and results of accuracy verification of volumetric efficiency values. Chapter 3 explains the development of an onsite performance evaluation system and proposes information providing methods. Chapter 4 presents analysis results of the field data and discusses approaching methods to users. Chapter 5 points out a verification of the CO_2 reduction effect by this system when automatic operation controls are applied and describes results of thermal comfort survey. Chapter 6 discusses a summary of each chapter and future topics.

2 Performance evaluation method for VRF systems

2.1 Compressor Curve method

The CC method is a practical approach to calculate the capacity by multiplying the refrigerant mass flow of compressors by the specific enthalpy difference of indoor units. VRF systems typically employ scroll and rotary compressors. These compressors have their own refrigerant mass flow and energy consumption characteristics. For this reason, we focused on the refrigerant mass flow for performance evaluation.

The capacity calculation is shown in (1). Q indicates the actual thermal output and G_{comp} is the refrigerant mass flow. Delta h is the specific enthalpy difference between the inlet-air and outlet-air of the indoor unit as shown in Figure 2.1-1 in the pressure-enthalpy chart. Delta *he* is used for cooling and *hc* for heating.

$$Q = G_{comp} \times \Delta h \qquad (1)$$

Q : Thermal output
G_{comp} : Refrigerant mass flow
Δh : Specific enthalpy difference

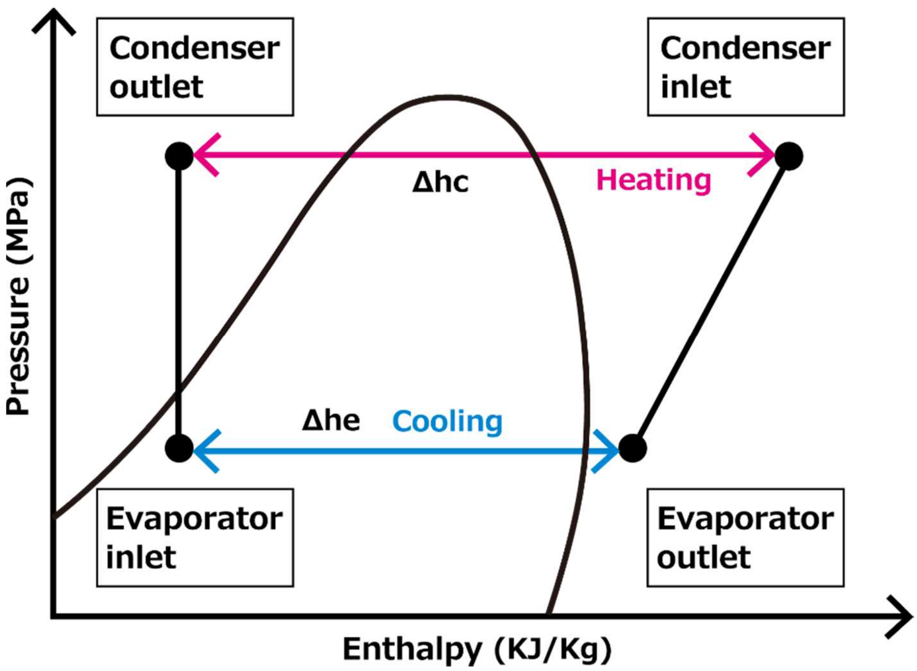

Figure 2.1-1 Pressure-enthalpy chart

It is necessary to measure temperature and pressure of refrigerant for inlet and outlet parts of the indoor unit and to also subtract the inlet enthalpy value from the outlet enthalpy value to obtain the enthalpy difference values. The equation is shown in (2). Technically speaking, it is necessary to consider the dryness fraction when the refrigerant is in the two-phase condition during the heating operation. However, we concluded that excluding the fraction would not affect the result because it was extremely small in this experiment.

$$\Delta h = h_{out} - h_{in} \tag{2}$$

The refrigerant mass flow is calculated using physical properties as shown in (3). ρ is the compressor suction density obtained by the calculation of temperature and pressure, V is the compressor displacement which is a characteristic value, N is the compressor revolution measured by power frequency and η is the volumetric efficiency which is the only unknown parameter.

$$G_{comp} = \rho \times V \times N \times \eta \tag{3}$$

ρ : Compressor suction density
V : Compressor displacement
N : Compressor revolution
η : Volumetric efficiency

The calculation flow of this performance evaluation method is shown in Figure 2.1-2.

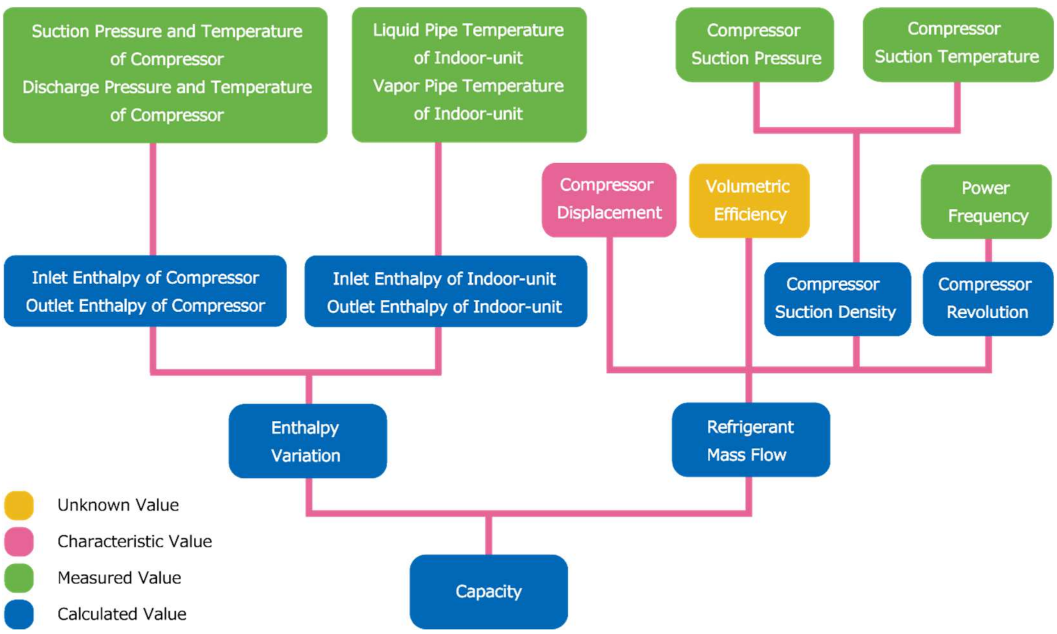

Figure 2.1-2 Calculation flow of the CC method

Volumetric efficiency plays a direct role when calculating refrigerant mass flow. It is calculated simply by the actual displacement volume and the theoretical displacement volume as shown in (4). The values, however, are not generally available to the public. Therefore, we employed (5) to estimate volumetric efficiency values.

$$\eta = \frac{V_{act}}{V_{the}} \quad (4)$$

$$\eta = \frac{G_{comp}}{\rho \times V \times N} \quad (5)$$

V_{act}: Actual displacement volume
V_{the}: Theoretical displacement volume

The suction refrigerant density and the refrigerant mass flow were obtained by the Air Enthalpy method (hereafter referred to as AE method). The compressor displacement is a characteristic value and the compressor revolution is a measured value. We employed data when the air conditioner was operated under different temperatures and load ratios to estimate volumetric efficiency values and to also calculate the average values. Regression equations in both cooling and heating operations were then acquired for more accurate performance evaluation.

2.2 Outline of measurements

2.2.1 Environmental test chamber

An environmental test unit was installed in the Tatsumi experimental center of the Kansai Electric Power Co., Inc. The diagram of the test unit is shown in Figure 2.2.1-1. Capacity was measured in the unit using the AE method. This method is highly regarded by the JIS Committee because of its accuracy: the error is less than 3 %. This test unit composes two rooms of outdoor-unit and indoor-unit rooms which can be set to any temperature and humidity conditions. Test conditions are shown in Table 2.2.1-1.

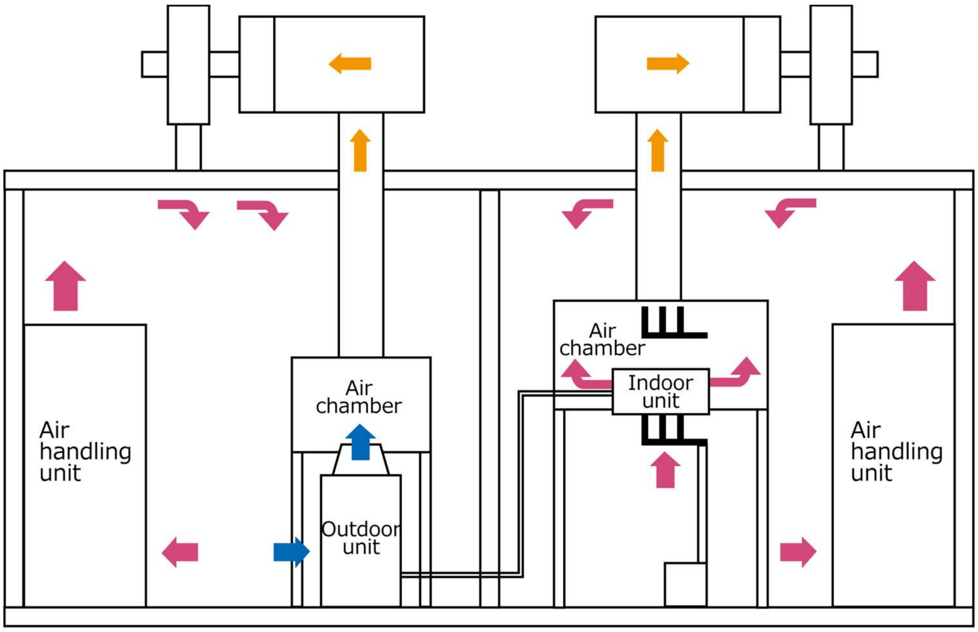

Figure 2.2.1-1 Diagram of the test unit

The air conditioner was set to various load ratios and was operated automatically in this experiment. The capacity was calculated by multiplying specific enthalpy difference of air by air volume in the AE method as shown in (6). In this method, all the outlet air is sucked into a duct which is attached to the indoor unit air chamber. Temperature, humidity and the air volume are then measured simultaneously. Accordingly, the enthalpy difference of refrigerant is calculated using temperature and pressure which are measured at the same time. The refrigerant mass flow was then calculated using (1). The physical properties were measured every five seconds and the tests were conducted when the capacity and power consumption were relatively stable.

$$Capacity(kW) = Specific\ enthalpy\ variation\ of\ air\ (kJ/kg) \times Air\ volume(kg/s) \qquad (6)$$

Table 2.2.1-1 Test conditions

	Indoor unit DB/WB（℃）	Outdoor unit DB/WB（℃）
Cooling	27/18	35/24
Heating	21/15	8/5

2.2.2 Specifications of the testing equipment

The electric driven heat pump (hereafter referred to as EHP) system consisting of 4 indoor and 1 outdoor units was employed. Measurement specifications are shown in Table 2.2.2-1. The total cooling capacity of indoor units is 28.4 kW while the heating capacity is 32.0 kW. Outdoor units expend 9.1 kWh of electricity to remove 28.0 kWh of heat for cooling rooms; while they expend 7.4 kWh of electricity to provide 28.0 kWh of heat for heating rooms. The equipment includes two rotary compressors and R-410A is used as the refrigerant. The test machine runs a special control to maintain lubricating oil in the process.

Table 2.2.2-1 Specifications of indoor and outdoor units

Designation		Specifications	
		Outdoor unit	Indoor unit
Electric source		Three phase 200V 50/60Hz	Single phase 200V 50/60Hz
Capacity	Cooling	28.0 kW	7.1 kW
	Heating		8.0 kW
Electric power consumption	Cooling	9.1 kW	0.05 kW
	Heating	7.4 kW	
Compressor	Type	Rotary compressor	
	Displacement	No.1,2: Same volume	
Refrigerant		R-410A	

2.3 Results

2.3.1 Volumetric efficiency values

Precise calculations of the volumetric efficiency are generally quite difficult because the exact estimation of internal leakage of compressors is not feasible. Additionally, the test machine runs a special control to maintain lubricating oil. As the accurate refrigerant mass flow values were calculated by the environment test unit in this study, we successfully estimated more precise volumetric efficiency values.

Figures 2.3.1-1 and 2.3.1-2 indicate volumetric efficiency values to load ratios in the cooling and heating operations. The regression equations are shown in (7) and (8). The coefficient of determination was 0.86 in both operations. The volumetric efficiency values decrease gradually in the low load range and increase in the high load range. The similar tendency was observed in the heating operation. Therefore, we determine that there is no issue in using the same equation in both operations. Consequently, the average volumetric efficiency values converged to 0.77 in the heating operation as well as in the cooling operation.

$$\eta = -0.0000138\, x^2 - 0.00263\, x + 0.672 \qquad (7)$$

(Cooling operation)

$$\eta = 0.0000772\, x^2 - 0.00973\, x + 1.034 \qquad (8)$$

(Heating operation)

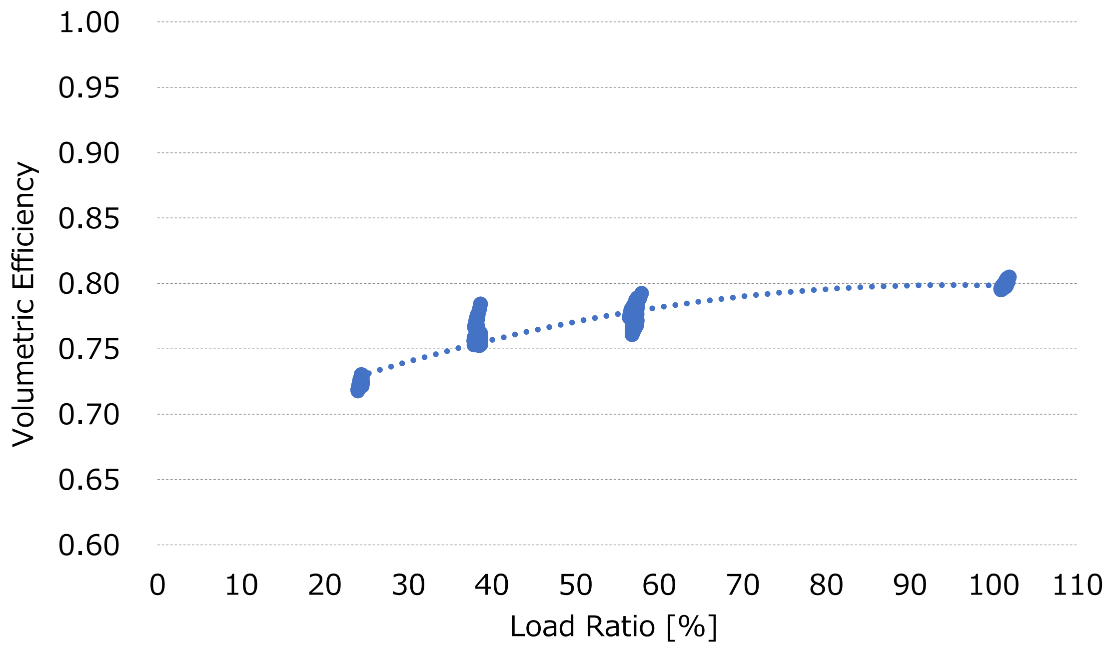

Figure 2.3.1-1 Volumetric efficiency in cooling operation

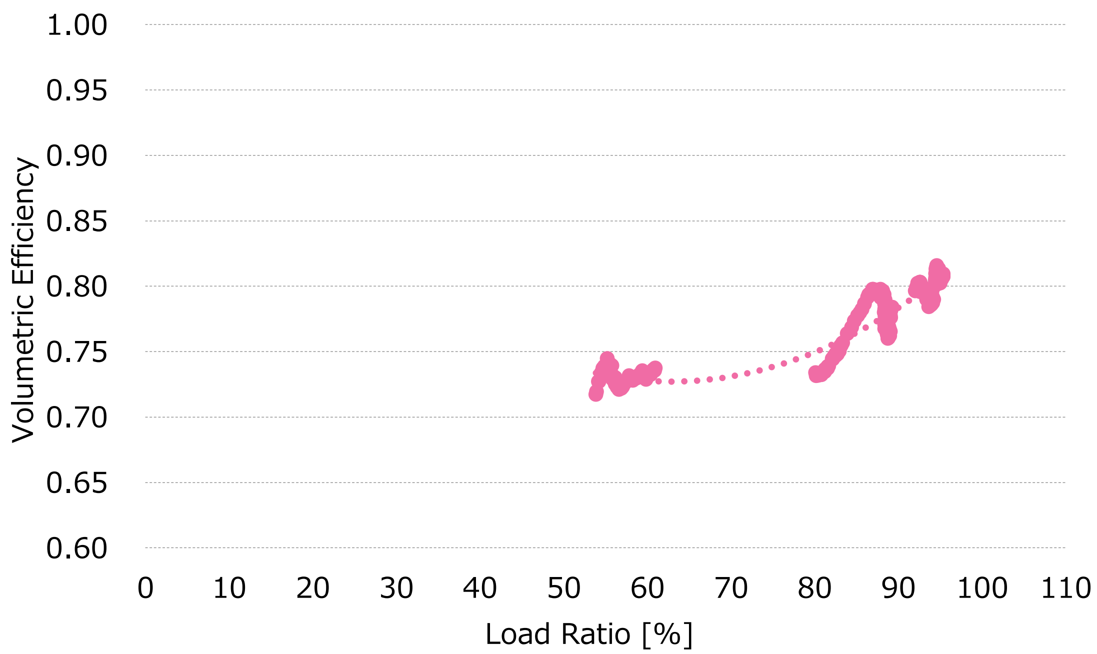

Figure 2.3.1-2 Volumetric efficiency in heating operation

2.3.2 Accuracy of volumetric efficiency

We defined the capacity values, which were obtained by the AE method, as the true values. We then compared the true values with the ones calculated by the regression equations, the average value of 0.77 and the constant value of 0.85 for verifying the accuracy of volumetric efficiency. The constant value is a representative value that was calculated in previous experiments and has been applied to the CC method.

Figures 2.3.2-1 to 2.3.2-6 are the comparison results when load ratios are 70, 60 and 30% in the cooling operation and 90, 80 and 50% in the heating operation and Table 2.3.2-1 indicates the relative errors. The errors of the regression equations were the smallest, which were 5.7% in the cooling operation and 2.8% in the heating operation. The relative errors of the constant value were less accurate than the ones of the average value. Consequently, it is imperative to apply a proper volumetric efficiency value for accuracy improvement in the CC method when a refrigerant mass flow is unknown.

Table 2.3.2-1 Average relative errors to quadratic equation, average and constant values

Operation	Quadratic equation	Average value	Constant value
Cooling	5.7 %	6.8 %	14.9 %
Heating	2.8 %	4.1 %	7.2 %

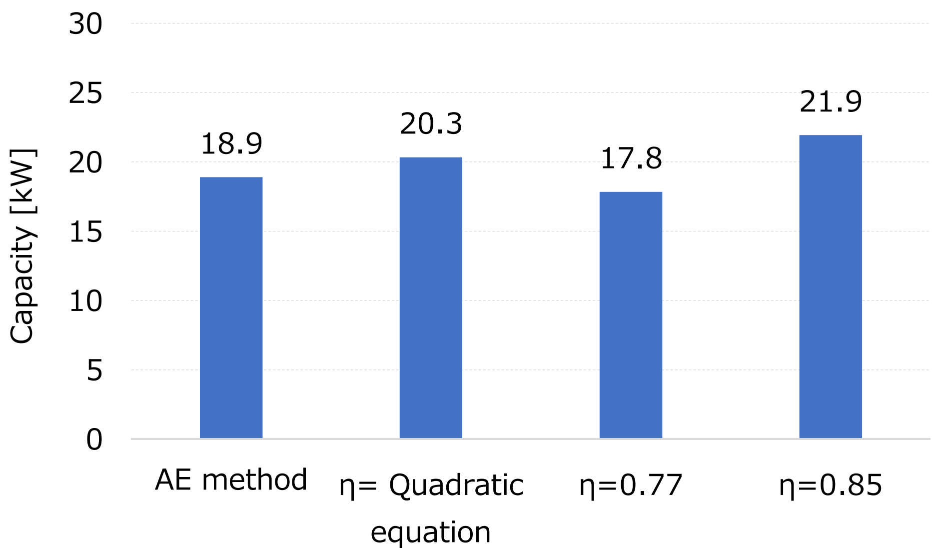

Figure 2.3.2-1 Accuracy of volumetric efficiency in the cooling operation (70%)

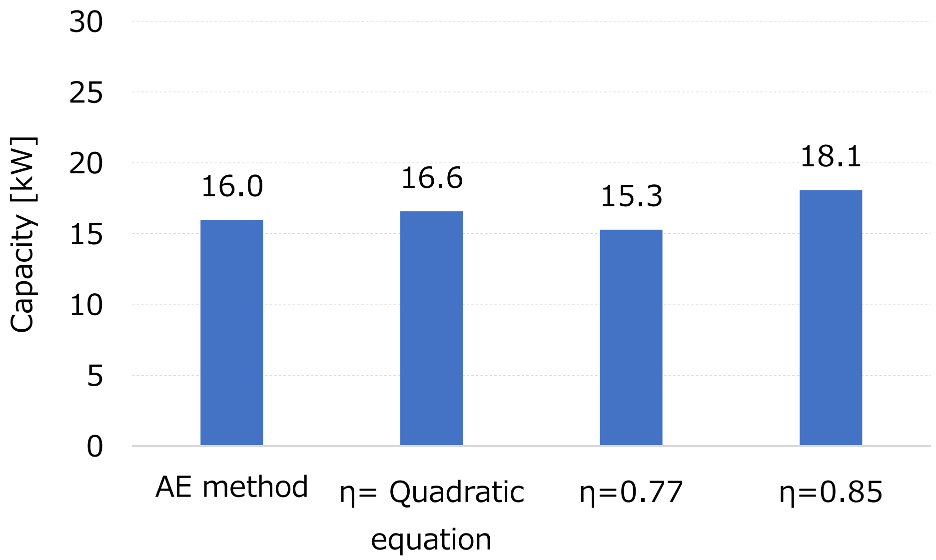

Figure 2.3.2-2 Accuracy of volumetric efficiency in the cooling operation (60%)

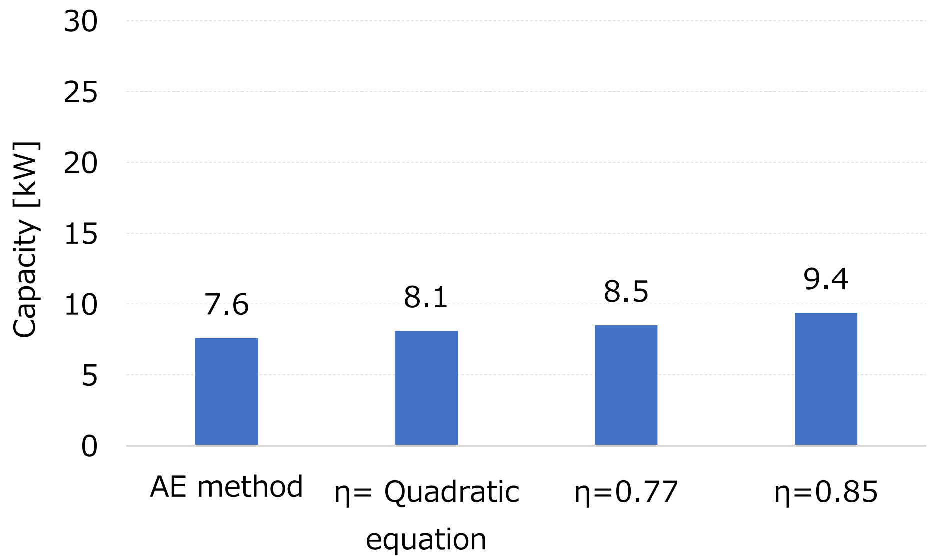

Figure 2.3.2-3 Accuracy of volumetric efficiency in the cooling operation (30%)

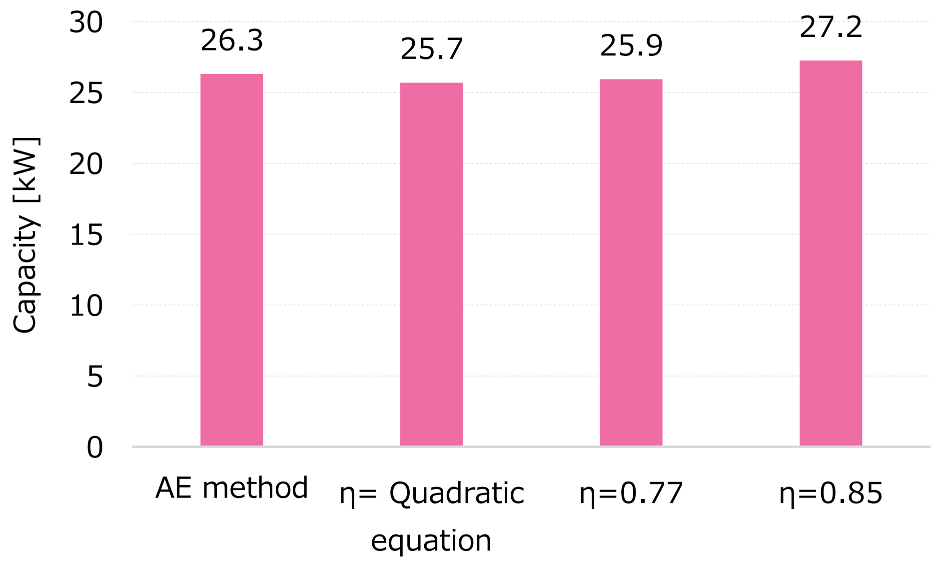

Figure 2.3.2-4 Accuracy of volumetric efficiency in the heating operation (90%)

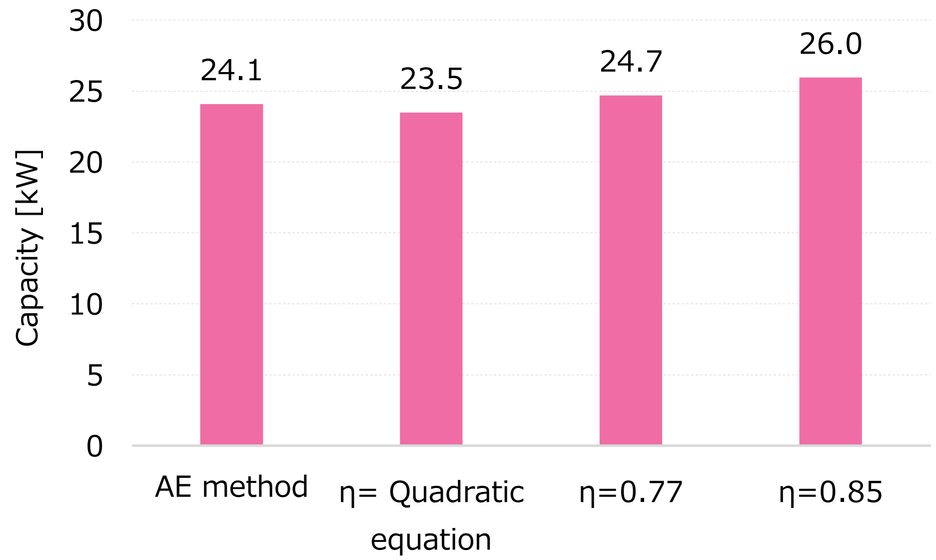

Figure 2.3.2-5 Accuracy of volumetric efficiency in the heating operation (80%)

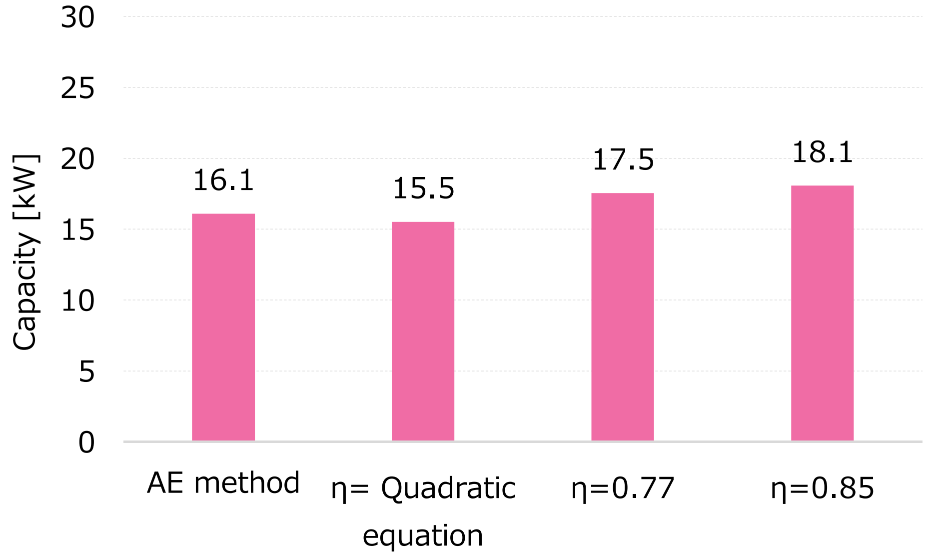

Figure 2.3.2-6 Accuracy of volumetric efficiency in the heating operation (50%)

3 Onsite performance evaluation system

3.1 Outline of the system

This chapter gives an outline of an onsite performance evaluation system as shown in Figure 3.1-1. It is a system that connects a control board of an outdoor unit to the terminal of a microcomputer (Armadillo) and acquires actual operation data. And then the data is transmitted to the cloud server via the Internet. The data includes the compressor revolution speed and refrigerant temperature and pressure values. Information on energy performance including refrigerant mass flow, heat exchange amount of refrigerant and ambient air in the indoor unit, air conditioning capacity, energy efficiency, load factor and installed capacity are calculated using the CC method. Details of a microcomputer and a control board are shown in Figure 3.1-2.

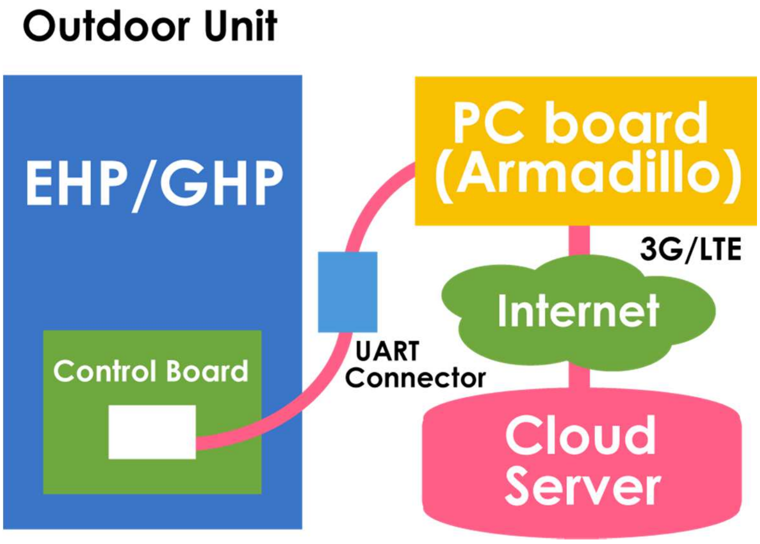

Figure 3.1-1 Outline of the onsite performance evaluation system

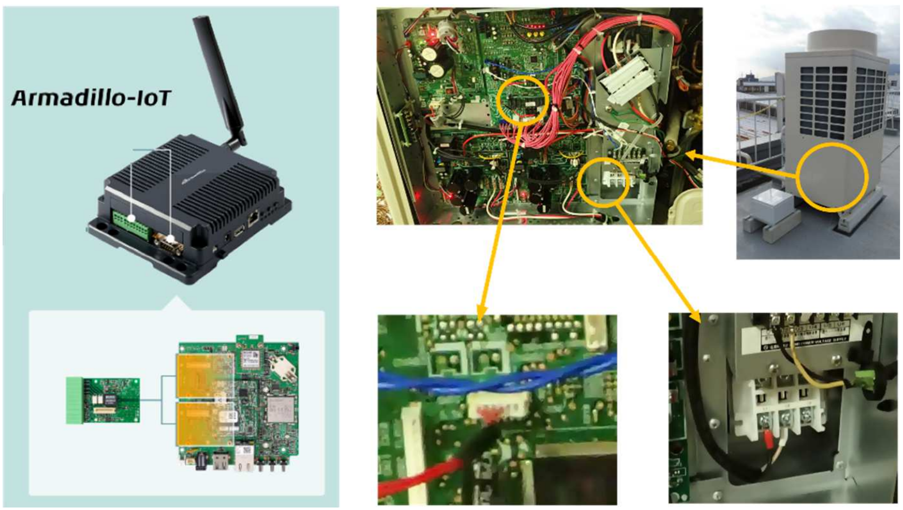

Figure 3.1-2 Details of a microcomputer and a control board

3.2 Demonstration of the system

This system was installed nationwide in various buildings with different uses and weather conditions as shown in Figure 3.2-1.

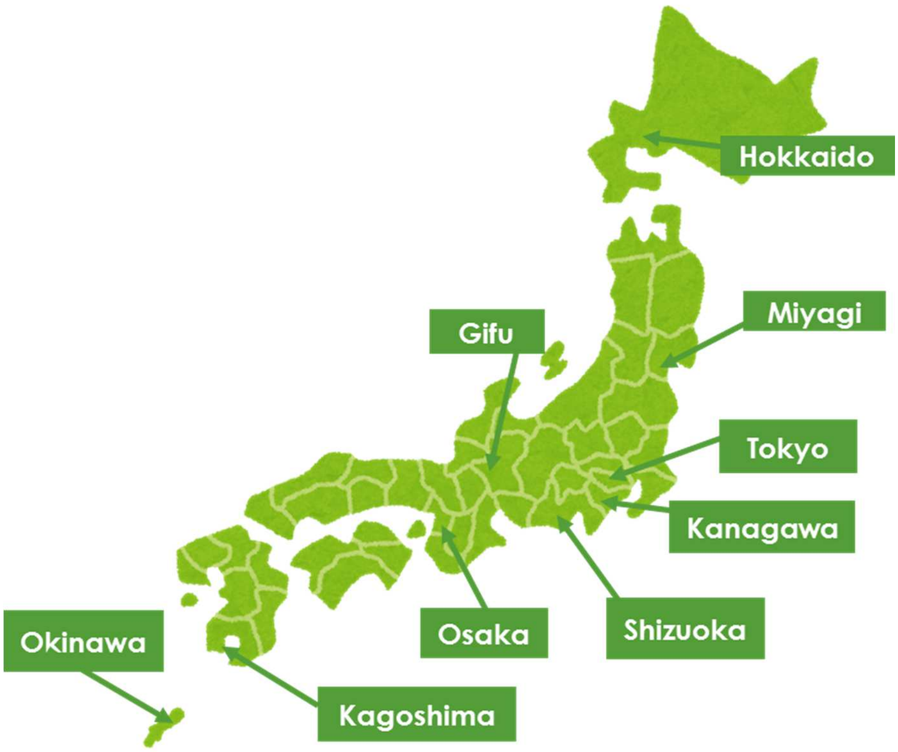

Figure 3.2-1 Installation locations

The list of installation sites is shown in Table 3.2-1. The uses of installation sites were chosen to be as different as possible, including offices, universities and stores. Capacities of outdoor units are from 8HP to 25HP and they are either single or multiple. Three to twelve indoor units are installed. As remote data collection and evaluation are being carried out in different studies for other manufacturers including Gas driven Heat Pumps (hereafter referred to as GHP), the present study mainly covers the EHP sites from 1 to 18 in the table.

Table 3.2-1 List of installation sites

#	Region	Use	Location of outdoor units	Type	Capacity of outdoor units	Operation method	Number of indoor units	Details
1	Shizuoka	Co.	Office building of factory (Rooftop)	EHP	8HP	Single	3	Office
2							3	Meeting room
3	Tokyo	Co.	Office building (Rooftop)	EHP	12HP	Single	6	4F Office (Southeast)
4					10HP×2	Multiple	9	4F Office (Sorthwest)
5	Miyagi	Co.	Building (Rooftop)	EHP	12HP	Single	6	2F Office、 3F Meeting room×2
6	Hokkaido	Co.	Complex facility	EHP	10HP	Single	4	1F Office
7					10HP×4	Multiple	8	2F Office
8					10HP＋8HP×2		5	2F Office
9	Kanagawa	Univ.	Lecture building	EHP	12HP×2	Multiple	7	1FLobby, EV Hall
10					12HP＋10HP		8	3F Classroom×2 (North)
11					12HP＋10HP		6	6F Classroom (South)
12			Laboratory building (Rooftop)	EHP	12HP	Single	3	1F Workshop
13					10HP		3	2F Workshop
14					12HP		3	3F Workshop
15					12HP		3	2F Office Laboratory
16	Tokyo	Univ.	Indoor	EHP	10HP	Single	4	Environmental test chamber
17				GHP	16HP		4	
18							4	Spare machine
19	Osaka	Univ.	Ground	GHP	16HP	Single	4	1F Office
20							4	
21	Okinawa	Univ.	Balcony	EHP	10HP	Single	6	1F Workshop
22	Kagoshima	Co.	Ground	GHP	16HP	Single	4	1F Office
23	Osaka	Co.	(Rooftop)	GHP	20HP	Multiple	8	3F Office
24	Gifu	Co.	Ground	GHP	20HP	Multiple	8	1F Store
25	Tokyo	Co.	Ground	GHP	25HP	Multiple	12	9F Office
26	Osaka	Co.	Indoor	EHP	25HP	Single	6	For operation verification
27							6	
28							6	

3.3 Information providing method for energy conservation

3.3.1 Outline of the method

VRF systems have increased their market share as they are easy to design for building designers and easy to start and stop and change the settings for general users, and has a certain air conditioning capacity as discussed in chapter 1. As a result, management has not been done properly. Neither air conditioning heat quantities nor operating patterns are known. Figure 3.3.1-1 shows the information providing method. Data on the cloud server is combined with weather data and they are sent to mobile devices and computers of users and building designers and operators after data analysis to raise user's energy-saving consciousness[14].

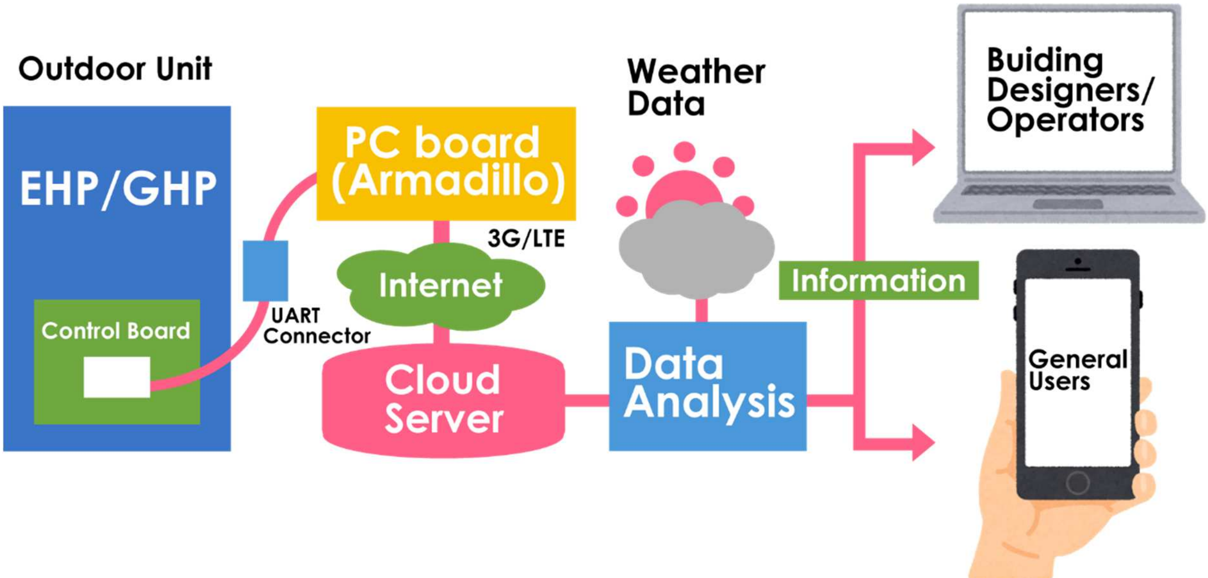

Figure 3.3.1-1 Information providing method

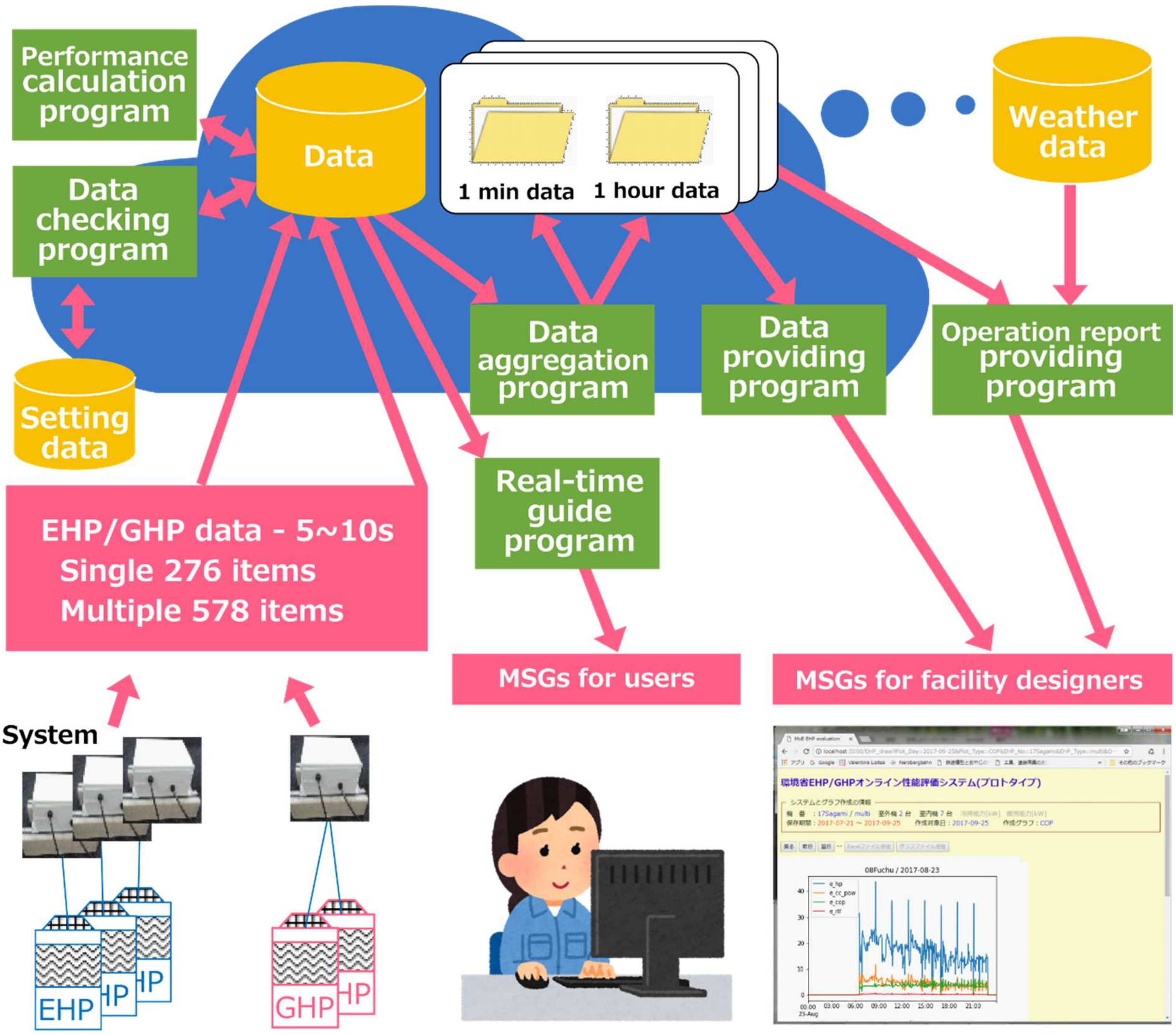

Figure 3.3.1-2 Details of the information providing system

Figure 3.3.1-2 shows the details of the information providing system. Data from EHP and GHP machines on the sites are collected using the system developed in this study and we carried out performance calculations using the CC method. The data were aggregated in 1-minute or 1-hour unit and a web system which we could monitor power consumption, load factor, and COP in real time was built. Furthermore, in combination with meteorological data, it is possible to evaluate operating performance and send advice and messages to users, building operators and designers.

3.3.2 The Nudge theory

The Nudge theory is referred to examine what kind of messages will encourage users and building designers to take action for energy-saving. The theory was proposed by an American economist Richard H. Thaler. The phrase nudge theory, or nudge, is a behavioral science concept which states that positive reinforcement can influence the motivations and decision-making of a person or group of persons. The six approaches, their explanations and examples of energy savings in the present study are shown in Table 3.3.2-1[(15)].

Table 3.3.2-1 The Nudge theory

Approaches	Explanations	Examples of energy-saving in the present study
Incentives	Motivate remarkably	●Indication of peak power ●Emphasize loss
Understand mappings	Show the relationship between choices and results clearly	●Indicates energy conservation and savings by operation improvement ●Compare with rated operation
Defaults	Most people choose the defaults	Set to energy-saving mode at shipment
Give feedback	Tell the results clearly	●Expose the power consumption values with company names
Expect errors	Design on the assumption that mistakes will occur	●Detect extreme increase in air conditioning load ●Carry out inspections regularly
Structure complex choices	When choices are complicated, narrow down recommendations	●Recommend maximum power and inverter frequency controls

3.4 Analysis methods

Causes of energy waste and analysis methods are defined for giving messages and advice to users, building operators and designers considering the Nudge theory as shown in Table 3.4-1.

Table 3.4-1 Causes of energy waste and analysis methods

No	Causes of energy waste	Analysis methods
1	Low load operation with excessive equipment	Confirm annual average load factor
2	Inappropriate temperature presets	Comparison of temperature preset values and number of temperature presets changes for each indoor unit
3	Unnecessary operations	Start-Stop times of operations
4	Frequent on-off cycles of outdoor units	Count on-off cycles of compressor
5	High suction air temperature of outdoor units	Mean values of temperature differences between outdoor unit suction and outside air temperatures
6	High power consumption per floor area	Comparison of power consumption values per floor area at each site

4 Validation by field data analysis

Air conditioning loads are affected by a variety of factors including weather characteristics, installation conditions and operation modes. Therefore, we analysed obtained data for operational improvement.

4.1 Outline of the data

The outline of the data downloaded from the cloud server is shown in Table 4.1-1. The data were collected every 5-second and aggregated in 1 minute and 1 hour.

Table 4.1-1 Data items of the performance evaluation system

Data items	Labels	Examples
Measuring time	measure_time	20170721 000002
Number of outdoor units	outer_count	4
Number of indoor units	inner_count	8
Compressor suction pressure	ps_0	1.46
Compressor discharge pressure	pd_0	1.62
Compressor discharge temperature	td1_0	45.1
Heat exchanger outlet temperature	te1_0	26
Compressor speed	sr1_0	0
Current value	cp1_0	0
Liquid pipe temperature of indoor units	tl_0	30.6
Liquid pipe pressure of indoor units	tc2_0	26
Gas pipe temperature of indoor units	o_tc1_0	31.7
Gas pipe pressure of indoor units	tc1_0	26.5
Outside air temperature	tp_0	25.5
Outdoor unit operation mode	dd_out_0	halt
Defrost mode	j_mode_0	other
Indoor unit operation mode	mdin_0	cool
Indoor unit air volume setting	mdfan_0	off
Indoor unit required capacity	scode_0	0
Rated capacity of indoor units	hp_0	5
Suction temperature of indoor units	ta_0	26.5
Temperature presets of indoor units	pt_0	23.0
Compressor suction density	e_di_0	52.40023
Compressor discharge density	e_dd1_0	52.40023
Refrigerant flow rate	e_rf3_0	0.033
Inlet enthalpy of indoor units	e_ei	252.89
Outlet enthalpy of indoor units	e_eo_0	445
Air conditioning capacity	e_hp	12.343
Power consumption	e_cc_pow	3.501
Energy efficiency	e_cop	3.659
Load factor	e_rlf	0.555

The data were collected from August 1st to December 31st in 2017. All the data were considered for the analysis.

4.2 Definitions of terms

Definitions of terms are defined in (9) to (12) as follows:

COP = Rated capacity (kW) / Rated power consumption (kW) (9)

Cooling load factor = Total cooling capacity (kW) / Rated cooling capacity (kW) (10)

Heating load factor = Total heating capacity (kW) / Rated heating capacity (kW) (11)

Operating time of outdoor unit = Compressor running time (12)

4.3 Load factor frequency

Figures 4.3-1 and 4.3-2 and Tables 4.3-1 and 4.3-2 show average load factors in the cooling and heating operations. Average load factor is 25.8% in the cooling operation and 22.2% in the heating operation. There are 3 outdoor units in Sapporo and average load factors are 19.2% in the cooling operation and only 14.9% in the heating operation. It is assumed that load factors are lower in Sapporo as outdoor units are installed excessively to avoid complaints.

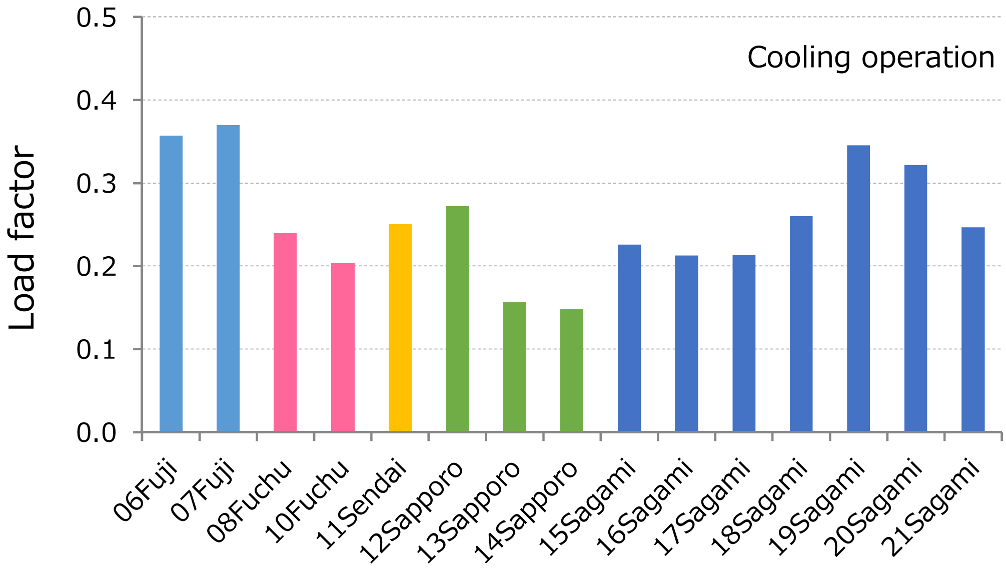

Figure 4.3-1 Average load factor in the cooling operation

Table 4.3-1 Average load factor by machine and location in the cooling operation

Locations	Load factor avg. by machine	Load factor avg. by location
#6Fuji	35.7%	36.4%
#7Fuji	37.0%	
#8Fuchu	23.9%	22.1%
#10Fuchu	20.3%	
#11Sendai	25.1%	25.1%
#12Sapporo	27.2%	19.2%
#13 Sapporo	15.7%	
#14 Sapporo	14.8%	
#15Sagami	22.6%	26.1%
#16 Sagami	21.3%	
#17 Sagami	21.3%	
#18 Sagami	26.0%	
#19 Sagami	34.6%	
#20 Sagami	32.2%	
#21 Sagami	24.7%	

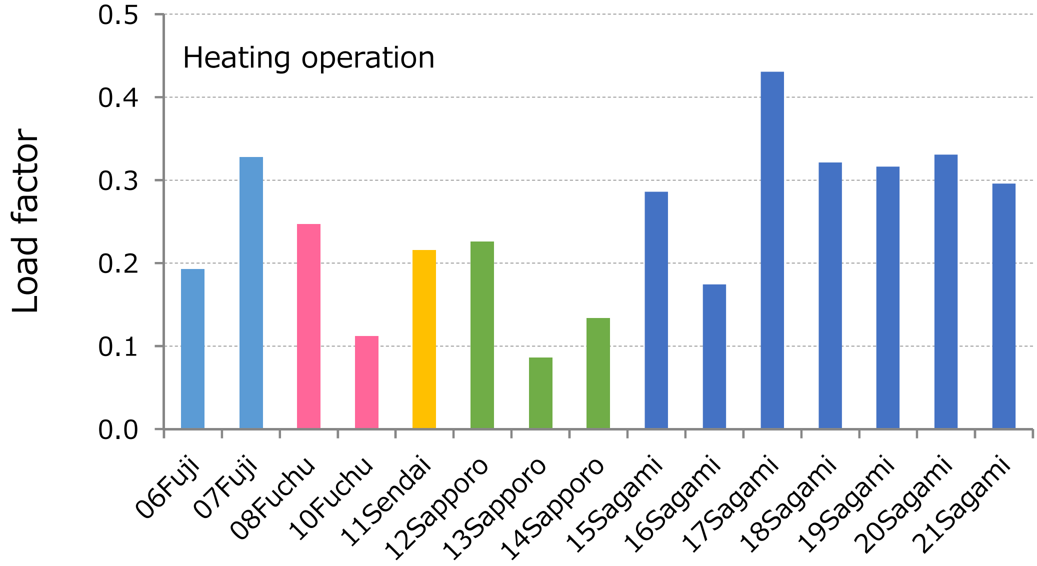

Figure 4.3-2 Average load factor in the heating operation

Table 4.3-2 Average load factor by machine and location in the heating operation

Locations	Load factor avg. by machine	Load factor avg. by location
#6Fuji	19.3%	26.0%
#7Fuji	32.8%	
#8Fuchu	24.7%	17.9%
#10Fuchu	11.2%	
#11Sendai	21.6%	21.6%
#12Sapporo	22.6%	14.9%
#13 Sapporo	8.6%	
#14 Sapporo	13.3%	
#15Sagami	28.6%	30.8%
#16 Sagami	17.5%	
#17 Sagami	43.1%	
#18 Sagami	32.2%	
#19 Sagami	31.6%	
#20 Sagami	33.1%	
#21 Sagami	29.6%	

4.4 Power consumption, capacity, and COP

Figures 4.4-1 to 4.4-6 show power consumption, capacity and Coefficient of Performance values (hereafter referred to as COP) in the cooling and heating operations. The results show that Sapporo's average COP values which are 3.1 in the cooling operation and 2.4 in the heating operation are relatively lower than Sagami's average COP values which are 6.6 in the cooling operation and 7.0 in the heating operation.

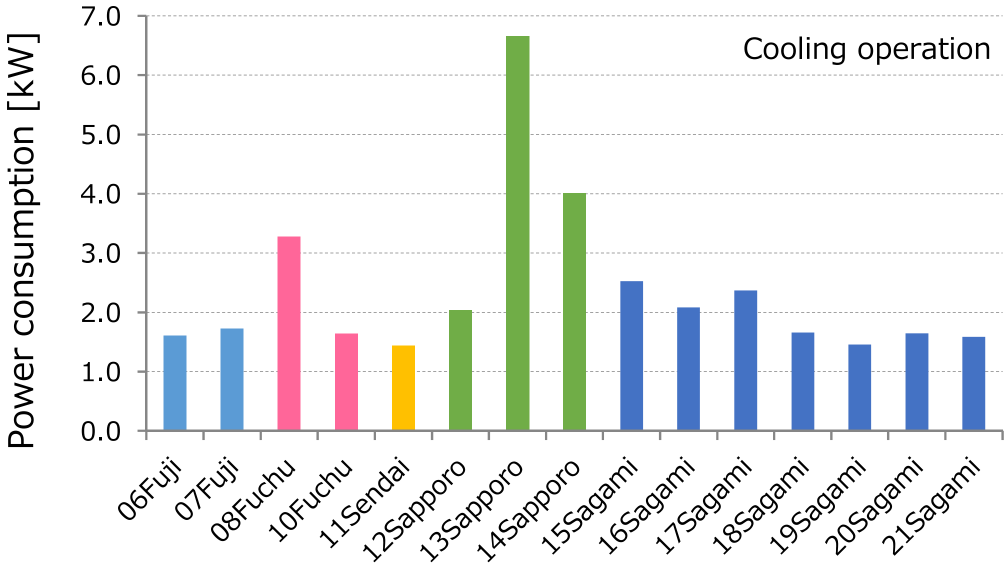

Figure 4.4-1 Power consumption in the cooling operation

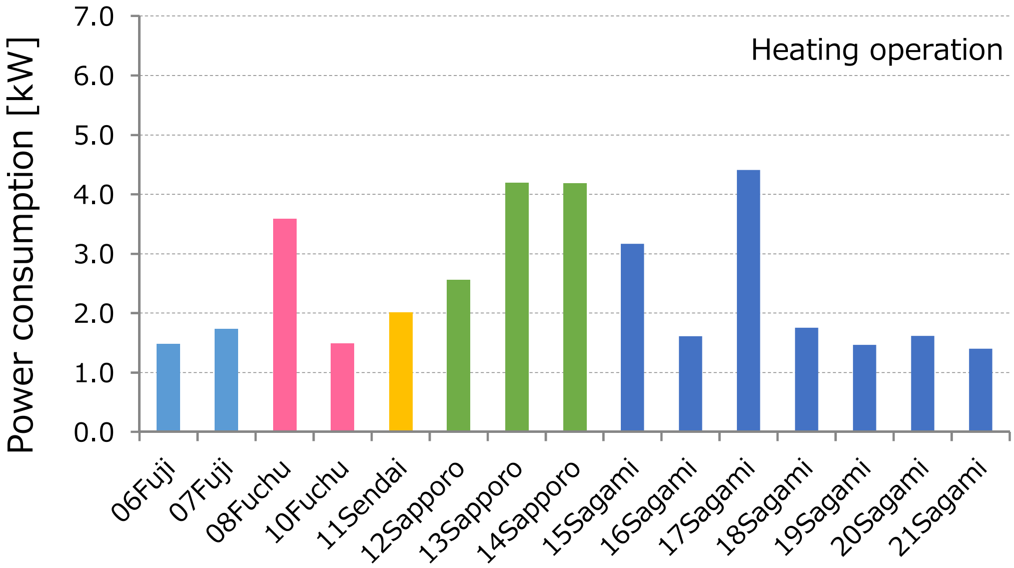

Figure 4.4-2 Power consumption in the heating operation

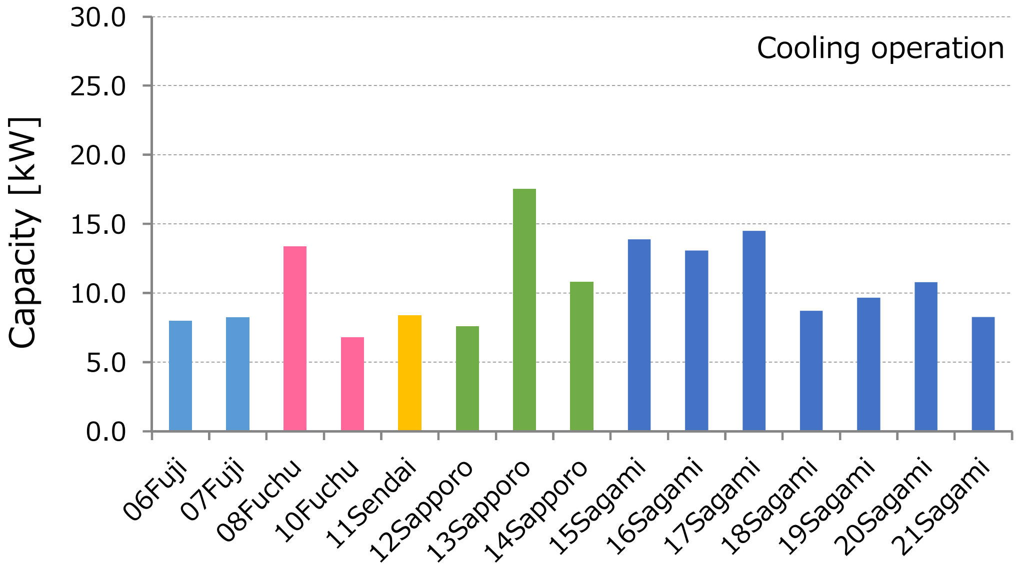

Figure 4.4-3 Capacity in the cooling operation

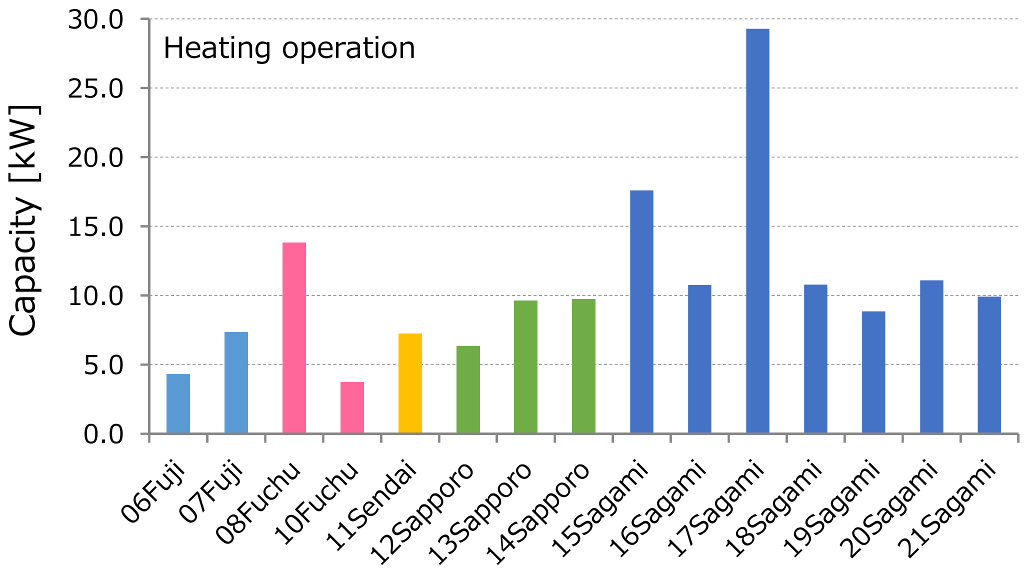

Figure 4.4-4 Capacity in the heating operation

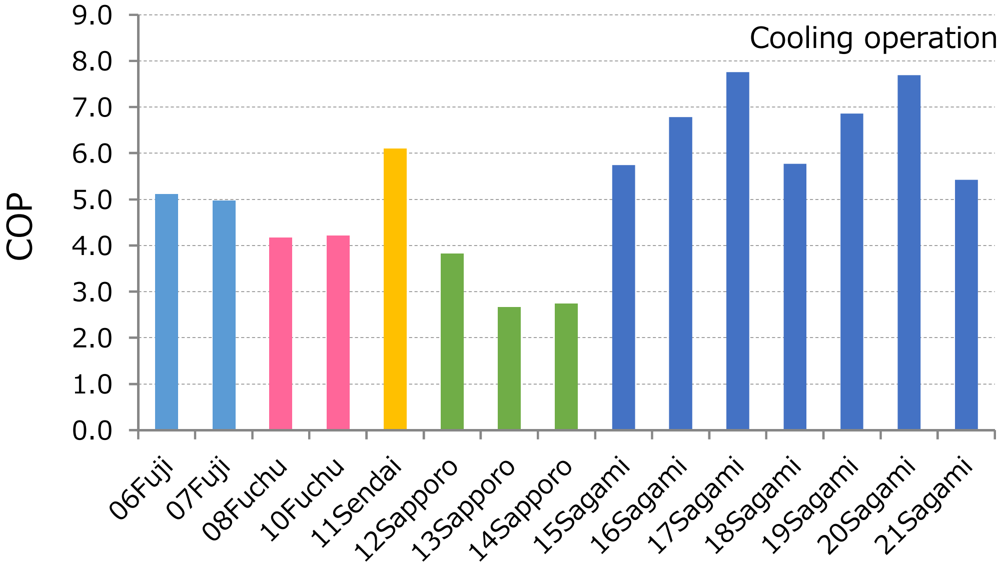

Figure 4.4-5 COP in the cooling operation

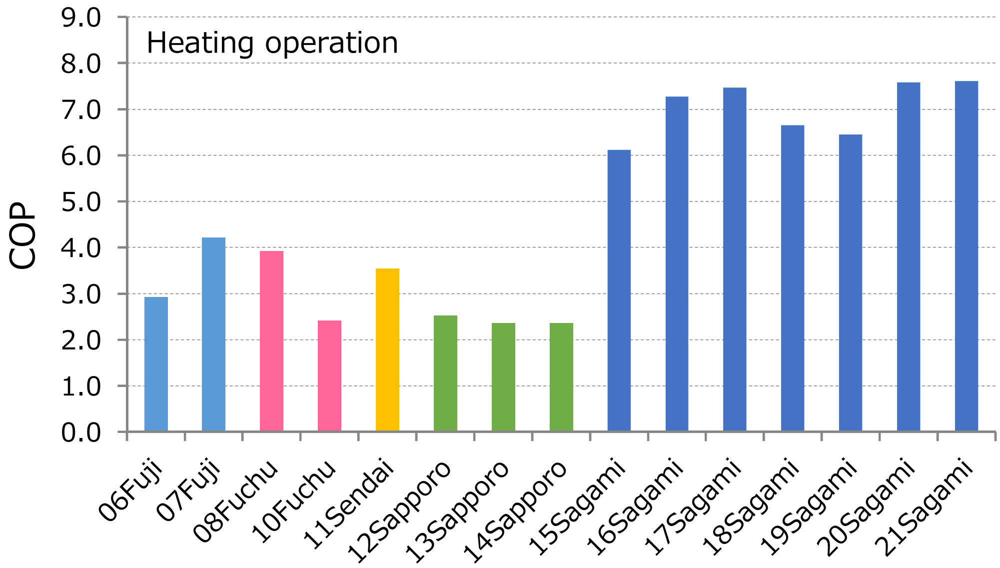

Figure 4.4-6 COP in the heating operation

4.5 Load factor and COP

Load factor-COP scatter diagrams of each site are shown in Figures 4.5-1 to 4.5-16. Fuchu site of #9 never operated in the measurement period. Sapporo sites rarely vary and show low COP values whereas Sagami sites vary widely and show high COP values as verified in the previous section.

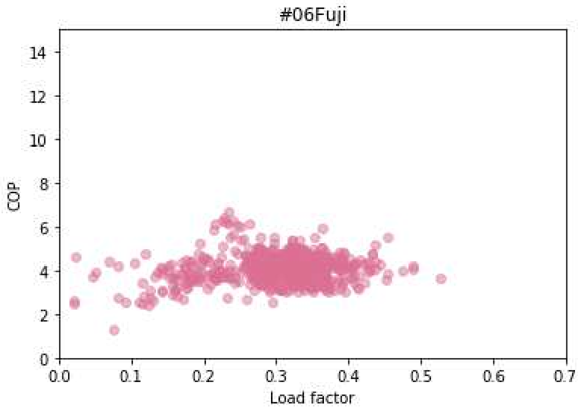

Figure 4.5-1 Load factor and COP

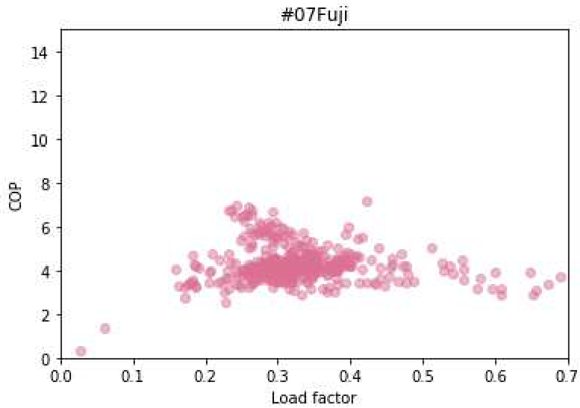

Figure 4.5-2 Load factor and COP

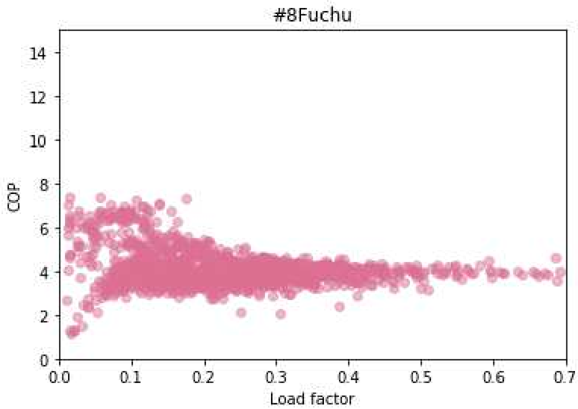

Figure 4.5-3 Load factor and COP

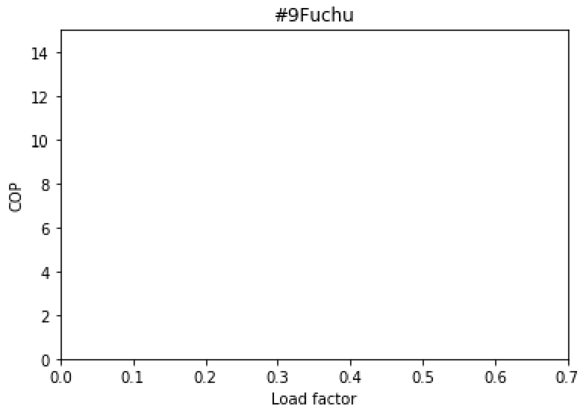

Figure 4.5-4 Load factor and COP

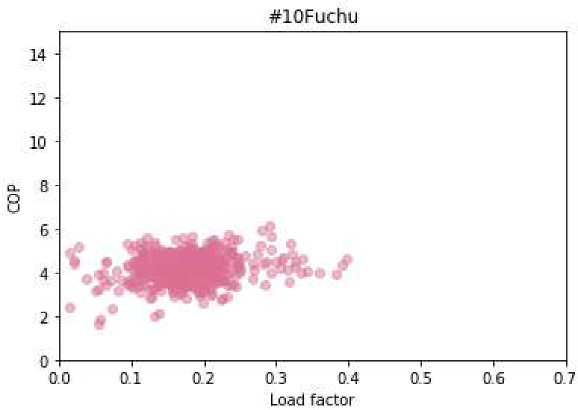

Figure 4.5-5 Load factor and COP

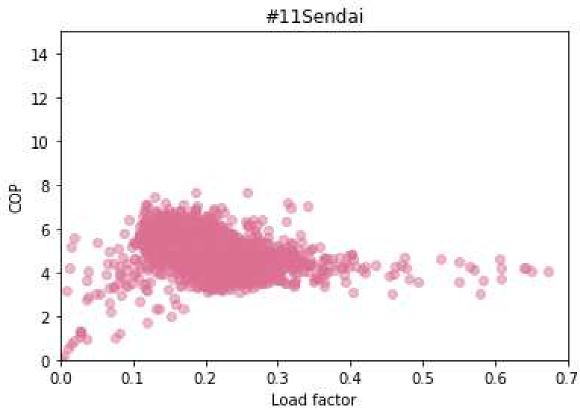

Figure 4.5-6 Load factor and COP

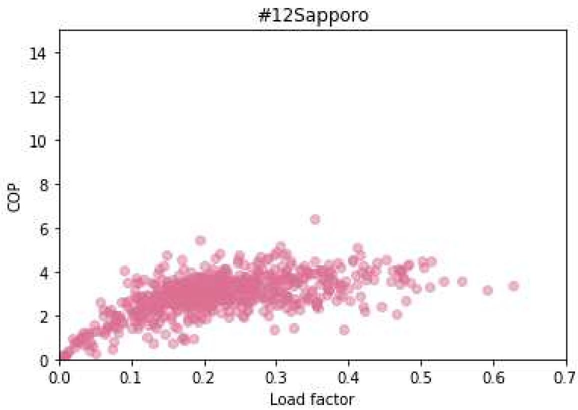

Figure 4.5-7 Load factor and COP

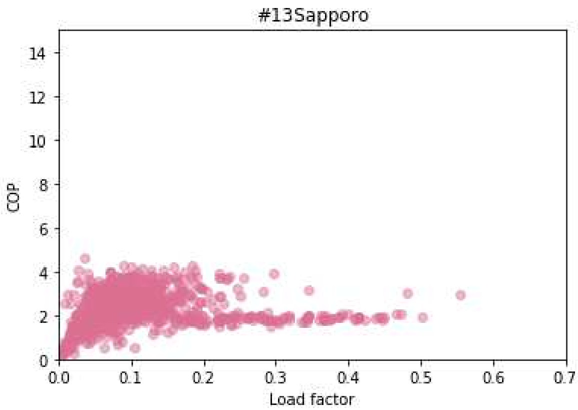

Figure 4.5-8 Load factor and COP

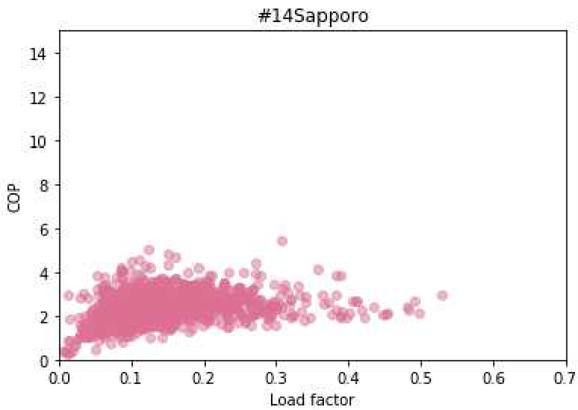

Figure 4.5-9 Load factor and COP

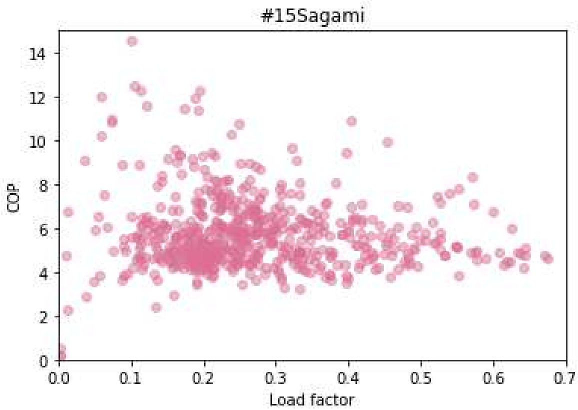

Figure 4.5-10 Load factor and COP

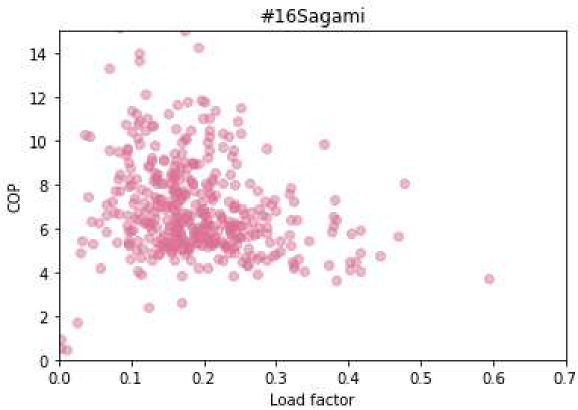

Figure 4.5-11 Load factor and COP

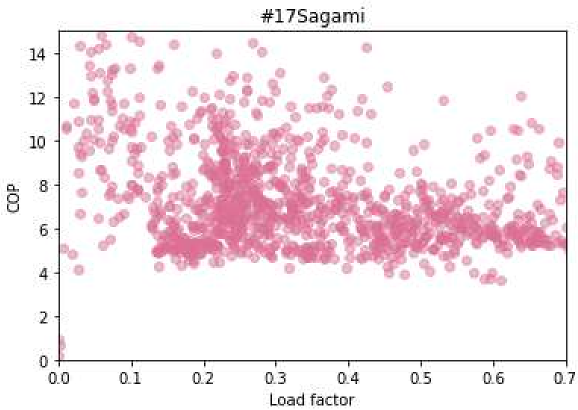

Figure 4.5-12 Load factor and COP

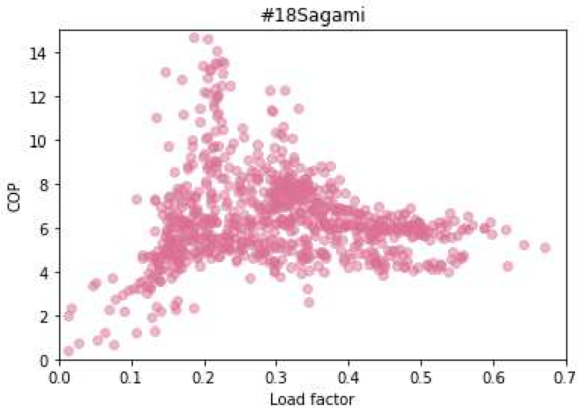

Figure 4.5-13 Load factor and COP

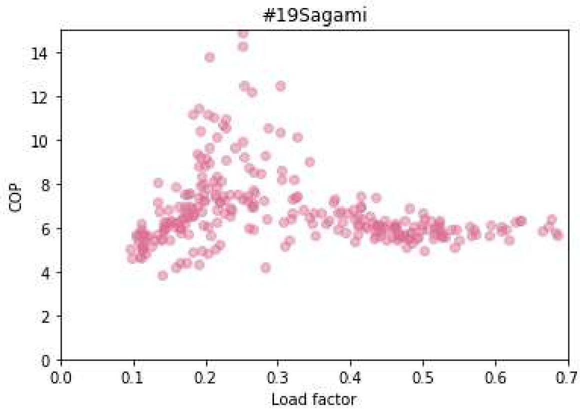

Figure 4.5-14 Load factor and COP

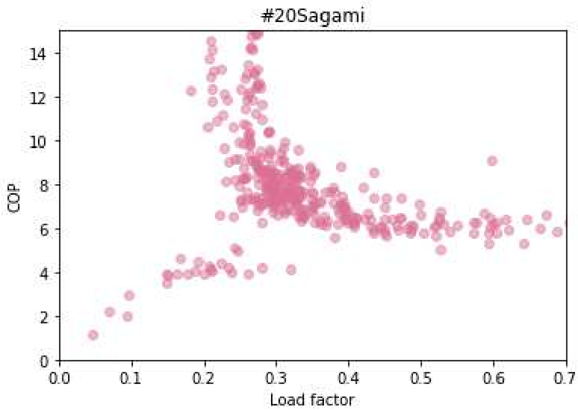

Figure 4.5-15 Load factor and COP

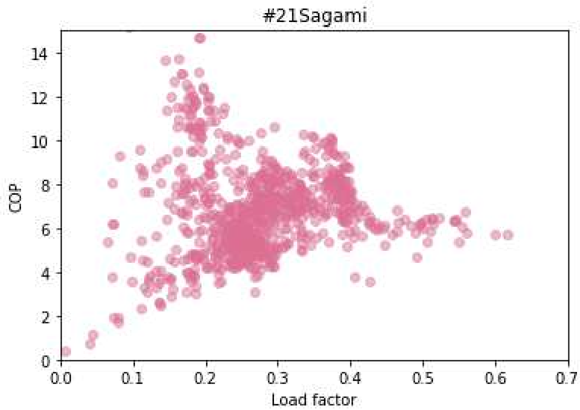

Figure 4.5-16 Load factor and COP

4.6 Temperature presets of indoor units

Figure 4.6-1 shows average outside air temperature and Figure 4.6-2 shows the average temperature presets at the sites.

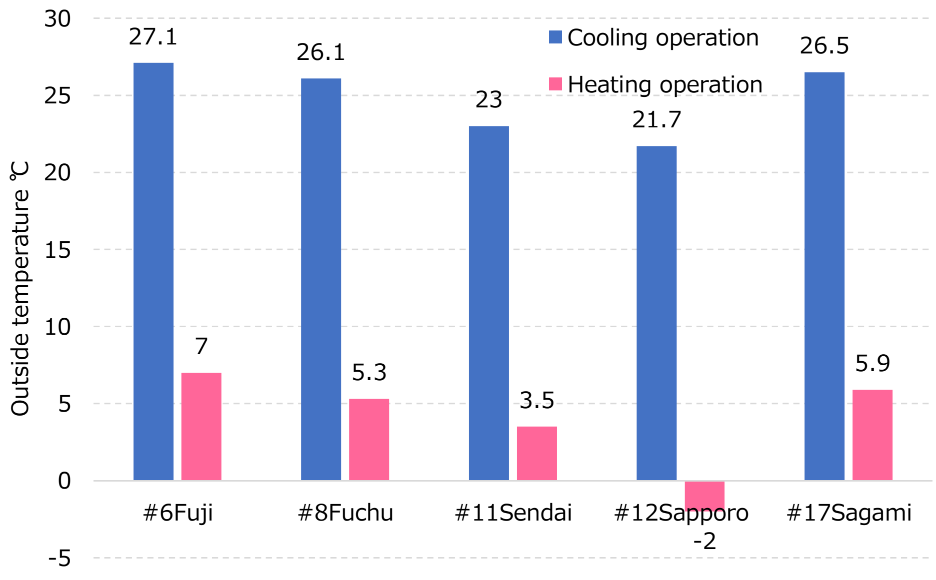

Figure 4.6-1 Avg. outside air temperature

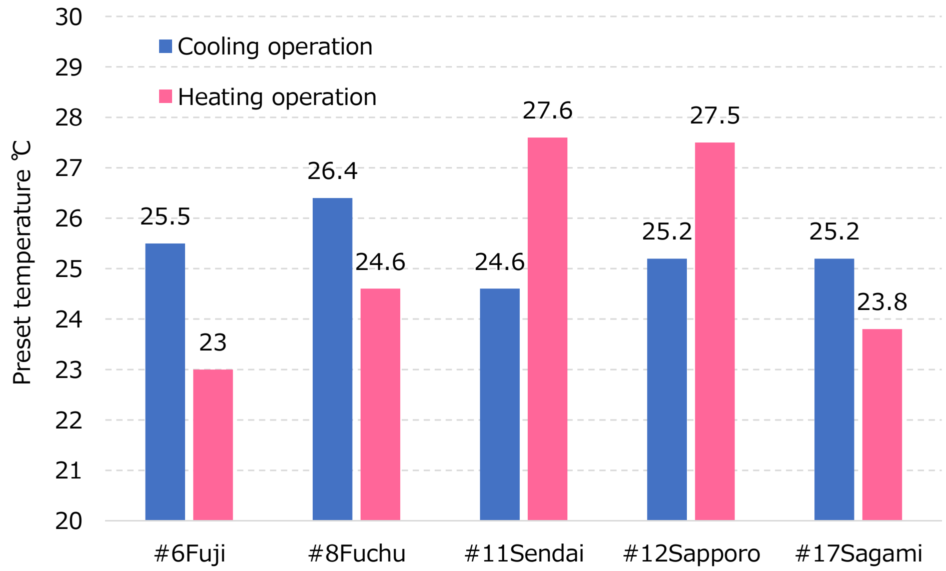

Figure 4.6-2 Avg. temperature presets

Figures 4.6-3 to 4.6-7 show the results of average temperature presets at each indoor unit in the cooling operation. Nine indoor units are installed in Fuchu and the units of pt_2, pt_7 and pt_8 are lower than other units.

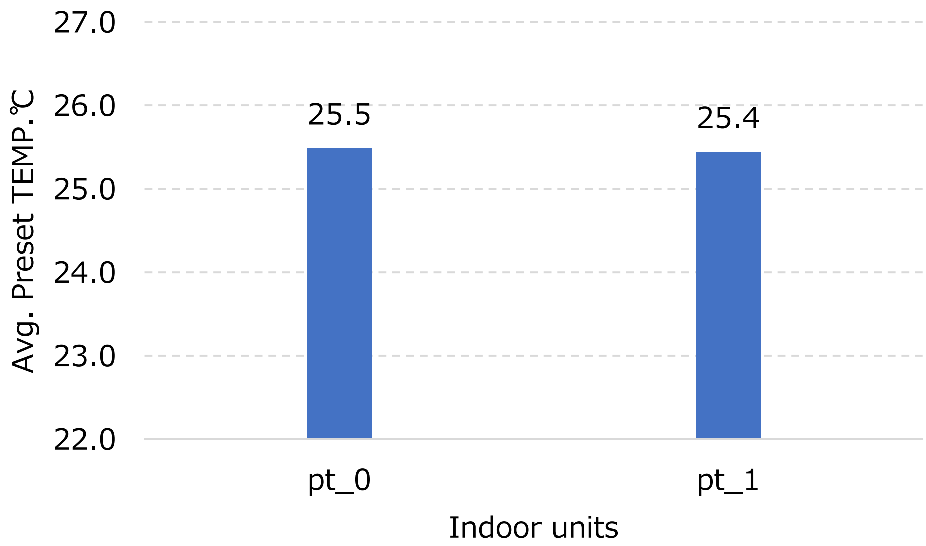

Figure 4.6-3 Avg. temperature presets in the cooling operation (#6Fuji)

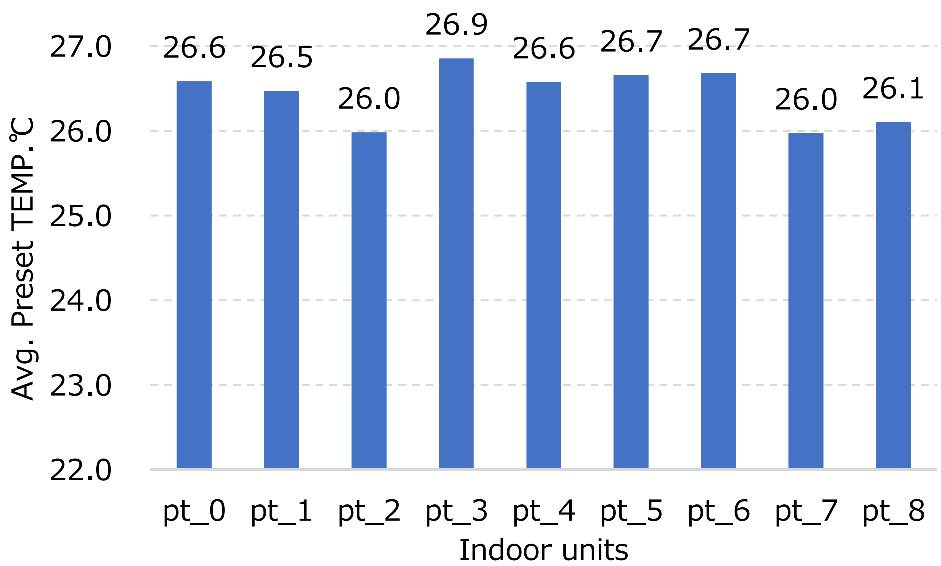

Figure 4.6-4 Avg. temperature presets in the cooling operation (#8Fuchu)

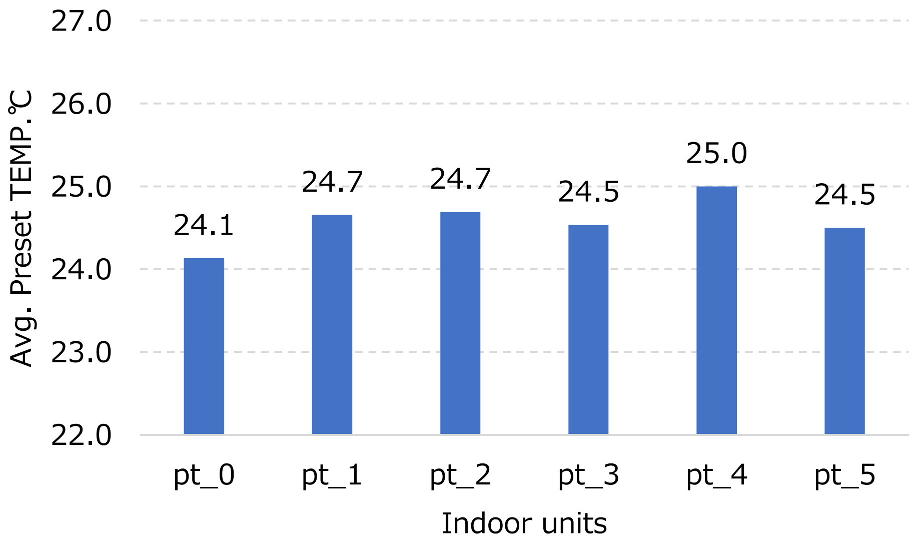

Figure 4.6-5 Avg. temperature presets in the cooling operation (#11Sendai)

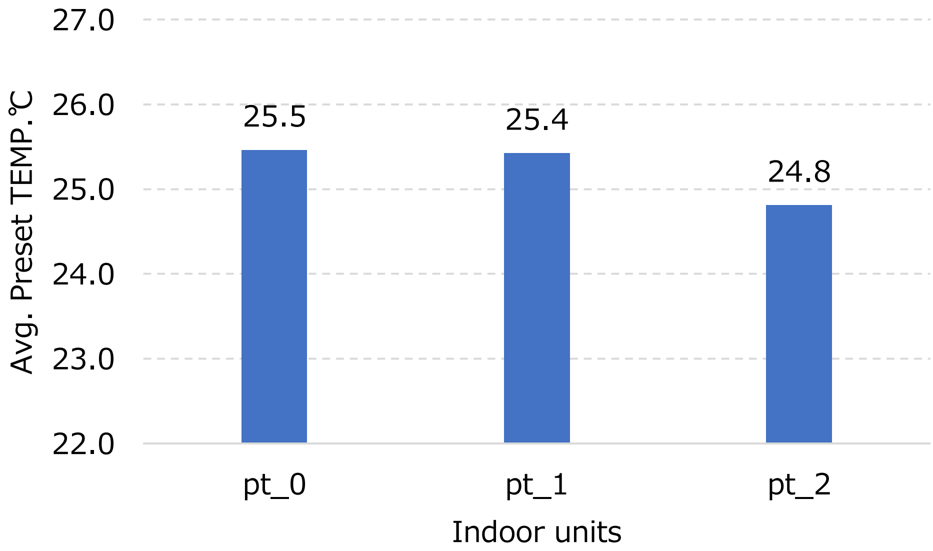

Figure 4.6-6 Avg. temperature presets in the cooling operation (#12Sapporo)

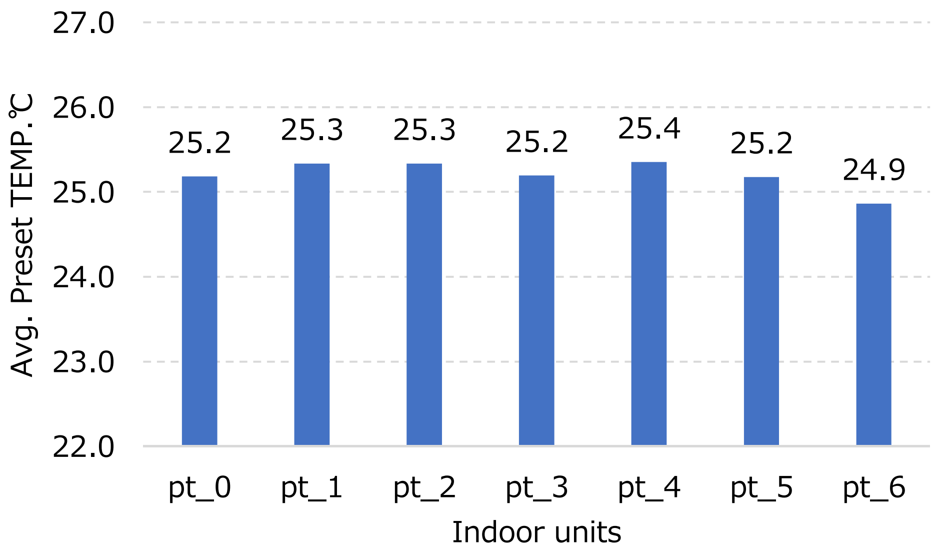

Figure 4.6-7 Avg. temperature presets in the cooling operation (#17Sagami)

Figures 4.6-8 to 4.6-12 show the results of average temperature presets at each indoor unit in the heating operation. The indoor unit of pt_1 in Fuchu is set to 25.7℃ and is higher than other units which are barely changed throughout the analysis period. The indoor unit of pt_0 in Sendai is set to 30.5℃ which is inappropriately high as well as pt_5. It seems that the people in the rooms are changing the settings frequently. Warnings including "Temperature preset is too high (low)" should be given to the users.

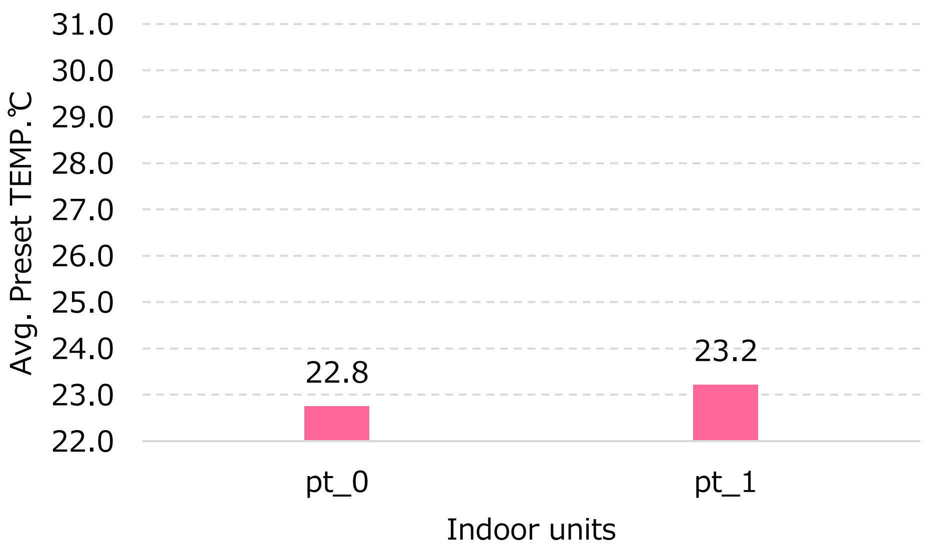

Figure 4.6-8 Avg. temperature presets in the heating operation (#6Fuji)

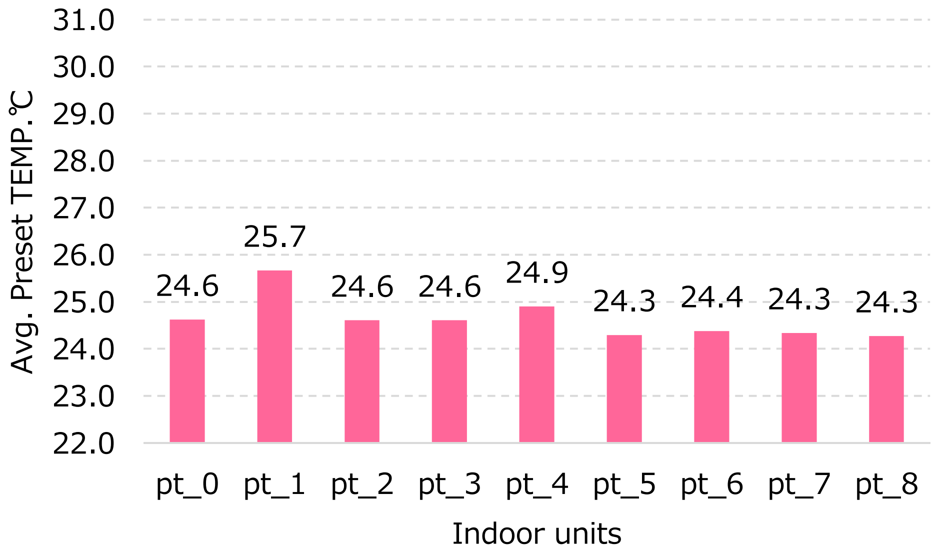

Figure 4.6-9 Avg. temperature presets in the heating operation (#8Fuchu)

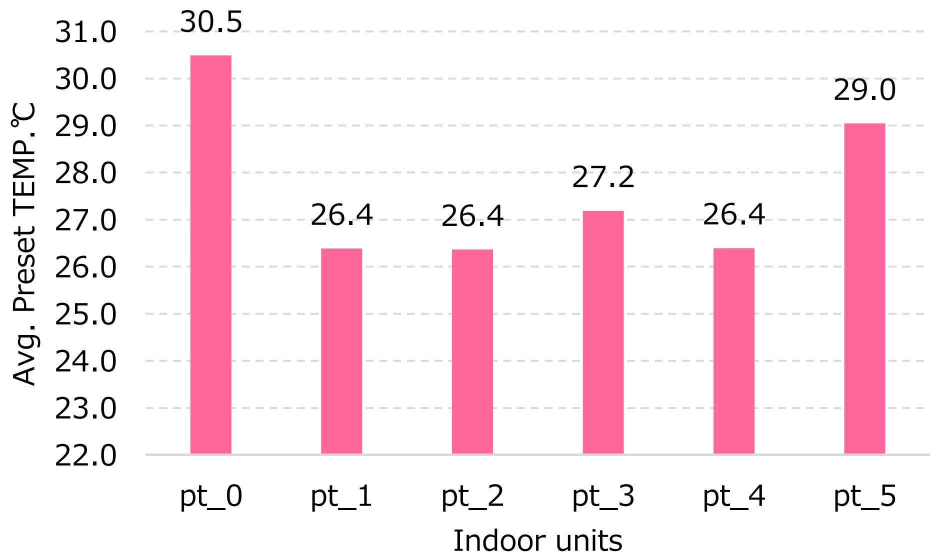

Figure 4.6-10 Avg. temperature presets in the heating operation (#11Sendai)

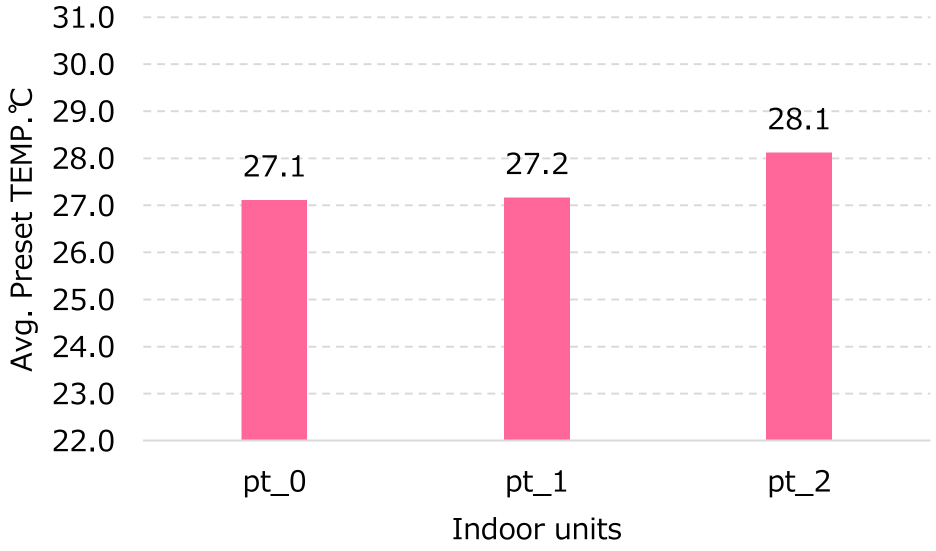

Figure 4.6-11 Avg. temperature presets in the heating operation (#12Sapporo)

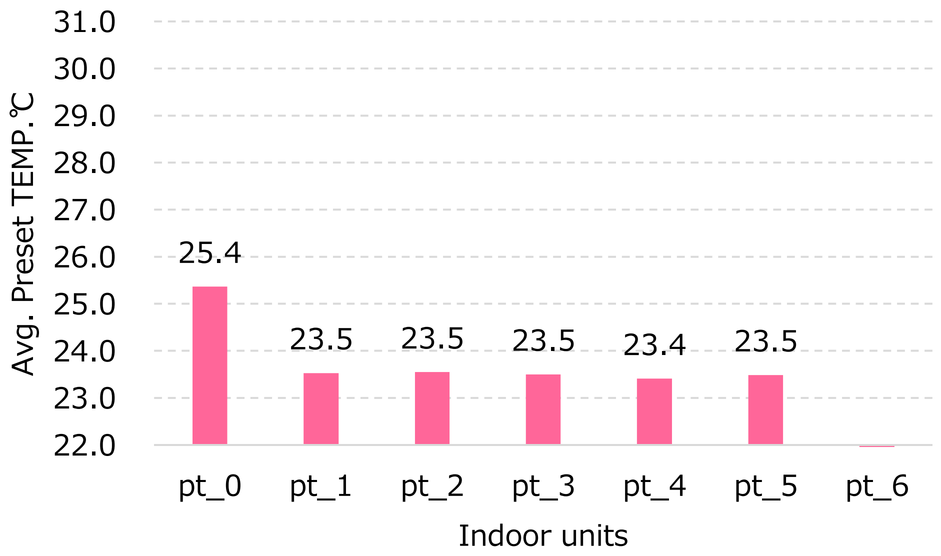

Figure 4.6-12 Avg. temperature presets in the heating operation (#17Sagami)

4.7 Operating hours

Figures 4.7-1 to 4.7-5 show the comparisons of outside temperature, operation hours and start-stop time of operations in the cooling operation from Aug 21st to Sep 1st. Weekend data is excluded as the offices are not in operation. The results show that #10 in Fuchu operated all night in the 29th and 31st and the air conditioners were turned on and off frequently as people went in and out. We also found that the machine in Sendai was operated continuously for the analysis period.

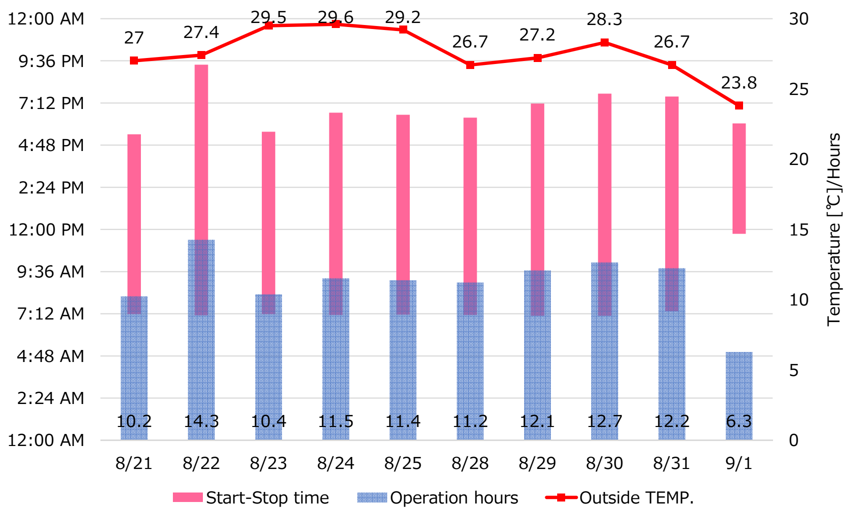

Figure 4.7-1 Operating hours in the cooling operation (#6Fuji)

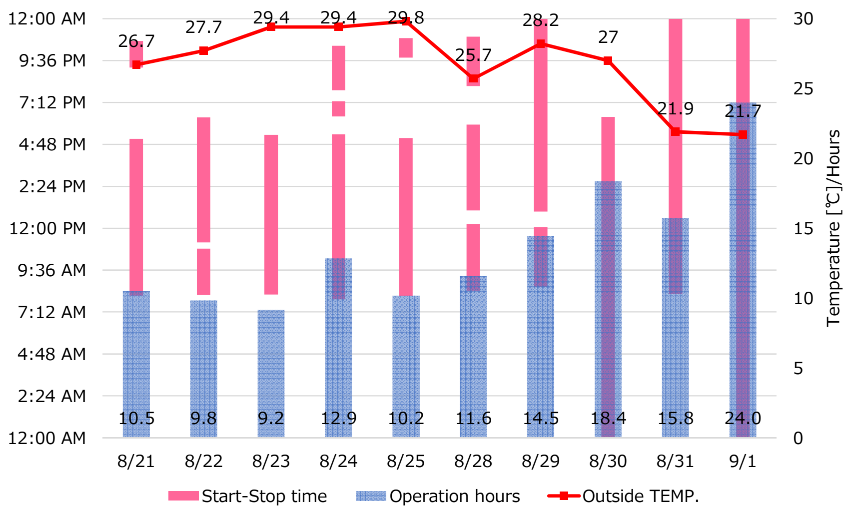

Figure 4.7-2 Operating hours in the cooling operation (#10Fuchu)

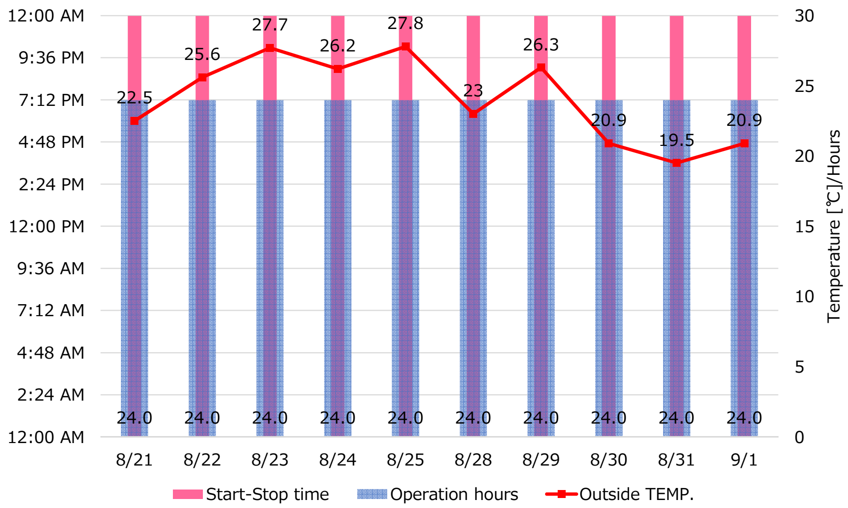

Figure 4.7-3 Operating hours in the cooling operation (#11Sendai)

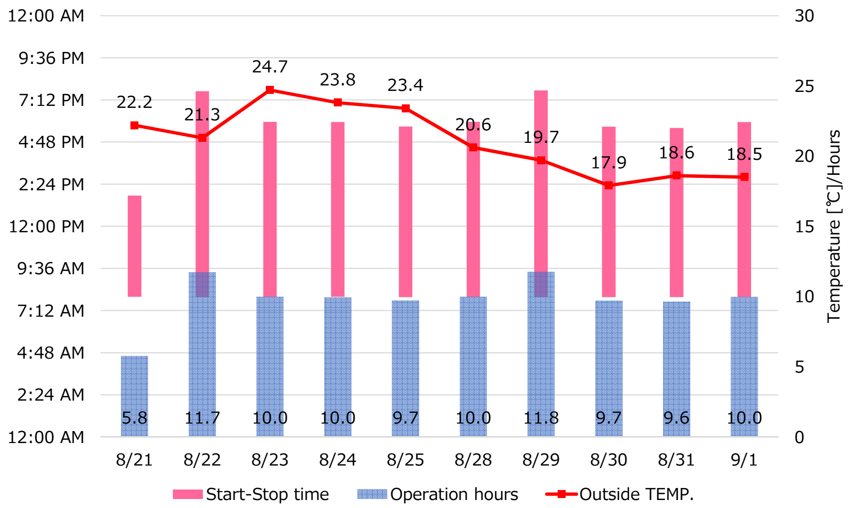

Figure 4.7-4 Operating hours in the cooling operation (#12Sapporo)

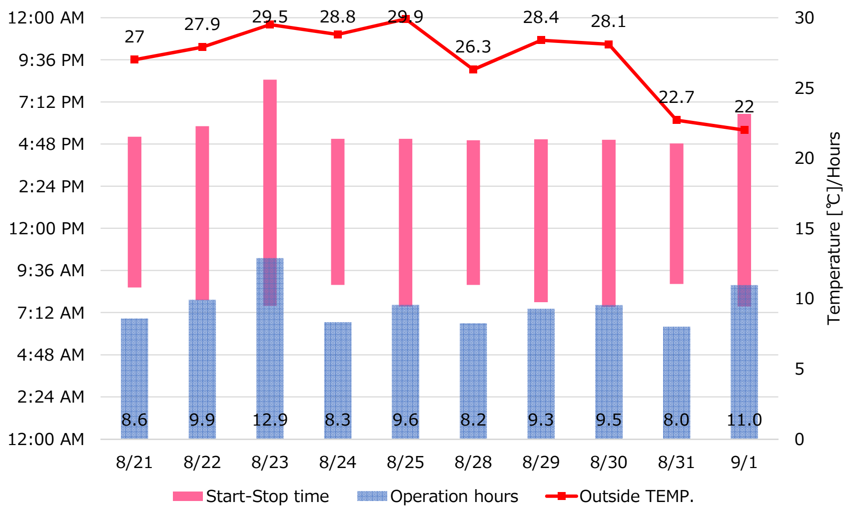

Figure 4.7-5 Operating hours in the cooling operation (#21Sagami)

Figures 4.7-6 and 4.7-7 show the comparisons in the heating operation from Dec 4th to 15th. The results show that #11 in Sendai which had been on all the time during the cooling operation turned off the air conditioners in the heating operation. Also, there is a possibility that the machine is operated all night on December 14th; an operation started at 7:37 a.m. on the 14th and it stopped at 8:44 p.m. on the 15th. People in #12 in Sapporo turned on and off frequently as they went in and out. Although no correlation was found between the outside air temperature and the operating time from the results, we detected unnecessary operations. Warnings should be given to the users about the operations including forgetting to turn off.

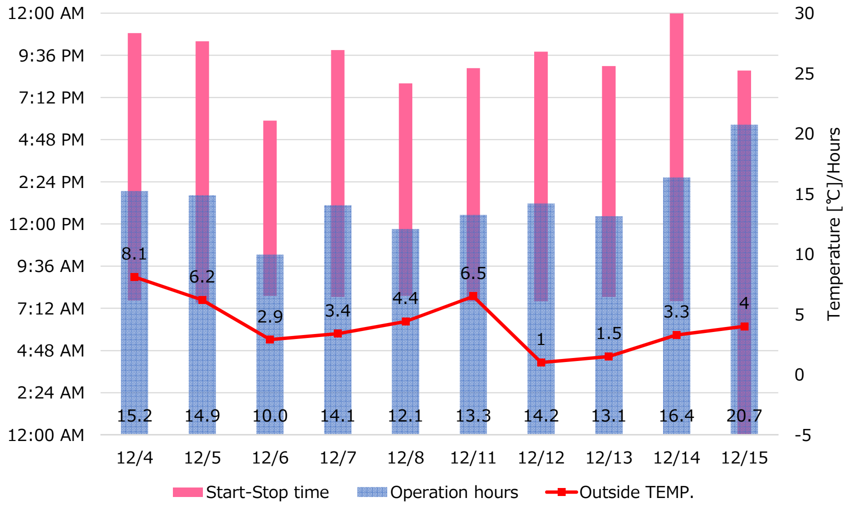

Figure 4.7-6 Operating hours in the heating operation (#11Sendai)

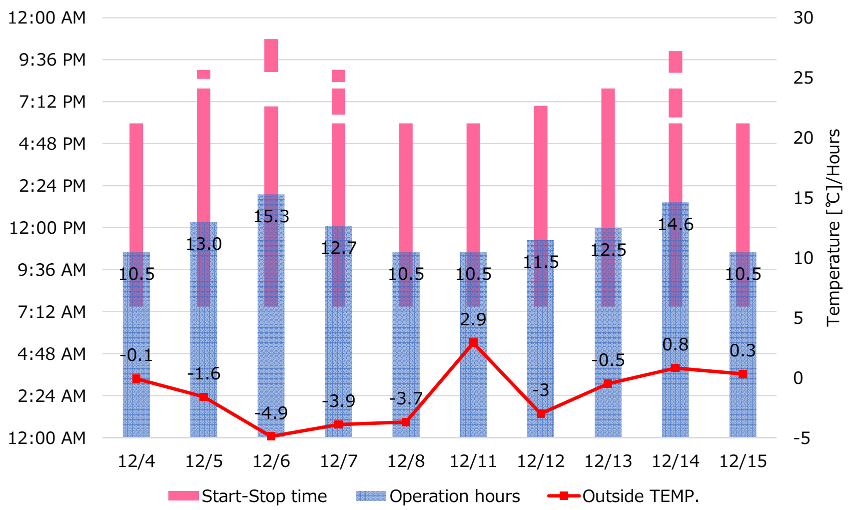

Figure 4.7-7 Operating hours in the heating operation (#12Sapporo)

4.8 On-off cycles of compressors

On-off cycles of compressors and COP values to the times at each point during the cooling and heating operations are shown in Figures 4.8-1 to 4.8-4. Average on-off cycle intervals are shown in Table 4.8-1. The data is from August 21st to 25th and from December 18th to 22nd and the time is from 8 a.m. to 4 a.m. when the compressors were in operation.

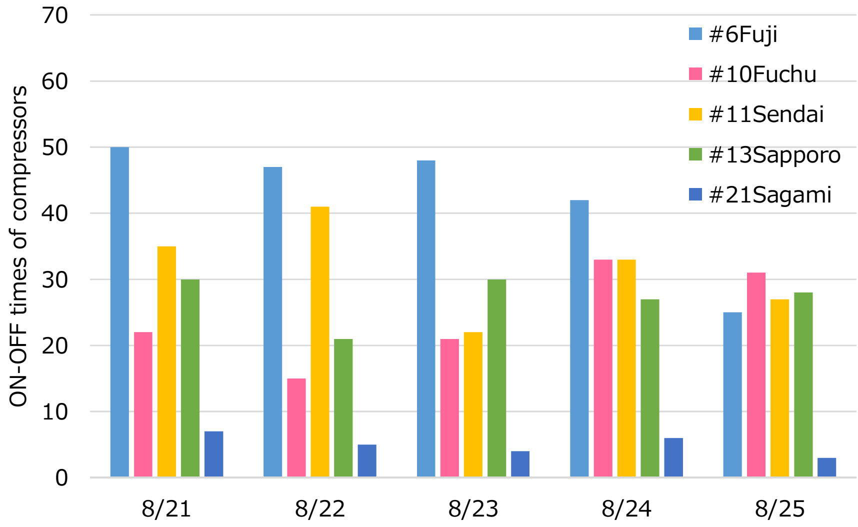

Figure 4.8-1 On-off cycles of compressors in the cooling operation

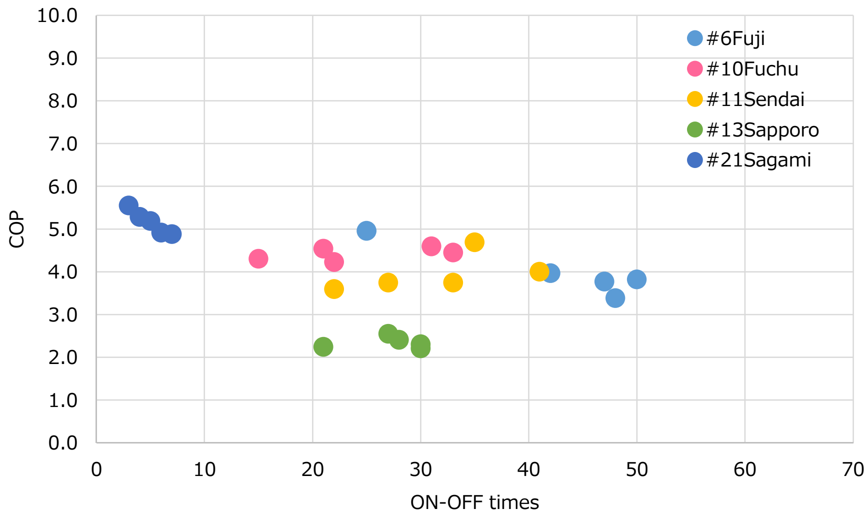

Figure 4.8-2 COP to on-off cycles in the cooling operation

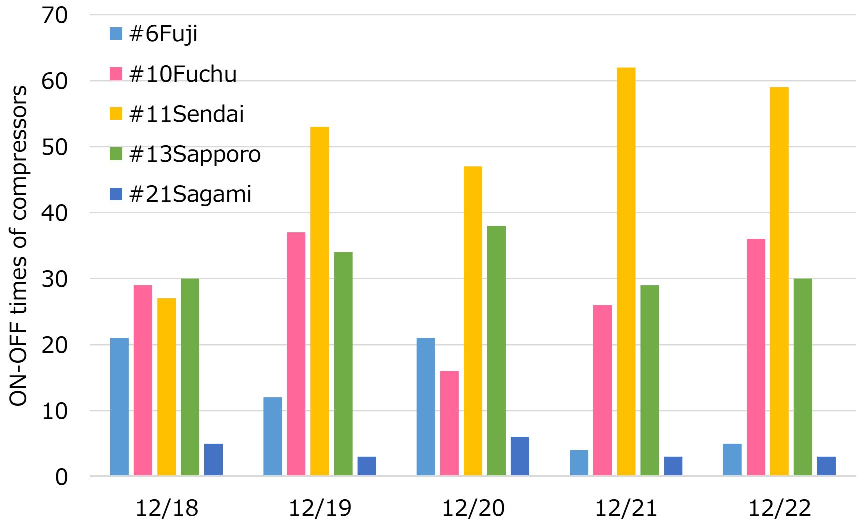

Figure 4.8-3 On-off cycles of compressors in the heating operation

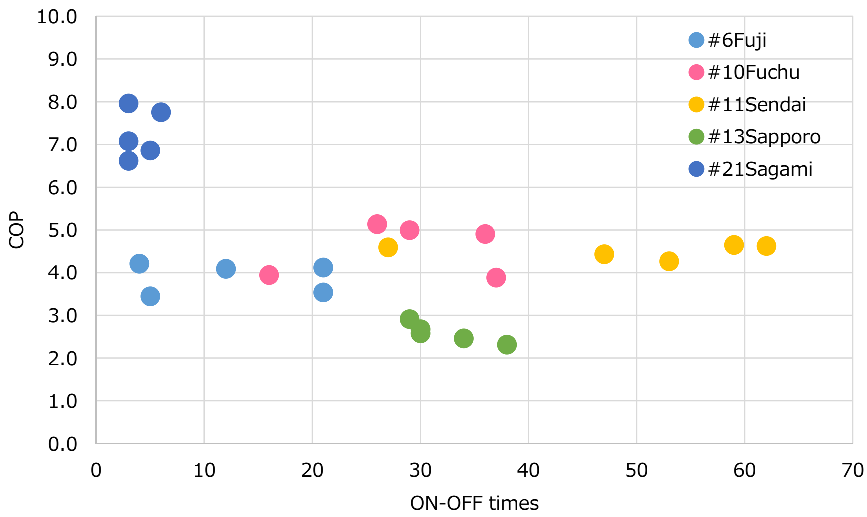

Figure 4.8-4 COP to on-off cycles in the heating operation

ONs and OFFs are repeated every 12-minute in Fuji in the cooling operation and every 11-minute in Sendai in the heating operation. Sagami's time intervals are relatively longer and COP values are higher in the heating operation. Except for Sagami in the heating operation, there is no obvious changes in COP values. As frequent on-off cycles of compressors will lead to energy consumption increases and durability decreases of equipment, management should be applied.

Table 4.8-1 Average ON-OFF time intervals

Operations	#6Fuji	#10Fuchu	#11Sendai	#13Sapporo	#21Sagami
Cooling	12 min	21 min	16 min	18 min	105 min
Heating	60 min	18 min	11 min	32 min	131 min

4.9 Suction temperature of outdoor units

A short circuit is a major problem for air conditioners. Figure 4.9-1 shows an image of a short circuit. Exhaust heat of outdoor units gets into the suction sides because of obstacles including walls and it causes low efficiency.

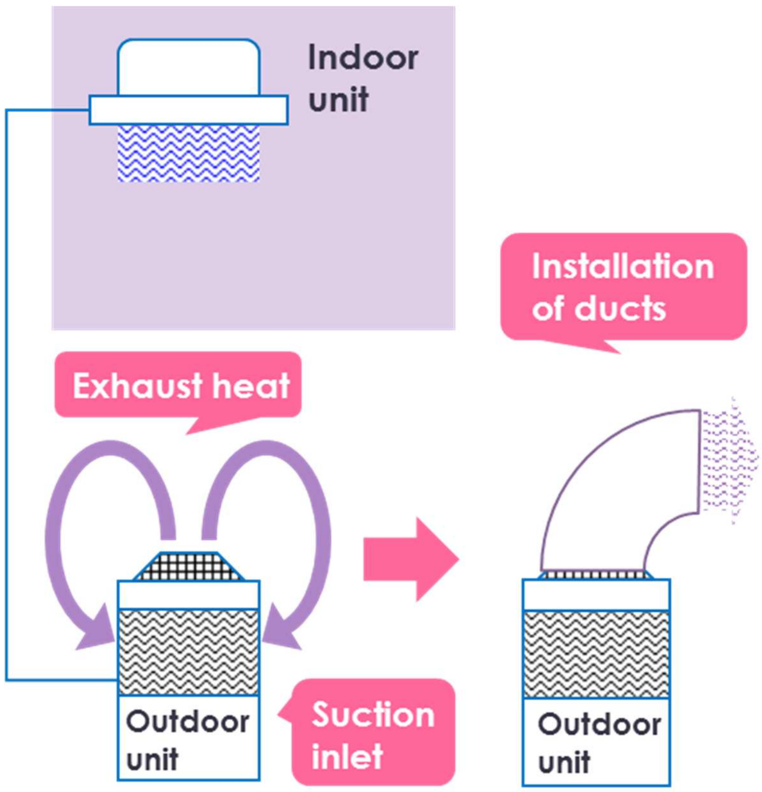

Figure 4.9-1 Image of a short circuit

Figures 4.9-2 and 4.9-3 show average suction temperature of outdoor units at each site in both cooling and heating operations. As #10 in Fuchu records the highest suction temperature of 34.6℃, it is possible that there is an influence of a short circuit. Installation of exhaust hoods should be advised to users.

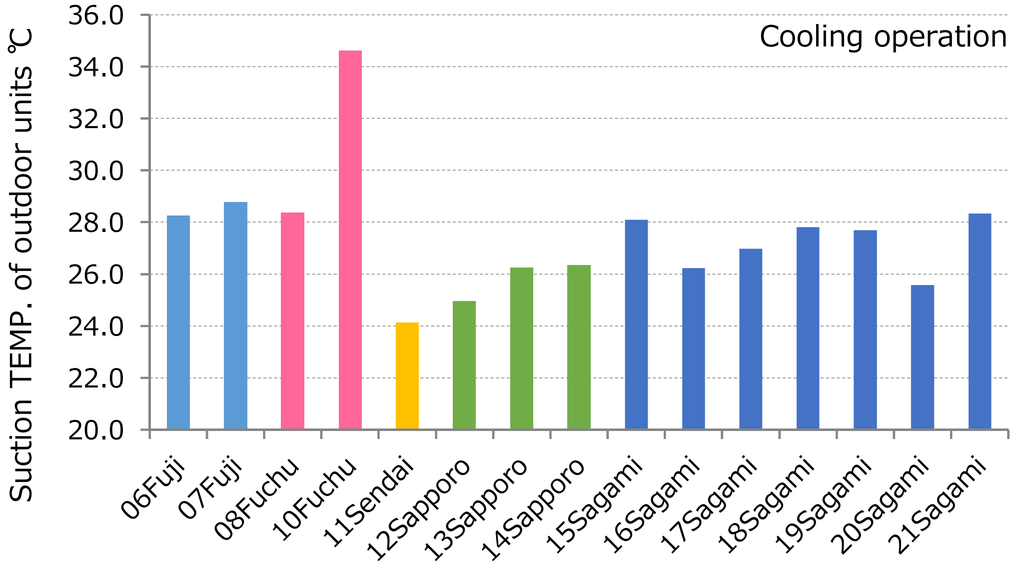

Figure 4.9-2 Avg. suction temperature of outdoor units in the cooling operation

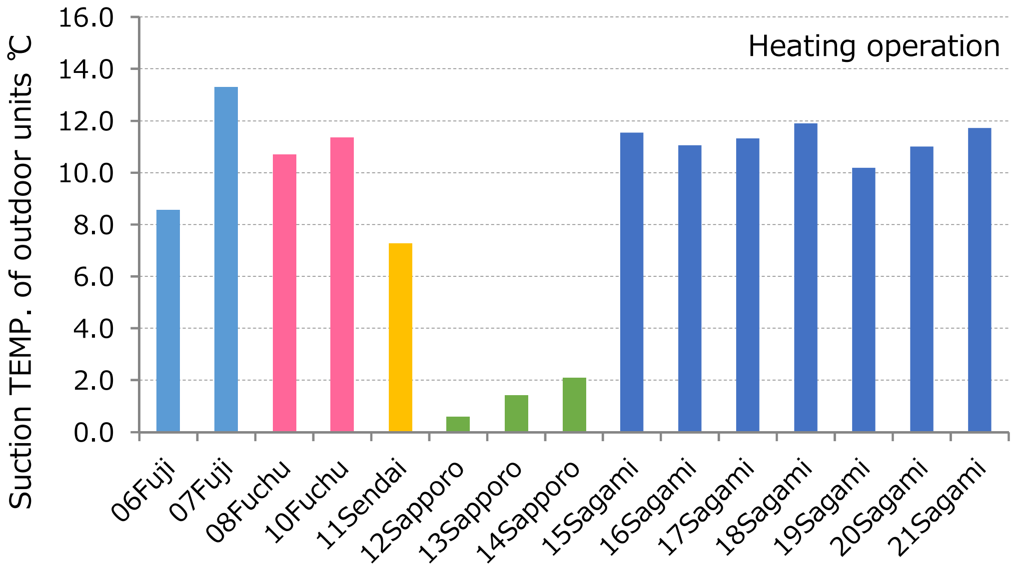

Figure 4.9-3 Avg. suction temperature of outdoor units in the heating operation

In order to analyse the influence of installation conditions of outdoor units, deviation values of suction temperature of outdoor units and average outside temperature in Sapporo and Sendai were compared as shown in Figure 4.9-4. Data from August 21st to September 1st except weekend and the average temperature of the Meteorological Agency are used. Sapporo's #12 and #13 show the similar trends and temperature deviation was 3℃ to 5℃. On the other hand, Sendai's #11 mostly remained at 1℃ to 2℃. Figure 4.9-5 shows the locations of Sendai and Sapporo outdoor units. The outdoor unit of Sendai is installed on a 3-story rooftop and there are no obstacles with excellent installation conditions. As outdoor units of Sapporo face the wall, there is a possibility that high exhaust temperature causes short circuits. Advice including installation of exhaust hoods should be given to the users.

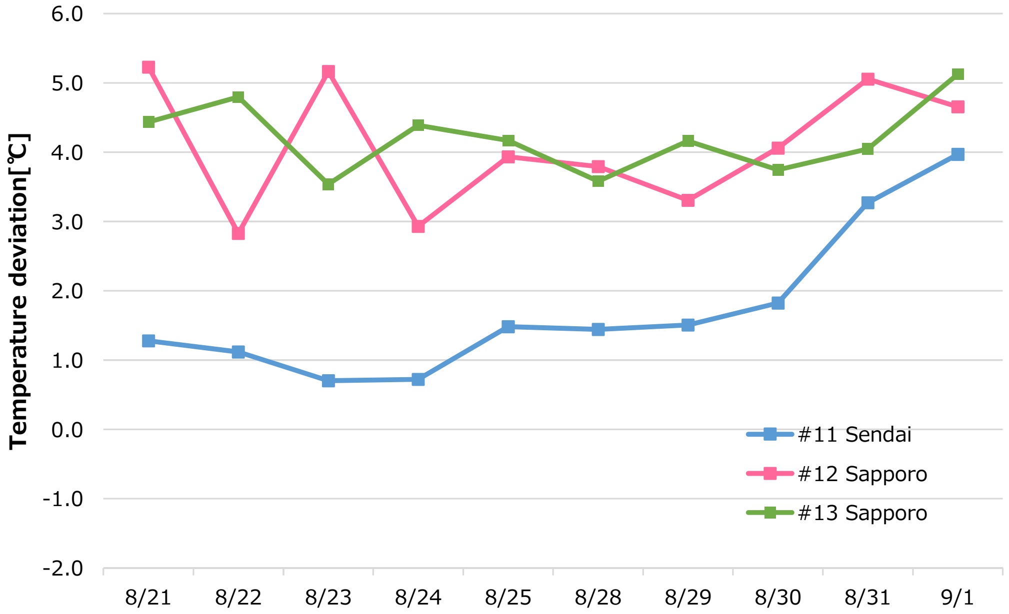

Figure 4.9-4 Temperature deviation of outdoor-unit suction and outside temperatures

Figure 4.9-5 Installation conditions in Sendai and Sapporo

4.10 Power consumption per floor area

Figures 4.10-1 and 4.10-2 show power consumption per floor area in the cooling and heating operations. Table 4.10-1 shows air conditioned floor area, power consumption and the calculation results. Power consumption per floor area in #13 in Sapporo is the highest which is 16kWh/m^2 in the cooling operation and #8 in Fuchu which is 17kWh/m^2 is the highest in the heating operation. #19 and 20 in Sagami are not in operation in the cooling operation. Warnings should be given to the users.

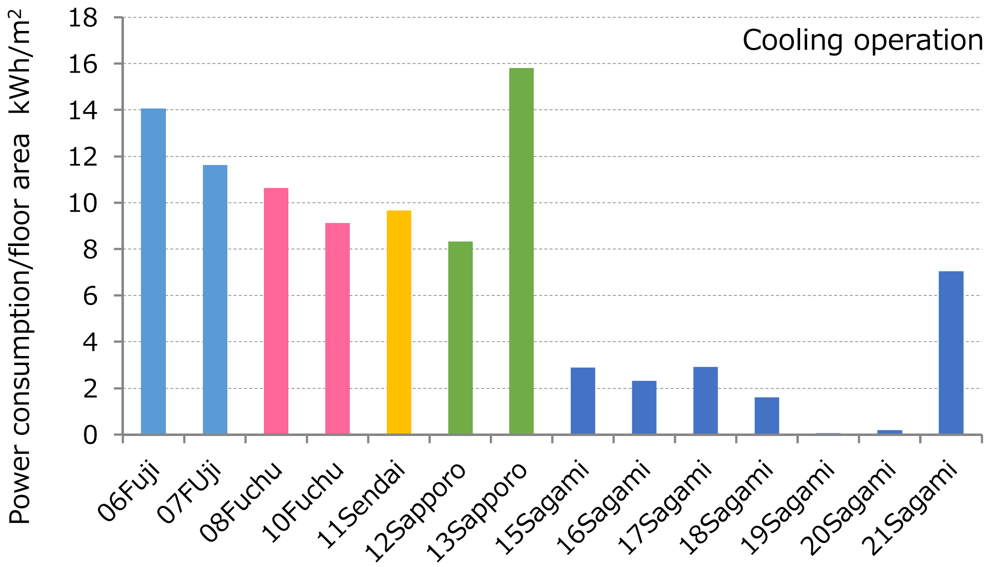

Figure 4.10-1 Power consumption per floor area in the cooling operation

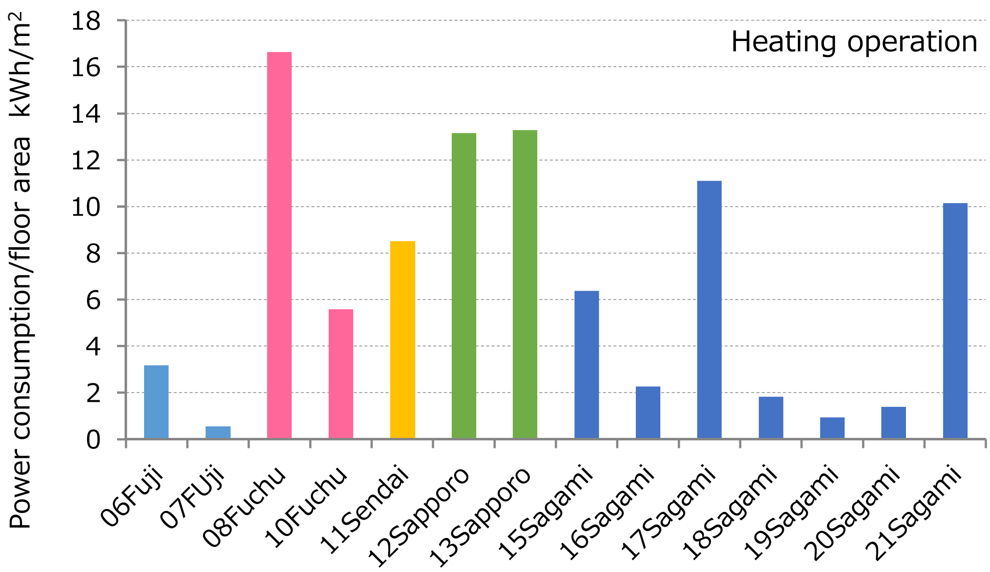

Figure 4.10-2 Power consumption per floor area in the heating operation

Table 4.10-1 Power consumption per floor area

Locations	Air conditioned floor area (m^2)	Power consumption (kWh)		Power consumption per floor area (kWh/m^2)	
		Cooling	Heating	Cooling	Heating
#6Fuji	64	904	203	14	3
#7Fuji	64	747	35	12	1
#8Fuchu	200	2125	3324	11	17
#10Fuchu	80	729	446	9	6
#11Sendai	148	1425	1257	10	9
#12Sapporo	82	682	1079	8	13
#13Sapporo	217	3431	2879	16	13
#14Sapporo	unknown				
#15Sagami	198	569	1259	3	6
#16Sagami	165	384	375	2	2
#17Sagami	337	983	3744	3	11
#18Sagami	416	669	763	2	2
#19Sagami	410	28	382	0	1
#20Sagami	380	73	527	0	1
#21Sagami	72	507	730	7	10

4.11 Results

The field data analysis revealed various problems including low load and low efficient operations, inappropriate temperature settings, unnecessary operations, excessive installed capacities and short circuits. Reporting these actual operations to users is a key to energy conservation. Examples of advice and messages to users considering the Nudge theory are shown in Table 4.11-1.

Table 4.11-1 Advice and messages to users

No	Causes of energy waste	Advice	Messages
		For users, building operators and designers	
1	Low load operation with excessive equipment	●Recognition of excessed equipment and reconsideration for the next replacement ●Optimum installed capacity selection	"Installed capacity of the air conditioner is too excessive." "Reconsider the capacity at the next replacement"
2	Inappropriate temperature presets	Adequate temperature settings	"Temperature preset is too high (low). Please set to 26 ℃ (22 ℃)." "Because the temperature presets is too high (low), you are making a loss of ¥300."
3	Unnecessary operations	Advice not to forget to turn off air conditioners	"Three hours have passed since the start of operation. " "The total operation time was 6 hours and 20 minutes yesterday. " "Don't forget to turn off the air conditioners. "
4	Frequent on-off cycles of outdoor units	●Excessive installed capacity and capacity optimization at replacement ●Present extraordinary ONs and OFFs	"Compressors of the air conditioner started 50 times today. " "Installed capacity of the air conditioner is too excessive. "
5	High suction air temperature of outdoor units	Improvement of installation environment of outdoor units and installation of exhaust hood	"As the outdoor unit installation environment is bad, consider installing an exhaust hood. "
6	High power consumption per floor area	Calls for power savings	"Save electricity as power consumption is high."

5 CO_2 reduction effect by the system

Energy-saving controls were carried out using the data obtained in the system and the reduction rate of electric energy amount was calculated. CO_2 reduction amount by spreading the system was also estimated. Additionally, a thermal comfort survey was carried out when energy-saving controls were in operation.

5.1 Automatic control operation

Currently, advising proper temperature settings, adding demand control systems, and replacing to new models are main methods for energy-saving approaches. By utilizing online measurement data developed in this project, it is possible to realize efficient operation of VRF systems. An output control device is added for energy-saving controls. After obtaining data on the system, low efficient operation and excessive capacity are detected and send signals to the device for adjusting output. And then energy-saving controls are applied for high efficient operations as shown in Figure 5.1-1.

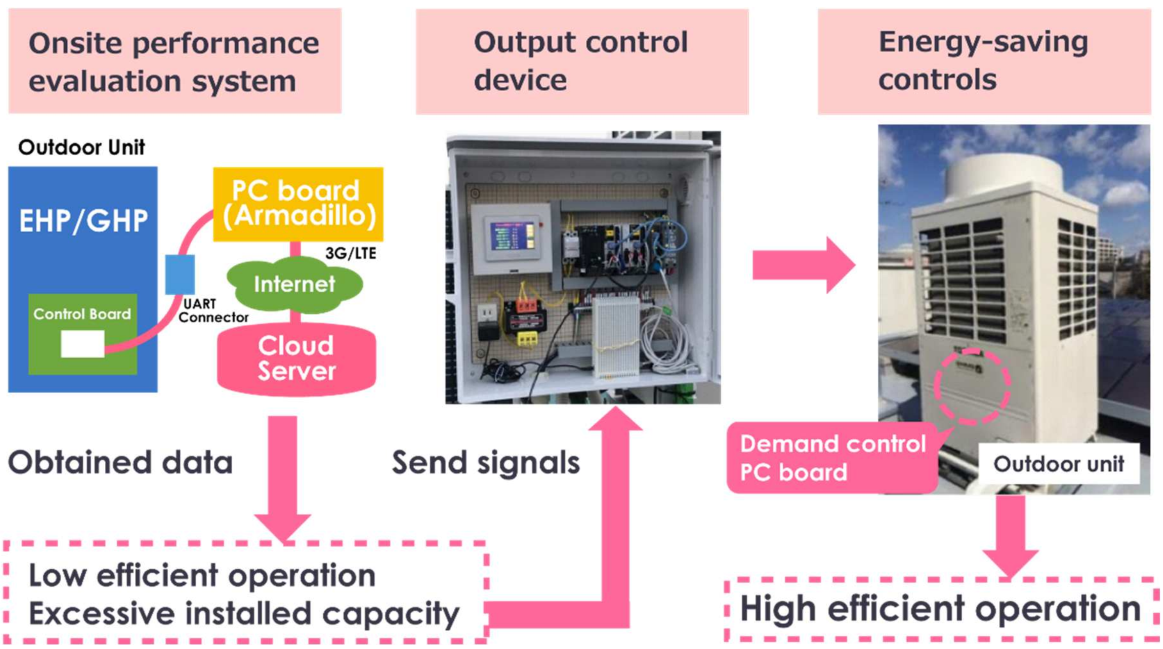

Figure 5.1-1 Concepts of energy-saving by automatic control operation

The experiment was carried out at a university's workshop in Sagami which has 3 outdoor units. The building and the plan of the university building are shown in Figures 5.1-2 and 5.1-3. Air-conditioning capacities are 12HP for AC1 and AC3 and 10HP for AC2. The experiment period is December 1st to 14th in 2017.

Figure 5.1-2 University building

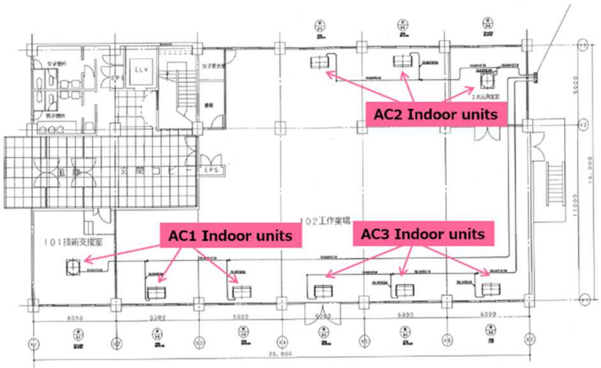

Figure 5.1-3 Plan of the university building

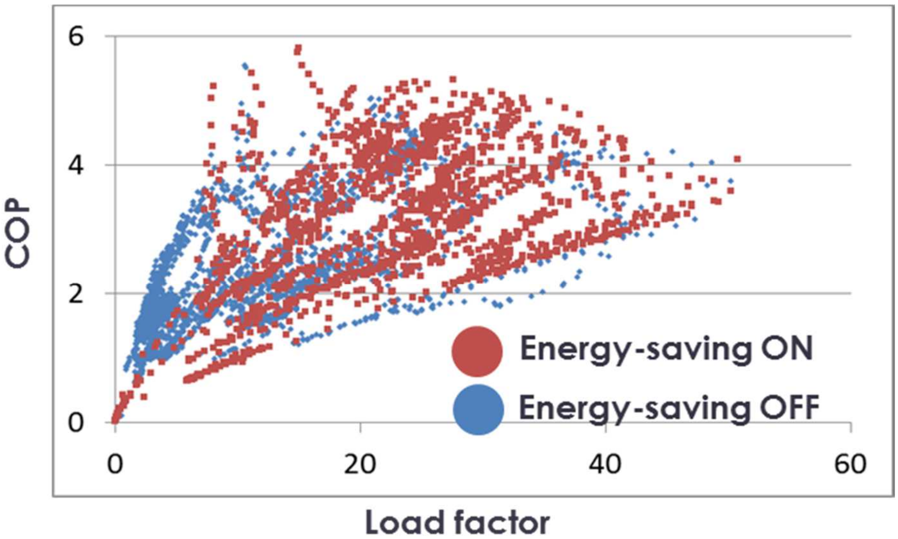

Figure 5.1-4 COP and load factor in Sagami

According to COP evaluation as shown in Figure 5.1-4, average COP values are 2.1 without the control and 3.1 with the control. Electricity is reduced when controls are ON as shown in Table 5.1-1. Average CO_2 reduction rate is 23.9%. It was found that a certain energy-saving effect was obtained by restraining the room temperature.

Table 5.1-1 Experimental results of automatic control operation

Outdoor unit	Energy-saving OFF			Energy-saving ON			CO2 reduction amount (kg-CO2)	Reduction rate	Operating hours
	Electric energy (kWh)	Outside air TEMP. (℃)	Room TEMP. (℃)	Electric energy (kWh)	Outside air TEMP. (℃)	Room TEMP. (℃)			
A C 1	16.3	9.1	28.7	12.1	8.6	27.9	2.0	**25.8%**	8:00～16:00
A C 2	3.5	10.7	26.2	2.7	10.1	26.7	0.4	**22.9%**	12:00～14:00
A C 3	3.5	9.7	28.5	2.7	10.8	29.3	0.4	**22.9%**	11:00～12:30

5.2 Cost-effectiveness

5.2.1 Estimation of CO_2 reduction amount

Annual production of VRF systems is shown in Table 5.2.1-1. World demand has been growing as well as Japan's demand which is about 130 thousand units according to The Japan Refrigeration and Air Conditioning Industry Association.

Table 5.2.1-1 Annual production of VRF systems

Year	2012	2013	2014	2015	2016
World total	994,000	1,104,000	1,180,000	1,156,000	1,312,000
Japan	125,000	126,000	134,000	129,000	131,000

CO_2 reduction amount was calculated as shown in (13) to (17). Values used for the calculation are shown in Table 5.2.1-2. The full load equivalent operating time is 635h/year in cooling operation and 500h/year(16) in heating operation, and CO_2 conversion factor is 0.486kg-CO_2/kWh(17). Also, we consider electric air conditioners with 36kW-capacity (cooling rated power consumption 11.9kW, heating 10.2kW) for the calculation. Based on the result of energy-saving controls, it is calculated with a reduction rate of 20%. Additionally, reduction due to building renewal is not included and we consider the average lifespan of an air conditioner as 15 years(18). Annual CO_2 reduction amount per unit will be 1.2 tons.

*635h/year * 11.9kW = 7569.2kWh/year* (Cooling operation) (13)

*500h/year * 10.2kW = 5095kWh/year* (Heating operation) (14)

7569.2kWh/year + 5095kWh/year = 12664.2kWh/year (Power usage) (15)

*12664.2kWh/year * 0.2 (20% reduction) = 2532.8kWh/year* (16)

*2532.8kWh/year * 0.486kg-CO_2/kWh = 1.23t-CO_2/year* (17)

Table 5.2.1-2 Values used for the CO_2 reduction amount calculation

Operations	Cooling operation	Heating operation
Full load equivalent operating time	635h/year	500h/year
Air conditioning capacity (EHP 36 kW)	11.9kW	10.2kW
Reduction rate	20%	
CO_2 conversion factor	0.486kg-CO_2/kWh	

Accordingly, CO_2 reduction amount in 2018, 2025 and 2030 are estimated. The results are shown in Table 5.2.1-3 and (18) to (20). The predicted number of this device will be 13 thousand units in 2018, 468 thousand units in 2025 and over 1 million units in 2030 as we assummed 10% of the annual production in 2018 and 100% in 2027 (10% increases every year). As a result, the total CO_2 reduction amount will be 15 thousand t-CO_2 in 2018, 561 thousand t-CO_2 by 2025 and over 1.3 million t-CO_2 by 2030.

$$1.2 t\text{-}CO_2/year * 13000 = 15600\ t\text{-}CO_2 \quad (18)$$

$$1.2 t\text{-}CO_2/year * 468000 = 561600\ t\text{-}CO_2 \quad (19)$$

$$1.2 t\text{-}CO_2/year * 1105000 = 1326000\ t\text{-}CO_2 \quad (20)$$

Table 5.2.1-3 Estimation of total CO_2 reduction amount

Year	2018	2025	2030
Predicted spread number of the system	13,000	468,000	1,105,000
CO_2 reduction amount / unit / year	1.2 t-CO_2	1.2 t-CO_2	1.2 t-CO_2
Total CO_2 reduction amount	15,600 t-CO_2	561,600 t-CO_2	1,326,000 t-CO_2

5.2.2 Estimation of cost-effectiveness

Cost-effectiveness as verification of CO_2 reduction effect was quantified. Annual cost including the Internet is about 5000 Japanese yen. We calculated the cost-effectiveness per t-CO_2 divided by CO_2 reduction amount per unit per year as shown in (21).

$$¥5000/year * year/1.23\ t\text{-}CO_2 = ¥4000/t\text{-}CO_2 \quad (21)$$

5.2.3 Comparison with other projects

Cost-effectiveness examples of other projects[19] are shown in Table 5.2.3-1. Compared with other cases, the present project is apparently cost-effective.

Table 5.2.3-1 Examples of other projects

Examples of other projects	Number of cases	Expenses
Waste energy projects	12	¥17,000/t-CO_2
Renewable energy projects	12	¥233,000/t-CO_2
Energy-saving technology of housing and building projects	57	¥20,000/t-CO_2

5.3 Thermal comfort survey

The number of VRF systems having energy-saving controls are increasing for electricity peak shaving. Although energy consumption is reduced by the operations, the quality of air evaluation has not been paid attention to. This section discusses thermal comfort on energy-saving controls which were carried out in the combination of the following three controls.

1. Evaporation and condensation temperature controls to suppress engine speed by changing the target evaporation and condensation temperatures
2. Maximum capacity limit control that limits the maximum engine speed
3. Engine speed control to suppress the engine speed by indoor unit suction temperature and temperature presets.

As shown in Table 5.3-1, users can select energy-saving levels from the room temperature threshold. Reduction amount of primary energy consumption during the cooling period was 25% at the maximum[20].

Table 5.3-1 Threshold temperatures of each energy-saving level (Cooling)

Energy-saving levels	Target energy-saving rate	Threshold temperature
Level 1	10 %	27℃
Level 2	20 %	26℃
Level 3	30 %	25℃

5.3.1 Outline of the building and equipment

Thermal comfort surveys were conducted in a three-story office building in Osaka City shown in Table 5.3.1-1. The equipment used for the measurement is the latest type GHP XAIR II machine and three types of indoor units with different outputs are installed for one outdoor unit including four units of 5.6 kW, six units of 7.1 kW and one unit of 9.0 kW. Installed capacity in cooling operation is 168W/m2. The specifications of outdoor units and indoor units are shown in Tables 5.3.1-2 and 5.3.1-3. Photos of the site are shown in Figure 5.3.1-1.

Table 5.3.1-1 Overview of the building

Address	Osaka
Scale	3 stories
Structure	RC structure
Use	Office
Air conditioning area	333 m^2

Table 5.3.1-2 Specification of the outdoor units

Gas	13A
Refrigerant	R410A
Rated capacity (Cooling/Heating)	56.0/63.0kW
Rated gas consumption (Cooling/Heating)	49.3/46.0kW
Rated energy consumption (Cooling/Heating)	0.914/0.628kW
Rated gas engine output	12.4 kW

Table 5.3.1-3 Specification of the indoor units

Cooling capacity	Heating capacity	Types	Number of units
5.6kW	6.3 kW	2-way ceiling cassette	4
7.1kW	8.0 kW	4-way ceiling cassette	6
9.0kW	10.0 kW	Ceiling embedded duct	1

Figure 5.3.1-1 Photos of the site

5.3.2 Temperature presets of indoor units

Figure 5.3.2-1 shows the locations of the indoor units on the 3rd floor. There are 9 indoor units in the office and 2 indoor units in the elevator hall. Indoor unit temperature presets from 8 a.m. to 10 p.m. are attached to the appendices. Data of 9.0 kW machine is excluded and because 5.6 kW is impossible to specify, it is included in the data. During the cooling period, it was set to 24℃ from August 22nd to 25th, but it was changed from 24℃ to 25℃ on the 26th and changed to 24℃ again on the 27th. In the intermediate period, all indoor units were set to 25℃ except one 5.6 kW machine from November 14th to 19th. As the data was collected on the 16th, it was excluded from the analysis. In the heating period, changes from 23℃ to 24℃ were repeatedly seen from January 30th to February 1st and all indoor units were set at 23℃ from 2nd to 4th.

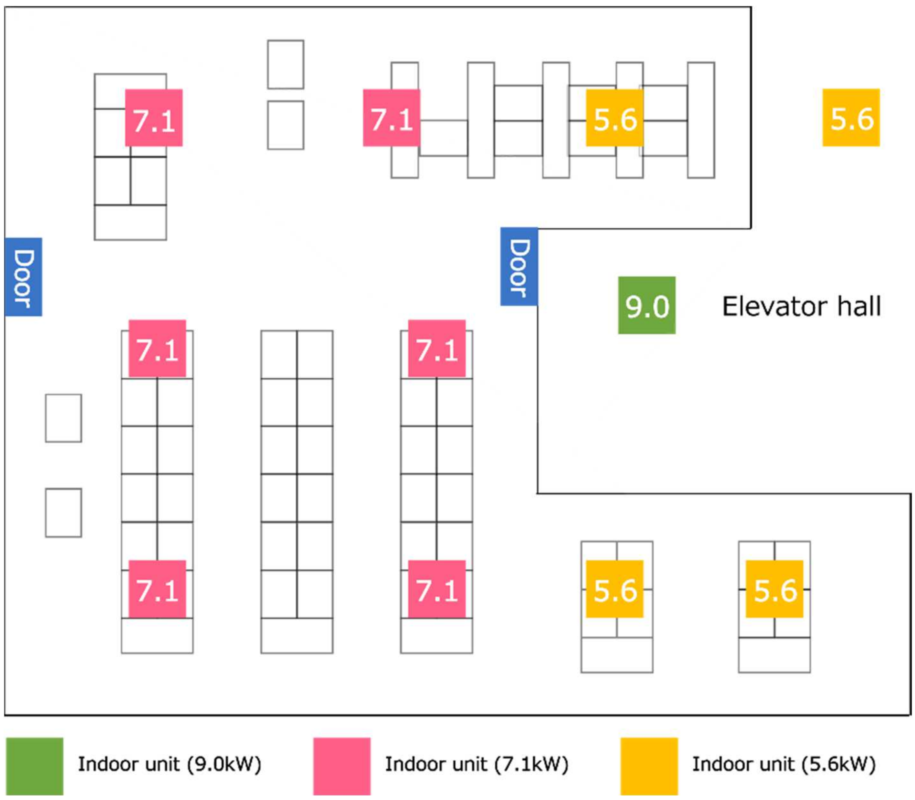

Figure 5.3.2-1 Locations of indoor units

5.3.3 Results of thermal comfort survey

We conducted surveys on employees in the cooling, intermediate and heating periods to find out the actual condition of thermal comfort due to energy-saving controls. The business day of this office is Monday through Saturday and business hours are from 8 a.m. to 10 p.m. There are approximately 60 employees, and around 50 people works away from the office and around 10 people work in the office. Survey contents are in Table 5.3.3-1 and a survey form is attached to the appendices as an example.

Table 5.3.3-1 Survey contents

Survey contents	Gender
	Age
	Work location
	Clothing
	Work contents
	Thermal sensation
	Humidity sensation
	Use of other equipment
	Cold draft
	Sunlight
	Heat source near working area
	Temperature adjustment

The periods of the surveys, number of respondents, number of copies and recovery rates are shown in Table 5.3.3-2. The survey was distributed 6 copies to per person and asked him/her to answer it at the end of the day. The recovery rate during the cooling period is 71.2%, the intermediate period is 33.3% and the heating period is 39.4%. Tables 5.3.3-3 to 5.3.3-5 show the survey results by gender and age.

Table 5.3.3-2 Summary of the survey results

Operation	Periods of survey	Number of respondents	Number of copies	Recovery rate
Cooling	2016/8/22(Mon)-27(Sat)	41	215	71.2%
Intermediate	2016/11/14(Mon)-19(Sat)	22	121	33.3%
Heating	2017/1/30(Mon)-2/4(Sat)	26	137	39.4%

Table 5.3.3-3 Survey results by gender and age in the cooling operation

	20s	30 s	40 s	50 s	60 s	Total
Male	6	10	7	7	1	31
Female	3	1	1	5	0	10
Total	9	11	8	12	1	41

Table 5.3.3-4 Survey results by gender and age in the intermediate operation

	20s	30 s	40 s	50 s	60 s	Total
Male	0	6	4	8	1	19
Female	1	0	1	1	0	3
Total	1	6	5	9	1	22

Table 5.3.3-5 Survey results by gender and age in the heating operation

	20s	30 s	40 s	50 s	60 s	Total
Male	2	5	6	6	1	20
Female	2	0	1	3	0	6
Total	4	5	7	9	1	26

Responses of temperature adjustment are shown in Tables 5.3.3-6 to 5.3.3-8. In the cooling period, many female respondents who work in the office reported "Put on a cardigan" and "Used a blanket". Also, many male respondents who work outside the office reported "Put a plastic bottle on neck", "Cooled head with water", "Put a wet towel around neck" and "Got working clothes off".

Table 5.3.3-6 Temperature adjustment in the cooling operation

Survey contents	Responses	Number of copies
Fans	Used	0
Objects that generate heat	Computer	5
Solar radiation	Got it directly	55
Temperature adjustment	Put on a cardigan	12
	Used a blanket	12
	Put a plastic bottle on neck	1
	Cooled head with water	1
	Put a wet towel around neck	1
	Got working clothes off	12

Table 5.3.3-7 Temperature adjustment in the intermediate operation

Survey contents	Responses	Number of copies
Objects that generate heat	Computer	11
Temperature adjustment	Put on a cardigan	5
	Used a blanket	5

Table 5.3.3-8 Temperature adjustment in the heating operation

Survey contents	Responses	Number of copies
Temperature adjustment	Used a heat pad	1
	Used a blanket	4

Figures 5.3.3-1 to 5.3.3-3 indicate the seats of respondents, the seats of those who reported to have cold draft, the location of indoor units, the location of temperature and humidity meters and the average values of temperature and humidity from 8 a.m. to 10 p.m. Regardless of the periods, there is no difference due to locations or energy-saving operation controls.

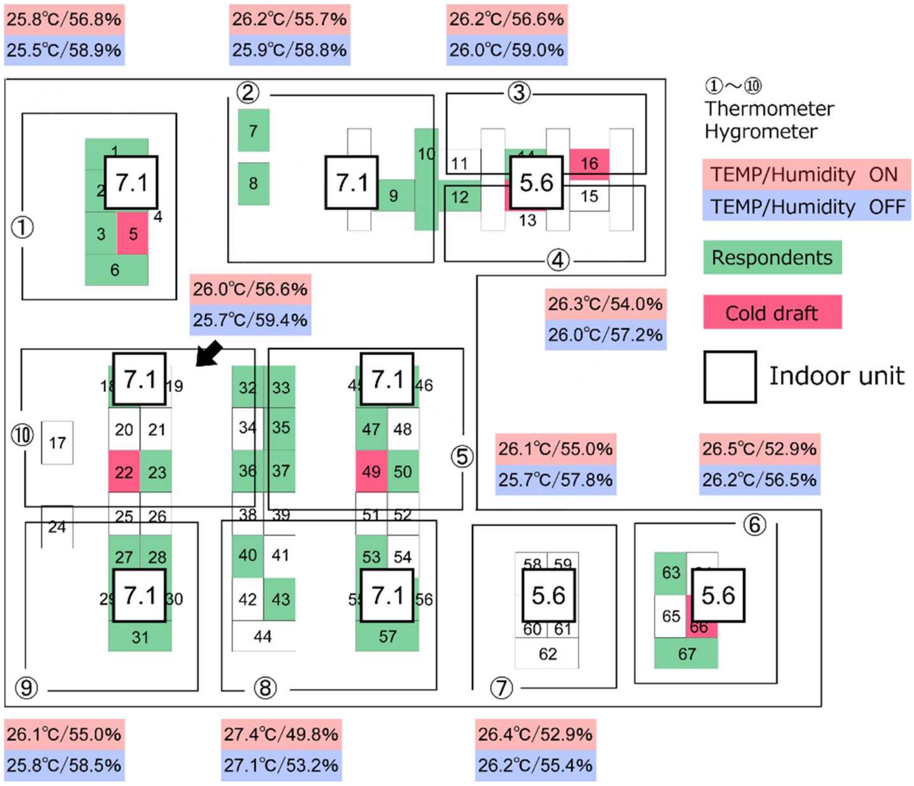

Figure 5.3.3-1 Floor plan and seating chart in the cooling operation

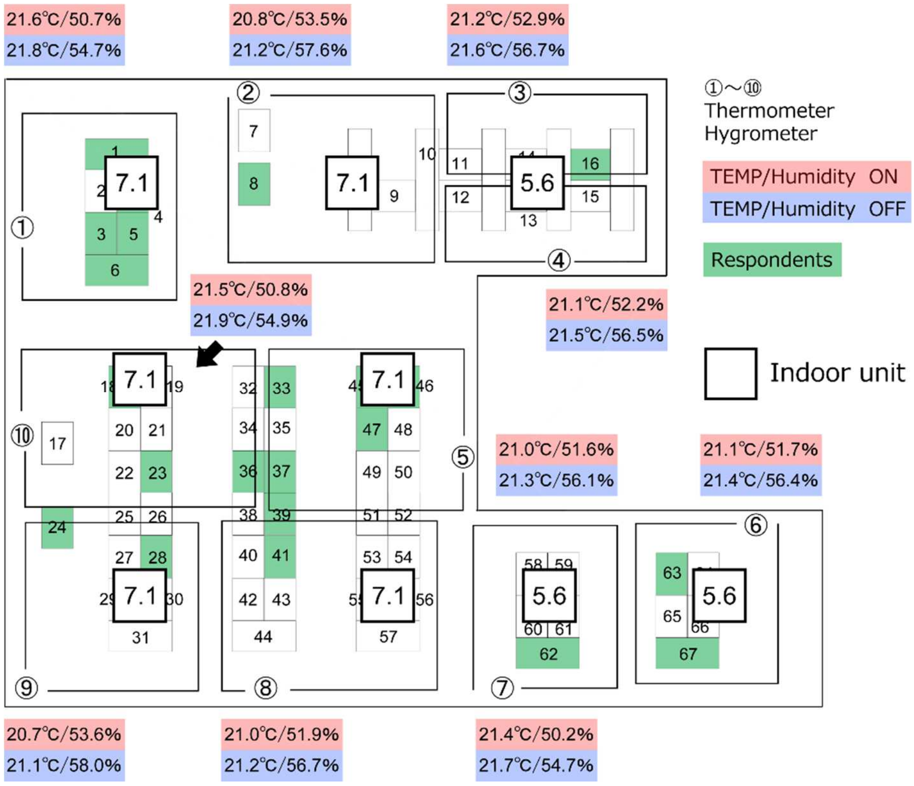

Figure 5.3.3-2 Floor plan and seating chart in the intermediate operation

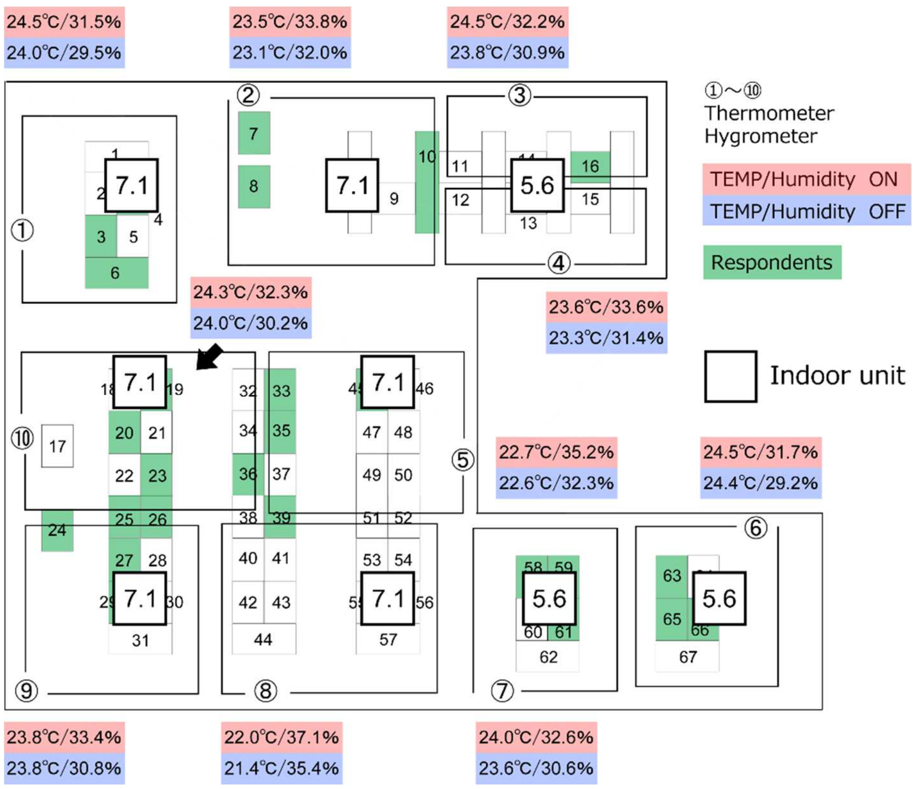

Figure 5.3.3-3 Floor plan and seating chart in the heating operation

Figures 5.3.3-4 and 5.3.3-5 show the results of thermal sensation survey during the cooling period. The rate of "Hot/Warm" and "Very humid/Humid" for both temperature and humidity is almost the same regardless of energy-saving operation control is ON or OFF.

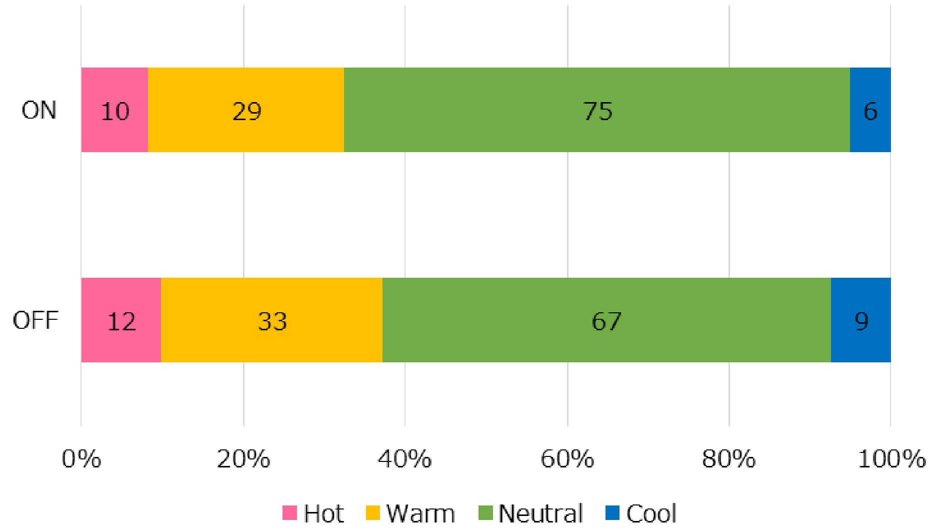

Figure 5.3.3-4 Energy-saving control ON/OFF - Temperature/Cooling

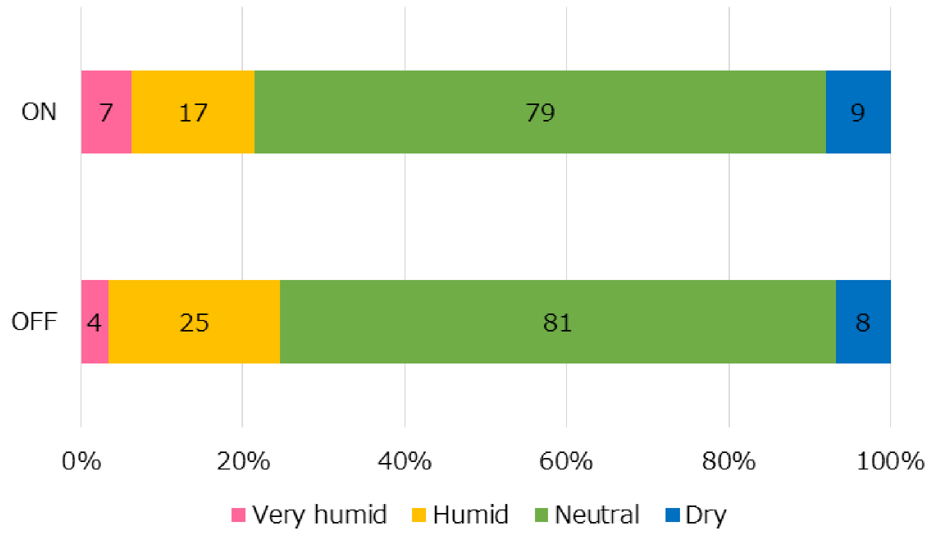

Figure 5.3.3-5 Energy-saving control ON/OFF - Humidity/Cooling

The results of thermal sensation for cold draft and energy-saving controls during the cooling period are shown in Figures 5.3.3-6 to 5.3.3-9. Regardless of whether a cold draft is present or not, many respondents report that they are comfortable when energy-saving controls are ON in both temperature and humidity.

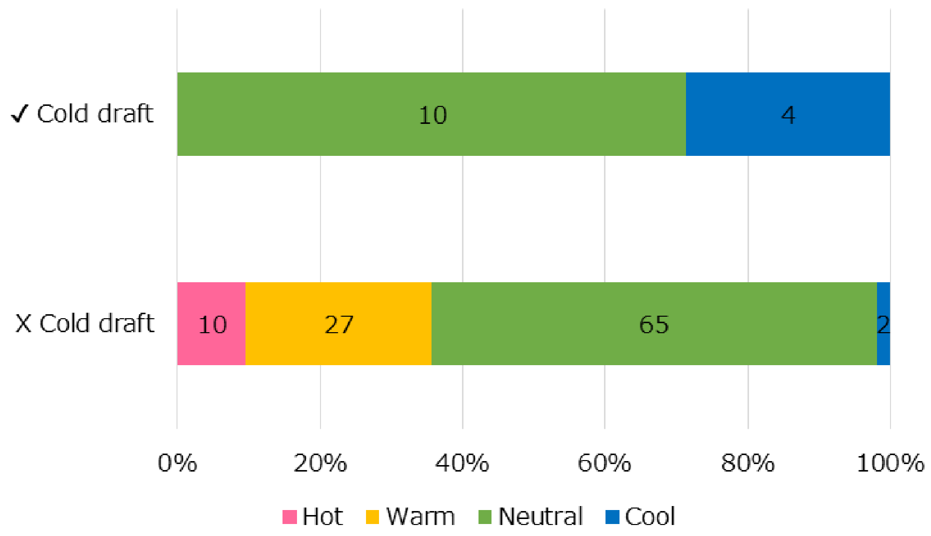

Figure 5.3.3-6 Temperature sensitivity by cold draft - Energy-saving control ON/Cooling

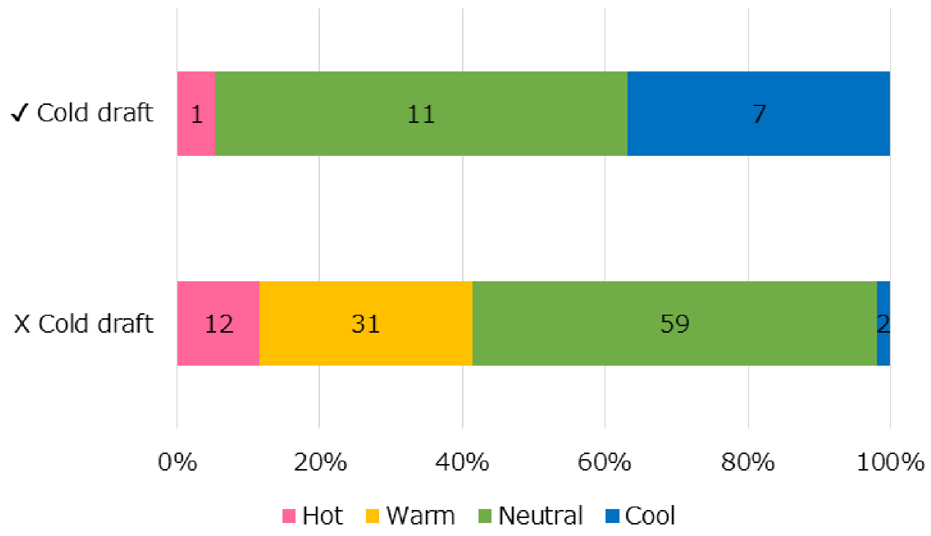

Figure 5.3.3-7 Temperature sensitivity by cold draft - Energy-saving control OFF/Cooling

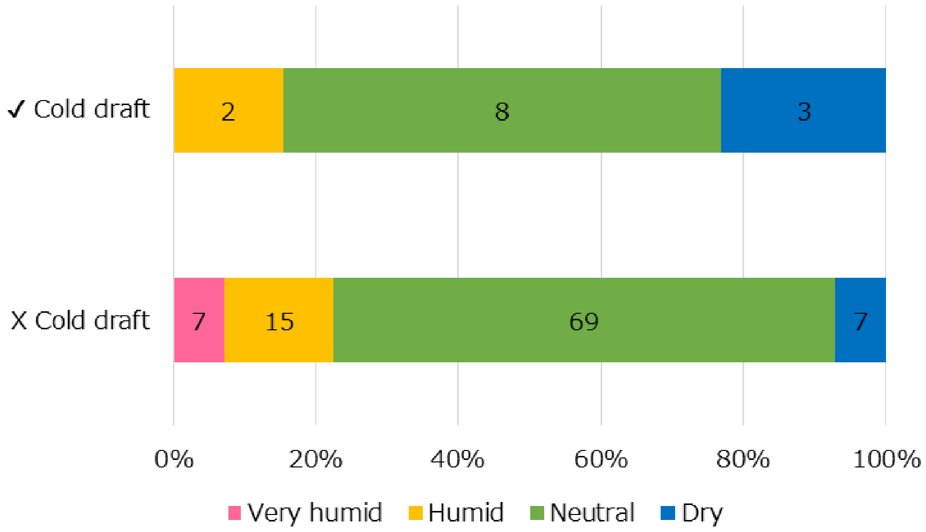

Figure 5.3.3-8 Humidity sensitivity by cold draft - Energy-saving control ON/Cooling

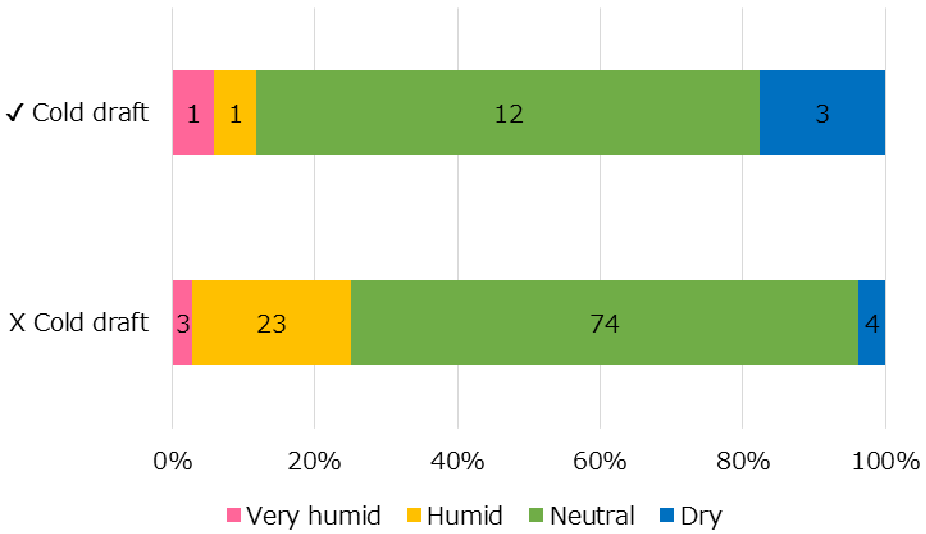

Figure 5.3.3-9 Humidity sensitivity by cold draft - Energy-saving control OFF/Cooling

The results of temperature and humidity by contents of work during the cooling period are shown in Figures 5.3.3-10 and 5.3.3-11. The results show that the office workers feel more comfortable compared to the outside workers.

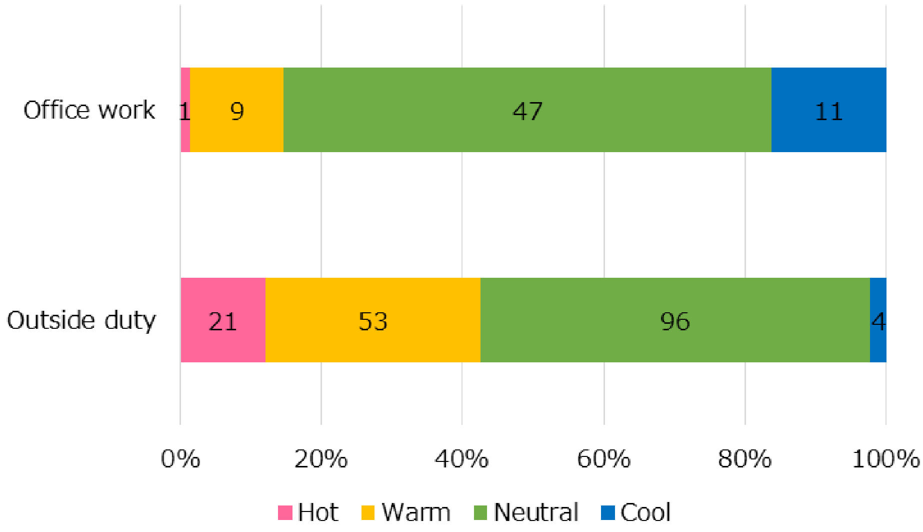

Figure 5.3.3-10 By contents of work - Temperature/Cooling

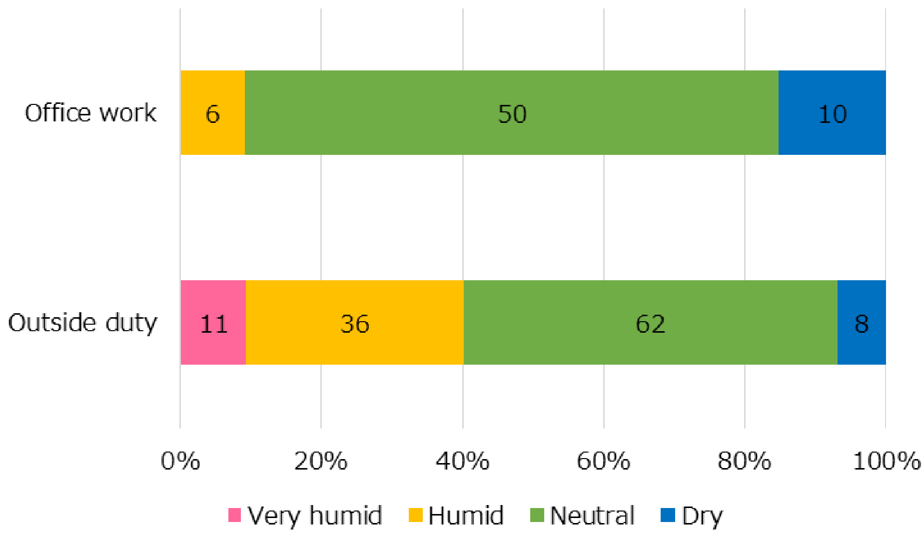

Figure 5.3.3-11 By contents of work - Humidity/Cooling

The results of temperature and humidity by age during the cooling period are shown in Figures 5.3.3-12 and 5.3.3-13. There is no correlation between the ages and the thermal sensation.

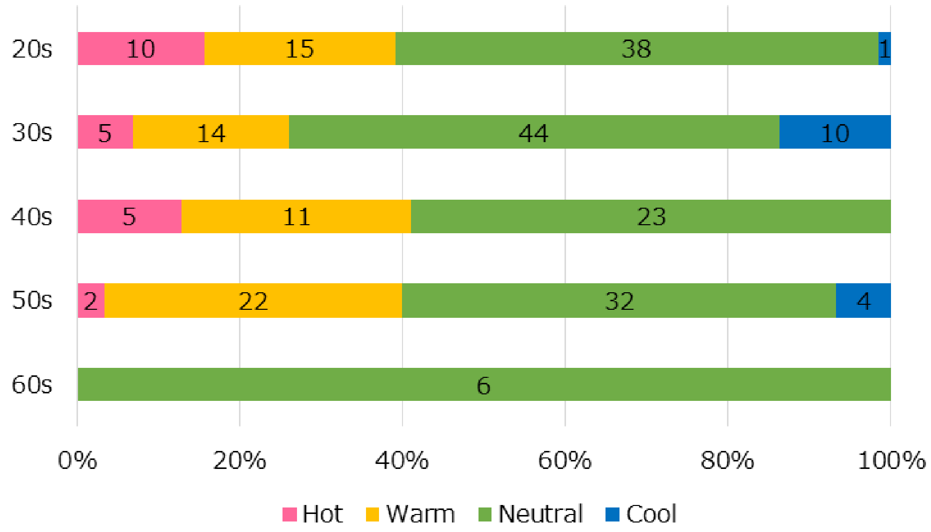

Figure 5.3.3-12 By age - Temperature/Cooling

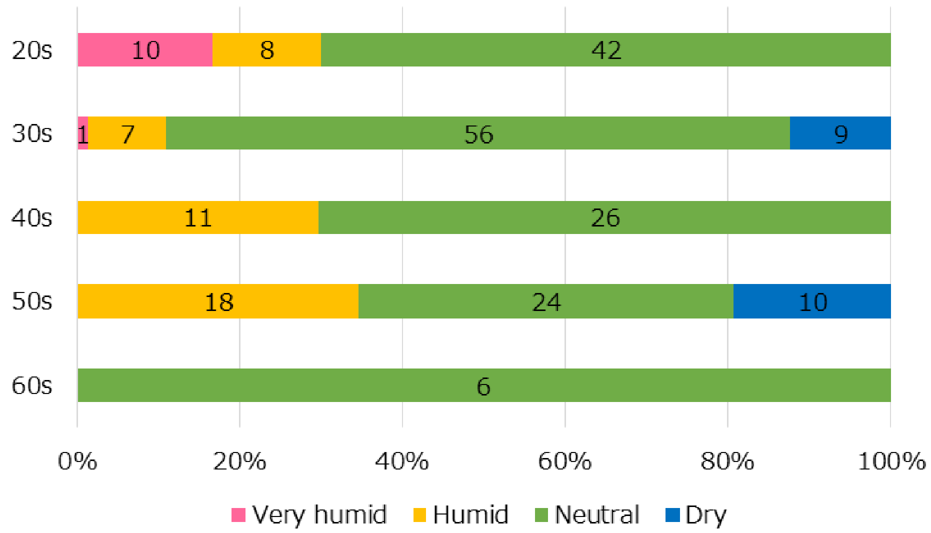

Figure 5.3.3-13 By age - Humidity/Cooling

The results of temperature and humidity by gender during the cooling period are shown in Figures 5.3.3-14 and 5.3.3-15. The rate of female workers who report comfort is larger. The major reason is that the majority of the outside workers are male who wear work clothes which have a large clo value. It will be discussed later in this section.

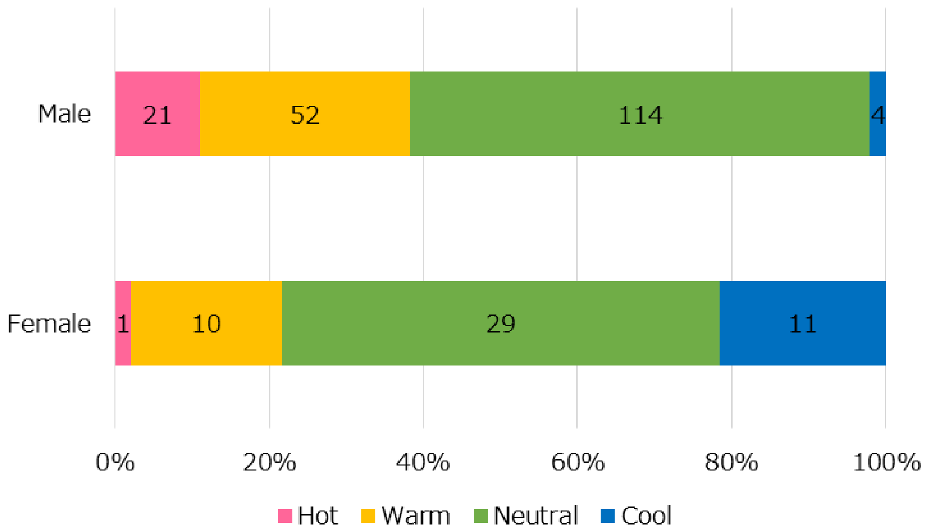

Figure 5.3.3-14 By gender - Temperature/Cooling

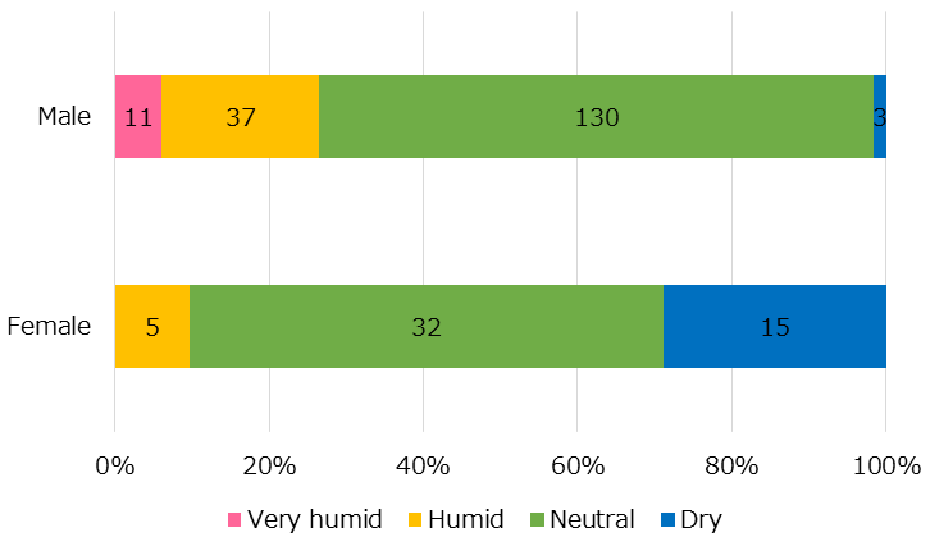

Figure 5.3.3-15 By gender - Humidity/Cooling

The results of the thermal sensation survey during the intermediate period are shown in Figures 5.3.3-16 and 5.3.3-17. Most respondents report "Neutral" and the results show that energy-saving operation controls have no effect on the thermal comfort.

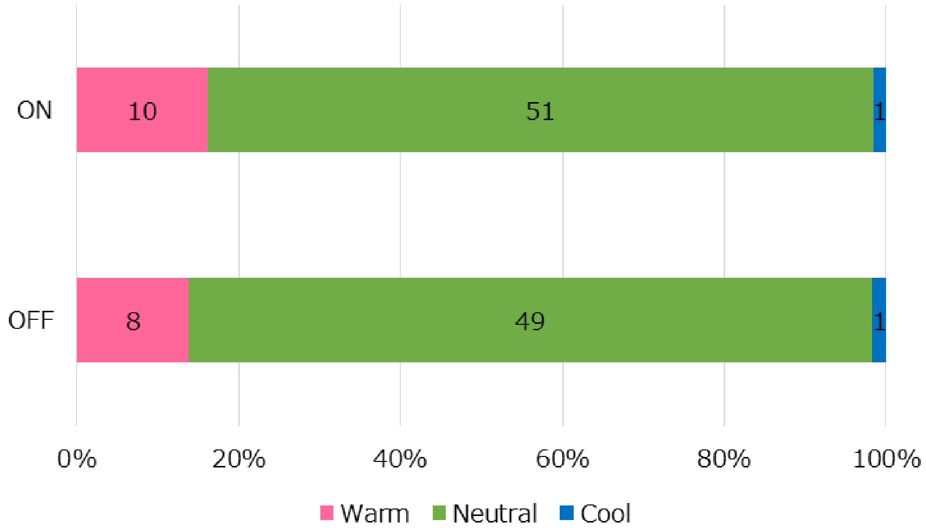

Figure 5.3.3-16 Energy-saving control ON/OFF - Temperature/Intermediate

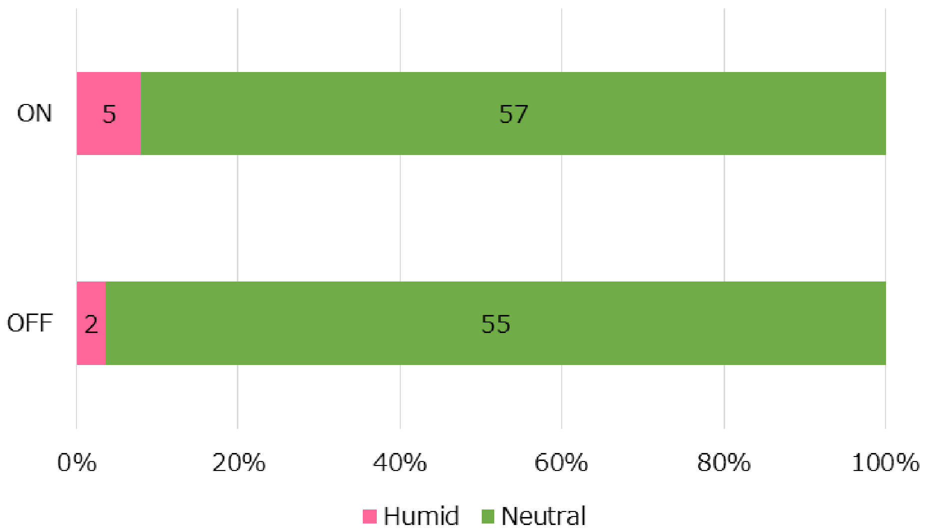

Figure 5.3.3-17 Energy-saving control ON/OFF - Humidity/Intermediate

The results of the thermal sensation survey during the heating period are shown in Figures 5.3.3-18 and 5.3.3-19. Most respondents also report "Neutral".

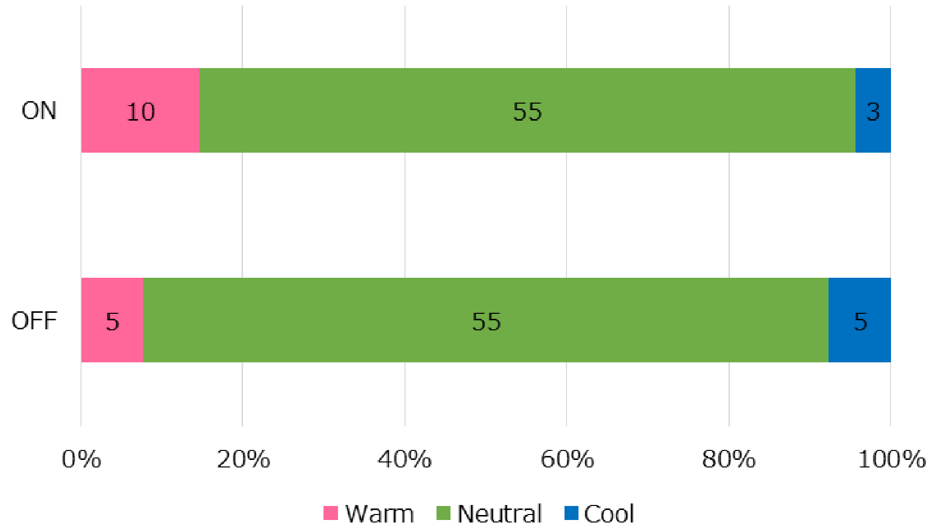

Figure 5.3.3-18 Energy-saving control ON/OFF - Temperature/Heating

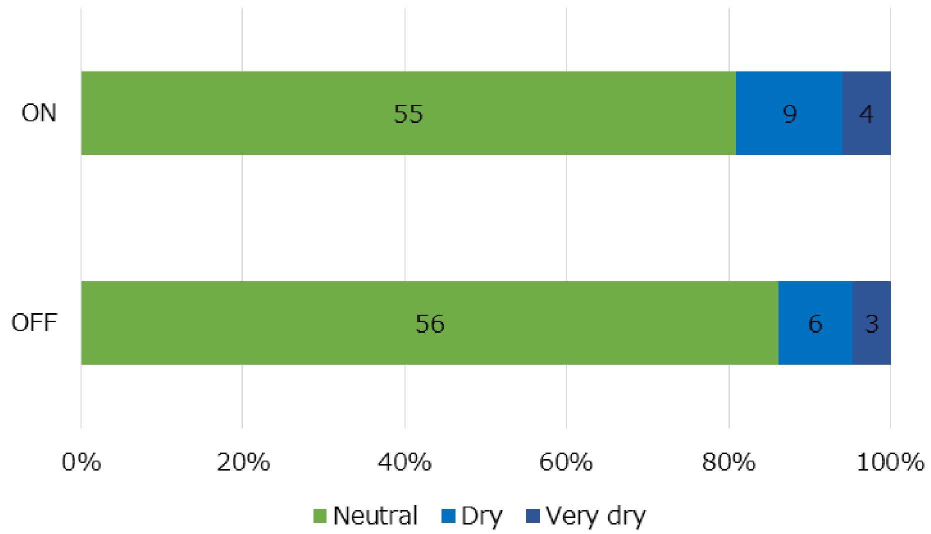

Figure 5.3.3-19 Energy-saving control ON/OFF - Humidity/Heating

5.3.4 Clothing insulation

Clo values are shown in Table 5.3.4-1 and equation is shown in (22)[21][22]. The clo values are the relative measure of the ability of insulation to provide warmth. One clo is defined as the amount of clothing required by a resting person to be indefinitely comfortable at ambient conditions where temperature is 21°C, relative humidity is less than 50%, and wind velocity is about 0.9 kilometers per hour according to ASHRAE[23][24].

Table 5.3.4-1 Clothing insulation

Garments	Clothing insulation
Short sleeve short	0.19
Long sleeve short	0.25
Jacket (for summer)	0.36
Jacket (for winter)	0.44
Trousers (for summer)	0.15
Trousers (for winter)	0.24
Skirt (for summer)	0.14
Skirt (for winter)	0.23
Vest (for summer)	0.10
Vest (for winter)	0.17
Work clothes	0.49

$$Icl = 0.835 \sum Iclu + 0.161 \qquad (22)$$

Icl = clo value

Iclu = Garment Description

Figures 5.3.4-1 to 5.3.4-3 show the clo value survey results. The male workers have a nearly constant value throughout the year whereas the female workers have clothing volume about twice the cooling period during the heating period.

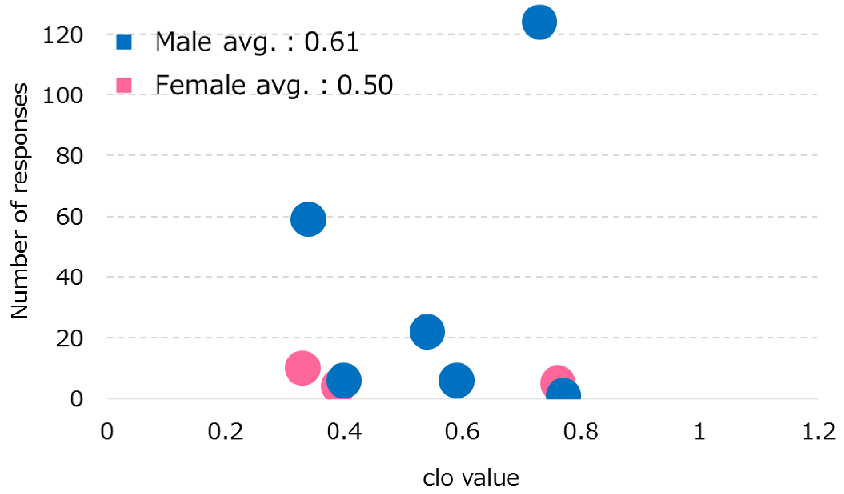

Figure 5.3.4-1 clo values in the cooling operation

Figure 5.3.4-2 clo values in the intermediate operation

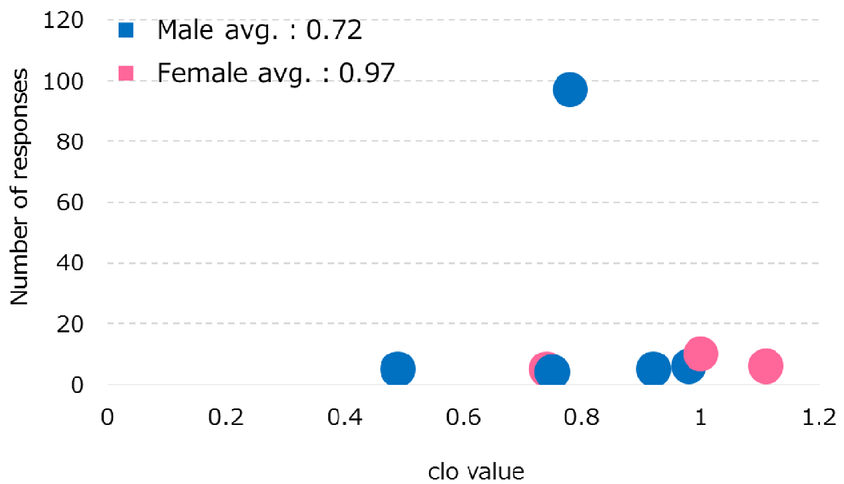

Figure 5.3.4-3 clo values in the heating operation

5.3.5 Predicted Mean Vote

The PMV sensation scale is shown in Table 5.3.5-1 and calculation equations are shown in (11) to (13)[25]. The PMV refers to a thermal scale that runs from Cold (-3) to Hot (+3), originally developed by Fanger. It is evaluated by factors on the environment side of temperature, relative humidity, average radiation temperature and wind speed, and on the human side of clothing insulation and metabolic rate. When the PMV value is zero, it shows neutrality and no thermal discomfort. The acceptable PMV range for thermal comfort according to the International Organization for Standardization is between -0.5 and +0.5 for an interior space. The set values of thermal environmental factors at the time of the survey are shown in Table 5.3.5-2. Temperature, relative humidity, and average radiation temperature were measured by thermometer and hygrometer and wind speed was measured by anemometer. Metabolic rate of 1.5 met[26] for desk work and the clo values of the result are used.

Table 5.3.5-1 PMV sensation scale

PMV value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

$$PMV = f(M) * S \qquad (23)$$

$$F(M)=0.303e^{-0.036M}+0.028 \text{ (Function of metabolic rate)} \qquad (24)$$

$$S=M-(C+R+E)-(C'+E') \text{ (Heat balance of human body)} \qquad (25)$$

M : Metabolic rate

S : Body heat storage

C : Sensible heat loss by convection

R : Latent heat loss by radiation

E : Sensible heat loss by sweat

Table 5.3.5-2 Set values of thermal environment factors

Factors	Determining factors	Setting values
Environmental factors	Air temperature	Measured by thermometer and hygrometer
	Radiant temperature	
	Relative humidity	
	Air velocity	Measured by anemometer (Fan speed) High 0.24m/s (Fan speed) Middle 0.20m/s (Fan speed) Low 0.12m/s
Personal factors	Metabolic rate	1.5 met (office work)
	Clothing insulation	Survey results

The scatter diagrams of the PMV when the fan speed is high, middle and low are shown in Figures 5.3.5-1 to 5.3.5-9. The red circles indicate energy-saving operation controls ON, the blue circles indicate OFF, and both vertical axis and circle size indicate the number of people. In the cooling period, the PMV value roughly ranges from +0.5 to +1.5 which indicates that people feel slightly hot. In the intermediate period, it converges between -1.0 and +0.5, and the PMV value increases as the air volume decreases. In the heating period, it converged between 0 and +1.0, and the PMV value increases as the air volume decreases similarly to the intermediate period. In any case, there are no significant differences in thermal comfort by energy-saving operation controls throughout the year.

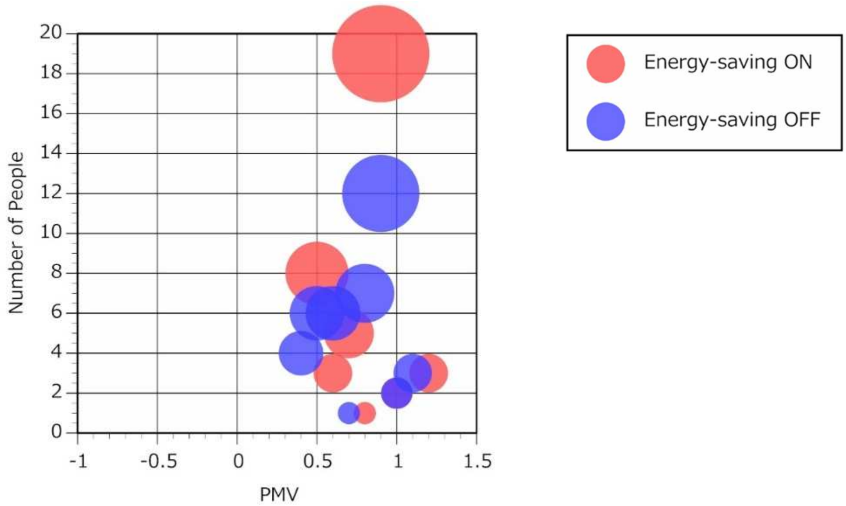

Figure 5.3.5-1 Scatter diagram of PMV (High) Cooling

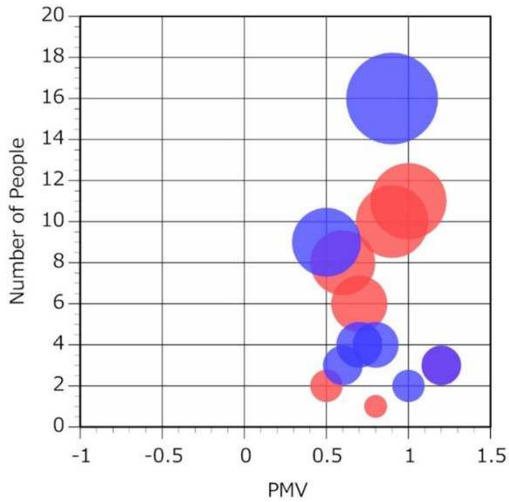

Figure 5.3.5-2 Scatter diagram of PMV (Middle) Cooling

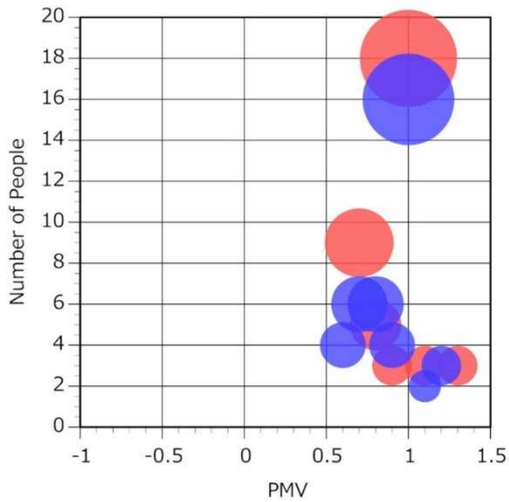

Figure 5.3.5-3 Scatter diagram of PMV (Low) Cooling

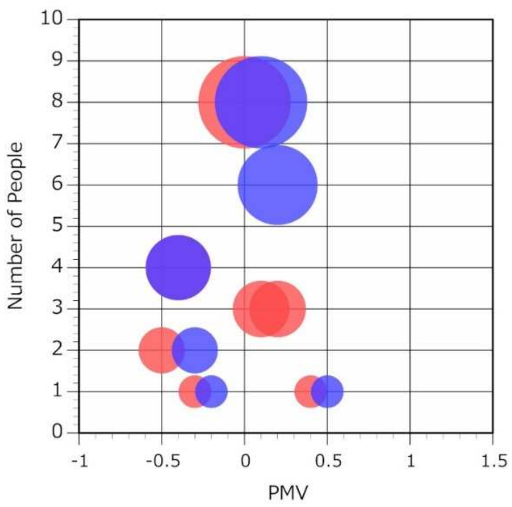

Figure 5.3.5-4 Scatter diagram of PMV (High) Intermediate

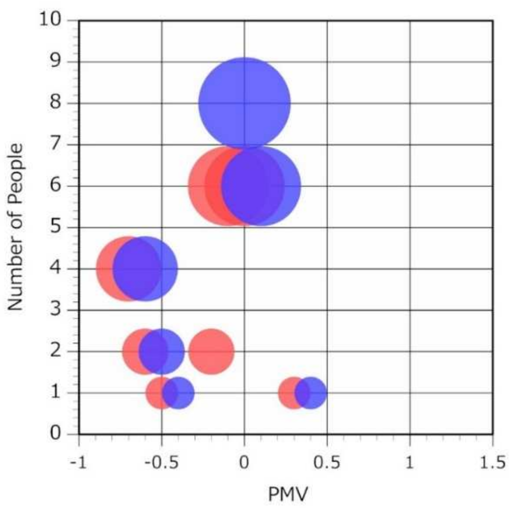

Figure 5.3.5-5 Scatter diagram of PMV (Middle) Intermediate

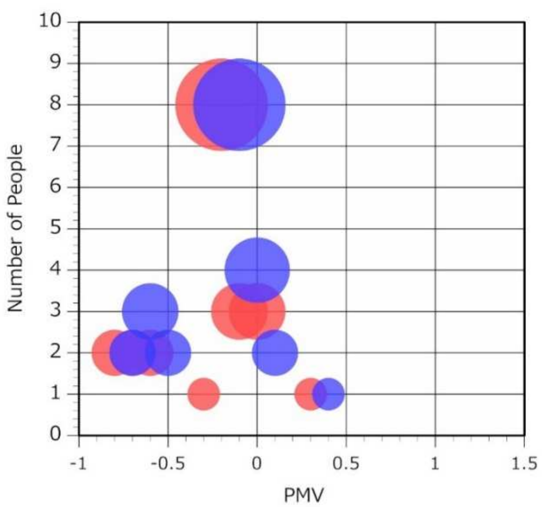

Figure 5.3.5-6 Scatter diagram of PMV (Low) Intermediate

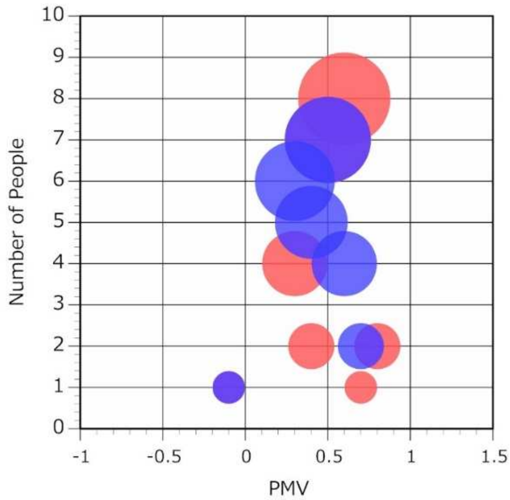

Figure 5.3.5-7 Scatter diagram of PMV (High) Heating

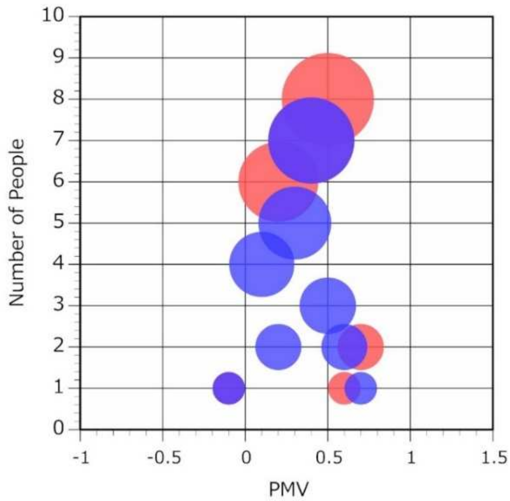

Figure 5.3.5-8 Scatter diagram of PMV (Middle) Heating

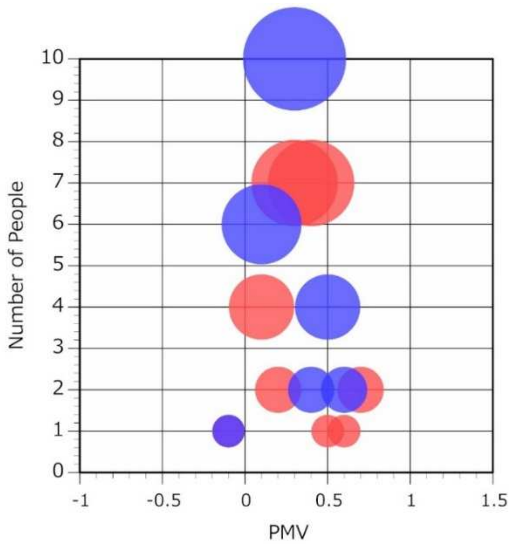

Figure 5.3.5-9 Scatter diagram of PMV (Low) Heating

5.3.6 Results

We carried out a thermal comfort survey concerning energy-saving operation controls of VRF systems and examined the influence of the operation controls on the air quality. There was no significant difference in the thermal comfort of workers depending on the operation controls. We found that the indoor air conditioning environment during the energy-saving operation controls is secured.

6 Conclusions

6.1 Summary

This paper discussed the development of an onsite performance evaluation method for VRF systems and approach to energy conservation.

In the first chapter, the current status and problems of VRF systems were outlined and the position of this study by comparing with previous studies was clarified. VRF systems have been increasing and energy consumption varies depending on how they are being used. Therefore, we pointed out that proper operation has a significant influence on CO_2 reduction effect.

In the second chapter, accuracy improvement of performance evaluation method was discussed. The CC method is a practical onsite performance evaluation method for VRF systems. We found that how the accuracy of volumetric efficiency affected the capacity. The regression equations were obtained for the estimation of volumetric efficiency values. The relative errors to the regression equations were the smallest, which were 5.7% in the cooling operation and 2.8% in the heating operation when compared with the average and constant values. Consequently, it is imperative to apply a proper volumetric efficiency value for accuracy improvement in the CC method when a refrigerant mass flow is unknown.

In the third chapter, an onsite performance evaluation system and information providing method were outlined. We focused on causes of energy waste and analysis methods using the Nudge theory.

In the fourth chapter, field data were analysed. The analysis revealed various problems including low load and low-efficiency operations, inappropriate temperature settings, unnecessary operations, excessive installed capacities and short circuits. It is possible to encourage users to take energy-saving actions by reporting these actual operations. Advice and messages to users, building operators and designers were demonstrated.

In the fifth chapter, the results of automatic operation controls were illustrated and energy reduction rates were obtained. Cost-effectiveness as verification of CO_2 reduction effect was estimated. We estimated that the amount of CO_2 reduction at 2018 will be 15,600 t-CO_2 in 2018, 561,600 t-CO_2 by 2025 and 1,326,000 t-CO_2 by 2030. We concluded that it would cost ¥4000 per t-CO_2 reduction. Finally, the results of thermal comfort survey on energy-saving operation controls of VRF systems were discussed. We examined the influence of the operation controls on the air quality. As a result, there was no significant difference in the thermal comfort of workers and we confirmed that the indoor environment during energy-saving operation controls was secured.

In conclusion, we developed an onsite performance evaluation method that reveals the operation performance of VRF systems. We verified the method of the performance calculation which calculates in real-time and with high accuracy within 10% on a microcomputer board and the method of sending data to the cloud server via the Internet. The system was installed nationwide in various buildings with different uses and meteorological conditions, and data were obtained and analysed. As a result, actual conditions including unnecessary operations and performance degradation causes were verified. Additionally, the energy conservation method using the Nudge theory was examined. It is now possible to encourage users to take action for energy-saving by suggesting better operational methods and energy-saving design information for users through mobile devices and computers. This study will definitely lead to the achievement of energy-saving in the building sector and contribute to CO_2 reduction.

6.2 Future prospects

In the next phases of this project, we intend to spread the system and increase the number of data by uses and regions not only in Japan but in the world to evaluate more accurately. It is also necessary to provide further information to general users, promote operational management advice to building operators and recommend energy-saving designs to building designers. Also, we intend to use this system as an energy censor of an indoor environment which improves air conditioning operations.

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Last but not the least, I would like to thank my family, friends and the members of the System Innovation Laboratory, Graduate School of Marine Science and Technology at Tokyo University of Marine Science and Technology for their hospitality and for supporting me spiritually throughout writing this thesis.

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Appendices

Photos of experimental sites

Fuji, Shizuoka (#6 and 7)

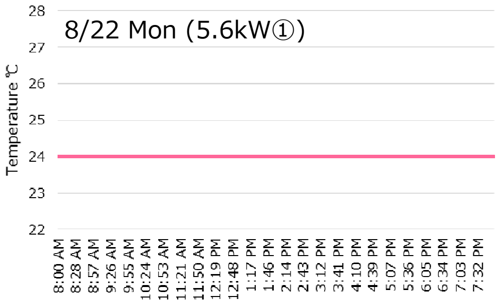
Fuchu, Tokyo (#8, 9 and 10)

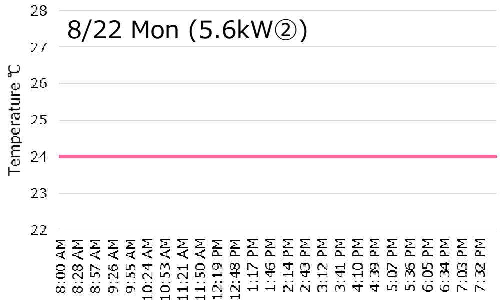
Sendai, Miyagi (#11)

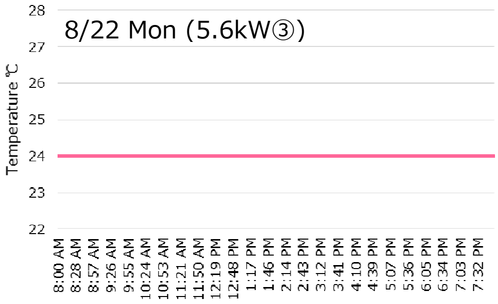
Sapporo, Hokkaido (#12, 13 and 14)

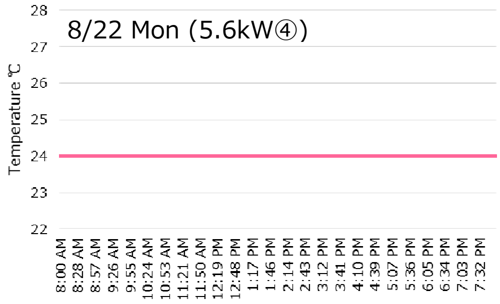
Sagami, Kanagawa (#15, 16, 17, 18, 19, 20 and 21)

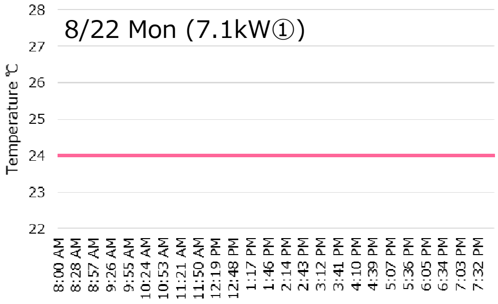
Indoor-unit temperature changes during the thermal comfort survey

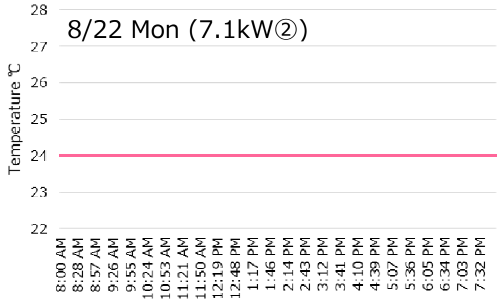


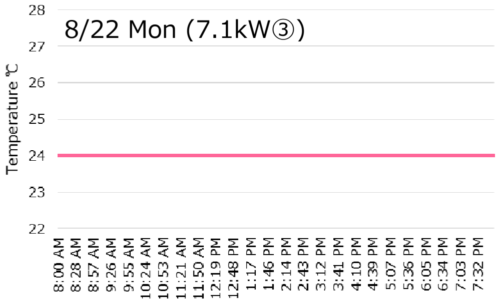


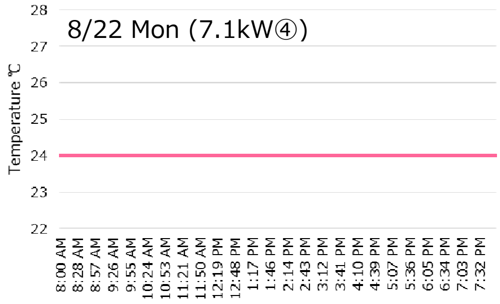


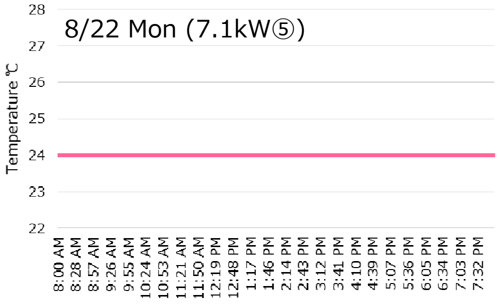


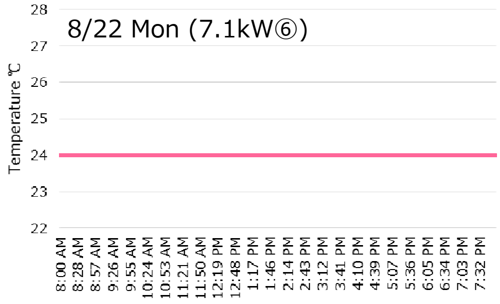


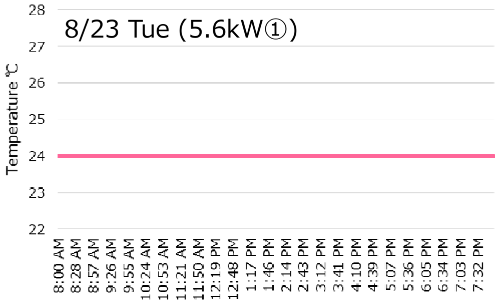








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Temperature ℃
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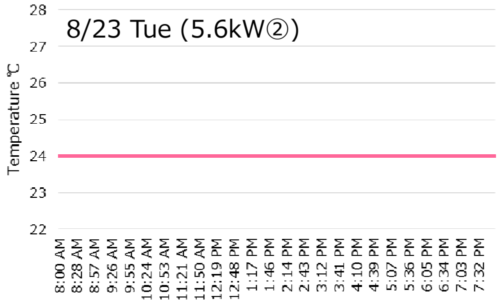
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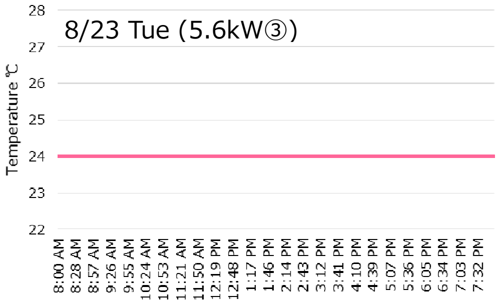
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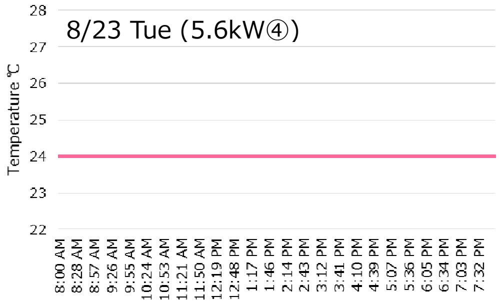
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Temperature ℃
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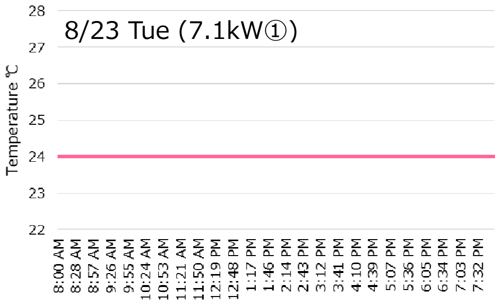
8:00 AM 8:28 AM 8:57 AM 9:26 AM 9:55 AM 10:24 AM 10:53 AM 11:21 AM 11:50 AM 12:19 PM 12:48 PM 1:17 PM 1:46 PM 2:14 PM 2:43 PM 3:12 PM 3:41 PM 4:10 PM 4:39 PM 5:07 PM 5:36 PM 6:05 PM 6:34 PM 7:03 PM 7:32 PM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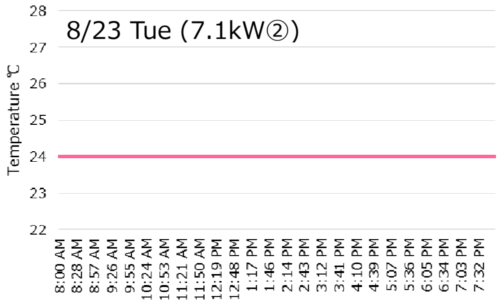
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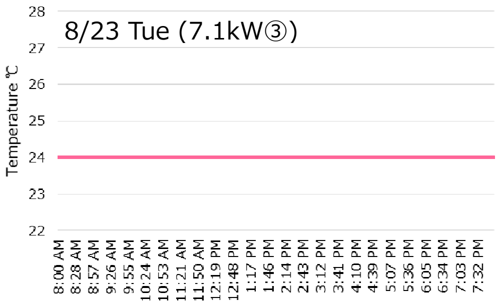
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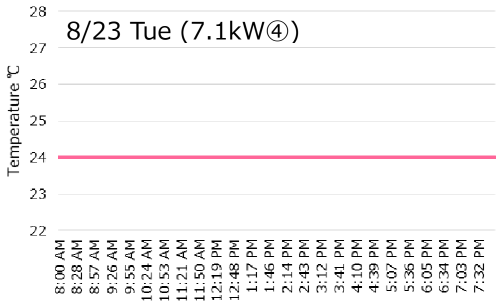
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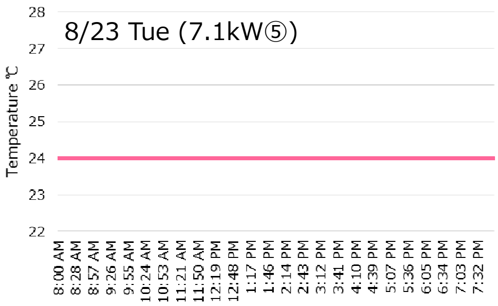
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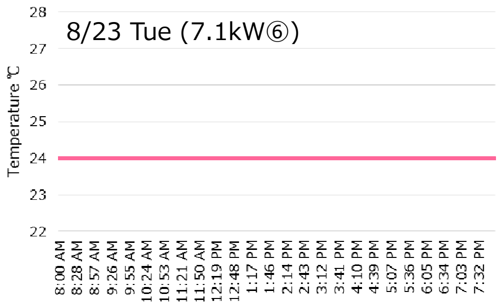
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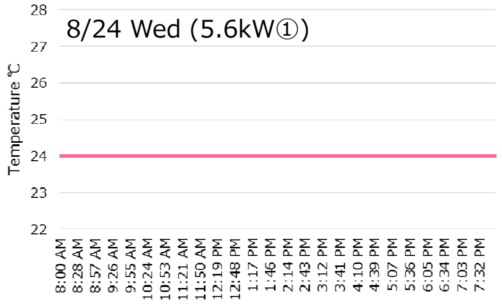
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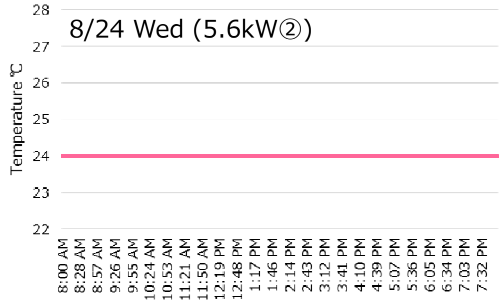
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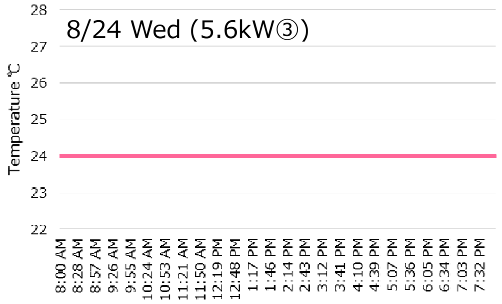
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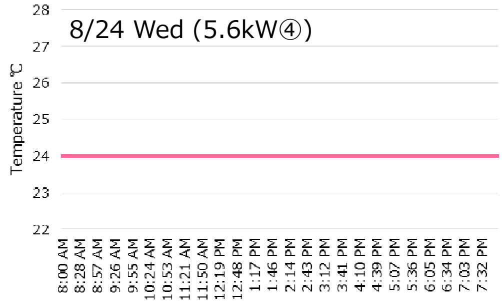
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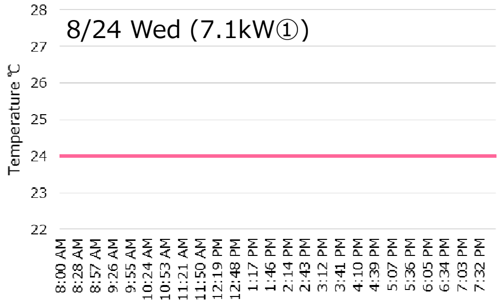
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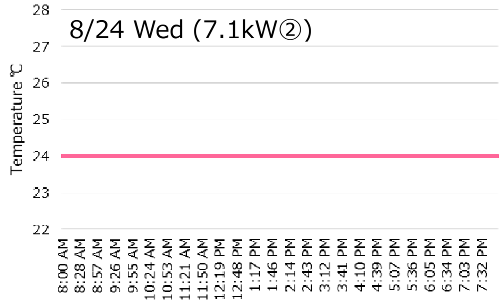
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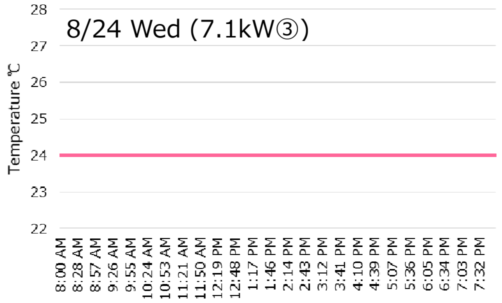
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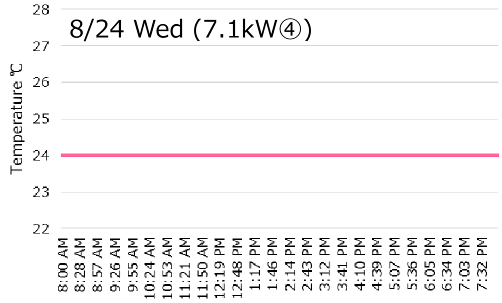
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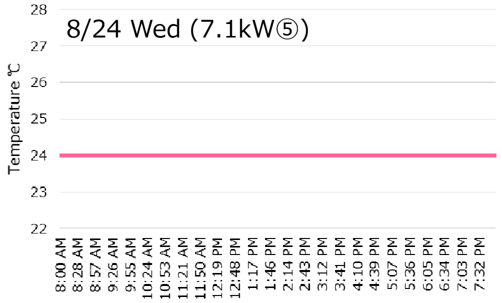
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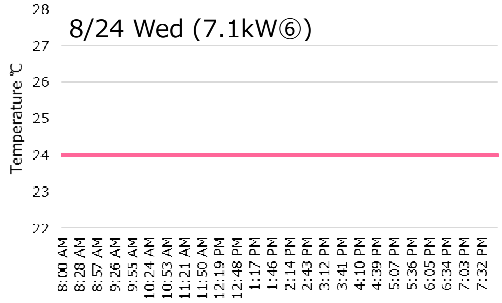
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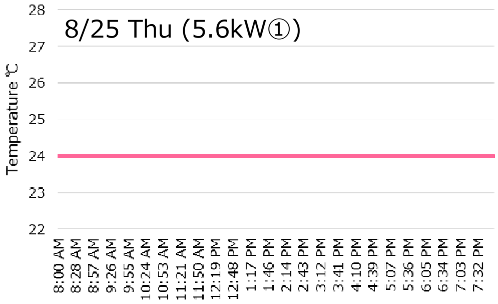
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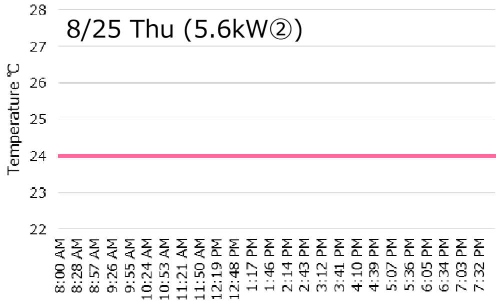
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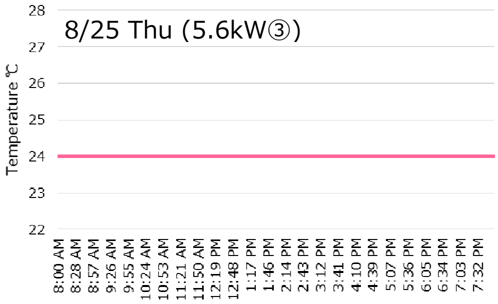
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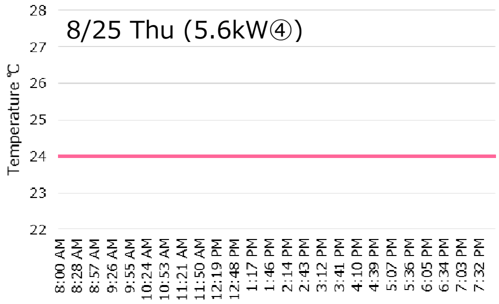
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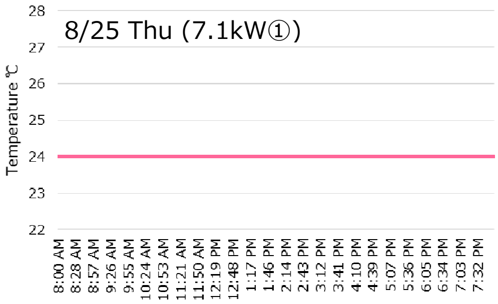
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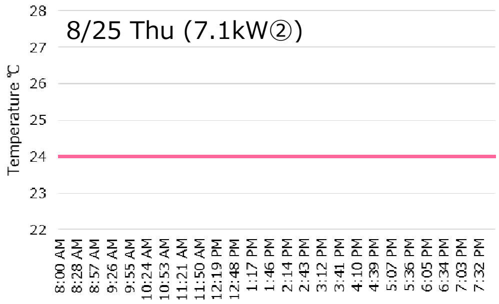
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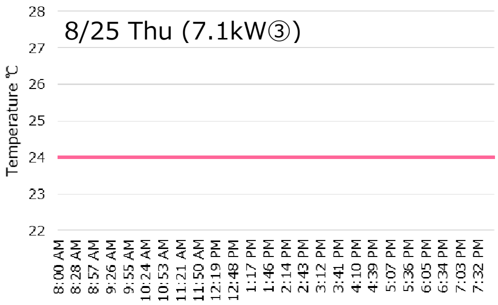
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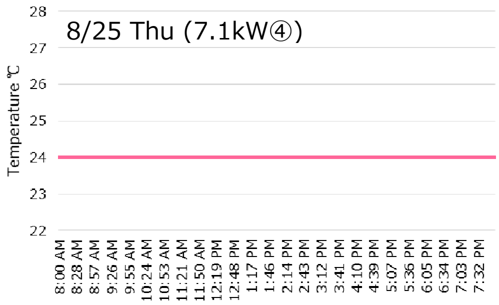
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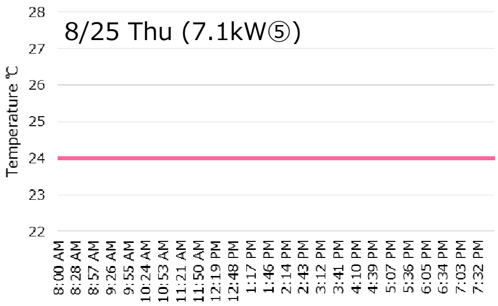
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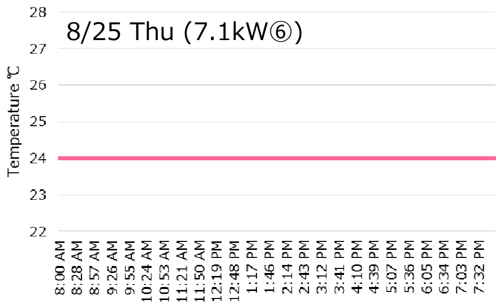
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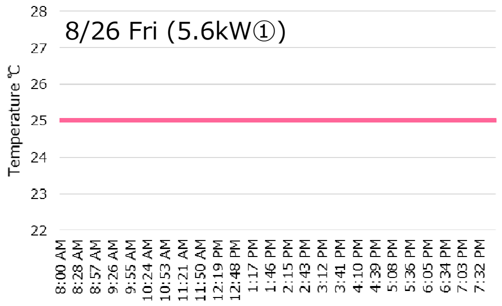
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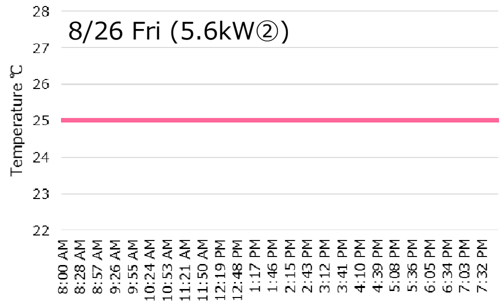
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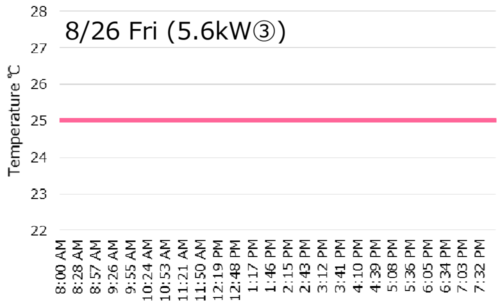
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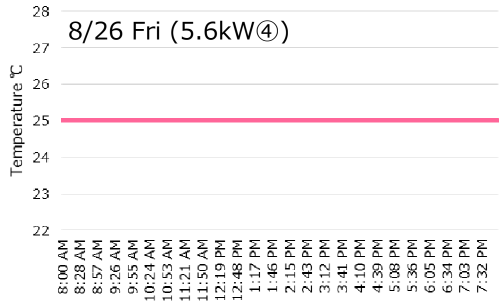
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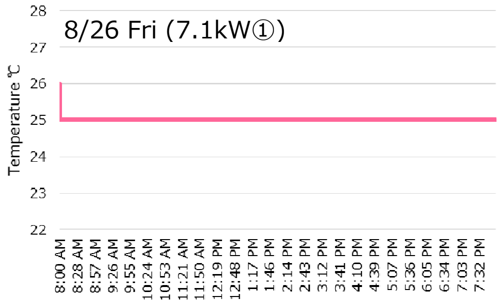
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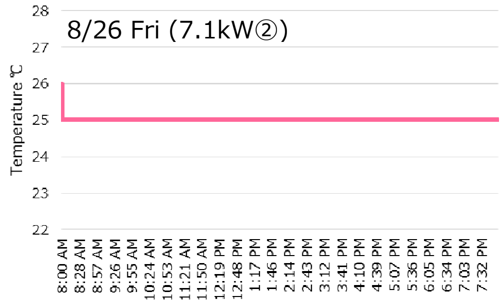
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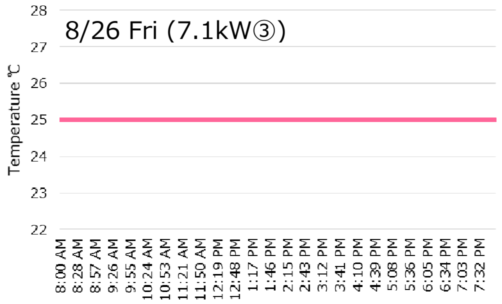
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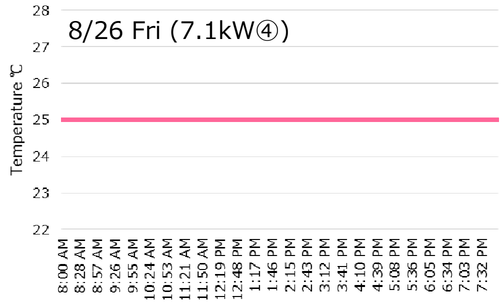
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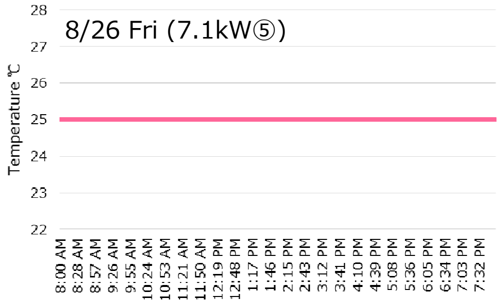
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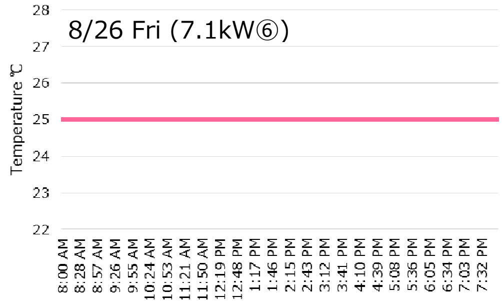
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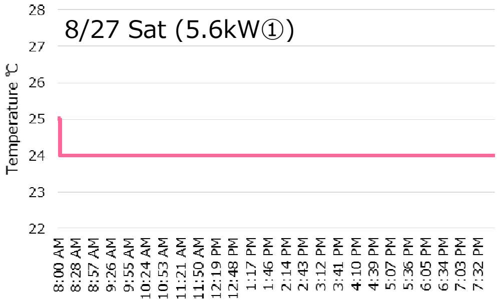
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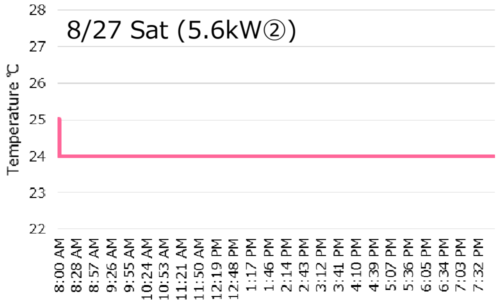
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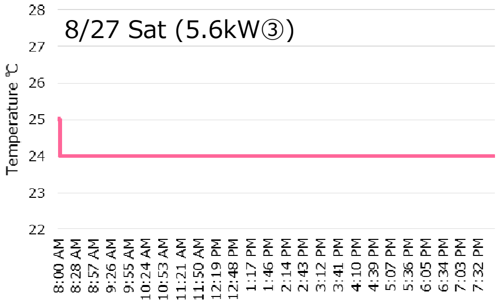
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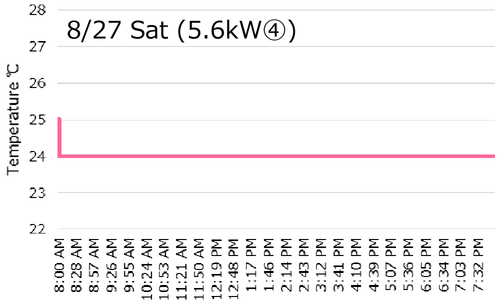
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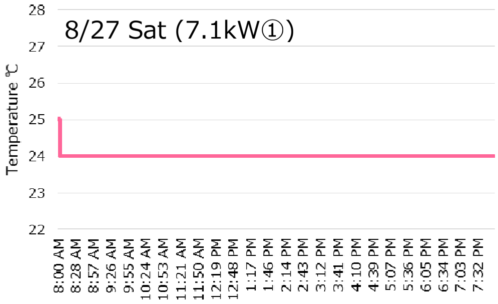
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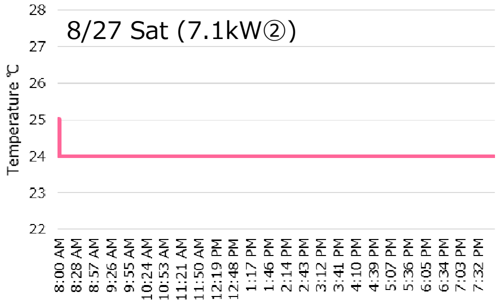
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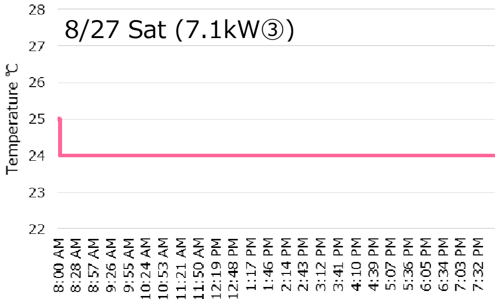
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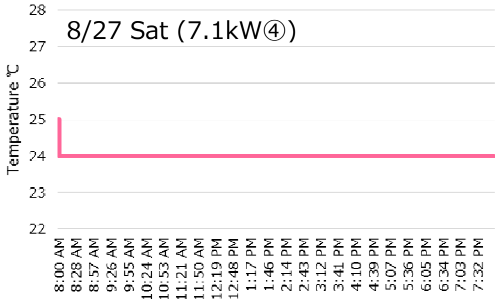
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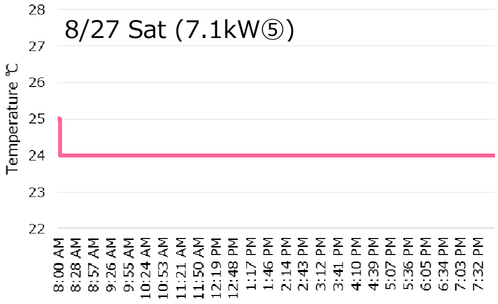
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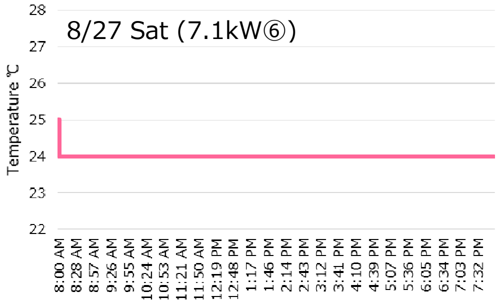
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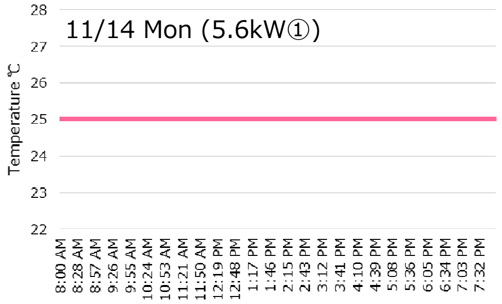
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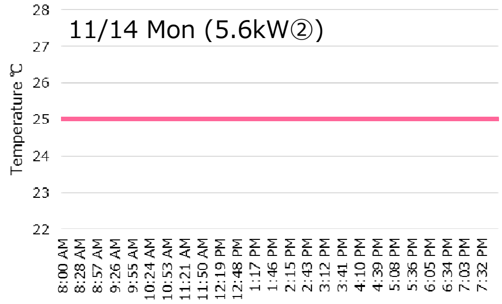
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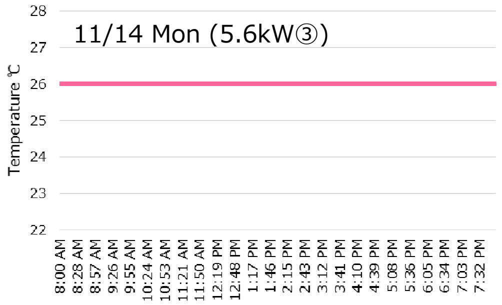
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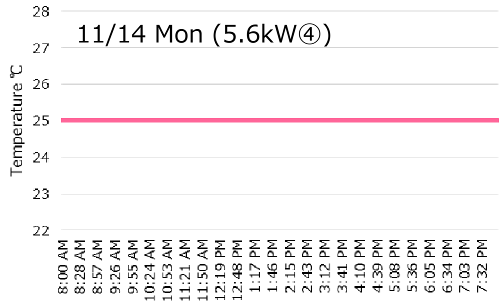
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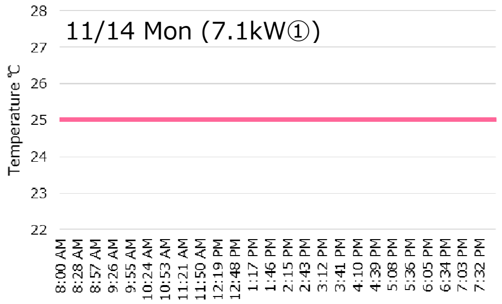
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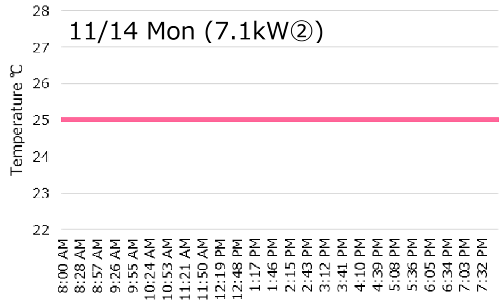
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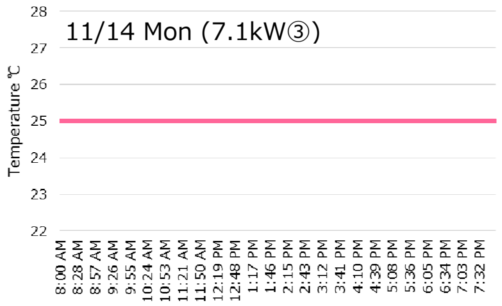
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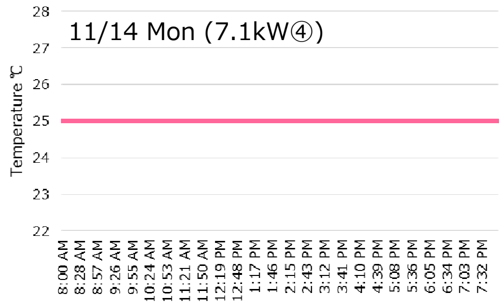
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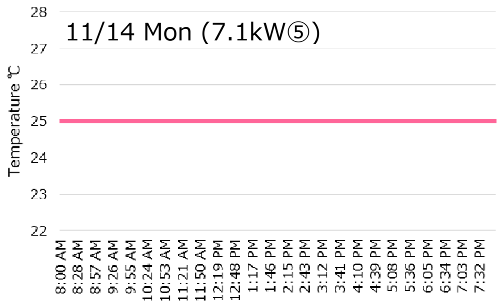
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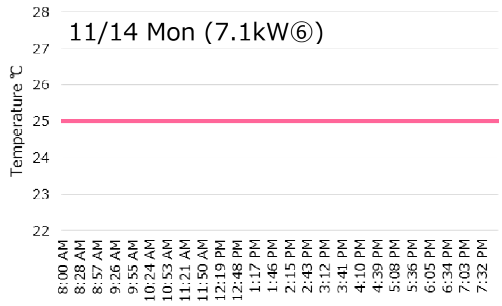
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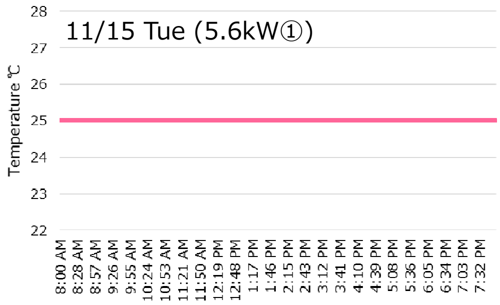
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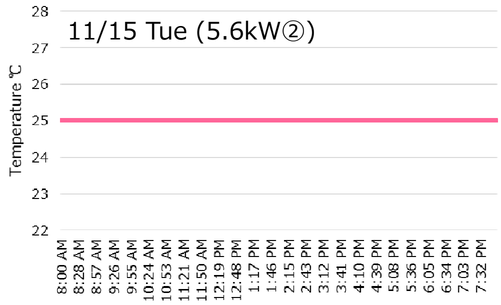
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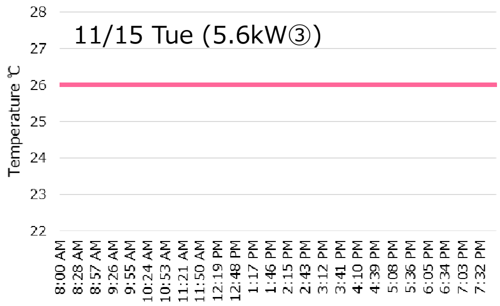
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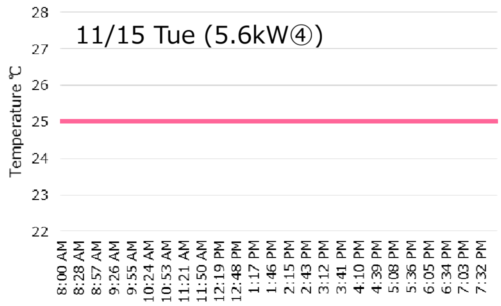
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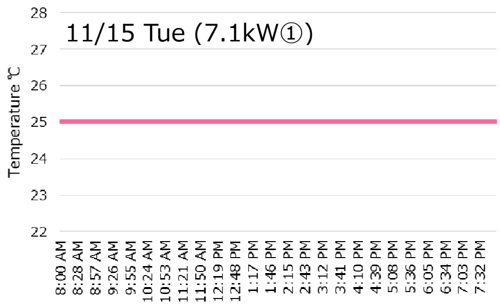
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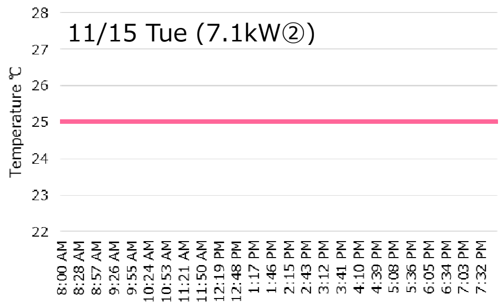
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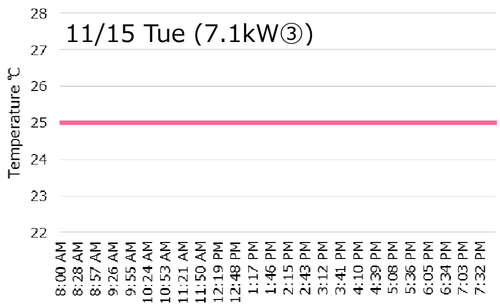
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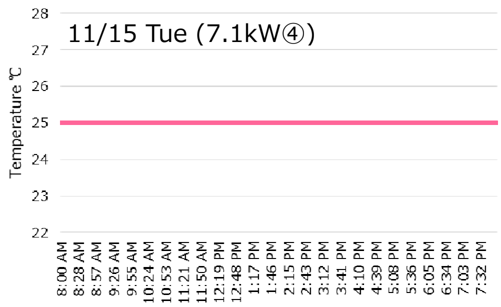
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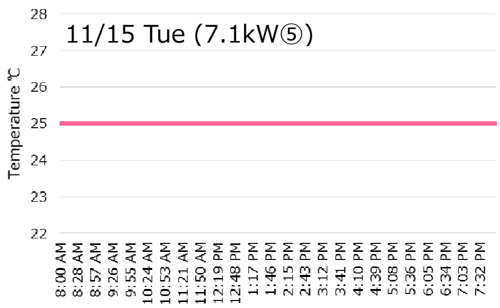
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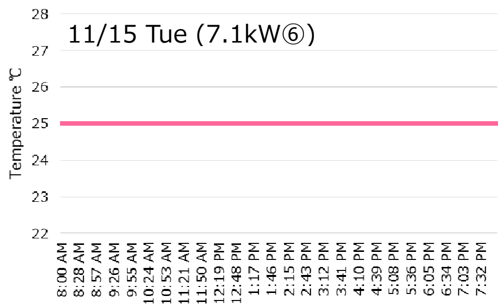
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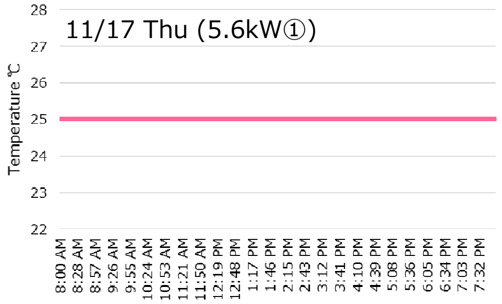
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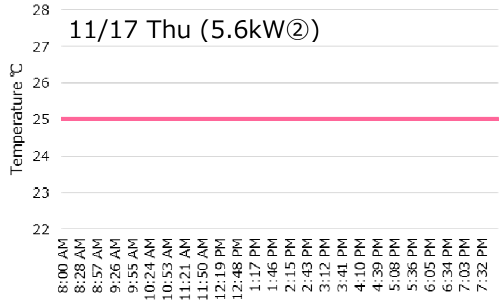
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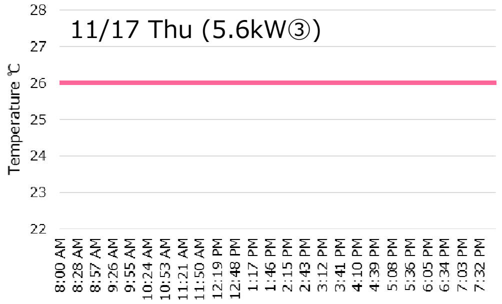
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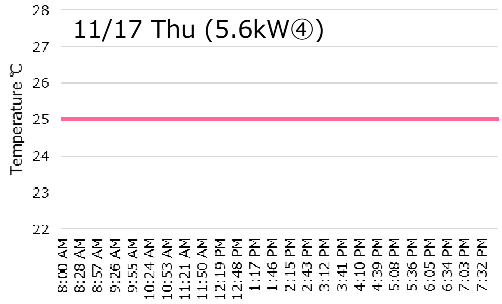
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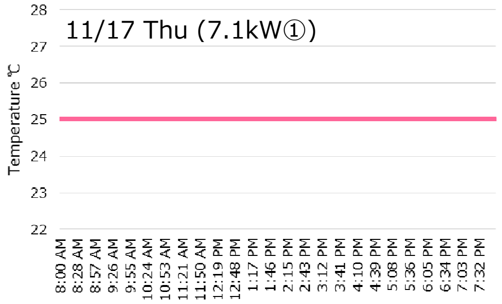
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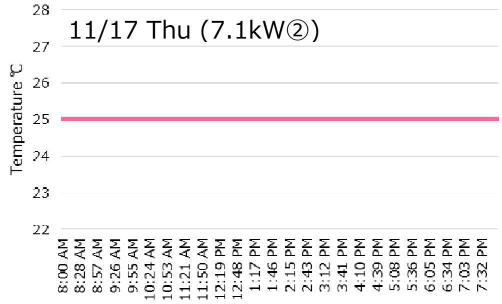
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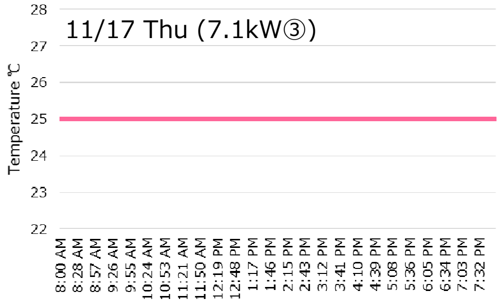
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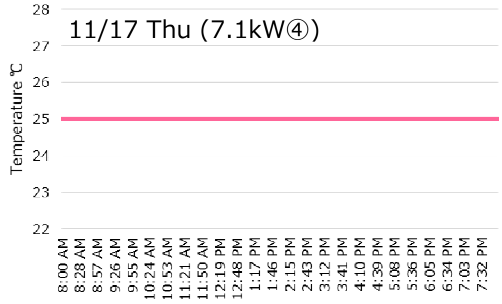
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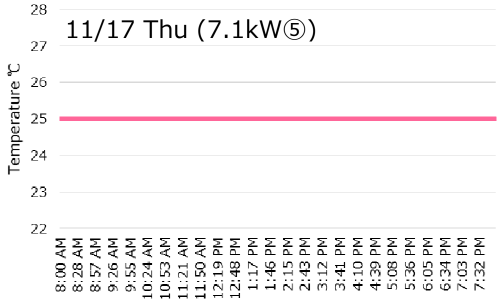
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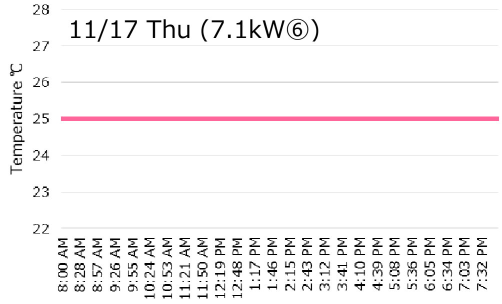
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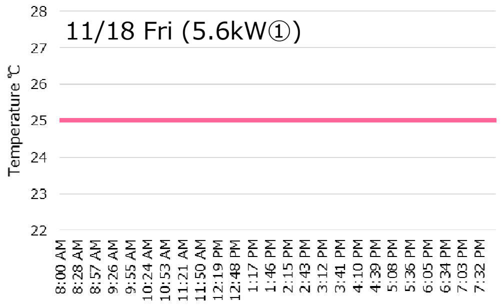
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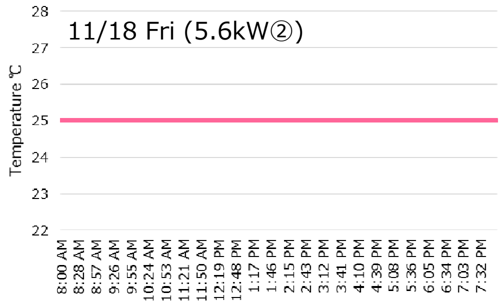
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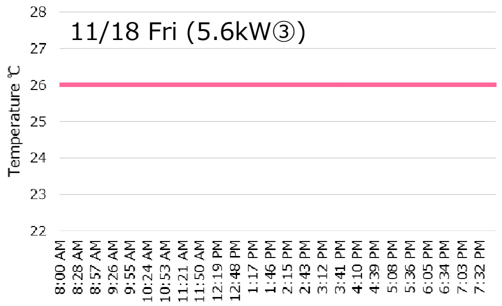
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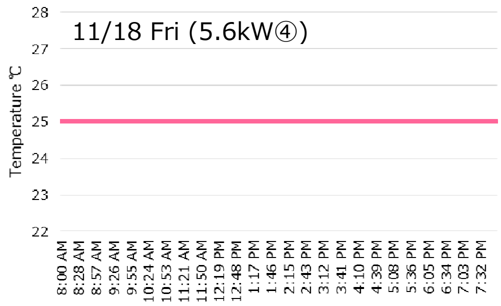
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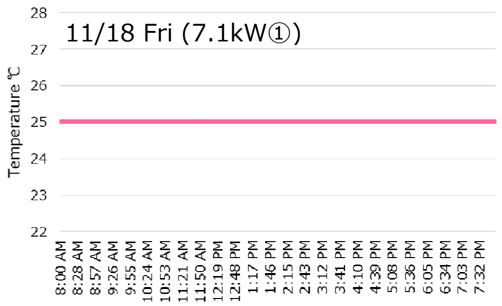
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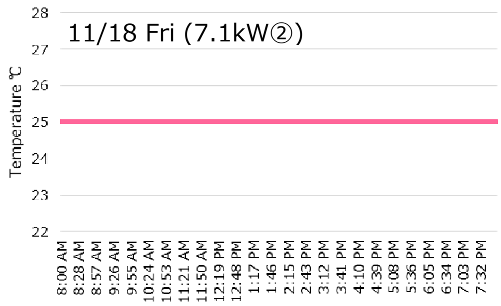
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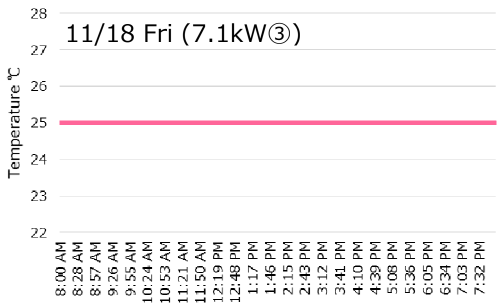
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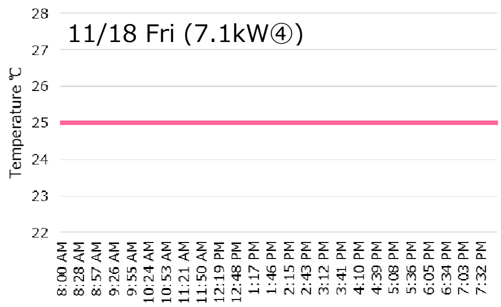
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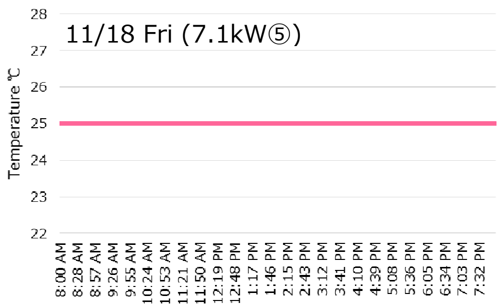
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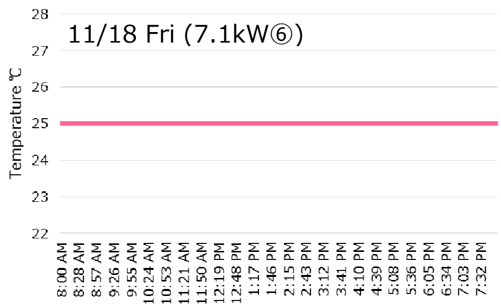
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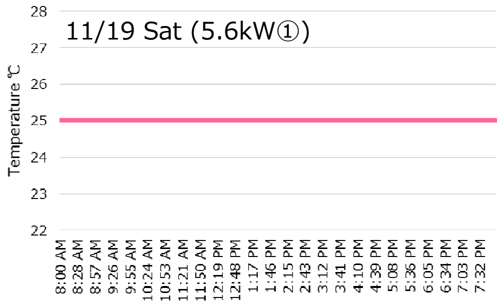
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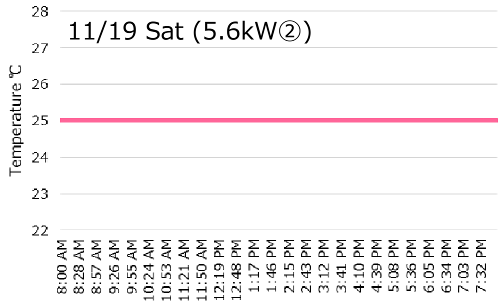
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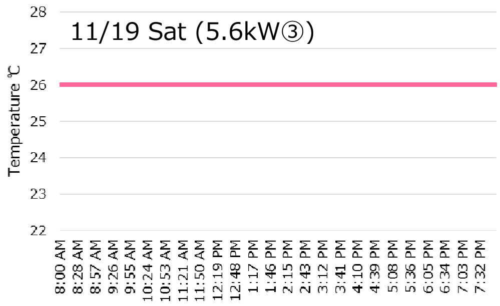
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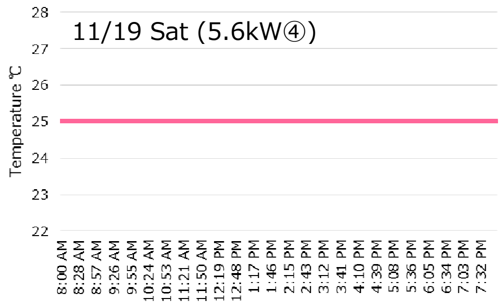
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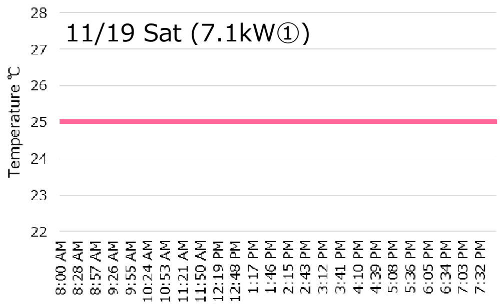
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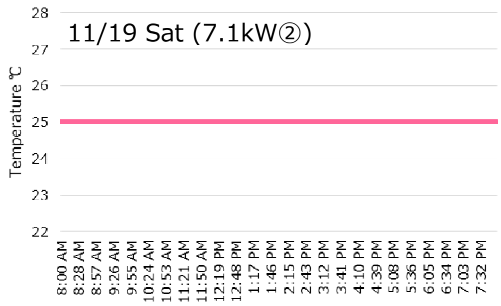
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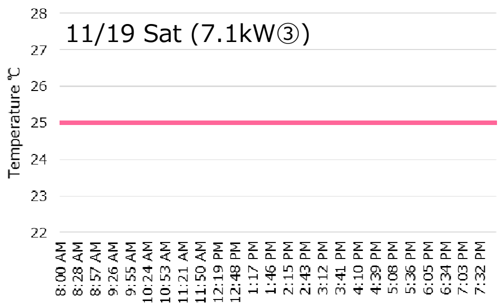
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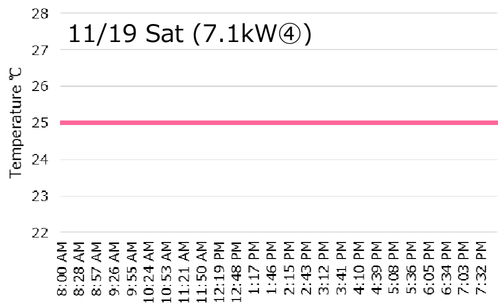
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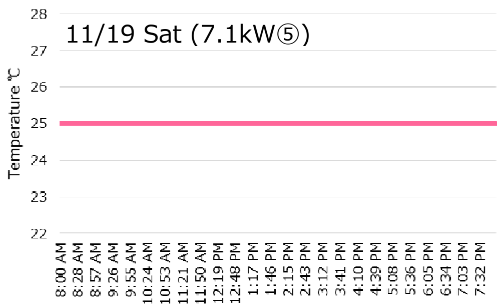
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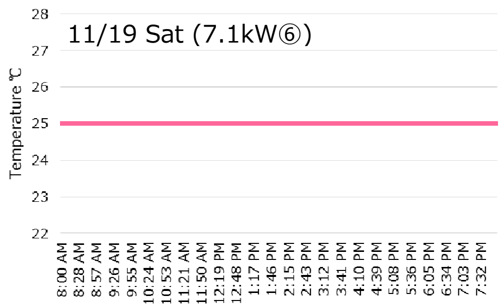
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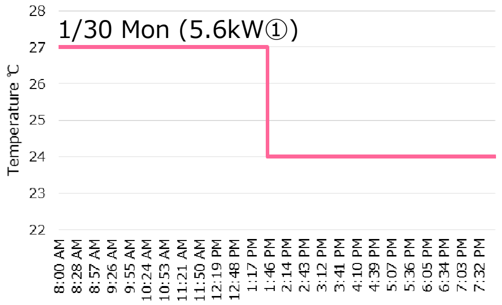
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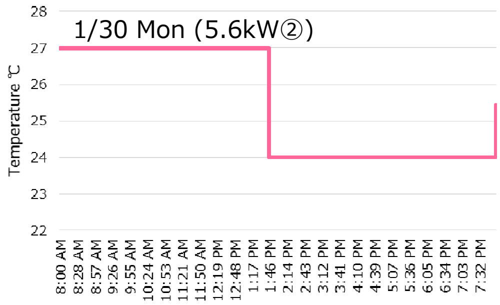
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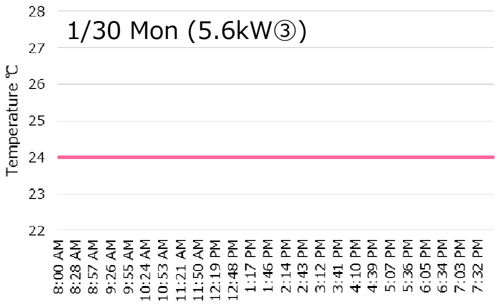
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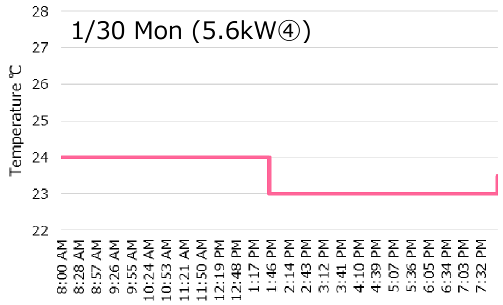
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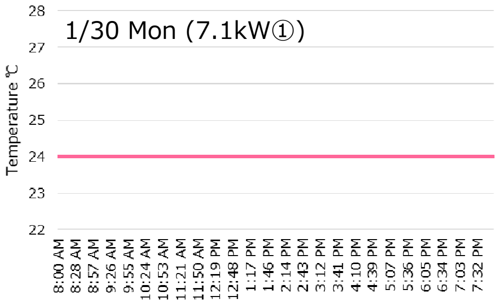
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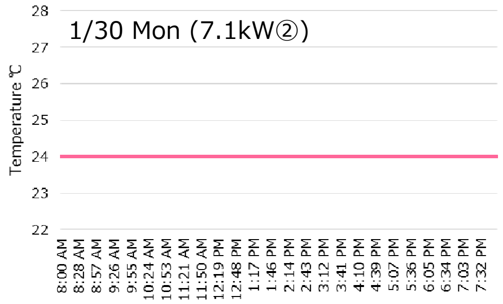
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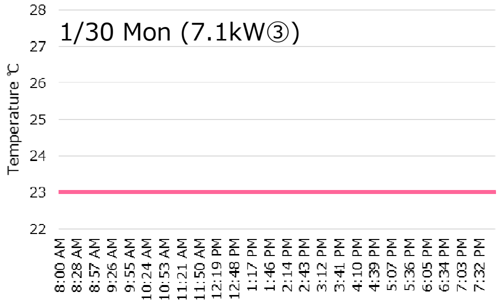
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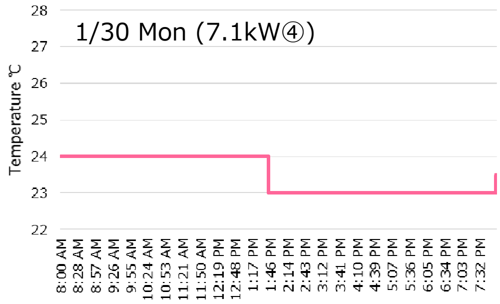
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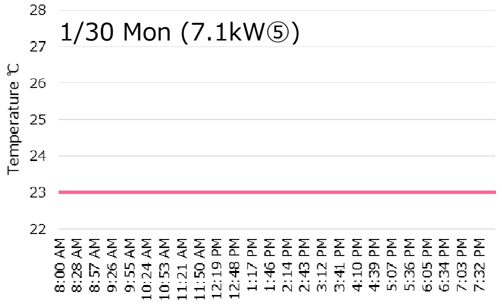
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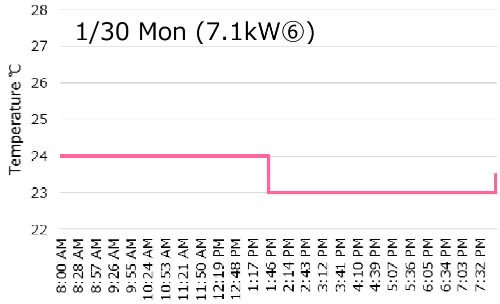
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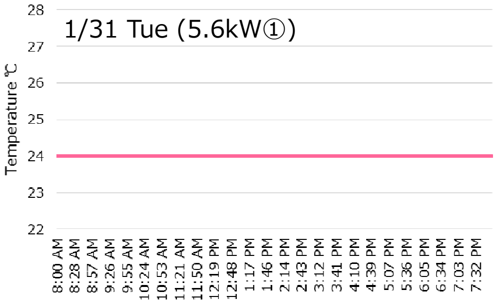
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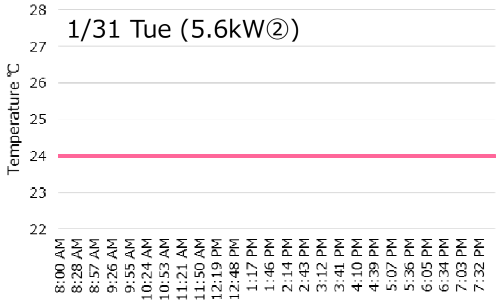
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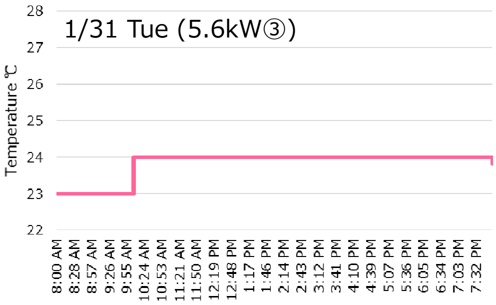
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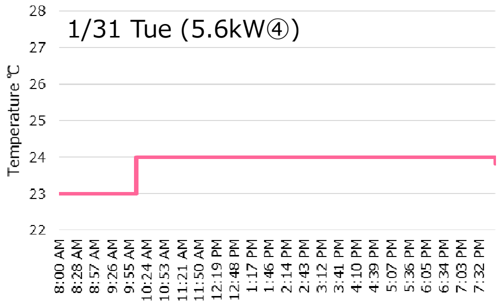
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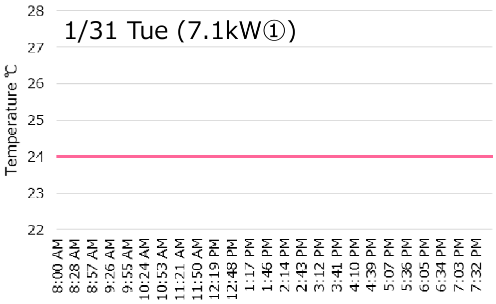
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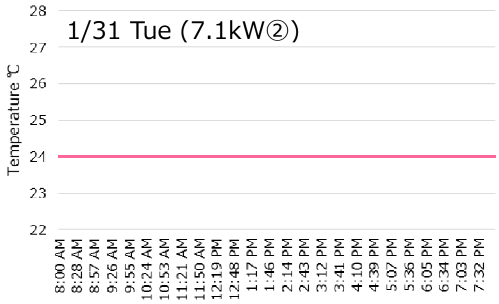
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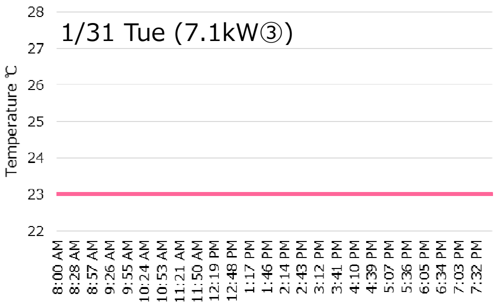
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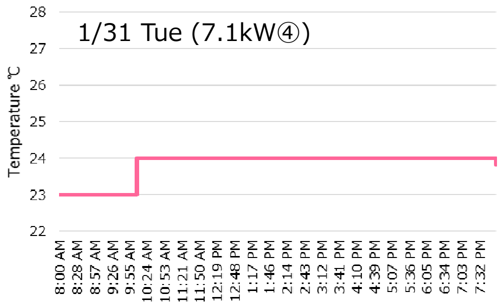
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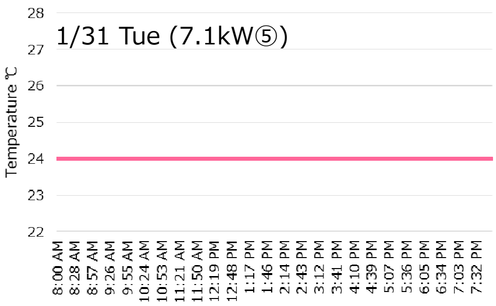
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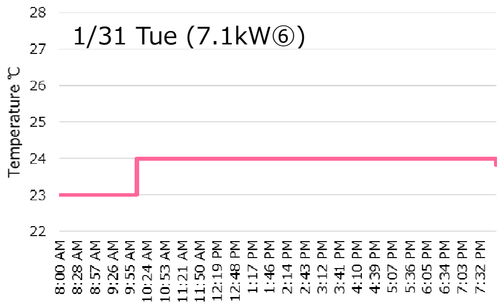
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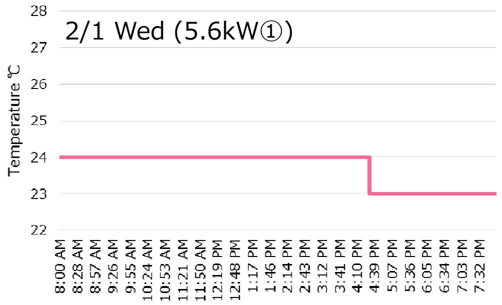
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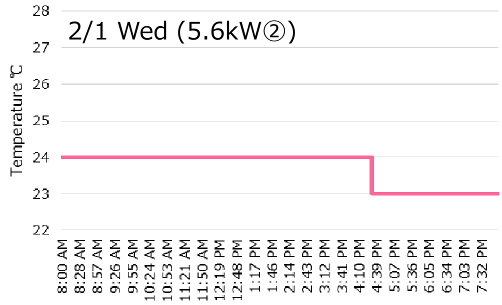
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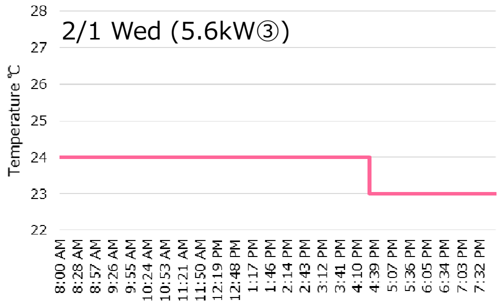
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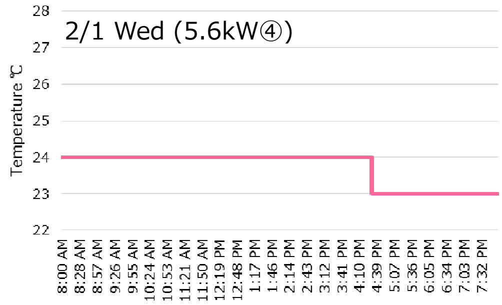
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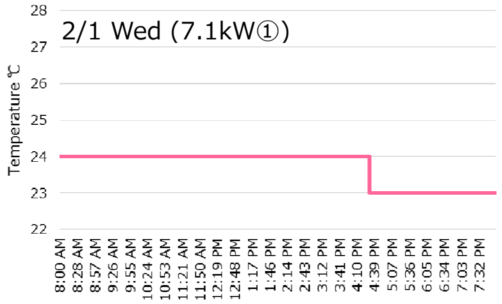
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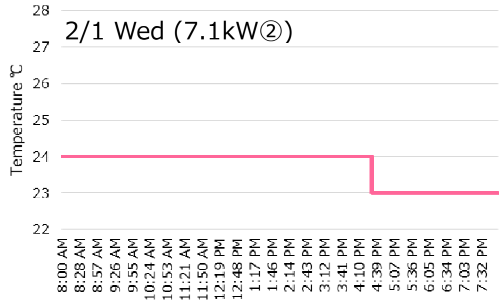
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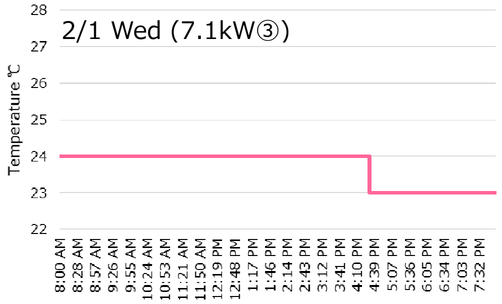
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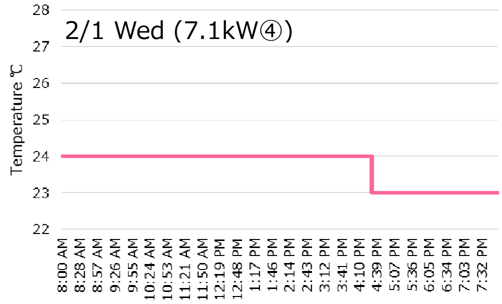
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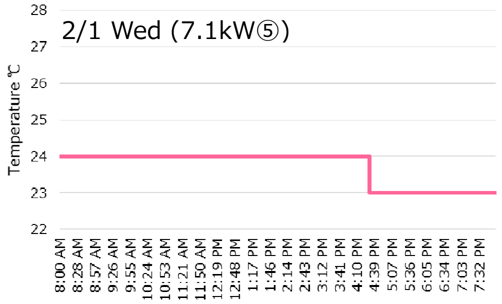
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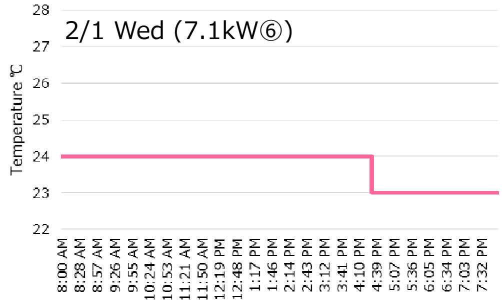
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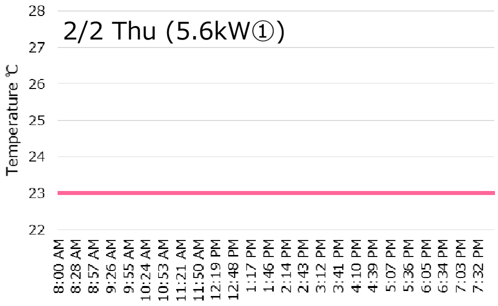
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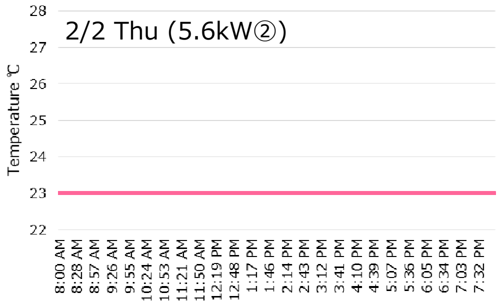
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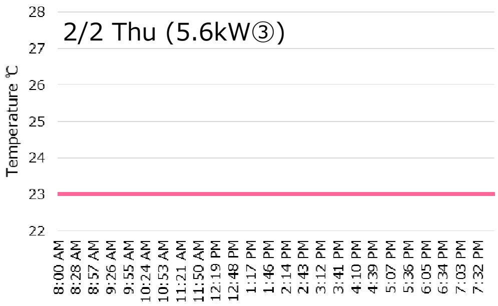
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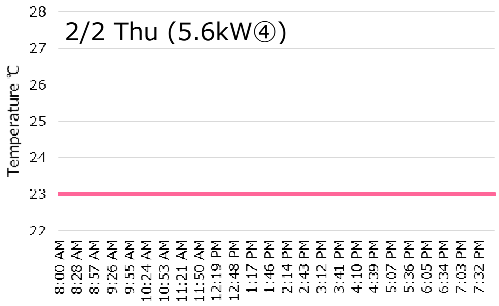
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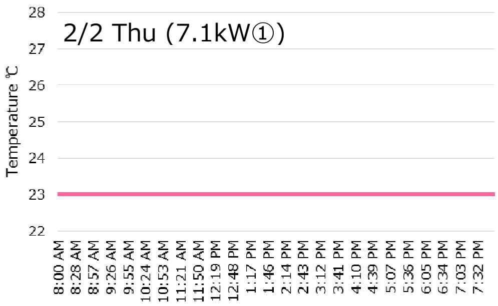
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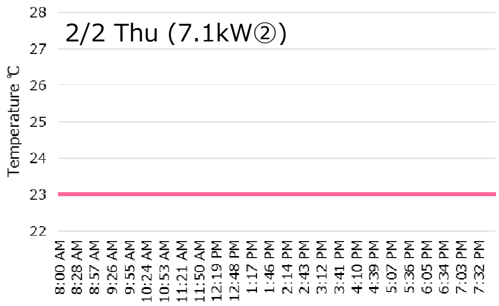
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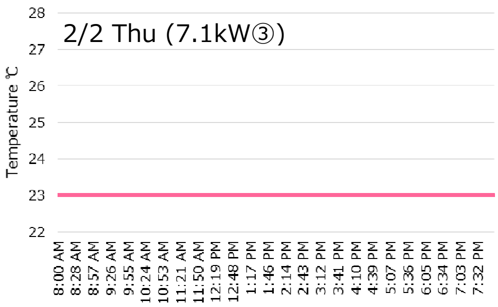
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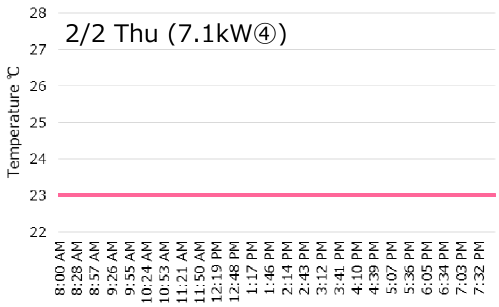
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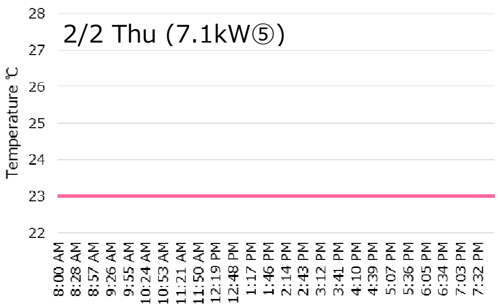
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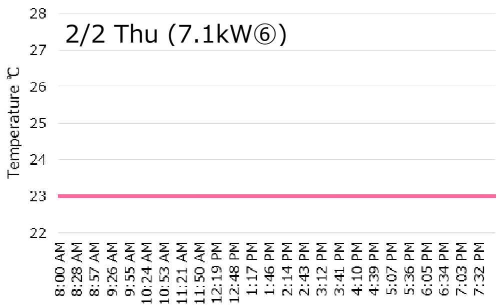
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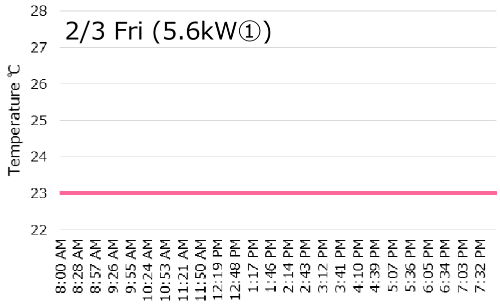
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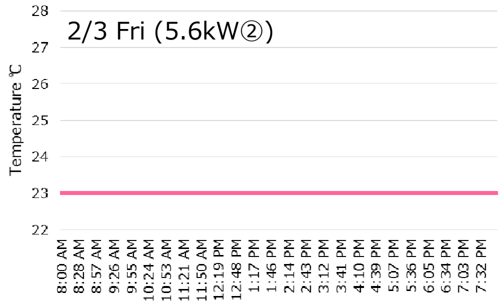
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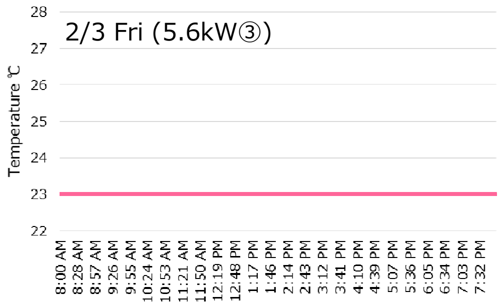
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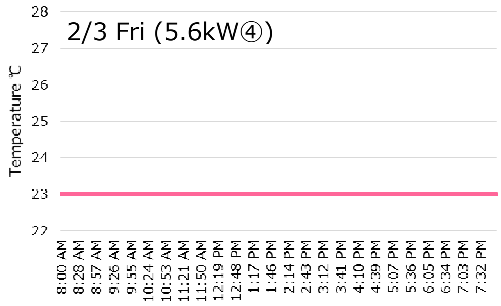
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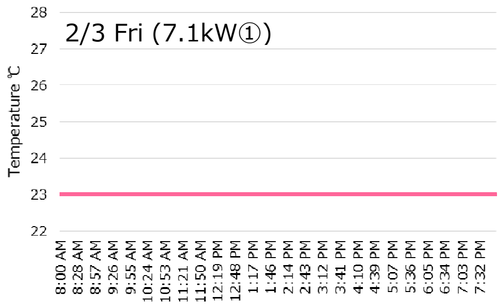
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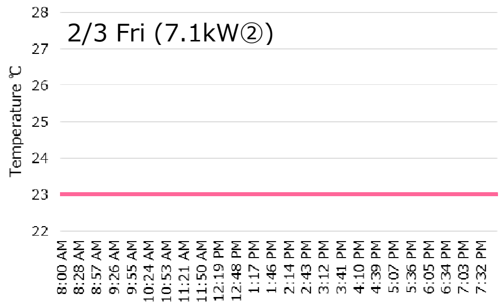
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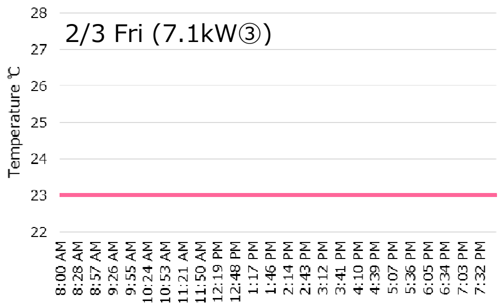
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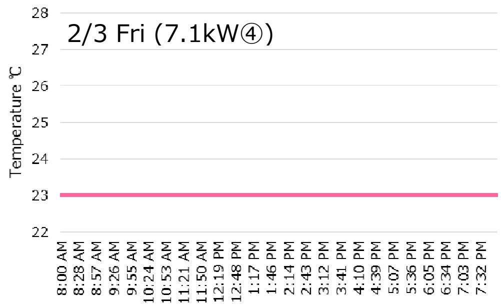
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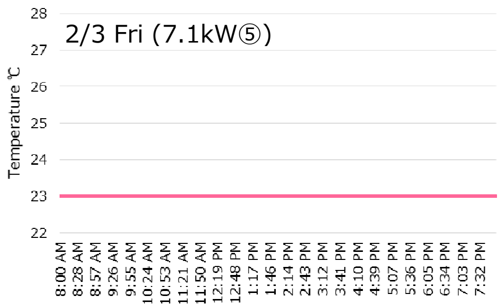
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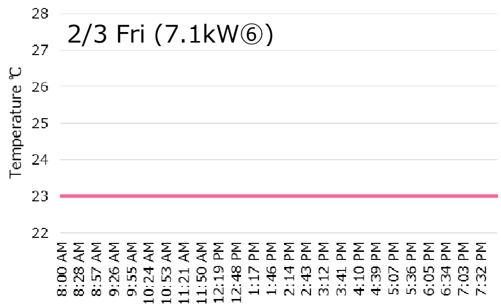
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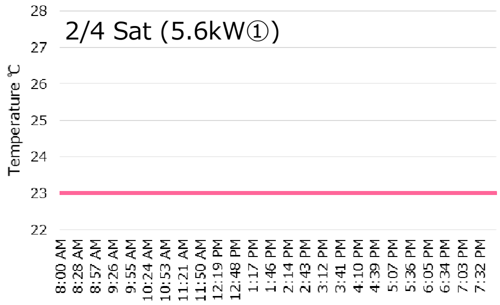
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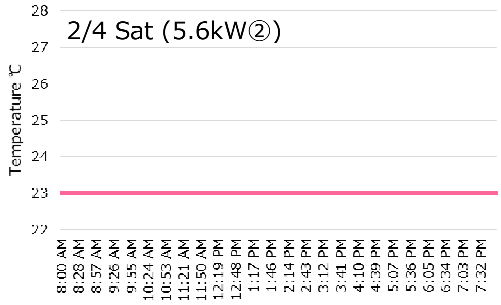
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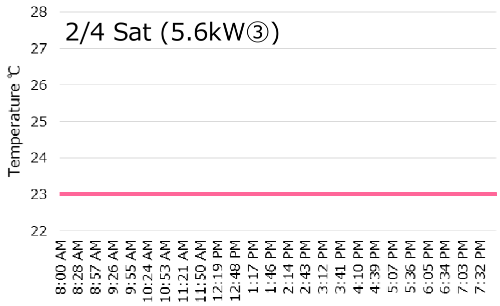
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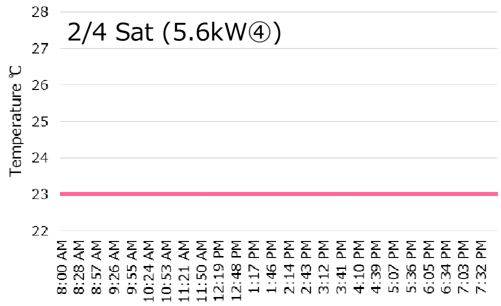
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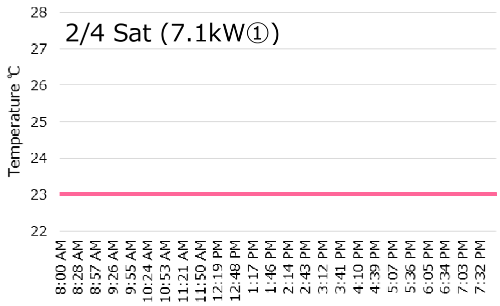
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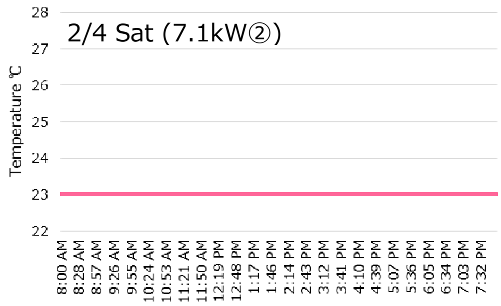
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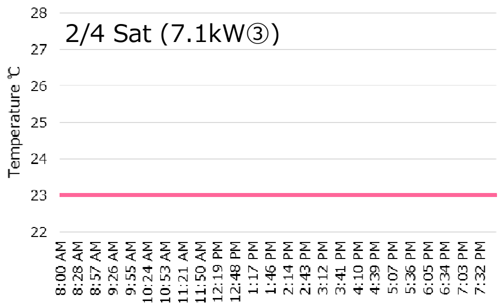
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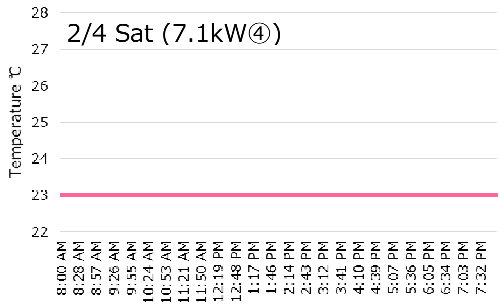
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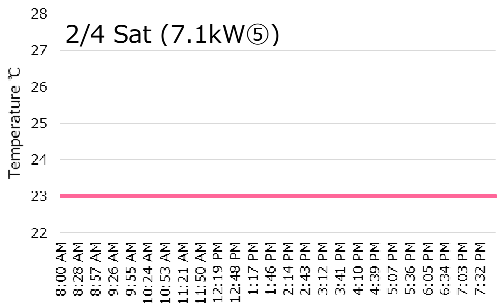
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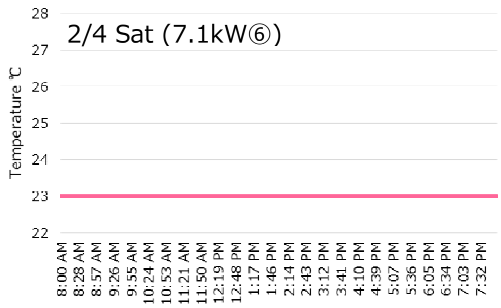
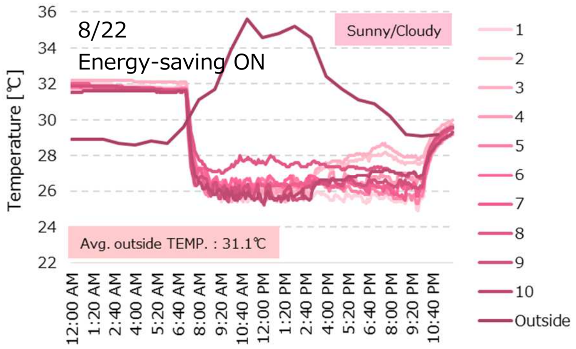
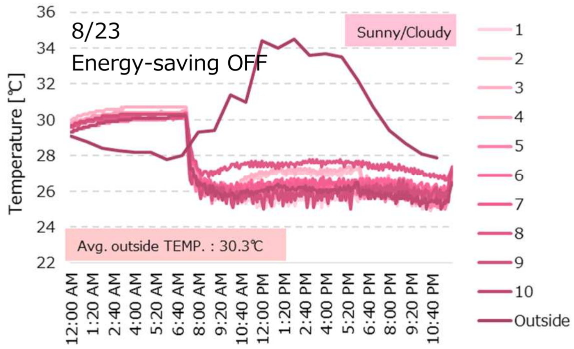
8:00 AM 8:28 AM 8:57 AM 9:26 AM 9:55 AM 10:24 AM 10:53 AM 11:21 AM 11:50 AM 12:19 PM 12:48 PM 1:17 PM 1:46 PM 2:14 PM 2:43 PM 3:12 PM 3:41 PM 4:10 PM 4:39 PM 5:07 PM 5:36 PM 6:05 PM 6:34 PM 7:03 PM 7:32 PM

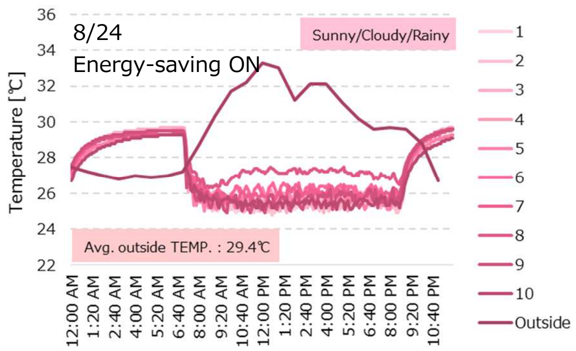

2/4 Sat (7.1kW⑥)
Temperature ℃
28 27 26 25 24 23 22
8:00 AM 8:28 AM 8:57 AM 9:26 AM 9:55 AM 10:24 AM 10:53 AM 11:21 AM 11:50 AM 12:19 PM 12:48 PM 1:17 PM 1:46 PM 2:14 PM 2:43 PM 3:12 PM 3:41 PM 4:10 PM 4:39 PM 5:07 PM 5:36 PM 6:05 PM 6:34 PM 7:03 PM 7:32 PM

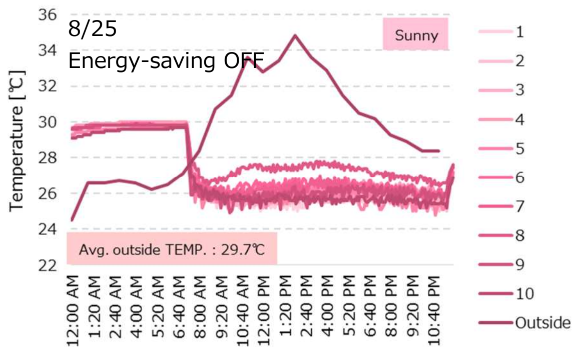
Temperature of indoor and outdoor during the thermal comfort survey

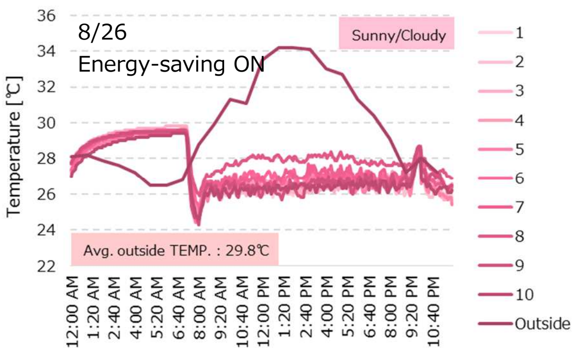
Temperature (Cooling operation)

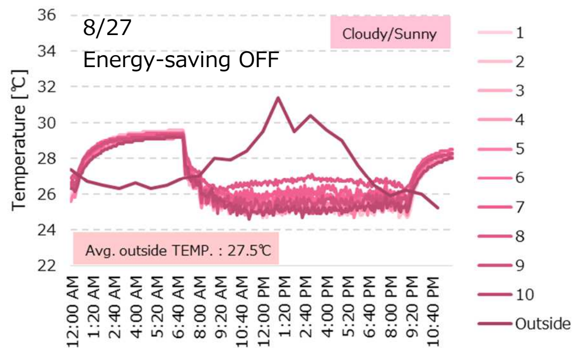




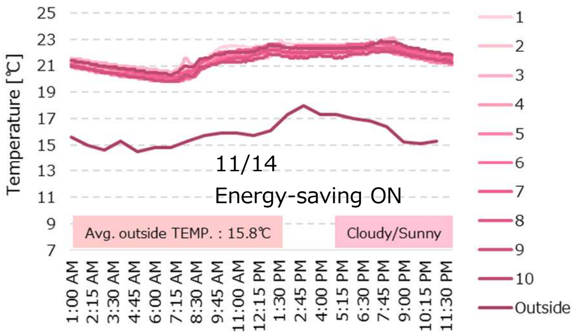


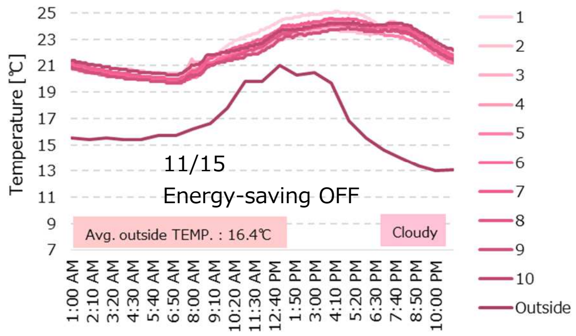


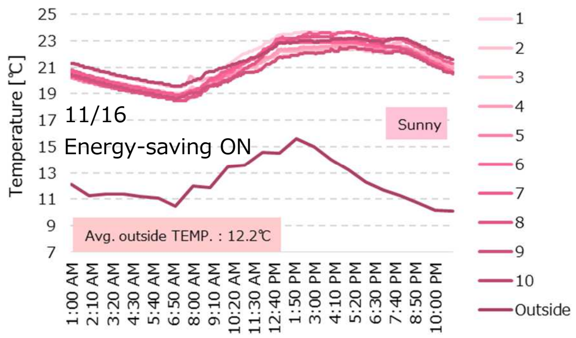


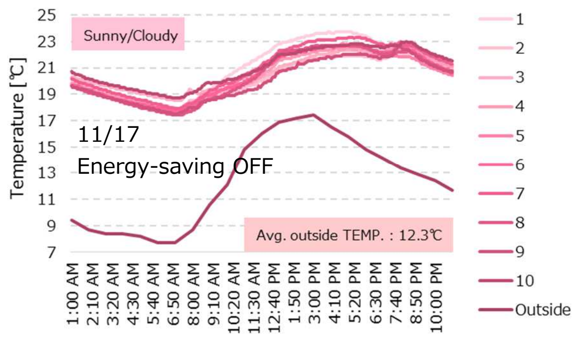


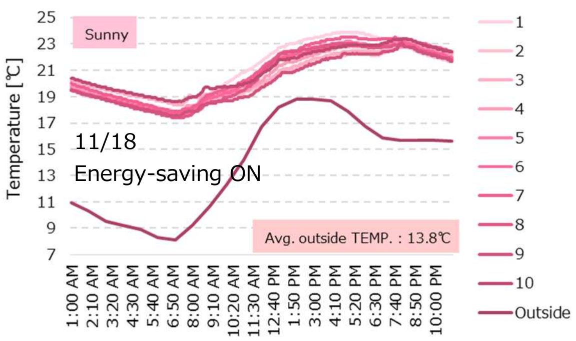
Temperature (Intermediate operation)

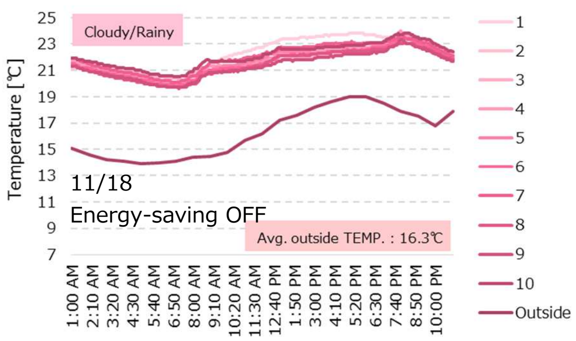




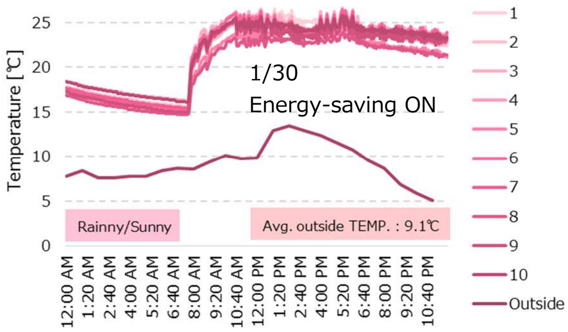


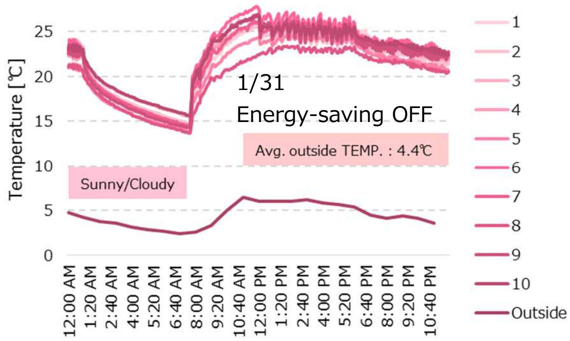


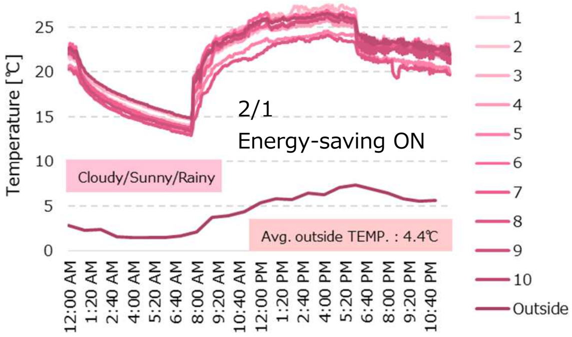


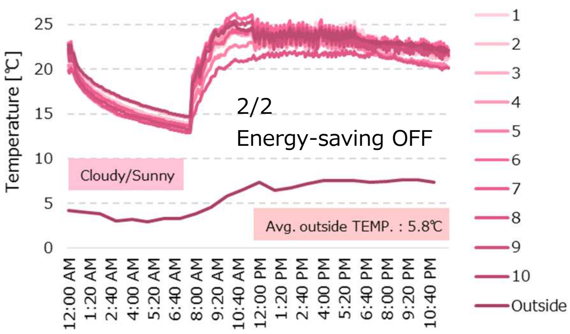


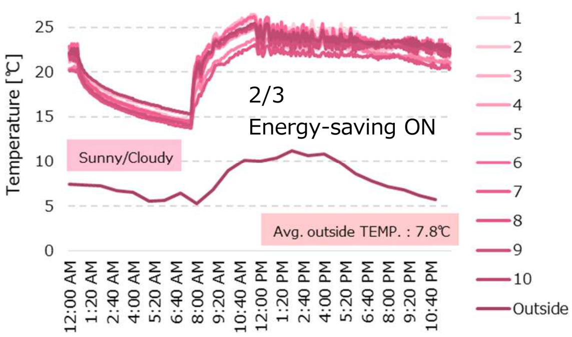
Temperature (Heating operation)

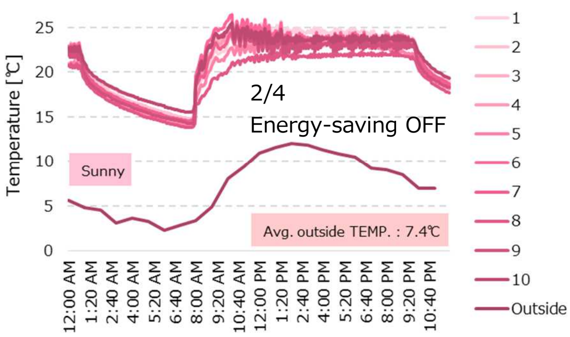






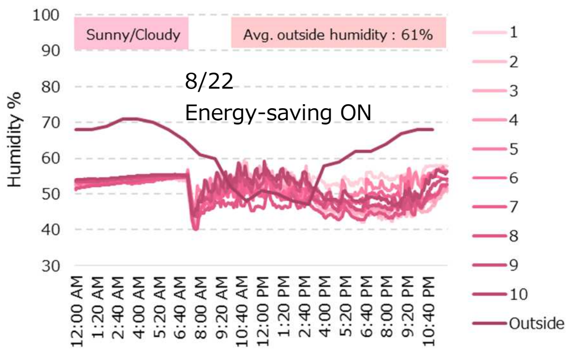


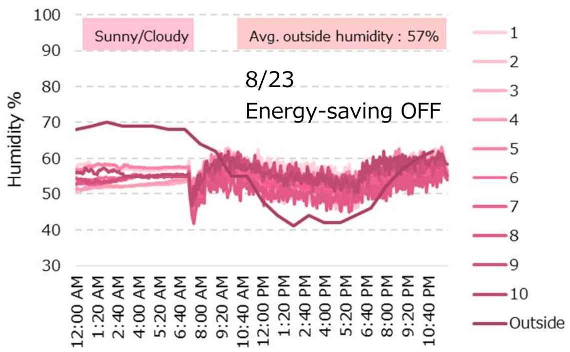


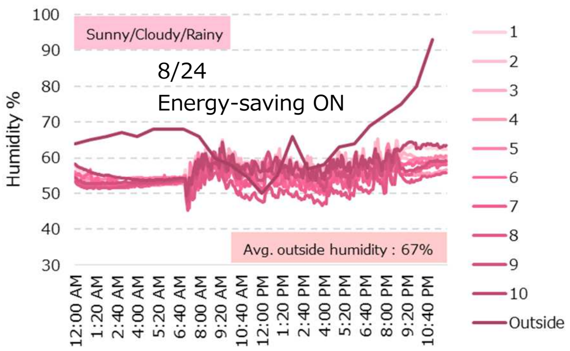


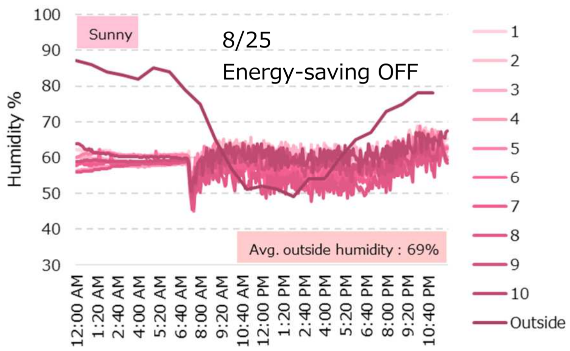
Humidity of indoor and outdoor during the thermal comfort survey

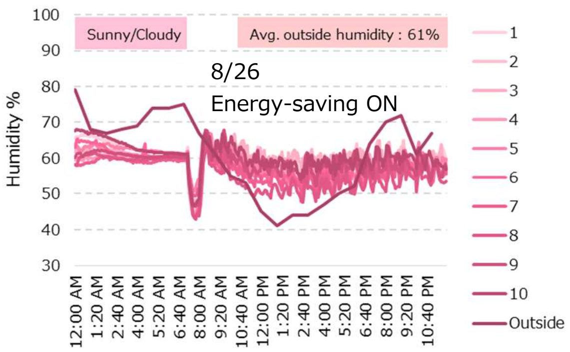
Humidity (Cooling operation)

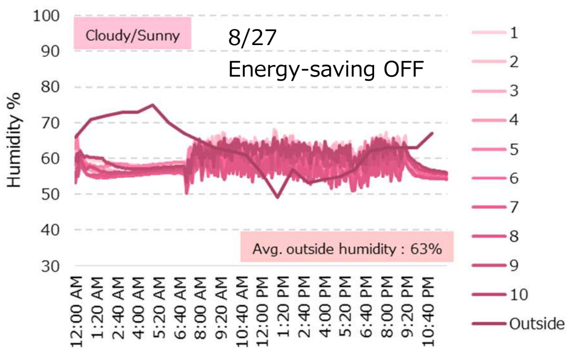




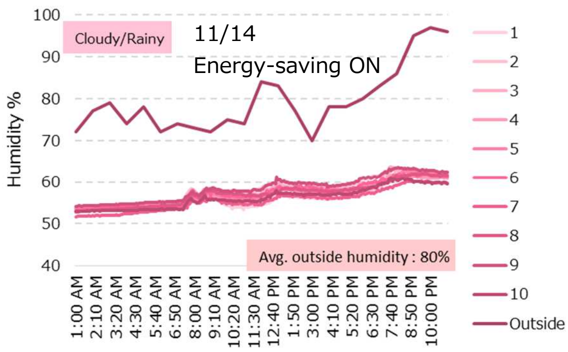


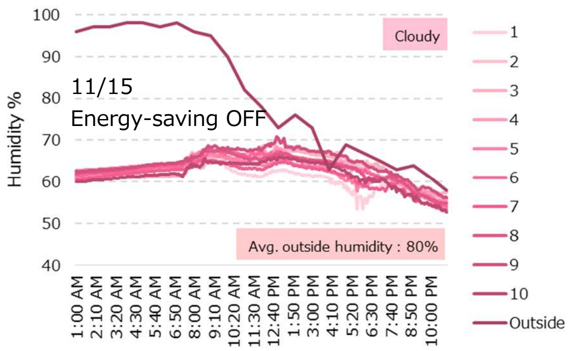


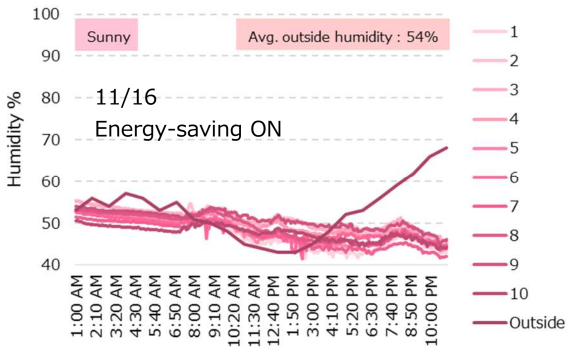


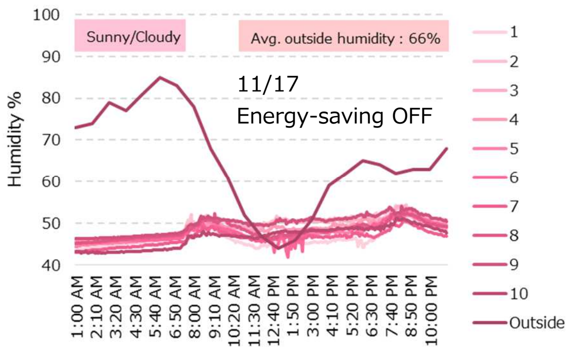


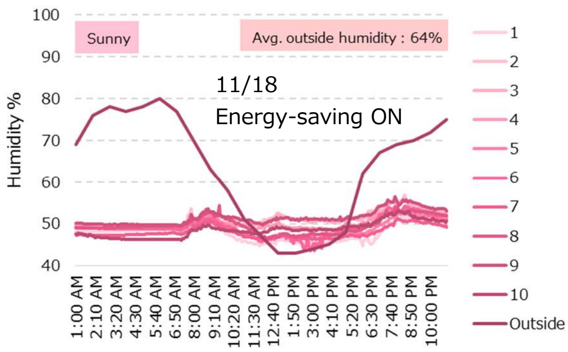
Humidity (Intermediate operation)

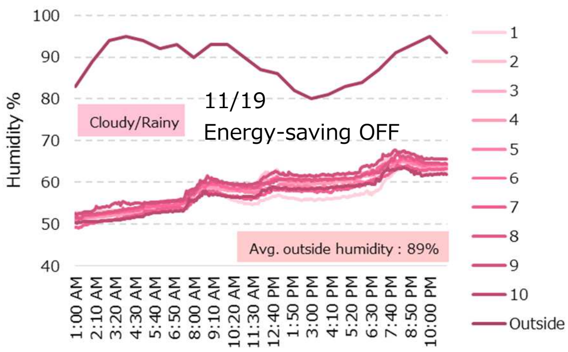




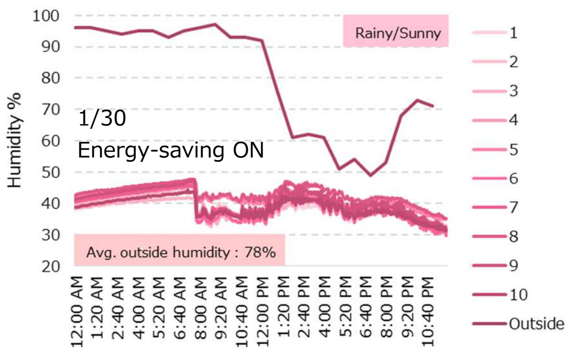


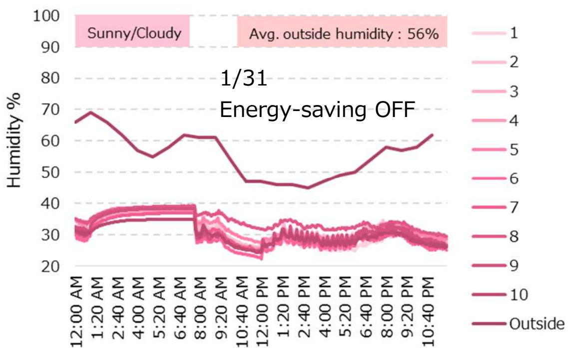


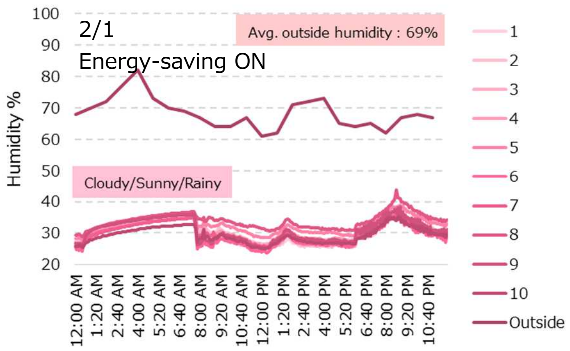


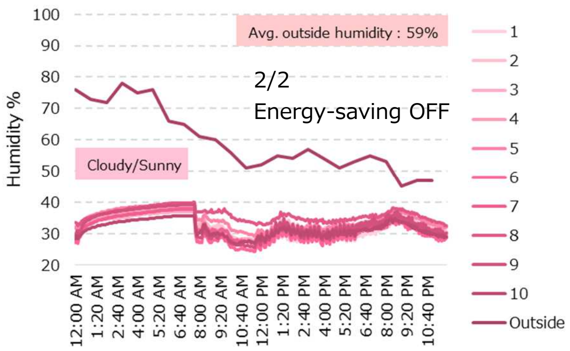


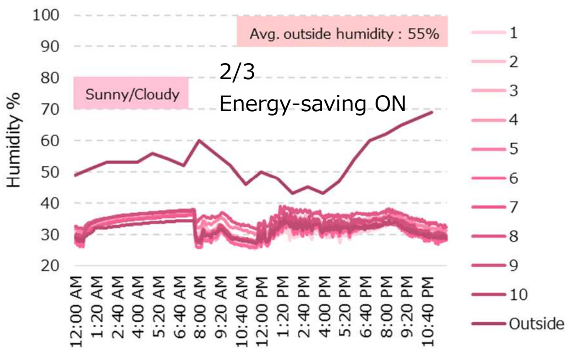
Humidity (Heating operation)

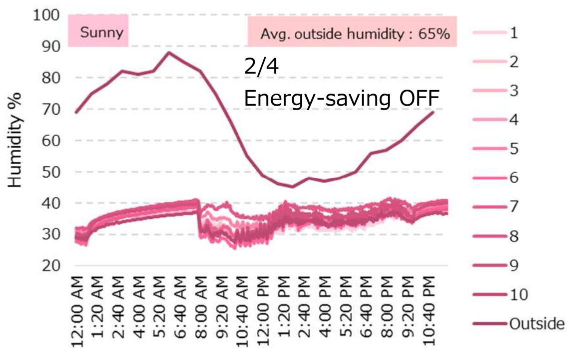












Thermal comfort survey

室内快適性アンケート調査【8 月 22 日（月）～27 日（土）】

■ 本調査の目的：GHP 空調機の省エネルギー性と快適性との関連性調査

空調用エネルギー消費量と快適性との関連を調査しております。ご多忙中誠に恐縮ですが、ご協力をお願い致します。

■ アンケート要領

・アンケート用紙の構成は以下の通りです。

基本事項アンケート（本用紙）　１ページ

１日ごとのアンケート回答用紙　６ページ

・この調査は１週間行います。出勤日ごとのご記入をよろしくお願い致します。

・必ず正しい日付の用紙に、１ページずつ記入を行ってください。

・アンケートは、１日の終わりに回答をお願いします。

・入口付近に回収ボックスを設置しますので、週の勤務最終日に入れください。

・なにかご不明な点等ございましたら、下記連絡先までご連絡お願い致します。

担当者連絡先
東京海洋大学　システム創成学研究室
修士１年　松井絵美
Email: m164026@edu.kaiyodai.ac.jp

基本事項アンケート

（1）性別（いずれかの番号に○を付けてください）

① 男性　　②女性

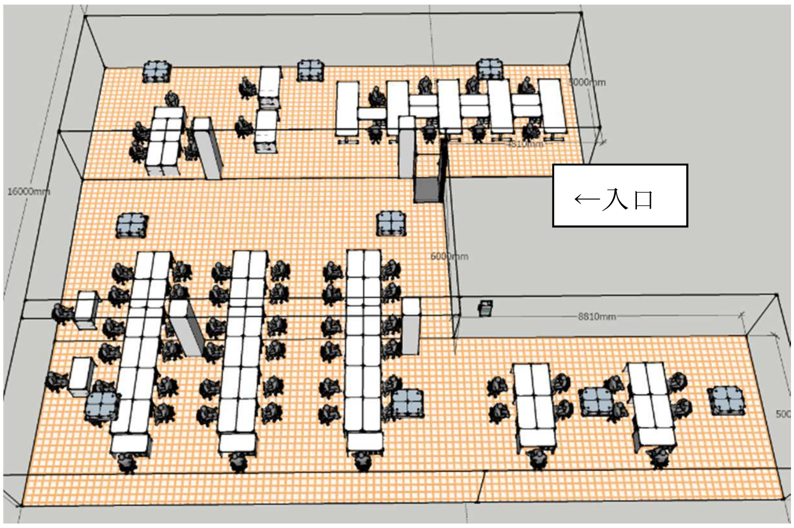
（2）年齢（いずれかの番号に○を付けてください）

①20 代　②30 代　③40 代　④50 代　⑤60 代

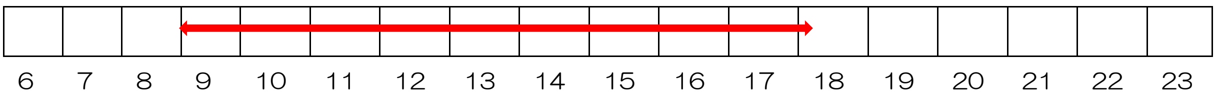
（3）主な勤務時間帯

（　　　　～　　　　）

（4）主な執務場所に○印を付けてください。



（勤務時間帯の記入例）9:00～17:00



８月 22 日（月）

本日の勤務時間帯

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

（1）　本日の服装について、あてはまるもの全てに○印を付けてください。

半袖シャツ　長袖シャツ　ジャケット　ベスト　作業着

スカート　ズボン　半袖ワンピース　長袖ワンピース　その他（　　　　　　　　　　）

（2）　以下の項目について、この中から最も近いものを１つ選び番号に○を付けてください。

（ⅰ）主な執務内容

①　事務執務　　　　　②外勤

（ⅱ）快適性について

[温度]：①暑い　②少し暑い　　③ちょうどよい　④少し寒い　⑤寒い

[湿度]：①湿度が高い　②少し湿度が高い　③ちょうどよい　④少し乾燥している　⑤乾燥している

（ⅲ）扇風機(USB 簡易扇風機を含む)・団扇・扇子等の使用の有無

①　使っている（　扇風機・団扇・扇子　）　　　　②使っていない

（ⅳ）執務中冷風が直接吹き付けていましたか？

①　冷風が吹き付けていた　　　　　②冷風は直接吹き付けていない

（ⅴ）執務中日射の影響がありましたか？

①　日射に直接当たる時がある　　　　②日射にほとんど当たらない

（ⅵ）執務場所の近傍に熱を発するものはありましたか？（PC ファン、冷蔵庫・コピー機の排熱等）

①　熱を発するものがあった（　　　　　　　　　）②熱を発するものは特になかった

（3）　その他、温度調整のために行った対処法があればご記入ください

（例：湿らせたタオルを首にまいていた、ひざ掛けを使っていた等）

（　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　）

Presented papers

Accuracy Verification of the Compressor Curve Method Using an Environmental Test Laboratory
April 15th, 2016
Proceedings of the 50th Japanese Joint Conference on Air-conditioning and Refrigeration
#45

Accuracy Improvement of Performance Evaluation for Variable Refrigerant Flow Systems
June 20th, 2016
ECOS 2016 (29th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy systems)
P424

Conversion Factors for Comparing the Performance of Variable Refrigerant Flow Systems
July 14th, 2016
Purdue University Conferences (16th International Conference of Refrigeration and Air Conditioning Conference)
#2227

Evaluation of Thermal Comfort due to Energy-saving Controls in Variable Refrigerant Flow Systems
September 13th, 2017
The Society of Heating, Air-conditioning and Sanitary Engineering of Japan
G-20 (P85-88)

(Expected to be presented)
Development of an Onsite Performance Evaluation Method for Variable Refrigerant Flow Systems
June 17th-22nd, 2018
ECOS 2018 (31th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy systems)