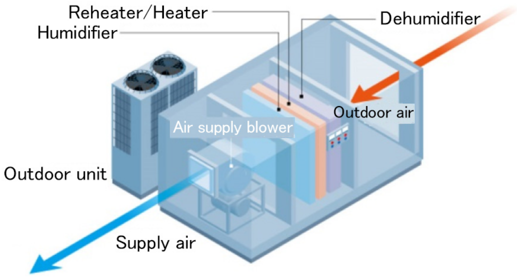
Development of Humidity Control Outdoor Air Processing Air Handling System (Direct X Comfort) Achieving Both Energy Saving and Comfort



KAZUYA MATSUO*1 MASASHI TOKOROTANI*2
TOMOHIRO SAKAGUCHI*3 TATSUYA KASAI*3
MASANORI SENGA*1

Today, it is recommended to raise the cooling temperature setting as a method of saving energy in building air conditioning. However, many air conditioners depend exclusively on dry-bulb temperature control and during the rainy season, their dehumidifying capacity for latent heat may be insufficient, resulting in discomfort. One of the causes of the latent heat load, which is a factor in this discomfort, is often the intake of outdoor air by ventilation. This time, we have commercialized a humidity control outdoor air processing direct expansion air handling system (Direct X Comfort), which has a cooling dehumidification function that controls the dew point temperature and a reheating function that utilizes waste heat, in addition to the functions of conventional outdoor air processing direct expansion air handling systems. By using waste heat from the heat pump as the heat source for reheating, this system has achieved a 60% reduction in power consumption compared to the conventional desiccant system that uses an electric heater as the heat source for regeneration.

1. Introduction

Direct expansion air handling systems are air conditioning systems mainly for offices, factories, schools and hospitals, and 75% of them are used not as indoor air circulation type air conditioners, but as outdoor air intake type outdoor air processors. Recently, it has been recommended to raise the cooling temperature setting as an energy-saving measure, but since the latent heat load cannot be controlled by the dry-bulb temperature control that ordinary multi-system building air conditioners use, the indoor environment may become highly humid and uncomfortable in exchange for energy saving. **Table 1** shows the human discomfort index with respect to the temperature and humidity environment. Even at the same air temperature, higher humidity causes the discomfort index to be higher and conversely, lower humidity suppresses the discomfort index. Therefore, when the humidity can be kept low, the same comfort level can be maintained even with a higher cooling temperature setting. In this way, humidity adjustment, which is latent heat load processing, is important for the realization of energy-saving air conditioning. There is also an increasing need in the recent market for separate latent and sensible air conditioning that controls both air temperature and humidity. In addition, the importance of ventilation frequency (outdoor air intake volume) has been reaffirmed due to the recent COVID-19 pandemic and the need for humidity control outdoor air processing direct expansion air handling systems has increased further.

The newly developed humidity control outdoor air processing direct expansion air handling system has realized excellent energy saving by utilizing waste heat from cooling operation for reheating. This report introduces the features of the developed Direct X Comfort system.

*1 Air Conditioning Headquarters, Mitsubishi Heavy Industries Air-Conditioning & Refrigeration Corporation
*2 Manager, Air Conditioning Headquarters, Mitsubishi Heavy Industries Air-Conditioning & Refrigeration Corporation
*3 Chief Staff Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

Table 1: List of air environment and discomfort index

Temperature (°C) \ Discomfort index	Relative humidity (%) 40	45	50	55	60	65	70
11	54	54	54	53	53	53	53
12	55	55	55	55	55	54	54
13	56	56	56	56	56	56	56
14	57	57	57	57	57	57	57
15	59	59	59	59	59	59	59
16	60	60	60	60	60	60	60
17	61	61	61	61	62	62	62
18	62	62	63	63	63	63	63
19	63	64	64	64	64	65	65
20	65	65	65	66	66	66	66
21	66	66	67	67	67	68	68
22	67	67	68	68	69	69	69
23	68	69	69	70	70	70	71
24	70	70	70	71	71	72	72
25	71	71	72	72	73	73	74
26	72	73	73	74	74	75	75
27	73	74	74	75	76	76	77
28	74	75	76	76	77	78	78
29	76	76	77	78	78	79	80
30	77	78	78	79	80	81	81

Discomfort index	Evaluation
Up to 55	Cold
55 to 60	Chilly
60 to 65	Neutral
65 to 70	Comfortable.
70 to 75	Not hot.
75 to 80	Slightly hot.
80 to 85	Sweaty hot.
85 and higher	Too hot.

The discomfort index is an index published by Earl Crabill Thom in 1957 and quantitatively indicates the humid heat of summer. In Japan, it is calculated by the following formula.

Discomfort index=0.81T+0.01H(0.99T-14.3)+46.3
(T: Temperature (°C), H: Relative humidity (%))

2. Features of Direct X Comfort air conditioning operation

2.1 Difference in latent heat load processing system

Figure 1 is a schematic view of a desiccant system and a cooling dehumidification system, which are major systems of latent heat load processing. The current mainstream of the latent heat load processing is the desiccant system. The desiccant system uses a desiccant material that adsorbs moisture in the air. This system has a desiccant rotor in the air supply path and heat exchangers in front of and behind that for temperature control, as well as a regenerative heat exchanger in the exhaust air path to remove the moisture adsorbed on the desiccant rotor. In order to continuously operate a unit using a desiccant material, which requires repeated cycles of adsorption and regeneration, the desiccant installation needs to be rotor-shaped and therefore the size of the housing increases. In addition, since high-temperature air (usually 50°C or higher) is required to regenerate the desiccant material, expensive heat source equipment such as an electric heater or hot water/steam supply device is necessary. Furthermore, since the desiccant material has a relatively short life and requires regular replacement, the maintenance cost is high.

On the other hand, the cooling dehumidification system consists only of a heat exchanger that cools air below the dew point temperature for dehumidification and a reheating heat exchanger that returns the overcooled air to the set value. Therefore, the housing dimensions can be flexibly determined. Conventional cooling dehumidification systems often adopt an electric heater as the heat source for reheating, which is a factor in increasing the power consumption of the system.

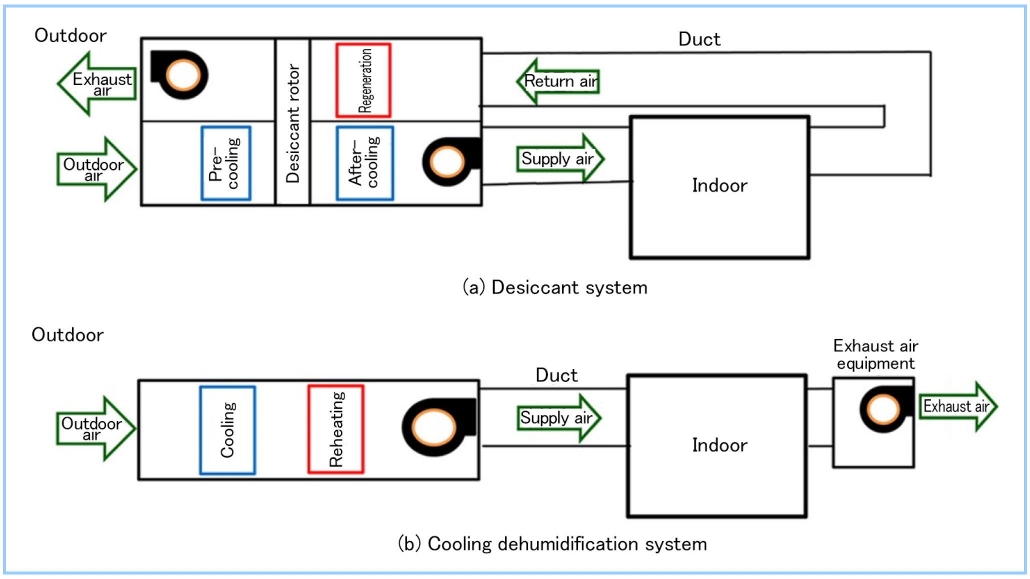


Figure1 Schematic view of latent heat load processing system

2.2 Latent heat load processing system of Direct X Comfort

The newly developed direct expansion air handling system uses waste heat from cooling dehumidification to reduce the power consumption during reheating. For this reason, the "heat recovery multi-system outdoor unit", a commercial air conditioner capable of cooling and heating operations at the same time, was adopted as the heat source unit. **Figure 2** is the system diagram. By installing a heating heat exchanger for reheating (reheater) on the downstream side and introducing the high-pressure gas refrigerant of the outdoor unit thereto, reheating to the supply air temperature setting is made possible. Therefore, the conventional electric heater for reheating can be eliminated, which reduces the power consumption.

Figure 3 presents the behavior on a psychrometric chart during the dehumidifying operation of the Direct X Comfort system. This system processes outdoor air to adjust the temperature and humidity appropriately for indoor air supply. The dew point temperature [2] is calculated based on the temperature and humidity set by the user (for example, the dew point temperature [2] is 15°C when the settings are 26°C DB and 50% RH) and the sucked outdoor air is cooled to that dew point temperature ([1] to [2]) by the cooling heat exchanger (cooling dehumidifier). After that, the air is heated to the target set temperature ([2] to [3]) by the heating heat exchanger and supplied to the room by the air supply blower.

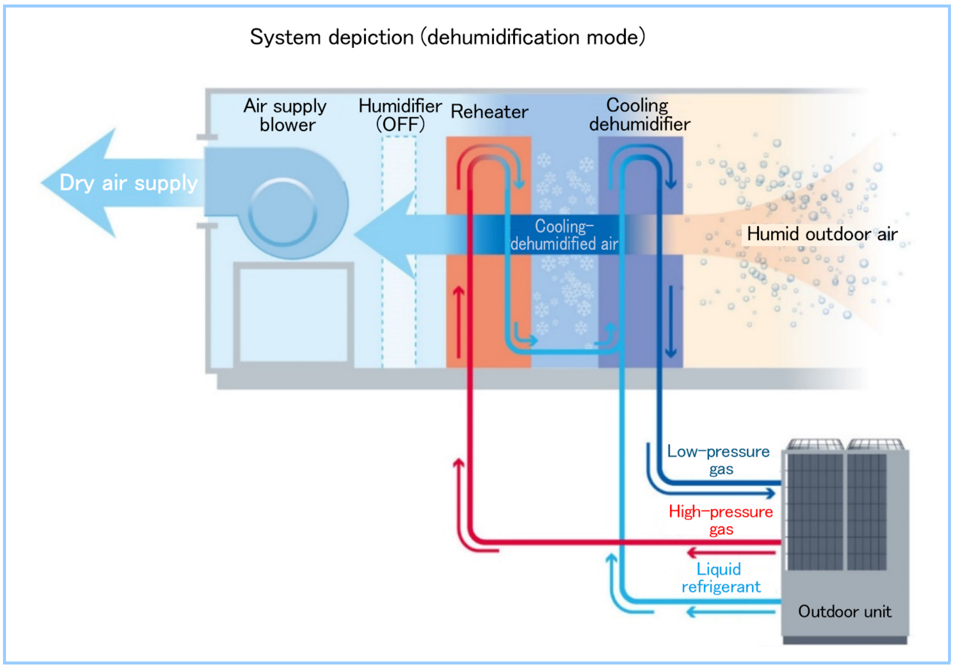


Figure 2 System diagram of Direct X Comfort system

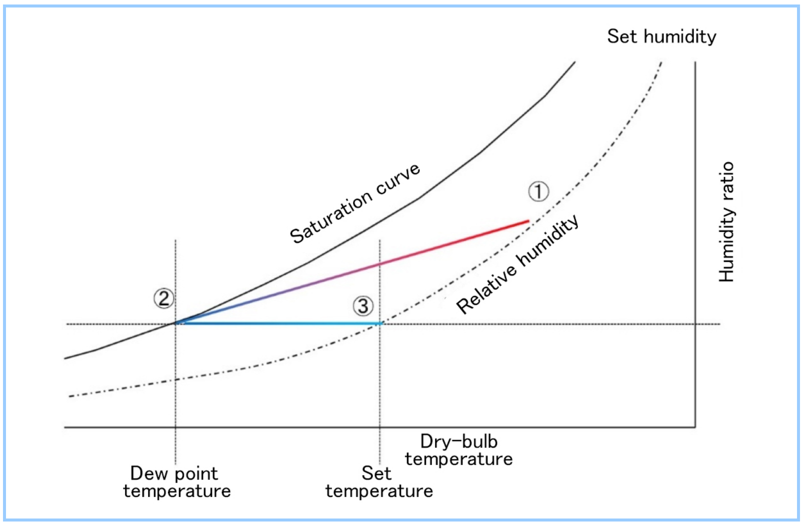


Figure 3 Psychrometric chart of dehumidification mode operation

2.3 Specifications of Direct X Comfort

Table 2 is the specification table of the newly developed Direct X Comfort. Direct X Comfort models ranging from 16 to 108 HP (cooling capacity of 42.4 to 286.2 kW) are available and can be operated in the outdoor air temperature range of 15°C to 43°C DB for cooling and -5°C to 24°C DB for heating. During operation in dehumidification mode, the humidity setting range is 30 to 70% RH and the supply air temperature setting range is 10°C to 30°C. During operation in heating mode, the supply air temperature setting range is 18°C to 30°C.

Table 2 Specifications of Direct X Comfort models

			Model										
Nominal power		Unit	16HP	20HP	28HP	32HP	42HP	48HP	64HP	72HP	84HP	96HP	108HP
Reference outdoor unit power × Number of units		HP	8×2	10×2	14×2	16×2	14×3	16×3	16×4	18×4	14×6	16×6	18×6
Power source		—	3-phase 200 VAC 50/60 Hz										
Cooling capacity		kW	42.4	53	74.2	85.2	111.3	128	170.6	190.8	222.6	254.4	286.2
Reheating capacity		kW	10	12.5	17.5	20	26.2	30.1	40.1	45	52.45	60	67.6
Heating capacity		kW	34.5	43.15	60.34	69.3	90.5	104	138.7	155.2	181	207.2	233
Air blower for air supply	Air flow volume	CMH	2290	2850	4000	4600	6000	6900	9200	10300	12000	13750	15450
	Outdoor air supply volume	CMH	2290	2850	4000	4600	6000	6900	9200	10300	12000	13750	15450
	Rated power output	kW	2.2	2.2	3.7	5.5	5.5	5.5	5.5	7.5	11	11	11
Humidifier		—	Vaporization type										
		kg/h	21.7	27.2	38	43.7	57	65.5	87.4	97.8	114.1	130.5	146.8
External dimensions		TW	1260	1260	1260	1260	1560	1860	1860	1860	2360	3060	3210
		TL	3460	3460	3560	3660	3760	3660	3810	3810	3910	4060	4060
		TH	1630	1630	1830	2130	2530	1930	2180	2180	2530	2130	2130
Estimated weight		kg	1420	1480	1620	1850	2230	2230	2550	2630	3450	3600	3750

Direct X Comfort has three operation modes: dehumidification mode, heating mode and air blow only mode. **Figure 4** illustrates the refrigerant circuit operations in dehumidification mode and heating mode.

(1) Figure 4 (a) illustrates dehumidification mode operation. This operation mode is started by a dehumidifying operation command from the remote controller. The cooling heat exchanger on the upstream side is used as an evaporator and the heating heat exchanger on the downstream side is used as a condenser to control the sucked outdoor air to the target humidity and temperature. The system calculates the target dew point temperature based on the supply air temperature (°C DB) and humidity (%) set on the remote controller, cools the air to the target dew point temperature with the cooling heat exchanger and heats the air to the target supply air temperature with the heating heat exchanger on the downstream side.

(2) Figure 4 (b) depicts heating mode operation. This operation mode is started by a heating operation command from the remote controller. The heating heat exchanger is used as a condenser for heating operation. The system calculates the target high pressure of the compressor operation based on the supply air temperature (°C DB) set on the remote controller, controls the compressor speed and the expansion valve opening of the heating heat exchanger to heat the air to the target supply air temperature.
Humidification control in heating mode is realized by controlling the humidifier installed on the downstream side of the heating heat exchanger with the humidity sensor on the air blow side.

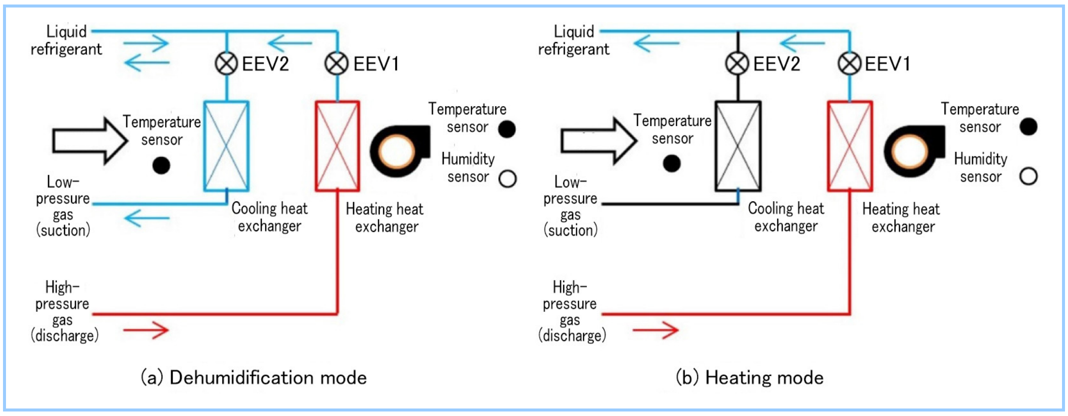


Figure 4 Dehumidification mode and heating mode of Direct X Comfort

2.4 Supply air temperature control of Direct X Comfort

The heat source equipment of this system has an additional control function that appropriately changes the high and low pressure of the compressor in order to control the supply air temperature. In dehumidification mode operation, the system calculates the target dew point temperature based on the temperature and humidity settings and controls the compressor speed and the opening of the electronic expansion valve on the air handling unit side so as to appropriately adjust the low pressure. In the case of heating, the system operates so as to adjust the high pressure to that pressure.

3. Energy-saving performance verification of dehumidifying operation of Direct X Comfort

In order to compare the energy-saving performance of the desiccant system, the conventional cooling dehumidification system and the newly developed Direct X Comfort, the power consumption during dehumidifying operation of each system was estimated.

For the estimation conditions, it was assumed that each system operates under conditions of an air flow volume of 7,000 m^3/h and intake temperature/humidity of 33°C DB/68% RH (JIS rated condition) targeting the supply air temperature/humidity of 26°C/45% RH. In order to make the comparison conditions uniform, all the systems used the same direct expansion cooling. Since the dehumidification capacity of the desiccant system differs depending on the regeneration temperature, this estimation was made for cases where the regeneration heat source was set to the regeneration temperature of 40°C and 51.2°C. For the regeneration temperature of 40°C, a heat pump can be used as the heat source, so as with Direct X Comfort, it was assumed to utilize waste heat (hot gas system) using the “heat recovery multi-system outdoor unit”. For the regeneration temperature of 51.2°C, which causes the condensation pressure to be close to the design pressure, the use of R410A refrigerant for commercial air conditioners was considered to be difficult, so the use of an electric heater was assumed. The power consumption of the conventional cooling dehumidification was estimated with the assumption that the reheating equipment was an electric heater. **Table 3** summarizes these estimation conditions.

Table 3 List of power consumption estimation conditions for desiccant system, cooling dehumidification system and direct X Comfort

Estimation pattern	(a) Conventional desiccant system	(b) Conventional cooling dehumidification system	(c) Direct X Comfort	(d) Desiccant system utilizing waste heat
Intake conditions (outdoor air temperature)	33°C DB/68% RH			
Discharge conditions (indoor temperature)	26°C DB/45% RH			
Air flow volume	7000m^3/h			
Heat source for cooling	Direct expansion	Direct expansion	Direct expansion	Direct expansion
Heat source for regeneration	Electric heater	—	—	Utilizing waste heat (hot gas system)
Heat source for reheating	—	Electric heater	Utilizing waste heat (hot gas system)	—
Note	The desiccant regeneration temperature is assumed to be 51.2°C.		The high-pressure gas of the heat recovery multi-system is used as the heat source.	- he desiccant regeneration temperature is assumed to be 40°C. - he high-pressure gas of the heat recovery multi-system is used as the heat source.

Figure 5 is a psychrometric chart of the behaviors of the desiccant system and the cooling dehumidification system. In Figure 5, the black line plots the behavior of the desiccant system and the red line plots the behavior of the cooling dehumidification system. In the case of the desiccant system, pre-cooling ([1] to [2]) is performed to suppress the regeneration heat amount and then moisture adsorption ([2] to [3]) with the desiccant material. Since the air temperature rises due to the heat generated during moisture adsorption, the target air temperature and humidity are generated by the after-cooling process ([3] to [5]). Therefore, the power consumption of the desiccant system was obtained by calculating the power consumption of the pre-cooling [1] to [2] and the after-cooling [3] to [5]. The total power consumption of the system is the sum of this and the power consumption for reheating to exhaust the adsorbed moisture.

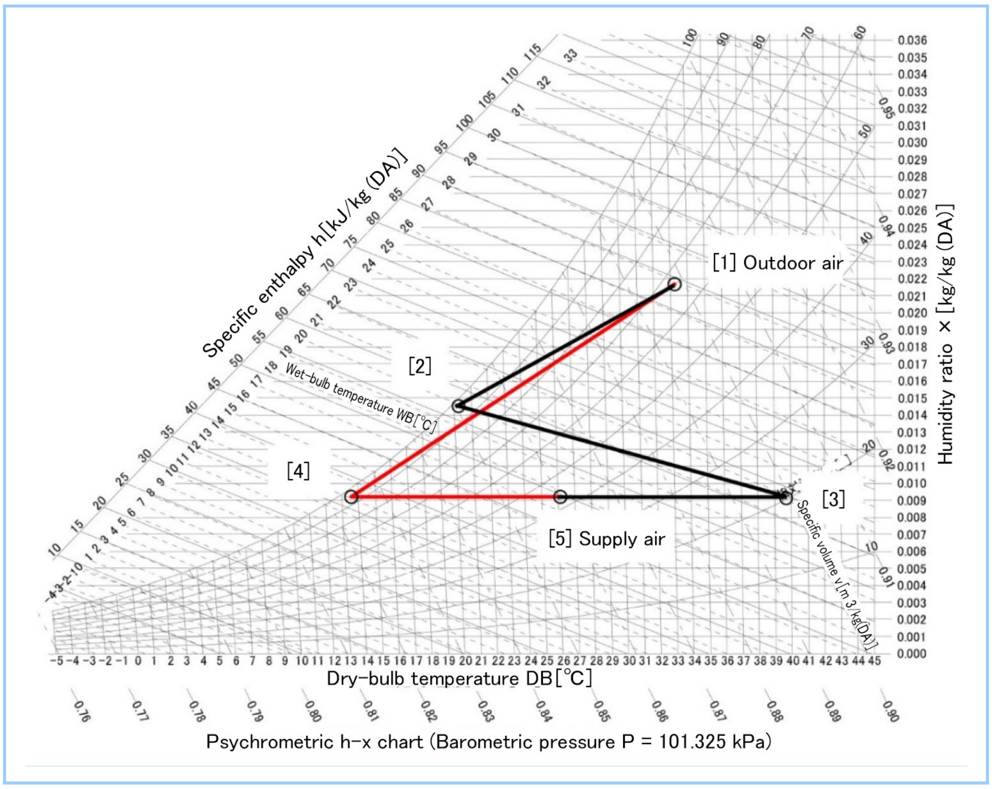


Figure 5 Psychrometric chart of dehumidifying operation of desiccant system and cooling dehumidification system

On the other hand, in the case of the cooling dehumidification system, cooling to the target dew point temperature ([1] to [4]) is performed with the cooling heat exchanger to condense the moisture in the air and then the air is heated with the heating heat exchanger ([4] to [5]) to generate the target air temperature and humidity. The conventional cooling dehumidification system uses an electric heater for this heating, but Direct X Comfort can eliminate the need for this electric heater by using waste heat from the cooling heat exchanger. Therefore, the total system power consumption of the conventional cooling dehumidification system is the sum of the power consumption of [1] to [5] and the total system power consumption of Direct X Comfort is the power consumption of the cooling [1] to [4].

Tables 4 and **Figure 6** explain the estimation results of the power consumption during the dehumidifying operation of each system. Table 4 (a) lists the calculation results of the power consumption of the conventional desiccant system using an electric heater as the regeneration heat source. The total power consumption is 86.31 kW, which shows that this system consumes the highest amount of power. Table 4 (b) shows the conventional cooling dehumidification system using an electric heater for reheating and the total power consumption is 60.69 kW. Table 4 (c) is the power consumption of Direct X Comfort under the same conditions, which is estimated to be 33.49 kW. This power consumption value is 60% lower than the conventional desiccant system using an electric heater as the regeneration heat source (Table 4 (a)).

We also made an estimation for the desiccant system that uses waste heat from the heat pump similar to Direct X Comfort. Table 4 (d) gives the estimation results. This system requires the regeneration temperature to be lowered to 40°C, which requires an increase in the cooling capacity of the dehumidification side, but does not require electricity for regeneration, resulting in a total power consumption of 33.51 kW. This desiccant system utilizing waste heat has the same energy-saving performance as Direct X Comfort, but air for recycling from the indoor side is required to regenerate the desiccant material, so the duct routing restriction becomes stricter.

In addition, since a desiccant rotor and a drive unit are required, the number of equipment components increases and there is the problem of air flow leakage from the rotor. On the other hand, the newly developed Direct X Comfort system realizes more design flexibility at the time of on-site installation and has a simpler device configuration compared to the desiccant system. Therefore, Direct X Comfort has a greater advantage in the market.

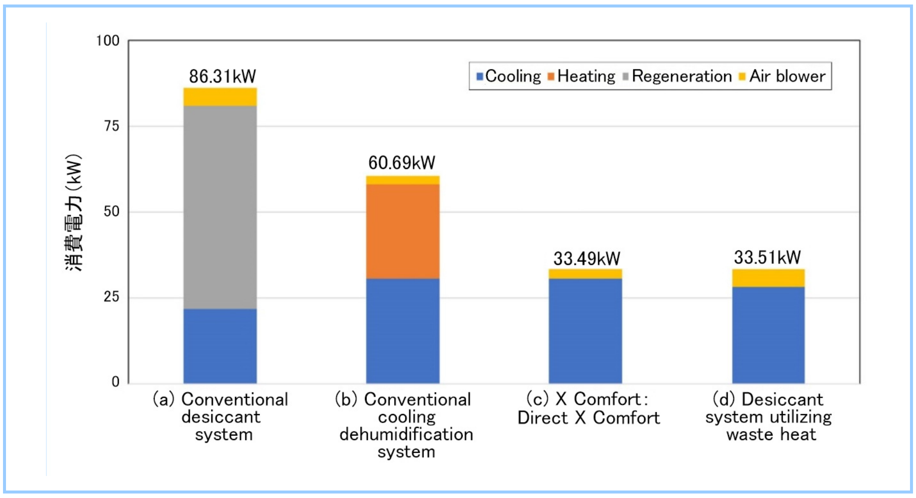


Figure 6 Estimation results of power consumption during dehumidifying operation of each system

Table 4 Power consumption of desiccant system, cooling dehumidification system and Direct X Comfort

(a) Power consumption of conventional desiccant system during dehumidifying operation

Dehumidification system	Conventional desiccant system		
	Required capacity [kW]	Power consumption [kW]	Note
Pre-cooling	80.0	16.30	–
After-cooling	34.0	5.50	–
Heating for regeneration	59.2	59.20	Electric heater
Air blower for indoor air supply	–	3.16	–
Air blower for regeneration	–	2.15	–
	Total power consumption	86.31kW	

(b) Power consumption of conventional cooling dehumidification system during dehumidifying operation

Dehumidification system	Conventional cooling dehumidification system		
	Required capacity [kW]	Power consumption [kW]	Note
Cooling dehumidification	124.0	30.80	–
Reheating	27.2	27.20	Electric heater
Air blower for indoor air supply	–	2.69	–
	Total power consumption	60.69kW	

(c) Power consumption of Direct X Comfort during dehumidifying operation

Dehumidification system	Cooling dehumidification system utilizing waste heat		
	Required capacity [kW]	Power consumption [kW]	Note
Cooling dehumidification	124.0	30.80	–
Reheating	27.2	0.00	Utilizing waste heat (hot gas system)
Air blower for indoor air supply	–	2.69	–
	Total power consumption	33.49	

(d) Power consumption of desiccant system utilizing waste heat during dehumidifying operation

Dehumidification system	Desiccant system utilizing waste heat		
	Required capacity [kW]	Power consumption [kW]	Note
Pre-cooling	97.2	25.83	–
After-cooling	16.1	2.37	–
Heating for regeneration	35.0	0.00	Utilizing waste heat (hot gas system)
Air blower for indoor air supply	–	3.16	–
Air blower for regeneration	–	2.15	–
	Total power consumption	33.51kW	

4. Verification with actual Direct X Comfort system

We installed an actual 16-HP system in our shop and conducted field tests. In this test, the controllability of the supply air humidity during dehumidifying operation and the supply air temperature during heating operation were verified with actual equipment. The target dew point for dehumidification is usually set to 13°C, but in this field test, it was set lower to 10°C for verification. In addition, the ability during heating operation to reach the 45°C supply air temperature setting, which took into consideration an after-humidification temperature drop due to heat of vaporization, was confirmed. **Figure 7** presents the measurement data of the dehumidifying operation and the heating operation of the tested equipment.

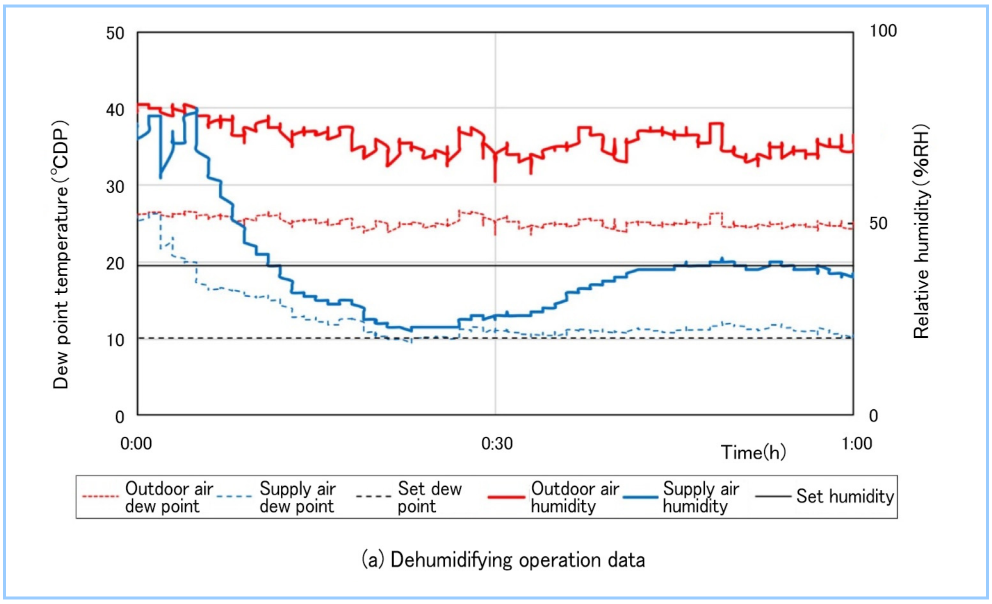


Figure 7 (a) Field test equipment verification results

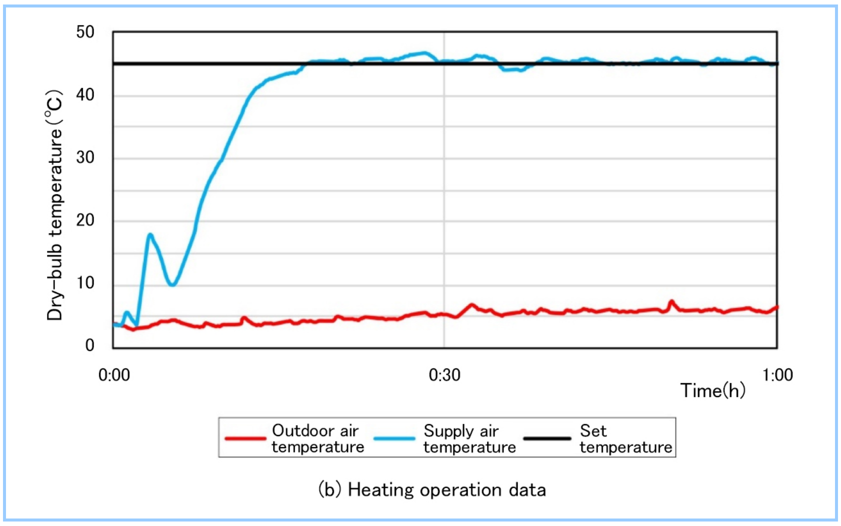


Figure 7 (b) Field test equipment verification results

Figure 7 (a) is the measurement data of the humidity of intake and supply air during dehumidification mode operation. Under the outdoor air temperature and humidity conditions of approximately 30°C DB and 70% RH, dehumidifying operation was performed with a target humidity setting of 39% RH (25°C DB, 10°C DP). It was confirmed that the dew point temperature reached the target value (10°C DP) about 20 minutes after the start of operation, the supply air humidity reached the target value (39% RH) after about 40 minutes and the humidity could be maintained.

Figure 7 (b) shows the measurement data of the temperature of intake and supply air during heating mode operation. Under the outdoor air temperature condition of approximately 5°C DB, heating operation was performed with a target supply air temperature setting of 45°C DB. It was confirmed that the air blow temperature reached the target value (45°C DB) about 20 minutes after the start of operation and the temperature could be maintained.

5. Other features of Direct X Comfort

The newly developed Direct X Comfort has other features as follows.

(1) Control function of humidifier for heating

Humidification during heating operation is performed by a humidifier located on the downstream side of the heating heat exchanger. The control software of this developed system incorporates ON/OFF control for the vaporization type humidifier and proportional control for the steam type humidifier and there is no need to purchase an additional control device for the humidifier. The control point can be also selected from two types, relative humidity and dew point temperature.

(2) Dispersed defrosting function

Since this system uses an air-cooled heat pump, in which the evaporator becomes covered with frost during heating operation, defrosting operation is required in heating operation. In defrosting operation, the evaporator is defrosted by switching between cooling and heating. This causes the supply air temperature to fluctuate during the defrosting operation. In order to minimize this effect, this system is equipped with an additional control function to control simultaneous defrosting of multiple heat source equipment. This function can minimize the fluctuation of the supply air temperature by controlling the timing of starting defrosting of the linked heat source equipment.

(3) Retrofit to existing equipment

An air handling unit that can be assembled on-site is also available. The air handling unit can be broken down to functional components, making carrying-in through existing doors and elevators to the existing machine room for assembly possible. In addition, unlike desiccant systems, this system can be used to construct a dehumidification system regardless of the presence/absence of exhaust air from the indoor side and independently of the temperature and volume of the exhaust air, so it can be used to retrofit any type of existing equipment.

(4) Connectable to central management system

This system uses “SUPERLINKR®II” for commercial air conditioners as the communication method between devices and can be connected to a non-polar 2-wire high-speed communication network with a maximum wiring length of 1500 m. It is also possible to connect this network to the central building management system via a gateway.

6. Conclusion

The newly developed humidity control outdoor air processing direct expansion air handling system (Direct X Comfort) has realized a significant reduction in power consumption compared to the conventional desiccant system. In addition, by using a commercial air conditioner for the heat source equipment, the installability and maintainability equivalent to those of commercial air conditioners are ensured. Furthermore, a common remote monitoring system can be used, so the ease of acceptance in the market can be taken into consideration. By adopting this system, the processing of latent heat load during intake of outdoor air is made possible throughout the year and it is possible to provide separate latent and sensible air conditioning that achieves both energy saving and comfort.