FIELD TEST OF DESICCANT HUMIDITY CONTROL SYSTEM USING WATER SOURCE HEAT PUMP

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Abstract: This paper reports on the field test of an air-conditioning system that can save energy by processing a latent heat load and a sensible heat load separately. A feature of this air-conditioning system is that it allows air-conditioning heat source equipment to be more efficient because the temperature difference between the hot and cold water used is smaller than conventionally would be the case. However, if cold water at a higher temperature than is conventionally used is employed, the cooling and dehumidification provided by the system would be insufficient. Therefore, the realization of a high-efficiency dehumidifier is vital. The authors built a prototype desiccant humidity control system that can make effective use of the waste heat generated by a water source heat pump, and conducted a field test to evaluate its humidity control performance. The results of the test were that the prototype had humidity control performance sufficient for office air-conditioning, and that the efficiency of the air-conditioning heat source equipment that produces cold water was significantly improved.

Key Words: desiccant air-conditioning system, polymer sorbent, waste heat, water source heat pump

1 INTRODUCTION

In recent years, expectations have been running high for an air-conditioning system that processes a latent heat load and a sensible heat load separately, as there is a high possibility that such technology can save energy and improve indoor heat environment quality.

Unlike conventional air-conditioning systems that use cold water with a maximum temperature of 7°C and hot water with a minimum temperature of 45°C, an air-conditioning system using hot and cold water with temperatures closer to ambient temperature (room temperature) can improve the efficiency of heat source equipment that produces hot and cold water and reduce the energy consumption of air-conditioning. On the other hand, as the temperature of cold water is higher than before, sufficient cooling and dehumidification are difficult. Therefore, a dehumidifier such as a desiccant air-conditioning system is needed.

Desiccant air-conditioning systems require a high-temperature heat source to regenerate adsorbed moisture. Therefore, research has been conducted to save energy for the system by, for example, using solar energy and the waste heat of power generators. However, if these regenerative heat sources are used, there is a possibility that sufficient heat energy cannot be supplied when dehumidification is needed. To solve this problem, a desiccant air-conditioning system that uses the condenser of an air source heat pump as a regenerative heat source and uses its evaporator for the cooling of air processed on the adsorption side has been proposed.

At the same time, fine humidity control performance is required as the indoor latent heat load varies with the number of human beings in the area. By only using the heat of condensation and vaporization of an air source heat pump, the cooling of processed air and the heating of regenerated air are simultaneously controlled. With the aim of making humidity control easier, the authors propose a desiccant humidity control unit that uses a water source heat pump in order to separately control the cooling of processed air and the heating of regenerated air.
This paper aims to achieve the practical application of a desiccant humidity control unit that uses a water source heat pump, provides an outline of a prototype, and gives the results of a field test for a hypothetical office space.

2 METHOD

2.1 FIELD TEST APPARATUS

The field test equipment was designed for a hypothetical air-conditioning system in which an office on one floor with an area of 1,000 m^2 is divided into two separate air-conditioning zones with a floor area of 500 m^2, where the system generates a latent heat load and a sensible heat load simulated for a hypothetical office in a chamber to air-condition it (Figure 1). A desiccant humidity control unit, which provides ventilation to supply the required amount of outside air and that controls indoor humidity, and an air-conditioning unit, which controls only room temperature, were installed. In this system, after the air supplied and the air returned by the desiccant humidity control unit were mixed upon the system completing the processing of the latent heat load, the air-conditioning unit processes only the sensible heat load. The amount of exhaust air used for regeneration by the desiccant humidity control unit, excluding the amount of exhaust air from a rest room, etc., is set to 70% of the air supplied.
Hot and cold water are supplied to the desiccant humidity control unit and the air-conditioning unit from an air source heat pump/chiller unit installed outdoors. The outlet temperature of the chiller is set to 13°C for cooling and 40°C for heating.

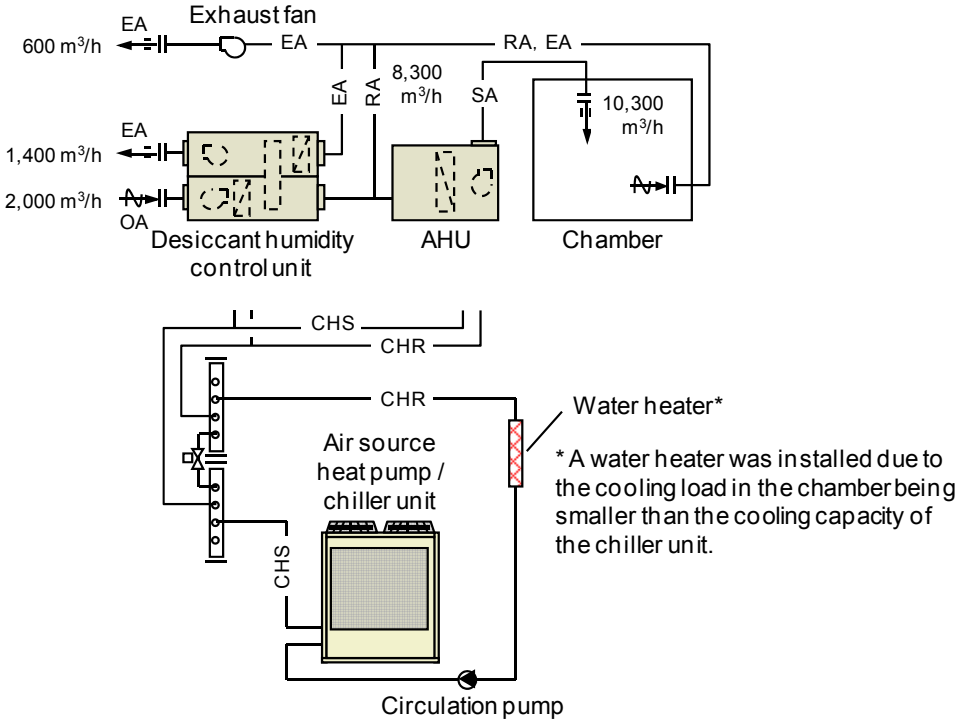


Figure 1: Field Test Apparatus

2.2 DESICCANT HUMIDITY CONTROL UNIT

Figure 2 shows the installation conditions of the desiccant humidity control unit, and Table 1 shows its specifications. The polymer sorbent used for the desiccant rotor is a high-efficiency dehumidifying material that can be sufficiently regenerated even when using air at a temperature of 50°C or less, and the waste heat of the heat pump equipment can be used. For the field test, a prototype desiccant humidity control unit with a small built-in water source heat pump was built.



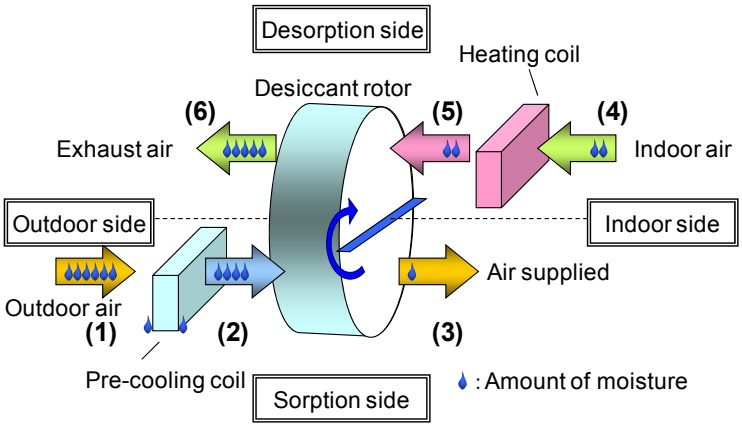
Figure 2: Prototype Desiccant Humidity Control Unit

Table 1: Desiccant Humidity Control Unit Specifications

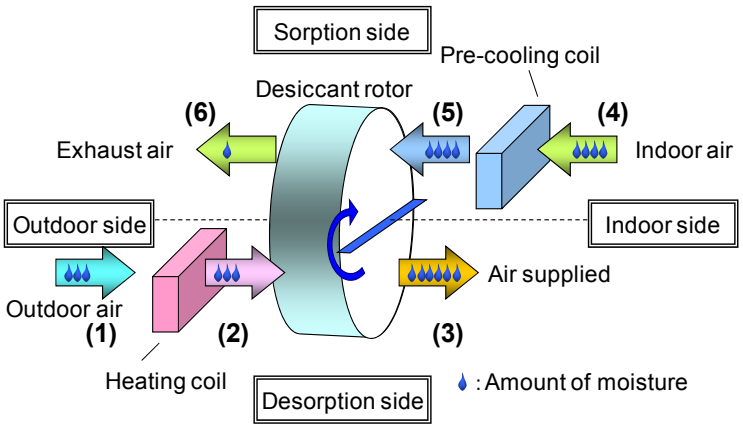
Desiccant rotor	Polymer sorbent, 770 mm in diameter, 200 mm in width, n = 30 rph
Supply line	Air flow rate: 2,000 m^3/h Cooling capacity: 27.7 kW Water flow rate: 4.8 m^3/h
Exhaust line	Air flow rate: 1,400 m^3/h Heating capacity: 11.3 kW
Water heat source heat pump	Compressor: hermetic rotary compressor, 2.7kW × 1 Refrigerant: R410A Cooling capacity: 8.5 kW Water flow rate: 2.45 m^3/h

Figure 3 shows the dehumidification and humidification processes. In the dehumidification process, after fresh outside air is pre-cooled to increase its relative humidity, it is passed through the desiccant rotor in order to obtain dry air. Indoor exhaust air is heated by the heat of condensation of the heat pump to use it as regenerated air, and moisture adsorbed on the desiccant rotor is discharged outdoors. In the humidification process, after indoor exhaust air is cooled by the heat of vaporization of the heat pump to increase relative humidity, it is passed through the desiccant rotor to adsorb the moisture contained in the exhaust air. After fresh outside air is heated to decrease relative humidity, the moisture is transferred to it. Therefore, this system allows humidification without a water supply.
Figure 4 shows the desiccant humidity control system using the water source heat pump and measurement points. The heat of condensation of the water source heat pump is used to regenerate the desiccant rotor, and the output of the compressor is automatically adjusted so

that the outlet temperature of the condenser is constant. On the evaporator side, after cold water at a temperature of 13°C supplied from the air source heat pump/chiller unit is further cooled by the heat of vaporization, it is used for the pre-cooling of intake air. For the prototype, a bypass control using a three-way valve is used in order to strike a balance between the absorption of the heat of condensation of the water source heat pump and the heat needed for pre-cooling. The temperature of cold water supplied to the desiccant humidity control unit and the air-conditioning unit is set to 13°C, which is higher than the range of temperatures generally used, in order to increase the efficiency of the air-conditioning system.
The measurement points are shown in Figure 4.



Dehumidification Process



Humidification Process

Figure 3: Humidity Control Using a Desiccant Rotor

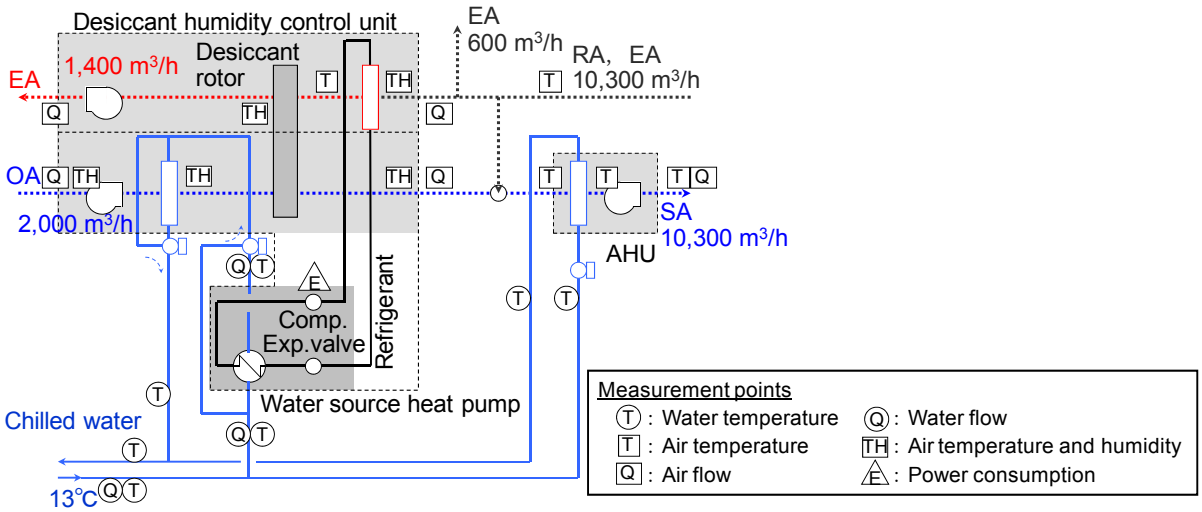


Figure 4: Desiccant Humidity Control System Using a Water Source Heat Pump and Measurement Points

2.3 HEAT SOURCE EQUIPMENT

An air source heat pump/chiller unit was adopted as a heat source unit. Table 2 shows the specifications of the equipment.
The performance of two models with different specifications was evaluated. Chiller A was equipped with multiple inverter scroll compressors, and chiller B was equipped with only one screw compressor. After selecting one of the chillers to use in the test, the equipment was operated.

Table 2: Specification of Air Source Heat Pump and Chiller Units

Chiller A	
Compressor	Inverter drive hermetic scroll compressor, 12.5 kW × 3
Refrigerant	R410A
Fan	0.6 kW × 6
Water flow rate	20.3 m^3/h (temperature of supplied water: 7°C, 13°C)
Cooling capacity	118 kW (temperature of supplied water: 7°C, 13°C)
Cooling power input	31.9 kW (temperature of supplied water: 7°C)
	26.8 kW (temperature of supplied water: 13°C)
Chiller B	
Compressor	Semi-hermetic screw compressor, 30.0 kW × 1
Refrigerant	R407C
Fan	1.0 kW × 4
Water flow rate	18.2 m^3/h (temperature of supplied water: 7°C)
	22.0 m^3/h (temperature of supplied water: 13°C)
Cooling capacity	106 kW (temperature of supplied water: 7°C)
	128 kW (temperature of supplied water: 13°C)
Cooling power input	27.8 kW (temperature of supplied water: 7°C)
	28.2 kW (temperature of supplied water: 13°C)

Note: This performance is based on JIS B8613.

3 RESULT

3.1 DEHUMIDIFICATION PERFORMANCE

In Japan, companies are encouraged to implement the measures recommended under the Japanese government's COOLBIZ campaign, whose aim is to contribute to the realization of a low-carbon society. The COOLBIZ campaign recommends that air-conditioning is set to a higher cooling temperature than before and that workers wear light clothing during working hours. Therefore, in the field test, the indoor temperature and humidity were set to 28°C and 40% RH (9.43 g/kg') to establish a low humidity environment compliant with the COOLBIZ recommendations.

In order to check the maximum dehumidification performance of the prototype, a latent heat load of 12.8 W/m^2, which corresponds to a personnel density of 0.2 persons/m^2, was generated in the chamber during the conducting of the experiment. Figure 5 shows a psychrometric t-h chart that shows measurement data obtained in the dehumidification process at intervals of one minute for three days.

The temperature and humidity of indoor air were 28.5°C and 9.2 g/kg', respectively, meaning that a desired low humidity environment compliant with the COOLBIZ recommendations was established.

The average temperature and humidity of fresh outside air was changed from 29.0°C and 16.2 g/kg' to 17.0°C and 10.5 g/kg' when it was passed through the pre-cooling coil. When the moisture contained in this pre-cooled air was adsorbed on the desiccant rotor, dry air whose average temperature and humidity were 31.5°C and 5.5 g/kg' was obtained. The difference between the humidity of the dry air and an indoor absolute humidity of 9.2 g/kg' was 3.7 g/kg', and it was found that the latent heat processing performance was 3.1 W per 1 m^3/h of the amount of outside air. Based on this result, it can be judged that sufficient processing of the indoor latent load generated from human beings is feasible.

The temperature of air used for the regeneration of the desiccant rotor was 46.6°C, which could be sufficiently regenerated by the heat of condensation of the water source heat pump.

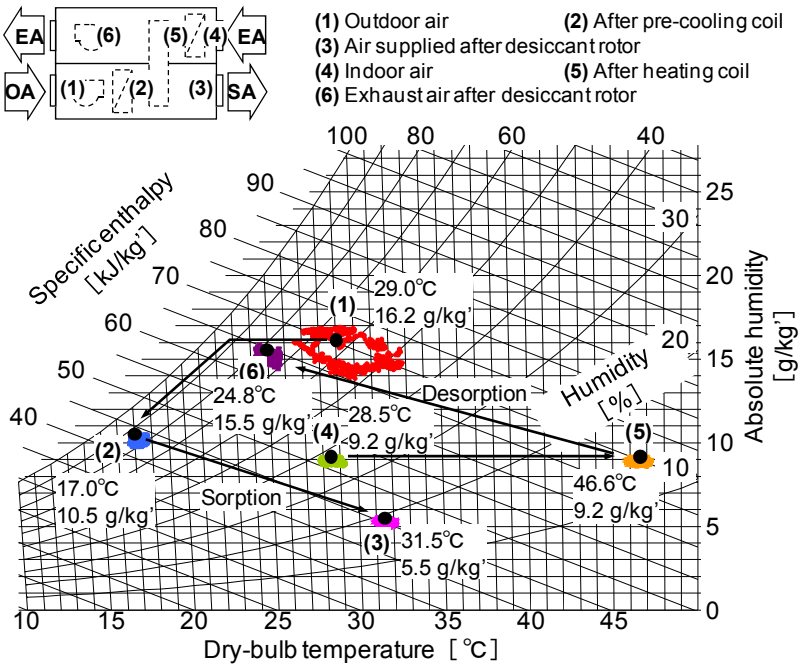


Figure 5: Measurement Data on Steady Dehumidification Process

3.2 HUMIDITY CONTROL PERFORMANCE

It is necessary to be able to adjust the degree of dryness of the air supplied from the desiccant humidity control unit as the indoor latent heat load varies with the number of human beings present. The prototype desiccant humidity control unit adjusts the degree of dryness of the air supplied to keep the indoor humidity constant by keeping the regeneration temperature constant and adjusting the amount of cooling at the pre-cooling coil.
In order to evaluate the humidity control performance of the prototype, the latent heat load generated in the chamber was changed and an experiment conducted. Figure 6 shows a psychrometric t-h chart that shows measurement data obtained at intervals of one minute for two days. The amount of cooling and dehumidification at the pre-cooling coil is adjusted in response to changes in the latent heat load, and air that has been passed through the pre-cooling coil is the result of controlling air conditions to be at a humidity close to 90% RH. The conditions of the air supplied by the desiccant humidity control unit varied in response to air conditions at the outlet of the pre-cooling coil, and it was found that indoor relative humidity could be controlled within ±10% of the value set.

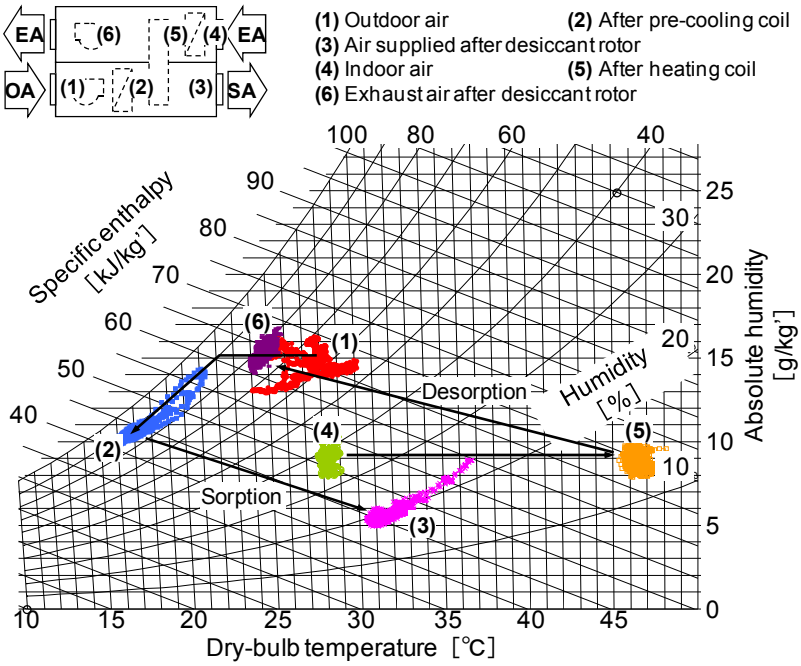


Figure 6: Humidity Control in Dehumidification Process

3.3 HUMIDIFICATION PERFORMANCE

An evaluation test on humidification using the desiccant rotor was conducted during wintertime, when the outside air is dry. In this test, a sensible heat load and a latent heat load were not generated in the chamber.
Figure 7 shows a psychrometric t-h chart that shows measurement data obtained in the humidification process at intervals of one minute, and the results obtained on days with an average outside air absolute humidity of 3.5 g/kg' or 1.7 g/kg'.
The amount of humidification, which is determined from the difference between the absolute humidity of outside air and the absolute humidity of air that has been passed through the desiccant rotor, is small when the absolute humidity of outside air is low. The amount of humidification is 3.1 g/kg' and 2.4 g/kg' when the absolute humidity of outside air is 3.5 g/kg' and 1.7 g/kg', respectively.
On the other hand, the indoor absolute humidity is 6.6 g/kg' at 22°C and 40% RH, which are typical air-conditioning conditions, and is 5.8 g/kg' at 20°C and 40% RH, which comply with

the recommendations under the Japanese government's WARMBIZ campaign. The humidity of the air supplied is 6.5 g/kg' when the absolute humidity of outside air is 3.5 g/kg'. Therefore, it can be judged that humidification can be conducted in an office without needing a water supply. However, the humidity of the air supplied is 3.9 g/kg' when the absolute humidity of outside air is 1.7 g/kg'. Therefore, it is difficult to achieve sufficient humidification with only the rotor if the fact that a room is humidified by the moisture generated by human beings is not taken into consideration.

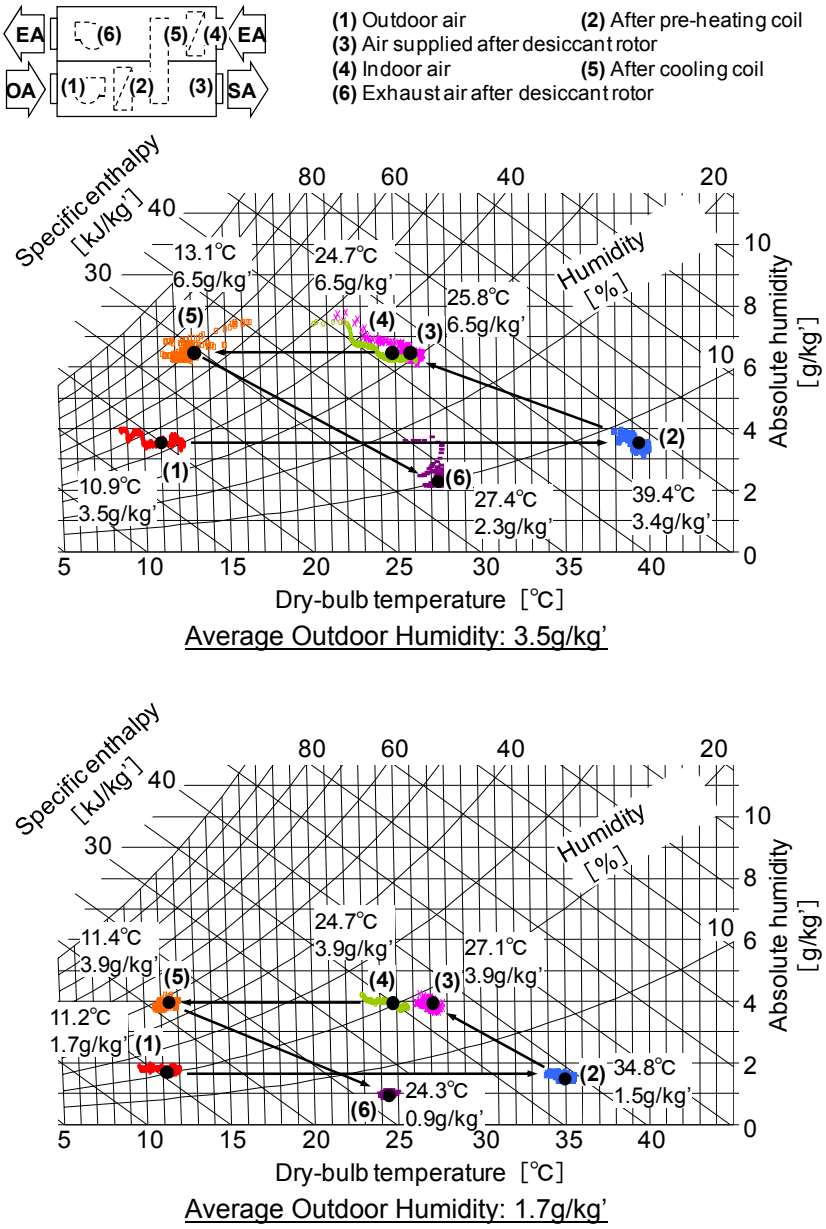
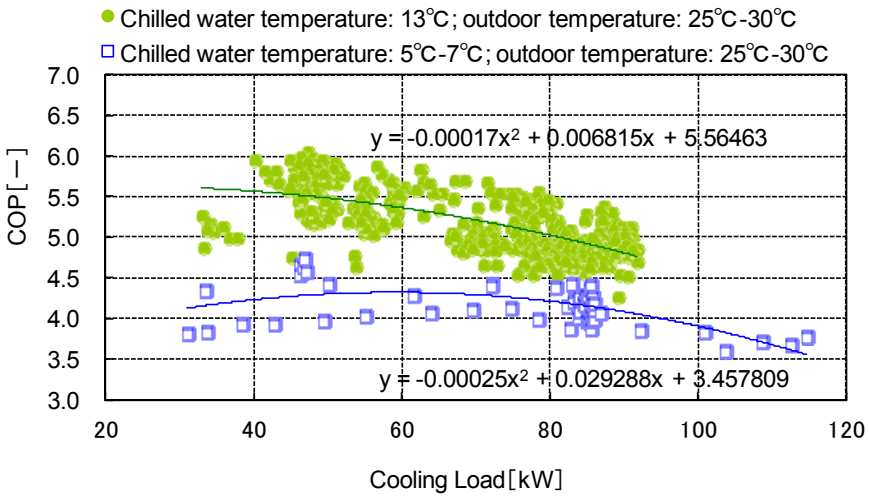


Figure 7: Measurement Data on Steady Humidification Process

3.4 HEAT PUMP/CHILLER UNIT EFFICIENCY

The coefficient of performance (COP) of the air source heat pump/chiller unit was evaluated under conditions where cold water at a temperature of 7°C or less was supplied by the air source heat pump, and where cold water with a temperature of 13°C was supplied. Figure 8 shows the relationship between the amount of heat generated by cooling caused by the heat

pump/chiller unit and COP. COP is the amount of heat generated by cooling caused by the heat pump/chiller unit divided by power input.
The values measured under the following conditions were evaluated: where the load factor against the cooling capacity of the chiller is 25% or more and the outside air temperature is between 25°C and 30°C (exclusive).
The COP distribution against the load factor clearly represents the characteristics of the compressor, and there is a difference in trends between chiller A and chiller B.
When the cold water temperature setting was changed from 7°C to 13°C, the COP for both chillers improved. For the evaluation of the COP improvement rate, a regression expression of the amount of heat generated by cooling and of COP was used. When the amount of heat generated by cooling was 50 kW and 80 kW, the COP improvement of the chiller A was 27.4% and 19.3%, respectively. When the amount of heat generated by cooling was 50 kW and 80 kW, the COP improvement of the chiller B was 24.8% and 17.6%, respectively.
This paper shows test results based on a general-purpose machine designed for cold water with at low temperature, and it is thought that efficiency would be further improved by specially designing heat source equipment for cold water at a somewhat higher temperature.



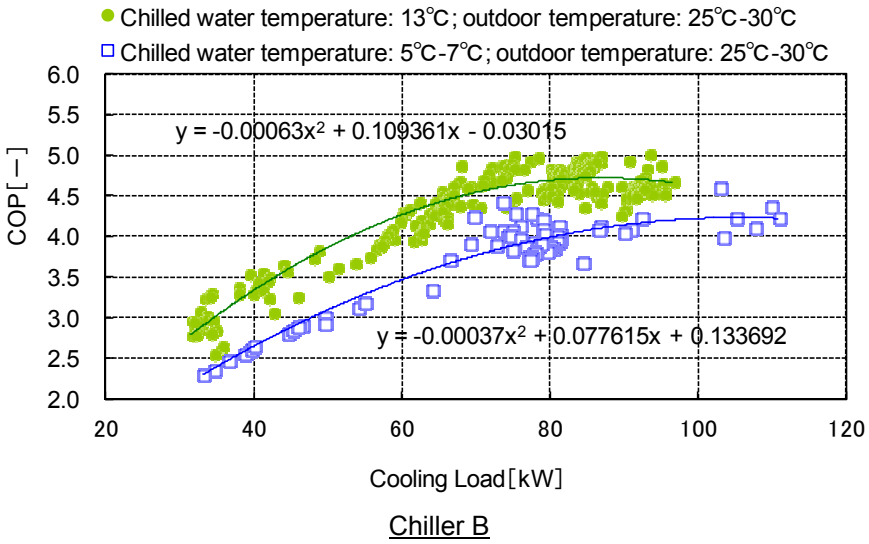


Figure 8: Coefficient of Performance under Conditions of Different Chilled Water Temperatures

4 CONCLUSION

A prototype desiccant humidity control unit using a desiccant humidity control unit was built, and a field test was conducted. The test results were that the dehumidification performance and dehumidification control performance of the prototype were sufficient for use in office environments. If moisture generated by human beings is not taken into consideration, humidification using only the desiccant rotor without a water supply can be conducted when the absolute humidity of the outside air is 3.5 g/kg' or more. Future evaluations are required that take into consideration the moisture generated by human beings.
The COP of the air source heat pump, which is a heat source device, was improved by approximately 20% at a temperature of 6°C higher than the cold water temperature range conventionally used.
Further development of technology for desiccant humidity control systems would be most desirable in order to contribute to the realization of a low carbon society.

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