

Comparison of Performance of Desiccant Air Handling Unit with Solar Thermal System under Various Control Methods

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Abstract. In hot and humid summer as in Japan, dehumidification is important process for air conditioning. Desiccant air handling unit is one of the major system for dehumidification in which absorbent or sorbent absorbs moisture in the air and hot heat source is required in order to regenerate them. In order to use solar thermal energy efficiently, flexible control, which controls the distribution of the dehumidification at pre-cooling coil and dehumidification wheel, is proposed and analysed its performance through simulation. Simulation results show that supply absolute humidity fulfils the set point even when solar thermal energy is not supplied to regenerating coil under flexible control. On the other hand, system with conventional fixed control can not fulfil the set absolute humidity when solar thermal energy is not supplied. The unprocessed latent heat load is around 49kW, which results in higher relative humidity around 56.5%. Solar thermal energy supplied to regenerating coil under flexible control is larger than fixed control.

1 Introduction

In hot and humid summer as in Japan, dehumidification is important process for buildings in terms of air quality and thermal comfort. Mechanical dehumidification is commonly used to reduce moisture content of the air flow. Most of the dehumidification process is conducted by reducing the air temperature lower than its dew point, which is so called condensation dehumidification. Alternatively, the desiccant air handling unit can reduce moisture of the air by adsorption phenomena of substances including silica gel or polymer sorbent. These are required to be regenerated periodically. For regeneration, waste heat from combined heat and power (hereafter, CHP) or heat pumps, and hot water from solar thermal system is typically used.

When all dehumidification load is processed by dehumidification rotor, the diameter will be large, and it results in larger amount of required hot water for regeneration. Lots of DAHUs in office buildings in Japan have pre-cooling coil because of the limitation of the size of DAHU itself and the amount of required hot water is reduced. This situation means that solar thermal energy will be effective for DAHU. Furthermore, according to White ¹⁾, when air state entering dehumidification wheel with sorbents and adsorbents is high relative humidity, it results in better dehumidification performance than low relative humidity. Pre-cooling coil can provide high relative humidity air to dehumidification wheel.

Solar thermal energy, which is one of the renewable energy, has fluctuation due to weather and season. When hot water from solar thermal collector is supplied to regenerating coil of DAHU, it has normally back-up

device such as boiler or CHP in order to provide enough stable hot water to regenerating coil for dehumidification. According to Ge's review²⁾ on solar powered rotary desiccant wheel cooling system, the desiccant systems have auxiliary heater as back up system for solar thermal system or regeneration air to handle the required dehumidification amount. However, as mentioned above, the desiccant air handling system without boiler or CHP as back-up system could be achieved by an appropriate control which aims the distribution of dehumidification at pre-cooling coil and dehumidification wheel.

In this study, in order to maximize the use of solar thermal energy, the new control method called flexible control is proposed and analysed its performance by simulation for July and August.

2 Target building and system

2.1 Target building

The target building is office building located in Tokyo, in Japan. It has five stories and air-conditioning area of typical floor is 983m² as shown in Figure 1. It is designed with some energy saving methods including eaves, high insulated walls and roofs, and LED lighting. The room set temperature is 28°C and relative humidity is 40% in cooling period according to comfort zone by Kato³⁾ and "COOL BIZ"⁴⁾ campaign where appropriate room condition and clothes are proposed. The load calculation is conducted with Micro HASP/TES which has periodic stationary calculation for one year.

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2.2 Design procedure of desiccant air handling unit

Figure 2 shows the configuration of the desiccant air handling unit and heat source system. Fresh outdoor air is supplied to desiccant system directly. The system in this study is composed of pre-cooling coil, dehumidification wheel, sensible heat exchanger, after-cooling coil and regenerating coil in Figure 4. Fresh air (1, the number in brackets is correlated to the number in Figure 4) is provided to pre-cooling coil to be precooled and dehumidified (2), and then passes dehumidification wheel (3), sensible heat exchanger with return air (4) and after-cooling coil (5). Return air (RA) (6) passes sensible heat exchanger (7), and then it is heated up at regenerating coil (8). High temperature air desorbs moisture from polymeric adsorbents and finally is exhausted (9).

Desiccant air handling unit processes all of the fresh outdoor load (sensible and latent heat), and all of the indoor latent heat, and part of indoor sensible heat. Indoor sensible heat processed by DAHU is derived from lighting and appliances. Each floor has air handling unit for remaining indoor sensible heat load.

In fixed control, air state leaving pre-cooling coil is set at 18°C because the performance of desiccant air

handling unit is high. Depending on the load distribution and specification of the DAHU shown in Table 1, required total cooling coil demand and hot water demand for regenerating coil is 335kW and 121kW. For chiller, in addition to the cooling demand of DAHU, coil demand of SAHU, 22.7kW and 29.5kW at typical floor and top floor respectively is considered. In total, chilled water demand is 387.2kW. The safety ratio is assumed as 1.05, therefore capacity of chiller is determined as 406.6kW. For solar collector, average collection factor is set at 50%, therefore area of collector is set at 242m². Table 2 shows the specifications of each system.

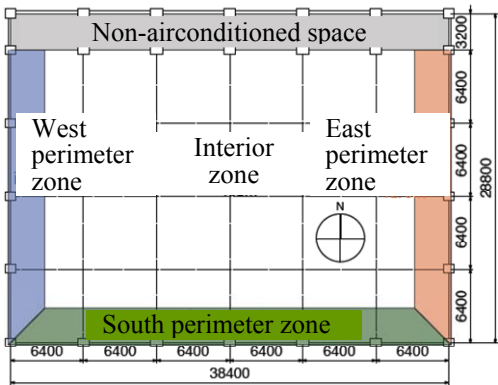


Fig 1 Typical floor plan of the building

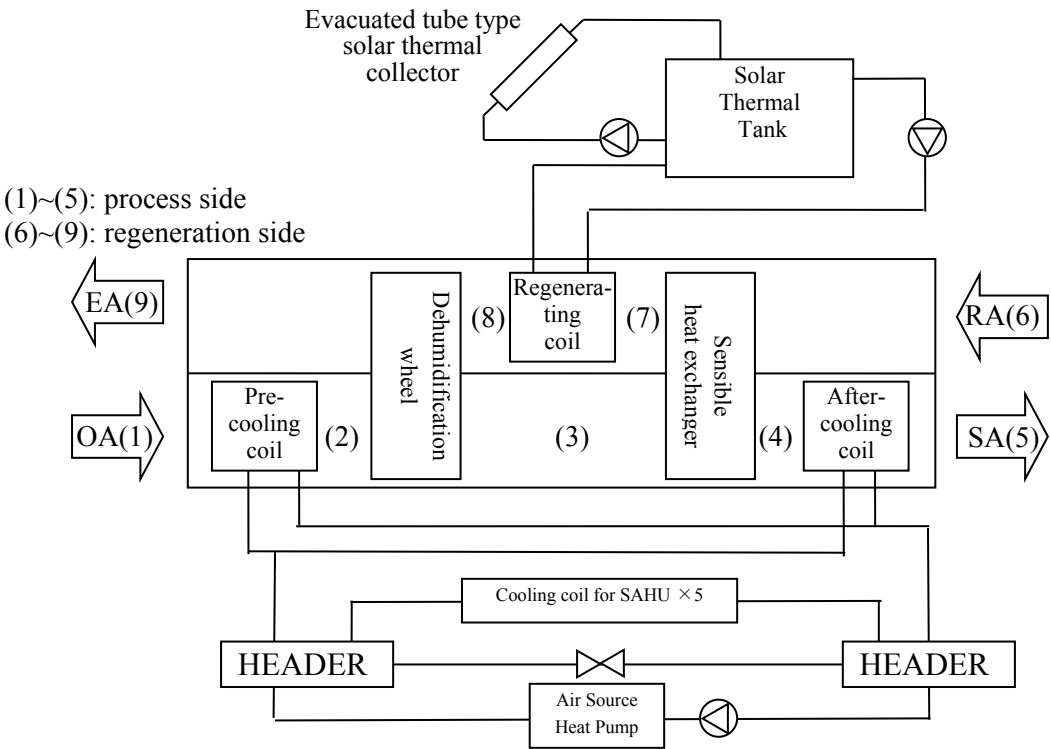


Figure 2 outline of the desiccant air handling system

Table 1 Design condition of desiccant air handling unit

Air state as shown in Figure 4	Temperature °C	Humidity g/kg'	Assumption and so on	Each coil demand
(1)	32.5	19.9	Outdoor condition given by load calculation	Pre-cooling coil demand: 253kW
(2)	18.3	12.3	Relative humidity is 95%	
(3)	33.3	6.5	Relative humidity efficiency is 90%	-
(4)	29.1	6.5	Efficiency is 80 %	After-cooling coil demand: 102 kW
(5)	15.4	6.5	Supply air condition at peak time is 15.4°C	
(6)	28.0	9.4	Room air condition (28°C, 40%)	-
(7)	31.8	9.4	Sensible heat exchange efficiency is 80%	Regenerating coil demand : 121kW*1
(8)	50.0	9.4	Absolute humidity is the same as return air	

*1 In design phase, the capacity of dehumidification wheel and heat transfer from regeneration side to process side due to rotation is not considered.

Table 2. Specifications of the system

Device	Abbreviations	Rated specifications	Number
Air-source HP	ASHP	Cooling capacity: 425kW, Electricity consumption: 119kW	1
Evacuated tube –type solar collector	SOL	242 m ² , tilt angle :15 , face to south	
Thermal storage tank for solar thermal system	TANK _{SOL}	10 m ³	1
Desiccant air handling unit	DAHU	Desiccant material: polymer sorbent Supply air volume: 22115m ³ /h Exhaust air volume: 19904 m ³ /h Pre-cooling coil: 253.0kW After-cooling coil: 121kW Regenerating coil: 102.0kW (coil demand is determined based on the fixed control)	1
Sensible air handling unit	SAHU	Supply/ Return air: 6612 m ³ /h, Cooling coil: 22kW (at typical floor) Supply/ Return air: 8941 m ³ /h, cooling coil: 29.5kW (at top floor)	4 1

3 Control methods

3.1 Fixed control (conventional control)

Figure 3 shows the diagram of the conventional fixed control. The ordinary fixed control controls air temperature leaving pre-cooling coil at fixed temperature, for example 19°C, and the relative humidity is 95%. Therefore, dehumidification amount at dehumidification wheel as well as regeneration coil demand does not fluctuate very much.

3.2 Flexible control

Figure 4 shows flexible control proposed in this study. Flexible control controls air condition leaving pre-cooling coil with absolute humidity of supply air and hot water temperature entering to regenerating coil. When hot water temperature is not enough hot, temperature leaving pre-cooling coil gets lower and dehumidification amount at pre-cooling coil increases.

4. Outline of the simulation

Simulation used in this study is LCEM tool ⁵⁾ which is developed under supervision of Ministry of Land, Infrastructure, Transport and Tourism.

4.1 Dehumidification wheel

In this model, factor of dehumidification wheel is coefficient of relative humidity. Coefficient of relative humidity is defined as below. The value is 0.90.

$$\eta_{RH} = \frac{RH_4 - RH_5}{RH_4 - RH_{10}} \quad (1)$$

4.2 Coils

Calculation method is based on coefficient of wetted surface. Heat transfer coefficient of partially wet coil is determined by those of dry coil and correction factor for wetted surface. In this method, inlet and outlet temperature of air, absolute humidity, volume of air, and

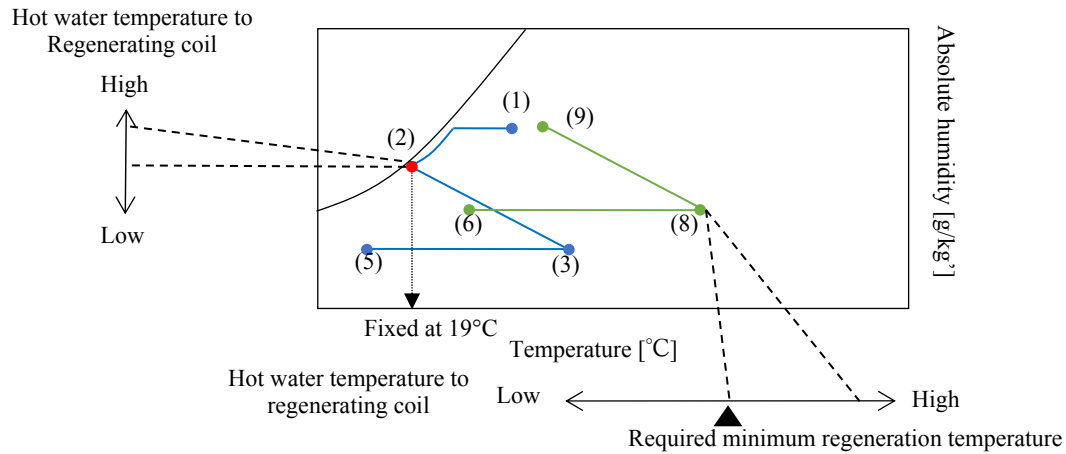


Figure 3 outline of fixed control

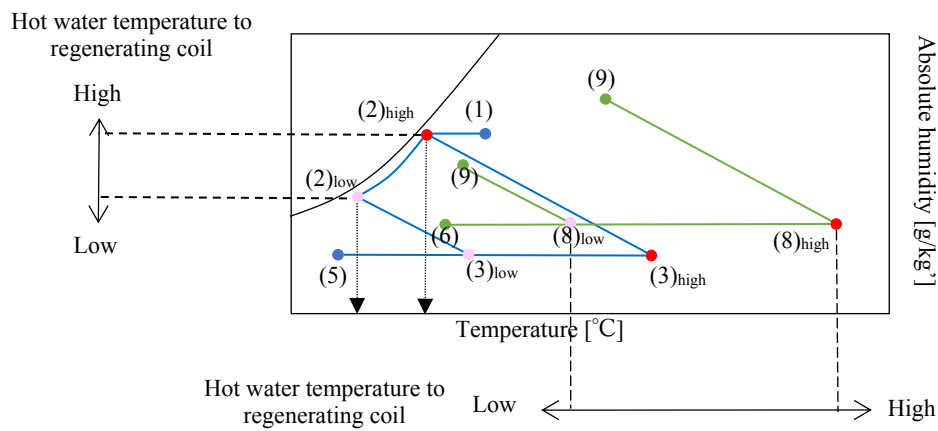


Figure 4 outline of flexible control

inlet temperature of water are boundary condition. The output of this model is outlet temperature and flow rate of water.

4.3 Sensible heat exchanger

Sensible heat exchanger is modelled with face velocity and air volume ratio to provide the efficiency as shown in equation (2) and (3). The a to l is default value.

$$\eta_{pro} = (ar + b)U_{pro}^2 + (cr + d)U_{pro} + (er + f) \quad (2)$$

$$\eta_{re} = (g/r + h)U_{re}^2 + (i/r + j)U_{re} + (k/r + l) \quad (3)$$

4.4 solar collector

The solar thermal collector object3) is modelled by equation (4) to (6).

$$\eta_{col} = m\Delta T / J + n \quad (4)$$

$$\Delta T = (T_{col_in} + T_{col_out}) / 2 - T_{amb} \quad (5)$$

$$Q_{col} = \eta_{col}JA \\ = cpW_{col}(T_{col_out} - T_{col_in}) / 3600 \quad (6)$$

Coefficient m and n are -0.473 and 0.561 respectively. Collectors are divided into two modules. Area of each module is 121 m², and they are arrayed in parallel. The collectors face to south and tilt angle is 15°.

4.5 Thermal storage tank

The characteristic of thermal storage tank is assumed as complete mixed. The thermal storage tank is modelled by equation (7).

$$cpV_{ts} dT_{ts} / dt = K_{ts}S_{ts}(T_{amb} - T_{ts}) + Q_{col} + Q_{sup} \quad (7)$$

When the temperature in the tank is higher than 55°C, hot water from the tank is supplied to regenerating coil in DAHU in both control.

4.5 Boundary condition

The same outdoor condition including temperature, humidity and solar radiation used for load calculation is provided. Supply and return air volume is stable at 22155 m³/h and 19904 m³/h respectively. Based on the load calculation, supply set point for desiccant air handling unit is given as boundary condition.

5. Results and evaluation

Simulation is conducted hourly from July to August.

5.1 Diurnal variation of the air state and unprocessed load

The day with the maximum enthalpy of the outdoor air condition is selected as peak day, which is August 11th. Figure 5 shows the air state of desiccant air handling unit and Figure 6 shows the hot water temperature to regenerating coil and regenerating coil demand. Under fixed control, air state entering dehumidification wheel is stable at 18°C, on the other hand, air state before dehumidification wheel with flexible control varies from 13.9°C to 19.5°C. Set point of supply absolute humidity

is set at 6.5g/kg' except 8:00 and 12:00. At 8:00 and 12:00, based on the load calculation, there are less occupants, therefore set absolute humidity is relatively high at 9.4 and 8.1g/kg' respectively. Absolute humidity with fixed control is not fulfilled the set point when solar thermal is not supplied to regenerating coil. On the other hand, absolute humidity with flexible control is fulfilled the set point even when solar thermal is not used to regenerating coil. Figure 7 shows the unprocessed load of the system with fixed control. On the peak day, approximately 49kW of latent heat is not processed properly. This means indoor absolute humidity increase up to 13.4 g/kg', results in that indoor room condition would be 28°C 56.5% which is outside of the comfort zone.

5.2 Performance evaluation

For evaluation, the performance of desiccant air handling unit itself is determined with the equation ().

$$COP_{des} = Q_{des} / (Q_{pre} + Q_{re} + Q_{after}) \quad (8)$$

Q_{des} is processed air amount. COP_{des} with flexible control and fixed control has the almost same value around 0.85. The total unprocessed latent heat load

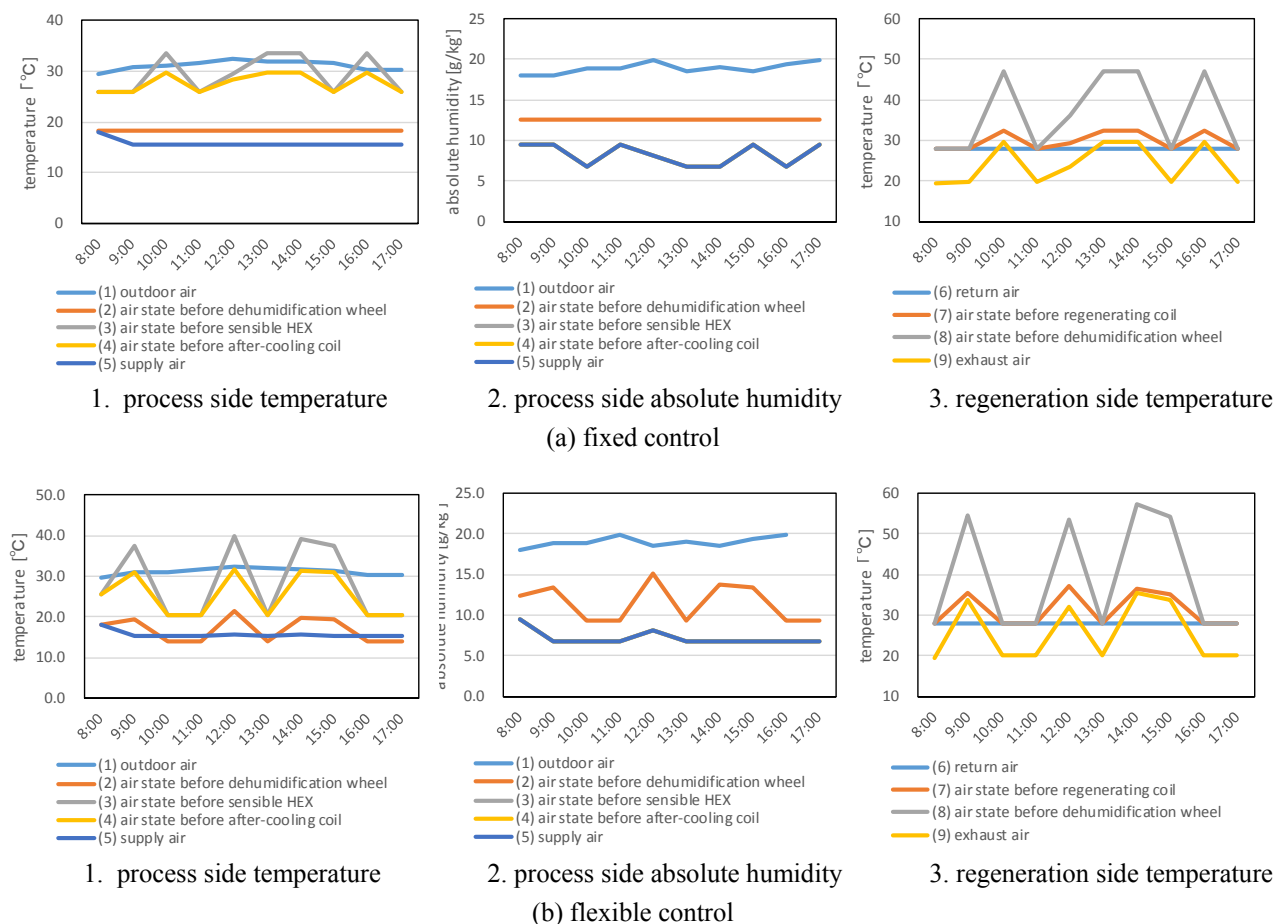
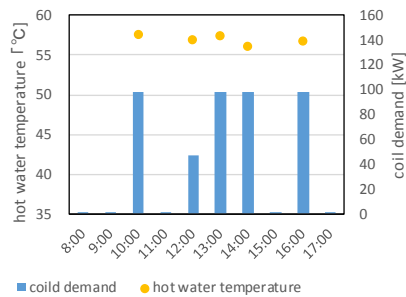
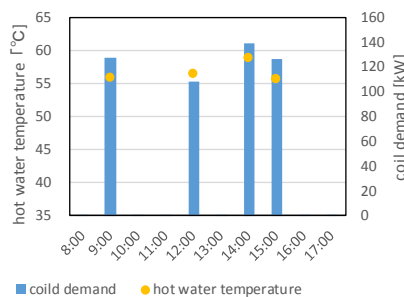


Figure 5 temperature and absolute humidity in desiccant air handling unit with both controls



(a) fixed control



(b) flexible control

Figure 6 hot water temperature and regenerating coil demand

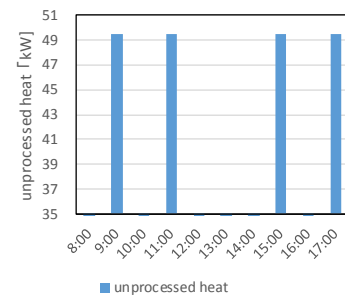


Figure 7 unprocessed heat with fixed control

with fixed control is 16GJ for two months, which accounts 5% of the required heat load processed by DAHU. Chilled water coil demand for DAHU with flexible control is larger than that with fixed control because it is necessary to lower the supply air up to about 14°C when the solar thermal can not be utilized.

Figure 9 shows the collected heat and solar energy supplied to regenerating coil for two months. The collected heat is almost 105 GJ with both fixed and flexible control. System with flexible control can supply more hot water to regenerating coil. In system with fixed control, almost 79% of collected heat is supplied to regenerating coil. In system with flexible control, approximately 87% of collected heat is supplied to regenerating coil.

6 Discussion

In this study, two control for desiccant air handling unit are analysed for July and August through simulation. Flexible control is proposed in order to supply solar thermal energy efficiently. It proves that solar utilization factor, which is the ratio between collected heat and solar energy supplied to regenerating coil, is high around 0.87. In flexible control, the time when solar thermal energy is used is 209h, which is almost 50% of operation time of desiccant air handling unit. Although solar thermal energy is not supplied to regenerating coil, the latent heat is processed fully. It would be effective for actual operation.

This study conducted simulation for only July and August. It is necessary to conduct June and September as cooling period, however it would be noted that it is required to consider the natural ventilation because outdoor condition of June and September is lower than room condition.

7 Conclusion

This study aims to analyse the performance of the desiccant air handling unit under two control methods, one is conventional fixed control and the other is flexible

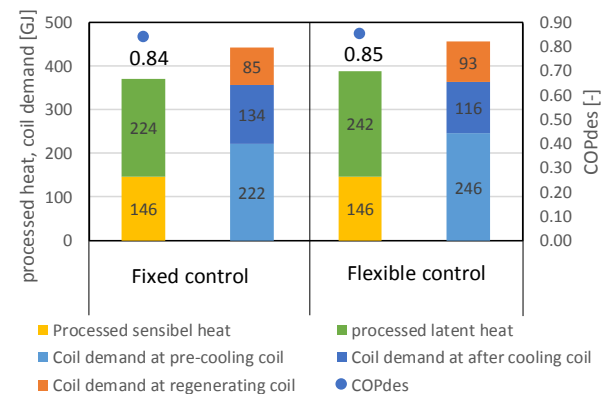


Figure 8 processed heat, coil demand and COP of desiccant air handling unit for two months

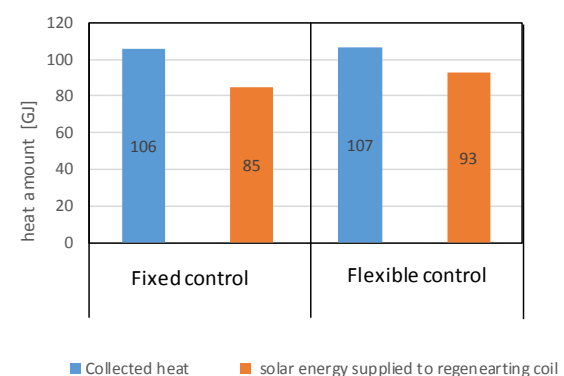


Figure 9 collected heat and solar energy supplied to regenerating coil for two months

control through simulation. The flexible control can distribute the dehumidification amount between pre-cooling coil and dehumidification wheel depending on the regeneration temperature. The simulation results show below.

- 1) System with flexible control can fulfil the supply absolute humidity even when solar thermal energy is

not supplied to the regenerating coil. It proves that there is possibility that room condition will be worse with fixed control under the designated condition in this study.

- 2) The performance of desiccant air handling unit is almost same both in two controls.
- 3) System with flexible control can utilized more heat from solar thermal collector.

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Nomenclature

A	: effective area of collector	[m ²]
C _p	: specific heat	[J/gK]
COP	: coefficient of performance	[-]
J	: Solar radiation on collector surface	[W/ m ²]
K	: total heat transfer coefficient	[J/K m ²]
Q	: heat amount	[W]
r	: air volume ratio	[-]
RH	: Relative humidity	[%]
S	: surface area	[m ²]
T	: temperature	[°C]
U	: face velocity	[m/s]
V	: volume	[m ³]
W	: flow rate	[m ³ /h]
ρ	: density of the dried air	[g/m ³]
η	: efficiency	[-]

Subscript

RH : Relative humidity
 pro : process side
 re : regeneration side
 col : collector
 col_in: inlet to collector
 col_out: outlet from collector
 amb : ambient
 ts : thermal storage
 sol.use: solar thermal energy used for regenerating coil
 des : desiccant air handling unit
 pre : pre-cooling coil
 re : regenerating coil
 after : after-cooling coil
 1~4 : the number explains the point of the desiccant air handling unit shown in Figure 4

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