Oral Presentation | Oral Presentation：2.energy efficient HVAC system and technologies

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Session I-4

Chair:Soma Sugano

4:40 PM - 4:55 PM JST | 7:40 AM - 7:55 AM UTC

[30I04-03] Energy conservation design method for a self-pre-cooling and reheating air conditioning system

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To achieve a society based on carbon neutrality, efforts are underway to make Net Zero Energy Building. In recent years, the indoor sensible heat ratio in office air-conditioning has tended to decrease due to improvements in building envelope performance and reductions in internal heat generation. This makes it difficult to achieve sufficient dehumidification with conventional air conditioning control.
In this study, the energy conservation design method for a self-pre-cooling and reheating air conditioning system was investigated. In this system, using a sensible heat exchanger inside the air handling unit, the intake outdoor air is pre-cooled by the air exiting the dehumidification-cooling coil, while the supply air is simultaneously reheated.
Previous research has shown that this system has advantages over air conditioning system that includes an outdoor air handling unit with reheating in terms of indoor environment and energy consumption. However, when compared to an air conditioning system that includes an outdoor air handling unit with only cooling, it has the advantage of indoor environmental grade, but it still has the problem of increased energy consumption. Therefore, the effects of introducing bypass control that performs self-pre-cooling and reheating process during the intermediate period and only cooling process during the summer period by adjusting the damper, as well as the effects of downsizing the air handling unit for room load processing made possible by introducing bypass control, were verified through simulation.
The introduction of bypass control resulted in a 2.9% decrease in the satisfaction rate (the percentage of cases where the target indoor temperature and humidity were maintained) from 95.6% to 92.7%, but the electricity consumption was reduced by 5.3%, from 149.9MWh to 141.9MWh. In addition, when downsizing was carried out, the satisfaction rate improved by 1.9%, from 92.7% to 94.6%, but the electricity consumption increased by 1.3%, from 141.9MWh to 143.7MWh.

Energy-conservation design method for a self-pre-cooling and reheating air-conditioning system

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Abstract. Recently, the indoor sensible heat ratios of office buildings have decreased. This makes it difficult to achieve sufficient dehumidification by using conventional air-conditioning controls. In this study, an energy-conservation design method for a self-pre-cooling and reheating air-conditioning system was investigated. In this system, using a sensible heat exchanger inside the air-handling unit, the intake outdoor air is pre-cooled by the air exiting the dehumidification-cooling coil while the supply air is simultaneously reheated. As the supply air temperature is affected by the outdoor air temperature, it is higher in summer, resulting in lower energy efficiency. Therefore, the effects of introducing a bypass control that performs self-pre-cooling and reheating processes during the intermediate period and only the cooling process during the summer period by adjusting the damper, as well as the effects of downsizing the air-handling unit for room-load processing, were verified through simulation. The introduction of bypass control resulted in a 1.0% decrease in electricity consumption, while maintaining the same satisfaction rate. In addition, when downsizing was performed, the satisfaction rate improved by 0.2 percentage points, from 99.3% to 99.5%, and the electricity consumption decreased by 2.3%.

1 Introduction

In recent years, office buildings have experienced a decrease in building envelope loads owing to improvements in thermal insulation and solar shading performance. In addition, indoor heat loads are decreasing owing to factors such as the adoption of LED lighting, improvements in office automation equipment performance, and reduced printer usage. Consequently, the indoor sensible heat load during the cooling season decreases significantly, leading to a lower sensible heat factor in the room. Furthermore, owing to the effects of climate change, the outdoor air temperature and absolute humidity tend to increase. Given the rising carbon dioxide concentrations in urban areas, there is a growing need to increase outdoor air intake. Therefore, appropriate humidity control in air-handling units has been identified as an important subject in the HVAC field, and latent-sensible heat separation air-conditioning systems are gaining attention.

A temperature and humidity independent control of air-conditioning system separates the sensible and latent heat loads within a room and processes each using separate air-handling units. It is often composed of an outdoor air-handling unit responsible for processing outdoor heat load and indoor latent heat, and an air-handling unit responsible for processing indoor sensible heat. When the outdoor air-handling unit appropriately handles indoor latent heat, it is necessary to apply a reheating process to avoid excessive cooling of the room owing to low supply air temperatures; however, this results in a decrease in the overall energy efficiency of the air-conditioning system.

In this study, we focused on an air-conditioning system consisting of an outdoor air-handling unit with self-pre-cooling and self-reheating, and an air-handling unit for indoor sensible load processing. The operational characteristics and energy performance of the system were analyzed. In this outdoor air-handling unit, an air-to-air sensible heat exchanger is installed inside the unit to exchange sensible heat between the high-temperature outdoor air and low-temperature air after cooling dehumidification, and then reheat the low-temperature air. This eliminates the need for reheating energy, to improve the overall energy efficiency of the air-conditioning system.

This study examined the necessity of appropriate supply air temperature control for outdoor air-handling units and the advantages of downsizing air-handling units for indoor sensible load processing by setting the supply air temperature.

2 Methodology

2.1 System configuration

The exterior of the outdoor air-handling unit with self-pre-cooling and reheating is shown in Figure 1. The psychrometric chart for the outdoor air-handling unit is shown in Figure 2, and the air-handling flow of self-pre-cooling and self-reheating is shown in Figure 3.

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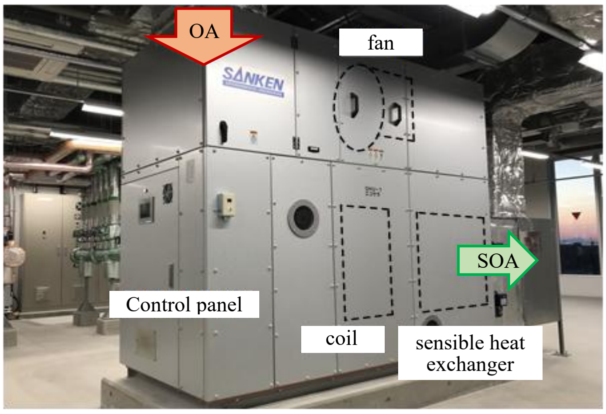

Fig. 1. Exterior of the device.

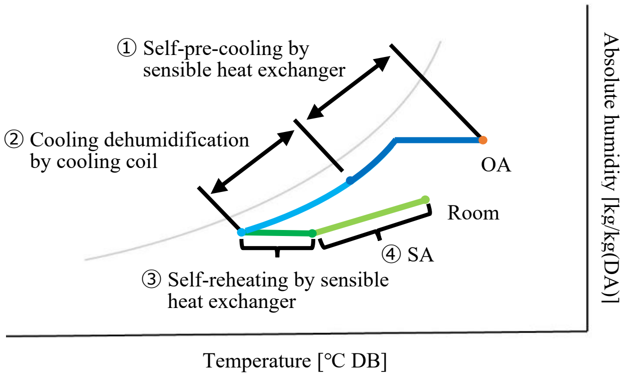

Fig. 2. Psychrometric chart for the outdoor air-handling unit

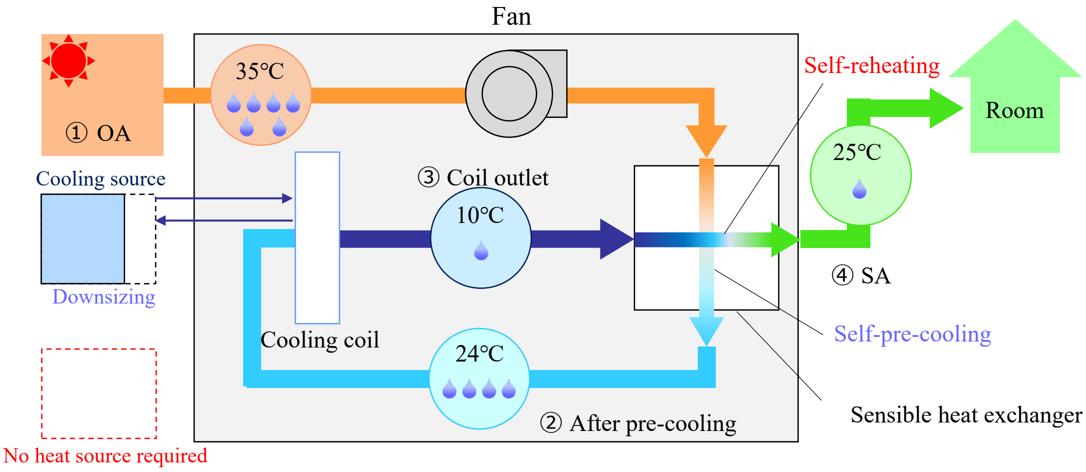

Fig. 3. Air-handling flow of self-pre-cooling and self-reheating

The outdoor air-handling unit simultaneous performs the pre-cooling of the outdoor air intake and reheat the air exiting the cooling coil through a sensible heat exchanger. The amount of reheating depends on the outdoor air temperature. Therefore, the supply air temperature is determined by the outdoor air temperature. However, self-pre-cooling suppresses the cooling energy of the outdoor air-handling unit, and self-reheating reduces the energy required for reheating.

A schematic of the target air-conditioning system is shown in Figure 4.

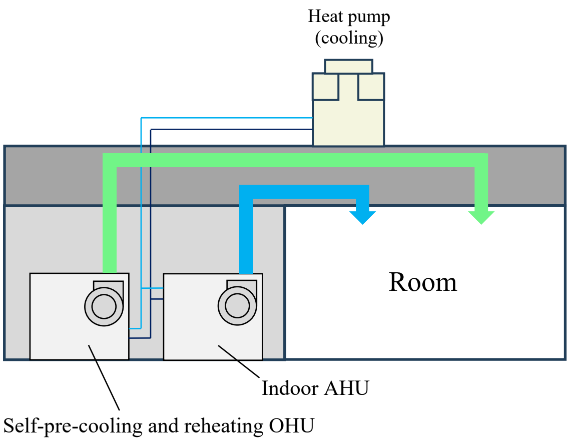

Fig. 4. Schematic of the air-conditioning system

The system consists of an outdoor air-handling unit with self-pre-cooling and reheating (which handles the outdoor air load and indoor latent heat load) and an air-handling unit for indoor air circulation (which handles the indoor sensible heat load). The air-handling unit processes the remaining room load by supplying air from the outdoor air-handling unit. In addition, the outdoor and indoor air-handling units received chilled water from the same heat source unit.

2.2 Proposal of control and design method

The operating patterns of the bypass control during the normal summer season are shown in Figure 5, and those during the mid-summer season are shown in Figure 6. During the normal summer season, the outdoor air passes through a sensible heat exchanger for self-pre-cooling and reheating. During the mid-summer season, the sensible heat exchanger is bypassed, and low-temperature supply air without reheating is used. This aims to reduce the fan power consumption of the air-handling unit. Typically, when supplying low-temperature air to a room, such as in bypass control, a reheating coil is used to prevent condensation at the air outlet and drafts within the room. Therefore, when applying bypass control, the damper opening is adjusted to regulate the airflow ratio between the outside air

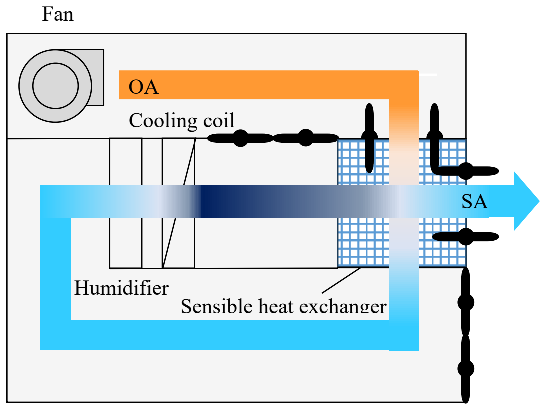

Fig. 5. Normal operation.

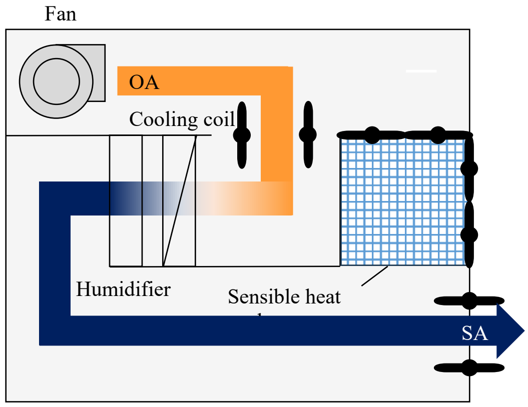

Fig. 6. Midsummer operation.

entering the sensible heat exchanger and the bypassed outdoor air, thereby ensuring a suitable supply air temperature. Alternatively, it is necessary to take measures such as installing an induced diffusion-type diffuser at the air outlet.

In this study, to evaluate the potential for introducing bypass control, we assumed a mode in which the reheat quantity was not adjusted and the sensible heat exchanger was completely bypassed. In addition, this mode improves the indoor load processing ability of the outdoor air-handling unit during peak cooling periods in summer, enabling the downsizing of the air-handling units used for indoor load processing. Therefore, we also examined the impact on energy consumption resulting from the downsizing of the air-handling units made possible by the introduction of bypass control.

3 Outline of system simulation

3.1 Model building

The floor plan of the reference building is shown in Figure 7. The reference building is located in Tokyo, has a total floor area of 10,353 m^2, and is a 7-story model office building. Office spaces 1 and 2 were designated as air-conditioned rooms, and one outdoor air-handling unit and one indoor air-handling unit were installed on each floor. The heat load calculation conditions are listed in Table 1. NewHASP/ACLD was used for the maximum heat load calculation required for equipment selection and the annual heat load calculation required for the simulation boundary conditions [1]. For the design meteorological data used in the maximum heat load calculation, the 2020 edition of the expanded AMeDAS design EA weather data with the cooling h-t standard and minimum danger rate was used. For the annual heat load calculation, standard-year EA weather data from the 2020 edition of the expanded AMeDAS were used.

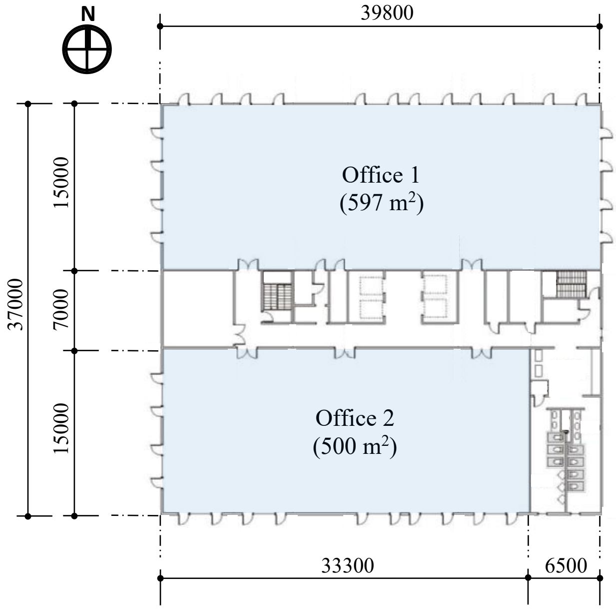

Fig. 7. Standard floor plan of the model office

Table 1. Heat load calculation conditions.

Operating Condition	Indoor Condition	26°C,10.5g/kg(DA),50% (Jun.～Sep.)
	Room Usage Time	WD 8 :00－21 :00
	Pre-cooling Time	WD 7 :00－8 :00 (Initial Condition)
Ventilation condition	Outdoor air volume	30m³/(h･people) (Human:10m²/people)
	Ventilation rate	0.1 time/h
Skin performance	Outer wall	Hard urethane 50mm (U=0.5W/(m²･K)
	Window	Low-E insulating glass (U=2.8W/(m²･K)
Internal framework	Inner wall	U=1.7W/(m²･K)
	Ceiling/Floor	Concrete 150mm (U=1.4W/(m²･K)
Internal heat generation	Lighting	9W/m² Load factor 100% (Annual)
	Appliances	25W/m² Load factor 60% (Annual)
	Human	10m²/人 Load factor 80%(Annual)

3.2 Simulation model

3.2.1 Air-conditioning system model

The simulations were performed using the LCEM tool [2]. The outdoor air-handling unit with self-pre-cooling and reheating was modeled previously [2], and the existing objects were used to model the air-conditioning system. To simulate the indoor environment simultaneously with the energy simulation, a simple room model was developed to calculate the indoor temperature and humidity using unprocessed and processed loads of the room.

Table 2. Simulation conditions.

<table>
<tr><th rowspan="2"></th><th colspan="4">Outdoor Air-handling Unit</th><th colspan="3">Indoor Air-handling Unit</th><th rowspan="2">Pre-cooling Hour [h]</th></tr>
<tr><th>Coil Capacity [kW]</th><th>Supply Air Volume [m³/h]</th><th>Dew Point of Cooling Coil Outlet Air [°C]</th><th>Set Point of Supply Air Temp. [°C]</th><th>Coil Capacity [kW]</th><th>Supply Air Volume [m³/h]</th><th>Set Point of Supply Air Temp. [°C]</th></tr>
<tr><td>Case-N</td><td>48.3</td><td rowspan="4">3300</td><td rowspan="4">11.1</td><td>Determined by outdoor Temp.</td><td rowspan="2">66.6</td><td rowspan="2">18600</td><td rowspan="4">17</td><td rowspan="3">1</td></tr>
<tr><td>Case-NB</td><td rowspan="3">64.9</td><td rowspan="3">Determined by outdoor Temp. (Jun. and Sep.) or 12.1 (Jul. and Aug.)</td></tr>
<tr><td>Case-DB1</td><td rowspan="2">48.3</td><td rowspan="2">13500</td></tr>
<tr><td>Case-DB2</td><td>2</td></tr>
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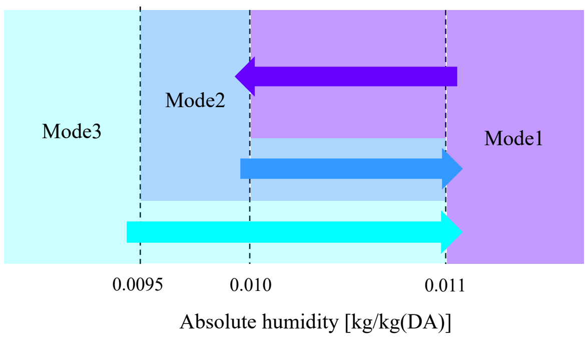

Fig. 8. Variable dew point temperature control logic

Additionally, to understand the indoor environment more accurately, a function was added to carry over the unprocessed and processed loads from the previous time step to the next. Furthermore, to simulate detailed air-conditioning control, the simulation time step was modified from the default 1 h to 1 min.

3.2.2 Control logic of air conditioning operation

Variable dew point temperature control was applied to the outdoor air-handling unit with self-pre-cooling and reheating to suppress the over-processing of the latent heat load in the room by fixing the supply air conditions at the design point. Three operating modes were assumed: mode 1: rated operation; mode 2: medium-load operation; and mode 3: low-load operation. The operating mode was switched based on the indoor absolute humidity. A schematic of the control logic is presented in Figure 8. The threshold values used for the mode selection were set based on an indoor reference absolute humidity of 0.0105 kg/kg (DA).

If the indoor absolute humidity exceeded 0.011 kg/kg (DA) from the previous time, mode 1 was selected; if it fell below 0.010 kg/kg (DA), mode 2 was selected; and if it fell below 0.0095 kg/kg (DA), mode 3 was selected. This operating mode was maintained until the next switching decision was made. Additionally, an outdoor air-cooling operation was applied when the outdoor absolute humidity fell below 0.00785 kg/kg (DA) (the design supply air absolute humidity of the outdoor air-handling unit).

3.3 Evaluation methods

This report evaluates the effects of introducing bypass control and downsizing indoor air-handling units from two perspectives: indoor environment and energy performance.

1) Indoor temperature and humidity satisfaction rate: The satisfaction rate was calculated by dividing the number of hours during which the conditions were maintained within the specified target temperature and humidity ranges by the total number of air-conditioning hours. The target temperature and humidity ranges were set to 26°C ± 1°C and RH 50% ± 10%, respectively.

2) Energy performance: This was evaluated based on the total power consumption of the air-conditioning system.

3.4 Simulation condition

The simulation conditions are listed in Table 2. The simulation period was from June 1 to September 30, which is the cooling season. The bypass control was applied in July and August. Case-N did not apply bypass control, whereas Cases-NB and Case-DB applied bypass control. The air handling unit for room-load processing was assumed to be a dry coil, which handles the remaining sensible heat load in the room after the supply of air from the outdoor air-handling unit with self-pre-cooling and reheating.

Case-N and Case-NB applied conventional design methods and determined the specifications for the indoor air-handling unit based on the supply air conditions of 26 °C and 7.9 g/kg (DA) for the outdoor air-handling unit at the time of peak cooling load. Case-DB assumed downsizing and determined the specifications for the indoor air-handling unit based on the supply air conditions of 12.1 °C and 7.9 g/kg (DA) for the outdoor air-handling unit at the time of peak cooling load. In addition, the supply air temperature of the outdoor air-handling unit for self-pre-cooling and reheating during bypass control was set to a constant 12.1 °C DB for low-temperature air supply. Furthermore, the pre-cooling time at the start of air conditioning was set to 2 h for Case-DB2 and 1 h for all other cases.

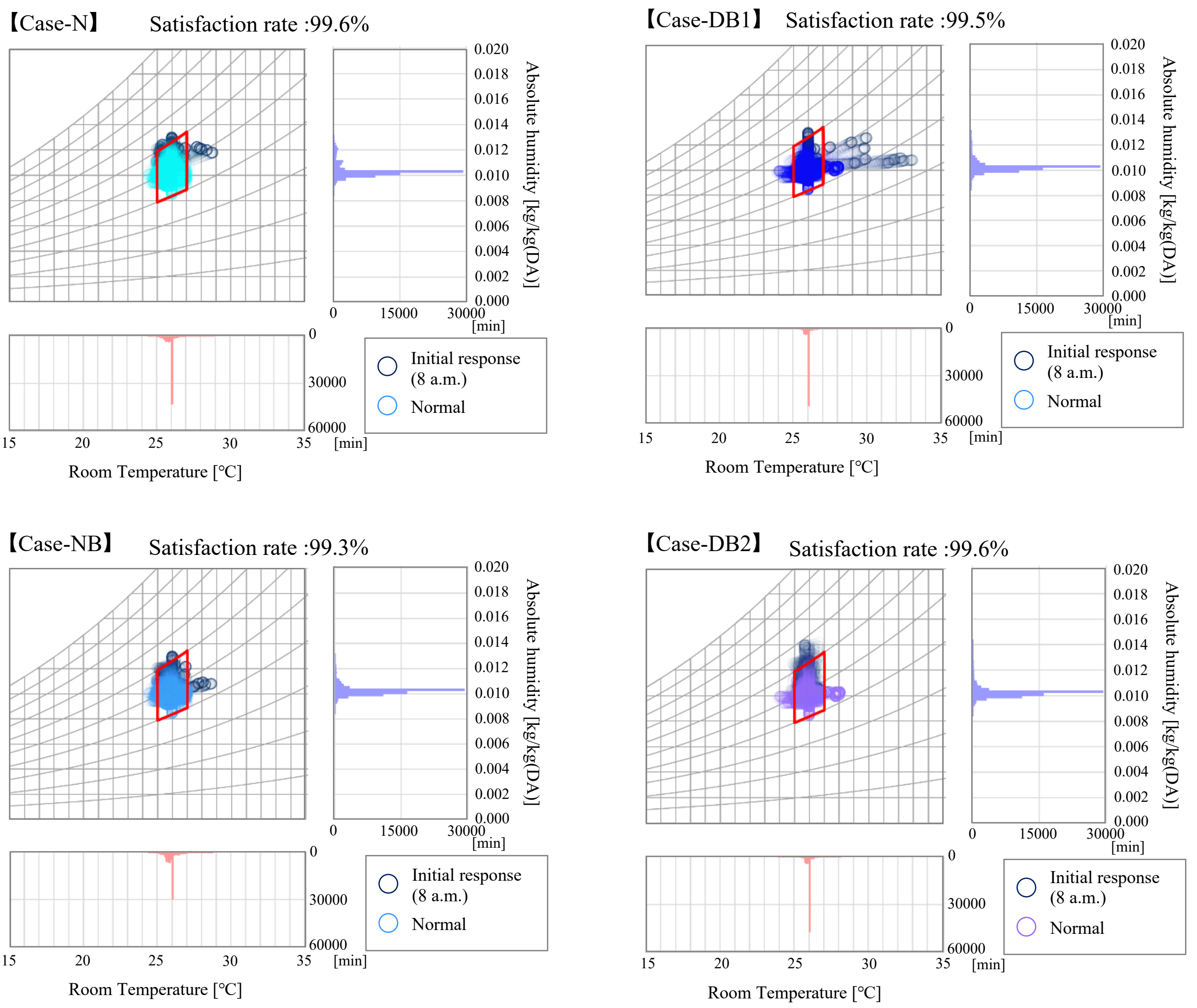

Fig. 9. Indoor environment simulation results

4 Results and discussion

4.1 Effect of bypass control

We compared Case-N and Case-NB and then, considered the effects of introducing bypass control.

The indoor environment of each case in office 1 is shown in Figure 9. The total power consumption of each system during the four-month period is shown in Figure 10, and the processing load of each air conditioner during the period is shown in Figure 11. The satisfaction rates for both cases were 99% or higher, indicating that the indoor environments were at the same level. The frequency distributions of the indoor temperature and indoor absolute humidity exhibited a similar trend.

As shown in Figure 10, the total power consumption decreased from 136.6 MWh in Case-N to 135.3 MWh in Case-NB, representing a reduction of 1.0% owing to the introduction of bypass control. By focusing on the calculation to the power consumption of indoor air-conditioner fans, a reduction of 5.2% was achieved.

As shown in Figure 11, the processing load of the indoor air-handling unit was reduced to 999 GJ in Case-N and 886 GJ in Case-NB, resulting in a reduction in the fan power of the indoor air-handling unit. However, although the processing load of the outdoor air-handling unit increased from 709 GJ to 798 GJ, the fan power did not increase because a fixed outdoor air intake volume was maintained.

The introduction of bypass control has been shown to reduce the operational energy consumption while maintaining a comfortable indoor environment by shifting the processing load between the air conditioners.

4.2 Effect of downsizing

We compared Case-NB and Case-DB1 and then, verified the effects of downsizing the capacity of indoor air-handling units.

The satisfaction rate was 99.3% for Case-NB and 99.5% for Case-DB1. As shown in Figure 9, downsizing the capacity of the indoor air-handling unit resulted in a slight increase in the time during which the indoor temperature deviated by more than 0.5°C from the target range of 26°C ± 1°C. In particular, the time exceeding 27.5°C increased from 2 min in Case-NB to 8.0 h in Case-DB.

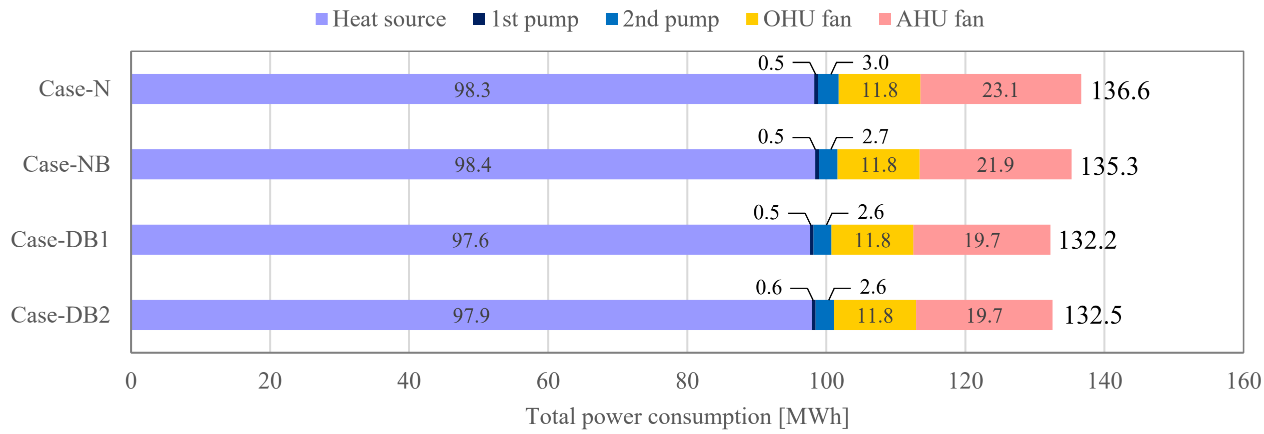

Fig. 10. Total power consumption of each system

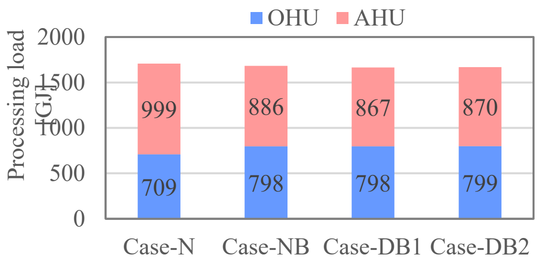

Fig. 11. Processing load

In Case-DB1, the indoor temperature increased to approximately 33 °C during the pre-cooling period (7 a.m.). This was attributed to the outdoor unit being shut off during the pre-cooling period. The capacity of the indoor air-handling unit was selected by subtracting the processing load of outdoor air-handling unit from its peak load. Therefore, when the outdoor air-handling unit is shut off and the indoor air-handling unit operates alone, there are periods during which the load cannot be processed. Consequently, the indoor temperature increases.

To solve this issue, Case-DB2, which extended the pre-cooling time from 1 h to 2 h, showed no temperature increase at startup, confirming that the heat storage load at the start of air conditioning was handled appropriately. The satisfaction rates improved from 99.5% in Case-DB1 to 99.6% in Case-DB2, an increase of 0.1 percentage points, and when converted to time, it improved from 8.0 h in Case-DB1 to 6.0 h in Case-DB2.

As shown in Figure 10, the total power consumption was reduced by 2.3% to 135.3 MWh in Case-NB and 132.2 MWh in Case-DB1 owing to downsizing. In particular, the power consumption of indoor air-handling unit fans was reduced by 10.0% in this application. This is the result of compacting the fan by downsizing the indoor air-handling unit. In addition, the total power consumption increased by 0.02% from 131.2 MWh in Case-DB1 to 131.6 MWh in Case-DB2 owing to a one-hour extension of the pre-cooling time. However, by adopting bypass control and downsizing in combination, the total power consumption was reduced by 3.0% from 136.6 MWh in Case-N to 132.5 MWh in Case-DB2.

Thus, the introduction of bypass control for outdoor air-handling units and downsizing the capacity of indoor air-handling units can slightly reduce energy consumption during operation, and the issue of unprocessed startup caused by downsizing can be addressed by extending the pre-cooling time.

5 Conclusion

In this study, we verified the effects of implementing bypass control and downsizing the indoor air-handling units as an energy-conservation design method for outdoor air-handling units with self-pre-cooling and reheating.

The introduction of bypass control demonstrated that the energy consumption during operation could be reduced by 1.0% while maintaining a comfortable indoor environment. Furthermore, implementing downsizing in addition to bypass control resulted in a total reduction of 3.0% in energy consumption during operation. The implementation of bypass control and downsizing contributes modestly to reducing operational carbon by slightly reducing energy consumption during operation, and contributes more significantly to reducing embodied carbon through the compact design of the indoor air-handling unit. We plan to examine the optimization of the entire air-conditioning system, including the heat sources.

References

Here are some examples:

1. Japanese Association of Building Mechanical and Electrical Engineers, NewHASP/ACLD
2. LCEM Tool Ver3.10, Ministry of Land, Infrastructure, Transport and Tourism, Office of the Minister, Public Works Bureau, 2014
3. Y. Tomuro, U. Makiko, H. Tanaka, H. Sato, *Transaction of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan*, Study on Energy Performance of Air-conditioning Systems using an Outdoor Air Handling Unit with Self Pre-cooling and Reheating Part1 Outline and Model Construction of an Outdoor Air Handling Unit, **4**, 113-116 (2022)