Study on Effect of Change in Differential Pressure Set Point on Chilled Water Temperature Difference

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ABSTRACT

As an energy-saving techniques such as variable water volume system assumes that the chilled water delta T is constant. However, at low loads, the delta T is much lower than the design. The reduction factor for the delta T may be considered to be variable. Thus, when the differential pressure set point is large, the delta T is reduced. The effect of the differential pressure setting on the delta T is still unclear. The purpose of this study was to clarify the effect of the differential pressure set point on delta T.
A heat medium-temperature-difference experiment was performed to confirm that changing the differential pressure set point reduced the delta T. In the experiment, low, medium, and high cooling loads were considered, and the differential pressure set point was set to 100, 200, and 300 kPa to consider the reduction in the delta T due to differences in load on the secondary side of the excessive differential pressure. Next, we reproduced the experiment in a simulation using the inlet water temperature of the AHU for each experimental case; using the temperature difference between the heat medium and the chilled water inlet, we attempted to reproduce the experiment.
The results showed that for a low load, the chilled water delta T decreased when the differential pressure set point was increased for a medium temperature difference. To reduce the delta T at low loads by increasing the differential pressure, the two-way valve is the minimum opening to cause hunting. The coil in the simulation also confirmed that hunting of the water flow rate was the cause of the reduced delta T of the air-handling unit. In conclusion, the delta T can be reduced by using a two-way valve as the minimum opening for a low cooling load with a large differential pressure for the flow rate to cause hunting.

KEYWORDS

Chilled water delta T, HVAC, Pressure, Hunting

INTRODUCTION

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A heating, ventilation, and air conditioning (HVAC) system consumes approximately 40% of the total energy consumed by an office building (Energy Conservation Center, Japan); the ratio may be considered to be overly large. Studies in this area have made active efforts to develop energy-saving techniques; the variable water volume system, which is a large-temperature-difference HVAC system, has been introduced. However, previous studies have provided many examples where the chilled water delta T was not constant and was assumed (SHASE 2007). In addition, effects to reduce the chilled water delta T have revealed that decreasing the heat storage in the heat storage system, reduces the system coefficient of performance (COP) (increases the number of driving heat sources) and increases the pump conveyance power. The chilled water delta T can be reduced by several factors. In that, when the differential pressure set point is large, the chilled water delta T is reduced (Kuniaki M.2008). The aim of this study was to clarify the influence of changing the differential pressure set point on reducing the chilled water delta T. Therefore, we performed a heat medium-temperature-difference experiment, a simulation for reproduction of the experiment, and a simulation of a model building. As a result, we made clear that hunting of the water flow rate reduced chilled water delta T by a differential pressure set point change using static coil model simulation. And, we assumed model Building and carried out simulation, assumed the hunting of a two-way valve happened. As a result, there is small influence that hunting of the water flow rate gives in the consumed power of each apparatus. In interim period and winter season, heat source exit setting temperature rise for energy saving. But, it might have an influence on the number control of each apparatus.

Heat Medium-Temperature-Difference Experiment

Figure 1 shows the target system. Table 1 presents the measurement points. The pumps were controlled to be at a constant speed. The differential pressure was maintained constant through control of a dialect bypass header. There were four controlling pumps. The number of driving pumps increased when the secondary side water flow rate was over 40 L/min. Table 2 lists the indoor conditions. Table 3 presents the cooling coil specifications. Table 4 presents the experimental cases. Cases 1–9 are for systems without an end bypass. The cooling load was varied to examine the influence of the differential pressure set point on reducing the chilled water delta T. The conditions are listed in table 5.

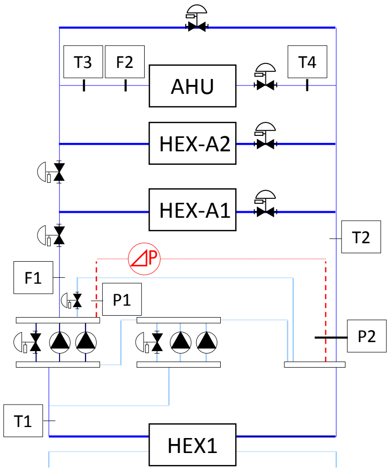

Figure 1. *Target system*

Table 1. *Measurement points*

Differential Pressure	(P1－P2)	AHU water flow rate	F2
Chilled water delta T	(T2-T1)	Secondary side water flow rate	F1
AHU delta T	(T4-T3)		

Table 2. *Indoor conditions*

Non-air conditioning room temperature degree	26℃
Method of the secondary side	Air handling unit (setting temperature : 26 deg℃)
Flow rate of air handling unit	Low load 680m^3/h High load 1500m^3/h
Internal fever	Heater and illumination : Low load 2000W (20%) High load 5000W (50%)

Table 3. Specifications of air-handling unit

Ability for cooling	10.44[kW]
Water flow rate	17.5[L/min]
Air flow rate	2800[m^3/h]
AHU delta T	10 [deg℃]

Table 4. Experimental cases

CASE	End bypass	Differential pressure set point[kPa]	Cooling load
1	unavailable	100	Low
2		200	
3		300	
4		100	Medium
5		200	
6		300	
7		100	High
8		200	
9		300	

Table 5. Cooling load conditions

Cooling load	Contents
Low	HEX-A1,A2:3000[W] (20% of peak load) AHU:2000[W] (20% of peak load)
Medium	HEX-A1,A2:7000[W] (50% of peak load) AHU:5000[W] (50% of peak load)
High	HEX-A1,A2:10000[W] (70% of peak load) AHU:5000[W] (50% of peak load)

Results of Heat Medium-Temperature-Difference Experiment

Figure 2 shows the chilled water delta T in cases 1–9 without an end bypass. Figure 3 shows the chilled water flow rate. When the cooling load was low (cases 1–3), the chilled water delta T decreased as the differential pressure set point was increased, while the chilled water flow rate tended to increase. When this made the differential pressure set point large, the two-way valve became the minimum opening, which caused hunting. Therefore, the chilled water flow rate also caused hunting (Figure 4). The reduction of the difference in the chilled water temperature to account for the same cooling load during hunting was assumed to produce more frequent driving to be greater than the stable state for the chilled water flow rate. The amplitude of hunting was larger in case 3 than in case 2. The relationship between hunting and the chilled water temperature difference was determined via a simulation. When the cooling load was medium and high (cases 4–9), increasing the differential pressure set point caused the difference in chilled water temperature to increase. However, case 4 also showed hunting, case 6 showed decreased processing heat capacity, and cases 7–9 did not show a constant chilled water temperature. The difference in temperature widened owing to a drop in the processing heat capacity in case 6. The possibility that the difference in temperature could not be secured was considered in cases 7 and 8, as the water supply temperature was increased.

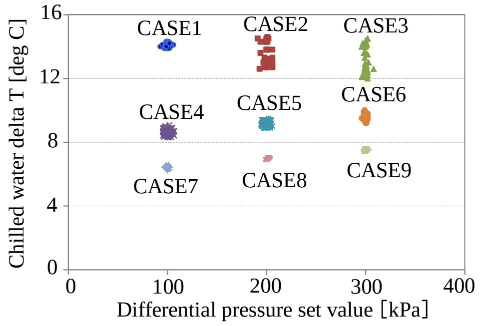

Figure 2. Chilled water delta T

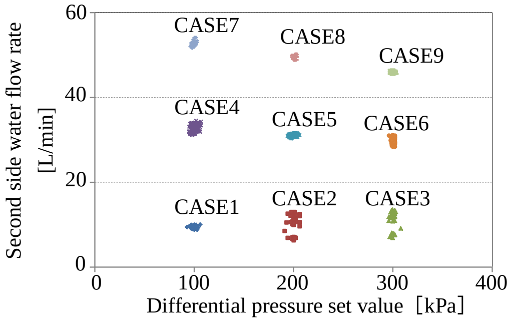

Figure 3. Secondary side water flow rate

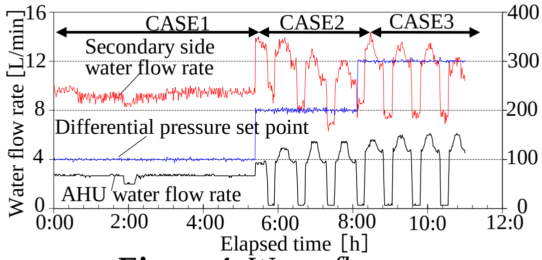

Figure 4. Water flow rate

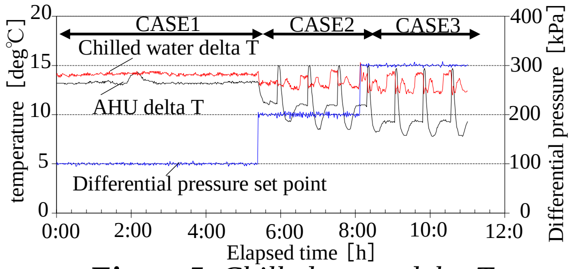

Figure 5. Chilled water delta T

Simulation for Reproduction of Experiment

The coil model used for simulation was a detailed static cooling coil of SIMBAD. The inlet water temperature, water mass flow rate, inlet air temperature, inlet air humidity ratio, and air mass flow rate were given. The outlet water and air temperatures were calculated. The calculation technique involved dividing the coil into dry, wet, and dry-wet coils. Next, the amount of all heat exchanges and bypass factors were calculated from the input conditions of the water and air by the formula given in table 6. Each outlet state was calculated according to the balance formula for the air and water sides.

First, the experiment was reproduced based on the specifications of the air-handling unit (AHU) coil used in the experiment. The validity and consistency of the coil model were confirmed. In addition, the influence of differences under a given condition examined in the experiment on the difference in chilled water temperature was confirmed. Table 7 describes the experiment reproduction. Next, given the chilled water flow rate of the heat medium-temperature-difference experiment in case 2, the influence of hunting of the chilled water flow rate on reducing the AHU delta T was confirmed. Table 8 presents an overview of the simulation conditions.

Table 6. *Calculation formula*

$$Q_t=E\times C\times(A_{in}-W_{in})$$
$$B_f=exp\{-A_{ext}/(C_{air}-R_a)\}$$
$$E=f(T_y,C_{air},C_{water})$$
$$C={}_{min}(C_{air},C_{water})$$
$$A_{in}=UA/C$$
$$UA=A_{ext}/(R_a+R_m+R_w)$$
$$C_{air}=C_{pi}\times M_A$$
$$C_{water}=C_{pw}\times M_W$$

Q_t	Quantity of all heat exchanger [kW]
B_f	Bypass factor [-]
E	Coil effect [-]
C	Thermal capacity of the coil [kW/K]
A_{in}	Inlet air temperature [℃]
W_{in}	Inlet water temperature [℃]
M_A	Air flow rate [kg/s]
M_W	Water flow rate [kg/s]
C_{pi}	Specific heat at constant pressure of the air [kJ/(kg・K)]
C_{pw}	Specific heat of the water [kJ/(kg・K)]
T_y	Coil type [-]
UA	Total heat transfer rate [kW/K]

Table 7. *Reproduction experiment*

CASE	Reproduction experiment CASE	End bypass	Differential pressure set point[kPa]	Cooling load
1-1	CASE7	Unavailable	100	High
1-2	CASE8		200	
1-3	CASE9		300	

Table 8. *Simulation cases*

CASE	Water flow rate	Cooling load	Remarks
1-4	Constant	Low	confirm whether hunting of chilled water flow rate give influence reduction of delta T.
1-5	Hunting		

Results of Simulation for Reproduction of Experiment

Figure 6 shows the results of the AHU delta T. The simulation results were almost in accordance with the experiment results. In the experiment, changing the differential pressure set point caused a difference in the AHU delta T. However, this was due to the difference in the chilled water supply temperature. Therefore, at medium and high heat loads, the differential pressure set point had a small influence on the difference in the chilled water temperature.

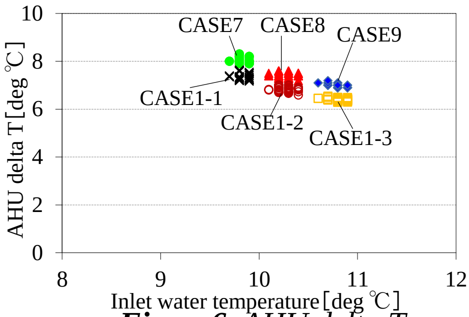

Figure6. *AHU delta T*

Figure 7 shows the water flow rate for each case. The water flow rate in case 1-11 was two periods of the heat medium-temperature-difference experimental case 2.

Case 1-10 showed a constant current flow. The multiplication heat capacity was handled equally. Figure 8 shows the AHU delta T. Thus, case 1-11 was generally less than case 1-10 except for the small flow rate. When comparing case 1-11 with the heat medium-temperature-difference experimental case 2, we found that there was a large slip from the range where water does not flow. Therefore, the mean AHU delta T was calculated using the formula in table 9. This formula weighs parameters by the water flow rate. Figure 9 shows the mean AHU delta T. Case 1-11 showed approximately 3.9 ℃ lower temperature than case 1-10. Thus, hunting of the water flow rate reduced the chilled water temperature difference.

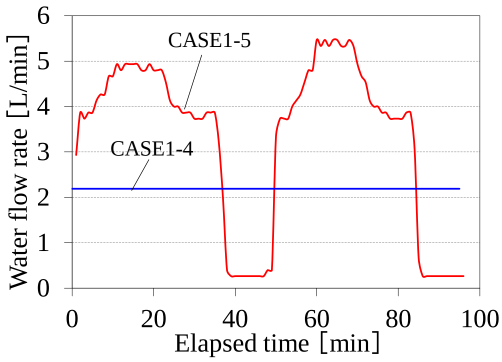

Figure7. *Water flow rate*

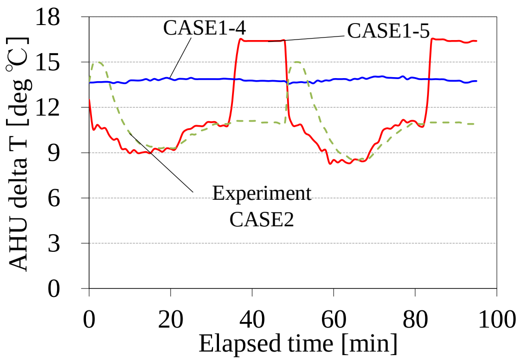

Figure8. *AHU delta T*

Table 9. *Calculation formula*

$$\text{Mean inlet water temperature} = \frac{\text{The multiplication that multiplied AHU water flow rate by inlet water temperature}}{\text{Multiplication of the AHU water flow rate}}$$

$$\text{Mean outlet water temperature} = \frac{\text{The multiplication that multiplied AHU water flow rate by outlet water temperature}}{\text{Multiplication of the AHU water flow rate}}$$

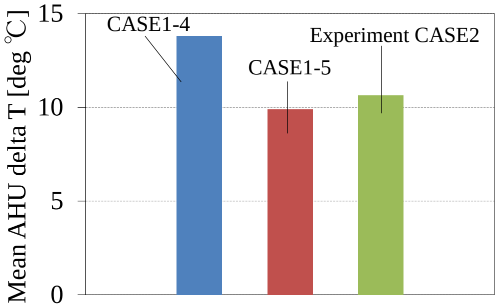

Figure9. *Mean AHU delta T*

Simulation of a Model Building

The previous section revealed that hunting of the water flow rate affected the reduction of the chilled water temperature difference. We performed a simulation of a model building. We assumed the hunting of a two-way valve happened. We examined how hunting of the water flow rate influenced the energy consumed by the heat source, primary pump, secondary pump, and fan of the AHU.

We assumed a 16-story office building in Tokyo. The total floor area was approximately 30,000 m^2. The building was heated by a central heat source. The building had three heat sources, primary pumps, and secondary pumps each installed. The system diagram is shown in Figure 10. The AHU are installed total 208 in 13 in 1 floor. The heat source and primary pump determined the driving number by the load factor and secondary side water flow rate. The secondary pump determined the driving number by the secondary side water flow rate. The primary pump operated at a constant speed. The secondary pump employed inverter control. Table 10 lists the specifications of each apparatus. Figure 11 shows the heat source properties.

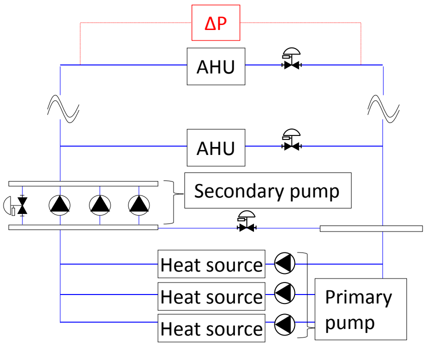

Figure 10. *System diagram*

Table 10. *Specifications of each apparatus*

Air-handling unit		Heat source（Air source heat pump）	
Ability for cooling [kW]	12.2	Ability for cooling [kW]	850
Water flow rate [L/min]	25.0	Water flow rate [L/min]	1740
Air flow rate [m^3/h]	2150	Inlet water temperature [deg ℃]	12
Rating consumption electricity [kW]	0.45	Outlet water temperature [deg ℃]	5
Static pressure[Pa]	450	Water delta T [deg ℃]	7
Inlet air dry bulb temperature [deg ℃]	26.9	Rating consumed power [kW]	237
Inlet air wet bulb temperature [deg ℃]	19.8		
water delta T [deg ℃]	7		
Primary pump		**Secondary pump**	
Water flow rate [L/min]	1740	Water flow rate [L/min]	1740
Total pump head [kPa]	200	Total pump head [kPa]	450
Rating consumption electricity [kW]	7.6	Rating consumed power [kW]	15.5

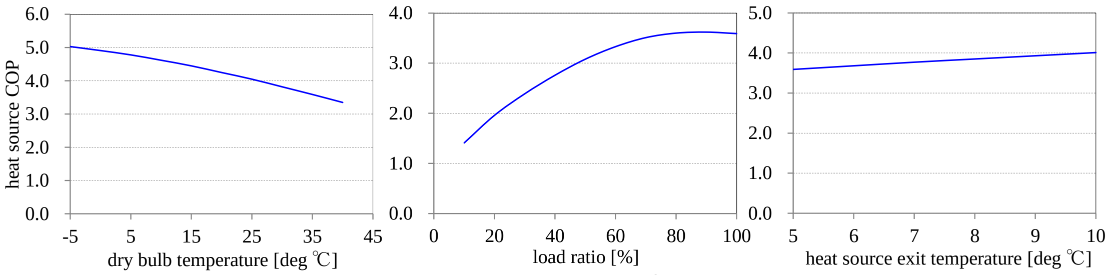

Figure 11. *Properties of heat source*

In the case we examined, we set the end differential pressure set point, water flow rate, air volume system, and heat source exit setting temperature as the parameters. Table 11 presents the simulation cases. The AHU fan drove a constant air volume with a rating-like value (2,150 m^3/h); this was fixed by the variable air volume method at an aeration temperature of 15 ℃ and regulated air flow rate.

Table 11. *Simulation cases*

CASE	Differential pressure set point[kPa]	Water flow rate	Air volume system	Cooling load per none of the AHU	Heat source exit setting temperature[deg ℃]
2-1	50	Constant	CAV	30% (3.7kW)	5
2-2		Hunting			
2-3	100				
2-4	200				
2-5	50	Constant	VAV		
2-6		Hunting			
2-7	100				
2-8	200				
2-9	50	Constant			9
2-10		Hunting			

We calculated the pressure loss ΔP of each floor from the cooling load and the differential pressure set point. We calculated the water flow rate by the pressure loss ΔP of each floor and synthetic resistance level k of the AHU coil and two-way valve. Figures 12 and 13 show plots of the hunting of a two-way valve opening and the water flow rate versus the time of the experiment. When comparing case 3 with case 2 which is low load, it was observed that the differential pressure set points were different, but the shape of the curve for hunting of the two-way valve opening did not change. Hunting of the two-way valve was based on case 2 of the heat medium-temperature-difference experiment. Movement in the upward and downward directions of the two-way valve was determined so that one period of the cooling load multiplication fit 30% (3.7 kW) by taking the magnification into account. When the two-way valve was less than 20% open, it was assumed to be completely shut.

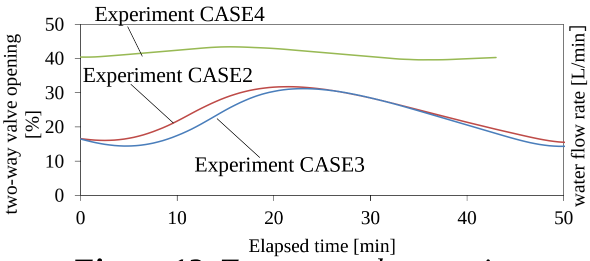

Figure 12. *Two-way valve opening*

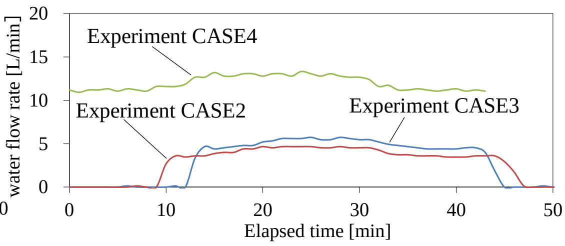

Figure 13. *Water flow rate*

The phase of hunting for each AHU slipped. Therefore, hunting of the water flow rate joined and became the average water flow rate. The water flow rate that passed the heat source was constant. And, the consumed power of each apparatus calculated it using LCEM tool published by Ministry of Land, Infrastructure, Transport and Tourism. In the heat source model, we calculated consumed power as input at dry-bulb temperature, water flow rate, exit water temperature set point and chilled water inlet temperature. In the pump model, we calculated consumed power as input at rating pump head and water flow rate. And, in the AHU fan model, we calculated consumed power as input at air flow rate.

Results of Simulation of a Model Building

Figure 14 shows the result of the AHU delta T based on the weighting average for the water flow rate in each case. This result showed that when the water flow rate caused hunting, the AHU delta T was reduced (cases 1–10). The ratio for reduction became large when the differential pressure set point was high. Figure 15 shows the secondary-side chilled water flow rate. Cases where the AHU delta T was large showed a small flow rate and vice versa. The secondary-side chilled water flow rate increased when hunting occurred.

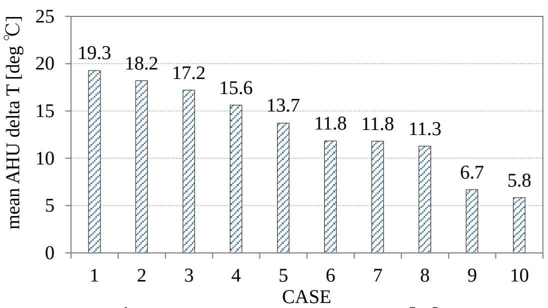

Figure 14. *Mean AHU delta T*

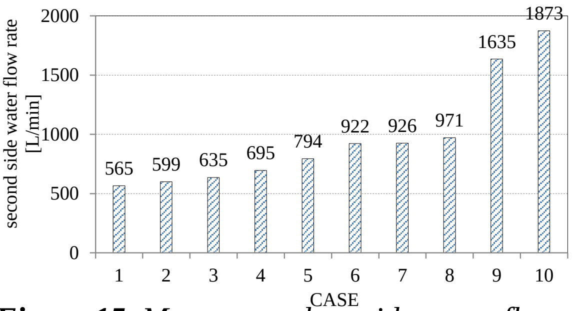

Figure 15. *Mean secondary side water flow rate*

Figure 16 shows the consumption power of each apparatus in each case. Because the flow rate of the secondary-side chilled water did not exceed 33% (1740 L/min), one heat source was driving in case 1-8. In addition, the number of driving heat sources did not change between cases because a primary bypass was controlled. Differences in the secondary-side chilled water flow, caused differences in secondary pump consumption power. However, there were few differences overall between each apparatus. There was a great difference in electricity consumption for cases 9 and 10, which assumed a heat source exit temperature of 9℃. The secondary-side chilled water flow rate in case 10 was over 33% (1740 L/min) when hunting occurred because the heat source, primary pump, and secondary pump run it. Case 10 consumed approximately 28% more electricity than case 9. The load was 0.80 for each heat source in cases 1–9; it became 0.40 in case 10. Thus, the number of driving heat sources in each apparatus was believed to increase because the difference in chilled water temperature was reduced by hunting of the water flow rate.

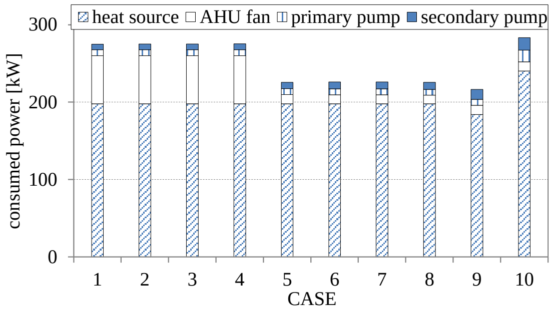

Figure 16. *Consumed power*

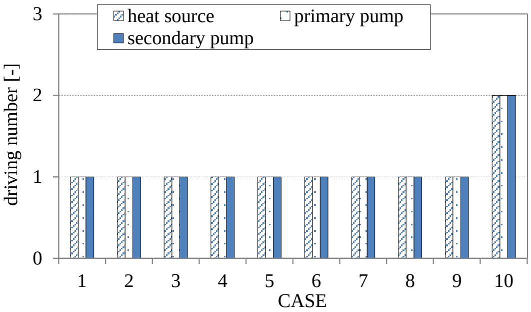

Figure 17. *Driving number*

CONCLUSION AND IMPLICATIONS

We examined the influence of the differential pressure set point on the chilled water temperature difference. At medium and high heat loads, the differential pressure set point had little influence on the chilled water temperature difference. However, when the differential pressure set point was large under a low heat load, the two-way valve became the minimum opening, which caused hunting. We clarified via a static-coil-model simulation that hunting of the water flow rate reduced the chilled water temperature difference owing to the change in the differential pressure set point. We conducted a simulation of a model building. The results showed that hunting of the water flow rate had little influence on the power consumed by each apparatus. In the interim period and winter season, the heat source exit temperature can be increased to save energy. However, this might influence the number of driving heat sources of each apparatus.

We assumed the hunting of a two-way valve happened and examined by the model-building simulation. For future problems, studies that consider the possibility of hunting are necessary.

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