Effect of the Specification of Chilled and Hot Water Coil on Efficiency of Air Conditioning System with Water Thermal Storage

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ABSTRACT

This study aims to examine the influence of the specification of heat exchange coils on the operation of air conditioning systems with water thermal storage. In this study, the influence of the specification of the air-handling unit coil on the operating condition of the water thermal storage system is examined using a simulation tool. The results indicate the importance of properly maintaining the relationship between the thermal storage tank capacity and secondary side temperature difference in both design and operation stages. Furthermore, this study shows that significant attention should be paid to the input of coil specifications when using the simulation tool.

1. INTRODUCTION

In recent years, global warming has become extremely serious to the extent that the reduction of carbon dioxide emissions has become an urgent necessity. Heating, ventilation, and air conditioning (HVAC) systems are the principal energy consumers in buildings, and technologies such as heat pumps and water thermal storage are considerably effective in reducing their energy consumption. However, the optimal design and operation of these systems are difficult to achieve. This study aims to examine the influence of the specification of heat exchange coils on the operation of air conditioning systems with water thermal storage. In the design of a water-thermal-storage-type air conditioning system, setting of the temperature difference on the secondary side significantly affects the tank volume. When the actual temperature difference between the input and output of the coil becomes smaller than the designed value, the thermal storage amount available for air conditioning also decreases. Thus, there is an apprehension that benefits derived from the thermal storage system, such as energy saving, cost saving, and CO_2 emission reduction, are diminished. In this study, the influence of the specification of the air-handling unit coil on the operating condition of the water thermal storage system is examined using a HVAC system simulation program. From the results, we aim to identify the precautions necessary for inputting coil specifications when examining the water-thermal-storage-type air conditioning system with this tool.

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2. OUTLINE OF THE BUILDING AND FACILITIES

The second section presents the outline of the building and facilities constructed by employing the model of a real building.

2.1 Outline of Air Conditioning Equipment

The floor plan of a typical floor is shown in Figure 1 and the outline of the building and air conditioning facilities is presented in Table 1. The buildings used as calculation models have 14 floors above the ground and one floor below the ground. The construction site of the building is in Tokyo, Japan. The target area for calculation is divided into an interior zone and east and west perimeter zones. The core zone, which includes the elevator hall, is excluded from the target area for calculation and the boundary wall between the core zone and the target area for calculation is considered as the inner wall. In the air conditioning system, an air-handling unit with a variable air volume system is installed in each zone. The air conditioning heat source system is a heat pump system with a water thermal storage tank of multi-connected complete mixing type. The details of the water thermal storage system are presented in the following section.

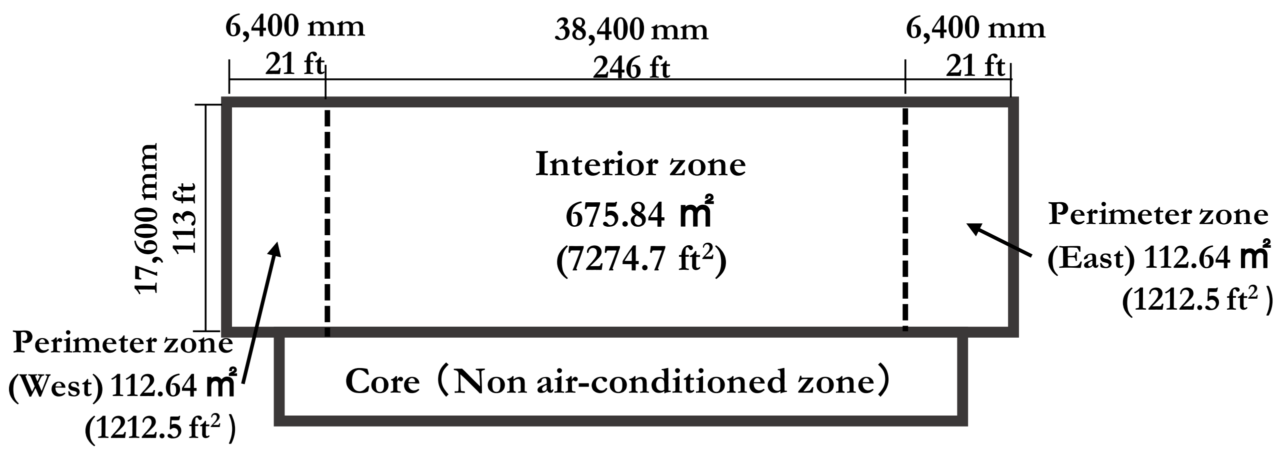

Figure 1 Floor plan of a typical floor

Table 1. Outline of the building and air conditioning facilities

Outline of the building	Location	Tokyo
	Building use type	Office building
	Building area	1,498 ㎡ (16,124 ft²)
	Total floor area	20,580 ㎡ (221,523 ft²)
	Number of stories	14 floors above the ground and the first basement level
Air conditioning facilities	Primary (heating/cooling) equipment	Air source heat pump Water thermal energy storage system with water storage tank of multi-connected complete mixing type
	Air conditioning facility	Air-handling unit with variable air volume system Interior zone (AHU1) East perimeter zone (AHU2), West perimeter zone (AHU3)

2.2 Design of Air Conditioning System with Water Thermal Storage

Figure 2 shows the calculation results of the hourly cooling load for the day on which the maximum value of the total cooling load per day during summer was recorded. Using this load, we designed the necessary heat source capacity and thermal storage tank capacity of the water-thermal-storage-type air conditioning system. Table 2 shows the outline of the air conditioning heat source equipment. These design values are calculated using the thermal energy storage estimation program–water (TESEP-W), which was developed by the author (Nakahara) to simulate water thermal storage HVAC systems using BASIC language based on his study (Nakahara et al. 1982, 1988). It helps operators/designers improve the efficiency of water thermal storage systems. The algorithm of TESEP-W is also installed in the tool. The temperature difference on the secondary side was designed to be 5 °C (9 °F) and 10 ° C (18 °F), and the capacity of the heat storage tank was 600 m^3 (21,189 ft^3) and 1200 m^3 (42,678 ft^3), respectively.

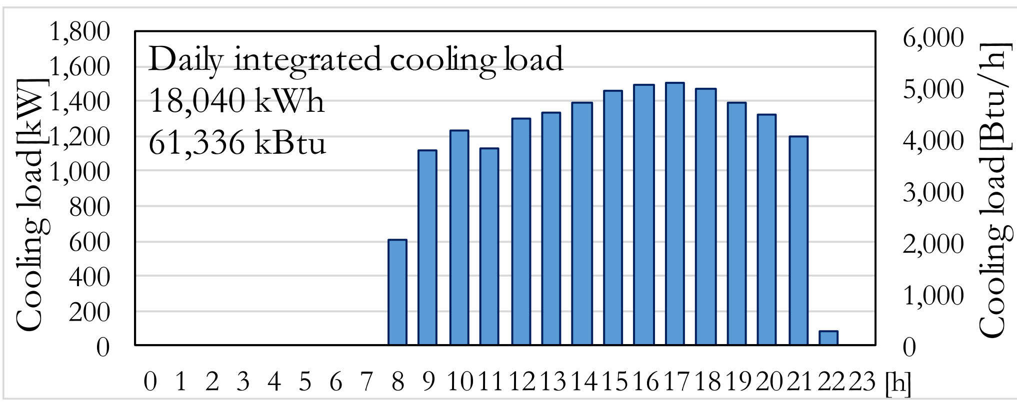

Figure 2 Cooling load for the day with the largest cumulative load (8/7)

Table 2. Outline of the air conditioning facilities

Air source heat pump	Refrigerating capacity : 800 kW （10 °C（50 °F）→5 °C（41 °F）） Design water volume : 2,300 (L/min) (81.19 cfm)	
Secondary side temperature difference	10 °C（18 °F）	5 °C（9 °F）
Design temperature of air-handling unit	inlet 7 °C（44.6 °F） outlet 17 °C（62.6 °F）	inlet 7 °C（44.6 °F） outlet 12 °C（53.6 °F）
Volume of thermal energy storage tank	600 m^3 (30 tanks) (21,189 ft^3)	1200 m^3 (60 tanks) (42,378 ft^3)
Thermal storage tank efficiency	105.9 %	105.9 %

3. DETERMINATION OF CALCULATION CONDITIONS AND COIL SPECIFICATIONS

This section describes the calculation conditions. Based on the calculation result of maximum cooling load, the cooling capacity of each air-handling unit was 97 kW for the interior zone and 30 kW for the perimeter zone. Table 3 shows the coil specification values of AHU1 and Table 4 shows the corresponding values of AHU2 and AHU3. The maximum air volume of the air-handling unit was calculated under the condition that the temperature difference between the diffused air of the air-handling unit and the indoor air was 10 °C (18 °F). The default value in the table is the value that was originally input to the tool. The air-handling unit coil was designed using four combinations of the secondary side temperature difference and air volume control, by employing the model of a real building for the calculation. Each setting was set for CASES 1 to 4 as shown in the table. The difference in setting owing to the secondary side temperature difference is reflected by the number of rows of coils, i.e., 6 rows at 5 °C (9 °F) and 8 rows at 10 °C (18 °F). As shown in Table 2, the tank capacity varies depending on the secondary side temperature difference. However, to confirm the situation in which the operation is different from the design, calculation was performed at 1200 m^3 (42,678 ft^3) and 600 m^3 (21,189 ft^3) for CASE 0 to CASE 4. Thus, the calculation result at 600 m^3 (21,189 ft^3) is expressed as CASE 0 to CASE 4, and the calculation result at 1200 m^3 (42,678 ft^3) is expressed as CASE 10 to CASE 14.

Table 3. Specification of AHU1 for each calculation case

AHU1	Default	Variable air volume		Constant air volume	
		5 °C/9 °F	10 °C /18 °F	5 °C/9 °F	10 °C /18 °F
	CASE-0	CASE-1	CASE-2	CASE-3	CASE-4
Cooling coil capacity (kW)	-	97	97	97	97
Maximum air volume (m^3/h) / (cfm)	15,000 / 8,828	15,000 / 8,828			
Minimum air volume (m^3/h) / (cfm)	2,800 / 1,648	2,800 /1,648		-	-
Supply air volume (m^3/h) / (cfm)	15,000/ 8,828	15,000/ 8,828			
Return air volume (m^3/h) / (cfm)	12,200 / 7,180	12,200 / 7,180			
Maximum water volume (L/min)/ (cfm)	330 / 11.6	278 / 9.8	139 / 4.9	278 / 9.8	139 / 4.9
Input temperature of coil (°C/°F)	-	7/44.6	7/44.6	7/44.6	7/44.6
Output temperature of coil (°C/°F)	-	12/53.6	17/62.6	12/53.6	17/62.6
Face area of coil (m^2) / (ft^2)	2.10 / 22.6	1.389 / 14.9			
Number of coil rows	6	6	8	6	8
Number of tubes	20	28	28	28	28
Flow type	Single	Single	Single	Single	Single

Table 4. Specification of AHU2 · 3 for each calculation case

AHU2・AHU3	Default	Variable air volume		Constant air volume	
		5 °C/9 °F	10 °C /18 °F	5 °C/9 °F	10 °C /18 °F
	CASE-0	CASE-1	CASE-2	CASE-3	CASE-4
Cooling coil capacity (kW)	-	30	30	30	30
Maximum air volume (m^3/h) / (cfm)	6,000 / 3,531	4,800 / 2,825			
Minimum air volume (m^3/h) / (cfm)	460 / 271	460 / 271		-	-
Supply air volume (m^3/h) / (cfm)	6,000 / 3,531	4,800 / 2,825			
Return air volume (m^3/h) / (cfm)	5,540 / 3,260	4,340 / 2,554			
Maximum water volume (L/min) / (cfm)	70 / 2.5	86 / 3.0	43 / 1.5	86 / 3.0	43 / 1.5
Input temperature of coil (°C/°F)	-	7/44.6	7/44.6	7/44.6	7/44.6
Output temperature of coil (°C/°F)	-	12/53.6	17/62.6	12/53.6	17/62.6
Face area of coil (m^2) (ft^2)	0.84 / 9.0	0.444 / 4.8			
Number of coil rows	6	6	8	6	8
Number of tubes	20	16	16	16	16
Flow type	Single	Single	Half	Single	Half

4. CALCULATION RESULTS AND DISCUSSION

4.1 Validation of Calculation Results

First, to confirm the validity of the coil design and tool calculation accuracy, it is shown that the design value of the coil temperature difference and tool calculation result are equal as shown in Figure 3. The average temperature difference on the secondary side is the average value during the period of air conditioning operation from July to September. It can be judged from this calculation result that the setting value of the coil specification is valid. Significant difference owing to the tank capacity and the air volume control was not observed. Figure 4 shows the calculation results of the power consumption of the heat source and the night transition rate. The night transition rate is higher when the capacity of heat storage tank is 1200 m^3 (42,678 ft^3), which is a reasonable result. However, it is not known why the power consumption of the heat source is smaller in the case of constant air volume control, and it may be due to a problem in the tool algorithm. Owing to this reason and the limitation of the number of pages, we consider only the result of the variable air volume control henceforth.

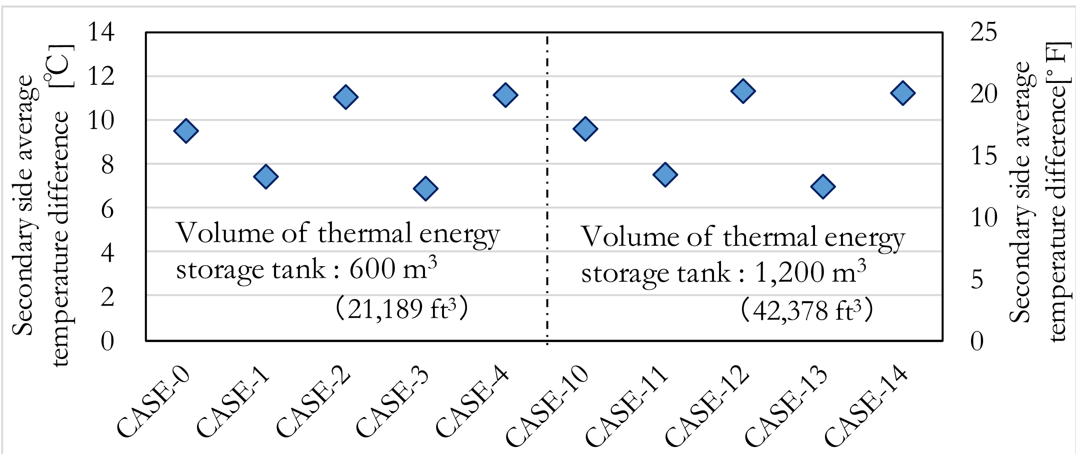

Figure 3 Average temperature difference on the secondary side for each case

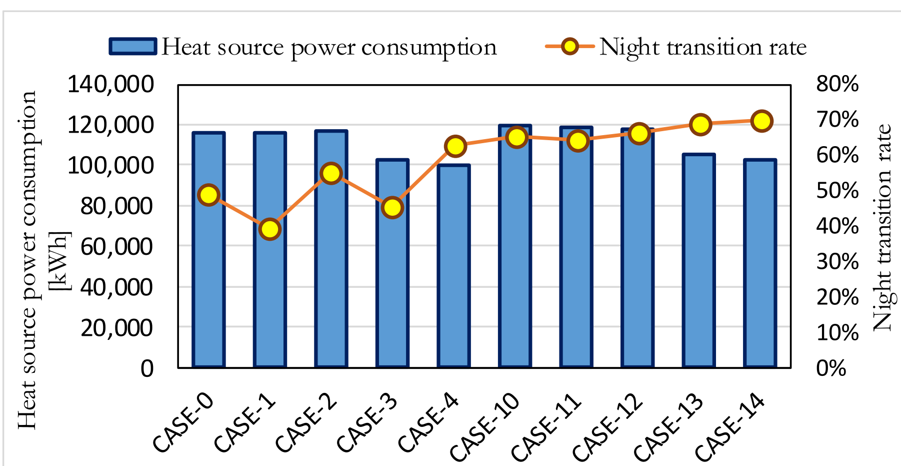

Figure 4 Calculation results of power consumption of heat source and night transition rate of each case

4.2 Effect of Coil Specification on Calculation Results

By comparing CASE 1 and CASE 2, we consider the influence of the differences in coil specification on the operating condition of the air conditioning system. Figure 5 shows the coil passing flow rate and the coil input and output water temperatures of AHU1 in CASE 1 and CASE 2. Calculation time interval is 5 minutes. The reason for the increase in the cold water flow rate at the start of operation is that the air conditioning is stopped at night so that the room temperature in the morning becomes high and a heavy load is generated. It can be confirmed that the flow rate of cold water passing through the coil is smaller in CASE 2 than in CASE 1 and cold water of approximately 6 °C (42.8 °F) is supplied during the air conditioning duration. In CASE 1, the input water temperature of the coil starts to rise around 15 O'clock and reaches 10 °C (50 °F) at around 17 O'clock. As the water temperature rises, the flow rate of cold water also increases.

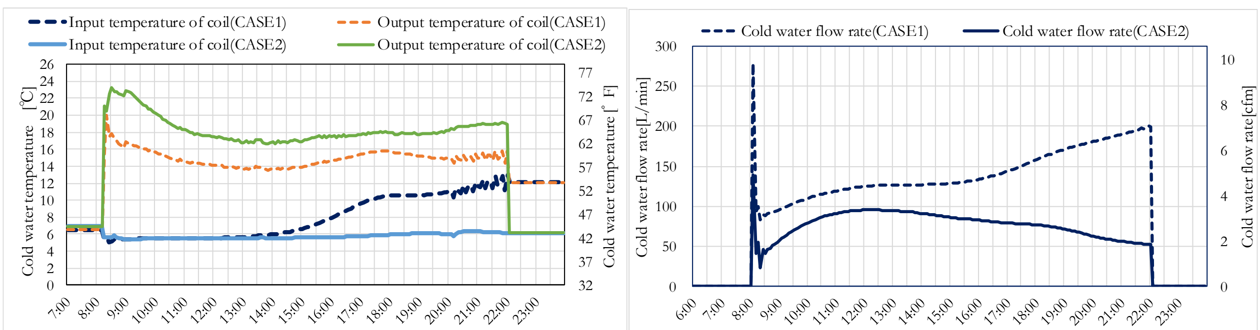

Figure 5 Input/output water temperature and flow rate through the coil of AHU1

Figure 6 shows the change in water temperature in the thermal storage tank during the air conditioning duration in CASE 1 and CASE 2. The difference between CASE 1 and CASE 2 in terms of the change in the water temperature in the thermal storage tank is shown; further, in CASE 1, the difference in usage temperatures of the thermal storage tank is small and the rise in water temperature on the starting tank side is remarkable. In CASE 1, there is a concern that room temperature and humidity will rise after 15 O'clock. In contrast, the difference in usage temperatures of the thermal storage tank in CASE 2 is 10 °C (50 °F) or higher, and the starting tank water temperature is maintained at a low temperature until the air conditioner operation ends. This situation can be judged as correct for operating the thermal storage tanks.

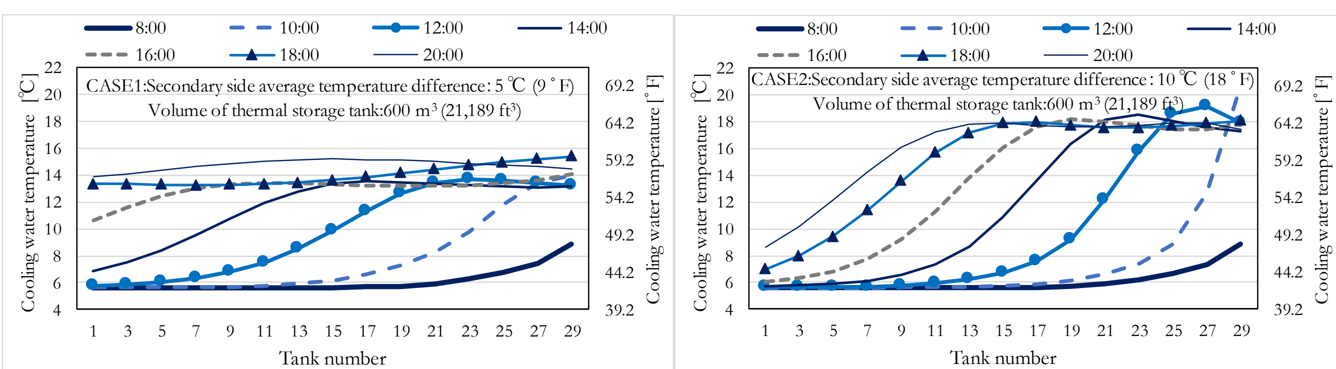

Figure 6 Change in water temperature in the thermal storage tank during the air conditioning duration

4.3 Influence of Differences in Thermal Storage Tank Capacity on Calculation Results

Figure 7 shows the coil passing flow rate and the coil input and output water temperatures of AHU1 in CASE 11 and CASE 12. Although a slight temperature increase can be observed in any of the cases, the input water temperature of the coil can be maintained at 8 °C (46.4 °F) or less until the end of air conditioning operation. The flow rate of cold water passing through the coil is also stable throughout the day, and noticeable change cannot be observed.

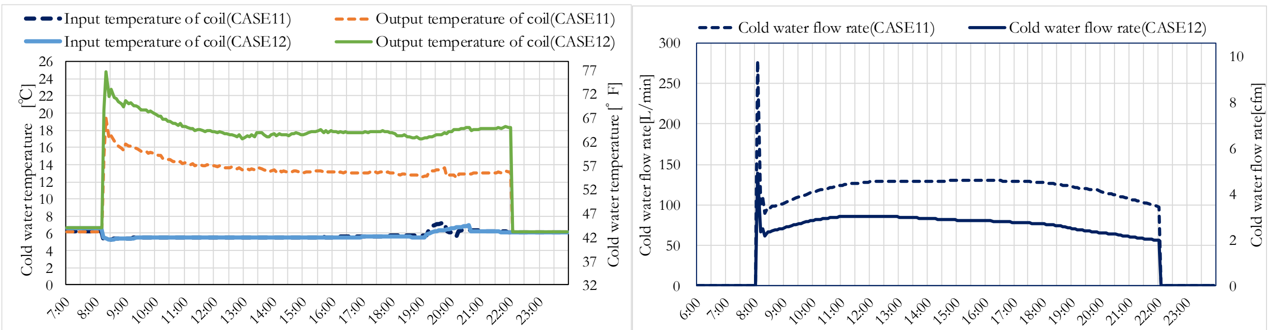

Figure 7 Input/output water temperature and flow rate passing through coil of AHU1

Figure 8 shows the change in water temperature in the thermal storage tank during the air conditioning duration in CASE 11 and CASE 12. In all the cases, the rise in water temperature on the starting tank side is slight and it is considered that there is no problem in the indoor temperature and humidity environment. However, in CASE 12, it can be observed that the water in the heat storage tank cannot be utilized effectively. Thus, when the secondary side temperature difference becomes larger than the design value, there are merits such as the reduction of the transportation power of the secondary side pump but, as the usage range of temperature of the thermal storage tank is different from the design, it is also necessary to change the setting value of the thermal storage controller. Regarding the specifications of coils, there is little design opportunity for the facility engineers by themselves, and it is expected that the recognition of importance of checking the specifications of coils will be low when using tools. However, the careful input of the coil specifications is very important especially in the water-thermal-storage-type air conditioning system.

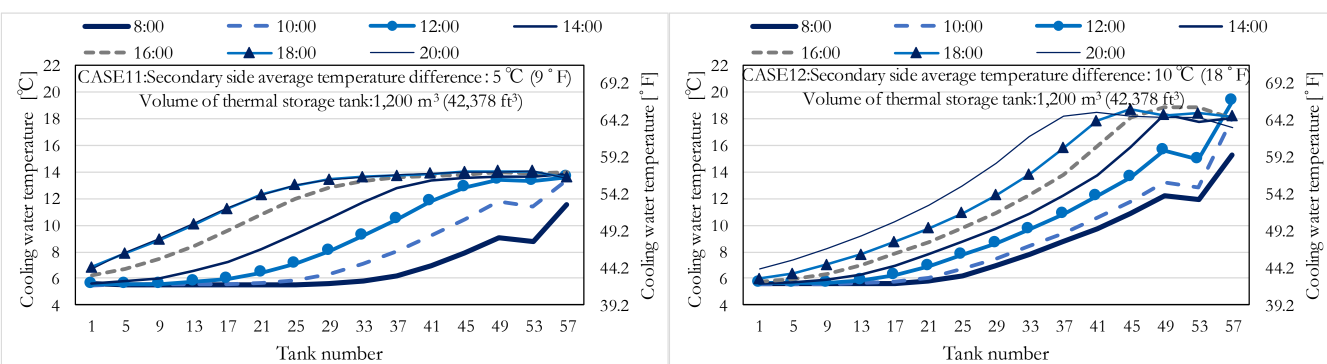

Figure 8 Change in water temperature in the thermal storage tank during the air conditioning duration

CONCLUSION

The calculation results showed that the benefit of the thermal storage system could not be sufficiently realized when the relationship between the secondary side temperature difference and thermal storage tank capacity is inappropriate, and an excess or deficiency in the thermal quantity of the tank is observed. The results of this study indicate the importance of properly maintaining the relationship between the thermal storage tank capacity and secondary side temperature difference in both design and operation stages. Moreover, this study shows that attention should be paid to the input of coil specifications when using the simulation tool.

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