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Analysis of Heat Accommodation Effect in District Heating and Cooling Systems

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Abstract. The purpose of this research is to investigate a method to improve the efficiency of heat source systems in two buildings by heat accommodation of cold/hot water between two facilities, and to clarify the energy saving effect. In this report, measured value analysis and simulation on the representative days are carried out. Heat source systems in two buildings located east and west across a road are targeted as the east district system and west district system. Overall, the equipment in the west area has better performance. First, the heat accommodation effect was verified by a measured values analysis. The analysis was carried out by comparing the representative days. Improvement of the east district SCOP was seen when remitting cold heat from the east district to the west district. In addition, it was confirmed that the heat recovery heat pump was operated by remitting hot water from the west district to the east district, and total SCOP of both districts improved. Next, efficiency is analyzed using a simulation model. We conducted a simulation to shift the load of each district and examined effective heat accommodation control. As a result of the simulation on the representative day, by remitting the load in the west district to the east district during the night and remitting the load in the east district to the west district during the day, heat recovery heat pump in the west district operated more, and the total SCOP of both districts improved. Examination by the measured value analysis and simulation showed that control to operate heat recovery heat pumps in the west area more is effective.

1. Introduction

The purpose of this research is to investigate methods to improve the efficiency of heat source systems in two buildings by using river water, highly efficient heat source devices and heat accommodation of cold/hot water between two facilities, and to clarify the energy saving effect of it. In previous studies, examinations were conducted from the pre-operation stage of heat accommodation. A calculation model that simulates the behavior of heat source equipment in both districts was created and has been confirmed that it has been created appropriately as a result of accuracy verification. Simulations based on the load assumed at the design stage were conducted to study appropriate seasonal and annual control methods. In this report, to analyze elements that lead to energy saving of heat accommodation, measured value analysis and simulation on the representative day are carried out.



2. Overview of the target system

The target of this research is heat source systems in two buildings across a road from one another, which is referred to as the east district system and west district system here. The target heat source systems have cold/hot water temperature stratified heat accumulating tanks and use river water as cooling/heating source water. Tables 1 and 2 show the building overview and equipment specifications of each system, and figure 1 shows the target heat source system flow, respectively. In this system, four heat-storage type heat source devices (R-01 to R-04 in the east area, R-A 01 to R-A 04 in the west area) accumulate heat in the heat accumulating tank for each area, and direct type heat source devices (R-05 - R-06 in the east district, R-A05 in the west district) to directly handle the load on the secondary side. The east district was completed in 2012, and the west district was completed in 2017.

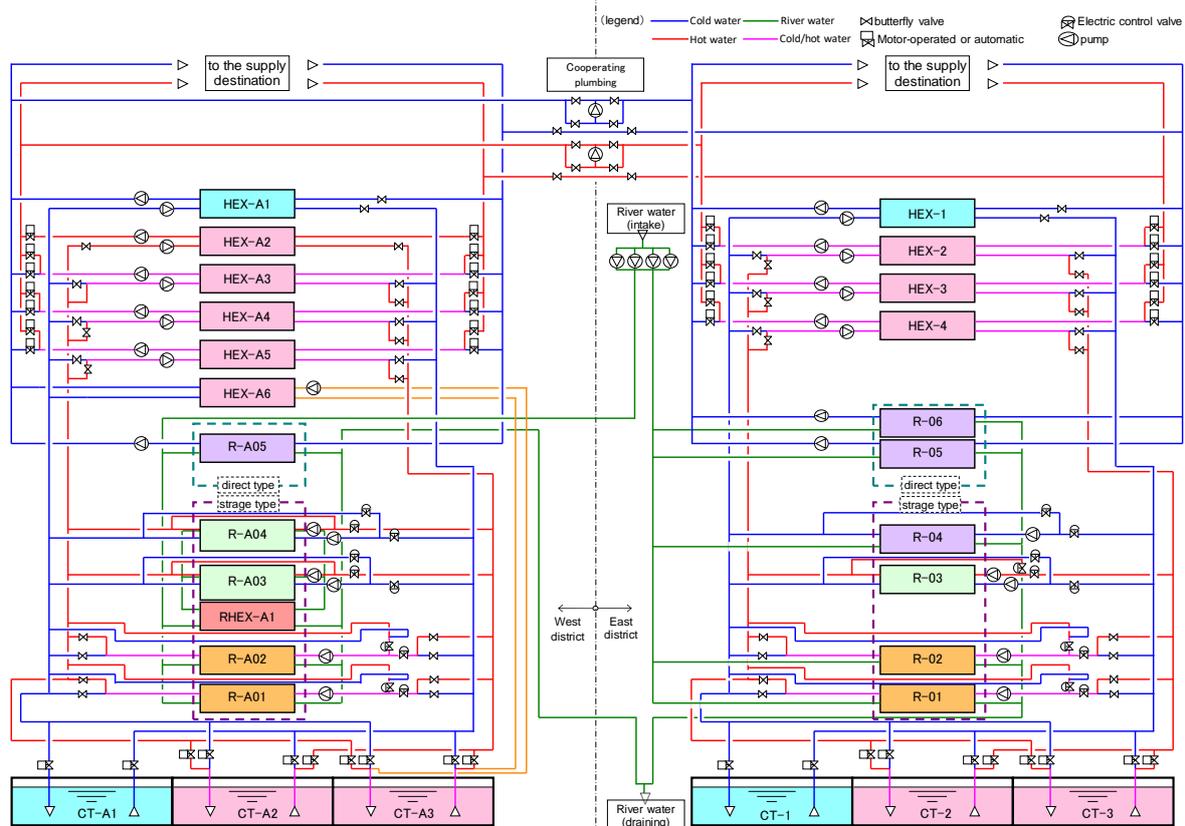


Figure 1. The target heat source system.

Table 1. Outline of the facilities.

	West District	East District
Address	Osaka, Japan	Osaka, Japan
Site area	8,377 m ²	8,150 m ²
Total floor space	150,432 m ²	146,209 m ²
The number of stories	41 floors above ground and 4 below	39 floors above ground and 3 below
Structure of Building	steel, reinforced-concrete, steel-reinforced concrete structure	
Main use of Building	office, commercial, cultural, hotel, etc.	
Completed	April 2017	November 2012

Table 2. Equipment specifications in each district system.

East District					West District				
No.	Equipment name	Specification		COP [-]	No.	Equipment name	Specification		COP [-]
R-01.	Heat pump	Refrigeration capacity	1,760 kW	4.18	R-A01,	Heat pump	Refrigeration capacity	2,750 kW	5.00
R-02		Heating capacity	2,000 kW	4.75	R-A02		Heating capacity	2,800 kW	5.09
R-03	Heat recovery heat pump	Refrigeration capacity	340 kW	3.30	R-A03, R-A04	Heat recovery heat pump	Refrigeration capacity	850 kW	3.27
		Heating capacity	450 kW	4.37			7.67	Heating capacity	1,100 kW
R-04	Turbo refrigerator attached inverter	Refrigeration capacity	1,410 kW	5.22	R-A05	Turbo refrigerator	Refrigeration capacity	3,200 kW	5.82
R-05, R-06	Turbo refrigerator	Refrigeration capacity	3,200 kW	5.71	RHEX-A1	River water heat exchanger	Exchange heat quantity	1,256 kW	-
HEX-1	Heat exchanger (cold water)	Exchange heat quantity (cold)	1,600 kW	-	HEX-A1	Heat exchanger (cold water)	Exchange heat quantity	1,600 kW	-
HEX-2	Heat exchanger (cold/hot water)	Exchange heat quantity (cold)	1,600 kW	-	HEX-A2	Heat exchanger (hot water)	Exchange heat quantity	1,600 kW	-
		Exchange heat quantity (hot)	1,600 kW	-	HEX-A3, HEX-A4, HEX-A5	Heat exchanger (cold/hot water)	Exchange heat quantity (cold)	3,200 kW	-
HEX-3, HEX-4	Heat exchanger (cold/hot water)	Exchange heat quantity (cold)	3,200 kW	-	HEX-A6	Heat exchanger for heat extraction	Exchange heat quantity (hot)	3,200 kW	-
CT-1	Cold water tank	Volumetric capacity	684 m ³	-	CT-A1	Cold water tank	Volumetric capacity	1,050 m ³	-
		Heat storage quantity	6,363 kWh	-			Heat storage quantity	10,378 kWh	-
CT-2	Cold/hot water tank	Volumetric capacity	1020 m ³	-	CT-A2	Cold/hot water tank	Volumetric capacity	650 m ³	-
		Heat storage quantity	9,488 kWh	-			Heat storage quantity	6,424 kWh	-
CT-3	Cold/hot water tank	Volumetric capacity	696 m ³	-	CT-A3	Cold/hot water tank	Volumetric capacity	2,000 m ³	-
		Heat storage quantity	6,474 kWh	-			Heat storage quantity	19,767 kWh	-

3. Analysis of heat accommodation effect based on measured value

Using the measured values from April to September of 2017, we verified the heat accommodation effect. We analyzed the heat quantity of heat accommodation, the change of system COP in each district, and behavior of each heat source device. In this report, April 19th and 20th were taken as the representative days and the results of these were summarized.

Based on these results, appropriate operation methods will be examined. For the evaluation index, a system COP (hereinafter referred to as SCOP) was adopted (Equations 1 to 3).

$$\begin{aligned} & \text{both districts SCOP}[-] \\ & = \text{total heat production of both districts [kWh]} / \text{total power consumption of both districts (primary side) [kWh]} \quad (1) \end{aligned}$$

$$\begin{aligned} & \text{east district SCOP}[-] \\ & = \text{total heat production of east district [kWh]} / \text{total power consumption of east district (primary side) [kWh]} \quad (2) \end{aligned}$$

$$\begin{aligned} & \text{west district SCOP}[-] \\ & = \text{total heat production of west district [kWh]} / \text{total power consumption of west district (primary side) [kWh]} \quad (3) \end{aligned}$$

Figures 2 to 7 show the driving situation of both districts on the representative day and comparison day. Each figure shows the heat production/heat transfer amount and load of the eastern district, the heat production/heat transfer amount and load in the west district, the eastern district/western district, and both districts SCOP. Regarding the heat transfer amount, "E → W" means that the load in the west district was covered by the heat produced in the east district.

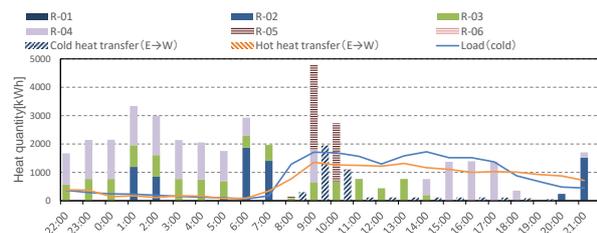


Figure 2. Production/transfer/load heat quantity in the east district (representative day).

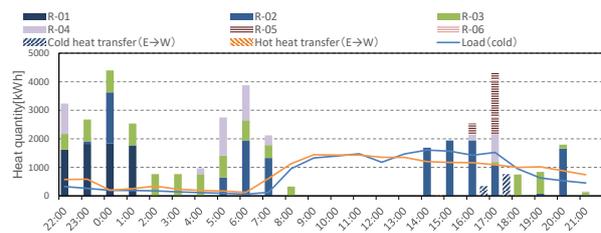


Figure 5. Production/transfer/load heat quantity in the east district (comparison day).

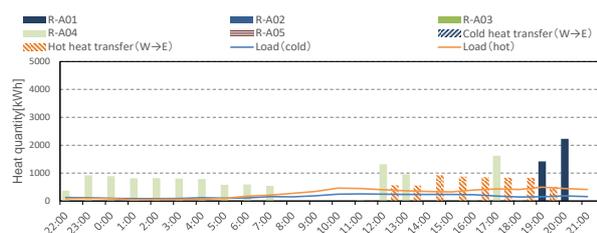


Figure 3. Production/transfer/load heat quantity in the west district (representative day).

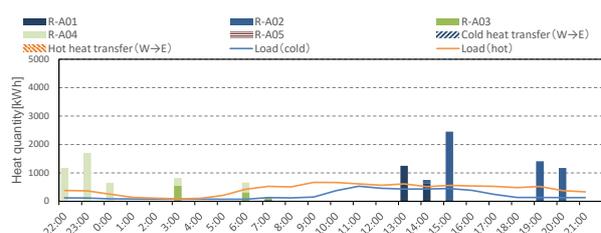


Figure 6. Production/transfer/load heat quantity in the west district (comparison day).

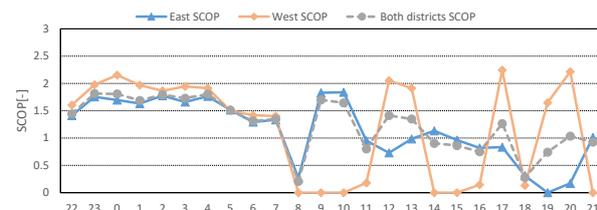


Figure 4. SCOP of the east/west district and both districts (representative day).

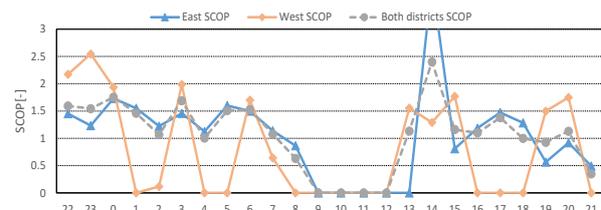


Figure 7. SCOP of the east/west district and both districts (comparison day).

In figures 2 and 4, it can be seen that between 9 and 11 on April 19, when cold heat was transferred from the east district to the west district, the operation of R-05 increased and the east district SCOP improved. There is a possibility to improve the eastern district SCOP if R-05 with high COP is operated by interchange. In addition, as shown in figures 3 and 4, the time when R-A 04 was operated can be seen frequently at night on April 19th when warm heat was transferred from the west district to the east district; the west district SCOP at this time was high. Improvement of both districts SCOP is expected by effectively using the heat recovery heat pump which produces cold and warm heat simultaneously by the accommodation of warm heat. On April 19th, when the operation time of the heat recovery heat pump (R-A04) was long, 0.044 (3.5%), both districts SCOP were improved compared with April 20th (since the value between 14 and 15 is abnormal, that time is excluded).

4. Analysis of heat accommodation effect based on simulation

In this chapter, we analyze the behavior of both districts using the simulation model developed in the past studies^{1) - 3)}, and investigate appropriate methods of heat accommodation. First, a simulation was carried out with the six basic cases, which are shown in table 3, and effective heat accommodation methods were examined. The date of examination was April 19th. The calculation results of SCOP are shown in table 4. Figures 8 to 11 show the behavior of both districts in Case 0. Figures 8 and 9 show the load transition, the heat production, and SCOP of the east district, and figures 10 and 11 show those of the west district.

Table 3. Condition of the considered cases.

Name	Case conditions
Case0	No accommodation.
Case1	Transfer the heat load from the east to the west as much as possible in the heat storage time period.
Case2	Transfer the heat load from the east to the west as much as possible in the heat storage time period.
Case3_n	When the heat load of the east district is lower than n [kW], transfer the heat load of the east district to the west district.
Case4_n	Transfer the heat load of n [kW] from the east to the west in all time periods.
Case5	Transfer the heat load from the east to the west as much as possible in all time periods.

Table 4. The calculation results of SCOP (April 19th).

	Case 0	Case 1	Case 2	Case 3_500	Case 3_2000	Case 4_500	Case 4_2000	Case 5
East district SCOP	1.502	1.498	1.548	1.486	1.038	1.545	0.000	0.000
West district SCOP	1.169	1.961	1.974	1.769	1.490	1.573	1.570	1.553
Both districts SCOP	1.441	1.591	1.593	1.564	1.478	1.564	1.570	1.553

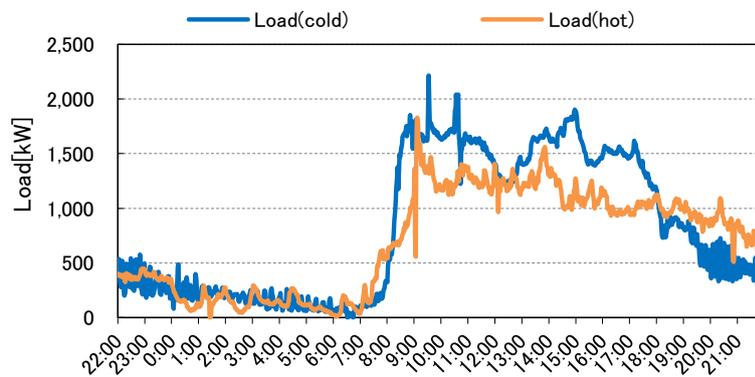


Figure 8. Load in the east district (Case 0).

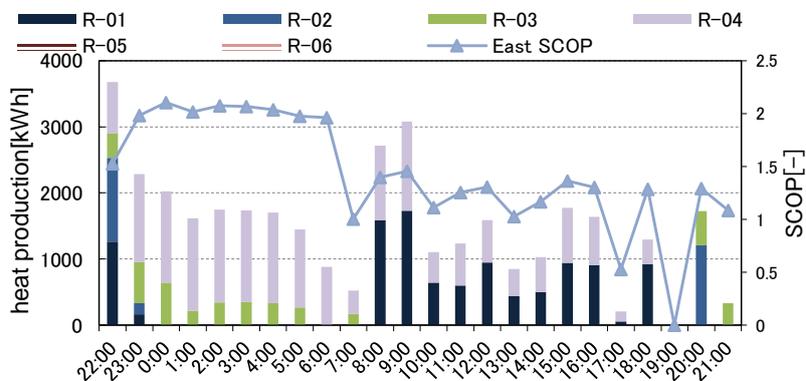


Figure 9. Heat production and SCOP in the east district (Case 0).

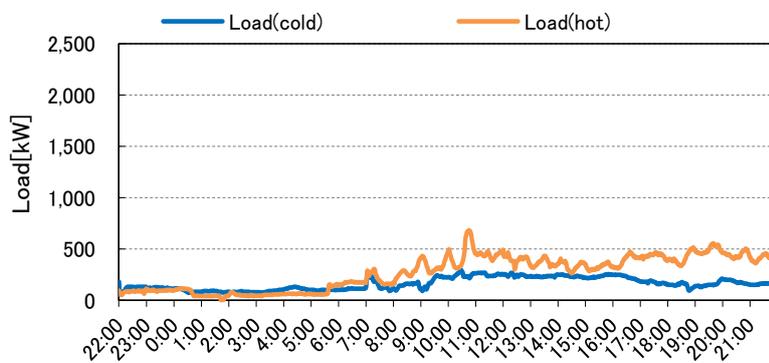


Figure 10. Load in the West district (Case 0).

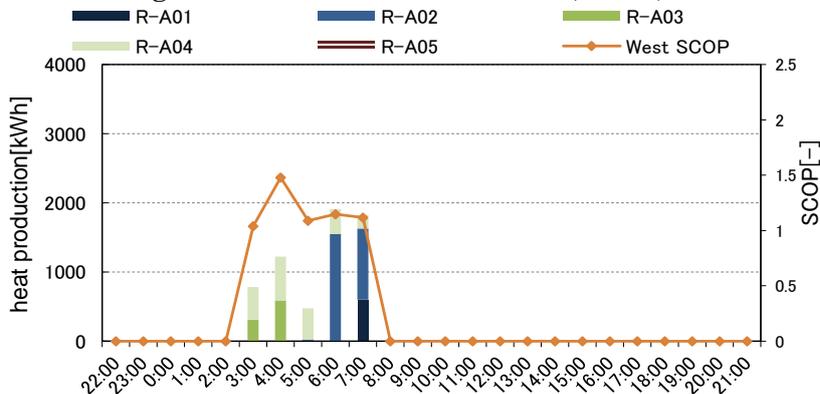


Figure 11. Heat production and SCOP in the West district (Case 0).

In the Case 0, in the east district, SCOP is high in the heat storage time zone when both R-03 and R-04 were in operation. In addition, the time zone in daytime during which R-04 operates tends to decrease in the east district SCOP when R-01 operates, but the rate of decrease in SCOP is small as the total production heat per hour is larger. In the west district, the total heat production was small and the SCOP was also lower than 1.5 between 3 to 6 when R-A03 and R-A04 were in operation. Between 6 and 8, R-A01 and R-A02 have been in operation and heat production has increased, but SCOP is not much different from 3 to 6.

As in Case 1 and Case 2, the control method that shifts the nighttime load as much as possible can be said to be an effective means to improve both districts SCOP.

Subsequently, Case 2 showing the highest SCOP is compared with Case 0. Figures 12 to 15 show the behavior of both districts in Case 2. Figures 12 and 13 show the load transition, the heat production and SCOP of the east district, Figures 14 and 15 show these of the west district. In the east district, the heat production by the highly efficient operation of the heat storage time zone is increasing, leading to the improvement of SCOP. In the west district, the heat production of R-A03 which produces cold and warm heat simultaneously is increasing, which makes it highly efficient operation in the west district. In the east district, there is a time zone during which SCOP falls during daytime when the load is high. As shown in Chapter 3, because the heat production of R-A04 was increased, both districts SCOP on April 19th when the warm heat was transferred from the west district to the east district was higher than that of comparison date (April 20th). Therefore, by transferring the load in the east district during time zone in daytime to the west district, the heat production of the heat recovery heat pump will increase, and SCOP is expected to improve as averaged over the day.

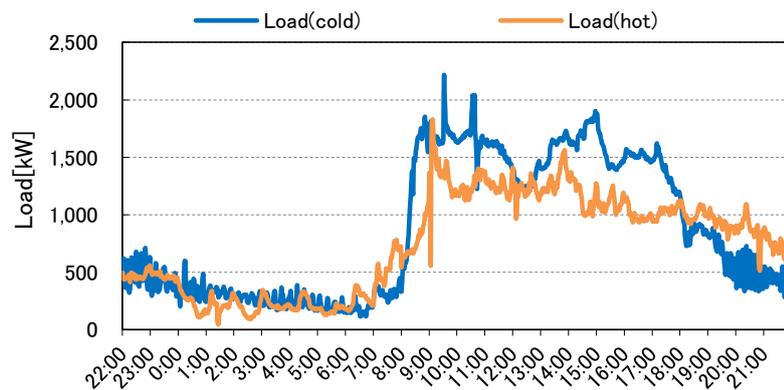


Figure 12. Load in the East district (Case 2).

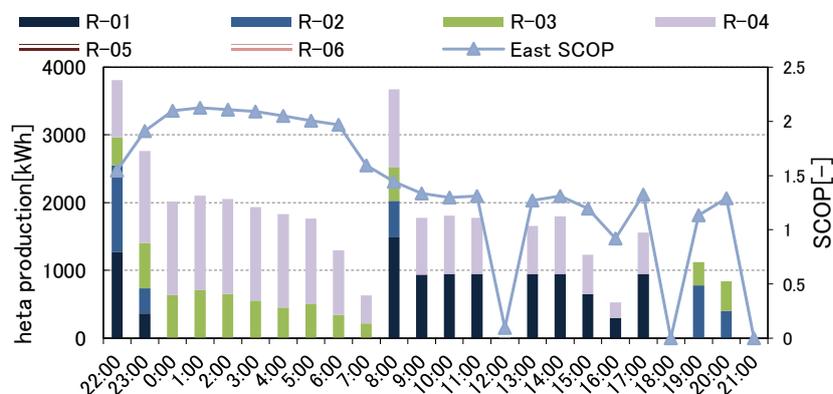


Figure 13. Heat production and SCOP in the East district (Case 2).

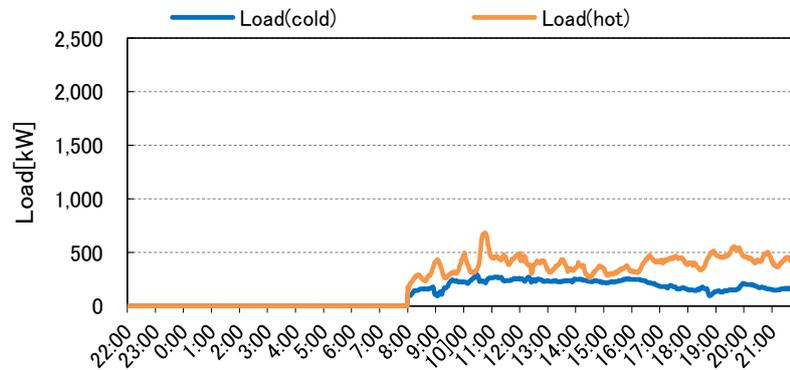


Figure 14. Load in the West district (Case 2).

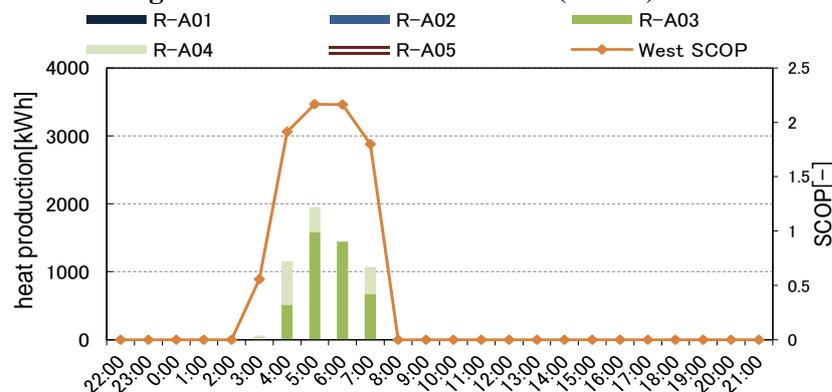


Figure 15. Heat production and SCOP in the West district (Case 2).

Based on the above consideration, the daytime control (Case 3 to Case 5) is combined with the Case 2 which both districts SCOP takes the highest value in the basic case, and a simulation is conducted for this new detailed case. The SCOP of the calculation result is shown in table 5. In the examination results of the detailed case, the larger the transition load calorific value, the better the eastern area SCOP and the western area SCOP tended to decrease.

Table 5. The calculation results of detailed case (April 19th).

	Case 0	Case 2	Case 2-4.250	Case 2-4.500
East district SCOP	1.502	1.548	1.568	1.581
West district SCOP	1.169	1.974	1.887	1.754
Both districts SCOP	1.441	1.593	1.664	1.660

In the examination results of the detailed Case, the larger the transition load from the east district to west district, the more the east district SCOP and the west district SCOP tended to decrease. Here, the analysis results will be described in detail for Case 2-4.250, which have the most improved efficiency. Note that Case 2-4.250 adopts Case 2 as nighttime control and adopts Case 4_250 as daytime control.

For the east district in figure 16 and the west district in figure 17, the heat production and the SCOP are shown.

Compared to Case 2, in Case 2-4.250, high efficiency operation by R-03 and R-04 is maintained at heat storage time period in the east district, and the heat production during the daytime decreased when the SCOP is low. In the west district, due to the increase in cool/warm load during the daytime, the heat production of R-A03 increased and the west district SCOP between 2 and 8, which produced heat, was higher than 2.0.

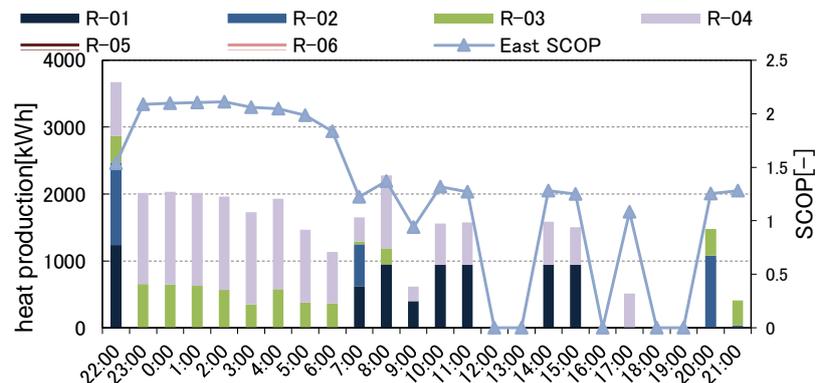


Figure 16. Heat production and SCOP in the east district (Case 2-4.250).

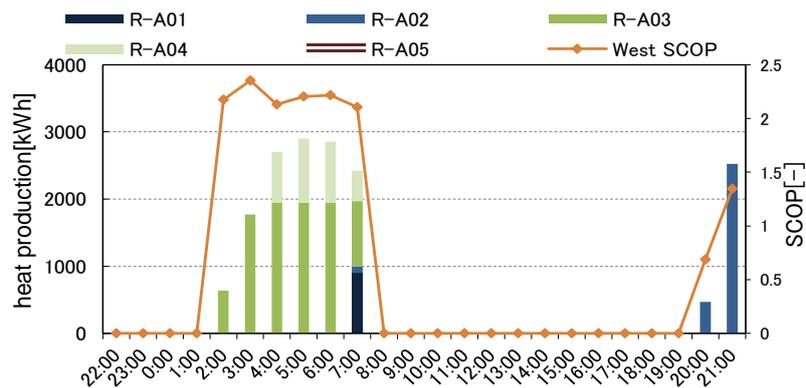


Figure 17. Heat production and SCOP in the west district (Case 2-4.250).

5. Conclusion

In this research, a detailed analysis on measured value and simulation was conducted, and the heat accommodation effect was examined. The examination by the measured value analysis took April 19 and April 20 as representative days, and analyzed the heat quantity of heat accommodation, the change of SCOP in each district, and behavior of each heat source device of those days. It also showed that there is a probability that SCOP will be improved by transferring cold heat from the east district to the west district and warm heat from the west district to the east district. The simulation study examined several time periods, quantity of heat, and direction of heat accommodation. Furthermore, it showed that transferring as much load as possible from the west district to the east district during heat storage time period and transferring a constant load from the east district to the west district during the daytime is effective. In the future, we will analyze measured values during the winter, clarify the trend through the year, and continue to consider optimal heat accommodation methods.

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