Study on the Operation of an Area Energy System That Interchanges Energy among Multiple Heat Source Plants

S. AMEMIYA[1,*] and M. OKUMIYA[1]

[1] Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan

ABSTRACT

Distributed energy systems are henceforth expected to function as area energy network models. However, the optimization of such a system is rather complex. Thus, it is very important to study effective heat source operation in the planning phase. The purpose of the present study is to optimize the operation of a distributed heat source system that interchanges energy among buildings or plants. In the present paper, a novel simulation model is developed for optimizing the operation of this system, and a case study is conducted using this model. In the case study, a restriction on spaces for constructing large-scale heat source plants, such as those in central urban areas, is implemented. Heat sources are distributed among a number of plants and connect heating and cooling equipment among these plants.

The simulation results show that the distributed heat source system conserves more energy or as much energy as a conventional large-scale district heating and cooling system, owing to optimized operation. Furthermore, optimum operation differs with the composition of the heat exchanging network and the amount of heat required.

KEYWORDS

area energy network, DHC, distributed energy system, energy-saving effect

INTRODUCTION

Recently in Japan, from the viewpoint of environmental protection, energy savings, and reduced CO_2 discharge, the Area Energy Network has become increasingly important. The Area Energy Network has also attracted attention with respect to risk reduction during disasters. The District Heating and Cooling (DHC) system is used as a model of the Area Energy Network. However, this system has a tendency to stagnate due to the security of the heat source plant and the decrease new construction district. Therefore, a new Area Energy Network model is needed in order to solve these problems.

The purpose of the present study is to optimize the operation of an area energy system that

---

[*] Corresponding author email: satoru_amemiya_19870506@yahoo.co.jp

interchanges energy among multiple heat source plants. The author developed a simulation model for optimizing the operation of this system using Excel and conducted a case study using this simulation model. In this model, the input data are the external wet-bulb temperature, the cooling load, the heating load, the refrigerator, boiler, cooling tower, and auxiliary machine properties, and the heat exchange conditions (distribution of pipeline length and heat loss rate). The output data is the primary energy (electricity and gas) consumption for a representative day of each month. In this case study, a scenario in which a space restriction exists for constructing large-scale heat source plants, such as those in central urban areas, is considered. By distributing heat sources among a number of plants and connecting heating and cooling equipment among plants, an energy service is established, and this system increases the energy performance by optimizing operation.

OUTLINE OF THE CASE STUDY AND OBJECT

Outline of the case study

There is an existing heat source plant (Plant A) for Building A. The author assumes that this heat supply is expanded to Buildings B, C, and D. However, new heat source equipments cannot be installed in Plant A. Therefore, new heat sources were distributed near Buildings B, C, and D. These plants interchange energy among themselves. The present study compares the distributed heat source case with individual heat source case. Moreover, the present study investigates the influence of heat source composition on the total energy performance and the existence and size of heat interchanging pipe.

Load pattern

Four buildings are complex buildings (office, hotel, commercial facility)**.** The load patterns were for a representative day of each month, as computed using the load unit classified according to building application. ***Table 1*** shows an outline of each load.

Heat supplying system

In the individual system (Case 1), each load corresponds to the load for an individual plant. The distributed system contains distributed heat sources for four plants and energy interchange. In the present study, Cases 2 through 7 differ from existence of interchanging pipe or these pipe sizes**.** ***Table 2*** shows an outline of the interchanging pipe size, and ***Figure 1*** shows this energy network.

Table 1 *Outline of each load*

	Cooling load		**Heating load**		**application**	**total floor space** [*m2*]
	peak load [*GJ/h*]	*annual load* [*GJ*]	*peak load* [*GJ/h*]	*annual load* [*GJ*]		
load A	140	332,218	43	126,156	office, hotel, commercial	450,000
load B	49	136,698	42	89,125	office, commercial	190,000
load C	135	178,902	77	203,319	office, hotel, commercial	260,000
load D	52	57,203	12	8,500	office, commercial	150,000

Table 2 *Outline of interchanging pipe size*

supply system	*name*	*A-B cooling water pipe*	*C-D cooling water pipe*	*C-D vapor pipe*
individual	Case 1	-	-	-
distributed	Case 2	450A	450A	200A
	Case 3	-	450A	200A
	Case 4	450A	350A	200A
	Case 5	-	350A	200A
	Case 6	450A	-	-
	Case 7	-	-	-

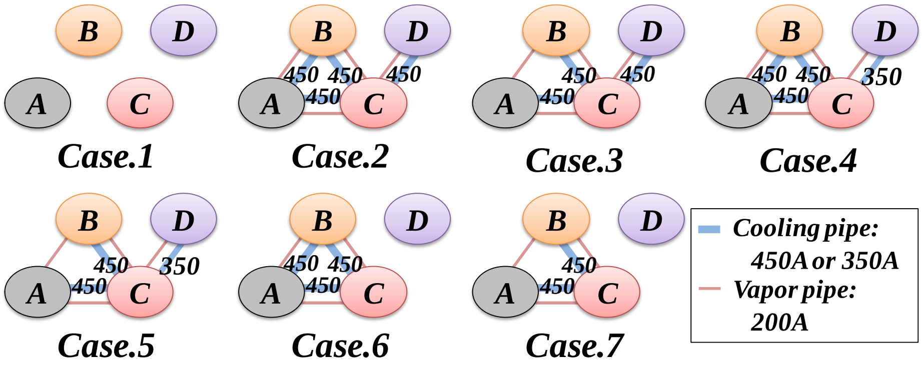

Figure 1 *Energy network*

SIMULATION METHOD

Heat source constitution

Table 3 shows the heat source constitution and the efficiency of the distributed system. In the distributed system, the heat source capacity does not support the accompanying load and premises energy network. Concretely, Plant B has a large machine room and so requires several refrigerators. In addition, Plant C has few refrigerators. Plant B has no boilers, and Plants C and D have a number of boilers. The individual system has a heat source constitution corresponding to each accompanying load, which differs from a distributed system. New heat source equipment has a higher coefficient of performance (COP) and a lower limit of circulating water temperature.

Restrictions

The heat source has operating limiting conditions based on the characteristics of the equipment. The pump heat loss between the plants at the time of interchange considers based on results data. The cooling heat loss rate ranges from 4.2% (August) to -12.1% (February). The vapor heat loss rate is constant at 2% for the year. ***Table 4*** shows the limiting conditions for heat source operation.

Method of heat source operation

Figure 2 shows the simulation flow. This simulation model calculates the predictive COP for all combinations of loads and heat sources in order to determine the appropriateness of the heat interchange and compares the predicted COPs. The combination that is relation to conduct heat interchanging uses predicted heat interchanging COP obtained by ***Eq. (1)***. The annual primary energy (electricity and gas) consumption is calculated through simulation.

Table 3 *Heat source constitution and efficiency of distributed systems*

Cooling Heat Source						
location	***heat source***	***capacity***		***number***	***limit lower circulation water***	***rating COP (primary energy)***
		RT	***GJ/h***			
plant A	brine turbo refrigerator	1,200	15.19	2	24	1.83
	sream absorption refrigerator	2,500	31.65	3		1.30
		2,000	25.32	2		1.30
	ice storage (ST) [RTh]	7,000	88.62	2		-
	heatexchanger (HX)	2,000	25.32	2		-
	total (except ST and HX)	13,900	175.97	-	-	-
plant B	brine turbo refrigerator	1,300	16.46	2	20	1.83
	turbo refrigerator	1,000	12.66	2		2.14
	sream absorption refrigerator	1,000	12.66	3		1.40
	ice storage (ST) [RTh]	4,300	54.46	2		-
	heatexchanger (HX)	1,200	15.19	2		-
	total (except ST and HX)	7,600	96.22	-	-	-
plant C	brine turbo refrigerator	1,400	17.72	2	20	1.83
	sream absorption refrigerator	1,000	12.66	2		1.40
	ice storage (ST) [RTh]	5,500	69.65	2		-
	heatexchanger (HX)	1,600	20.26	2		-
	total (except ST and HX)	4,800	60.77	-	-	-
plant D	brine turbo refrigerator	1,400	17.72	2	20	1.83
	sream absorption refrigerator	1,200	15.19	3		1.40
	ice storage (ST) [RTh]	3,900	49.37	2		-
	heatexchanger (HX)	1,200	15.19	2		-
	total (except ST and HX)	6,400	81.02	-	-	-

Heating Source					
location	***heat source***	***capacity***		***number***	***efficiency***
		t/h	***GJ/h***		
plant A	CGS waste heat boiler	4.45	11.21	3	1.00
	flue and smoke tube boiler	15.00	37.80	3	0.90
		12.00	30.24	1	0.90
		4.80	12.01	1	0.90
	total (except CGS)	75.20	189.50	-	-
plant B	-	-	-	-	-
plant C	flue and smoke tube boiler	12.00	30.24	2	0.92
plant D	flue and smoke tube boiler	12.00	30.24	2	0.92

Table 4 *Heat source operating limiting conditions*

CGS	CGS is operated to use up waste heat as much as possible
	CGS waste heat is evaluated as a thing produced by a efficient 1.0 virtual boiler
Boiler	boiler is not considered part load performance and operated rating of efficiency constant
Refrigerator	Steam absorption refrigerator is operated at least 4 hours and if stops, continues stopping 4 hours
	brine turbo refrigerator is only operated cool storage in the night (it can support operation in the daytime)
	refrigerators are not start more than twice
Ice storage	Quantity of heat storage is regulated 100% or 50% 0% for keeping the balance of quantity of heat release and storage
	Heat release in summer conducts peak cut operation
	Hear release except summer conduct fixed quantity basically

$$COPt=Qo+Qt\times(1-HLR)/[\{Qo+Qt/F(x)\}+P(y)] \qquad (1)$$

Nomenclature	
COPt	predictive heat interchaning COP
Qo	the heat quantity that is already generated
Qt	the intercanging heat quantity
HLR	heat loss rate
F(x)	COP properties equation
P(y)	pump power

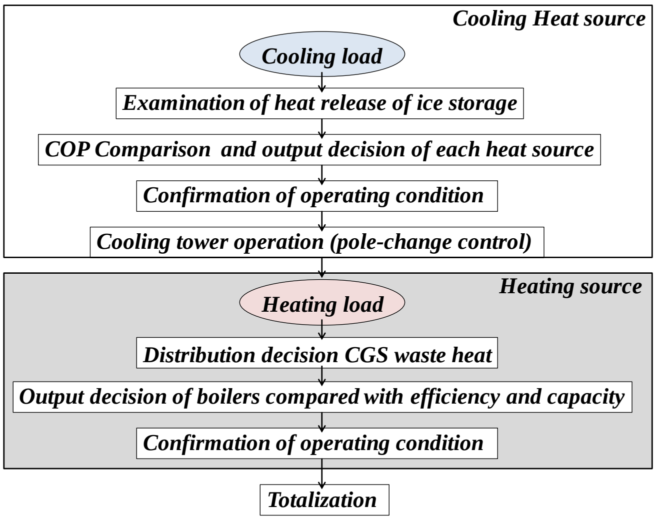

Figure 2 Simulation flow

RESULTS AND DISCUSSION

Annual primary energy consumption and energy-saving rate

Figure 3 shows the results for the annual primary energy consumption and the energy saving rate for each case. The energy saving rate indicates the primary energy reduction rate based on the individual system (Case 1). All cases for the distributed system are anticipated to provide energy savings of more than 4%. Cases 6 and 7, in which Plant D is not incorporated in the energy network, shows relatively small energy savings. Therefore, the energy network is expanded to Plant D, and a higher energy savings effect is obtained.

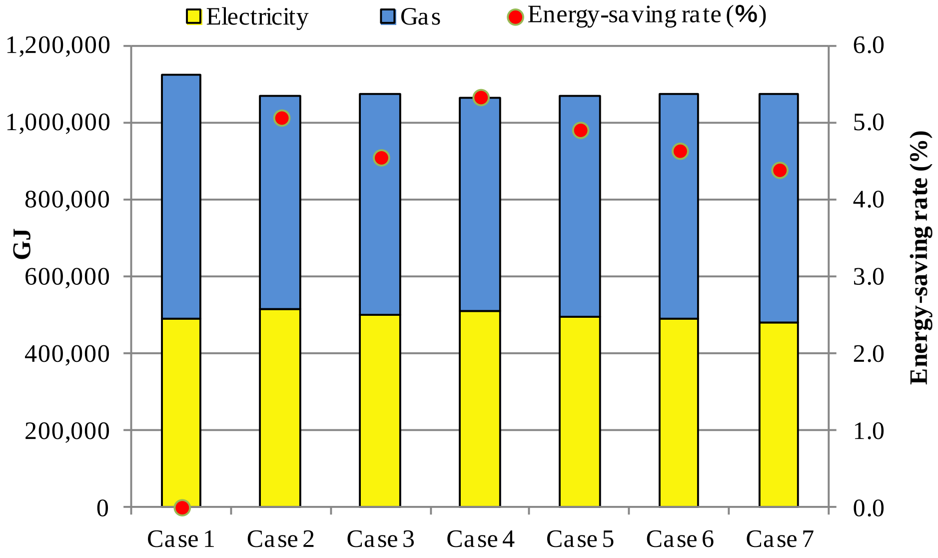

Figure 3 *Annual primary energy consumption and energy-saving rate*

CGS waste heat availability

Figure 4 shows the annual CGS waste heat availability. Case 1, in which heat interchange among plants cannot occur, has an annual CGS waste heat availability of approximately 83%. In particular, the CGS waste heat availability is low in spring and autumn with a low cooling or heating load. On the other hand, the distributed system has an annual CGS waste heat availability of approximately 100%. Therefore, the energy performance is considered to be improved because the CGS waste heat in Plant A can be supplied to other plants.

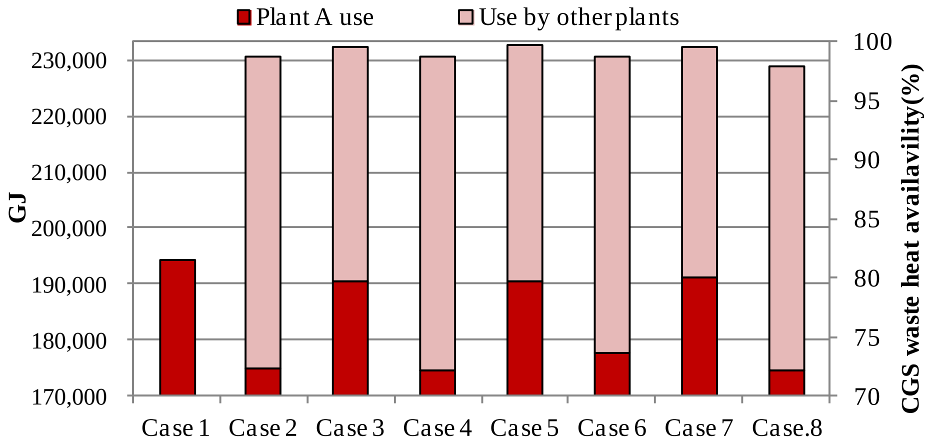

***Figure 4** Annual CGS waste heat availability*

Annual interchanging heat amount and energy saving rate

Figure 5 shows the quantity of annual cooling water supply among plants based on the course and energy saving rate for each case. ***Figure 6*** shows the quantity of annual vapor supply among plants based on the course and energy saving rate. As shown in ***Figure 5***, for the cases in which Plant D is incorporated into the energy network, the supply from Plant D to Plant C accounts for a relatively large proportion. Therefore, the energy performance in this system is improved. On the other hand, ***Figure 6*** shows that the difference was slight among cases in the distributed system. Therefore, the difference in energy performance is caused primarily by the quantity of annual cooling water supply among plants.

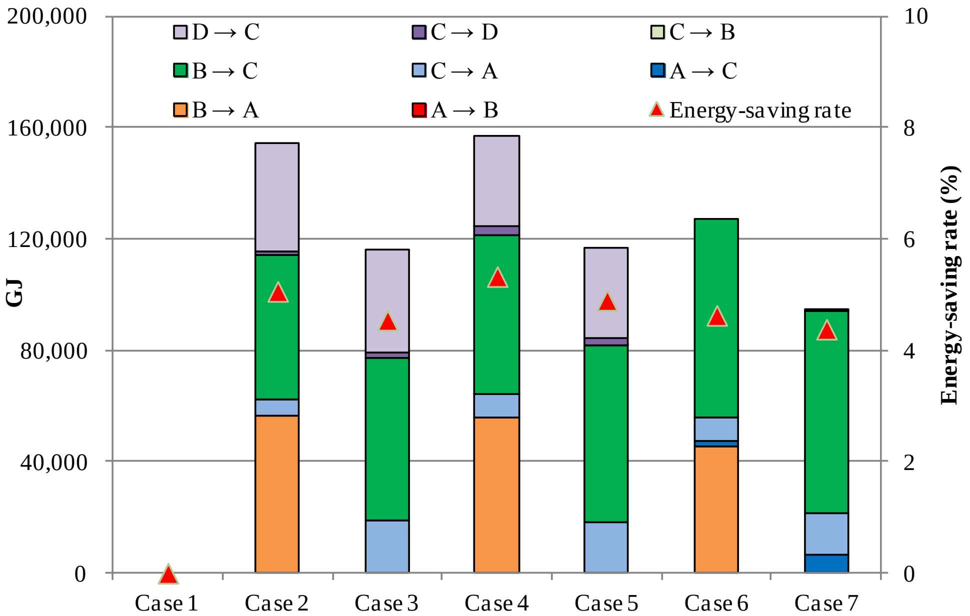

***Figure 5** Quantity of annual cooling water supply among plants based on the course and energy-saving rate*

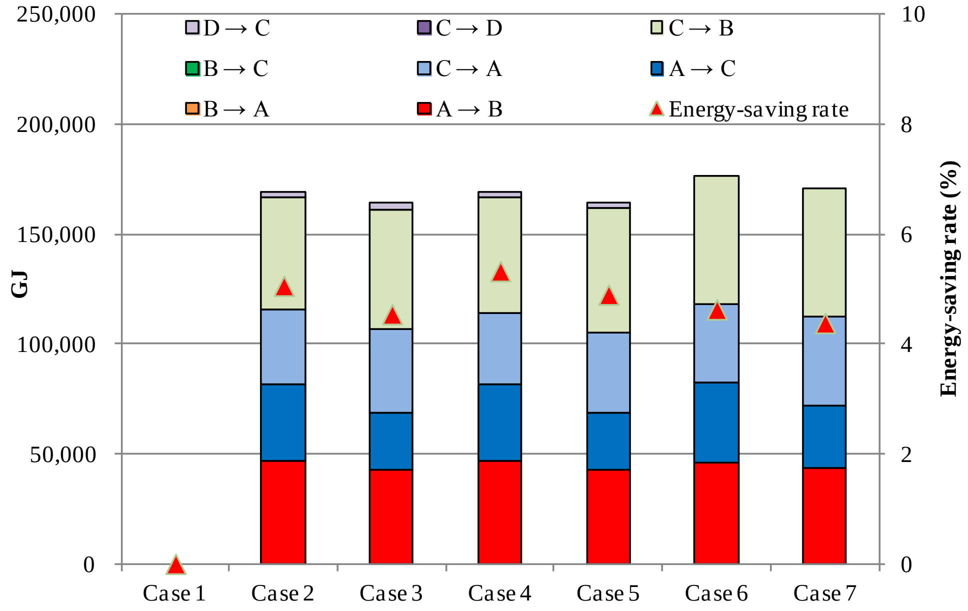

Figure 6 *Quantity of annual vapor supply among plants based on the course and energy-saving rate*

Hourly quantity of cooling supply among plants

Figure 7 shows the hourly quantity of the cooling supply among plants for Cases 2 and 6 as an example of the simulation results. In particular, ***Figure 7*** shows that the quantity of the cooling supply from Plant D to Plant C in summer accounts for significant proportion. As shown in ***Figure 7***, Load C is satisfied by the cooling water supply from Plant B to Plant C or the Plant C refrigerators. Load C cannot be satisfied by the cooling water supply from the Plant B and Plant C refrigerators, and so is supplied from Plant A. Therefore, the cooling water supply from Plant D significantly influences the energy performance.

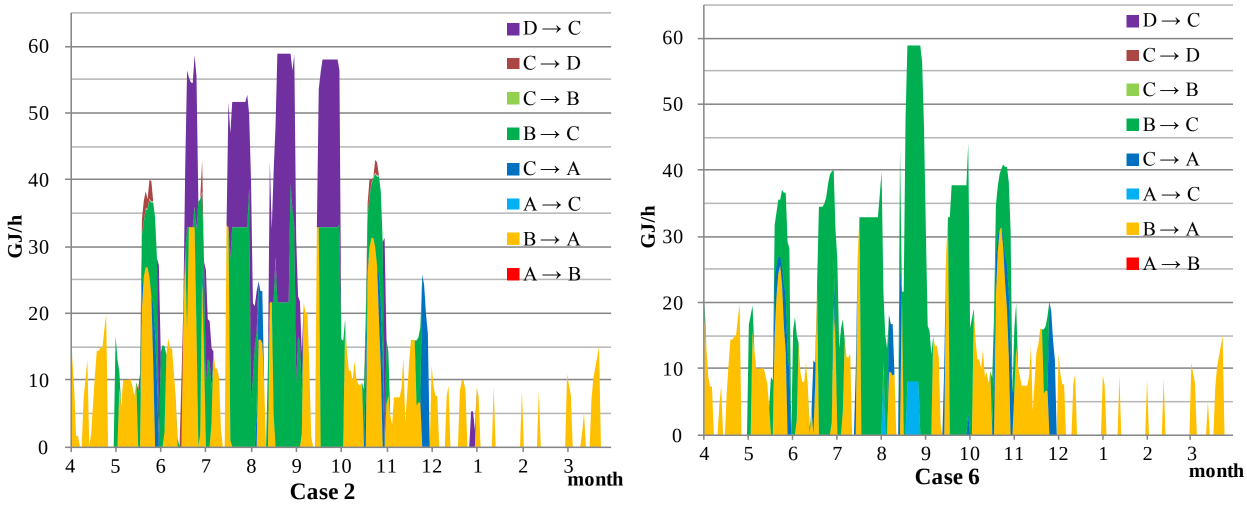

Figure 7 *Hourly quantity of cooling supply among plants in Cases 2 and 6*

Detailed analysis of cooling water supply among Plants C and D

Comparing the cooling water interchanging pipes of sizes 450 (Cases 2 and 3) and 350 (Cases 4 and 5), the size 350 pipe has a higher energy saving rate. This means that the energy performance decreases even if the pipe size is far too large. ***Figure 8*** shows the distribution of the quantity of cooling water interchange based on the size of the pipe between Plants C and D. The cause for the decline in energy performance is that the pipe size is designed to be large, and the permitted minimum supply quantity increases and decreases the transportation efficiency during times when the supply is short.

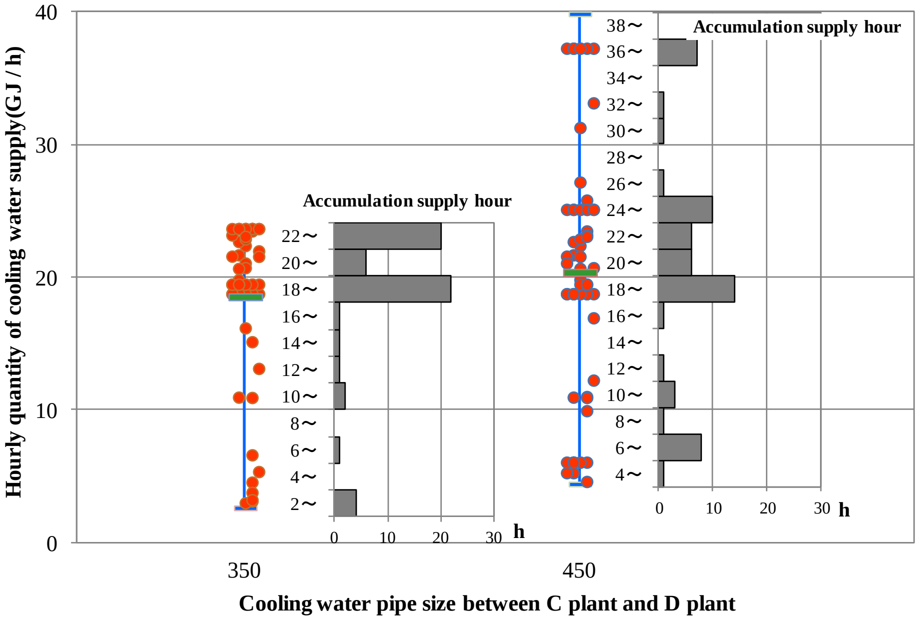

Figure 8 *Distribution of quantity of cooling water interchanging based on the size of pipe between Plants C and D*

SUMMARY

The present study shows that the distributed heat source system conserves more energy or as much energy as a conventional large-scale district heating and cooling system, owing to optimized operation. The author will conduct a long-term investigation in the future.

ACKNOWLEDGEMENTS

The author would like to thank NAGOYA Energy Service Co., Ltd., T. HOSHIDA and A. OGUCHI for providing assistance of this simulation.

REFERENCES

T. Kobayashi et al. 2011. *Study on Area Energy Networks at Central Urban Area, SHASE (in Japanese)*

S. AMEMIYA et al. 2012. *Study on Operation of Area Energy System that Interchanges Energy among Multiple Heat Source Plants, AIJ (in Japanese)*