Basic consideration on improvement of efficiency of heating system using absorption heat pump

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ABSTRACT

In Japan, further energy saving is needed than the current state for achieving a greenhouse gas reduction target shown in COP21. Substantial reduction in energy consumption of residential/commercial sectors is required as a basis of a target and further improvement of efficiency of the air-conditioning system is needed.

Based on the above mentioned background, in this study efficient utilization of absorption chiller is investigated. Absorption chiller is usually used as a boiler in heating season, therefore the coefficient of performance is the boiler efficiency and it is less than 1. This study focuses on absorption chiller heater which used as heat pump in heating season. It is called as an absorption heat pump in this paper and its performance is studied by a system simulation (LCEM tool which is system simulation program developed under supervision of Ministry of Land, Infrastructure and Transport).

In this paper, performance of the absorption heat pump was discussed especially for heating season. Well water is used as heat source of absorption heat pump. It causes the increase of energy consumption because well water pump consume additional energy. While COP (coefficient of performance) of absorption heat pump become much higher than that of boiler, therefore total energy performance can be improved. From the results of simulation it was confirmed that absorption heat pump system with well water heat source can reduce the energy consumption.

KEYWORDS

Absorption heatpump, LCEM tool, Energy conservation, Well Water

INTRODUCTION

In Japan, further energy saving is needed than the current state for achieving a greenhouse gas reduction target shown in COP21. Substantial reduction in energy

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consumption of residential/commercial sectors is required as a basis of a target and further improvement of efficiency of the air-conditioning system is needed.

Based on the above mentioned background, in this study efficient utilization of absorption chiller is investigated. Absorption chiller is usually used as a boiler in heating season, therefore the coefficient of performance is the boiler efficiency and it is less than 1. This study focuses on absorption chiller heater which used as heat pump in heating season. It is called as an absorption heat pump in this paper and its performance is studied by a system simulation (LCEM tool which is system simulation program developed under supervision of Ministry of Land, Infrastructure and Transport).

OVERVIEW OF EXAMINATION

Overview of objective building heat source system

The objective building in this study is an office building model built in Tokyo. Objective building has 5 story of ground, total floor area about 5,000m^2. It has core in the north and window façade side in the south, the east, the west. Objective building is good insulation and airtightness, and lighting equipment is LED (4 W/m^2, 500lx) and internal heat load is 15 W/m^2.

Overview of objective heat source system

In this study, energy performance of 3 systems shown in table 1 is examined. Case-1 is the system using direct-fired absorption chiller. This case is named basis case. Case-2 consists of exhaust heat input type absorption chiller and co-generation system which is called CGS in this paper. Case-3 is the system replacing absorption heat pump with absorption chiller in Case-2. The specification of main equipment estimated in this study is shown in table2. Case-2 and Case-3 has gas-engine generators of two 35kW and 31kW. At Case-1, direct-fired absorption chiller meets cooling and heating load. At Case-2, exhaust heat input type absorption chiller meets cooling load. And, heat exchanger using exhaust heat from CGS and exhaust heat

Table 1 : Examination case

Case No.	Case Name	Heatsource equipment
Case-1	Basis case	Direct-fired absorption chiller ×1
Case-2	General CGS system	Exhaust heat input type absorption chiller×1
Case-3	Absorption heat pump system	Absorption heat pump ×1

Table 2 : Specification of main equipment

	Exhaust heat input type absorption chiller	Absorption heat pump
Rated capacity	Cooling : 422kW , Heating : 338kW	Cooling : 422kW , Heating : 338kW
Rated chilled & heated water condition	Cooling : 15—7 deg.C , 756.7liter/min Heating : 38.6—45 deg.C , 756.7liter/min	Cooling : 15—7 deg.C , 756.7liter/min Heating : 40—45 deg.C , 968.3liter/min
Cooling water condition	32—37.4 deg.C , 2000 liter/min	32—37.4 deg.C , 2000 liter/min
Heatsource water cond.	-	20—16.7 deg.C , 916.7 liter/min
Exhaust heat water cond.	Cooling : 88.1—79.3 deg.C , 191.7liter/min	Cooling : 88.1—79deg.C , 191.7liter/min Heating : 88.1—66.6deg.C , 191.7liter/min
Rated exhaust heat recover quantity cond.	Cooling : 118 kW	Cooling : 122 kW , Heating : 20 kW
Rated 13A Gas consumption (right : at exhaust heat input)	Cooling : 25Nm 3/h、19.5Nm 3/h Heating : 30.4Nm 3/h	Cooling : 25Nm 3/h、19.3Nm 3/h Heating : 13.4Nm 3/h、11.5Nm 3/h
Auxil Elec. Power cons.	7.7kW	7.7kW
	Primary chilled water Heatsource water pump (Case-3)	Well water pump (Case-3)
Design flow	Chilled water : 756.7liter/min, Heatsource water : 916.7 liter/min	916.7 liter/min
Design lifting	Chilled water : 196 kPa Heatsource water : 150kPa	150 kPa
Actual lifting	0 kPa	20 kPa
Auxil Elec. Power cons.	Chilled water : 3.4 kW Heatsource water : 3.7kW	3.7 kW
	Open type cooling tower (Case-1,2)	Close type cooling tower (Case-3)
Cooling water condition	37.4—32 deg.C , 2000 liter/min	37.4—32 deg.C , 2000 liter/min
Auxil Elec. Power cons.	4.5 kW	9.0 kW

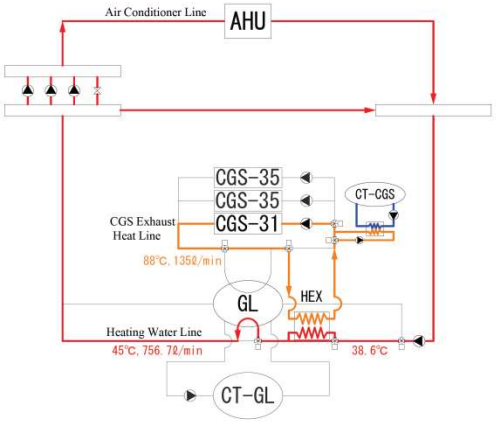

Figure 1 : Case-2 heating system

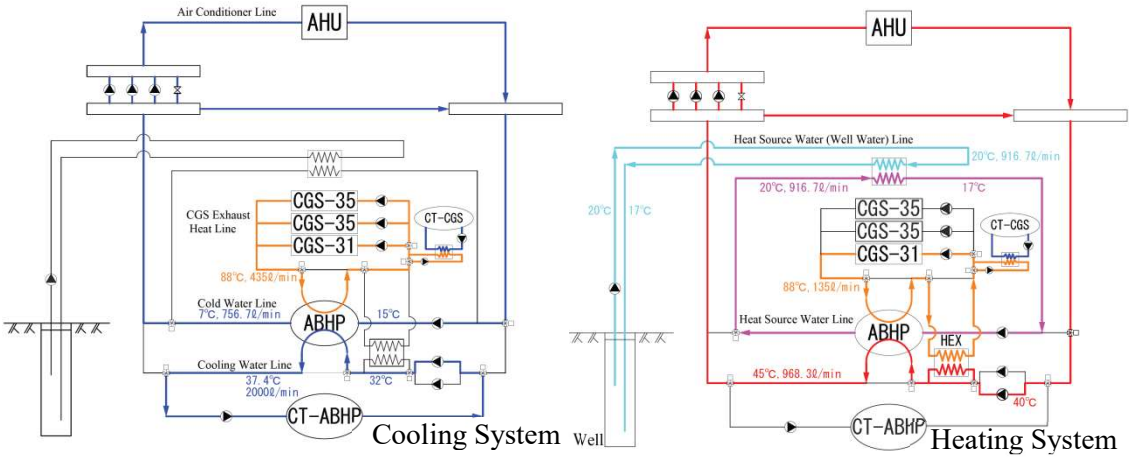

Figure 2 : Case-3 cooling and heating system

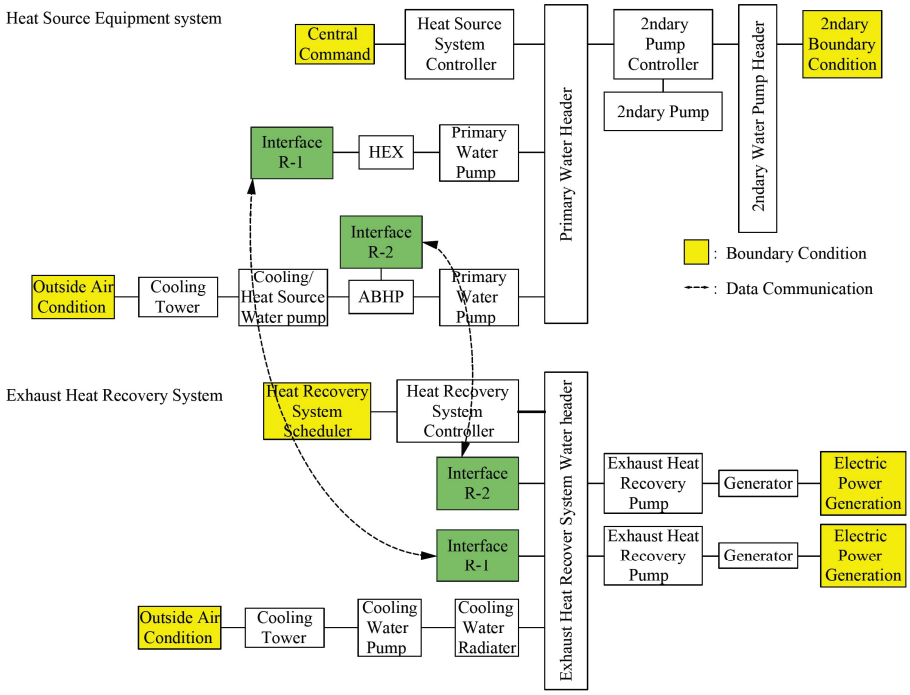

Figure 3 : The object diagram of the heat source system created by using the LCEM tool

input type absorption chiller meet heating load. Heat exchanger meets priority. At Case-3, absorption heat pump (it has the same specification and characteristic as exhaust heat input type absorption chiller of Case-2) meets cooling load. At heating time, heat exchanger using exhaust heat from CGS and absorption heat pump meet load. Absorption heat pump pumps up heat from well water. This heat source water temperature is 20 deg. C. Figure 1 shows the diagram of the Case-2 heating system and figure 2 shows the diagram of the Case-3 cooling and heating system. ABHP is absorption heat pump in these figures.

OVERVIEW OF THE SIMULATION

Overview of heat load boundary condition

Heat load of building is calculated by MICRO-PEAK/2010 (Japanese Association of Building Mechanical and Electrical Engineers). Simulations of the heat source

system were conducted using a free simulation tool for air conditioning systems : LCEM tool Ver. 3.10 of the Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. At the heat load calculation, cooling season is decided from April to October, heating season is decided from November to March. The temperature and humidity setting is 28 deg.C, 50% at the cooling time and 20 deg.C, 40%. The office hours are from 8 a.m to 6 p.m.

Overview of the heat source system model

The heat source system model is created by remodeling the sample system of exhaust heat recovery system in the LCEM tool. Figure 3 shows the object diagram of the heat source system created by using the LCEM tool. Elements of the system shown with boxes in the figure correspond to respective equipment objects as provided in the tool. The yellow boxes represent elements to which boundary condition data are entered for simulation. For the simulations, it is necessary to enter data on the outside air temperature and humidity, thermal load boundary conditions,

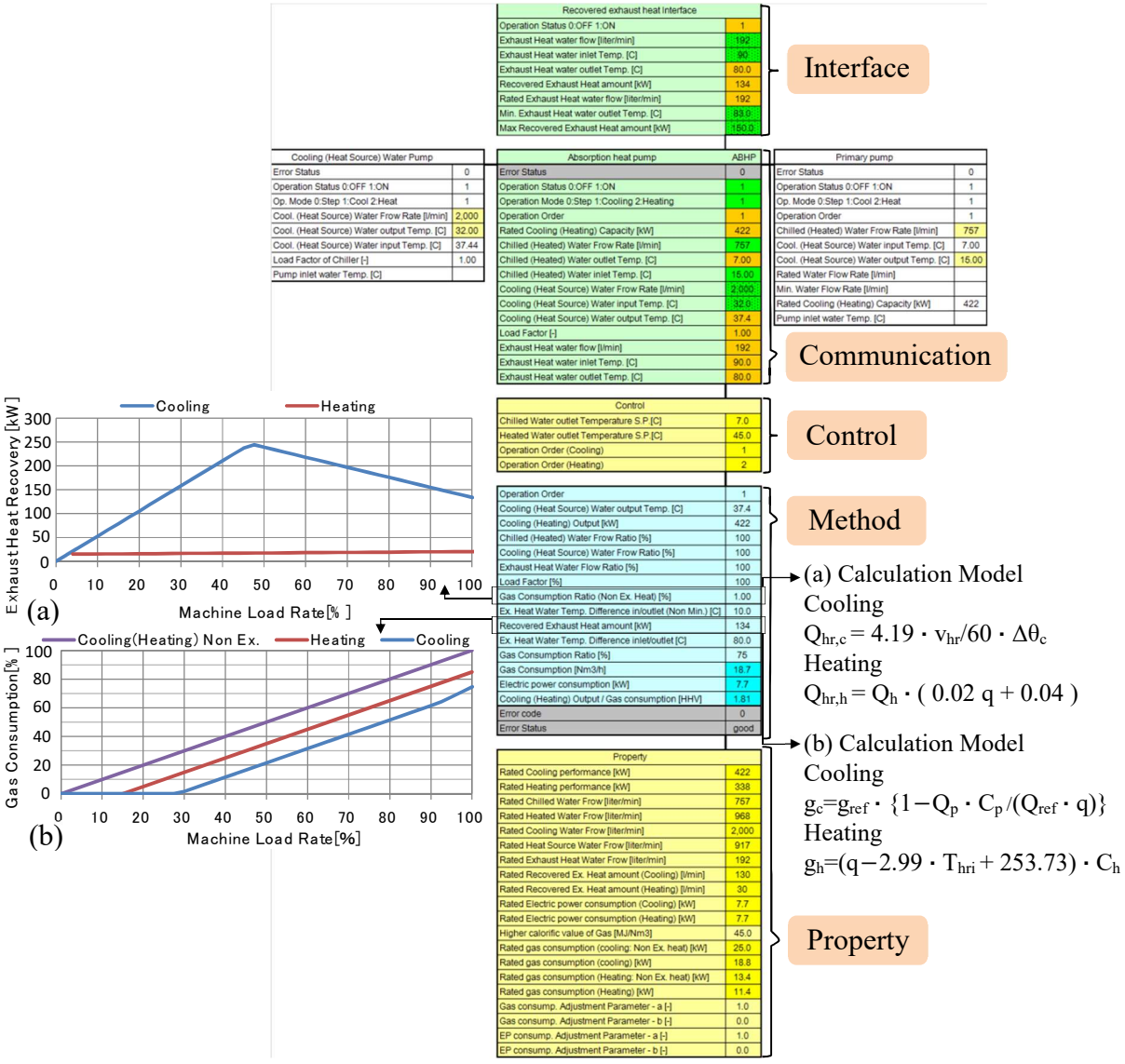

Figure 4 : The object diagram of the absorption heat pump created by using the LCEM tool & Partial load characteristics

and control parameters. This thermal load boundary condition is calculated by the MICRO-PEAK.

Modeling of absorption heat pump

The model of absorption heat pump is created by remodeling the model of exhaust heat input type absorption chiller. The equipment characteristics (for example, gas consumption) are decided by technical material. Figure 4 shows the object of absorption heat pump. Figure 4 (a),(b) shows the partial load characteristics of the gas consumption and exhaust heat recovery.

Evaluation index

In this study, heat source equipment COP and heat source system COP (it is called system COP) is used as evaluation index. When heat source equipment COP is calculated, gas and auxiliary electricity consumption is used. Each calculation expression is shown below.

$$\text{Heat source equipment COP} = \frac{\text{Phs}}{\text{Ehs}} \quad (1)$$

$$\text{System COP} = \frac{\text{Qload}}{\text{Eall} - \text{WCGS}} \quad (2)$$

In this study, cooling (heating) performance and cooling-heating load, energy consumption, CGS electric power generation is converted into primary energy.

COMPARING ENERGY PERFORMANCE OF SYSTEM

Setting period of simulation

In the simulation, a representative day of each month is calculated. The total count of representative days from April to October and from November to March are set as summer total and winter total. The total of these is set as annual total and used evaluation.

Comparing heat source equipment COP and System COP

Figure 5 shows cooling (heating) load and energy consumption to process the load, CGS electric power generation, heat source equipment COP, System COP. Table 3 is shown the detail of energy consumption and CGS electric power generation, heat source equipment COP, System COP shown at figure 5.

In the cooling season, heat source equipment COP of Case-2 and Case-3 is about 1.5 higher than COP of Case-1. It is the reason that gas consumption of heat source equipment at Case-2 and Case-3 is reduced by using exhaust heat of CGS at the heat source equipment. In this simulation, capacity of CGS and operation condition is equal setting at Case-2 and Case-3. Heat source equipment COP is equal at Case-2 and Case-3. However, system COP of Case-3 is lower than Case-2. At Case-3, close

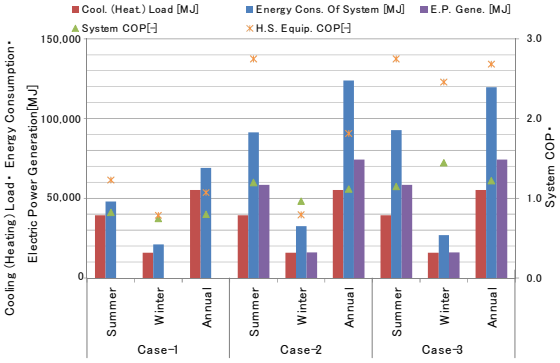

Figure 5 : Cooling(Heating) Load・Energy Consumption ・E.P. Gene. & COP

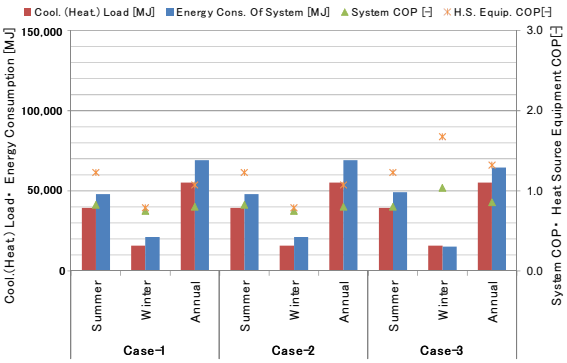

Figure 6 : Cooling(Heating) Load・Energy Consumption & COP (Non Ex.)

Table 3 : The detail of Energy Consumption & COP

Energy Consumption [MJ]	Case-1			Case-2			Case-3		
	Summer	Winter	Annual	Summer	Winter	Annual	Summer	Winter	Annual
H.S. Equip. Gas	30,501	16,644	47,144	11,915	12,080	23,995	11,915	3,133	15,047
H.S. Equip. E.P.	3,072	1,870	4,942	3,072	1,290	4,362	3,072	1,468	4,540
Primary Pump	2,629	1,991	4,620	2,629	1,491	4,120	2,629	1,861	4,490
2ndary Pump	1,242	621	1,863	1,242	621	1,863	1,242	792	2,034
Cool Water Pump	9,269		9,269	9,269		9,269	9,269		9,269
Cool Tower Fan	1,264		1,264	1,457		1,457	2,905		2,905
CGS Gas				58,959	16,215	75,175	58,959	16,215	75,175
CGS Elb. Power				1,411	388	1,799	1,411	388	1,799
CGS Pump				1,253	348	1,602	1,253	348	1,602
Well Water Pump								1,385	1,385
H.S. Water Pump								1,385	1,385
Total	47,978	21,125	69,103	91,208	32,434	123,642	92,656	26,974	119,631
CGS Gene. [MJ]				58,306	16,036	74,342	58,306	16,036	74,342
Total—CGS Gene.	47,978	21,125	69,103	32,902	16,398	49,300	34,350	10,939	45,289
System COP [-]	0.82	0.75	0.80	1.20	0.96	1.12	1.15	1.44	1.22
H.S. Equip. COP [-]	1.23	0.79	1.07	2.75	0.79	1.83	2.75	2.46	2.68

Table 4 : The detail of Energy Consumption & COP (Non Ex.)

Energy Consumption [MJ]	Case-1			Case-2			Case-3		
	Summer	Winter	Annual	Summer	Winter	Annual	Summer	Winter	Annual
H.S. Equip. Gas	30,501	16,644	47,144	30,501	16,644	47,144	30,501	6,661	37,162
H.S. Equip. E.P.	3,072	1,870	4,942	3,072	1,870	4,942	3,071	1,832	4,903
Primary Pump	2,629	1,991	4,620	2,629	1,991	4,620	2,629	2,405	5,035
2ndary Pump	1,242	621	1,863	1,242	621	1,863	9,269	792	10,061
Cool Water Pump	9,269		9,269	9,269		9,269	2,516		2,516
Cool Tower Fan	1,264		1,264	1,264		1,264	1,242		2,034
CGS Gas									
CGS Pump									
Well Water Pump								1,790	1,790
H.S. Water Pump								1,790	1,790
Total	47,978	21,125	69,103	47,978	21,125	69,103	49,229	15,270	64,499
System COP [-]	0.82	0.75	0.80	0.82	0.75	0.80	0.80	1.03	0.86
H.S. Equip. COP [-]	1.23	0.79	1.07	1.23	0.79	1.07	1.23	1.67	1.32

type cooling tower is used to reduce pump power, and cooling water line at the cooling season and heated water line at the heating season are shared. Therefore, cooling tower fan power of Case-3 is twice as larger as open type cooling tower fan power used Case-1 and Case-2. To increase energy consumption at the cooling tower caused declining of system COP at Case-3.

In the heating season, heat source equipment COP of Case-3 is about 1.7 higher than 0.79 at Case-1 and Case-2. It is the reason gas consumption of absorption heat pump is reduced by about 81% compared heat source equipment of Case-1, and about 74% compared Case-2. System COP of Case-3 is the highest of the three cases, and system COP of Case-2 is higher than Case-1. It is the reason that gas consumption of heat source equipment is reduced by used exhaust heat at the heat exchanger, and generated electric power is consumed in the objective building. At Case-3, system COP is about 0.5 higher than 0.96 at Case-2. It is the reason that the reduction of gas consumption at heat source equipment is larger than the increase of energy consumption of well water pump and heat source water pump by using as heat pump.

In the annual total, system COP of Case-3 is the highest of the three cases, and system COP of Case-2 is higher than Case-1. At the heat pump system, energy consumption of cooling tower fan in cooling season and well water pump, heat source water pump in heating season increase. However, energy conservation effect that absorption chiller is used as heat pump in heating season is larger than the increase of energy consumption. Therefore, absorption heat pump system has energy conservation effect at the annual energy consumption.

Energy conservation effect of absorption heat pump (Case study at non CGS case)

Energy performance of the case without CGS is considered to directly evaluate the energy conservation effect of absorption heat pump. Figure 6 shows cooling (heating) load and energy consumption to process the load, heat source equipment COP, System COP. Table 4 is shown the detail of energy consumption, heat source equipment COP, System COP shown at figure 6.

In the cooling season, heat source equipment COP is same value at the Case-1 and Case-2, Case-3. In this simulation, heat source equipment all specification and characteristics is equal at Case-1 and Case-2, Case-3. However, system COP of Case-3 is lower than Case-1 and Case-2. It is the reason that cooling tower fan power of Case-3 is twice as larger as open type cooling tower fan power used Case-1 and Case-2.

In the heating season, heat source equipment COP of Case-3 is about 0.9 higher than 0.79 at Case-1 and Case-2. It is the reason that the energy efficiency of absorption heat pump is greater than the energy efficiency of boiler. System COP of Case-3 is about 0.2 higher than 0.75 at Case-1 and Case-2. It is the reason that the reduction of gas consumption at heat source equipment is larger than the increase of energy consumption of well water pump and heat source water pump by used as heat pump at the non CGS case too.

In the annual total, heat source equipment COP and system COP of Case-3 are the highest of the three cases. Therefore, the annual energy consumption can be reduced by the energy conservation effect of the absorption heat pump at the heating season, in spite of the increase of energy consumption at the cooling tower fan in cooling season and well water pump, heat source water pump in heating season.

Examination of the optimum number of CGS

At the Case-3, three CGS are installed, but only one is used in the heating season. So, the optimum operating numbers of CGS were considered. In the simulation, total energy consumption and the difference between CGS×1 and other cases is used as evaluation index.

$$E_{tot} = E_{sys} + E_{build} - W_{CGS} \quad (3)$$

$$E_{tot}' = E_{sys} - W_{CGS} \quad (4)$$

$$\Delta E = E_{tot}\ (\text{CGS}\times 1) - E_{tot} \quad (5)$$

E_{build} is energy consumption of lighting and electronic device, etc in this objective building. Table 5 shows the simulation results of energy consumption of the system (E_{sys}) and CGS electric power generation (W_{CGS}), total energy consumption (E_{tot}'), the

Table 5 : Results of energy consumption of system and CGS electric power generation, total energy consumption, difference of total energy consumption

	Energy Consumption of System (E_{sys}) [MJ]	CGS Electric Power Generation (W_{CGS}) [MJ]	Total Energy Consumption (E_{tot}') [MJ]	Difference of Total Energy Consumption (ΔE) [MJ]
CGS×1	27,469	16,036	11,433	0
CGS×2	41,612	34,140	7,472	3,961
CGS×3	57,540	52,245	5,295	6,139

difference of total energy consumption between CGS×1 and the other cases (ΔE).

The more CGS operating number increase, the smaller total energy consumption become. Therefore, the difference of total energy consumption gradually increases. CGS electric power generation increase causes this result. From the above results which are based on total energy consumption, three CGS operations become the best operating way in this assumption.

CONCLUSION

In this paper, performance of the absorption heat pump was discussed especially for heating season. Well water is used as heat source of absorption heat pump. It causes the increase of energy consumption because well water pump consume additional energy. While COP of absorption heat pump become much higher than that of boiler, therefore total energy performance can be improved. From the results of simulation it was confirmed that absorption heat pump system with well water heat source can reduce the energy consumption.

GRAPHIC LIST

$Q_{hr,c}$, $Q_{hr,h}$: exhaust heat recovery (Cool.), (Heat.) [kW], v_{hr} : exhaust heat water flow [m^3/h]
$\Delta\theta_c$: exhaust heat water temperature difference (Cool.) [deg.C], Q_h : heating performance [kW]
q : machine load rate [%], g_c,g_h : gas consumption (Cool.), (Heat.) [Nm^3/h]
g_{ref} : rated gas consumption (Cool.) [Nm^3/h], Q_p : exhaust heat recovery [kW]
C_p : COP of using exhaust heat [-], Q_{ref} : rated exhaust heat recovery [kW]
T_{hri} : exhaust heat water inlet temperature [deg.C], Q_{load} : heat load [MJ]
C_h : influence coefficient of heat source water inlet temperature [-]
P_{hs}, E_{hs} : heat source equipment performance, energy consumption [MJ]
E_{all} : all energy consumption [MJ], W_{CGS} : CGS power generation [MJ]
E_{sys} : energy consumption of system [MJ]
E_{build} : energy consumption of lighting and electric device, etc [MJ]
E_{tot} : total energy consumption [MJ], E_{tot}' : total energy consumption (non E_{build}) [MJ]
ΔE : difference of total energy consumption [MJ]

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