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Development of an Integrated Energy Simulation Tool for Buildings and MEP Systems, the BEST
Simulation Study of cogeneration system in hotels using BEST program 2013

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ABSTRACT

The BEST cogeneration study sub working group has been developing simulation models related to cogeneration systems (CGS) since 2008 to simulate the system including CGS using the BEST program. This paper describes simulation case studies of CGS in a hotel which has high hot water loads using BEST for energy conservation standards revised in 2013 (BEST program 2013) and summarizes input parameters about CGS and utilization of exhaust heat from CGS equipment. Simulation case study results show that exhaust heat is used efficiently for hot water loads in most cases, and it would be better to use exhaust heat to hot water load than cooling/heating load.

1. INTRODUCTION

BEST is a simulation tool that calculates and visualizes annual energy consumption of a building. The simulation includes HVAC and plumbing equipments, telecommunications and all other building loads.
The Japanese Government aims to reduce the annual CO2 emission 15% by 2020; 80% by 2050. In order to meet the large reduction in CO2 emission, an effective design tool for calculating CO2 emissions by building and for analyzing overall building energy consumption, especially for commercial buildings that emit one-third of total CO2 emission, is required. BEST (Building Energy Simulation Tool) is an effective computer simulation program for building energy research and evaluation.
It generates overall building energy consumption (annual CO2 emission) at every phase (design, construction, operation and retrofitting phase), and identifies the optimal solution (minimum) for the integrated building envelope and HVAC system.
As one of the major parts of the BEST, models related to simulating energy system including CGS has been developed since 2008.

In the initial version, exhaust heat from CGS was only available for heat source of air conditioning. Therefore, design examples of energy system including CGS and the case study results aimed at the office were reported in the previous study[1)], using BEST program 2013 Ver.1.0.5. From Ver.1.0.10, the function of CGS utilization of exhaust heat from CGS was extended so that it can be used for hot water supply. In this paper, case study results of the energy system including CGS aimed at the hotel with large hot water demand were reported. The input parameters of CGS in BEST program 2013 were also introduced. It should be noted that this report was described using Ver.1.1.2 at the time of writing, but there is a possibility that there are some items to be changed by future upgrades.

2. INPUT PARAMETERS OF CGS IN BEST PROGRAM 2013

2.1. Input Parameters of CGS Utilization of exhaust heat from CGS Function

Figure 1 shows an example of input screens for each heat source. Required parameters are generator control method, the number of generator, the specifications of generator and cooling towers for thermal radiation, priority of utilization of exhaust heat from CGS, operation schedule, and so on. The available heat source devices are "air conditioning / central heat source". "Absorption chiller / utilization of exhaust heat from CGS type (utilized only for cooling)" and "hot water heat exchanger (Exhaust heat from CGS)".

Figure 1. Input screen of “Adsorption chiller / type of utilization of exhaust heat from CGS type”

Table 1 shows the main input parameters (input parameters of the primary pump, cooling tower etc. are omitted in this table). In the registration screen of the heat sources, heat source on the left side is primary operated. Therefore, it is necessary to place the hot water heat exchanger to the left side to utilize exhaust heat from CGS preferentially during heating.

Table 1. Main input parameters of equipment for utilization of exhaust heat from CGS

Heat source equipment	Input parameters	Remarks
Absorption chiller (including utilization of exhaust heat from CGS type)	Cooling / Heating capacity (kW)	
	Cooling / Heating power consumption (kW)	
	Cooling / Heating fuel consumption (kW)	Fuel consumption during cooling must be entered the value in the case of no exhaust heat. (See Fig.3)
	Cooling / Heating outlet temperature (°C)	
	Cooling load factor in operating with utilization of exhaust heat from CGS only (%)	See Fig.3.
	Rated The amount of exhaust heat recovery (kW)	See Fig.3.
Exhaust heat from CGS exchanger	The amount of heat exchange (kW)	
	Primary side outlet water temperature (°C)	
	Secondary side outlet water temperature (°C)	

Figure 2 shows the relationship among the fuel consumption for cooling operation without supply of exhaust heat from CGS, the cooling load factor in operations with utilization of exhaust heat from CGS only, and the rated amount of heat recovery. The cooling load factor in operations with utilization of exhaust heat from CGS only, is the upper limit of cooling load factor in this type of operation. It is shown in either values or graphs in catalogues. If the load factor is greater than or equal to the upper limit of cooling load factor, it will be operated with both exhaust heat and gas.

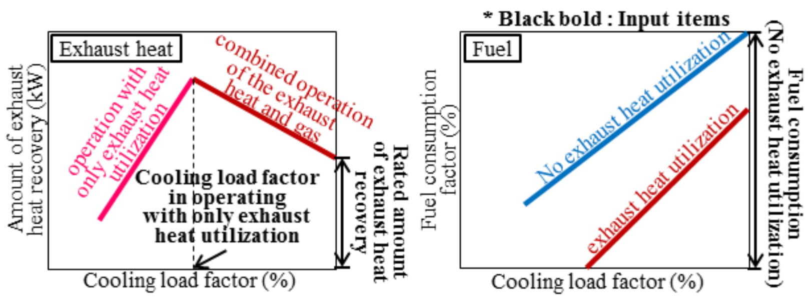

Figure 2. The relationship among the input parameters of "Absorption chiller / type of utilization of exhaust heat from CGS"

3. CASE STUDY FOR A HOTEL

Using BEST program 2013 ver1.1.2, case studies including CGS in a hotel is described below.

3.1. Simulation Conditions

Estimated target is a hotel located in Tokyo which has seven stories above the ground with about 10,000m^2. The hotel is a so-called business hotel which does not have equipment such as a banquet hall. Table 2 shows the specifications of generator, hot water supply, cooling system, and heating system. Table 3 shows the method and operation schedule of the air conditioning systems in the main target rooms. In addition, Figure 2 shows the duration curve of power consumption in the case of using direct fired adsorption chiller for the heat source of air conditioning.

Table 2. Generator and heat source equipment specification

Shaded items : They are automatically calculated on the input screen.

Equipment	Items	Specification
Generator	Type	Gas engine
	Power output	Rated output : 100kW / Min. output : 50kW
	Rated efficiency of power generation	40.5% (LHV basis)
	Rated efficiency of exhaust heat recovery	34.5% (LHV basis)
	Power consumption rate of auxiliary power	5%
	Operating schedule	24 hours/day
Gas water heater	Heat capacity	650kW
	Gas consumption	707kW
	Rated efficiency	0.92
	Tank capacity	Hot water storage tank : 15m^3 Preheated water storage tank: 15m^3
Absorption chiller (including Direct fired double-effect type and high efficiency type)	Rated output	Cooling : 352kW / Heating : 231kW
	Rated gas consumption	Cooling : 274kW / Heating : 274kW
	Rated COP	Cooling : 1.27 / Heating : 0.84
	Rated power consumption	2.34kW
	Rated flow rate	Hot and cold water : 630L/min Cooling water : 1667L/min
Absorption chiller (including exhaust heat utilization type)	Rated output	Cooling : 352kW / Heating : 231kW
	Rated gas consumption	Cooling : 274kW (No utilization of exhaust heat from CGS) Heating : 274kW
	Rated COP	Cooling : 1.27 / Heating : 0.84
	Rated power consumption	2.34kW
	Rated flow rate	Hot and cold water : 630L/min Cooling water : 1667L/min
	utilization of exhaust heat from CGS	Cooling load factor in operating with only utilization of exhaust heat from CGS : 43% The rated amount of exhaust heat recovery : 111kW
Hot water heat exchanger	The amount of heat exchange	85kW
	Rated flow rate	244L/min (Change in temperature 75°C→55°C)

Table 3. Air conditioning system of the main air conditioning target room

Air conditioning target room	Air conditioning System	Air conditioner type	Operating schedule
First floor entrance	Central	FCU	24 hours/day
First floor lobby	Central	VAV	24 hours/day
First floor Reception	Central	VAV	24 hours/day
First floor lounge	Central	VAV	24 hours/day
First floor restaurant	Individual	Multi-type air-conditioners for buildings	From 6am to 9pm
First floor office	Individual	Multi-type air-conditioners for buildings	From 7am to 9pm
2-7floor guest room	Central	CAV*, FCU	From 7pm to 10am

* : Outlet temperature of the air conditioner is fixed at 26 °C during cooling and fixed at 22 °C during heating.

3.2. Case Study Conditions

Table 4 shows the conditions of case studies. Energy estimation based on these conditions was carried out. Case 1 is the only case without CGS. Case 2, which is a case with 100 kW gas engine and power load following operation, is the reference case. The conditions on power generation control system, priority of utilization of exhaust heat from CGS, and etc., were changed in the other cases. The items in red letter in Table 5 show the difference in conditions with respect to Case 2

Table 4. Conditions for case study

Red bold paremeters : They are different from the reference case (Case 2).
W : Hot Water, C : Cooling, H : Heating

Case No.	Case name	Whether to use CGS or not	Power generation control system	Power output[kW]		The number of generator	Priority of utilization of exhaust heat from CGS			Heat source of air conditioning	Preheated water storage tank capacity [m^3]
				Max.	Min.		1	2	3		
Case 1	Direct fired adsorption chiller	Nonuse	—	—	—	—	—	—	—	**2 Direct fired adsorption chiller**	—
Case 2 (Reference case)	Power load following operation	Use	Power load following operation	100	50	1	W	C	H	Exhaust heat input type absorption chiller, Direct fired adsorption chiller	15
Case 3	Fixed power control	Use	**Fixed power control**	100	50	1	W	C	H		15
Case 4	Thermal load following operation, Reverse power flow	Use	**Thermal load following operation, Reverse power flow**	100	50	1	W	C	H		15
Case 5	Thermal load following operation, No reverse power flow	Use	**Thermal load following operation, No reverse power flow**	100	50	1	W	C	H		15
Case 6	Power load following operation (No generator operation)	Use	**Power load following operation (No generator operation)**	100	50	1	W	C	H		15
Case 7	Power load following operation, Cooling/Heating/Hot water	Use	Power load following operation	100	50	1	**C**	**H**	**W**		15
Case 8	Power load following operation, Half of preheated water storage tank capacity	Use	Power load following operation	100	50	1	W	C	H		**7.5**
Case 9	CGS(50kW), Power load following operation	Use	Power load following operation	**50**	**25**	1	W	C	H		15
Case 10	2 CGS(100kW in total), Power load following operation	Use	Power load following operation	**50**	**25**	**2**	W	C	H		15
Case 11	CGS(200kW), Power load following operation	Use	Power load following operation	**200**	**100**	1	W	C	H		15
Case 12	CGS(200kW), Fixed power control	Use	**Fixed power control**	**200**	**100**	1	W	C	H		15
Case 13	CGS(200kW), Thermal load following operation, Reverse power flow	Use	**Thermal load following operation, Reverse power flow**	**200**	**100**	1	W	C	H		15
Case 14	CGS(200kW), Thermal load following operation, No reverse power flow	Use	**Thermal load following operation, No reverse power flow**	**200**	**100**	1	W	C	H		15

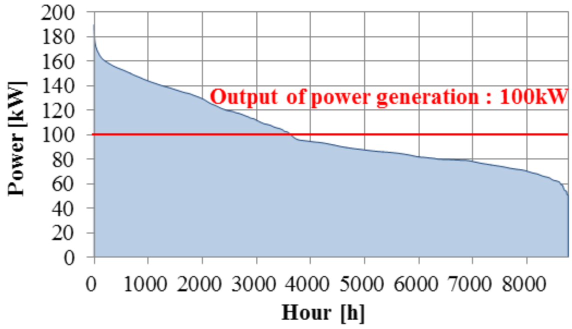

Figure 3. The duration curve of power consumption in the case of using direct fired adsorption chiller for heat source of air conditioning

3.3. Results and discussion

Figure 4 shows the annual primary energy consumption, annual efficiency of power generation, and the average power load factor, as a result of case studies. Total amount of the annual primary energy consumption, which is equal to the difference between total primary energy consumption and the amount of power generated by CGS, is shown with red frame and red bold. Figure 5 shows the amount of gas consumption as a heat source of air conditioning and COP of heat sources, and Figure 6 shows the heat balance of exhaust heat. There are two reasons why the amount of gas consumption for the heat source of cooling system is less than the other cases.

One is that the outlet air temperature of ventilating facilities in rooms with cooling system is fixed at 26ºC, and the other is that ventilating facilities are operated at night, which the outside temperature is low.

The amount of gas consumption for the heat source of air conditioning is almost equal to the result from Case1, "Direct fired adsorption chiller", in most of CGS cases except for Case 7, "Power load following operation, Cooling/Heating/Hot water", and the cases with 200 kW of power output. The amount of gas consumption for the heat source of cooling system in each case is slightly more than that of Case 1, "Direct fired adsorption chiller". It is assumed that this result is due to the equipment characteristics of exhaust heat input type absorption chiller.

In Case 4, "Thermal load following operation, Reverse power flow", and Case 5, "Thermal load following operation, No reverse power flow", the amount of power generated by CGS in each case is equal to that of Case3, "Fixed power control". In Case 13 and 14, with the output of power generation equals to 200 kW, power generation control is carried out depending on the heat demand, so that the amount of gas consumption in each heat source, such as hot water supply and air conditioning, is less than that of Case 2.

In Case 7, "Power load following operation, Cooling/Heating/Hot water", annual primary energy consumption is larger than that of Case 2, which indicates that the exhaust heat from CGS should be used preferentially for hot water supply. In Case 8, "Half of preheated water storage tank capacity", the annual primary energy consumption is slightly less than that of Case 2, although the amount of gas consumption for the heat source of hot water supply is slightly larger than that of Case 2. In Case 9, " CGS (50 kW), Power load following operation", the annual primary energy consumption is larger than that of Case 2 since the exhaust heat from CGS is not enough.

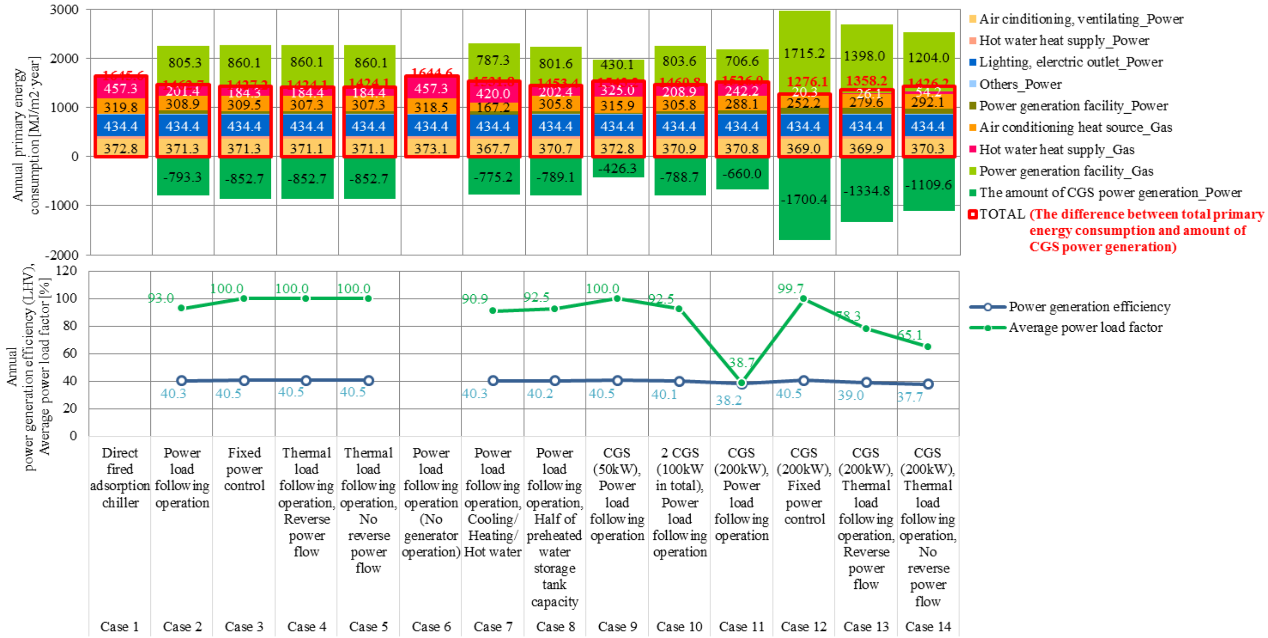

Figure 4. Case study results of CGS aimed at a hotel (Primary energy consumption)

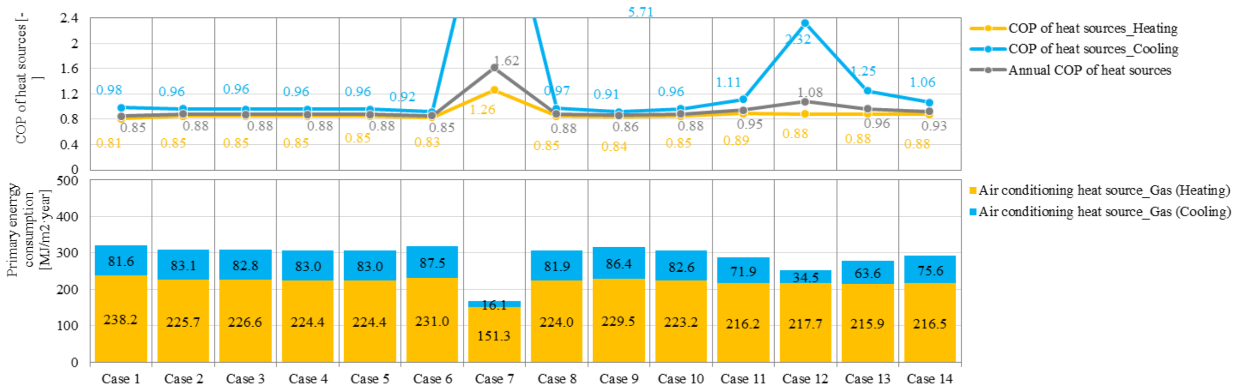

Figure 5. Case study results of CGS aimed at a hotel (The amount of gas consumption for the heat source of air conditioning)

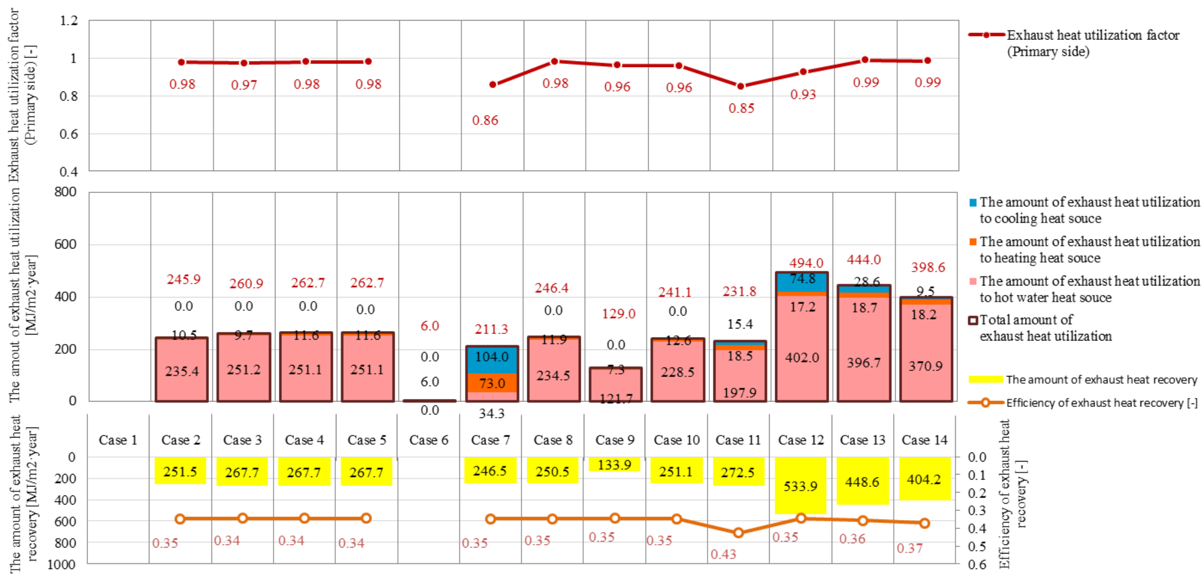

Figure 6. Case study results of CGS aimed at a hotel (Waste heat balance)

4. CONCLUSIONS

The input parameters of CGS in BEST program 2013 Ver.1.1.2 were introduced and the case studies of the energy system including CGS aimed at the hotel with large hot water demand were carried out. As a future work, further calculation cases such as ZEB simulation in the system of PV, storage battery and CGS should be carried out.

5. REFERENCES

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