System Simulation for Adequate Capacity Design of Multi-split Type Air Conditioner based on Operational Data

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ABSTRACT

Multi-split type air conditioners which have been widely used in Japan, has begun to spread to the world including Asia. The system has advantages such as relatively inexpensive system construction cost and easy-to-use, ease of replacement, etc. On the other hand, the cooling/heating capacity of the system often become excessive capacity from the consideration of large safety factor in its capacity design stage. The excessive system capacity leads to increase of low partial load operation hours responsible for inefficient system operation.

On retrofit / renewal of air-conditioning equipment in existing buildings, if there is a thermal load and operating data of the previous equipment, the system can be designed along the actual situation and the reduction of air conditioning energy consumption by optimizing the system capacity can be expected. However, the multi-spirit type air conditioner is direct expansion system, is installed a large number of it per building in general. Therefore, it is not easy to grasp the actual thermal load of the building and/or individual rooms.

In this paper, by using a utility cost dividing system for multi-sprit type air conditioner in rental office building, energy consumption of the individual air conditioning indoor unit were estimated in order to grasp the actual heat load condition of per room. And an objective system is a gas heat pump type multi-sprit type air conditioner of the agricultural research building.

Then the effect of energy saving was analyzed by system simulation software (LCEM tool) using the estimated actual thermal load under the assumption of retrofit / renewal for air-conditioning equipment in existing buildings.

The results of this simulation for the energy savings from the current situation was that the case of proper capacity repair is 5% reduction, and the case of equipment renewal can be reduced 15% of the operation energy consumption.

KEYWORDS

LCEM (Life cycle Energy Management) tool, Multi-split type air conditioner,
Energy conservation, Adequate Capacity Design

INTRODUCTION

Multi-split type air conditioners have been broadly used in small and medium-sized buildings in Japan[1]. However, there are quite a few cases in which their installed capacity is larger than actually needed due to a variety of factors. If the installed capacity has a large margin for the actual air conditioning load, the amount of time to operate the system with a low partial load is long throughout the year in practical operations, causing inefficient system operation.

In addition, when renewing the air conditioner of an existing building, if there are thermal load data or operation data of the existing facility, it will be possible to predict the reduction effect of energy consumption for air conditioner in a state closer to reality by conducting simulation based on these data.

In this study, the thermal load of a multi-split type air conditioner, which is difficult to calculate, was estimated for each indoor unit by the "energy consumption proportional division system for air conditioner," which is generally used to collect heating and cooling expenses of rental office buildings, and the actual condition of thermal load was grasped. Moreover, this study considered the effect of energy saving when the system capacity is retrofitted or the system is renewed based on the thermal load data which were estimated by system simulation using the LCEM tool[2].

SPECIFICATION OF THE SYSTEM

The applicable building was the research building of bio-agricultural sciences on the campus of Nagoya University, which has a reinforced concrete structure with six stories and a total floor area of approximately 6,500 m^2. The rooms are used as a professor's room, student laboratory, biochemistry laboratory, freezer room, and so on. The percentage of each room area and the reference floor plan are shown on Fig.1.

A multi-split type gas heat pump air conditioner (GHP) with a compressor driven by a gas engine is used in the air conditioning facility of each room except some rooms, and ventilation is processed by each room using the unit type ventilating fan. Eight systems of GHP air conditioners (eight outdoor units) are introduced in this building. The specification of this equipment is as shown in Table 1.

The introduced GHP air conditioner is a twin type with two outdoor units configured into one system, and the number of the outdoor units is controlled according to the amount of the thermal load. In addition, a concentrated management

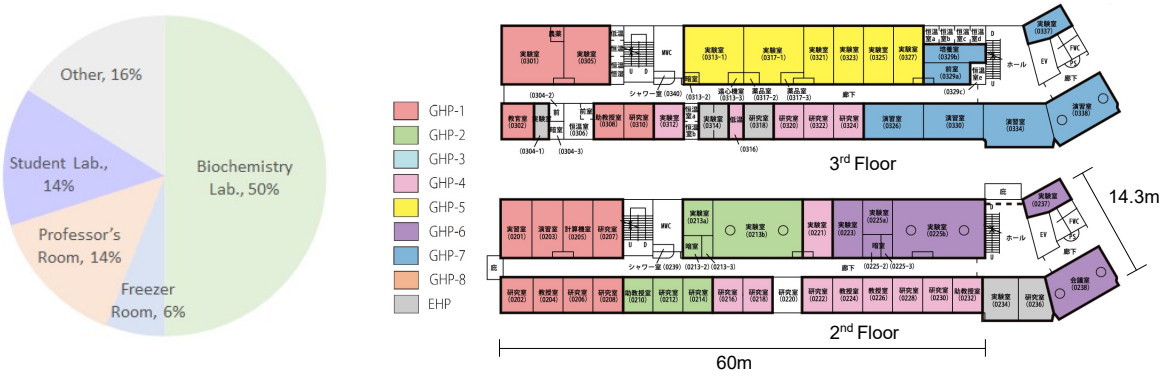


Figure 1 *Usage percentage of room area and the reference floor plan*

Table 1 *The specification of GHP air conditioners*

System No.		Outdoor unit			Indoor unit		
		Capacity [kW]	*Rated gas cons.* [kW]	*Rated COP*	*Number of unit*	*Total Capacity* [kW]	*Capacity ratio of In/Out door unit*
GHP-1	*Cooling*	71×2	57.7×2	1.22	24	137.6	97 %
	Heating	80×2	57.6×2	1.38		155.0	97 %
GHP-2	*Cooling*	56×2	46.9×2	1.19	16	114.2	102 %
	Heating	63×2	46.2×2	1.36		128.2	102 %
GHP-3	*Cooling*	56×2	46.9×2	1.19	14	107.6	96 %
	Heating	63×2	46.2×2	1.36		120.5	96 %
GHP-4	*Cooling*	71×2	57.7×2	1.22	23	124.0	87 %
	Heating	80×2	57.6×2	1.38		138.7	87 %
GHP-5	*Cooling*	45×2	35.2×2	1.27	12	82.0	91 %
	Heating	50×2	35.1×2	1.42		91.6	91 %
GHP-6	*Cooling*	45×2	35.2×2	1.27	10	79.9	89 %
	Heating	50×2	35.1×2	1.42		89.9	90 %
GHP-7	*Cooling*	71×2	57.7×2	1.22	16	127.1	90 %
	Heating	80×2	57.6×2	1.38		142.7	90 %
GHP-8	*Cooling*	71×2	57.7×2	1.22	19	139.7	98 %
	Heating	80×2	57.6×2	1.38		155.6	97 %

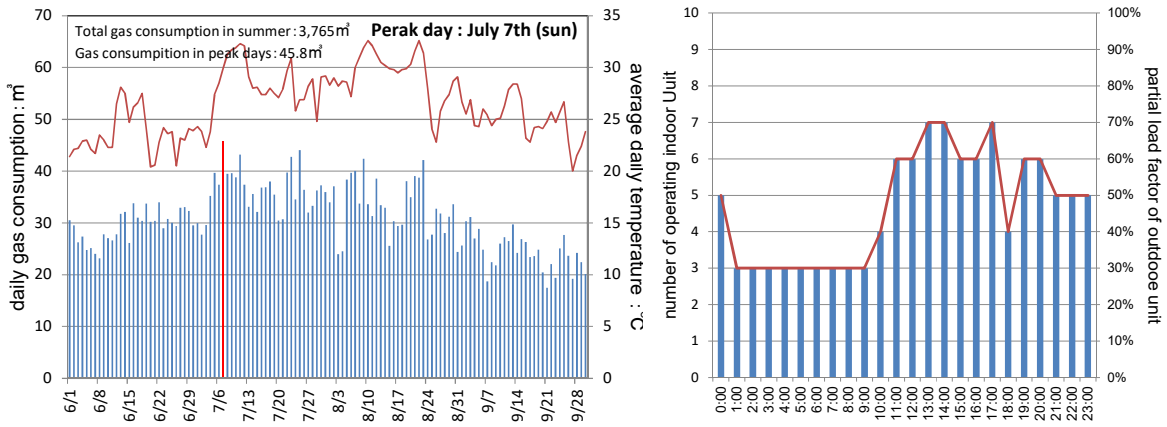


Figure 2 *Daily GHP-1 gas consumption and operating indoor units on the peak day*

controller is introduced to control this GHP air conditioner group, and the "energy consumption proportional division system for air conditioner" is used as part of the controller's functions.

ACTUAL CONDITION OF THERMAL LOAD

The energy consumption proportional division function of this concentrated management controller can proportionally divide the energy consumption measured for each outdoor unit (this is gas consumption when a GHP air conditioner is adopted) on an every-one-hour basis based on the estimated processing load for each indoor unit. This estimated processing heat load is calculated from the opening degree of the expansion valve and the inlet air temperature of the indoor unit (room temperature). Based on this thermal load, the proportional division rate is calculated, and results data are finally saved as gas consumption for each indoor unit. The actual condition of the thermal load of this building was grasped from the gas consumption data of the actually measured GHPs on an every-one-hour basis using this function.

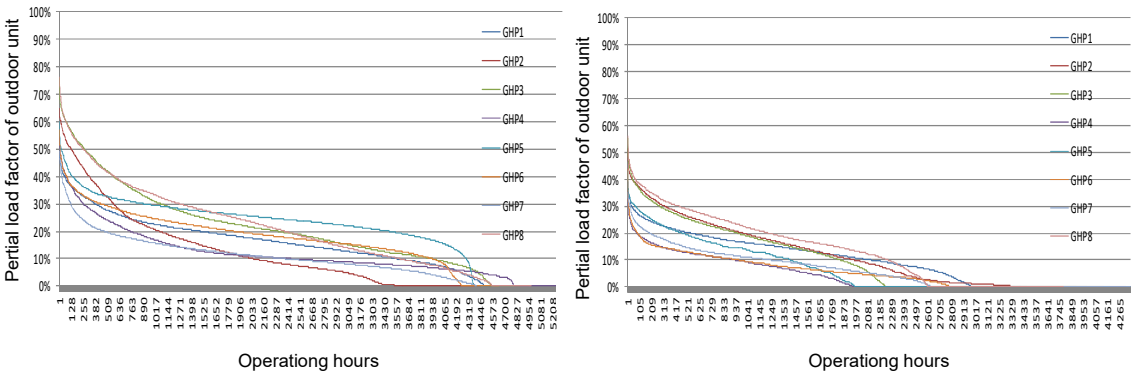
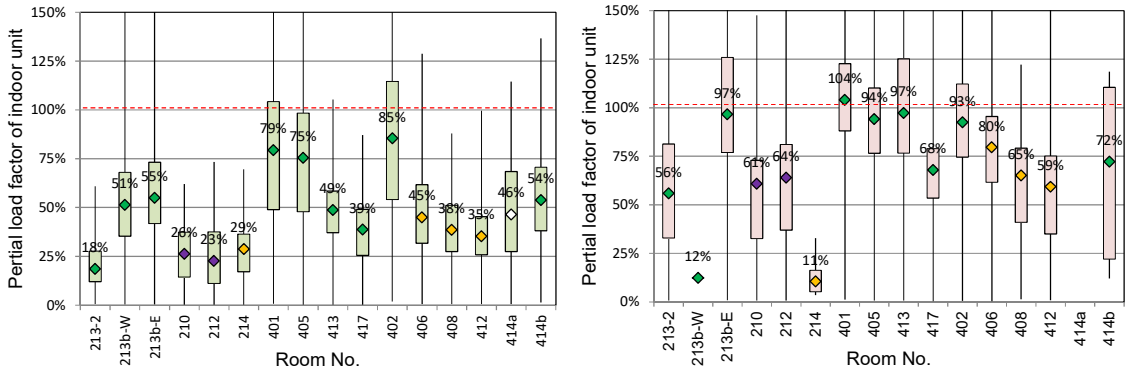


Figure 3 *The duration curve of the load rate of the GHP's outdoor units.*



(1) Cooling season (2)Heating season

Figure 4 *Box-and-whisker diagram of partial load factor of indoor unit*

The day on which integrated gas consumption was the highest was extracted as the peak day, and the number of operating indoor units and the rate of simultaneous use every hour of the day were calculated. Fig. 2 shows the analysis results of the GHP-1.

In addition, Fig. 3 shows the duration curve (sorted in descending order) of the load rate of the outdoor units calculated an every-one-hour basis for each GHP system (ratio of hourly gas consumption to the rated gas consumption for two outdoor units). As a result, the maximum load rate of the outdoor units was approximately 50-75% and 35-55% in the cooling and heating seasons, respectively. The amount of time in which the outdoor units were operated at a load rate of 30% or less throughout the cooling season was 70-plus percent of the total time.

The gas consumption data of each indoor unit is obtained by proportionally dividing the gas consumption data of each outdoor unit on every hour. The thermal load of each indoor unit was estimated by multiplying the gas consumption data (kW equivalent) by the rated COP (applied because actual hourly COP cannot be estimated). In addition, the load rate of each indoor unit was calculated by dividing this estimated thermal load by the rated cooling/heating capacity of the indoor unit.

Fig. 4 shows an example of the experimental results in the cooling and heating seasons expressed as a box-and-whisker diagram. These results clearly show that the load rate of the indoor unit is especially small in the teacher's room and student laboratory, so selection of the indoor units for these rooms is a factor of the trend that indoor units with larger capacity are selected preferably.

RETROFIT/RENEWAL SIMULATION

The analysis results of estimated thermal load showed that the capacity of the outdoor units has a large margin, so that the rate of the outdoor units which are operating with lower partial load is high. Based on this fact, in order to improve the partial load operation of the outdoor units, simulation of retrofit/renewal of the outdoor units was conducted and the energy saving effect of the improvement was confirmed. Table 2 shows the equipment capacity when it is assumed to implement the retrofit and renewal of the outdoor units.

1) For the retrofit of the outdoor units, use of the outdoor units for the GHP-2 system is removed, and the indoor units of this system are reconnected with the outdoor units of another system to improve the load rate of the outdoor units. Then, the effect of gas consumption reduction is verified.
2) For the renewal of the outdoor units, based on the currently estimated thermal load, the outdoor units are renewed by selecting new ones with proper capacity. Then, the effect of energy saving is verified.

Table 2 *The specification of GHP air conditioners*

System No.		Retrofit case			Renewal case		
		Num. of Indoor unit	*Total capacity of Indoor unit*	*Capacity ratio of In/Out door unit*	*Actual peak load* [kW]	*Outdoor unit Capacity* [kW]	*Rated COP*
GHP-1	*Cooling*	24	137.6 [kW]	97 [%]	72.9	45×2	1.30
	Heating		155.0	97	(*cooling*)	50×2	1.46
GHP-2	*Cooling*	(removed)			72.6	45×2	1.30
	Heating				(*cooling*)	50×2	1.46
GHP-3	*Cooling*	14	107.6	96	45.9	28×2	1.26
	Heating		120.5	96	(*cooling*)	31.5×2	1.35
GHP-4	*Cooling*	35	183.0	128.9	76.9	45×2	1.30
	Heating		198.3	123.9	(*cooling*)	50×2	1.46
GHP-5	*Cooling*	12	82.0	91	54.0	28×2	1.26
	Heating		91.6	91	(*cooling*)	31.5×2	1.35
GHP-6	*Cooling*	16	113.5	126.1	51.1	28×2	1.26
	Heating		127.7	127.7	(*cooling*)	31.5×2	1.35
GHP-7	*Cooling*	16	127.1	90	69.8	35.5×2	1.36
	Heating		142.7	90	(*cooling*)	40×2	1.49
GHP-8	*Cooling*	21	164.9	116.1	107.9	56×2	1.21
	Heating		184.1	115.1	(*cooling*)	63×2	1.39

METHOD OF SYSTEM SIMULATION

In this study, simulations of GHP air conditioners were conducted using a free simulation tool for air conditioning systems: LCEM (Life Cycle Energy Management) tool Ver.3.10 of the Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan.

Fig. 5 shows an example (a cooling tower) of equipment simulation model which is called "object" at the LCEM tool[3]. The object is composed of “Communication, Control, Method (calculation) and Property (Specification)” sections. Each object exchanges information with only the neighboring objects on both sides. In this process, the objects calculate the output(s) based on an energy balance calculation. The calculation adopts a static simulation and its time step is one hour.

The simulation model was created by altering the GHP outdoor unit object of the LCEM tool to the twin type in accordance with the actual equipment. The performance characteristics obtained by simulating the actual machine (especially the characteristics of the condition of the outdoor air and partial load rate) are reflected to this object.The multiple unit control for the twin type GHP outdoor unit is considered by creating a new object. The two units are operated in parallel when the partial load rate of the first outdoor unit has exceeded 80% (40% of the entire capacity) according to the actual load condition.

Fig. 6 shows the simulation model and an example of the partial load COP's characteristics of the GHP systems, respectively.

As the boundary condition of the simulation, gas consumption for each GHP system is calculated by specifying weather conditions on the input section at the left end and specifying estimated thermal load based on actual measurement on the thermal load condition section at the right end on hourly basis.

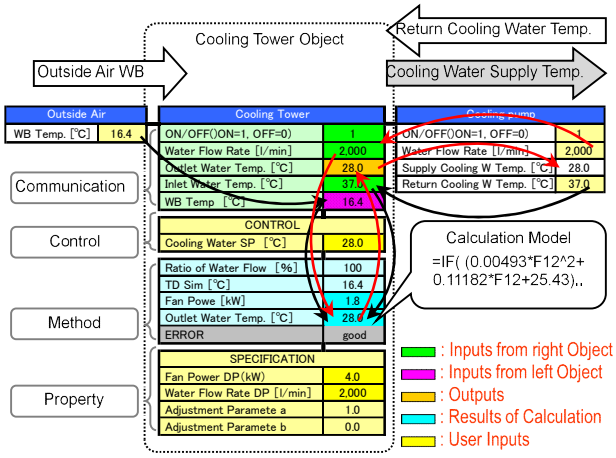


Figure 5 *Example of an cooling tower object*

SIMULATION RESULTS

The simulation was conducted based on the same weather conditions and thermal load boundary conditions in the current case shown in Table 1, retrofit and renewal case shown in Table 2.

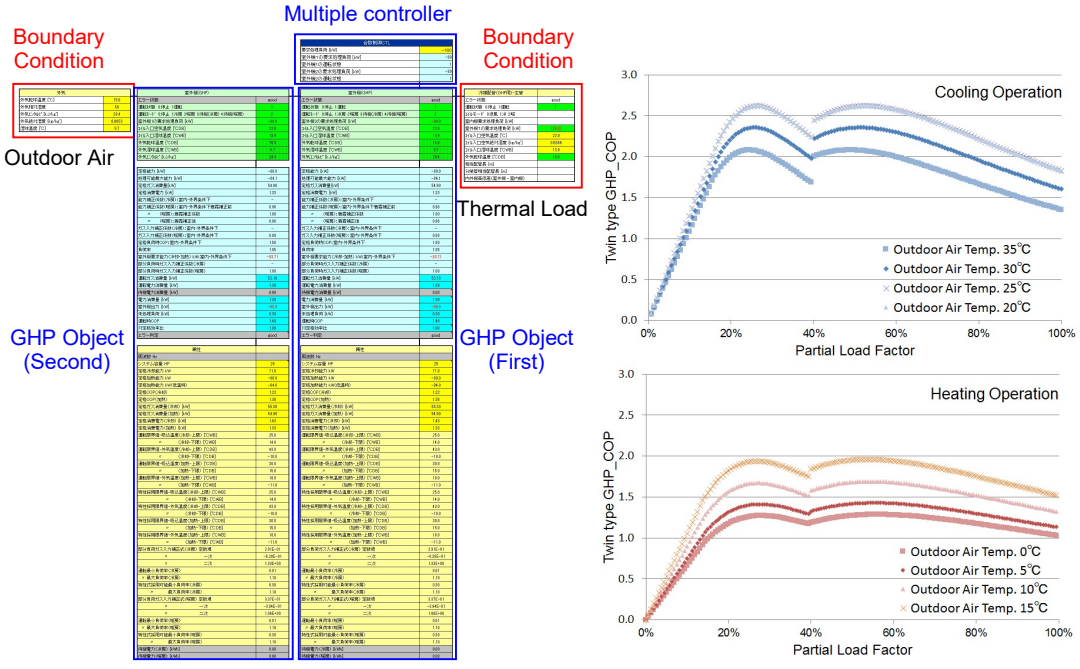
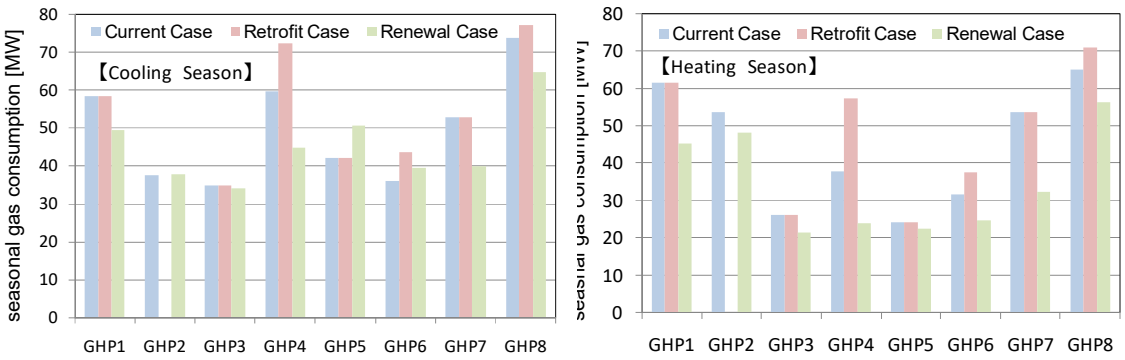


Figure 6 *Simulation model & an example of GHP partial load COP's characteristics*



(1) Cooling season (2)Heating season

Figure 7 *Comparison of seasonal integrated gas consumption in each case.*

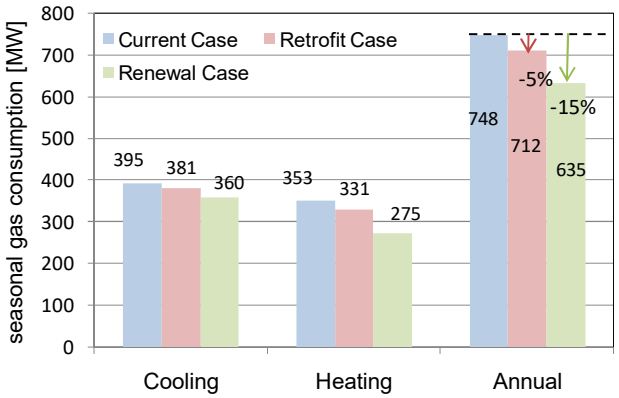


Figure 8 *Comparison of annual gas consumption in each case.*

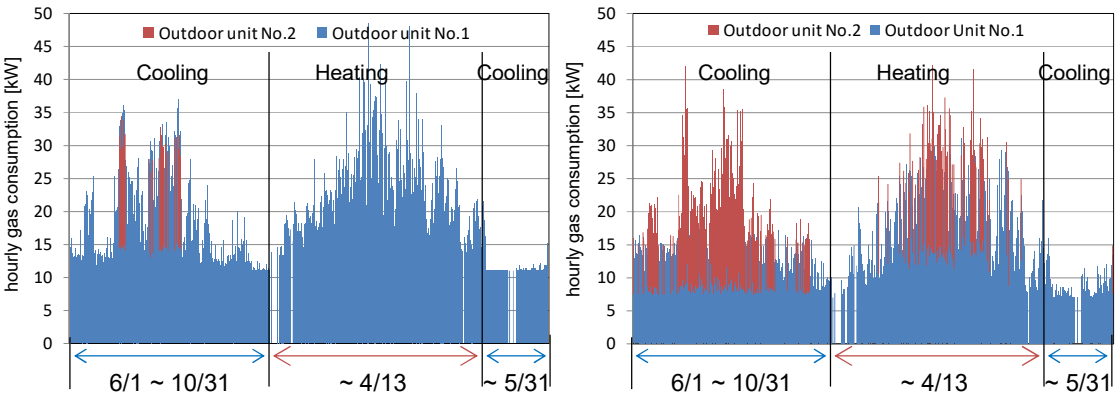
Fig.7 and Fig.8 shows comparison of seasonal and annual integrated gas consumption among these three cases, and Fig.9 shows an example of gas consumption of the GHP-1 system measured on an every-one-hour basis. Fig.10 and Fig.11 are comparison by duration curbs of the partial load ratio in cooling season and COP of outdoor unit between the current case and the renewal case.

In the retrofit case, the effect of partial load operation of each outdoor unit was improved by removing one outdoor unit, so that the annual average partial load rate of the overall GHP systems was improved from 28% of the current case to 31%, the COP of the equipment was improved from 1.43 of the current case to 1.50, and the annual reduction rate of gas consumption reached 5%. In the renewal case, more proper capacity was introduced to the actual load, so that the annual average partial load rate of the overall GHP systems was improved to 39%, the COP of the equipment was improved to 1.61, and the annual reduction rate of gas consumption reached 15.2%.

CONCLUSION AND IMPLICATIONS

As discussed in this study, when renewing the air conditioning system of an existing building, if thermal load data or operation data of the existing facility are available, it becomes possible to precisely consider renovation of energy saving according to the actual condition of the applicable system by using such data together with simulation utilization.

However, on the other hand, obtaining the actual condition data of the thermal load is generally very difficult when the multi-split type air conditioner is the experimental subject. The trend of the actual thermal load can be grasped by utilizing the fuel and light expenses proportional division function of a commercial controller even if it is not so precise. So, this study embodied a method to utilize thermal load data for simulation as grasping the trend of the collected data.



(1) Cooling season (2) Heating season

Figure 9 *Example of hourly gas consumption of the GHP-1 system*

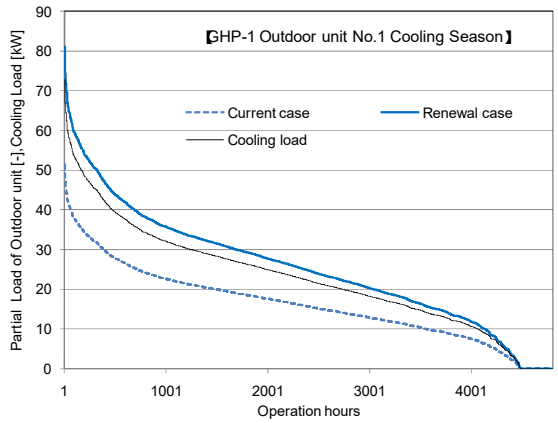


Figure 10 *Duration curb of the partial load ratio of GHP-1 in cooling season*

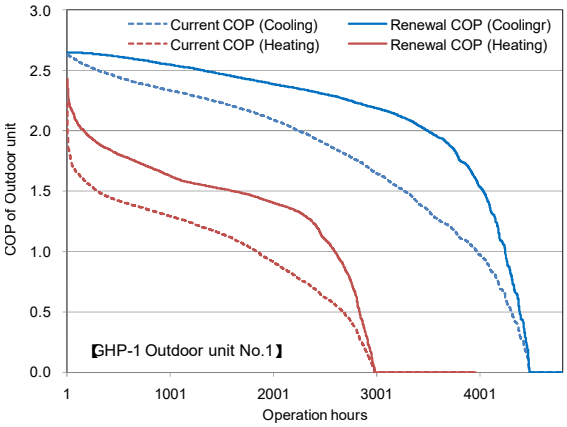


Figure 11 *COP of GHP-1 outdoor unit between the current and the renewal case*

Note: Higher heat generation rate for gas consumption: 45.0 [MJ/Nm^3]

REFERENCES

[1] The volume of shipments for refrigeration and air conditioning equipment in Japan (1986-2015), https://www.jraia.or.jp/statistic/index.html, last accessed on 20 Sep. 2016, The Japan Refrigeration and Air Conditioning Industry Association (JRAIA)

[2] LCEM tool Ver.3.1, http://www.mlit.go.jp/gobuild/sesaku_lcem_lcem.html, last accessed on 20 Sep. 2016, Ministry of Land, Infrastructure, Transport and Tourism

[3] M.Ito , Y.Sugihara et al., Development of HVAC system simulation tool for life cycle energy managements, Part 1: Outline of the developed simulation tool for life cycle energy management, Part 2: Development of component models for HVAC equipment, Proceedings of Building Simulation 2007, pp.1610 -1622, 2007