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DEVELOPMENT OF RESIDENTIAL GAS ENGINE CHP SYSTEM OPTIMIZED FOR COLD REGIONS AND ITS EVALUATION ON ENVIRONMENTAL PERFORMANCE

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ABSTRACT

This paper describes the effectiveness of a residential load following gas engine combined heat and power (CHP) system optimized for cold regions for energy conservation.

Residential CHP system has attracted attention for its high energy saving and environmental performance, and systems using gas engines and fuel cells have recently been introduced into the market in Japan. In Hokkaido as a cold region, high heating demand exists, which causes a large amount of CO_2 emissions and energy consumption compared to national average. It makes the introducing effects of CHP high in this area.

However, the conventional gas engine CHP system has some problems in cold regions. One is that the large indoor space is needed for the hot-water storage unit, which stores the exhaust heat from gas engine in order to utilize it as hot-water supply or heating. The hot-water storage unit is an indoor installation system in Hokkaido because of its severe cold weather, different from an outdoor installation system in other area in Japan. The other problem is that the backup boiler of this system is not condensing type with high efficiency. The heat demand that cannot be covered with the exhaust heat from gas engine is supplemented with a backup boiler installed in the hot-water storage unit. In non-cold regions with little heat load, the adoption of non-condensing boiler with focus on cost is reasonable, since exhaust heat can support most of heat. On the other hand, since the operation rate of the backup boiler is high in cold regions, the adoption of condensing boiler produces considerable merit.

Under such circumstances, AISIN SEIKI Co., Ltd. developed a residential gas engine CHP system optimized for cold regions and conducted evaluation tests in cooperation with Hokkaido Gas Co., Ltd. and Hokkaido University. The remarkable feature of this system is that the exhaust heat during the power generation is used only for heating. The engine operates only when heating is required and electric demand is over certain value, so a hot-water tank for heat reserving is unnecessary. Hot-water supply and heating that cannot be covered by engine’s exhaust heat are supplied with a condensing boiler. By using the small-scale condensing boiler while omitting the hot-water tank, the abovementioned problems in cold regions can be solved.

From the feature, this gas engine does not operate when heating is not required. However, when heating is used, electrical demand tends to be high. Therefore, the gas engine can operate at high load, which brings high power generation efficiency. According to the data of demonstration tests, the amount of CO_2 reduction has reached about 1.2 tons/year on average compared to the performance of the conventional type (commercial power + non-condensing boiler). The amount of reduction in primary energy was averagely about 16.7 GJ/year, equivalent to crude oil of 438 L/year.

Then, a simulation was carried out to confirm the introduction effects under various energy loads. The objects of the analysis were set at actual 35 residences in cold regions. We compared the newly-developed gas engine system with the conventional system. The comparison indicated that in all the residences tested, the new type of gas engine surpasses the conventional type.

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2. BODY OF PAPER

2.1 Introduction

Carbon dioxide emissions originated from energy generation in FY2008 in Japan increased by 7.5% from 1990, the reference year of the Kyoto Protocol. The emissions from the residential sector, which accounts for 15% of the total, increased by 34.2% from the reference year. Under such background, condensing boilers for hot-water supply and heating have become common. In addition, due to higher energy saving and environmental performance, residential CHP system has attracted attention, and systems using gas engines and fuel cells have recently been introduced into the market in Japan.

Meanwhile, in Hokkaido as a cold region, compared with the national average, CO_2 emissions in the household sector are about 1.6 times, and energy consumption about 1.5 times.

Under such circumstances, AISIN SEIKI Co., Ltd. developed a residential gas engine CHP system optimized for cold regions and conducted evaluation tests in cooperation with Hokkaido Gas Co., Ltd. and Hokkaido University. This system have been on sale since May this year, and expected to contribute to reduction in greenhouse gas emissions in Hokkaido. In addition, since many big cities belong to cold regions in the world, this system has great potential in future's sales strategy.

2.2 Conventional System and Its Problems in Cold Regions

The residential gas engine CHP system has been widely spread since its release in Japan. The composition of the conventional gas engine system is shown in Fig. 1. This engine is operated to follow residence's electrical load. When engine's power generation is insufficient, commercial power is used.

The exhaust heat during power generation is stored in a hot-water tank, which is used for hot-water supply and heating. The heat demand that cannot be covered with the hot water in the storage tank is supplemented with a backup boiler installed in the hot-water storage unit. The hot-water storage unit is an indoor installation system in Hokkaido because of its severe cold weather, different from an outdoor installation system in other areas in Japan. Although this system is excellent in both environmental performance and amenity, it has some problems in cold regions. One is that the hot-water storage unit is larger than common gas boiler, requiring a large indoor space. The other is that the backup boiler of this system is not condensing type with high efficiency. In non-cold

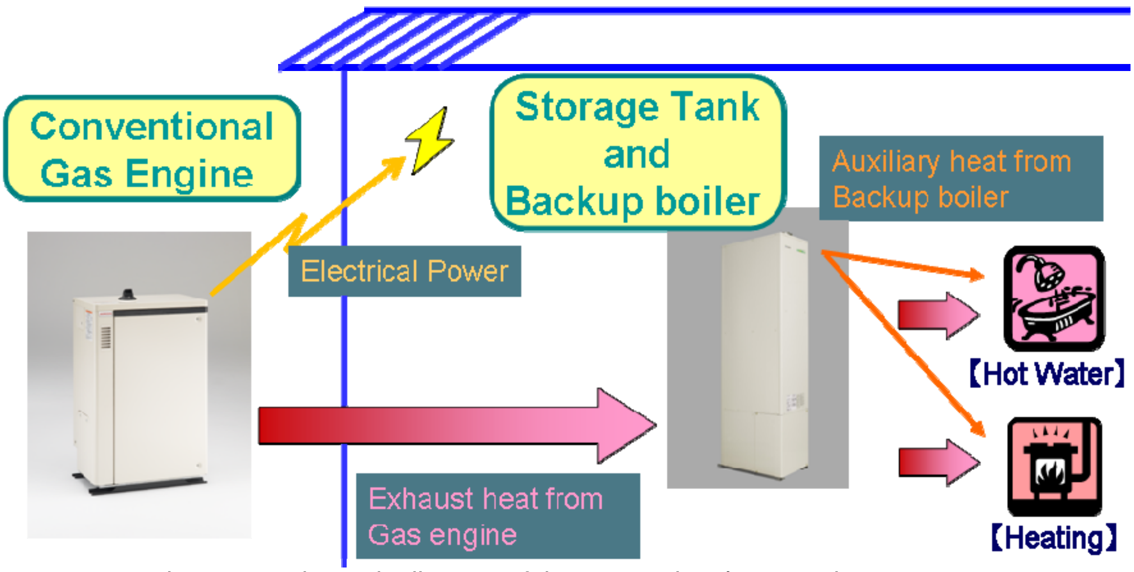

Fig.1 A schematic diagram of the conventional gas engine CHP system

regions with little heat load, the adoption of non-condensing boiler with focus on cost is reasonable, since exhaust heat can support most of heat. On the other hand, since the operation rate of the backup boiler is high in cold regions, the adoption of condensing boiler produces considerable merit.

2.3 Features of Newly-developed System

The composition of a newly-developed system is shown in Fig. 2, and the photograph in Fig. 3. The remarkable feature of this system is that the exhaust heat during the power generation is used only for heating. The engine operates only when heating is required and electric use is over a certain value, so a hot-water tank for heat reserving is unnecessary. Meanwhile, the power that is insufficient through engine's power generation is supplemented with commercial power. Hot-water supply and heating that cannot be covered by engine's exhaust heat are supplied with a condensing boiler. By using the small-scale condensing boiler while omitting the hot-water tank, the abovementioned problems in cold regions can be solved, and in addition the effect of cost reduction due to the omission of the hot-water tank can be expected. Specifications of the system is shown in Table 1.

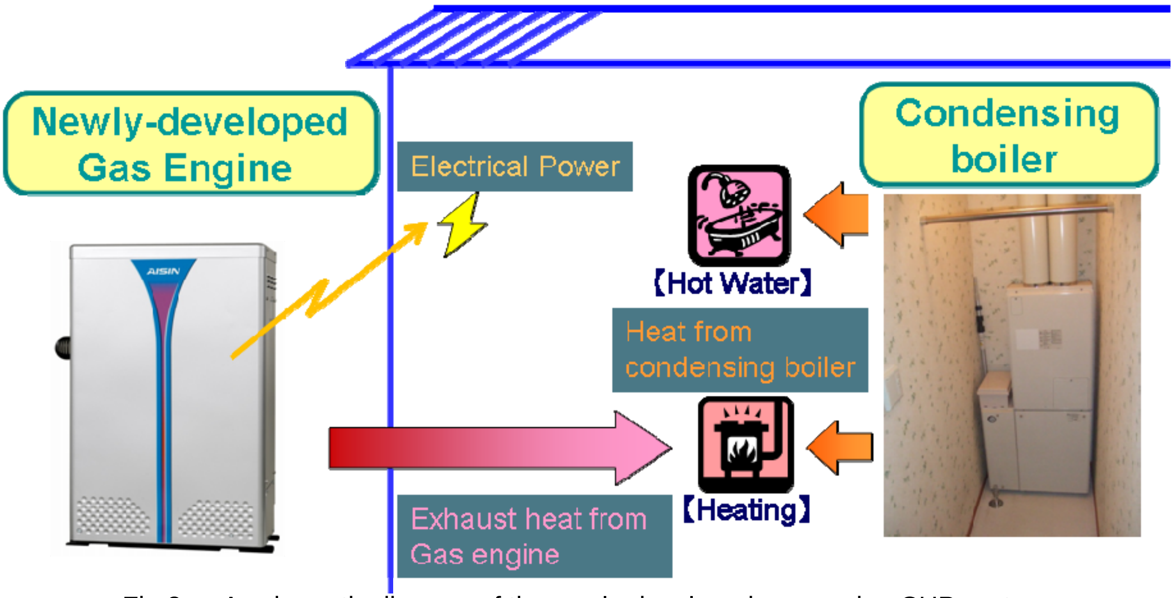

Fig.2 A schematic diagram of the newly-developed gas engine CHP system

Fig.3 Photo of the gas engine

Table 1 Specifications of the system

Maximum power output	1.5kW
Minimum power output	0.5kW
Power generation efficiency	26.0%LHV (at rated operation)
Heat generation efficiency	59.0%LHV (at rated operation)
Dimension	W755×D420×H1157
Weight	151kg
Fuel gas consumption	5.8kW (at rated operation)

2.4 Demonstration Tests

This system has been tested at common residences since FY2008, and totally 14 units have been installed in Hokkaido. A map of the system installed and the lowest temperatures of those areas are shown in Fig.4. According to the data of the Meteorological Agency, gas engines were exposed to temperatures of -23°C, and about 7.4 m snowfall for a year. Actual installed condition is shown in the photograph of Fig. 5.
Despite such severe conditions, this system has demonstrated high effects and reliability. In particular, regarding 11 units that were improved reliability since FY2009, any mechanical failure had not occurred during the monitoring period.

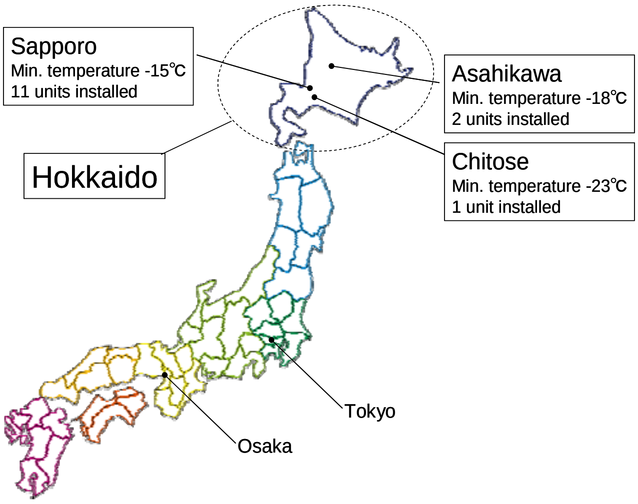

Fig.4 Area of the system installed

Fig.5 Photo of the system installed

2.5 Introducing Effects through Demonstration Tests

Nine test units were selected from abovementioned 14 systems for measurements in order to confirm introducing effects. The operating results for one year of installation are shown in Table 2. The data of three systems (residence A,B,C) out of nine had been taken by flowmeters, thermocouples and power meters as shown in Fig.6 in order to find partial load efficiency. As for other six units (residence D,E,F,G,H,I), only electricity generated had been measured. Therefore introducing effects were analyzed from the abovementioned partial load efficiency, monthly electrical usage and monthly gas usage.
The obtained results were excellent. Compared with the conventional type (commercial power + non-condensing boiler), the amount of CO_2 reduction totally surpassed 0.9 tons/year, reaching the average of about 1.2 tons/year. The amount of reduction in primary energy compared with the conventional type was averagely as large as 16.7 GJ/year, equivalent to crude oil of about 438 L/year.

Table 2 Operating results (Jan., 2010 - Dec., 2010)

Name	Installation Aria	Electric Demand	Supplied Power from Gas Engine	Domestic Hot Water Demand	Domestic Heat Demand	Supplied Heat from Gas Engine	Heating Time	Operating Time of Gas Engine	Contribution Rate of Supplied Power	Contribution Rate of Supplied Heat	Amount of Primary Energy Reduction	Amount of CO_2 Reduction
		kWh	kWh	kWh	kWh	kWh	h	h	%	%	MJ	kg-CO_2
Residence A	Sapporo	4,247	2,120	6,096	16,920	8,321	3,975	3,571	49.9%	49.2%	19,543	1,404
Residence B	Sapporo	3,431	1,287	5,530	15,505	5,307	3,151	2,720	37.5%	34.2%	15,588	1,043
Residence C	Sapporo	5,389	2,562	4,571	9,936	9,305	4,400	4,059	47.5%	93.6%	13,733	1,191
Residence D	Asahikawa	4,295	1,590	4,226	17,240	5,728	2,676	2,617	37.0%	33.2%	17,760	1,212
Residence E	Asahikawa	4,008	1,250	3,579	15,207	4,369	2,085	2,053	31.2%	28.7%	14,752	994
Residence F	Sapporo	5,140	2,376	4,761	20,926	9,048	4,559	4,037	46.2%	43.2%	23,560	1,659
Residence G	Sapporo	4,123	1,532	3,712	14,642	5,501	2,791	2,538	37.2%	37.6%	15,912	1,107
Residence H	Sapporo	3,276	1,104	4,501	13,649	4,609	2,714	2,086	33.7%	33.8%	14,887	973
Residence I	Chitose	3,173	1,176	2,264	18,664	5,991	3,260	2,996	37.0%	32.1%	14,782	981
Average		4,120	1,666	4,360	15,854	6,464	3,290	2,964	40.4%	40.8%	16,724	1,174

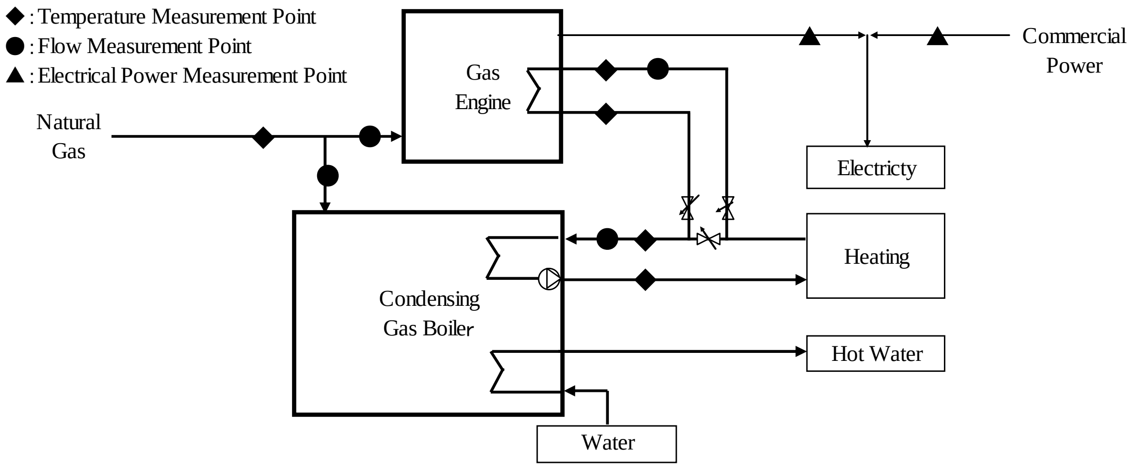

Fig.6 A schematic diagram of the measurement apparatus (Residence A,B,C)

Using a lot of electricity or using heating long time brought high supplied power from gas engine, which would lead to large amounts of CO_2 reduction. If in the case of generated electricity was rather low, high efficiency condensing boiler supplied heating that could not be covered by engine's exhaust heat. It follows from these results that the residential gas engine CHP system is suitable for various types of energy usage in cold regions.

The typical operating patterns of residence A,B,C are shown in Fig.7 The gas engine in residence A had been operating continuously except midnight while there was not heating demand. Such operating pattern is reasonable because electric load tends to be low around midnight. The feature of residence B was intermittent and high heating usage, so the contribution rate of supplied heat from gas engine was not high. Nonetheless environmental effect was high because heating that could not be covered by engine's exhaust heat was supplied with a condensing boiler. Residence C was one of the most suitable sites for the gas engine. The heating had been operated all day and night, and the electrical load was high. Therefore, supplied power from gas engine was rather high. Most of the heat demand was supplied from gas engine's exhaust heat.

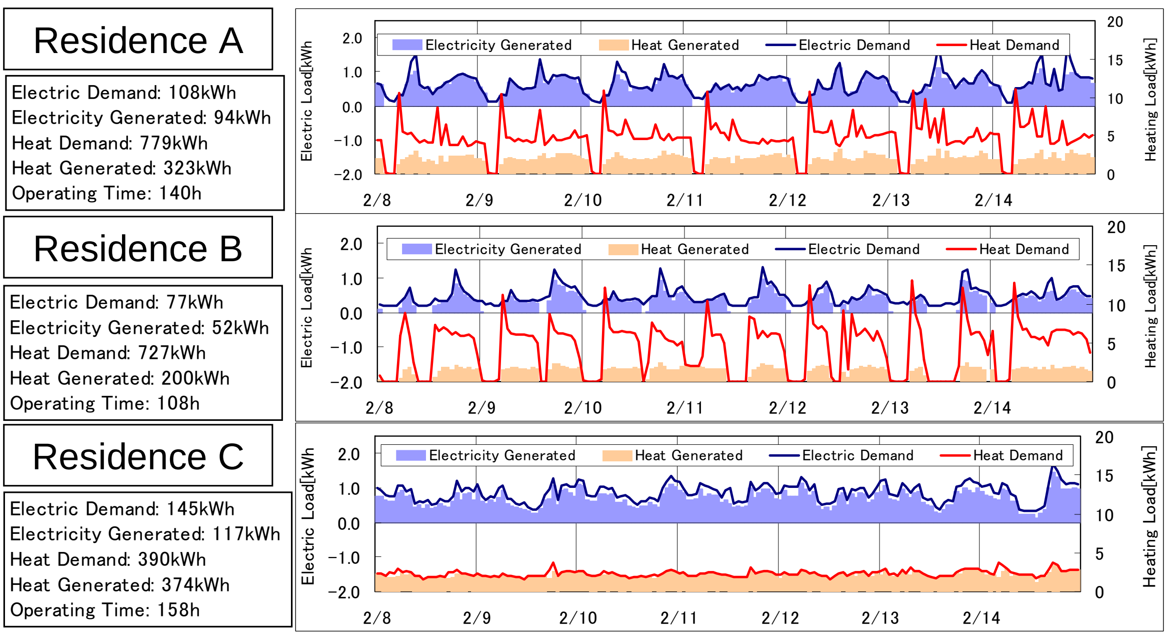

Fig.7 Operating patterns from Feb.8 to 14 (Residence A,B,C)

2.6 Evaluation on Introducing Effect through Simulation

In order to confirm the introducing effects under various energy loads, a simulation was carried out. The objects of the analysis were set at actual 35 residences near Sapporo City, and the load characteristics are shown in Fig.8. On the other hand, the analysis on conventional gas engine system was also conducted for comparison. The analytical results of the amount of primary energy reduction compared with the conventional system are shown in Fig. 9. The average value of all residences was 13.8 GJ/year for the conventional gas engines, and 19.1 GJ/year for the new type. In all the residences tested, the new type of gas engines surpassed the conventional type, which verifies the superiority of the new type of gas engine in cold regions.

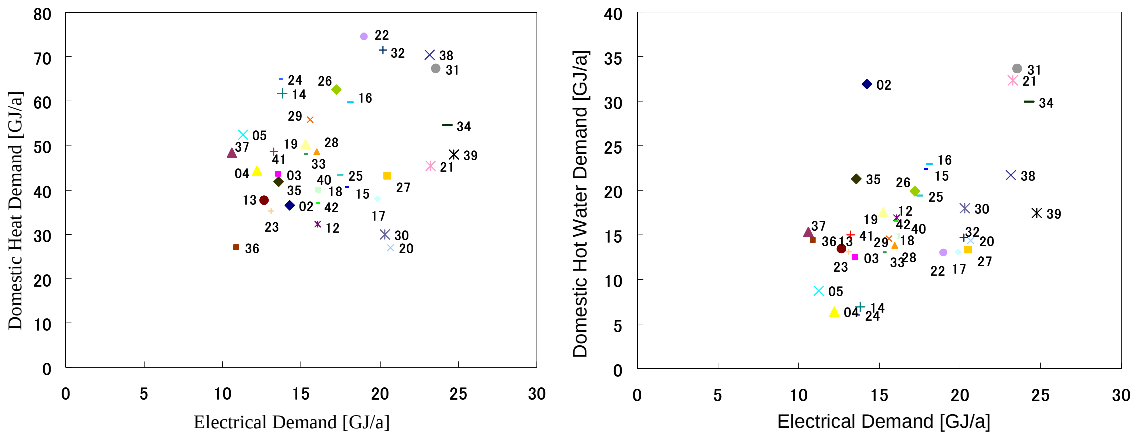

Fig.8 Energy consumption characteristics of simulated residences

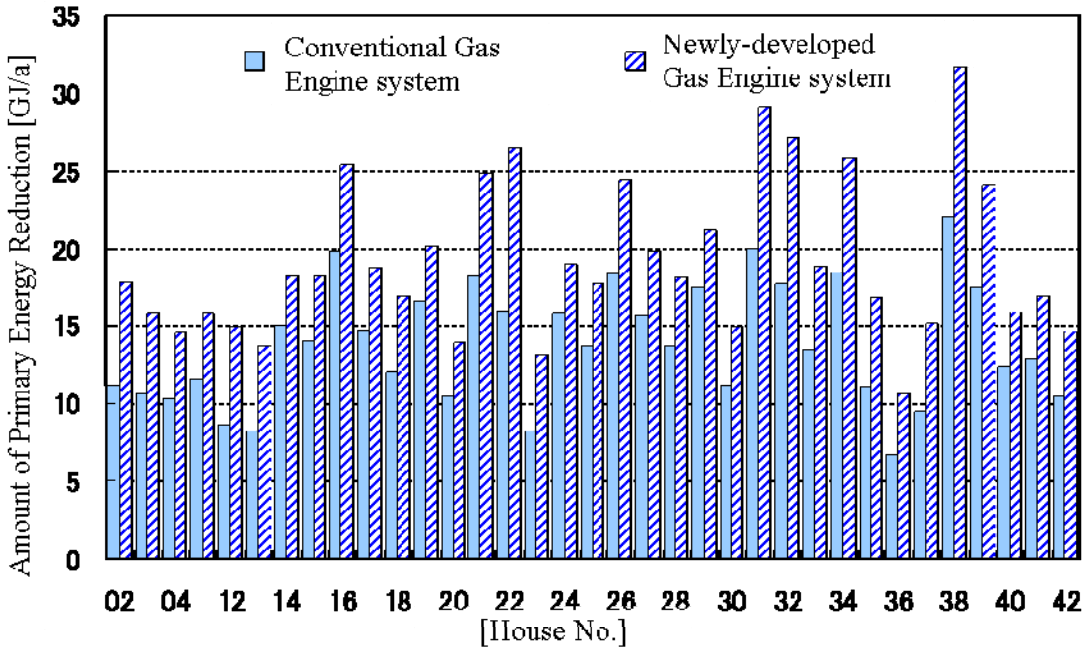

Fig.9 Simulated results of Primary energy reduction

2.7 Conclusions

From the feature, this gas engine does not operate when heating is not required. However, when heating is used, electrical demand tends to be high. Therefore, the gas engine can operate high load, which brings high power generation efficiency. The demonstration test results showed that the amount of CO_2 reduction and primary energy reduction compared to the conventional type (commercial power + non-condensing boiler) were quite high: 1.2 tons/year, 16.7GJ/year respectively. The numerical simulation showed the amount of primary energy reduction was 19.1GJ/year on average.
This system has completed its final evaluation, and it has been on sale since May this year. Usability, installation and maintenance performances have already been verified, and we are confident that an excellent system has been completed. It is expected that this system would widely spread, reduce greenhouse effect gases and energy consumption, and play a role for realizing sustainable society.

3. REFERENCES

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