Evaluation of the Energy and Environmental Performance by Introducing a District Energy System
----Summer Field Study at Kitakyushu Science and Research Park

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Abstract
In Kitakyushu Science and Research Park, a new district energy system has been introduced. In this study, we chose this system as a case study and have carried out an analysis on the efficiency of the power generation and heat release utilization of the fuel cell and gas engine in summer by using recorded data. The results can be summarized as follows: 1) Although the power generation efficiencies of the gas engine and fuel cell are slightly lower than the standard designated value, they are almost constant throughout the period of study. 2) The collected heat energy is lower than the designated value. The heat release utilization, which is used for cooling and hot water, is lower than expected. Considering the efficient use of energy for such systems, it is important to have a good use of heat release when we introduce a district energy system. 3) The discarded heat energy of the system is very big in this investigation when evaluating the system as a whole. It is fundamental to the future of energy conservation to use primary energy more efficiently.

Keywords: regional energy system; efficiency; evaluation; gas engine; fuel cell

1. Introduction
The demand for energy is following an increasing trend with improving living standards. Consequently, the efficient utilization of energy and energy conservation are becoming more important. Cogeneration energy systems that effectively utilize the heat released during electrical power generation using city gas have attracted considerable attention1,2). In Kitakyushu Science and Research Park, a fuel cell and gas engine system have been introduced as a new energy system to raise power generation and heat release utilization efficiencies. The district energy system produces steam and hot water as well as electrical power using city gas as the primary energy source.

Currently in Japan much research interest exists regarding cogeneration systems3-6). Murakami4) discussed the feasibility of introducing a cogeneration system into the district heating/cooling system in a public building. Yanagi5) examined the effects of the energy demand characteristics of a building on the scale and operation of a cogeneration system. These research projects referred to theoretical simulations. However, very little research exists that is based on field studies of actual operating systems. In this research, an analysis has been conducted on the power generation and heat release efficiencies of an actual system by collecting operational data from the summer season. Also an environmental impact evaluation has been reported.

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(Received November8, 2003 ; accepted September 13, 2004)
2. Researched system

Figure 1 is a schematic of the district energy system installed in the Environment Energy Center of Kitakyushu Science and Research Park. The system supplies hot and cold water by making use of the heat discarded from the fuel cell and gas engine. In winter, the system supplies heating directly from the heat released by the fuel cell and gas engine systems. By making use of discarded heat energy, the system attempts to utilize the primary energy source more efficiently.

Table 1 shows details and the nominal power generation and heat utilization efficiencies of the fuel cell and gas engine used in the system when the equipment and the system are running at full capacity. The equipment capacity of the fuel cell is 200kW with a nominal electrical power production efficiency of 40% and a heat release efficiency of 20% for both circuits, one at a high temperature of 90°C and another at 50°C. A high temperature hot water circuit pre-heats the hot water supply system. The system operates for 24 hours continuously throughout the whole year.

The equipment capacity of the gas engine is 160kW with a nominal power generation efficiency of 28.7% and a heat release efficiency of 47.7%.

The order of priority of the system is first for the fuel cell and then for the gas engine to operate. The cogeneration system prioritizes electricity production with a consequent use of the heat produced. The system has operated since April 2001.

3. Investigation methodology

During the research investigation, power generation data were recorded hourly using an electricity meter. In order to analyze the heat release utilization efficiency, the difference between the input and output hot water temperatures and the hot water flow rates were measured for each system at hourly intervals. Consequently the heat released and utilized by the systems could be quantified.

4. Results

The quantities of electrical energy generated and the heat release from the fuel cell and gas engine were analyzed and the efficiencies of the system components derived as shown in figures 2 to 5. The situation for the summer period was analyzed by accumulating the data collected during the entire season.
4.1 The variation of operational with time

Figure 2 shows the variation of power generation efficiency over a 24-hour period of the fuel cell and gas engine on a weekday, a weekend and July 24. July 24 is representive day for summer, that is fine day and in that day, the fuel cell and gas engine run for 24-hours. The fuel cell and gas engine maintained almost constant power generation efficiency over the 24-hour period. The power generation efficiency of the gas engine was about 22%, which was about 6% lower than the designated value of 28.7%. The power generation efficiency of the fuel cell was about 32%, 8% lower than the designated value of 40%. During the weekday and weekend periods 1am-8am, the average efficiencies of the gas engine were lower because the gas engine system operation was stopped on some days when the heat load was expected to be very small.

Similarly, the heat release efficiency in terms of t time for the fuel cell and gas engine are shown in figure 3 on a weekday, a weekend and July 24. The heat release efficiency in the fuel cell is very low and almost constant at about 10%. The heat release efficiency in terms of the time of the gas engine was erratic, especially during the period 1am-8am, fluctuating between 29%-42%. The average value was about 37%, 10% lower than the designated value of 47.7%.

Figure 4 shows the heat release utilization efficiency for the total energy system, which includes the use of the heat release from the fuel cell and gas engine. The figure shows that the fluctuation of the efficiency is dramatic. On July 24, for example, in the daytime about 53% of the collected heat energy was used, but at nighttime only 10% of the collected heat energy was used effectively. The average efficiency varied between 26%-50% on a weekday and 10%-50% on a weekend day.

The total energy utilization efficiency is shown in Figure 5. The efficiency of primary energy use is the ratio of the power generation and heat release utilization to the input of primary energy, which in this case was city gas. For July 24, the efficiency of primary energy use was about 28%-39%. The average efficiencies for a weekday and a weekend day were about 40%.

Figures 2-5 demonstrate that although there was some difference between the designated value and actual operational value of power generation and heat release efficiencies, low released heat utilization efficiency was a problem. Consequently, the total energy utilization efficiency was lower.

Whilst the power generation efficiency and heat collection efficiency were raised, the heat release utilization needs to be improved if the total efficiency of the system in the energy center is to be increased.

4.2 Situation in summer seasons

The accumulation curve of the power generation efficiency of the fuel cell and gas engine in the summer season are shown in figure 6. Although the systems sometimes have been stopped because of operational malfunctions, the fuel cell and gas engine have run at almost stable power generation efficiencies.

The power generation efficiency of the fuel cell was maintained at over 30% for up to about 1800 hours. Meanwhile, the power generation efficiency of the gas engine was over 20% for up to about 1500 hours. The difference in running hours between the two systems can be explained by the fact that priority was given to the fuel cell system over the gas engine system.

Figure 7 is the accumulation curve of the heat release efficiency in the summer season, and shows that the heat release efficiency of the fuel cell was over 20% for up to about 500 hours, which was the same as the designated
value. Also, the heat release efficiency of the gas engine operating for up to 100 hours had a similar value to the designated value of 47.7%. However, these heat release efficiency became lower with an increase of the operational time because for long periods the heat released was not actually used. Increasing the heat collection efficiency can raise the energy use efficiency for the whole system. Therefore, the problem is how to make good use of the heat released by the fuel cell and gas engine.

Figure 8 shows the accumulation curve of heat release utilization efficiency for cooling, which used the heat released by the fuel cell and gas engine. The time for which the collected heat was totally used for cooling was only about 500 hours. At other times the utilization of the heat released was lower and so the heat release utilization efficiency was reduced.

Figure 9 shows the accumulation curve of the total energy efficiency expressed as a percentage of the primary energy used. The efficiency varies from 76% to 23%. It can be concluded that the input (primary) energy of the system was not being used effectively.

In order to raise the efficiency of the energy system in Kitakyushu Science and Research Park, better use should be made of heat released as well as improving the power generation and heat release efficiency.

4.3 Monthly energy balance

Figure 10 shows the balance of monthly energy consumption. The electrical power was generated by the fuel cell and gas engine. The heat release collected from the fuel cell and gas engine can be divided to parts. One is defined as heat release utilization that is used by the absorption chiller and hot water generator, while the other is defined as the heat release that was not used in the absorption chiller or the hot water generator and which was emitted to atmosphere as waste heat through the cooling tower. Waste heat energy is defined as energy that was not utilized by the system or was emitted to atmosphere through the cooling tower.

The proportion of the waste heat energy was largest in June, comprising 52% of the total energy. The proportion of the heat release energy collected was between 20% and 30% of the total energy, with the heat release actually utilized being about half of this. The proportion of the total quantity of input energy that was generated as electrical power was 27.7%.

The proportion of the energy discarded as waste heat in July was about 50%, while the percentage of the released heat that was actually utilized was 9% of total energy input. The proportion generated as electrical power was 26.6% of the total energy input. In the summer season, the utilization of the energy released as heat was lowest in July.

The proportion of the total energy that was rejected as waste heat was lowest in August at about 45%. The proportion of the energy used in the heat generation in August was the largest for the summer season at which is about 24% of total energy. The proportion of the input energy generated as electrical power was 27.7% of the total input energy.

The energy rejected as waste heat throughout the summer season accounted for about 50% of the input energy and is very high. The major reasons for this is that there was not enough demand for hot water in the Kitakyusyu Science and Research Park and that the system did not service sufficient of the cooling demand available on the site. Although the power generation efficiency was 28.3% in the summer season, the efficiency of the heat release utilization was only 14.9%. In order to use heat released effectively, it is necessary to find new uses for this commodity.

5. Evaluation of energy conservation and the environment

For the purposes of comparison a conventional energy-supply system is shown in figure 11. This will allow the benefits of introducing the district energy system to be assessed. In the conventional system, a boiler is used to supply heating energy and a steam absorption chiller is used to supply cooling energy through a district heating/
cooling system. The basic parameters of the equipments and the discharge quantity of CO₂ are shown in table 2. For electricity generation, two cases were assumed: (p) electricity from all power supply sources with an average carbon dioxide emission 0.104 kg-C/kWh and (q) electricity from thermal power generation only with a CO₂ emission of 0.175 kg-C/kWh.

A comparison is made between the energy and carbon dioxide emission of conventional systems and the district energy system with measured power generation efficiency 28.3% and the efficiency of the heat release utilization 14.9%.

Figure 12 shows the comparison of primary energy input in summer for the two systems. The primary energy input in summer was 7.7% higher for the district energy system at Kitakyushu Science and Research Park. This demonstrates that the expected energy savings from the district energy system were not achieved. The reason being that the heat energy released was not utilized fully.

The comparison of the quantity of CO₂ discharged between the district energy system and conventional system is shown in figure 13. When it is assumed that the electricity in the conventional system is supplied by thermal power plant alone, the district energy system achieves a reduction of CO₂ discharge quantity of 31%. If we use the carbon dioxide emission rate related to the average for all power supply sources, the CO₂ discharge quantity in the district energy system displays an increase of 14%.

As mentioned previously, the expected energy savings and efficiency improvement utilizing a combined heat and power system were not achieved because insufficient use was made of the heat generated by the system. In order to assess the potential for reduced energy consumption and improved efficiencies for the district energy system it has been assumed that the heat release utilization efficiency has been doubled to 30% while all other parameters have been kept the same. As shown in figure 13, after raising the efficiency of heat use to 30%, the energy saving achieved with the district energy system has been assessed as 10% when compared to the all power supply sources conventional system. Also, with this assumed heat energy utilization efficiency, the CO₂ discharge quantity has been further reduced, as shown in figure 14. Therefore, it has been clearly demonstrated that for the district energy system it is important to raise the efficiency of heat utilization in order to achieve the high efficiencies expected.

6. Summary

In Kitakyushu Science and Research Park, a new district energy system has been introduced. This system has been used as a case study for an analysis using recorded data of the efficiencies of the power generation and heat release utilization of a combined fuel cell and gas engine cogeneration system operating in summer.

The results can be summarized as follows.

1) The fuel cell and gas engine run with almost constant power generation efficiencies. The power generation
efficiency of the gas engine was about 22%, which is about 6% lower than the designated value of 28.7%. The power generation efficiency of the fuel cell is about 32%, which is 8% lower than the designated value of 40%.

2) The heat release efficiency in the fuel cell was very low at about 10%. The heat release efficiency of the gas engine was erratic and varied with time between 29%-42%. The average was about 37%, 10% lower than the designated value of 47.7%. Furthermore, the heat release utilization efficiency of the district energy system was low and fluctuated considerably. Considering the efficient use of energy, it is a vital to have energy demands to utilize the heat released by a district energy system.

3) The discarded waste heat energy of the system was very large in this investigation when evaluating the systems as whole. It is central to the future of energy conservation to use primary energy efficiently.

4) Compared with the conventional system, the expected reduced environmental impact, assessed in terms of CO₂ generation and reduced energy consumption, for the district energy system was not observed. However, if it is assumed that the efficiency of heat release utilization is increased to 30%, then a decrease of 10% of primary energy input in summer can be expected. This demonstrates that it is essential to have sufficient demand for the heat generated by the system.

The research shows the importance of ensuring that realistic evaluations of the potential uses of the thermal energy generated should be made at the design stage and that this is a key consideration when deciding whether or not to adopt cogeneration in favour of a conventional system.

The study, on the other hand, indicates that it is necessary to examine potential additional demand sources for summer operation.

Further investigations are assessing the district energy system performance for other seasons and year.

References
1) Inukai, “energy and earth environment”, Maruzen Co., Ltd., 2000
2) Agency of Natural Resources and Energy, “The present and future of cogeneration system”, Research Institute of economy, trade and industry, 1997
3) Moriya Hiroyuki, iResearch (the comparison with the conventionally cogeneration system) on the introduction of the fuel cell cogeneration system in district cooling/heating system” Annually conference of AIJ, D-2 separate volume, p.943, 1996
4) Shisei WARAGAI, Shuji FUJII, Kazuhiro YUASA, Tsuneyo UEKUSA and Yutaka MUROTA, Influence of cogeneration system design and fluctuation in building load on energy saving. Journal of Archit. Plann. Environ. Engng., NO.531, p.59, May.2000
5) Hiroyuki ONISHI, Kuniya MURAKAMI and Toshio OJIMA, Study on the effectiveness of introducing a cogeneration system to the district heating and cooling plant considering sending generated electricity to the public facilities, Journal of Archit. Plann. Environ. Engng., NO.532, p.57, Jun.2000
6) Masahide YANAGI, Shisei WARAGAI, Tsuneyo UEKUSA, Yoshihiro KITAGAWA and Shigeru SAITO, Effects of energy demand characteristics of a building on the scale and operation of a cogeneration system, Journal of Archit. Plann. Environ.Engng. , NO.555, p.85, May2002
7) Y. Kondo and Y. Moriguchi, Carbon dioxide emission intensity based on the Input-Output Analysis, Center for Global Environmental Research, 1997

Acknowledgement
The authors would like to express thanks to Mr. Mori, Chiyoda Keiso and Mr. Katsuragi, Nihon Sekkei for cooperation in data analysis.

This research is partly supported by JSPS “Grants-in-Aid for Scientific Research” (KibanC14550591)