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ANALYSIS OF A HEAT PUMP SYSTEM DRIVEN BY A GAS ENGINE FOR DOMESTIC USE

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1. ABSTRACT

A heat pump system driven by a gas engine (i.e., a GHP system) is described, which is used for 3-room air-conditioning and the hot water supply in a residential house. This GHP system was developed in cooperation with GAS Utilities . The system construction, test conditions, operating characteristics and economic estimations are described in this paper.

Heat recovered from the engine is used for water heating and space heating. The system is a high-energy recovery type with a hot water storage tank. This GHP system is compared with a conventional gas furnace, gas fired water heater and room coolers system, using a simulation program to estimate the energy consumption of each system.

2. INTRODUCTION

Although the energy situation has recently eased in Japan with the reduction of oil prices, saving energy is still nationally important and much energy-saving equipment has been developed since the energy crisis of increased oil prices in 1973. Electric power demand during the summer increases rapidly in Japan, and it has become difficult to provide power plant to meet this seasonal demand. Consequently, cooling other than by electricity is very important.

A heat pump system driven by a gas engine is now attracting great interest. This system has high energy-conversion efficiency, because it uses heat recovered from the gas engine. This paper gives an outline of this GHP system and the results of an economic analysis.

3. SYSTEM SPECIFICATIONS

The basic specifications and schematic diagram of the system are shown in Figure 1. This GHP system has a refrigerant heating cycle to recover exhaust heat from the engine for heating using a refrigerant pump, and a 200 ℓ hot water storage tank was provided. Figure 2 shows a picture of the GHP system outdoor unit, hot water storage tank and one of the indoor units. An alternative system was compared with the GHP system; namely a conventional gas furnace, gas-fired water heater and room cooler combination system.

The cooling capacity of the GHP system was 6.28 kW (5400 kcal/h), its space heating-capacity was 9.30 kW (8000 kcal/h) and its water heating capacity was 9.88 kW (8500 kcal/h). The speed of the engine was varied from 1100 rpm to 2200 rpm corresponding to the heat load. The efficiency of heat recovery from the engine exhaust gas was about 70%. The efficiency of the comparative gas furnace and gas-fired water heater was assumed to be 80%, and the EER of the room coolers was 2.6.

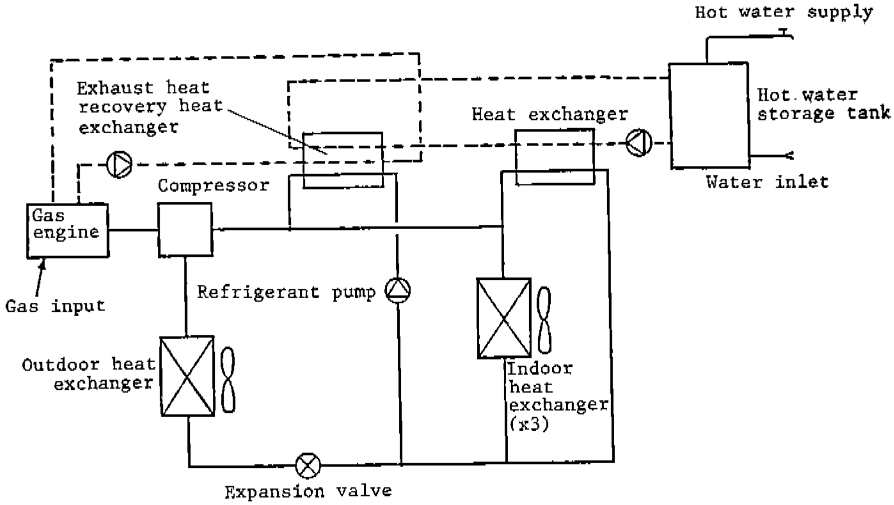
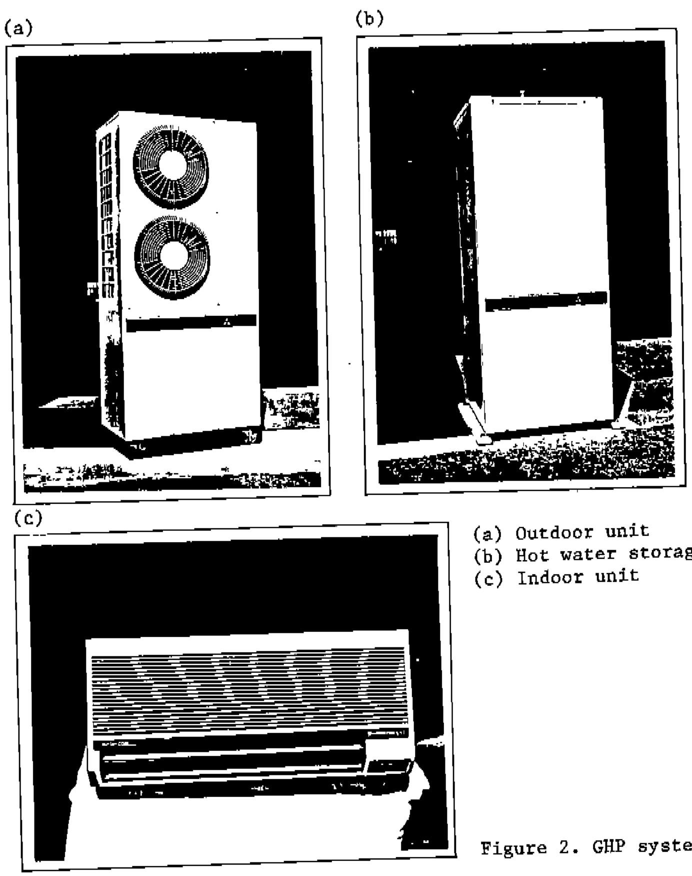


Figure 1. Schematic diagram of the GHP system with a hot water storage tank



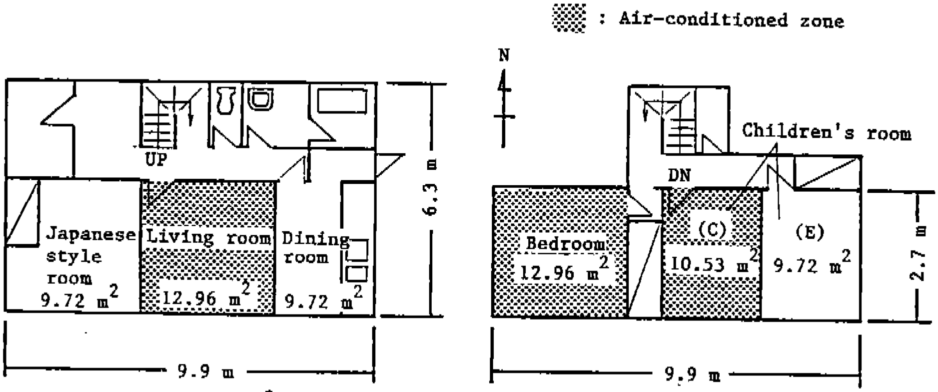
(a) Outdoor unit
(b) Hot water storage tank
(c) Indoor unit

Figure 2. GHP system components

4. INPUT CONDITIONS

For the computer simulation, a wooden two-storied residential house (cf. Figure 3) was selected, three rooms (living room, children's room and bedroom) being air-conditioned and any two of them being air-conditioned simultaneously.

The original air-conditioner operating pattern was set, and the air-conditioning heat load was calculated by the currently used method(1)(2). The results of calculation are shown in Figure 4. In Tokyo, the normal heating season is from December to March, and the cooling season, from June to September. The hot water usage pattern was set and the load was calculated from this pattern. The results are shown in Figure 4. The other input conditions were the temperature of inlet city water, weather probability and outdoor temperature. The unit price of gas was 154.72 yen/m^3, the electric power price was 31 yen/kWh, and the calorific value of the gas energy was 13 kWh/m^3.



1st floor area: 57.51 m^2

2nd floor area: 46.17 m^2

Total floor area: 103.68 m^2

Figure 3. Model residential house plan

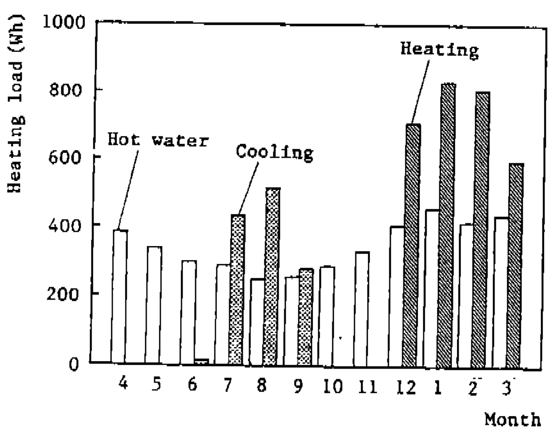


Figure 4. Monthly air-conditioning load and hot water supply (in Tokyo)

5. SYSTEM OPERATING CHARACTERISTICS

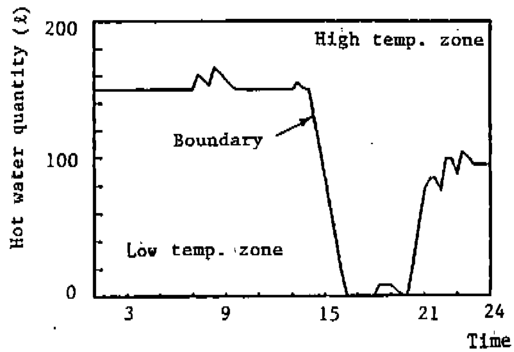
This GHP system can use exhaust heat from the gas engine to heat the water supply for domestic use. The quantity of hot water and its temperature for each season are shown in Table 1 with and without bath usage. During the winter, 50 ℓ of hot water was maintained for uses other than taking baths in the GHP system.

Table 1. Hot water storage temperature and amount

	GHP with HWST			
	bath		non-bath	
Season	temp. C°	amt. ℓ	temp. C°	amt. ℓ
Winter	85	200	85	50
Intermediate seasons	65	200	65	50
Summer	65	200	65	200

6. RESULTS OF COMPUTATION

The computer simulation calculation was run at 20-minute intervals, and the results of storage temperature transition and hot water quantity in the storage tank are shown in Figure 5. In this case, water in the hot water storage tank was heated from 14:00 to 16:00, to provide a high temperature zone of 200 ℓ at 16:00. In the case of bath usage, about 100 ℓ of hot water at 85°C was used at around 20:00, and it was desirable that the water heating time should be close to that time for reduction due to heat loss, this heat loss from the hot water storage tank being about 10% during the winter (7% during summer).



Variation of hot water quantity
(January, weekday, fine weather, bath usage)

Figure 5. Results of simulation for the GHP system with a hot water storage tank

The monthly energy consumption of each system is shown in Figure 6. During the summer, the electric power consumption of the GHP system was less than one-third that of the comparative system. During the winter, the comparative system used about 1.5 times as much energy as the GHP system.

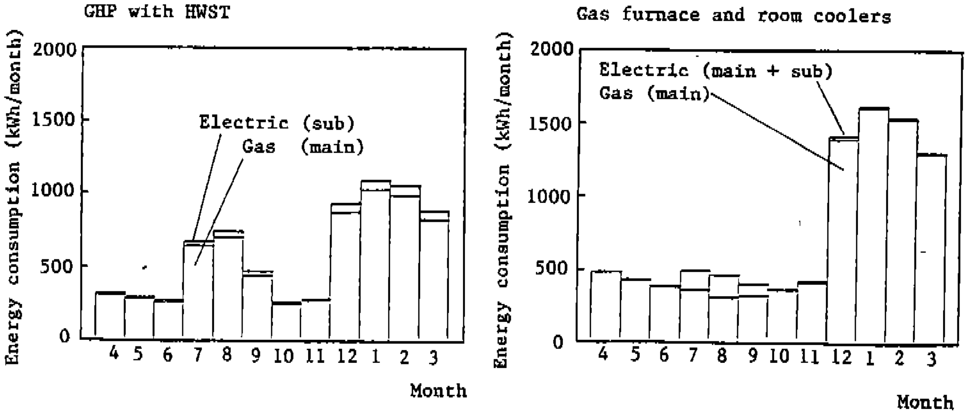


Figure 6. Comparison of monthly energy consumption

Figure 7 shows the monthly running costs of each system.

The average annual cooling load for domestic use in this case was 1.25 MWh, the space heating load was 2.94 MWh and the water heating load was 4.04 MWh, giving an annual total load of 8.33 MWh. Using these figures produced the following results: the annual running cost for the GHP system with a storage tank was about 450 dollars (1 dollar converted at 200 yen). This system offers more economy than the comparative system, which gave annual running costs of about 600 dollars.

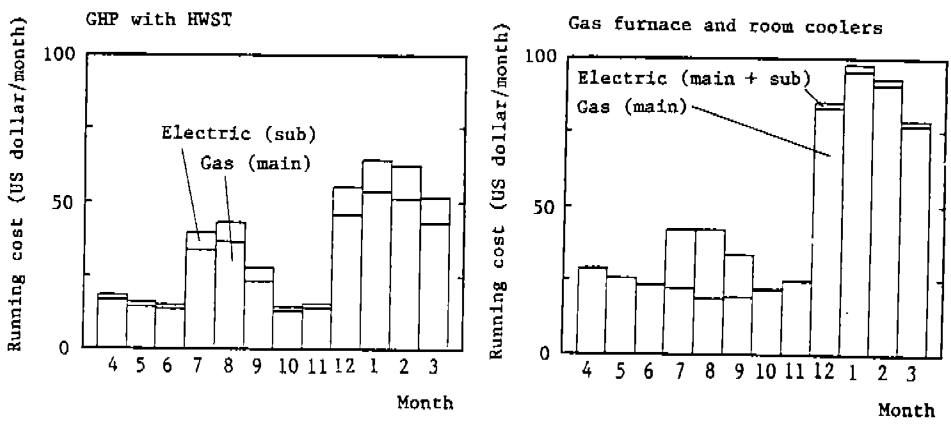


Figure 7. Comparison of monthly running cost

7. CONCLUSION

When the GHP system and the conventional system were compared according to their energy performance and running cost, it became clear that the GHP system offers advantages over its alternative. A more detailed economic study will follow later.

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(2) The Society of Heating, Air-conditioning and Sanitation Engineers of Japan, Handbook II, 16 - 59, 1975.

ANALYSE D'UN SYSTEME DE POMPE A CHALEUR ENTRAINE PAR MOTEUR A GAZ POUR USAGE DOMESTIQUE

RESUME: Ce rapport décrit un système de pompe à chaleur, entraînée par un moteur à gaz (c'est-à-dire un système GHP), qui est utilisée pour le conditionnement d'air et l'alimentation en eau chaude de deux pièces d'une maison d'habitation. Ce système GHP a été mis au point en coopération avec les services publis de distribution du gaz (Gaz de Tokyo, Gaz d'Osaka et Gaz de Toho). Le principe de construction du système, les conditions d'essai, les caractéristiques de fonctionnement et les évaluations économiques sont décrits dans de rapport.

La chaleur récupérée du moteur est utilisée pour le chauffage de l'eau et le chauffage des pièces. Ce système est de type à haute récupération d'énergie, avec réservoir de stockage de la chaleur. Nous avons comparé le système avec un système classique de chauffage d'eau et de conditionnement de pièces d'habitation par fourneau à gaz, à l'aide d'un programme de simulation en vue d'évaluer la consommation énergétique de chacun des systèmes.

ANALYSIS OF A HEAT PUMP POWERED BY A GAS MOTOR FOR HOME-USE

ABSTRACT

The paper describes a heat pump system powered by a gas motor (a GHP system) that is used for air-conditioning and warm water supply of two rooms in a house. This GHP system was designed in cooperation with the gas-supply public services (Tokyo Gas, Osaka Gas and Toho Gas). The build-up principles of the system, as well as its testing conditions, characteristics of use and economic evaluation are described in the study.

Heat recuperated from the motor is used to warm water and rooms. This system has a high energy performance, with a storage tank for heat. Thanks to a model and computer simulating program to evaluate their energy costs, we have compared this system with a conventional water warming and air-conditioning gas system.

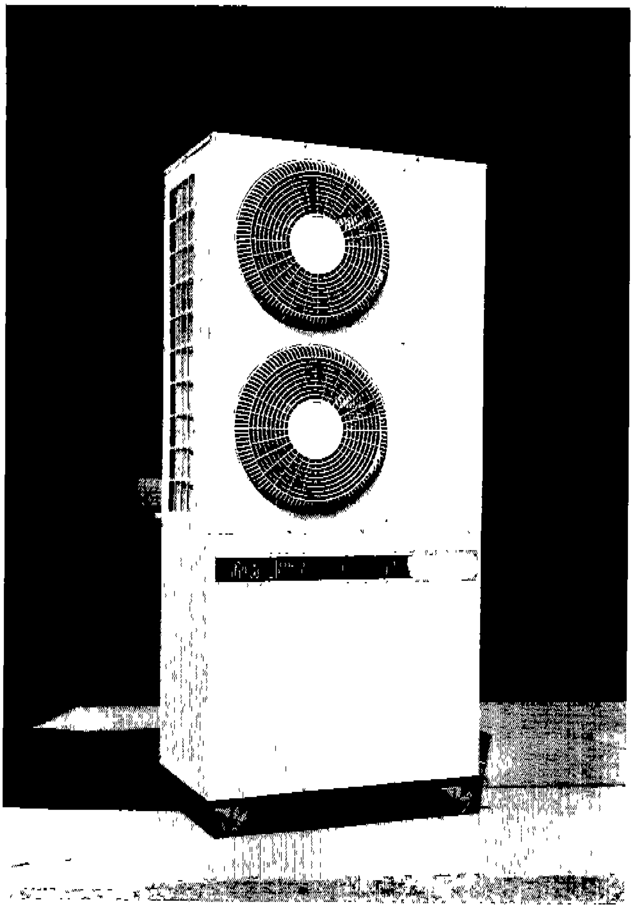

Figure 2. GHP system components
(a) Outdoor unit

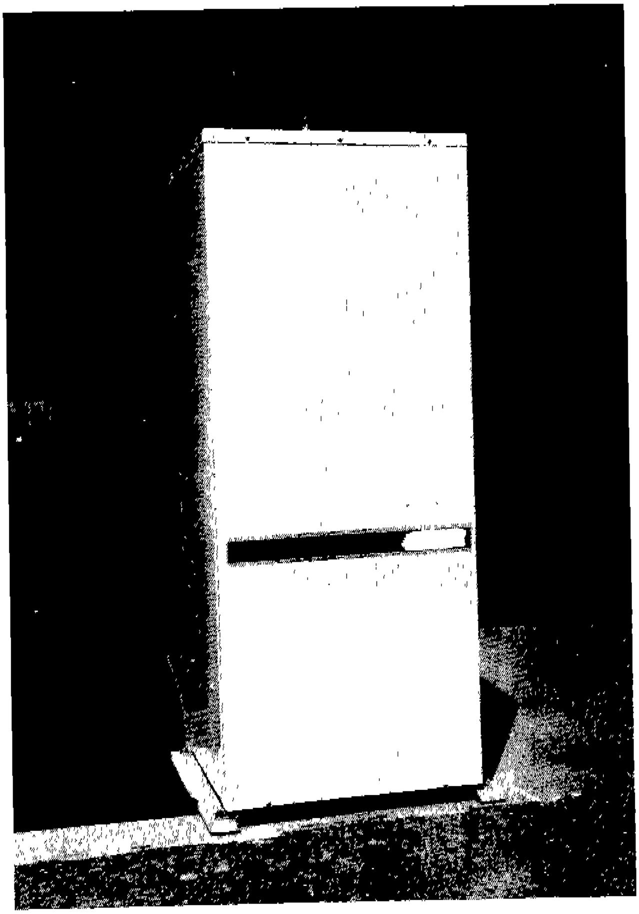

Figure 2. GHP system components
(b) Hot water storage tank

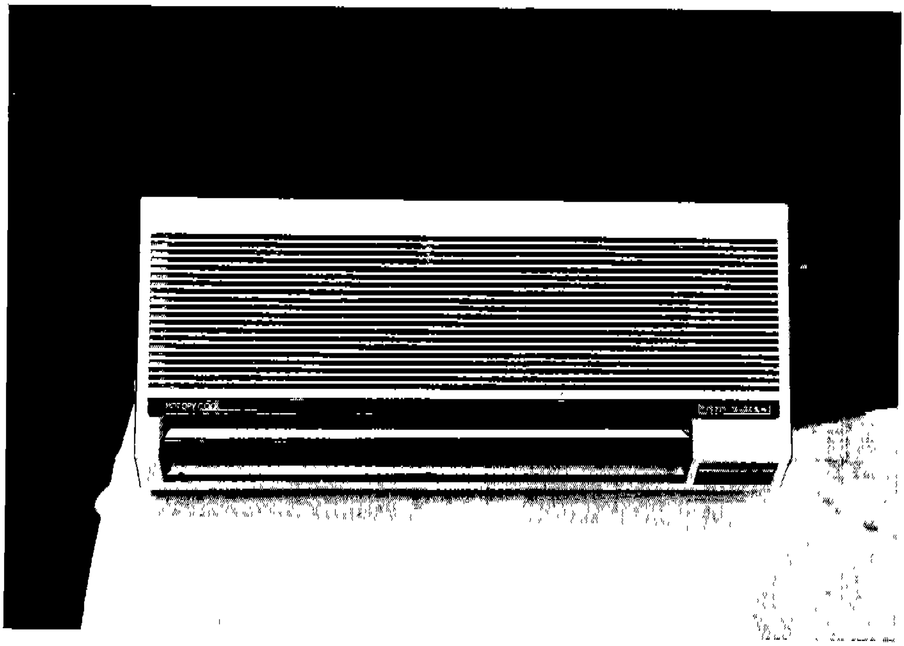

Figure 2. GHP system components
(c) Indoor unit