Research on Waste Heat Recovery System for Residential Gas Engine-Driven Heat Pump

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Abstract

With their background of energy-saving and environmental attributes, gas engine-driven heat pumps (GHPs) are growing in popularity. They have created a firm position in the medium-to-small-scale commercial space cooling and heating market in particular, but products developed for residential applications have recently been attracting attention. On the other hand, even greater efficiency is being demanded in order to cope with global environmental problems and energy issues. As for GHPs, in addition to more highly efficient devices such as engines and compressors, waste heat recovery is an effective method to improve efficiency. This paper describes systems for utilizing the waste heat from residential GHPs to provide comfortable air conditioning and efficient supplies of hot water.

Introduction

In recent years, the issue of global warming problems is increasing importance. In Japan, the amount of energy consumption of a public welfare field is increasing. In such a background, we have involved in improving efficiency of Gas Engine-Driven Heat Pumps (GHPs). Improvements on components such as engines, compressors are, of course, important. In addition, it can also be attained by using waste heat recovery of GHPs effectively. This paper describes systems for utilizing the waste heat from residential GHPs to provide comfortable air conditioning and efficient supplies of hot water.

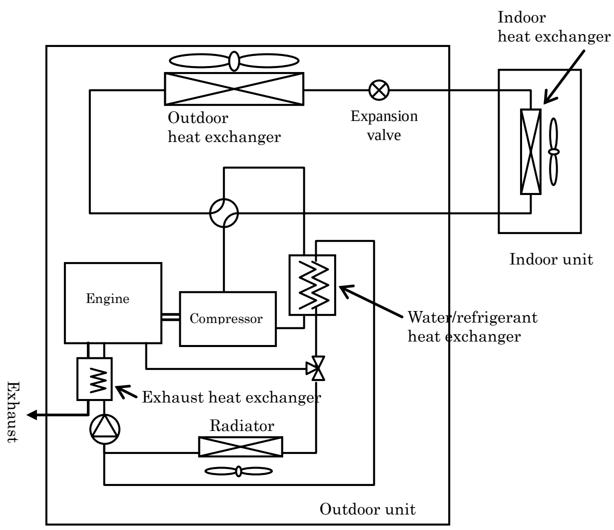

Fig.1 Heating Cycle of GHP

Waste heat recovery system of present GHPs

Refrigerant and cooling-water system of the typical GHPs is shown in Fig. 1. P-h diagram of refrigerant in heating operation is shown in Fig. 2. Engine cooling water collects waste heat through an exhaust heat exchanger and an engine jacket, and the temperature of which goes up to around 80 degrees C. In cooling operation the engine cooling water is led to radiator, and heat is radiated to the ambient air. On the other hand, in heating operation, it is led to a water/refrigerant heat exchanger, and evaporates some of the refrigerant. Thereby, following merits are obtained.

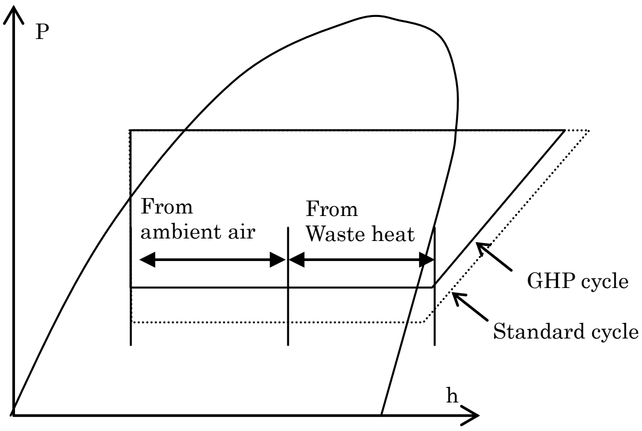

Fig.2 P-h Diagram

1) High heating capacity can be obtained even when outdoor temperature is low.
2) Heating COP improves because refrigerant pressure at the evaporator becomes high.

However, as shown in Fig. 2, since about 50% of the amount of heat to evaporate refrigerant is covered by waste heat, the amount of heat from the ambient air decreases. For this reason, COP does not increase considerably.

Duct Air-conditioning System

Recently, residences with high airtight and high insulation attract attention. The central duct air-conditioning system for residential use, which is designed for such houses, grows in a near future. GHP will fit for such system, to use indoor unit which has refrigerant heat exchanger and hot water heat exchanger to provide cooling, heating and dehumidification air. The simulation analysis was conducted to evaluate the performance of GHP with such indoor unit.

Improvement in Heating COP

As mentioned above, the waste heat recovery system of the present GHPs has a fault that the amount of heat collected from the ambient air decreases. In the duct system, it is possible to provide waste heat from the engine to indoor unit directly. Therefore the amount of heat absorbed from the ambient air increases because all the refrigerant circulating evaporates at the outdoor heat exchanger(this system is hereafter called cooling-water circulation system). The

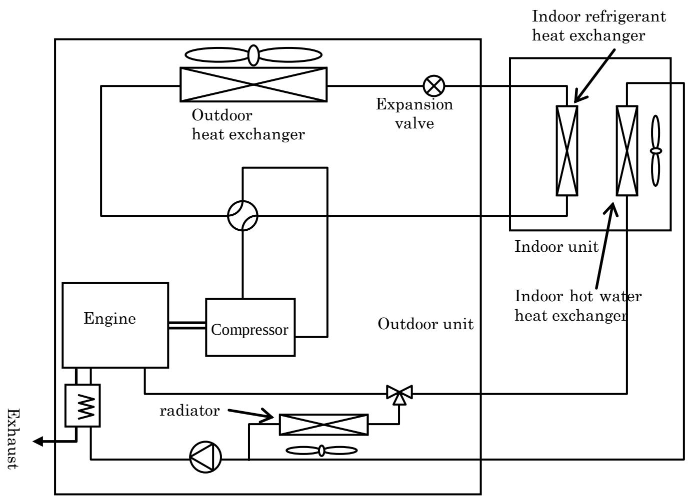

Fig.3 Heating Diagram of GHP

schematic diagram of a duct system with GHP is shown in Fig. 3. The water/refrigerant heat exchanger is abolished, and cooling water is circulated to the indoor hot water heat exchanger. The indoor hot water heat exchanger is located at the downstream of the refrigerant heat exchanger. The simulation examined the effect in efficiency of this system. COP was calculated on three systems as follows.

- The normal heat pump cycle (hereafter "standard cycle")
- The heating cycle of the GHP conventional system (hereafter "GHP cycle")
- Cooling-water circulation system

Simulation Conditions

The following conditions were used in the simulation.

Refrigerant	HCFC22
Heating capacity	Fixed on All system
Engine efficiency	30%
Waste heat recovery efficiency	50%

Pressure loss of piping and heat dissipation is not taken into consideration.

Moreover, the operation conditions of a standard cycle were carried out as follows.

Saturation temperature of condenser	45 degrees C
Saturation temperature of Evaporator	-2 degrees C
Superheating	5 degrees C
Subcooling	5 degrees C
Compressor heat insulation efficiency	80%
Compressor mechanical efficiency	80%
Outdoor temperature conditions	7DB/6WBdegree C
Indoor temperature conditions	20degree C

The heat exchanger performance was specified as follows.

$$\begin{aligned} Q &= Gr(hri - hro) \\ &= Ga(hai - hao) \\ &= KA\frac{(Tr - Tain) - (Tr - Tao)}{\ln\left(\dfrac{Tr - Tai}{Tr - Tao}\right)} \end{aligned} \quad (1)$$

K,*A* and *G*a :constant on all system.

Q : Quantity of heat [kW]

G : The amount of circulation [kg/h]
h : Enthalpy[kJ/kg]
K : Heat transfer coefficient [kW/m2K]
A : Area [m2]
T : Temperature [K]
a :Air
r : Refrigerant
in: Inlet
o : Outlet

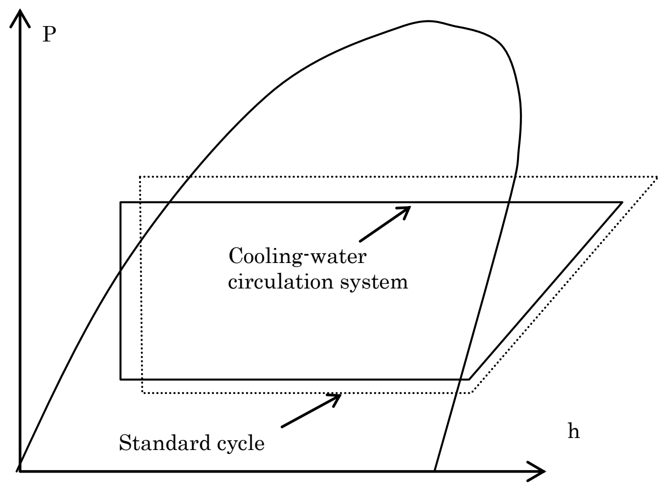

Fig.4 P－h Diagram

Simulation result

The simulation results are shown in Figs. 5 and 6. The heating COP of a cooling-water circulation system is 1.90, and it turns out that COP is improving by leaps and bounds compared with the conventional system. The following three points are mentioned as this factor.

1) Waste heat is used for heating indoor air directly

Waste heat is used for heating of indoor air in the cooling-water circulation system. For this reason, since waste heat recovery efficiency is added to COP of a heat pump cycle, COP of this system increases.

2) Refrigerant condensation pressure can be lowered

Indoor refrigerant heat exchanger is located at the upstream, and it can decrease condensation temperature, thus condensation pressure of a refrigerant may be low, and cycle COP can be improved (Figs. 4 , 6).

3) Refrigerant evaporation pressure can be raised

Since the circulation flux of the refrigerant for acquiring heating capacity equivalent to the

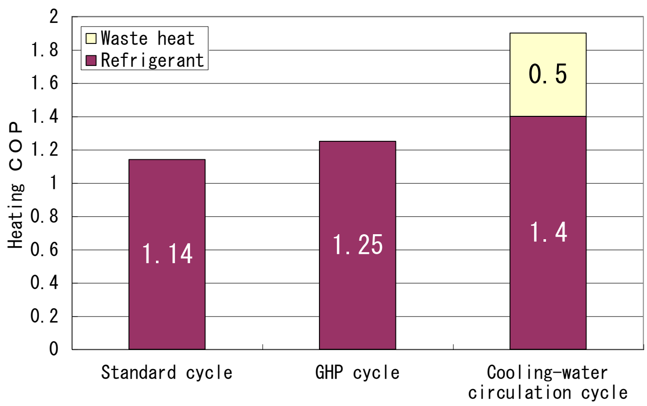

Fig.5 COP Comparisons (Heating)

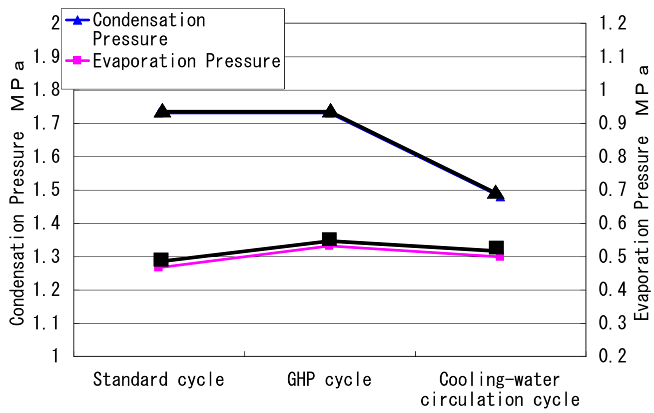

Fig.6 Evaporating and Condensing Pressure

conventional system decreases, the evaporation pressure of a refrigerant can be raised and cycle COP will improve as a result (Figs. 4 and 6).

Dehumidification Air-conditioning

In a duct system, since the refrigerant heat exchanger and the hot water heat exchanger are installed, cooling operation of the GHPs can be carried out, and re-heat dehumidification operation can be performed by sending waste heat to the indoor hot water heat exchanger. Although re-heat dehumidification operation by the electric air-conditioner and gas boiler is performed in the existing duct air-conditioning system, it is thought by using waste heat of GHPs, boiler can be eliminated and the energy-saving is attained. The simulation examined the improvement effect in efficiency of dehumidification operation using GHPs. The amount of primary energy consumption was calculated about three systems as follows.

- The existing duct system

The system which carries out cooling by EHP and re-heat with the hot water supplied from boiler. Cooling COP is 2.8, Boiler efficiency is 80%.

- Efficient duct system

The assumption system which consists of EHP and gas boiler of highest efficiency up to date. Cooling COP is 5.0, boiler efficiency is 95%.

- GHP system

Cooling COP is 1.0. Waste heat recovery efficiency is 50%

Simulation Conditions

The following conditions were used in the simulation.

Indoor temperature conditions	27degree C / 60%
Outlet air temperature conditions	27degree C
The amount of dehumidification.	3 L/min
Efficiency of commercial power plant	36%.

Simulation Result

The result of a simulation is shown in Fig. 7. In existing duct system, it turns out that the primary energy for re-heat has accounted for about 40%. When dehumidifying without lowering indoor outlet air temperature like these simulation conditions, the ratio of cooling capacity and re-heat capacity is

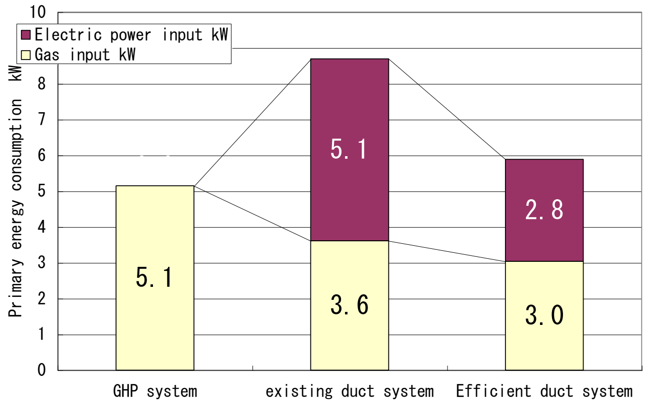

Fig.7 Primary Energy Comparisons

about 1:0.5, and the amount of primary energy consumption will increase by the re-heat system by the boiler. On the other hand, in a GHP system, to the existing duct system, efficient dehumidification operation is possible and by using waste heat for re-heat shows that primary energy reduces to 60%. Moreover, it can check being better in energy-saving than the system which combined EHP and the boiler with the efficiency of the present highest level.

Hot-Water Supply System

Although how to use waste heat for air-conditioning has been examined above, it is possible to use waste heat for hot-water supply. We are developing a residential GHP for water heating in collaboration with Osaka Gas Co., Ltd., Toho Gas Co., Ltd., Saibu Gas Co., Ltd., and HARMAN Co., Ltd. The outline of the system is shown in Fig. 8. The system is composed of GHP, hot water tank and burner for backup. Without air-conditioning load, GHP is operated and efficient hot-water supply is performed using heat pump. The features are as follows.

1) Efficient hot-water supply using waste heat and heat pump.
2) Hot water shortage does not happen by operating the burner for backup

Figs. 9 and 10 are the hot-water supply heating capacity and COP of this system. COP is 1.42 under conditions with an

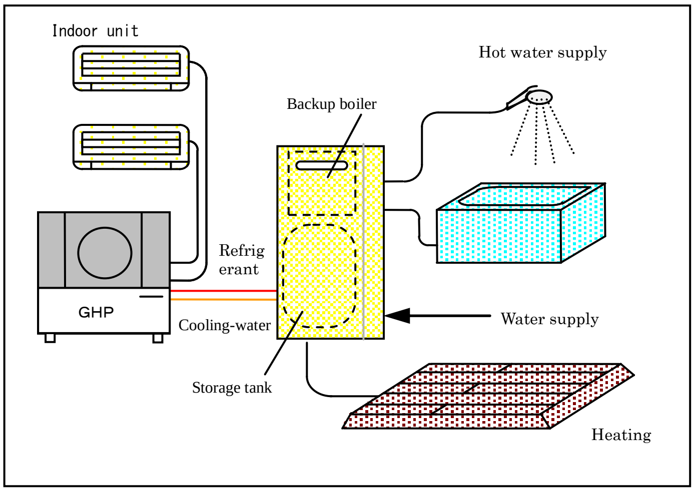

Fig.8 GHP for Water Heating

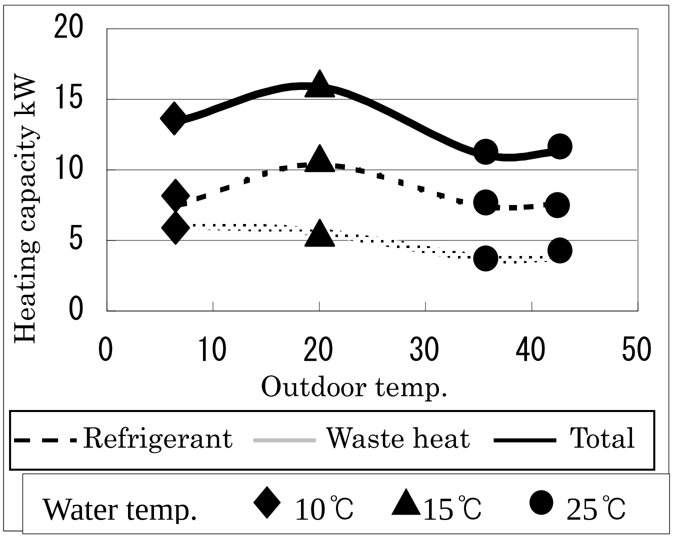

Fig.9 Water Heating Capacity

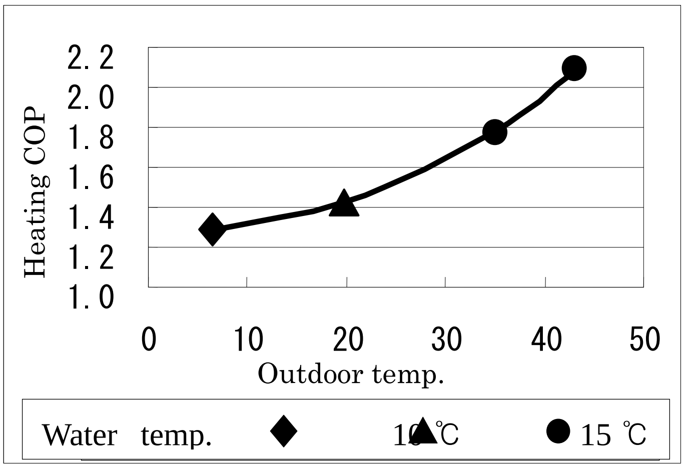

Fig.10 Water Heating Efficiency

outdoor air temperature of 20 degrees C. The field test of this system was carried out at the four sites of Japan in 1999. Fig. 11 is a photo of a site. In the field test, the system worked successfully over about eight months.

Conclusion

The usage of waste heat of GHPs was analyzed and tested above and it was shown clearly that construction of an efficient system is possible in air-conditioning and a hot-water supply field. We want to continue examination towards commercialization of these systems.

Fig.11 Field Test Site