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ABSTRACT

Gas Engine-Driven Heat Pumps (GHPs) were commercialized in Japan in 1987, and since then, the market has grown rapidly in the commercial sector. However, for the product to be accepted in the residential market, GHPs should be highly advanced in terms of specifications, quality, functions and comfort. To develop residential GHPs, various technologies were tried and tested for downsizing and noise reduction. Owing to these efforts, GHPs for residential use have been finally developed and put into the market since the spring of 1998.

For the next phase of residential GHPs' development, work was performed on developing high efficiency systems utilizing heat from the gas engine exhaust.
One example of this new system is a GHP equipped with a floor heating system, which can provide energy savings and added comfort to customers.

This paper describes the development of the systems making use of exhaust heat from gas engine, which is lower in energy consumption and environmentally friendly, compared with conventional systems.

BACKGROUNDS

In Japan, development of residential gas air-conditioners has merits for not only gas utilities, but also nation energy policies, customers and environment. Residential gas air-conditioning can;

(1)Improve annual load patterns of gas and electricity

(2)Decrease electricity peak demands in summer, and thus solve the problems below;

①Lack of electricity in summer

②Construction of new power plants

(3)Contribute to reduction of energy price because of competition between gas and electricity in air-conditioning market

Improvement of Load Patterns

Figure 1 shows the annual load patterns of both gas and electricity in Japan. As can be seen, electricity has its peak demand in summer, while gas has its peak in winter. Gas air-conditioning can shift the electricity demand in summer to gas.

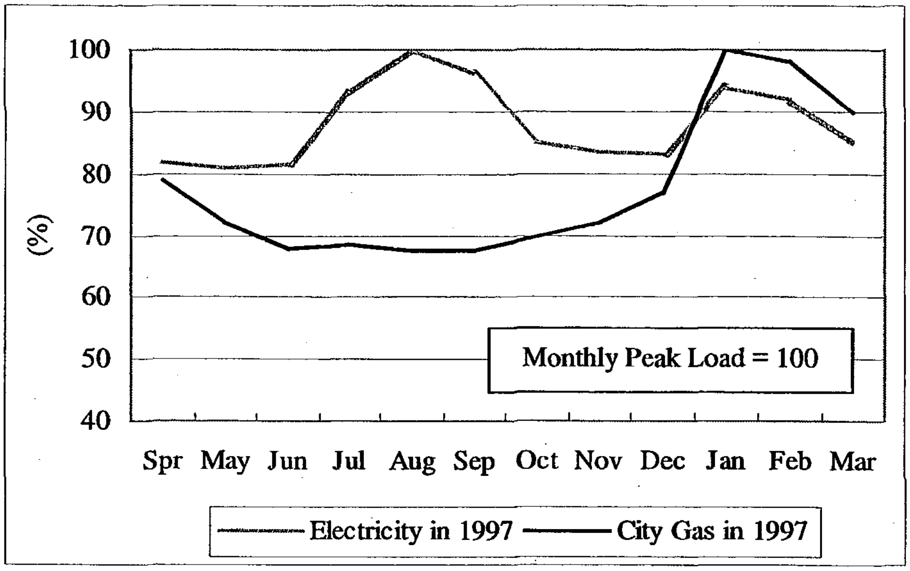

Figure 1. Trend of Annual Load Patterns of Gas and Electricity in Japan

Reduction of Electricity Peak Demand in Summer

As shown in Figure 2, electricity peak load in Japan is increasing almost every year. Increase of peak demand will cause the problems such as lack of electricity, construction of new power plant, deterioration of load pattern, and increase of electricity production cost.

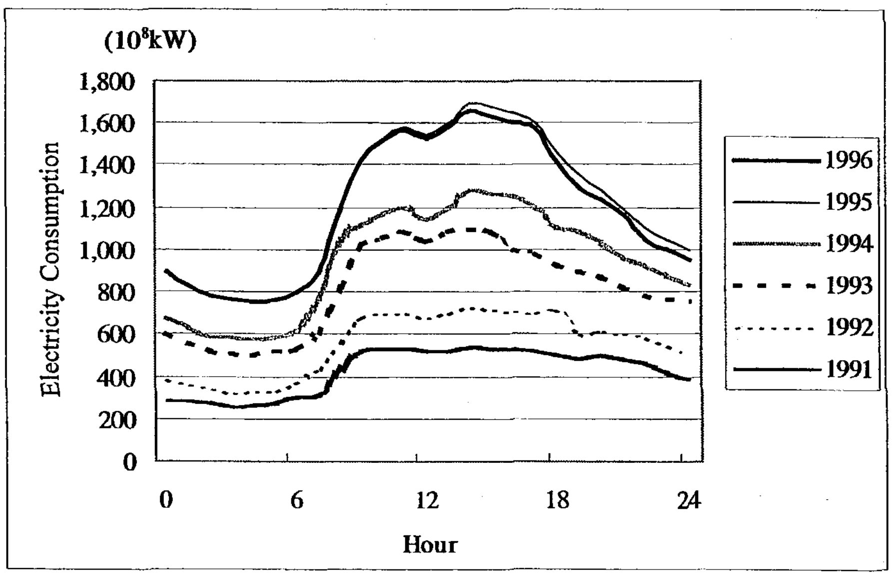

Figure 2. Daily Trend of Electricity Supply when the Maximum Electricity Load Occurred

GHPs for RESIDENTIAL USE

Gas Engine-Driven Heat Pumps (GHPs) were commercialized in Japan in 1987, and since then, the market has grown rapidly in the commercial sector, and the number of shipments has been increasing since then. It can be said that GHP has obtained a certain share in commercial air-conditioning market.

However, for the product to be accepted in the residential market, GHPs should be highly advanced in terms of specifications, quality, functions and comfort. To develop residential GHPs, various technologies were tried and tested for downsizing and noise reduction. Also, field tests of numbers of units have been conducted for three years to evaluate comfort and reliability. Owing to these efforts, GHPs for residential use have been finally developed and put into the market since the spring of 1998.

The unit was improved as to size, maintenance interval and comfort. Table 1 shows the specifications.

Table 1. Specifications of the 8 kW type GHP

Capacity (Cooling) (Heating)	8.0 kW 10.0 kW
COP (Cooling) (Heating)	0.96 1.02
Noise level	49 dB(A)
Size (H-W-D)mm	1,300-1,015-340
Weight	235 kg
Number of Indoor Units	7 at maximum
Maintenance interval	6,000h (Operating hours)

DEVELOPMENT to USE EXHAUST HEAT of RESIDENTIAL GHPs EFFICIENTLY

Principle of Floor Heating System using GHP

For the next phase of residential GHPs development, work was performed on developing high efficiency systems utilizing heat from the gas engine exhaust.

One example of this new system is a GHP equipped with a floor heating system, which can provide energy savings and added comfort to people.

Recently in Japan, floor heating system using instantaneous water heater is getting popular because it is more comfortable compared with the system using a split type air-conditioner. The other reason why floor heating system is popular is that the gas utilities in Japan are making efforts in development. In the floor heating system, piping is mounted in the floor, and hot water, supplied by instantaneous water heater, circulates in the piping.

It is difficult for electric heat pumps to be used for heat source of floor heating system, because it requires water of high temperature (more than 333 K (60 ℃)). To obtain high temperature, condensing temperature and pressure should be very high; thus capacity and efficiency will decrease significantly.

As GHP operates heat pump cycle in heating mode, it is also difficult to supply high temperature water. However, this problem was overcome by using the waste heat from the engine. As the cooling water temperature is higher than 343 K (70 ℃), it is easy to raise the hot water temperature above 333 K (60 ℃).

Figure 3 shows the schematic diagram of the water heating system. As described in the figure, optional kit, which consists of two heat exchangers and water pump, is required in addition to the outdoor unit. Water circulating the floor-heating panel is first heated by refrigerant in the Heat Exchanger 1, and then water is again heated by cooling water in the Heat Exchanger 2. As the temperature of circulating water at the inlet of the optional kit is usually under 313 K (40 ℃), it is possible to heat the water by refrigerant. In this way, it is possible to use both the heats from refrigerant and cooling water, which makes the COP very high. COP of the floor heating system, when the GHP is operating only as floor heating system, reaches 1.0.

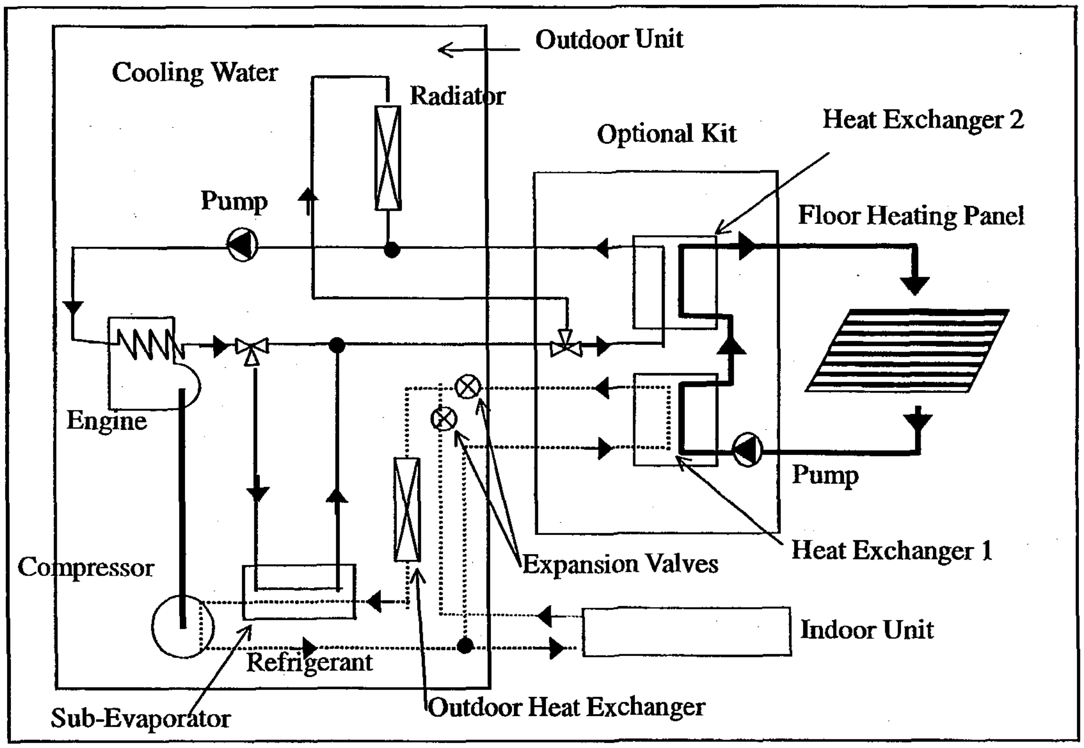

Figure 3. Schematic Diagram of the Floor Heating System

In this system, it is possible to operate only floor heating system. It is also possible to operate both indoor unit and floor heating system. When both indoor units and floor heating system are operated, refrigerant is distributed according to heating load of indoor units and floor heating system, using the expansion valves. Also, cooling water is distributed to sub-evaporator and optional kit according to loads.

Experiment to Measure Floor Heating Performance

We made an experiment to measure GHP's floor heating performance. The experiment conditions and the results are shown below.

Experiment Conditions

We conducted the experiment at an environmental laboratory. The specifications of the lab and floor heating unit (optional kit) are shown in figure 4 and table 2, 3.
The starting condition of this experiment and the operation control of floor heating system are shown in table 4, 5.

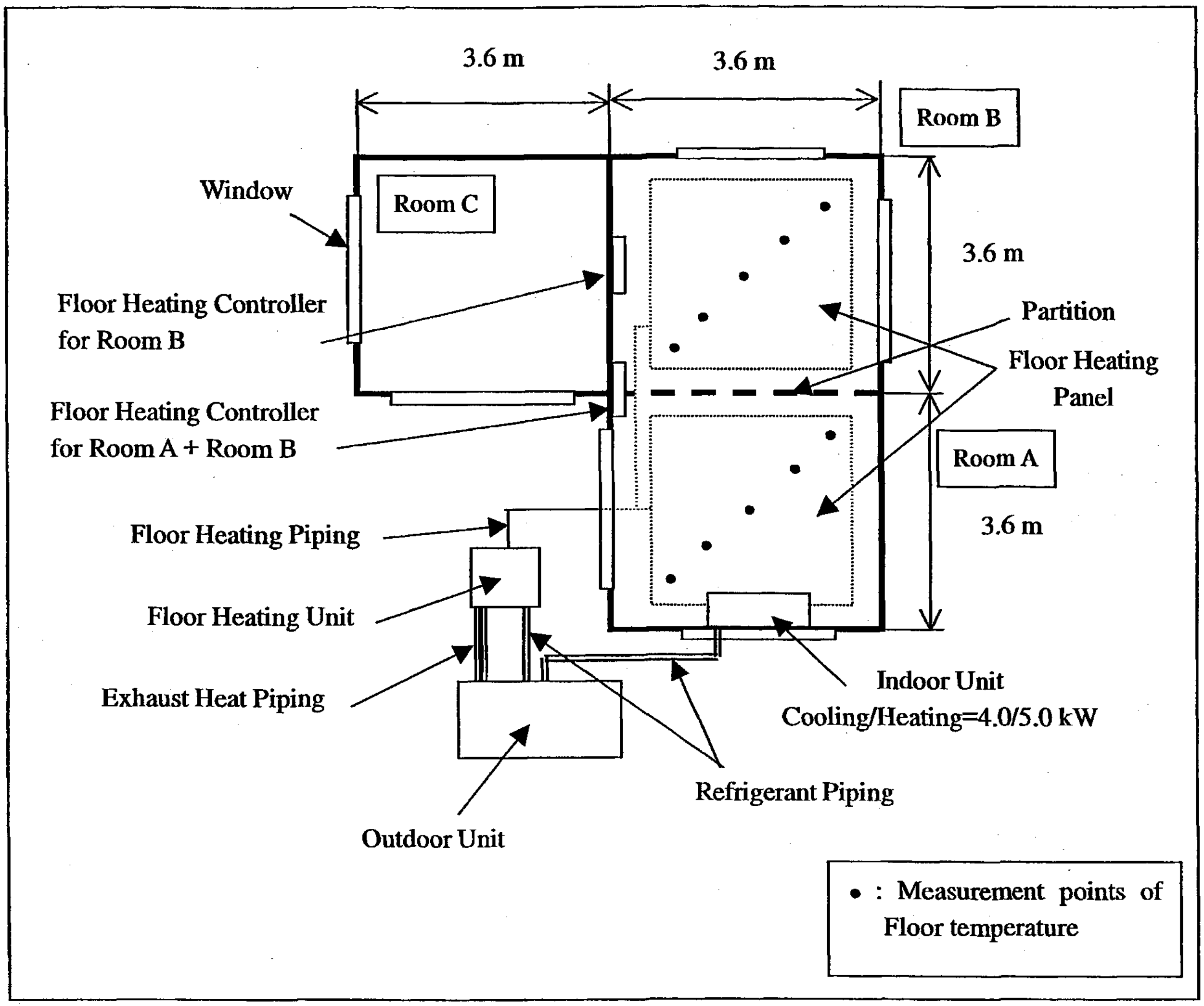

Figure 4. Layout of Laboratory for the Environmental Experiment (Overview)

Table 2. Specifications of the Lab

Number of Rooms	3
Dimensions for Each Room	W 3.6 m×D 3.6 m×H 2.5 m
Overall Heat Transfer Coefficient	Room A 2.09 W/m²K
	Room B 2.09 W/ m²K
	Room C 0.93 W/ m²K

Table 3. Specifications of the Heating Floor Unit

Dimensions	W 0.43 m×D 0.31 m×H 0.45 m
Weight	35 kg
Heating Performance	3.4 kW
Type of Heat Exchanger	Double Pipe Heat Exchanger for Refrigerator
	Double Pipe Heat Exchanger for Cooling Water

Table 4. Starting Condition of the Experiment

Test Room	Room B ($12.96\ m^2$)	• Average Temperature of 5 Floor points = 282 K (9 ℃) • Temperature of Room A and Room C = 293 K (20 ℃) • Temperature Setting of the Controller in Room B = 293 K (20 ℃) • Outside Temperature = 278 K (5 ℃)
	Room A + B ($25.92\ m^2$)	• Average Temperature of 10 Floor points = 282 K (9 ℃) • Temperature of Room C = 293 K (20 ℃) • Temperature Setting of the Controller in Room A+B = 293 K (20 ℃) • Outside Temperature = 278 K (5 ℃)

Table 5. Operation Control of the Floor Heating System

Case	Condition 1	Condition 2 (temperature of hot water to the floor heating panel)	Controlled condensing pressure of refrigerant
Only floor heating operation	For 60 min. after turning on	—	2.25 MPa
	Under the temperature setting of rooms	Under 333 K (60 ℃)	2.25 MPa
		Over 333 K (60 ℃)	1.76 MPa
	Over the temperature setting of rooms	—	1.76 MPa
Air-conditioners and floor heating operation	For 60 min. after turning on	—	2.06 MPa
	—	—	1.96 MPa

Results

Performance of the Starting State (until temperatures of the floor reach to 27 ℃)

We measured the time and the maximum temperature of hot water to the floor heating panel until temperatures of the floor reach to 300 K (27 ℃). The results are shown in table 6. As the circulating water temperature can be as high as the system using instantaneous water heater (gas boiler for residential use), floor temperature can also reach comfortable area (around 300 K (27 ℃)) almost as fast as instantaneous water heater. Figure 5 shows the trend of temperature from the start of the operation.

Table 6. Performance of the Starting State (Test room is Room B)

	This system (only floor heating operation)	This system (5kW indoor unit operation at the same time)	instantaneous water heater using natural gas
Time until temperatures of the floor reach to 300 K (27 ℃)	0.85 hr	0.75 hr	0.87 hr
Maximum temperature of hot water to the panel	342.4 K (69.4 ℃)	341.4 K (68.4 ℃)	346.7 K (73.7 ℃)
Ratio of heat of refrigerant and cooling water	69:31	56:44	—

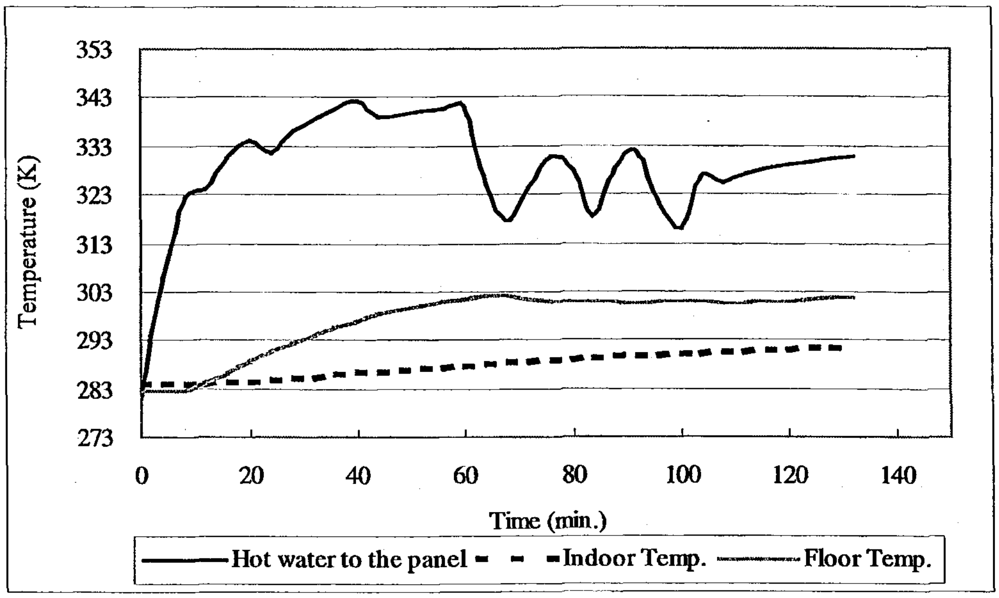

Figure 5. Trend of the Temperature of Floor Heating System using GHP

Performance of the Steady State

After the system reaches the steady state, The temperature of the floor does not fluctuate at all as shown in Figure 6 and table 7. To smooth the temperature of the floor, we take the operation control for this system that when the temperature of the room reaches to the expected temperature, GHP changes the target temperature of hot water to the panel to blow 333 K (60 ℃) (In general, if the temperature of room reaches to the expected temperature, instantaneous water heater turns off.). In this way, we realized to give people comfortable.

In addition, we report the COP of this system in steady state in table 8.

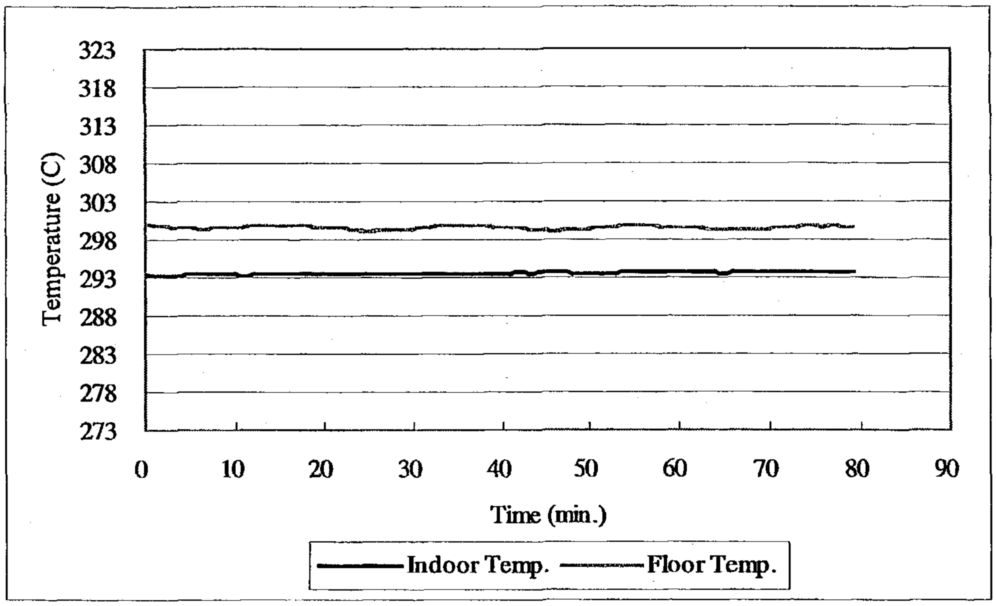

Figure 6. Trend of Temperature of Floor Heating System using GHP after Reaching the Steady State

Table 7. Comparison of Fluctuation in the Steady State

	This system (only floor heating operation)	instantaneous water heater using natural gas
Fluctuation of the floor temperature	0.7 K	1.3 K

Table 8. COP of This System under Only Floor Heating Operation in the Steady State

Test room	B+C
Temp. of hot water to the panel	328.8 K (55.8 ℃)
Ratio of heat of refrigerant and cooling water	47:53
COP	0.98

CONCLUSIONS

We developed a high COP floor heating system by using exhaust heat from GHPs efficiently.

(1) In the starting state, to heat quickly we took the operation control of condensing pressure of refrigerant without reducing its reliability.

(2) In the steady state, to smooth the temperature of the floor we took the operation control of circulating water.

(3) By detecting this system, we showed the possibility to develop the system using exhaust heat for the demand of whole the residential hot water. This system can make hot water whole a year. In addition it will be able to achieve higher COP because of heating city water, it is even colder than circulation water of floor heating.