SPREAD OF GHP AND FUTURE DEVELOPMENT

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ABSTRACT

A Gas Heat Pump air conditioner (GHP) is the air-conditioning system that drives the compressor equipped in the outdoor unit with the gas engine. The number of GHP installed is growing every year due to increased awareness of their advantages such as energy efficiency, small power consumption and low running cost.

In Japan, more than 20 years passes since GHP was released in 1987. We steadily carried out the development of high efficiency GHP, improvement of the reliability, reduction in cost and the expansion of the product variety. As a result, there is the sale number of GHP in a tendency to increase steadily and establishes a firm position in an air conditioner for commercial use by the present.

Recently, the nuclear power plant is damaged by East Japan great earthquake disaster, and electricity shortage is concerned about, and there is the need for reduction in power consumption recently in Japan. GHP which is electric power saving attracts attention more and more in Japan.

In this paper, we introduce the spread of GHP and the latest trend.

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Paper

1. Introduction

1.1 What is GHP?

The gas engine-driven heat pump air conditioner (GHP) has outdoor compressors powered by a gas engine. This is a gas air-conditioning system that heats and cools by means of heat-pump operation. The GHP, in contrast to an electric type of heat pump air conditioner (EHP) that drives the compressor by means of an electric motor, drives the compressor by means of a gas engine. Thus it follows that the GHP has the advantage of using very little electrical power as compared to EHP. The refrigeration cycles for both the GHP and EHP are based on the same fundamentals. However there are advantages such as a significantly reduced defrost operation because, it’s possible for the GHP to utilize the engine exhaust heat during heating.

1.2 Operating principle of GHP

The refrigerant circuit of GHP has compressor(s), outdoor air heat exchanger, expansion valve gear, and indoor air heat exchanger. The refrigerant flow this circuit changing its phase from gas to liquid and from liquid to gas.

In case of cooling cycle, the refrigerant circuit utilizes the behavior of the refrigerant that absorbs the heat of vaporization when it evaporates from liquid to gas as shown in Figure1.

a. The refrigerant gas compressed by the compressor has high temperature and high pressure. This refrigerant gas passes through the four-way valve and condenses in the outdoor air heat exchanger. The condensing heat is radiated to the atmosphere. At this step, the phase of refrigerant changes from gas to liquid, but its pressure still remains high.
b. This refrigerant liquid passes through the expansion valve gear. The refrigerant lowers its temperature and pressure, then portion of refrigerant liquid vapors to gas.
c. The refrigerant changes its phase from liquid to gas in the indoor air heat exchanger. At this time the refrigerant absorb the heat of vaporization from room air, then the temperature of room air is lowered.
d. The refrigerant gas goes back to the outdoor unit and is compressed by the compressor again and repeats same cycle.

In case of heating cycle, the refrigerant flows in the reverse direction. The four-way valve changes the path of the circuit as shown in Figure2.

e. The refrigerant gas is compressed by the compressor then its temperature and pressure rises. This refrigerant gas passes through the four-way valve and goes into the indoor air heat exchanger. The refrigerant condenses from gas to liquid in the indoor air heat exchanger. At this time, the condensing heat is radiated to the room (- the indoor unit blows the hot wind and warms the room temperature).

f. After that, the refrigerant liquid returns to the outdoor unit and passes through the expansion valve gear. And then the refrigerant lowers its temperature and pressure, portion of refrigerant liquid vapors to gas.

g. The refrigerant goes into the outdoor air heat exchanger, and there changes its phase from liquid to gas with absorbing the heat of vaporization from atmosphere. After this step, almost all refrigerant is gas phase with lower temperature and lower pressure.

h. In addition the refrigerant passes trough the exhaust heat recovery exchanger. There the refrigerant absorbs heat from coolant water (hot water) of gas engine.

i. The refrigerant is compressed by the compressor again and repeats same cycle.

Referring to the refrigerant cycle, GHP is different from EHP at "h." step above substantially. GHP have high heating capacity because utilize the exhaust heat of engine. So GHP can operate defrosting cycle without interrupting the heating operation.

1.3 Feature of GHP

1.3.1 Electrical power saving

GHP uses electrical power for only cooling fan and some components. So GHP don't use much electrical power. For example, GHP with 14kW cooling capacity consume electrical power of 0.7kW. The electricity consumption level is equivalent to that of hair dryer. If GHP is installed as air-conditioning equipment, access to electricity can be cut down. And we can utilize the saved electricity that is supposed to be consumed by EHP for illumination or office automation equipment.

1.3.2 The effect of the temperature of outdoor air on heating capability

The heating capability of EHP decreases when the temperature of outdoor air becomes lower because the heat source is outdoor air. In contrast, as previously explained, because GHP utilizes the engine exhaust heat, there is little decrease of the heating capability.

2. Advantages and the spread of GHP

The accumulated sales capacity of GHP in Japan from FY1995 to FY2010 becomes 21.2 million kW (104% compared with the previous fiscal year) as shown in Figure3. The sales volume in Japan is about 227,700 units from FY2003 to FY2010 whereas the volume of it in other regions in the world is about 34,400 units as shown in Figure4. The volume of sales in Japan is about 6.5 times of it in other regions in the world. This depends on the following reason.

a. In the summer, an air-conditioner is used in Japan because of its hot and high humidity. Power peak appears in daytime of summer to use the air conditioner. That is why Power peak cut by GHP is socially necessary.

b. The gas consumption of the summer is smaller in Japan than the winter, and it is necessary for the gas company to let gas consumption of the summer increase from the viewpoint of utilization of a gas storage and supply facilities. Therefore the gas company handles GHP as a strategic product, and we build the system to sell the GHP.

Furthermore, to enlarge a GHP market, it will be necessary in future that the improvement of the efficiency and the correspondence to the huge variety of customer needs.

3. The latest trend

The performance and the reliability of GHP improved drastically in these 20 years, and the product variety has been expanded, too. Furthermore, we have developed the GHP that uses the advantage of the gas engine to the maximum.

3.1 Upsizing

As for the lineup of GHP, the maximum ability was 56kW since release for a while. However, upsizing of GHP is recently required for the large-scale buildings. GHP manufacturers commercialize a large-capacity GHP of 71kW or 85kW. As a result, its economical competition for the large-scale buildings improves and the variation of its cooling capacity spreads.

As another tendency of upsizing the outdoor unit, there is combination multi-type. This connects two outdoor units of 45kW-85kW and offers large capacity of 90kW-170kW. The reliability of this system improves because it can run backup with another outdoor unit even if one outdoor unit breaks down. Furthermore, the efficiency of the system improves because air conditioning load is in a small state and can run it with one outdoor unit. In addition, the extension of life of the system is realized by a rotation function to operate from an outdoor unit of little one of accumulated driving time so that driving time every outdoor unit is made a measuring level.

3.2 Multifunction

3.2.1 GHP with power generating function

GHP uses gas engine as driving source for compressor. So GHP uses electrical power for only cooling fan, coolant pump and some components. The electric power consumed by GHP is just 1/10 or 1/20 of that by EHP of the same capacity. In other words, GHP has the aspect as the electrical power saving air-conditioning system. And the installation of GHP contributes to reducing the peak demand for electrical power in summer significantly.

This feature was evolved further. GHP with power generating function was commercialized in 2003. This system generates 1 kW of electric power using the excess capacity of the gas engine during cooling and heating operations, and this electrical power is supplied to the cooling fan motor and coolant pump, reducing the external power consumed by the outdoor unit. The electric power consumed by this GHP air conditioning system is just 1/500 of that by EHP of the same capacity at the minimum.

GHP with power generating function consumes more fuel gas than standard type in some degree, but the generating efficiency is high because generator utilizes the excess capacity of gas engine. As a result, this system has both merit of low running cost and low CO2 emission.

Furthermore, we commercialized the GHP equipped with 4kW generator as shown in Figure5 in 2006. This system supplies generated power out of an outdoor unit through a grid interconnection. Electric power is generated using the excess power of the gas engine during cooling and heating operations. As a result, the generating efficiency* during the rated cooling/heating operation is about 45% (in terms of low calorific value (LHV)), and during partially loaded operation is about 45–55% (LHV), surpassing the average demand-end generation efficiency of domestic fossil-fired power stations, which is approximately 40%.

* The power-generating efficiency of a generator installed in an outdoor unit is obtained by the following equation (1):

$$\text{Generating efficiency} = \frac{\text{Generated output (kW)}}{\text{Gas consumption increased by power generation (kW)}} \qquad (1)$$

Fuel consumption of GHP is decreasing in recent years because of its performance improvement. GHP with power generating function can make up for the decrease of gas sales partially because the amount of the gas sales increases by power generation.

3.2.2 Simultaneously cooling and heating

GHP that operates cooling and heating at the same time by one outdoor unit has been commercialized. This system is shown in Figure6. With this system one can choose cooling or heating any time with respect to each indoor unit though there is only one outdoor unit. So this system can operate individually for some different conditions at the same time effectively. Under the simultaneously cooling and heating conditions, the performance of this system is very high because the waste heat of the indoor unit in cooling operation and the engine waste heat are effectively used as a heat source of the heating operation.

3.2.3 Supplying hot water

GHP with the function of hot water supply improves total efficiency of GHP because it can effectively use the engine waste heat of it. This function is evaluated in Europe by the overseas presence of GHP, and this function has been almost added to GHP for Europe.

4. Improvement of efficiency

It stands to reason that the development of high-efficiency GHP has steadily progressed since the product entered the market as shown in figure7. However, with the current energy conservation trend, and from the viewpoint of counteracting global warming through the reduction of CO2 emissions, there is a pressing need to further improve GHP efficiency. Accordingly, since 2008 we have worked on the development of a high-efficiency GHP. As a result, we commercialized the GHP having maximum efficiency in the market segment for variable refrigerant flow in April of 2011. In this chapter, we report the high-efficiency GHP in detail.

4.1 Performance evaluation index

The performance of GHP has been evaluated up to now in COPp (Coefficient Of Performance [Primary Energy Base]) at the rated point. However, GHP is hardly driven in rated point actually, and is mostly driven by the partial load. Recently, the evaluation of performance under the condition near an actual usage has come to be attached to importance with the rise of the concern to the energy conservation. APF (Annual Performance Factor) was provided for as a performance evaluation index considered the partial load driving in JIS (Industrial Standards of Japan) in 2006 (see Figure8). To evaluate the performance of GHP and EHP by the same standard, it is necessary to convert the amount of all energy consumption including power consumption into primary energy. APF converted into primary energy is shown APFp. In Rationalization in Energy Use Law in Japan, it is provided to the conversion of the electric power of 1kW into primary energy 9760kJ.

4.2 Initiatives for efficiency improvement

The efficiency of GHP is determined by the product of the gas-engine drive source’s efficiency and the refrigeration cycle efficiency. Accordingly, for our development we decided to work on both aspects of the issue: efficiency improvements for the gas engine as well as the refrigeration cycle.

As previously discussed, we focused on the APFp as the efficiency during the partial-load operation. It was particularly important to improve the efficiency during 50% load in order to improve the APFp. Consequently, it was important for us to incorporate a number of technologies that improved the partial-load operation efficiency. There are differences in the adopted technologies, depending on the GHP manufacturer, but the key technical details are explained below.

4.3 Gas engine efficiency improvements

4.3.1.1 Downsizing the gas engine

In order for an engine to intake combustion air into the combustion chamber, as well as to expel the exhaust gases, a pumping motion is used. A portion of the engine output power is used for this pumping motion, and that portion is seen as a loss from the net power of the engine. This is referred to as the "pumping loss." A throttle valve is used to regulate the amount of intake air, which controls the output power of the gas engine, but under conditions in which the throttle is constricted, the throttle valve resists the incoming air and the efficiency is reduced.

Regarding the case where identical output power is obtained from engines having different displacements, because there is no power margin in the smaller-displacement engine, the throttle tends to stay open, resulting in a lower degree of pumping loss. On the other hand, because there is an output power margin for the larger displacement engine there is a tendency for the throttle to be constricted and the pumping loss to increase. Because this difference in pumping loss becomes apparent in the engine efficiencies, generally speaking, for cases in which the identical output power is obtained from engines having various displacements, the engines with smaller displacements will have lower fuel consumption.

For the gas engines used for the GHP, the engine displacement corresponding to the air-conditioning capacity is selected. However, because general-purpose engines are diverted to this application there are cases in which a small amount of excess power will be provided. Focusing on that fact in our product development, in order to optimize the engine output we sought improved efficiency by reducing the engine displacement (downsizing).

4.3.1.2 Drive at high torque

As shown in Figure 9, in the RPM range of gas engines for the GHP, there is a basic tendency for the efficiency of an engine to improve as it operates at higher torque. A typical GHP is shown in Figure 10, showing that the rotational motion of the gas engine is output to a pulley, whereupon a belt transmits the power to the compressor pulley, rotating the compressor. Because of this arrangement it is possible to increase the rotational torque by increasing the diameter of the engine pulley.

Another basic characteristic of GHP is that the air-conditioning power output is controlled by adjusting the engine RPM up or down. Because the air-conditioning power output is proportional to the quantity [engine RPM x torque] when only the torque is increased, it isn't possible to run at conventional low-load conditions. Therefore, for identical air-conditioning output it is necessary to reduce the engine RPM in the case of high-torque operation. For conventional GHP, the engine RPM is also reduced to be near the limit, and even lower engine-rotation speeds will give rise to issues such as vibration and durability. These are challenges we are undertaking.

In our development, when the engine pulley diameter was increased it was possible to operate at high torque by simultaneously expanding the engine range on the low-RPM side. In this way the engine efficiency was improved and an improvement in GHP efficiency was achieved.

4.3.2 Efficiency improvements of the refrigeration cycle

The outdoor air heat exchanger is an important component that influences the efficiency of the refrigeration cycle. During cooling operation we can see that the outdoor air heat exchanger functions as a condenser, with the high-pressure gas refrigerant from the compressor being cooled by the outside air and thereby condensing into a liquid refrigerant. We worked on the performance improvement of the outdoor air heat exchanger with the objective of improving the efficiency of the refrigeration cycle.

4.3.2.1 Optimizing the path of the outdoor air heat exchanger refrigerant

The heat exchanger performance is dependent on the heat-transfer coefficient on the refrigerant side. Here the heat-transfer coefficient is expressed as a function of the Reynolds number, as shown in the equations below. Because the Reynolds number is proportional to the flow rate, it is possible to improve the performance of the heat exchanger by increasing the flow rate of the refrigerant. On the other hand, when the flow rate is increased there is also an increase in pressure loss. Because there is an increased pressure loss when the flow rate of the gaseous portion is increased, the average condensation temperature is decreased and the performance of the heat exchanger is degraded. Moreover, the pressure loss decreases as the refrigerant density increases. Therefore, for the gas portion of the flow, the pressure loss increases; for the liquid portion, the pressure loss decreases.

$$h = Nu\ k/L$$
$$Nu = 0.664 Re^{1/2} Pr^{1/3} \quad (Re<10^5)$$
$$Re = UL/v$$

h: heat-transfer coefficient [W/(m2K)]
k: fluid thermal conductivity [W/(mK)]
U: flow rate [m/s]
L: length in flow direction [m]
Nu: Nusselt number
Re: Reynolds number
Pr: Prandtl number
v: kinematic viscosity [m2/s]

For conventional outdoor air heat exchangers, as shown in the upper part of Figure 11, the gas refrigerant that is compressed in the compressor diverges at the entrance to the heat exchanger, where there are multiple rows of pipes and flows are in parallel. At the exit of the heat exchanger, the piping arrangement allows the streams of the refrigerant, now liquid, to recombine. As shown in the lower portion of Figure11, the structure of our developed system separates the liquid and gas portions of the flow. For the gas portion the flow path is increased over conventional arrangements, resulting in reduced pressure loss. On the liquid side, where the pressure loss is small, the flow path is reduced; such an arrangement yields an increased flow rate. Thus there is both a reduction in pressure loss and an increase in the heat-transfer coefficient, resulting in an improvement in the heat exchanger performance.

4.3.2.2 Modification of the outdoor air heat exchanger fin pitch

GHP outdoor air heat exchangers are of the direct-flow type, with aluminum plate fins attached to copper refrigerant pipes as shown in Figure12. The spacing alignment of these aluminum fins has been made narrower than in the prior versions, and consequently it has become possible to increase the number of fins without increasing the size of the heat exchanger. Accordingly, the heat transmission area was increased and the heat exchanger performance was improved.

4.4 New model performance

4.4.1 Efficiency

There is a lineup of newly developed GHPs with cooling capacities ranging from 45 kW to 85 kW, available for sale since 2011. By combining the technologies introduced in this paper, the efficiency targets have been reached, with the frontrunners attaining an APFp of 2.05. Each model has an APFp of 2.00 or greater as shown in Figure13. An APFp of 2.05 is the highest efficiency in the market segment for variable refrigerant flows (regardless of gas or electric type).

4.4.2 Environmental performance

Accompanying the improved efficiency, environmental performance is also improved. An objective comparison of the environmental performance as compared to a prior model is given in Figure14. For the 45 kW model having the greatest efficiency improvement, the year-long primary energy consumption amount is reduced by 19%, and the yearly CO2 discharge amount is reduced by 20%.

4.4.3 Installation

More than 25 years have elapsed since the first GHP units were sold, and there is increased demand to replace the old models that have outlived the service life. As a result of this demand for updating, there is a minimum requirement that the installation area should be equal to or less than that of the old models. From that standpoint it was possible to provide all models of the newly developed GHP with footprints equal to or less than those of the prior models.

5. Added value

5.1 Blackout start GHP

Recently, the nuclear power plant is damaged by East Japan great earthquake disaster, and there are threats of electricity shortage and power interruption. For this reason there is the need for operating air conditioning system during electrical power interruption. Furthermore, at emergency evacuation area like school, there is the need for utilizing GHP with power generating function equipped with 4kW generator as the electrical source.

GHP with power generating function equipped with 4kW generator cannot operate in case of power outage because this system utilizes the external power supply to start.

We develop the black out start GHP which can start and operate in case of power outage shown as Figure15. This system is based on GHP with the power generating function and has a battery that enables it to air-condition and generate power in case of power interruption. When there is excess electrical power during power interruption, this system supplies excess power to illumination or outlet.

5.2 Remote supervisory control system

The remote supervisory control system provides the service that observes operating condition of GHP for 24 hours. Breakdown information is automatically sent to the control center even if GHP breaks down by any chance, so we can learn the detailed information before receiving the call from the user. This system enables the failure detection at the early stage and repair in a short time.

Service in which the user can monitor the condition of GHP and the gas consumption on the Internet has been put to practical use as additional service as shown in Figure16. Moreover, we are providing service which the operating start/stop and the temperature management of the GHP indoor unit are automatically done by remote control while observing a useless operation such as forgetting to stop the GHP indoor unit and an excessive temperature setting. This service supports the user's energy conservation operation throughout the year.

5.3 The hybrid power generating system using renewable energy

The photovoltaic power generation is very clean energy. However, as for the quantity of generation, the quantity of generation fluctuates based on quantity of sunlight which changes with weather and time. On the other hand, as for GHP with power generating function equipped with 4kW generator, the generation output fluctuates based on air conditioning load to control quantity of generation by the surplus power of the gas engine as shown in Figure17.

In addition, this system cannot generate electricity during the period not to operate air conditioning because this system realizes high efficiency generation by generating electricity at the time of air conditioning driving. In this way, the generation output is not stable when facilities that the generation output fluctuates based on a setting condition and operating conditions individually is installed. The generation output often becomes small for the inverter rating output. Therefore the system which fused in photovoltaic power generation and GHP with power generating function equipped with 4kW generator was developed as shown in Figure18. In this system, a rate of operation of the inverter improves by using inverter in common and enables stable generation by controlling quantity of generation generally. This system as shown in Figure19 was released in April, 2011.

This system uses the photovoltaic power generation output with precedence. This system controls quantity of generation to add generation by this GHP with quantity of generation to be short for the inverter rating output. This system enables the reduction of the energy consumption by using more than 40% of high efficiency generation of GHP together with photovoltaic power generation.

Usually, this GHP gives priority to air conditioning performance and runs generates electricity in the range of engine surplus energy, so this system may not generate electricity to inverter rating when generation from photovoltaic power generation decreases. Therefore this system comprises the generation priority function that becomes able to add to engine surplus power by regulating air conditioning ability to stabilize peak power reduction more.

This system combines a natural energy with high efficiency gas generation and is the product which can contribute to electricity load equalization by stabilizing the generation output.

6. Future development

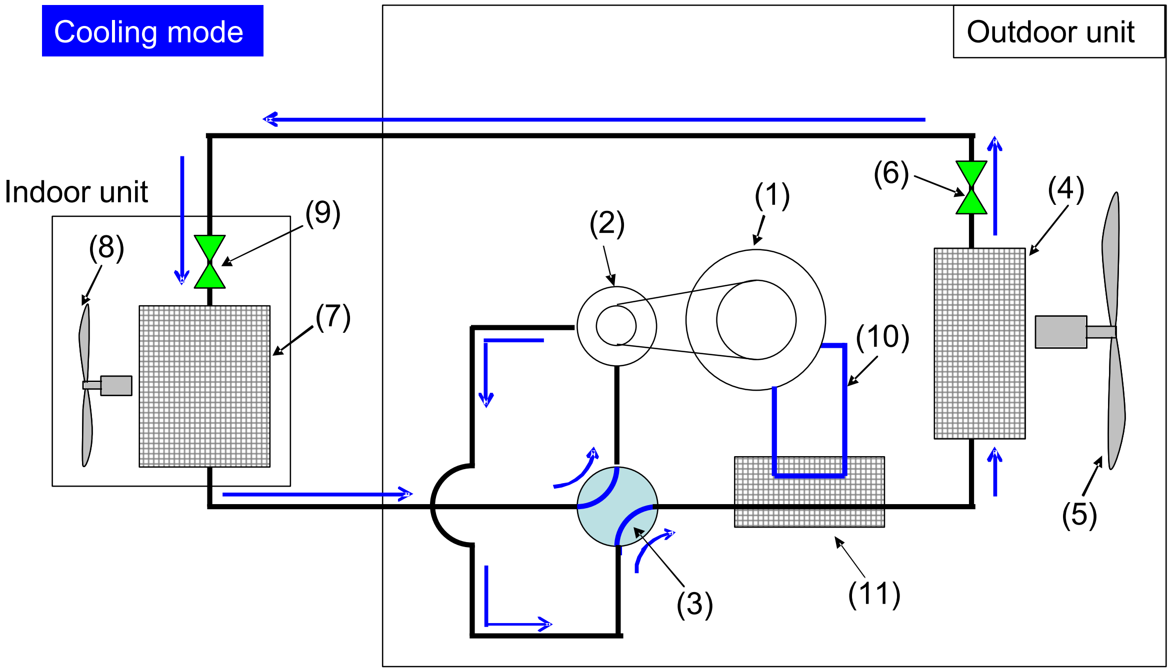
Recently, customer needs of energy saving and environmental improvement have risen. Therefore development of high efficiency GHP required.

In addition, the hybrid generation system which fused in photovoltaic power generation and GHP with power generating function equipped with 4kW generator was developed in April 2011 as the challenge to the construction of the low-carbon society. This system is that power generation by GHP with 4kW generator supports the natural energy that is easy to fluctuate based on a climate, and the stable generation output is provided. That is why this system makes it possible to reduce peak power effectively.

Recently, the nuclear power plant is damaged by East Japan great earthquake disaster, and electricity shortage is concerned about, and there is the need for reduction in power consumption recently in Japan.

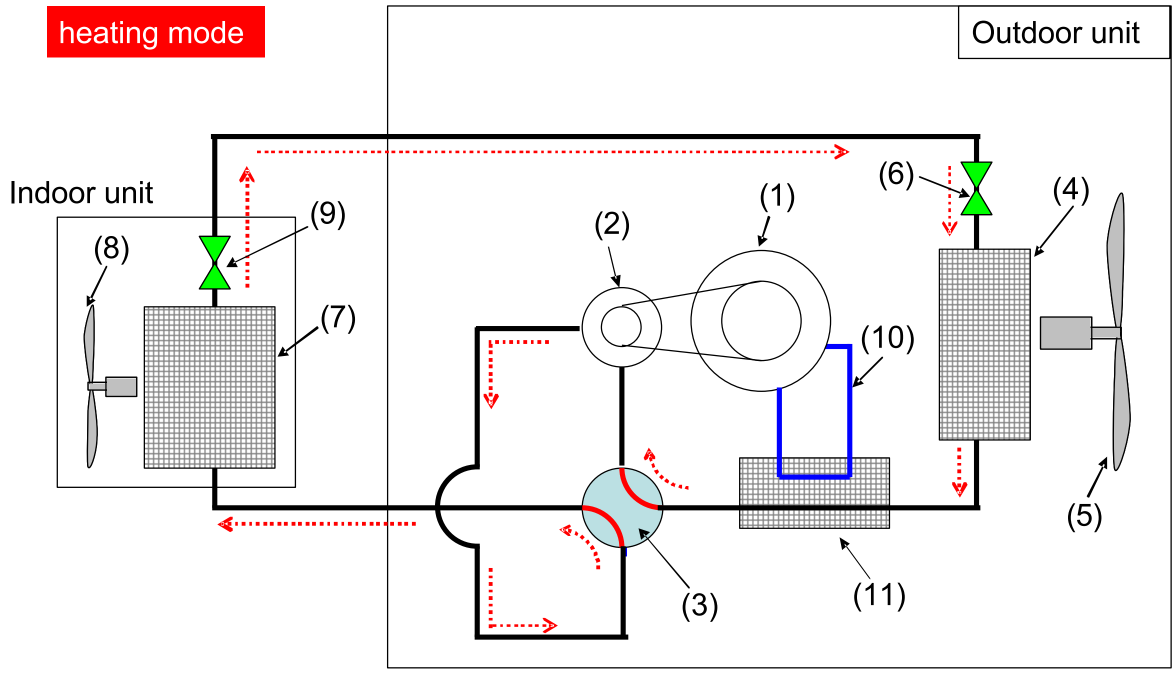
We will work in the development of the GHP that may be able to use the waste heat effectively and the improvement of more highly efficient GHP in the near future.

7. List of Figures



(1)gas engine, (2)compressor, (3)four-way valve, (4)outdoor air heat exchanger, (5)outdoor cooling fan, (6)outdoor unit expansion valve gear, (7)indoor air heat exchanger, (8)indoor fan, (9)indoor unit expansion valve gear, (10)coolant water circuit, (11) exhaust heat recovery exchanger

Figure1.Refrigerant circuit of GHP when cooling mode



(1)gas engine, (2)compressor, (3)four-way valve, (4)outdoor air heat exchanger, (5)outdoor cooling fan, (6)outdoor unit expansion valve gear, (7)indoor air heat exchanger, (8)indoor fan, (9)indoor unit expansion valve gear, (10)coolant water circuit, (11) exhaust heat recovery exchanger

Figure2. Refrigerant circuit of GHP when heating mode

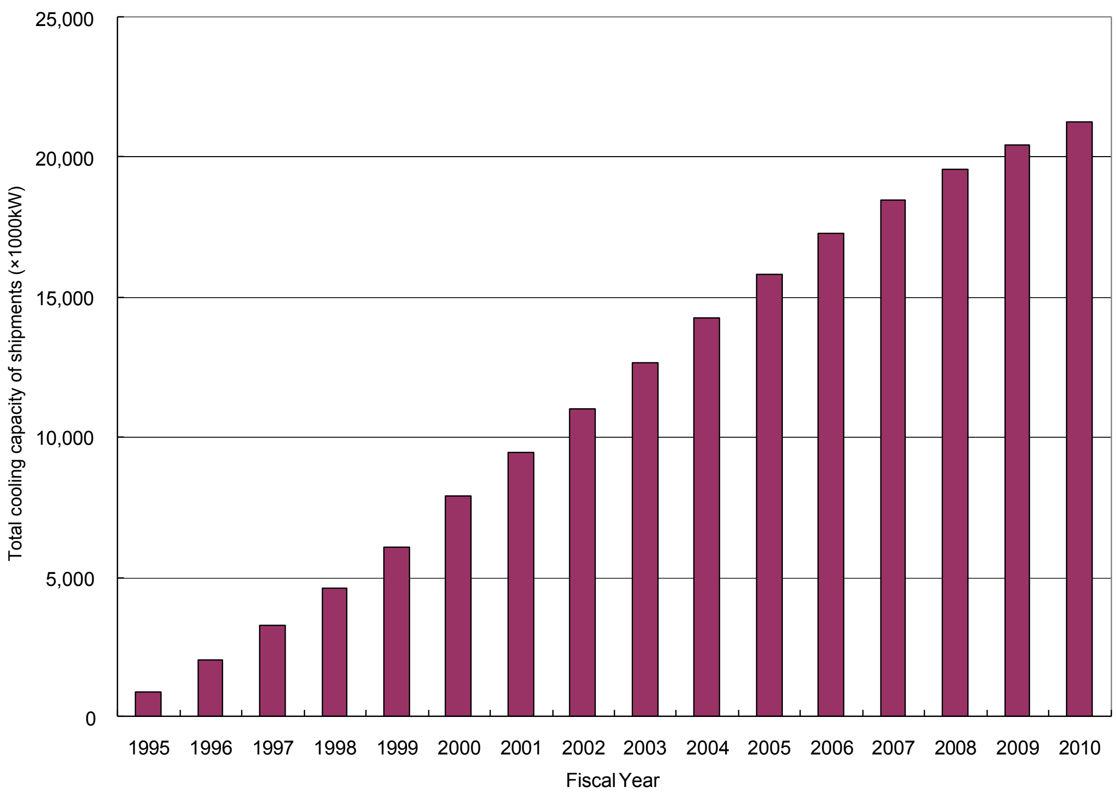


Figure3. Spread of GHP in Japan (FY1995-FY2010)

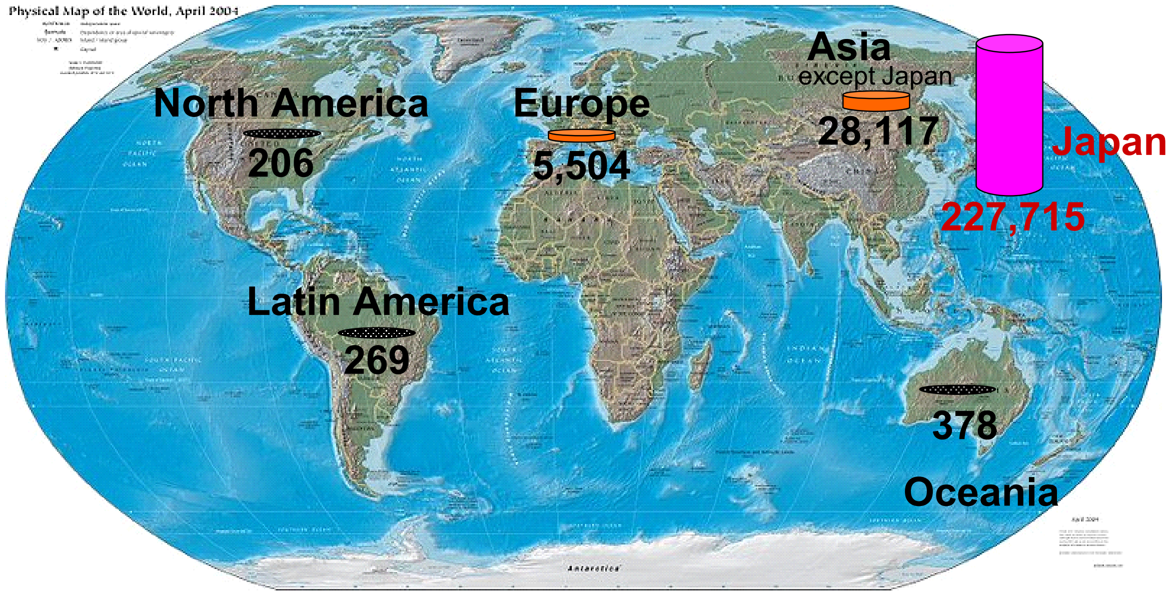


Figure4. Spread of GHP in the world (FY2003-FY2010)

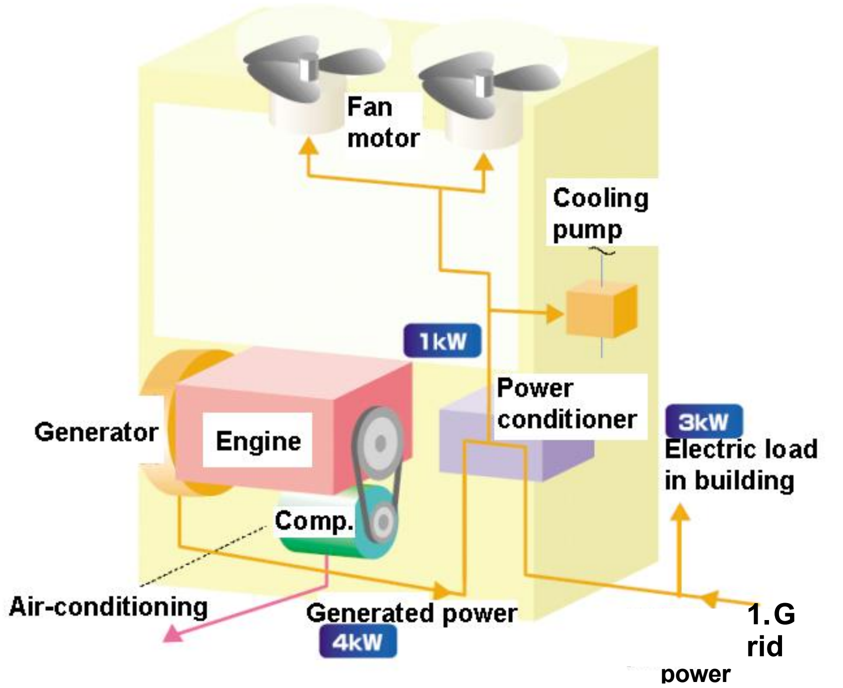


Figure5. System Outline of GHP equipped with 4kW generator

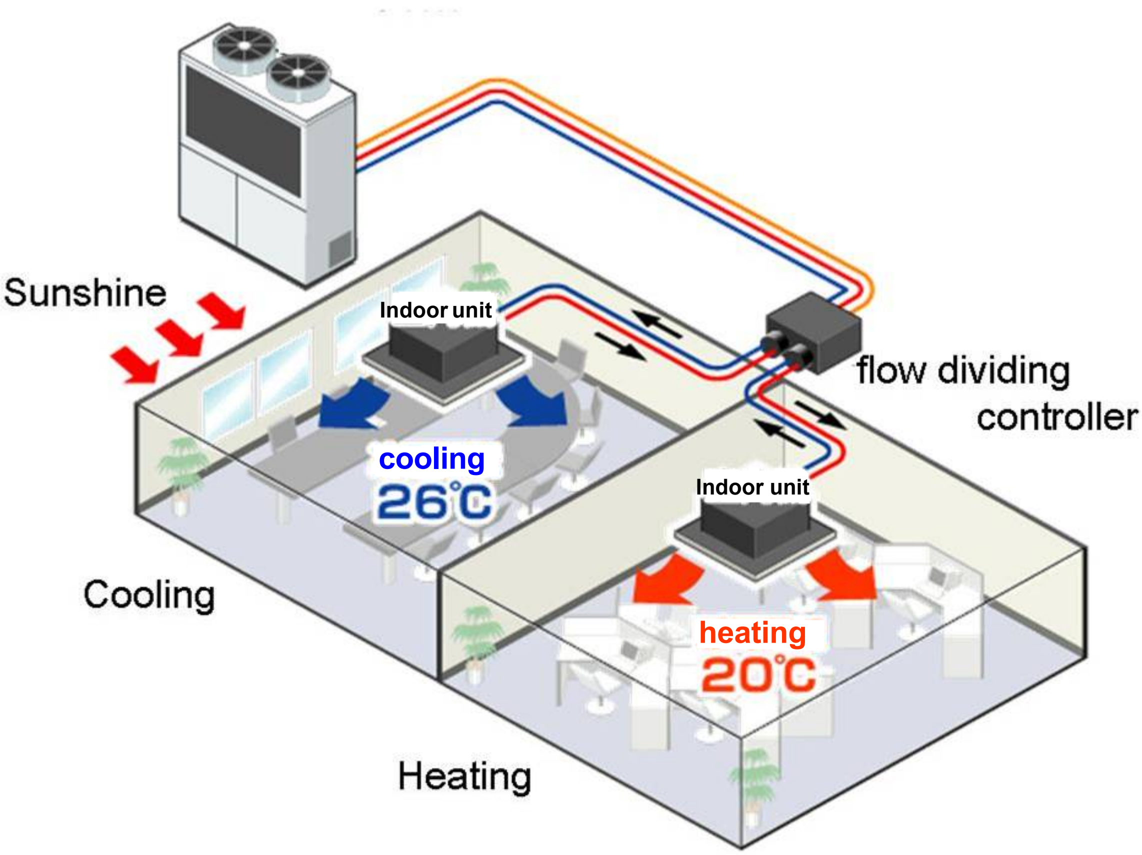


Figure6. Simultaneously cooling and heating system

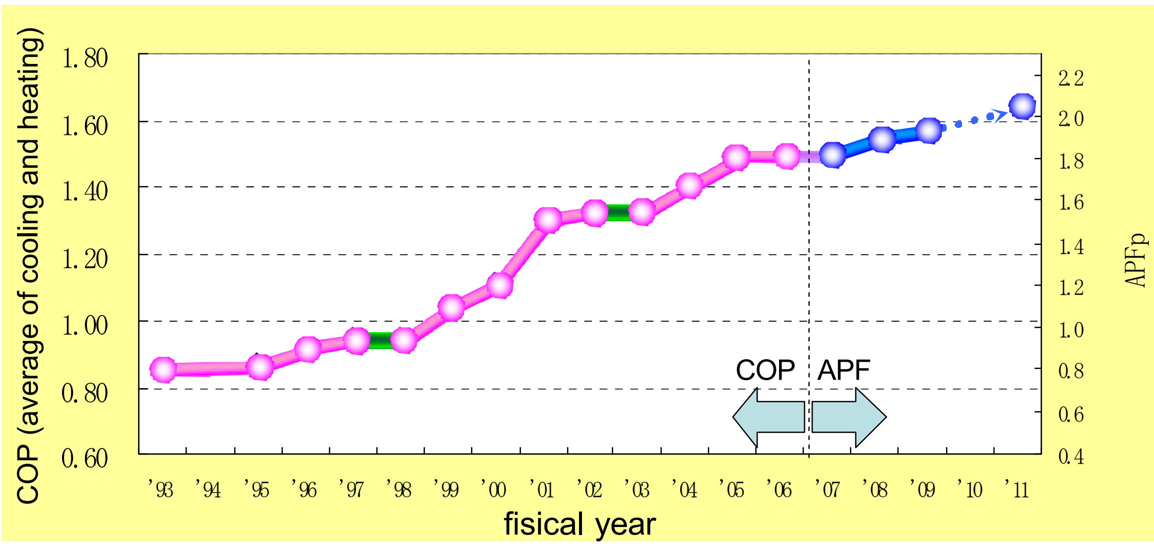


Figure7. GHP efficiency trend

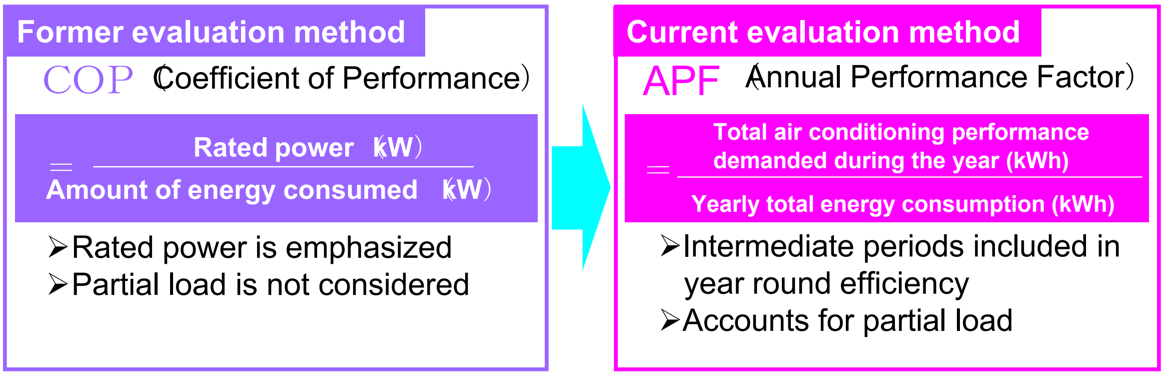


Figure8. Efficiency indicators

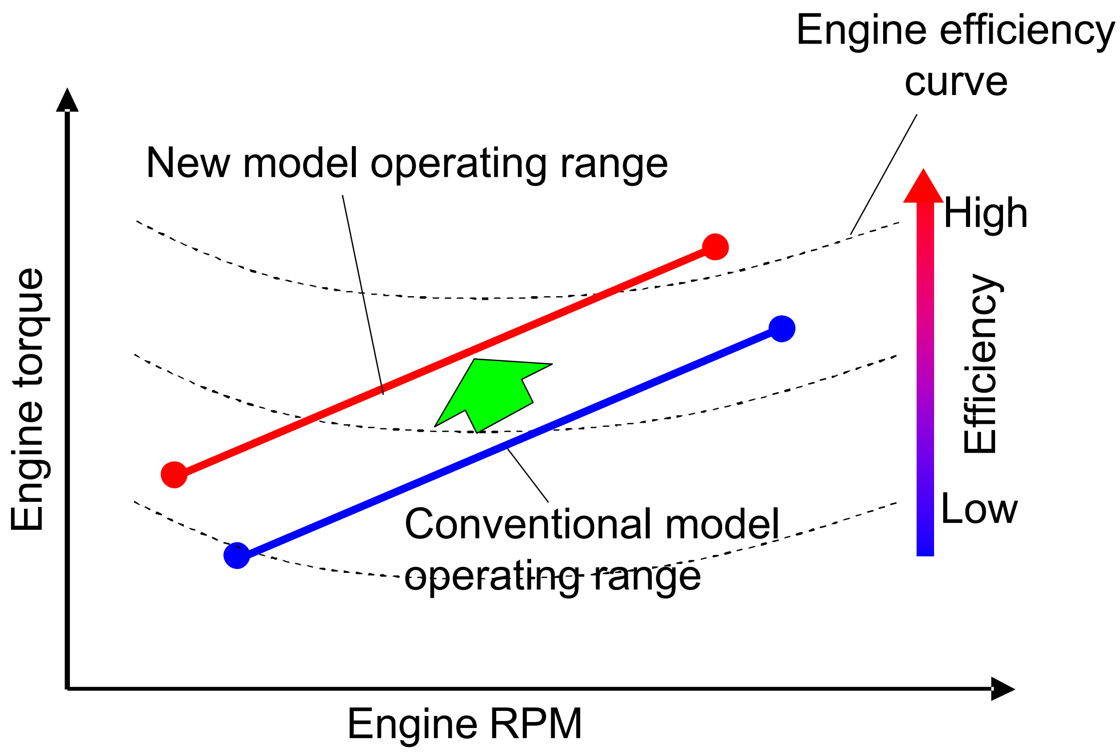


Figure9. Engine efficiency characteristics

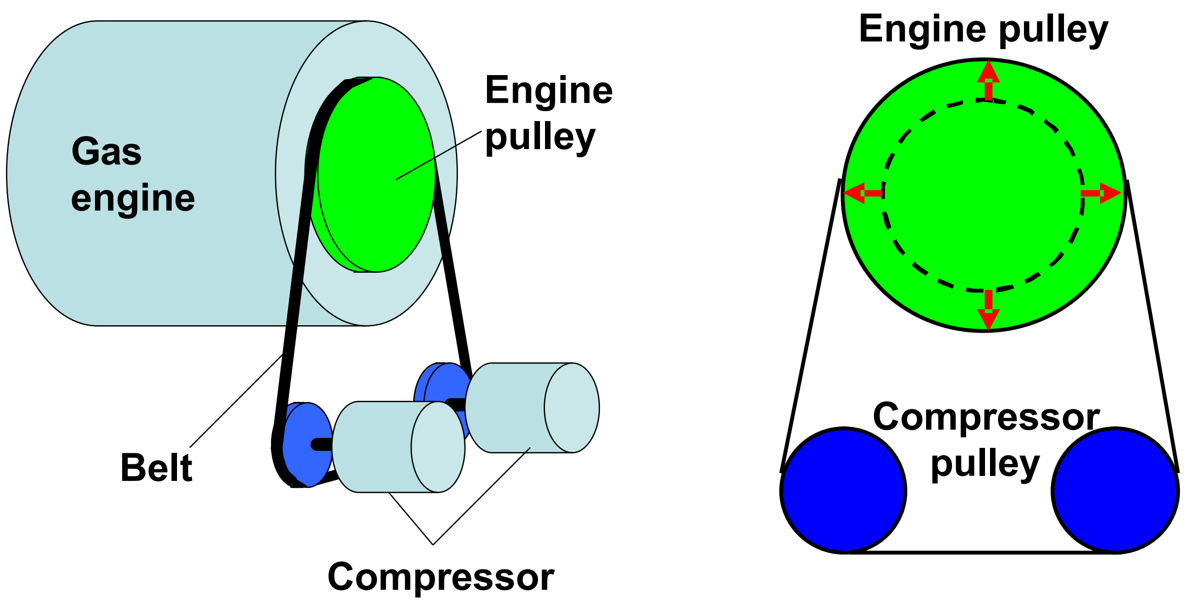


Figure10. Rotational power transmission schematic diagram

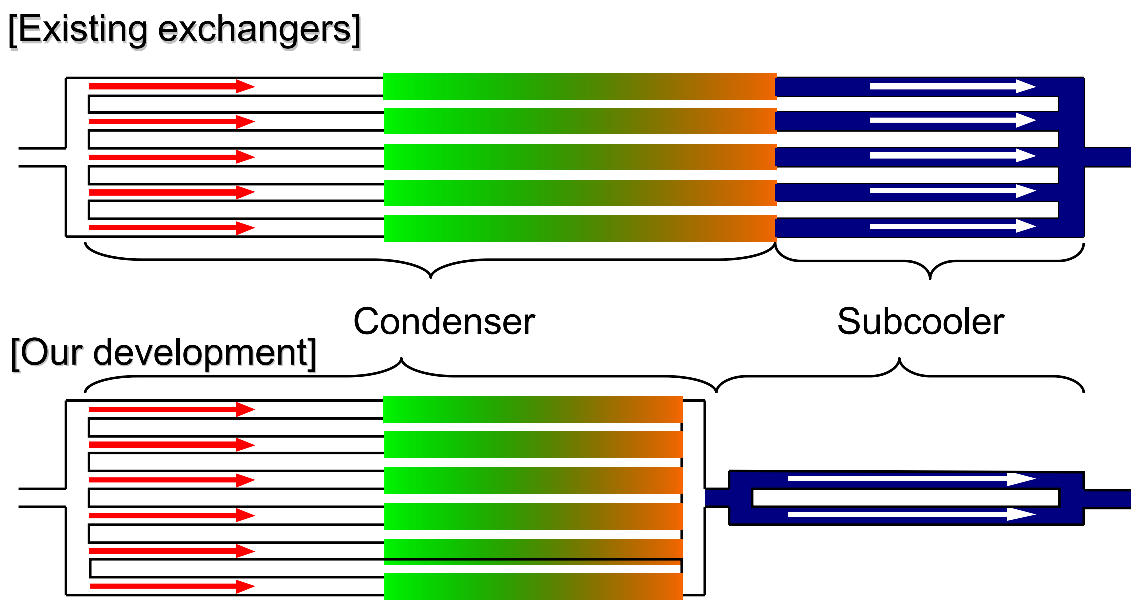


Figure11. Outdoor air heat exchanger refrigerant flow path

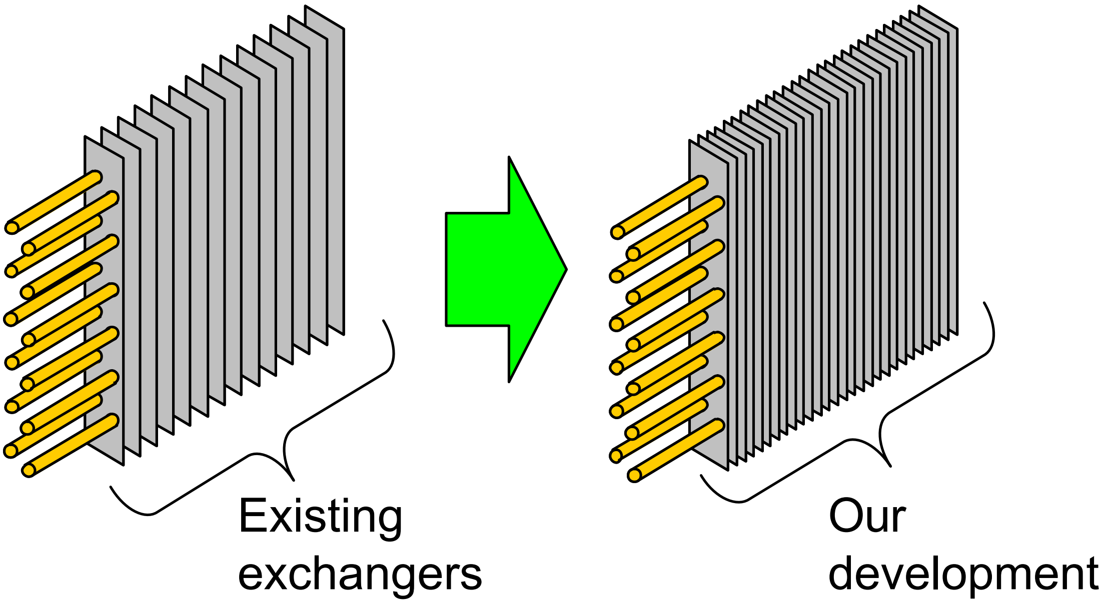


Figure12. Heat exchanger fin pitch

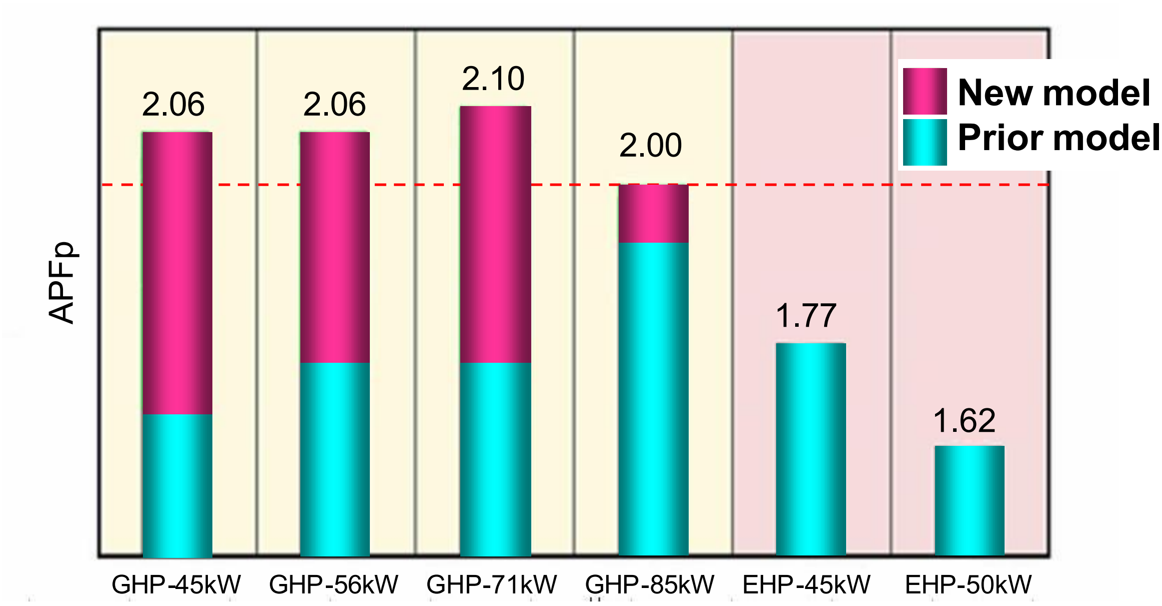


Figure13. New model GHP efficiencies

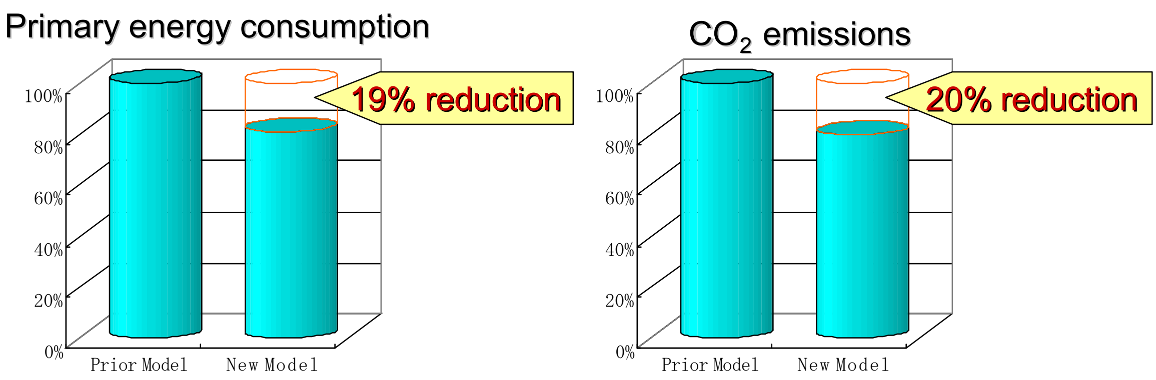


Figure14. Environmental performances of the new model GHP

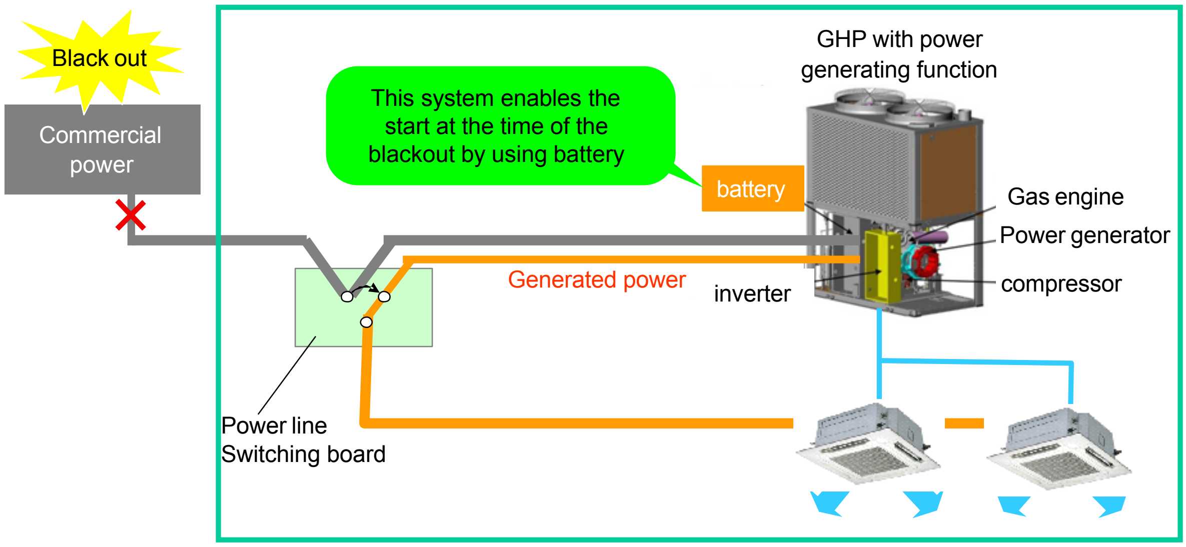


Figure15. Blackout start GHP

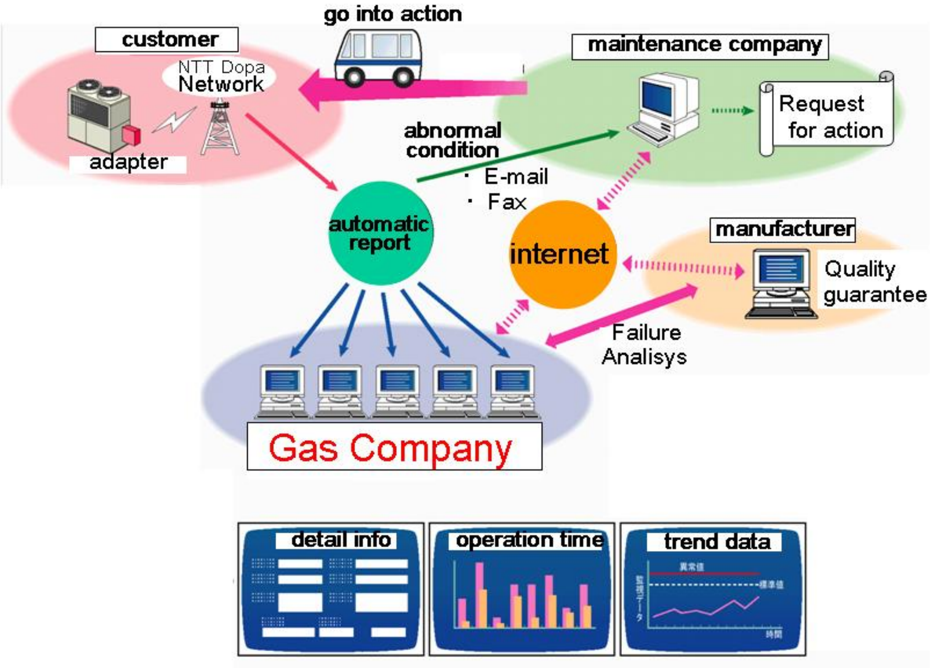


Figure16. Remote supervisory control system

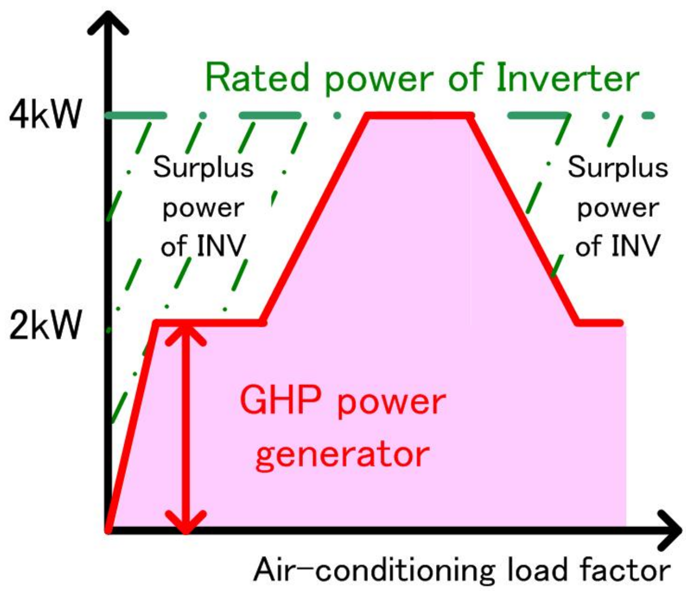


Figure17. Relations of air-conditioning load factor and the generation output of GHP equipped with 4kW generator

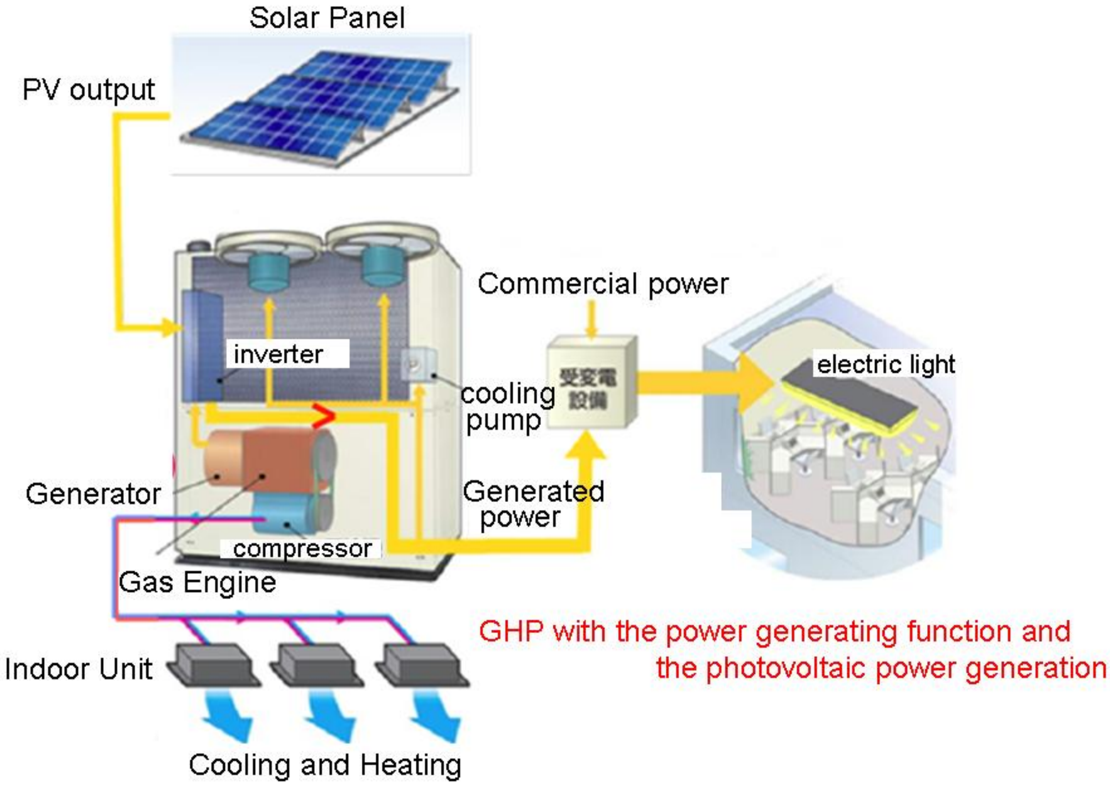


Figure18. Overview of the hybrid power generating system using renewable energy

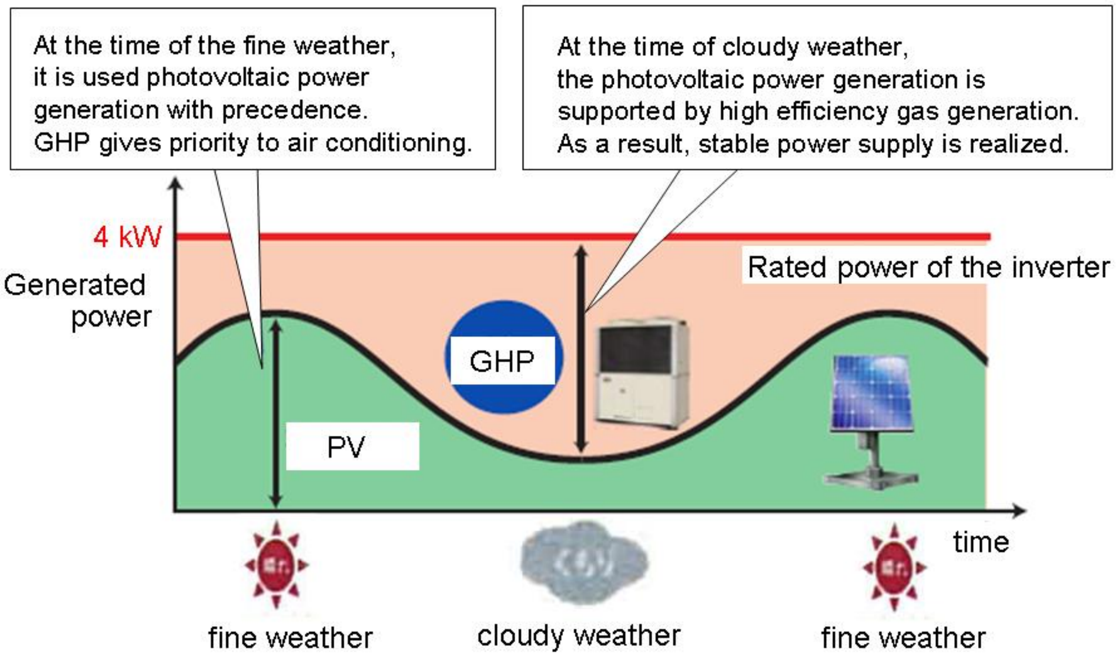


Figure19. The power generation image of the hybrid power generating system using renewable energy