3

Further guide to the Heat Pumps

Q1. Why does the wide use of heat pumps contribute to prevention of global warming?

Trump Card in Measures Against Global Warming Doing Without Combustion

Reducing CO_2 emitting combustion of fossil fuels as much as possible is effective to prevent global warming.

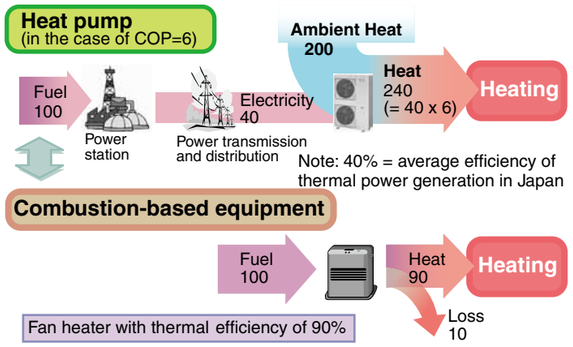
From this point of view, heat pumps do not burn fuels at the places of use of heat. Instead, heat pumps efficiently utilize clean and inexhaustible unused energy such as "heat in the air" and "heat in the ground," which exist everywhere. As heat pumps make it unnecessary to burn fossil fuels, they significantly reduce CO_2 emissions in large quantity, and are very effective as a measure to prevent global warming.

With the wider use of heat pumps, it is no longer a distant dream to create combustion-free and low-carbon society.

Breakthrough of Limit of Energy Efficiency

Heat pumps collect heat energy several times as large as the amount of electricity inputted to operate them. Moreover, the performance of heat pumps has continued to improve year by year, and the amount of electricity needed to collect the same amount of heat has decreased. As a result, heat pumps make it possible to utilize the amount of heat energy in far excess of the amount of primary energy inputted at power stations, even though the loss at the time of power generation is taken into consideration. If a heat pump of COP6 (= 600% thermal efficiency) is operated by the electricity of 40% generating efficiency, the input of primary energy of 100 produces heat energy of 240 (= 100 x 40% x 600%) that is more than twice as large the inputted energy. Heat pumps have largely broken through the limit of efficiency of conventional combustion-based equipment that cannot produce larger heat energy than the amount of primary energy inputted under the thermal efficiency limit of 100%.

Figure 3.1.1 "Heat Pumps" Can Utilize Heat Energy in Excess of Energy Inputted at Power Station.



Expectations on Synergistic Effect with Efforts to Reduce Carbon of Power Sources

Highly efficient heat pumps consume a small amount of electricity when they convey heat, and CO_2 is emitted when this electricity is generated. However, this amount of CO_2 is much smaller than the amount of CO_2 emitted by directly burning fossil fuels with combustion-based equipment to produce heat.

Moreover, as the electricity to operate heat pumps is generated not only by CO_2 emitting thermal power generation but also by CO_2-free energy such as nuclear power, hydroelectric power, wind power, photovoltaic, etc., CO_2 emissions from heat utilization can be drastically reduced by the synergistic effect of the progress of carbon reduction in power source portfolio and further improvement of energy efficiency of heat pumps.

Heat Pumps to Simultaneously Achieve 3 Es

As mentioned above, the promotion of reduction in usage of fossil fuels and improvement of efficient use of energy through "utilization of ambient heat" with heat pumps can bring about triple merits, i.e., energy utilization can be ensured with less cost, less usage of fossil fuels and less CO_2 emissions. In other words, three Es that stand for Economic Growth, Energy Security and Environmental Protection can be achieved at a time, bringing about a great effect of not merely preventing global warming.

From another point of view, heat pumps bring about a paradigm shift from an "expendable" way of energy utilization that directly burns fossil fuels as finite and natural resources to a recycling use of "heat in the air" as inexhaustible renewable energy of solar origin. Heat pumps can be evaluated as the key technology to create sustainable society.

Q2. What merits does the use of heat pump air-conditioner for heating bring about?

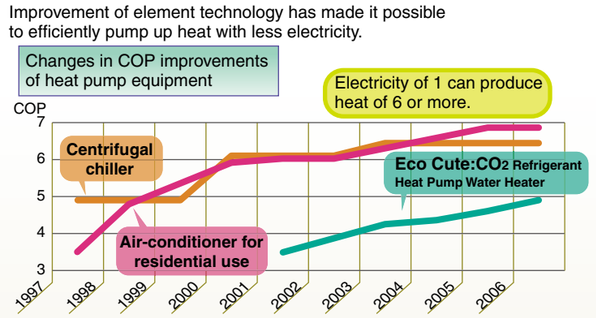
World's Top Class Energy-Saving Air-Conditioners of Japan

Japan is the country where air-conditioners of the world's highest efficiency have come into wide use. It is no exaggeration to say that such air-conditioners are the energy-saving technology that holds the foremost position in the world.

In Japan blessed with a mild climate, heat pump air-conditioners used at home and in offices play a double role as both cooler in summer and heater in winter.

According to a survey conducted by the Cabinet Office, heat pump air-conditioners were found in about 87% of Japanese households on the national average as of the end of March 2006.

Figure 3.2.1 Heat Pumps of Japan Are Remarkably Increasing Their Efficiency in Recent Years



COP (Coefficient of Performance:energy consumption efficiency)
= cooling or heating capability / power consumption
<As for air-conditioners for residential use, COP at the time of cooling by the most efficient air-conditioner with the cooling capability of 2.2 kW class>

Improvement of Efficiency by Inverter Air-Conditioners

With the advent of inverter air-conditioners, the full-scale age of air-conditioners came in the 1980s. An inverter is a mechanism that freely changes the RPM of a compressor that compresses the refrigerant that conveys heat. With alternative current, the RPM of a motor is constant in proportion to the frequencies of electricity. For this reason, air-conditioners in olden days had poor efficiency as they could not cope with temperature changes because of "operation at a constant RPM speed." With the advent of inverter air-conditioners, their performance significantly improved.

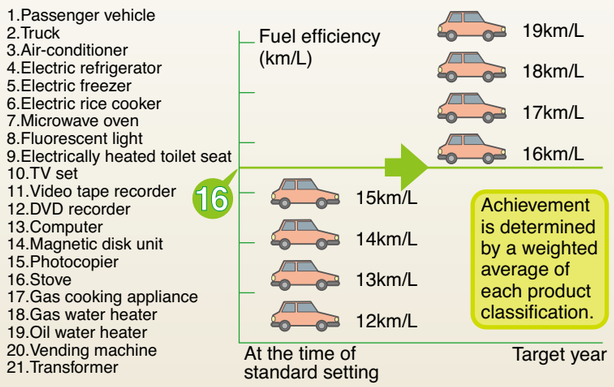
Inverters made it possible to "operate air-conditioners at variable RPM in proportion to frequencies. Inverter air-conditioners operate at a high RPM speed at the start of operation and achieve the set temperature in a short time. For both cooling and heating, inverter air-conditioners shift to low-RPM operation once they achieve a desirable preset temperature, and then operate at flexible RPM to maintain the temperature. Therefore, comfortable room temperatures can be maintained by small power consumption.

Competition for Efficiency Under Top Runner Regulations*

In Japan, moreover, the efficiency (COP) of heat pump itself has drastically improved in recent years. In the early 1990s, COP was about 3. Since 1999 when the top runner regulations were applied under the revised Law Concerning the Rational Use of Energy, manufacturers began competing for high-efficiency products. Element technologies such as compressors, heat exchangers, motors, etc. were polished up. At present, a large number of products with efficiency in excess of COP = 6 are sold on the market. As a result, air-conditioners have reduced power consumption by one-half from ten years ago and they have become the best heating appliance in terms of cost, energy conservation, and environmental protection.

* The top runner regulations are a regulatory program that was introduced in the latter half of the 1990s in Japan as a mechanism to foster continuous improvement of efficiency of energy-consuming equipment such as vehicles and home electric appliances. Specifically speaking, the top runner regulations have made it mandatory for those companies that produce or import the specific products designated by the Law Concerning the Rational Use of Energy to improve the energy-saving performance of their products higher than that of respective best products now made available on the market by the target fiscal year.

Figure 3.2.2 Image of Top Runner Regulations of Japan
Specific types of equipment (21 types) and examples of top runners



Least Costly and Least CO_2-Emitting Heating System

In Japan, however, though air-conditioners have been improved to increase efficiency and reduce cost in reality, there are still many general users who have a wrong preconceived notion that "electric heating with heat pumps requires high running cost" probably because of the impression of inefficiency home air-conditioners in olden days in Japan. Maybe for this reason, despite the high ownership rate of heat pump air-conditioners that can play a double role as both cooler and heater, they are not used for heating in winter in reality.

The comparison of energy prices per MJ in the Tokyo metropolitan area as of November 2006 shows that the energy price of high-efficiency air-conditioners of COP = 6.6 is 0.9 yen, that of kerosene stoves with thermal efficiency of 100% is 2.1 yen, and that of gas stoves with thermal efficiency of 100% is 2.5 yen.

Similarly, the comparison of CO_2 emissions per MJ shows that CO_2 emissions of high-efficiency air-conditioners of COP = 6.6 are 0.015 kg-CO_2, that of kerosene stoves with thermal efficiency of 100% are0.068 kg-CO_2, and that of gas stoves with thermal efficiency of 100% are 0.051 kg-CO_2. [see. chapter 1. Figure 1.4]

As indicated above, the running cost for heating and CO_2 emissions of heat pump air-conditioners are one-third to one-fourth of that of oil and gas combustion-based equipment. Actively utilizing such efficient equipment to reduce CO_2 emissions is a very realistic measure.

CO_2 emissions from homes in Japan amount to about 3.5 tons per household a year, and heating accounts for 20% thereof. Oil and gas combustion-based equipment accounts for 90% of energy consumption for heating. Utilization of heat pump air-conditioners, of which CO_2 emissions are as small as one-third to one-fourth of that of kerosene and gas stoves, allows comfortable energy conservation.

In the not-distant future, equipment that recycles heat within a home in various forms may make its debut such as those that have functions to boil water with waste heat from cooling, recover heat from hot water in a bathtub, etc. by capitalizing on the characteristics of heat pumps.

Q3. I understand that heat pumps are now utilized for hot water supply in Japan. What is the current situation of such heat pumps?

World's First Revolution in Hot Water Supply

The world's first natural refrigerant heat pump water heater named "Eco Cute" was developed in 2001. Eco Cute is an epoch-making product that "boils water with heat in the air," and does not emit CO_2 at homes. Eco Cute involves only a small amount of CO_2 that is emitted when the electricity to operate its heat pump is generated. Compared with conventional combustion-based water heaters, Eco Cute reduces CO_2 emissions by one half or more. Because of such characteristics, the widespread use of Eco Cute has been actively promoted with the Japanese government as the central figure as the trump card in energy conservation and CO_2 emission reductions with a target to putting 5.2 million units into wide use (about one million units are now in use as of 2007) by 2010.

Large Room Remaining in Hot Water Supply Field for CO_2 Emission Reductions

About one-third of the energy used at homes in Japan is used for hot water supply. Hot water used at homes is used at kitchens and bathrooms. Most of such hot water is supplied by gas and oil combustion-based equipment.

Eco Cute is much more efficient than conventional water heaters because Eco Cute collects ambient heat in the air to boil water, rather than burning gas and oil to take out heat energy. Moreover, Eco Cute needs electricity that is only about one-third to one-fifth of "one unit of heat" to collect. Therefore, Eco Cute produces heat energy that far exceeds the primary energy consumed at power stations, even if the loss at the time of generation of electricity is taken into consideration. For this reason, Eco Cute can dramatically reduce the damage to the environment.

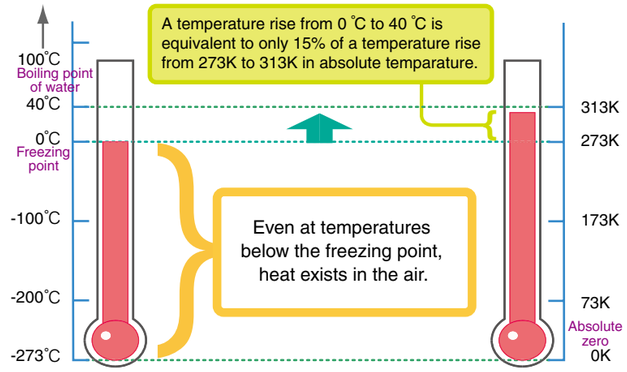
Method of Boiling Water with Heat in the Air

When we boil water for bathing, we usually burn fuels such as oil and gas, create a "high temperature" of 1,000℃ or higher with the energy contained in fuels, and create hot water of 40℃.

On the contrary, Eco Cute collects "low-temperature" heat of ambience to boil water.

As defined by a physical law, heat flows from a high-temperature substance into a low-temperature substance. For example, therefore, hot water in a coffee cup gets cool over time.

Figure 3.3.1 "Heat in the Air" Pumped up by Heat Pump



However, even though hot water gets cool, "heat" in hot water does not disappear but the heat just moves into the air around the coffee cup. Therefore, if the heat moved into the air is pumped up somehow and returned into the coffee cup, cooled water becomes hot water again. This mechanism to pump up heat is a heat pump.

Unused Energy Existing in the Air

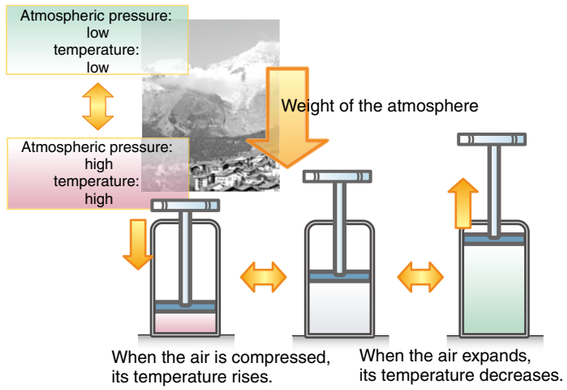
Heat energy is the molecular motion energy of substances. When molecules stop moving, the temperature does not go down anymore. This state is called the "absolute zero (0K)," which is equivalent to minus 273.1℃. Therefore, the air at 0℃ where water freezes seems to have no temperature but actually has heat of as much as 273K in terms of 0℃. If this heat is utilized by a heat pump, it is easy to raise the water temperature up to 40℃, even when the ambient temperature is 0℃ in midwinter, just by raising the temperature from 273K by only 15%. To raise the temperature by 40℃ or so, it is not necessary to create heat of 1,000℃ or higher by burning oil and gas.

Mechanism of Heat Pump

Now, we would like to explain the mechanism of a heat pump to pump up heat from the air and boil water.

The pressure and temperature of the air have the relation that "the higher the pressure increases, the higher the temperature rises, and contrariwise the lower the pressure decreases, the lower the temperature drops." If such characteristics of substances are utilized, close compression of the "gas that has taken in heat from the air" raises the temperature. If this high-temperature and high-pressure gas is contacted with cold water, the water takes heat away from the gas and become high-temperature hot water. In other words, a heat pump is a device that artificially creates a "high-pressure and high-temperature" state and a "low-pressure and low-temperature state to collect heat in the air.

Figure 3.3.2 Relations Between “Pressure” and “Temperature” of the Air Utilized byHeat Pump (Boyle-Charle’s law)



Development of CO_2 Refrigerant Mechanism

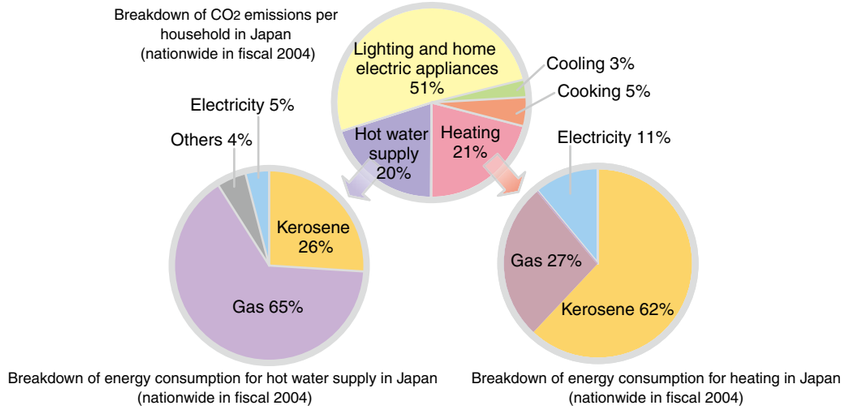
In the past, heat pump air-conditioners for cooling and heating used chlorofluorocarbons (CFCs) as the substances (refrigerants) to convey heat. However, CFCs have a weak point that cannot efficiently acquire necessary heat for hot water supply. In the case of Eco Cute, this weak point was surmounted by using CO_2 as a refrigerant. Central Research Institute of Electric Power Industry that was engaged in the research on CO_2 refrigerant water heaters in Japan, Denso Corporation that was engaged in the research on CO_2 refrigerant automotive air-conditioners, and Tokyo Electric Power Co. started a joint research in 1998.

If CO_2 is compressed by a super-high pressure, CO_2 enters an intermediate state between gas and liquid (supercritical state). According to the past research, it was found that heating with a large temperature difference is easy and heating to 90℃ or higher is possible, if such intermediate state is utilized.

Therefore, they developed new equipment and technology such as a compact and high-performance compressor to apply a pressure of 100 atmospheres, about five times as large as the pressure applied to CFCs, to CO_2 and create a supercritical state. As a result, "Eco Cute" heat pump water heater that uses a natural refrigerant for the first time in the world was put on the market in May 2001 in Japan.

As a result of research and development to utilize substances that exist in the natural world as refrigerants to avoid ozone depletion and global warming due to the use of CFCs, an epoch-making water heater that saves energy and reduces CO_2 emissions was born. As of 2006, COP = 4.9 models (that can produce heat of 4.9 with electricity of 1) are now on sale.

Figure 3.3.3 Heating and Hot Water Supply Fields Dominated by Combustion-based Equipment Have a Large Room for CO_2 Emission Reductions.



Effect of Eco Cute to Reduce CO_2 Emissions

Now, we would like to explain the effect of Eco Cute to reduce CO_2 emissions at homes.

In the case of COP = 4 Eco Cute, CO_2 emissions are reduced by about 65% compared with conventional water heaters. It can contribute to CO_2 emission reductions by about 0.8 tons a year per household in Japan. The figure represents about 20% of 3.5 tons of CO_2 emissions per household a year.

In Japanese households, hot water supply accounts for about 20% of CO_2 emissions. In this hot water supply field, CO_2 emitting combustion-based water heaters had the largest share. In the hot water supply field where there is such a large room for CO_2 emission reductions, the technology that can dramatically reduce CO_2 emissions in a realistic manner was developed.

Recycling Use of Heat in the Air

If natural resources such as oil and gas are burned as fuels, they run out in due course. If they are used as chemical products, they can be recycled and reused. Taking this point into consideration, it is "wasteful" to burn valuable natural resources, which can be used for other applications, merely to boil water up to 100℃. Instead, if a lot of unused heat distributed in the air is collected and heated by using electricity, hot water can be produced easily and efficiently.

At the COP9 conference held in Milan in December 2003, Japanese Environment Minister (then) Yuriko Koike introduced to the world the Eco Cute as "Japan's state-of-the-art technology to prevent global warming," together with CFC-free refrigerators and hybrid cars. We hope such evaluation is established soon in the world.

Q4. I understand that heat pumps are utilized in a wide range of fields. What applications are they used for?

In Japan, heat pumps for residential use have long been used in refrigerators and air-conditioners for cooling and heating, and are now used at almost all households in Japan. In recent years, moreover, heat pumps are incorporated in water heaters and clothes washing and drying machines, and they are rapidly coming into wide use as their performance to save energy and reduce CO_2 emissions and cost is highly evaluated.

As is the case with homes, heat pumps are also used for space cooling and heating in office buildings and shops as well as in refrigerators. Heat pumps are widely utilized for refrigerated display cases for sale of fresh food, and cooling and keeping warm of soft drinks in vending machines.

On the city level, heat pumps are utilized for "district heating and cooling " to supply heat to multiple buildings and structures in a collective manner. Warm heat and cold heat for district heating and cooling is also produced by “combustion-based” equipment such as oil and gas boilers, waste heat from co-generation and the like. However, heat-pump-based equipment that utilizes various types of unused heat such as heat in the air, river water and sewage boasts much higher energy efficiency and much lower environmental loads compared with "combustion-based" equipment.

In the industrial field, heat pumps are utilized in: cryogenic warehouses for frozen storage of fresh foods; the method to maintain the freshness of agricultural products with cold and humid air; the method to freely reproduce natural environment such as temperatures and humidities and efficiently cultivate various agricultural products; and the efficient heating method to drastically reduce boiler fuels by utilizing "vapor recompression" that compresses vapor that is usually thrown away and recycles the heat of the vapor.

The most advanced semiconductor plants have clean rooms where highly efficient heat pumps for business use are introduced to hold temperatures and humidities constant in all seasons around the year. Highly efficient inverter centrifugal chillers, which are capable of variable-speed operation and of which the part-load operation efficiency is dramatically improved, have been recently made available on the market, and there are many high-tech companies that have enhanced the competitiveness of their products as they succeeded in significant energy conservation and CO_2 emission reductions by fully utilizing such centrifugal chillers.

Moreover, warm heat in manufacturing plants was usually supplied by the steam produced by boilers in the past. As for such application, heat pumps have been also introduced because heat pumps are more efficient to meet the demand for heat at relatively low temperatures such as in the fields of hot water supply, warming and drying.

Figure 3.4.1 Various Applications of Heat Pumps in Proportion to Scale and Temperature

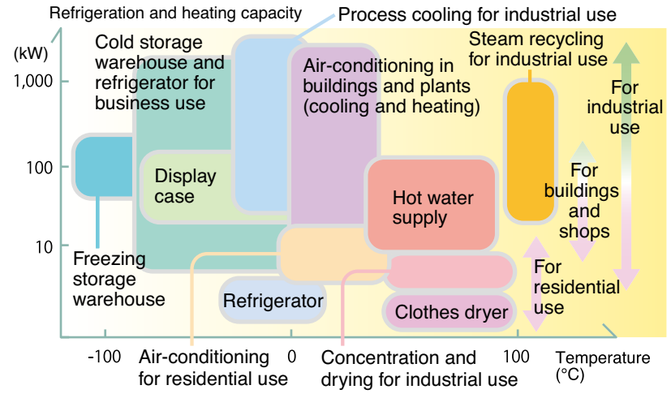
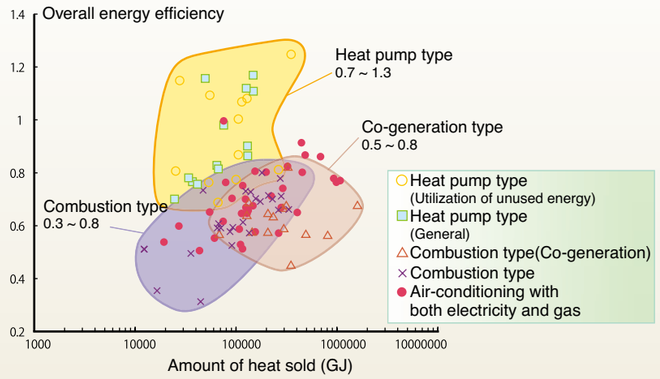


Figure 3.4.2 Heat Pumps Are also Highly Efficient for District Heating and Cooling in Japan. (Overall energy efficiency at each typical point: actual results in fiscal 2005)



Q5. I understand that the performance of centrifugal chillers as large cooling equipment is also rapidly improving. What is the current situation of such centrifugal chillers?

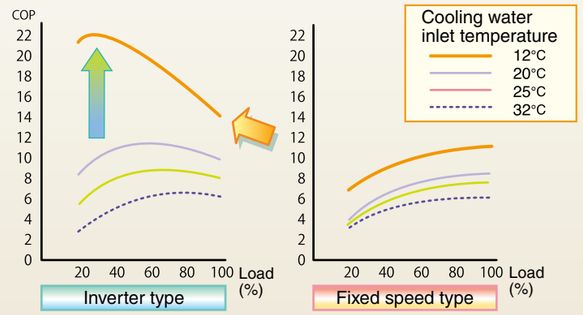
Heat pumps convey heat by repeating the process of compression and expansion of refrigerant as the substance to convey heat. To efficiently compress the refrigerant in large quantities, centrifugal chillers rotate impellers at high speed, blow off a large quantity of refrigerant gas with the centrifugal force and efficiently compress the gas. Centrifugal chillers are mainly used for air-conditioning in large facilities such as buildings and factories, etc.

The efficiency of centrifugal chillers has increased by 30% or more in the past ten years or so. As a result of such rapid improvement of performance, the energy efficiency of centrifugal chillers at their rated output has reached COP = 6 or higher. This is because of the inventions made in the manufacturing of equipment such as designs of efficient shapes of impellers by using the three-dimensional computational fluid dynamics (CFD) that is applied for the development of aircraft and rockets, processing of impellers by fully utilizing numerically controlled processing technology, and drastic improvement of performance of heat exchangers.

Moreover, advanced centrifugal chillers , of which the efficiency is increased to COP = 20 or higher by inverter-controlled variable-speed operation at the time of partial load, are also newly developed.

Such high performance is highly evaluated by industrial and institutional users, and centrifugal chillers are actively introduced by 24-hour air-conditioning semiconductor plants equipped with clean rooms, computer centers, etc. as the trump card to save energy and reduce CO_2 emissions. As a result, new shipments of centrifugal chillers exceeded that of combustion-based absorption-refrigerators that had a large share in Japan in the past. The market of centrifugal chillers is rapidly expanding.

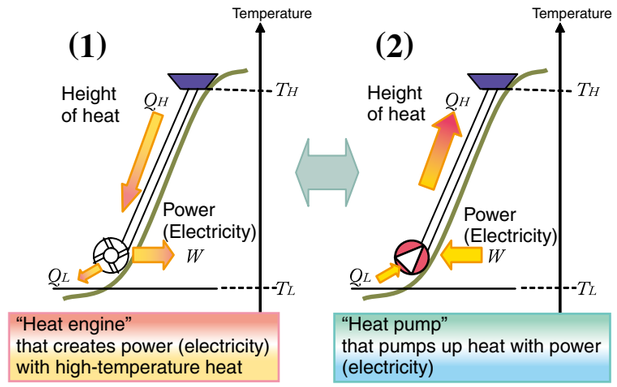
Figure 3.5.1 COP of Partial Load Performance of Centrifugal chiller by Inverters



Data provided by Mitsubishi Heavy Industries, Ltd.
(AART type/cool water 7°C specifications, US1000Rt class)

Q6. Heat pumps are now used to utilize heat in a wide range of applications. What history do heat pumps have?

Figure 3.6.1 Concept of Heat Pump Invented by Carnot
(To reversely perform the work performed by a heat engine)



Discovery of Principle

The theory about the principle of heat pump to "pump up temperatures from the lower temperature side" was formulated in 1824 when Sadi Carnot, a French physicist presented for the fist time the results of his research on a series of cycles where a heat pump operates as an ideal engine.

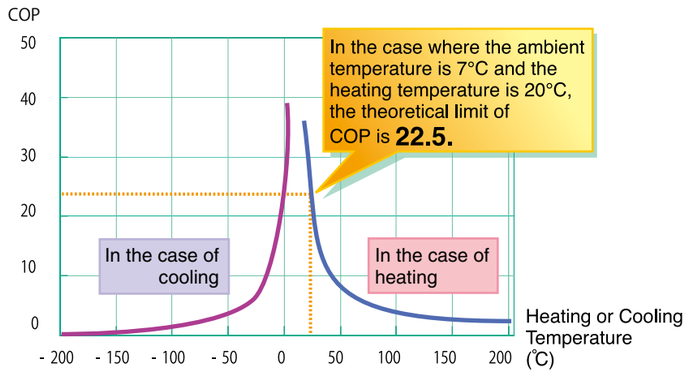
The concept of the heat pump system invented by Carnot is shown in the diagram. The "heat engine" in Figure (1) produces power (electricity) with high-temperature heat. He invented that low-temperature heat can be pumped up by the power (electricity) as high-temperature heat as shown in Figure (2), if the engine is operated in a reverse manner.

Such concept was actually made fit for practical use in the 1850s. Refrigerators that use natural refrigerants such as the air and ammonia were developed in the U.S. and France.

Then, refrigerators began being applied for cooling in the 20th century.

Heat pumps as a mechanism to pump up heat can be used for both cooling and heating, but they were used mainly for cooling because the efficiency of then heat pumps was low and fuel prices were also low.

Figure 3.6.2 Theoretical COP of Heat Pump
(in the case where the environmental temperature is 7℃



Smaller the Temperature Difference, Higher the Efficiency

As a result of improvement of efficiency since then, heat pumps are also used for heating. Today, heat pumps are expected to be the most promising tool as a measure against global warming.

The efficiency of heat pumps has very interesting characteristics, i.e., "the smaller the temperature difference between the temperature to be created and the temperature of heat source is, the larger the COP becomes, and contrariwise the larger the temperature difference is, the smaller the COP becomes." For example, in the case where the room temperature is heated to 20℃ when the ambient temperature is 7℃ (280K), the theoretical value of COP is 22.5. This value is calculated by "293K / (293 - 280) K." In reality, however, the COP has not reached the theoretical value because of a mechanical loss, etc.

This means, however, that heat pumps are more efficient than combustion-based equipment for cooling and heating to create a "temperature difference of a few tens of ℃" needed for daily life such as cooling and heating, hot water supply, etc.

Q7. Japan seems to be actively promoting technology development of and giving policy-based support to heat pumps. How about Europe and America?

Mainly Utilization of Heat in the ground in Europe and America

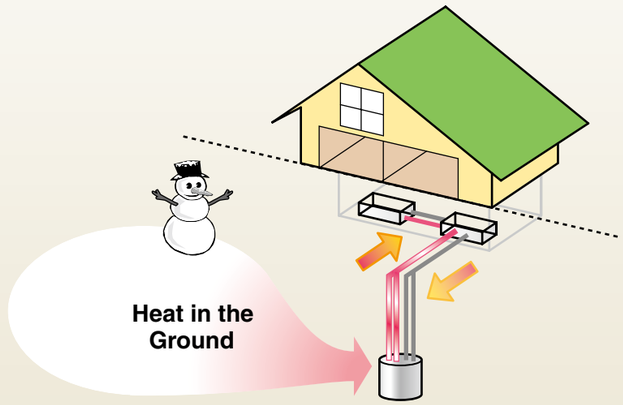
In Japan where the climate is mild, "heat in the air" is generally collected and used as the heat source for cooling, heating and hot water supply by heat pumps. Even if the ambient temperature is 20℃ below zero, hot water can be supplied by Eco Cute. However, the efficiency cannot help but decrease as the lower the temperature drops, the larger the temperature difference increases at the time of pumping up.

Therefore, in Europe and North America where the climate is rather cold, ground source heat pumps that utilize "heat in the ground," of which the temperature remains stable in all seasons because of almost no effect of ambient temperature, are widely used. As the temperature in the ground is cooler than that of the outside air in summer and warmer in winter, heat in the ground can be an effective heat source that can be utilized as a heat source for both cooling and heating. Moreover, heat in the ground comes from the earth surface warmed by the sun, and can be utilized by anyone and anywhere, as is the case with heat in the air.

In Europe and North America, heat in the ground began being utilized early by ground source heat pumps for heating in place of boilers.

Ground source heat pumps were introduced before World War II. In the wake of the oil crises in the 1980s, the widespread use of ground source heat pumps was accelerated. At present, about 600,000 units of ground source heat pump are reportedly installed in North America, and about 450,000 units of this type in Europe.

Figure 3.7.1 Ground Source Heat Pump Widely Used in Cold Climate Areas in Europe and America



Under the action plan (1995-2000) of the U.S. Department of Energy (DOE), the widespread use of ground source heat pumps was promoted as part of "Promotion of Renewable Energy Market and Ground Source Heat Pumps." Ground source heat pumps are installed at the private residences of former President Bill Clinton and President George W. Bush.

According to the European Heat Pump Association (EHPA), the number of ground source heat pumps installed in 2005 increased by 16% from the previous year. In the context, energy prices such as oil and electric power increased, and replacements of boilers and electric heaters with ground source heat pumps increased. Moreover, citizens' interest in environmental issues and global warming issues has been growing and the opportunities for utilization of renewable energy have been enhanced. In response to such trends, governments of many countries have started adopting measures to foster the introduction of ground source heat pumps.

Figure 3.7.2 Utilization of Renewable Energy by Use of Ambient Heat

In Germany, the heat in the ground, water and air, which is used by heat pumps, is defined as “renewable energy” of solar origin, and the introduction of heat pumps is promoted under the government policy.

Primary energy source	Manifestation	Natural Energy conversion	Technical energy conversion	Secondary energy
Sun	Biomass	Biomass production	Co-generation plant / Conversion plant	Heat, electricity and fuels
	Hydropower	Evaporation, Precipitation and Melting	Hydropower plant	Electricity
	Wind power	Atmospheric motion	Wind turbine	Electricity
		Wave motion	Wave power station	Electricity
	Solar radiation	Ocean currents	Ocean currents power station	Electricity
		Heating of Earth's surface and atmosphere	**Heat pump**	Heat
			Ocean thermal energy conversion	Electricity
		Solar radiation	Photolysis	Fuel
			Solar cell, Photovoitaic power station	Electricity
			Solar cell, Solar-thermal power station	Heat
Moon	Gravity	Tides	Tidal power station	Electricity
Earth	Mainly Isotope decay	Geothermal	Geothermal cogeneration plant	Heat , electricity

Source: “Renewable Energies” (2006) of German Environment Ministry

In Sweden, the widespread use of heat pumps is very actively promoted. Sweden takes energy measures that focus on the utilization of renewable energy with an importance attached to CO_2 reductions and energy conservation. In the past, heating was provided by boilers in general in Sweden. In the 1980s, the Swedish government started providing subsidies for the use of heat pumps. As a result, heat pumps rapidly came into wide use in the latter half of the 1990s, and heat pumps have come into the widest use in Sweden among European countries. The number of heat pumps installed in Sweden has reached about 400,000, and 70% of which are ground source heat pumps. Moreover, about 90% of newly built houses that are highly insulated and highly airtight collect and reuse ventilation waste heat with heat pumps.

In Switzerland, the government developed its energy conservation strategy in 2000 with a target to replace 3.5% of heat produced by fossil fuels with renewable energy by 2010. The target is placed on heat pumps. The government plans to introduce 100,000 heat pumps in 50% of newly built houses by 2010 and supports the introduction of this type of appliances. At present, half of heat pumps in Switzerland utilize heat in the air and another half utilize heat in the ground.

Germany is eager for wind power generation and photovoltaic power generation, and actively promoting the introduction of heat pumps in recent years as "heat pumps are renewable energy." In 2005, the number of heat pumps for space heating newly sold amounted to 17,600, up 35% from the previous year, and the number of heat pumps in use reached about 100,000. In Europe, Germany has rapidly grown to the second largest market of ground source heat pumps.

German Environment Ministry showed the "concept of renewable energy" in Figure 3.7.2. According to the concept, it is understood that the sources of renewable energy are the energies of the sun, the earth and the moon, and these sources appear in various forms of natural phenomena on the earth and are used as energy. For example, as the heat energy from the sun changes into "wind" on the earth's surface, it is understood that heat in the air and heat in the ground, which are utilized by heat pumps, are originally the energy conveyed from the sun like wind power and sunlight.

Figure 3.7.3 Heat Pumps Are Recognized as “Renewable Energy” in EU’s energy statistics (at the end of 2004)

RES Installed capacity (Installed capacity of renewable energy)	
Total RES	196,802MW
Hydro	131,440MW
of which Small HPP	11,598MW
Tide, Wave, Ocean	241MW
Wind	33,566MW
Total Biomass	11,549MW
of which biogas	1,899MW
Solar PV	1,010MW
Solar Heating	10,754MW
Geothermal el	695MW
Geothrmal th	2,059MW
Heat Pumps	4,531MW

Source:EU-25 Energy Fiches (http://ec.europa.eu)

In EU as a whole, a total of about one million heat pumps are now in use. Of this total, ground source heat pumps account for 450,000 units. Other heat pumps utilize heat in river water, lake water and the air. Which heat resource to utilize varies with geographical conditions, energy policies, etc. Therefore, the number of heat pumps in use and statistical handling vary from country to country. On the EU level, the utilization of heat in the ground by heat pumps is included in the framework of renewable energy according to white papers of some European countries.

Please see EU's renewable energy statistical table (EU 25 Energy Fiches) published in 2006. Heat pumps are handled as renewable energy like sunlight and wind power. EU has set its target to increase the share of renewable energy to 20% by 2020, and heat pumps are included in this target.

Utilization of heat in the ground, the air and river water with heat pumps is handled as utilization of renewable energy in Switzerland, the Netherlands, Denmark, Finland, Norway, Germany and the U.K.,and so on.

Recognition of heat pumps as renewable energy means that heat pumps are acknowledged as a means of utilization of alternative energy of fossil fuels that are essentially finite.

Q8. How little do heat pumps emit CO_2 compared with various types of combustion-based equipment?

Though the answer varies with the efficiency and fuel of combustion-based equipment for comparison, power source of electricity to operate heat pumps, power generation efficiency, efficiency of heat pumps, etc., heat pumps can reduce CO_2 emissions to a level much lower than combustion-based equipment in both heating and cooling and hot water supply.

Heat pump equipment that efficiently produce heat by utilizing "heat in the air" can provide cooling, heating and hot water supply with far less energy than conventional stoves and boilers. Such high efficiency is specifically described as follows.

In the Case of Heating

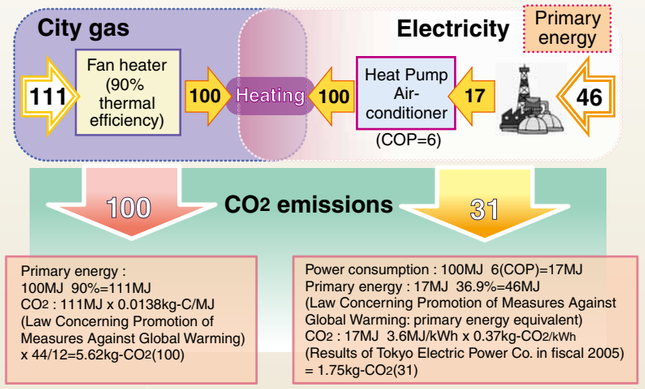
A combustion-based equipment like a stove is compared with a heat pump air-conditioner in the case where warm heat of 100 MJ is produced for heating.

In the case of a gas stove with 90% thermal efficiency, the natural gas fuel to be burnt is 100 MJ / 0.9 = 111 MJ. The amount of CO_2 emissions from this heating is calculated as 111 MJ x 0.0138 kg-C / MJ x 44 / 12 = 5.62 kg-CO_2.

On the other hand, in the case of heating of 100 MJ by a heat pump, the amount of electricity consumed by a heat pump air-conditioner (COP = 6) is calculated as 100 MJ / 6 (COP) = 17 MJ.

The amount of CO_2 emissions from this heating is calculated as 17 MJ / 3.6 MJ / kWh x 0.37 kg-CO_2 / kWh = 1.75 kg-CO_2. (Note: 0.37 kg-CO_2 / kWh is the result of Tokyo Electric Power co. district in 2005)

Figure 3.8.1 Energy-saving and CO2 Emission Reductions Performance of Heat Pumps (Comparison between fan heater and air-conditioner at the time of heating)



As described above, for the same level of heating, the amount of CO_2 emissions from the heat pump air-conditioner is only one-third of the amount of CO_2 emissions from the gas stove that uses natural gas in reality.

The above-mentioned calculations are applicable to the case where natural gas that emits relatively a small amount of CO_2 is used. In the case of oil (kerosene) that is generally used in Japan for heating, the CO_2 emission factor is 0.0183 kg-C / MJ, and the CO_2 emissions are 30% larger than a gas stove. (The amount of CO_2 emissions from a heat pump air-conditioner is only 20% of the amount of CO_2 emissions from an oil stove.)

Furthermore, in the case of heating by heat pumps, it should be noted that the amount of CO_2 emissions per electric energy varies with factors such as the power source portfolio of the electric power supplied, i.e., the ratios of non-fossil fuel power sources (hydroelectric power, nuclear power and renewable energy), high or low carbon content that varies with types of fossil fuels such as coal, oil, natural gas, etc., and high or low power generation efficiency.

As for this point, in the case where CO_2 emissions per electric energy can be expected to be reduced by the efforts of electric power companies in the future, the use of heat pump devices makes it possible for customers to enjoy the effect of CO_2 emission reductions.

In the Case of Hot Water Supply

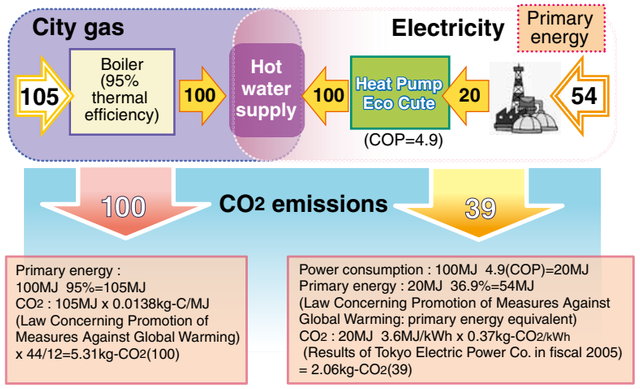
A combustion-based equipment such as a boiler is compared with a heat pump water heater in the case where warm heat of 100 MJ is produced for hot water supply.

In the case of a gas boiler with 95% thermal efficiency, gas fuel to burnt is calculated as 100 MJ / 0.95 = 105 MJ. The amount of CO_2 emissions from this heating is calculated as 105 MJ x 0.0138 kg-C / MJ x 44 / 12 = 5.31 kg-CO_2.

On the other hand, in the case of hot water heating of 100 MJ by a heat pump water heater, the amount of electricity consumed by a heat pump water heater is calculated as 100 MJ / 4.9 (COP) = 20 MJ. The amount of CO_2 emissions from this heating is calculated as 20 MJ / 3.6 MJ / kWh x 0.37 kg-CO_2 / kWh = 2.06 kg-CO_2. (Note: 0.37 kg-CO_2 / kWh is the result in the Tokyo district in 2005)

As described above, for the same level of water heating, the amount of CO_2 emissions from the heat pump water heater is 60% less than that from the gas water heater that uses natural gas.

Figure 3.8.2 Energy-saving and CO_2 Emission Reductions Performance of Heat Pumps
(Comparison between boiler and Eco Cute at the time of hot water supply)



Q9. What policies does Japan proceed with to promote heat pumps?

Heat pumps that receive attention as the energy-saving technology to contribute to CO_2 emission reductions are old and unglamorous technology. But this technology has been transformed into attractive technology to reduce CO_2 emissions by adopting leading-edge materials and technology, and the scope of applications has been rapidly expanding from refrigeration and cooling to heating and hot water supply.

We would like to introduce what position is given to heat pumps under Japan's energy and environmental policies in such circumstances.

As heat pumps can be expected to save energy and reduce CO_2 emissions with reliability, Japan has a system to provide subsidies for the introduction of heat pumps and promotes the wide use thereof under its energy policy. For example, subsidies are granted to the installation of Eco Cute and high-efficiency air-conditioners for business use.

As for environmental policies, at the COP9 conference held in Milan in December 2003, Japanese Environment Minister (then) Yuriko Koike introduced to the world the Eco Cute as "Japan's state-of-the-art technology to prevent global warming," together with CFC-free refrigerators and hybrid cars.

The Council for Science and Technology Policy of the Cabinet Office decided in April 2003 that the "development of technology to improve efficiency of heat pumps for cooling and heating and hot water supply" is a particularly important measure against global warming.

As for official prospects for the widespread use of equipment to be promoted, the report compiled in March 2005 by an advisory organ to the Minister of Economy, Trade and Industry concerning prospects for energy supply and demand assumed that 11.5 million units of Eco Cute for residential use will come into wide use as of fiscal 2030, and forecasted that 20 million units could come into wide use, if "instantaneous water heating" becomes possible.

As a short-term introduction target, the Kyoto Protocol Target Achievement Plan that was decided by the Cabinet in 2005 set the target to introduce 5.2 million units of Eco Cute and some 12,000 high-efficiency air-conditioners for business use in fiscal 2010 as the pillar of measures for the commercial sector.

Heat pumps are regarded as renewable energy in Europe. On the other hand, in Japan where a large number of "air source" heat pumps are already introduced, though the widespread use of heat pumps has been promoted, they have not been regarded as renewable energy. However, in the proposal compiled in 2006 by an advisory organ to the Minister of Economy, Trade and Industry concerning a new energy policy, heat pumps were defined as important and "innovative technology for advanced utilization of energy," paying attention to the dramatic improvement of efficiency of heat pumps and the great effect of CO_2 emission reductions thereof.

As for energy policies, the "New National Energy Strategy" that was decided by the government in May 2006 mentioned that Japan is committed to promoting the development of "hyper combustion technology" and the "widespread use and efficiency improvement of energy-saving equipment for the commercial sector such as high-efficiency water heaters, high-efficiency air-conditioners (heat pump), etc." in order to achieve the target to further save energy by 30% by fiscal 2030.

Under the "revised Energy Master Plan" decided by the Cabinet in March 2007, Japanese government formulated its policy to "support the creation of initial demand for tools and machinery of higher energy utilization efficiency," showing Eco Cute as an example. As high-priority research and development of technology, moreover, Japan clarified its policy to "accelerate the introduction of heat pump technology that efficiently collects low-temperature unused heat energy in the air and create utilizable temperature energy, and expand the scope of applications of heat pumps."

Figure 3.9.1 Policy-based Expectations Running High for Heat Pumps in Japan

<Kyoto Protocol Target Achievement Plan (2005)>
Target of widespread use by 2010: 5.2 million units of Eco Cute and 12,000 high-efficiency air-conditioners for business use.

<Liberal Democratic Party's interim Report on Integrated Energy Strategy (2006)>
Energy conservation is purely a domestic non-fossil energy. It is necessary to further promote Japan's energy-saving technologies that are foremost advanced in the world (high-efficiency water heaters, high-efficiency air-conditioners, etc. such as air source heat pumps).

<Report to the Ministry of METI on New Energies (2006)>
Heat pumps that drastically improve energy efficiency are defined as the "innovative technology for advanced utilization of energy," to which policy-based resources should be intensively inputted.

<New National Energy Strategy (2006)>
"Hyper combustion technology" and "technology to utilize energy beyond time and space" are expected to be realized, and "energy-saving equipment for commercial use such as high-efficiency water heaters, high-efficiency air-conditioners, etc. are expected to come into wider use and the efficiency thereof is expected to be improved."

<Energy Master Plan of the Cabinet (2007)>
As high priority technology to be developed, Japan declares its policy to accelerate the introduction of the "heat pump technology that efficiently collect low-temperature unused heat energy in the air to create utilizable temperature energy," and expand the scope of utilization of heat pumps.

Q10. How much potential do heat pumps have to reduce CO_2 emissions?

Potential of Reduction by 130 Million Tons of CO_2 in Japan as a Whole

The fields where the utilization of heat in the air with heat pumps can be applied instead of using equipment that burn inefficiently CO_2-emitting fossil fuels are the applications of cooling and heating and hot water supply in the commercial sector such as homes and buildings, and the applications of heating and drying in the industrial sector. If heat pumps come into wide use in these fields, the amount of CO_2 emissions to be reduced in Japan as a whole is estimated at about 100 million tons per year in the commercial sector and 30 million tons in the industrial sector. As a total of Japan's CO_2 emissions now amounts to total 1.3 billion tons, Japan's CO_2 emissions can be reduced by about 10%. For reference, this estimation is based on the present power source portfolio and present power generation efficiency. If low-carbon power sources and power generation efficiency are increased in the future, the amount of CO_2 emissions to be reduced is expected to further increase.

Immediately Viable and Highly Effective Control Technology

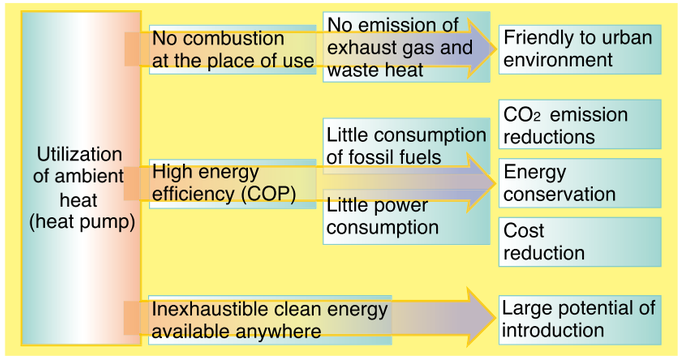
Japan's greenhouse gas emissions total 1.3 billion tons. Of this total, the commercial sector accounts for about 30%. According to the Kyoto Protocol Target Achievement Plan decided by the Japanese government, the reduction target of the commercial sector is about 60 million tons per year. Therefore, the potential of heat pumps to reduce emissions by 100 million tons is 1.5 times as much as the target. No other single technology can be expected to yield such a large effect. Heat pumps have such a large room for reduction as a measure against global warming. This means that heat pumps are the technology that has not come into wide use yet and that is in the course of widespread use. However, air conditioners and water heaters that utilize heat pumps are already sold on the market. If such air conditioners and water heaters are installed, they can immediately start exerting a large effect as an immediately effective and realistic measure against global warming.

Amount and Effect of Ambient Heat Used as Resource

If combustion-based air-conditioners and water heaters are replaced by heat-pump-based air-conditioners and water heaters in Japan's commercial sector, 45 million kiloliters of crude oil equivalent is replaced by ambient heat. This is also equivalent to about 20% of the amount of crude oil imported per year by Japan. It is also equivalent to about 60% of the amount of natural gas (LNG) imported per year by Japan. Heat pumps have an effect of proportionately reducing Japan's dependence on overseas resources. The amount of ambient heat used to replace combustion-based equipment is equivalent to about 2 trillion yen (17 billion dollars) per year, if crude oil costs 60 dollars per barrel (1 dollar = 120 yen). As heat in the air is inexhaustible, having heat pumps means developing large oilfields and gasfields that can be exploited by anyone and anywhere.

Gaining such an enormous amount of energy from heat in the air can be highly evaluated in terms of substantial expansion of usage of renewable energy, as is the case with photovoltaic power generation and wind power generation.

Figure 3.10.1 Many Advantages Provided by Utilization of Ambient Heat



Energy-Saving Effect

Heat pumps also have a great effect in terms of the improvement of efficiency of energy utilization. The "New National Energy Strategy" formulated in 2006 by the government set the target of reducing the final energy consumption per GDP by 30% by 2030. The effect of CO_2 emission reductions by 100 million tons through the application of heat pumps to the commercial sector reduces the final energy consumption in the same sector by 40%, which is equivalent to 10% of the final energy consumption in Japan as a whole. Together with the energy-saving effect from heat pumps for industrial use, most of the target can be achieved by heat pumps only.

Potential in the World

Similarly, if the ownership rate of heat pumps reaches 30%, the world's CO_2 emissions can be reduced by 6% or 1.2 billion tons, according to the past estimation made by IEA (International Energy Agency). It is important to calculate again the effects of widespread use in the world based on new information about the efficiency of latest equipment, application of heat pumps to hot water supply, etc. and reflect them in actual energy policies.