Heat Pumps

Long-Awaited Way out of the Global Warming

Heat Pump & Thermal Storage Technology Center of Japan

Heat Pumps

Long-Awaited Way out of the Global Warming

Publisher : THE DENKI SHIMBUN
(Energy & Electricity Daily News)
Address : 1-7-1,YURAKUCHO,CHIYODA-KU,TOKYO,JAPAN 100-0006
URL : http://www.shimbun.denki.or.jp/

Author : Heat Pump & Thermal Storage Technology Center of Japan
URL : http://www.hptcj.or.jp/

Production Support : The Federation of Electric Power Companies of Japan
URL : http://www.fepc.or.jp/

Tokyo Electric Power Company
URL : http://www.tepco.co.jp/

Ohmsha
URL : http://www.ohmsha.co.jp/

Reference : Search the Heat Pump!(Publisher by THE DENKI SHIMBUN)

Design : Sano Design office
URL : http://www.sanodesign.jp/

Executive Summary

Introduction

Would you believe it? That such realities are already within our reach. That "the use of CO_2-emitting 'fire' has become a thing of the past." And that "here comes a new era that we can use the clean, renewable and inexhaustible energy source we haven't ever been aware." This is not at all fantasy: in fact, the dream technology that meets all these challenges is in our hands already.

Problems associated with global warming and energy supply and demand are the issues that humankind in the 21st century must overcome. The key to resolving these problems lies in realizing "dramatic improvements in energy utilization efficiency" and "decarbonization of energies." A technology that can accomplish both these tasks simultaneously is the heat pump.

As a resource-scarce nation, Japan has waged a government-orchestrated campaign to promote energy efficiency, drawing lessons from the Oil Crisis in the 1970s that triggered the unrest of resource imports. These efforts helped the nation to achieve the highest energy conservation standards in the world. And it was the heat pump technology that made this feat possible as a major pillar of energy-saving technology in the residential and business sectors.

Most households in Japan are equipped with heat pump-based heating and cooling equipment. Under the government's Top Runner Regulations, a unique program even by global standards, home appliance retailers dispense at reasonable prices air-conditioners that vie for the world's highest level performance. Highly efficient heat pumps are also employed in large-scale district heating and cooling (DHC) services. Moreover, Japan developed, for the first time in the world, a CO_2 refrigerant heat pump water heater, an equipment that takes advantage of "heat in the air" to supply hot water. As such, Japan is one of the most advanced countries in heat pump technologies.

It is our earnest hope that more and more people in the world would learn the truth – by obtaining correct information and knowledge – about the "heat pump technology" that has an enormous impact on energy conservation and CO_2 reduction, so that each one of us would be motivated to do what he or she can to tackle global warming. We look forward to the aggregate achievement of such endeavors bearing fruit. And we wish to make a contribution globally through the dissemination of this innovative technology to save our planet earth that is on the verge of crisis.

Current Situation

Today, as problems associated with global warming increasingly threaten our environment, the time has come for heat pumps, with their rapid technological innovation, to show its true ability on the international scene as the Trump Card in the Measures Against Global Warming.

Based on a concept devised by Sadi Carnot and developed by Lord Kelvin and others in the 1800s Europe, this thermal utilization technology has a long history for use in refrigerators and for cooling.

In contrast to cutting-edge technologies under development that tend to attract public attention with loud fanfare and drum up expectations, however, the public has shown little interest in the fundamental mechanism of heat pump, which is a mature conventional technology. For all these reasons, the truth about heat pumps – that widespread dissemination of the heat pump technology holds a huge and realistic potential for resolving both energy and environment issues confronting humans – has not been fully understood in spite of its monumental significance.

Need for Combustion-free Systems: A Conversion from Fossil Fuel-dependent Culture

In the commercial sector that includes residences and office buildings, the bulk of the energy has been consumed for heating, hot water supply and other purposes to sustain living. This energy comes primarily from “combustion” systems that utilize thermal energy generated by burning fossil fuels.

The 4th Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that global warming, which today calls for urgent response, is "very likely" to have been caused by an increase in the atmospheric concentration of carbon dioxide (CO_2) that accompanies mass consumption of fossil fuels as a result of human activity.

In order to resolve global warming issues, break away from the constraints posed by fossil energy resources and realize environmental preservation along with sustainable development of our economy and society, we will need to build a “low-carbon society” that accomplishes a substantial reduction of CO_2 and other GHG emissions and stabilization of the atmospheric concentration of GHGs at levels that would not adversely impact the climate.

In this regard, heat pump is the key technology that would enable energy suppliers and consumers to make an active choice to join the movement to halt global warming towards this goal.

Outstanding Features of Heat Pump: A Highly Efficient Heat Transport Engine

Heat pumps have two outstanding features.

First, a heat pump moves thermal energy between out-of-doors and indoors instead of “generating” thermal energy from scratch by combustion. The heat pump, based on a simple heat transport engine that applies basic principles of thermodynamics, is already widely used in refrigerators and for cooling and other purposes.

Second, theoretically speaking, the energy consumption efficiency of a heat pump system is much higher than that of a combustion-based system by several times to more than tenfold. The amount of thermal energy transported is much larger than the inputted energy (normally electric power) consumed to power thermal transport. This means that collecting ambient heat by a heat pump after converting fossil fuels into electricity is a more efficient – resource-saving and CO_2 reducing – means of obtaining “heat” than burning fossil fuels directly.

In the past, attention on the heat pump, being an essential technology for cooling purposes, has been focused primarily on the first feature as a heat transport engine. Although its theoretically high efficiency had been known, little attention has been paid to the energy-saving properties, the second feature, of this technology partly because the technology was in the developing stage and also because fossil fuels for competing combustion equipment could be obtained at low cost.

However, amid major transformations in energy, environment and other social conditions in the past decade or so, the appearance of many kinds of heat pump equipment with higher energy consumption efficiency on the market has reinvigorated interest in the energy-saving properties of heat pumps.

Rapid Technological Progress

Rapid technological innovation in the heat pump technology has been fueled by two major factors: continuous improvement or "kaizen" at the production site toward even greater leaps in energy conservation and expectations for a "combustion-free technology" that would help combat global warming.

A monumental breakthrough was achieved with Eco Cute, a CO_2 refrigerant heat pump water heater, which was developed in 2001 in Japan as the first such product in the world. Eco Cute opened up new possibilities for the application of heat pump in hot water supply systems, an accomplishment that had been difficult with CFC-based refrigerants, while its high efficiency led to substantial improvements in both energy conservation and CO_2 reductions.

The Japanese government has introduced a scheme named the Top Runner Regulations in an effort to encourage continuous improvement in the energy-saving performance of various home electric appliances. This one-of-a-kind program in the world has served to double the energy consumption efficiency of air-conditioners for residential use in just ten years and consolidated the status of heat pumps as being far superior to combustion-type heaters in terms of energy-saving and CO_2-reducing performance.

Globally, high-efficiency centrifugal chillers, developed in the U.S. with the application of heat pump technology, are widely used for cooling office buildings and district cooling. Also, in recent years, further advances in the energy conservation performance have been achieved with the commercialization of centrifugal chillers that allow variable speed operation with inverter control.

In Europe, systems that employ heat pumps to utilize heat in the ground for heating have been increasing. Ground source heating can only be realized with the application of heat pump technology.

Furthermore, in Japan, heat pumps are now being used in clothes dryers, signifying a new stage in their applications.

Potential of CO_2 Reduction

Controlling CO_2 emissions has been a major motivating force behind the recent surge in the development of numerous heat pump systems in Japan. In the commercial sector for residential and business uses of Japan,energy consumption has been constantly expanding for these years. In this sector, heating and hot water supply account for nearly half of the energy consumed, which is one of the main contributors to the CO_2 increase. Moreover, about 90% of hot water supply, heating and other heat-based demands are met by the heat generated by burning CO_2-emitting fossil fuels. It is against this background that heat pumps are drawing huge attention as an alternative, CO_2-reducing technology for fulfilling heat-related demands.

Also, expectations for the dissemination of heat pump air-conditioners run high in replacement of absorption type refrigerators that burn fossil fuels now, commonly used in business sector of Japan for cooling, primarily in large-scale facilities, in an effort for reducing the enormous volume of CO_2 emissions.

By replacing fossil fuel-based direct combustion systems prevalent today with heat pump equipments, which drastically improve energy utilization efficiency with the use of "ambient heat" to meet such demands for cooling and heating, primary energy consumption and CO_2 emissions can be reduced substantially without changing the amount of thermal energy available to users. The estimation was made on the basis of current energy demand figures in Japan to gauge the impact of the maximum possible introduction of heat pumps on CO_2 emission reductions. Thanks to extraordinary progress in the heat pump technology that led to drastic improvements in energy utilization efficiency in recent years and an expansion in the scope of application, the projected CO_2 emission reductions totaled 130 million tons per year, equivalent to about 10% of Japan's total emissions at present.

A simulation by the IEA Heat Pump Center estimates that more widespread use of heat pumps would cut CO_2 emissions by about 6% or 1.2 billion tons.

Furthermore, this advantage of CO_2 reduction can be quite easily realized by heat pump equipment that are already available on the commercial market, instead of having to place expectations on the development of unreliable future technology or equipment. In other words, we should draw much attention to this highly effective and realistic measure because the advantage of significant CO_2 reductions can be obtained immediately by anyone, anywhere, anytime who would care to purchase and install a heat pump-based unit.

Significance of Dissemination that Extends beyond CO_2 Reduction

As we have seen, the replacement of fossil fuel consumption with the “ambient heat” amassed by heat pumps carries great significance in various ways. Its CO_2 reduction performance would not only have a huge impact on controlling global warming, but also significantly cut back on the amount of resource imports and contribute to energy security, and promote the utilization of renewable energy that takes advantage of heat in the air that relies on a clean and - inexhaustible supply that exists in abundance in the natural world.

Japan, a nation scarce in natural resources, is not the only country that carries out measures to disseminate heat pumps. In an effort for doing without oil and without global warming, steps to promote the use of heat pumps are actively pursued in Europe and the U.S. with a view to promoting the thermal utilization of renewable energy and also mitigating the energy supply-demand situation that has tightened further in response to the growth in global energy demand that is expected to continue into the future.

Japan’s Position

With the intensification of measures to tackle global warming in recent years, the reputation of the heat pump technology has come to be established as a realistic and highly effective means for energy conservation and CO_2 reduction. This, in turn, further raised expectations on heat pumps as a tool for resolving both energy and environmental problems at the same time.

Also, the successful development of various types of heat pumps in Japan may be attributed to its climatic conditions – warmer and more humid than in Europe or the U.S. – that are fit for heat pumps. By installing a heat pump air-conditioner, heating and cooling needs can be met without having to install separate units, which means small energy consumption and less energy costs. The same applies to heat pump hot water supply.

However, due to their high initial costs in comparison to simple combustion-based systems, the dissemination of heat pump systems has been far from adequate.

At present, the Japanese government is launching campaign to promote the use of heat pump units, rating them highly in the Kyoto Protocol Target Achievement Plan, New National Energy Strategy, reports by environment and energy-related government councils and other programs. Also, the government hopes to make a positive contribution by disseminating Japan’s energy conservation technology, which ranks among the top in the world, toward building a “low-carbon society” for a better global environment.

Conclusion

Heat pumps – using the power of technology to recycle the “heat” found in the “air” and “ground” – a recyclable, clean and inexhaustible supply with the blessing of the sun. A solar energy recycling society, which recycles the blessing of the sun – the heat in the air, heat in the ground, heat in the lake water and heat in the river water – is the ultimate sustainable society. The time has come for people in the world to join hands, with each individual citizen and business utilizing the technology and putting the achievements together toward building a sustainable society.

This text introduces the heat pump technology and its evolution up to its advanced stage in its entirety. It also reveals that the action toward building a sustainable “low-carbon society,” in a departure from dependence on the use of fossil fuels, while sustaining comfortable and convenient way of life and highly efficient economic activities, has already begun through greater utilization of natural energy including ambient heat generated by heat pumps.

Furthermore, it is our earnest hope that this text, which explains in detail the current condition of such technologies, impact of their dissemination, policy trends in Japan and elsewhere, among others, would be of help in the policy planning of governments that care sincerely for our planet and humankind.

1

Heat Pumps contribute to Environmental Protection and Energy Security

Global Environmental Protection by Heat Pumps

It is almost concluded that global warming is caused by greenhouse gases that are emitted by human activities, and the largest cause of global warming is the emission of carbon dioxide (CO_2) produced by energy consumption. Realistic measures to stop the increase in CO_2 in the atmosphere are to increase the area of forests to absorb CO_2 or to reduce the consumption of fossil fuel energy as an emission source of CO_2 and make efforts for doing without carbon.

The applications of fossil fuels used as energy, moreover, can be roughly classified into the case where they are burnt by customers as the primary energy to produce the heat energy required for power and heating and cooling, and the case where they are burnt to generate electricity (secondary energy) to be used by customers. In either case, effective measures for CO_2 reduction are to reduce energy consumption itself such as improvement of efficiency of energy utilization and shift to low-carbon energy sources.

From the viewpoint of reduction in CO_2 emissions of energy origin, which have such characteristics, considerations are given to what roles can be played by heat pumps.

First, in the field of heat utilization, heat pumps are a mechanism to convert unused "ambient heat" into heat of utilizable temperatures by inputting a very small amount of primary energy without burning fuels as a source of CO_2 emissions.

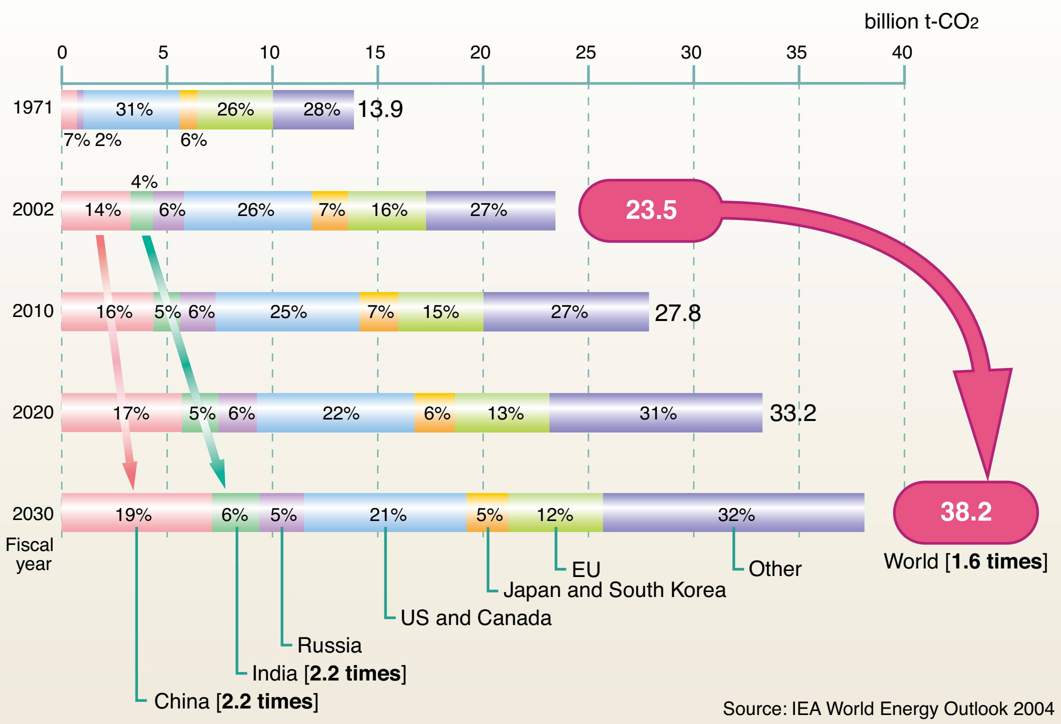


Figure 1.1 Changes in and Prospects for CO_2 Emissions of Energy Origin in the World by Region

Shifting to such heat utilized by heat pumps has the significance of shifting the energy source to utilize heat from direct combustion of "fossil fuels" to "electric power," a large part of which is generated by non-fossil fuels. Such shift, moreover, has the significance of fully utilizing the ambient heat (inexhaustible, renewable and no CO_2 emission) that occurs in the natural world and using only a small amount of electric power to produce heat, instead of using the heat of combustion of fossil fuels (the efficiency of utilization is 100% at the maximum in the case of high temperatures).

In the case where such heat pumps fully come into wider use in the air-conditioning and hot water supply fields, there estimated to be a potential of reducing Japan's CO_2 emissions by about 10%. No other technology can make such a large-scale contribution as a single technology to reduction in greenhouse gas emissions.

Moreover, it should be also very significant that heat pumps are the technology that has been already established. For example, there is a technique called CCS (Carbon Dioxide Capture and Storage) to recover CO_2 emitted from the flues of thermal power stations into the atmosphere and store CO_2 in strata.But this technique still has many problems yet to be cleared including, among others, environmental impact assessments, monitoring methodologies, effectiveness of measures, costs, selection of storage sites, international agreement, etc.Similarly, fuel cells that provide combined heat and power generation (CHP) through chemical combination of hydrogen with oxygen now still depend on the fossil fuel reforming technique that produces CO_2 as a means to supply hydrogen. Unexpectedly, it is not widely known that fuel cells produce CO_2 emissions as much as fossil fuel combustion systems.

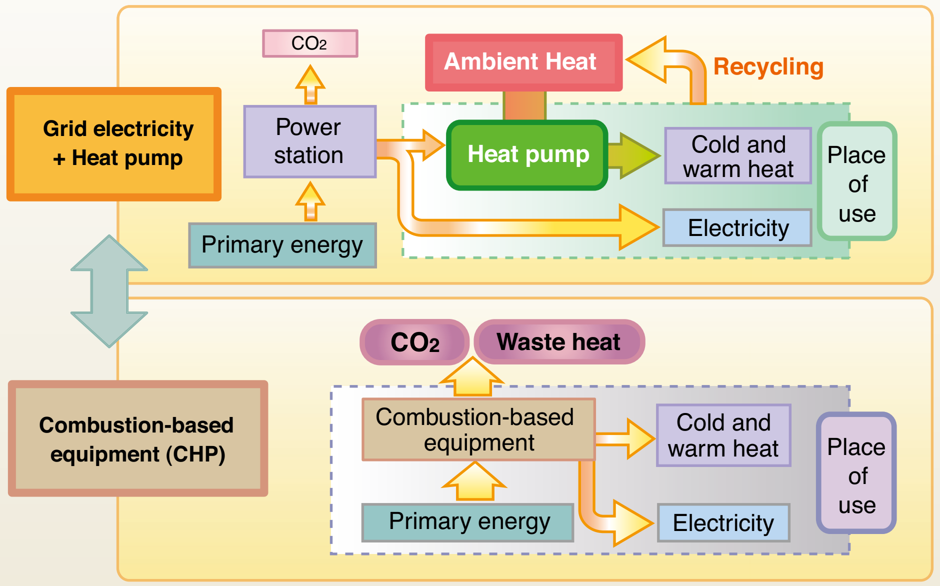
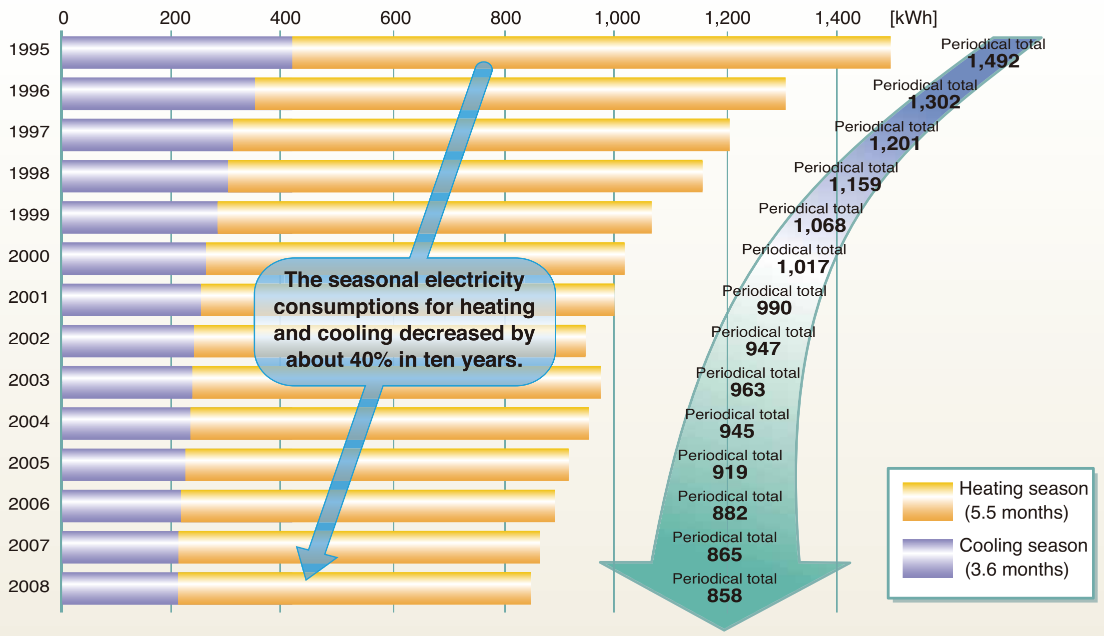


Figure 1.2 Clean and Efficient "Ambient Heat Utilizing Heat Pumps"

Unlike these technologies that may be promising in the future but can hardly yield the effect of CO_2 reduction immediately as of this point in time, the heat pump technology already has a long history of practical utilization. Moreover, more efficient new models of heat pumps can be available in the market and installed at competitive and realistic prices. Heat pumps have an advantage of allowing every one to immediately have the effect of CO_2 reductions, representing a promising measure against global warming.

Such advantage can be explained by pointing out that it is actually available by referring to heat pump air-conditioners in Japan as an example. Today, heat-pump air-conditioners are found in 90% of Japanese households as commonplace home cooling and heating equipment. If anyone says that such heat pump air-conditioners are "actually a device that has a great effect of preventing global warming," you may not readily believe it.

However, the efficiency of air-conditioners (= less consumption of electricity) has dramatically improved since the Top Runner Regulations were applied in Japan since 1999 under the revised Law Concerning the Rational Use of Energy generally known as the Energy Conservation Law.

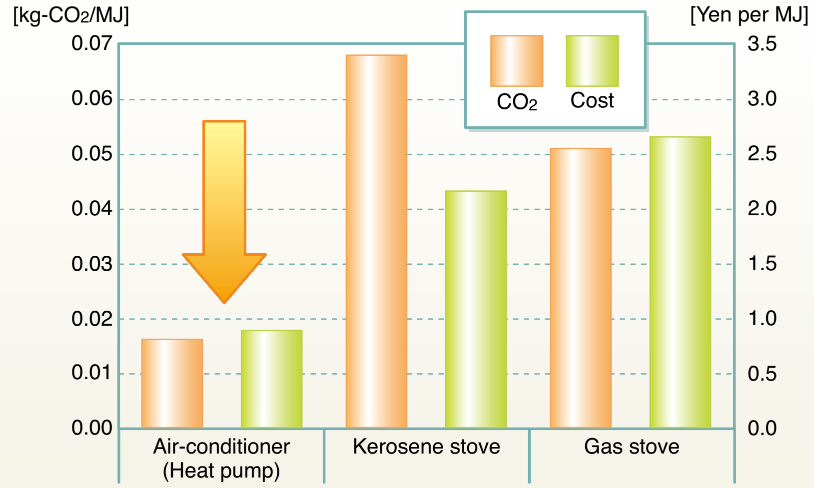


* Simple average values of the seasonal electricity consumption by typical energy-saving wall-mounted models of cooling power of 2.8 kW for both heating and cooling.
* The seasonal electricity consumptions are based on the Japan Refrigeration and Air-Conditioning Industry Association's Standard JRA4046.Source : The Japan Refrigeration and Air-Conditioning Industry Association

Changes in Annual Consumption of Electric Power by Heat-Pump Air-Conditioners of Japan

The efficiency of conventional air-conditioners before the Top Runner Regulations stood at about COP=3. As of 2006, the efficiency of air-conditioners exceeded COP=6(COP represents energy consumption efficiency.The ratio of cooling or heating output divided by the energy inputted.COP=6 means that input of 1 is required to produce heat of 6.) across the board, and air-conditioners that have efficiency close to COP=7 have made their debut. In about only ten years, the energy utilization efficiency expressed by COP has increased by twice as high. This means that the same amount of heat can be produced by a half of the amount of electricity consumed by conventional air-conditioners. In other words, all of the input energy, CO_2 emissions and running cost have been reduced by half.

This efficiency improvement with specific values is summarized below. Comparison was made on how much CO_2 is emitted and how much running cost is required by a heat-pump air-conditioner and combustion-based equipment (gas fan heater and kerosene stove), respectively, to produce a high temperature of 1MJ at the time of heating (Figure 1.4). As a result, it is found that the most efficient air-conditioner with efficiency of COP=6.6 as of 2006 emits half or one-third of the amount of CO_2 emitted by combustion-based equipment and also requires half or one-third of the cost required by combustion-based equipment. (Note: The CO_2 emission factor of electricity and prices of each type of energy are those in the Tokyo district as of 2006.)



<Conditions of calculations>
1.CO_2 emission intensity: electricity 0.37 kg-CO_2 per kWh (results of Tokyo Electric Power Co. in fiscal 2005), city gas and kerosene (the Enforcement Ordinance of the Law Concerning the Promotion of Measures to Cope with Global Warming of Japan)
2.Electricity rate: Tokyo Electric Power Co.'s 2nd block rate unit price in the "Meter-rate Lighting B" category (as of November 2006)
3.Gas charge: Tokyo area of Tokyo Gas Co.'s Tariff B in the "General Contract" category (Applied from October through December 2006)
4.Kerosene price: the Oil Information Center's Petroleum Products Market Data "Kerosene (Sticker Price)" (as of November 2006)
5.Efficiency of equipment: efficiency of heating by air-conditioner is set at COP6.6, and efficiency of heating by gas stove and kerosene stove is 1.0.

Figure 1.4 Comparison of CO_2 Emissions and Running Costs of Heating Equipments of Japan (Per MJ)

However, despite such actual conditions of high efficiency, heat-pump air-conditioners are not necessarily utilized for heating in Japan. Probably because of a still strong preconception that "air-conditioners consume a lot of electricity and are inefficient," air-conditioners for heating and cooling are not used in winter despite the high ownership rate of air-conditioners, and nearly 90% of the heating energy for household use is now still produced by inefficient combustion-based equipment in reality. Rather, CO_2 emissions of heating appliances can be drastically reduced by correct understanding about the realities of such equipment, correct selection of equipment at the time of buying, and utilization of air-conditioners for heating.

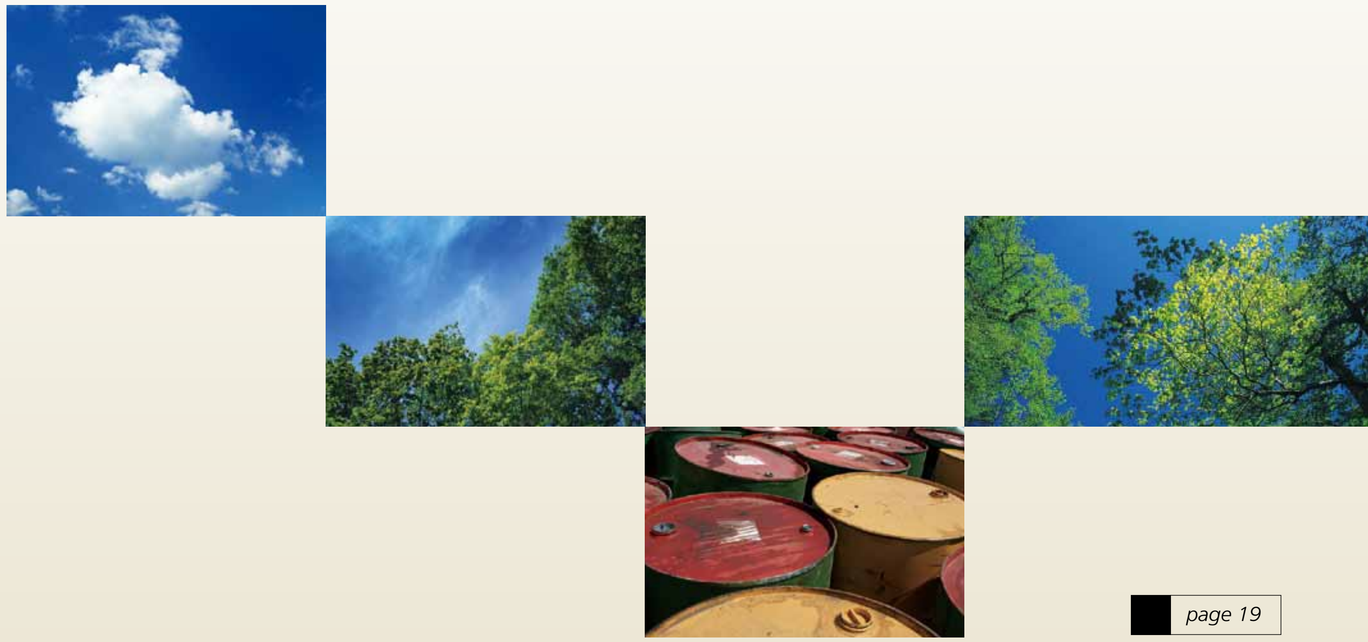
This is not necessarily confined to heating. Nearly 100% of the energy used in hot water supply is produced by combustion of fossil fuels. However, the fact that the development of CO_2 refrigerant Heat Pump water heater(Eco Cute) has made it possible to apply heat pumps to hot water supply means that hot water supply is now added to the fields where measures for drastic energy conservation and drastic reduction in CO_2 emissions can be taken. As is the case with heating, the heat efficiency of fossil-fuel-based combustion boilers is about 80%. Even the efficiency of the recently developed high-efficiency water heater that recovers latent heat of steam from exhaust gas is 95%, whereas the COP of Eco Cute as a heat-pump water heater is 4.9 as of 2006. Even if the power generation efficiency of the electricity to drive a heat pump (about 40% in Japan) is taken into consideration, heat energy in excess of the energy inputted by a power station can be produced by a water heater of COP=3 or higher (40% x COP3 = 120%). For these reasons, one unit of Eco Cute (COP=4) is estimated to reduce 0.8 tons of CO_2 a year or produce 65% less CO_2 than conventional water heaters.

Moreover, Eco Cute has an effect of cooling the atmosphere as it pumps up the heat in the air when it boils water. If Eco Cute is installed in all households in Tokyo, Eco Cute is estimated to have an effect of lowering the average atmospheric temperature at dawn in Tokyo by 0.5℃, representing the possibility of measures against the heat island phenomenon problem.

Just as outlined above, heat pumps make a great contribution to the reduction in environmental loads in individual homes, buildings and on a district level. The result of accumulation of such reduction in environmental loads is the "potential of reducing CO_2 emissions by 130 million tons in Japan as a whole" as mentioned later. The aforesaid potential of reducing CO_2 emissions by 130 million tons is not a pipe dream at all. It is a feasible target dependent on the degree of proliferation of the equipment that has already been commercialized and can be introduced.

This effect of prevention of global warming is not necessarily confined to Japan. It can be addressed internationally. There is already an example of a CDM project to introduce heat pumps to renew and replace inefficient heat sources in developing countries. According to the estimation of IEA Heat Pump Center, if the ownership rate of heat pumps reaches 30% in the world at large, its effect is estimated to reduce CO_2 emissions by 1.2 billion tons that account for 6% of the world's total CO_2 emissions.

As mentioned above, various processes to produce heat by burning conventional fossil fuels are expected to yield a large effect of reducing environmental loads through a drastic reduction in CO_2 emissions and exhaust heat on the user side by utilizing the "ambient heat" with various heat-pump appliances.



Energy Security with Heat Pump

Even compared with the food self-sufficiency rate of 40% (on a calorie basis), Japan's energy self-sufficiency rate is by far as low as only 4%. Almost all energy needed by Japan depends on imports from overseas. Its energy basis is very weak. Nevertheless, Japanese people has rarely been aware of such a low energy self-sufficiency rate until recently as an abundance of inexpensive energy has continued to be available amid waning memory of the oil crises that took place more than 30 years ago. However, as a result of changes in the environment of international politics and international energy market, it has begun to be understood with reality that the weak energy basis imposes a large economic burden on the national economy, once the international energy supply and demand has become tight and the prices of various types of energy as the goods traded in the market has started rapidly rising.

For these reasons, amid the changes in international supply and demand situation, each country must take various measures from a security point of view to stably ensure the energy it needs in the future in terms of both quantity and price. In the context of such security, considerations should be given to what roles can be played by heat pumps.

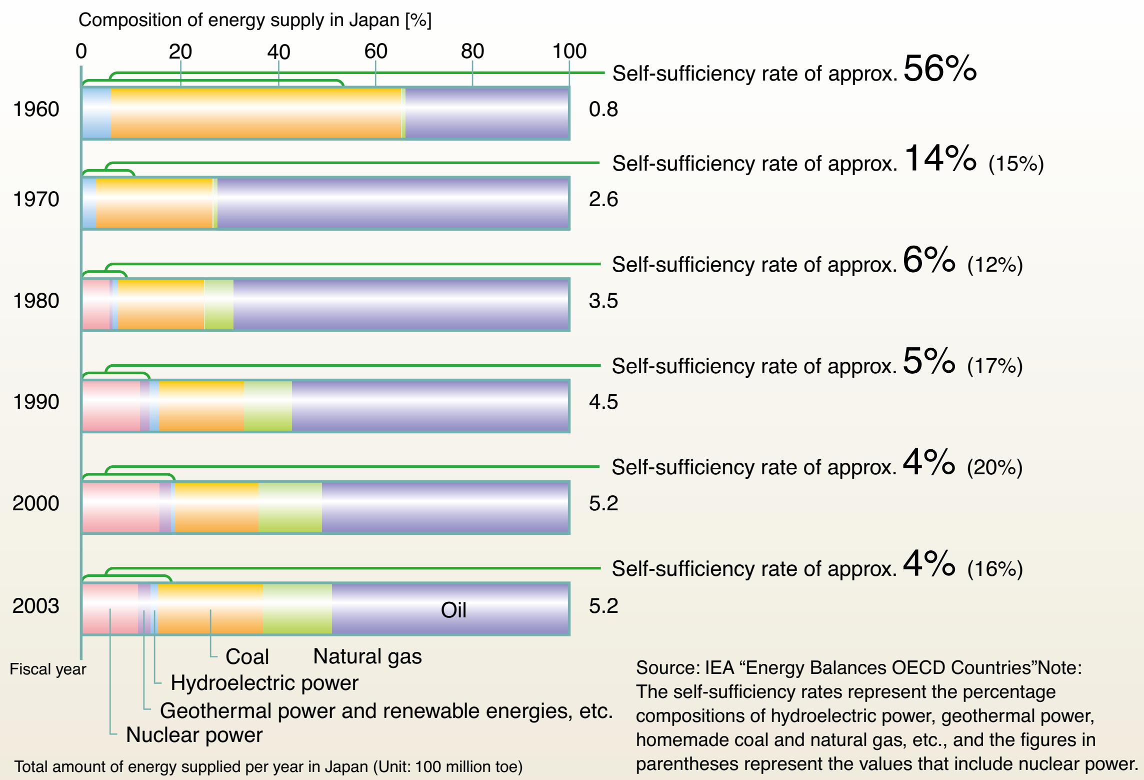


Figure 1.5 Energy Self-Sufficiency Rate of Japan

The basics of the ensuring of security are not to cause a contingency of disruption of energy supplies. To minimize and decentralize such risk, it is possible to take various measures such as "not to depend on specific energy sources," "not to depend on specific countries for energy imports," "to participate in development and reinforce relations with producing countries to obtain the rights for stable procurement," "to select stable energy sources with little risk of disruption of supplies," "to stockpile energy to avoid impact of short-term risk," "to develop domestic energy such as renewable energy to increase the self-sufficiency rate," "to promote international energy conservation led by technology to ease supply and demand," etc.

The "New National Energy Strategy of Japan" that was formulated in 2006 declared "Establishment of Energy Security," "Integrated Solution of Energy and Environmental Issues," and "Contribution to Conquest of Energy Issues in Asia and in the World" as the strategic targets to be achieved, aiming at creating a national strategy that is centered on energy security. As a long-term numerical target for this purpose, the strategy declared an aggressive energy conservation target at the outset of various activities to increase the energy use efficiency rate (per GDP) by 30% or more from the present level by 2030.

Moreover, this strategy of Japan shows the examples of technologies that are expected to be realized by 2030 to further promote energy conservation. For example, the strategy pointed out the need to develop "hyper-combustion system technology" to reduce as much as possible the combustion that loses values of energy, and proposes that the heat pump technology concerning, for example, high-efficiency hot water supply, high-efficiency air-conditioning, etc. should be put into widespread use as the "technology to create energy-saving type informative life space," and the efficiency of heat pump technology should be further improved.

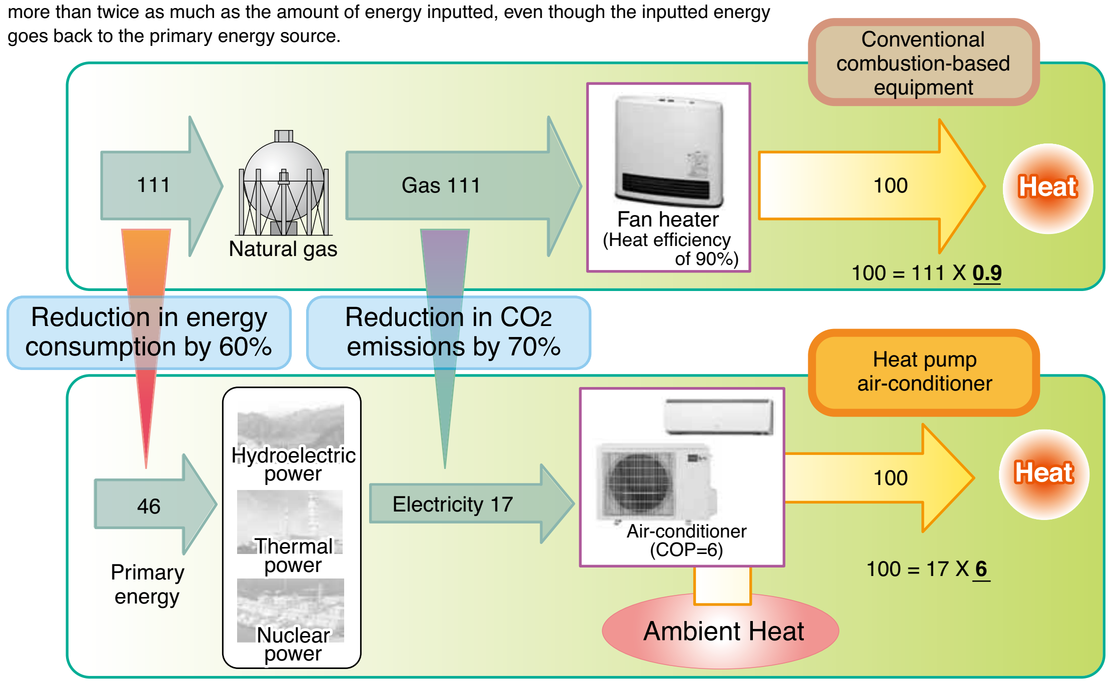
The National Energy Strategy of Japan that is centered on security also has high expectations for widespread use of heat pumps because it is the technology, of which the widespread use yields the social effect that can also yield the effect of reducing CO_2 emissions as described in the preceding section, and at the same time achieves a drastic reduction in consumption of fossil fuels, solving both environmental and energy security issues at the same time.

Conventional combustion-based equipment directly burns fossil fuels such as petroleum, gas and coal to produce necessary "heat" for heating and cooling and hot water supply, whereas highly efficient heat pumps input electric energy that is only a fraction of fossil fuels needed by combustion-based equipment to produce the same amount of heat. Even if the loss at the time of power generation, etc. should be taken into consideration, electrically operated heat pumps require less consumption of primary energy than combustion-based equipment to produce heat. Moreover, the consumption of fossil fuels to operate heat pumps is far less than combustion-based equipment as non-fossil fuel power sources such as hydroelectric power, nuclear power and natural energy account for about half of the electric power to operate heat pumps, though it may vary with the power source portfolio of respective electric power companies. This means that the "ambient heat" used by heat pumps replaces heat of combustion of fossil fuels.

The potential of reducing CO_2 emissions in the commercial sector's air-conditioning and hot water supply fields through the widespread use of heat pumps in Japan is estimated to reach about 100 million tons, but the heat demand covered by the calculation of this potential, which is now produced by direct combustion of fossil fuels, is equivalent to 45 million kiloliters of crude oil. This figure accounts for about 20% of the amount of crude oil imported per year by Japan or 60% of the amount of LNG similarly imported. It is no exaggeration to say that the replacement of such a huge amount of heat demand with supplies by heat pumps that use the "heat in the air" as a major energy source is the same as that Japan as a resource-less country develops purely homemade large oilfields and large gas fields where Japan can freely mine resources.

It is not only confined to the effect of development of purely homemade resources. If the heat utilization in the commercial sector's air-conditioning and hot water supply fields is changed from the present direct combustion of fossil fuels to the electric power used by heat pumps, of which the COP is several times as high, the total amount of final energy consumption in the commercial sector decreases by about 40%. The division of this energy conservation effect with Japan's overall energy consumption represents an energy conservation rate of about 10%. It should be of note that the widespread use of heat pumps in the commercial sector alone can make such a large contribution, compared with the 30% energy conservation target declared in the national energy strategy.

With the combustion-based equipment (in the upper diagram), it is impossible to utilize the amount of heat in excess of the amount of energy inputted. With the high-efficiency heat pump that uses heat in the air (in the lower diagram), it is possible to utilize the amount of heat that is more than twice as much as the amount of energy inputted, even though the inputted energy goes back to the primary energy source.



Note: As for the CO_2 intensity, the values of Tokyo Electric Power Co. are applied.

Figure 1.6 Use of Ambient Heat by Heat Pumps Is the Key to Energy Conservation and Reduction in CO_2 Emissions

The effect of widespread use of heat pumps is expected to also foster changes in energy supply structures. When heating and hot water supply are provided by heat pumps, though the electric power demand increases, there is no effect on the formation of peak in summer, contributing to the improvement of availability factors of electric power equipment through the leveling of electric power load curve. A 1% improvement of electric power load factor in Japan is said to have an effect of reducing the electricity supply cost by about 1%, and the benefit of which is widely enjoyed by society at large. It is generally understood that the use of electricity for cooling is a cause of increasing peak power demand in summer. But the renewal and replacement of conventional cooling equipment with high-efficiency and low-power-consumption latest equipment has an effect of contributing to power peak cut. It is also possible to easily avoid accumulation of peak in summer and promote load leveling by combination with thermal storage equipment to meet new cooling demand such as shift from other heat sources.

Like this, the load leveling of electric power, particularly the creation of loads during the time zone of midnight light loads contributes to an increase in the supply capability of nuclear power generation that conducts output-constant operation as a base supply capability.

In Japan subsidies are provided to the heat pump water heater Eco Cute. The budget of such subsidies is disbursed from the account involved in the development of power sources. The Japanese Ministry of Economy, Trade and Industry appropriated funds for "Leveling of Electric Power Demand" as one of the "Important Matters Related to Nuclear Energy." (This is because it is necessary to subsidize the practical application of high-efficiency water heaters (CO_2 refrigerant heat pump water heaters) and promote the widespread use thereof, which have a large effect of leveling electric power demand day and night, rather than utilizing nighttime power with modest supply and demand, in order to promote efficient utilization of base power sources such as nuclear power generation as the load leveling of electric power demand is a big challenge.)

This load leveling effect is simply described as follows. As one unit of Eco Cute consumes 1 kW of electricity, if 20 million units thereof come into wide use, midnight loads increase by 20 GW and the availability factor (load factor) of electric power equipment as a whole increases.

The point that attention should be paid to here is that, in addition to mere improvement of availability factors of equipment at light load during nighttime, there is an effect of increasing the ratio of nuclear power and that of non-fossil fuels to generated energy, i.e., a large effect of improving the CO_2 emission intensity of electric power, because if additional nuclear power plants equivalent to 20 GW are constructed, these plants can also be operated during daytime when Eco Cute is not operated. In other words, fossil fuels in energy utilization on the demand side are replaced (electrification and utilization of heat in the air by heat pumps), and the effects of replacing fossil fuels and reducing carbon in primary energy on the supply side are yielded at the same time.

Like this, heat pumps can yield the effects of drastically reducing the consumption of imported fossil fuels by "utilizing ambient heat" as a pure domestic resource, expanding the scope of development of nuclear power as a base load through load leveling of electric power, etc. The increased utilization of such heat pumps is expected to create a virtuous cycling of encouraging the demand side to casually use heat pumps just because "they are convenient" and "they are clean," and unwittingly reinforcing energy security of society at large. Moreover, heat pumps also contribute to effective utilization of renewable energy, too. It can be said that the combination of heat pumps, which do not cause the power generation side to produce CO_2, provide high energy utilization rates on the user side and emit no CO_2, is a very effective system as a measure against global warming, which produces no CO_2. Though current situation related to heat pumps by using examples in Japan is outlined here, they can be applied not only to Japan but also to almost every country.

2

CO_2 Reduction by Heat Pumps

CO_2 Reduction Potential of Japan

How much emissions of CO_2 produced by energy consumption can be reduced by heat pumps as a whole? The estimation of potential CO_2 emission reductions in Japan is introduced as follows.

Japan's CO_2 emissions now total about 1,300 million t-CO_2. Of this total, the industrial sector accounts for nearly a half, and the commercial(business and residential sectors) and transport sectors account for the remaining half. However, the comparison of growth rates of CO_2 emissions by sector from fiscal 1990 through fiscal 2004 shows that CO_2 emissions in the industrial sector decreased by 3.3% but CO_2 emissions in the business sector increased by 38.4%, that in the residential sector by 32.3% and that in the transport sector by 20.7%. CO_2 emissions in the commercial sector and transport sector have remarkably increased.

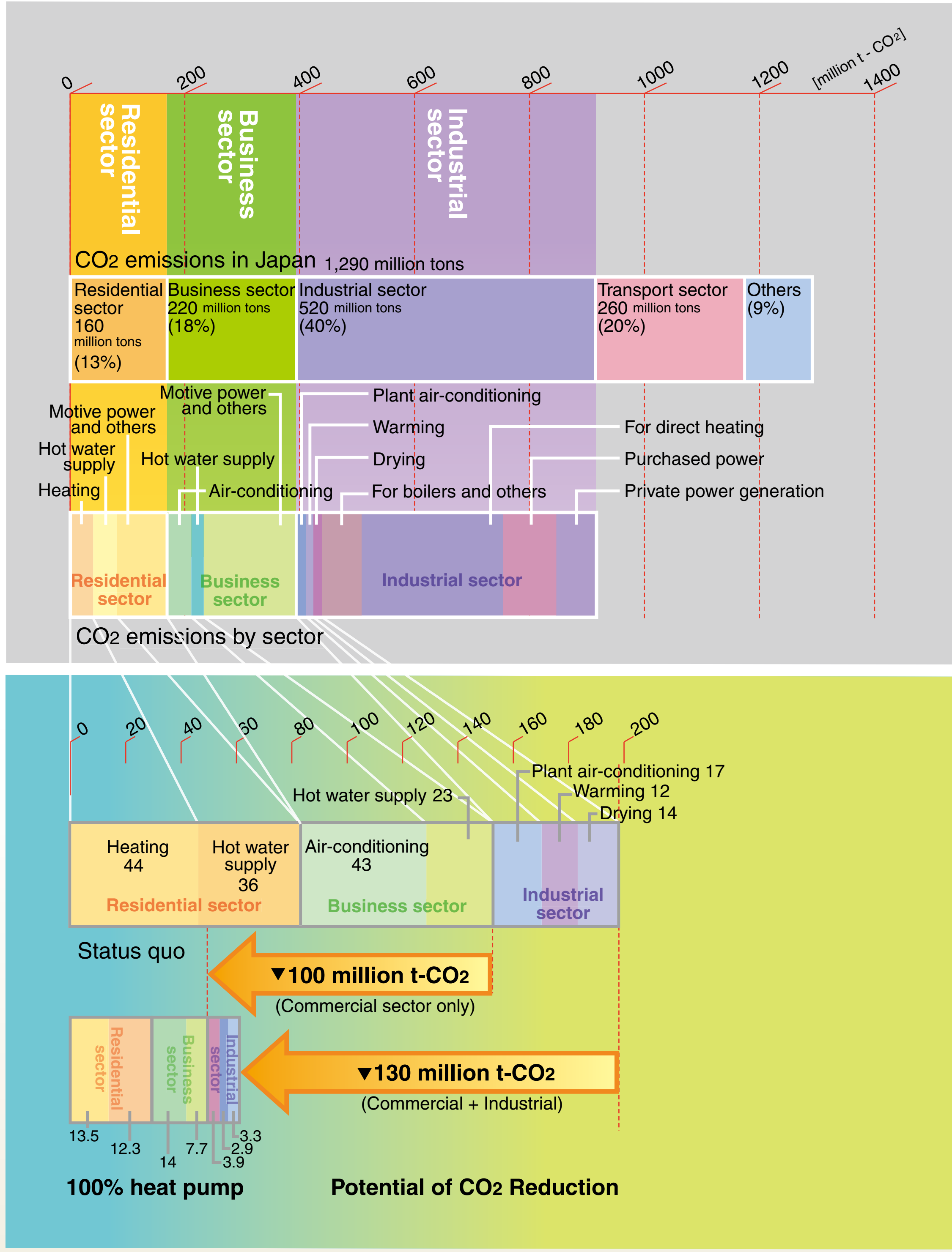
As for further details of composition of energy consumption in the commercial sector, heat demand such as heating and cooling and hot water supply accounts for about two-thirds in the residential sector. Similarly, heating and cooling and hot water supply account for more than 50% in the business sector, too.

This heat demand is mainly satisfied by heat energy, which is still generated by combustion of fossil fuels, representing a major cause of increase in CO_2 emissions.

The potential CO_2 emission reductions by meeting such heat demand with heat pumps instead of fossil fuel-combustion equipments in Japan as a whole amounts to about 100 million t-CO_2 in the commercial sector and about 30 million t-CO_2 in the industrial sector, for a total of about 130 million t-CO_2, which accounts for about 10% of Japan's total CO_2 emissions of about 1.3 billion t-CO_2.

[see. Figure 2.1 Table2.1]

The details of the estimation for each sector showed the following results:



Source: Greenhouse Gas Inventory, based on data quoted from CGER-Report 2004, Ministry of the Environment
Handbook of Energy and Economic Statistics in Japan, 2004 and 2006 Editions, based on data of FYs 2002 & 2004, The Institute of Energy Economics, Japan Survey of Oil Consumption Structure by Sector, 2001 Edition, Ministry of Economy, Trade and Industry

Figure 2.1 Potential of Reducing CO_2 Emissions by Heat Pumps

① Residential Sector

(Heating)

As for the potential CO_2 emission reductions in houses, it is possible to reduce the present estimated CO_2 emissions from heating of 44 million t-CO_2 per year to 13.5 million t-CO_2 per year, representing a potential of reduction by 30.5 million t-CO_2 per year on the assumption that heating by conventional equipment in cold climate areas is replaced with heat pump heaters of COP = 3 and that in general areas with heat pump air-conditioners of COP = 6. [see. Figure 2.2]

(Hot water supply)

On the assumption that conventional water heaters are totally replaced with heat pump water heaters of COP = 4, the present estimated CO_2 emissions of 36 million t-CO_2 per year can be reduced to 12.3 million t-CO_2 per year, representing a potential of reduction by about 23.7 million t-CO_2 per year. [see. Figure 2.3]

② Business Sector

(Air-conditioning)

As for the potential CO_2 emission reductions in buildings for business purposes such as office buildings, stores, etc., the present estimated CO_2 emissions from air-conditioning of 43 million t-CO_2 per year can be reduced to 14 million t-CO_2 per year, representing a potential of reduction by about 29 million t-CO_2 per year, on the assumption that air-conditioners of COP = 6 come into widespread use.
[see. Figure 2.4]

(Hot water supply)

On the assumption that conventional water heaters are totally replaced with heat pump water heaters of COP = 4, the present estimated CO_2 emissions of 23 million t-CO_2 per year can be reduced to 7.7 million t-CO_2 per year, representing a potential of reduction by about 15.3 million t-CO_2 per year. [see. Figure 2.5]

Commercial Sector (= ① + ②)

As mentioned above, the commercial sector alone has a potential of reduction by about 100 million t-CO_2 per year. This figure represents a potential that far exceeds the target to reduce CO_2 emissions of energy origin by about 60 million t-CO_2, which was assigned to the commercial sector under the Kyoto Protocol Target Achievement Plan (decided by the Cabinet of Japan in April 2005).

		Present CO_2 emissions 1	CO_2 emissions after totally replaced by heat pumps 2	Potential of CO_2 reduction 3 = 1 - 2	
① Residential	Heating	44	13.5	30.5	Commercial 100 million tons
	Hot water supply	36	12.3	23.7	
	(Subtotal)	80	25.8	54.2	
② Business	Air-conditioning	43	14	29	
	Hot water supply	23	7.7	15.3	
	(Subtotal)	66	21.7	44.3	
③ Industrial	Plant air-conditioning	17	3.9	13.1	Industrial 30 million tons
	Warming	12	2.9	9.1	
	Drying	14	3.3	10.7	
	(Subtotal)	43	10.1	32.9	
	Total	189	57.6	131.4	

[million t - CO_2]

Table 2.1 Potential of Reducing CO_2 Emissions by Heat Pumps in Japan

③ Industrial Sector

The CO_2 emissions in the industrial sector have remained almost unchanged since 1990, but this sector involves many heating fields where fossil fuels are directly burnt. As for the demand that can be met by heat pumps at present in such heating fields, plant air-conditioning, warming and drying at lower than 100°C by boilers are realistic.

As for plant air-conditioning, the present estimated CO_2 emissions of 17 million t-CO_2 per year can be reduced to 3.9 million t-CO_2 per year, presenting a potential of reduction by about 13.1 million t-CO_2 per year.

As for warming, the present estimated CO_2 emissions of 12 million t-CO_2 per year can be reduced to 2.9 million t-CO_2 per year, presenting a potential of reduction by about 9.1 million t-CO_2 per year.

As for drying at lower than 100°C, the present estimated CO_2 emissions of 14 million t-CO_2 per year can be reduced to 3.3 million t-CO_2 per year, representing a potential of about 10.7 million t-CO_2 per year.

All together, there is a potential of reduction by about 32.9 million t-CO_2 in the industrial sector.
[see. Figure 2.6]

Figure 2.2

Potential of Reducing CO_2 Emissions from Residential Heating in Japan

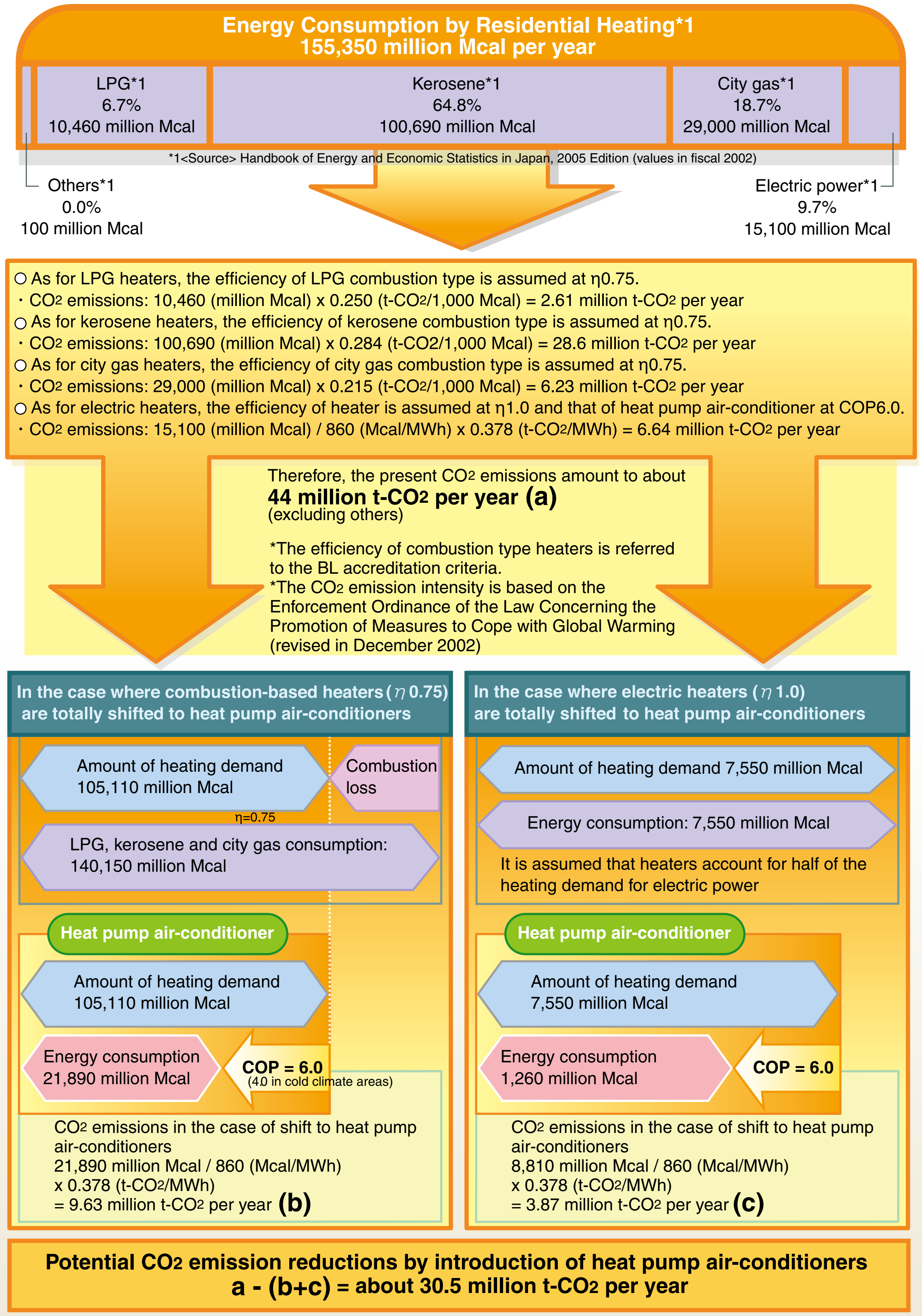


Figure 2.3

Potential of Reducing CO_2 Emissions from Residential Hot Water Supply in Japan

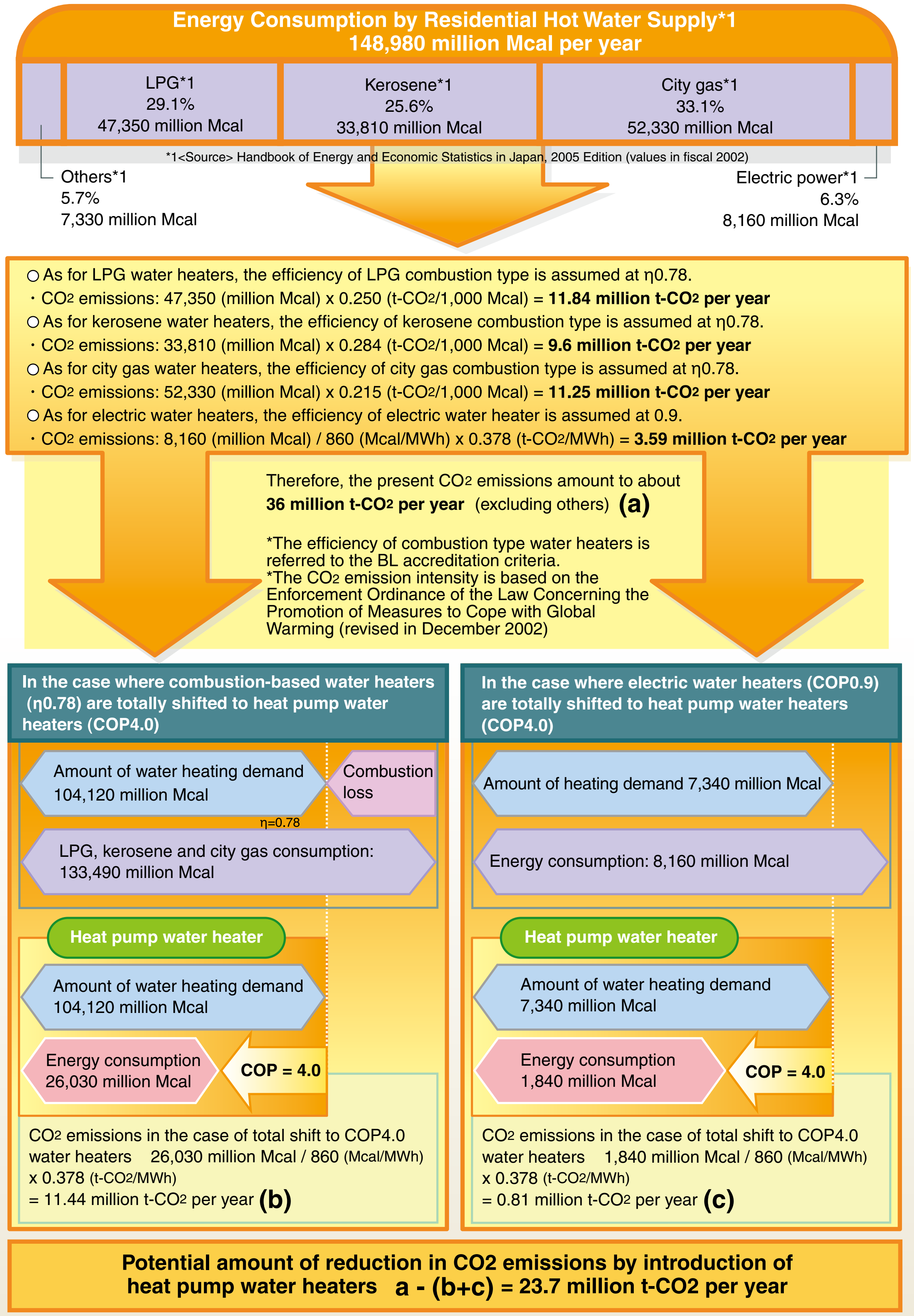


Figure 2.4

Potential of Reducing CO_2 Emissions from Air-Conditioners for Business Use in Japan

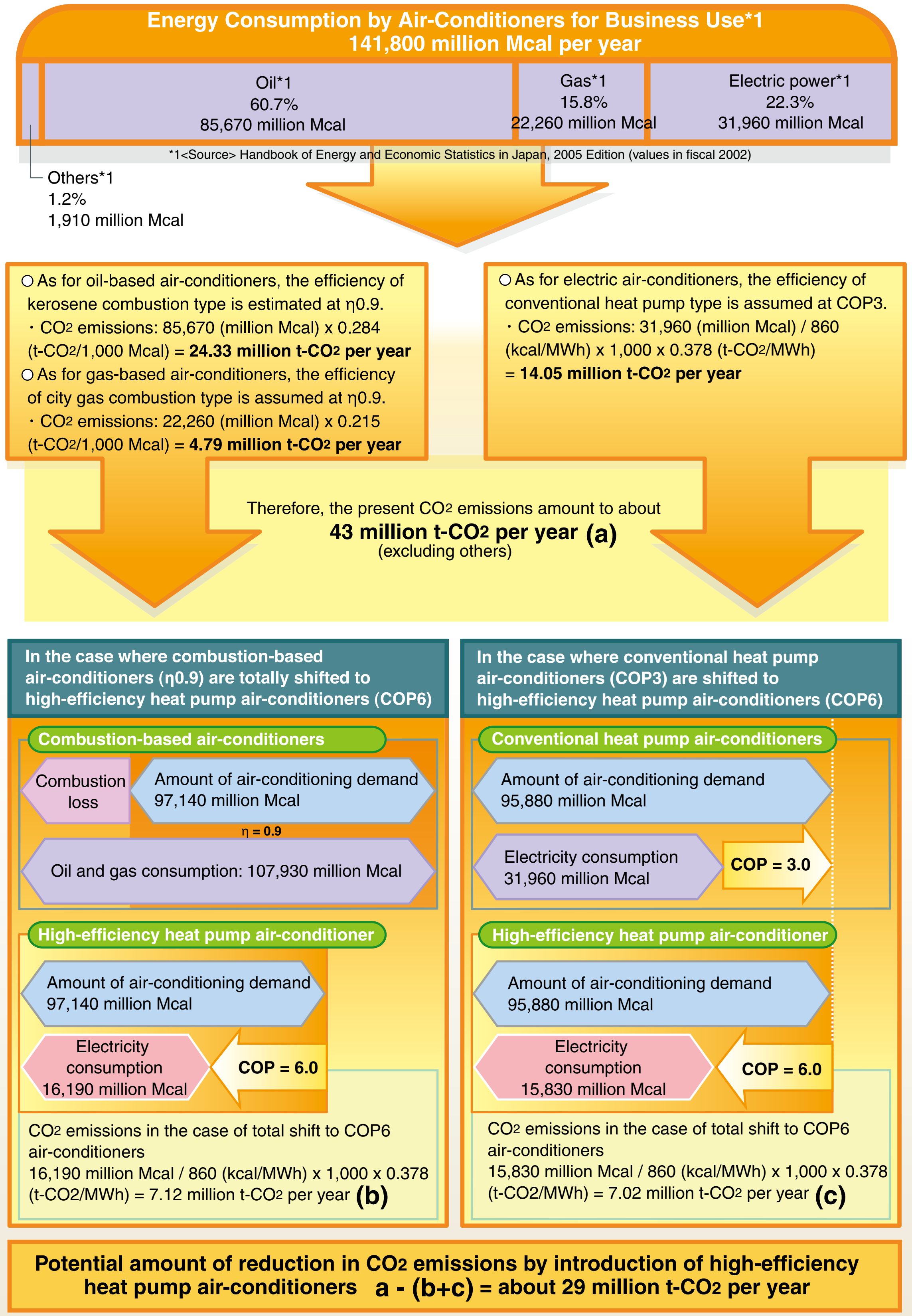
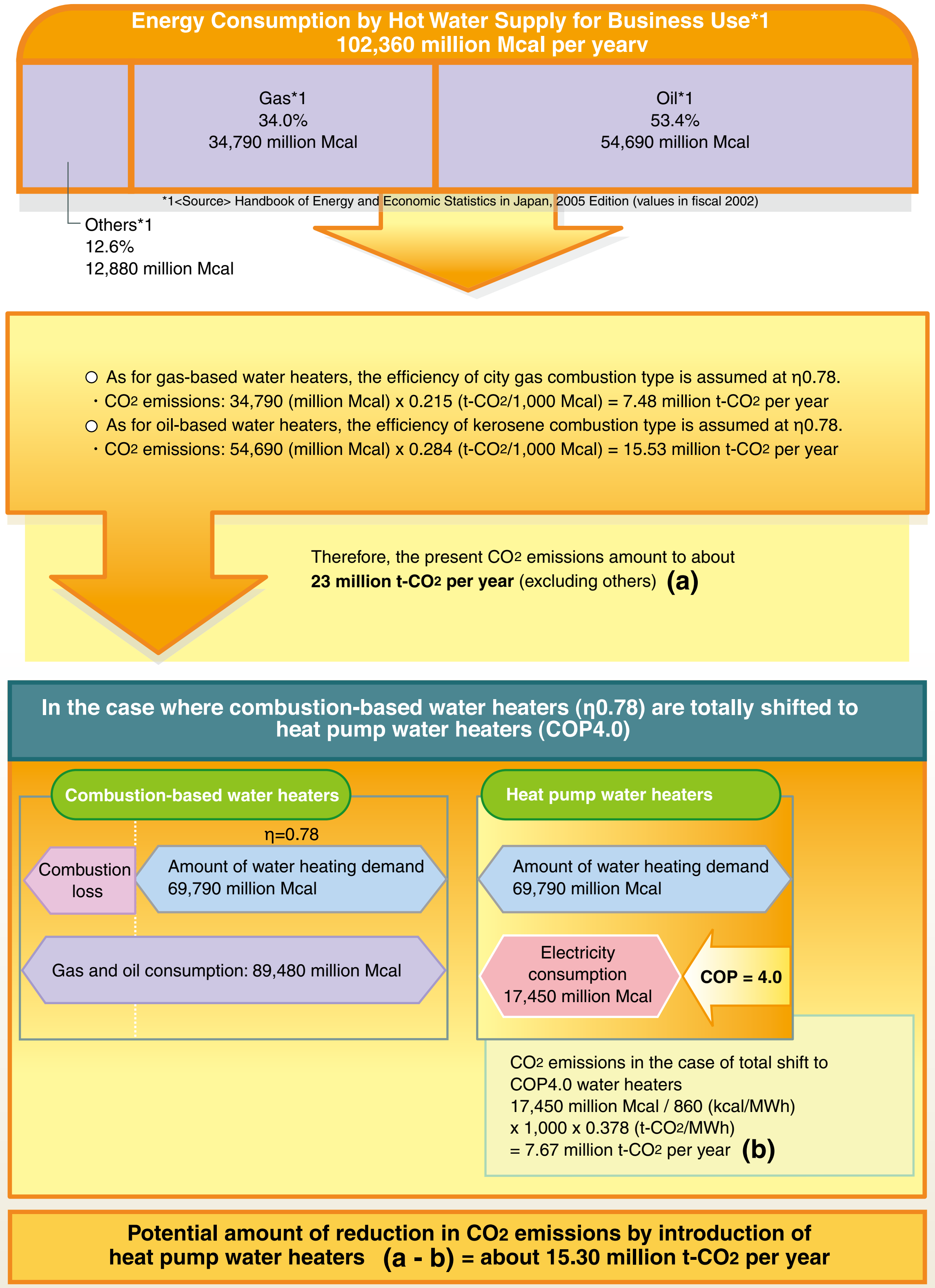


Figure 2.5

Potential of Reducing CO_2 Emissions from Hot Water Supply for Business Use in Japan



3

Further guide to the Heat Pumps

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

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

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

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

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

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

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

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

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

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

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.

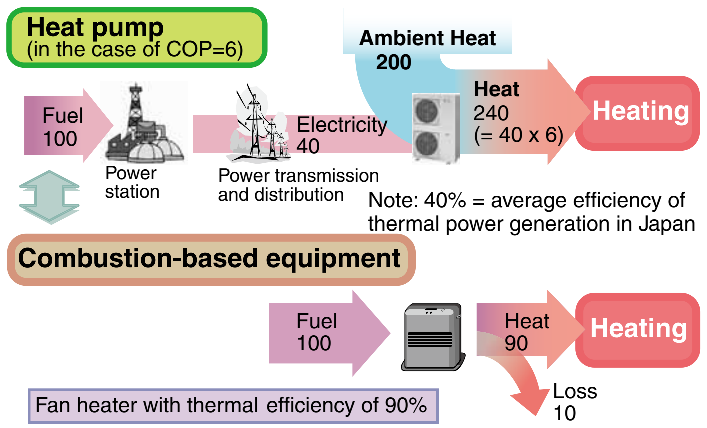
From this point of view, heat pumps do not burn fuels at the places of use of heat. Instead, heat pumps efficiently utilize clean and inexhaustible unused energy such as "heat in the air" and "heat in the ground," which exist everywhere. As heat pumps make it unnecessary to burn fossil fuels, they significantly 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?

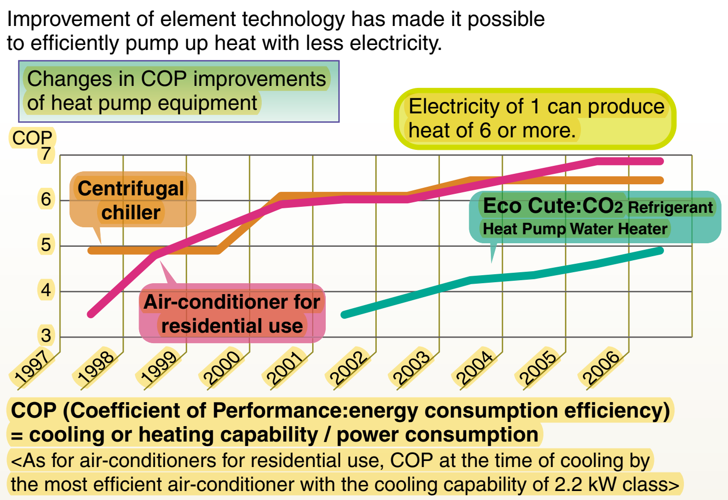
World's Top Class Energy-Saving Air-Conditioners of Japan

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



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.

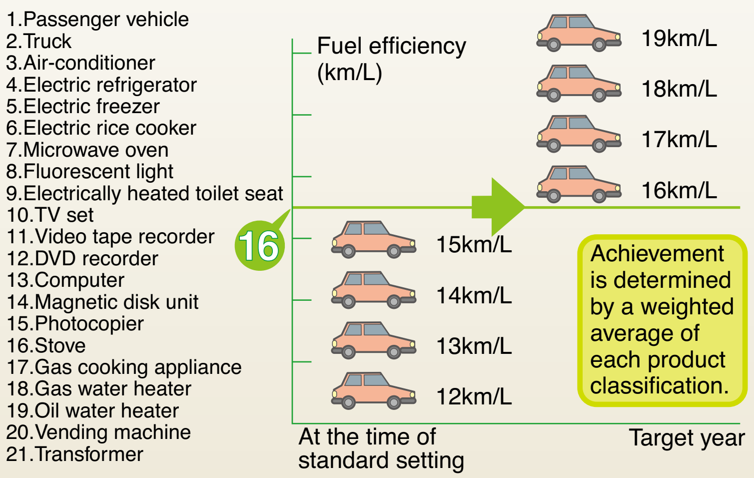
Competition for Efficiency Under Top Runner Regulations*

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.

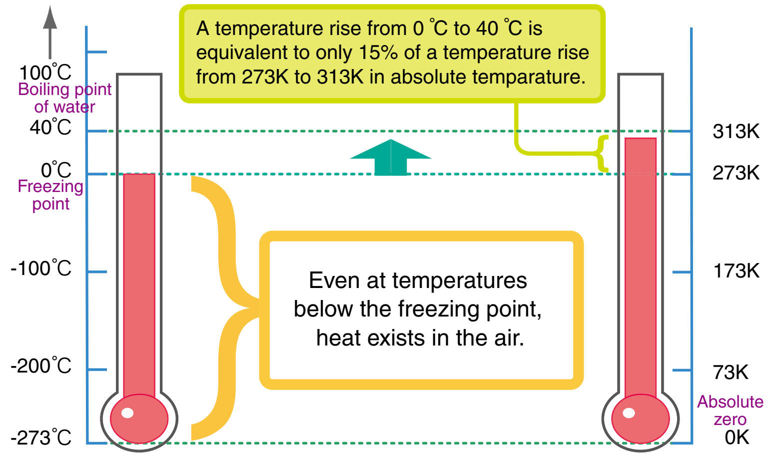
Method of Boiling Water with Heat in the Air

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)

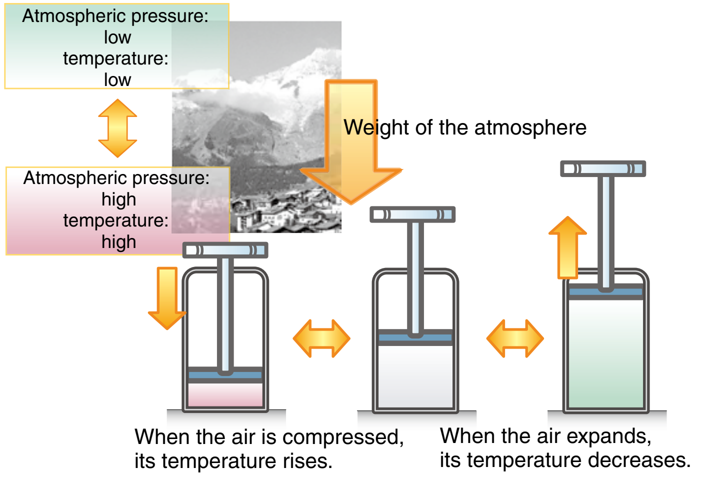
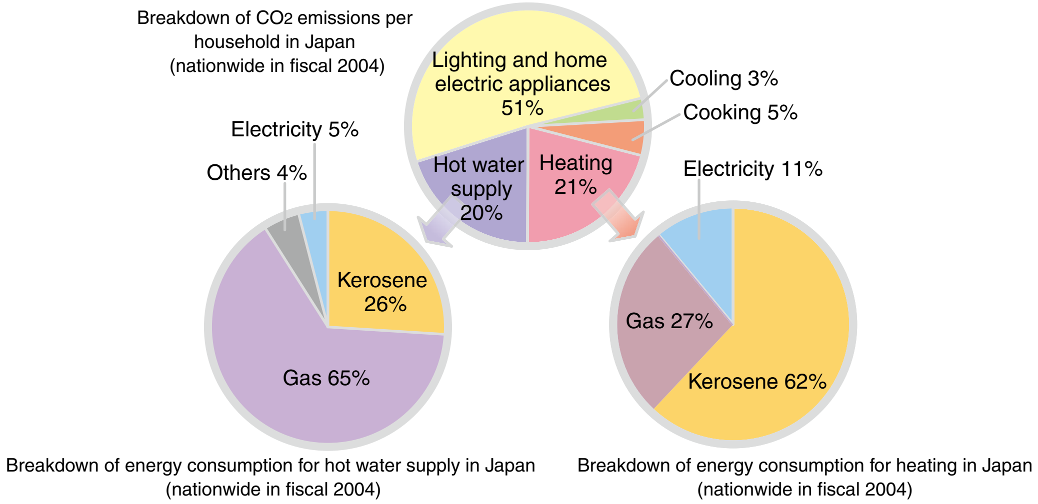


Figure 3.3.3 Heating and Hot Water Supply Fields Dominated by Combustion-based Equipment Have a Large Room for CO_2 Emission Reductions.



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.

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

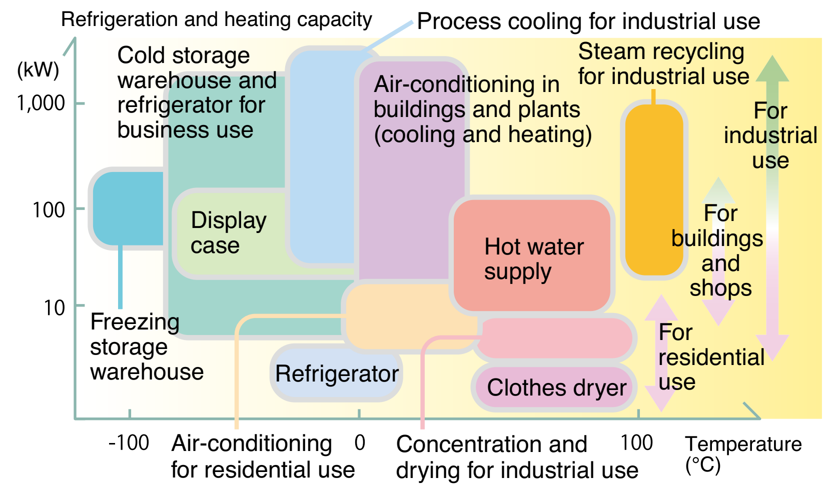
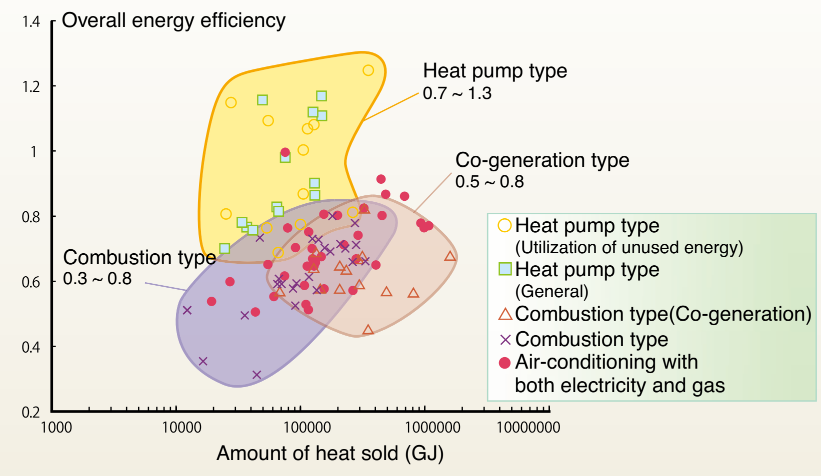


Figure 3.4.2 Heat Pumps Are also Highly Efficient for District Heating and Cooling in Japan. (Overall energy efficiency at each typical point: actual results in fiscal 2005)



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?

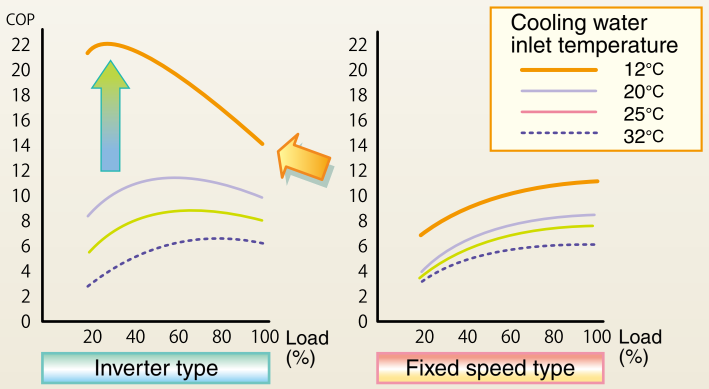
Heat pumps convey heat by repeating the process of compression and expansion of refrigerant as the substance to convey heat. To efficiently compress the refrigerant in large quantities, centrifugal chillers rotate impellers at high speed, blow off a large quantity of refrigerant gas with the centrifugal 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.

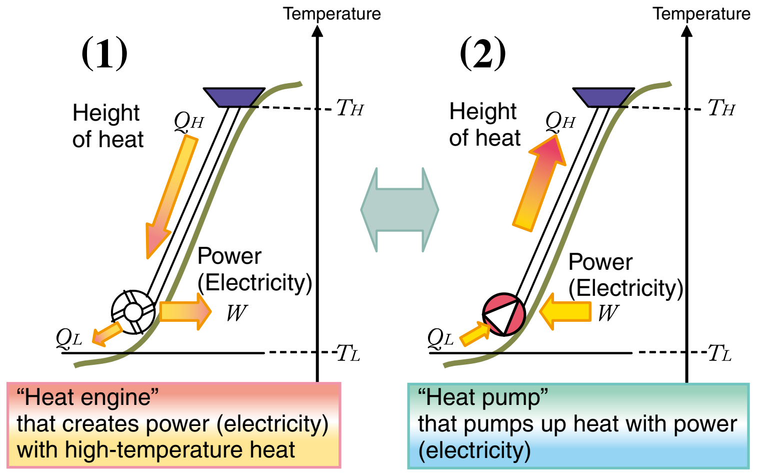
Figure 3.5.1 COP of Partial Load Performance of Centrifugal chiller by Inverters



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.

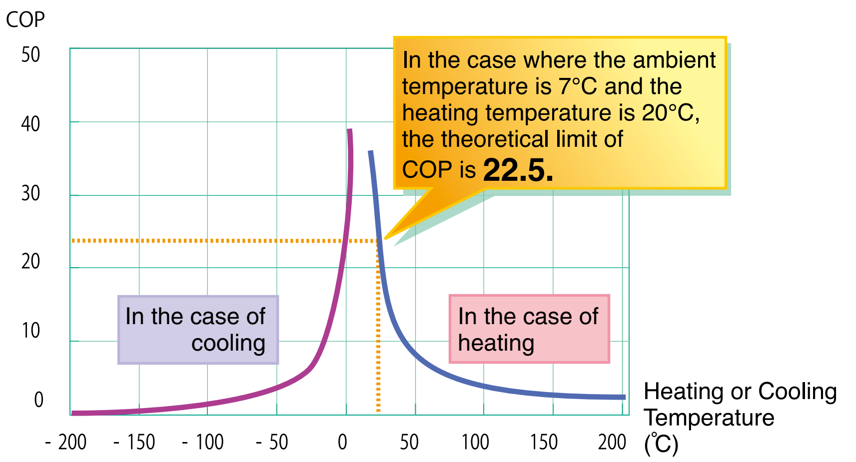
The concept of the heat pump system invented by Carnot is shown in the diagram. The "heat engine" in Figure (1) produces power (electricity) with high-temperature heat. He invented that low-temperature heat can be pumped up by the power (electricity) as high-temperature heat as shown in Figure (2), if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

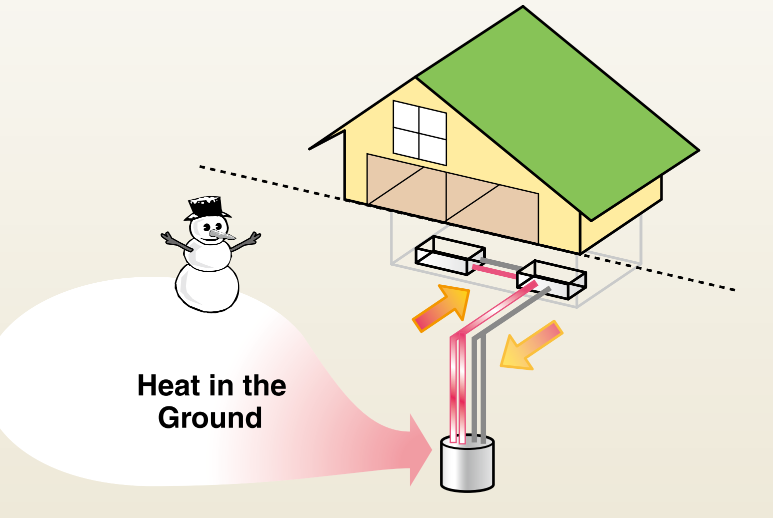
In Japan where the climate is mild, "heat in the air" is generally collected and used as the heat source for cooling, heating and hot water supply by heat pumps. Even if the ambient temperature is 20℃ below zero, hot water can be supplied by Eco Cute. However, the efficiency cannot help but decrease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

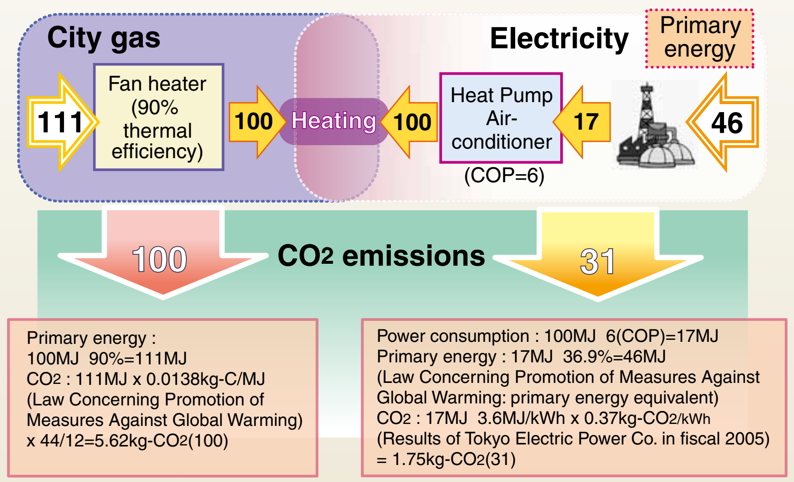
A combustion-based equipment like a stove is compared with a heat pump air-conditioner in the case where warm heat of 100 MJ is produced for heating.

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

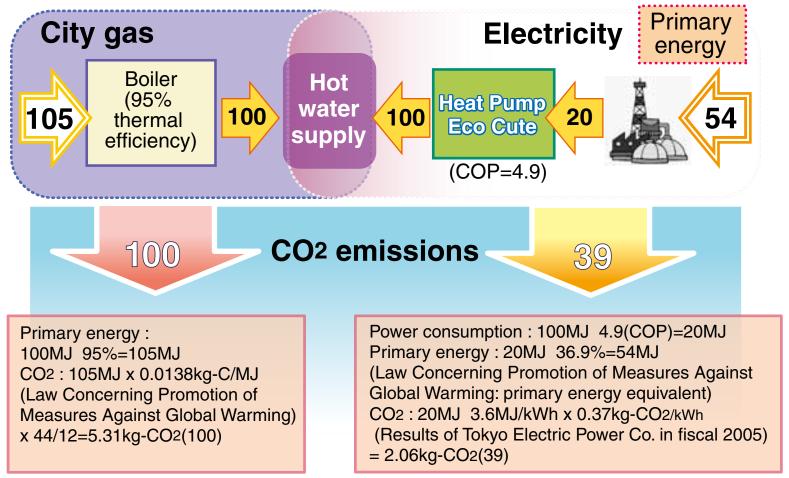
A combustion-based equipment such as a boiler is compared with a heat pump water heater in the case where warm heat of 100 MJ is produced for hot water supply.

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

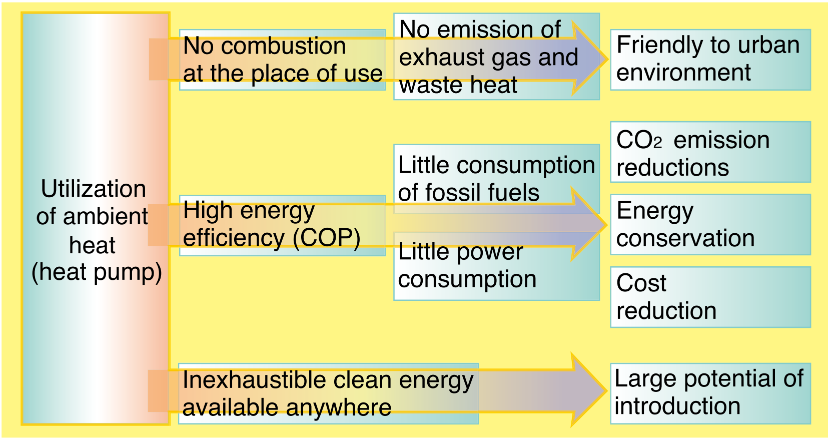
Japan's greenhouse gas emissions total 1.3 billion tons. Of this total, the commercial sector accounts for about 30%. According to the Kyoto Protocol Target Achievement Plan decided by the Japanese government, the reduction target of the commercial sector is about 60 million tons per year. Therefore, 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.

4

Toward the Low-Carbon Society with Heat Pumps

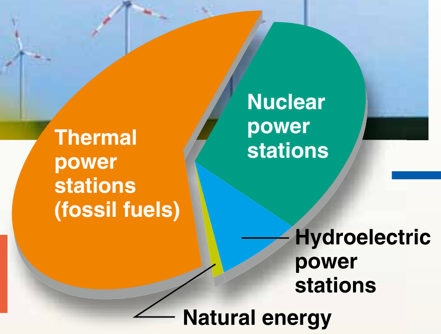
Ambient Heat Energy Society to be Opened by Heat Pumps

Heat pumps widely support our life and society.

Heat pumps are used for space heating and cooling ,refrigerators, water heating and space drying at home and in offices and shops. They supply heat at the temperature you want to use in a clean and efficient manner by utilizing ambient heat.

Heat pumps also give an outstanding performance on a town scale. They make it possible to efficiently supply heat by pumping up not only ambient heat but also familiar unused heat sources such as heat in rivers, the sea, sewage, waste heat, etc.

Power station



Power output composition

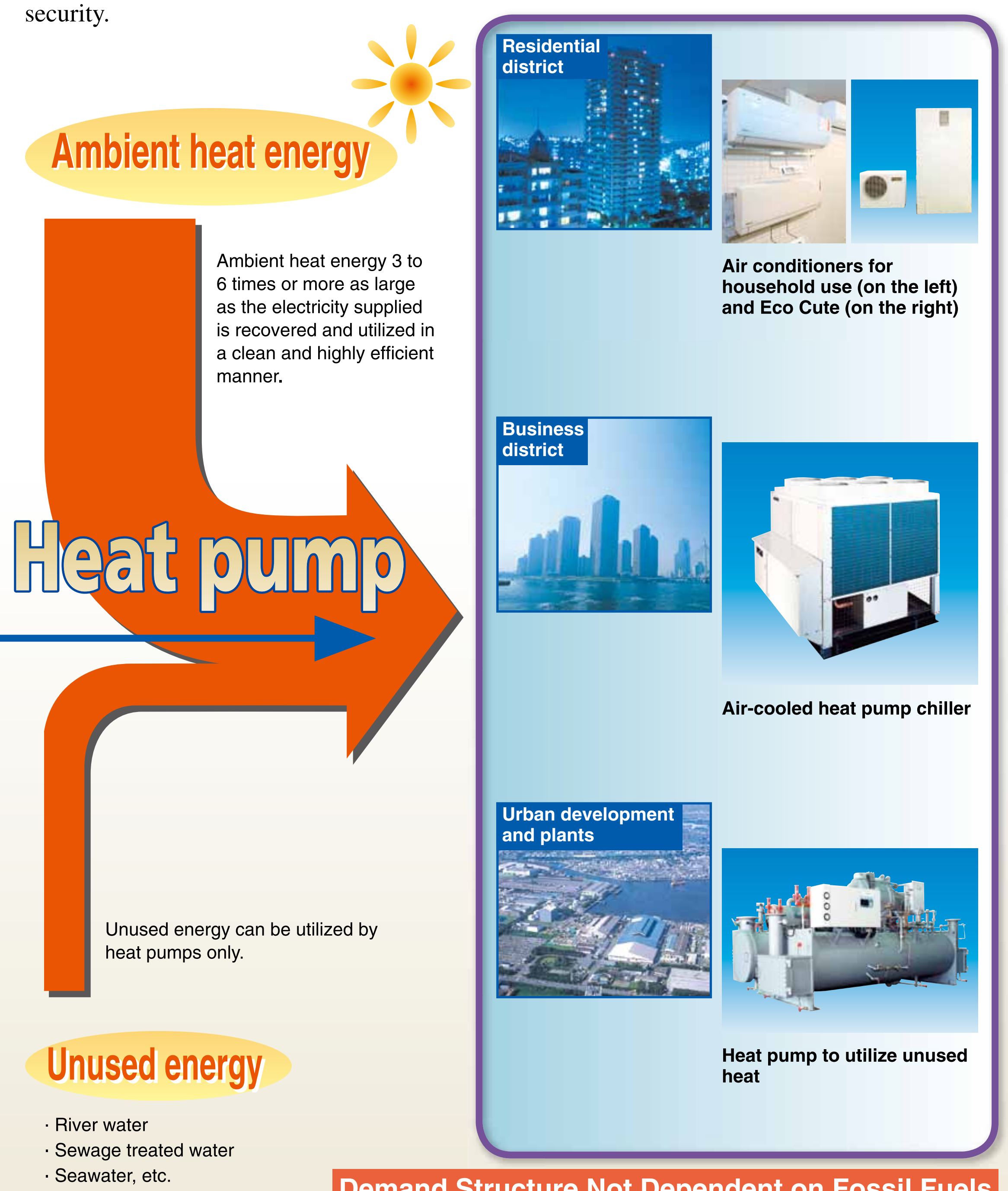
Best Mix of resources Not Dependent on Fossil Fuels Only

Heat pumps consume a little electricity when they pump up ambient heat. Heat pumps themselves do not emit any CO_2, but CO_2 is emitted from thermal power stations where fossil fuels are burnt to produce electric power. In addition to thermal power, however, about half of the sources that generate electricity do not emit CO_2 such as hydroelectric power, nuclear power, natural energy, etc.

For providing heat, combustion system and heat pump are available. However, it is important to go back to the primary energy sources and examine what are good energy systems from an overall point of view in order to consider how society ought to be in the future, rather than paying attention only to the efficiency on the demand side. In this respect, utilizing a clean, highly efficient and stable electric power system where fossil, non-fossil and natural energies are mixed in a well-balanced manner in combination with heat pumps that pump up inexhaustible ambient heat is the cleanest and most efficient way in terms of both energy supply and demand.

Combination of Heat Pumps That Utilize Ambient Heat and High-Efficiency Power Sources enhance "Energy Security"

If noncombustion is promoted by utilization of ambient heat and electric power on the demand side, and the share of power generation by non-fossil fuels such as nuclear power, etc. is increased on the supply side, their synergistic effects contribute to enhancement of energy security.



Demand Structure Not Dependent on Fossil Fuels

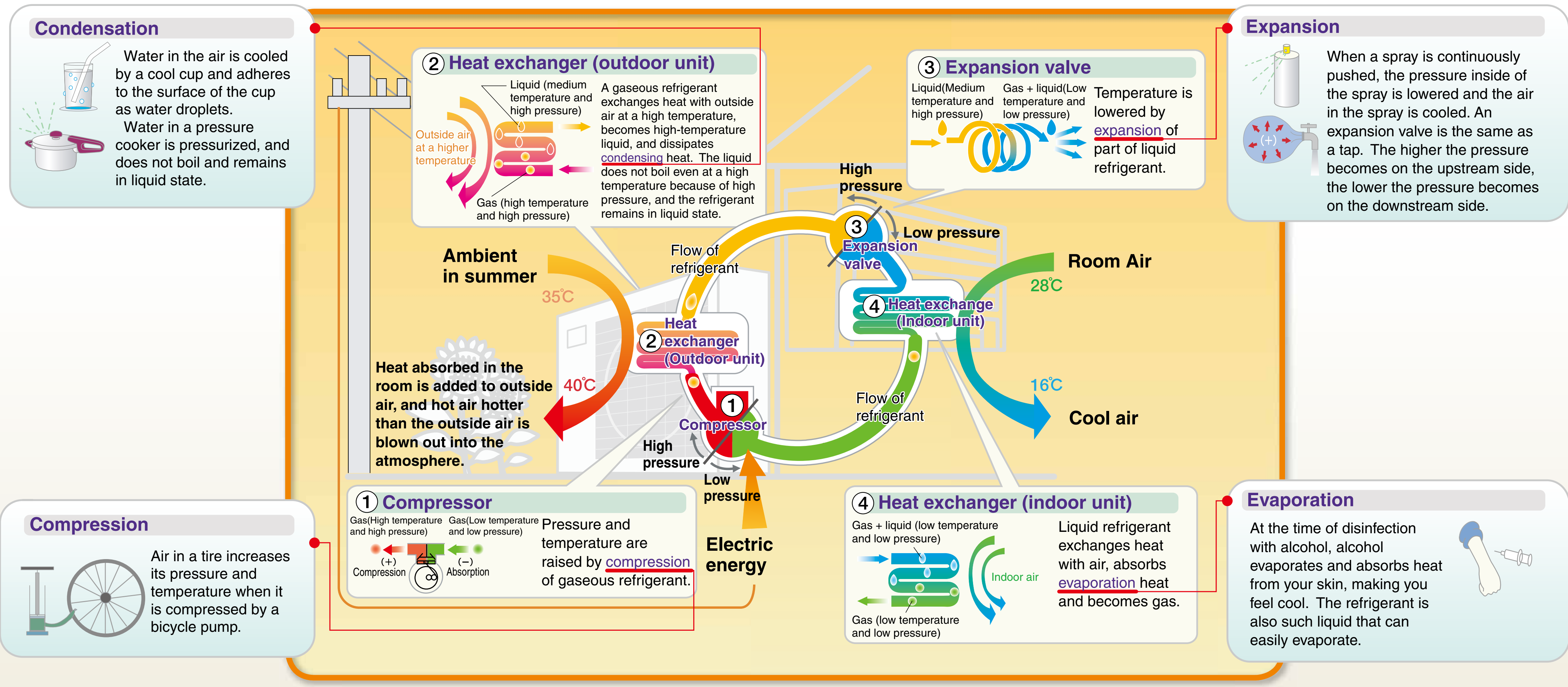
Mechanism of Heat Pump

Heat Pump's Mechanism to Pump up Heat

· A heat pump pumps up heat from lower temperatures to higher temperatures.
· A heat pump can do so because it utilizes the following two basic characteristics:
"Gas increase by nature its temperature when it is pressurized, and decrease its temperature when it is depressurized." (Boyle-Charle's law)
"Heat flows by nature from higher temperatures to lower temperatures."
(The second law of thermodynamics)

· We would like to explain this mechanism with an air conditioner as an example. There is a substance (refrigerant) that carries heat in a pipe between an outdoor unit and an indoor unit. This refrigerant is compressed and expanded to raise and lower its temperature and pump up heat from the inside to the outside. Its cycle is shown in the picture below.

Comparison to Familiar Phenomena



· If this cycle is reversed, heat pumps can heat rooms and supply hot water.
· Pumping up such heat consumes electricity as the power to compress a refrigerant. A great advantage of heat pumps is that the amount of electricity used is very small compared with the amount of heat pumped out.

Centrifugal Chiller

Heat pumps have a mechanism that carries heat by repeatedly compressing and expanding refrigerants. Therefore, what is important is how efficiently heat can be pumped up more with less electricity.

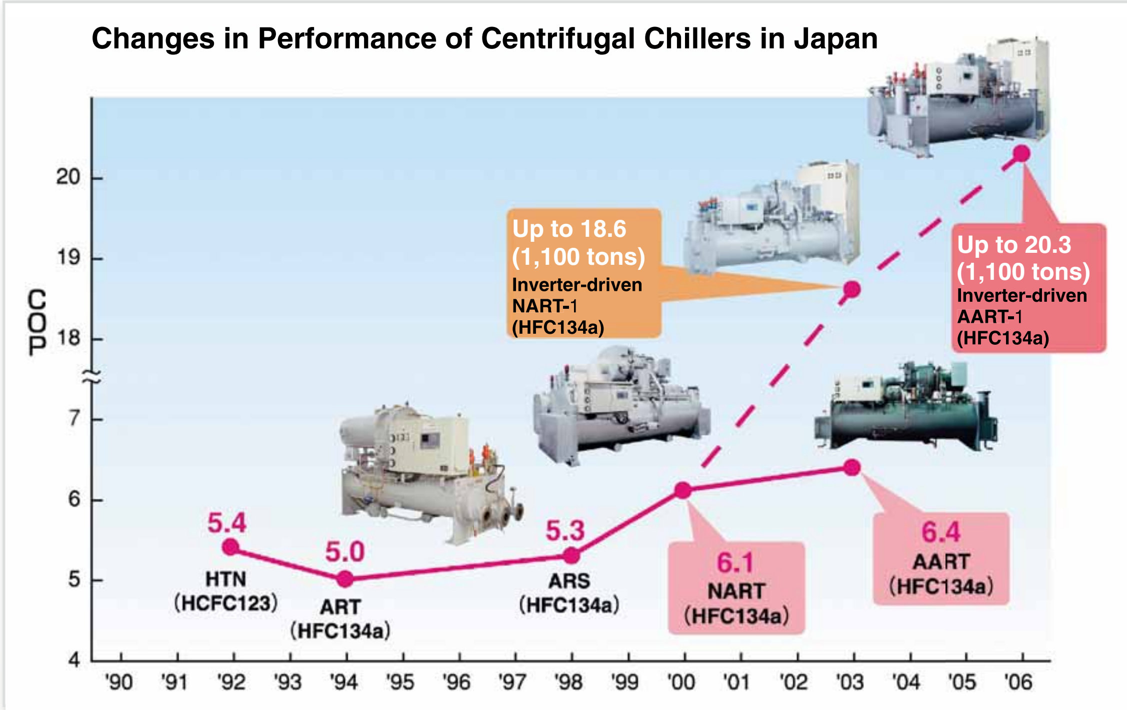
Now a "high-efficiency centrifugal chiller" has become a focus of attention because of its epoch-making energy-saving performance in the field of large cooling equipment.

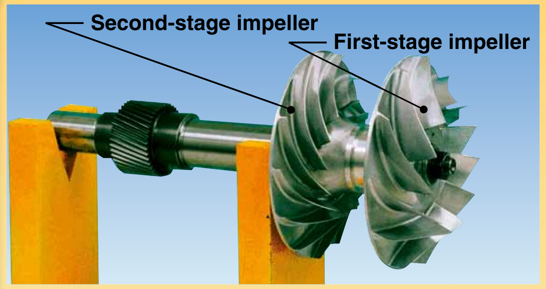
As the word "centrifugal" suggests, the centrifugal chiller has impellers that rotates at high speeds of several thousand and even several tens of thousand revolutions per minute (RPM) to blow off refrigerant gas radially by centrifugal force and efficiently compress the gas. As a result, its energy consumption efficiency (in terms of COP) is as high as COP = 5.7-6.5 at the rated power. Its energy-saving performance is very high.

Recently, moreover, an inverter-equipped model is also developed. The inverter is able to change the frequency of alternating current electricity and change the RPM of the compressor that compresses the refrigerant. With the inverter, power consumption at the time of operation with less loads can be drastically saved and COP is improved by a wide margin. In the case of the inverter model, when the cooling water temperature is low in spring, fall and winter and at the time of partial loads, the efficiency of COP in the order of up to 20 or higher was achieved. As such high energy-saving performance and high reliability are evaluated, many centrifugal chillers have been introduced in semiconductor plants that are air conditioned throughout the year. At a certain high-tech manufacturers, an annual average COP is 10 or more, for example.

In the past, absorption type refrigerators were widely used in large buildings and for DHC in Japan. The share of centrifugal chillers that have such high energy-saving performance and CO_2-reducing performance is now on an upward trend. The Japanese government also has a target of introducing 12,000 high-efficiency air conditioners for business use by 2010 as part of its plan to achieve the target prescribed by the Kyoto Protocol.

* COP (Coefficient of Performance)
COP represents energy consumption efficiency. The ratio of cooling (heating) output divided by the energy inputted. COP = 6 means that input of electricity of 1 is required to produce heat of 6. In other words, it shows the efficiency when heat energy of 1 is pumped up, electric energy of only one-sixth of the heat energy is required.





Impellers of centrifugal chiller

Compressor of small centrifugal chiller


Impellers of small centrifugal chillers

< Source: Mitsubishi Heavy Industries, Ltd. >

Thermal Storage Air Conditioning

A heat pump is a mechanism that freely creates the temperature you want to use when you want . However, the demand for air conditioning in offices reaches a peak during daytime, and air conditioners are rarely used during nighttime. If equipment is prepared in proportion to such demand, the availability factor of such equipment remains low.

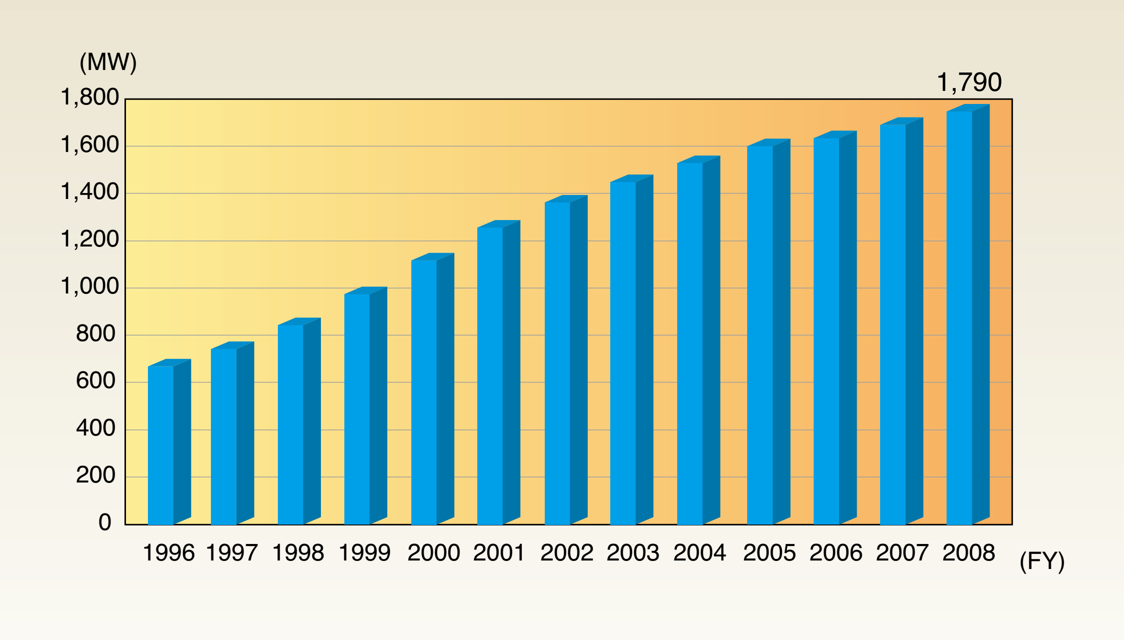
For this reason, "thermal storage" air conditioning that produces and stores the heat needed for air conditioning during nighttime when the demand for air conditioning is small and utilizes the stored heat at a peak during daytime is now receiving much attention.

If this thermal storage system is compared to a car for easy understanding, it is similar to hybrid cars that have recently come into wide use. The engines of hybrid cars differ little from that of conventional cars. However, as the former mainly uses the most efficient part of the engine, its fuel efficiency is drastically improved. As the thermal storage system can also allow heat pumps to operate more efficiently, it is congenial to heat pumps.

With this thermal storage system, large air conditioning systems that are made proportional to the peak during daytime will be unnecessary, and the basic charge of electricity contract can be saved. Moreover, as the system produces and stores heat by using an inexpensive nighttime electricity service, overall running cost is lowered. Moreover, as the heat source equipment is efficiently operated at a constant speed, it saves energy consumption by about 10%.

Thermal storage stores heat in the water and ice stored in tanks.

In Japan as a whole, a peak of 1.6GW or equivalent to 1.5 large power plants is reduced by thermal storage. Thermal storage is expected to come into wide use as a mechanism to further exploit the advantages of eco-friendly heat pumps.



Peak Shift in MW by Thermal Storage Air Conditioning Systems in Japan

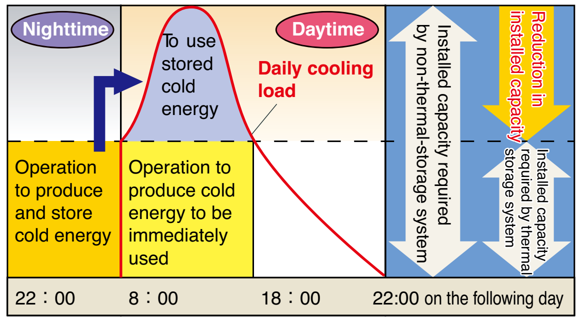
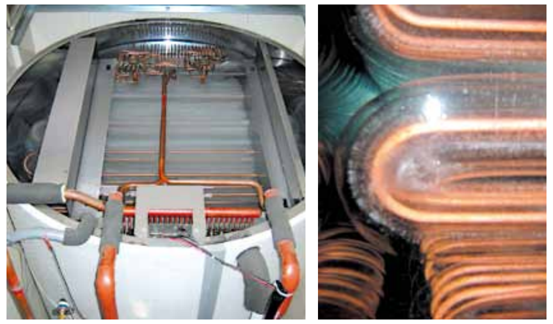
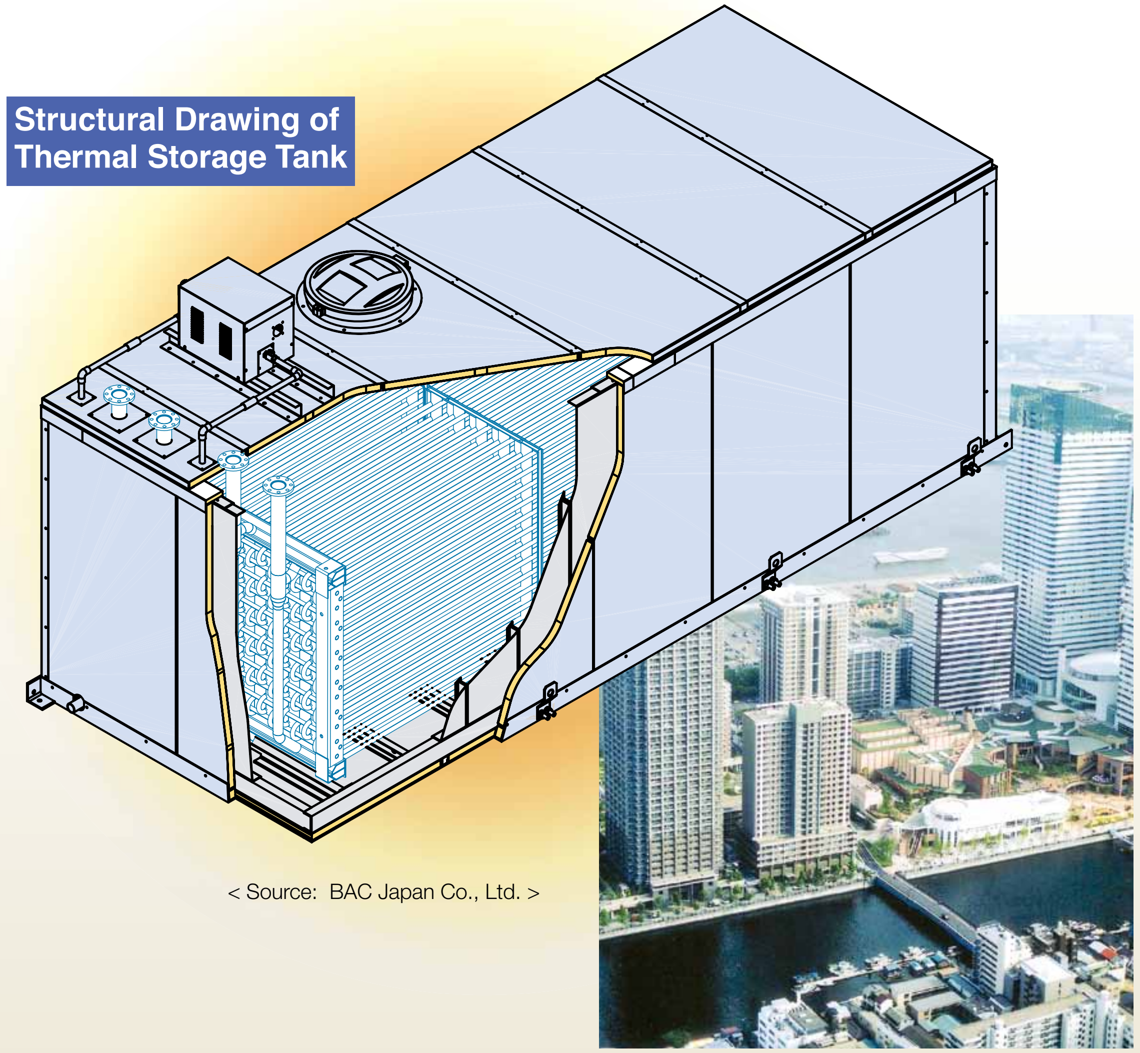


Image of Thermal Storage Operation



Overall appearance (on the left) and inside (on the right) of ice thermal storage tank

< Source: Meiwa Service Inc. >



< Source: BAC Japan Co., Ltd. >

Home Air Conditioner

Heat pumps familiar to us are those for home air conditioners. According to a survey made by Japanese Cabinet Office, the nationwide diffusion rate of home air conditioners stood at 87% in Japan, as of the end of March 2006.

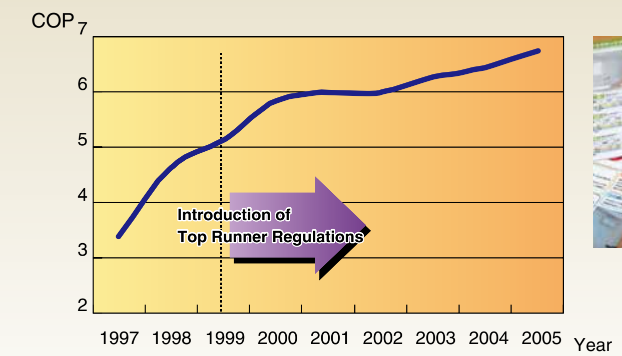
In Japan, cooling only air conditioners were introduced to the market late 1950s. In 1970s, air conditioners for both cooling and heating were introduced in the market. But, in those days heating capability was not sufficient and to make up for the defects, an auxiliary heater was integrated into an indoor unit.

Then, in 1980s when inverter air conditioners were introduced, the situation drastically changed. Advent of variable frequency operation has enabled high-speed revolution to achieve a preset temperature in a small amount of time, and turning into low-speed revolution can reduce power consumption, thus attaining higher power and significant energy saving.

By early 1990s, home air conditioners had reached a level similar to COP = 3 in performance efficiency, which is comparable to combustion type equipment. In addition,Top Runner Regulations under the revised Law Concerning Rational Use of Energy (so called Energy Conservation Law), which took into effect in 1999, has promoted competition among the manufacturers in efforts to develop highly efficient home appliances, resulting in achieving efficiency as high as nearly COP = 7.

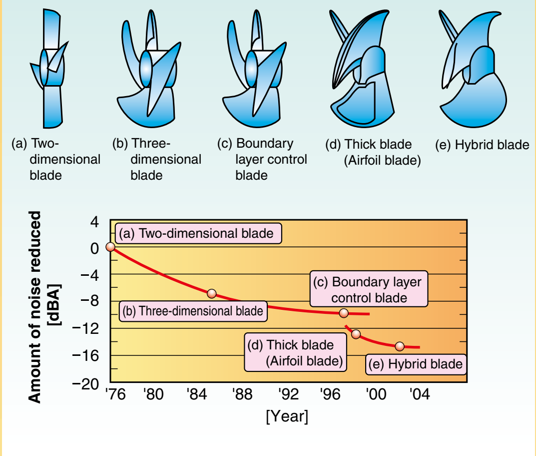
Thus, due to rapid changes, including cutting power consumption by half over the past ten years, a heat pump air conditioner is able to heat for a running cost about half of other heating equipment burning oil or gas, although it is a little known fact.

Under the circumstances as such, advances in various elemental technologies adopted in systems have enabled such a rapid improvement in efficiency. Based on advanced airflow analysis, fan structure has been improved to efficiently absorb heat in the air with pumping up a large amount of air from an outdoor unit, while consuming less electricity. In order to enhance heat transfer performance at fin in a heat exchanger, advanced processing technique was employed to efficiently exchange heat between air and refrigerant. As for a compressor to compress refrigerant, power consumption is reduced by developing a high-performance motor. Also, more efficient compression became available through adoption of scrolling.

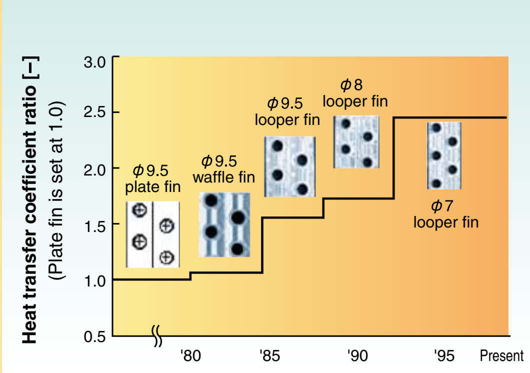


Heat pump applied home air conditioners feature significantly improved COP

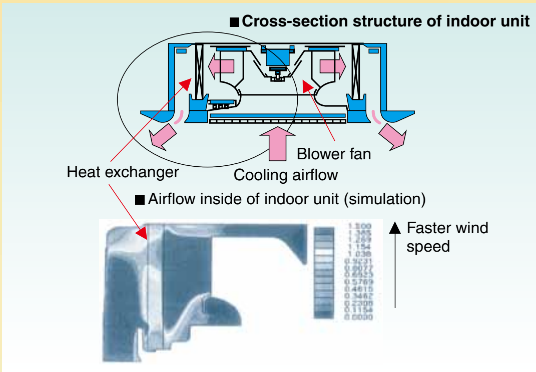
< Source:"Energy-Saving Performance catalog" published by The Energy Conservation Center, Japan (ECCJ) - COP during cooling operation of the best home appliance among 2.2 kW-class air conditioners >



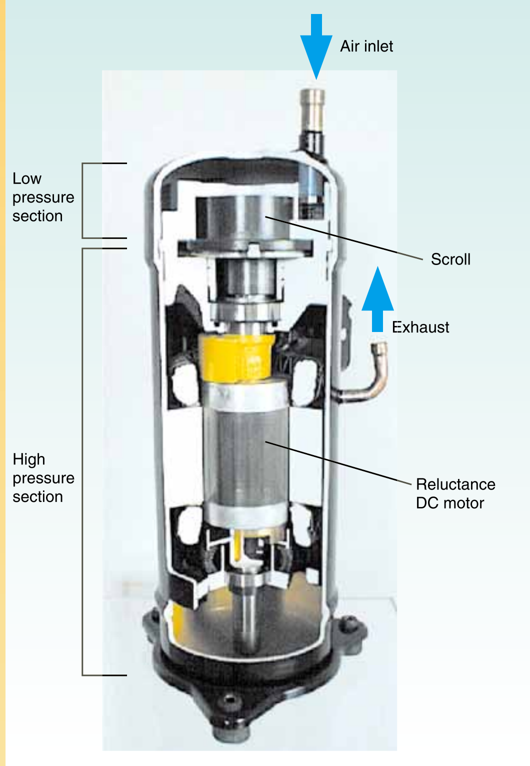
Changes in Propeller Fan Improvement



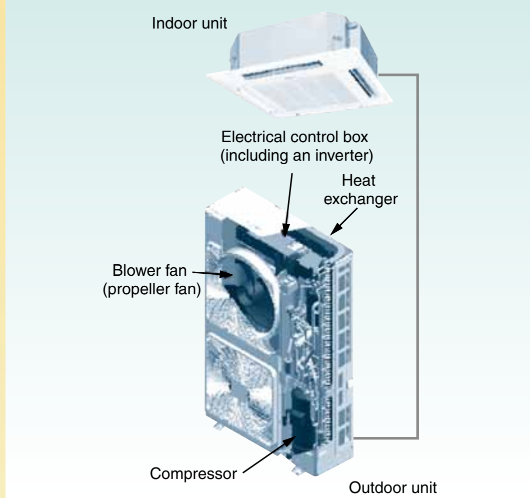
Changes in Fin Configuration



Conditions of cooled air inside of heat exchanger



Structure of Scroll-Type Compressor



Internal Structure of Air Conditioning System for Business Use

< Source: Daikin Industries, Ltd. >

Non-Chlorofluorocarbon Refrigerator

Another important application of heat pump for residential use is a refrigerator. Nowadays, refrigerators are installed very close to a wall. Earlier models had black tubes extending vertically and horizontally on their backside. The black tubes released heat, which a heat pump collected from the inside of refrigerator.

Electric refrigerator has a long history among home appliances. Freezing system, using a heat pump, was developed in 1834 in the U.S. First successful ice making in Japan, using a freezing machine, took place in 1870. First electric refrigerator was imported to Japan in 1923. Japan began domestic production of electric refrigerator in 1930s. In those days a refrigerator was priced at a level similar to a price of house. Accordingly, the majority of refrigerators were ice box types cooled by inserted blocks of ice.

A refrigerator fitted with a freezing room was introduced to the market in 1963, a year before Tokyo Olympic Games. During a high-growth period a refrigerator was one of the "three most popular consumer products," together with a black & white television and a washing machine, to which the people were yearning to purchase.

Later refrigerators began to adopt a frequency controlled inverter, as did air conditioners, as well as vacuum heat insulation materials, thus achieving great energy-saving. As a result, present generation models consume much less power than the refrigerators in 1980s.

In 2002, non-chlorofluorocarbon refrigerators became available in the Japanese market. These models using natural refrigerant called isobutene, which is used as fuel for lighters, has become rapidly widespread. At present almost all refrigerators are based on non-chlorofluorocarbon specifications.

Old and familiar heat pump refrigerators have advanced with the flow of the times.

Energy-saving, eco-friendly non-chlorofluorocarbon refrigerators

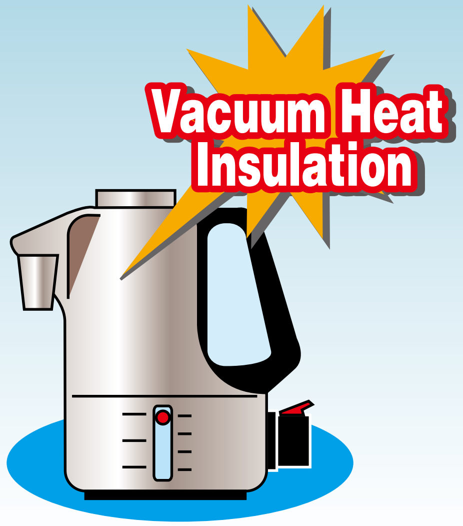
The black tubes extended from a compressor below a refrigerator release heat outside from a refrigerator.

"Vacuum Heat Insulation Materials" Has Drastically Improved Energy-Saving Feature of Refrigerator

In order to reduce power consumption to pump up heat from a refrigerator required to cool inside of it, it is needed to prevent invasion of heat from wall surfaces. The industry used to adopt glass wool or urethane foam to insulate heat in the past. Use of vacuum heat insulation materials has drastically improved heat insulation performance.

A thermos bottle utilizes vacuum state by creating vacuum space between dual containers, where no gas exists that transmits heat, to keep the temperature constant inside of a bottle, which is made of glass or stainless steel.

Creation of vacuum state inside a bag which is laminated by filling porous powder or fiber, became possible under the same principle. The technology has enabled flexible mats or heat insulating panels for putting thin covers on various shapes. As a result, products featuring significantly improved energy-saving features have been introduced, including lower power-consuming refrigerators and bathtubs keeping water hot over a long period.



From Chlorofluorocarbon to Natural Materials: Changes in Refrigerant

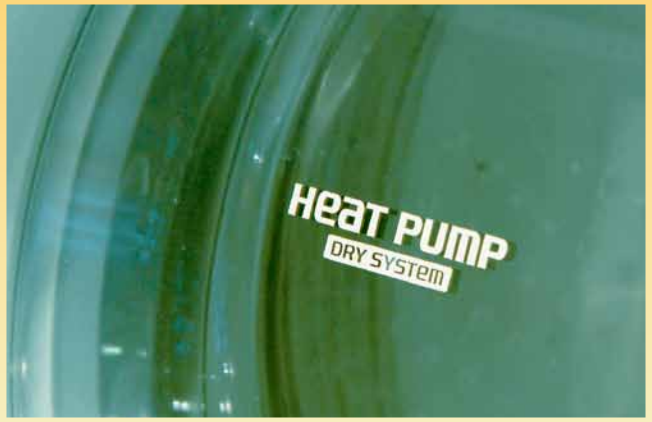
When heat pumps began to be used as a freezer to make ice about 150 years ago, natural materials such as air and ammonia were adopted as refrigerant.

In 1930s, chlorofluorocarbon was developed as an artificial refrigerant. Artificially synthesized from hydrocarbon such as methane, chlorofluorocarbon has superior features as refrigerant, including odor-free, harmless, nonflammable, stability, and high-performance. Chlorofluorocarbon played a major role in spreading the use of air conditioners and refrigerators.

It was learned that chlorofluorocarbon is decomposed by ultraviolet ray in the stratosphere, releases chlorine atoms, and destroys ozone layers. In late 1980s, an international agreement was signed to ban the use of specified chlorofluorocarbon and switch to using chlorofl uorocarbon alternative (HFC). However, it has a shortcoming of causing global warming. So, regulations have been adopted to take measures, including recovery of such gases after use.

In search of heat pump refrigerant, the industry looked at the materials existing in the nature in a new light. Such efforts have resulted in the development of excellent products, including non-chlorofluorocarbon refrigerator using isobutan and Eco Cute using CO_2.

Heat Pump Drying Machine



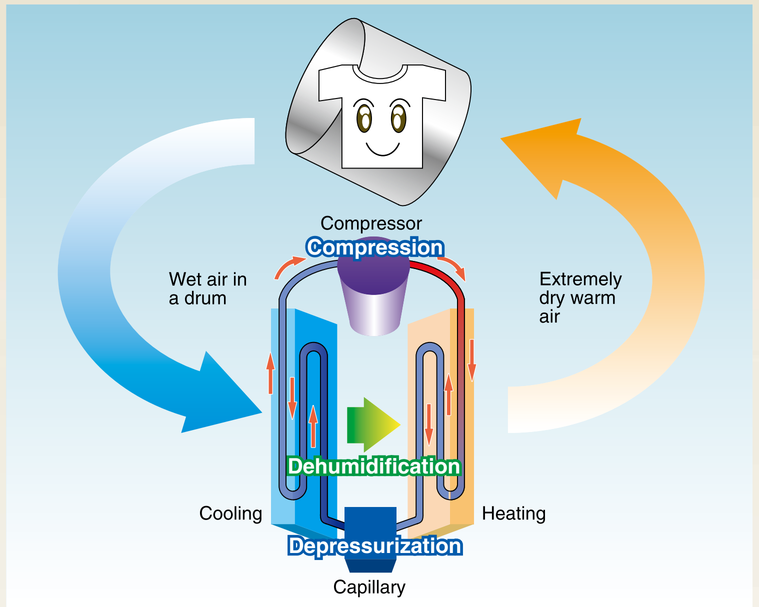
In November 2005, the world's first washing machine that dries clothes by heat pump was introduced to the Japanese market. Operating on the same principle as outdoor and indoor units of an air conditioner, the machine is so unique that it performs simultaneously drying and heating with warm air.

During air conditioner's heating operation, an outdoor unit's cold refrigerant deprives heat from the air, letting an indoor unit blow warm air. A heat pump washing and drying machine operates on the same principle. Wet air in a washing drum is reflected to a heat sink (equivalent to air conditioner's outdoor unit) to be cooled. Dew condensation water is disposed. Then, dry air is moved forward to a radiator (equivalent to air conditioner's indoor unit) on the opposite side. Dry air turns into warm air and returns to inside of drum.

Conventional generation models of washing and drying machine use a heater with a capacity of over 1 kW to make warm air. Also, they use large amount of tap water for cooling and drying. All these can be replaced by one heat pump. As a result, heat can be produced with much less power consumption, compared to a heater. In addition, the heat of once warmed air in a drum is recycled by a heat pump. Also, water vapor condenses into water droplets, when a heat pump deprives the air of heat.

As a result, it is reported that power consumption, amount of water used, and the time needed for drying are reduced by around half, compared with the conventional models. In addition, compared with the conventional heater-type dryers blowing hot air with the temperature of over 100℃ to clothes, newly developed heat pumps blow dry and cooler air reaching about 65℃, thus significantly lessening the problems of shrinking or damages found in less heat-resistant clothing materials.

As mentioned above, heat pumps are expected to be utilized in various applications, including washing and drying machines, dishwashing and drying machines, bathroom drying machines, garbage processing equipment, in addition to air conditioning.



Principle of Heat Pump Drying

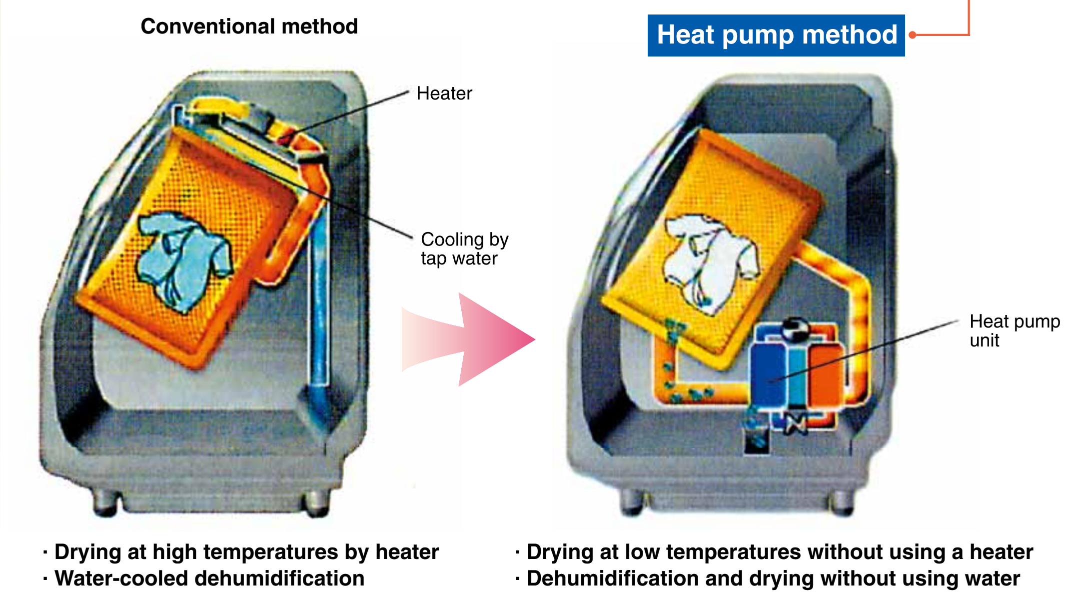
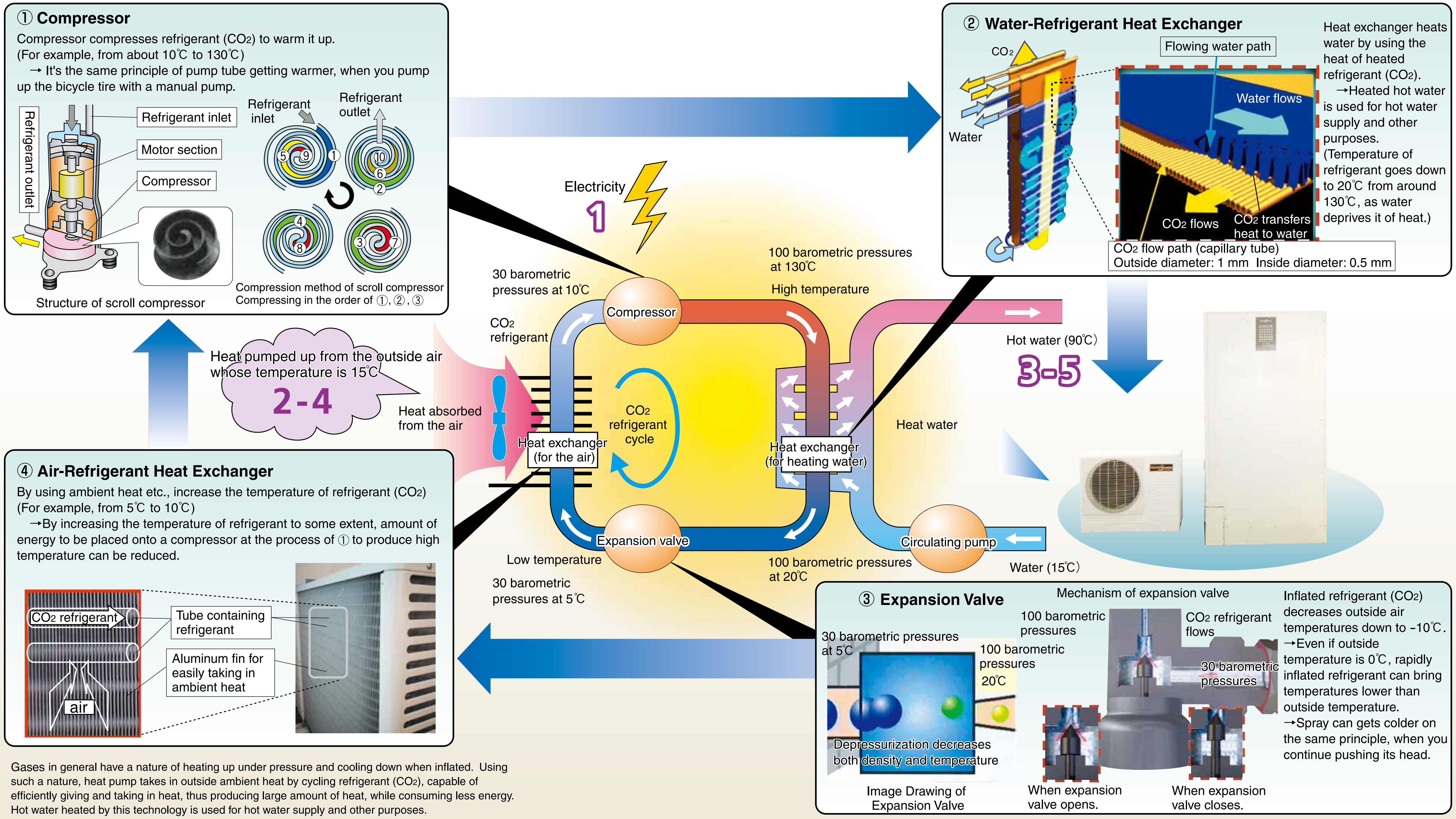


Image Drawing

< Source: Matsushita Electric Industrial Co., Ltd >

Mechanisms of CO_2 Refrigerant Heat Pump Water Heater for Residential Use (Eco Cute)

Electricity of 1 takes in 2-4 of thermal energy and gets 3-5 of hot water supply (thermal) energy.



Gases in general have a nature of heating up under pressure and cooling down when inflated. Using such a nature, heat pump takes in outside ambient heat by cycling refrigerant (CO_2), capable of efficiently giving and taking in heat, thus producing large amount of heat, while consuming less energy. Hot water heated by this technology is used for hot water supply and other purposes.

Characteristics of Eco Cute

Eco Cute pumps up the heat of the air to boil water. Chlorofluorocarbon used as refrigerant in air conditioners are not able to efficiently produce high temperatures required for hot water supply. Using CO_2 as refrigerant has solved this bottleneck.

Compressed CO_2 up to 100 barometric pressures reaches supercritical state, a state somewhere between a gas and a liquid. CO_2 in this state can be easily heated up to much higher temperatures, enabling heating water over 90℃, necessary for hot water supply. Then, in 1998, Central Research Institute of Electric Power Industry of Japan, DENSO CORPORATION, and Tokyo Electric Power Company (TEPCO) started joint development of the world's first natural refrigerant heat pump water heater. Eco Cute was introduced to the Japanese market in 2001.

The largest advantage of Eco Cute is that "it does not burn fuel." "The common sense of burning fuel to boil water" has become completely outdated.

Instead of burning, necessary heat is taken in from the "air." Accordingly, no CO_2 is emitted, as contrasted to a burning process.
A small amount of CO_2 is emitted at the time of power generation to obtain marginal power required for pumping up heat from the air. But, the amount of CO_2 emission is much less than a combustion type water heater.

A combustion type water heater is unable to take in energy more than the amount put in. On the other hand, Eco Cute has improved its efficiency to COP = 4.9 in the 2006 model from COP = 3.5 of the initial model. Even taking into account of 40% of power generation efficiency, it produces heat greater than the energy put in a power station. Its primary energy consumption is much less than combustion type water heater.

As a result, in case of Eco Cute with COP = 4, it releases some 65% less CO_2, compared with conventional water heaters. Reduction in CO_2 emission totals 0.8 ton a year per household in Japan.

One-third of total household energy consumption of Japan is for hot water supply. Currently, combustion type water heaters have a majority market share. If efficient Eco Cute spreads, significant energy-saving and reduction of CO_2 emissions would be possible. Residential sector account for 15% of total energy consumption
in Japan. If all home water heaters are replaced by Eco Cute of COP = 4, 25 million tons of CO_2 emissions, or some 2% of the total, could be reduced a year in Japan.

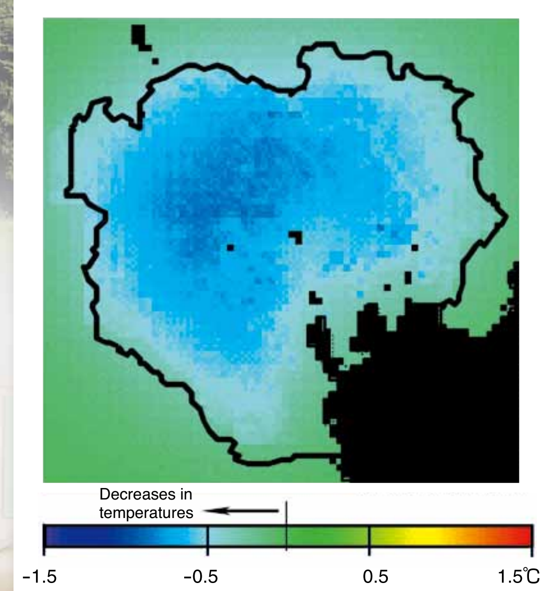
Appreciating such a great potential for reduction of CO_2 emissions, the Japanese government sets a plan to introduce 5.2 million units by the time of 2010 as part of efforts to achieve the targets of the Kyoto Protocol. The government introduces a subsidizing system to help its wider use.

Effect of Eco Cute

CO_2 emissions reduction equivalent to preserving forest areas of:

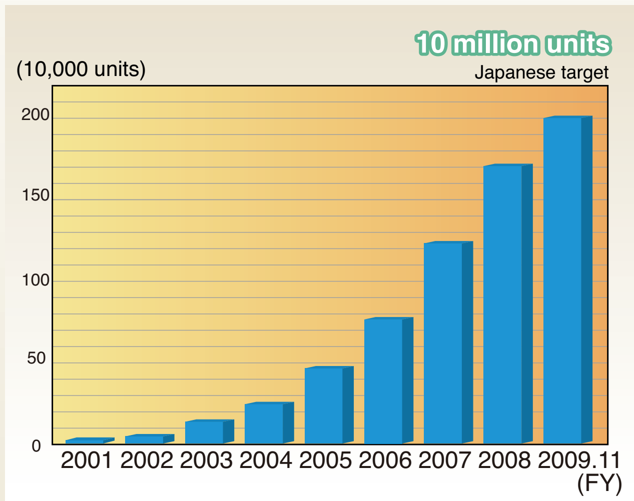
If all households in Suginami ward use Eco Cute (a total of 280,000 households), 230,000 tons of CO_2 emissions could be reduced.

Heat island controlling effect

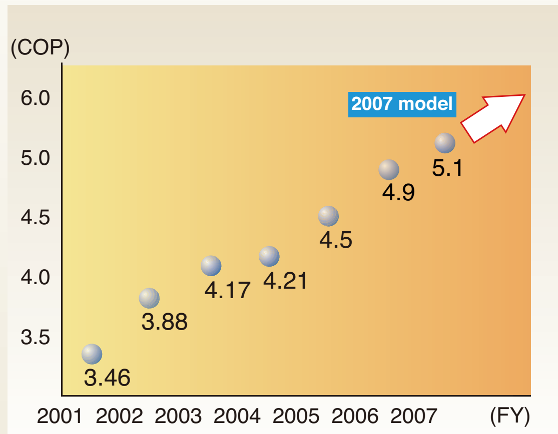


< Source: Central Research Institute of Electric Power Industry >

It is estimated that some 0.5°C would drop, if all households in Tokyo's 23 wards, totaling some 4 million, use Eco Cute, which recovers urban waste heat.



Actual Diffusion Results of Eco Cute in Japan (Installed Base)



Improvement of Eco Cute's COP

Prevention of Global Warming by Heat Pumps

As a result of massive consumption of fossil fuel after the Industrial Revolution, a large amount of CO_2 has been emitted, leading to rapidly increasing CO_2 concentration in the atmosphere. The earth's temperatures have increased by 0.74℃ in average over time of the past 100 years. A report by Intergovernmental Panel on Climate Change (IPCC) warns several problems associated with global warming:
By 2100, the earth's average temperature will increase by 1.8℃ - 4.0℃ ; Sea level will rise by 18 cm-59 cm; Unusual weather such as drought and heavy rain will occur; Ecological changes will happen; and Infectious diseases may increase.

"Kyoto Protocol," an international treaty setting mandatory targets for the reduction of CO_2 emissions, entered into force in February 2005. Finally, the terms of the agreement at the Third Conference of Parties to the United Nations Framework Convention on Climate Change (COP3) in 1997 took effect. Kyoto Protocol calls for the reduction of greenhouse gas emissions in advanced nations between 2008 and 2012. From the levels in 1990, Japan must reduce by 6%, the U.S. 7%, and the EU 8%.

Following the Kyoto Protocol taking effect, the Japanese Cabinet decided on the "Kyoto Protocol Target Achievement Plan" in April 2005, proposing implementation of every possible means both by the government and private sectors. Japan's greenhouse effect gas emissions had increased by 8.3% by 2003 since 1990. To achieve the goal, emissions need to be reduced by over 14%. Increases in emissions have been attributable to commercial sectors, including residential and business sectors, and transport sectors. It's very important to bring efficiency to energy consumption in these sectors and control CO_2 emissions.

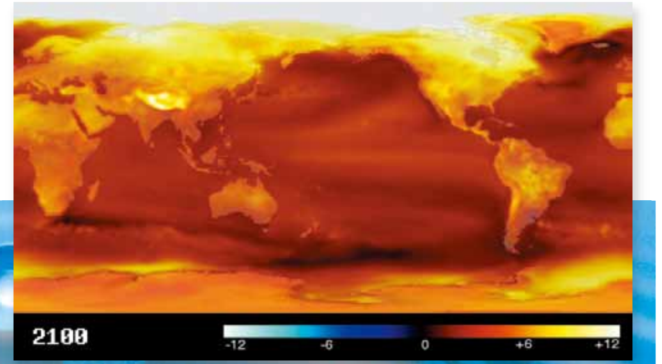
Consequently, as part of efforts to achieve the goals of the Kyoto Protocol, the Japanese government sets a plan to introduce 5.2 million Eco Cute units for residential use and 12,000 highly-efficient air conditioning systems for business use by 2010 as one of major measures in commercial sectors.

Fuel-burning type models dominate in the commercial sectors, including hot water supply, residential heating equipment, and air conditioning equipment for businesses. If highly-efficient heat pumps were fully introduced to these sectors, up to 100 million tons of CO_2 emissions could be reduced a year in Japan. In addition to simply reducing CO_2 emissions, utilization of ambient heat has another advantage of developing purely domestic natural resources that replace the crude oil consumption of 45 million kiloliters a year.

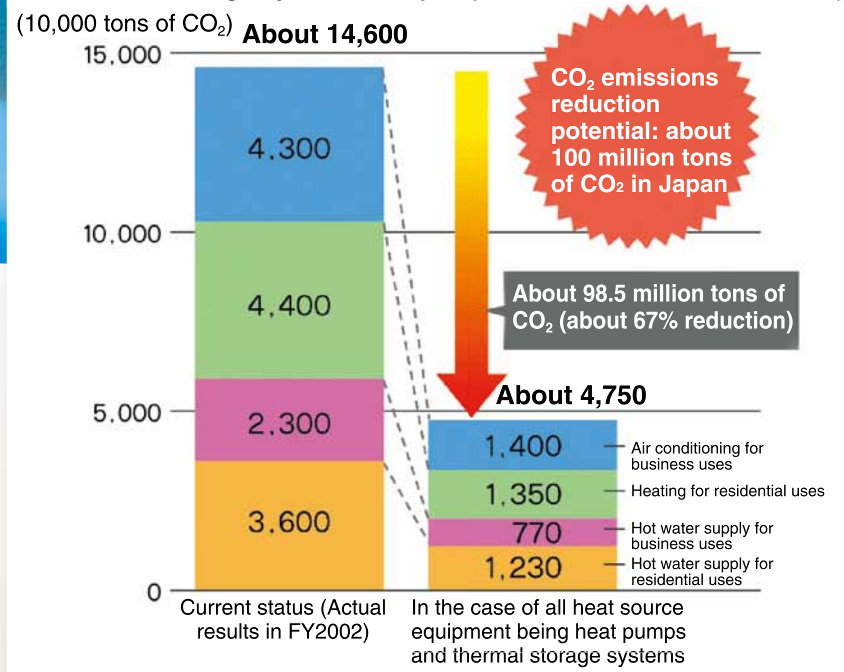
Distribution of Average Increases of the Earth's Surface Temperature in Around 2100

Simulated geographical distribution of average increases of the earth's surface temperature between 2071 and 2100 (reference year: 1900)

< Source:
Center for Climate System Research, University of Tokyo
National Institute for Environmental Studies Frontier Research Center for Global Change>



CO_2 Emissions Reduction Potentials of Heat Pumps and Thermal Storage Systems in Japan (Residential & Business Sectors)



Air conditioning and hot water supply systems just in use at office buildings and households release 150 million tons of CO_2 a year. In such a situation, in the case of all heat source equipment used in business and residential sectors were replaced by highly-efficient heat pumps and thermal storage systems, a total of 100 million tons of CO_2 emissions would be reduced.

The amount of 100 million tons of CO_2 is equivalent to 1.5 times of the target (60 million tons) set for the commercial sector by Kyoto Protocol Target Achievement Plan of Japan.

5

MERITS 10

Ten Merits of Heat Pump as an Energy Supply System to Simultaneously Achieve Both Improvement in Energy Security and Measures Against Global Warming

--- To realize an energy conservative world to support sustainable development ---

Recent developments in energy situation

- ◯Global warming issues
- ◯Ensuring of energy security
- ◯Measures to avoid a steep rise in crude oil prices

Increase in problems that must be urgently resolved

Measures

- ◯Strategy for resources and energy
- ◯Measures for prevention of global warming

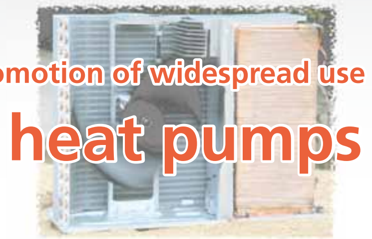
Approaches taken at national level

Desirable future to be pursued

- ◯Development and diffusion of energy conservation technologies
- ◯Carbon-free society
- ◯Resource diplomacy

Setting of strategic targets

- ◯ Technological innovation is not necessarily confined to cutting-edge fields.
- ◯ Technological innovation is rapidly under way in existing technologies.



Epoch-making and cutting-edge technology for measures against global warming on the demand side

What is heat pump?

- ◯ Technology to utilize inexhaustible heat of solar energy origin in the air for air-conditioning, hot water supply, cooling etc. without involving any combustion.
- ◯ Technology that has been already established in the field of heat utilization where positive effects will be immediately and significantly realized.
- ◯ If air-conditioning, hot water supply and humidification equipment are replaced with heat pump-based equipment, there is a potential of reducing emissions of CO_2 as a greenhouse gas by as much as about 130 million t-CO_2 only in Japan.

MERITS 10

Viewpoint of Environmental Protection

- **#1** It is highly worthwhile for the world at large to make efforts for promotion of widespread use of heat pump technology as a "technology to cope with global warming."
- **#2** Ambient heats, such as heat in the air or heat in the ground are "renewable energy."
- **#3** Reduction in artificial waste heat and recycling of heat ease "heat island" phenomena.

Viewpoint of Energy Security

- **#4** Replacement of fossil fuels with ambient heat improves "energy security."
- **#5** A realistic tool to "decarbonization" on the demand side.
- **#6** Widespread use of thermal storage systems promotes "load leveling" of energy.

Viewpoint of Technological Contribution

- **#7** "International contribution" can be facilitated by using the energy conservation technology
- **#8** Promotion of energy conservation technology "invigorates the manufacturing industry."
- **#9** Heat pump technology can evolve as an "advanced environmental technology" because it is expected to find other large fields of application in the future.

Overall Viewpoint

- **#10** "High feasibility" that allows anyone to immediately address practical application of heat pump technology.

Viewpoint of Environmental Protection

Reduction of Environmental Load Will Be Realized by Variety of Global Warming Control Measures by Utilizing Inexhaustible Ambient Heat Energy

MERIT #1 Technology to Cope with Global Warming

It is highly worthwhile for the world at large to make efforts for promotion of widespread use of heat pump technology as a "technology to cope with global warming."

○ There is a potential of reducing CO_2 emissions by 130 million tons (100 million tons in the commercial sector + 30 million tons in the industrial sector) in Japan.

○ This figure exceeds the Japanese government's target to reduce CO_2 emissions in the commercial sector by about 60 million tons.

Potential is large → Diffusion is not enough by now

○ Highly efficient appliances that utilize heat pump technology are already developed. If efforts to disseminate heat pumps are made, heat pumps are products of the most realistic technology to cope with global warming, which immediately yields the effect of reducing CO_2 emissions.

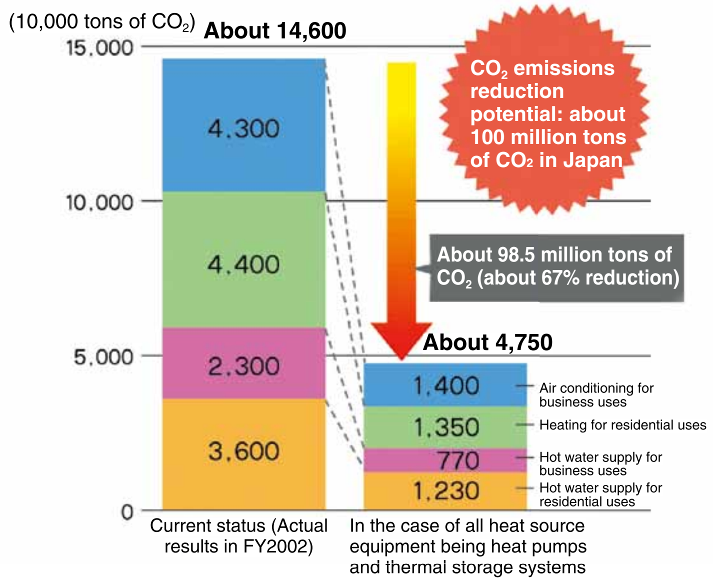
Feasible right now and its effect is large

○ As no combustion is involved, there are no emissions of not only CO_2 but also NOx, SOx and other air-polluting substances at places of demand.

Also effective to prevent air pollution

No CO_2 emissions at places of demand

CO_2 Emissions Reduction Potentials of Heat Pumps and Thermal Storage Systems in Japan (Residential & Business Sectors)



MERIT #2 Renewable Ambient Heat Energy

To increase the amount of renewable energy to be introduced by utilizing ambient heat energy

○ Heat pumps are internationally classified into renewable energy (together with geothermal energy utilization) in thermal energy area, and many European countries include heat pumps in international statistics.

○ In Japan, there are 830,000 heat pump water heaters (Eco Cute) now in use and 100 million heat pump air-conditioners in use.

The photovoltaic and wind power energy supplied in Japan amounts to 654,000 kiloliters (oil equivalent)

About three times as much

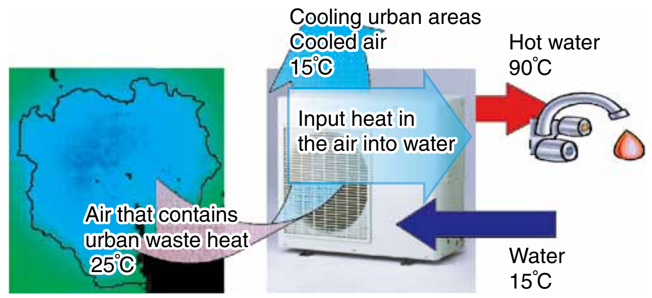
Heat energy in the air utilized by heat pumps amounts to 1,725,000 kiloliters (oil equivalent)

MERIT #3 Heat Island Phenomenon Problem in Urban Areas

To ease heat island phenomena through reduction in artificial waste heat and recycling of heat

○ Reduction of artificial waste heat generated by air-conditioners:
Highly efficient heat pump air-conditioners are effective to reduce waste heat from cooling and heat of combustion at places of demand.

○ Recycling of urban waste heat:
Eco Cute that heats water by using atmospheric heat also has an effect of recovering urban waste heat and cool urban areas.



If heat pump equipment are installed at all households in Tokyo (about 4 million units)

there is an effect of lowering the temperature by about 0.5˚C

Viewpoint of Energy Security

Improvement in "Energy Security" by Heat Pumps Utilizing Ambient Heat and Highly Efficient Power Sources

The synergistic effect of promotion of decarbonization on the demand side through utilization of atmospheric heat energy and an increase in shares of non-fossil fuels on the supply side contributes to the improvement in energy security.

MERIT #4 Energy Strategy

Decarbonization in energy supply

○ Improvement in self-sufficiency through expansion of utilization of nuclear energy and renewable energy, efficient utilization of fossil fuels, etc.

○ Combination of various energy sources in consideration of their characteristics to reinforce energy security.

Aiming at the cutting-edge energy supply and demand structure

○ Diversification and decentralization of energy sources

○ Maintenance of appropriate surplus energy supply capacity to cope with tight supply and demand

○ Promotion of carbon-free nuclear energy

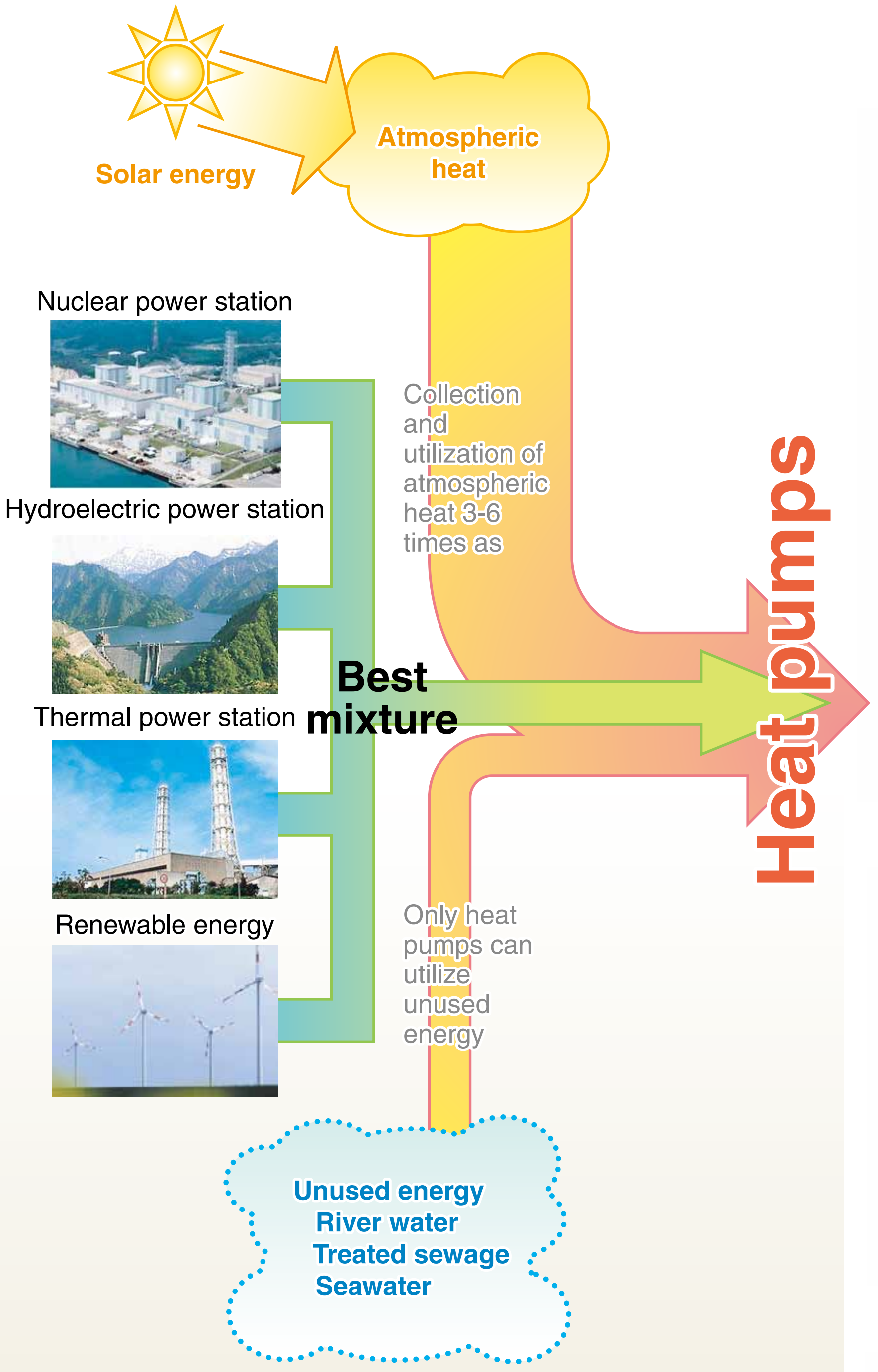
MERIT #6

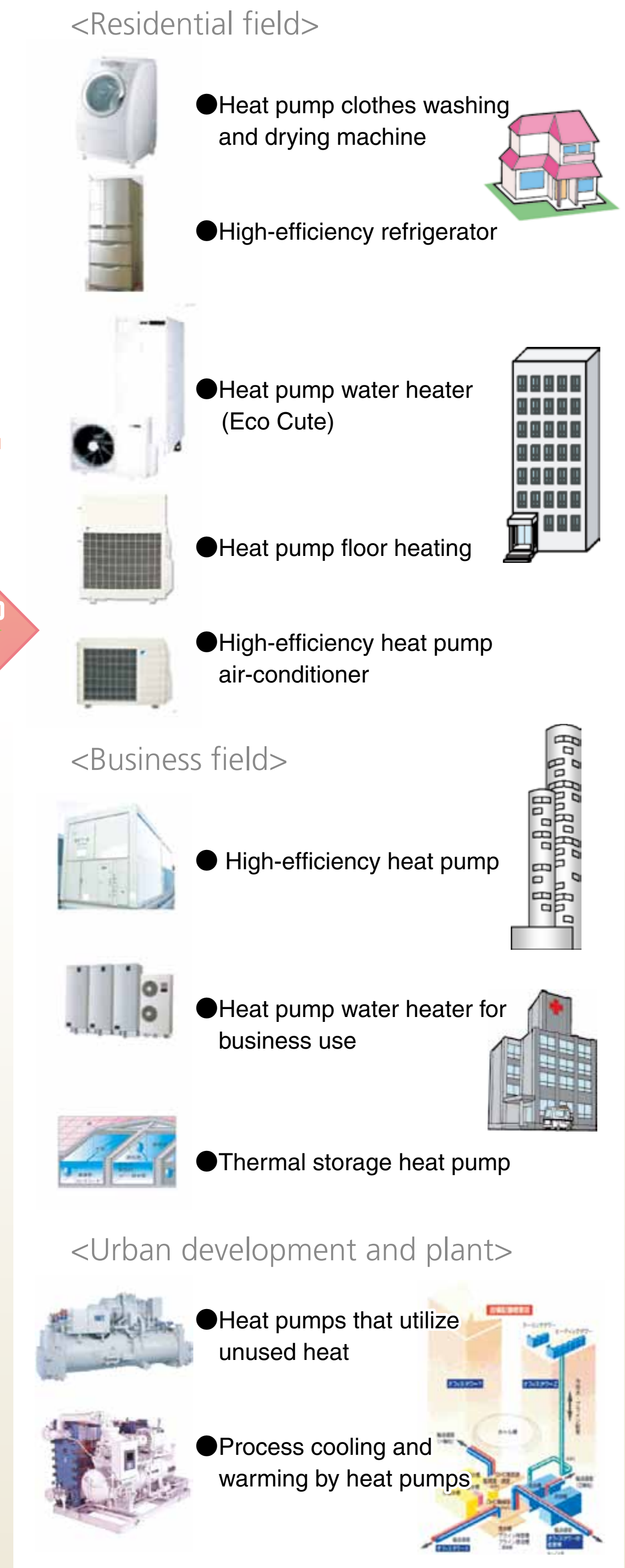
Heat Pumps also Contribute to Stabilization of Supply Systems.

○ Wider use of highly efficient heat pumps constrains the peak of energy consumption.

○ Increased use of thermal storage systems contributes to the progress in terms of load leveling.

→ Surplus energy supply capacity increases (In the case of Japan, if 20 million units of Eco Cute are installed (one out of every two households), the share of nuclear energy exceeds 50%.)





MERIT #5 Carbon-free Society on the Demand Side

Creation of CO_2-free society

○ Efforts not to emit CO_2 at places of demand are necessary.

○ Reduction in dependence on primary energy (direct combustion of fossil fuels)

○ Shift to utilization of secondary energy (electric power) and renewable energy (wind power and atmospheric heat)

○ Heat energy in the air (energy conservation) is homemade energy.

Heat pump technology as a carbon-free technology

○ Heat energy produced by combustion is replaced with atmospheric heat energy.

○ Heat pump technology that can produce heat energy without combustion is a carbon-free technology.

Achievement of energy load leveling

○ Promotion of load leveling of energy is effective for efficient operation of equipment. Energy cost is also reduced.

○ It is possible to shift daytime energy demand for air-conditioning to nighttime, and create energy demand for hot water supply during nighttime by combining heat pumps with thermal storage systems as the "energy utilization technology that goes beyond time and space."

○ The use of heat pumps in combination with electricity storage systems is also effective.

Supply System not Dependent on Fossil Fuels

Utilization of mature and established power transmission and distribution networks

Universal infrastructure that has been built up over the years

○ Quick restoration of overhead line systems damaged by major earthquakes, etc.

○ No need to invest in new infrastructure

Toward a Demand System not Dependent on Fossil Fuels

Viewpoint of Technological Contribution

"International Contribution" by Heat Pumps Through the Use of Energy Conservation Technology

MERIT #7 "International Contribution" Through the Use of Energy Conservation Technology

○ Heat pumps were born in Europe and have come into wide use in Japan.

○ Japan has made efforts to improve the efficiency of heat pumps to date. Now is the time to contribute to mitigation of global environmental and resource issues by disseminating heat pumps in the world.

○ In cold climate areas in Europe and North America, a lot of energy is consumed for heating, and most of which is based on combustion.

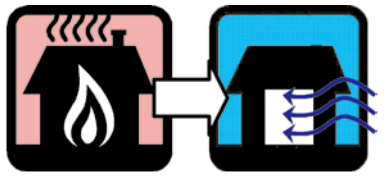
○ Heat demand for heating, cooling, hot water supply, etc. is increasing in developing countries because of an increase in commercial demand.

Heat pumps can contribute to significant energy conservation in heating, cooling and hot water supply that consume a lot of energy in both developed and developing countries.

Potential of CO_2 reduction (Examples of estimation)

○France: 70 million t-CO_2 a year

○China: 200 million t-CO_2 a year



- **The advent of natural refrigerant heat pump water heaters for hot water supply and heating**
- **The advent of heat pump air-conditioners for not only cooling but also for both heating and cooling**
- **The COP of high-efficiency heat pump air-conditioners is now 6.0 or higher.**

MERIT #9 Heat Pump Technology Can Evolve as an "Advanced Environmental Technology" Because They Are Expected to Find out Other Large Fields of Application in the Future.

○ Heat pumps increased the efficiency of air-conditioners for heating and cooling by about twice as much and that of refrigerators by five times as much or more over the past ten years in Japan.

○ CO_2 refrigerant heat pump water heaters were introduced in the market in 2001. During the six years since then, their efficiency has increased further by about 50%.

○ Heat pumps were also applied to clothes washing and drying machines for residential use in 2005.

○ Heat pumps has started being used for road heating to melt natural snow by heat in the air, which is introduced to prevent road from being frozen for traffic safety in winter.

Heat pumps for use in conventional heaters, coolers and refrigerators are the top runner models of energy conservation, and are the "leading-edge environmental technology" as represented by the advent of new environmental products in the heat utilization equipment and field such as water heaters, clothes washing and drying machines, etc.

MERIT #8 Promotion of Energy Conservation Technology Invigorates "Design and Manufacturing Activities" of the Manufacturing Industry.

Sales of Eco Cute have amounted to 350,000 units a year (results in fiscal 2006) only in six years since it was put on the market and created a market of about 250 billion yen.

↓

Conventional industries have grown by producing things that satisfy consumer needs. However, consumers' awareness has changed in these days of environmental issues. As a result, consumers have begun finding values in low-emission, low-impact products.

↓

The increase in the value of energy conservation creates a new market where consumers willingly purchase equipment of higher energy-saving performance.

↓

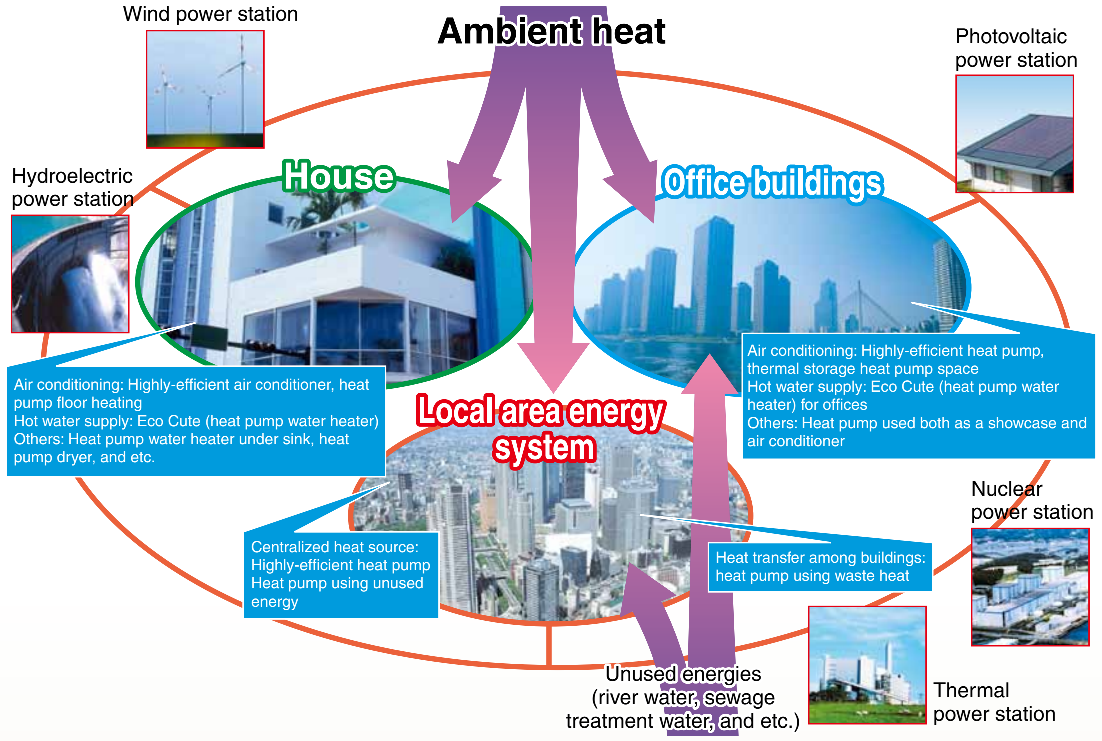
Contribution to both economy and environment in a sustainable manner

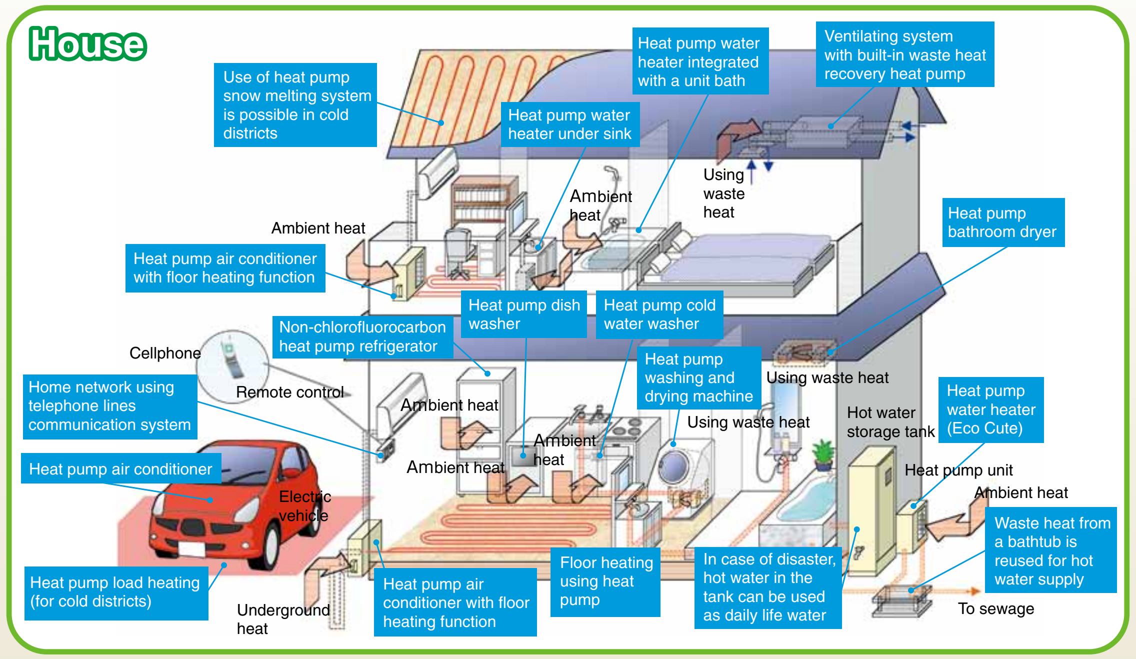
↓

Amid the changing distribution of industrial productivity in the world, heat pump systems are expected to provide a new style of "industries and design and manufacturing" as well.

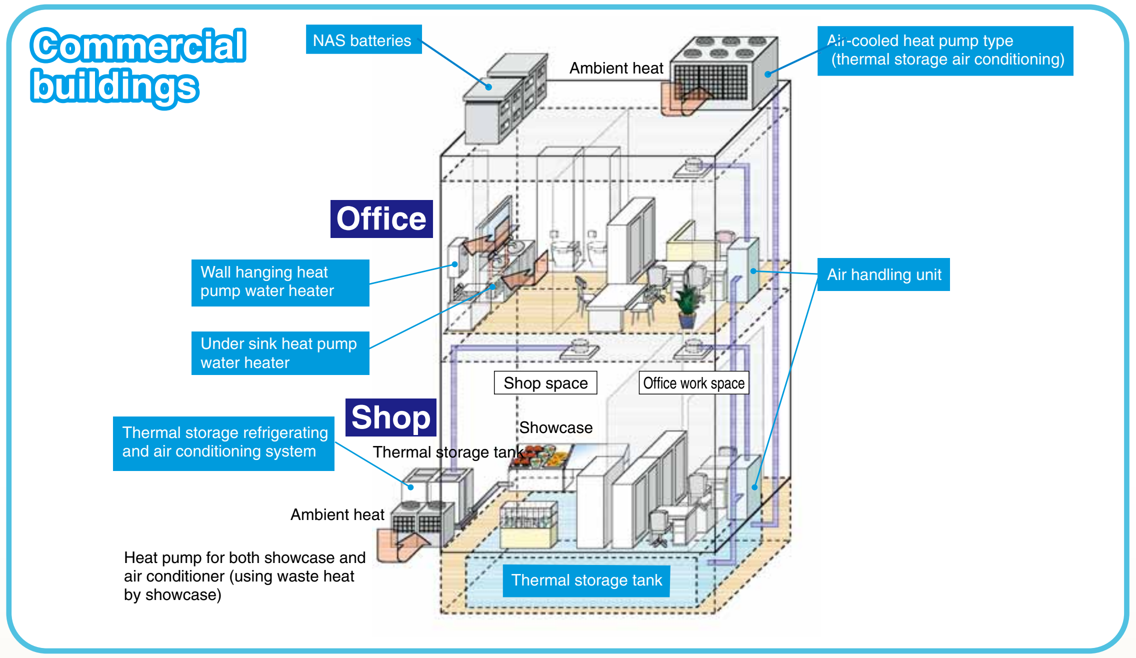
Overall Viewpoint MERIT #10

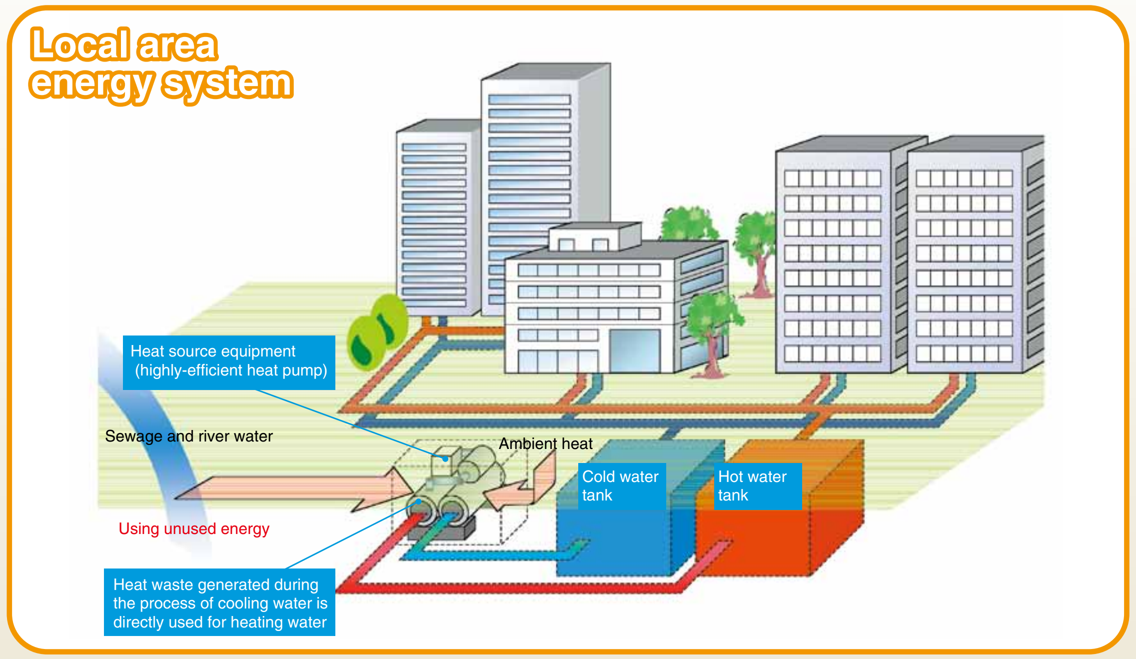
Energy Conservative World Where Heat Pumps Are Fully Utilized





Keys toward simultaneous achievement of both global warming prevention and stable energy supply are "to do without carbon," "to do without burning" and "to build a society using the highly efficient energy." The society in the 21st century should be the most promising and highly realizable, as long as "heat pumps" are fully utilized with the best possible use of clean and inexhaustible "ambient heat" and other various unused energies very efficiently.

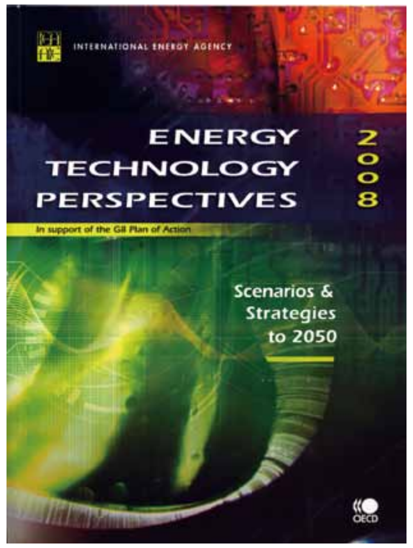




6

Annex
The Latest Topics

Energy Technology Perspectives (ETP) 2008



In 2008, International Energy Agency (IEA) launched "Energy Technology Perspectives (ETP) 2008" as reply to request by G8 Summit in Hokkaido for energy and environment policy scenario toward 2050.

ETP 2008, aiming realization of sustainable energy future with the challenging target of halving world's CO_2 emissions by 2050, offers a global energy scenario to attain this target. In this scenario, from energy efficiency, power generation and transport areas, 17 key technologies were expected to play the central role to mitigate CO_2 emissions. Heat pump is one of such important energy technologies including nuclear, CCS, photovoltaic, wind, electric vehicle, etc.

In ETP 2008, roadmap of each technology was also drawn to show the current technological development and provide the CO_2 abatement potential so as to deploy such technologies around the world.

Key Roadmaps in This Study

Supply side	Demand side
CCS fossil-fuel power generation	Energy efficiency in buildings and appliances
Nuclear power plants	**Heat pumps**
Onshore and offshore wind	Solar space and water heating
Biomass integrated-gasification combinedcycle and co-combustion	Energy efficiency in transport
Photovoltaic systems	Electric and plug-in vehicles
Concentrating solar power	H_2 fuel cell vehicles
Coal: integrated-gasification combined-cycle	CCS in industry, H_2 and fuel transformation
Coal: ultra-supercritical	Industrial motor systems
Second-generation biofuels	

Heat Pump and Renewable Energy

In 2007, EUROPEAN PARLIAMENT agreed that by 2020, (1) GHG emissions to be reduced by 20% in comparison to 1990 level, (2) EU targets for the overall share of energy from renewable sources in gross final consumption of energy as 20% and (3) reduction of gross final consumption of energy by 20% (so called "Triple 20").

In 2009, EUROPEAN PARLIAMENT adopted a directive, establishing a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy.

The Directive defines aerothermal, geothermal and hydrothermal energy captured by heat pumps as energy from renewable sources.(Annex VII to the Directive)

ANNEX VII

Accounting of energy from heat pumps

The amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps to be considered energy from renewable sources for the purposes of this Directive, ERES shall be calculated in accordance with the following formula:

ERES = Qusable * (1 – 1/SPF)

where

— Qusable = the estimated total usable heat delivered by heat pumps fulfilling the criteria referred to in Article 5(4), implemented as follows: Only heat pumps for which SPF > 1,15 * 1/η shall be taken into account.

— SPF = the estimated average seasonal performance factor for those heat pumps.

— η is the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on Eurostat data.

By 2013, the Qusable and SPF guidelines of each heat pump technology should be established by taking into consideration differences in climate conditions.

By 1 January, 2013, the Commission shall establish guidelines on how member states are to estimate the values of Qusable and SPF for the different heat pump technologies and applications, taking into consideration differences in climate conditions, especially very cold climates.

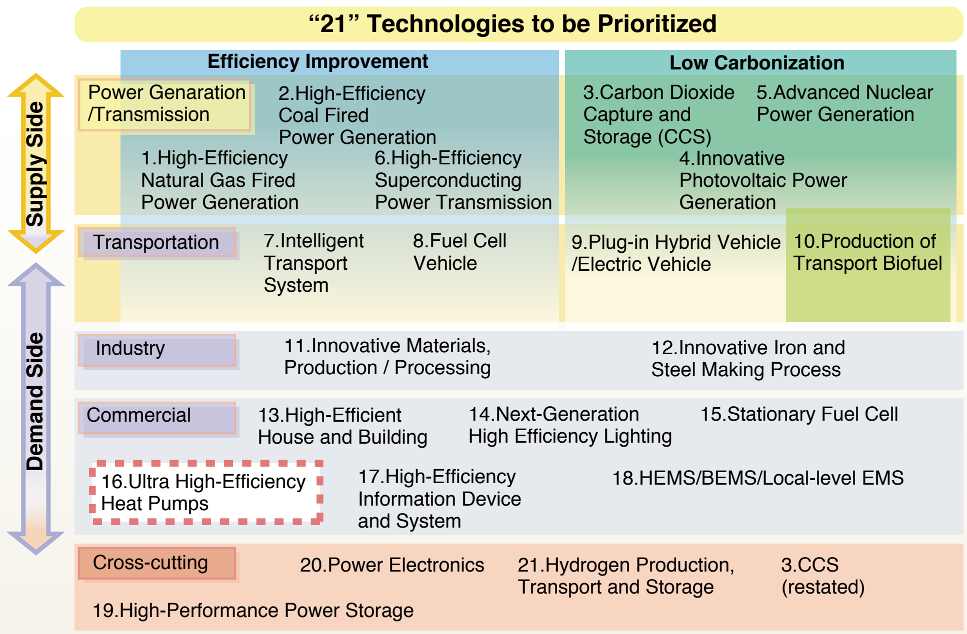
Following such European policy, the government of Japan begins to clarify the ambient heat captured by heat pumps as renewable energy in its energy policies and legislation.

Current Status of Heat Pumps in Japan

Japan's Ministry of Economy, Trade and Industry established the "Cool Earth-Innovative Energy Technology Program" in March 2008. In this strategic program toward 2050, the ministry selected the technologies that must be intensively addressed for the deployment to combat global warming. In this program, "ultra high-efficiency heat pump" was adopted as one of these important demand side energy technologies, particularly feasible and effective for the GHG reduction in the commercial sector. This program also drew the technology development roadmaps both to decrease the cost of heat pumps by half and to double the efficiency from the present level by 2050 through development of technological elements such as refrigerants and heat exchangers.

Based on this program, the ministry has started the advanced study of seeking such technological development toward next-generation heat pumps.

Japan's 21 Innovative Technologies for GHG Reduction



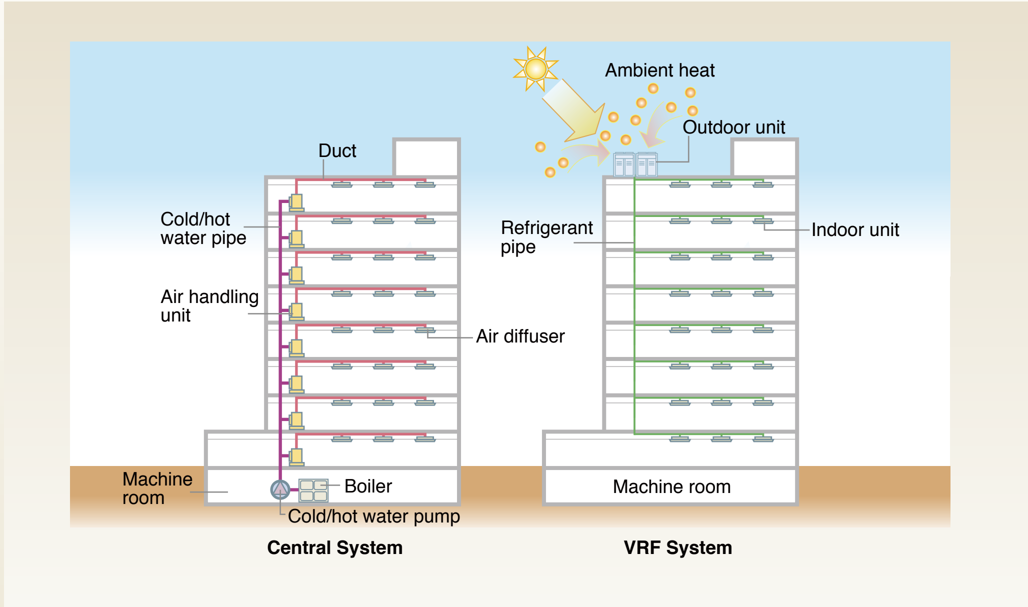
(Source : Cool Earth-Innovative Energy Technology Program 2008)

Variable Refrigerant Flow System

Central heating and cooling system, for which it is very common to apply duct-type appliance, usually accompanies auxiliary equipment such as air handling unit and cold/hot water pumps necessary to transport heat. In the actual situation, keeping the energy efficiency of such central system high is quite hard because of the difficulties to adjust its operation in accordance with the heat demand fluctuation of each room.

To overcome such barrier, VRF (variable refrigerant flow) heat pump heating and cooling system, which has been originally used for small-to-medium-size buildings, has been invented for large office buildings to replace central systems. VRF is now expanding its share because of its high efficiency, high energy-saving performance and low cost. Different from the duct-type air-conditioner, VRF has directly connected refrigerant pipes with one outdoor unit and two or more indoor units. VRF can substantially reduce the energy consumption to operate its system because it doesn't have auxiliary equipment and the inverter enables variable speed operation efficiently. Without the inverter, fixed speed of operation requires frequent starting and stopping of equipment and causes inefficient operations. In this consequence, the inverters enable drastic improvement in efficiency particularly of its partial load operation.

Furthermore, VRF can cope with a broad range of capacity from detached houses to large office buildings and hotels by connecting two or more outdoor units.



Heat Pumps for Use in Cold Climate Areas

In cold climate areas, air-source heat pumps which utilize ambient heat are less efficient than those in warmer areas. In the past, when the heat pump technology was not so advanced as today, the heating performance of some pieces of heat pump equipment drastically declined when the outside air temperature became low. Therefore, air-source heat pumps were rarely introduced for heating purposes, while fossil fuel combustion boilers were mainly used under such cold climate.

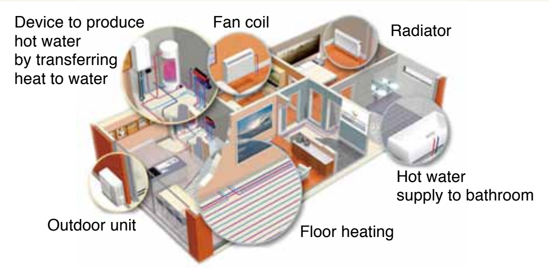
However, the performance of air-source heat pumps has been remarkably improved in recent years, and some products newly born have sufficient heating performance even at an outside air temperature of -25°C due to the enhanced performance of compressors and heat exchangers.

For example, an air-source heat pump water heating system for residential use that was invented by Daikin Industries, Ltd. in 2006 can supply sufficient heat in a climate below freezing point, and its specifications are reliable enough for use in cold climate areas such as Northern Europe. In 2007, approximately 10,000 units were shipped to Europe. At present, they are exported to China and North America in addition to Europe, and the annual shipment is more than 50,000 units.

Another air-source heat pump room heater and water heater that Mitsubishi Electric Corp. started producing in 2009 in the U.K. have also captured a new market. The expectations for air-source heat pumps are rapidly growing.

As it is easy to replace existing boilers with these air-source heat pumps, they foster the demand not only for new installation but also for the replacement of boilers.

Up to now, approximately 6 million boilers are sold annually in Europe. Air to water heat pumps are expected to account for about 1 million of these 6 million units in the coming years. Moreover, France and several other European countries are offering subsidies as an incentive to purchase heat pump equipment, which are providing a needed boost to heat pump water heating market expansion.



Example of installation of air-source heat pump room heater and water heater

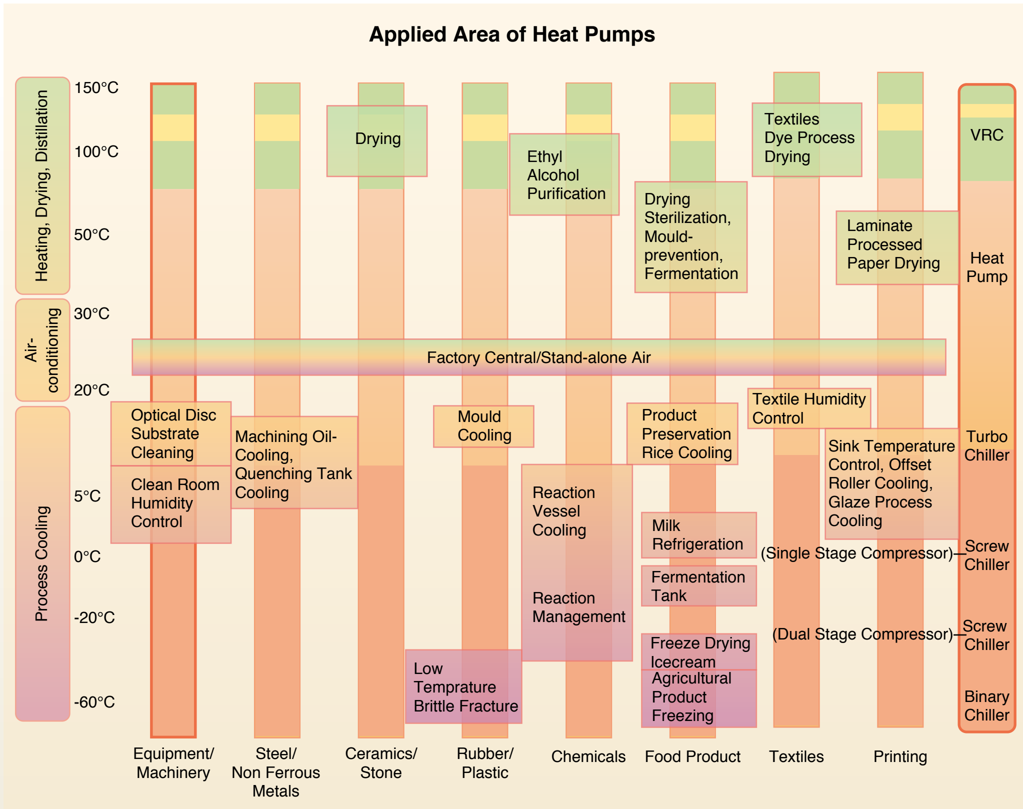
For reference, high-efficiency multitype air-conditioners with heat pumps for buildings, which were commercialized by Daikin Industries, Ltd. in 2007, achieved a level of COP3 or higher at an outside air temperature of -10°C.

Industrial Heat Pump Utilization with Technology Development

Heat pumps for industrial uses are now often found in various sectors with many different applications that range in temperature from tens-of-degrees below 0°C to over 100°C. The diagram below illustrates sample categories in which industrial heat pumps are used in each temperature range.

Heat pumps supplying heat at temperatures over 100°C, which had been almost impossible for conventional heat pumps, are being commercialized now. A Japanese heat pump manufacturer, Toyo Engineering Works, Ltd., began selling heat pumps in 2006, that utilize waste heat from brewery production process, etc. at 55-75°C, for the production of both steam at 100-120°C, as well as hot water at 60-95°C. And another Japanese manufacturer, Mayekawa Mfg. Co., Ltd., has developed heat pumps that can produce hot air at 120°C, even without utilizing waste heat.

These two products can reduce CO_2 emissions by more than 70% compared with fossil fuel combustion systems, according to the estimates. To expand the applied area, further research and development for higher temperature heat pumps is now proceeding by a number of manufacturers.



Heat Pump Reduces Heat Losses of Factory's Boiler

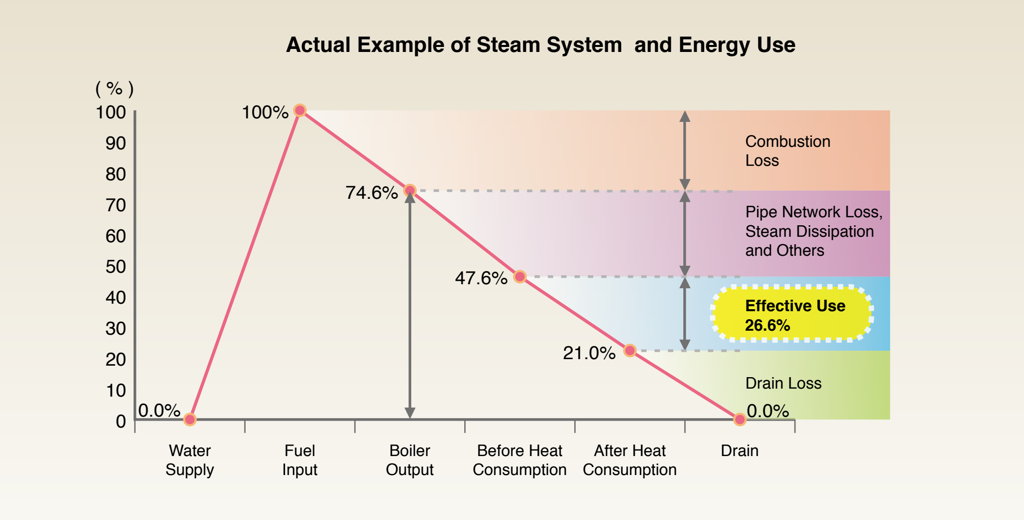
In order to reduce CO_2 effectively, it is quite necessary to focus on the actual performance of energy system. Today, steam supplied by combustion boiler with the long piping network is the main source of heat that is used for drying, washing and hot-water supply equipment, process machinery and heating machinery, etc.

According to the actual measurement of steam energy system in an automobile factory in Japan, only 26.6% of energy inputted into the steam system is used effectively. The rest of three quarters of the energy is dumped in the drain, leaked in the pipe and lost in the combustion process.

In other words, it should be noted that the steam system cannot be recognized as the only way to supply heat for manufacturing process without improving its efficiency.

Another solution which is getting more attentions from manufacturers is to improve energy efficiency and reduce CO_2 emissions with heat pumps. This is because they bring the following advantages that the steam systems are hard to obtain;

- Heat pumps should be located where energy is necessary.
- Heat pumps should produce heat at temperatures that is demanded.
- Heat recovery heat pumps should be adopted if possible.



THE DENKI SHIMBUN
(Energy & Electricity Daily News)
2007