4

Toward the Low-Carbon Society with Heat Pumps

Ambient Heat Energy Society to be Opened by Heat Pumps

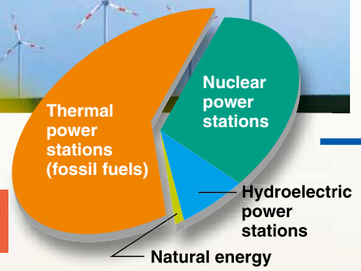
Heat pumps widely support our life and society.

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



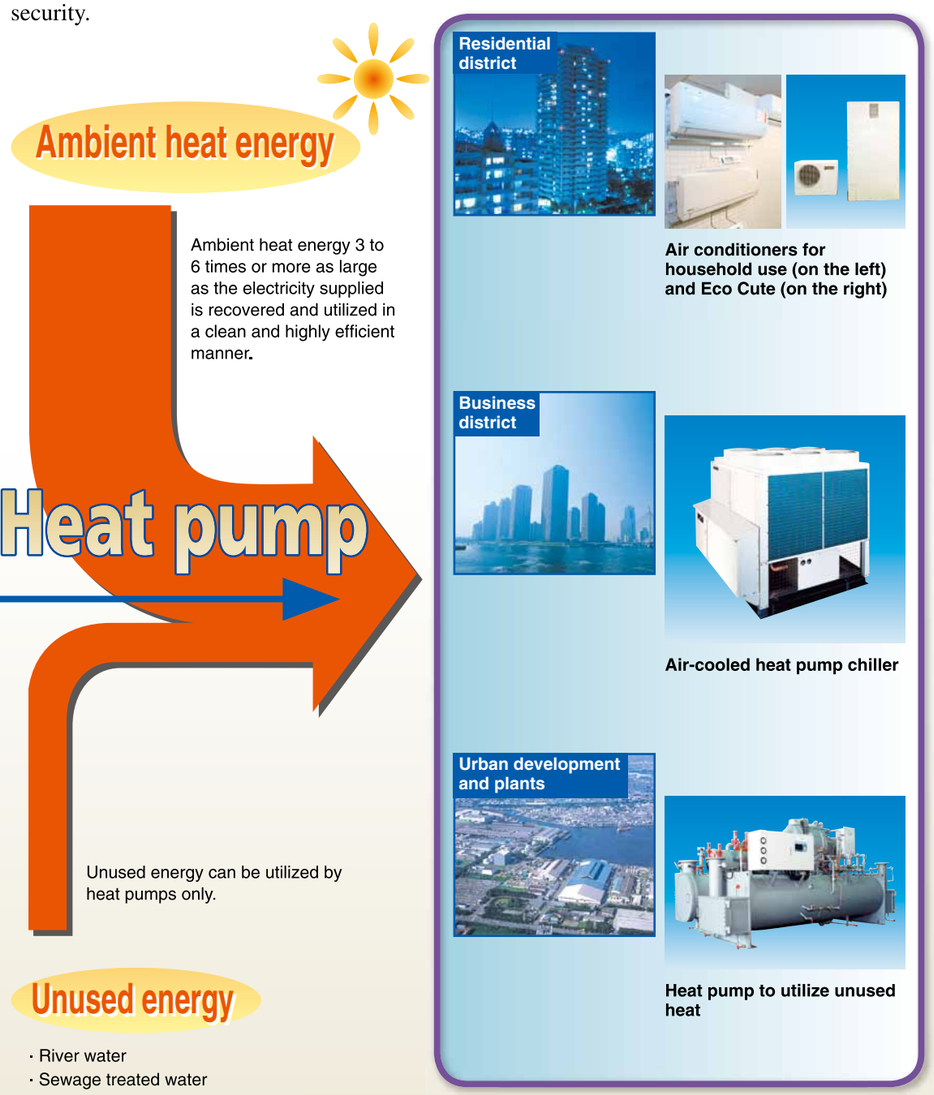
Best Mix of resources Not Dependent on Fossil Fuels Only

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

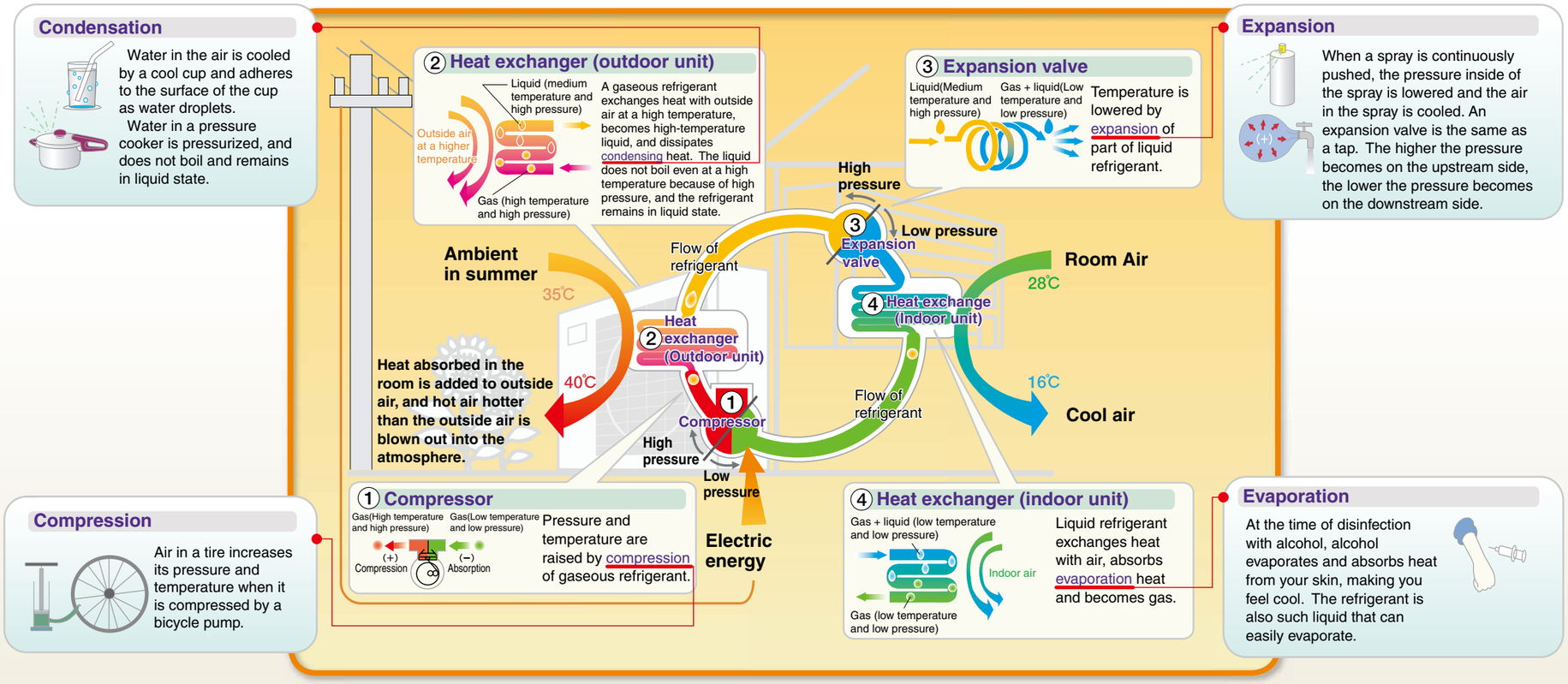
Mechanism of Heat Pump

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.

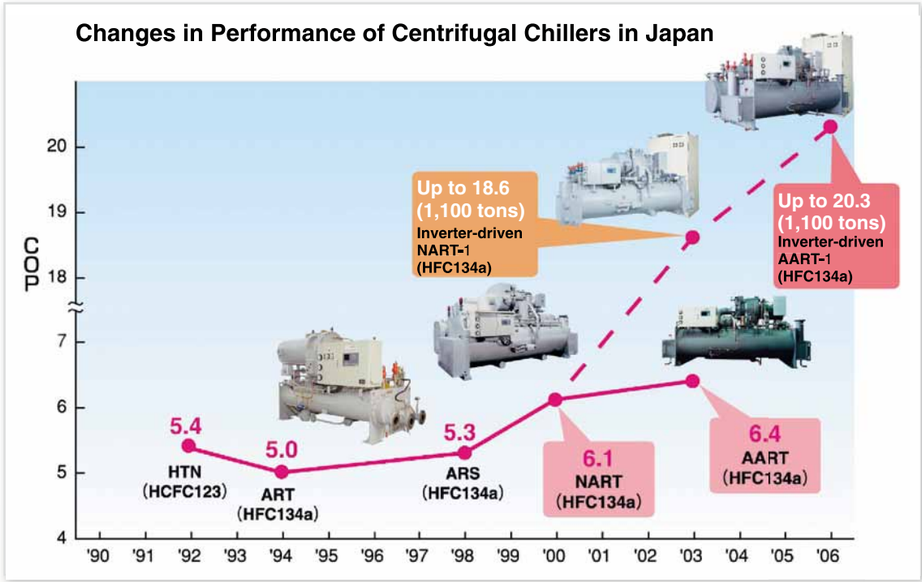
Now a "high-efficiency centrifugal chiller" has become a focus of attention because of its epoch-making energy-saving performance in the field of large cooling equipment.

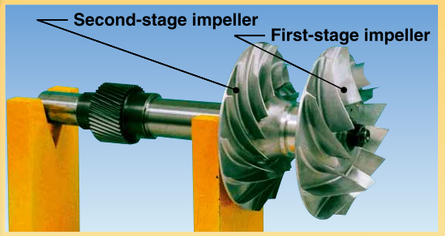
As the word "centrifugal" suggests, the centrifugal chiller has impellers that rotates at high speeds of several thousand and even several tens of thousand revolutions per minute (RPM) to blow off refrigerant gas radially by centrifugal force and efficiently compress the gas. As a result, its energy 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

Impellers of small centrifugal chillers

Compressor of small centrifugal chiller

< 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.

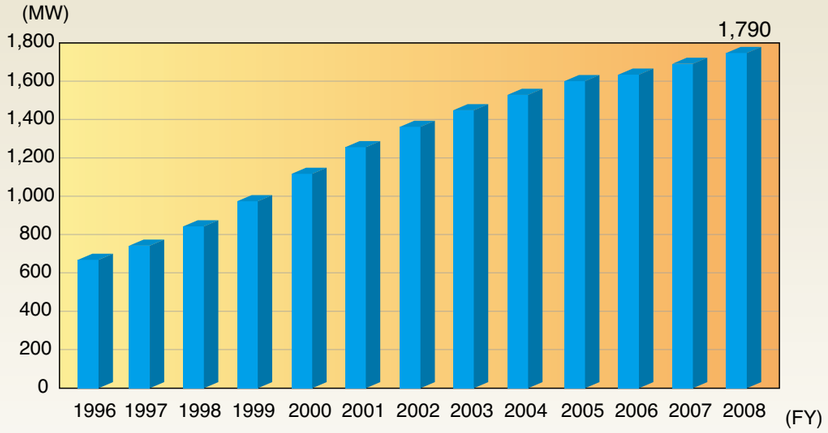
For this reason, "thermal storage" air conditioning that produces and stores the heat needed for air conditioning during nighttime when the demand for air conditioning is small and utilizes the stored heat at a peak during daytime is now receiving much attention.

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

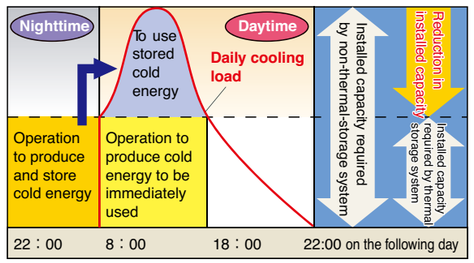
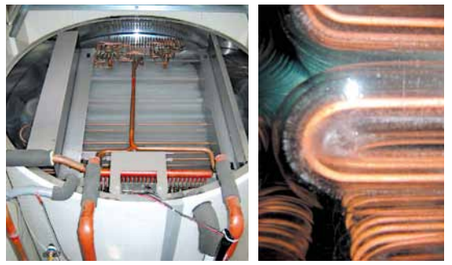


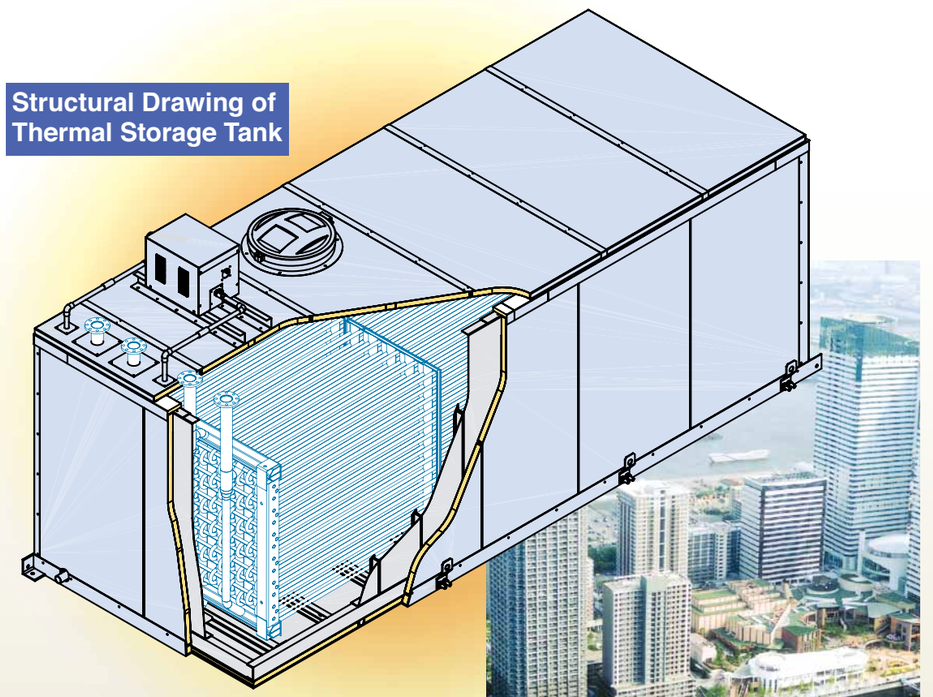
Image of Thermal Storage Operation



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

< Source: Meiwa Service Inc. >

Structural Drawing of Thermal Storage Tank



< 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.

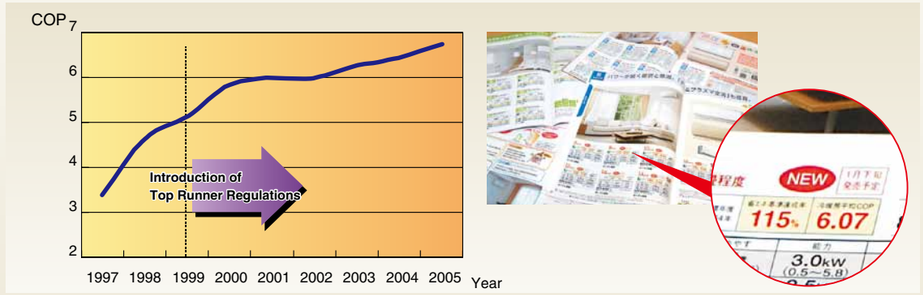
In Japan, cooling only air conditioners were introduced to the market late 1950s. In 1970s, air conditioners for both cooling and heating were introduced in the market. But, in those days heating capability was not sufficient and to make up for the defects, an auxiliary heater was integrated into an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

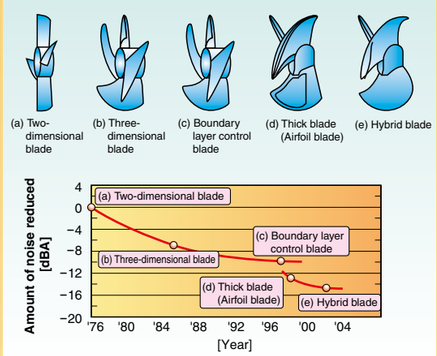
Thus, due to rapid changes, including cutting power consumption by half over the past ten years, a heat pump air conditioner is able to heat for a running cost about half of other heating equipment burning oil or gas, although it is a little known fact.

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.

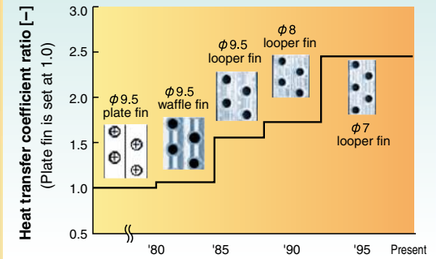


Heat pump applied home air conditioners feature significantly improved COP

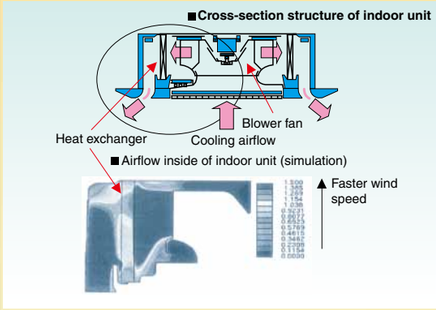
< Source:"Energy-Saving Performance catalog" published by The Energy Conservation Center, Japan (ECCJ) - COP during cooling operation of the best home appliance among 2.2 kW-class air conditioners >



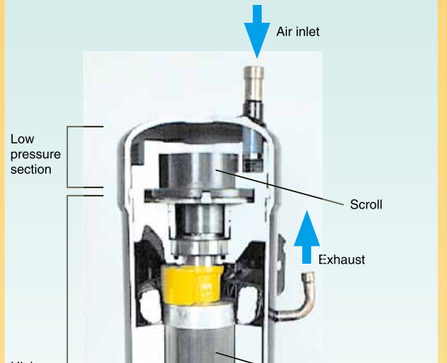
Changes in Propeller Fan Improvement



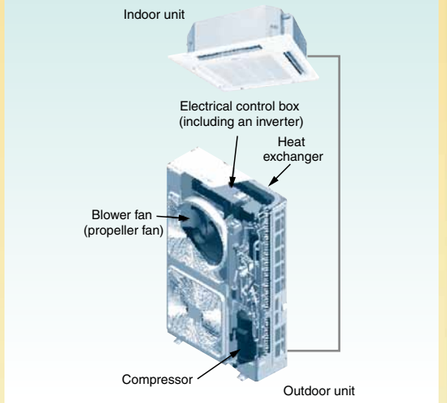
Changes in Fin Configuration



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

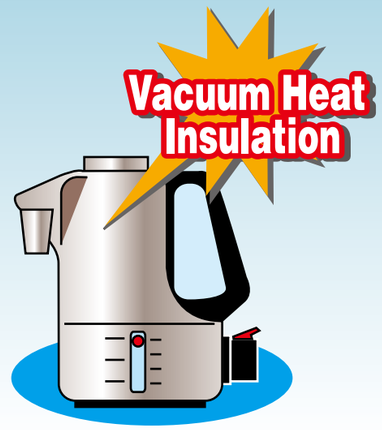
The black tubes extended from a compressor below a refrigerator release heat outside from a refrigerator.

"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

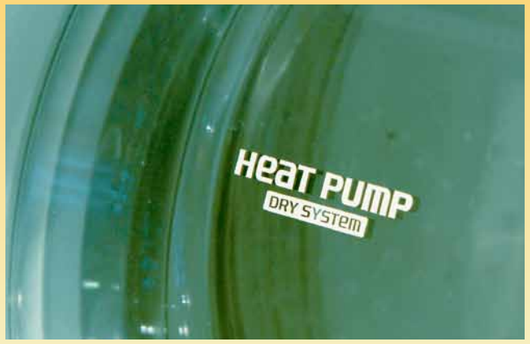
When heat pumps began to be used as a freezer to make ice about 150 years ago, natural materials such as air and ammonia were adopted as refrigerant.

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



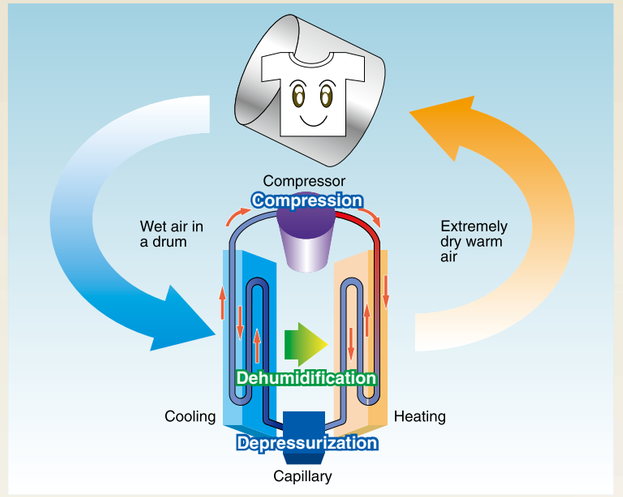
In November 2005, the world's first washing machine that dries clothes by heat pump was introduced to the Japanese market. Operating on the same principle as outdoor and indoor units of an air conditioner, the machine is so unique that it performs simultaneously drying and heating with warm air.

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

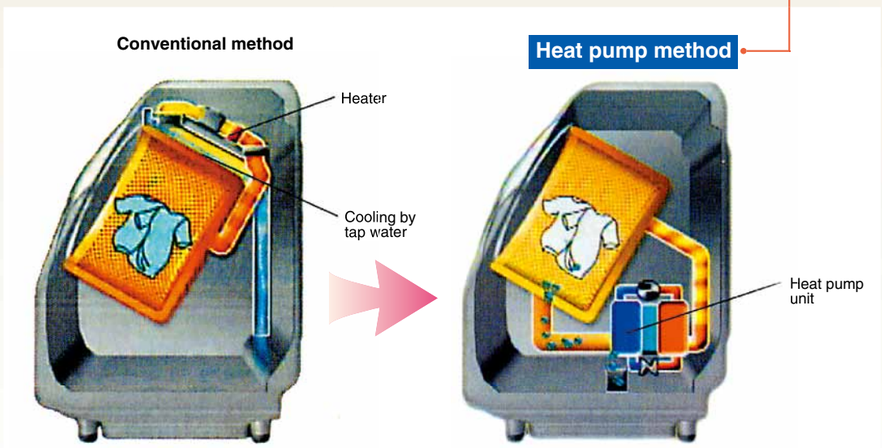


Image Drawing

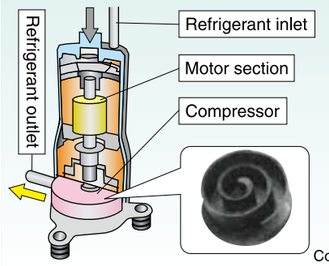
< Source: Matsushita Electric Industrial Co., Ltd >

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

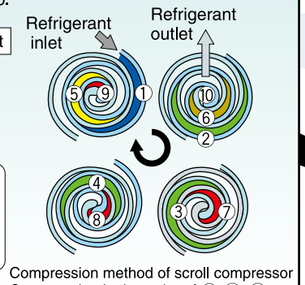
Electricity of 1 takes in 2-4 of thermal energy and gets 3-5 of hot water supply (thermal) energy.

① Compressor

Compressor compresses refrigerant (CO_2) to warm it up.
(For example, from about 10℃ to 130℃)
→ It's the same principle of pump tube getting warmer, when you pump up the bicycle tire with a manual pump.

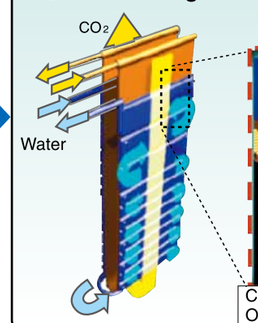


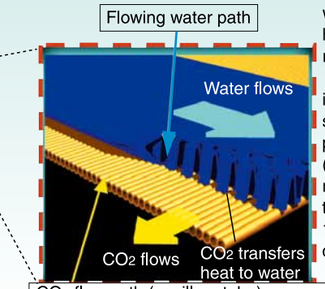
Structure of scroll compressor



Compression method of scroll compressor
Compressing in the order of ①, ②, ③

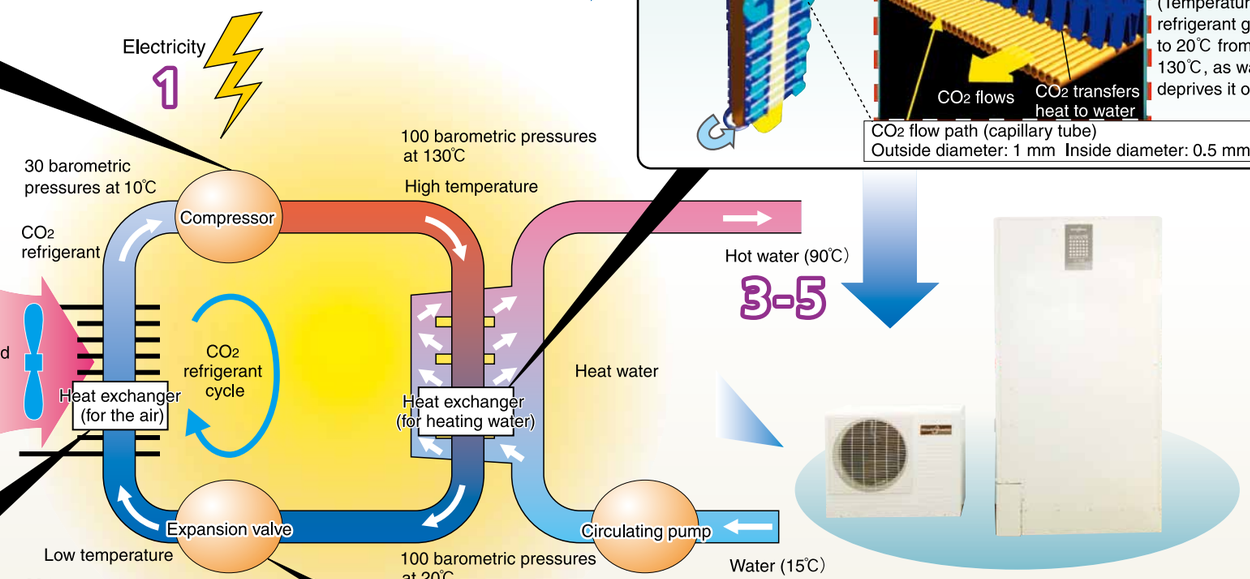
② Water-Refrigerant Heat Exchanger





CO_2 flow path (capillary tube)
Outside diameter: 1 mm Inside diameter: 0.5 mm

Heat exchanger heats water by using the heat of heated refrigerant (CO_2).
→Heated hot water is used for hot water supply and other purposes.
(Temperature of refrigerant goes down to 20℃ from around 130℃, as water deprives it of heat.)



③ Expansion Valve

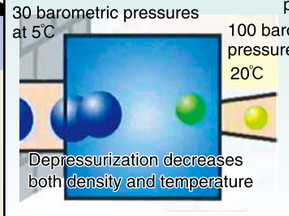
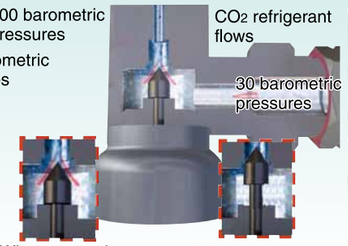


Image Drawing of Expansion Valve

Mechanism of expansion valve

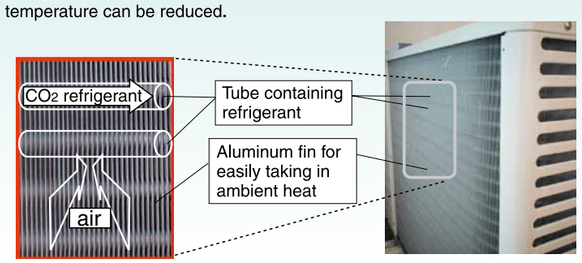


When expansion valve opens.
When expansion valve closes.

Inflated refrigerant (CO_2) decreases outside air temperatures down to -10℃.
→Even if outside temperature is 0℃, rapidly inflated refrigerant can bring temperatures lower than outside temperature.
→Spray can gets colder on the same principle, when you continue pushing its head.

④ Air-Refrigerant Heat Exchanger

By using ambient heat etc., increase the temperature of refrigerant (CO_2)
(For example, from 5℃ to 10℃)
→By increasing the temperature of refrigerant to some extent, amount of energy to be placed onto a compressor at the process of ① to produce high temperature can be reduced.



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.

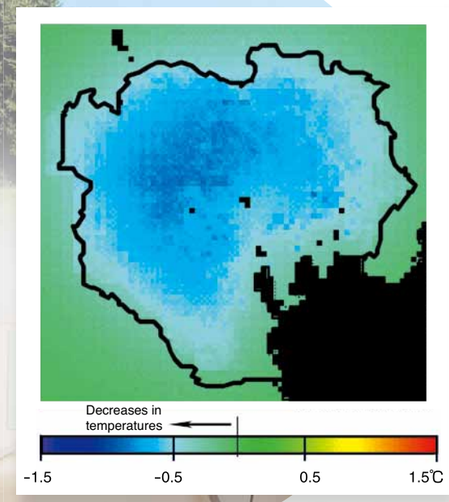
Effect of Eco Cute

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.

Eco Cute will have the same effect as entire areas of Tokyo's 23 wards are covered by forests.

Heat island controlling effect

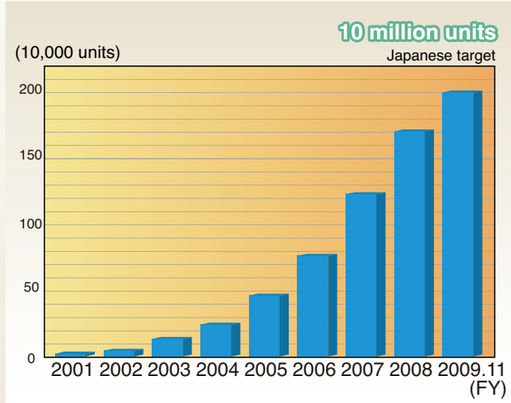


< Source: Central Research Institute of Electric Power Industry >

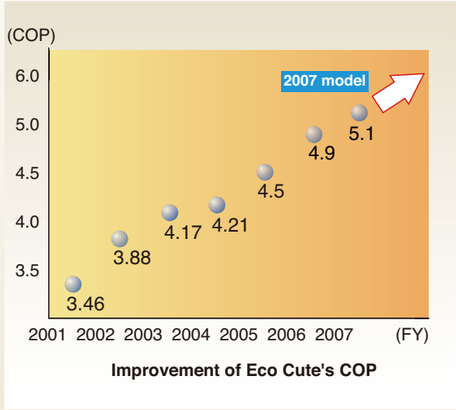
It is estimated that some 0.5°C would drop, if all households in Tokyo's 23 wards, totaling some 4 million, use Eco Cute, which recovers urban waste heat.

Suginami ward

Image of CO_2 emissions reduction



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.

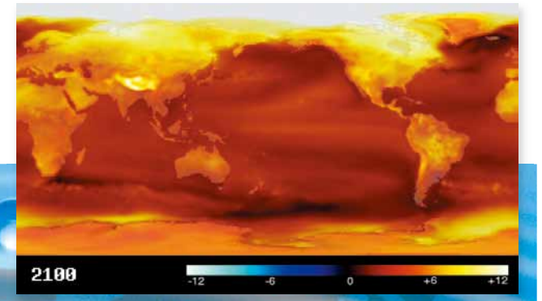
Consequently, as part of efforts to achieve the goals of the Kyoto Protocol, the Japanese government sets a plan to introduce 5.2 million Eco Cute units for residential use and 12,000 highly-efficient air conditioning systems for business use by 2010 as one of major measures in commercial sectors.

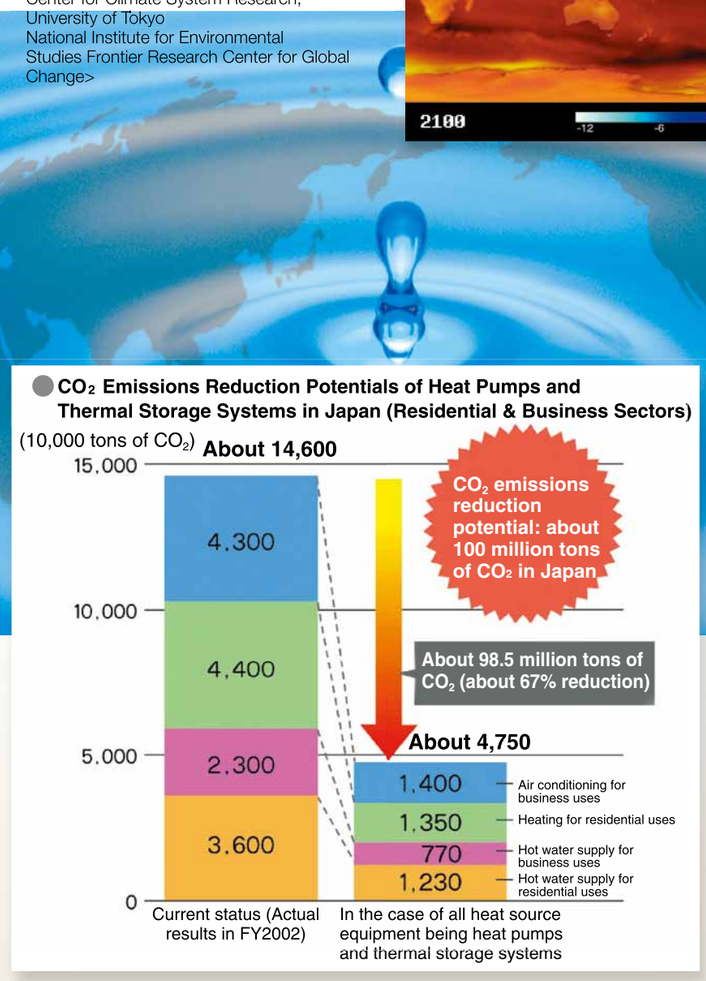
Fuel-burning type models dominate in the commercial sectors, including hot water supply, residential heating equipment, and air conditioning equipment for businesses. If highly-efficient heat pumps were fully introduced to these sectors, up to 100 million tons of CO_2 emissions could be reduced a year 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>





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.