INNOVATE HOT WATER SUPPLY TECHNOLOGY CONDUCTIVE TO ARRESTING GLOBAL WARMING

- DEVELOPMENT AND SIGNIFICANCE OF CO_2 HEAT PUMP WATER HEATER –

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ABSTRUCT

The need to promote energy-saving efforts and reduce CO_2 emissions at home is increasing. Particularly, "hot tap water supply" which accounts for about 35% of residential final energy consumption, now depends largely on direct combustion of fossil fuels such as gas and oil.

Against such a background, The Tokyo Electric Power Co., DENSO CORP., and Central Research Institute of Electric Power Industry have jointly developed a CO_2 heat pump water heater for residential use, which uses a natural refrigerant (carbon dioxide) that has very little impact on global warming, and boasts a very high coefficient of performance (COP). After performance evaluation and service tests of a field testing machine, we have made it available in the market for the first time in the world.

The CO_2 refrigerant heat pump water heater we have recently developed boasts very high efficiency with a coefficient of performance (COP) of more than 3.0 a year on average. Compared with conventional combustion type water heater, our new water heater saves energy by about 30%.

1. INTRODUCTION

Of the total amount of final energy consumption in Japan, residential customers account for 14%, and their share has consistently increased since the oil crises (Figure 1).

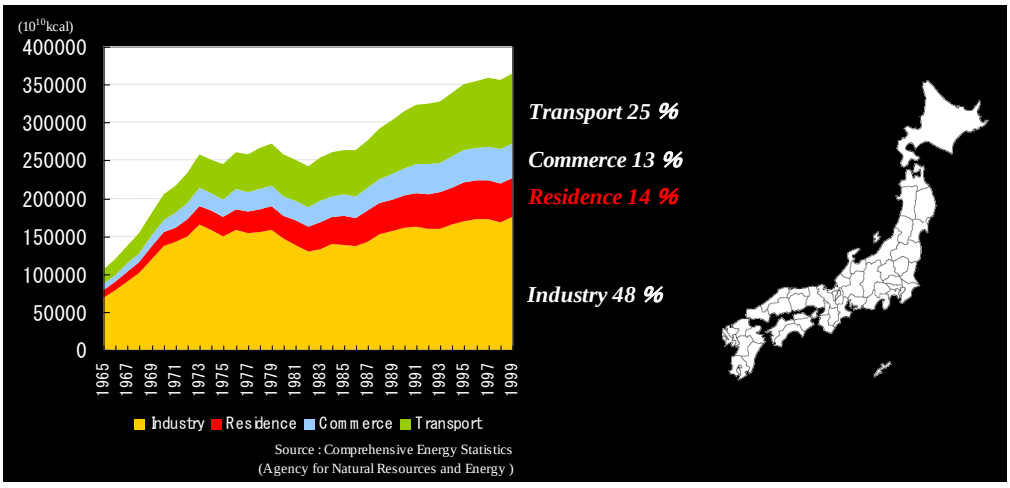


Figure 1. Changes in Amount of Final Energy Consumption in JAPAN

Energy consumption in the residential sector, as shown in Figure 2, showed an approximately 1.8 times increase from levels prevailing 30 years ago. In order to affordably conserve energy at home, this and other sectors are needed to use energy as efficiently as possible.

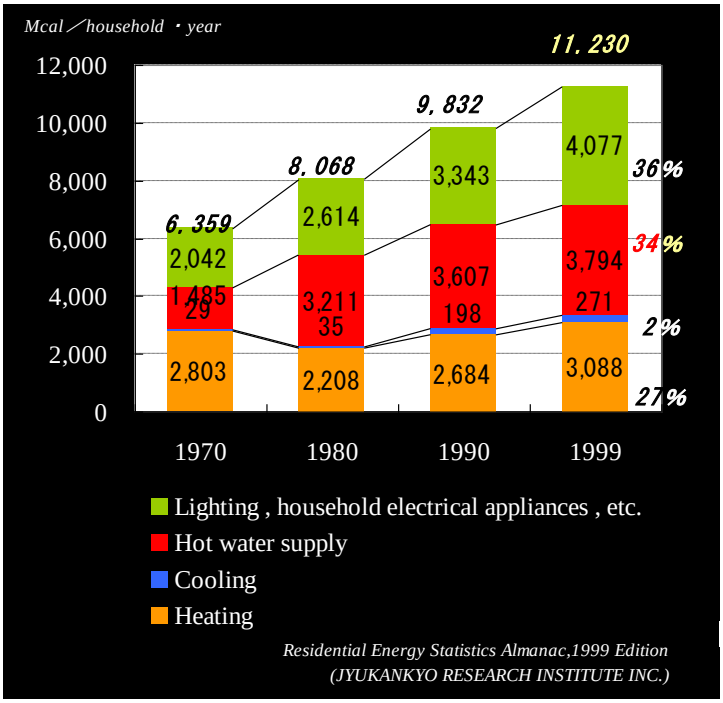


Figure 2. Classification of and Changes in Residential Energy Consumption by Applications

By uses, air conditioning systems, water heaters, lighting equipment and household electrical appliances each account for roughly one third of energy consumption. Regarding air conditioning systems, housing manufacturers are keen on developing houses that meet next-generation energy-saving standards. Progress is made in the spread of advanced airtight, insulation-efficient houses that have high levels of energy-saving performance. Moreover, as the revision of the Energy Conservation Law has led to the introduction of the top runner approach, air conditioners that have dramatically high levels of the coefficient of performance (COP) are on the market. Both buildings and equipment are now highly energy-efficient.

In the field of lighting and household electrical appliances viewed as a single unit, tremendous progress has been made in the development of energy-saving appliances over the last few years. With the introduction and expansion of the top runner approach, much more energy-efficient products will be turned out.

Meanwhile, in the category of hot water supply, which increased at the highest rate (an increase of approximately 2.6 times) over the past 30 years and account for 1/3 of energy consumption, progress in energy conservation is rather slow primarily because it is difficult to improve the efficiency of equipment.

The project designed to develop CO2 heat pump water heaters for residential use was begun in September 1998, aiming at energy conservation in the field of residential hot tap water supply.

2. CHARACTERISTICS OF CO_2 REFRIGERANT HEAT PUMP WATER HEATER

The heat pump water heater is designed to produce high-temperature water by repeatedly compressing and expanding a refrigerant such as fluorocarbon with the power of motor, pumping out heat from the air, and rejecting the heat into water. One of its characteristics is a higher coefficient of performance (COP) than that of combustion type water heaters. It is a storage type water heater that can reduce its running cost by a wide margin by effectively using inexpensive night-only service (Figure.3).

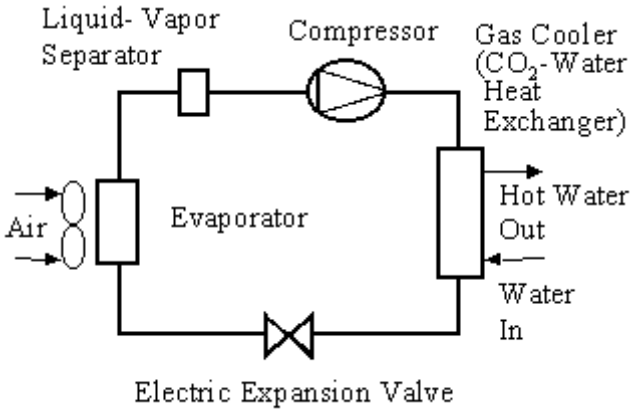


Figure 3. A Concept of the CO_2 Water Heater

To date, we have used mainly a fluorocarbon refrigerant (HCFC22) as the refrigerant of the heat pump water heater. This time, we noticed a natural refrigerant (carbon dioxide) for two reasons. One is an environmental reason that CO_2 is not a composite like fluorocarbon, but CO_2 is a substance that exists in the natural world. The other is a physical reason that CO_2 is suited to the heating process that has a wide margin of temperature climb like that of a storage type water heater.

The characteristics of CO_2 as a natural refrigerant are shown together as follows:

- CO_2's environmental impact is minimal as its ozone depletion potential (ODP) is 0, and its global warming potential (GWP) is 1 (Table 1).

Table 1. A Comparison of the Characteristics of Refrigerants

	CFC-based refrigerants	Natural refrigerants		
	HCFC22	Propane	Ammonia	CO2
GWP(100years)	1,700	3	0	1
ODP	0.055	0	0	0
Combustibility	Incombustible	Combustible	Combustible	Incombustible
Explosion limit [vol %]	-	2.3～9.5	16～25	-
Permissible concentration [vol ppm]	500	1,000	25	5,000

GWP: Global warming potential
ODP: Ozone depletion potential

- CO_2 is safe because it is non-toxic, inflammable, as well as inexpensive.
- CO_2's critical temperature is low (31℃), and it becomes a transcritical cycle in which the high-pressure side of the cycle becomes supercritical for use in air conditioning and hot tap water supply.
- In the case of a simple cycle, therefore, a high COP can be expected in the heating process that has a wide margin of temperature climb like once-through heating, though COP is low for use in air conditioning.
- As CO_2 has a large heating capacity per compressor absorption unit, the system can be made compact as well.
- As CO_2 has a high heat transfer coefficient , the heat exchanger can be made compact.
- As CO_2 refrigerant does not need be recovered, no recovery cost is required.
- As CO_2 works under high pressure, the equipment has to be newly designed. CO_2 requires a low pressure of 3MPa and a high pressure of about 10MPa, while fluorocarbon requires a low pressure of 0.5MPa and a high pressure of about 2.5MPa.
- CO_2 requires a compressor of low compression ratio and high differential pressure.

The Figure.4 shows the results of trial calculation (temperature T - enthalpy h diagram) done by Central Research Institute of Electric Power Industry for the hot tap water supply cycle. CO_2's critical temperature is low (31℃), and it becomes a transcritical cycle in which the high-pressure side of the cycle becomes supercritical. So, it can be understood that a high COP can be expected in the process that has a wide margin of temperature climb like the hot tap water supply by once-through heating. In the case of Figure II, as a heat exchange temperature difference in the gas cooler is set, the pressure of the high-pressure side is determined to achieve the set temperature difference.

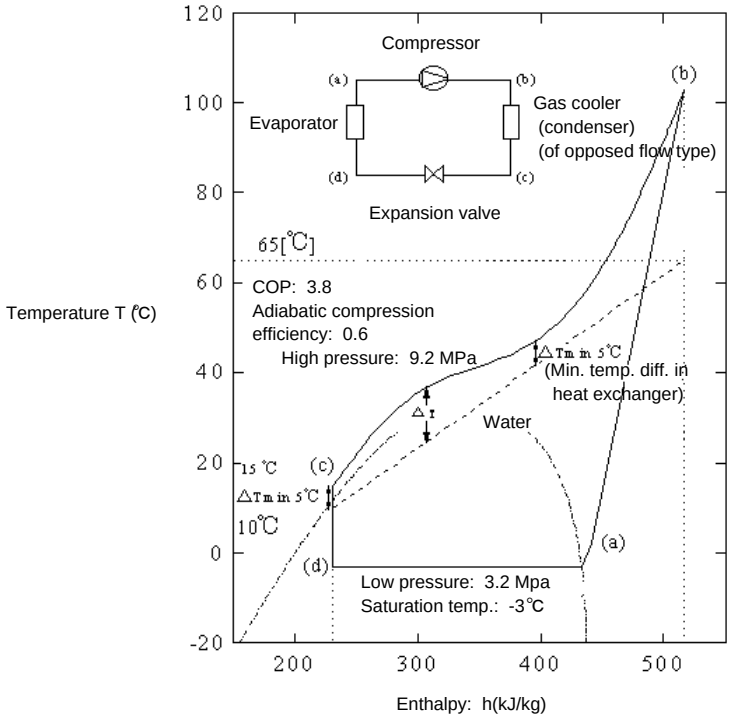


Figure 4. Trial Calculation Results on Hot Tap Water Supply Cycle (T-h Diagram)

3. Specifications for the Commercial Product

In September 1998, The Tokyo Electric Power Co., Central Research Institute of Electric Power Industry, and DENSO CORP. started the joint development of the CO_2 refrigerant heat pump water heater, aiming at energy conservation in the field of residential hot tap water supply.

After several improvements were made in the prototype model, a commercial product was announced in January 2001. Figure 5 shows an external view of the commercial product. Table 2 describes specifications of the commercial product.

Figure 5. External View of the Commercial Product

The commercial product has a simple cycle with a vapor-liquid separator and a rated heat capacity of 4.5kW. Its heating capacity is almost the same as that of an electric water heater (370 litters and 4.4kW for a four-member family).

The compressor is an inverter-motor-driven, full-hermetic scroll type, and its hot water supply capacity is variable. The evaporator (air heat exchanger) is a fin and tube type that is typically used in air conditioners, and the water heat exchanger (gas cooler) is a counter-flow type.

COP varies depending on conditions such as heating capacity, outside temperature, water temperature, and hot water temperature. COP stand at 3.5 at rated heating capacity and 2.5 at winter hot heating capacity.

The noise performance is 45dB (A) under winter conditions. It is designed to be quiet enough to avoid complaints about noise, even if the heat pump is operated during night in an area where houses are densely built.

The tank unit has two 150 litters tanks for a total of 300 litters hot water storage. In consideration of Japan's housing conditions that houses are often built on narrow and small sites, the unit is made thin for easy installation (Figure 6).

Table 2. Specifications of The Commercial Product

System	Rated voltage	Single phase , AC 200V
	Maximum current	25A
	Hot water temperatures	65～90 degrees centigrade
Hot water storage tank unit	Tank capacity	300L(150L*2)
	Maximum working pressure (Relief value)	170kpa
	Outside dimensions	W1,090 * D450 * H1,515mm
	Weight	Approx.95kg (approx.395kg with full tank of water)
	Bath keep-warm heater power	1.1kW
	Anti-freezing heater power	0.1kW
	Control power	20W
	Control mode of water heating	Automatic control mode, full-tank mode, and only late-night modes
	Bath hot water supply function (full-auto function)	Automatic bathtub filling, Automatic temperature retaining, Automatic refilling, hot water injecting, hot water adding, and cold water injecting
Heat pump unit	Outside dimensions	W810 * D320 * H670mm
	Weight	Approx. 62kg
	Rated heating capacity/input electrical power	4.5kW / 1.3kW *1
	Winter high heating capacity/ input electrical power	4.5kW / 1.8kW *2
	Summer heating capacity/input electrical power	4.5kW / 1.2kW *3
	Winter heating capacity/input electrical power	4.5kW/ 1.4kW *4
	Operating noise	45dB (*1)
	Operating current	7.5A (*1)
	Refrigerant (filled amount)	CO_2 (0.63kg)

∗1 JRA reference operating conditions: Outside temperature (DB/WB) 16℃/12℃, water temperature 17℃, hot water temperature 65℃

*2. JRA reference operating conditions: Outside temperature (DB/WB) 7℃/6℃, water temperature 9℃, hot water temperature 90℃

*3. JRA reference operating conditions: Outside temperature (DB/WB) 25℃/21℃, water temperature 24℃, hot water temperature 65℃

*4. JRA reference operating conditions: Outside temperature (DB/WB) 7℃/4℃, water temperature 9℃, hot water temperature 65℃

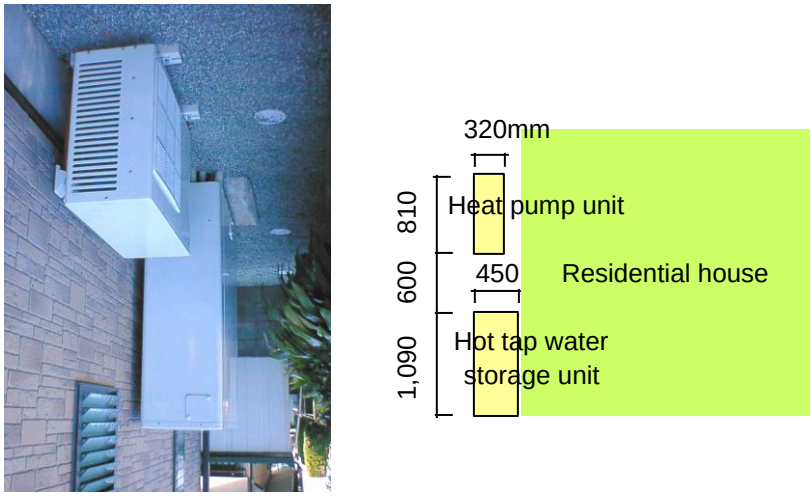


Figure 6. Installation at Small Site

In Japan, a large amount of hot tap water is used because of the national character of the Japanese people who love taking a bath. In the case of a hot water storage type water heater, the storage volume of hot water is generally set at 370 - 460 litters (temperature of storage hot water is up to 85℃) for a four-member family. In the case of our commercial product, it is made possible to reduce the volume of hot water in storage through improved control of water heating. In other words, the water heater memorizes the maximum calorie used in the past week, forecasts the volume of hot water to be used next day at 11:00 p.m. when the night-only service (of which the electricity rate is about 70% lower than that of daytime service), and decides the storage temperature of hot water. Moreover, if a large amount of hot water is used during daytime, the water heater forecasts again the volume of hot water to be used by the family at the time of 5:00 p.m., and automatically controls the volume of hot water not to run out of hot water (Figure 7).

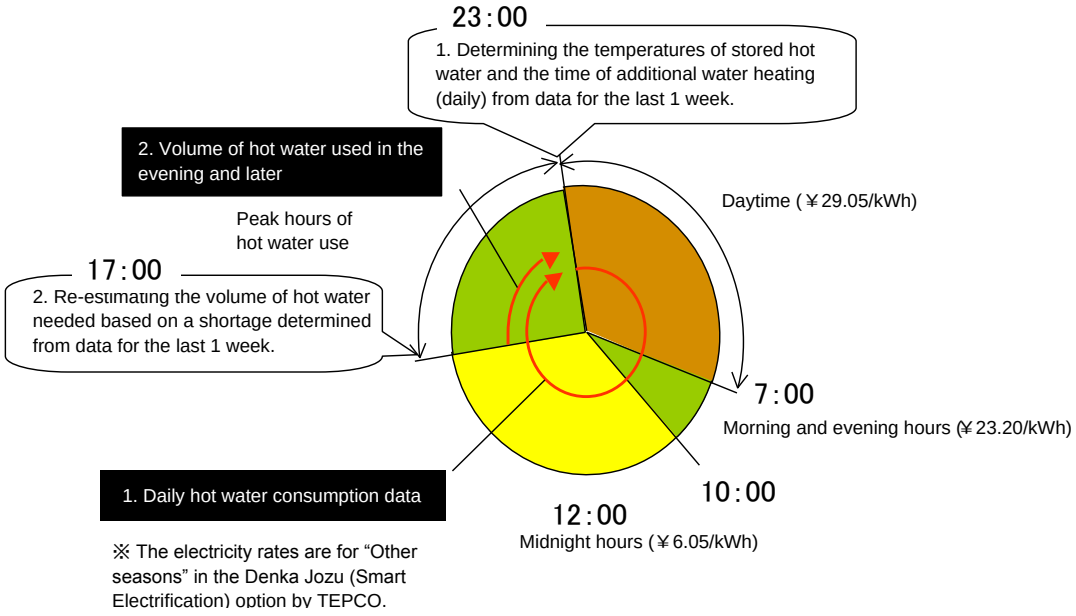


Figure 7. Automatic Control Mode

As a function to pursue user-friendliness, we added a "full-auto function" that supplies hot water into a bath with one switch, getting the bath ready and keeping the bath water hot.

4. Data on the Operation of the Commercial Product in the Coldest Part of the Winter

CO2 heat pump water heaters for residential use are exposed to the severest conditions in the coldest part of the winter. Data on the operation of the commercial product installed at an actual house in the coldest part of the winter (from January to February 2002) are introduced. Figure 8 shows daily data. Table 3. gives a summary of the measurement results.

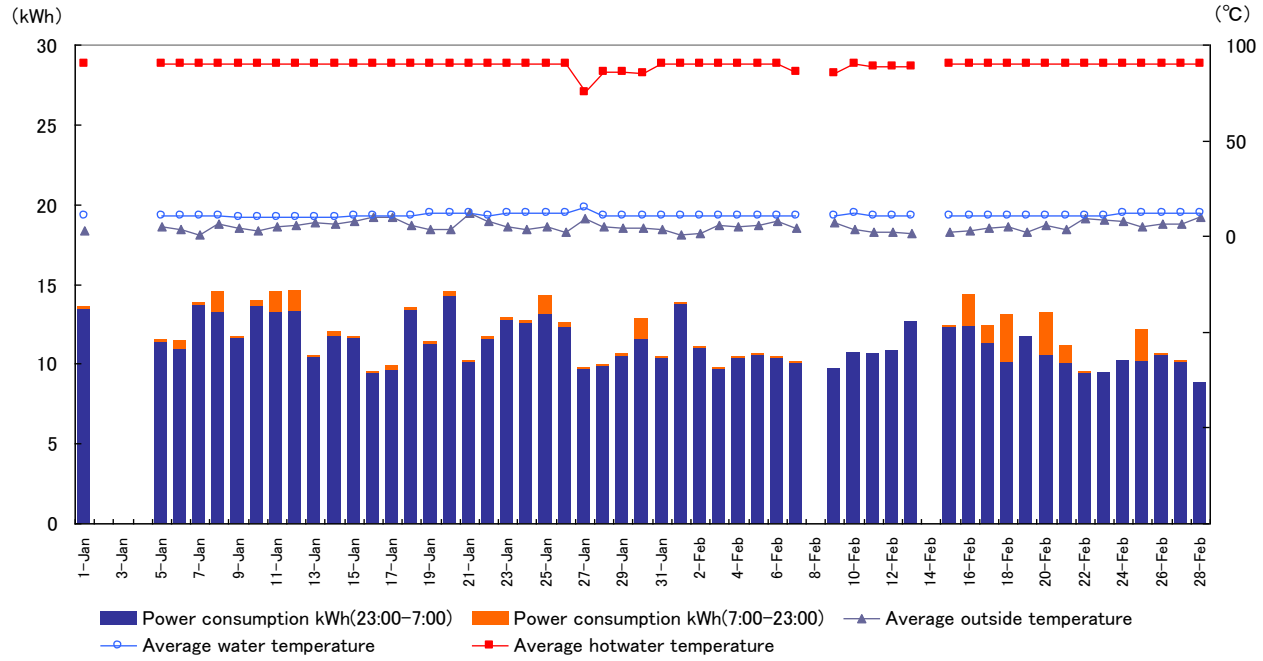


Figure 8.Operation Data in the Coldest Part of the Winter

Table 3. A Summary of the Measurement Results

Location	Nishio City in Aichi Prefecture
Measurement period	January 1 – February 28, 2002 (data obtained on January 2, January 4, February 8 and February 14 are missing)
Average outside temperature during hot water supply operation	5.3℃
Average water temperature	11.2℃
Average hot water supply load	92,839kj/day (= 589L/day (at 43℃)
Control mode of water heating	Automatic control mode
Average hot water temperature	89.3℃
Late-night energy consumption rate	96%
Average COP	2.2

A hot water supply load at this house is approximately 1.4 time as large as that for the average household (IBEC L mode) and hot water temperatures in the automatic control mode are as high as about 90℃. The late-night energy consumption rate stands at 96%, suggesting that even a large hot water supply load is met by hot water supplied using inexpensive power during a late-night period without causing a hot water shortage.

During the measurement period, the average COP was 2.2. This level represents roughly 10% lower than COP levels attained at winter hot heating capacity under JRA conditions. It may be attributable to the fact that average outside temperatures during hot water supply operation varied greatly from 1℃ to 12℃, so that energy consumption included power needed for defrosting operation.

5. Evaluation of the Yearly Average COP

Figure 9 shows the results of evaluation of the yearly average system COP of the commercial product in the Tokyo area. The average outside temperature during late-night hours (23:00 to 7:00) and a hot water supply load for the average family of four (equivalent to the IBEC L mode) were applied.

Under these given conditions, hot water temperature came to 65℃ throughout the year and COP attained the highest level. The development target value of 3.0 of the yearly average COP has been attained, with consideration well given to heat loss of hot water tank and power needed for defrosting operation.

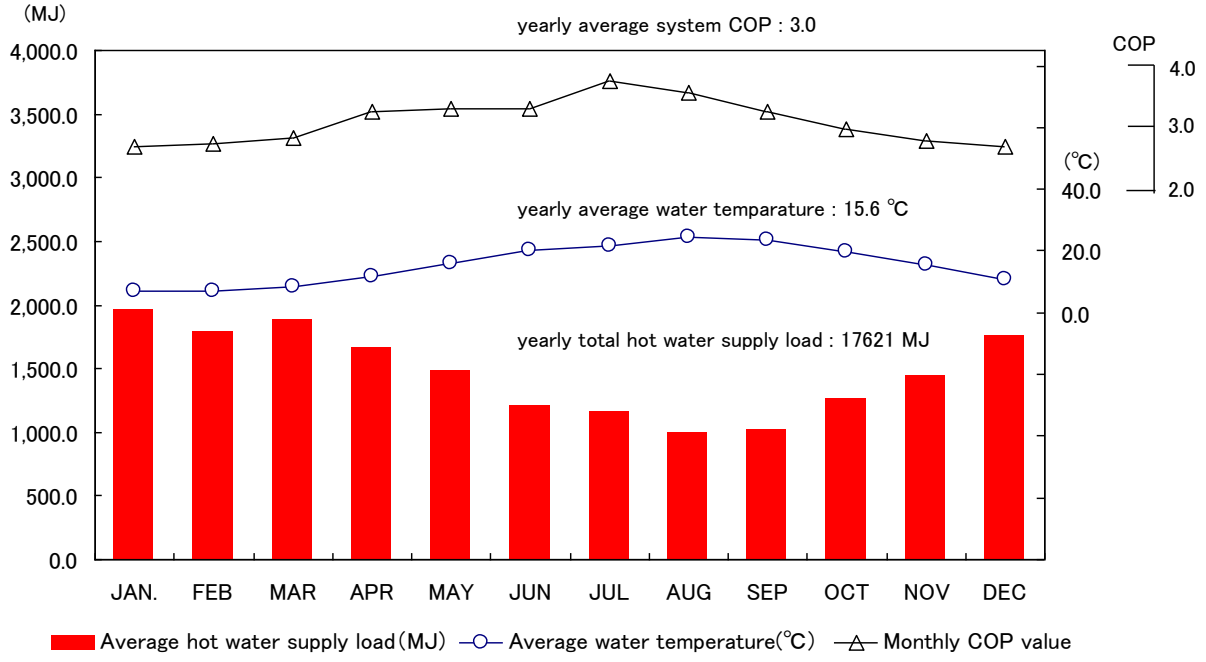


Figure 9.Monthly system COP of the commercial product in the Tokyo area

6. Evaluation of Energy-Saving Characteristics and CO_2 Emissions

We compared the energy-saving characteristics of the CO_2 refrigerant heat pump water heater, of which the annual average system COP is 3.0, with that of a combustion type water heat on a primary energy basis. The results are shown in Figure 10.

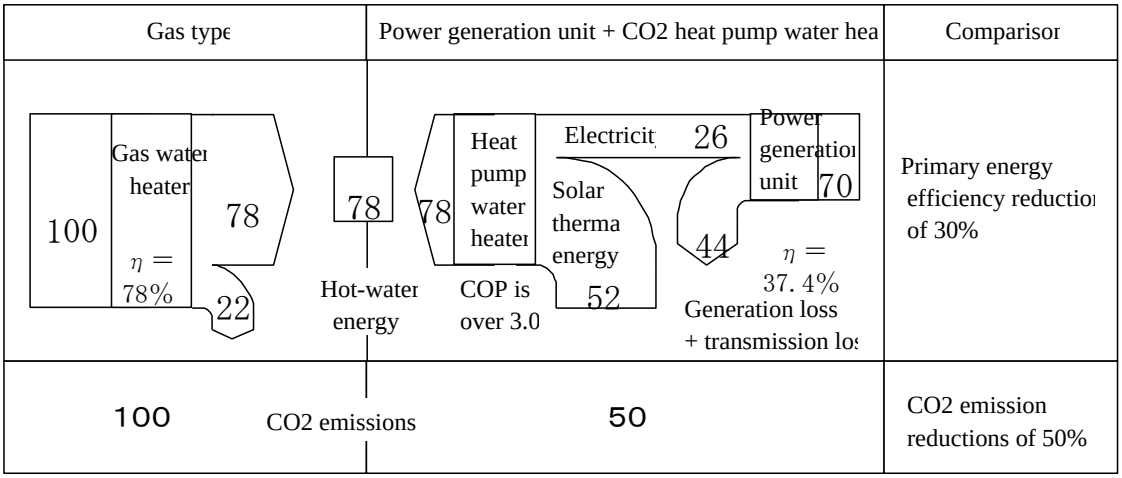
If the primary energy efficiency of the combustion type water heater is 0.78, that of the natural refrigerant (CO_2) water heater is calculated as:

$$\text{Power generation efficiency } 0.37 \times \text{COP } 3.0 \fallingdotseq 1.1$$

This shows that the natural refrigerant (CO_2) water heater saves energy by about 30% compared with the combustion type water heater.

The natural refrigerant (CO_2) water heater also reduces CO_2 emissions by about 50% compared with the combustion type water heater.

At present, combustion type water heaters account for 95% of Japan's water heater market. Replacement of combustion type water heaters with the natural refrigerant (CO2) water heaters can provide a very large effect of reduction of CO2 emissions.



※Power generation efficiency (0.37 = 860/2,300) is based on the energy equivalent nightly available electricity purchase of 2,300 kcal/kWh under the Energy Conservation Law.

※CO2 emission coefficient and intensity: Electricity = 0.357 kg CO2/kg; utility gas = 2.360kg CO2/m3 (Environment Agency /2000)

Figure 10. Evaluation of Energy-Saving Performance and CO_2 Emission Intensity

7. CONCLUSION

This paper outlined CO2 heat pump water heaters for residential use and described specifications and data on evaluation of the performance of the commercial product.

Although COP slightly changes with various conditions such as ambient air temperature, water supply temperature, and hot water supply load, we believe that we could achieve our initial target of the annual average system COP of higher than 3.0 in Tokyo.

The research and development has already been completed, and the CO_2 refrigerant heat pump water heater for residential use, which we have developed, is now made available and marketed by a total of 6 home electrical products and electric water heater manufacturers.

As an evaluation statement of the government level, the "Report on Ideal Measures for Energy Conservation in Future: Energy Conservation Subcommittee of Advisory Committee for Resources and Energy," which was announced by the Ministry of Economy, Trade and Industry in June 2001, said "The outcome of recent technology development has reached a stage where highly energy-saving equipment (highly efficient equipment) has been developed and commercialized," introducing our water heater, and said "The energy-saving effect of the new water heater is about 30% higher than that of Combustion type water heater. ”

Since its launch in the market, our CO2 heat pump water heater was highly valued in various fields and won various prizes.

- October 2001: The 11th Nikkei Global Environment Technology Award of the Nihon Keizai Shimbun, Inc.
- January 2002: The 44th Ten Best New Product Award of the Nikkan Kogyo Shimbun
- January 2002: The Energy Conservation Grand Prize of the Energy Conservation Center (the Minister of Economy, Trade and Industry’s Award)
- March 2002:The EPA Climate Protection Award 2002
- April 2002:The Technical Prize of the Japan Society of Mechanical Engineers
- May 2002:The Technical Prize of the Institute of Refrigeration and Air Conditioning Engineers of Japan

The CO_2 refrigerant heat pump water heater is highly efficient, and at the same time, its market is worldwide because it can produce high-temperature hot water even at a low ambient air temperature. It also has growth potential such as hot water supply for business use, and practical use for car air conditioning.

The CO_2 refrigerant heat pump water heater is a trump card energy-saving technology that has come up in time for the new century.