# THE PRESENT STATUS AND FUTURE VIEW OF THE $CO_2$ REFRIGERANT HEAT PUMP WATER HEATER FOR RESIDENTIAL USE

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## ABSTRACT

In January of 2001, for the first time in the world, The Tokyo Electric Power Co., DENSO CORP., and Central Research Institute of Electric Power Industry have reported the practical use of the CO2 refrigerant heat pump water heater for residential use, which can save more than 30% of energy compared to conventional combustion type water heater.

The nation has started a subsidy system in September of 2002, and at the end of March, 2003, about 120,000 of the system have accumulatively forwarded to the whole market and now it continues to spread around well. As the market spreads, many types of system according to their uses and functions; such as system for apartments, for cold places, system with floor heating, have been positively developed.

In this report, the present status of the spread in Japan, the improvement of performance compared to the first model which was reported in the last conference (The 7th IEA Heat Pump Conference 2002, Beijing), the variations, and the future view of the CO2 refrigerant heat pump water heater for residential use are discussed.

**Key Words:** ***$CO_2$ refrigerant, heat pump water heater for residential use.***

## 1 INTRODUCTION

Measures to cope with global warming issues are becoming increasingly important, and energy saving efforts and CO2 emission reduction in the residential sector are also becoming urgent and important in Japan. Particularly, in a field of “hot tap water supply” that accounts for about 34% of final energy consumption in the residential sector, and that depends largely on combustion of fossil fuels such as gas and oil, the emission reduction has become one of the major issues. (Fig. 1).

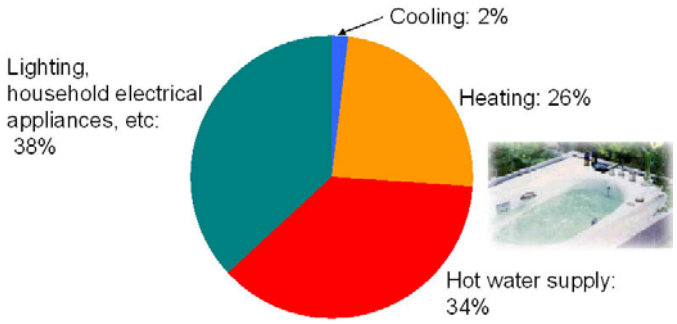



**Fig. 1. Breakdown of Energy Consumption in Residential Sector**
**Statistic Yearbook on Energy for Residential Use, 2002 national edition**

The natural refrigerant (CO2) heat pump water heater (Fig. 2) uses a natural refrigerant (CO2) that has very little impact on global warming. It is an innovative energy-saving water heater utilizing the principle of a heat pump that has a very high coefficient of performance (COP). It has the following features:

1. High efficiency: Based on the principle of a heat pump, it heats water by pumping out heat in the air, therefore, it can produce heat energy as much as 3 or 4 times of the energy (electricity) applied to it (Fig. 3). Compared with a conventional combustion type water heater (Fig. 4), it can save primary energy by about 30% and reduce CO2 emissions by about 50%.[1]

2. Natural refrigerants (CO2): Instead of using a fluorocarbon refrigerant as the refrigerant for the heat pump, it uses a natural refrigerant (CO2) that has very little impact on global warming. It can heat water as high as up to a maximum of 90℃ by solely operating a heat pump due to the physical properties of CO2 refrigerant.

3. Low running cost: By combining inexpensive electricity of the night-only service with the highly efficient heat pump system, it was able to achieve superior running cost performance as low as about ¥1,000 a month on average.[2]

※The name of "Eco Cute" is used by electric power companies and water heater manufacturers as the nickname to collectively call natural refrigerant heat pump water heaters.

**Fig. 2. Natural Refrigerant (CO2) Heat Pump Water Heater**

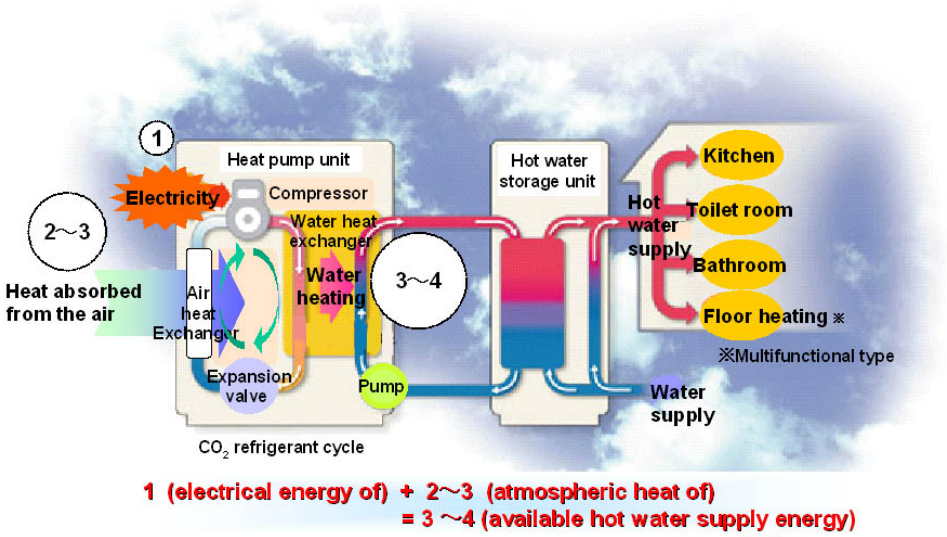



**Fig. 3. Principle of Natural Refrigerant (CO2) Heat Pump Water Heater**

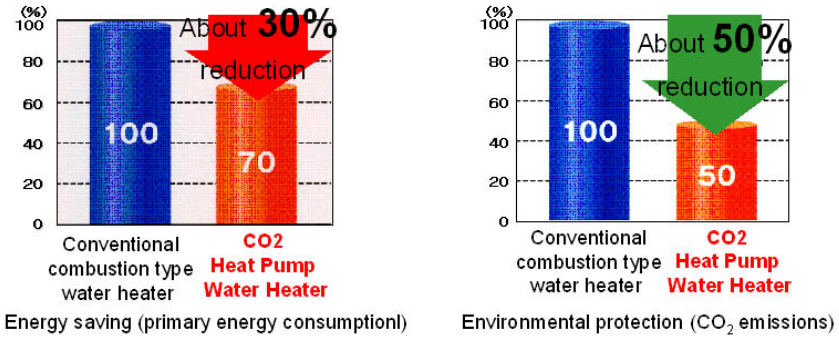



**Fig. 4. Energy Saving and Environmental Protection Performance**

The previous report (7th IEA Heat Pump Conference 2002, Beijing) described the outline of the natural refrigerant (CO2) heat pump water heater, development activities, and significance of the development, focusing on the performance evaluation data of the first model.

This report describes the present status of the spread of these heaters in Japan after the last report, performance improvements achieved on the first model which was reported in the previous report, model and function variations, user evaluation and prospects for future development.

## 2 PRESENT STATUS OF THE SPREAD

In January, 2001, Denso Corporation, Central Research Institute of Electric Power Industry, and Tokyo Electric Power Company (TEPCO) reported the world's first practical application of the natural refrigerant (CO2) heat pump water heaters for residential use as the result of the joint study. In the same year, the result of joint study of Daikin Industries, The Kansai Electric Power Company, and Chubu Electric Power Company was announced, followed by that of Sanyo Electric Co. and The Kansai Electric Power Company. These joint studies fueled the practical application of the natural refrigerant (CO2) heat pump water heaters.

It has passed 4 years since then, and natural refrigerant (CO2) heat pump water heaters are now manufactured and sold by such 17 companies as Corona Corporation, Mitsubishi Electric Corporation, Kyuhen Co., Shihen Technical Corporation, Hitachi Air Conditioning Systems Co., Matsushita Electric Works, Chugoku Electric Equipment Manufacturing Co., Toshiba Electric Appliances Co., TOTO, INAX Corporation, Daikin Industries, Chofu Seisakusho co., Takara Standard co., Sanyo Electric Co., Hitachi Housetec Co., Choshu Industry Company Limited, Matsushita Electric Industrial Co. (in random order).

The government has started the subsidy system for commercial availability in September, 2002 as the support measures to promote smooth introduction to the markets. Thanks to the effects of such measures, the shipments are increasing steadily. In fiscal 2004 only, about 120,000 units were shipped throughout the country and it is now reaching about 250,000 units in total (Fig. 5).

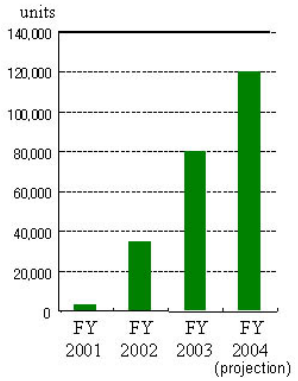



**Fig. 5. Shipments of Natural Refrigerant (CO2) Heat Pump Water Heaters (Nationwide)**

There was concern about the spread in apartments at first due to installation space problems. However, already a total of 10,883 households in 100 apartments have adopted these heaters in the TEPCO service areas.

## 3 PERFORMANCE IMPROVEMENT

### 3.1 Performance Improvement of Heat Pump Units

As the market for these products grows, competition among the manufacturers is getting fierce.

This has led to rapid progress in improvement of the heat pump unit performance and in reduction of operating noises.

The COP (Coefficient of Performance) of the model (a heating capacity of 4.5kW) first introduced into the markets under the JRA (The Japan Refrigeration and Air conditioning Industry Association) rated heating condition was improved from 3.46 to 4 or more, and operating noises were reduced from 45dB to 40dB or less (Fig. 6).

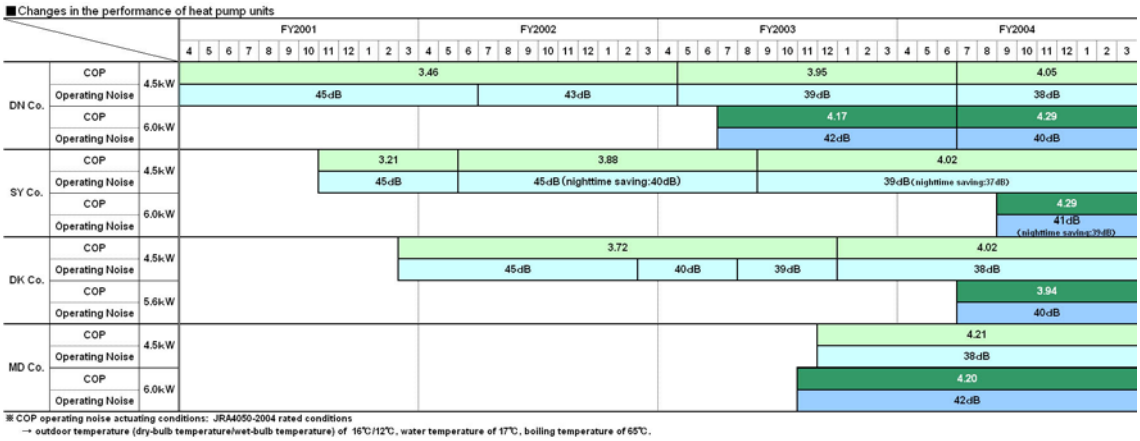



**Fig. 6. Progress in Performance Improvement of Heat Pump Units**

### 3.2 Efficiency of Commercial Product

The test standards (JRA: 40501) of JRA (The Japan Refrigeration and Air Conditioning Industry Association) are applicable to the single unit performance test of heat pump units, but there is no yardstick to evaluate the periodical performance of the system as a whole, and such yardstick is studied by each organization concerned.

The periodical performance of the system as a whole varies with the following three conditions.

1. The regional environment where units are installed such as outdoor temperature, feed water temperature, etc.
2. The usage pattern such as the quantity of hot water, time of use, etc.
3. The capability and control inherent in the unit such as heating capability, boiling temperature, etc. (the natural refrigerant (CO2) heat pump water heater is a hot water storage water heater that uses low-cost nighttime power (11:00 p.m. to 7:00 a.m.), and it is designed to learn the hot water supply load in the past several days before deciding the boiling temperature and heat value to prevent it from running out of hot water).

Together with Hihara (of Tokyo University), TEPCO proposed the methodology that can calculate the annual periodical efficiency (efficiency of commercial product) in consideration of three conditions with relatively simple methods, while giving simulated hot water supply load close to that in real life, at the time of cooperation in the test of IEA Annex 28.

#### 3.2.1 Conditions of outdoor temperature and feed water temperature

Prescribed by the test conditions (Table 1) of JRA4050 Standard.

**Table 1. Test Conditions for Periodical Performance**

| Season | Outdoor temperature(℃) | | Feed water temperature(℃) |
|---|---|---|---|
| | Dry-bulb | Wet-bulb | |
| Summer season | 25 | 21 | 24 |
| Intermediate season | 16 | 12 | 17 |
| Winter season | 7 | 6 | 9 |

As for the seasonal performance, hot water supply load tests are conducted under the test conditions prescribed by Table 1, and the annual assessment is worked out in consideration of the number of typical days occurred. The number of typical days occurred was assumed to be 92 in the summer season from July through September, 153 in the intermediate season from April through June and from October through November, and 120 in the winter season from December through March.

### 3.2.2 Hot water supply load

Of the hot water supply load modes (L, M and S) that have been widely used by the Institute for Building Environment and Energy Conservation (IBEC), the L mode that seemed to represent an average usage of hot water supplied was selected based on the hot water supply loads of about 50 field monitors conducted by TEPCO (Table 2).

**Table 2. Outline of IBEC's L Mode Hot Water Supply Loads**

| | Usage | HW temp(℃) | TW temp(℃) | Amount of HW supply(liter) |
|---|---|---|---|---|
| 6:00 | Kitchen and lavatory | 42 | Summer season: 24℃<br>Intermediate season: 17℃<br>Winter season: 9℃ | 15.9 |
| 6:30 | | | | 15.9 |
| 7:00 | | | | 15.9 |
| 7:30 | | | | 15.9 |
| 8:00 | | | | 15.9 |
| 12:00 | | | | 15.9 |
| 18:00 | | | | 15.9 |
| 18:30 | | | | 15.9 |
| 19:00 | | | | 15.9 |
| 19:30 | | | | 15.9 |
| 21:00 | Hot water supply to bathroom | 42 | | 180 |
| 21:30 | Shower | 42 | | 40 |
| 22:00 | Additional hot water or reheated hot water in the bathtub | 60 | | 22 |

Hwtemp: Hot water supply temperature
TWtemp: Tap water temperature
Amount of HW supply: Amount of hot water supply

### 3.2.3 Methodology of hot water supply load test

The following two-day tests are conducted under respective periodical conditions:

1st Day: The hot water storage tank unit of the test model installed in the environment test room that is controlled at the temperature prescribed by Table 1 is filled with the water supplied at the temperature prescribed by Table 1. While keeping the system learned about the past hot water supply loads, the system starts boiling the necessary amount of hot water from 11:00 p.m. on the first day with the control by the test model.

2nd Day: Hot water is sent out according to the hot water supply mode prescribed by Table 2, and the boiling operation is conducted according to the control of the test model.

### 3.2.4 Test results (example)

The results of the test model (Company C's 460L multifunctional type) are shown in Tables 3– 5.

**Table 3. Summary of Conditional Test of Each Period**

| Season | Summer season | Intermediate season | Winter season |
|---|---|---|---|
| Number of days | 92 | 153 | 120 |
| Amount of heat produced by HP (MJ/day) | 39.81 | 54.83 | 74.21 |
| Amount of electric energy imput to HP(kWh/day) | 2.3 | 3.6 | 5.5 |
| Amount of heat load (MJ/day) | 33.04 | 45.66 | 56.65 |
| Total amount of electric energy imput (kWh/day) | 2.6 | 3.9 | 5.9 |
| Efficiency of overall system | 3.5 | 3.2 | 2.8 |

**Table 4. Annual Development Table of Test Results**

| | |
|---|---|
| A:Amount of heat produced by HP (MJ/year) | 21.0 |
| B:Amount of heat load (MJ per year) | 17.1 |
| C:Amount of electric energy imput toHP (MWh/year) | 1.43 |
| D:Total amount of electric energy imput (MWh/year) | 1.55 |

**Table 5. Annual Efficiency of Test Model**

| | |
|---|---|
| Annual efficiency of HP unit (A÷C) | 4.1 |
| Annual efficiency of HP actually used (A÷D) | 3.3 |
| Annual efficiency of overall system (B÷D) | 3.1 |

Of these, the efficiency of the system as a whole is represented by the efficiency of commercial product. The difference between this value and the efficiency of the heat pump actually used represents the decrease in efficiency due to auxiliaries such as circulating pump, standby power, etc., and the difference between the efficiency of the heat pump actual used and that of commercial heat pump represents the decrease in efficiency due mainly to the heat storage tank such as heat radiation loss.

In the case of the test model, the annual efficiency of overall system was about 3.1.

## 4 VARIATIONS IN MODELS AND FUNCTIONS

### 4.1 Variations in Models and Functions

The Japanese people are one of the most bath-loving people in the world, and therefore, there are many variations in models and functions of electric water heaters.

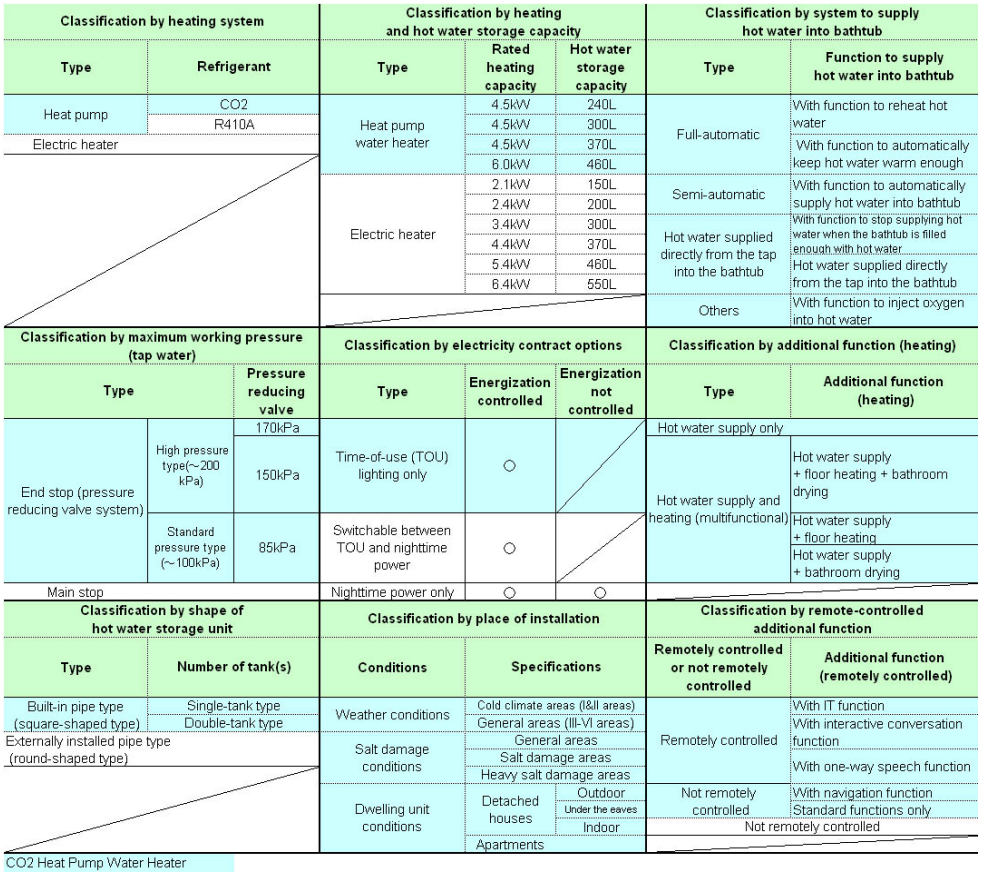



**Fig. 7. Model and Function Variations of Electric Water Heaters and Natural Refrigerant (CO2) Heat Pump Water Heaters**

As a result of the market expansion, a wide range of variations are made available in models and functions of natural refrigerant (CO2) heat pump water heaters, as well. Figure 7 shows models and functions of electric hot water heaters which are classified according to heating methods, heating capacities/hot water storage capacities, bath water heater types, maximum-pressure-applied (tap water) types, electricity contract options, additional functions (floor heating etc.), shapes of hot water storage units, installation places and additional remote control functions, etc. Various types of the natural refrigerant (CO2) heat pump water heaters that accommodate varying user needs are now available on the market.

### 4.2 Development of TEPCO

Tokyo Electric Power Company started the joint study with DENSO CORPORATION and Central Research Institute of Electric Power Industry in October, 1998, and publicly announced the world's first practical application of natural refrigerant (CO2) heat pump water heaters for residential application in January, 2001. This company is not engaging in manufacturing and marketing of the water heaters as a manufacturer. However, TEPCO is continually making proposals to promote wide spread use of natural refrigerant (CO2) heat pump water heaters through the joint development conducted with manufacturers. In 2002, TEPCO developed "a slim type for use in apartments" which made installation in apartments possible. In 2003, TEPCO developed "a multifunctional type (for both hot water supply and room heating) that accommodates the growing needs for floor heating. TEPCO has been conducting the joint development to meet varying needs, and products meeting these needs are now made available in the market by the above mentioned water heater manufacturers (Fig. 8).

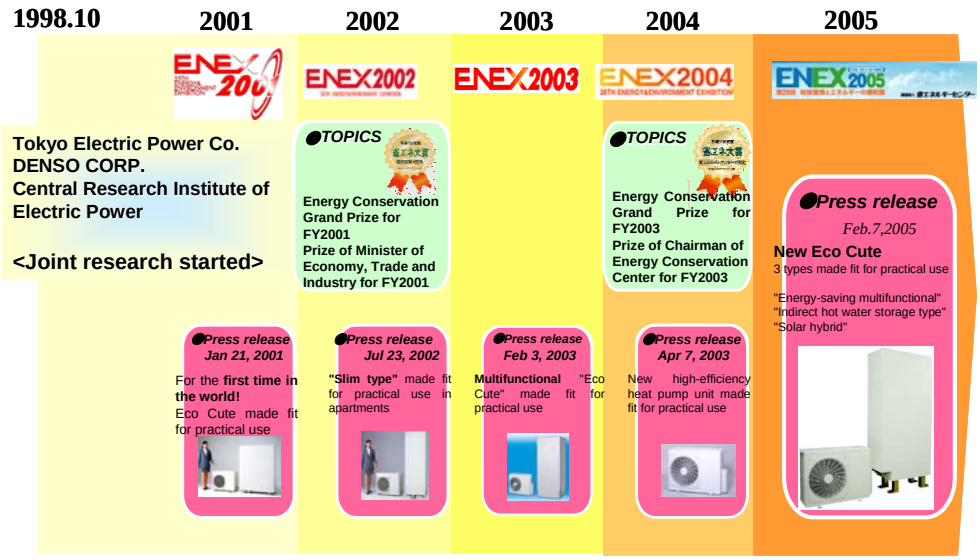



**Fig. 8. TEPCO's Efforts toward Development of Natural Refrigerant (CO2) Heat Pump Water Heaters**

Particularly in TEPCO service areas, it is a key issue to promote the use of these heaters in apartments which have more installation constraints than detached houses. Therefore, in addition to high efficiency and multi-functionality, TEPCO is constantly making efforts toward seeking the improvement of installation requirements.

The table given below shows the hot water storage capacity and installation places of the hot water storage units and the heat pump units in 100 fully-electrified apartments which adopted the natural refrigerant (CO2) heat pump water heaters in the TEPCO service areas (Table 6).

The hot water storage capacity and the installation places show the following features:

- The storage capacity: About 80% of the units are 300L types.
- The installation places: About 70% of heat pump units and storage units are installed on the balconies.

**Table 6. Features of Natural Refrigerant (CO2) Heat Pump Water Heaters Installed in Apartments.**

| | | Hot water storage unit | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Capa-city | Meter Box | | Balcony | | Inside dwelling units | | Total | | |
| | | | Number of apartments | Number of dwelling units | Number of apartments | Number of dwelling units | Number of apartments | Number of dwelling units | Number of apartments | Number of dwelling units | Share |
| HP unit | Outdoor corridor | 240L | 0 | 0 | | | | | 0 | 0 | 0% |
| | | 300L | 7 | 1,174 | | | | | 7 | 1,174 | 11% |
| | | 370L | 1 | 87 | | | | | 1 | 87 | 1% |
| | | 460L | 0 | 0 | | | | | 0 | 0 | 0% |
| | | Sub-total | 8 | 1,261 | 0 | 0 | 0 | 0 | 8 | 1,261 | 12% |
| | Balcony | 240L | 0 | 0 | 2 | 135 | 0 | 0 | 2 | 135 | 1% |
| | | 300L | 18 | 1,091 | 58 | 6,335 | 1 | 14 | 77 | 7,440 | 68% |
| | | 370L | 3 | 876 | 4 | 296 | 2 | 118 | 9 | 1,290 | 12% |
| | | 460L | 1 | 116 | 2 | 488 | 1 | 153 | 4 | 757 | 7% |
| | | Sub-total | 22 | 2,083 | 66 | 7,254 | 4 | 285 | 92 | 9,622 | 88% |
| | Total | 240L | 0 | 0 | 2 | 135 | 0 | 0 | 2 | 135 | 1% |
| | | 300L | 25 | 2,265 | 58 | 6,335 | 1 | 14 | 84 | 8,614 | 79% |
| | | 370L | 4 | 963 | 4 | 296 | 2 | 118 | 10 | 1,377 | 13% |
| | | 460L | 1 | 116 | 2 | 488 | 1 | 153 | 4 | 757 | 7% |
| | | Total | 30 | 3,344 | 66 | 7,254 | 4 | 285 | 100 | 10,883 | 100% |
| | | Share | 30% | 31% | 66% | 67% | 4% | 3% | 100% | 100% | |

※The apartments where Eco Cutes are introduced in TEPCO's service areas as of February 2005
※The 460L is a multifunctional type (hot water supply + floor heating)

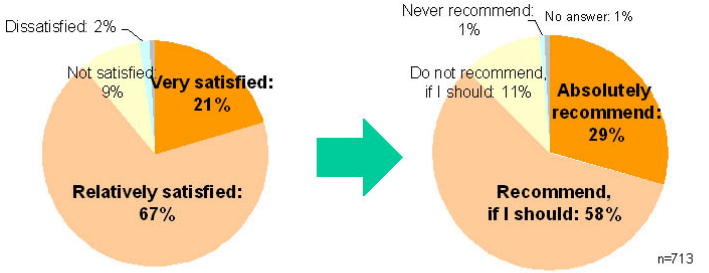
Most of the electric water heaters used by typical families (of 3 to 5 members) are those with a capacity ranging from 370L through 460L. The “Eco Cute” models are highly efficient, and have a re-heating function operated by learning control. The smallest type (300L types) of this model is commonly used by one-generation household in the apartments having constraints in the installation space. It was found out that such “slim types for the use of apartments” triggered the widespread use in apartments.

Regarding installation places that are now mostly selected in balconies, situations may soon be changed. In February, 2004, the Ministry of Land Infrastructure and Transport issued the notification as an technical advice to prefectural and city governments to the effect that the deregulated program for floor-area ratios could be applied, saying that “under the approval of application of Item 1 of Paragraph 13 of Article 52 of the Building Standard Law, it is advisable that from the viewpoint of reducing environmental loads, a certain kinds of equipment such as heat pump units using natural refrigerants and heat storage systems , should be covered by this approval and the use of those equipment should be actively promoted”. This approval allows the deregulated program to be applied if industry firms obtain permission in consultation with relevant government agencies when the firms plan to install the natural refrigerant (CO2) heat pump water heater, and installation of a hot water storage unit in or near to the electricity meter box, for example, without reducing users’ floor areas.

## 5 USER EVALUATION

### 5.1 User Evaluation of the Natural Refrigerant ($CO_2$) Heat Pump Water Heaters

In August, 2004, PEPCO conducted a questionnaire survey (n=713) on the users who used the natural refrigerant (CO2) heat pump water heaters for more than 1 years. This survey shows that about 90% of such users are satisfied, and about the same rate of the users intends to recommend these heaters to others.




Survey on users of fully electrified detached houses by TEPCO (conducted in August 2004)
(1,000 households were selected on a random basis from the users of fully electrified houses and Eco Cute for more than one year in TEPCO's service areas)

**Fig. 9. User Evaluation of Natural Refrigerant (CO2) Heat Pump Water Heaters**

Although it seems users don't have a interest in the heat source of water heater, it seems they have a good impression and accept the characteristic of the natural refrigerant (CO2) heat pump water heater which is “eco-friendly and low running cost.”

### 5.2 Heating and Lighting Expenses of the Household Using the Natural Refrigerant ($CO_2$) Heat Pump Water Heater (an Example Case)

Figure 10 shows the change in the heating and lighting expenses of a certain household living in a detached house (located in Saitama prefecture living with 4 family members in an area of 130m2) that remodeled a fuel-burning water heater to the natural refrigerant (CO2) heat pump water heater, and the fuel-burning kitchen stove to the IH cooking heater.

The result shows that the heating and lighting expenses have reduced by ¥73,000/year in comparison with those before and after remodeling.

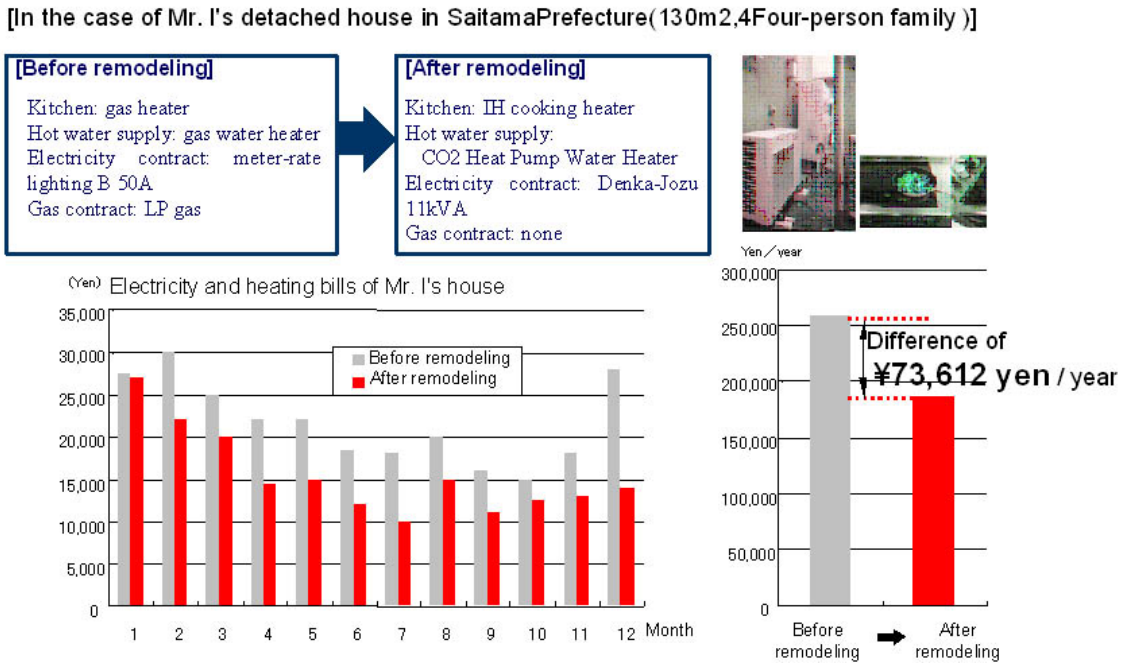



**Fig. 10. Heating and Lighting Expenses of the Household Using Natural Refrigerant (CO2) Heat Pump Water Heater (an example case)**

## 6 CONCLUSIONS

This report describes the spread of these heaters in Japan during 4 years after the natural refrigerant (CO2) heat pump water heaters were introduced into the markets, performance improvement achieved on the first model, model and function variations and user evaluation of the natural refrigerant (CO2) heat pump water heater.

Shipments are increasing, performance is improving, and variety in the models and available functions is increasing. These water heaters are highly evaluated by many users now. However, the government is intending to accelerate further spread of these water heaters. The documents released by the Demand and Supply Subcommittee of the Advisory Committee for Natural Resources and Energy said that the “Eco Cute” would be one of the pillars of the measures for energy saving in the home, together with the next generation energy saving standard appliances and Top Runner electric home appliances (Fig. 11). In the case of additional measures, it is estimated that about 5.2 million units will be widely used by the year 2010.

Unit: crude oil equivalent 10,000 kL

| | | Present target | Reference Case | Current Measure Promotion Case | Additional Measure Case | Remarks |
|---|---|---|---|---|---|---|
| Common to houses and buildings | Efficiency improvement by Top Runner program | about 660 | about 570 | | | |
| | Expansion of scope of Top Runner program | – | – | | about 10 | Gas and oil equipment, electronic oven, electric rice cooker |
| | Reduction in consumption of standby power | about 40 | about 40 | | | |
| Mainly for houses | Improvement of energy-saving performance of houses | about 300 | about 240 | about 280 | about 300 | Houses that meet the next-generation energy-saving standards |
| | Spread rate of houses that meet the next-generation energy-saving standards | about 50% | – | – | – | Spread rate in and after FY2008 Report by Energy Conservation Subcommittee in June 2001 |
| | Spread of high-efficiency water heater | about 50 | about 20 | about 110 | about 260 | |
| | CO2 refrigerant heat pump water heater | | About 610,000 units | About 3,150,000 units | About 5,200,000 units | |
| | Latent heat recovery water heater | | | | About 2,800,000 units | |
| | Spread of HEMS | about 90 | about 0 | about 50 | about 90 | |
| | Spread rate of HEMS | | | about 17% | about 30% | |
| Mainly for buildings | Improvement of energy-saving performance of buildings | about 560 | about 250 | about 530 | about 560 | |
| | Spread of high-efficiency lighting | about 50 | about 0 | about 50 | | |
| | Spread of high-efficiency air-conditioner for business use | – | – | | about 30 | |
| | High-efficiency air-conditioner that capitalizes on HP technology | | – | | About 12,000 units | |
| | Spread of BEMS | about 160 | about 120 | about 170 | | |
| | Spread rate of BEMS | | about 23% | about 32% | | |
| | Efforts for full compliance with regulations under the Energy Conservation Law and implementation of overall inspection of establishments | – | – | | about 70 | |

※This was worked out based on the Outlook for Energy Demand and Supply for 2030 (Interim Report) by the Demand and Supply Subcommittee of the Advisory Committee on Natural Resources and Energy.

**Fig. 11. Energy-Saving Measures in Commercial Sector**

To promote accelerated spread, it is required, in addition to features given to the existing types, to realize downsizing of equipment, higher output of heat pump units, more performance improvements for use in cold regions, and further cost reduction. Therefore, the government, manufacturers and electric power companies are now working together with concerted efforts.

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"Energy Conservation Handbook 2004", IBEC (the Institute for Building Environment and Energy Conservation)


[1] [Calculation conditions]

- Hot water supply load: The amount of hot water equivalent to IBEC L Mode 43℃ is converted by the feed water temperature of each month.
- Weather conditions: The nighttime average value of Tokyo district (the data of standard year (January 25, 2000) of Expanded AMeDAS Weather Data of Architectural Institute of Japan.
- Feed water conditions: Tokyo district (the research study on design standards of solar systems by Solar System Development Association).

- Primary energy heating value intensity: Eco Cute (2.3 Mcal/kWh of electricity (nighttime), conventional combustion type water heater (11 Mcal/m3 of city gas).
- $CO_2$ emission intensity: Calculated by the values prescribed by "Results of Study on Calculation of Global Warming Gas Emissions (September 2000)."
- The efficiency of Eco Cute is the value mentioned above, and that of conventional combustion type water heaters (city gas) is the value (78%) prescribed by the BL certification standards.

[2] The electricity rate: Tokyo Electric Power Company's "Season- and Time-Specific Lighting (Denka-Jozu)" (the discount for fully-electrified homes and the discount for energization-controlled nighttime thermal storage type appliances are applied. In this case, an amount due to the fuel cost adjustment is not applied). The electric power consumption is based on the condition below:

1. The equivalent hot water amount at the temperature of 43℃ on the L mode of IBEC (Institute for Building Environment and Energy Conservation) is used for the standard water heater load.
2. The outside air temperature and the feed water temperature are based on the standard of The Japan Refrigeration and Air conditioning Industry Association (JRA4050:2004).
3. Equipment efficiency, defrosting, and boiling out loss are included in the calculation.
4. The calculations are made on the electric power consumption of three periods; shoulder, winter and summer seasons.

The electricity cost required for heat retention of bathtub water is not included. The actual running cost of the water heater may vary depending on the amount of hot water consumed, family structures and seasons.