Technology Collaboration Programme
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Technology Collaboration Program on Heat Pumping Technologies (TCP-HPT)

HPT-Annex 46
Domestic Hot Water Heat Pumps

Annex 46

Task 1 Market Overview

Country Report Japan

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Production Heat Pump Centre, Borås, Sweden

Report No. HPT-AN46-02-04

Preface
This project was carried out within the International Energy Agency Technology Collaboration Program on Heat Pumping Technologies (HPT TCP).

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Program. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a Program of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

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The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) forms the legal basis for a Program of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP, called participating countries, are either governments or organizations designated by their respective governments to conduct. The Program is governed by an Executive Committee (ExCo), which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Annexes
The core of the TCP are the “Annexes”. Annexes are collaborative tasks conducted on a cost-sharing and/or task-sharing basis by experts from the participating countries. Annexes have specific topics and work plans and operate for a specified period, usually a number of years. The objectives range from information exchange to the development and implementation of heat pumping technologies. An Annex is in general coordinated by an expert from one country, acting as the Operating Agent (manager). This report presents the results of one Annex.

Triennial Heat Pump Conference
The IEA Heat Pump Conference is one of the three major products of the Technology Collaboration Program on Heat Pumping Technologies. The Executive Committee supervises the overall organization and its quality and selects from a tender procedure the host country to organize the Conference and establishes an International Organization Committee (IOC) to support the host country and the ExCo.

The Heat Pump Centre
The Heat Pump Centre (HPC) offers information services to support all those who can play a part in the implementation of heat pumping technologies. Activities of the HPC include the publication of the quarterly Heat Pumping Technologies Magazine and an additional newsletter three times per year, the HPT TCP website, the organization of workshops, an inquiry service and a promotion Program.
The HPC also publishes results from the Annexes under the TCP-HPT.
For further information about the Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Contents

1. Preface

From the viewpoint of global environmental conservation, prevention of global warming has now become one of the great challenges of the 21st century, with a focus on reduction of CO_2 emissions. Japan has set a target of a 26% reduction of greenhouse gas emissions by FY2030 from the level of FY2013 (25.4% reduction from the level of FY2005) as its "Intended Nationally Determined Contributions" and has submitted it to the Secretariat of the United Nations Framework Convention on Climate Change. In addition, it is striving for an 80% reduction of greenhouse gas emissions by the year 2050 as a long-term goal.

To achieve this environmental target, various air-conditioning systems are required to significantly reduce primary energy consumption by drastic measures for innovation in energy utilization such as substantial improvement of system efficiency and effective utilization of renewable or unutilized energy.

Heat pump technology is capable of converting heat to a reusable temperature level with small power consumption by utilizing air heat and exhaust heat that are renewable. Because this technology has such excellent benefits, Japan is striving to promote the technology.

Under such circumstances, ANNEX 46, which deals with heat pump water heaters for residential use is receiving considerable attention in Japan, and productive discussions are being held in the Japanese National Team, which started with the participation of academics from five universities; public research institutes under the Ministry of Economy, Trade and Industry; the research laboratories of electric power companies; The Japan Refrigeration and Air Conditioning Industry Association; and eight major manufacturers that are developing heat pumps.

In TASK1, the following two subjects have been discussed as very important topics to be covered:

- Market overview for heat pump water heater for residential use either as standalone equipment or as combined equipment with other technologies
- Manufacturing and cutting-edge technology for heat pump water heater for residential use, refrigerant, future new development, and the like

In addition, the subject that is most important in TASK1 is to not only study concepts, systems, and technical innovations of various types of heat pump water heaters for residential use but to also understand the use conditions for such heaters. The Japanese National Team conducted investigations in line with such considerations.

With regard to heat pump technology in Japan, popularization of heat pump technology started in 2001 with efforts to promote heat pumps using carbon dioxide (CO_2) as a refrigerant, and 5,000,000 units of such equipment for residential use were put on the market in less than 15 years. Most of such heat pumps use the natural refrigerant CO_2 in place of chlorofluorocarbons, of which the global warning potential may reach as high as several thousand times that of CO_2, and are quite environment-friendly. Also for business use, more than 35,000 heat pump water heater system units were put on the market in 10 years. There is no other country in the world where heat pump technology has become so popular. Thus, Japan is considered as an advanced nation for heat pumps. While introduction of heat pump water heaters has progressed so quickly, a lot of hot-water supply equipment using fossil fuel is still being used. Under such circumstances, analysis is conducted through market research to confirm that there is still large potential for the introduction of heat pump water heaters.

Along with the quick popularization of heat pumps, various technologies have also been developed. Especially for equipment using CO_2 as a refrigerant, new development of compressors and heat exchangers have been enhanced because refrigerant pressure exceeds 10 MPa. Many overcrowded residential areas in Japan also contributed to downsizing technologies. Because heat pump water heaters for residential use in Japan have all-in-one construction that integrates heater systems and hot-water tanks into one unit, heat insulation technology for hot-water storage tanks has also achieved significant improvement along with the development of heat pump technology. Research into total systems in which heat pumps, air-conditioning equipment, sun-heat collectors and solar panels are connected is also being conducted.

The research by the Japanese National Team on the subjects relating to TASK1 were conducted as above and the results are reported hereunder.

2. Japan's Heat Pump Water Heater Market

2-1. Water Heater Market

2-1-1. Energy Consumption and Position of Heat Pump Water Heaters

If energy consumption is segmented by application, water heating occupies quite a big portion. According to data of 2014, energy consumption by space heating and air-conditioning for households accounts for 27.1%, and for water heating the figure is 27.5%, almost the same (see Figure 2-1-1). On the other hand, those for business use are estimated to be 26.2% for space heating and air-conditioning and 12.6% for water heating (see Figure 2-1-2). For both cases of household and business use, approximately 90% of the energy source for water heating is fossil fuel.

Since the beginning of 2000, heat pump water heaters that realize a significant reduction of CO2 emissions have started spreading in the category of residential use, and the need for downsizing, noise reduction, and cold weather specifications as well as higher efficiency and lower price have also started rising. Different variations of products have also been studied to respond to the needs for multi-functionality including floor heating and central heating; a snow melting facility; direct hot-water supply type; small-scale hot-water supply unit for local areas such as toilet bowls; utilization of exhaust heat (such as leftover bathtub water, and others); heat recovery type (cold/hot heat supply); hybrid type; business use; industry use; and so on. A hybrid system has two major categories. One utilizes boilers to meet large-scale demand such as that of industries, and another utilizes solar heat such as solar panels and ground heat. Also, there are two types of system configuration. One is parallel configuration that mixes heat from solar panels and heat pumps in hot-water storage tanks or at hot-water outlets, and another is an integrated type that integrates solar panel evaporators or evaporators with built-in solar-panel using decompression boiling into heat pump (for installation on roofs, balconies, or walls).

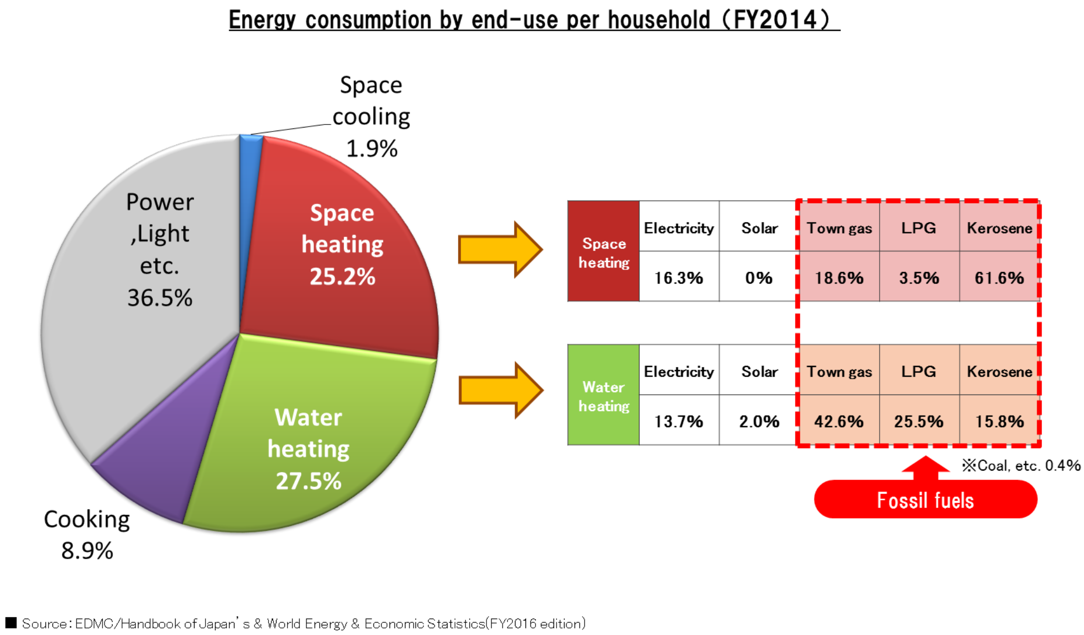


Figure 2-1-1: Proportion of Energy Consumption in Residential Use Category

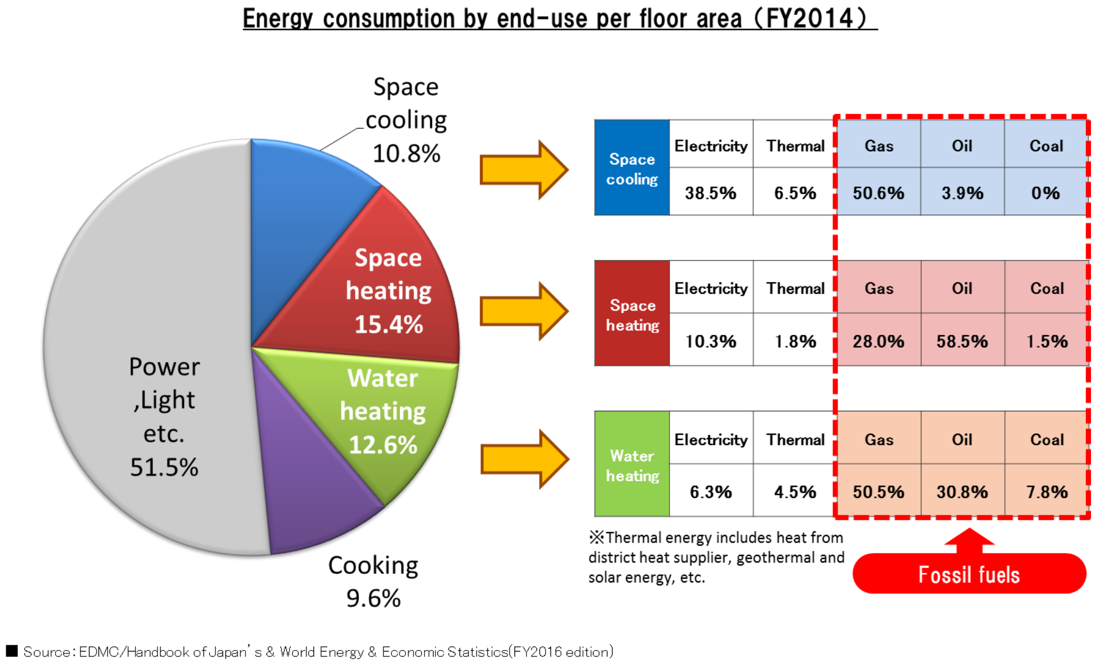


Figure 2-1-2: Proportion of Energy Consumption in Business Use Category

2-1-2. Outline of Heat Pump Water Heater

Water heaters using the principle of a heat pump have a high reputation in terms of energy conservation and are classified into two types: for residential use and for business use.

Most water heaters for residential use are such systems that boil water (up to hot-water storage temperatures of 65°C to 90°C), keep hot-water in a storage unit, and supply hot-water from a hot-water storage unit to a bathtub, lavatory basin, kitchen, and so on when required. They use night-time electric power for boiling water to lower the electricity cost in many cases.

Regarding refrigerant, equipment using hydrofluorocarbon (HFC) was commercialized in the past. But after 2001 when equipment using carbon dioxide (CO2) as a refrigerant was developed, most heat pump water heaters for residential use have been using CO2. Some of the heat pump water heaters for small groups of people are using the refrigerant R32, which is typical for air-conditioning. On the other hand, some equipment for business use is using the refrigerant CO2 and R410, an HFC.

(1) Heat Pump Water Heater for Residential Use

There are several types of equipment depending on the shape of the storage tank, capacity, and functionalities. The storage tank capacity of popularly marketed equipment is classified into several main groups: a down-sized unit with capacity of 150 to 200 liters (for a family of one to four), 300 liters (for a family of two to four), 370 liters (for a family of three to five), 460 liters (for a family of four to seven), and 560 liters (for a family of five to eight). There are several varieties in functionalities such as “Automatic Hot-Water Filling”, “Hot-Water Adding”, “Automatic Retaining of Warmth”, “Reheating”, and “Bathroom Floor Heater”. Bathtubs also have several types including the one that fills hot water from a faucet.

Heat pump water heaters are also divided into one-can type and multi-can type depending on the configuration of the hot-water storage tank. In most cases, the multi-can type has a hot-water storage unit with multiple cans of small capacity combined to make its shape thin so that it matches the space of the installation location. From the viewpoint of performance for energy saving, the multi-can type is further classified according to the number of hot-water cans, because of its large heat dissipation area and potential inefficiency due to lower heat retention capability.

According to the shipment statistics (Figure 2-1-3) of The Japan Refrigeration and Air Conditioning Industry Association, the shipments of heat pump water heaters for residential use using natural refrigerants started around 2001. The cumulative shipments continued to grow steadily and exceeded 5,000,000 units in March 2016. In recent years, approximately 400,000 to 500,000 units are being shipped every year. Such substantial shipment growth was the result of support by the "Introduction Subsidy Scheme" initiated by the Japanese Government in 2002 to subsidize a part of the cost for introduction of heat pump water heaters. This scheme is, however, not currently implemented. There are 12 major manufacturers in Japan and very little imported equipment is sold in the domestic market.

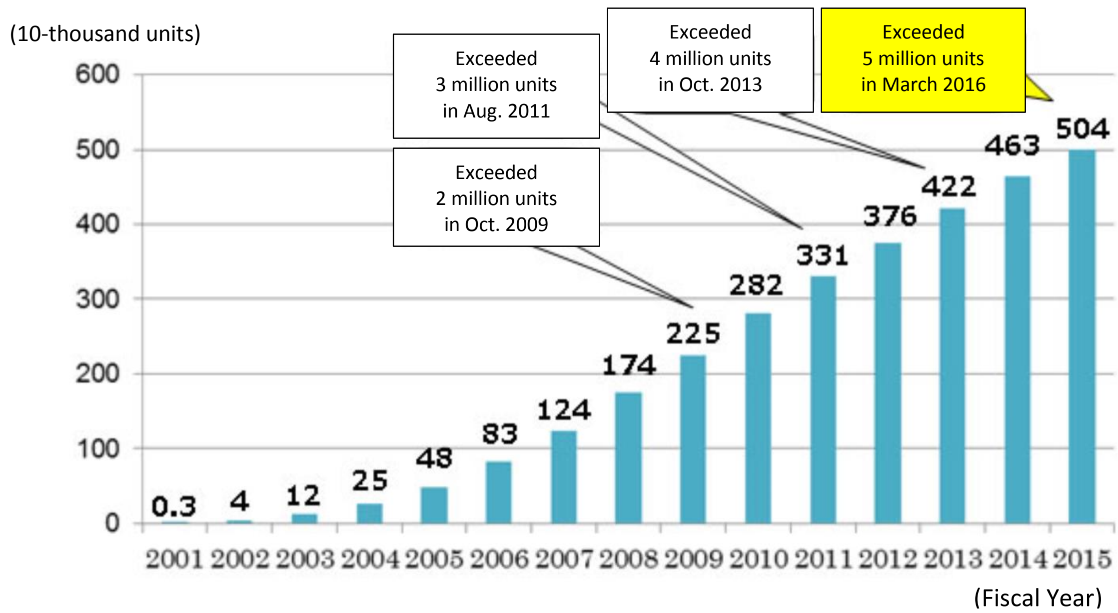


Figure 2-1-3: Transition of Cumulative Shipments of Heat Pump Water Heaters Using Natural Refrigerants for Residential Use (Source: Statistics of the Japan Refrigeration and Air Conditioning Industry Association)

(2) Heat Pump Water Heater for Business Use

Heat pump water heaters for business use are divided into large-scale systems and small-scale systems based on the quantity of hot-water to be used and the scale of buildings for business purposes such as office buildings, accommodation facilities, amusement facilities, and hospitals.

- Examples of small-scale building: Restaurant, Inn, Shop, Small-Scale Welfare Facility
- Examples of large-scale building: Economy Hotel, Hospital, Large-Scale Welfare Facility, Sports Complex, School Lunch Center

According to the statistics of The Japan Refrigeration and Air Conditioning Industry Association, yearly shipments showed an upward trend from around 2006 when statistical analysis started, and the yearly shipment levels have been keeping between approximately 3,000 and 5,000 units. Cumulative shipments exceeded 35,000 units in 2015. There are currently about ten manufacturers, but further growth is foreseen in view of the trend in market size.

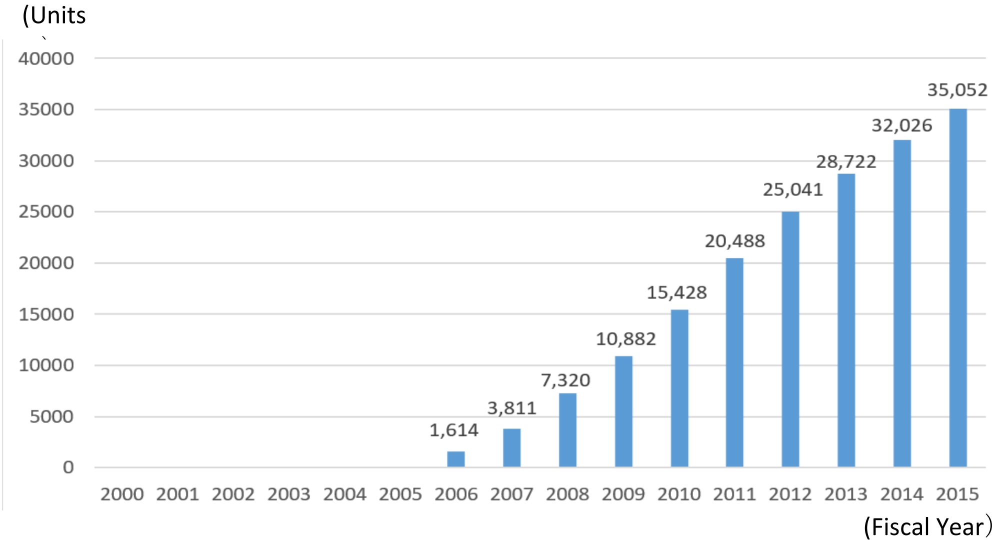


Figure 2-1-4: Transition of Cumulative Shipments of Heat Pump Water Heaters for Business Use (Source: Statistics of the Japan Refrigeration and Air Conditioning Industry Association)

2-1-3. Market Trend of Hot-Water Supply Equipment

Table 2-1-1 shows the transition of shipments of hot-water supply equipment categorized to residential use based on the classification according to electric water heater, gas-fired water heater, gas-fired bathtub boiler, oil-fired water heater, solar-powered water heater, and heat pump water heater for residential use. Yearly demand for hot-water supply equipment in the residential use category is between 4,000,000 and 4,500,000 units, out of which approximately 1,500,000 units are gas-fired bathtub boilers and approximately 3,000,000 units are hot-water supply equipment and hot-water supply/space heating equipment. The expected service life of hot-water supply equipment is about 15 years, and malfunctions or needs for better functionalities generate needs for replacement. If the number of bathtub boilers is added to the number of water heaters, the aggregate total of those two that are currently working slightly exceeds 60,000,000 units, which almost corresponds to the number of currently existing home units. This indicates that every single home unit in Japan has one unit of either hot-water supply equipment or a bathtub heater.

The demand for heat pump water heaters for residential use is approximately 400,000 units, which rises to approximately 500,000 units when demand is strong. Such heat pump water heaters seem to be spreading as replacement for electric heaters and oil-fired water heaters. The percentage of heat pump water heaters for residential use is still as low as 10% of the total number of all hot-water supply equipment. Heat pump water heater has been popularized by using low cost night-time electricity, but since the night-time electricity price has more than doubled due to the liberalization of electricity and the promotion cost of renewable energy, the dissemination has been temporarily slowed down. On the other hand, the market for multi-purpose waterheaters, of which one example is hot-water supply/space heating equipment, is growing. A multi-purpose water heater has the functions of hot-water supply, bathtub boiler, and hot-water space heater. Therefore, it is possible multi-purpose water heaters will gradually replace bathtub boilers. Because of these reasons, as well as the advantage for energy saving, heat pump water heaters for residential use still have potential for further market expansion.

As shown in Table 2-1-2, varieties of high efficiency hot-water supply systems (such as ENE-FARM®, ECOWILL®, Eco-Feel®, Ecojozu®, EcoCute®) have been introduced to the market after the Great East Japan Earthquake in 2011 and such new systems have realized diversification of the heat source (namely, the source of the driving force) and integration of power generation systems, in addition to energy saving performance.

Table 2-1-3 shows the shipment transition of hot-water supply equipment in the business use category based on the classification according to oil-fired hot-water boilers, gas-fired hot-water boilers, vacuum/no-pressure-type hot-water generators (oil-fired), and vacuum/no-pressure-type hot-water generators (gas-fired). Yearly demand for hot-water supply equipment for business use is approximately 30,000 units, out of which approximately 10,000 units are through-flow-type boilers and the other 20,000 units include 3,000 to 5,000 (at most) units of heat pump water heaters for business use. Just like the case in the residential use category, heat pump water heaters for business use account for approximately 10% of the total number of hot-water supply equipment in the business use category. Because of this fact, as well as the advantage for energy saving, it still has potential for further market expansion.

Table 2-1-1: Transition of Domestic Shipments of Hot-Water Supply Equipment of Residential Use Category

[units]

FY	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Electric water heaters	256,892	250,828	220,017	217,102	214,615	205,103	257,211	228,085	204,221	192,826	223,616	231,896	236,574
Gas-fired water heaters	3,642,693	3,627,710	3,327,451	3,326,042	3,273,968	3,261,890	3,141,752	2,769,414	2,689,232	2,609,668	2,699,392	2,597,090	2,604,330
Bath tub gas-fired water heaters	1,611,753	1,545,188	1,481,222	1,580,189	1,727,708	1,824,840	1,835,621	1,677,067	1,581,652	1,719,991	1,694,429	1,601,805	1,535,289
Oil-fired water heaters	687,248	709,070	674,648	739,440	802,864	908,164	909,065	761,451	666,482	680,309	704,273	697,480	599,855
Solar water heaters	165,311	165,991	136,909	137,616	182,364	198,931	185,203	90,989	72,735	71,218	73,015	73,442	65,210
Heat pump water heaters for household use	–	–	–	–	–	–	–	–	–	–	–	3,399	37,230

[units]

FY	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Electric water heaters	238,910	247,532	245,792	236,752	229,711	198,976	141,975	115,697	112,963	115,629	112,785	109,011
Gas-fired water heaters	2,493,547	2,432,485	2,446,310	2,566,435	2,515,702	2,306,877	2,210,541	2,254,489	2,359,493	2,173,011	2,275,336	2,097,790
Bath tub gas-fired water heaters	1,549,697	1,462,530	1,353,347	1,332,676	1,204,222	1,194,470	1,198,246	1,275,845	1,304,652	1,357,925	1,435,506	1,333,046
Oil-fired water heaters	603,169	554,145	500,009	423,167	371,670	330,262	352,508	390,532	418,569	403,672	416,130	382,868
Solar water heaters	54,665	58,807	56,344	53,318	47,939	56,517	39,193	39,688	41,918	40,759	39,328	21,594
Heat pump water heaters for household use	80,775	130,813	225,628	349,822	413,132	500,222	508,141	566,379	496,752	446,730	459,458	415,042

■ Source : "Yearbook of Machinery Statistics" and "Yearbook of Statistics on Iron & Steel, Non-ferrous Metals and Metal Products," Ministry of Economy, Trade and Industry; The Japan Refrigeration and Air Conditioning Industry Association

Table 2-1-2: Transition of Domestic Shipments of Hot-Water Equipment of Business Use Category

[units]

FY	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Oil-fired hot water boilers (Commercial use)	38,999	39,076	35,455	31,746	31,605	34,168	34,507	33,548	26,752	25,747	21,409	19,588	17,638
Gas-fired hot water boilers (Commercial use)	–	–	–	–	–	1,645	1,172	1,252	1,056	1,051	957	890	462
Vacuum or non-pressure type hot water boilers (Oil-fired)	6,029	6,928	5,560	5,993	5,871	5,578	5,541	4,880	4,436	5,144	4,365	4,449	3,468
Vacuum or non-pressure type hot water boilers (Gas-fired)	2,616	2,785	2,290	2,421	2,348	2,331	2,555	2,472	2,520	3,037	2,677	2,319	2,481
One-through boilers	–	–	25,380	23,880	18,590	17,250	17,200	16,800	15,249	17,287	16,892	15,839	15,772
Heat pump water heaters	–	–	–	–	–	–	–	–	–	–	249	161	340
(kW)	–	–	–	–	–	–	–	–	–	–	11,291	7,250	15,278

[units]

FY	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Oil-fired hot water boilers (Commercial use)	16,189	15,555	13,869	10,234	9,739	7,244	7,013	7,807	10,469	10,197	10,850	10,687
Gas-fired hot water boilers (Commercial use)	790	659	576	612	543	572	400	527	403	358	388	341
Vacuum or non-pressure type hot water boilers (Oil-fired)	4,370	4,070	3,284	2,751	2,464	2,155	2,181	2,185	2,052	2,005	2,264	2,097
Vacuum or non-pressure type hot water boilers (Gas-fired)	2,856	2,144	2,507	2,435	2,286	2,160	1,700	1,787	1,834	1,852	2,075	2,136
One-through boilers	15,502	15,041	15,271	14,517	13,539	13,219	11,893	11,275	11,492	11,262	11,814	10,780
Heat pump water heaters	300	490	806	1,614	2,197	3,509	3,562	4,546	5,060	4,553	3,681	3,304
(kW)	12,195	18,003	23,801	52,177	52,882	73,900	74,325	93,073	108,972	86,160	71,082	65,472

(※) The capacity of oil-fired hot water boilers (for commercial use) is 30,001 kcal/h or larger (1989-1996), larger than 34.9 kW (1997 and beyond)
(※) The rated output of vacuum or non-pressure type hot water boilers (oil-fired) and that of vacuum or non-pressure type hot water boilers (gas-fired) are 46.5 kW of larger.
(※) Combustion type small water heaters for business use are not included here.

Table 2-1-3: Example of High-Efficiency Hot-Water Supply System

	Fuel Cell Co-Generation System (ENE-FARM®)	Engine-Driven Co-Generation System (ECOWILL®)	High-Efficiency Gas-Fired Hot-Water Supply System (Ecojozu®)	High-Efficiency Oil-Fired Hot-Water Supply System (Eco-Feel®)	Natural Refrigerant Heat Pump Water Heater (EcoCute®)
Heat Source	Gas	Gas	Gas	Oil	Electric Power
Configuration	Fuel Cell Unit ＋Hot-water storage unit ＋Backup Heat Source Unit	Power Generation Unit ＋Hot-water storage unit	Main Body of Water Heater	Main Body of Water Heater	Heat Pump Unit ＋Hot-water storage unit
Power Generator	Available	Available	Not Available	Not Available	Not Available
Price (for reference only)	(Approx. 2.0 – 3.0 mil. Yen)	(Approx. 0.8 – 1.0 mil. Yen)	(Approx. 0.2 – 0.4 mil. Yen)	(Approx. 0.1 – 0.4 mil. Yen)	(Approx. 0.7 – 1.0 mil. Yen)
Features	・Power generation by chemical reaction of atmosphere oxygen with hydrogen extracted from city gas, LP Gas or the like (Fuel Cell). ・Approx. 50 – 60% of yearly power consumption can be covered if based on typical automatic operation mode in standard household	・Gas-engine generates in-home electricity for own consumption, and exhaust heat therefrom generates hot water to be connected to hot-water supply system, gas-fired hot-water floor heating system, bathroom dryer, and so on. ・Approx. 30 – 40% of yearly power consumption of typical standard household can be covered.	・Thermal efficiency of hot-water supply equipment is raised to 95% from the conventional upper limit of approx. 80% by collecting latent heat (the heat released into the air by way of water vapor) which causes exhaust heat loss of gas-fired water heater.	・Utilization of high temperature exhaust heat that was not used in the past improved the thermal efficiency up to 95%. ・Exhaust gas temp. wa lowered to approx. 60°C from 200°C with lower moisture content. This improved thermal efficiency and decreased steamy exhaust in winter.	・Running cost can be decreased by use of CO_2 and night-time electricity, which is cheaper than day-time, combined with higher efficiency of heat pump system.

* Regarding the handling of names (trade names) of each high-efficiency hot-water supply system

- "ENE-FARM" is the nickname of a fuel cell co-generation system for residential use, and is a registered trade name (ENE-FARM®) of Osaka Gas Co., Ltd., Tokyo Gas Co., Ltd., and JX Nippon Oil & Energy Corporation.
- "ECOWILL" is the nickname of a gas engine-driven co-generation system for residential use, and is a registered trade name (ECOWILL®) of Osaka Gas Co., Ltd.
- "Ecojozu" is the nickname of latent heat collection-type gas-fired heat-source equipment for hot-water supply/space heating using natural gas, and is a registered trade name (Ecojozu ®) of Tokyo Gas Co., Ltd.
- "Eco-Feel" is the nickname of a latent heat collection-type high-efficiency direct pressure oil-fired water heater, and is a registered trade name (Eco-Feel®) of Japan Industrial Association of Gas and Kerosene Appliances.

2-2. Guidelines for Measures to Prevent Legionnaires' Disease Caused by Hot-Water Supply Equipment

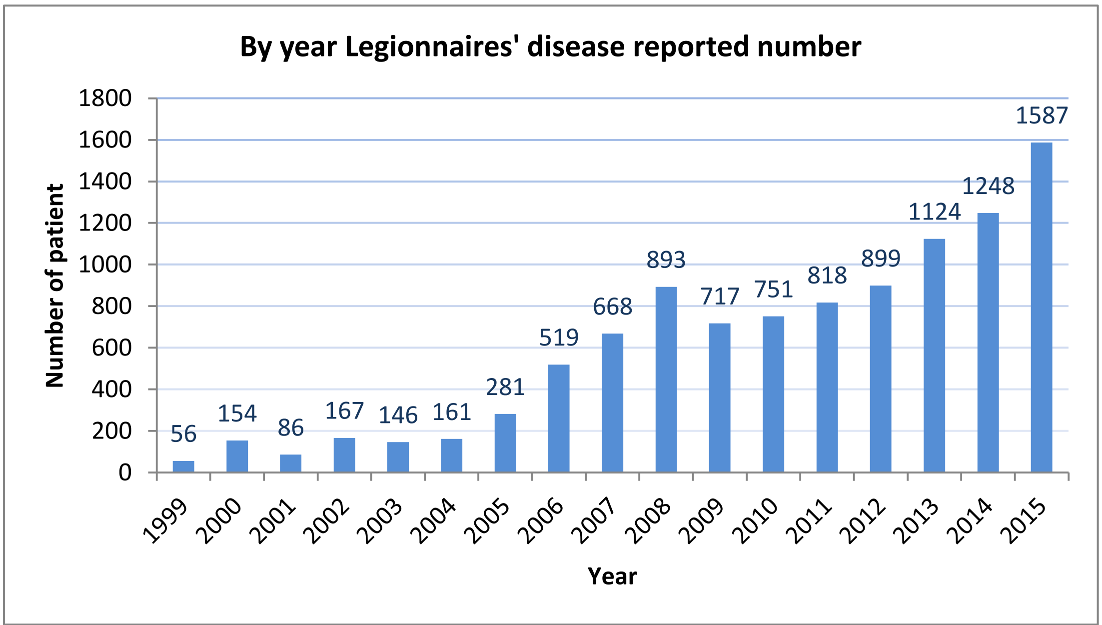
Hot water supply equipment is divided into three large categories: instantaneous type such as instantaneous water heaters installed in kitchens of standard households, hot-water reservoir type such as electric water heaters, and circulation type that boils water at a centralized location in buildings such as office buildings to supply hot-water to each floor. Typical heat pump water heaters for residential use in standard households in Japan fall under the classification of the hot-water reservoir type. In the case of the hot-water reservoir type, there were cases where Legionella had been detected due to dissipation of chlorine residual, long residence time, temperature decrease, and the like. Thus, measures against Legionella-related problems have been an issue that needs to be addressed during determination of product specification by Japanese manufacturers of heat pump water heaters.

This report presents technical guidelines for measures to prevent Legionnaires' disease in relation to hot-water reservoirs and hot-water supply equipment in Japan.

2-2-1. Explanation on Legionnaires' Disease

In Japan, Legionnaires' disease is defined as a bacterial infectious disease caused by Legionella bacteria (such as Legionella pneumophila) and has been designated as a class 4 infectious disease by the "Act on Prevention of Infectious Diseases and Medical Care for Patients of Infectious Diseases" enforced on April 1, 1999 (Infectious Disease Law, Act No. 114 of October 2, 1998). There are two types of this disease: fulminant pneumonia and transient Pontiac fever, and complete reports on both of them are mandated by the Infectious Disease Law, which means the doctor who diagnosed the disease must report to the nearest public health department.

Originally, Legionella bacteria are bacteria that normally exist anywhere in the soil or environment. However, the increase of indoor and outdoor artificial environments for comfortable living and energy saving that generates aerosols (such as amenity water facilities like fountains, cooling towers on the roof of buildings, Jacuzzi baths, and humidifiers) as well as bathtubs that use the circulation of hot-water is considered to have increased the chances of infection. According to Infection Disease Surveillance started in April 1999 pursuant to the Infection Disease Law, the number of outbreaks of Legionnaires' disease in Japan exceeded 1,000 cases in 2013 and is still on the increase (see Figure 2-2-1).



* Prepared based on Data from Infectious Disease Weekly Report (IDWR) published by National Institute of Infectious Diseases (NIID)

Figure 2-2-1: Number of Reported Cases of Legionnaires' Disease for each Fiscal Year

2-2-2. Preventive Measures against Legionnaires' Disease caused by Hot-Water Supply Equipment

Legionella bacteria breeds in large volumes within the cells of microorganisms living in biological slime attached to water-use facilities such as bathing facilities, cooling towers for air-conditioning equipment, and hot-water supply equipment. It is known that Legionnaires' disease is caught by inhalation of aerosol generated by such facilities. Therefore, infections caused by Legionella bacteria from such facilities can be prevented by hygienic measures undertaken in those facilities.

In Japan, the Ministry of Health, Labour and Welfare announced "Technical Guidelines Concerning Necessary Measures to Prevent Legionnaires' Disease" (July 25, 2003 Ministerial Notification No. 264 of the Ministry of Health, Labour and Welfare) to show the hygienic measures to be taken in the facilities that become an infection source of Legionnaires' disease, and is making efforts to prevent this disease.

These guidelines mention the following "Hygienic Measures for Hot-Water Supply Facilities":

"Hygienic Measures for Hot-Water Supply Facilities"

1. Basic Concept for Hygienic Measures for Hot-Water Supply Facilities

   With regard to Legionnaires' disease originated from hot-water facilities, cases of hospital-acquired infection of which the origin was supposed to be hot-water supply equipment were reported in Japan, and there were some cases of group infection in foreign countries. Therefore, such facilities need to be paid due attention.

   In the case of hot-water supply equipment, the control of the hot-water temperature is most important for prevention of bacterial contamination.

   Also, stagnation of hot-water in a hot-water reservoir or hot-water supply piping helps microorganisms including Legionella bacteria to breed. Therefore, it is important to take measures to prevent stagnation of hot-water within the equipment especially for the circulation-type centralized hot-water supply facility.

2. Facility-Related Measures

   For installation of hot-water reservoir-type hot-water supply equipment and circulation-type centralized hot-water supply equipment, it is necessary to install a heating device to keep the water temperature at 60°C or higher inside the hot-water reservoir or 55°C or higher at the faucet at the end of hot-water piping. It is also necessary to provide a drain valve in the hot-water reservoir and others to drain stagnated water, and for circulation-type centralized hot-water supply equipment, it is additionally necessary to provide a flow valve to make the hot-water circulation constant throughout the equipment.

3. Measures to Be Taken during Maintenance

   The hot-water reservoir must be cleaned at least once a year, in addition to regular drainage of water stagnating in the hot-water reservoir. Proper adjustment of the circulation pump and flow valve is also necessary to secure a constant and even circulation of hot water throughout the equipment in the case of the circulation-type centralized hot-water supply equipment.

2-2-3. Temperature Conditions Required for Hot-Water Reservoir and Hot-Water Supply Equipment

The Ministry of Health, Labour and Welfare specifies the hot-water supply temperature for hot-water supply equipment of the hot-water reservoir type and the circulation-type centralized hot-water supply equipment in the “Maintenance Manual for Buildings” (January 25, 2008, Notification No. 125001, Environmental Health Division, Health Service Bureau) as follows. These specifications have been considered as one of the standards for the design of the hot-water reservoir and hot-water supply equipment.

(1) Concept for Temperature Control

As preventive measures against Legionella contamination, it is important to discharge initial flowing water and to keep the water temperature at 55°C or higher at hot-water supply taps and others of all sections of hot-water supply equipment after the water temperature has become constant. Therefore, it is necessary to arrange the preset temperature in the hot-water reservoir and others to be adequately high for such temperature at all taps and others. In the case of installation of hot-water reservoir-type hot-water supply equipment and circulation-type centralized hot-water supply equipment, the water temperature in the hot-water reservoir and at taps at the end of piping shall be maintained at 60°C or higher and 55°C or higher, respectively.

(2) Point to Consider

Attention shall be paid to heat burn in relation to the hot-water supply temperature. A higher temperature hot-water supply is more effective for prevention of Legionella contamination but, at the same time, has a higher risk of heat burn. Therefore, preventive measures for heat burn become necessary.

It is advisable not to set the hot-water supply temperature higher than necessary from an energy and resource saving point of view. On the other hand, however, it is still important to keep the hot-water supply temperature not dropping beyond 55°C.

Regarding preventive measures against other bacteria, the measures for Legionella bacteria can also be valid for other bacteria.

The safety standards for these kinds of Legionella contamination have been determined with reference to the ASHRAE evaluation test.

Literature Citation

1）ASHRAE Journal January 1955,ASHRAE, USA(1995)

3. Japanese Heat Pump Water Heater for Residential Use

3-1. Development of CO_2 Heat Pump Water Heater for Residential Use (EcoCute)

Approximately 30% of the final energy consumption by households in Japan is used for the hot-water supply, of which approximately 90% is covered by direct burning of fossil fuel (see Figure 3-1-1). Spread of efficient heat pump water heaters may contribute significantly to energy saving (see Figure 3-1-2).

In the past, it was difficult to effectively generate hot water at 65°C, which is the required outlet temperature, if chlorofluorocarbons are used as refrigerants. The Central Research Institute of Electric Power Industry invented a two-stage compression cascade heater-type hot-water supply heat pump and achieved high efficiency as basic research data. Thereafter, they continued their research into multi-purpose heat pumps for residential use and heat pump water heaters for business use, such as for hotels and others, but were not successful in commercialization due to various reasons[1)].

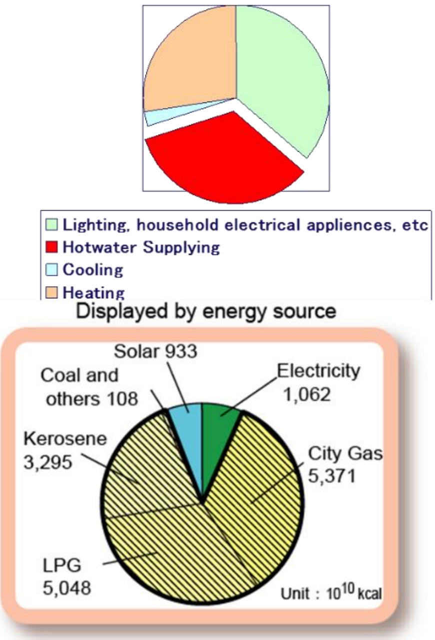


Figure 3-1-1: Breakdown of Final Energy Consumption by Household in Japan and Fuel-Type-Based Energy Consumption by Water Heaters

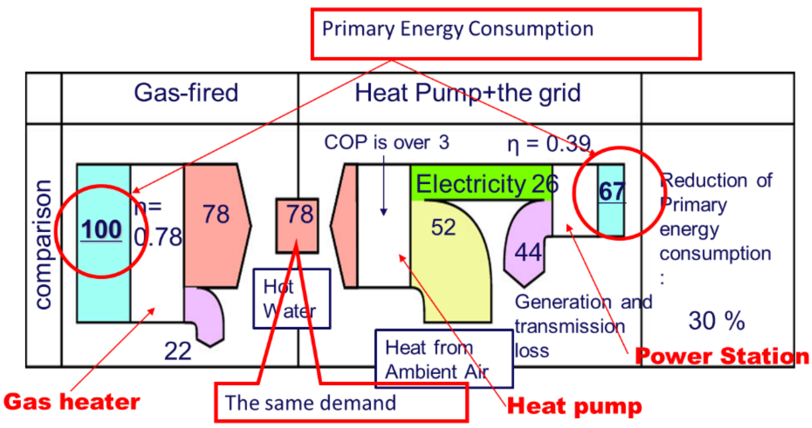


Figure 3-1-2: Preliminary Calculation of Energy Saving Effect by Hot-Water Supply Heat Pump

The Central Research Institute of Electric Power Industry started research into natural refrigerants in 1995. Among others, carbon dioxide (CO_2) is a very advantageous element because it has no toxicity, no flammability, zero ozone depletion potential, and zero global warming potential. However, it also had research challenges such as the fact that pressure is four times as high as that of chlorofluorocarbon and its low critical temperature, as low as 31°C, induces a supercritical state at high pressure side.

As a result of a potential assessment by a cycle calculation of CO_2 trans-critical cycle, it was discovered that a heat pump water heater using CO_2 has such excellent performance that it heats water from 10°C to 65°C. The Institute further proved that performance degradation is small even at a tap temperature of 85°C (see Figure 3-1-3). They also structured a supercritical CO_2 heat pump heat transfer flow loop (completed in 1996, hereinafter referred to as "Base Loop") (see Figure 3-1-4), and proved by using this equipment that a trans-critical cycle is achievable, that various control devices (inverter-type compressor, expansion valve) can be used, and that a hot-water supply temperature of 65°C is practically achievable [2,3].

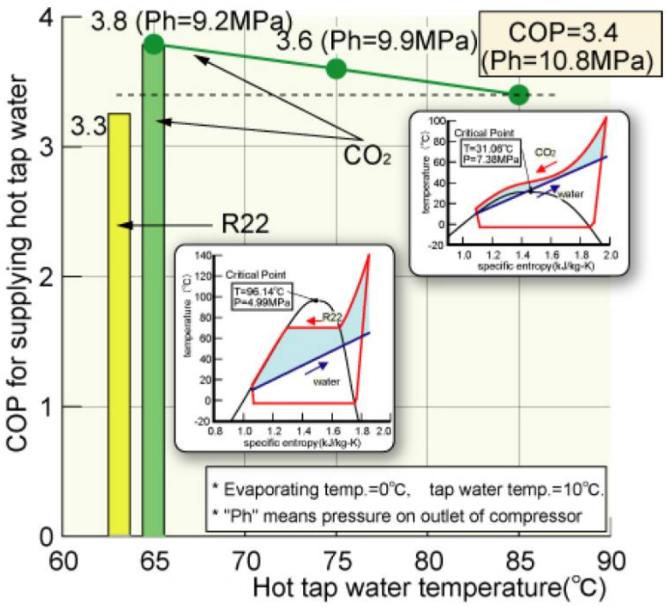


Figure 3-1-3: Result of Preliminary Calculation of CO_2 Refrigerant Hot-Water Supply Cycle

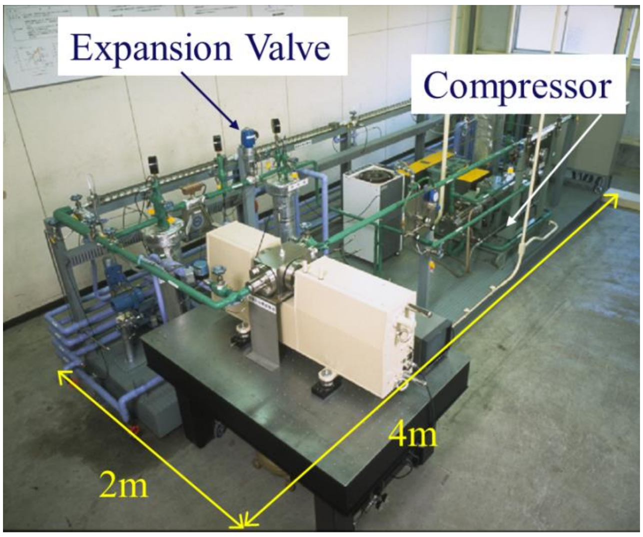


Figure 3-1-4: Supercritical CO_2 Heat Pump Heat Transfer Flow Loop (Central Research Institute of Electric Power Industry, Yokosuka Area, 1996)

In 1998, Tokyo Electric Power Company, Denso Corporation, and the Central Research Institute of Electric Power Industry started research and development of CO_2 heat pump water heaters for residential use. The goal of the development was to achieve a hot-water supply temperature of 90°C, yearly COP of 3 or higher, and down-sizing to fit Japanese households. The development tasks were to develop a high-efficiency compressor, a high-efficiency hot-water supply heat exchanger, and to structure a new control method. The Central Research Institute of Electric Power Industry conducted the evaluation of a prototype (see Figure 3-1-5) and made a proposal for higher efficiency. As a result of the joint research, the final prototype achieved COP of 3.5, improved from 2.1 with the first prototype (see Figure 3-1-6). Improvements of the compressor and hot-water heat exchanger mainly contributed to the achievement. After the field test in various localities, a natural refrigerant CO_2 heat pump water heater for residential use was commercialized in May 2001 (see Figure 3-1-7) as the world's first commercialized unit. The output of the heat pump main unit was 4.5 kW with a hot-water supply tank capacity of 300 liters which was suitable to supply hot-water to a family of four.

To put it on the market, the "hot-water supply heat pump using CO_2 refrigerant for residential use" was named "EcoCute" (tradename of Kansai Electric Power Co., Inc.) as its nickname "Cute" is a play on the English word "cute" and the Japanese word "kyuto", which stands for "hot-water supply".

Use of this equipment will save on primary energy by 30% compared to a conventional unit.

Figure 3-1-5: Experimenting during Joint Research (Central Research Institute of Electric Power Industry, Yokosuka Area in 1999)

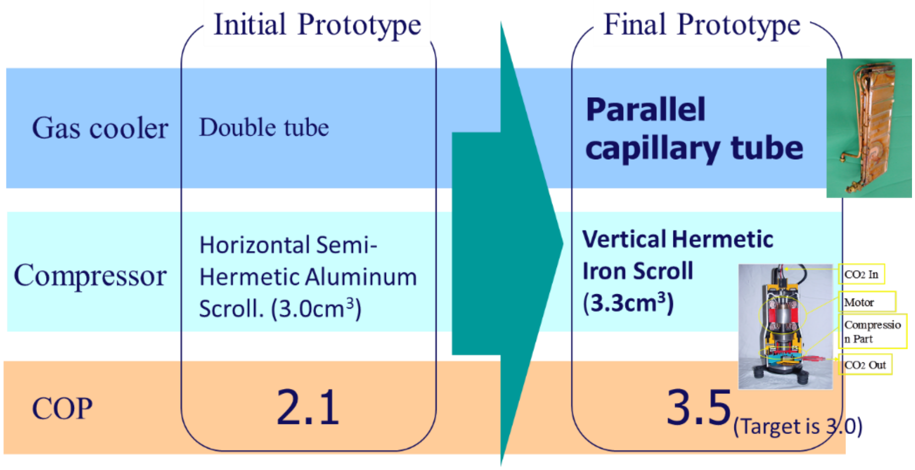


Figure 3-1-6: Efficiency Improvement from First Prototype to Final Prototype of CO_2 Refrigerant Heat Pump

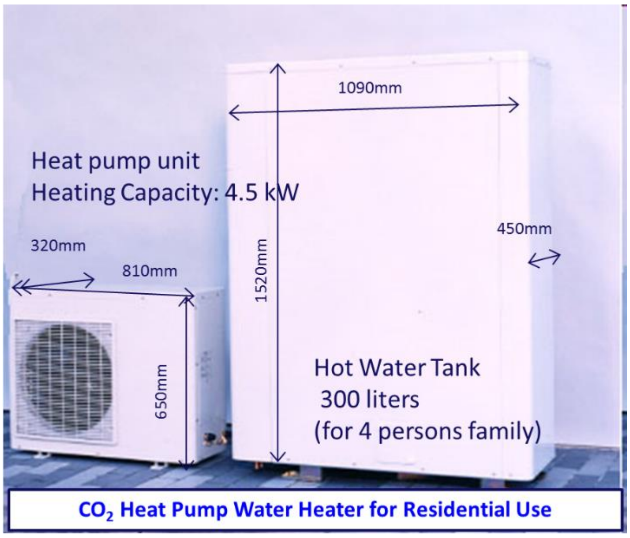


Figure 3-1-7: The World's First Commercialized CO_2 Refrigerant Heat Pump Water Heater Unit for Residential Use (May 2001)

Thereafter, other manufacturers also put their EcoCute units, developed by themselves, on the market. Although it is not well-known internationally, each manufacturer developed its own EcoCute utilizing different core technologies and has put such EcoCute units on the market. This may be a good example to show the excellence of Japanese manufacturers' technical competence in the development of air-conditioning equipment.

The Japanese government implemented a subsidy system for further popularization and NEDO also implemented projects to overcome challenges against popularization. In addition, the competitive market lowered the price level.

By such measures and policies[4)], the shipment volume of EcoCute in one single year exceeded 500,000 units in 2010 (see Figure 3-1-8). Because the volume of annual shipments of water heaters in Japan is 4,000,000 units, that number accounts for approximately 10% of all water heaters. The cumulative shipments exceeded 5,000,000 units in April 2015, and this also represents approximately 8% of the total number of all water heaters that were then working. The annual shipment volume declined and has been hovering at the 400,000-unit-level since 2012 due to the impact of the Great East Japan Earthquake.

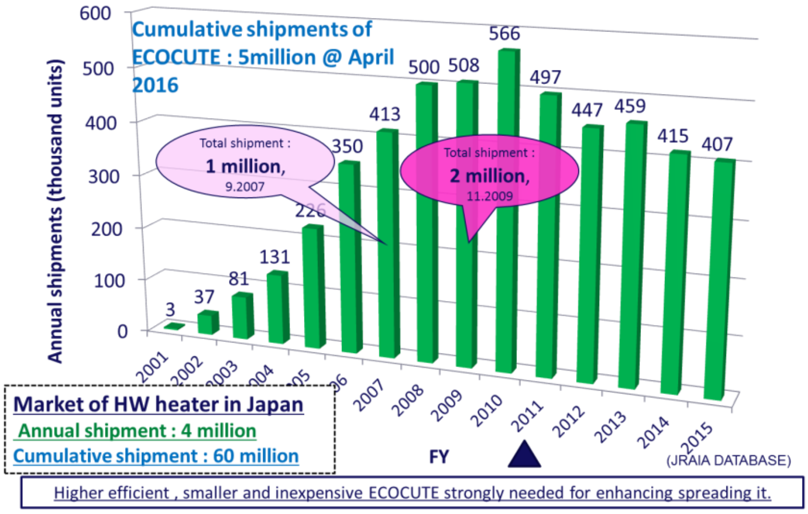


Figure 3-1-8: Transition of Shipment Volume of EcoCute (Source: Statistics of The Japan Refrigeration and Air Conditioning Industry Association)

The further spread of EcoCute is expected in view of its advantage in energy saving performance.

Not only in Japan but internationally, hot-water supply heat pumps have been drawing attention as an energy-saving measure. On the other hand, low-priced equipment using chlorofluorocarbon refrigerants still dominates the market. Certain manufacturers mention the higher cost and lower performance in hot-water supply quantity as the disadvantage of EcoCute, which keeps the market in such a situation. However, the key components have already been manufactured on a commercial basis in Japan and the cumulative shipments have exceeded 5,000,000 units. In view of the world's requirements for further measures against global warming (as well as regulation of chlorofluorocarbons), it is desirable that the utilization of CO_2 heat pump technology, which has already been commercialized, will be encouraged.

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1) Michiyuki Saikawa, 2015, *An Inside Story Behind the Advent of "Eco Cute" CO2 Heat Pump Water Heater for Residential Use*, IEA Heat Pump Centre Newsletter, Vol.33, No.4

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4) Kazutoshi Kusakari, 2006, The Spread Situation and the Future View of the CO2 Refrigerant Heat Pump Water Heater in Japan, 7th IIR Gustav Lorentzen Conference on Natural Working Fluid, Trondheim, Norway – also published in HPC Journal 2008

3-2. State of Development of EcoCute by Mitsubishi Electric Corporation

3-2-1 Introduction

Heat pump water heaters, which came onto the market as equipment for residential use in 2001, are raising their energy saving performance and added value in concert with their popularization. Features of EcoCute manufactured by Mitsubishi Electric Corporation are introduced hereunder[1)]:

3-2-2 EcoCute of Mitsubishi Electric Corporation

Figure 3-2-1 shows the exterior of a typical Mitsubishi EcoCute with a 370-liter hot-water storage tank. EcoCute is composed of a heat pump using CO_2 as a refrigerant and a hot-water storage tank. It has a heat pump capacity of either 4.5 kW or 6 kW and the capacity of the hot-water storage tank ranges from 180 to 550 liters, while the main equipment models have either 370- or 460-liter tanks. Considering the installation in a limited space, the company has also put other equipment models on the market such as a thin tank model having a 430-liter tank capacity with a depth of 430 mm (see Figure 3-2-2) and a down-sized model with a small tank capacity of 180 liters (see Figure 3-2-3).

The down-sized model can be installed in a small and narrow space, which is typical in Japan, with dimensions suitable for such a space (see Figure 3-2-4).

Fig.3-2-1: Heat pump water heater, 370L tank

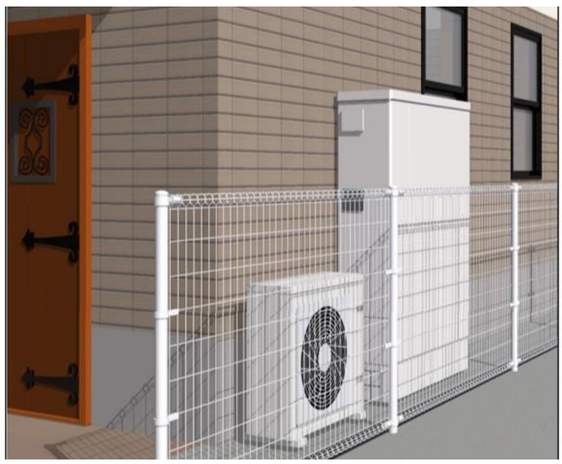

Fig.3-2-2: Heat pump water heater, 430L thin tank

Fig.3-2-3: Heat pump water heater, 180L compact tank

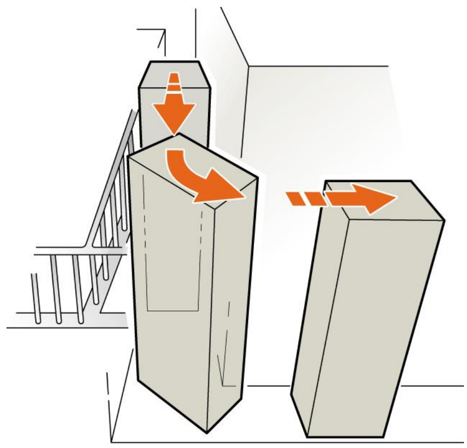

Fig.3-2-4: Installation of 180L tank for narrow space

3-2-3 Element Technologies for Equipment

Mitsubishi's unique technologies for the key parts of EcoCute are explained here under:

(1) Compressor[2)]

Mitsubishi adopts the single-stage rotary method to a compressor for a CO_2 heat pump water heater (see Figure 3-2-5). Because of the simple construction of a rotary compressor composed of parts having a mostly cylindrical or flat shape, which contributes to machining accuracy, high efficiency can be secured even for a compressor for CO_2 refrigerant that has a small displacement volume of a cylinder. By adding improvements of their own to such rotary compressor, enough reliability and performance is secured even for operation with a CO_2 refrigerant that has high operating pressure. Furthermore, employment of a high-performance motor named "Poki-Poki Motor" (see Figure 3-2-5) having a new iron core structure and high speed/high density winding, both of which are Mitsubishi's own technologies, helped them develop a compressor with high efficiency and small dimensions. Mitsubishi was honored with the Technology Award of FY2017 of the Prize of the Japan Society of Refrigerating and Air Conditioning Engineers for this technology.

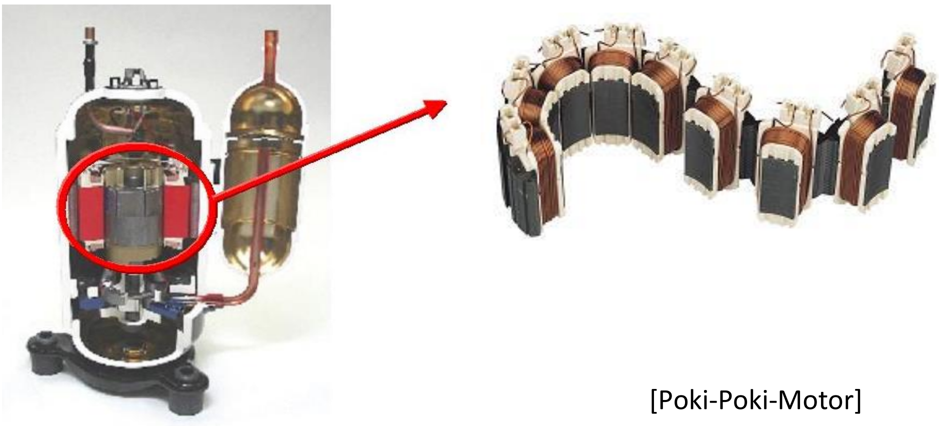

Fig. 3-2-5: CO2 rotary compressor

(2) Hot-Water Supply Heat Exchanger[3)]

A hot-water supply heat exchanger, which exchanges heat between the CO_2 refrigerant and water, uses Mitsubishi's unique spiral tube gas cooler. Figure 3-2-6 shows the exterior of a gas cooler and configuration of spiral tubes (gas cooler water tube). A gas cooler consists of a twisted tube having three lines of grooves and three refrigerant tubes. Three refrigerant tubes are wound around the twisted tube into the grooves and soldered. The reason for a spiral tube gas cooler using a twisted tube for water is to enhance heat transfer by a spiral flow, to increase the heat transmission area with refrigerant tubes, and eventually to improve heat exchanging efficiency.

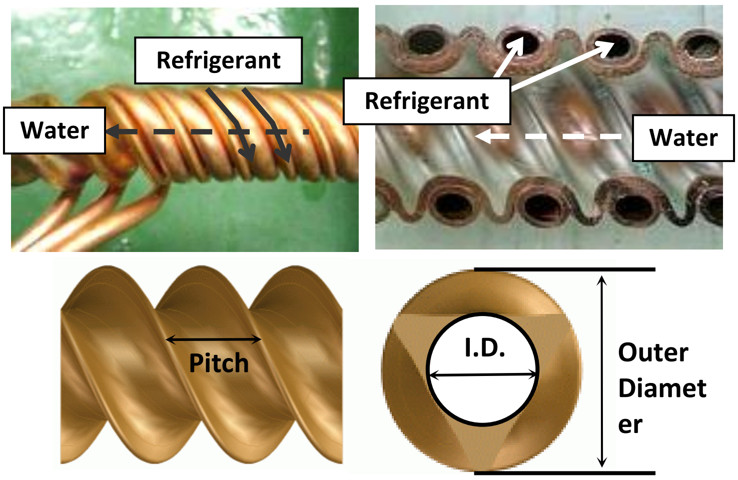

Fig.3-2-6: CO_2-water heat exchanger

(3) Vacuum Insulation Panel

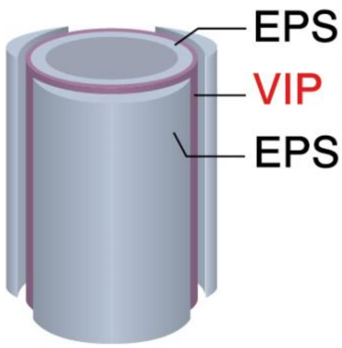

Figure 3-2-7 shows the heat insulation structure of a hot-water storage tank. Expanded polystyrene and vacuum insulation panel (VIP) are used as insulation material for the hot-water storage tank. VIP has a much higher heat insulation capacity compared to expanded polystyrene to lower the heat dissipation loss of the tank so that the energy saving performance can be improved.

*VIP: Vacuum Insulation Panel
EPS: Expanded Poly-Styrene

Fig.3-2-7: Tank insulation (VIP + EPS)

3-2-4. High-Value-Added Functions

In addition to basic functions such as hot-water storage and hot-water filling, Mitsubishi EcoCute has high-value-added functions such as automatic understanding of water heating control that automatically optimizes volume of hot-water storage, cleanliness, and comfort. The typical functions are as follows:

(1) Automatic Understanding of Water Heating Control

EcoCute boils up water in the middle of the night for consumption the following day. Therefore, an accurate forecast of hot water consumption for the following day is important. An accurate forecast will eliminate unnecessary boiling to improve energy saving performance. The automatic understanding of water heating control highlights the volume of noticeable consumption of hot water during a day (Concentrated Hot-Water Volume) against past conditions of hot-water consumption, and employs additional boiling control that matches the conditions of hot-water consumption. The outline of the control is shown in Figure 3-2-8. This enables efficient boiling operation of the water heater in accordance with hot-water consumption patterns of each household while preventing a shortage of hot water.

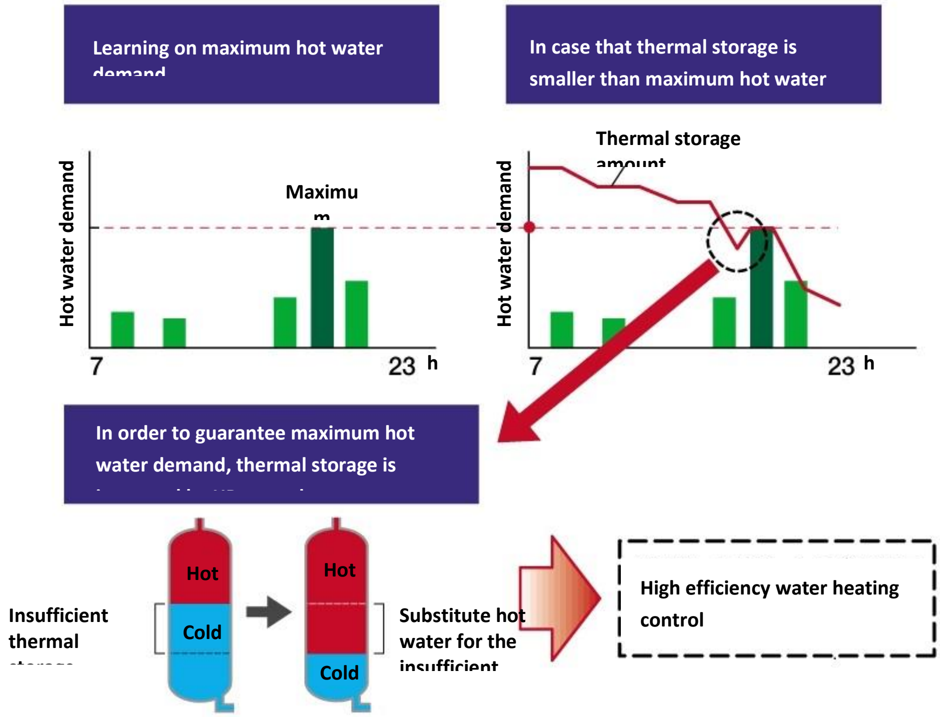

Fig.3-2-8: Automatic learning of water heating control

(2) Pipe Cleaning by Microbubbles

Many Japanese heat pump water heaters have a reheat function for heat retention and reheating of bathtub water. However, it is unavoidable that grease-related dirt from humans accumulates inside bathtub piping through long-time use. According to consumers' research, end-users have a substantial desire for a lighter maintenance burden and for bathing in clean hot water. As a method to increase added value, manufacturers employed "Microbubble Pipe Cleaning", which is a practical application of "microbubble cleaning technology" using approximately 0.1-mm-diameter microbubbles. Figures 3-2-9 and 3-2-10 respectively show photos of microbubbles and configuration of microbubble devices. The technology features an environment-friendly solvent-less cleaning method using microbubbles that enables cleaning of piping without using chemicals such as an anti-union agent for bubbles. In addition, two microbubble generation valves provided in the midstream of the piping help achieve equal cleaning performance in different installation conditions.

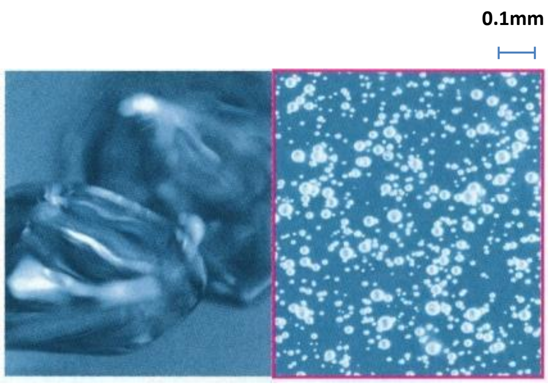

Fig.3-2-9: Normal bubble (L) / Micro bubble (R)

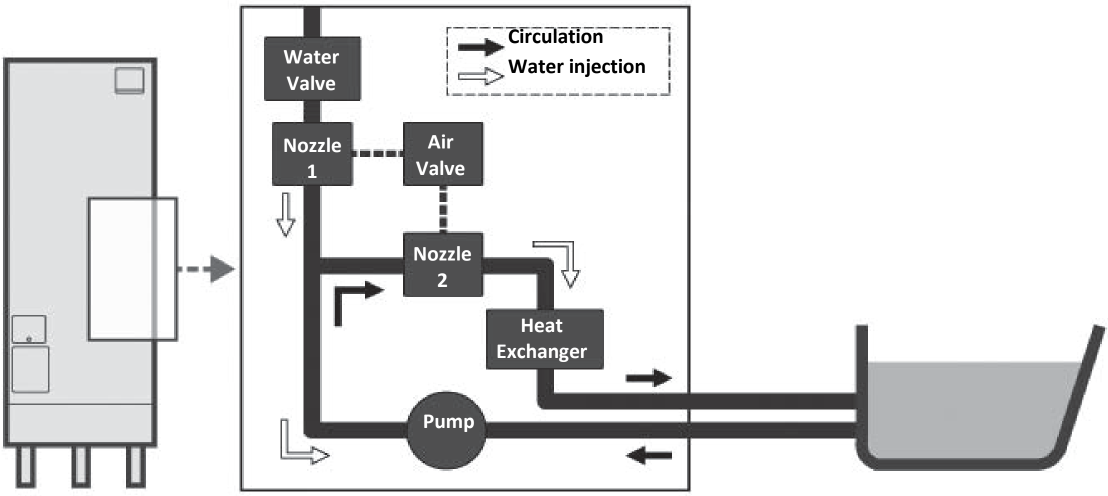

Fig. 3-2-10: Micro bubble pipe cleaning function

3-2-5. Conclusion

EcoCute manufactured by Mitsubishi Electric Corporation features functions based on their own technologies such as microbubble application technology, automatic understanding of water heating control and so on in addition to high energy saving performance of a CO_2 heat pump water heater utilizing natural refrigerant, and is enjoying high popularity among users.

In 2016, sales were started in Europe of hot-water supply/space heating equipment using a CO_2 heat pump as heat source equipment, and further worldwide popularization in the future is expected.

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3-3. State of Development of EcoCute by Daikin Industries Ltd.

Daikin Industries Ltd. has been selling EcoCute since 2002 and has made various improvements while expanding its product line-up. The transition of models, functions, and specifications of its EcoCute are outlined hereunder.

3-3-1. Line-up of Equipment Models

The company only had seven models in their product line-up in 2003; however, this had increased to 23 models by 2015 based on the hot-water storage capacity and bathtub functions. Each model has an optional specification for anti-salt damage and anti-heavy-salt damage, and the company now has 69 models including those with optional specifications. The product line-up and functions of those models are as follows:

3-3-2. Product Line-up to Meet Market Requirements

(1) Product Line-up According to Area and Number of Users

Because Japan is surrounded by the sea and has areas where the lowest outside air temperature drops lower than -10°C, specifications that withstand salt damage and cold weather become necessary. Therefore, from the beginning of sales, the company had equipment models with specifications that withstood salt damage or heavy salt damage and specifications for cold weather areas of which the allowable lowest outside air temperature for installation was -20°C, which has been lowered to -25°C to meet the requirements of the market.

The product line-up based on the number of users has also been expanded. The company only had a model with a hot-water storage capacity of 370 litres for three to five persons at the beginning. But a 460-liter capacity model for four to seven persons in 2004 and a model with a 180-liter capacity for two to four persons in 2009 were put on the market. The model with a hot-water storage capacity of 180 litres works differently from other conventional models. The conventional models fulfil most of the required heat load volume for hot-water supply by boiling and storage during the night time. The 180-liter model accommodates the hot-water supply load by additional boiling when it becomes necessary to supplement the shortage of stored hot-water boiled during the night time, and its maximum heating capacity that the heat pump unit can output has been upgraded to do this.

(2) Product Line-up to Meet Requirements of Installation Location

EcoCute consists of a heat pump unit that boils water and a hot-water storage unit that stores hot water. The largest hot-water storage unit has a capacity as large as 460 litres and requires a suitable space for installation. Therefore, Daikin offers a product line-up to match each installation location. The most popular box-shaped model available from the beginning of their sales measures approximately 63 cm in width and approximately 73 cm in depth. In 2004, they added a thin-type model to their line-up for installation in a small and narrow space. The thin type has a smaller depth and its dimensions are approximately 108 cm in width and approximately 44 cm in depth. In 2009, a down-sized model with a 180-liter tank for a smaller number of persons was introduced, and its space requirements for installation are as small as 43 cm in width and 56 cm in depth that is almost the same as the size of a newspaper. The height varies depending on the hot-water storage tank capacity.

(3) Product Lineup to Match Water Quality

EcoCute of Daikin Industries Ltd. is basically designed and manufactured for operation using city water. On the other hand, there is a requirement by the market for utilization of groundwater and well water. After basic research for many years to respond to such requirements, the company started offering an equipment model that realizes such requirements in 2011. They conduct prior inspection and assessment of water quality, and if they find the result to be acceptable according to their own criteria for water quality, they provide a manufacturer’s warranty for the equipment.

3-3-3. Function-Based Product Lineup

(1) Product Lineup According to Hot-Water Filling Function in Bathtub

EcoCute manufactured by Daikin Industries Ltd. has three types according to bathtub-related functions: full-automatic type, automatic type, and a type for hot-water supply only. The full-automatic type performs all tasks in a fully automated manner. With just one push of a button, it automatically fills the bathtub with hot water, retains the heat of the bathtub water when the temperature drops, and adds hot water to the bathtub when it runs low. The automatic type only automatically fills the bathtub with hot water. The type for hot-water supply does not have function to automatically fill the bathtub with hot water but performs only feeding of hot water. Because filling the bathtub with hot water is a part of the daily routine in Japanese households, bathtub-related functions are indispensable. Therefore, Daikin has included the full-automatic type and automatic type models in their EcoCute lineup since the start of their sales in 2003, and such models account for the majority of their sales.

The full-automatic type, which has the heat retention function of bathtub water, also has functions such as ecological heat retention with high energy saving performances and automatic cleaning of bathtub piping. The ecological heat retention function learns the patterns of temperature drops of bathtub water to decrease the reheat frequency during the time when the bathtub is not in use. In this way, it has the ability to improve the heat retention efficiency and to decrease power consumption during heat retention up to 37%. Automatic cleaning of bathtub piping cleans bathtub piping by automatic water injection when the hot water in the bathtub is drained to lessen the cleaning burden.

(2) Powerful Shower

EcoCute manufactured by Daikin Industries Ltd. has a powerful high-pressure type (pressure reducing valve is set at 300 kPa) and a high-pressure type (pressure reducing valve is set at 170 kPa). Compared to the conventional high-pressure type, the powerful high-pressure type can supply hot water up to the third floor. It also has the ability for quicker hot-water filling in the bathtub and maintains a comfortable level of hot-water supply quantity even during the simultaneous supply of hot water to both the kitchen and shower.

3-3-4. Other Functions

(1) Twin Hot-Water Supply

This function enables simultaneous setting of two different temperatures of the hot-water supply individually, one temperature for taps and shower and another for the bathtub. For example, hot water of 38°C can be supplied to the kitchen for dishwashing while the bathtub is being filled with 42°C hot water.

(2) Boil Up Control

This function controls unnecessary boiling up and any unexpected shortage of hot water by calculating the boil up temperature and boil up quantity of hot water based on the past record of hot-water consumption. Hot water is used by many different users in many different ways. Therefore, improvement needs to be continued all the time. In the case of the heat retention function of bathtub water that raises the temperature of bathtub water by heat transfer from hot water in a storage unit to bathtub water, not only the quantity but also the temperature of hot-water storage is an important factor to be considered and this function needs to be controlled taking such a fact into consideration. The setting of boil up can be done by the user through a remote controller.

(3) Operability

A remote controller has functions for verbal communication, check of the ecological state, information on hot-water supply quantity, notification of tap turn-off failure, and so on in addition to basic functions such as a change of the setting of the hot-water supply temperature and presetting bathtub water boil-up time. A verbal communication function provides a communication function between the remote controller in the kitchen and the one in the bathroom, namely, a bathing person can talk to a person outside the bathroom without going out. The ecological state check function displays, either graphically or numerically, the quantity of hot-water consumption for the day, average hot-water consumption volume for a one-month period, the length of time during which hot-water consumption continued, the length of time during which bathtub water was reheated, and the available quantity of hot water. Users can see the state of their own use of hot water with this function. Every time hot water is used, the information function of the hot-water supply quantity is added up and displays the quantity of hot water used each time. The function for notification of tap turn-off failure gives an alarm when it detects a continuous flow of a small quantity of hot water from a tap, shower or others. Even if users should forget to turn off a tap, users can notice it easily, and a sense of ease can be given to users.

(4) Operation by Tablet-Type Device (Connection with Domestic LAN)

These days, it is becoming possible to operate home appliances from tablet-type devices and others. EcoCute manufactured by Daikin Industries Ltd. can also be operated easily from a tablet anywhere in the residence by using an optional adapter for a wireless LAN connection.

(5) Use of Hot-Water in Emergency

Because EcoCute has a hot-water storage tank, hot-water stored in the tank can be utilized even when the water supply is disrupted by a disaster or other event. EcoCute manufactured by Daikin Industries Ltd. has a valve located at the lower part of the hot-water storage unit, so hot water stored in the day-tank can flow out by opening the valve for daily life use. In addition, hot water will be usable through taps or showers as long as hot water remains in the tank, even during a blackout.

(6) Installation-related Matters

EcoCute, like other water heaters, requires piping connection of water on-site. Efforts have been made to make installation work easier, such as a wider distance between pipe joints for easier connection work during installation, and introduction of automatic test operation for absolute elimination of errors in test operation after piping connection. Through introduction of an automatic test operation, the test operation after piping connection will never be completed unless the test is conducted fully in accordance with instructions given by a remote controller. This also has the advantage to reduce the time required for test operation because most of the necessary work is conducted automatically by equipment.

3-3-5. Components Affecting Performance Improvement

The performance criteria of EcoCute used to be based on the performance (COP) of a stand-alone heat pump. Currently, it has been changed to the annual efficiency called Annual Performance Factor (APF) of the total system including heat dissipation and others of the hot-water storage unit. Annual efficiency also used to be for the performance only when the load of the hot-water supply exists, but it has now been changed to the performance based on not only the load of the hot-water supply but also the heat retention load.

Daikin Industries Ltd. has been making various efforts to realize performance improvement. For instance, the heat insulation material to cover the tank inside the hot-water storage unit has been changed from glass-wool to expanded polystyrene and vacuum insulation panels, which have higher heat insulation capacity. Measures for performance improvement have been taken also for the water circuit of the hot-water storage unit. When hot-water is supplied, hot-water taken from the upper part of storage tank is usually mixed with city water to lower the hot-water temperature to the preset temperature. However, the company put a hot-water outlet in the middle part of the tank to utilize lukewarm water therefrom. In this way, they efficiently utilize lukewarm water from the middle part of the tank. Such lukewarm water as it is can neither be used as hot-water nor be heated up by a heat pump because such heat up causes the heat pump to be inefficient. This also results in another advantage: keeping the volume of use of hot-water in the upper part of the tank low. In addition to such advantages, it has a design that takes out overflowing hot-water not from the upper part but from the lower part of the tank. This contributes to a decrease of heat loss by preventing the overflow of hot-water from the upper part of the tank caused by thermal expansion due to higher temperature during boiling up of hot-water in the tank by the heat pump. As for the heat pump unit, Daikin has been successful in improving performance by using their unique swing-type compressor which integrates the piston and blade into one piece. Improvement of the internal shape of the piping of the refrigerant-and-water heat exchanger and improvement of the fin shape of the refrigerant-and-air heat exchanger have also been made to achieve an improvement in the performance.

Literature Citation

The Development of Heat Pump Water Heaters Using CO2 Refrigerant ○ Shigeharu TAIRA* * DAIKIN Industries, Ltd., 1000-2 Aza-Ohtani, Okamoto-cho, Kusatsu, Shiga 525-8526

3-4. State of Development of EcoCute by Corona Corporation

The high-end model of EcoCute manufactured by Corona Corporation (see Figure 3-4-1) achieved 4.0 for annual efficiency for hot-water supply and heat retention (JIS), which is a benchmark of energy saving performance. This value of 4.0 for annual efficiency for hot-water supply and heat retention (JIS) is the best value in the industry for a heat pump water heater for residential use, which means No. 1 for energy saving performance (as of November 2016).

Corona Corporation put EcoCute on the market in April 2001 as the world's first natural refrigerant CO_2 heat pump water heater. With a steady increase of sales, the cumulative number of shipments of the total industry exceeded 5,000,000 units in March 2016, which was 15 years from the start of sales. EcoCute of Corona Corporation was developed jointly by Corona Corporation and Denso Corporation. Corona undertook development of the hot-water storage unit and operational control and Denso undertook development of the heat pump unit. Their technologies were integrated, and such integration has contributed to the improvement of equipment efficiency.

When JIS was established and the performance indication system therefrom started in 2011, the annual efficiency for hot-water and heat retention (JIA) of their standard equipment model was 3.2. During the five years thereafter, they improved the efficiency by 0.8 point (see Figure 3-4-2). They also improved annual consumption of electric power by approximately 20%, which was a significant improvement in energy saving performance.

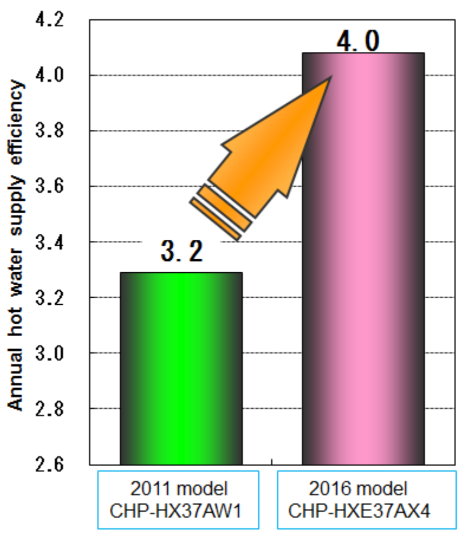


Figure 3-4-1: EcoCute Manufactured by Corona

Figure 3-4-2: Annual Efficiency for Hot-Water Supply and Heat Retention

3-4-1. Three Developments in Energy Saving Technology for Heating, Storage, and Use of Hot-Water

(1) Technology to Heat Up Water Efficiently

There are three main categories of the characteristics in the technology for energy saving for heat pump units.

The first one is a low-pressure dome-type scroll compressor, which achieved both high efficiency and reliability by use of a thrust bearing of a low pressure drop.

The second one is "EJECTS II*1" cycle, which is a highly efficient refrigerating cycle having improved frost resistance achieved by employing an ejector and by differentiating the evaporating temperature between front and rear rows of the air heat exchanger

The third one is the water refrigerant heat exchanger, which is a heat exchanger with high efficiency and a thin and compact size having a combination of an ultrafine offset inner fin at the water-side and high-density small-diameter coil at the refrigerant-side.

The unique "EJECS II" cycle and improvement of control by "Faster Start-up of Boiling Operation" are illustrated hereunder:

1) "EJECT II" Cycle

The ejector mounted on the refrigerant circuit reduces energy loss by recovering the refrigerant's own expansion energy that used to be wasted.

The "EJECS II" cycle that has a unique circuit configuration (see Figure 3-4-3) raises the heat collection efficiency from the air by differentiating the evaporating temperature between the front row and rear row of the air heat exchanger. In the case of a conventional system, frost formation concentrates at the rear row (windward side) of the air heat exchanger where the temperature difference from ambient air is larger under frosting conditions, and the frost concentration blocks the air flow. In the case of "EJECT II", in order to avoid such a phenomenon, a variable ejector and variable expansion valve are combined to make the evaporation temperature at the rear row (windward side) higher and at the front row (leeward side) lower to equalize the temperature difference from ambient air between the rows. With this arrangement, the frosting of fins can be equalized and the frosting time becomes longer to improve COP.

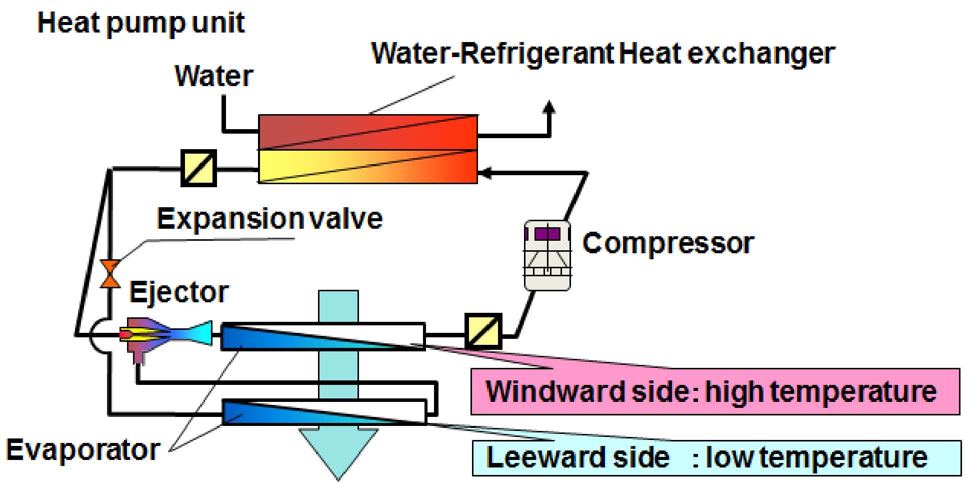


Figure 3-4-3: "EJECT II" Cycle

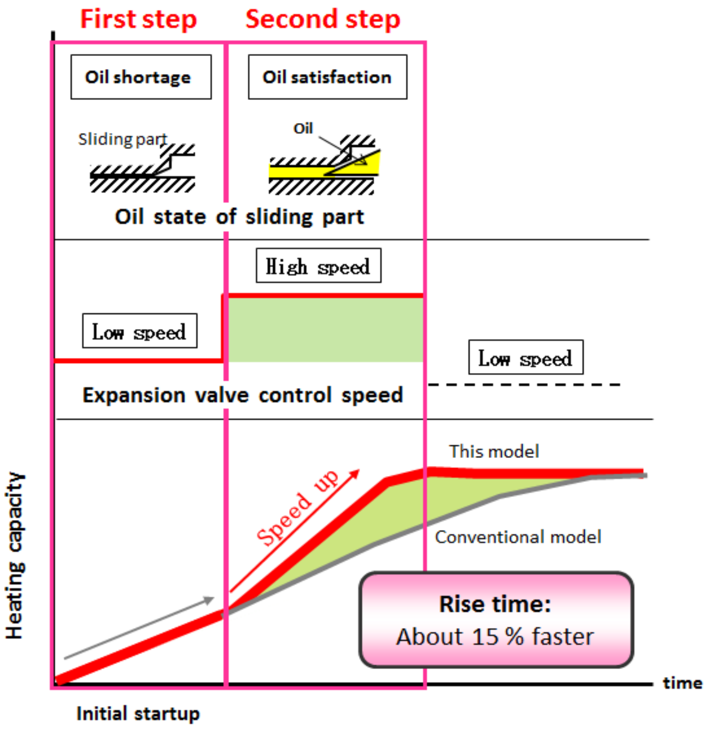


Figure 3-4-4: 2-Step Pressure-Rise Control

2) Faster Start-up of Boiling Operation

A low-pressure dome-type scroll compressor used in heat pump units has the advantage of quick start-up of boiling operation thanks to smaller heat loss in the high temperature and high pressure section. For further enhancement of such an advantage, a "2-step Pressure-Rise Control (see Figure 3-4-4)" was newly developed to change the control speed of the expansion valve in two steps during the interval from start-up of boiling operation to the moment when heating capacity reaches a predetermined point. In order to prioritize oil lubrication of the sliding part of the compressor, this control operates in two steps: "the first step (reliability prioritized)" where the control speed of the expansion valve is suppressed right after the start-up and "the second step (speed-prioritized)" where control speed of the expansion valve is increased to prioritize the speed of pressure rise after oil lubrication becomes sufficient. This control system achieved a quicker start-up while satisfying both reliability and speed, and the start-up time in the winter season was reduced by approximately 15% compared with conventional models. This contributes to the higher efficiency of boiling up thanks to the considerable effect of a quicker start-up, because defrosting operation is performed once or twice every one hour in seasons with frost.

(2) Technology for Effective Storage of Hot Water

1) Improvement of Heat Retention Performance of Tank

Because of limitations in the outer dimensions of the housing, the thickness of expanded resin for heat insulation of the tank body could not be increased. Therefore, the company employed a "Vacuum Heat Insulation Panel" that had approximately 15 times higher heat insulation performance than expanded resin. Equipment with higher performance has "Double Heat Insulation Construction" (see Figure 3-4-5), which is composed of a vacuum insulation panel attached directly all around the tank and expanded resin insulation material wrapped over the vacuum insulation panel so that the high performance of such heat insulation material can be maximized. This method secured the contact between the tank and vacuum insulation panel and contributed to the reduction of heat loss caused by heat dispersion from the clearance. Because the upper part of the tank had enough space between the expanded resin insulation material and the exterior, the thickness of expanded resin insulation material that had already been employed was doubled. As a result of all the above, the heat retention performance has been improved by approximately 20%.

In addition, thanks to the improved heat retention performance, it became possible to lower the boiling up temperature of the heat pump. In the case of the models with higher performance, the operating efficiency of the heat pump unit has been improved by approximately 5.0% by lowering the boiling up temperature during the winter season. In winter, the heat dissipation loss of the tank due to heat dispersion becomes significant. Control of the boiling up temperature is performed responsively to the use condition of users. Therefore, this can effectively supply hot water at temperatures suitable for each residence.

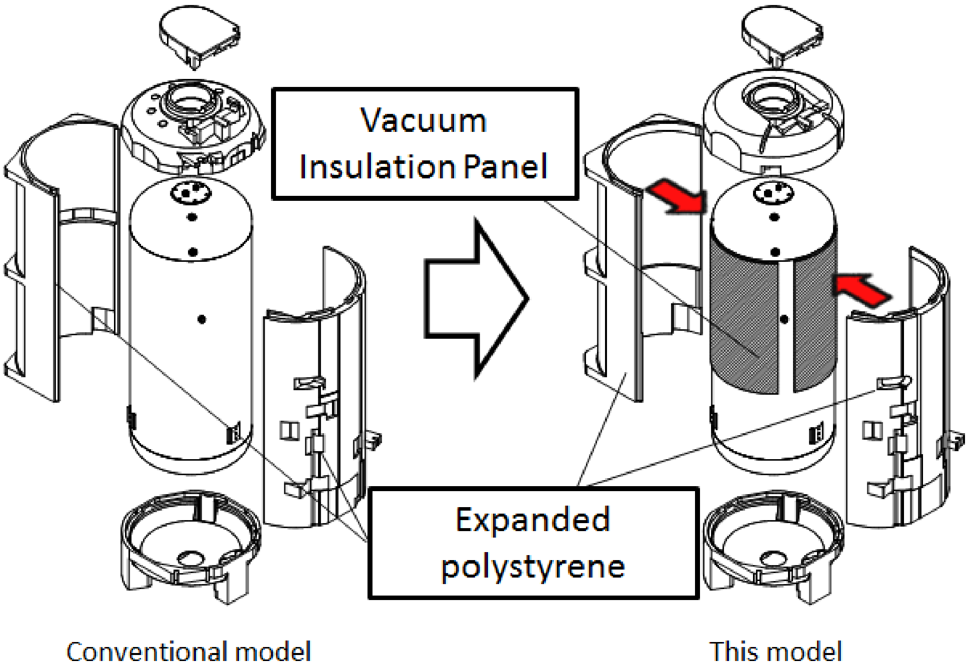


Figure 3-4-5: Construction of Tank Heat Retention "Double Heat Insulation Construction"

2) Improvement of Boiling Up Operation Control

The heat exchanger for bathtub water reheating is in the hot-water storage tank. Therefore, it features high efficiency with no heat dispersion into the air during reheating. In the case of this type of heat exchanging system, it was indispensable to keep a minimum required quantity of hot water in the tank (minimum hot-water storage quantity) to secure reheating performance and to avoid a hot water shortage. In the past, the system kept more than enough hot water because the "minimum hot-water storage quantity" was set at a certain fixed level. The higher performance models are now equipped with a control system with a precise learning function that responds to using hot water conditions and is able to reduce the unnecessary storage quantity by precise adjustment and optimization according to the suitable quantity of each residence.

3) Reduction of Standby Electricity

Standby power has been reduced by approximately 80% from 5 W to 1 W by use of a liquid crystal with high brightness and a high-precision LED for the remote control, improvement of the power supply circuit of the circuit board of the remote control and the hot-water storage unit, and the standby power cut-off function to disconnect the power supply to the heat pump unit.

(3) Technology for Effective Use of Hot Water

1) Improvement of Circuit for Energy Saving Hot-Water Supply

The heat exchanger of the coil-shaped tube for reheating bathtub water that is built-in to a hot-water storage unit performs reheating and heat retention through indirect heating. However, this reheating also generates lukewarm water (medium temperature warm water). This medium temperature warm water causes a decline of heat pump efficiency when it is reheated by a heat pump unit. An energy saving circuit for the hot-water supply is employed so that it can take out such medium temperature warm water as the heating capacity and can use up all such heat. In this way, at the time of boiling up, hot water can be efficiently produced by feeding low temperature water to the heat pump.

Also, they have consolidated each part in a hot-water storage unit, have improved piping by making it as short as possible, and have reduced the quantity of hot-water that remains in the piping when the hot-water supply tap is closed. These measures have reduced wastewater (low temperature hot-water before the temperature reaches the preset supply temperature) produced at the time of supplying hot water.

3-4-2. Addition of Functions to Meet Customers' Needs

After full liberalization of electricity retail sales in April 2016, various new electricity rate structures have been introduced.

In connection with some of the newly added electricity rate structures, such as "a menu providing a time zone for a higher unit rate during daytime" and a "contract based on actual quantity" that sets a basic charge based on the peak power (peak of electricity consumption), the following "three functions to lower peak power" have been added to flexibly take advantage of the features of such new structures.

Peak Cut Function

> Function that contributes to energy saving by stopping heat pump operation for boiling up during preset time zone

Time Shift Function for Boiling Up

> The function to lower the power consumption peak by advancing the start of night operation for boiling up so that boiling up can be completed before the morning time zone during which power consumption is large.

Power Saving Function

> The function to lower the power consumption peak by restricting heating performance so that power consumption can be reduced while maintaining the high efficiency of the heat pump unit for boiling up operation.

3-4-3. Conclusion

Corona Corporation put the "EcoCute" natural refrigerant CO_2 heat pump water heater for residential use on the market in 2001, ahead of anyone else in the world. Since then, they have expanded the market by developing energy saving technologies and accumulation of experience in promotion activities for 15 years. The company has positioned water heaters as products with which they can expect the generation of a significant impact to reduce energy consumption in households and to prevent global warming, and actively promote research, development, and sales including educational activities.

*1 "EJECS" is a registered trade name of Denso Corporation.

4. Other Heat Pump Water Heaters

4-1. Development of Water-Source Heat-Based Heat Pump Water Heater by Mayekawa Mfg. Co., Ltd

4-1-1. Introduction

Heat pumps are garnering attention as equipment capable of supplying heat while realizing energy saving, reduction of CO_2 emissions, and reduction of running costs by effective utilization of thermal energy such as heat collection from air or heated wastewater and simultaneous utilization of cold/hot heat.

EcoCute as a heat pump for a water heater using CO_2 natural refrigerant is becoming popular as a water heater for households, businesses, and for industrial purposes because of its potential for reducing CO_2 emissions and running costs compared with gas- or oil-fired boilers.

Since 2008, Mayekawa Mfg. Co., Ltd. has been marketing "Water-source heat-based EcoCute for Industrial and Business Use" capable of supplying hot water with high efficiency and high temperature by using not "air" but "water" as its heat source.

Water-source heat-based EcoCute operates quite effectively by collecting heat from heated wastewater and cooling water discharged without effective utilization, or can perform highly effective operation such as simultaneous utilization of cold/hot heat in which water as the heat source is utilized for refrigeration purposes.

[Water-Source Heat EcoCute]

[EcoCute for an Air/Water Dual Heat Source]

Figure 4-1-1: Exterior View of Water-Sourced Heat EcoCute and EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.

For operation of the water-source heat-based EcoCute, it had the problem that it was necessary to secure a heat source such as discharged water and cooling water and to secure usage of refrigeration. For example, while the demand for a hot-water supply exists throughout the year, the demand for refrigerated air-conditioning is limited only to the hot season. The problem was that operation of the hot-water supply is not possible under the conditions in winter where the user does not require the equipment to operate for refrigerated air-conditioning.

They developed and put EcoCute for an air/water dual heat source on the market in 2013. It can accommodate both requirements for continuous hot-water supply throughout the year and simultaneous supply of cold/hot heat to solve the problem of heat source securement. Figure 4-1-1 shows water-source heat-based EcoCute and EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd.

Features and installation examples of EcoCute for an air/water dual heat source as a heat pump for the hot-water supply that effectively utilizes the heat to reduce energy consumption and running costs are illustrated hereunder.

4-1-2. Outline of EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.

This equipment has the following features:

- It uses the natural refrigerant CO2 that is inflammable and safe with very low toxicity.
- CO2 refrigerant has less impact on global warming compared to chlorofluorocarbon refrigerant and is not subject to the Act on Rational Use and Proper Management of Fluorocarbons.
- It is the only EcoCute in Japan that employs a switchover system for the heat source.
- It is a large-scale EcoCute having a hot-water supply capacity in the range of 100 kW, which is the largest in Japan.
- It can supply chilled water simultaneously with a hot-water supply when operation by a water-source heat is selected, which means it has the ability for highly efficient operation.
- It has the ability for highly efficient supply of hot-water by selecting operation by air-source heat even in winter, at night, and so on during which there is neither demand for chilled water nor availability of waste heat or cooling water.
- The temperature range of the cold/hot heat supply is as wide as -5°C to 32°C when it uses a water-source heat. It has the ability to supply cold heat for ice thermal storage and refrigerated air-conditioning and the ability to respond to heat recovery from cooling water and heated wastewater.
- It employs a semi-hermetic reciprocating compressor dedicated for CO2 refrigerant. The compressor is Mayekawa’s in-house product.
- When the outlet temperature is 90°C, the upper limit of feed water temperature is 65°C. This feature enables circulated heating operation.
- It has no burning section because boiling is performed using heat pump technology. This contributes to safety and security.
- It achieves COP t = 6.6 with feed water temperature of 17°C, outlet hot-water temperature of 65°C, and outlet chilled water temperature of 7°C.

COP t = (Hot-water supply capacity + Refrigeration capacity) / Power consumption

Table 4-1-1 shows specifications of equipment. Also, Figure 4-1-2 shows comparison between air-source heat method and water-source heat method in EcoCute for an air/water dual heat source.

Table 4-1-1: Specifications of Water-Source Heat-Based EcoCute and EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.

Name		Water heat source EcoCute			Air and water heat source EcoCute	
Model		HE-HWW-2HTCR			HE-HWAW-2HTCR	
Heat source		Water			Water	Air
Cooling conditions		Brine	Cold water	Heat recovery	Cold water	—
Cooling temp (in → out)		-5℃→-9℃	12℃→7℃	37℃→32℃	12℃→7℃	—
Ambient temp DB/WB		—	—	—	—	16℃/12℃
Performance (Water supply 17℃ → Hot water supply 65℃)	Heating capacity〔kW〕	53.2	85.8	116.8	81.8	79.2
	Cooling capacity〔kW〕	37.9	64.0	94.8	60.9	—
	Power consumption〔kW〕	17.9	21.4	22.1	21.7	19.1
	Heating COPh	3.0	4.0	5.3	3.8	4.2
	Total COP※1	5.1	7.0	9.6	6.6	—
Outer dimensions〔mm〕		W1,100×L1,200×H1,893			W2,100×L1,100×H2,105	
Weight〔kg〕		1,007			1,530	
Compressor	Motor〔kW〕	25				
Temperature range	Inlet water〔℃〕/Heating	5～40℃(Outlet temp 65℃) , 5～65℃(Outlet temp 90℃)				
	Hot water outlet〔℃〕	65, 90				
	Inlet water〔℃〕/cooling	-5～40			-2～37	—
	Ambient temp〔℃〕	-10～43				

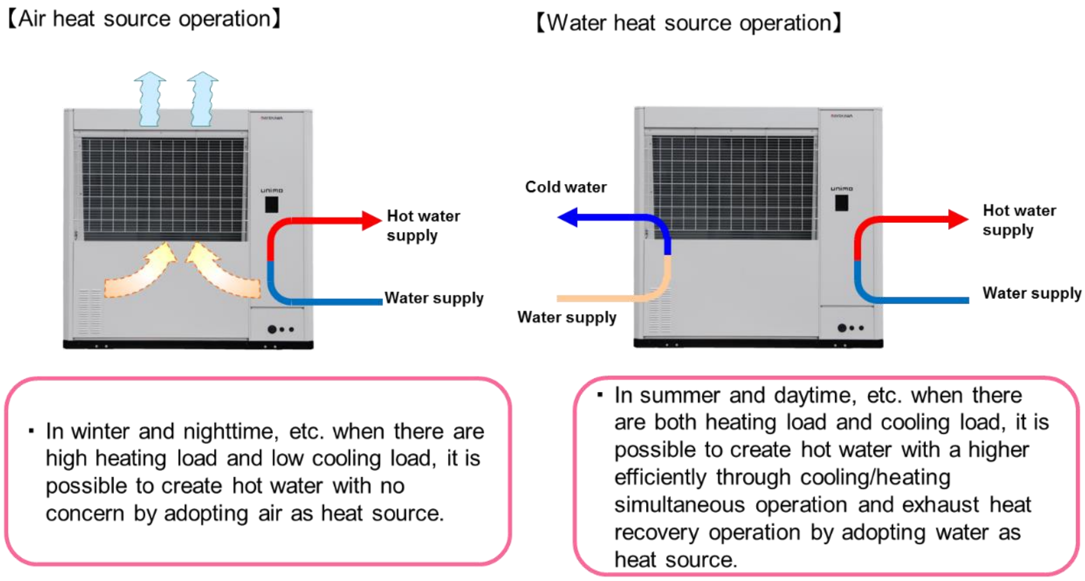


Figure 4-1-2: Comparison between Air-Source Heat-Based and Water-Source Heat-Based Operation

4-1-3. Installation Examples

(1) Outline of Cold/Hot heat Supply System

The below-mentioned case describes the installation example of EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd. at a newly constructed factory of a vendor of goods for convenience stores.

A factory that produces goods for convenience stores requires 24/7 operation. Because of a huge amount of energy required for long operating hours, energy saving is one of the key issues.

Food such as lunch-boxes and others prepared in the factory are refrigerated by quick freezing with a vacuum chiller to prevent growth of bacteria. Chilled water is required to operate refrigerators. On the other hand, a huge volume of hot water is also required for washing cooking devices as well as for cooking processes. In the company's previous factory, they used an air-cooled chiller for chilled-water supply and a steam boiler for the hot-water supply.

From the early stage of the new factory design, the company studied the introduction of an air-source heat-based heat pump as a measure for energy saving and reduction of running costs through the use of EcoCute, which is capable of storing hot water through utilization of low-cost midnight power.

In addition, they were also considering simultaneous utilization of cold/hot heat where refrigeration of goods is performed by a vacuum chiller and hot-water supply utilizes heat recovered from heated chilled water.

However, the simultaneous utilization of cold/hot heat also had a problem. Namely, a vacuum chiller that operates during the daytime can supply heat-source water, which is chilled water heated and exhausted by the vacuum chiller, during daytime only; however, the company could not secure the heat source water supply during night-time when the vacuum chiller stops and the hot-water supply operation cannot be continued.

EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd. was adopted to solve the problem of a time-related load unbalance between hot heat and cold heat. Mayekawa's EcoCute can automatically switch the operation modes by an operation command given from outside between water-source heat-based operation that supplies cold/hot heat simultaneously and air-source heat-based operation that utilizes the heat of ambient air to allow a hot-water supply.

By prioritizing water-source heat-based operation for simultaneous cold/hot heat, higher efficiency of the hot-water supply will be achieved and the designed reduction of the running costs of the cold/hot heat supply is expected to be 55% in total.

In Yamagata, where the ambient temperature in winter will be as low as -10°C, simultaneous utilization of cold/hot heat has considerable advantages because the performance drop in low ambient temperature is unavoidable if it operates only with an air-source heat.

In the course of designing the cold/hot heat supply system, BCP was also seriously studied.

Two heat pump units can cover the hot-water supply load. However, a hybrid system with a steam boiler was built for the hot-water supply and an air-cooled chiller was installed for the cold heat supply as backup.

Such arrangements have enabled heating during peak periods and have provided measures for BCP, and are also contributing to lighter maintenance work. Thus, this has become an optimum system for the new factory for which 24/7 operation is mandatory.

Table 4-1-2 shows specifications of equipment in the facility, Table 4-1-3 shows design load of equipment, Figure 4-1-3 shows system flow of cold/hot heat supply equipment, and Figure 4-1-4 shows exterior view of cold/hot heat supply equipment.

Table 4-1-2: Specifications of Equipment in the Facility

Name of Equipment	Specification (Yearly Average Value)
EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.[*1, 2, 3]	Numbers of Unit: 1 Refrigerant: CO_2 Heating Capacity: (Air) 68.2 kW (Water) 74.0 kW Chilling Capacity: (Water) 52.5kW Power Consumption: (Air) 28.4 kW (Water) 24.6 kW Outer Dimension (mm): W2,100 × L1,100 × H2,105
Air-Source Heat-Based EcoCute Manufactured by Mayekawa Mfg. Co., Ltd.[*1, 2]	Number of Units: 1 Refrigerant: CO_2 Heating Capacity: 71.8 kW Power Consumption: 24.6 kW Outer Dimension (mm): W1,900 × L1,100 × H2,082
Air-Cooled Chiller[*3]	Number of Units: 2 Refrigerant: R410A Heating Capacity: 45 kW/Unit Power Consumption: 15 kW/Unit
Stainless Steel Panel-Type Hot-Water Storage Tank	Numbers of Unit: 1, Double Reservoir Type Effective Capacity: 19 m^3

*1 Source: Ambient temperature of Japan Meteorological Agency in Yamagata 2012, daily average of each month

*2 Equipment incoming water temperature 17°C, water outlet temperature 90°C

*3 Cold water inlet temperature 12°C, cold water outlet temperature 7°C

The outline of cold/hot heat supply system installed at this factory is summarized below:

- The operation ratio of the air-cooled chiller was reduced by EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd. that produces hot-water while it also chills the cooling water of the vacuum chiller for goods.
- 96% of the heat load was covered by two EcoCute units.
- The boiler is used for generation of steam for peak periods, tank cleaning, and reheating of heat dissipation loss, and is a hybrid system of electricity and gas fuel.
- The hot-water storage tank has a double reservoir construction made of stainless steel panels to restrict the high temperature hot-water mixing with low temperature hot-water cooled down by circulation heating.
- By using low cost midnight power, EcoCute stores hot-water and accumulates heat in the hot-water storage tank for cleaning.

Table 4-1-3: Design Load of Equipment

(Hot-Water Equipment)	
◆Usage of Hot-Water:	For Production (25°C)
	For Production Equipment and Equipment Cleaning (60°C, 70°C)
◆Hot-Water Supply Quantity:	70°C System <13.5 m3/day>
	60°C System <32.1 m3/day>
	25°C System <Circulating Heating via Indirect Heat Exchanger Heat up from 17°C to 25°C >
◆Hot-Water Supply Hours:	Hot-Water Available Hours: 14 hours (Hot-Water Storage in Night Time: 10 hours)
(Chilled Water Equipment)	
◆Usage of Chilled Water:	Cooling of cooling water for vacuum refrigerator
◆Cooling Load:	86.9 kW
◆Cooling Temperature:	Chilled water of 7°C is supplied

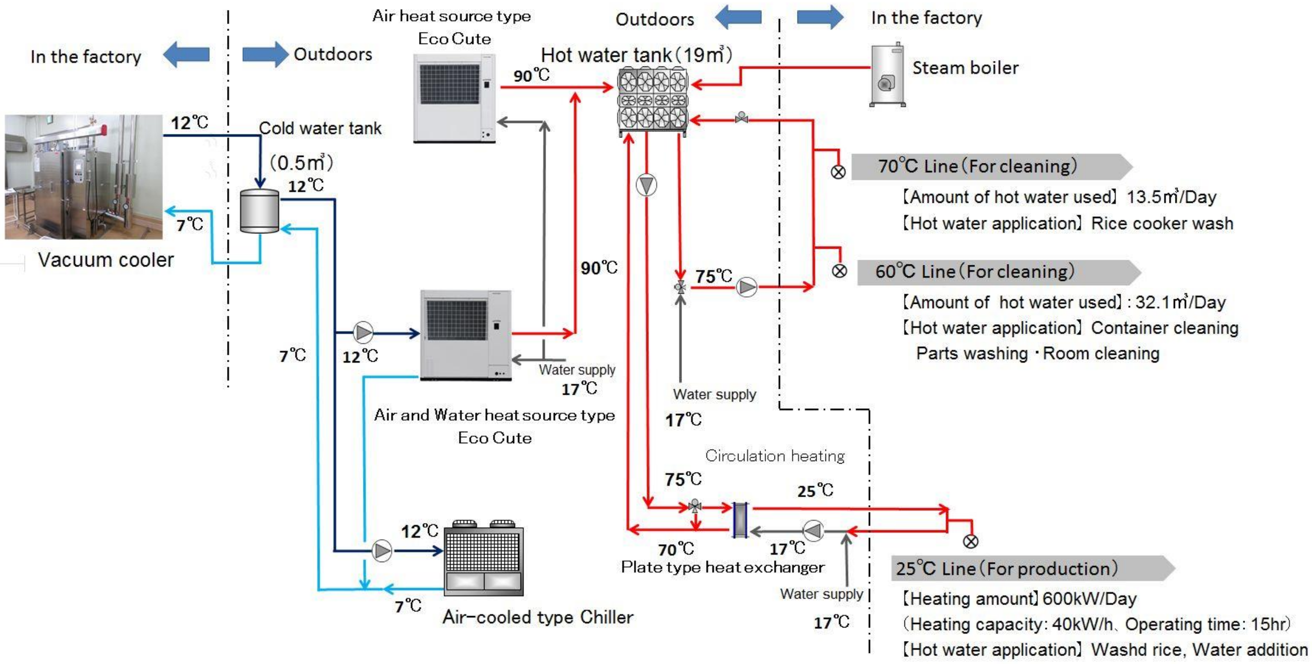


Figure 4-1-3: System Flow of Cold/Hot Heat Supply Equipment using EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.

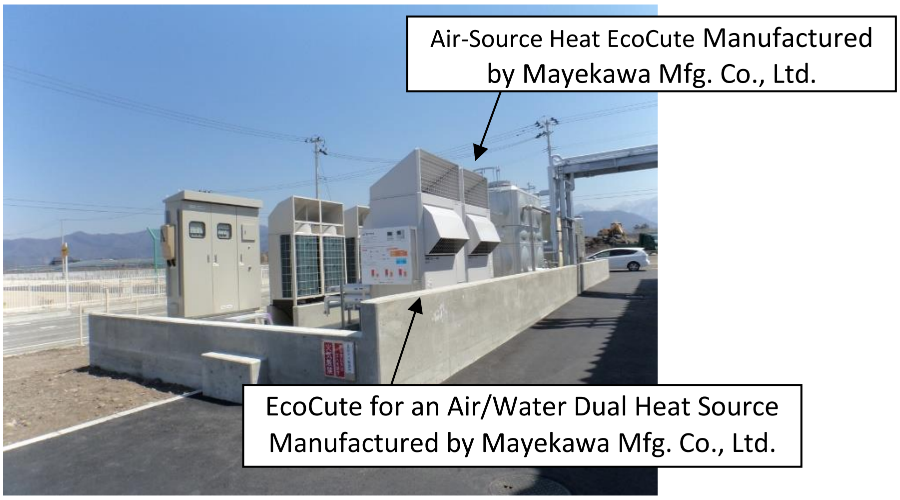


Figure 4-1-4: Exterior View of Cold/Hot Heat Supply Equipment using EcoCute for an Air/Water Dual Heat Source Manufactured by Mayekawa Mfg. Co., Ltd.

(2) Expected Effects of Installation

The cold/hot heat supply system employing EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd. started operation in February 2014 and is successfully continuing operation.

Figure 4-1-5 describes the operation pattern of the cold/hot heat supply system based on which the system was designed.

As for the heat volume, 96% of the full heating load is covered by two EcoCute units and approximately 4% is covered by the boiler; the majority of said 4% is for reheat and others of the heat dissipation loss of the hot-water circulation heating system.

Cold water load exists from 08:00 a.m. to 10:00 p.m. 60% of the total cold water load is supplied by the water-source heat-based operation of EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd., and the remaining 40% is supplied by the air-cooled chiller.

If this is viewed from the operation pattern of EcoCute for an air/water dual heat source manufactured by Mayekawa Mfg. Co., Ltd., operation for simultaneous supply of cold/hot heat in water-source heat mode continues from 08:00 a.m. to 10:00 p.m. and operation in air-source heat mode exclusively for hot-water supply is performed from 10:00 p.m. to 08:00 a.m.

Figure 4-1-6 shows the benefit value by employing EcoCute assumed at the time of system design.

The referenced conventional systems with which the comparisons were made are an air-cooled chiller (COP = 2.7) and a LP gas-fired boiler (Boiler overall efficiency = 80%) for cold heat supply. And comparison bases are primary energy conversions based on Electric Power = 9.76 MJ/kWh and LP Gas = 5.08 MJ/kg; CO2 Emission Coefficients of Electric Power = 0.546 t-CO2/kWh and LP Gas = 6.09 tCO2/1000 m3; and Electricity Costs of Standard Rate = \14/kWh, Midnight Rate for Night Time Storage = \8/kWh, and LP Gas Cost = \200/m3.

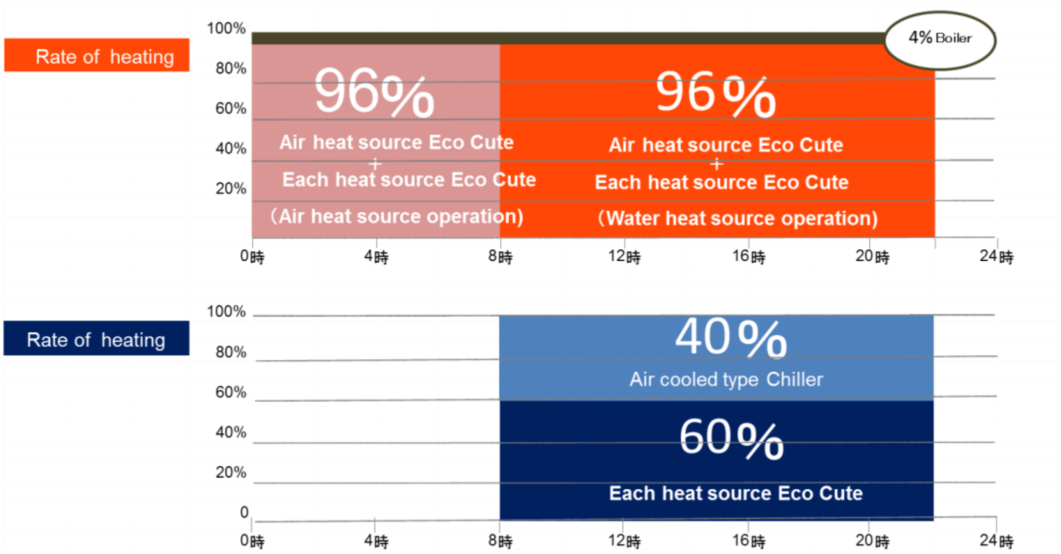


Figure 4-1-5: Designed Operation Pattern of Cold/Hot Heat Supply System

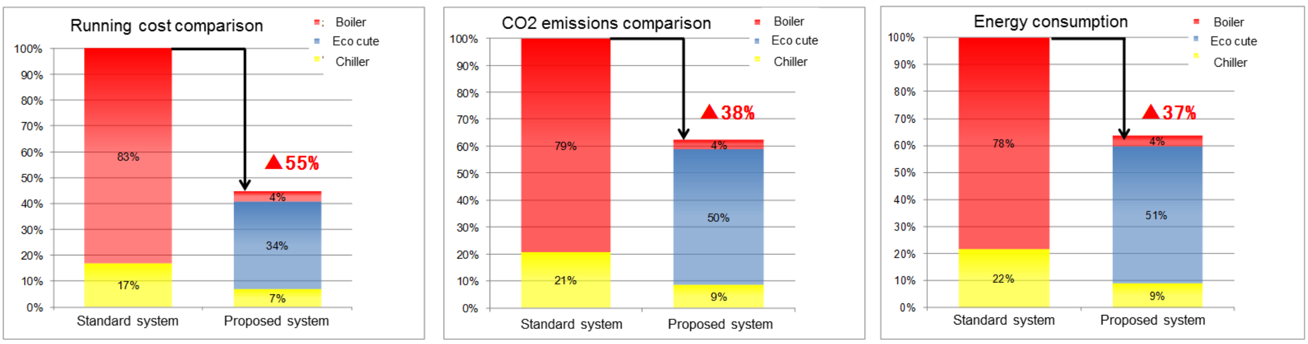


Figure 4-1-6: Benefit of Employment of EcoCute (Designed Value)

4-1-4. Conclusion

Mayekawa Mfg. Co., Ltd. has three equipment types in their product line-up for CO2 refrigerant heat pumps for the hot-water supply: air-source heat, water-source heat and air/water dual heat source switchover type. Therefore, the company considers that they can offer the best fit heat pump system for hot-water supply usage ranging from business use to industry use.

In this report, their heat pump for hot-water supply is introduced. Their product line-up, however, also includes a heat pump for hot-air supply based on heat pump technology of a CO2 refrigerant heat pump for the hot-water supply, and it has been successful in delivering a highly effective hot air supply at 60°C to 120°C.

Water-source heat-based EcoCute and EcoCute for an air/water dual heat source have the ability to collect and utilize the heat from hot water and cooling water discharged from factories or other facilities without utilization.

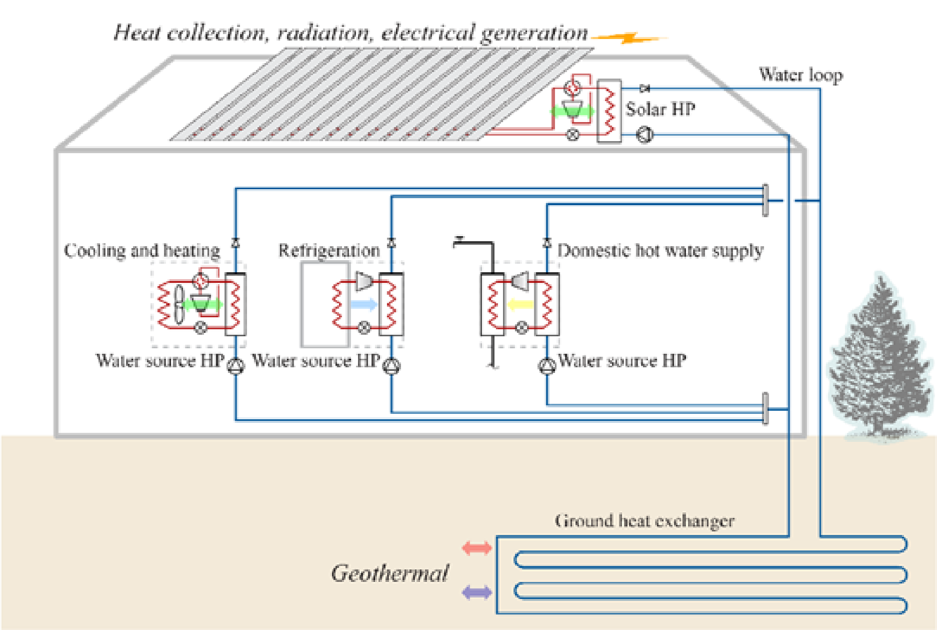
They have added EcoCute for an air/water dual heat source to their product line-up and are now able to meet the requirements of customers who had concerns because of the conventional problem of difficulties in balancing the loads of heat-up and cool-down. The company is now anticipating that the heat pump market expands further.

4-2. Development of Multi-Source and Multi-Use Heat Pump System by LIXIL Group Corporation

4-2-1 Overview

To facilitate energy saving in buildings, it is important to utilize every kind of natural energy available everywhere in the environment. However, individual utilization of each of the various types of natural energy has both merits and demerits. With this technology, the company offered a hybrid system of the “Multi-Source and Multi-Use Heat Pump System (hereinafter referred to as “MMHP System”), namely, the heat pump system combining various types of natural energy (i.e., Multi-Source) and various types of usage (i.e., Multi-Use)”, in which the merits and demerits supplement each other, and developed and manufactured the “Water-Source Heat-Based Instantaneous Hot Water Supply Heat Pump”, which is a water heater focused on higher efficiency by utilization of the MMHP System1,2). As a result, the company has achieved COP of 5.2 (based on conditions in winter), COP of 6.6 (based on conditions in spring and autumn), and COP of 8.5 (based on conditions in summer).

4-2-2. Outline of MMHP System



This system is divided into three major elements: (1) a sun-heat/air-source heat-based heat pump, namely an outdoor unit utilizing solar energy, infra-red radiation, air, wind, rain, and so on, (2) a water-source heat-based heat pump, namely, an indoor unit to supply heat for air-conditioning, hot-water supply, refrigeration, and so on, and (3) a shallow ground-type ground heat exchanger that utilizes ground heat and soil in the ground as heat storage medium. This system is structured by a thermal network of water loops made based on the technology of the above three elements.

Figure 4-2-1: Conceptual Model of MMHP System for Household Application

Figure 4-2-1 shows a conceptual model of this system assuming future household application. In case of application to buildings for business purposes, the basic concept of the system will be the same, although air-conditioning will be the main purpose of its operation.

The temperature of the circulating water of the water loop of this system is controlled to maintain the natural soil temperature (almost the same as the yearly average of the ambient temperature) with fluctuations within ±5 K (for example, between approximately 12°C and 22°C, if in Tokyo) for the purpose to effectively operate both water-source heat-based heat pumps, namely, one for hot heat demand, which has a refrigerant cycle, of air heating and hot-water supply and another for cold heat demand of air-conditioning and refrigeration. Such control is performed by "spontaneous regeneration by ground heat exchanger" and "forced regeneration of the diurnal rhythm by using a sun-heat/air source heat-based heat pump". Because this temperature range is close to earth temperature, it does not cause dissipation of heat stored in soil, and ground heat can be effectively utilized. It is also the temperature range that enables direct utilization of radiation cooling, an outdoor-air processing unit, heat recovery from exhaust gas/waste water and so on. On the other hand, if it is utilized for both purposes as the heat collection source for air heating and hot-water supply and as the heat dissipation medium for air cooling and refrigeration, it results in the heat interchange of hot heat and cold heat within the water loop. Namely, it enables the utilization of the equipment's own exhaust heat. The refrigerant circulation device for this system shall be the dispersion type and shall be invertor controlled using a small size compressor. With regard to water circulation, small-size DC pumps shall be installed exclusively for each device so that on/off of switch and flow control can be conducted individually to reduce the power requirement for heat transportation.

4-2-3. Background and Outline of Development of Water-Source Heat-Based Instantaneous Hot-Water Supply Heat Pump

In recent years in Japan, the CO2 Heat Pump Water Heater, as a highly efficient hot-water supply system that can utilize natural energy, has become more popular to facilitate the reduction of energy consumption for hot-water supplies. The majority of popular water heaters of CO2 heat pumps have air-source heat-based heat pumps with hot-water storage tanks of which energy consumption efficiency gets worse when ambient temperatures go lower, though demand for hot-water will increase on cold days. In addition, the storage tank-type equipment needs to keep the high temperature of hot water in consideration of heat dissipation loss as well as measures against Legionnaires' disease, and this results in higher energy loss. Considering such facts, development was conducted for a water-source heat-based instantaneous hot-water supply heat pump that can overcome such problems.

By making the heat-source side of the water heater of the development prototype be the water-source heat that uses circulating water of the MMHP system, the heat source can utilize a relatively stable and high temperature compared with an air-source heat. The water-source heat type is also able to collect a large volume of heat by increasing the flow rate. The instantaneous-type heat pump was adopted to utilize these advantages. Unlike the hot-water storage type, the instantaneous type does not need to store hot water and can eliminate the necessity for hot water of 60°C, which is just for avoidance of Legionella bacteria. Thus, the hot-water supply temperature can be lowered to around 40°C, which is the practical requirement of toilets, showers, and bathtubs of households and buildings. This lowered temperature of the hot-water supply is a substantial benefit for equipment efficiency. As an additional benefit, the elimination of a hot-water storage tank removes the possibility for hot-water shortage and enables down-sizing as well as cost reduction. Also, because a water-source heat-based heat pump, unlike most air-source heat based heat pumps, does not have specific requirements for its installation place, it can also be housed even in kitchen sink cabinets or spaces under floors.

However, regardless of the abovementioned benefits, tests of water-source heat-based instantaneous hot-water supply heat pumps have barely been conducted because of reasons such as there is no heat source system that can stably keep enough volume of heat and the initial cost of the system becomes higher even if such heat source system were available. Therefore, the actual design, experimental manufacturing, and testing of an experimental prototype of a water-source heat-based instantaneous hot-water supply heat pump were conducted and this report describes the results of testing and checking on its performance value and behavior.

Table 4-2-1 shows specification of a prototype of a water-source heat-based instantaneous hot-water supply heat pump, and Figures 4-2-2 and 4-2-3 show a photo and outline drawing, respectively.

Table.4-2-1 ：Prototype specification

Description		Specification
Performance	Temperature setting range	35～45 (°C)
	Heating capability	Max. 14.4 (kW)
Compressor	Type	Rotary (Inverter fed motor drive)
	Power dissipation	1.8 (kW)
Expander	Type	Drainer (Vapor trap)
Heat exchanger of heat source side	Type	Plate
	Surface area	1.2 (m²)
	Volume	2.45 (L)
Heat exchanger of hot water side	Type	Plate
	Surface area	1.2 (m²)
	Volume	2.45 (L)
Refrigerant	Type	HFC-410A
	Enclosed capacity	2.2 (kg)

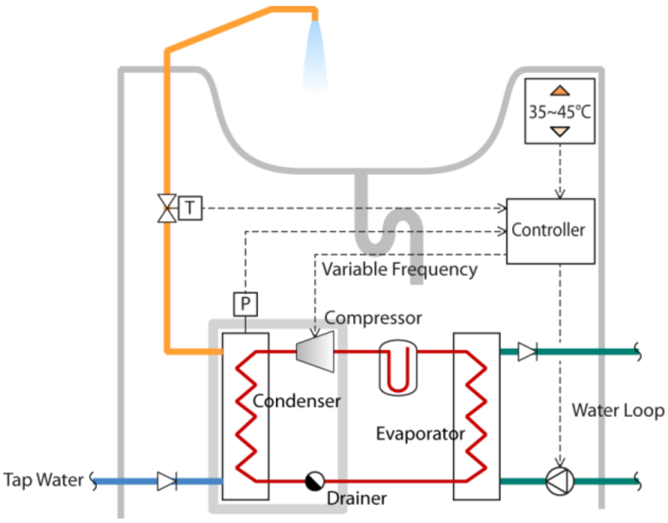


Fig.4-2-2 : Details of prototype

Fig.4-2-3 : Photograph of prototype

4-2-4. Test Conditions and Result

The test was conducted under certain conditions to verify the yearly performance of the prototype. The test conditions are shown in Table 4-2-2. Three levels were set for heat source temperature assuming 12°C for winter, 17°C for spring and autumn, and 22°C for summer for the use in the water loop of the MMHP system. The flow rate of city water was set at 5 L/min. assuming restrooms of buildings. The test was conducted after adjustment of prototypes and water loop systems to these conditions (Test date: June 6, 2011).

As a confirmation of behavior during operation, the relation between temperature, flow rate, power consumption, and operating hours based on the assumption for spring and autumn are shown in Figure 4-2-4. The temperature at the hot-water supply outlet reaches 40°C in one minute after start of operation. For seven minutes thereafter, the temperature was kept higher than 40°C (overshoot). After seven minutes and thereafter, the hot-water supply and temperature were stabilized at 40°C at the outlet, and the state of the instantaneous hot-water supply was confirmed. Power consumption exceeded 2 kW immediately after the start of operation but was stabilized at approximately 1.1 kW after the hot-water supply temperature at the outlet was stabilized at 40°C. The city water temperature at the test facility (inlet temperature of the water heater) was between 18°C and 21°C, but brief rises of 2°C to 5°C were seen in every 100 to 110 seconds, which were treated as abnormal values.

Table.4-2-2 : Experimental conditions

Season of assumption	Heat source		Hot water		
	Tempe-rature (°C)	Flow rate (L/min)	Inlet tempe-rature (°C)	Outlet tempe-rature (°C)	Flow rate (L/min)
In winter	12.0	22.5		40.0	5.0
In spring and autumn	17.0	22.5	Allow to chance	40.0	5.0
In summer	22.0	22.5		40.0	5.0

Results of tests under conditions assuming summer and winter seasons showed the same characteristics. Therefore, the behaviour of an instantaneous hot-water supply was confirmed. As for the overshoot, it has been confirmed that the problem was solved by changing the control from hot-water supply temperature detection to refrigerant pressure (condensation temperature) detection.

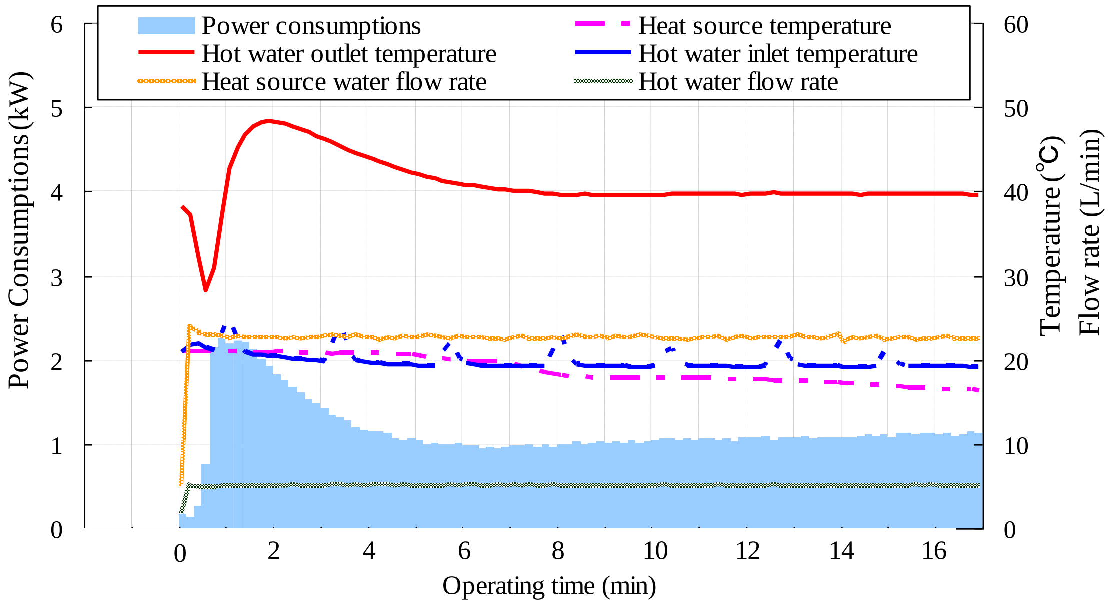


Fig 4-2-4: Actual operating conditions (In spring and autumn)

The results of performance values were calculated based on data obtained after the prescribed conditions of Figure 4-2-4 had been fulfilled and the operation had been stabilized (data from 13 min. 00 sec. to 16 min. 10 sec. under conditions assuming spring and autumn). The same was applied to the test results for summer and winter. Test result data used for performance value calculations are shown in Table 4-2-3, and output and performance values are shown in Table 4-2-4. Relatively high efficiency was confirmed, such as the COP for winter was 5.2, the COP for spring and autumn was 6.6, and the COP for summer was 8.5.

Table.4-2-3: Condition data and data used for COP calculated

Season of assumption	Heat source		Hot water			Power Consumptions (kW)
	Temperature (°C)	Flow Rate (L/min)	Inlet temperature (°C)	Outlet temperature (°C)	Flow Rate (L/min)	
in winter	12.2	22.5	18.4	39.7	5.0	1.44
in spring and autumn	17.0	22.5	19.2	39.7	5.0	1.10
in summer	21.8	22.5	19.1	39.5	5.0	0.84

Table.4-2-4: Heat quantity applied and actual COP

Season of assumption	Heat quantity applied (kW)	Actual COP (-)
in winter	7.42	5.2
in spring and autumn	7.14	6.6
in summer	7.11	8.5

4-2-5. Conclusion

In this report, a new hot-water supply method of a water-source heat-based instantaneous hot-water supply heat pump was proposed and operating capabilities were confirmed. And a high-performance value was indicated. This technology, however, has many disadvantages in practical use, such as the necessity for a water-source heat system, temporary jump of power consumption, difficulty in levelling of power consumption, and the requirement for a large compressor that is too large for residences. On the other hand, the test results also indicated its potential for substantial energy saving. In the future, it would be quite possible that water-source heat system utilizing solar power, geothermal energy, and the like would be introduced for effective utilization of natural energy sources. Therefore, it is expected that improvement and development of equipment will continue and that the energy saving performance of the MMHP system will be pursued further.

Literature Citation

1) Satoshi Yoshida, Ryozo Ooka, Toshiyuki Hino, Kazuo Kodama, Bulletin of The Society of Heating, Air-Conditioning and Sanitary Engineering of Japan No. 208, pp. 11-20 Technology Development of Multi-Source/Multi-Use Heat Pump System (1st Report) Development and Performance Verification of Water-Source Heat-Based Instantaneous Hot-Water Supply Heat Pump (July 2014)

2) Satoshi Yoshida, Ryozo Ooka, Toshiyuki Hino, Kazuo Kodama, Journal of Energy and Power Engineering Vol.8, pp1703-1711, Development of Instantaneous Hot Water Dispenser Based on Water Source Heat Pump (2014/10)

5. Conclusion

As described in the above, the National Team of Japan conducted research and studies under TASK1 in Japan where heat pumps are popular, and summarized the information on the market conditions surrounding hot-water supply equipment, the recent state of heat pump water heater development, and studies on utilization of new heat pump water heaters. To put it concretely, the following information was acquired:

1) In Japan, a large number of heat pump water heaters have been released on the market: 5,000,000 units for residential use in 15 years and 35,000 units for business use in 10 years. However, fossil fuel still accounts for 90% of the energy consumed for the hot-water supply. This means there is enough room for further expansion of the market.
2) With regard to preventive measures against Legionella contamination, it is important that the initial flowing water at all hot-water supply valves, taps, and the like of any section within the hot-water supply equipment shall be discharged and that the hot-water temperature shall be kept higher than 55°C once the temperature is stabilized.
3) In the course of the development of a heat pump water heater for residential use, a new compressor and heat exchanger were developed. In addition, a hot-water reservoir with highly efficient heat insulation performance was also developed in relation to the fact that a heat pump water heater for residential use in Japan is integrated with a hot-water reservoir. Also, many other new technology developments such as down-sizing, performance upgrading by using an ejector, and so on were achieved.
4) Many heat pump water heaters were also introduced into the business use equipment market. One of the examples is the development of a dual system that can change the heat source back-and-forth between air and water, which may expand the market significantly.
5) As one example of the new applications of heat pumps, a highly effective energy network of various equipment having a heat pump as its core technology can be structured. The network will be thermally interconnected by a water loop that consists of outdoor equipment that utilizes solar energy, infrared radiation, air, wind, rain, and so on; a sun-heat/air source heat-based heat pump; indoor equipment that supplies heat for air-conditioning, hot-water supply, and even for refrigeration; a water-source heat-based heat pump; and a shallow ground-type ground heat exchanger that utilizes ground heat and soil in the ground as a heat storage medium.

While it is expected that the introduction of heat pumps will be further promoted worldwide, the situation for heat pumps in Japan will be a useful reference for such countries throughout the world that are looking to introduce heat pumps. It is our obligation to continue under the next TASK to report about the results of our active research and study.

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