

POPULARIZATION OF THE COMMERCIAL ECO-CUTE

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Abstract: In Japan, the commercial-type CO₂ heat pump water heater is steadily being popularized in parallel with the rapid penetration of the domestic one. It was developed first by Itomic Kankyou System Co. Ltd. and called the Eco-Cute. Its potential for drastically reducing greenhouse gases is expected to play messianic roles in achieving the CO₂-reduction goal of the Kyoto Protocol and electric load leveling. Itomic's commercial Eco-Cute was released in August 2002 as the world first CO₂ heat pump water heater in commercial use. Over 1000 units have been delivered, and 976 are in service as of October 2007, of which 143 units are currently in South Korea. In Japan, the Eco-Cute is most successfully applied at elderly healthcare facilities, followed by hospitals, hotels, school catering and food factories. It makes great contributions to promote shifting to nighttime electrical power utilization because of its operation cost being set up about a half cheaper than daytime one. In South Korea, the application example of the Eco-Cute can be seen mainly at the public baths (sauna).

The Eco-Cute has been employed for versatile applications in wide areas; its practical issues have been solved and functions for ease of use have been developed. The development of the heat pump for cold regions is planned to be launched in the future.

Key Words: *CO₂ heat pump water heater, GHG reduction, natural refrigerant, COP, thermal storage, commercial Eco-Cute*

1 INTRODUCTION

Since the adoption of Kyoto Protocol in 1997, the natural refrigerant (R744) has been drawing more attentions worldwide as a vital refrigerant in heat pump application in terms of ozone layer protection and global warming prevention. Itomic Kankyou System Co.Ltd. was the first who developed a CO₂ heat pump water heater called the Eco-Cute. This paper describes the purpose and process of the commercial natural refrigerant (CO₂) heat pump water heater

(hereinafter, Eco-Cute) development.

The first domestic CO₂ heat pump water heater (i.e. Eco-Cute) was launched in April 2001. At the same time, practical realization of the commercial Eco-Cute was also required urgently for meeting strong demands for hot-water supply in kitchen facilities and/or bathroom from restaurant and hotel industries, as well as elderly healthcare facilities. In response to such demands, we commenced joint development of the commercial Eco-Cute with Tokyo Electric Power Co., Inc. (TEPCO) at the end of 2000.

Firstly, a prototype model with 7KW heating capacity was developed in December 2000. After verification of its basic performance, we launched the prototype model of 26KW for commercial mass production. We eventually achieved the practical use of the world's first Eco-Cute in commercial application in August 2002, after success in field testing verification. We launched the sale of the commercial Eco-Cute domestically in August 2002, and overseas in 2006.

Now 5 years has past since the introduction of the world's first commercial Eco-Cute; however, we are still long way from achievement of the specified greenhouse gas (GHG) reduction target since Kyoto Protocol became effective in February 2005 (i.e., 6% is the mandatory emission target posed on Japan). Thus, we are requested more substantial reduction target and more eco-friendly products worldwide in the future. Under these circumstances, we have been dedicating ourselves to developing new features in order to expand the use of the wider commercial Eco-Cute with enhanced environmental friendliness and improved energy-saving effects.

Recently, unprecedentedly soaring oil price serves as a tailwind to prevalence of electric commercial water heater. This paper describes the outline and new features of Itoic's Eco-Cute, as well as the process of its popularization in the following sections.

2 OUTLINE OF THE ECO-CUTE UNIT AND SYSTEM

The Eco-Cute system, i.e., the heat pump water heater with the rated heating capacity of 26KW-50Hz_(30KW-60Hz) is shown in Figures 1 and 2, which is composed of a heat pump unit and tank unit. The heat pump unit consists of a compressor, gas cooler (water heat exchanger), air heat exchanger, fan, water pump and control panel. During its operation, the water pump sends feed water to the gas cooler, in which high-temperature CO₂ gas discharged from the compressor exchanges heat with feed water and the latter be used for hot water supply. Figure 1 shows the photograph of our Eco-Cute system. The heat pump unit size is (H1814×W1312×D842mm).

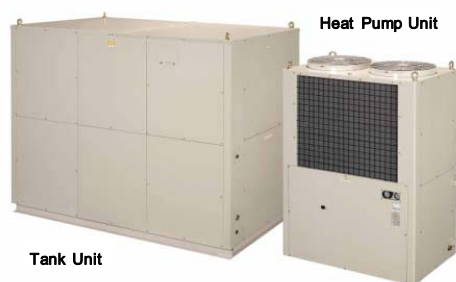
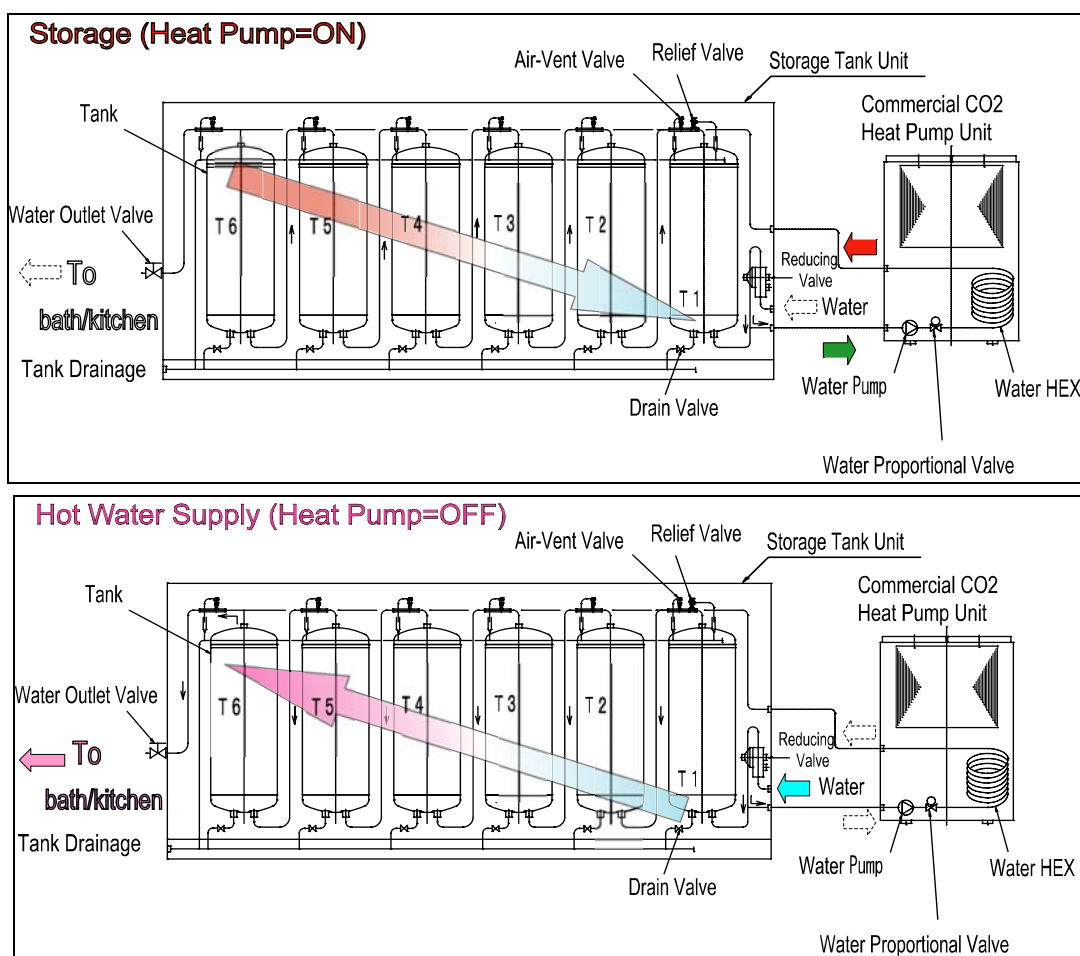


Figure 1: Photograph of Commercial Eco-Cute



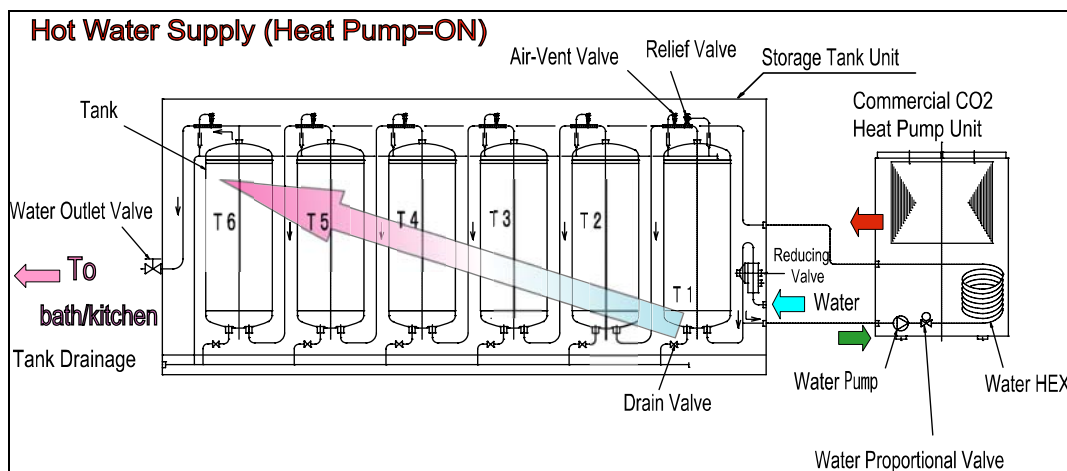


Figure 2: Overall view of Eco-Cute System

Its high heating capacity realizes the high-temperature, 90°C, hot water supply at any time of the year. Only by such a high-temperature it becomes applicable in general use as the hot water supply such as rinsing for the dish washer. In other word, the conventional heat pump water heater has been so far inapplicable due to its insufficient heating capacity. Therefore, compared with the combustion-type water heater, significant reduction of the running cost is expected due to its high coefficient of performance (COP) of 3.8* and reasonable nighttime power utilization in Japan.

*This value refers to Japan Refrigeration and Air Conditioning Industry (JRA) Standard 4050 for the rated condition of heat pump water heater with the carbon dioxide gas refrigerant (Ta: 16°C DB(dry-bulb temp.), 12°C WB(wet-bulb temp.), Water inlet temperature: 17°C, Water outlet temperature: 65°C).

Figure 2 shows the overall view of the Eco-Cute system. The tank unit consists of 6 tanks with a capacity of 500 liters respectively for its total storage capacity of 3000 liters. The tandem arrangement of 6 mass-produced reasonable tanks successfully maintains the temperature stratification thin and small in the manner of avoiding mixing of inlet cold water with outlet hot water. Nighttime storage, daytime hot water supply and daytime additional water heating require piping or flow system alteration as illustrated in Figure 2.

3 ELECTRIC-LOAD LEVELING EFFECT (RATIO OF NIGHTTIME POWER UTILIZATION)

Nighttime power utilization is highly promoted in Japan. In 2007, our commercial Eco-Cute is awarded by Heat Pump and Thermal Storage Technology Centre of Japan (HPTCJ) for its significant contribution to promoting nighttime power utilization as described below.

In general, load of the Eco-Cute as the hot water supply is considered to be for baths, showers and kitchens. Here, let consider elderly healthcare facilities with the capacity of 40

people. It requires the hot water supply load with the design heat quantity of 1700MJ for 10h and hot water supply requirements of 5500L. The above requirements are satisfied by 2 sets of Eco-Cute system, consisted of one heat pump unit and one tank unit with the storage capacity of 3000L. Then,

Required operating time: $1700[\text{MJ}]/(888[\text{MJ}/10\text{h}]\times 2[\text{systems}])=9.57[\text{h}]$

Power consumption: $7.5[\text{KW}]\times 9.57[\text{h}]=71.78[\text{kWh}]$

Since its thermal energy and hot water amount can be provided only during nighttime electric power, the following formula can be derived:

Ratio of energy shift to nighttime power(%):

night power [kW]/(daytime[kWh]+nighttime power[kWh]) $\times 100=71.78/71.78\times 100=100\%$

Specification of the heat pump unit are as follows.

Power supply: 3 phase, 200V, 50Hz

Storage capacity: 291L/h

Power consumption: 7.5KW

Ambient temperature: 16°C DB, 12°C WB

Water inlet temperature: 17°C

Water outlet temperature: 90°C

Storage amount for 10 hr: 888MJ (2910L)

4 ENERGY EFFICIENCY

We conducted the unit's performance verification tests under a variety of operating conditions, changing ambient temperature, feed water inlet and outlet temperatures. It was made in the air-conditioning equipment performance analysis laboratory of TEPCO.

The test results are presented in Figure 3. The annual average COP of 3.3 is attained even in the mode of constant hot water supply at 90°C (H-mode). Further more, much higher annual average COP of 3.6 with the peak COP=4.22 is realized in the mode of seasonal water outlet temperature alteration (L-mode for COP-priority operation) under the same temperature conditions of ambient air and feed water inlet. Because of its high COP the energy output is much larger than the primary energy supply, that is, the primary energy efficiency is much larger than 1.0. It indicates our product brings about the higher energy saving efficiency, compared with the previous water heaters such as combustion type, electric type and conventional heat pump type. Consequently, CO₂ emission reduction is expected.

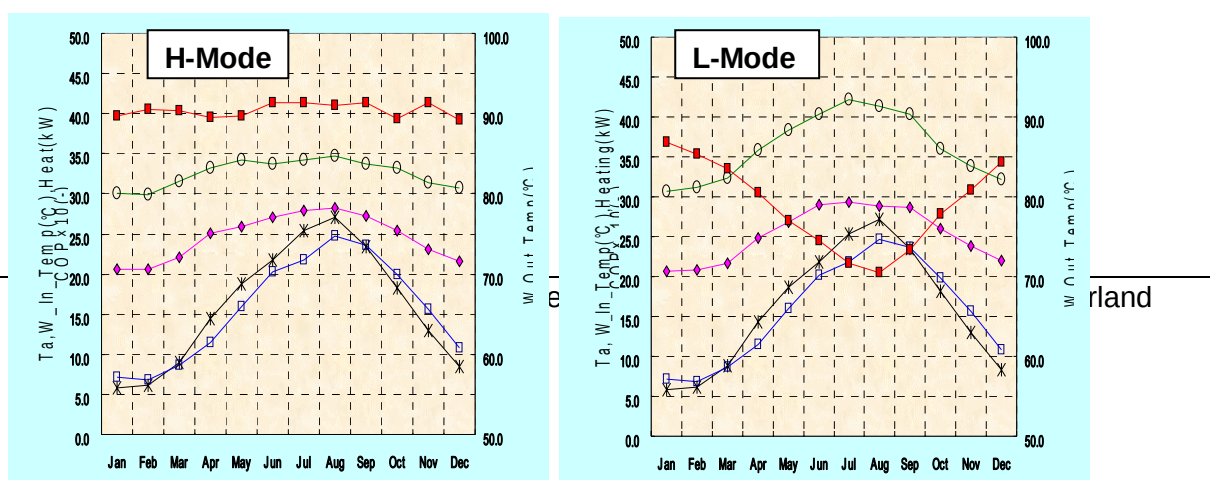


Figure3: Test Results of H-mode(constant temperature hot water supplying mode at 90°C) and L-mode(seasonally-changing temperature hot water supply mode) for 3-phase 200V and 50Hz

*The test conditions are in accordance with seasonal operating conditions in Tokyo as stipulated in Japan Refrigeration and Air Conditioning Industry Association(JRA) Standards 4050.

Primary energy efficiency of commercial natural refrigerant (CO₂) heat pump water heater is :

$$\text{Primary energy efficiency} = 3600\text{kJ/kWh}/9830\text{kJ/kWh}$$

$$\times 3.3 \text{ (annual average COP for } 90^{\circ}\text{C)} = 1.2$$

where the primary energy conversion value of 9830KJ / kWh refers to the ratio of electric power to fuel energy in thermal power generation in the law concerning rational use of energy in the year of 2003 in Japan, the value of 3600KJ/kWh is the unit conversion factor from kWh to kJ and the annual average COP of 3.3 is derived in the mode of constant water supply at 90°C under the performance testing condition in Tokyo.

5 ENVIRONMENTAL FRIENDLINESS

The CO₂ emission of our product can be reduced up to 52 and 61%, compared with the city-gas water heater and kerosene water heater, respectively, which are calculated as follows for the same heating capacity of our natural refrigerant water heater.

Itomic's Eco-Cute for hot water supply at 90°C during the operation time of 10 hours:

Heating capacity: $88.8(\text{MJ} / \text{h}) \times 10(\text{h}) = 888 (\text{MJ})$

CO₂ emission: $0.378 (\text{kg} / \text{kWh}) \times 7.5(\text{kW}) \times 10(\text{h}) = 28.4(\text{kg})$

City-gas water heater

Gas consumption: $888 (\text{MJ}) / (41.4 (\text{MJ} / \text{Nm}^3) \times 0.85) = 25.2 (\text{Nm}^3)$

CO₂ emission: $2.36 (\text{kg} / \text{Nm}^3) \times 25.2 (\text{Nm}^3) = 59.5 (\text{kg})$

Reduction Rate: $(59.5-28.4) / 59.5 \times 100 = 61\%$

Kerosene water heater:

Kerosene consumption: $888 (\text{MJ}) / (35.6(\text{MJ} / \text{L}) \times 0.85) = 29.3(\text{L})$

CO₂ emission: $2.49(\text{kg} / \text{L}) \times 29.3 (\text{L}) = 73.0(\text{kg})$

Reduction Rate: $(73.0-28.4) / 73.0 \times 100 = 61\%$

where the CO₂ emission factor of electric power is 0.378 (kg-CO₂/kWh) and those of city-gas and kerosene are 2.36(kg-CO₂/Nm³)and 2.49(kg-CO₂/L), respectively.

Note: Calorific value of city-gas (13A) is 41.4(MJ / Nm³)

Calorific value of kerosene is 35.6(MJ / Nm³)

Boiling efficiency is 85 %.

6 ECONOMIC EFFICIENCY

Its high COP over 3.0 and reasonable nighttime power utilization enables our Eco-Cute to reduce the running cost more drastically than the electric water heater or combustion-type water heater does.

Table 1: The Comparison of the energy-costs in Tokyo (November 2006)

Type of water heater	City-gas heater	Electric heater	CO ₂ heat pump
Annual average energy cost	¥917,600	¥315,000	¥92,600
Monthly average energy cost	¥76,500	¥26,200	¥7,700
Daily average energy cost	¥2,549	¥875	¥257
Energy Source	13A (9,900kcal/Nm ³)	Electric power	Electric power
Unit Price	¥101.17/Nm ³	¥3.43/kWh	¥3.43/kWh
Annual energy consumption	9,070Nm ³	91,837kWh	27,000kWh
Difference in energy cost	¥825,000	¥602,600	-

Table 1 presents an example of energy costs of the Eco-Cute CO₂ heat pump system for the daily supply of 3000L hot water at 90°C accumulated by nighttime electrical power utilization, compared with the city-gas water heater and electric water heater. The utilities in this table exclude the basic cost. Nighttime power utilization enables 3000L of water to be boiled at JPY 257 per day.

7 NEW FEATURES UNDER DEVELOPMENT

The following features have been developed as solutions to various practical issues, or in response to new demands for a variety of applications and for enhanced usability which are not covered by the existing system. These developments will bring about wider prevalence of the CO₂ heat pump water heater system for various applications.

7.1 Circulating Heating System

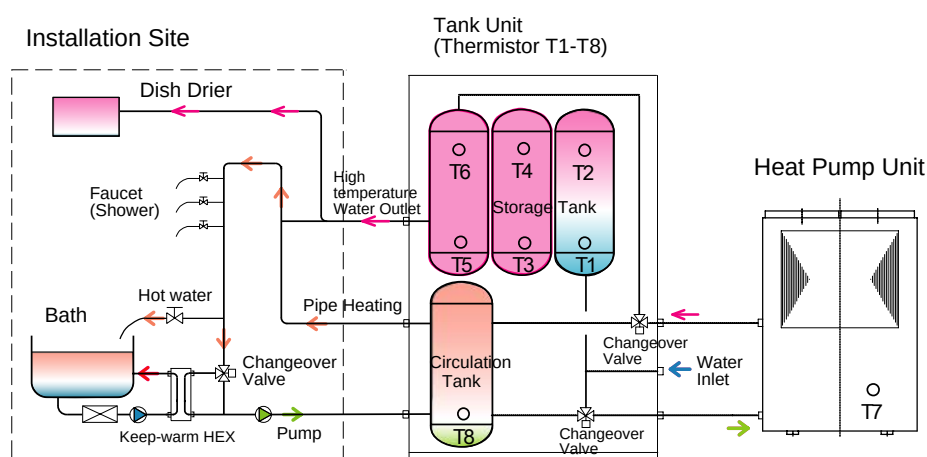


Figure 4: Schematic diagram of the circulating heating operation.

In addition to the normal water heating operation, we have introduced the circulating heating operation system for maintaining the outlet water temperature up to 63°C in the feed pipes for dish driers and baths and so on, which is currently patent pending. This system operates with 1 tank for heat-circulation and the remaining 3 or 5 tanks for heat storage, and both the circulating heat and stored heat are utilized at the same time, depending on the temperatures of the circulating tank bottom (T8) and its set-point, as shown in Figure 4.

This system configuration separates the circulating tank from the remaining storage tanks by changeover valves. It perfectly protects the temperature stratification in those tanks from

destruction or mixing during circulating heating operation and ensures the maximum COP. When the temperature at the circulating tank bottom (T8) is depressed, the changeover valves are switched on for the circulating heating operation, despite the water outlet temperature in the circulating heating operating is not fixed but dependent on the operating conditions.

7.2 Independent Operation of the Heat Pump Unit as a heat source

When an old hot water supply system with a storage tank unit is renewed, the commercial Eco-Cute can be used as a new heat source by changing its control setting, that is, by replacing the old heat source with it and by still utilizing the existing old tank units as they were. Figure 5 shows an installation example. When the system detects a decrease in the existing old tank temperature, the upper controlling device inputs driving signals to operate the Eco-Cute heat pump unit until the water boils up to the desired temperature. The stop signal from the upper control device also stops the unit operation. This operation method is introduced to a number of public baths in South Korea. This system also mostly applies to larger tank capacities requiring multiple heat pump units.

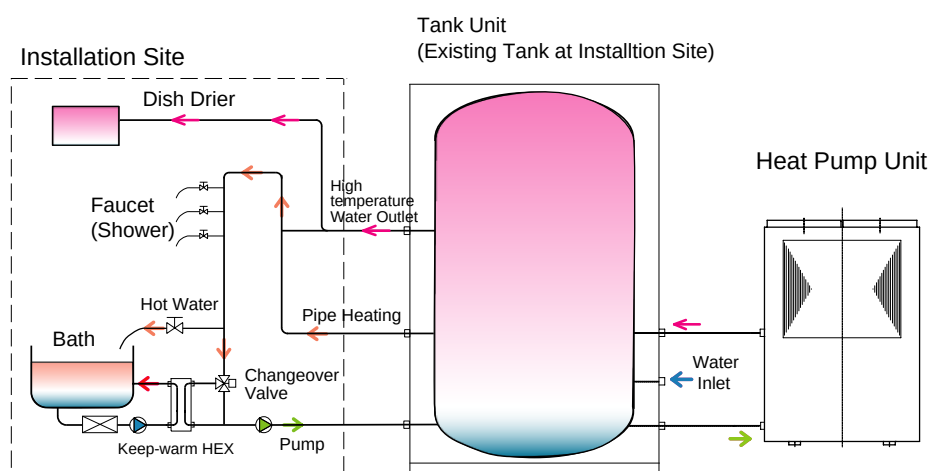


Figure5: Installation example of the independent heat pump unit operation

7.3 Multiple Unit Control

In the case of multiple units operation in parallel connection, it is inevitable that stored water is distributed unevenly among respective tanks. We have developed the multiple unit control method as a mean for solving heat loss and random water consumption issues. The base heat pump unit controls the hot water amount in each tank in order to use water preferentially from tanks with larger storage amount. That also realizes well-balanced water consumption.

Up to 7 units are controllable for normal operation and 4 units are controllable for simultaneous water supply.

7.4 Learning Function

This function, aiming at heat loss reduction, boils up the required amount of water by the time just before stopping nighttime power utilization in the early morning. It also calculates the daily water consumption for the past 4 weeks and estimates the required water amount which should be boiled for each day of the coming week. This function has an efficacy for unit operation under fixed loaded conditions on each day of the week. The unit automatically adjusts the required water amount for boiling to seasonally changing loads.

7.5 Hybrid Operation

In response to industry demands for immediate increase in hot water supply or as a solution to unexpected breakdown of the heat source unit, this function automatically changes the heat source from the heat pump unit (i.e. Eco-Cute) to other heat source, including a kerosene or city-gas boiler or electric heater. This heat source shift establishes the efficacy of the Eco-Cute's environmental performance and cost reduction. Simultaneously, this method realizes effective investment without overcapacity.

8 DEVELOPMENT OF COMMERCIAL ECO-CUTE FOR COLD CLIMATE APPLICATION

Efficiency of the current model of Eco-Cute decreases in the cold climate regions, e.g., at the ambient temperature of -20°C or lower. It is not only COP but also its heating capacity. That is the reason for discouraging penetration of the Eco-Cute in the cold climate regions. In order to overcome this inefficiency, it is essential to introduce a high-performance inverter motor drive compressor in the heat pump unit. Here, we mandate the development of the product suitable both for the cold climate region and for normal operating conditions.

9 CONCLUSIONS

Eco-Cute has been hailed as a highly reliable and eco-friendly device by clients and widely supplied, cooperating with both domestic and overseas agents. Numbers of unit for various applications are shown in Figure 6. Pictures of application examples of our products in Japan and South Korea are shown in Figure 7. In the future, we will dedicate ourselves to further

development and product enhancement for supplying more user-friendly and eco-friendly water heaters.

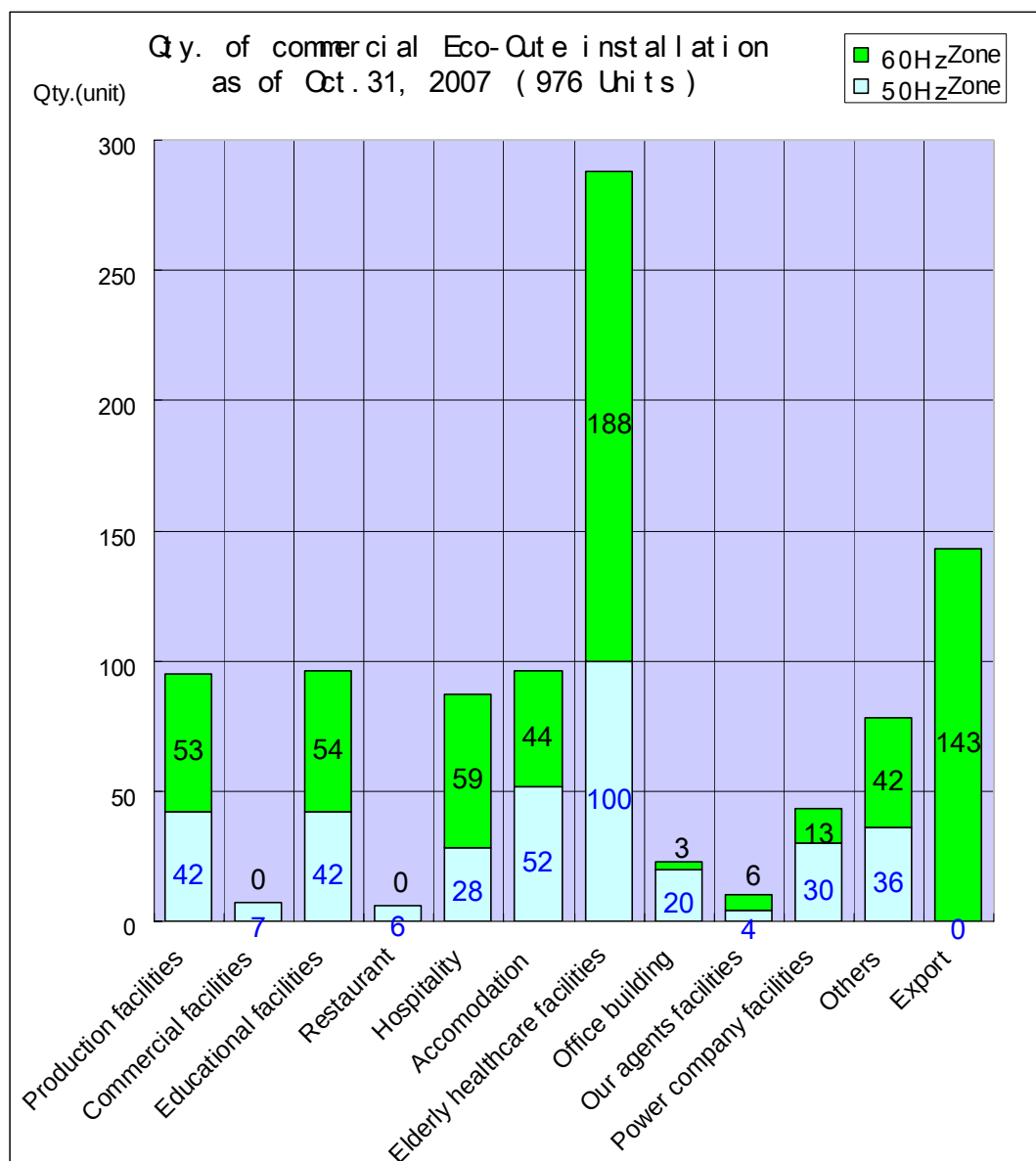


Figure 6: Number of units installed as of August 2007



- Elderly Healthcare Facility, JAPAN
- Dimension
- Site Area: 6985m²
- Total Floor Area: 3362m²
- Application: Kitchen, Bath
- Lavvy (60°C)
- Storage: 90°C
- Tank3000L*1
- Heat Pump unit *1



- Hotel, JAPAN
- Rising 10 stories from the ground
- 125 Rooms
- Application: Central feeding water
- (60°C)
- Storage: 90°C、
- Tank3000L*4
- Heat Pump Unit*4



- University, JAPAN
- Application: Electric Kitchen
- (2000meals/ day)
- Shower Room(Gym)60°C
- Storage: 90°C
- Tank 3000L*4
- Heat Pump Unit*4



- University, South Korea
- Application: ShowerRoom (Dormitory)
- Storage: 75°C
- Specification: HP- unit Independent
- Operation
- 5units of Heat Pump are connected
- to the tank unit of 10t and 20t.

Figure7: Application Example of Eco-Cute in Japan and South Korea

ACKNOWLEDGEMENT

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10 REFERENCES

Heat Pump & Thermal Storage Technology Center of Japan, 2005. "Estimation of CO₂ Emission per Water Heater," *COOL & HEAT*, Vol.22.