Successful Application of Heat Pumps to a Dhc System in the Tokyo Bay Area

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Abstract: The Harumi-Island District Heating & Cooling (DHC), which is located in the Tokyo Bay area, introduced the heat pump and thermal storage system with the aim of achieving minimum energy consumption, minimum environmental load, and maximum economical efficiency. It started operating in 2001, achieving high efficiency and a large amount of reduction of greenhouse gas emission, as well as low heat-charge. The system performance was verified by the continued commissioning of the system.

Key words: District Heating & Cooling, heat pumps, thermal storage system, large difference of temperature for cold & hot water, commissioning

1 .INTRODUCTION

The first DHC system was introduced in Japan in 1970 and developed on a nationwide scale to about 150 areas as of 2003. The introduction of the heat pump system to DHC started in 1983 and kept increasing year by year supported by the advancement of heat pump and thermal storage system technologies. The historical trend of total supply capacity of heat pumps in DHC in Japan is shown in Fig. 1. Currently heat pumps are introduced in about 50 areas, and the amount of heating capacity is about 1,600GJ/h, which means about 11% of all the heating capacity of DHC in Japan. during the year in office buildings, so heat recovery has been handled by using heat pumps. Another reason is the necessity of utilizing unused heat sources, for example, seawater, river water, and sewage water, etc., to reduce greenhouse gas emission, The DHC utilization of unused energy extends to 15 areas as of 2003.

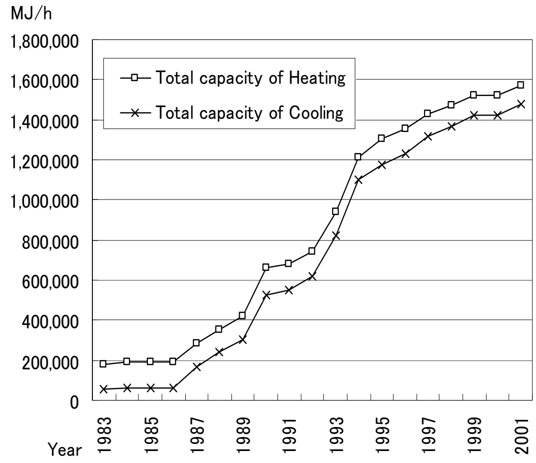

Fig. 1. Total capacity of heat pumps in DHC in Japan.

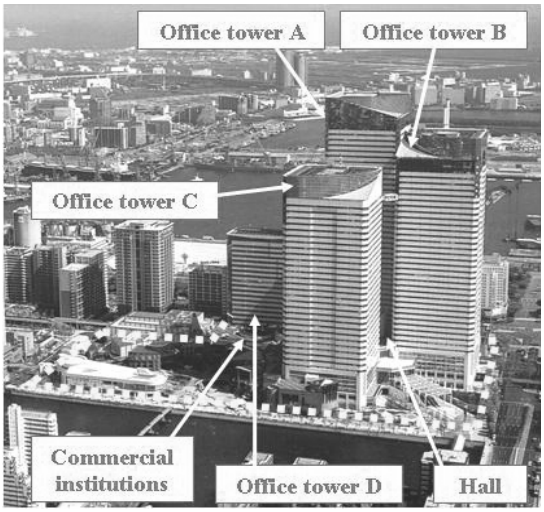

Fig. 2. The view of Supply area of Harumi-Island

One of the reasons why heat pumps are introduced in DHC systems is the increase of cooling demand

2 OUTLINE OF THE HARUMI-ISLAND DHC

The Harumi Island DHC is a typical example of successfully adopting the heat pump and thermal

Tab. 1. Outline of facilities

Kind of Facility	Name of Facility	Specification	numbers
Heat-source Machine	Turbo Chiller (TR)	Cooling capacity 14.9GJ/h	2
	Heating-Tower Turbo Heat Pump (HTHP)	Cooling capacity 18.3GJ/h Heating capacity 12.6GJ/h	2
	Double-Bundle Turbo Heat-recovery Heat Pump (DB)	Cooling capacity 5.4GJ/h Heating capacity 6.8GJ/h	2
Cooling/Heating Tower	Cooling Tower (CT)	for TR	1
	Cooling/Heating Tower (CHT)	for HTHP,DB	2
Thermal Storage Tank	Cold water (ST-C)	4,700m^3	2
	Cold/Hot water (ST-CH)	4,700m^3	2
	Hot water (ST-H)	260m^3	1

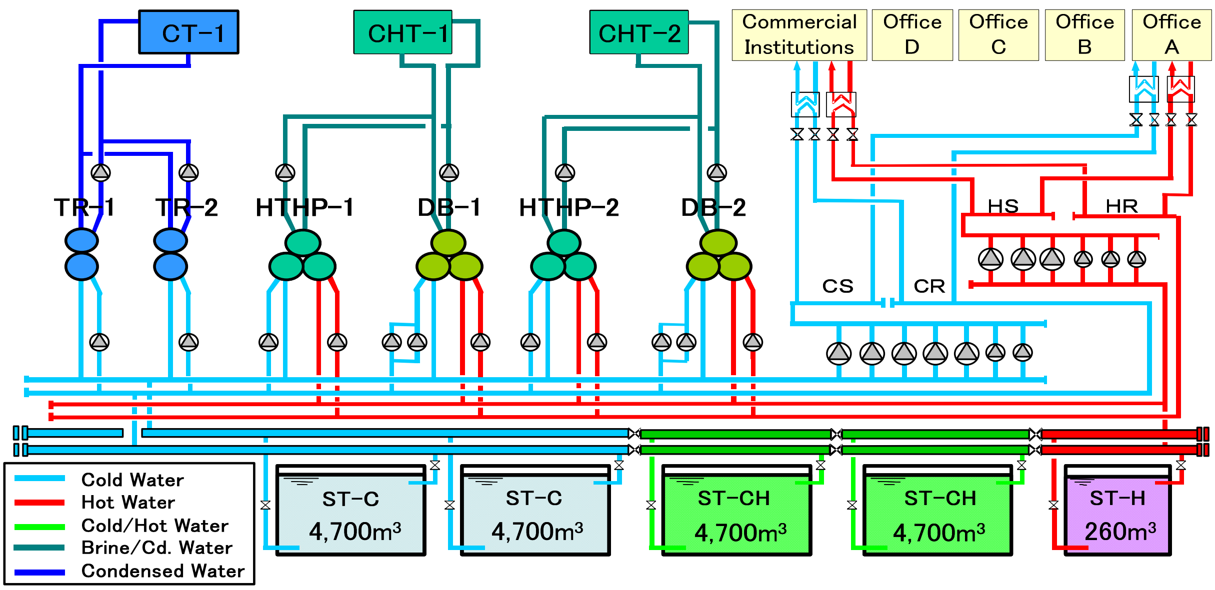

Fig. 3. Heat-source system of DHC

storage system. The view of supply area is shown in Fig. 2, and the outline of the DHC is as follows:

Entrepreneur : Tokyo Toshi Service Co.

Service start-up : 1/4/2001

Supply area : 6.1 ha

Supply floor area : 437,600 ㎡

Maximum heat capacity : (cooling)122GJ/h, (heating)57GJ/h

Supply/return temperature : (cooling) 6/16 deg.C, (heating) 47/37 deg.C

The outline of the facility is shown in Table 1 and Fig. 3. This DHC has large-scale thermal storage tanks that can store about 50% of the total cooling load of peak cooling day in summer. The heat-source machines consist of two turbo chillers (TR), two heating-tower turbo heat pumps (HTHP), and two double-bundle turbo heat-recovery heat pumps (DB). In winter, brine water of HTHP absorbs heat from the atmosphere by the open heating tower. The temperature of brine water rises from -11 deg.C to -7 deg.C by absorbing heat from the atmosphere. In summer, brine water is collected in a reservoir tank and switched to cooling water.

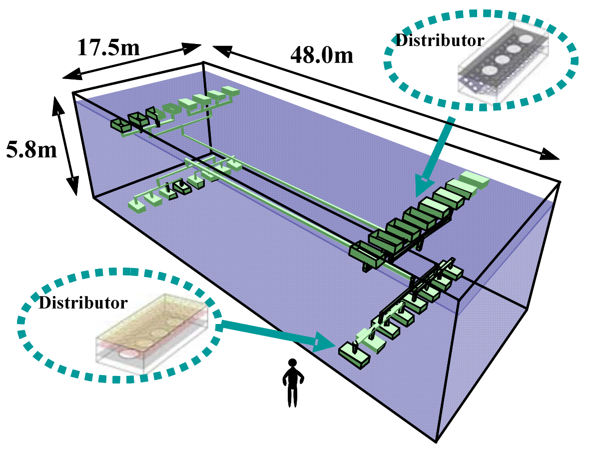

Fig. 4. Schematic of thermal storage tank

3 FEATURES OF THE HARUMI-ISLAND DHC

3.1 High Efficiency of Heat-Source Machines

To reduce the primary energy consumption of DHC, the most efficient heat-source machines in the market at that time were selected. The COP of TR, which is expected to have the longest operation time throughout the year, was 5.4. While the COP of DB was 6.7 for heat-recovery, and COP of HTHP was 4.7 for cooling, and 3.2 for heating.

3.2 Large-scale Thermal Storage Tanks

The total capacity of water thermal storage tanks, which were constructed in the basement of super-high-rise office buildings, is 19,060m^3 in volume. They consist of two tanks for cooling, one for heating, and two for both cooling and heating which are switched by the season. All the water thermal storage tanks are temperature-stratified type with a depth of 5.8m.

In order to achieve efficient thermal energy storage, special distributor was developed and tested by simulation model. The schematic of thermal storage tank is shown in Fig, 4.

3.3Temperature Differences for Cold Water and Hot Water

From the viewpoint of both reducing the pumping power for cold/hot water supply and using the thermal storage tanks effectively, large-temperature-difference water supply system was introduced. As for the supply/return temperature condition, it was chosen to be 6 deg.C (supply) /16 deg.C (return) for cold water and 47 deg.C (supply) /37 deg.C (return) for hot water.

3.4 Pursuit of Economic Efficiency

In the Harumi-Island DHC, low heat-charge was achieved as a result of incorporating high-efficiency of heat-sources, appropriate heat-source capacity corresponding to heat demand, large-scale thermal storage tanks, and large temperature difference heat supply system. The flat-rate of heat based on model load achieved the lowest level in the domestic DHC systems which started operation within the past 10 years.

4. RESULT OF OPERATION

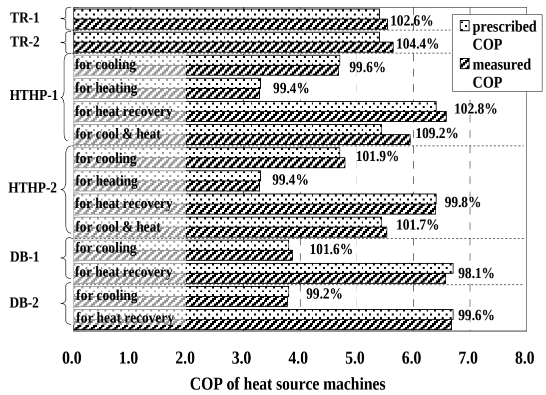

Fig. 5. Result of commissioning at acceptance step for heat-source machines.

To verify the performance of DHC system in the construction phase and operation phase, commissioning committee was set up with members comprised of university professors, customer, designers, constructors, and the operators.

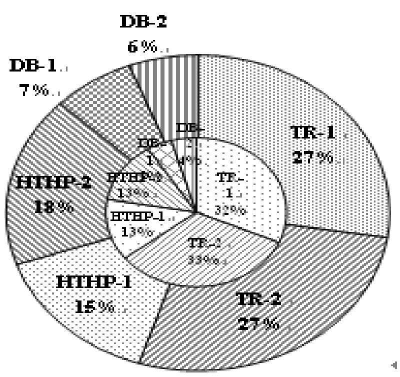

Fig. 6. The rate of cold water production in 2001and 2002.

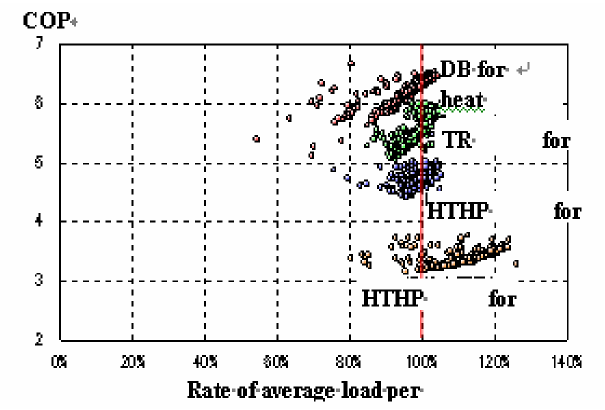

Fig. 7. The rate of average load per day and COP of heat-source machines in 2002.

4.1 Commissioning at the Acceptance Step

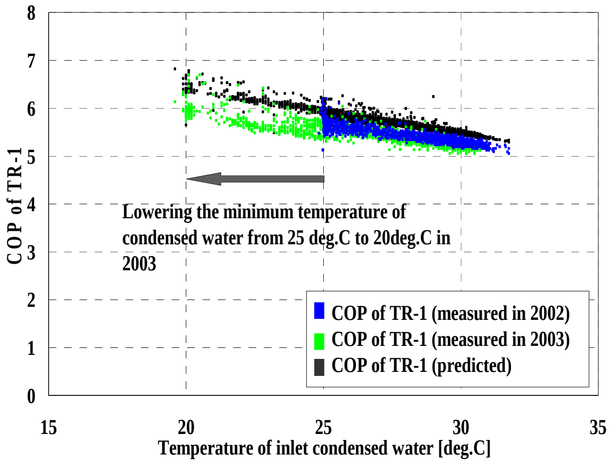

Fig. 8. COP and cooling water temperature of TR in 2002 and 2003.

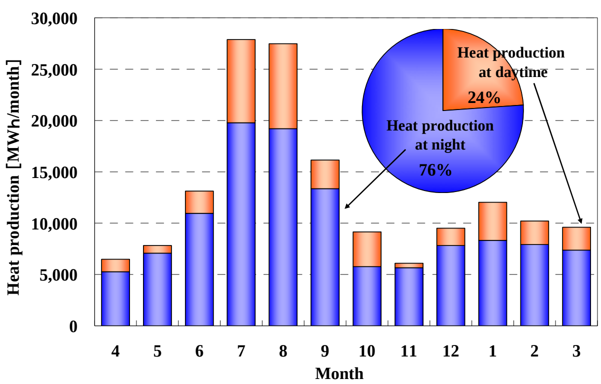

Fig. 9. Night-shift rate of heat production in 2002

At the acceptance step, the performance test, both in the factory and in a local installation, was executed for each heat-source machine, cooling/heating tower, pump, and heat storage tank.

The performance test of heat-source machines was held from January to March in 2001 in the DHC plant, the result is shown in Figure 5. The shown % is a rate of measured COP divided by prescribed COP. The acceptable criterion was assumed to be 98% or more. As the result of performance test, each heat-source machine was confirmed to achieve both prescribed capacity and COP.

4.2 Result of Commissioning at the Operation Phase

4.2.1 Performance of heat-source machines

At the operation phase since April 2001, the commissioning committee was held to examine the system performance. The rate of the cold water production by heat-source machines is shown in Figure 6. In fiscal year 2001, TR was mainly operated as base machine for its high COP. During fiscal year 2002, on the other hand, HTHP and DB were operated as much as possible at nighttime instead of operating TR at daytime, aiming at the improvement in night-shift-ratio. Therefore, the operating rate of TR decreased in 2002, and the rate of HTHP and DB increased compared with 2001.

The rate of average load per day and COP of heat-source machines in 2002 is shown in Figure 7. Each machine was operated throughout the yearwith load rate of more than 90%. This is because the Harumi-Island DHC has large thermal storage capacity, and each heat-source machine can be operated at almost full load. In general, system COP, including attachments such as water circulation pumps and cooling-towers fan, lowers extremely during a part load operation. Therefore, it can be said that the large-scale thermal storage tank is essential to achieve high COP performance.

COP of the heat-source machine depends on the rate of load, the cold water outlet temperature, and the condensed water inlet temperature. The approximation to which COP was obtained from these three variables was made based on the performance curve that the maker presented. Predicted COP was requested from the measurement load factor, cold water outlet temperature, and condensed water inlet temperature of TR by using this approximation, and comparing it with measurement COP. The result is shown in Fig. 8. The measurement COP has decreased compared with the predicted COP, seemingly by the adhesion of dirt to the condenser. In 2003, it was aimed at a more highly efficient operation by lowering the minimum temperature of condenser water from 25 deg.C to 20 deg.C.

4.2.2 Performance of the thermal storage tank

The efficiency and heat loss of thermal storage tanks were measured during operation. The efficiency of all thermal storage tanks was 98% or more and the heat loss of thermal storage tanks, measured by several ways, were very low of the order of 0.25% to 0.38%.

4.2.3 Result of the operation of the plant

The monthly production of heat classified by day (8:00-22:00) and night (22:00-8:00) in 2002 is shown in Figure 9. The night-shift-rate of heat production decreased in summer and winter, but achieved a high night-shift-rate of 76%.

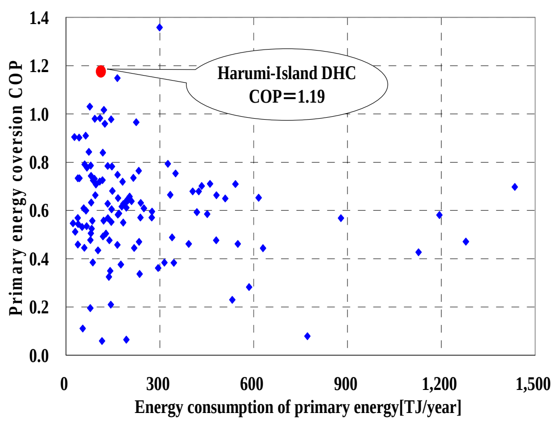

Fig. 10. Comparison of primary energy based COP o fdomestic DHC in 2002.

Primary energy based COP of the domestic DHC in fiscal year 2002 is show n in Figure 10. The primary energy based COP of the Harumi-Island DHC was 1.19, the largest value in DHC systems which do not depend on the unused energy.

CO2 emission divided by the heat production at the Harumi-Island DHC in 2002 was 26.8g-CO2/MJ, about 60% less than average CO2 emissions of 67.0g-CO2/MJ of all the domestic DHC systems. Thus the Harumi-Island DHC achieved large amount of reduction in CO2 emission.

5 CONCLUSIONS

In the system planning process of the Harumi-Island DHC plant, we introduced heat pump and thermal storage system aiming to achieve saving in energy consumption, reduction of environmental load, and low heat charge. The main features of the plant are as follows: 1) incorporation of high-efficient heat-source machines; 2) incorporation of large-scale thermal storage tanks of the largest capacity domestically; and 3) in corporation of large temperature difference in supply-return of chilled water and hot water.

In the operation phase, continuous commissioning was carried out to verify the performance of the system and to improve the operation. As a result, we achieved the following favorable performances:

1) The primary energy based system COP was 1.20 in 2001, 1.19 in 2002, and 1.18 in 2003, the largest value in the DHC systems which do not depend on unused energy. 2) CO2 emission from the plant was set to 26.8 g-CO2/MJ, less than about 60% of the average value of domestic DHC systems. 3) Flat-rate of heat by the model heat load was the lowest in the domestic DHC systems which started operation within the past 10 years.

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