PREDICTION ABOUT PROGRESS IN PERFORMANCE OF DISTRICT HEATING AND COOLING SYSTEM USING COMBINED HEAT AND POWER

Reiko Kubara [1], Yoshiyuki Shimoda [1], Tomoji Nagota [1], Naoaki Isayama [1], and Minoru Mizuno [1]

Division of Sustainable Energy and Environmental Engineering, Osaka University, Suita, Japan

ABSTRACT

This study aims to reveal the advantages of district heating and cooling system (DHC) in energy efficiency as an urban energy system in the future. In this study, an existing absorption-chiller-and-boiler-type DHC plant, which utilizes large-scale combined heat and power (CHP), is chosen for a case study. We evaluate the energy-saving potential of the plant in the future by a simulation model. The simulation model is developed based on actual equipment specifications and operating conditions of the plant, and the accuracy of this model is proved to be high based on comparisons with measurement data. The results show that the energy efficiency ratio will reach 2.13 by the introduction of various measures to conserve energy, including future advanced technologies. In particular, the utilization of CHP exhibits a great energy-saving effect. However, these results depend on future technical developments.

KEYWORDS

Actual condition analysis, Simulation, Performance progress, District heating and cooling system, Combined heat and power

INTRODUCTION

In Japan, district heating and cooling system (DHC) has a 35-year history, and now more than 150 plants are running. DHC has many social advantages, such as air-pollution abatement. Above all, energy-saving gains attention as one of the most important advantages of DHC in recent years with regard to the mitigation of global warming.

The Agency for Natural Resources and Energy in Japan showed the advantages of DHC in energy efficiency by comparing the measured energy efficiency of individual heat-source systems to that of DHC plants (2003). Shimoda et al. revealed the advantages of DHC in energy efficiency due to the concentration effect, the economy of scale in energy efficiency of chillers and the grade of operation (2005). However, nowadays the energy-saving effect of DHC is not clear as ever, because a variety of energy-saving technologies such as building energy management system and high-efficiency, small-capacity chillers are being introduced in individual heat-source systems. Even in this circumstance, DHC could retain its energy-saving effect in the future since DHC has unique advantages such as the utilization of natural and unused heat-source/sink or large-scale combined heat and power (CHP), which cannot be utilized in individual heat-source systems from an economic point of view. Thus, it is important to predict the energy-saving potential of DHC in the future. The results could contribute to not only the adoption of energy systems in the city planning phase but also the improvement of energy efficiency of existing DHC plants.

There are several studies reporting the energy-saving potential of DHC and heat-source systems. For example, Fujinami et al. showed the energy-saving potential of DHC through the utilization of exhaust heat from CHP (2004), and Liao Z. et al. showed the energy-saving potential of heating systems through improving boiler controls (2004). However, in these studies, the simulation models are developed with numerous assumptions. As a result, the calculated energy-saving potential seems to be an overestimation.

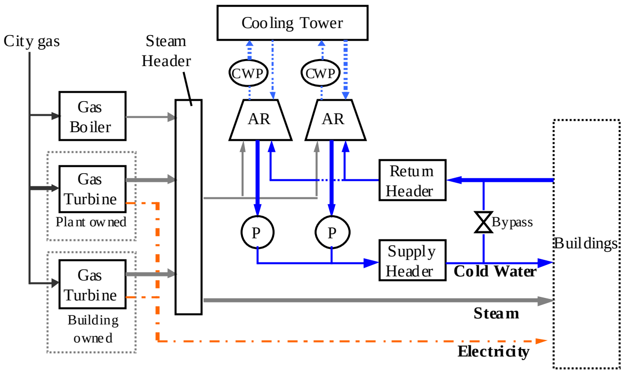
In this study, we target at the absorption-chiller-and-boiler-type DHC plant, which accounts for one-third of all DHC plants in Japan. This type of DHC is expected to save energy drastically by the technical innovation of CHP. We selected an actual DHC plant (A-Plant) that has the largest scale of CHP in Japan as a case study. A-Plant is modeled based on actual equipment specifications and operating conditions, and the accuracy of the model is proved to be high by comparisons with measurement data. With this simulation model, the energy-saving potential in the future is evaluated.

We use the energy efficiency ratio (EER) as the evaluation index of the energy efficiency. EER is defined as follows.

$$EER = \frac{Total\ amount\ of\ supplied\ heat\ [GJ/year]}{Total\ primary\ energy\ consumption\ [GJ/year]} \quad (1)$$

The primary energy conversion factor of electricity is set to 9.83 [GJ of primary energy / kWh of electricity] in accordance with the energy-saving law in Japan.

SIMULATION MODEL



AR: absorption chiller , P: cold water pump , CWP: cooling water pump

Note: The number of absorption chillers and gas turbines is different from the actual plant.

Figure 1. System configuration of A-Plant

Table 1. Heat source equipment (A-Plant)

	Heat source equipment	Performance	Number of equipment
Cooling heat source system	Absorption chiller	7032kW	4
	Absorption chiller	3516kW	3
Heating heat source system	Steam boiler	15.0t/h	3
	Steam boiler	4.8t/h	2
Other facilities	Gus turbine (Power)	1500kW	4
	(Steam)	4.45t/h	4

Figure 1 shows the system configuration and Table 1 shows the heat-source equipment. The EER of A-Plant is 0.77, and this EER is higher than average of Japanese absorption-chiller-and-boiler-type DHC plants. A-Plant has four gas turbines. Three gas turbines are building-owned, and one gas turbine is plant-owned. However, all CHP are installed at the plant, and all electricity from CHP is transmitted to one building in the region. The electricity demand of the building is nearly constant throughout the year, and the maximum demand is about 5600 [kW]. DHC plant utilizes only exhaust heat from CHP.

In order to precisely simulate the actual condition, following parameters are basically determined by the measured data of A-Plant. However, missing parameters are determined by the measured data of other DHC plants.

Factors considered in the simulation model

1. Heating and cooling load

In order to correctly simulate the chiller sequence control, the cooling load is supplied as the measured flow rate of chiller water and the measured temperature difference between the supply and return water. The cooling load data includes the heat loss from the pipeline and internal use, and the heating load data includes only the heat loss from the pipeline.

2. Efficiency of chiller and boiler

The coefficient of performance (COP) of the double-effect absorption chiller is set as 1.2 at the rated condition from the measured data of A-Plant. A change in the COP caused by part-load performance and the cooling water temperature is modeled from characteristics provided by a manufacturer.

The efficiency of the steam boiler is set at 0.82 under any load factor. This value includes the power consumption of accessories in the boiler system.

3. Power consumption of pumps, accessories of chillers and cooling tower

A-Plant has variable-speed control in the cooling water pump and the cold water pump. Hence, the power consumption of pumps is calculated using the equation that is derived from the relationship between the flow rate and the power consumption of the pump.

The power consumption of accessories of absorption chillers and cooling tower is set by the measured data of other DHC plants. The power consumption of accessories of chillers *Pa* is modeled as a function of the cooling capacity of the chiller *R[kW]*, as follows:

$$Pa[kW] = -2.43\times10^{-7}\times R^2 + 0.00785\times R \qquad (2)$$

The power consumption of the cooling tower per unit of waste heat from the chiller is calculated, and the average value of two DHC plants is used.

4. Multiple chiller control sequence

The number of operation chillers is determined according to the amount of heat demand and flow rate. The multiple chiller control sequence of A-Plant is set optimally depending on the heat load, and it is different each month. This operation is simulated in the model. In a general way, in order to respond to the sudden increase in the cooling load, chillers are operated in a manner such that they have a margin of load factor. This margin is 10% at A-Plant.

5. CHP

CHP is equipment that generates electricity and heat at the same time. In Japan, 50 DHC plants introduce CHP, and electricity from CHP is not used in a DHC plant in almost all cases. There are various methods to evaluate the exhaust heat from CHP (COGEN Europe Briefing 2001, Fujinami et al. 2004). In this study, we calculate the theoretical energy consumption for exhaust heat. In this approach, the input energy increment caused by utilizing CHP instead of using commercial power is considered as the input energy for obtaining the exhaust heat. We use “CHP exhaust heat coefficient” to show the efficiency of steam production with CHP. With this value, we can compare the efficiency with the steam boiler. Figure 2 shows this evaluating method. With this method, in the case where the generating efficiency of CHP is higher than that of commercial power, the input energy for exhaust heat becomes a negative number. However, it is set to zero in this simulation model.