Conduit Pressure Analysis and Renewal Effect of a District Heating and Cooling Plant

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Conduit Pressure Analysis and Renewal Effect of a District Heating and Cooling Plant

T Doyama [1, 5], M Kondo [2], H Imaoka [1], D Sumiyoshi [3], H Kitayama [4], J Lim [5] and Y Akashi [5]

[1] Kyudenko Corporation, Fukuoka, Japan
[2] Fukuoka Energy Service Co., Inc., Fukuoka, Japan
[3] Kyushu University, Fukuoka, Japan
[4] Kyushu Sangyo University, Fukuoka, Japan
[5] The University of Tokyo, Tokyo, Japan

E-mail: t-doyama@kyudenko.co.jp

Abstract. The Seaside Momochi District Heating and Cooling (DHC) plant in Fukuoka, which has been operated for more than 25 years, directly uses seawater as heat source water. The current system COP is nearly 1.00, the improvement of which is a focal point in renewal of the DHC plant. The purpose of this study is, through renewal, to present a proposal for a new management and control method of DHC including customers as well as plants. For optimal plant control, energy loss in the whole system should be analysed in detail. In this study, as a kind of energy, pressure distribution is investigated in focus on regional conduit. First, for comprehension of renewal effect, the system COP after renewal is simulated. By optimization of the operation priority order, the system COP is calculated to be about 1.20 at least. Then, for water supply system, pressure loss inside regional conduit is calculated to be very small. By minimization of the energy loss including regional conduits and customer receiving facilities, the total pump water power could be reduced by more than 40 percent. This means that further consideration of supply pump control and system management would significantly contribute to effective energy saving.

1. Introduction

The Government of Japan has supported district heating and cooling (DHC) projects for promoting a regional use of energy toward establishing low-carbon urban structures. In DHC, the heat supply agreement should be observed for all customers, which leads to an important issue today for renewal of old DHC plants. Especially in a suburb-type DHC, because of not much increase of heat supply buildings and load since completion, the heat source system has been overdesigned. The aim of this research is, as an example of an old suburb-type DHC plant utilizing seawater as heat source water, to propose a new management and control method of DHC including customers as well as plants. In Japan, although there are many cases of DHC plant renewal in terms of efficiency improvement such as extension of sub-plants, few renewal cases have rebuilt the whole system flowchart of old plants. Unlike the case of new construction, in renewal, underground buried piping should continue to be used. This means that the analysis of detailed behavior of water in regional conduits is important for catching operational problems that had passed before and deciding an improvement direction. In order to clarify reality of heat consumption in the whole water supply system, a flow balance and energy loss inside regional conduits and customer receiving facilities should be simulated, which contributes to develop a DHC control method that can realize effective energy saving. Perez-Mora et al. (2018) conclude that heat loss could be reduced by optimal supply temperature, and Castro Flores et al. (2017) also remark that heat loss and pumping energy could be decreased by return temperature change. In this research, after renewal effect analysis, firstly with attention of pressure loss, the investigation of the flow pattern and the friction loss of cold and hot water in regional conduits and the simulation of the reduction of pump water power would be conducted.

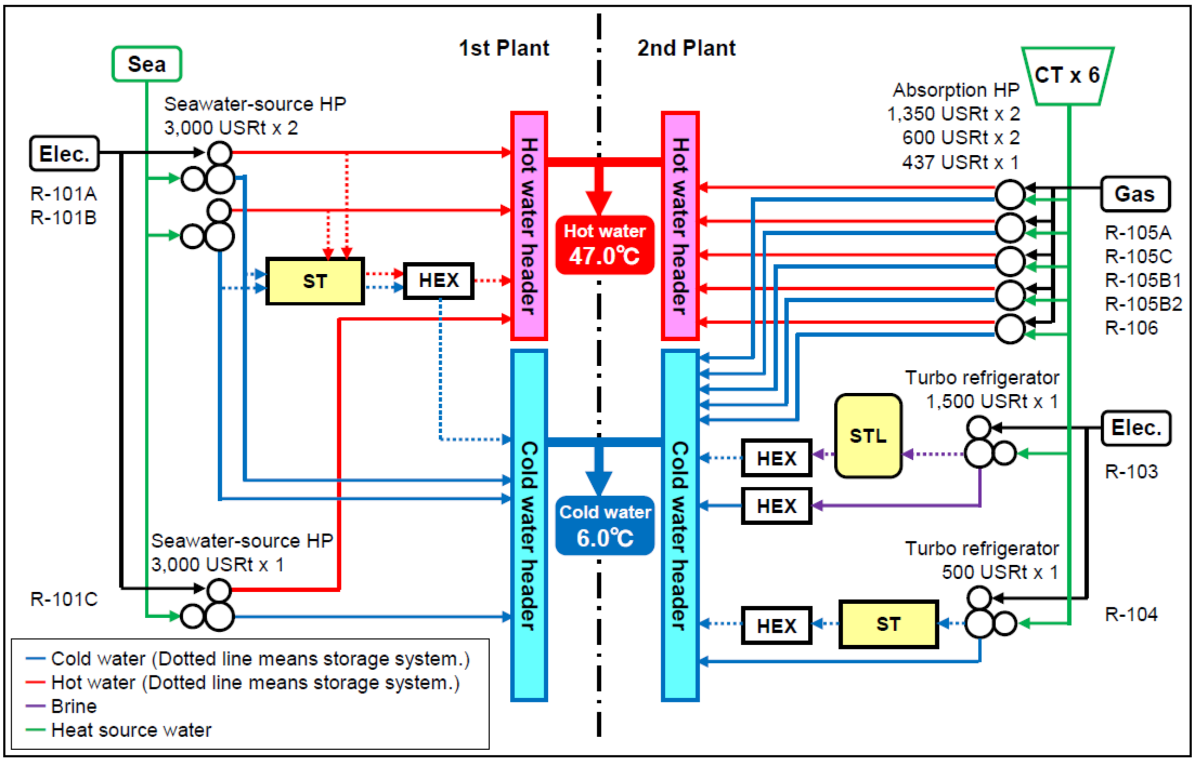

Figure 1. Current system flowchart of the Seaside Momochi DHC plant.

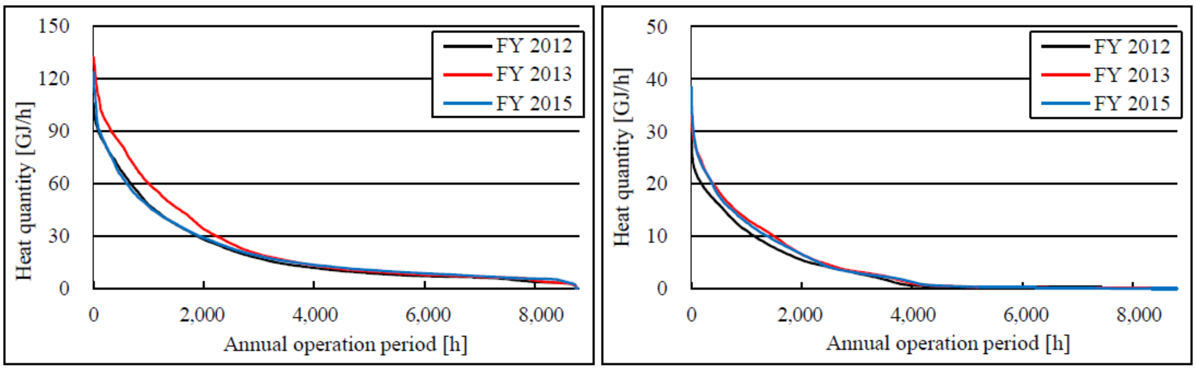

Figure 2. Cold (left) and hot (right) heat load duration curve.

2. Plant summary and heat load characteristics

The Seaside Momochi DHC plant in Fukuoka, which is composed of two plants, has been operated for more than 25 years since April 1993, and it is time to consider renewal of the heat source system of the whole plant (Figure 1). Although recently in 2008, the replacement of an absorption heat pump at the 2nd plant was conducted, three 3,000 USRt seawater-source heat pumps at the 1st plant are still as they were at the completion. At the 1st plant, space for two air-source heat pumps and two rooftop cooling towers is secured for the future and should be effectively used in renewal. Cold and hot water is supplied to 20 buildings through underground buried regional conduits, and the supply and return temperature of the heat supply agreement is respectively 6.0 to 12.0 °C for cold water and 47.0 to 40.0 °C for hot water. Seawater is to be discharged from -3.5 to +5.0 K with respect to intake temperature. The average annual heat load of fiscal year 2012, 2013, and 2015 is 1.88 x 105 GJ/yr for cold heat and 3.49 x 104 GJ/yr for hot heat, and the peak load is about 120 GJ/h for cold heat and around 35 GJ/h for hot heat (Figure 2). Although the cold heat is stably demanded throughout the year, especially during summer season, hot heat demand is very few, which is less than 1 GJ/h (Kondo et al. 2018).

3. Analysis of operational performance

3.1. Current system

Seawater-source heat pumps at the 1st plant have the highest priority of operation, which are currently in base operation throughout the year, and nearly 90 percent of annual heat production amount is dependent on these machines. On the other hand, absorption heat pumps at the 2nd plant are mainly operated at the peak load, which contributes to electric power peak-cut. Seawater-source heat pumps correspond to heat storage operation, and a heat storage tank is 4,000 m3 at the 1st plant and 1,900 m3 at the 2nd plant. In water supply system, about 15 percent of cold water in a supply header is bypassed to a return header, and around 35 percent of hot water is also bypassed, which should be minimized. As for use temperature difference, the operation period with the temperature difference secured is about 3,000 h/yr for cold water and nearly 1,000 h/yr for hot water. The operation frequency of seawater-source heat pumps is concentrated on a partial load region of 20 to 50 percent, which occupies about 50 percent of annual operation period for cooling and nearly 80 percent for heating. This means excessive capacity of existing machines (Figure 3).

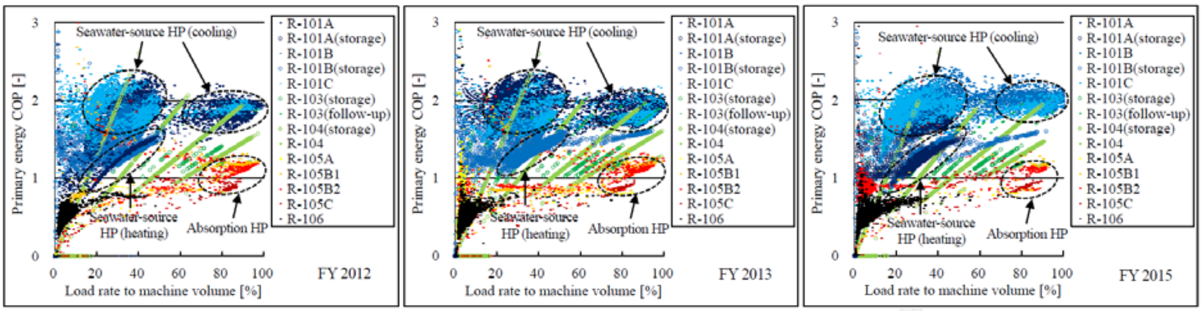

Figure 3. Existing machine COP of FY 2012 (left), 2013 (central), and 2015 (right).

3.2. Renewal system

The seawater withdrawal capacity has decreased compared to 6,600 m3/h at the completion due to adhesion of shells, and three 3,000 USRt seawater-source heat pumps cannot be operated at a full load state at the same time. The current total machine capacity is 277 GJ/h including heat exchangers for heat radiation of 83 GJ/h, which is considerably larger than the current peak load. In renewal, existing machines should be downsized and the system flowchart of two plants would be reconsidered (Figure 4). Especially for the 1st plant, switch to indirect seawater utility and backup by cooling towers during seawater system maintenance have been planned. Two turbo refrigerators (R-11, 12) are respectively 1,500 USRt for only cooling, and two turbo heat pumps (R-13, 14) are respectively equivalent to 500 USRt for only heating. These are future base operation machines throughout the year. A turbo heat pump (R-15) is for only heat storage operation with fixed-speed motor. A turbo heat pump (R-16) corresponds to both direct supply and heat storage for cold and hot water, which is projected to be firstly introduced in the renewal construction (Doyama et al. 2018).

In order to calculate machine efficiency, the priority of machine operation should be decided based on supply stability. For simplification, base operation machines (R-11, 12, 13, 14) are followed by heat storage tank discharge, heat storage machine follow-up operation (R-15), and absorption heat pumps (Figure 5). A turbo heat pump (R-16) is expected to be a spare machine for them and not covered by the simulation. Input data are cold or hot heat load and seawater temperature, which are 60-minute data. Heat load is a sum of heat supply amount of the 1st and 2nd plant, and the approach temperature of seawater heat exchanger is assumed to be constant 1.0 K.

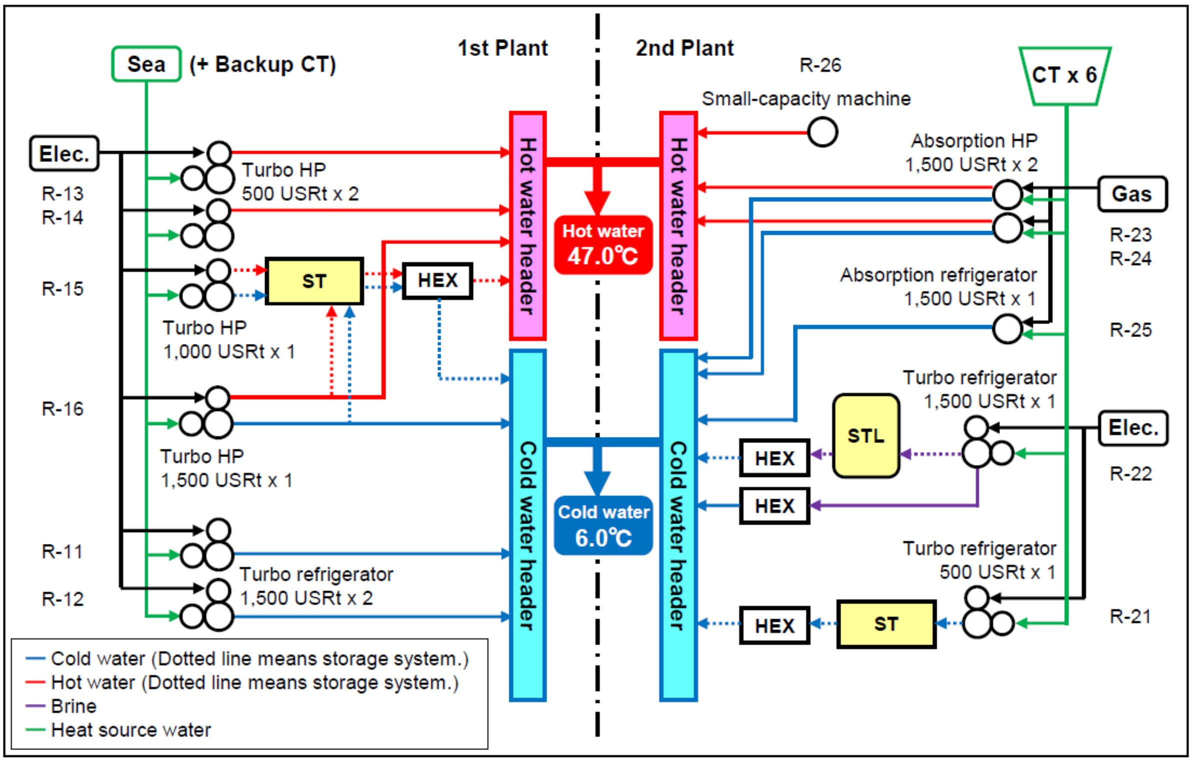

Figure 4. Future system flowchart of the Seaside Momochi DHC plant.

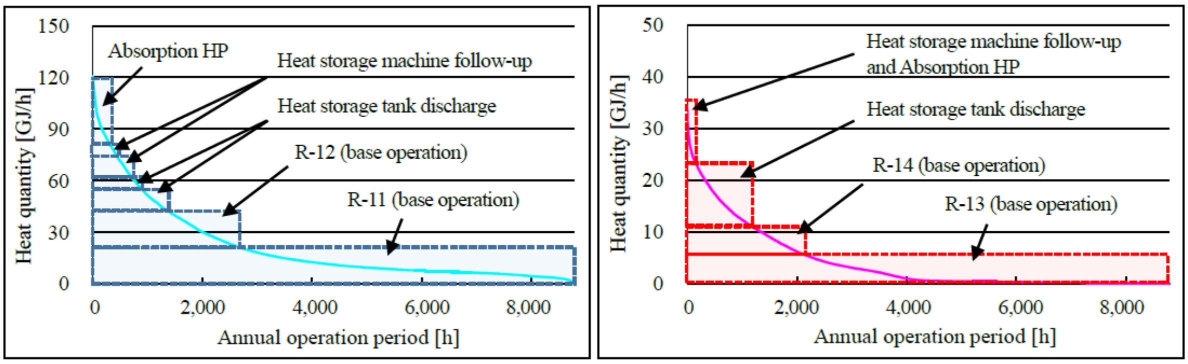

Figure 5. Operational order of new machines for cold (left) and hot (right) heat load.

Calculation results of new machine efficiency show that the COP of turbo refrigerators (R-11, 12) significantly improves at a partial load area by adoption of variable-speed motors (Figure 6). By halving heat pump capacity, the operation frequency increases at a full and high load area of 90 to 100 percent, which occupies around 40 percent of annual operation period. The 1st base operation machine (R-11) could be operated more efficiently than the 2nd machine (R-12), which means that an inverter effect occurs in winter to intermediate seasons. For heating machines (R-13, 14), because of restriction of a partial load property range, a very low load operation is unexpected. On the assumption that the

COP of heat storage machine or absorption heat pump should be 1.84 (equivalent to 5.00 on electricity) or 1.00 for cold heat production and 1.48 (equivalent to 4.00 on electricity) or 0.80 for hot heat production, the system COP is estimated to be approximately 1.20, 1.30 for cooling, and 0.80 for heating. If auxiliary machine power could be reduced by 25 percent, the system COP is expected to be nearly 1.35, 1.50 for cooling, and 0.90 for heating. This indicates the importance of reduction of pump water power.

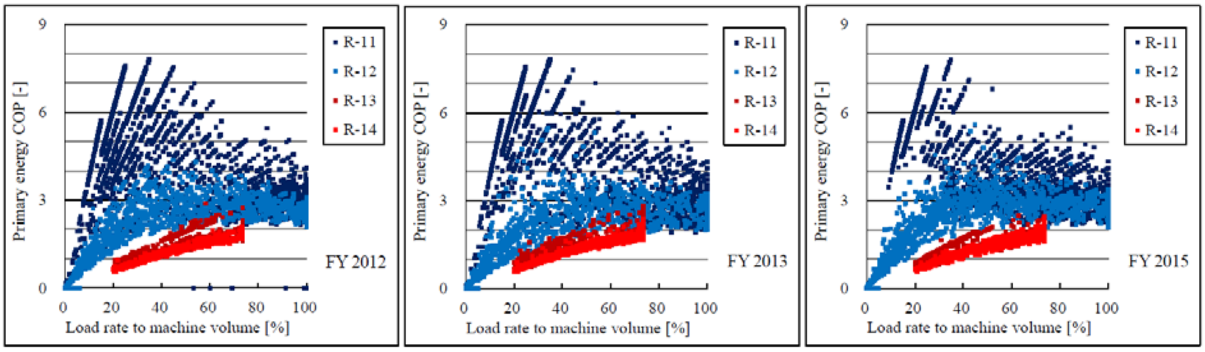

Figure 6. New machine COP for FY 2012 (left), 2013 (central), and 2015 (right) load.

4. Analysis of conduit pressure distribution

As for water supply system, pump head is dependent on pressure loss through regional conduits and customer receiving facilities as well as piping and refrigerators inside plants (Figure 7). In a customer facility, a pressure control valve, an automatic flow volume control valve, and a heat exchanger are introduced on regional conduit. A pressure tank is connected to a return header inside a plant, where gauge pressure is controlled. In order to estimate pressure distribution in regional conduits, a flow balance at all sections should be analysed for cold and hot supply and return piping. Input data are customer receiving water flow volume, which are 30-minute data, and plant supply flow volume and header bypass flow volume, which are 60-minute data. In simulation, because of angle complexity of welded piping, the joint ratio is assumed to be constant 50 percent for all customers.

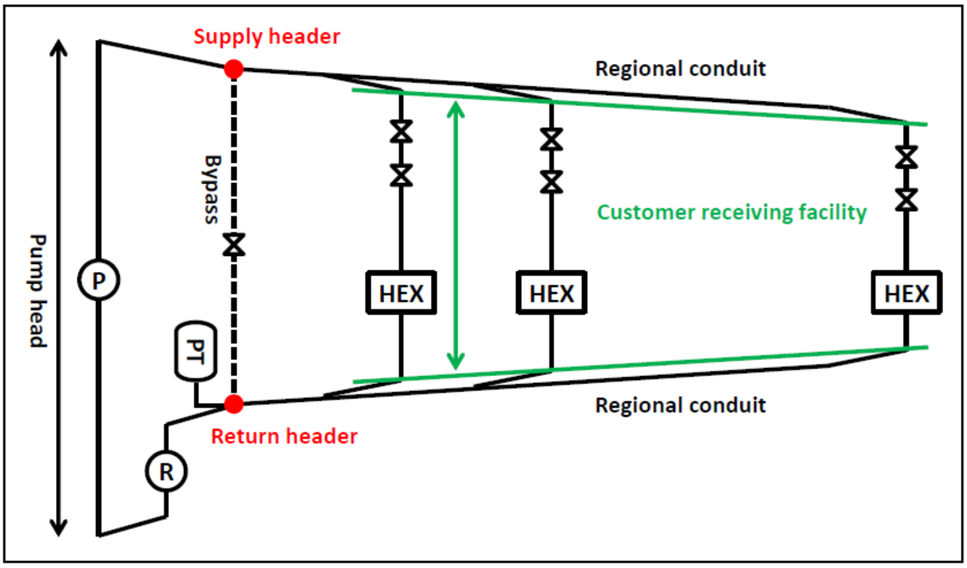

Figure 7. Water supply system flowchart.

The 1st and 2nd plant are connected by bypass piping, where a water flow direction is varied by flow balance in the whole conduit (Figure 8). The flow is divided into five patterns and influences a calculation origin of conduit pressure loss to customers. The pattern A or E is the case that the 1st or 2nd plant alone is in operation. The pattern B, which is common in the Seaside Momochi DHC, is the case that the 1st plant is mainly operated and can cover the east area demand. When the east area demand is very high and above the 1st plant supply, the pattern B becomes C, which frequently occurs on the peak time. The pattern D is a rare case. These five flow pattern could be decided by flow balance of all customer receiving water flow volume, and pressure loss in regional conduits of customers is calculated based on the flow pattern.

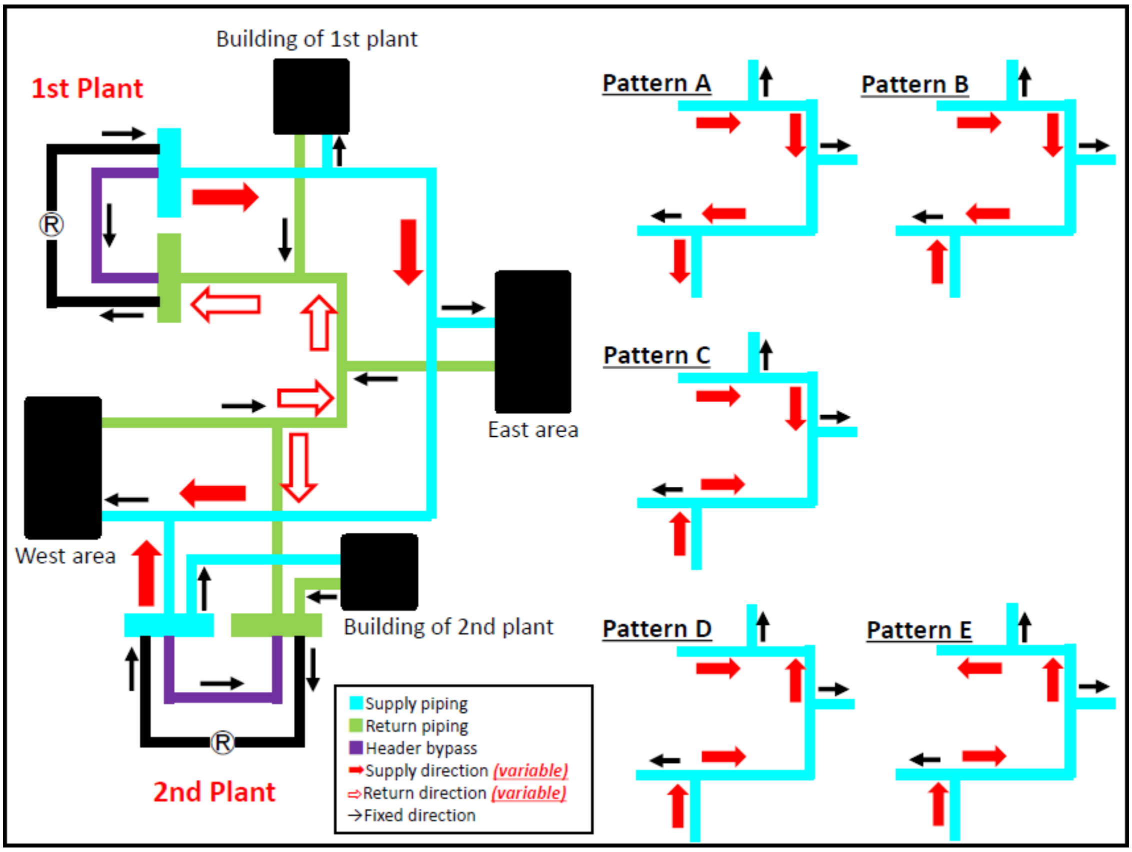

Figure 8. Water flow pattern in regional conduit.

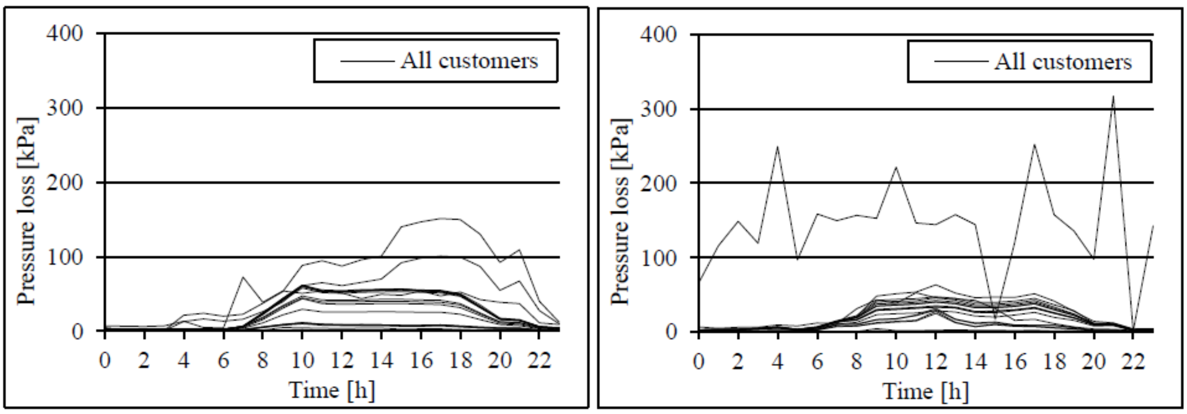

Figure 9. Pressure loss through regional conduit of cold (left) and hot (right) water on the peak day.

Calculation results of flow balance inside the regional conduits show that the pressure loss throughout regional conduits is very small, whereas a drastic pressure loss is found at the customer receiving facilities (Figure 9). In current operation, the constant differential pressure control has been conducted, which would cause the decrease of the opening of pressure control valves at customer receiving facilities. By minimization of the bypass flow volume at plants and maximization of the opening of pressure control valves due to the flow control of inverter pumps, a significant reduction of pump water power could be expected. Even on the summer peak load time, on the supposition that the pressure loss at the customer facility and plant should be 300 kPa, the pump head of cold water is required to be about 450 kPa and possible to be reduced by nearly 40 percent compared to 720 kPa at the present. The improvement of control method of water supply system enables further energy saving.

5. Discussion
Results of renewal effect prove that feedback on reduction of auxiliary machine power leads to further energy saving, and results of pressure loss inside regional conduits remark that supply pump water power could be extremely reduced by optimal pump control. The necessity of variable head control by inverter pumps is signified for effective water supply. In DHC design, although the decision of pump capacity is a very important factor, excessive pumps tend to be introduced because of excessive heat source machines compared to estimated real heat load. In this research, the pressure distribution in regional conduit is simulated, and an improvement direction in renewal is clarified such as supply pump control. By analysis of flow balance, an operational control method including customers could be considered in the next step. Furthermore, by simulation of energy loss through underground buried piping, a proposal of optimal management method could be expected.

6. Conclusion and implications
The energy loss problem of regional conduit is a very important challenge in DHC. In this research, pressure loss in buried regional conduit is focused, which has not been minutely analysed in previous studies on DHC. By pressure analysis in the whole conduit, a breakthrough in control optimization toward renewal is implied. The heat supply agreement of the Seaside Momochi DHC says that the supply header pressure should be 0.53-0.78 MPa for cold and hot water. In order to propose a new management method based on this research, the supply agreement might be modified in the future.

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