A PRACTICAL STUDY ON APPLICATION OF COMMISSIONING
TO A DHC PLANT DURING THE OPERATION AND MAINTENANCE STAGE

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1. BACKGROUND

Increased in public awareness of the need to reduce environmental load has led to growing interest in efficient energy management strategies such as thermal storage systems. However, problems are likely to be encountered if a thermal storage system is installed without commissioning (Cx) to ensure that the system operates as intended. A thermal storage system consists of numerous machines, so the system requires Cx or at least “TAB” (Test Adjust and Balancing). In Japan, the importance of Cx or TAB is well known to engineers, but there are as yet few examples of their application.

2. SUBJECT OF STUDY

In this paper, we carried out a practical study of Cx with the DHC with the largest thermal storage tanks (19,060 m³) in Japan, (completed in March, 2001, in Tokyo: Fig. 1). Details on the customers are shown in Table 1. This DHC (district heat and cooling) plant is located near the Tokyo waterfront, and provides chilled and hot water to three office skyscrapers (over 150 m): one tall office building, a commercial institution, and a hall. A redevelopment plan for this area was announced in 1988, and the guidelines for the plan and specific were determined by a committee comprising academic experts, owners, power companies and designers. This was an innovative approach at the time. The committee decided the following for both environmental preservation and economic reasons. 1) To install the main plant in the center of this area; 2) to use a temperature difference of 10 °C; 3) to adopt huge thermal storage tanks, and

Table 1: Details of customers

<table>
<thead>
<tr>
<th>Use</th>
<th>Office tower A</th>
<th>Hall</th>
<th>Office tower B</th>
<th>Office tower C</th>
<th>Office tower D</th>
<th>Common part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stories</td>
<td>Above ground</td>
<td>45</td>
<td>6</td>
<td>40</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Below ground</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total floor area</td>
<td>131,197m²</td>
<td>4,871m²</td>
<td>119,500m²</td>
<td>103,781m²</td>
<td>31,610m²</td>
<td>71,444m²</td>
</tr>
<tr>
<td>Air conditioning area</td>
<td>83,400m²</td>
<td>3,400m²</td>
<td>77,900m²</td>
<td>63,400m²</td>
<td>24,000m²</td>
<td>30,260m²</td>
</tr>
</tbody>
</table>

Fig. 1 Buildings in DHC area
3. OUTLINE OF FACILITIES

The area plan of this plant is shown in Fig. 2 and the facility outline is shown in Figure 3. This DHC has huge storage tanks that can supply half of the peak day load in summer. They are installed under office towers B and C and consist of five tanks and with a total capacity of 19,060 m³: two tanks exclusively for cooling, one tank for heating only, and two switch tanks for cooling and heating to adapt to seasonal changes. All are temperature-stratified-type thermal storage tanks. The capacity of the chillers is 16,088 kWh in total. They consist of two electric turbo refrigerators (TRs), two heating tower heat pumps (HTHPs), and two double bundle heat-recovery turbo refrigerators (DBs). Concerning the supply conditions, the chilled water temperature is 6 °C (supply) - 16 °C (return) and the hot water is 47 °C (supply) - 37 °C (return). Reduction of transporting power and pipeline diameter was realized by using large temperature differences. It also appears feasible to improve the performance of the thermal storage tanks. All the customers’ secondary systems employ closed circuits with heat exchangers. Secondary pumps are controlled by VVV with inverters and contribute to maintaining the temperature differences and reducing transporting power. Moreover, fan-coil units and air-handling units which can maintain a temperature difference of 10 °C were adopted.

Fig. 2 Area plan of plant

4. OVERVIEW OF OPERATION RESULTS

4.1 Cooling and heating loads

Figure 4 shows the monthly heating and cooling loads. The peak cooling load comes in July or August and the peak heating load is in June. Although the common part makes up one eighth of the entire air conditioning area, the cooling and heating loads for the part occupies a quarter of all. The principal reason for this is that the common part includes restaurants. Cooling load in the winter is much lower than estimated when the plan was formulated, since the customers’ interior systems use double piping. Therefore, most of the zones change to only heating in winter.

Fig. 4 Cooling and heating loads
4.2 Electric power consumption

Figure 5 shows the details of electric power consumption over a three-year period. Chillers occupied about three quarters of the total (72%). However, the ratio accounted for by transportation pumping is very small (11%). VWV control with inverters, appropriate quantity control and the short distance from the plant to customers are the reasons for this low pump ratio.

![Figure 5 Details of electric power consumption](image)

4.3 Operation of chillers

Figure 6 shows monthly COP values for the chillers, calculated from the total electric power consumption by the chiller compressors and auxiliary heaters (not including transportation pumps). When different operation modes (chilling, heating and heat recovery mode) are mixed in the same month, the COP is calculated simply as the total of electric power consumption and quantity of heat. The COP of the TRs in summer exceeded 5. However, this performance afforded no advantages in winter, since the cooling load in winter was very small. The COP of the HTHPs dropped in winter since they switch to heating mode (COP: 3.2). Between autumn and spring, the DBs had been operated in cooling and heating mode at the same time (heat recovery mode), so they had operated very efficiently.

Figure 7 shows the hourly load factor for the chillers. The load factor of the chillers had been maintained at a very high level. Therefore, the COP was maintained at a constant value around the rated specification. This ideal state was due to the use of a huge thermal storage tank, showing that installing sufficient thermal storage tanks leads to the chillers' high load factor.

![Figure 6 COP in each of Chillers](image)

![Figure 7 Hourly load factor of chillers in each of operation mode](image)
5. EFFECTIVENESS OF COMMISSIONING

5.1 Readjustment of cooling water temperature for turbo refrigerators

In April 2003, we readjusted the cooling water temperature to enhance the COP of the TRs. Previously, the lower limit of the cooling water temperature had been set to 25 °C. This temperature was the recommended limit which included a safety margin. We then asked the manufacturer what the real lower limit was and readjusted the lower limit temperature to 20 °C. Figure 8 shows the result for the COP before and after readjustment. This readjustment allowed us to enhance the COP.

![Fig.8 Readjustment result of the cooling water temperature for TR (hourly data)](image)

5.2 Readjustment of increasing and a decreasing point of pump quantity control

Based on an analysis of the pump operation data, we checked whether the pumps were under the appropriate quantity control. Figure 9 shows the readjustment result of an increasing (and decreasing) point for pump quantity control. Before April 2003, electric power loss appeared to be around 400 m³/h and 1250 m³/h. We confirmed that these regions were located around the increase and decrease value of pump quantity control. Therefore, the increasing point was changed to 100% from 95%, and the decreasing point was changed to 85% from 75%. These values were set after confirmation using pulsation tests. Our calculations confirmed that an electric power saving of 5% would be achieved by this readjustment.

![Fig.9 Readjustment of increasing and decreasing point of pump quantity control](image)
5.3 Readjustment for maintaining large temperature differences

The temperature difference of this DHC was set high at 10 °C. However, it was not easy to maintain such a large difference of temperature, especially at lower flow volumes. Figure 10 shows chilled water flow and temperature difference. Low flows were seen for most of the operating time. We therefore had to readjust the system to prevent the pumps wasting electric power and to guard against loss of temperature stratification in the storage tanks. From an analysis made in 2001, we found that bypass flow adjustment was not sufficient. The mean temperature difference in 2002 was therefore enhanced by 0.8 °C compared to 2001. We also changed the supply water temperature to 5 °C from 6 °C at the end of 2002. The chilled water temperature from the chiller was measured at 5 °C in spite of the default supply temperature from this DHC being 6 °C. This margin (1 °C) was added in consideration of temperature rise during thermal storage. However, we found from a detailed measurement of the thermal storage tanks that this margin was not necessary in this DHC: storage loss was small enough so that a margin is not necessary. In the light of these results, the mean temperature difference in 2003 was enhanced by 0.5 °C compared to that in 2002.

![Fig. 10 Chilled water flow and temperature difference](image)

5.4 Enhancement of use of night rates

Power companies have an electric load-leveling agenda. In Japan, thermal and hydro power are not in principle used for night-time power generation: nuclear power generation is the chief type of power generation used. This means that CO2 emissions are low for night-time electric power. Due to this situation, discount contracts are arranged. Electricity charges during the night are about 20% of those during the day. Therefore, greater use of nighttime rates is very important for not only power companies but users. Daily cold energy, split into daytime and nighttime in descending order is shown in Figure 11. As a result, annual night-shift-rate increased year by year.

![Fig.11 Daily cold energy sorted into descending order (split into night-time and day-time)](image)
6. RESULTS OF PLANT OPERATION

Previously discussed COP does not include electric consumption of pumps. To evaluate DHC plant efficiency, we used primary energy conversion COP*3 of this plant. In addition, standard value of DHC in Japan is between 0.6 and 1.2. Figure 12 shows the primary energy conversion COP of this plant. In summer, plant COP is more than 1.3. This reflects effectiveness of base operation of TRs (COP: 5.3) in generating cold energy. On the one hand, in winter, the plant COP falls to less than 1.0. This is due to basic operation of HTHPs (heating mode COP: 3.2). The original design assumed greater cold energy demand in winter than was actually the case. For this reason, the DB heat recovery mode could not generate enough cold and hot energy. In 2001, the COP for primary energy conversion was 1.20. This rose to 1.19 in 2002. In 2003, it was 1.18. These figures show that the DHC system had been operated at a high COP of about 1.2 that has not been influenced by deterioration due to age or weather conditions.

![Fig. 12 primary energy conversion COP of the DHC](image)

7. CONCLUSION

By means of continual measurement, analysis and readjustment, we demonstrated the advantages of continual Cx. The following results were shown in the “Operation & Maintenance Stage”.

1) It was shown that this DHC had been operated at a high primary energy conversion COP (about 1.2) that has not been influenced by deterioration due to age or weather conditions.
2) As the result of continual Cx, the temperature difference rose to about 10 °C.
3) Due to the efficient operation of large thermal storage tanks, most of the energy consumption was shifted to the nighttime and chillers were operated with a high load factor.

These results are one of the first case examples of a practical study of Cx during the “Operation & Maintenance Stage” in Japan.

REFERENCES


NOMENCLATURE

*1: COP [-] = energy production / electric power consumption

*2: Night-shift-rate (quantity of heat) [-] = quantity of heat production at night [MJ] / quantity of heat production on all days [MJ]

*3: Primary energy conversion COP[-] = quantity of heat production on all days [MJ] / (electric power consumption in the day-time [kWh] * 10.25 [MJ/kWh] + electric power consumption at night [kWh] * 9.62 [MJ/kWh])