Study on Commissioning Process for Control Logic of Thermal Storage System

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Summary

The Heating, Ventilation, and Air-Conditioning (HVAC) System Control Logic Tracer, or 'CLT' , can trace the control moves of an HVAC system and display it on a flowchart based on operation data collected in BEMS. Through comparison between estimates and measurements of the control output, the CLT can detect faults relating to operation. The present paper reports the result of commissioning of a heat exchanger secondary control in a thermal storage system in an actual building using the CLT.

Introduction

In thermal storage systems, as large temperature difference between the supply water and the return water as possible should be maintained in order to ensure high system efficiency. However, this may be difficult in some cases if an operation fault occurs due to improper system control. The HVAC System Control Logic Tracer ("CLT") can trace the control moves of an HVAC system and display it on a flowchart based on operation data collected in BEMS. Through comparison between traced value and measurements of the control output, the CLT can detect faults relating to operation. [1)]

This paper reports the result of commissioning of the control moves, using the CLT, at the secondary water circuit of a heat exchanger installed between the thermal storage system and secondary HVAC system of an actual building. One of the authors, Nakahara, acted as Commissioning Authority during construction phase and later as a consultant of on-going commissioning. Several note added in the following explanation are his notes as reminder. This does not affect the purpose of the research of the present paper.

The study was conducted as part of the committee works on the Performance Evaluation and Commissioning of Thermal Storage System conducted by the Heat Pump & Thermal Storage Center of Japan (HPTCJ) in fiscal 2002.

1. Outline of target building

1.1 Building

- Floors: Four stories above ground
- Building area: 702.67 m^2
- Total floor area: 1968.75 m^2
- Application: Offices and research facilities

1.2 Heat source equipment

(1)Heat source system

The building uses a water thermal storage system. The system has a multi-connected temperature stratified tanks in an open circuit for storing chilled and heating water in change-over mode by season. In addition it allows to form a closed circuit for a short term of intermediate season and for experimental operation as well. The following shows general information about the heat source system based on design documents:

a. Thermal storage tanks: S-shaped penetration pipe type thermal stratification tanks (60 m^3, 9 tanks)
Supply water temperature to the heat exchanger: 7°C for cooling, 45°C for heating

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b. Air-source heat pump chiller

Cooling capacity: 56 kW, chilled water temperature: 12°C → 5°C (rated flow rate: 145 l/min)

Heating capacity: 63 kW, heated water temperature: 47°C → 40°C (rated flow rate: 145 l/min)

c. Plate type heat exchanger

Cooling: outlet/inlet temperature - primary 5°C/12°C, secondary 7°C /14°C

Heating: outlet/inlet temperature - primary 47°C /40°C, secondary 45°C /38°C

The heat source system is shown in Figure 1.

Note 1: Actually, there is a design fault at rating heat exchanger temperatures. Rating the same value for the heat pump's outlet and heat exchanger's inlet water temperatures makes thermal storage efficiency enormously low. Therefore, in actual operation, there shall be two degree C difference between the two in order to keep reasonable storage tank thermal capacity.

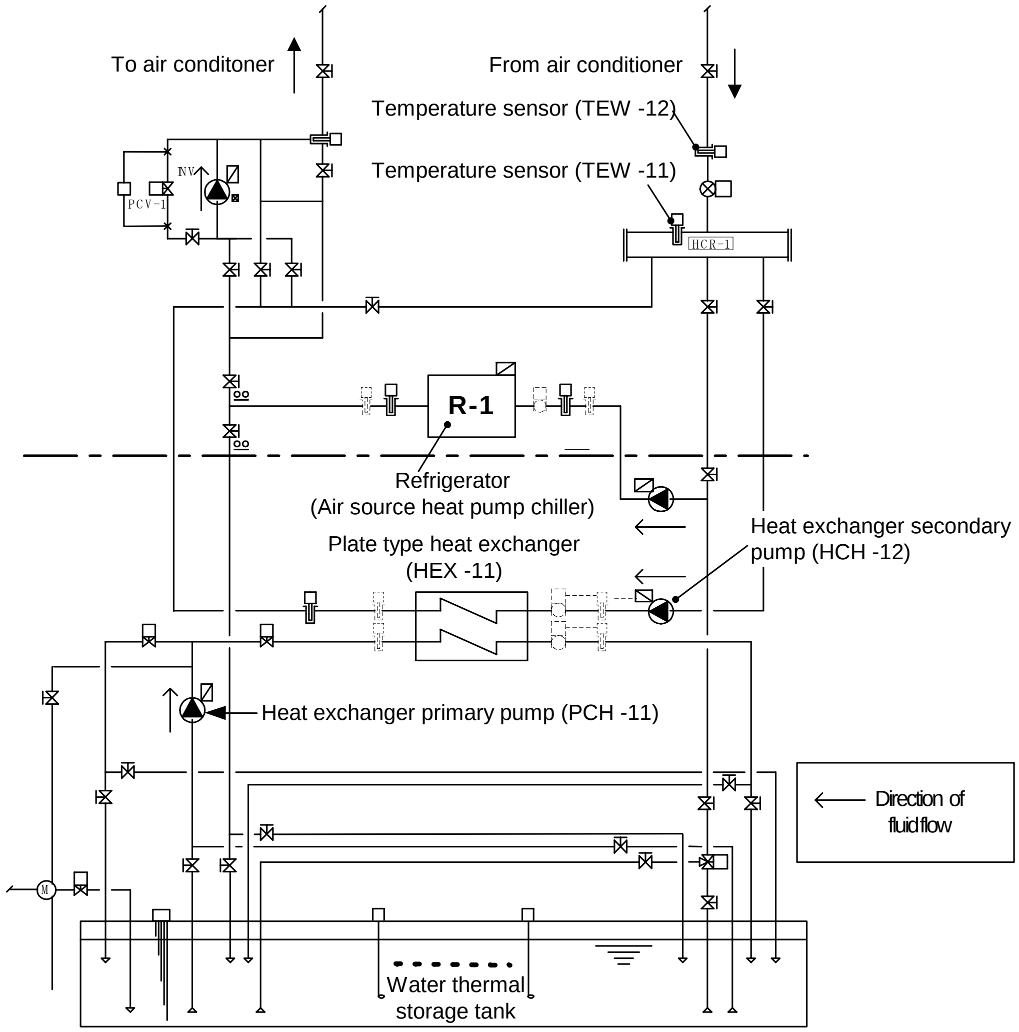

Figure 1. Heat source system

(2) Heat source control logic

a.Load-side supply water temperature control

During automatic control mode, the secondary supply water temperature is calculated from a reference cooling/heating water temperature (17°C for cooling, 38°C for heating) and the deviation between the heat exchanger secondary supply water temperature and the secondary return water header temperature. During manual control mode, the secondary supply water temperature is set to a fixed value (9°C for cooling, 47°C for heating). Figure 2 shows the control logic.

b.Heat exchanger secondary pump inverter control

The deviation between the secondary return water temperature and its setting is determined. The result is used to determine the inverter control output using a cooling/heating mode equation. Figure 3 shows the control logic.

Note 2: During on-going commissioning process as well as initial commissioning process, the CA advised that some unfavorable moves might occur in this pumping diagram using two pumps in series and control algorithms concerning these pumps and around headers and heat exchangers, as well, while they were left as original design as one of subjects to be solved during on-going control commissioning process.

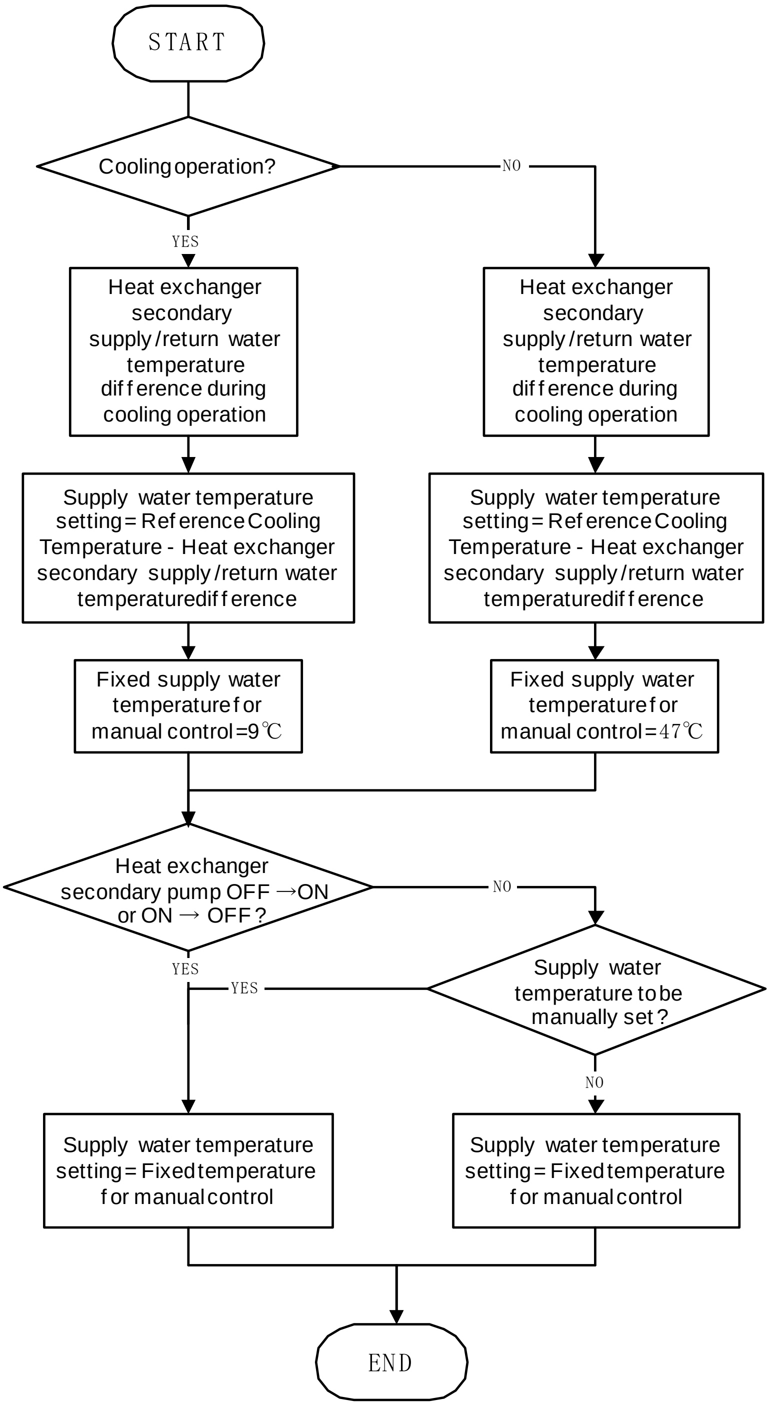

Figure 2 Supply water temperature control logic

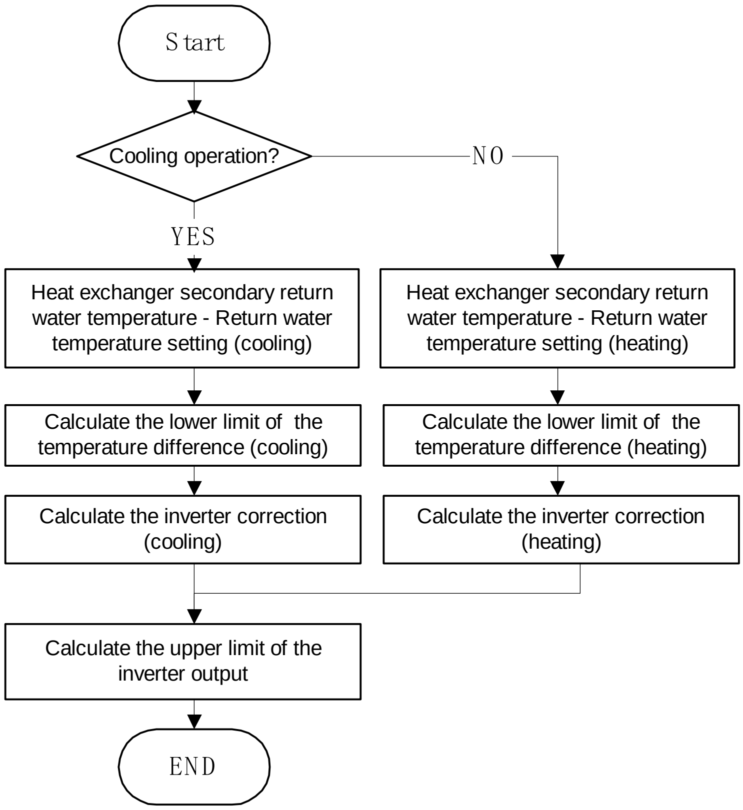

Figure 3. Heat exchanger secondary pump inverter control logic

2. Operational performance of heat source system

2.1 Primary side of heat exchanger

Figures 4 and 5 show the supply and return water temperatures, the temperature differences between the two, and the instantaneous flow rate in the primary side of the heat exchanger on a typical day in a winter season (January) and in a summer season (August) in 2002.

(1)Heating operation

For the winter season (January 21, 2002), the primary supply water temperature to the heat exchanger is between 45°C and 47°C from the start of operation of the HVAC system until around noon. This performance almost meets the design value of 47°C. From noon onward, the supply water temperature drops by about 2°C, and the return water temperature remains at around 39°C. This result indicates that the heat exchanger primary temperature difference almost satisfies the design value of 7°C.

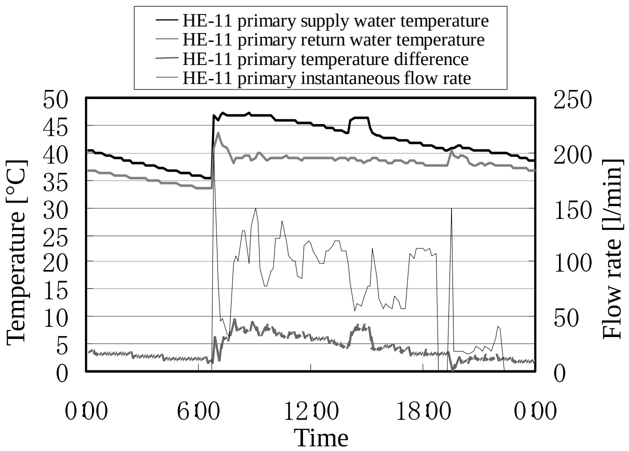

Figure 4. Heat exchanger primary side performance (January 21, 2002)

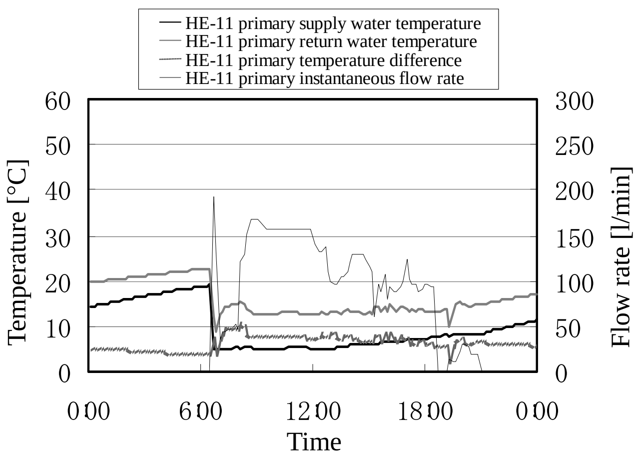

Figure 5. Heat exchanger primary side performance (August 19, 2002)

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(2)Cooling operation

For the summer season (August 19, 2002), the supply water temperature is around 5°C, which is the design value. The temperature rises after 17:00, and yet the primary temperature difference of the heat exchanger is kept between 5°C and 9°C, which meets the design value of 7°C.

Note 3: Temperature rise of the inlet water, that is, the temperature rise of the initial tank, is a normal result coming from storage operation in order to keep proper efficiency and storage capacity as having been reminded at Note 2.

2.2 Secondary side of heat exchanger

Figures 6 and 7 show the supply and return water temperatures, the temperature differences between the two and the instantaneous flow rate at the secondary side of the heat exchanger on a typical day in the winter season (January) and in the summer season (August) in 2002.

(1)Heating operation

For the winter season (January 21, 2002), the heat exchanger secondary supply water temperature is between 38°C and 46°C, while the return water temperature is between 37°C and 43°C, which is rather high, and the secondary temperature difference is between 0.5°C and 4°C. These values are far below the design value of 7°C. Comparing the secondary return water temperature (TEW-11 in Figure 1) in the return water header (HCR-11 in Figure 1) with the secondary return water temperature before the header (TEW-12 in Figure 1), the former is higher than the latter by about 4°C while the HVAC system is on operation.

(2)Cooling operation

On a typical summer day (August 19, 2002), the supply water temperature is around 7°C, which is the design value. The pattern of temperature variation that the water temperature rises after 15:00 appears again here. The heat exchanger supply/return water temperature difference is between 5°C and 9°C, which meets the design value of 7°C. Comparing the secondary return water temperature between in the header and before the header, the former is lower than the latter by about 4°C for some specific periods during HVAC operation.

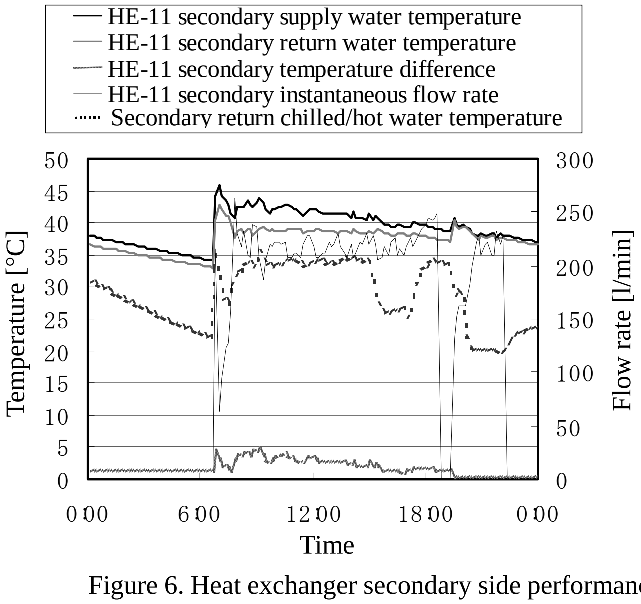

Figure 6. Heat exchanger secondary side performance (January 21, 2002)

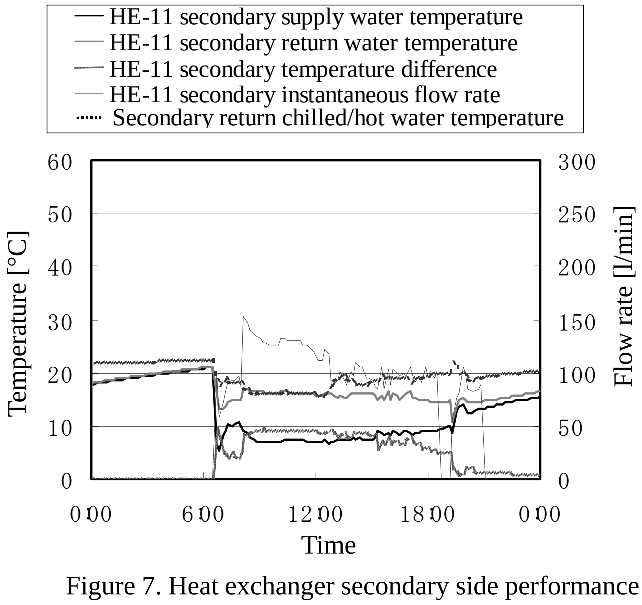

Figure 7. Heat exchanger secondary side performance (August 19, 2002)

(3)Total count of heat exchanger secondary inlet/outlet temperature differences

Figures 8 and 9 show the distribution of the total counts of the heat exchanger secondary inlet/outlet temperature differences for January and August of 2002 respectively. The figures show that in the winter season, which should be accompanied by low heating load and secondary flow according to the design, small temperature differences occur more frequently than in the summer season, and that in the summer season, which should be accompanied by high cooling load and secondary flow according to the design, large temperature differences occur more frequently than in the winter season.

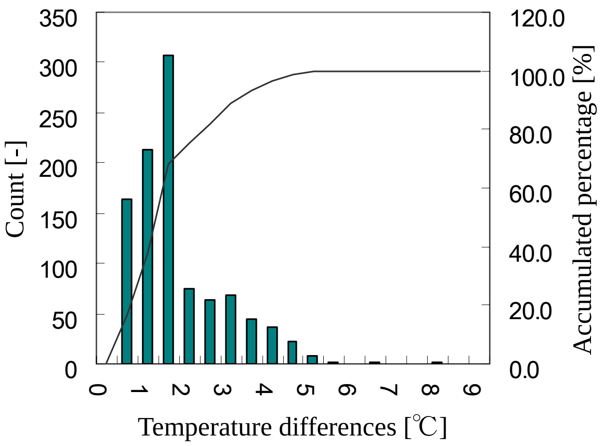

Figure 8. Distribution of total counts of heat exchanger inlet/outlet temperature differences (January 2002)

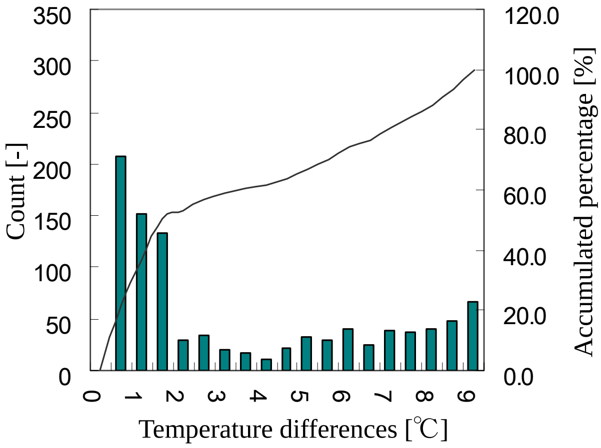

Figure 9. Distribution of total counts of heat exchanger inlet/outlet temperature differences (August 2002)

3. Estimation of control output using CLT

The CLT was used to trace the moves of the control output (ex. valve output, supply temperature setpoints). When there is a large difference between estimated values and actual measurements, it can be judged that the system was operated outside of the control logic due to some fault. The following describes the result of commissioning of the control logic for the secondary side of the heat exchanger stated above.

3.1 Load-side supply water temperature control

Based on the control logic shown in Figure 2, the temperature settings for the secondary supply water of the heat exchanger (HEX-11 in Figure 1) were estimated. The estimated settings were compared with the actual temperature settings and measurements.

(1)Heating operation

Figure 10 shows the traced data for January 21, 2002 as a typical winter day. In the figure, the estimated secondary supply water temperature settings almost coincide with the actual settings. Thus, the trace produced by the CLT reveals that the secondary supply water temperature was actually set according to the control logic.

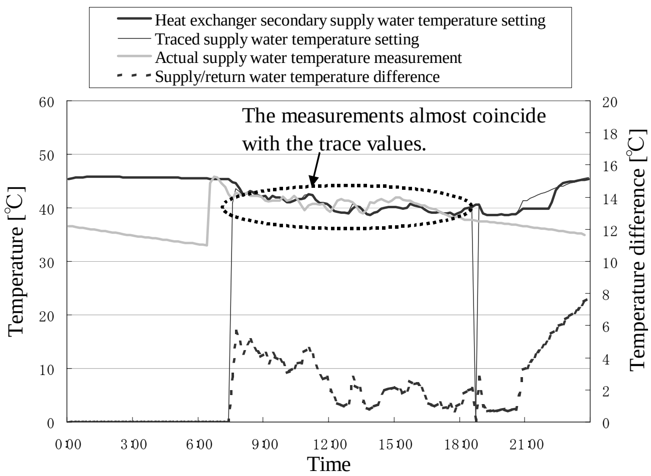

Figure 10. Comparison of load-side supply water temperature control output between trace values and measurements (January 21, 2002)

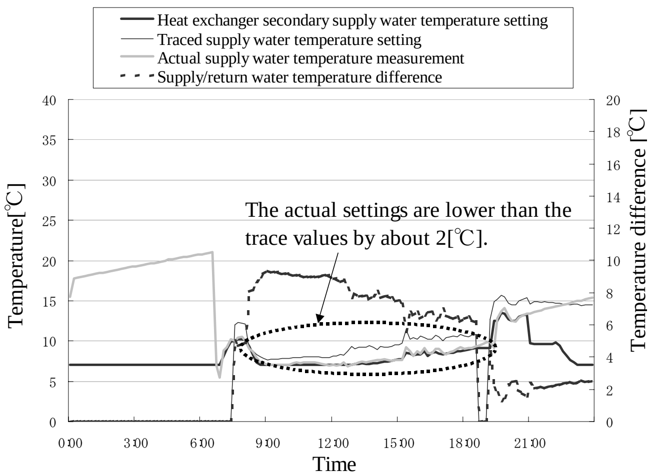

Figure 11. Comparison of load-side supply water temperature control output between trace values and measurements (August 19, 2002)

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(2)Cooling operation

Figure 11 shows the traced data for August 19, 2002 as a typical summer day. The estimated secondary supply water temperature settings given by the CLT are higher than the actual settings by about 1°C or 2°C. Thus, the trace produced by the CLT reveals that the secondary supply water temperature settings were probably outside of the control logic

3.2 Heat exchanger secondary pump inverter control

(1)Heating operation

Figure 12 shows the traced data for January 21, 2002 as a typical winter day. Substantially different from the estimated values drawn from the control logic, the actual pump inverter control output remains the maximum (100%) almost all the time the HVAC system is operating.

(2)Cooling operation

Figure 13 shows the traced data for August 19, 2002 as a typical summer day. The actual inverter control output almost coincides with the traced values. This indicates that the system was correctly controlled according to the control logic.

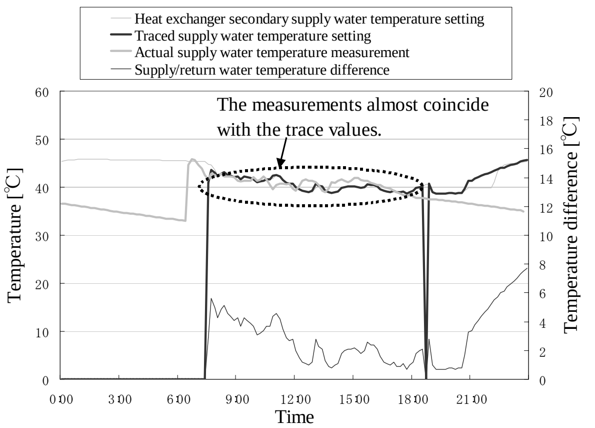

Figure 12. Comparison of pump inverter control output between trace values and performance (January 21, 2002)

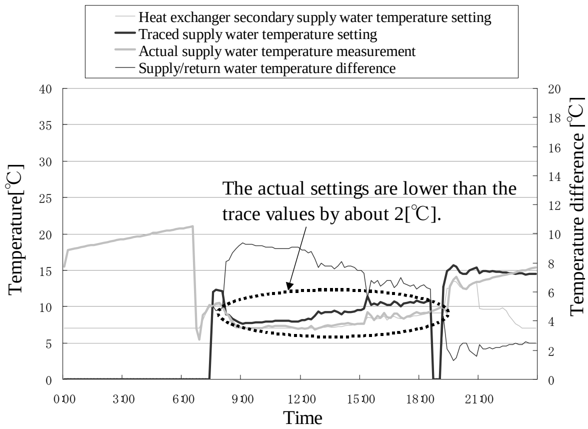

Figure 13. Comparison of pump inverter control output between trace values and performance (August 19, 2002)

4.Commissioning of operation control

4.1 Load-side supply water temperature control

With the result of commissioning using the CLT, the DDC was checked for the related control parameters. Three settings including the Reference Cooling Temperature were found to have been set to values that were different from those specified in the as-built documents. The supply water temperature for the summer season had been set to a value lower than that given by the original control logic. This lower temperature setting probably caused more water to flow into the return water header through the bypass pipe, reducing the temperature of the return water. As a result, the predetermined temperature difference between the supply water and the return water could not be obtained.

4.2 Heat exchanger secondary pump flow rate control

Similarly, the DDC was checked for the related control parameter settings. It was found that the parameter setting for the control output equation, which uses the deviation between the secondary return water temperature and its setting as a variable, had been changed. This must be the reason why the inverter was operated with large control outputs of 70% to 100%. Particularly with a temperature difference of 4°C or more, the inverter was continuously operated with a control output of 100%. Since the secondary side is under low-load operation and with restricted flow, the supply chilled water may have been diverted to the return water header through the bypass pipe. The water was then mixed with the return chilled water. This may be the reason why the supply/return water temperature difference could not be ensured.

5. Conclusion

Control logic is often not well understood by designers and operation managers, and in many cases it is hard to identify the causes of troubles associated with control. In this study, the CLT was successfully used to reproduce the control history of an HVAC system, and identified a fault of the system control.

The result observed was partly due to the basic problems included in the original piping and control design an noted in Note 1 to Note 3. These problems are being corrected during on-going commissioning as follows. Items 3) and 4) are not budgeted yet.

1) Two pumps installed in series in the secondary circuit of heat exchanger are which are controlled individually, request necessity of bypass valve between headers that causes malfunctions. Two pumps have been controlled by the same control manipulation signal.
2) In addition, as need for bypass still remains, bypass valve opening was set minimum as not to be burnt up even at the smallest flow rate.
3) Secondary pump speed control and its direct bypass valve control that presently depend on the pressure at the pump delivery with reset have been discussed about replacing by maximized terminal valve openings control.
4) Introduction of optimal setting of storage temperature and secondary pump delivery temperature using performance function as minimum energy and constraints as environmental conditions represented by terminal valve openings has been discussed.

6. Acknoledgement

This CLT was developed through joint research between Tokyo Electric Power Co., Inc. and Kajima Technical Research Institute. The authors acknowledge their assistance in applying the CLT in this study. The study was conducted as part of the Performance Evaluation and Commissioning of Thermal Storage System conducted by the Heat Pump & Thermal Storage Center of Japan (HPTCJ) in fiscal 2002. Also they acknowledge the responsible people of Heat Pump & Thermal Storage Center of Japan and Yamatake Corporation for their kind admission to publicize their achievements.

References

1) Shioya and Tsubota, Development of HVAC System Control Logic Tracer (Part 1); General Tool Information and Practicality Study, Papers of The Society of Heating, Air-Conditioning and Sanitary Engineering of Japan (September, 2002), pp. 1225–1228
2) Tsubota and Shioya, Development of HVAC System Control Logic Tracer (Part 2); Application of VAV Control to Commissioning Process, Papers of The Society of Heating, Air-Conditioning and Sanitary Engineering of Japan (September, 2003) ,pp 1245-1248
3) Nakahara, et al., Practical Study on Initial Commissioning of Heating, Ventilation and Air-Conditioning System (Report No. 1–6), Papers of The Society of Heating, Air-Conditioning and Sanitary Engineering of Japan (September, 2001), pp. 309–332