Practice and Study on the Total Building Commissioning for a University Facility: Thermal load, Energy consumption data and evaluation of OPR using LCEM Tool

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ABSTRACT
This paper reports study on life cycle commissioning for a university facility. In this building, commissioning in the whole fields of architecture has been conducted since planning phase. Total energy consumption in operation phase was calculated in the final stage of design phase. The predicted value was compared with required condition of OPR (Owner’s Project Requirement) to examine the validity of design. Then, performance in operation phase was examined by means of comparing measurement value with predicted value. According to the examination, it was found that there was difference between design and measurement values for the use of air conditioning. In this paper, as a commissioning in operating phase, causal factors for difference of the energy consumption for air conditioning were extracted by analyzing measurement data. The influence of each causal factor was confirmed by simulation using LCEM tool. This paper proves that LCEM tool is useful through the life cycle commissioning by above mentioned verifications.

KEYWORDS
commissioning, energy consumption, LCEM tool

INTRODUCTION
It is rare that building services such as air conditioning system are maintained in proper condition in terms of energy saving. Thus, there are many buildings that waste energy for the owner of building without noticing. Therefore, Commissioning and energy management through life cycle from planning to demolition grows to be important increasingly (BSCA).

Life cycle energy management by using LCEM tool was developed in Japan. LCEM tool was made for all subjects who engage in life cycle of a building like designers, builders and facility managers to use easily. LCEM tool is a simulation tool that

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enables to easily calculate the energy consumption of air conditioning system in various conditions (MLIT).

In this study, the university building is the object. For the building, commissioning from planning phase is applied. The purpose of this study is to prove usefulness of commissioning and LCEM method.

**RESEARCH METHODS**

In design phase, for the air conditioning system, the energy consumption is calculated by LCEM tool with thermal load obtained using MicroHASP/TES. In the lighting and plug, the energy consumption of that is calculated based on rated electric consumption and utility schedule those are inputted to MicroHASP/TES. The energy consumption of the elevator is calculated based on primary energy consumption rate.

Then, data measured by BEMS of the first year operation (2013/4/1~2014/3/31) is analyzed and compared with design value. Causal factors are extracted by analyzing measurement data. Using LCEM tool, simulation with causal factors as boundary conditions is run in order to confirm the influence of causal factors. The object period of simulation is the summer (2013/6/1~2013/9/30) and the winter (2013/12/1~2014/3/31).

**BUILDING OUTLINE**

The target building is the university facility completed at the end of February, 2013. This building is in operation phase. That is located in Aichi Prefecture, Japan and the total floor area of that amounts to 7046.9 m². Main use for the building is research rooms, laboratories, and offices. On planning the building, the research rooms and the offices where hour of use is periodical are divided from the laboratories where hour of use is irregular. The central air conditioning system with a water source heat pump chiller and two temperature-stratified type of thermal storage tank support the research rooms and the offices. On the other hand, the individual air conditioning system corresponds with the laboratories. In the building, well water is able to be used as heat source water. The well water is limited to up to maximum 500L/min and it is preferentially used for the central air conditioning system. The heat source system diagram is illustrated in Figure 1.

![Figure 1. Heat source system diagram](image-url)
ANALYSIS OF THE PRIMARY ENERGY CONSUMPTION

Figure 2 shows the primary energy consumption of design and measurement values. The primary energy consumption of the well water lifting pump is the design value because it is not measured. The energy consumption of the fan coil units and indoor units are included in the lighting and plug.

The measured primary energy consumption per unit area of the entire building is 1.93GJ/m² a. It is almost equal to the design value of 1.94GJ/m² a. However, there is difference between design and measurement values for the use of air conditioning.

Figure 3 and Figure 4 show the monthly primary energy consumption for central air conditioning and individual air conditioning. The measured energy consumption in the central air conditioning system is 403.8GJ/a (116.6% of the design value) and that in the individual air conditioning system is 1401.3GJ/a (73.1% of the design value). For the central air conditioning, the measurement value is 64.8% of the simulation value in the summer and 182.4% of that in the winter. For the individual air conditioning, obvious difference can be seen in the energy consumption of cooling tower. It is because the lower limit of cooling water temperature is not set in simulation at design phase.

Figure 2. Primary energy consumption of the entire building

Figure 3. Monthly primary energy consumption in the central air conditioning system
ANALYSIS IN THE CENTRAL AIR CONDITIONING SYSTEM

Causal factors that cause the difference between design and measurement values are analyzed in the central air conditioning system.

Comparing of the thermal load
The thermal load in the central air conditioning system is illustrated in Figure 5. In the summer, the measured load is 56.7% of the simulated load. As in the summer, the difference of thermal load caused the difference of energy consumption of the chiller because measured energy consumption is 64.8% of the simulated value. However, in the winter, the measured load is 98.1% of the simulated load.

Verification of the heat source water temperature
The heat source water temperature is illustrated in Figure 6. This figure shows that the decrease of the flow rate of the well water caused the rise of heat source water temperature in the summer and the fall of it in the winter. Comparing with design temperature 21°C, it reaches 30°C in the summer and 15°C in the winter. The difference from design caused the decline of performance of the heat source equipment.
Performance verification of the water source heat pump chiller
COP distribution for cooling is illustrated in Figure 7. Design load factor for cooling is 75% according to investigation in planning phase. The load factor from 0.7 to 0.8 accounts for 78.9% of all operation time. Therefore, it is confirmed that the chiller operates properly. COP distribution for heating is illustrated in Figure 8. The load factor from 0.15 to 0.25 accounts for 90% of all operation time because the chiller is set at low load factor. This is because the heat source water temperature falls too much and the chiller stops if the load factor remains high.

Figure 6. Heat source water temperature and flow rate of well water

Figure 7. COP distribution for cooling (2013/6/1~2013/9/31)

Figure 8. COP distribution for heating (2013/12/1~2014/3/31)
SIMULATION OF THE CENTRAL AIR CONDITIONING SYSTEM
The influence of the causal factors extracted in previous section is investigated by simulation.

Identification of the performance of the heat pump chiller
Performance of the heat pump chiller is identified based on least squares method by using hourly measurements data of electric consumption in the summer and the winter. The identification result is illustrated in Figure 9.

![Figure 9. Identification result for cooling (left) and for heating (right)](image)

Investigation of influence of causal factors
The boundary conditions are thermal load and the heat source water inlet temperature. On controlling the heat source system, in case1, thermal storage tank is charged when lower water temperature in the tank rises beyond design water supply temperature 7°C in summer and higher water temperature falls below design water temperature 40°C in winter.

In case2 and case3, heat storage targeted value calculated in BEMS is added as the operating condition. The heat pump chiller operates till amount of heat storage in tank reaches the heat storage targeted value. In the winter, it is assumed that the heat pump chiller is controlled to load factor 20%. Table 1 shows condition of simulation in each case.

<table>
<thead>
<tr>
<th>Case</th>
<th>load condition</th>
<th>heat source water temperature condition</th>
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<tbody>
<tr>
<td>Case1</td>
<td>design value</td>
<td>design value(fixed 21°C)</td>
</tr>
<tr>
<td>Case2</td>
<td>measurement value</td>
<td>design value(fixed 21°C)</td>
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<tr>
<td>Case3</td>
<td>measurement value</td>
<td>measurement value</td>
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RESULTS AND DISCUSSION
Simulation results in the summer and the winter are illustrated in Figure 10 and Figure 11.
Influence of thermal load: comparing Case1 with Case2
In the summer, the primary energy consumption of Case2 is lower than that of Case1 by 87.9GJ. Therefore, as in the summer, it is confirmed that the difference of thermal load causes the difference of primary energy consumption of the chiller between design and measurement values. In the winter, the primary energy consumption of Case2 is lower than that of Case1 by 5.7GJ.

Influence of heat source water temperature: comparing Case2 with Case3
The primary energy consumption of Case3 is more than that of Case2 by 16.5GJ in the summer and by 10.1GJ in the winter. It suggests that the improvement of the heat source water condition enables the reduction of the primary energy consumption of 26.6GJ/a.

Repeatability verification: comparing Case3 with measurement value
In the summer, the difference between Case3 and measurement value is 5.4%. Case3 is 168.6GJ and measurement value is 160.0GJ. Therefore, repeatability verification by LCEM tool is confirmed. In the winter, the difference between Case3 and measurement value is 32.7%. Case3 is 122.1GJ and measurement value is 181.3GJ. It is supposed that this difference is caused by heat loss from the storage tank. Figure 12 shows relationship between input and output energy of the storage tank. In Figure 12 (b), there is significant difference between input and output energy. It is under investigation.
CONCLUSION AND IMPLICATIONS
In this paper, performance in operation phase was examined. Measurement value was compared with predicted value calculated in design phase. Then, it was found that there was difference between design and measurement values for the use of air conditioning.

Causal factors for difference of energy consumption for air conditioning were analyzed. It was found that there were differences between design and measurement values in thermal load and heat source water temperature. Therefore, those were extracted as causal factors. The influence of each causal factor was evaluated quantitatively by simulation using LCEM tool.

Analyzing causal factors by simulation using LCEM tool enables to propose of operational improvement of air conditioning. It proves that LCEM tool is useful through the life cycle commissioning.

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