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/m^{2}a. It is almost equal to the design value of 1.94GJ/m^{2}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.

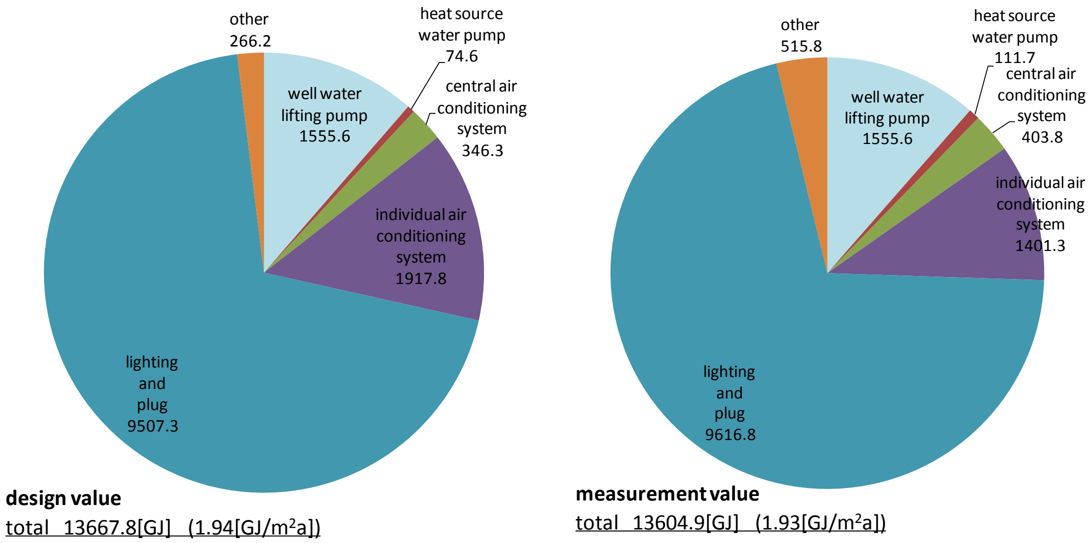


Figure 2. *Primary energy consumption of the entire building*

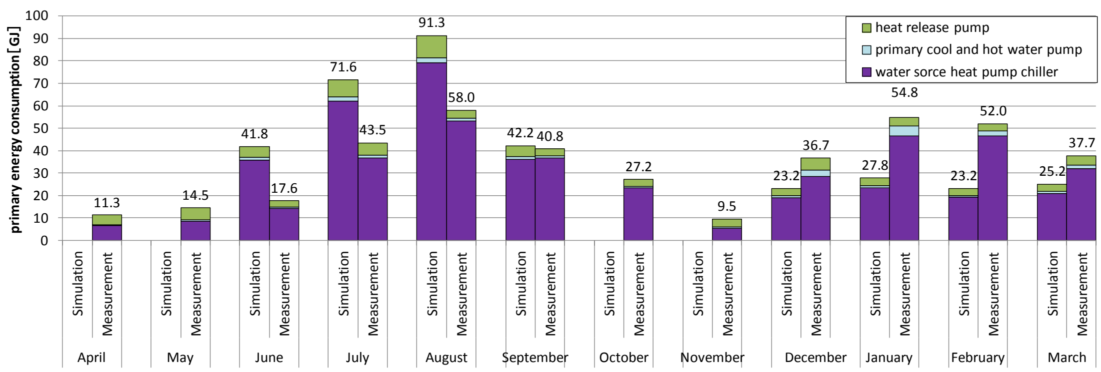


Figure 3. *Monthly primary energy consumption in the central air conditioning system*

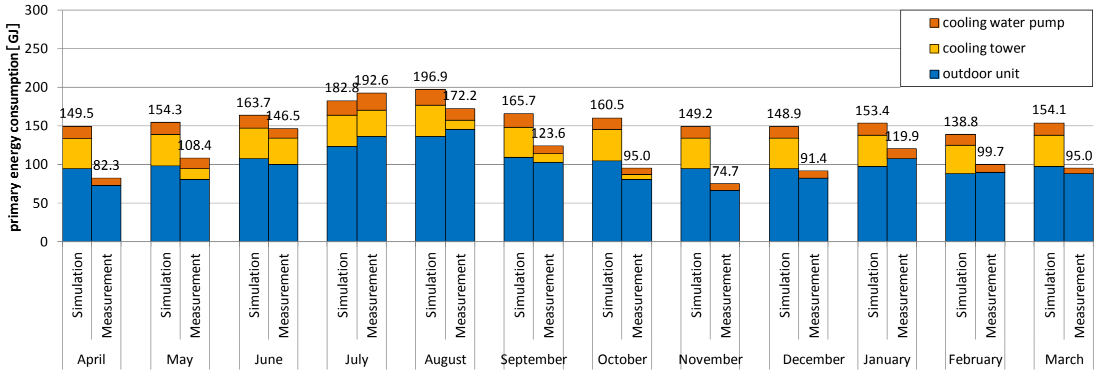


Figure 4. *Monthly primary energy consumption in the individual air conditioning system*

ANALYSIS IN THE CENTRAL AIR CONDITIONING SYSTEM

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

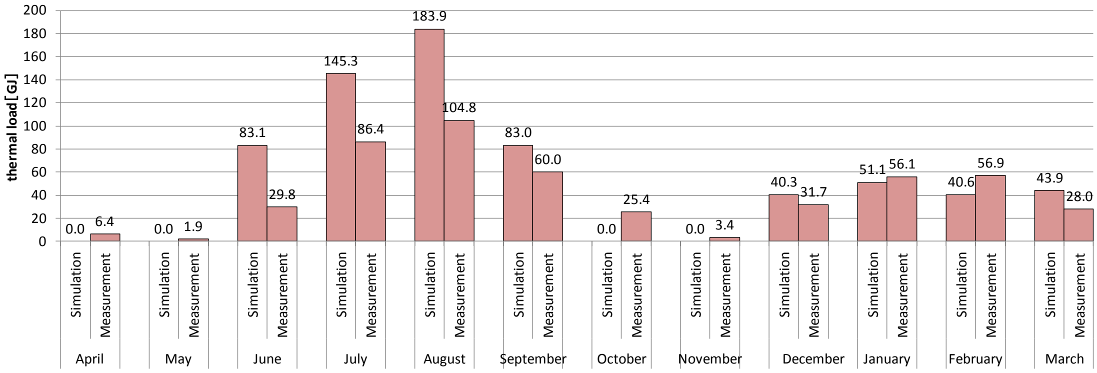


Figure 5. *Thermal load comparing with design and measurement values*

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.

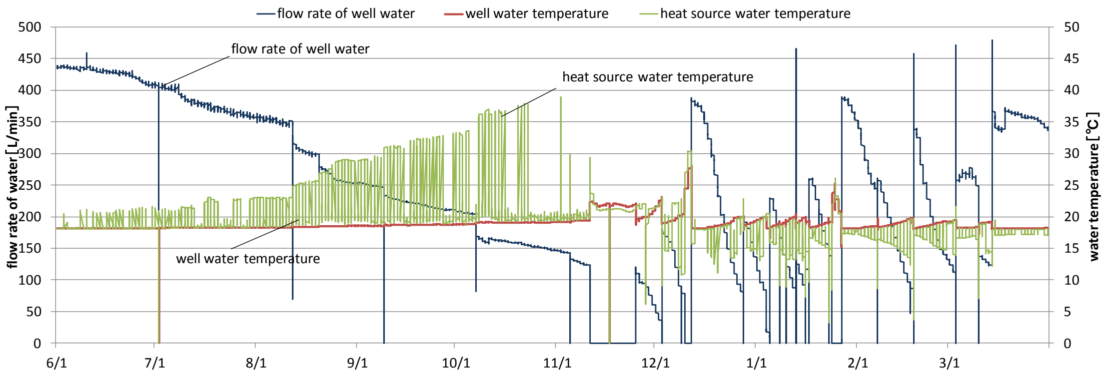


Figure 6. *Heat source water temperature and flow rate of well water*

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.

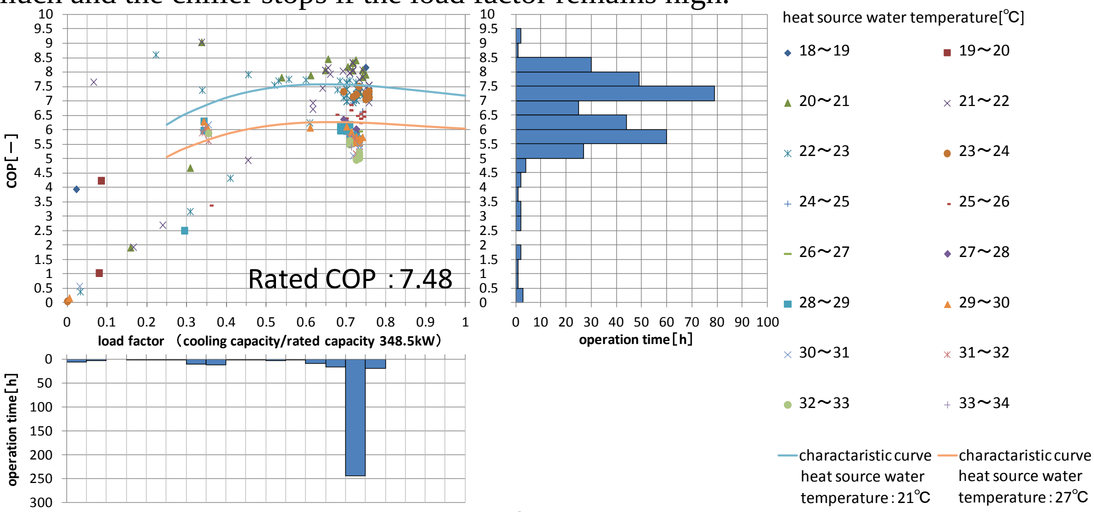


Figure 7. *COP distribution for cooling (2013/6/1~2013/9/31)*

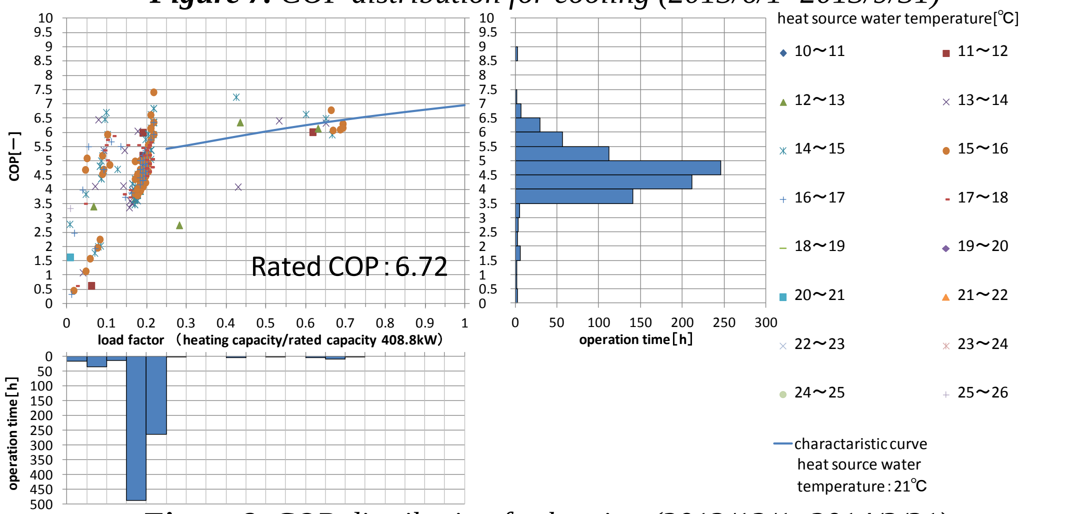


Figure 8. *COP distribution for heating (2013/12/1~2014/3/31)*

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.

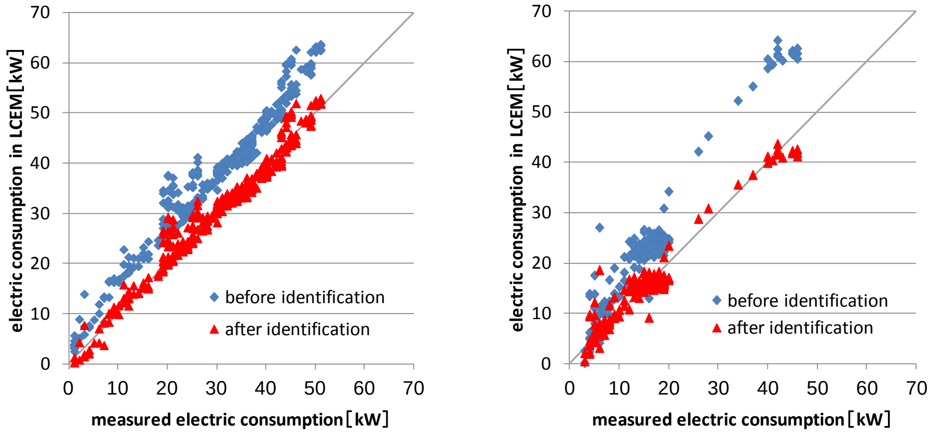


Figure 9. *Identification result for cooling (left) and for heating (right)*

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 1. Condition of simulation in each case

	load condition	heat source water temperature condition
Case1	design value	design value(fixed 21℃)
Case2	measurement value	design value(fixed 21℃)
Case3	measurement value	measurement value

RESULTS AND DISCUSSION

Simulation results in the summer and the winter are illustrated in Figure 10 and Figure 11.

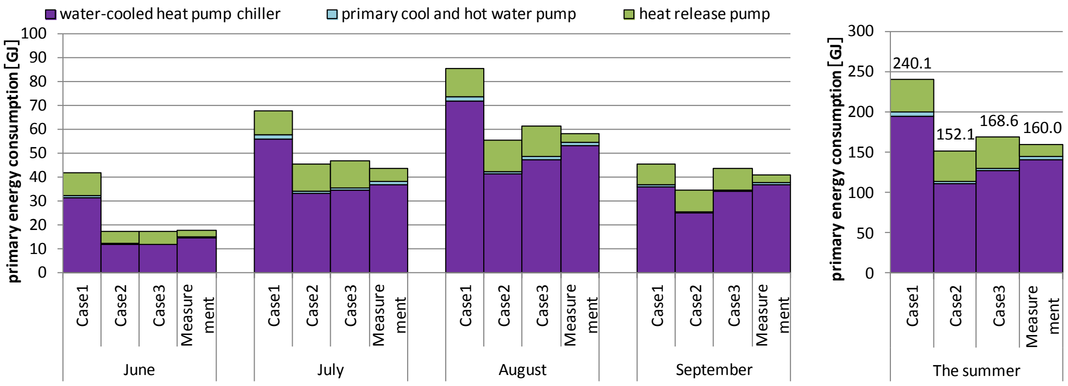


Figure 10. *Simulation result in the summer*

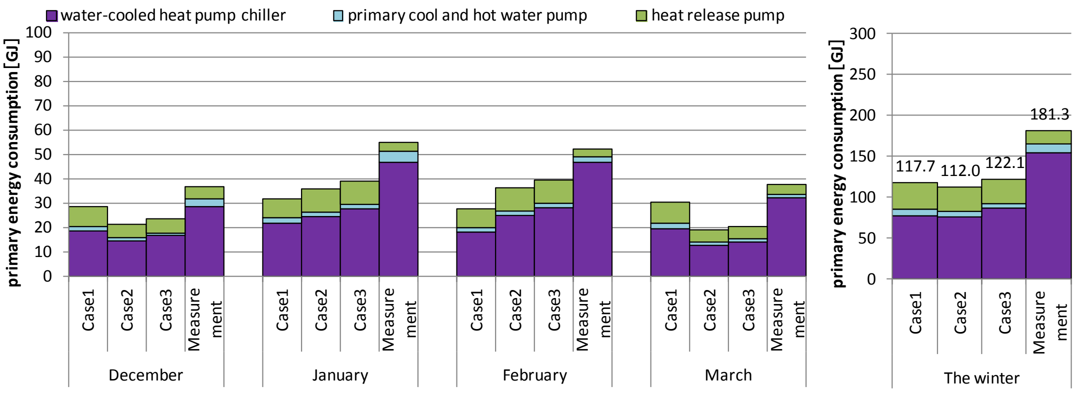


Figure 11. *Simulation result in the winter*

Influence of thermal load: comparing Case1 with Case2

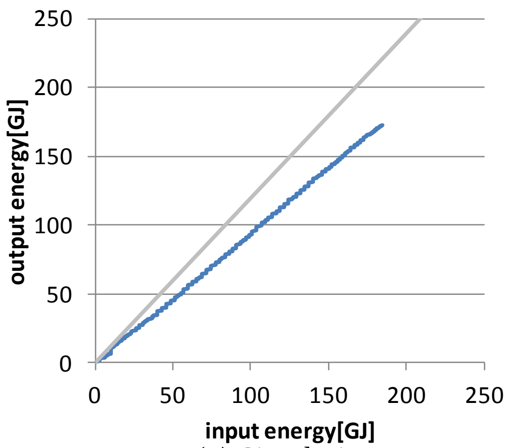
In the summer, the primary energy consumption of Case2 is lower than that of Case1 by 87.9GJ. Therefore, as in the summer, it is confirmed that the difference of thermal load causes the difference of primary energy consumption of the chiller between design and measurement values. In the winter, the primary energy consumption of Case2 is lower than that of Case1 by 5.7GJ.

Influence of heat source water temperature: comparing Case2 with Case3

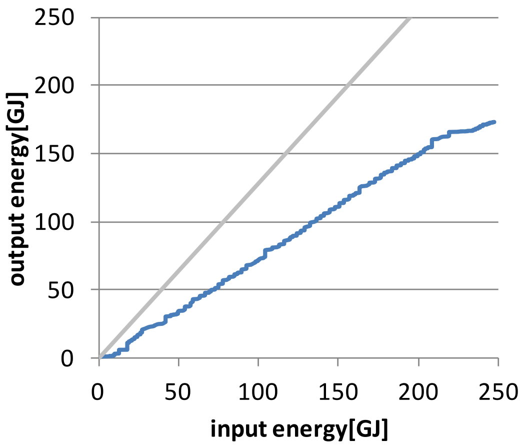
The primary energy consumption of Case3 is more than that of Case2 by 16.5GJ in the summer and by 10.1GJ in the winter. It suggests that the improvement of the heat source water condition enables the reduction of the primary energy consumption of 26.6GJ/a.

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.



(a) Simulation



(b) Measurement

Figure 12. *Relationship between input and output energy of the storage tank*

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.

ACKNOWLEDGEMENTS

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