Analysis on Performance and Behavior of Thermal Storage Air-conditioning System applied to City Hall Building

T.Nakano[1,*] , H.Tanaka[1] and M.Okumiya[1]

[1]Graduate School of Environmental Studies, Nagoya University,
Furo-cho, Chikusa-ku, Nagoya 4648601, Japan

ABSTRACT

Recent years, rapid increase in final energy consumption in commercial/residential sectors has been seen in Japan. In particular, it is a remarkable increase in commercial sector. Local government office buildings are base facilities in an area, so an aggressive energy saving policy is required. In this study energy management of thermal storage air conditioning system is conducted.

In this paper an analysis on performance and behavior of thermal storage air-conditioning system applied to city hall building was conducted for the first operation year by the use of data from building energy management systems (BEMS). It was found that thermal storage type air-conditioning system is being driven well mostly as a result of the performance verification. However the mistake of setting of the target for stored heat and the threshold of supply water to secondary caused decline of the operating characteristic of the heat source.

According to verification of system performance on the first year, measure for improving operation was proposed. And the validity of the proposed measure is confirmed by a system simulation. Then the measure with the validity will be reflected. Therefore it was verified whether behavior of an actual system can be reproduced by a system simulation in this paper.

KEYWORDS

LCEM tool, BEMS, system simulation

INTRODUCTION

In Japan, remarkable increase in final energy consumption has been seen in commercial sector. Building design comes to focus on energy saving by the recent trend of consideration to environmental preservation and BCP (Business Continuity Plan) by disruption of energy supply in Great East Japan Earthquake and tsunami in March 2011. However, there are many bad operations of building and heat source against the intention of a designer. That is because buildings are planned separately in design, construction and operation phases. Accordingly, energy management is inclined to fragmental one. Using LCEM tool (Life Cycle Energy Management tool)

* Corresponding author email:

in common, the energy simulation tool released by Japanese Ministry of Land, Infrastructure, Transport and Tourism, enables consistent energy management from the design phase to the operation phase. LCEM tool allows engineers to easily calculate the energy consumption of air conditioning system in various conditions.

Monitoring energy consumption for new construction or renovation by visualized data acquired from BEMS (Building Energy Management Systems) has been general in Japan. Nevertheless, there are not many examples yet using these data to analyze and improve an HVAC system.

In this study, Life Cycle Energy Management for thermal storage air-conditioning system applied to city hall building is focused on. The purpose of this study is for analysis on performance and behavior of thermal storage air-conditioning system and to check whether that system operated properly. A mistake of setting was found and measure for improving operation was proposed in consequence. In addition, actual operation is simulated on LCEM tool to verify the effects of suggestions.

BUILDING OUTLINE

The target building is a city hall located in Aichi Prefecture, Japan, with 5 floors above ground and about 15,000 m^2 of total floor space. This building construction was completed in January of 2015, and has been in an operation phase. The building consists of offices, meeting rooms, restaurant, and so on. This paper targets at offices on thermal storage air-conditioning system as a central heat source.

ENERGY SYSTEM AND OPERATION

Energy management by simulation using LCEM tool has been applied to the target building in each construction phase. In baseline design phase, heat source composition and capacity were considered. Combined heat source of electric and gas has been adopted from the point of view of reliability as a city hall building, whereas only electric one could save energy most. In detailed design phase, heat storage was investigated and introduced to reduce operating expense with lowering COP. In construction phase, the operation order of heat source components was simulated. Figure 1 shows the heat source system diagram for the target building.

Heat storing operation by night discount electric power conducted from 10 p.m. of previous day to 8 a.m. the next day. This operation continues until meeting either of the following three conditions; temperature of higher side reaches 6°C (cooling operation), that of lower side reaches 46°C (heating operation), heat storage amount reaches target value. (cooling;15.37 GJ, heating; 11.53 GJ) The storing operation don't be conducted on Sunday morning. Heat radiating operation conducted from 8 a.m. to 10 p.m. This operation also continues until meeting either of the following three conditions; temperature of lower side reaches 14°C (cooling operation), that of higher side reaches 40°C (heating operation), heat storage amount reaches 0 GJ. While heat radiating of daytime, the number of heat sources increases according to thermal load in the order of HE-1, AHP-1~4, AB-1. In addition, that increases according to keeping temperature below 10°C to secondary.

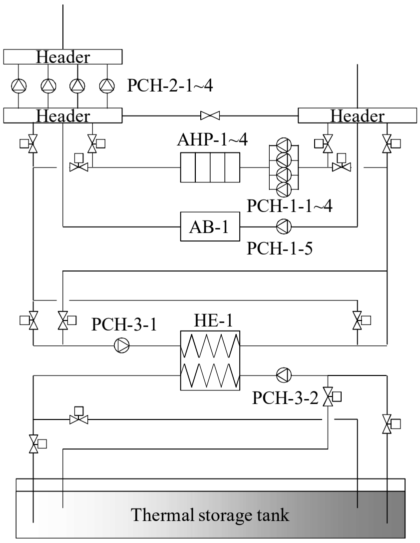

***Figure 1**. Heat source system diagram*

***Table 1.** Major equipment capabilities*

Air-cooled heat pump module chiller AHP-1~4	Cooling capacity : 150 kW Electric power consumption : 49.25 kW Heating capacity : 113 kW Electric power consumption : 40.0 kW	× 4
Primary pump PCH-1-1~4	Flow rate : 269 l/min Electric power consumption : 1.5 kW	× 4
Absorption chiller/heater AB-1	Cooling capacity : 527 kW Gas consumption : 31.4 m^3N/h Electric power consumption : 5.1 kW Heating capacity : 395 kW Gas consumption : 35.5 m^3N/h Electric power consumption : 4.3 kW	× 1
Primary pump PCH-1-5	Flow rate : 945 l/min Electric power consumption : 3.7 kW	× 1
Cooling tower CT-1	Cooling capacity : 872 kW Electric power consumption : 5.5 kW	× 1
Cooling water pump PCD-1	Flow rate : 2500 l/min Electric power consumption : 15.0 kW	× 1
Secondary pump PCH-2-1~4	Flow rate : 774 l/min Electric power consumption : 11.0 kW	× 4
Heat exchanger HE-1	Cooling capacity : 600 kW Heating capacity : 450 kW	× 1
Heat source water pump PCH-3-1	Flow rate : 1075 l/min Electric power consumption : 11.0 kW	× 1
Heat source water pump PCH-3-2	Flow rate : 1075 l/min Electric power consumption : 5.5 kW	× 1
Thermal storage tank	Volume : 612 m^3 Amount of heat storage : 15.37 GJ (cooling) 11.53GJ (heating)	× 1

RESEARCH METHOD

The data of the first year operation(2015/1/1~2015/12/31) measured by BEMS for the unit of 1 hour. Analysis of the data found the mistake of setting and operation problem. The influence of the mistake to the actual operation was investigated by simulation of LCEM tool. Simulation was reproduced by operation by using measurement data as boundary conditions. Calculation of energy consumption made closer multiplied by the correction. Verification of improvement plans conducted similarly. The object period of simulation is in summer season(2015/7/1~2015/9/30).

ANALYSIS ON THEAMAL STORAGE AIR-CONDITIONING SYSTEM

In operation, critical temperature of supply water from heat source has changed from 9°C to 14°C in summer. This is due to the intention of city to reduce operation time of gas heat source. Result of the analysis found some problems.

Comparison of the thermal load

Figure 2 shows the comparison of the thermal load between design and measurement. Measurement thermal load in winter is close to design one except March. On the other hand, measurement in summer is less than design (29%~66%). Heat source capability in summer is bigger than in winter. Therefore, low-priority heat source operation in summer is shorter than in winter.

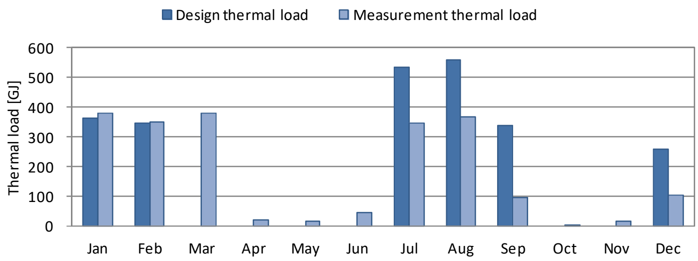

***Figure 2**. Comparison of the thermal load between design and measurement*

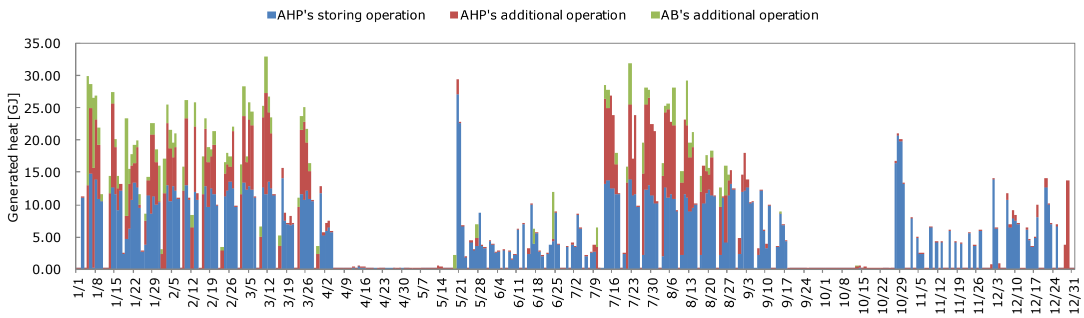

***Figure 3**. Operating performance of generated heat ('2015)*

Verification of thermal storage temperature

Heat source operation and thermal storage temperature on July 13, peak load day in summer, is illustrated in Figure 4, 5. In, heating storing operation, there was an insufficiency of the thermal storage. By checking the setting of heating storing, the mistake of target setting of thermal storage amount was found. This was because the setting in winter (11.53 GJ) wrongly applied to the setting in summer (15.37 GJ). Thus, maximum amount of thermal storage in summer was only 75% of expected operation.

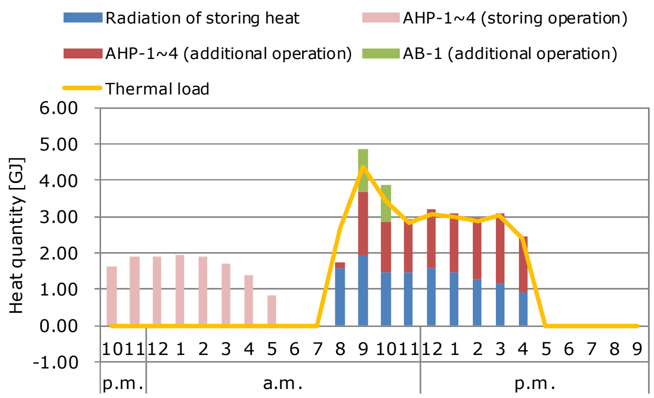

***Figure 4**. Heat source operation on July 13*

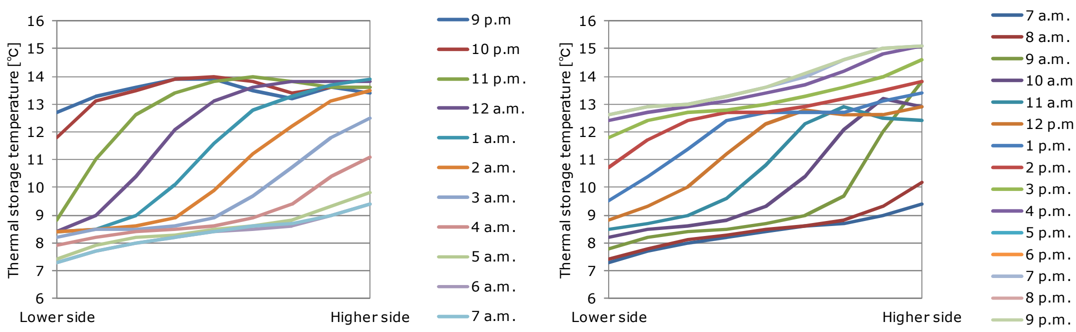

***Figure 5**. Thermal storage temperature on July 13*

Verification of the supply water temperature to secondary

Critical temperature of supply water from heat source has changed to 14°C in summer. Therefore, operation time of heat source is seemed to be longer by keeping temperature to secondary. Then primary flow amount increases, and temperature difference between headers is smaller. Thus, the threshold of supply water to secondary caused decline of the operating characteristic of the heat source. For example, heat source temperature on July 13 rose gently after 12 p.m. as a whole.

SIMULATION OF THEAMAL STORAGE AIR-CONDITIONING SYSTEM

The influence of mistake of setting and change of critical temperature of supply water extracted in previous sections is investigated by system simulation.

Correction of the performance of the heat pump chiller

Electric consumption of the heat pump chiller is corrected by using measurement data. Correction result is illustrated in Figure 5 .

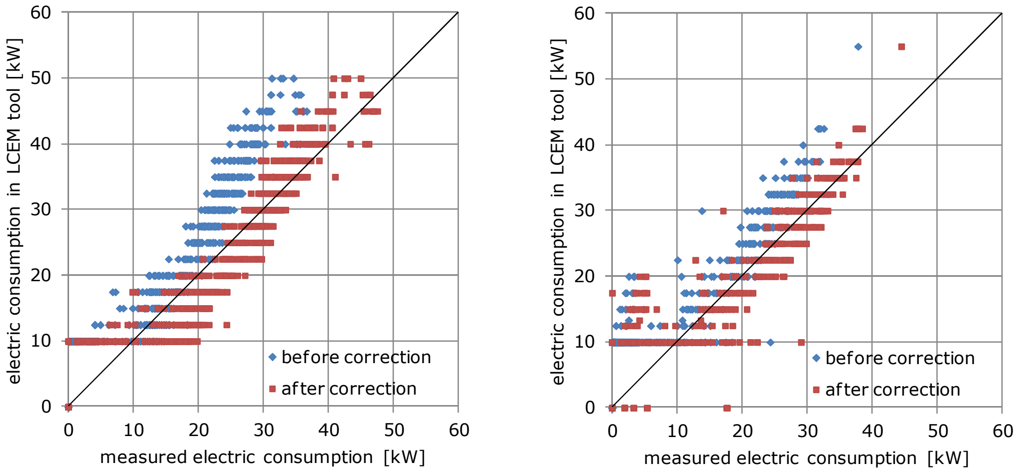

Figure 6*. Correction results for storing (left) and for radiating (right)*

Investigation of influence of causal factors

Differences of heat storage amount and critical temperature of supply water from thermal storage are specified in the six cases in Table 2. The simulation in conditions of actual operation is Case1-3.

Table 2. *Condition of simulation in each case*

	Heat storage amount	Critical temperature of supply water from thermal storage	
Case1-1	11.53 GJ	9℃	
Case1-2	11.53 GJ	12℃	
Case1-3	11.53 GJ	14℃	Actual operation
Case2-1	15.37 GJ	9℃	Detailed design phase
Case2-2	15.37 GJ	12℃	
Case2-3	15.37 GJ	14℃	Expected operation

RESULTS AND DISCUSSION

Simulation results are illustrated in Figure 7, 8, 9. By the thermal load of the summer in 2015, there was not much operation of absorption chiller in both of simulated cases and measurement. Case1-1, the least primary energy consumption case, also generated heat least. On the other hand, the rate of transferred load to night is minimum. Accordingly, investigation in the side of electricity rate might be conducted.

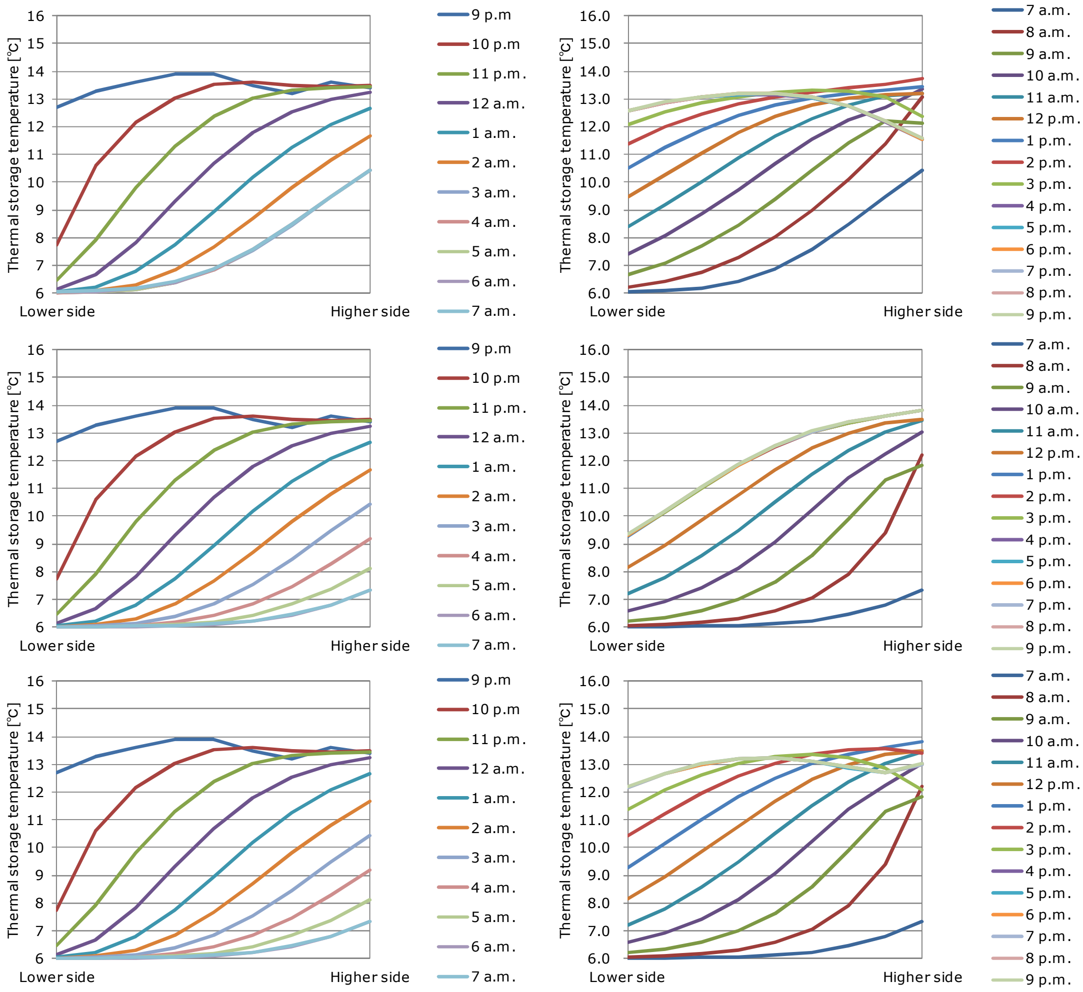

Figure 7*. Thermal storage temperature on July 13 (Top : Case1-3, Middle : Case2-1, Bottom : Case2-3)*

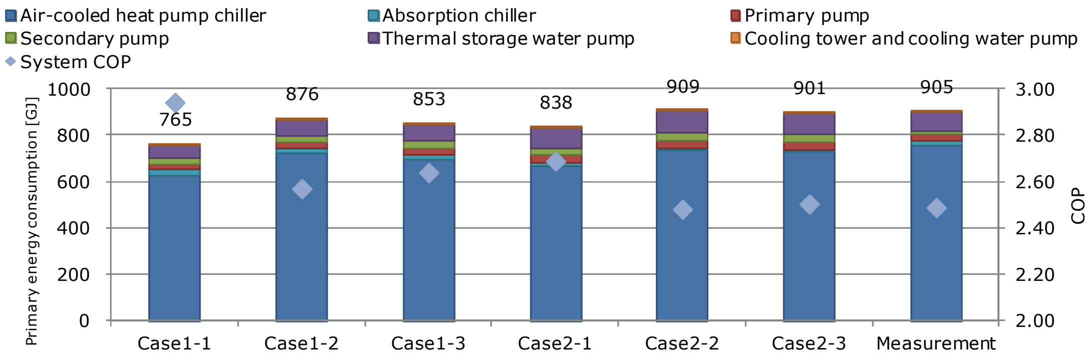

Figure 8*. Energy consumption of heat source system and system COP*

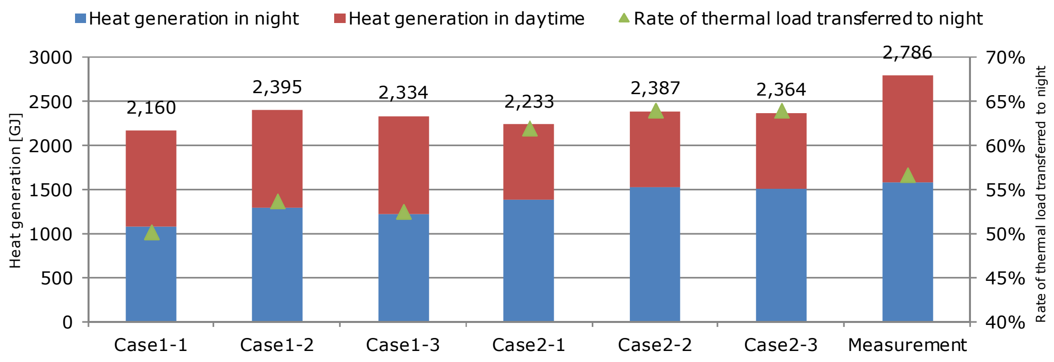

***Figure 9**. Heat generation night and day*

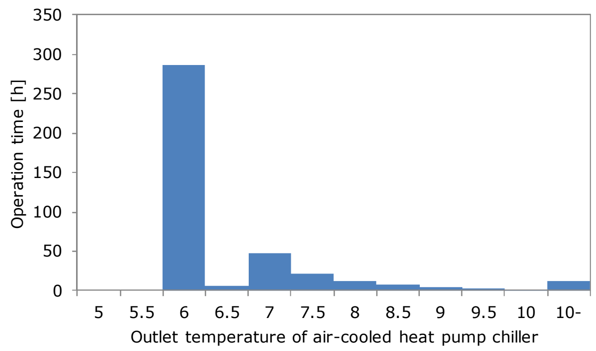

***Figure 10**. Frequency distribution of measured outlet temperature of air-cooled heat pump chiller (heat storing operation)*

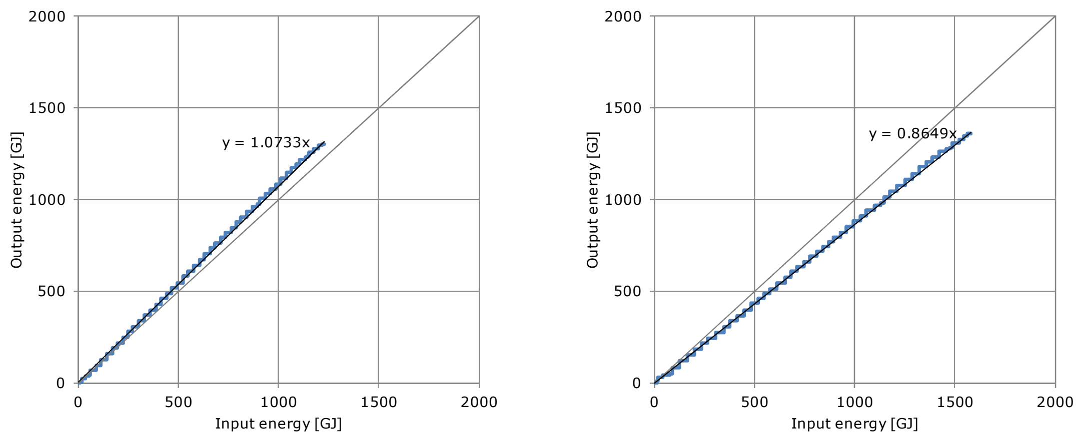

***Figure 11**. Relationship between input/output energy of thermal storage tank (Left : Case1-3, Right : Measurement)*

Repeatability verification: comparing Case1-3 with Measurement

Thermal storage temperature on July 13 in Case1-3 makes more difference between lower/higher temperature side than Measurement. This is probably caused by measured outlet temperature of air-cooled heat pump chiller. Figure 10 shows the Frequency distribution of that in heat storing operation. The setting of that in actual operation and LCEM tool is 5°C, nevertheless real measurement is over 6°C.

The difference of primary energy consumption between Case1-3 and Measurement is 5.7%. Case1-3 is 853 GJ and Measurement is 905 GJ. Therefore, repeatability verification by LCEM tool is confirmed. Meanwhile, the difference of heat generation is 16.2%. Case1-3 is 2,334 GJ and Measurement is 2,786 GJ. It is likely that heat loss from thermal storage tank caused this difference.
The relationship between input/output energy in Figure 10 probably affected to this difference. From an inclination of the approximation straight line, heat loss is 13.5% (Measurement), -7.3% (Case1-3). This negative value in simulation is under investigation.

Influence of heat storage amount: comparing Case1-3 with Case2-3

The primary energy consumption of Case1-3 is lower than that of Case2-3 by 48 GJ (5.3% reduction). This means that less heat storage amount make less operation of thermal storage water pump, and make less heat loss. By contrast, the rate of transferred load to night of Case2-3 is higher than Case1-3. This implies Case2-3 is able to use more night electric power than Case1-3.

Influence of critical temperature of supply water from thermal storage: comparing Case2-1 with Case2-3

The primary energy consumption of Case2-3 is more than that of Case2-1 by 63 GJ (7.5% increase). This is due to the increase of heat storing operation.

CONCLUSIONS AND IMPLICATIONS

In this paper, performance in operation phase was analyzed. The mistake of setting of thermal storage amount was found from results of thermal storage temperature. There is also the setting change of critical temperature of supply water from thermal storage in operation phase. In order to compare with several cases from these conditions, repeatability verification by system simulation of LCEM tool is confirmed. According to the results of simulation, there are differences of thermal storage temperature, energy consumption, and heat generation in each case. Case1-1, the least primary energy consumption case, electricity rate probably become higher. As mentioned, simulation by LCEM tool support owners for decision from various aspects.
Using LCEM tool enables analyzer to reproduce the mistake of setting and change in operating phase. Energy management using LCEM tool is proved to be useful for decision making process.

ACKNOWLEDGEMENTS

The present work was supported by the LCEM party.

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