The Energy Optimization of a Large Scale Complex Building by Detailed Data Analysis of Cutting-edge BEMS and Simulation.

K. Mitamura[1,**], H. Okubo[1], Y. Shimoda[1], Y. Tanaka[2], and S. Tanabe[2]

[1] Graduate School of Engineering, Osaka University, Suita, Osaka, 565-0871, Japan
[2] Nikken Sekkei Ltd., Japan

ABSTRACT

This paper presents a case study of data analysis from Building Energy Management System (BEMS) and an examined measures of energy saving. The authors analyze both demand side and supply side systems of a large complex building with cutting-edge BEMS. The fault detection and optimal operations for demand side are established by using the Valuable Air Volume (VAV) and avoiding hunching phenomenon. The methods of energy saving for the supply side are established by changing the chillers control sequence and by changing the cooling water temperature. In order to evaluate the effect of the energy saving, the simulation model of the heat source system in this building is developed. By using the simulation model, the combination of the energy saving measures for the demand side and for the supply side system can be calculated. The simulation results revealed that the combination of the energy saving measures can reduce the building energy consumption by 4.8%.

KEYWORDS

Data analysis, BEMS, Optimal operations

INTRODUCTION

In recent years, the development of sensing technology and information and communication technology enables us to obtain high-resolution energy data of buildings.Accordingly, the quantity of data of built environment is rapidly growing (Azam Khan, 2011). These data is valuable to detect faults and find possibly an energy-efficient operation methods in a building heat source system by the support of the building simulation. However, methodology to find energy related knowledge in cyber space had not been established. Therefore, it is very important to demonstrate a case study of analyzing the energy big data from existing building. In this study, we analyze data from about 60,000 measurement points in a large scale complex building equipped with cutting-edge BEMS. Those data from the BEMS enables us to know the detailed energy consumption and operational status of the heat source system. The purpose of this study is to demonstrate the future possibility of the big data analysis for buildings. In this paper, the procedures of energy data analysis, fault diagnosis and assessment of

* Corresponding author email: mitamura@ue.see.eng.osaka-u.ac.jp

energy efficiency measures are discussed using the large-scale energy data of complex buildings. In addition, the simulation model of heat source system of the building is developed. In the simulation model, the energy saving potential by the improvement of the heat source operation and the heat demand reduction by fixing the faults in the building heat source system is evaluated.

DESCRIPTION OF THE CASE STUDY BUILDING

The selected case study is a large scale complex building located in Osaka, Japan. Description of the building is shown in Table 1. The building consists of office, hotel and convention center etc. In this paper, the data of commercial area and offices is analyzed. The equipment of heat source system is listed in Table 2. The heat source system is divided into an upper part and lower part. This design is aimed to minimize the power consumption of water transport power. The building has cutting-edge BEMS with about 60,000 measurement points which is originally installed to enhance energy saving activities of this building, by observing the operation status of the heat source system. In this paper, primary energy conversion factor of electricity and city gas are set to 9.76 and 45[MJ of primary energy/kWh of electricity or m^3] in accordance with energy conservation laws in Japan.

Table 1. *Description of building*

Location	Osaka City, Osaka Prefecture, Japan
Number of stories	38 stories above ground level/ 3stories underground
Total floor area	about 300,000m^2
Main use	Office, Hotel, Residential service, Convention, Commercial facility
Period for measurement	April 1, 2014 to March 31, 2015

Table 2. *Equipment list of heat source system*

Locations	Model		number	Cooling capacity [kW]	Heating capacity [kW]
rooftop	Gas absorption chiller		6	15,402	11,646
	Screw chiller		1	2,080	-
	Boiler		5	-	4,650
underground	Brine turbo chiller	Ice-making operation	2	3,860	-
		Cooling operation		5,274	-
	Inverter turbo chiller		2	7,032	-
	Ice thermal storage tank		2	5,280*	-
Total capacity			-	33,648	16,296

*Maximum heat dissipation

ENERGY SAVING MEASURES FOR DEMAND SIDE

By analyzing the data, several faults and the way of optimal operation are detected. In this section, the energy saving potential of two energy saving measures are evaluated.

Use of VAV

In the commercial area, the VAV system with high air volume mode (high-mode) or low air volume mode (low-mode) is introduced to each store. Change mode is done by manually scheduling. In our case study, the energy saving potential is calculated based on the assumption that each store could turn on low-mode. However, the low-mode is not used in reality. By using the low-mode, thermal load of outdoor air, fan power of Outdoor-air Processing Unit (OPU) and fan power of ventilation can be reduced. The requirements of using low-mode VAV are that the value of thermal load of outdoor air must be positive, and it could only be turned on in weekdays. The VAV for the kitchen exhaust air must always be set at high-mode in the consideration of safety on sanitation. The thermal load of outdoor air reduction can be calculated by Eq. (1) and (2). The reduction of fan power is calculated by Eq. (3).

$$q_{out} = q_{ac} - \rho c_p Q_1 \Delta T \quad (1)$$

$$\Delta q = q_{out} - q_{out} \times \left(\frac{Q_2}{Q_1}\right) \quad (2)$$

$$\Delta W = \left\{1 - \left(\frac{Q_2}{Q_1}\right)^3\right\} \times W_1 \quad (3)$$

q_{out} Thermal load of outdoor air
q_{ac} Heat consumption in OPU
ρ Density of air
c_p Specific heat of air
Q_1 OPU air volume of the current situation
ΔT Temperature difference between the supply air temperature and the indoor setting temperature
Δq Reduction of thermal load of outdoor air
Q_2 OPU air volume of the low mode
ΔW Reduction of the power consumption of fan
W_1 Fan power consumption of current situation

Table 3 shows the summary of the detailed energy saving effect by changing into low-mode. The change of the heat source system Coefficient Of Performance (COP) due to a change of the heat load are ignored in this section. The largest reduction is obtained at the hot water demand. The heating load is susceptible the outside air entered because the load for heating outside air occupies the large percentage in total the heating load. The reduction potential for the total energy consumption of the building is 3.2%.

Table 3. *Summary of energy saving potential*

	Reduction[GJ]	Reduction potential
Fan power (OPU and ventilation fan)	2,945	7.3%
Thermal load of outdoor air (Cold water demand)	1,265	2.7%
Thermal load of outdoor air (Hot water demand)	3,680	8.1%
Total	7,891	3.2%

Avoidance of Hunching

The analysis of the BEMS data from complex areas in the building verifies that there is a simultaneous consumption of cold water and hot water on Fan Coil Unit (FCU). This is the hunching phenomenon that is caused because the capacity of the FCU is excessive. If alleviation of the temperature of the cooling and heating water is carried out, the wasting energy consumption of heat supply caused by hunching can be prevented. Therefore the energy saving potential is calculated when the hunching is fixed.

The condition that both cold and hot water are demanded in FCU in one hour is defined as a hunching phenomenon. The heat demand from cold and hot water at the same time can be reducible. And total energy saving can be calculated by diving reducible heat demand with heat source COP. Same as the discussion in VAV, the changes of energy efficiency in heat source system are also ignored, further discussion will be provided in the following chapters.

As shown in Table 4, the energy saving potential by avoiding hunching is 0.6% for the total energy consumption of the building. The reduction of FCU hot water demand is larger than FCU cold water demand.

Table 4. *Summary of energy saving potential*

	Reduction [GJ]	reduction potential
FCU cold water demand	605	5.0%
FCU hot water demand	853	30.8%
Total	1,458	0.6%

ENERGY SAVING MEASURES FOR THE SUPPLY SIDE SYSTEM

In the preceding chapter, the energy saving potential of the demand side is evaluated. In this section, the energy saving measures for the supply side system is evaluated.

Summary of the Simulation Model for the Heat Source System

The simulation model for the heat source system of the building is developed. Figure 1 shows a flow chart of the simulation model. The calculation interval of this model is one hour and in this model, the factors of operation for the heat source are water flow and heat capacity. Hourly data (chilled and hot water demand, cooling and heating demand, wet and dry bulb), measured in the building from April 2014 to March 2015, was used as the input data for the simulation. The details of each parameter are shown below.

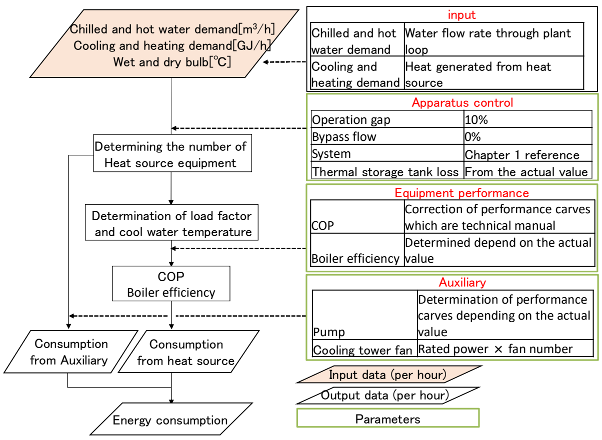

Figure 1. *Flow chart of simulation model*

(1) The Energy Efficiencies of the Chillers

The heat source efficiency is calculated based on the performance curve of the manufactures technical manual. However, there is a difference between the real performance curve and the performance curve in the manufactures manual book.

Therefore standardized performance curve needed to be corrected by the ratio of real COP and COP of the manufactures technical manual. When the operation of the heat source is regarded as intermittent (with a load factor of the heat source under 20%), the energy required for starting is ignored.

(2) Cooling Tower Model

The cooling tower model can simulate an increase of the capacity of the cooling tower and a change of cooling water quantity. The cooling towers of the building have multiple units of fans (4 fans in connected electric chillers, 12 fans in connected gas absorption chillers) and number of control is carried out. The total power consumption of the cooling tower fans can be calculated by multiplying operating numbers of fans and the rated power in the manufactures technical manual.

(3) Pump Model

The pump model calculates the power consumption by using performance curve determined by pump flow quantity and pump power of actual equipment

Verification of Simulation Model

By comparing the actual data obtained from BEMS, the reproducibility of the simulation model is verified. In the case of verification, the same heat source operation equipment was applied as the actual situation. Figure 2 shows the comparison of measurement and simulation. The annual error between simulated and measured is 1.6%. There is no significant difference observed between simulated and measured in both annual and summer day model. This result is regarded as the base case, and will be compared with the energy saving case in the following chapter.

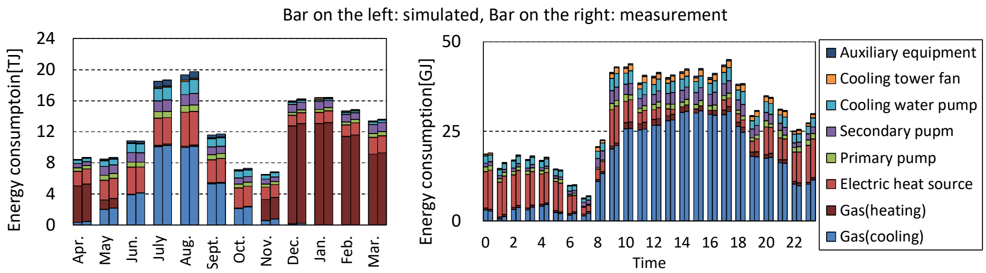

Figure 2. *Comparison of measurement and calculation (Left: monthly, Right: Summer representative date)*

The Evaluation of Energy Saving Effect

In this section, energy saving effects of changing the chillers sequence in the operation of the heat source and changing cooling water temperature are evaluated.

(1) The Change of the Chillers Control Sequence

With the analysis of the BEMS data, it is known that the gas absorption chiller mainly operated in certain periods. However, the electric chiller has better COP than gas absorption chiller. Therefore, the energy saving effects of change in the chiller control sequence can be calculated. System COP is defined by Eq. (4).

$$\mu = \frac{Q}{E_r + E_C + E_{CP} + E_{PP} + E_{SP} + G} \quad (4)$$

μ	System COP
Q	Production amount of heat
E_r	Power consumption of the heat source
E_c	Power consumption of cooling tower fan
E_{cp}	The power consumption of the cooling water pump
E_{pp}	The power consumption of primary pump
E_{sp}	The power consumption of the secondary pump
G	Gas consumption

The result of chillers sequence change is shown in Figure 3. The annual system COP increase 5.2%. The largest increase is obtained in September. This is because the absorption chiller is actually operated a significant amount of time in September. In contrast, the change of system COP is small in winter because the electric chiller is originally in prior sequence.

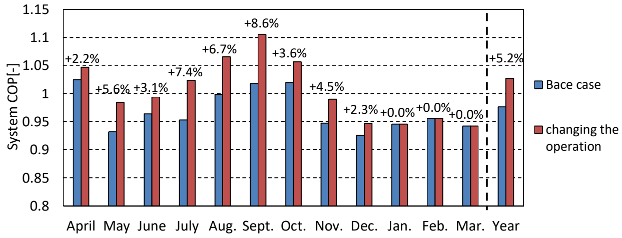

Figure 3. *The effect of changing the chiller control sequence*

(2) The Change of Cooling Water Temperature

Although the power consumption of the cooling tower is increased, the reduction of the cooling water temperature can lead to the improvement of the COP. The cooling towers of the building have multiple units of fan (4 fans in connected electric chillers, 12 fans in connected gas absorption chillers). And the number controls are also carried out. In this section, the effect of changing the cooling water temperature is evaluated by using the simulation model. Figure 4 shows the cooling tower control method of gas absorption chillers. The set cooling water temperature is different depending on each season. We examine the cases of changing the cooling water temperature by -3°C to +3°C. However the minimum cooling water temperature for the gas absorption chiller is set to 20°C for the requirement of the stable operation of the heat source.

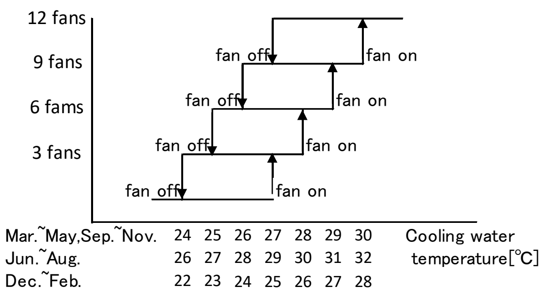

Figure 4. *Cooling tower control method of base case (gas absorption chillers)*

Table 5 shows the result of the simulation. The largest energy saving potential is obtained at the case of -3°C. In the case of -3°C, although the power consumption of the cooling tower fan increases 41% compared to the base case, the total energy consumption decrease by 1.9% due to the decrease of heat source energy consumption.

Table 5. *The result of sensitivity analysis on the cooling water temperature*

	Electric chillers	Gas absorption chillers	Cooling tower fan	Total
+3°C	+7%	+2%	-25%	2.4%
+2°C	+5%	+1%	-18%	1.7%
+1°C	+3%	+1%	-10%	1.0%
Base case	0%	0%	0%	0.0%
-1°C	-3%	-1%	+13%	-0.8%
-2°C	-5%	-2%	+27%	-1.4%
-3°C	-7%	-2%	+41%	-1.9%

THE COMBINATION OF THE ENERGY SAVING MEASURES

In the preceding chapter, the energy saving potential of the demand side is evaluated, in which case is evaluation of only for the demand side. However, the heat demand changes actually cause the heat source system performance change. Therefore the energy saving measures for the demand side must be evaluated conjunction with the supply side. In this section, the combination of the energy saving measures, considering the change of the heat source system efficiency, is discussed. We evaluate the case which is carried out the energy saving measures for the demand side (use of VAV and avoiding the hunching) and for the supply side system (changing of the chillers control sequence and changing the cooling water temperature to -3°C).

As a result, the combination of energy saving measures cause the 4.8% reduction of the energy consumption for the building (reduction of the fan power is 1.2%, reduction of the heat source system is 3.6%).

THE COMPARISON OF EACH CASES

In this section, we make a comparison of three cases. The first case is case1 which is the base case. The second case is case2 which is carried out with energy saving measures for the supply side system. The third case is case3 which is carried out with energy saving measures for the demand side and for the supply side system. In order to remove the effect of heat dissipation given to the COP, the energy consumption involved in thermal storage, heat dissipation and the secondary pump are excluded when calculating the COP in this section.

Figure 5 shows the result of simulation. In the case2 and case3, the improvement of the COP is overserved comparing with the case1 especially in low load factor. The improvement of the COP at the low load factor is due to the reduction of the heat source energy consumption. This is because the sequence of chillers is changed. The improvement of the general COP is caused by the change of cooling water temperature. In contrast, the energy consumption of the cooling tower is increasing in order to lower the temperature of the cooling water. As a result, the annual cooling COP is improved (case2: 9.1%, case3: 8.8%).In the comparison between case2 and case3, the improvement of the cooling COP of case2 is larger than that of case3. The difference of the cooling COP is observed in high load factor. This is because the reduction of the heat demand by the energy saving measures for demand side is large in high load factor. Therefore, the load factor of individual heat source is lowered and the cooling COP is getting worse. This result represent there is a possibility that the energy saving measures for the demand side cause the decrease of the COP.

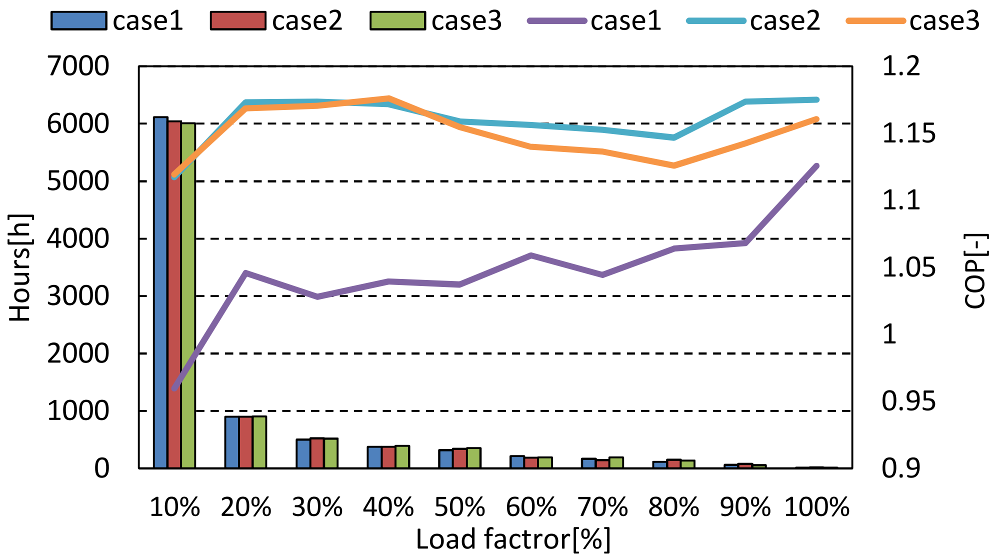

Figure 5. *The load factor and the average cooling COP of each load factor*

CONCLUSION

This paper presented a case study of the analysis of the big data from BEMS to detect the fault and calculating the effect of the energy saving measures. Firstly, by analyzing the data from BEMS, the energy saving measures for the demand side was become apparent. Subsequently, the energy saving potential is calculated. Use of the VAV and avoiding the hunching were admitted as valid. Secondly, the heat source system simulation model of the building was developed. Using the simulation model, the energy saving measures for the supply side system were examined. It became clear that the chillers sequence change of the heat source and lowering of the cooling water temperature create the energy saving effect. Finally, the combination of energy saving measures was examined. With the combination of energy saving measures of the demand side and the supply side system, it was estimated that 4.8 % of the energy saving effect was obtained. Furthermore there is a possibility that the energy saving measures for the supply side cause the decrease of the COP.

REFERENCE

A.Khan K. Hornbæk. 2011. Big data from the built environment, Proceedings of the 2nd International Workshop on Research in the large (Large '11). ACM, Beijing, China, 2011, PP.29-32