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DEVELOPMENT OF THE AUTOMATIC OPTIMIZATION AND DEGRADATION DETECTION TOOL FOR HVAC PRIMARY SYSTEM

Daisuke Sumiyoshi[1], Naomiki Matsushita[2], Je-Hyeon Lee[3], and Yasunori Akashi[1]
[1] Faculty of Human-Environment Studies, Kyushu University, Japan
[2] Aleph Networks Corporation, Japan
[3] Graduate School of Human-Environment Studies, Kyushu University, Japan

ABSTRACT

Automatic optimization and degradation detection tool for HVAC primary system was developed. It synchronizes with Building Energy Management System (BEMS), and it does optimization and degradation diagnosis automatically. Generally, the tools based on the simulation are low generality because of the complex input. Therefore, the targeted system of this tool is limited to the primary system that is specific standard configuration to reduce the input data. The optimization function outputs the best set point according to the outside temperature and the load etc. The degradation diagnosis function analyzes degradation of the primary system equipment once a day. The function and the measurement result of the tool are reported in this paper.

INTRODUCTION

In many building air-conditioning systems, the fixed set points are generally used throughout the year, concerning each set point of supply air temperature, outlet temperature, pressure, etc. However, it is possible to achieve energy-saving by the optimization of the air-conditioning system operation, which involves selecting the best set point according to the ever-changing outside environment and the thermal load of the building. In addition, equipment containing an air-conditioning system gradually degrade through everyday use. This is the reason they fail to fully demonstrate the level of performance, which was estimated when they were designed. For this reason, if we understand such a degradation condition, we could determine the appropriate timing to repair, exchange and overhaul the equipment. Moreover, we could possibly prevent energy waste and complaints caused by their incapability.

The optimization of the air-conditioning system operation and degradation detection is considered to be one of the ongoing commissioning. In fact, in only a few buildings with cutting-edge technology, it has already been achieved by combining a high-level control system with a calculation system, which is based on a simulation model. However, concerning the simulation-based tool, it is necessary to input data into the simulation according to the specifications of each building, and also necessary to adjust it according to the actual environment surrounding the system. As a result, it costs a significant amount of time and money.

Moreover, high simulation accuracy is requested from the optimization based on the simulation model. The deterioration of equipment in every day is one of the factors to decrease the simulation accuracy. Therefore, it is important to grasp the deterioration situation of the equipment and to reflect it in the simulation to improve the effect of optimization.

In this study, we developed an optimization and degradation detection tool. This tool can apply to the primary system in building air-conditioning system. In this paper, "the primary system" indicates the system composed by chillers, primary pumps, cooling towers, and cooling water pumps in the central air-conditioning system of the building.

Despite being a simulation-based tool, it is easy to input data into it. Also it can be introduced into an existing primary system. In order to reduce the input information for the simulation, applicable primary system is squeezed only to the primary system that is specific standard configuration. Furthermore, with the automatic tuning mechanism, which makes adjustments according to the real system, we designed this software tool as a user-friendly application by removing the complicated data input, which had been a conventional problem. As a result, less time is required for tuning and it became close to a general-purpose software.

THE OUTLINE OF THE DEVELOPED TOOL AND CALCULATION LOGIC

THE FORMATION OF THE TOOL

The formation of this tool is shown in Figure 1. The tool mainly has the 3 following functions, which are automatically operated:

a. Optimization of the set points

Based on the simulation using the data about the outside environment and present thermal load of the building, the most appropriate combination of the set points is determined. All possible subsets method is adopt as optimization method in this tool.

b. Parameter automatic tuning

Due to the individual difference of the equipment and the condition of their degradation, the performance of the equipment shows a different value from the manufacturer's specifications. In order to conduct a highly accurate simulation of the real system, it is necessary to install parameters, which can realize the real system's performance, into the models, and also tune them in accordance with the actual measurement. These parameters are numerical values that show the gap of the simulation result and the actual measurement value. In this tool, parameters are automatically tuned once a day.

c. The degradation detection report

The parameters obtained by tuning, which was mentioned in b, becomes an index to represent the degree of the degradation and fault of the equipment. We can figure out the progress of degradation and fault by accumulating the past results of parameter tuning and seeing the change of the results. Every time the parameters are tuned, data are supposed to accumulate.

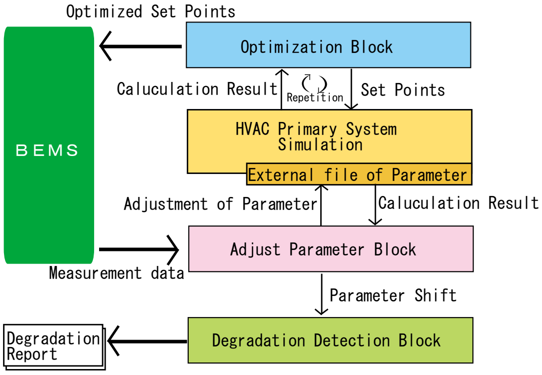

Figure 1 The formation of the tool

THE ENVIRONMENT OF THE SYSTEM FUNCTION AND THE APPLICABLE PRIMARY SYSTEM

In order to introduce our tool, we need to install a PC for data calculation (optimization PC shown in Figure 2) beside BEMS so that data can be exchanged between BEMS and the PC through a csv file. Moreover, we need to prepare a mechanism to export data to the PC from BEMS, and also a mechanism to import the set points from the file in the PC and reflect them on the primary system, by remodeling BEMS.

In order to simplify the data input, the applicable system is a primary system consisting of up to 5 sets of the chiller (absorption type refrigerator), the primary pump, the cooling tower and the cooling water pump, as Figure 3 shows. The secondary side is not a target. The outlet cooling water temperature of the cooling tower and the difference between the inlet and outlet cooling water temperature of the chiller are the targeted set points of optimization. The set point of the outlet temperature of chilled and hot water from chiller was excluded from the object of optimization. The secondary side culculation model is needed to examine about the change in the outlet temperature of chiller becase it influences the load and the achievement room temperature on the secondary side. However, adding it makes the tool more complex and more difficult to use. Therefore we exclude it in this study.

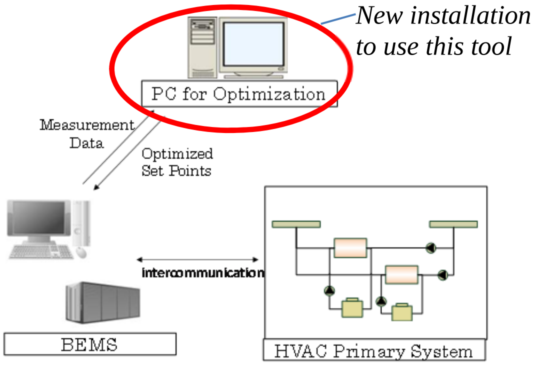

Figure 2 The introduction method *of the assumed tool*

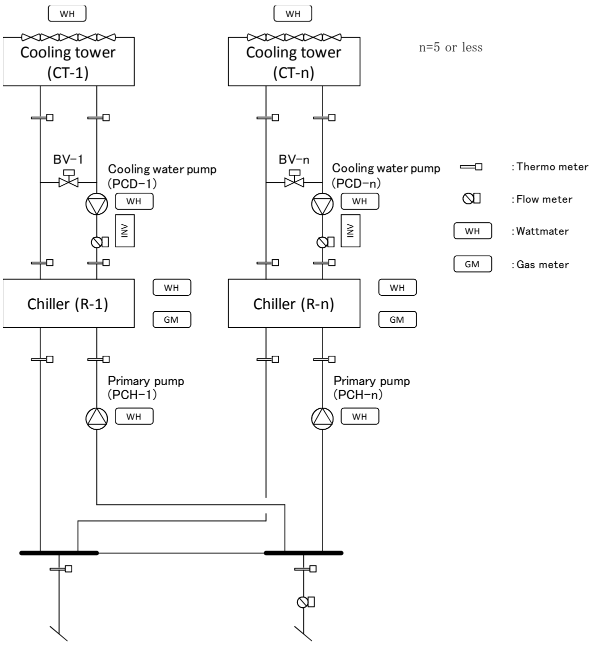

Figure 3 Applicable primary system and measurement points

THE CALCULATION LOGIC

THE PRIMARY SYSTEM SIMULATION MODEL

The calculation flow of the primary system simulation is shown in Figure 4. After the optimization PC inputs the equipment specifications, it inputs the actual measurement data of the outside temperature and humidity, each of the measurement points and the set points for calculation. Then, it implemented a repetitive calculation at specified points in time. The actual measurement data are

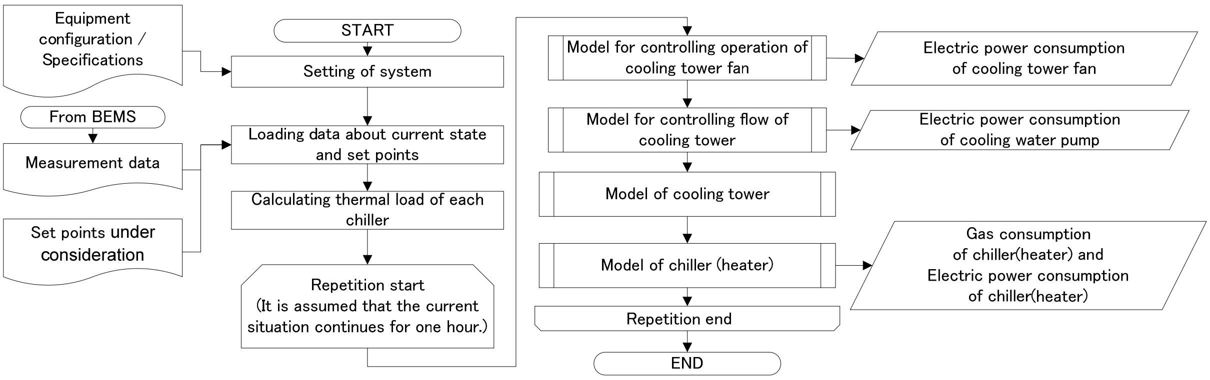

Figure 4 Calculation flow of the primary system simulation

output from the BEMS and the set points are output from the optimization block. The time step for the calculation was one minute. A repetitive calculation was conducted in the order of the number of the working cooling tower fan, the amount of the cooling water flow, the condition of both the working cooling tower and chiller. As a result, the temperature of each system, the energy consumption of the chiller, the cooling tower fan and cooling water pump were all calculated.

THE EQUIPMENT MODELS

The simulation model of the primary system mentioned in the foregoing section holds sub-models of the chiller, cooling tower and cooling water pump, in order to calculate the function and the energy consumption. Here in this chapter we will explain the chiller model.

The model formulae of the chiller are shown in formula(1)～(3). Formula (1) is a formula that calculates the energy consumption by third-order expression of the partial load rate. The change of efficiency, which is influenced by the cooling water temperature, is added to each coefficient of a～d, as Formula (2) shows. Each coefficient of a_0～d_3 in formula(2) should be calculated in advance by obtaining the characteristic formulae of the targeted chiller from the manufacturer. On the other hand, since coefficient k_g is a parameter that represents the degradation condition of the actual equipment, it is adjusted in the parameter tuning block. This means that the larger the number shown by the parameter, the more the energy consumption increases, (which means greater degradation), compared to the equipment performance that the specifications of the manufacturer show. Such parameters are also installed in the equipment models of the cooling tower and the cooling water pump. As a result, if the energy consumption is calculated, the outlet cooling water temperature of the chiller can be calculated by using Formula (3).

$$r_g = k_g\left(a + br_q + cr_q^{\ 2} + dr_q^{\ 3}\right) \qquad \cdots\cdots (1)$$

$$\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} a_0 & a_1 & a_2 & a_3 \\ b_0 & b_1 & b_2 & b_3 \\ c_0 & c_1 & c_2 & c_3 \\ d_0 & d_1 & d_2 & d_3 \end{bmatrix} \begin{bmatrix} 1 \\ \theta_{wrc,i} \\ \theta_{wrc,i}^{\ 2} \\ \theta_{wrc,i}^{\ 3} \end{bmatrix} \qquad \cdots\cdots (2)$$

$$\theta_{wrc,o} = \theta_{wrc,i} + \frac{r_q Q_r + Q_g r_g G_r}{c_{pw} v_{wrc}} \qquad \cdots\cdots (3)$$

r_g: Gas consumption rate[-],
k_g: Revision parameter[-],
a,b,c,d :Coefficients of gas consumption[-],
r_q: Partial load rate[-],
$\theta_{wrc,i}$: Inlet cooling water temperature of chiller[℃],
$\theta_{wrc,o}$:Outlet cooling water temperature of chiller[℃],
Q_r: Rated refrigeration capacity [kJ/h],
Q_g: Calorific value of gas [kJ/Nm3],
G_r: Rated gas consumption [Nm3/h],
c_{pw}: Specific heat of water[kJ/kg/K],
ν_{wrc}: Quantity of cooling water flow[kg/s]

THE OPTIMIZATION BLOCK

The calculation flow of the optimization block is shown in Figure 5. Users can choose one out of time intervals for optimization implementation, such as 10, 20, 30, 40, 50, and 60minutes. The optimization PC collects data, including the present thermal load of building and the outside weather factors from BEMS. Then, it gives the set points to the primary system simulation and receives the calculation result of the energy consumption, assuming that such a condition continues until the next changing time of the set points. Optimized set points are the following 3 values. The superiority or inferiority of set points is decided based on the simulation result. Conducting round-robin calculation for every possible combination of the candidate set points given in advance, optimization PC outputs the set points, which show the minimum optimization index(Users have the choices of primary energy consumption, electricity consumption, gas consumption and cost) as the best set points.

1) The set point of outlet cooling water temperature of the cooling tower

2) The set point of inlet cooling water temperature of the chiller
3) The set point of outlet cooling water temperature of the chiller

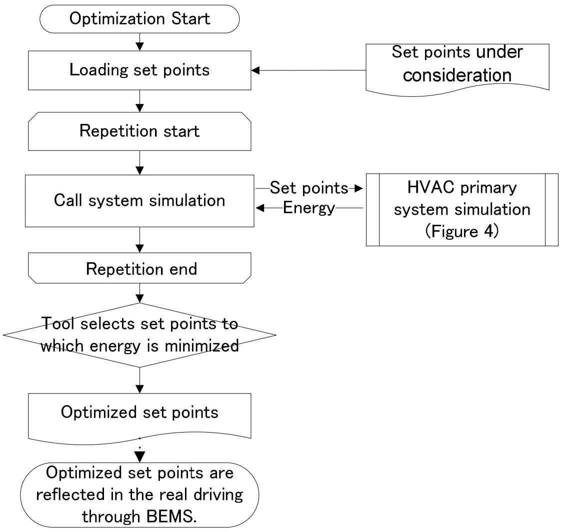

Figure 5 Calculation flow of the optimization block

THE PARAMETER TUNING BLOCK

If the degradations of the equipments are not considered, the accuracy of the simulation decreases. As a result, the primary system simulation, which is the base for the optimization, cannot be based on the real situation. For this reason, corrective parameters of the respective equipment explained in the chapter " the equipment models" are tuned by using the actual measurement data.

Targeted corrective parameters are as follows.

1) The parameter of gas consumption in the gas absorption type chiller model
2) The parameter of electricity consumption in the gas absorption type chiller model
3) The parameter of electricity consumption in the cooling tower model
4) The corrective parameter of electricity consumption in the cooling water pump model

The tool compared the calculation result with the actual measurement data for the respective equipment by the data for the past 14 days, including the calculation implementation day. Then it calculated the parameter, of which the difference between calculation and measurement values is the smallest, by using the least-square method. This calculation is conducted once a day.

THE DEGRADATION DETECTION BLOCK

The degradation detection block records the change of parameters, which are identified in the parameter tuning block, and visualize the degradation condition. The data are output in csv style, so that the degradation condition can be detected from the accumulated parameters.

A drastic change of parameters in the short term is considered to be a fault of the equipment, while a gradual change of parameters in the long term is considered to be a degradation of the equipment.

THE EFFICACY OF THE TOOL

THE TARGETED PRIMARY SYSTEM FOR VERIFICATION

Our tool was introduced into the primary system of a school facility and the result was verified. The primary system is shown in Figure 6 and the list of component equipments is shown in Table 1. The optimization PC and additional electric power meter were installed to introduce, and also the BEMS software was remodeled (adding a mechanism to export the measurement data to optimization PC and to import the set point file). The overall cost for the introduction was about ¥900,000 ($11,105).

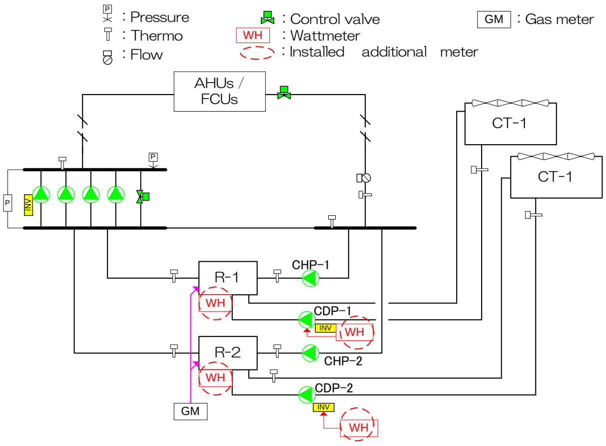

Figure 6 The targeted primary system

Table 1 The list of component equipments in the targeted hear source system

Equipment	Number	Rated Specification
Gas fired absorption chiller (R-1,2)	2	Refrigeration Capacity: 1,582kW Chilled water flow: 3,240 l/min Cooling water flow: 7,400 l/min Heating Capacity: 1,324kW Hot water flow: 3,240 l/min Gas consumption: 123 Nm3/h (Town gas13A)
Primary pump (CHP-1,2)	2	Flow: 3240 l/min Electric capacity: 15kW
Cooling water pump (CDP-1,2)	2	Flow: 7500 l/min Electric capacity: 37kW
Cooling tower (CT-1,2)	2	Cooling capacity: 2,878kW Cooling water flow: 7,500 l/min Electric capacity of fan: 5.5kW×3
Secondary pump (HP-3,4,5,6)	4	Flow: 5,140l/min Electric capacity: 37kW

THE EXPERIMENT SCHEDULE

The experiment schedule is shown in Table 2. The optimization operation period, in which our tool was applied, and the ordinary operation period alternated for 14 days from September 2nd in 2010. The system was operated for 10 hours from 9:00 to 19:00. In addition, during ordinary operation, the system was operated, after the set point of the outlet cooling water temperature of the cooling tower was fixed at

32 ℃ and the set point of the cooling water temperature difference of the chiller was fixed at 4K.

Table 2 The experiment schedule of optimization operation

Date		Case
2-Sep	Thu	Optimization
3-Sep	Fri	Optimization
4-Sep	Sat	Optimization
5-Sep	Sun	Optimization
6-Sep	Mon	Ordinary
7-Sep	Tue	Ordinary
8-Sep	Wed	Ordinary
9-Sep	Thu	Optimization
10-Sep	Fri	Optimization
11-Sep	Sat	Optimization
12-Sep	Sun	Optimization
13-Sep	Mon	Optimization
14-Sep	Tue	Ordinary

VERIFICATION OF OPTIMIZATION RESULT

The result of the measurement is shown in Table 3 and Figure 7. The outside temperature was slightly lower on ordinary operation days than on optimization operation days. Since the load of the air conditioning system on Sundays was smaller than the other days, the system COP was considerably low. The system COP here means the value of the air conditioning load being divided by the energy consumption of the whole primary system (chiller, cooling water pump and cooling tower fan). Concerning the targeted system, as figure 7 shows, the ratio of gas energy consumption is highly occupied in the whole energy consumption. Therefore, it is assumed that energy consumption of the whole system becomes smaller by improving the efficiency of the chiller, rather than reducing the electricity consumption of the pump and the fan.

The relation between the cooling water temperature and chiller COP is shown in Figure 8. It was obvious that the chiller COP increased by lowering the cooling water temperature during the optimization operation. As a result, as Figure 9 shows, if the level of load is the same, the optimization operation of our tool enhanced system COP changes by 10%. The data for Sundays were excluded in Figure 8 and 9, because the thermal load of building in Sundays was likely to be considerably different from that of the other days.

September 2nd and 3rd (optimization operation), and September 6th and 7th (ordinary operation) were chosen out of all the experiment days. Figure 10 and 11 show a comparison of the set point of the outlet cooling water temperature of the cooling tower and the measurement value on those days. The set point was 32℃ during ordinary operation. This value is usually used in this system. 24℃ was chosen in most time zones during the optimization operation. 24℃ in cooling water is a lower bound value that the chiller allows. As a result, the measurement value during the optimization operation was also lower than the ordinary operation by almost 2K. For this reason, the optimization operation could enhance the chiller COP, as Figure 8 shows. Meanwhile, there is no mechanism to check whether the water temperature actually realizes the set points or not. Therefore, the actual measurement of the outlet cooling water temperature of the cooling tower has not realized the set point. There is no problem in terms of the operation, however, there is a possibility that ordinary users might misunderstand that the system has malfunctioned if the optimization PC outputs the set point, which cannot be realized. For this reason, it is necessary to revise the tool in the future.

In figure 10, 28℃ has been selected as a set point in a part of time zones during the optimization operation. It is because the tool judged that it is more advantageous to raise the set point of cooling water temperature and to reduce the electric power of the cooling tower fan than to lower the temperature of cooling water and to raise the efficiency of the chiller.

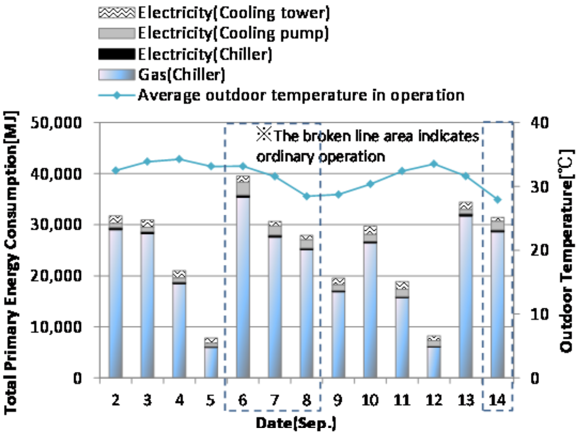

Figure 7 Energy consumption

Table 3 The result of measurement

			Average outdoor temperature in operation	Average cooling water temperature in operation	Thermal load of Building	Quantity of produced heat	Gas consumption of chiller	Electric power consumption			Total primary energy	System COP	Partial load rate of chiller	COP of chiller
								Chiller	Cooling pump	Cooling tower				
			℃	℃	MJ	MJ	MJ	kWh	kWh	kWh	MJ	–	–	–
2-Sep	Thu	Optimization	32.5	28.8	22,540	27,800	29,025	41.0	87.1	149.3	31,732	0.71	0.49	0.96
3-Sep	Fri	Optimization	33.9	29.1	21,610	26,800	28,260	40.6	86.4	148.4	30,948	0.70	0.47	0.95
4-Sep	Sat	Optimization	34.3	28.5	14,370	19,090	18,450	29.5	88.7	148.5	21,053	0.68	0.34	1.03
5-Sep	Sun	Optimization	33.1	27.1	2,670	5,750	5,985	14.8	75.2	97.4	7,814	0.34	0.10	0.96
6-Sep	Mon	Ordinary	33.2	32.1	25,740	31,160	35,370	49.3	256.2	121.8	39,540	0.65	0.55	0.88
7-Sep	Tue	Ordinary	31.6	32.3	22,000	27,310	27,585	40.1	179.9	94.1	30,651	0.72	0.48	0.99
8-Sep	Wed	Ordinary	28.4	32.1	18,640	23,540	25,065	37.6	172.9	85.3	27,952	0.67	0.41	0.94
9-Sep	Thu	Optimize	28.7	25.8	17,070	19,620	16,875	23.9	117.8	133.8	19,564	0.87	0.34	1.16
10-Sep	Fri	Optimize	30.4	28.3	22,260	24,920	26,460	34.8	138.2	161.8	29,728	0.75	0.44	0.94
11-Sep	Sat	Optimize	32.4	30.3	12,160	14,170	15,705	26.5	142.1	159.4	18,906	0.64	0.25	0.90
12-Sep	Sun	Optimize	33.5	31.6	2,700	3,770	6,075	13.9	110.6	99.3	8,259	0.33	0.07	0.62
13-Sep	Mon	Optimize	31.6	28.1	25,620	31,020	31,725	43.7	87.7	147.2	34,444	0.74	0.54	0.98
14-Sep	Tue	Ordinary	27.9	32.0	19,000	24,080	28,575	42.7	174.0	75.8	31,430	0.60	0.42	0.84

To grasp the tendency of the selected set point in optimization operation, the mean value of set points according to the outside temperature and the load is shown in Table 4. The outside temperature is categorized by 1 ℃ interval, and the load is categorized by 500MJ/h intervals. As for a set point of the outlet cooling water temperature of the cooling tower, the tendency to rise when the load is less is shown. As for a set point of the outlet cooling water temperature of the chiller, the tendency to rise when the load is less and the outside temperature is high is shown.

VERIFICATION OF DEGRADATION DETECTION FUNCTION

In this tool, the result of the parameter tuning for the respective equipment was updated and output in the file once a day. The tuning result is shown in Table 5. Concerning the targeted system, the corrective value of the chiller gas consumption was more than 1.4, which indicated that the energy consumption of the targeted system increases, compared to the energy consumption calculated from the performance characteristics provided by the manufacturer. This gap is mainly caused by the unbridgeable gulf between the performance characteristic and the realities, and by the progress of the degradation.

Basically the degradation detection is to analyze the degradation condition by grasping the change of parameters. This time, however, we have not sufficiently analyzed the result of the automatic parameter tuning because only a short-term measurement has been made. Figure 12 shows the change of the chiller parameter in other building that has fault. The parameter has rapidly become small since about the 130th day. The fault can be detected from such a rapid change in a parameter. It was confirmed that the reason is the measurement sensor fault.

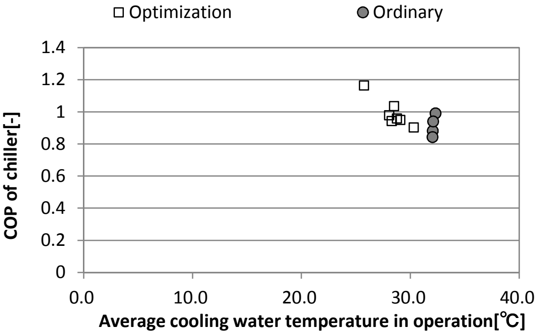

Figure 8 The relation between average cooling water temperature and COP of chiller

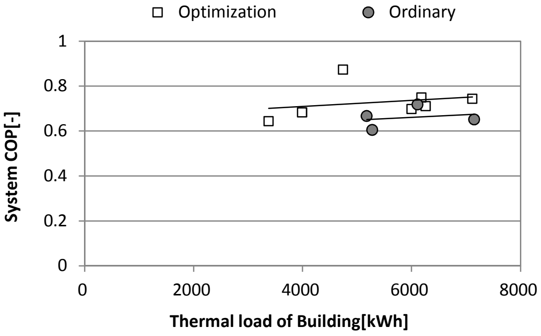

Figure 9 The relation between thermal load of the building and system COP

Table 4 Mean value of set points

a) Set point of the outlet cooling water temperature of the cooling tower

		Load[MJ/h](The value shows the upper bound value of the category.)							
		500	1000	1500	2000	2500	3000	3500	4000
Outside temperature[℃]	27	24.0	–	–	–	–	–	24.0	–
	28	24.0	24.0	–	24.0	24.0	24.0	24.0	–
	29	24.0	24.0	24.0	24.0	24.0	–	–	–
	30	24.0	24.0	24.0	24.5	24.5	24.0	–	–
	31	26.0	24.0	24.0	24.0	24.0	24.0	24.0	–
	32	24.2	24.0	25.0	24.0	24.0	24.0	24.9	24.0
	33	24.9	24.4	24.0	24.0	24.0	24.0	24.0	24.0
	34	24.5	24.0	24.0	24.0	24.0	24.0	24.0	–
	35	24.5	24.0	24.0	24.0	24.0	24.0	24.0	–
	36	27.3	24.0	24.0	24.0	24.0	24.0	24.0	24.0

b) Set point of the outlet cooling water temperature of the chiller

		Load[MJ/h](The value shows the upper bound value of the category.)							
		500	1000	1500	2000	2500	3000	3500	4000
Outside temperature[℃]	27	26.0	–	–	–	–	–	26.0	–
	28	26.2	26.0	–	26.0	26.0	26.0	26.0	–
	29	26.0	26.9	26.0	26.0	26.0	–	–	–
	30	26.0	26.0	26.7	26.8	26.5	26.0	–	–
	31	28.1	26.0	26.0	27.0	28.0	27.0	26.0	–
	32	26.4	26.3	27.2	27.4	27.7	27.5	29.1	26.0
	33	27.0	26.8	26.8	28.1	30.2	30.6	30.8	31.0
	34	26.6	26.0	26.5	27.6	29.9	30.4	30.8	–
	35	26.5	26.2	27.8	28.1	29.3	29.0	31.0	–
	36	29.5	27.7	27.6	29.0	29.9	30.3	31.0	31.0

Table 5 The result of parameter tuning

Calculation date	Data period used for tuning	Paramater about gas consumption of chiller			Paramater about electric power consumption of cooling tower			Paramater about electric power consumption of cooling pump		
		Before adjustment	After adjustment	Number of used data	Before adjustment	After adjustment	Number of used data	Before adjustment	After adjustment	Number of used data
2-Sep	19-Aug～2-Sep	1.45	1.42	4,249	0.99	1.00	4,275	0.77	0.77	3,691
3-Sep	20-Aug～3-Sep	1.42	1.41	4,032	1.00	1.00	4,688	0.77	0.77	3,510
4-Sep	21-Aug～4-Sep	1.41	1.40	3,730	1.00	1.00	4,997	0.77	0.77	3,261
5-Sep	22-Aug～5-Sep	1.40	1.39	3,942	1.00	1.00	5,135	0.77	0.79	3,519
6-Sep	23-Aug～6-Sep	1.39	1.39	3,942	1.00	1.00	5,619	0.79	0.79	3,519
7-Sep	24-Aug～7-Sep	1.39	1.38	3,574	1.00	1.00	5,763	0.79	0.79	3,204
8-Sep	25-Aug～8-Sep	1.38	1.38	3,408	1.00	1.00	6,020	0.79	0.79	3,057
9-Sep	26-Aug～9-Sep	1.38	1.37	3,062	1.00	1.00	5,727	0.79	0.79	2,776
9-Sep	27-Aug～10-Sep	1.37	1.41	3,643	1.00	1.00	6,785	0.79	0.80	3,298
10-Sep	28-Aug～11-Sep	1.41	1.40	6,342	1.00	1.00	5,487	1.00	0.78	6,122
11-Sep	29-Aug～12-Sep	1.40	1.40	5,921	1.00	1.00	5,116	0.78	0.78	5,751
12-Sep	30-Aug～13-Sep	1.40	1.40	5,593	1.00	1.00	4,830	0.78	0.78	5,465
13-Sep	31-Aug～14-Sep	1.40	1.39	6,018	1.00	1.00	5,271	0.78	0.78	5,910
14-Sep	1-Sep～15-Sep	1.39	1.40	6,185	1.00	1.00	5,231	0.78	0.78	6,128

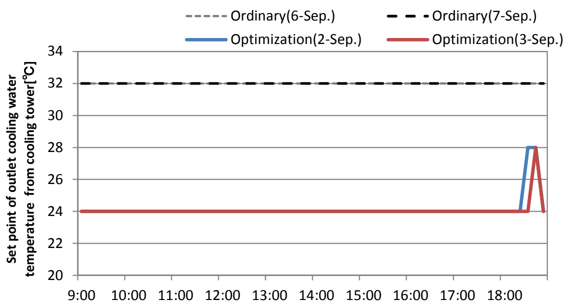

Figure 10 The comparison of set point of outlet cooling water temperature of the cooling tower

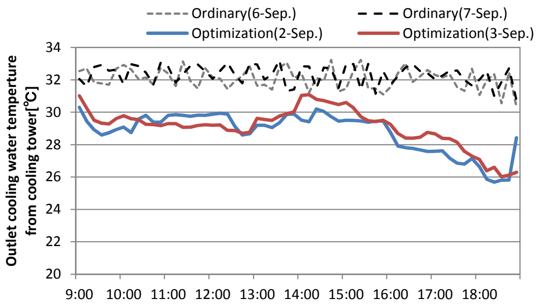

Figure 11 The comparison of real measurement of the outlet cooling water temperature of the cooling tower

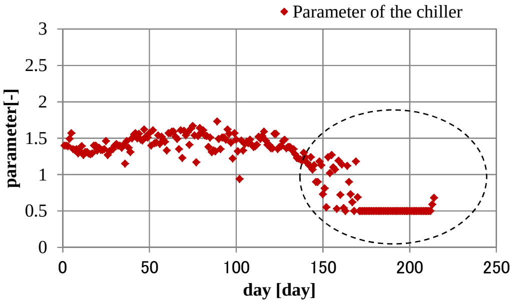

Figure 12 Change of parameter about chiller's gas consumption when there is a fault in the system

Accuracy of simulation

The function to output the actual measurement value and the simulation value of the primary energy consumption after the operation hour is installed in this tool. Table 6 shows the comparison between the actual measurement value and the simulation value. The actual measurement values of the energy consumptions were measured with the gas meter and the watt-hour meter on each equipment. The simulation error margin is within 10% on most days. Because the energy consumption of the chillers is large, the influence of the error margin in the chillers is strong in the system. Figure 13 shows the relation between the average part load rate of chillers and the simulation error margin of the energy consumption of the system. It is understood that the error margin is large when a partial load rate is small. In this simulation, Figure 14 is used as a characteristic of the gas input rate of the chiller. There is no line in the range of 20% or less in partial load rate, and it is assumed the chiller become on-off control in this range. It is thought that the error margin is growing in this part because it differs from actual behavior. It is planned to improve it in the future.

Optimization is a function to decide the best set point on the assumption that the simulation model can reproduce the realities. If the error margin of the simulation model is large, the optimization result doesn't become a best answer. Therefore, such a system of checks is indispensable.

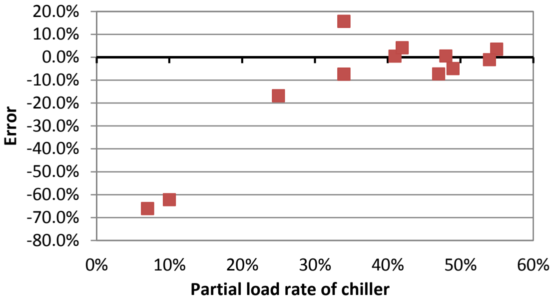

Figure 13 Relation between chiller partial load rate and simulation error margin

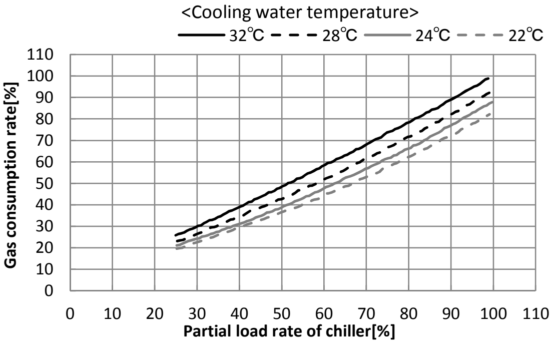

Figure 14 The characteristic of the gas input rate of the chiller

Table 6 Comparison between actual measurement value and simulation value of energy consumption

	Primary Energy Consumption of Chiller[MJ] (Total of gas and electricity)			Total Primary Energy Consumption of System[MJ] (Total of gas and electricity)			Partial load rate of chiller
	Measurement	Simulation	error	Measurement	Simulation	error	
2-Sep	29,025	27,864	-4.0%	31,732	30,149	-5.0%	49%
3-Sep	28,260	26,352	-6.8%	30,948	28,669	-7.4%	47%
4-Sep	18,450	17,559	-4.8%	21,053	19,493	-7.4%	34%
5-Sep	5,985	2,192	-63.4%	7,814	2,951	-62.2%	10%
6-Sep	35,370	36,864	4.2%	39,540	40,893	3.4%	55%
7-Sep	27,585	28,260	2.4%	30,651	30,798	0.5%	48%
8-Sep	25,065	25,871	3.2%	27,952	28,073	0.4%	41%
9-Sep	16,875	20,633	22.3%	19,564	22,623	15.6%	34%
10-Sep	26,460	missing data	-	29,728	missing data	-	94%
11-Sep	15,705	13,977	-11.0%	18,906	15,723	-16.8%	25%
12-Sep	6,075	1,899	-68.7%	8,259	2,802	-66.1%	7%
13-Sep	31,725	31,410	-1.0%	34,444	34,049	-1.1%	54%
14-Sep	28,575	30,456	6.6%	31,430	32,706	4.1%	42%

CONCLUSION

In this paper, first we outlined the automatic optimization and degradation detection tool of the HVAC primary system that we developed. The characteristics of the tool are as follows:

- It automatically conducts an optimization and degradation detection by linking with the BEMS.
- The tool is applicable for the existing primary systems of central air-conditioning system in the building.
- The applicable systems are limited in order to save time while data is being input.
- As a measurement result, it can improve the system COP by applying the best combination of set points in simulation that is inputted the outside temperature and humidity as well as the thermal load of the building.
- The parameters, which indicate the degradation condition, are installed into equipment models. As a result, the degree of the degradation condition of the equipment is detected by tuning the parameters in accordance with the actual measurement data.

Secondly, in order to verify the result of the developed tool, we introduced the tool into the real primary system in a school facility. The verification of the tool was implemented for about 2 weeks. While introducing it, the optimization PC and additional electric power meter were installed, and also the BEMS software was remodeled. The overall cost for its introduction was about ¥900,000 ($11,105).

After the actual measurement was implemented, it was confirmed that the system COP of the primary system improved as the efficacy of optimization by this tool. Still, this was the result brought about in the mid-term (September). It is assumed that the result might fluctuate according to the season.

On the other hand, with regard to the degradation detection function, we have not fully understood its efficacy since the verification was conducted in the short term. Concerning the verification of the result of the degradation detection function, we confirmed that the parameters were identified and also accumulated by the automatic parameter tuning function of the equipment, which used measurement data. In this sense, we assume that it is possible to understand the malfunction and degradation condition of the equipment by detecting the change of parameters.

The error margin of the simulation was within 10% excluding the low load day. The day when the error margin was large was seen on the low load day. If the error margin of the simulation model is large, the optimization result doesn't become a best answer. Therefore, such a system of checks is indispensable.

Since this tool has been just developed, there are not enough accumulated measurement data. Therefore, in the future, it is important for us to continue conducting measurements and verify the efficacy of the optimization and degradation detection.

In conclusion, in order to realize automatic ongoing commissioning in many air-conditioning systems, we will make every effort to improve this tool by expanding targeted system.

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