DEVELOPMENT OF HVAC SYSTEM SIMULATION TOOL FOR CYCLE ENERGY MANAGEMENT
PART 3:CASE STUDIES USING DEVELOPED TOOL ON EACH PHASE OF LIFE CYCLE

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ABSTRACT

The HVAC system in a real building was simulated by the energy simulation tool being developed (Ito et al. 2007, Sugihara et al. 2007). In order to confirm the practical utility of the tool, the studies are conducted on each phase: Program/Planning/ Design phase, Construction phase, Pilot-Operation phase and Operation phase. The tool was used to simulate from small systems such as simple equipment to total HVAC systems and might have applicability to fault detection and maintenance management.

In this paper, first the phases in a lifecycle and evaluation index of air-conditioning system in a life cycle are discussed. How the developed tool was used on each stage is also discussed. Then the case study in which applications of simulation by the developed tool are demonstrated was conducted.

KEYWORDS
Lifecycle Energy Management, Simulation, HVAC System

INTRODUCTION

Previous papers reported the outline of the developed simulation tool for life cycle energy management (LCEM) and the component models for HVAC Equipments. In this paper shows the case studies using developed tool on each phase of life cycle of HVAC system.

PHASE IN LIFECYCLE AND APPLICATION OF SIMULATION

Table 1 shows the several stages (phases), the calculation condition and an evaluation index of air-conditioning system corresponding to each phase in the life cycle. The cycle starts with the phase of Project/Plan/Design phase. Then Approving Equipments, Workout, Acceptance phase follows. After Acceptance, long-term Operating phase exists.

The boundary and calculation conditions for the simulation are the load and operating conditions, and the equipment specifications. These conditions differ depending on the lifecycle phase. From planning phase to trial operation and adjustment phase, the

Table 1 Phases in lifecycle and application of simulation

Phase	Program Planning Design	Construction Approval of Equipment	Pilot-Operation Adjustment	Operation	
				From 1st year up to 15years	15years or more have passed; Consider retrofit
Condition of Load	Calculated load or measured load of similarly used building	Calculated load or measured load of similarly used building	Calculated load or measured load of similarly used building	Actual measured load	Actual measured load
Condition of Opeartion & Management	Design condition	Design condition	Design condition	Actual condition	Actual condition
Characteristic of Equipments	Design specification	Caracteristics of approved equipment	Caracteristics of approved equipment	Caracteristics of approved equipment	Caracteristics of equipment which deteriorated
Management Index	Energy Consumption (Annual/Seasonal) COP of Total System / COP of Subsystems (HTF, WTF, ATF, COP of Heat Source System)				

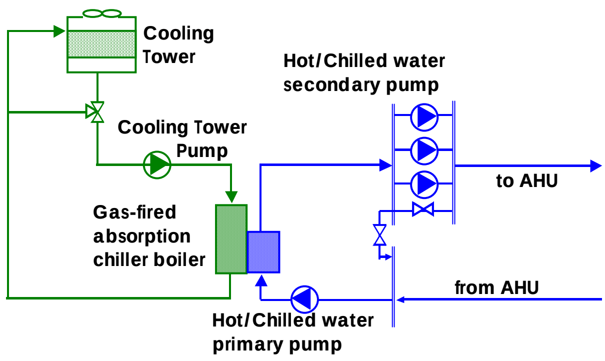
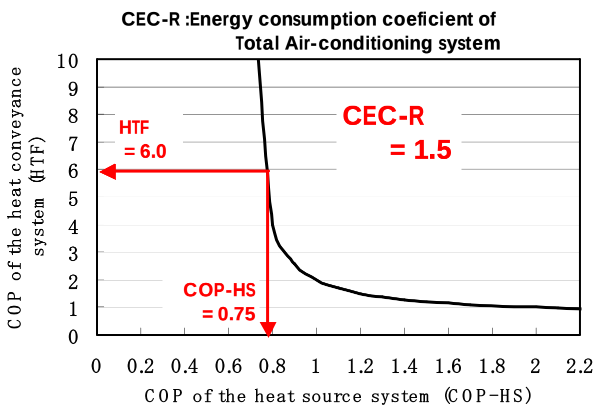


Figure 1 Outline of heat source system



$$\text{CEC-R} = \frac{\text{Wtotal}}{\text{QAC, Load}} = \frac{\text{WHS + WHC}}{\text{QAC, Load}}$$

$$= \frac{1}{\frac{\text{QAC, Load}}{\text{WHS}}} + \frac{1}{\frac{\text{QAC, Load}}{\text{WHC}}}$$

$$= 1/\text{COP-HS} + 1/\text{HTF}$$

Figure 3 Set up of the management index and its desired value

calculated air-conditioning load and design operating condition are used. In the operating phase, the measurement load and the actual operating condition are used for several examinations. Design equipment performance is used for planning phase and approved performance is used after the approval phase.

When about 15 years have passed from beginning of operation, the equipment characteristic in which the deterioration due to age is considered and the equipment characteristic after repairs will be used for examination of retrofit.

The developed simulation tool is able to account for the above conditions that vary with lifecycle phase.

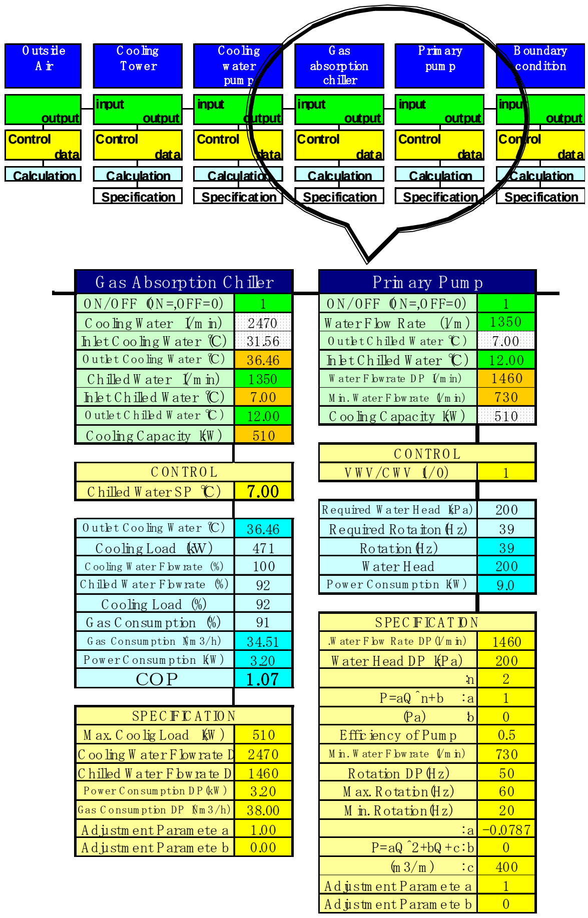


Figure 2 Example of model construction using developed tool

OUTLINE OF BUILDING AND HEAT SOURCE

A government building having a total floor area of about 5,000 m^2 was selected for the case study. Figure 1 shows a schematic diagram of the heat source system with the measurement points. Variable water volume control systems are used for the cooling water system and the primary chilled water system. Gas direct-fired absorption water chiller boiler is installed.

MODEL CONSTRUCTION AND CALCULATION

Figure 2 shows the construction of the model of the heat source system shown in Figure 1 by using development objectives (Sugihara et al. 2007). This system consists of a cooling tower, a cooling water pump, a gas direct-fired absorption water chiller boiler, and a hot- and chilled water primary pump. Only the spreadsheet functions (Excel) of the developed simulation tool were essentially used. The I/O macro will be useful, however, when measured values and other hourly data are used as boundary conditions.

CASE STUDY

The example of a case study is shown below. Although the object building and the system were existing ones, for the planning phase – test operation / adjustment stage, it was assumed that we went back to those stages, and design examination that was probably performed in the stage was reproduced.

Program phase

The management index and management desired value in connection with the energy performance that should be realized are set up. If it is assumed that the desired value of energy consumption coefficient (CEC-R) is set to 1.5, and COP of heat conveyance system (HTF) is 6, COP of heat source system (COP-HS) must be 0.75 or more as shown in Figure 3. In the following design phases, examination of the system is made aiming for this value.

Preliminary Design Phase

In this phase, it is assumed that examination is conducted on the control strategy of chilled water system and cooling water system. The number of ~~a~~ heat sources is one. The assumed cases are the following three:

Case 1: Constant water volume for cooling water and chilled water

Case 2: Variable water volume for cooling water and constant water volume for chilled water

Case 3: Variable water volume for cooling water and chilled water

Moreover, in preliminary design phase examination shall be conducted using standard load pattern instead of calculating detailed load. Load for every time for one year shall not be used, but design and examination shall be performed for the simplified load pattern. After the load for every time is sorted in descending order, it is divided into sections of every 100 hours. Then each section is represented with the average value in that section as shown in Figure 4.

The examination results are shown in Figure 5. It turns out that case 2 and case 3 demonstrate the performance exceeding the management desired value set up in the planning stage according to the examination result.

Working Design Phase

In this stage, examination of the number of heat source equipment is conducted. According to the examination results in the preliminary design, both cooling water and chilled water are controlled as constant water volume. The assumed cases are the following three:

Case 3-1: One water heater and chiller unit (563 kW)

Case 3-2: Two units having a capacity ratio of 50%:50% (282 kW x 2)

Case 3-3: Two units having a capacity ratio of 70%:30% (394 kW + 159 kW)

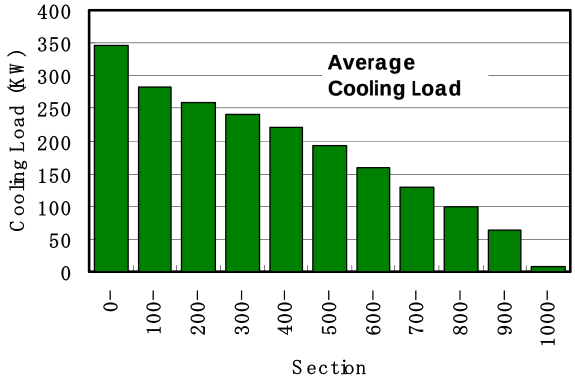


Figure 4 Simplified load pattern

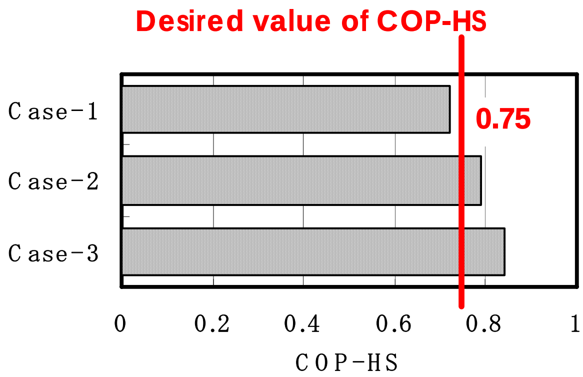


Figure 5 Examination results of the performance of heat source system

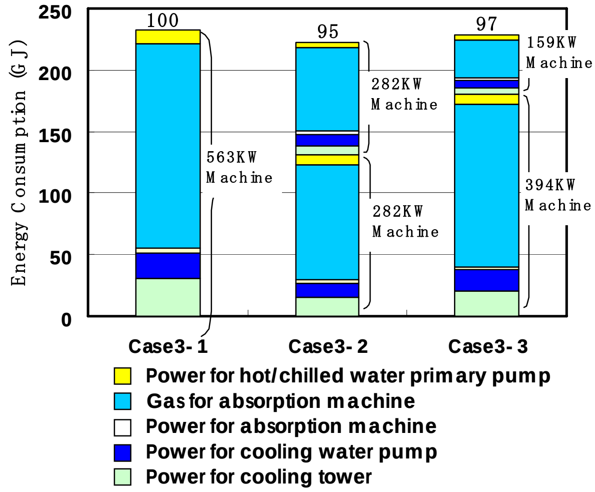


Figure 6 Examination of the number of heat source equipment

Figure 6 shows the calculation results. Case 3-2 has the smallest energy consumption, but it is only 5% less than that of case 3-1. When the installation space and cost were taken into consideration, it was decided to use only one unit (Case 3-1).

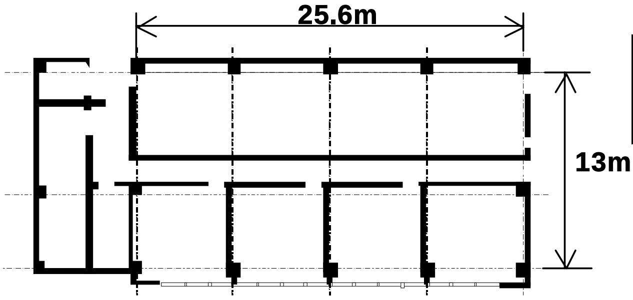


Figure 7 Typical floor of subject building

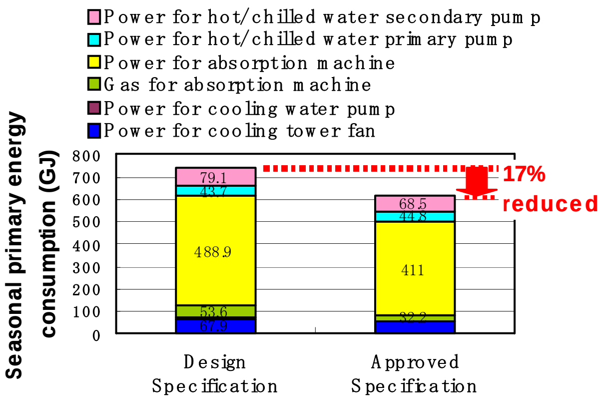


Figure 9 Approval of equipment considering seasonal energy consumption

Furthermore, in this stage, examination of a secondary side air-conditioning system shall also be performed. Figure 7 is a plan of the typical floor of the subject building for this paper. For this examination the load for every time calculated using the load calculation program is used. When outdoor air cooling is performed, the energy consumption can be reduced considerably. If a total heat exchanger is installed, the energy consumption of the heat source can be minimized. However, the energy consumption for the fan of the air handling unit increases.

Construction Phase – Approval of equipment

In a construction stage, the tool developed by this research is applicable to approval of equipment. In this examination, the value of the management index is calculated using an LCEM tool with two characteristics of the equipment. One is the characteristic which was assumed at Working Design Phase and the other one is the characteristics of equipment which are undergoing approval. Then it is checked whether the management index value set up in the Working Design Phase can be fulfilled.

Figure 9 shows the result of the examination for heat source equipment. It turns out that the energy consumption which is calculated for the characteristics of equipment to be approved does not exceed the energy consumption calculated at Working Design Phase. Therefore, this equipment can be approved. In this examination, the energy consumption and the system COP for every time can also be checked using the duration curve as shown in Figure 10.

	Ratio of minimum supply air volume of VAV	Total heat exchanger	Outdoor air cooling
Case-4	5%	equipped	applied
Case-3	5%	not equipped	applied
Case-2	5%	equipped	not applied
Case-1	5%	not equipped	not applied
Case-0	30%	not equipped	not applied

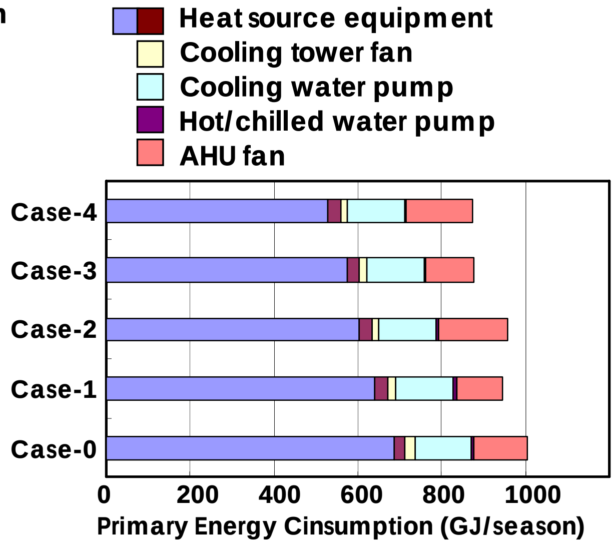


Figure 8 Examination on secondary side

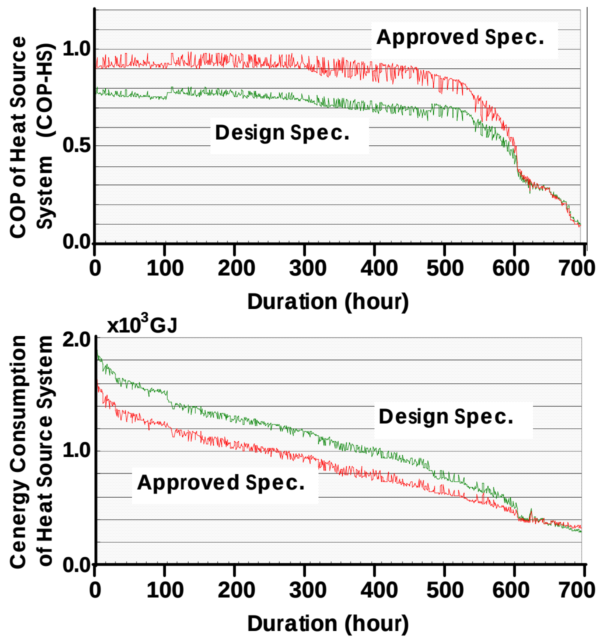


Figure 10 Approval of equipment by checking the performance for every time

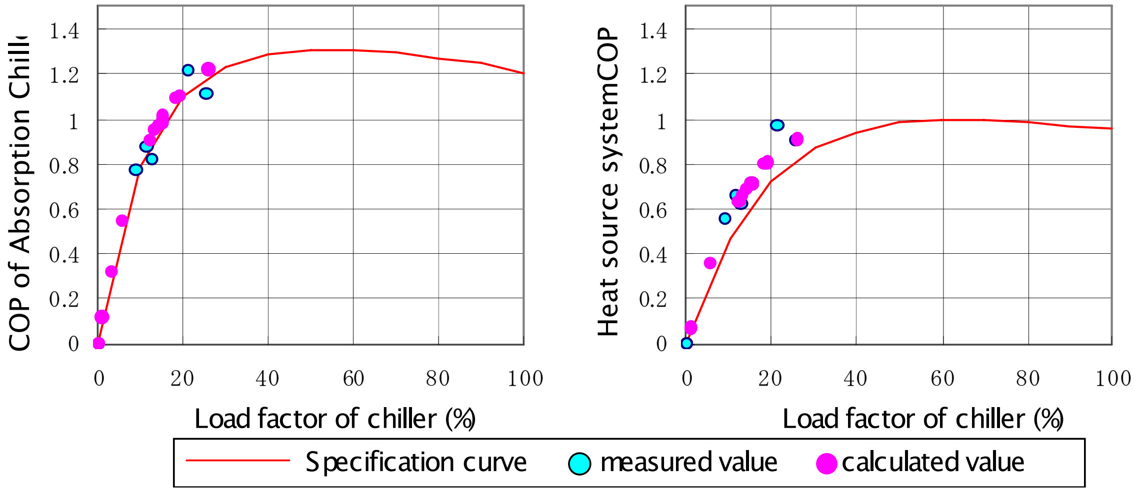


Figure 11 Verification of COP of chiller and heat source system (Pilot Operation)

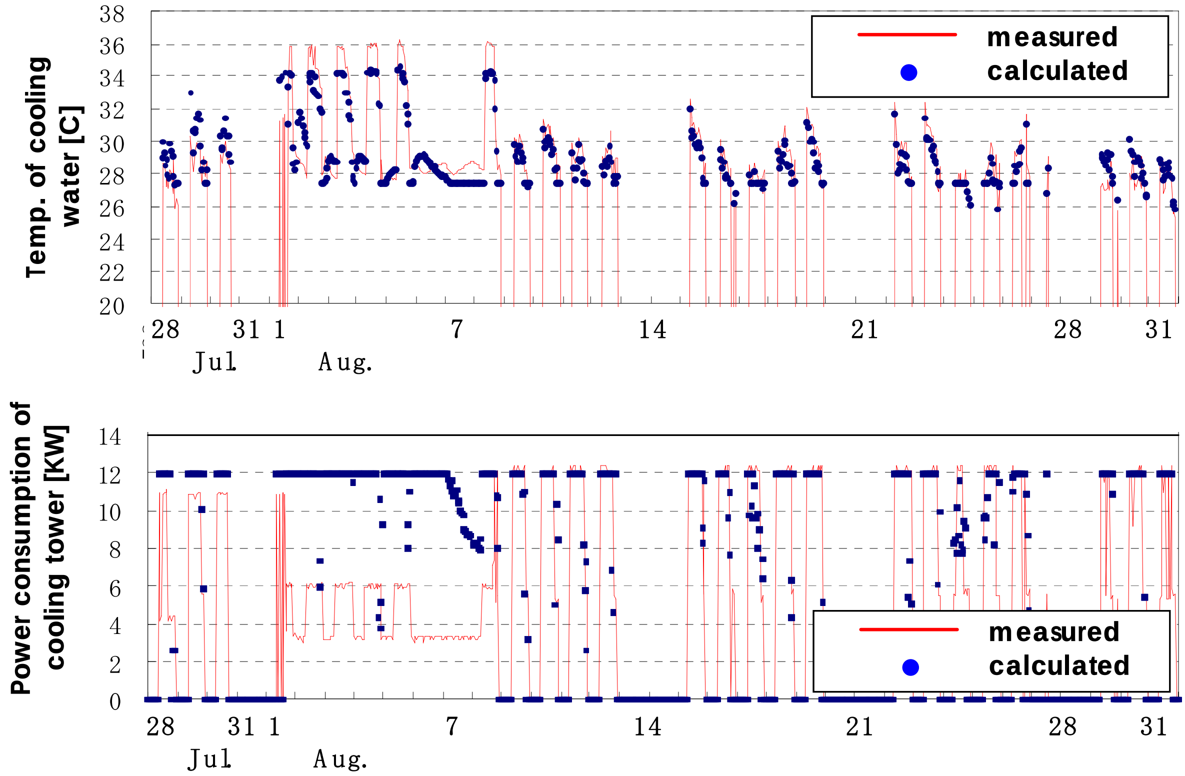


Figure 12 Comparison the measured and simulated values cooling water temperature and power consumption

Pilot-Operation and Adjustment Phase - Verifying the Heat Source Performance

Figure 11 shows the verification results of the performance of chiller and heat source system. In spite of operation at the low load factor, the COP of chiller itself is mostly in agreement with the specification performance. The system COP of based on the primary energy that includes the energy consumption of chiller, cooling tower and pumps has exceeded the specification performance. This is considered to be an effect of variable water volume control of the cooling water pump.

Operation Phase - Fault Detection

For appropriate operation management, it is important to monitor the equipment performance continuously and to detect faults early. By focusing on the cooling tower, the authors discuss the possibility of detecting faults in the operation phase.

Cooling-water outlet temperature and power consumption were calculated by inputting the measured values of outdoor air wet bulb temperature, cooling-water flow rate and cooling-water return temperature into the developed tool. By comparing these calculated values with measured ones, the monitoring of equipment performance can be conducted.

Figure 12 compares the measured and simulated values of the cooling water temperature and the power consumption for the period from July 28 to August 31 by. From July 28 until 30, no problems were experienced with the cooling water temperature. However, the power consumption tended to be smaller than the calculated value during this period and the cooling water temperature exceeded 35°C in the following week. These faults could be attributed to bearing damage. This example demonstrates that comparing measured data with values calculated using the developed simulation enables performance monitoring and early fault detection.

Operation Phase – Optimization

COP of a chiller can be made higher by raising the chilled water outlet temperature of the chiller. Therefore, effect of chilled water outlet temperature on energy consumption under actual air conditioning load conditions was examined. The examination results are shown in Figure 13.

1. When the chilled water outlet temperature is changed from its designed value of 7°C to 12°C, the energy consumption of the absorption chiller decreases by 12%.
2. When the chilled water outlet temperature is changed to 12°C, the energy consumption of the secondary pump increases remarkably and the total energy reduction is suppressed to 3.5%.
3. When the inverter control of the secondary pump (secondary pump VWV) is applied, the energy consumption is reduced by 10% from the standard case, reflecting the effect of raising the chilled water transportation temperature.

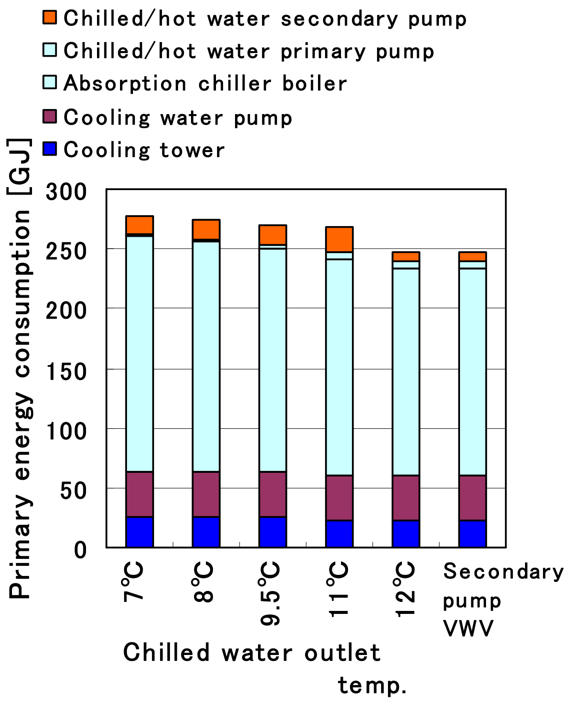


Figure 13 Effect of chilled water outlet temperature on energy consumption

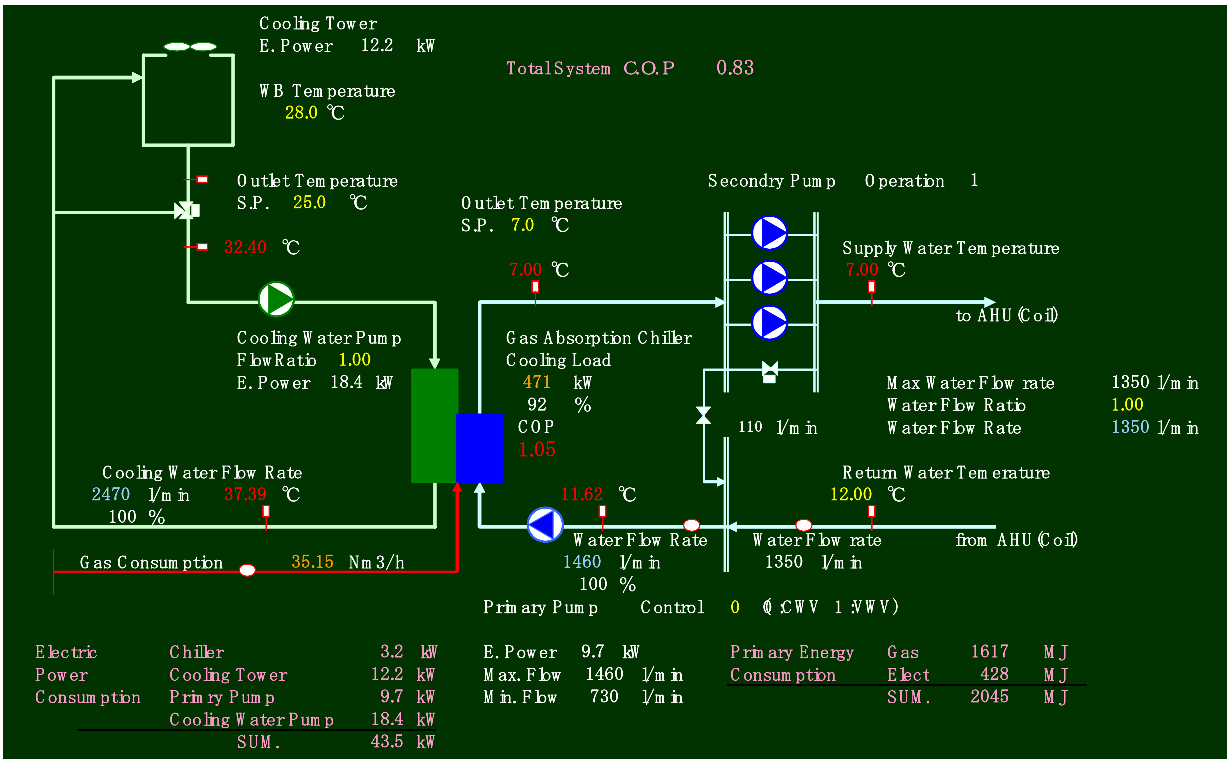


Figure 14 Diagram of heat source system on BEMS screen

The above results indicate that the developed simulation is applicable even when combinations of several techniques are used.

Operator Support

Since the developed simulation uses general-purpose spreadsheet software, the simulation results can be displayed easily in various formats. Figure 14 shows a heat source system diagram on a screen of BEMS (Building Energy Management System); it shows the simulation boundary conditions, automatic control settings, and the temperatures of the chilled water, hot water, and cooling water.

It is expected that this developed simulation can be used as an operator support tool since the screen settings and conditions can be varied allowing easy monitoring on the screen of the system status and changes in the energy consumption.

CONCLUSION

In this study, a developed air-conditioning system simulation tool for LCEM was applied to an existing building. The results of its application and estimation were reported in this paper. The developed simulation was demonstrated to be capable of simulating each component in an entire system and to be applicable to the planning and design phase, the pilot operation and adjustment phase, and the maintenance and management phase. In future, its method of application will be established by performing repetitive case studies.

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REFERENCES

Ito M. et al. 2007. “DEVELOPMENT OF HVAC SYSTEM SIMULATION TOOL FOR LIFE CYCLE ENERGY MANAGEMENT PART 1: OUTLINE OF THE DEVELOPED SIMULATION TOOL FOR LIFE CYCLE ENERGY MANAGEMENT” Building Simulation 2007

Sugihara Y. et al. 2007. “DEVELOPMENT OF HVAC SYSTEM SIMULATION TOOL FOR LIFE CYCLE ENERGY MANAGEMENT PART 2: DEVELOPMENT OF COMPONENT MODELS FOR HVAC EQUIPMENTS” Building Simulation 2007