Research Concerning the Amount of Energy Consumption of Heat Source Systems at University Facilities

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Summary
We investigated the energy consumption of heat source equipment in the university research facility building. The purpose is to clarify the current operation state of the heat source facility and propose a more efficient heat source facility system at the time of renewal.

The survey method used BEMS data to calculate every hour of COP used by the heat pump of electric energy, inlet and outlet temperature and primary pump flow rate. As a result, the heat source efficiency of the heat pump had the average COP=1.98 during cooling in 2016 and COP=1.98 during heating in 2016. The heat source efficiency at the time of designing the heat pump was COP=2.38 during cooling and COP=1.95 during heating. Therefore, it was revealed that the heat source efficiency average in 2016 was lower than the heat source efficiency at the time of designing the heat pump.

Also, energy simulation of the target building was carried out and the energy consumption was estimated. As a result, we grasped the detailed energy consumption of the target building.

Keywords: Energy consumption, University, Heat source system, COP, The BEST program

1. Introduction

More than 30% of the energy consumption in Japan today is ultimately consumed by consumer appliances related to human activities. The increase of energy consumption in this sector is larger than the increase in other sectors, therefore the promotion of energy conservation in this sector is importance. University facilities in particular consume a lot of energy because of the size of their buildings and the applications for which they are used. Furthermore, since many of the buildings in the universities are old, there are a possibility that their equipment results old.

The building that served as the target for this study is the Department of Electrical and Electronic Engineering (hereinafter referred to as “The building”) on the Tokiwa campus of Yamaguchi University. The edifice became 23 years old in 2017 and has aged significantly since it was built. The heat source system of the building employs a pair of air-cooled heat pump chilling units (hereinafter referred to as “heat pumps”), one of which broke down in January 2015. Since then the system has been operating on a single heat pump. The heating efficiency of the heat pump (hereinafter referred to as “COP” [Coefficient of Performance]) also appears to have declined.

Therefore, the objective of this research is to determine from BEMS data how the equipment of university facilities is operated and how much energy it consumes. BEMS is system that collects data such as temperature and flow rate of building equipment and piping, and evaluates the building\(^1\). In addition, we tried calculations using the BEST program of energy calculation software and compared it with actual value.

2. Overview of Target Building

2.1 Overview of building
Table 1 shows an overview of the building. The area of the building is 992m\(^2\) and the total floor space is 6450m\(^2\). The structure is of RC construction, with 8 floors above ground and a basement. There is an entrance hall on the ground floor, part of which contains a stair well leading up to the second floor. The first and second floors are used for holding meetings and discussions. The third floor and up are used for conducting research and experiments.

Because the rooms on those floors are used for conducting research and experiments, energy consumption is 1305 MJ/m\(^2\) (confirmed results for 2014).

Table 1. Overview of the building

<table>
<thead>
<tr>
<th>Building name</th>
<th>the Department of Electrical and Electronic Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Yamaguchi prefecture Ube City Tokiwadai 2-16-1</td>
</tr>
<tr>
<td>Building area</td>
<td>992 m(^2)</td>
</tr>
<tr>
<td>Extended floor</td>
<td>6450 m(^2)</td>
</tr>
<tr>
<td>Floor</td>
<td>8 floors above ground and a basement</td>
</tr>
<tr>
<td>Construction</td>
<td>RC construction</td>
</tr>
<tr>
<td>Completion</td>
<td>1994</td>
</tr>
</tbody>
</table>

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2.2 Overview of Equipment

Fig. 1 shows the system diagram of the building, Table 2 shows an overview of the equipment the building is furnished with and Table 3 shows an overview of the equipment used for heat source the building. The system consists of a pair of ASHPs and a thermal storage tank. The rated cooling capacity of the heat pumps is 359 kW and the rated heating capacity is 294 kW. Hot/cold water volume is 735 l/min. The COP at the time the heat pumps were designed was COP = 2.38 for cooling and COP = 1.95 for heating. We calculated COPs by using thermal energy and electric power consumption of heat pump and circulation pump. The air conditioning system includes a fan coil unit in each room. The ventilation system consists of a mechanical ventilation system in the parlor and ventilation system using exhaust fan in the restrooms. The lighting system consists primarily of fluorescent lighting equipment.

![System diagram](image)

### Table 2. Overview of the equipment

<table>
<thead>
<tr>
<th>Heat source</th>
<th>Two heat pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal storage capacity: 1700 m³</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>Fan coil unit</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Ventilation system using exhaust fan in the restrooms</td>
</tr>
<tr>
<td>Lighting</td>
<td>Fluorescent lighting</td>
</tr>
<tr>
<td>Elevator</td>
<td>One load capacity: 1000 kg</td>
</tr>
</tbody>
</table>

### Table 3. Overview of the heat source

| Heat pump 1, 2 | Rated cooling capacity: 359kW (outside temperature 33.3°C, 60.4%) |
|               | Rated heating capacity: 294kW (outside temperature -4.0°C) |
|               | Hot/cold water volume: 735 l/min (cold water 13→6°C) (hot water 40→47°C) |

3. Operation of Heating Equipment

3.1 Overview of field study

A field study focusing on the heat pumps of the heat source system was conducted. The study utilized 1-hour segments of BEMS data of the building obtained for a period of approximately 5 years (May 2013 through September 2017). COP data including heat pump calorific value, difference in temperature at inlets/outlets and electric energy was used for the study. The calorific value was determined from the difference in temperature and flow rate at the inlets/outlets of the heat pump. COP was determined from the calorific value of the heat pump and electric energy of the heat pump and primary pump. Automated Meteorological Data Acquisition System (AMeDAS) data for Ube City in Yamaguchi Prefecture provided by the Japan Meteorological Agency (JMA) was used for the outdoor atmospheric temperature.

3.2 Operating modes

Three operating modes are used for the heat source system. Mode 1 is the thermal storage mode whereby hot and cold water created by the heat pump at night is sent to the thermal storage tank, and the water inside the tank is used to store thermal energy. Mode 2 is the heating (or cooling) supply from thermal storage tank whereby cold and hot water stored in the thermal storage tank at night is sent to various buildings during the day. Mode 3 is the Heating (or cooling) supply from thermal storage tank + ASHPs whereby cold and hot water created by the heat pump is sent to various buildings without modification after thermal energy is discharged from the thermal storage tank. These are the operating modes of the heat source system of the building.

3.3 Findings of study

3.3.1 Heat pump operation

The heat pump is run during the summer from June through September for cooling, during the winter from November through March for heating, and shut down during the months of April, May and October.

Fig. 2 shows the operating status of the heat pump during a 1-week period from Monday, January 23rd to Sunday, January 29th, 2017 while Fig. 3 shows the operating status of the heat pump during a 1 week period from Monday, July 31st to Sunday, August 6th, 2017. The heat pump is operated in the thermal storage mode from 10 pm to 8 am, and in the mode 3 from 8 am to 1 pm, and from 4 pm to 10 pm. (The operating time zone for mode 3 varies depending on the atmospheric temperature of the day and temperature inside the thermal storage tank.) The heat pump is shut off from 1 pm to 4 pm to limit maximum...
power consumption. The mode 2 is used at this time to send cold and hot water from the thermal storage tank to the various buildings. To concentrate on thermal storage, the thermal storage mode is used for a long period of time on Friday, Saturday and Sunday instead of the mode 3.

The inlet temperature during heating is 39.2 to 42.4°C, while the outlet temperature is 41.2 to 42.4°C. The amount of electric energy consumption by the heat pump at this time to produce 82 to 153 kWh of thermal energy is 133 to 153 kWh, and the COP is COP = 0.56 to 2.04. The inlet temperature of the heat pump when cooling is 8.5 to 12.9°C while the outlet temperature is 4.6 to 7.9°C. The amount of electric energy consumption at this time to produce 93 to 257 kWh of thermal energy is 40 to 126 kWh, and the COP is COP = 1.56 to 2.36.

3.3.2 COP and difference in temperature between the inlet/outlet

Table 4 shows the average COP and difference in temperature between the inlet/outlet for the heat pump in summer and winter, plus the average outdoor temperature for each month during a 5-year period (2013 through 2017). Values for the thermal storage mode were used for the average COP. The data in winter 2017 is missing.

The COP for heat pump 1 since 2013 in summer was COP = 1.67, 1.85, 1.9, 1.98, 1.82. The COP since 2013 in winter was COP = 1.68, 1.6, 1.81, 1.98. COP increases as the years elapse, and this is due to the difference in outdoor atmospheric temperature and change in difference in temperature between the inlet/outlet. If you look at the data for the 5-year period, you can see the COP values for heat pump 1 are all lower than the value when it was designed.
It is because control is not done firmly and it is not able to secure the difference in entrance and exit temperature at the time of design.

Heat pump 2 was operated in summer 2015, but the fact that the pump broke down reflects clearly in the average COP = 0.86.

4. Study by Simulation

4.1 Overview of simulation

The energy calculation software used in this study is the BEST program leading reference tool and the BEST program energy saving standard tool. Table 5 shows each version and manual. The input of conditions to the calculation software was input with reference to the design drawing of the target building and the field survey. Also, the BEST program can calculate many systems, it also supports heat storage tank system, clean room, so you can enter in detail.

4.2 Simulation results

Table 6 shows simulation results. From the data of DECC, the average value of data of 685 universities in the 6th regional section was used as the reference value, 947 MJ/(m²·year) was used. The calculation results were 1457 MJ/(m²·year) in the BEST program leading reference tool and 1352 MJ/(m²·year) in the BEST program energy saving standard tool.

Therefore, the BEST program energy saving standard tool showed the closest value to the actual value. In addition, it was found that the primary energy consumption of BEST result and actual value is higher than the reference value.

5. Summary

The research described herein reveals how heat source systems are operated at university facilities. It also includes a study of energy consumption by these heat source systems by conducting an energy simulation.

A summary of data for a 5-year period shows the COP values for heat pump 1 in its current state have declined since when it was designed.

The simulation study shows that the BEST program energy saving standard tool showed the closest value to the actual value. Therefore, we grasped the detailed energy consumption of the target building.

References

1) Yuki Naito, Ryoichi Kawahara, Makoto Koganei: Research concerning the amount of energy consumption of Heat Source Systems at University Facilities, ACRA2018
3) Method and explanation of calculation and judgment in compliance with 2013 energy conservation standard I Non-residential building (2nd edition), IBEC