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System for Optimal Control of Heating and Cooling Equipment to Reduce CO_2 Emissions and Save Energy

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OVERVIEW: Hitachi has commercialized a system for the optimal control of heating and cooling equipment to minimize system-wide energy consumption. This is an optimal control system for entire heating and cooling systems, including thermal sources, cooling towers, and pumps, that works by determining the optimal combination of control targets and number of machines to operate based on the outside air conditions and thermal load. The control system has been supplied to provide optimal control of the heating and cooling system in the ABENO HARUKAS, building, Japan's tallest mixed-use skyscraper, and is currently in operation. The control techniques developed for the system have also been incorporated as a function in an integrated energy and equipment management service.

INTRODUCTION

THE growing demand to reduce electricity, gas, and other running costs in factories and other buildings, and to prevent global warming, means that heating and cooling equipment is also being called on to become more energy efficient and to emit less carbon dioxide (CO_2). Hitachi deals with system solutions for energy efficiency, and has commercialized a system for the optimal control of heating and cooling equipment to minimize system-wide energy consumption. This is an optimal control system for the entire heating and cooling system, including thermal sources, cooling towers, and pumps. To determine the optimal combination of control targets and number of machines to operate, it uses a simulator that is tuned for high accuracy using sensor data.

This article provides an overview of the system for optimal control of heating and cooling equipment and describes an example application.

OVERVIEW OF SYSTEM FOR OPTIMAL CONTROL OF HEATING AND COOLING EQUIPMENT

Fig. 1 shows an overview of the system for optimal control of heating and cooling equipment. The system performs optimal control of equipment such as heater/chillers, cooling towers, and pumps. Based on inputs such as the load and outdoor sensor measurements, the system determines the parameters (control targets and number of machines to operate) that minimize the performance function and then outputs these to the equipment. The performance function criteria, such as primary energy, CO_2 emissions, or running costs, can be selected by the user. In the case of cogeneration systems such as those that utilize waste heat from gas engine generators, the system can obtain optimal values that take account of the amount by which use of waste heat reduces the gas consumption of the heating and cooling equipment.

Optimization of Control Targets

The control system obtains a set of control targets for the temperature and flow rate of chilled water and cooling water that has been optimized to minimize a performance function that considers factors such as primary energy, CO_2 emissions, or running costs based on the outside air conditions and thermal load, and then outputs these targets to the heating and cooling equipment.

Fig. 2 shows the principle of optimal control for an example in which the aim is to minimize primary energy use by individual machines. For example, reducing the flow of cooling water reduces the amount of primary energy used by the cooling water pump, but the reduced flow of cooling water to the chiller causes it to use more primary energy due to the fall in its coefficient of performance (COP). Similarly, setting a higher cooling water temperature reduces the amount

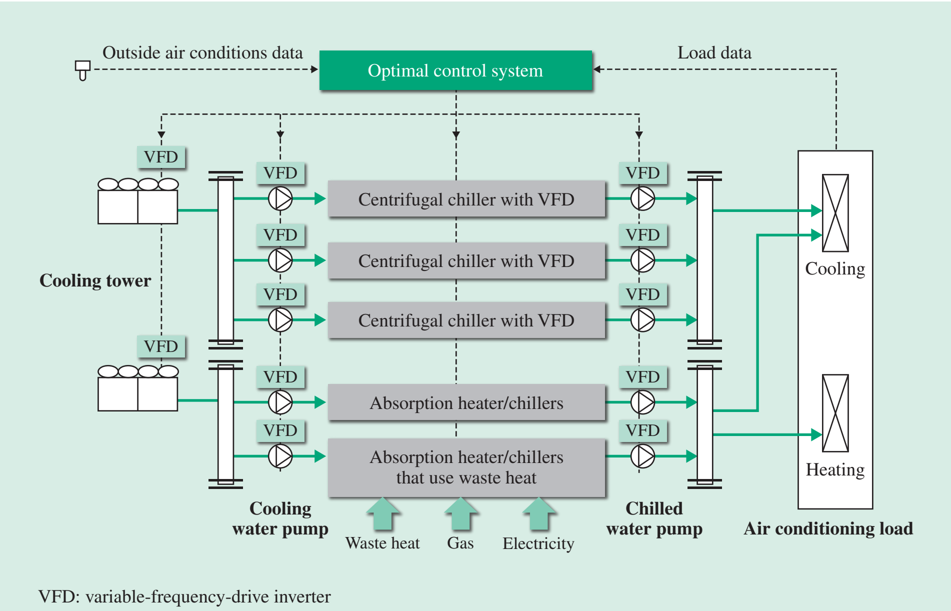

Fig. 1—Overview of System for Optimal Control of Heating and Cooling Equipment.
The system for optimal control of heating and cooling equipment, including heater/chillers, cooling towers, and pumps, works by using sensor measurements of the outside air conditions and thermal load to determine the optimal combination of control targets and number of machines to operate so as to minimize energy consumption across the entire system, and then outputting these settings to the equipment.

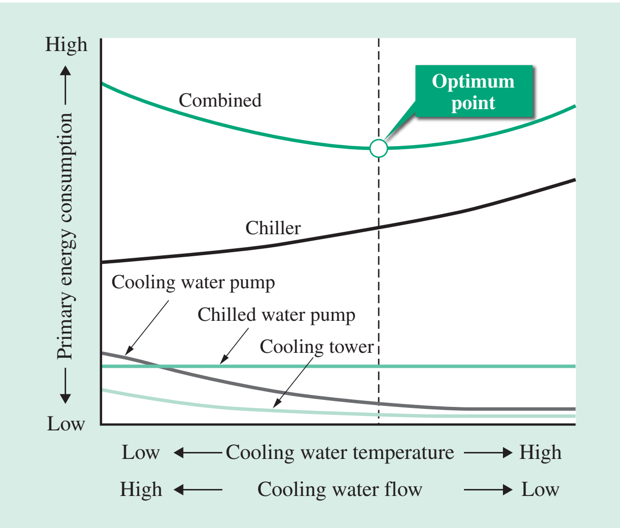

Fig. 2—Principle of Optimal Control.
Optimal control targets are obtained to minimize primary energy consumption across the entire system.

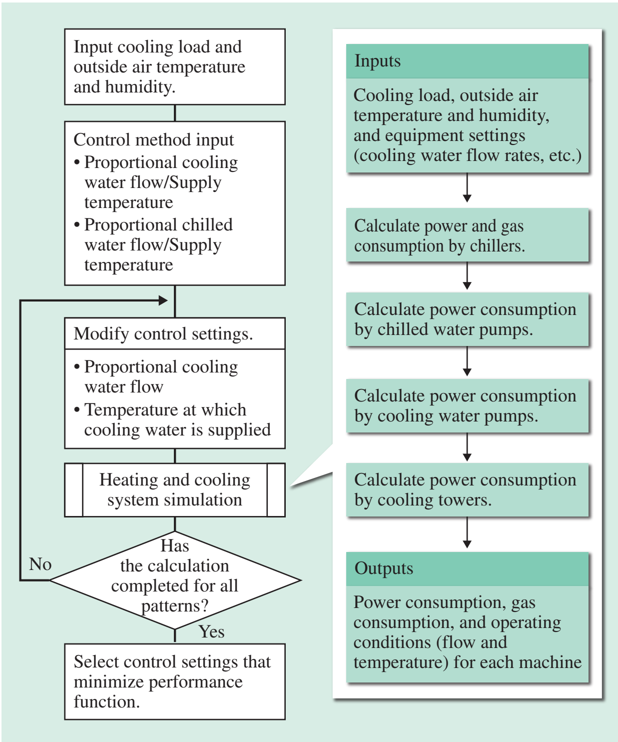

Fig. 3—Flow Chart of Optimal Control.
The system for optimal control of heating and cooling equipment uses simulation to obtain the optimal combination of control targets.

of primary energy used by the cooling tower but raises primary energy use by the chiller. These trade-offs are reflected in the parameters for the temperature and flow rate of chilled water and cooling water, and the optimal combination of values varies depending on the outside air conditions and thermal load.

Fig. 3 shows the flow chart of optimal control. The optimal control system determines the optimal combination of control targets by using an iterative calculation that incorporates simulation.

Fig. 4 shows the energy savings when operating in cooling mode for two absorption heater/chillers with a capacity of 240 tons (RTs). The figure indicates energy savings of about 24% compared to the previous system, which used a constant temperature and flow rate for chilled water and cooling water. While the energy savings provided by optimal control depend on the system configuration, thermal load, and outside air conditions, they are in the 10% to 30% range.

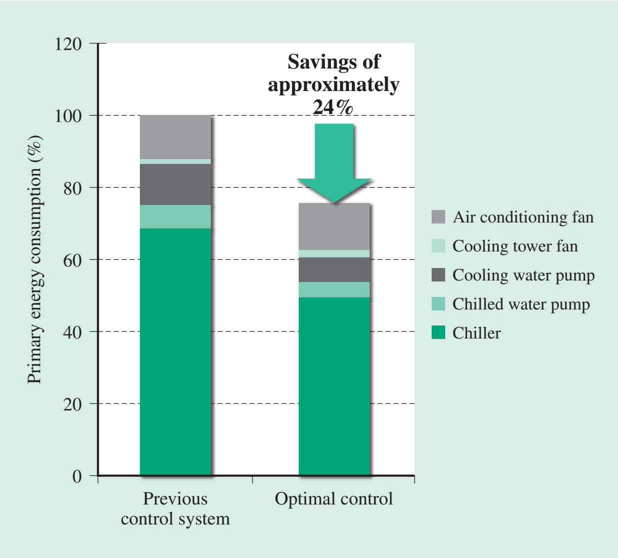

Fig. 4—Energy Savings Made by System for Optimal Control of Heating and Cooling Equipment (Cooling Mode).
The graph shows the energy savings, where 100% represents energy use by the previous system that used a constant temperature and flow rate for chilled water and cooling water. Optimal control reduced this energy use by approximately 24%.

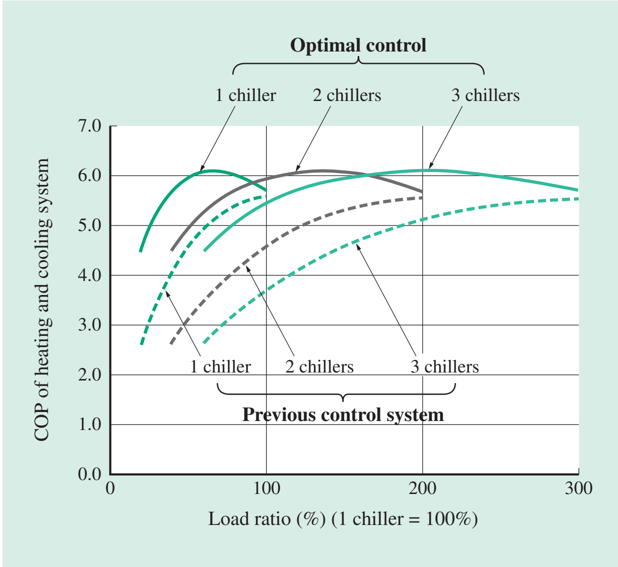

Fig. 5—Optimization of Number of Chillers to Run.
Whereas the COP of the heating and cooling system under the previous control system was highest when the fewest number of chillers were operating, this does not always apply in the case of optimal control. Optimal control of the number of chillers to operate works by using a simulation to determine the optimal load ratios that minimize energy consumption across the entire system.

Optimization of Number of Machines to Operate and Load Distribution

Fig. 5 shows the relationship between load and COP for three centrifugal chillers with VFDs. In the case of previous control systems that used a constant temperature and flow rate for chilled water and cooling water, the COP of the system tended to be highest when operating at full load. Accordingly, all such a control system needed to do was to run the minimum number of machines needed to cover the required load, thereby allowing each to operate at as high a cooling load as possible. In the case of equipment operated in accordance with optimized control targets, on the other hand, minimizing the number of machines being used does not necessarily maximize the COP of the heating and cooling system. Accordingly, the optimal control system developed by Hitachi optimizes the number of machines to operate by using a simulation to calculate the energy consumption and then determines the number of machines that minimizes the energy consumption across the entire heating and cooling system.

Fig. 6 shows the operating priorities for equipment when using a performance function that minimizes running costs. In the case of a system that combines a number of different types of heating and cooling equipment, such as cogeneration systems, centrifugal chillers with VFDs, or absorption heater/chillers, the operating priorities are determined so as to minimize the performance function used as an indicator. While Fig. 6 shows a case with a performance function that minimizes running costs, the performance function for this system could be changed to one that minimizes a different parameter, such as CO_2 emissions, in which case the operating priorities would change in accordance with the conversion coefficient used in the performance function calculation.

A function for optimizing the load distribution by adjusting the chilled water flow rate is also provided for the case when different types of heating and cooling equipment are operating at the same time.

EXAMPLE APPLICATION

System for Optimal Control of Heating and Cooling Equipment at ABENO HARUKAS Building

The optimal control system has been supplied to the ABENO HARUKAS building (location: Osaka, height: 300 m), Japan's tallest mixed-use skyscraper, and is currently in operation. ABENO HARUKAS is a mixed-use building that was fully opened in March 2014. Its numerous facilities include a railway station, department store, art gallery, offices, hotel,

Cooling						
	Summer (July to September)		Mid-season (May, June, October)		Winter	
Operating priorities	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
1	Absorption heater/ chiller that uses waste heat	Centrifugal chiller with VFD	Absorption heater/ chiller that uses waste heat	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD
2	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD
3	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD	Centrifugal chiller with VFD
4	Centrifugal chiller with VFD	Absorption heater/chiller	Centrifugal chiller with VFD	Absorption heater/chiller		
5	Absorption heater/chiller		Absorption heater/chiller			

Heating			
Operating priorities	Summer (July to September)	Mid-season (May, June, October)	Winter
1		Absorption heater/chiller	Absorption heater/ chiller that uses waste heat
2			Absorption heater/chiller

Fig. 6—Optimization of Equipment Operating Priorities.
This optimizes the priority order for equipment operation to minimize running costs. The priorities change depending on the electric power tariff, which varies by season and time of day.

and observation deck. As an advanced "vertical city" that hosts all of these facilities, the ABENO HARUKAS building incorporates a variety of leading environmental technologies that reduce its CO_2 emissions and energy use. The aim is to reduce its annual CO_2 emissions by approximately 5,000 t. Hitachi's optimal control system is included among these "leading environmental technologies" (see Fig. 7).

The optimal control system supplied by Hitachi works by collecting operational information from the heating and cooling equipment in realtime, performing calculations to determine the combination of equipment and other control settings that will minimize CO_2 emissions, running costs, or whatever it is that is being targeted, and then automatically provides these to the equipment in the form of control targets. To ensure reliable and flexible operation, the heating and cooling equipment used in the ABENO HARUKAS building consists of a combination of electric and gas-powered machines, with the CO_2 emission coefficients and energy prices being different for each type. Accordingly, multiple calculations are required to perform optimal control of heating and cooling equipment, including determining which type of equipment to use first and what control settings to use. This can be achieved by using the system for optimal control of heating and cooling equipment.

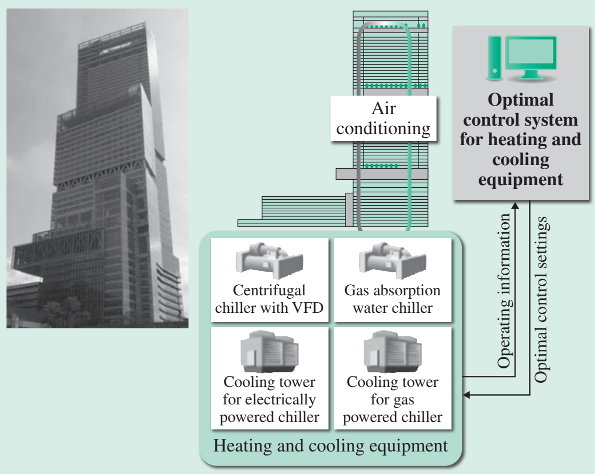

Fig. 7—ABENO HARUKAS Building.
The optimal control system for heating and cooling equipment has been supplied to the ABENO HARUKAS building, Japan's tallest mixed-use skyscraper.

Hitachi has also supplied a system for centralized management and data presentation that utilizes energy data, such as data on the electric power and gas used by the heating and cooling equipment at the ABENO HARUKAS building, and heat quantity, temperature, flow rate, and other analog data collected from the equipment. This enables operational management based on efficiency data, such as that for energy use by individual items of heating and cooling plant or by

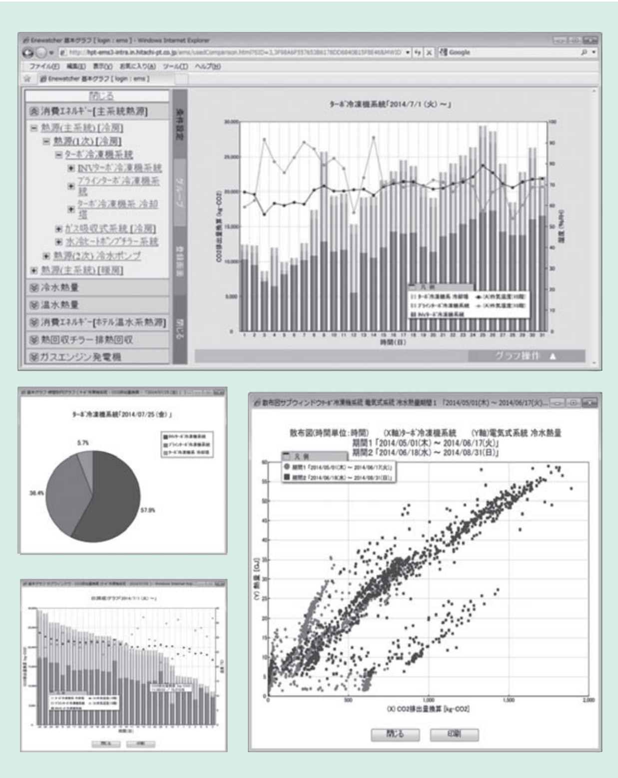

Fig. 8—Viewing Graphs in Web Browser.
Hitachi has also supplied an energy management system for centralized management and data presentation that utilizes energy data, such as data on the electric power and gas used by the heating and cooling equipment, and heat quantity, temperature, flow rate, and other analog data collected from the equipment.

the entire system, CO_2, and operating costs. Because this information can be viewed as graphs using a web browser on a personal computer (PC) connected to a dedicated network in the ABENO HARUKAS building, it enables sharing of information by everyone involved in facilities management (see Fig. 8)

CONCLUSIONS

This article has provided an overview of an optimal control system that minimizes energy consumption across an entire heating and cooling system, and has described an example application.

The optimal control technique has also been included as a function in a service for integrated energy and equipment management. This is a core product in Hitachi's energy management service business and the company intends to deploy it as a service for solving management problems that supports improvements in consumers' energy and business efficiencies, and also activities such as business continuity planning (BCP).

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