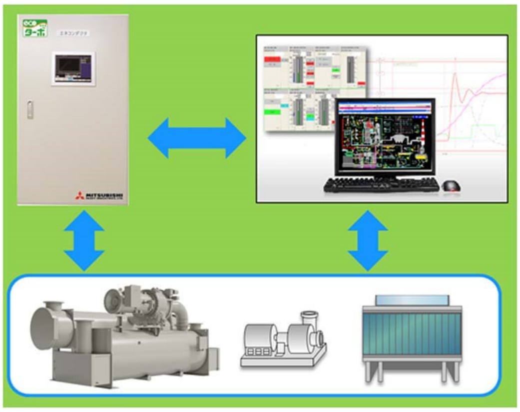
Proposal of Heat Source Composition and Optimal Control System Suitable for Large-scale District Cooling Plants



LINRI CUI*1 SATOSHI NIKAIDO*1
TAKAAKI MIURA*2 KIYOKAZU TSUJI*2
HIROSHI HIRAYAMA*3

In recent years, the heat supply business in Japan has been on a decreasing trend since reaching its peak sometime around 2007. There is still high demand for large-scale district heating and cooling around the world, mainly in the Middle East and Asia regions, and a number of district heating and cooling plants (hereafter district cooling plants) have been constructed or are being planned. However, the optimal plant design and operational method with consideration for the meteorological conditions and integrated characteristics of each region have yet to be established. Mitsubishi Heavy Industries Thermal Systems, Ltd. proposed a heat source system with consideration for the meteorological conditions and load characteristics of each region, and made a comparison of the annual energy consumption between the conventional system and the proposed system. As a result, we found that it is effective to select a type of chiller suitable for the meteorological conditions and to manage an optimal number of chillers.

1. Introduction

A district cooling plant is generally a large-scale facility and its construction cost and running cost are high. Therefore, from the viewpoint of plant construction and operation, it is important to reduce costs by making the optimal plant design with consideration for regional meteorological conditions and cooling load characteristics and optimization of the operational method.

In this article, we propose a method of optimally controlling a district cooling plant using a heat source system suited for the Middle East and Asia, where many large-scale district heating and cooling plants exist. This is achieved by the supervisory control and data acquisition (SCADA) system, which is constructed by linking the "Ene-Conductor" heat source control system, in which optimal logic is incorporated, with the "Netmation" distributed system. Toward the actual use of the method at district cooling plants overseas, the energy consumption in the climate and the load characteristics of each region were calculated to show the effectiveness of the proposed method.

2. Meteorological conditions and load characteristics

The meteorological conditions and the cooling load characteristics of the regions we studied are shown in **Figures 1 to 3**. Figure 1 shows the assumed cooling load patterns in the regions. A comparison of the meteorological conditions of Japan, Singapore as a typical city in Southeast Asia and Makkah as a typical city in the Middle East was made, and the details are described below.

(1) Dry-bulb temperature

Figure 2 shows that in Tokyo, the dry-bulb temperature largely varies by season (the average dry-bulb temperature in January is about 6°C, while the average dry-bulb temperature in August is about 28°C) and the temperature difference is also large (about 22°C). In

*1 Chiller & Heat Pump Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.
*2 Manager, Chiller & Heat Pump Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.
*3 Senior Manager, Sales Department, MHPS Control Systems Co., Ltd.

Singapore, the dry-bulb temperature is high (the average annual dry-bulb temperature is about 30°C), but the temperature difference throughout the year is small (about 8°C). On the other hand, in Makkah, the dry-bulb temperature exceeds 40°C, such a high temperature range that is not normally observed in Japan, and the dry-bulb temperature largely varies by season (with the temperature difference being about 15°C). Makkah has both the characteristics of Tokyo where the difference in the dry-bulb temperature between winter and summer is large and Singapore where the dry-bulb temperature is high.

(2) Wet-bulb temperature

Figure 3 shows that in Tokyo, the wet-bulb temperature largely varies by season (the temperature difference is about 25°C). In Singapore, the wet-bulb temperature hardly varies throughout the year (the temperature difference is about 2°C). In Makkah, the wet-bulb temperature change is small (the temperature difference is about 12°C to 15°C), and the wet-bulb temperature is lower than that of Singapore. Therefore, the cooling water inlet temperature becomes low, and it is expected that the performance of the chiller is improved as a result.

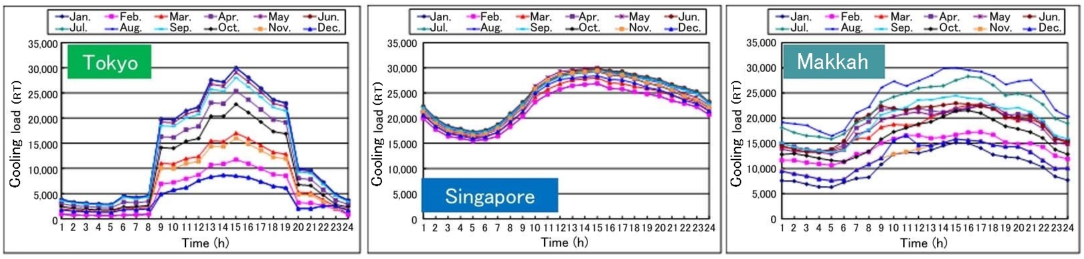


Figure 1 Estimated cooling load for each region

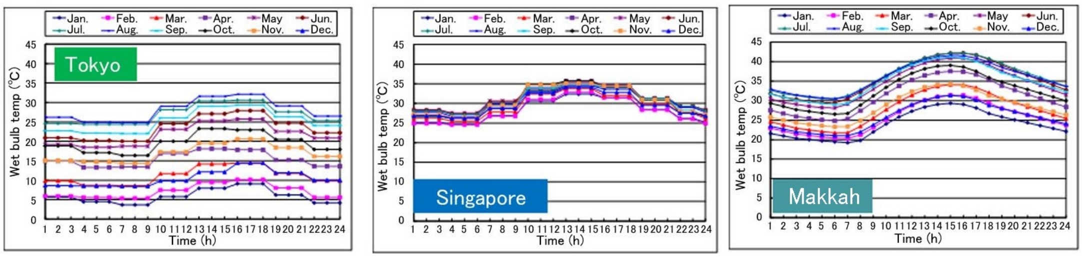


Figure 2 Dry-bulb temperature of outside air for each region

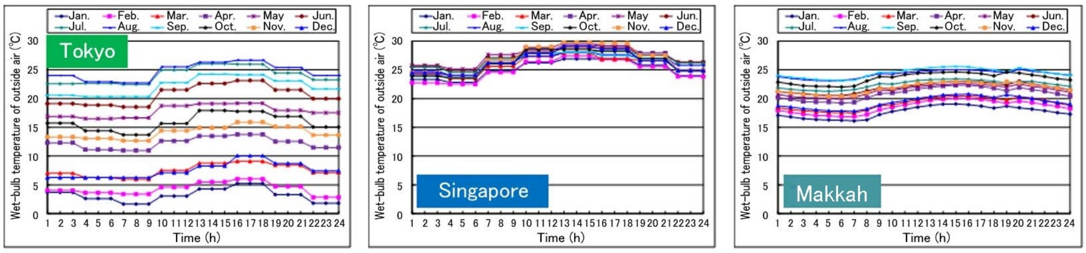


Figure 3 Wet-bulb temperature of outside air for each region

3. Proposal of heat source system for large-scale district cooling plants

In the design stage of a district cooling plant, 1) the construction cost, 2) operational method, 3) the performance of a chiller unit, and 4) the performance of the overall system including auxiliary machines need to be studied. In consideration of the above items, the chiller and plant designs for the Middle East are proposed below.

3.1 Chiller design for district cooling plant in the Middle East

(1) Chiller design concept

The proposed concept for chiller design is as follows:

(i) large capacity (3,000 RT to 6,000 RT)

(ii) space saving, and

(iii) high efficiency under the conditions of the Middle East.

In order to satisfy the above design concept, a chiller that meets the following conditions is required:

(i) a large-capacity compressor can be applied. (Increase in cooling capability)

(ii) a parallel-type unit*1, with two compressors mounted on one chiller (Space-saving)

(iii) a parallel-type unit or a series counterflow type*3 configured with two single-compressor units*2 (High-efficiency chiller)

*1: Parallel type: A chiller with two compressors mounted on one chiller to increase the capability and space saving

*2: Single type: Standard chiller with one compressor mounted on one chiller

*3: Series counterflow type: Two single type chillers are arranged in series and the flow of chilled water and the flow of cooling water are made counter to each other (counterflow) to increase the capacity and performance.

(2) Optimal operation system

In order to reduce the operation cost, the number of operating chillers and the flow rate of chilled water and the flow rate of cooling water should be controlled according to the cooling water temperature and the cooling load using the optimal control system. Not only can high-performance chillers be used under the operating conditions in the Middle East, but the operation cost can be effectively reduced through optimal operation of the overall system with consideration for auxiliary machines.

3.2 Plant specification

In this section, the specifications of the centrifugal chiller and the plant are described.

(1) Specification of chiller for 30,000 RT plant

Assuming that the plant capacity is 30,000 RT (the amount of heat to be removed for freezing 3,000 tons of water of 0°C into ice in one day (24 hours)), the configuration with six 5,000RT chillers is studied. The system performances of the fixed speed drive centrifugal chiller (hereafter FSD chiller) and the variable speed drive centrifugal chiller (hereafter VSD chiller) at the rated point are shown (**Table 1**). The coefficient of performance (COP) of the VSD chiller is reduced by about 3% at the rated point, due to the electrical efficiency loss, compared to that of the FSD chiller. The elements other than the power input, COP and cooling water flow rate exhibit the same values.

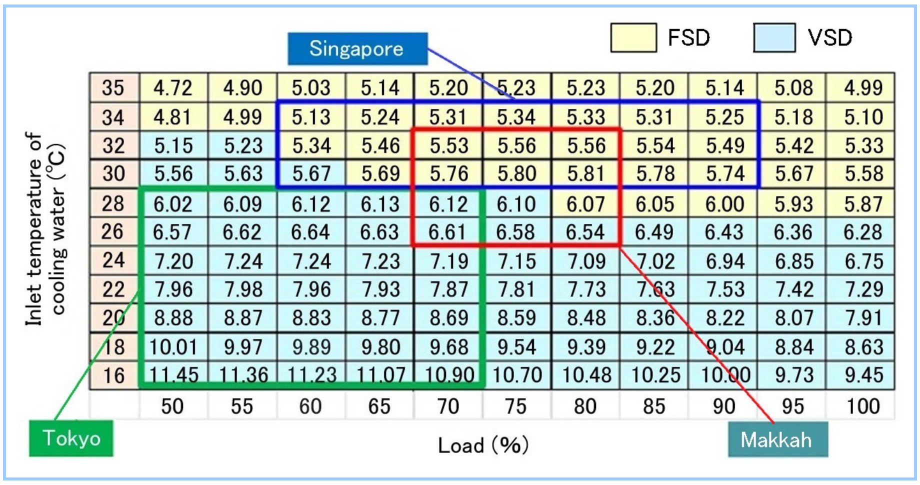
Table 1 System performance of the FSD chiller and the VSD chiller

	Model	FSD	VSD	
	District cooling plant capacity (RT)	30,000	30,000	
	Capacity (RT)	5,000	5,000	Large capacity
	Number of units	6	6	
	Power input (kW)	3,498	3,680	
	Rated COP	5.0	4.8	High efficiency
Large temperature difference	Chilled water inlet temp. (℃)	4.4/13	4.4/13	
	Chilled water flow rate (m^3/h)	1,655	1,655	
	Evaporator pressure drop (kPa)	53.4 *1	53.4 *1	Small pressure drop
	Pump head (mAq)	13.0	13.0	
	Chilled water pump power (kW)	90	90	
Large temperature difference	Cooling water pump outlet temp. (℃)	43.5/35	43.5/35	
	Cooling water flow rate (m^3/h)	2,107.8	2,170.6	
	Condenser pressure drop (kPa)	31.0 *2	31.0 *2	Small pressure drop
	Pump head (mAq)	20.0	20.0	
	Cooling water pump power (kW)	200	200	

*1 Chilled water pump head = Head loss of straight pipe + Strainer(3 mAq) + Control valve(3 mAq) + Head loss of Evaporator + Piping fittings, valves and others.

*2 Cooling water pump head = Head loss of straight pipe + Strainer(3 mAq) + Control valve(3 mAq) + Open-type cooling tower(10 mAq) + Head loss of Condenser + Piping fittings, valves, and others.

Figure 4 shows the COP of the chiller according to the cooling water inlet temperature and the cooling load. Comparing the COP between the FSD chiller and the VSD chiller, the values of a chiller with a higher COP are shown in Figure 4. The FSD chiller shows better performance in the range of high cooling water temperature and high cooling load. According to Figure 4, it is advantageous to adopt the VSD chiller in Tokyo, the FSD chiller in Singapore and the FSD chiller or the VSD chiller in Makkah.



Inlet temperature of cooling water (°C) \ Load (%)	50	55	60	65	70	75	80	85	90	95	100
35	4.72	4.90	5.03	5.14	5.20	5.23	5.23	5.20	5.14	5.08	4.99
34	4.81	4.99	5.13	5.24	5.31	5.34	5.33	5.31	5.25	5.18	5.10
32	5.15	5.23	5.34	5.46	5.53	5.56	5.56	5.54	5.49	5.42	5.33
30	5.56	5.63	5.67	5.69	5.76	5.80	5.81	5.78	5.74	5.67	5.58
28	6.02	6.09	6.12	6.13	6.12	6.10	6.07	6.05	6.00	5.93	5.87
26	6.57	6.62	6.64	6.63	6.61	6.58	6.54	6.49	6.43	6.36	6.28
24	7.20	7.24	7.24	7.23	7.19	7.15	7.09	7.02	6.94	6.85	6.75
22	7.96	7.98	7.96	7.93	7.87	7.81	7.73	7.63	7.53	7.42	7.29
20	8.88	8.87	8.83	8.77	8.69	8.59	8.48	8.36	8.22	8.07	7.91
18	10.01	9.97	9.89	9.80	9.68	9.54	9.39	9.22	9.04	8.84	8.63
16	11.45	11.36	11.23	11.07	10.90	10.70	10.48	10.25	10.00	9.73	9.45

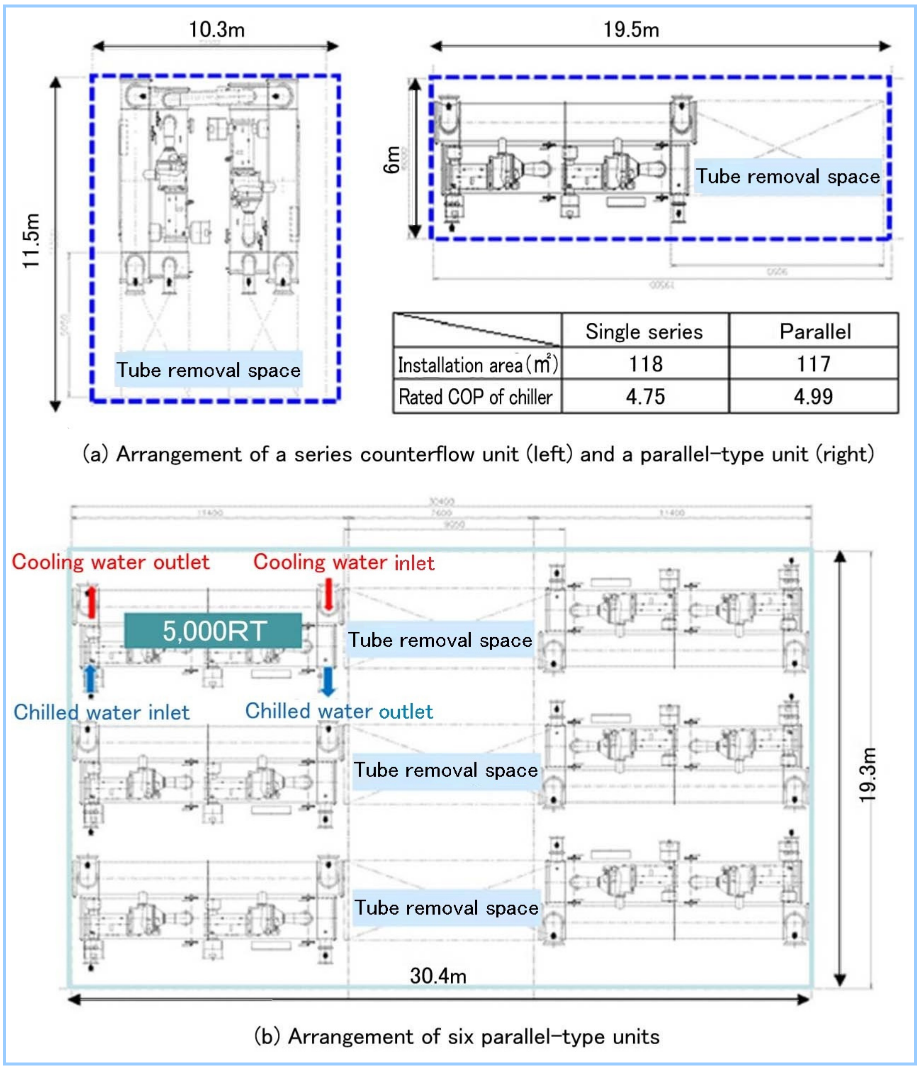
Figure 4 Comparison of COP between the FSD chiller and the VSD chiller

(2) Comparison of plant layout

Figure 5 shows an example arrangement of chiller units.

Figure 5a shows the arrangement of series counterflow type units and parallel-type units. Both units have a capacity of 5,000 RT and the installation area is the same. In this article, in order to reduce the number of chillers and simplify the control of the number of chillers, the parallel-type was selected as the chiller to use in the district cooling plant.

One example layout for a plant with a cooling capability of 30,000 RT with six parallel-type units in the minimum installation area is shown in Figure 5b. One chilled water pump, one cooling water pump and two cooling towers are installed for one chiller.



	Single series	Parallel
Installation area (m²)	118	117
Rated COP of chiller	4.75	4.99

Figure 5 Examples of arrangement of chillers

3.3 Outline of optimal control system

For the optimal operation of the heat source system at the actual plant, the method for determining optimal operation parameters using the simulation model devised by Maehara, et al.[(1)(2)] is proposed. In this article, the heat source system control is explained. The optimal control system controls items (1) to (6) shown in **Figure 6**. Here, the following three control methods are described: (1) multiple chiller control, (2) chilled water variable flow rate control, and (3) the cooling water variable flow rate control. The COP of the chiller and the COP of the system are affected by these control methods.

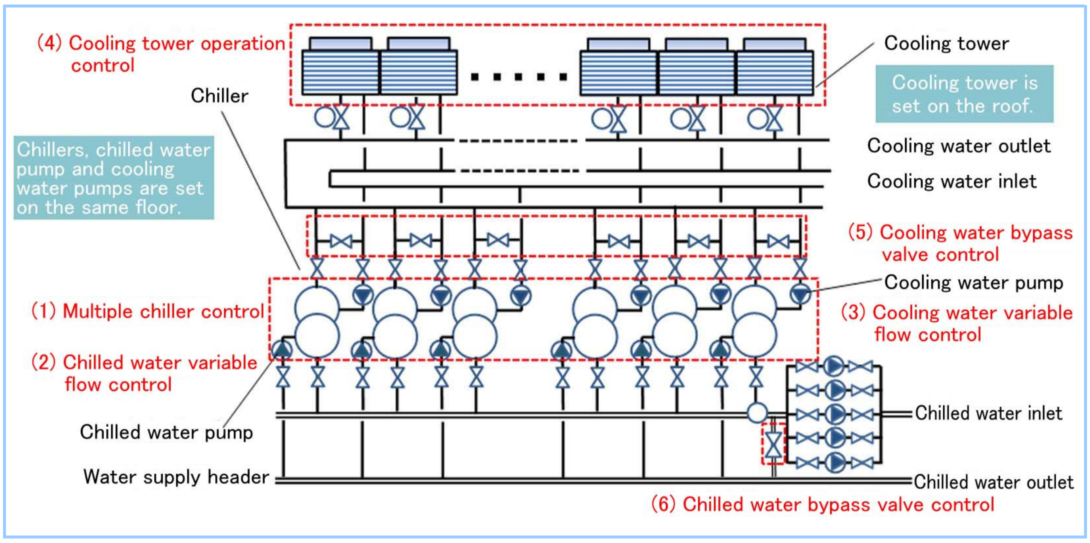


Figure 6 District cooling plant system flow

(1) Multiple chiller control

As shown in **Figure 7**, each chiller has an optimal load area according to the cooling water temperature. In the FSD chiller, the optimal load area is around the rated point (Figure 7(a)). In the VSD chiller, there is an optimal load range for each cooling water inlet temperature (Figure 7(b)). The range is calculated on the operation panel of each chiller, and the calculation results are sent to the optimal control system. The number of chillers required is determined by the cooling load, the optimal load range of each chiller and the specifications of peripheral auxiliary machines.

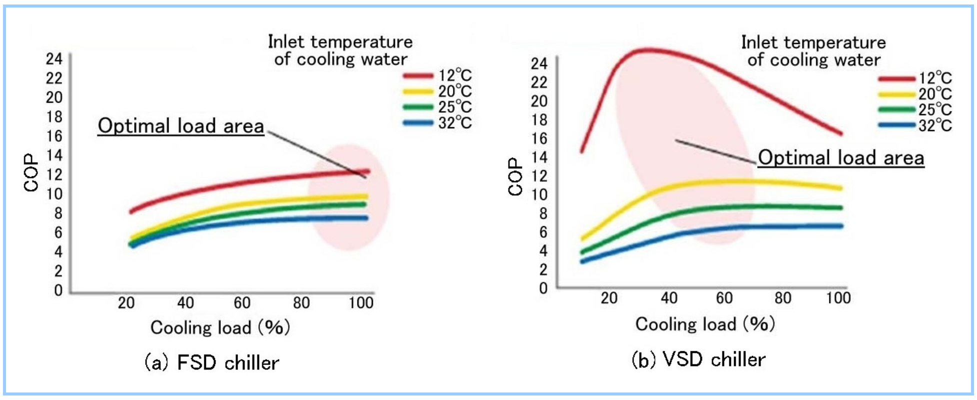


Figure 7 Optimal load areas of the FSD chiller and the VSD chiller

(2) Chilled water variable flow rate control

The chilled water flow rate to each chiller is determined so that the bypass flow rate in the water supply header shown in Figure 6 is zero. That is, the pump frequency is designated so that the chilled water bypass valve is fully closed to determine the chilled water supply flow rate.

(3) Cooling water variable flow rate control

The optimal flow rate of cooling water is determined so that the energy consumption (system power) of each device (cooling tower, cooling water pump, chiller) shown in **Figure 8** is minimized according to the loading factor of the chiller and the wet-bulb temperature.

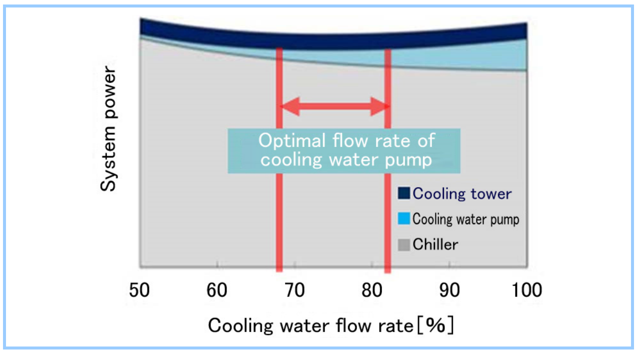


Figure 8 Control of cooling water variable flow rate

4. Evaluation of energy consumption

In this section, the calculation results of annual power consumption for the assumed district cooling plant are described below.

(1) Tokyo

Figure 9(a) shows the comparisons of the annual power consumption and the annual system COP. The application of the VSD chiller and the conventional control reduces the annual power consumption by about 7% compared to the FSD chiller. In addition, the application of the VSD chiller and the optimal control reduces the annual power consumption by about 4% compared to the conventional control. Accordingly, in Tokyo, where the cooling water temperature and the cooling load vary by season, a system to which VSD chillers and optimal control are applied minimizes the annual power consumption. Figure 9(b) shows the annual system COP of FSD chiller and that of the VSD chiller adopted in Tokyo under the respective operating conditions. Since the cooling water temperature and the loading factor largely vary by season in Tokyo, the COP of the VSD chiller is large, resulting in an increase in the overall system COP.

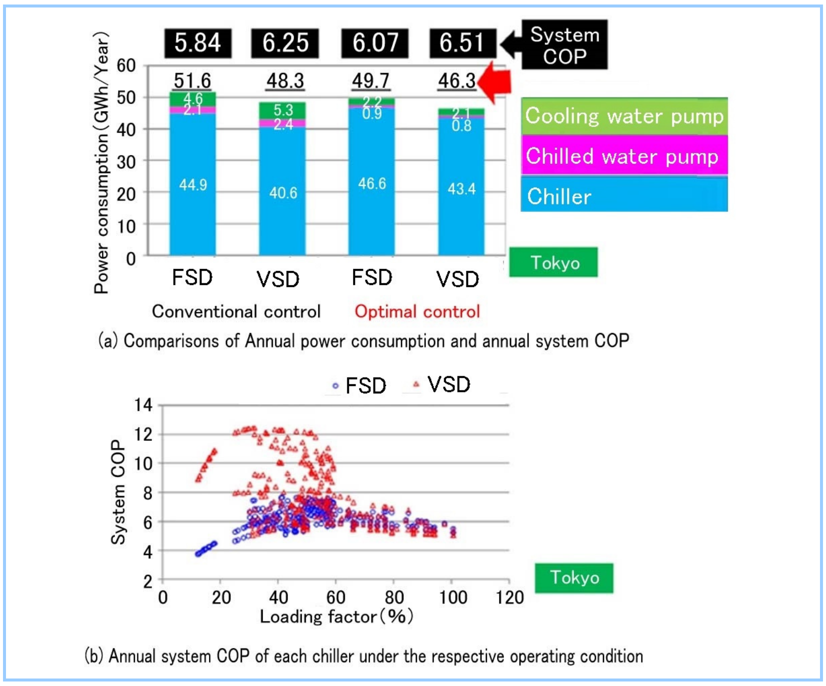


Figure 9 Annual power consumption and annual system COP (Tokyo)

(2) Singapore

Figure 10(a) shows the comparisons of the annual power consumption and the annual system COP. In Singapore, the use of a high-efficiency FSD chiller is appropriate. Figure 10(b) shows the annual system COP under each operating condition of the FSD chiller and the VSD chiller adopted in Singapore. Since the cooling water temperature change throughout the year is small in Singapore, the use of the FSD chiller results in a higher overall system COP.

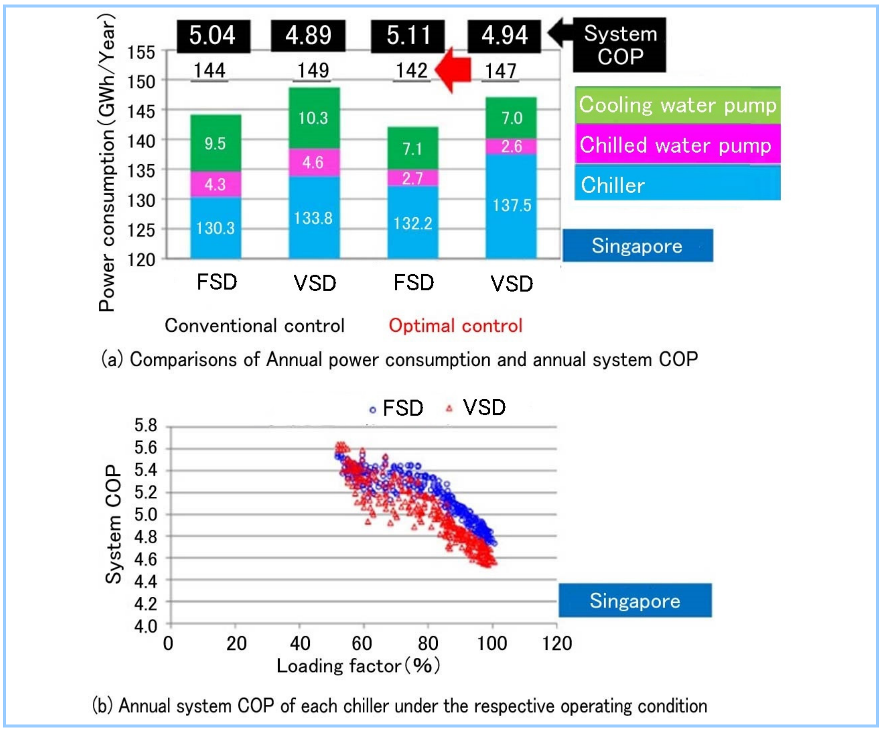


Figure 10 Annual power consumption and annual system COP (Singapore)

(3) Middle East (Makkah)

Figure 11(a) shows the comparisons of the annual power consumption and the annual system COP. In Makkah, which was selected as a typical city in the Middle East because the cooling water temperature is high, the combination of the FSD chiller and optimal control is most suitable. Figure 11(b) shows the annual system COP in each operating condition of the FSD chiller and VSD chiller adopted in Makkah. The FSD chiller exhibits a high performance at a loading factor of 60% to 100%, while the VSD chiller exhibits a high performance at the loading factor of 60% or lower. As is the case with Singapore, the annual cooling water temperature is generally high and the temperature change is small in Makkah. Therefore, a high-efficiency FSD chiller is suitable, with which the annual power consumption is almost the same and the initial cost is lowered. In addition, the application of the optimal control system reduces the energy consumption by about 3%.

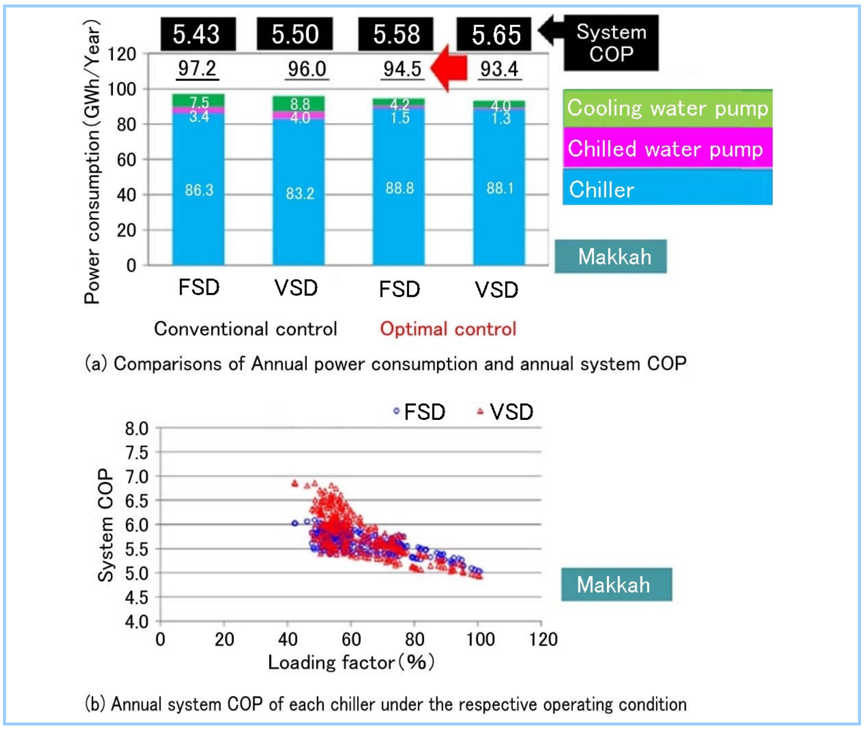


Figure 11 Annual power consumption and annual system COP (Makkah)

5. Realization of large-scale SCADA by linkage of Ene-Conductor and Netmation

Ene-Conductor is a heat source controller in which the above control functions are installed, as standard, in the incorporated software and allows the easy optimization of a heat source system[3]. In addition, bearing a large-scale system in mind, the Mitsubishi Heavy Industries Group has been preparing for the proposal of a SCADA system with a function of optimizing the overall energy supply for district cooling plants in the Middle East, in which MHPS Control Systems Co., Ltd.'s Netmation, which is broadly applied for the control and monitoring of power generation plants, is installed in the higher level of Ene-Conductor. The proposed system configuration is shown in **Figure 12**. Netmation is linked with multiple Ene-Conductor units and functions as SCADA for central monitoring, etc., while executing optimization control of the overall system.

The first example of the present system (excluding the central monitoring function) was introduced at a domestic semiconductor plant with a heat source system with four VSD chillers and four FSD chillers. It has operated stably since operations began in March 2016.

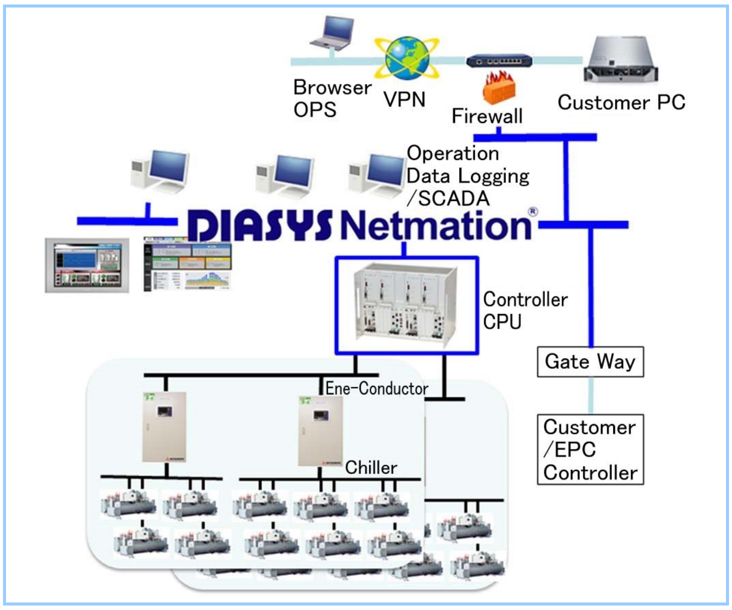


Figure 12 Ene-Conductor + Netmation system configuration

6. Conclusion

(1) In cases where the temperature largely varies throughout the year in Japan, the combination of the VSD chiller and the optimal control system is the most suitable and increases the performance of district cooling plants by about 10%.

(2) As the cooling water temperature is high in the Middle East and Southeast Asia, high-efficiency FSD chillers are suitable for district cooling plants.

(3) In cases where the cooling load and the cooling water temperature do not largely vary as in the Middle East, etc., the application of the optimal control system can reduce the energy consumption of a district cooling plant by about 3%.

(4) The parallel-type unit or the series counterflow type are effective for the achievement of a large capacity and high efficiency, as well as the reduction of the installation area at district cooling plants in the Middle East.

(5) In order to realize the optimal control of large-scale district cooling plants, Ene-Conductor incorporating the optimal logic can be linked with Netmation to construct a SCADA system.

References

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