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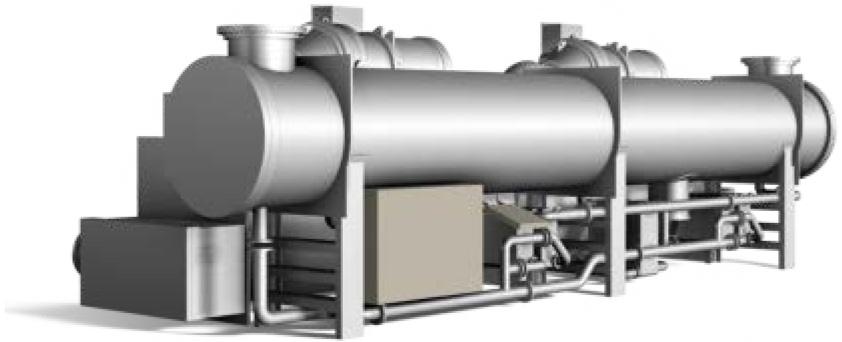
Optimal centrifugal chiller system for the middle east region considering the climate and the cooling load.



15th Dec 2016

MITSUBISHI HEAVY INDUSTRIES THERMAL SYSTEMS, LTD.

Contents

MITSUBISHI HEAVY INDUSTRIES THERMAL SYSTEMS, LTD.

1. Introduction

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1. High DC plant demand in GCC[1]

Total capacity of DC plants in UAE, KSA and Qatar is **29%** of the world in 2014.

2. Further growth of DC plant market

Large capacity DC plants have been constructed and under development in GCC region. The DC plants in the region will be **30 million RT** until 2030[2].

3. Large capacity of DC plant.

Scale of new DC plants is much larger than conventional plants, like Madinah Hajj City and Makkah.

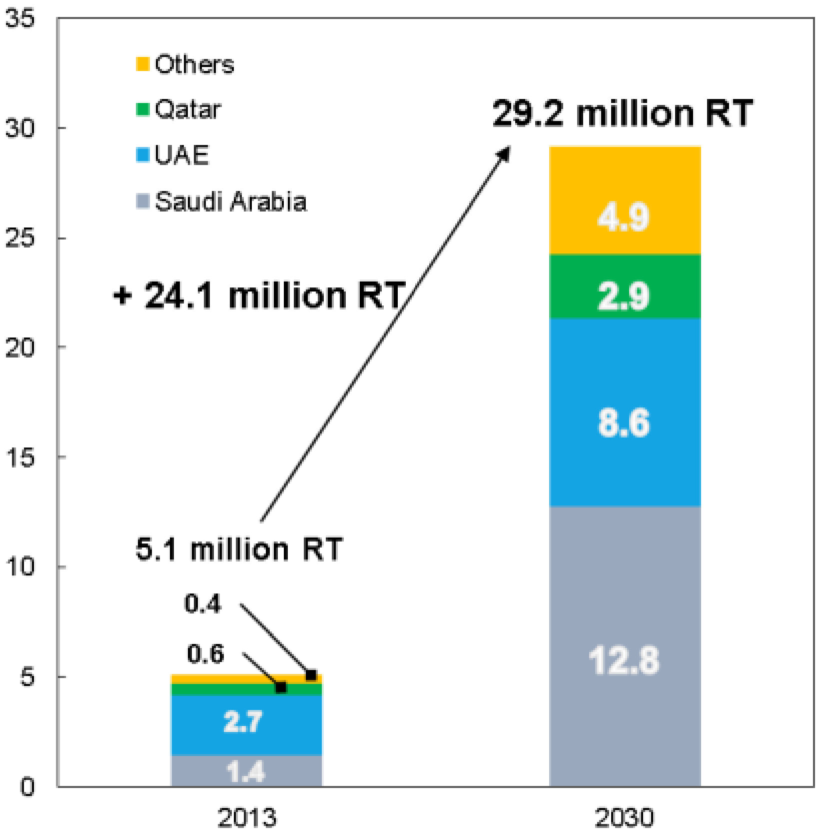

Fig1.Estimated cooling capacity of DC plant in GCC region

1)UAE, Bahrain, Kuwait, Oman, Qatar, KSA.
The value includes the value of UAE, KSA, Qatar and Iran.
2) 4th Annual District Cooling Saudi Arabia Summit , Sep 2013.

1.2 Issue for DC Plant in GCC Region

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Design & method of operation for DC plant should be optimized to suit **the climate** and **the characteristic of cooling load** in each region. The technologies would reduce both **capital and operating expenditure** of the DC plants.

1. Optimal method for operating expenditure

A operation method should be based on actual site condition in each region. Following method would reduce the expenditure for DC plants.

1.1 Chiller number control: Operate chiller in efficient and high performance range

1.2 Control flow rate of chilled water variably

1.3 Control flow rate of cooling water variably

2. Optimal design for capital expenditure

Following design for chiller and DC plant would reduce the expenditure.

2.1 Use large capacity chiller with 3,000 RT or more

2.2 Reduce footprint for large capacity chiller without cooling capacity

2.3 Reduce total chiller number installed in each DC plant

We have considered DC plant design and operation by using these methods in Japan, Singapore and GCC region.

2. Experiences of District Heating and Cooling

DHC Plant in Tokyo, Shinagawa Station-East Area[1]

Fig3.Appearance of Shinagawa Station-East Area

1. Climate and operation

(1)Humid summer, cold winter

(2)Chilled water supply throughout the year, and steam supply in winter for offices, hotels and so on

(3)Ice storage at night because of high electrical bills ($0.15 – 0.16/kWh)[2]

2. Commercial Operation: since April, 2003

3. Supply Capability

Chilled Water: **16,800 RT** Steam: **71.3 t/h**

4. Main Units

(1)Chilled Water Supply

Absorption Chiller: 2,500 RT×4, 850RT×2

Centrifugal Chiller: 900 RT×3

Ice Storage Bath : 5,700 RTH×3

(2) Steam Supply

Steam boiler: 15 t/h×3, 9.6 t/h×1

Exhaust heat boiler: 8.35 t/h×2

1) http://www.jdhc.or.jp/article/%E5%93%81%E5%B7%9D%E9%A7%85%E6%9D%B1%E5%8F%A3/
2) http://www.tepco.co.jp/ep/corporate/plan_h/plan06.html

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Marina Bay Sands, in Singapore

Fig4. Appearance of Marina Bay Sands[1]

1. Climate and operation

(1)Humid summer throughout the year

(2)Chilled water supply for offices, hotels and so on.

(3)Ice storage at night because of High electrical bills ($0.08 – 0.13/kWh)[2]

2. Commercial Operation

since July, 2005

3. Supply Capability: 43,531 RT

4. Main Units

Centrifugal chiller: 3,697 RT × 2 (ice storage)
2,844 RT × 11(5, ice storage)
2,000 RT × 2
853 RT × 1

1) http://www.mhi.co.jp/discover/graph/inquiry/no169.html
2) http://www.nna.jp/articles/show/20160401spd011A

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Madinah Hajj City Project, in KSA

Fig5. Appearance of Madinah Hajj City Project[1]

1. Climate and operation

(1)Hot summer and relative warm climate throughout the year

(2)Chilled water supply for offices, hotels and so on. Electrical bills ($0.04 – 0.08/kWh)[2]

2. Commercial Operation: since 2018

3. Supply Capability: **200,000 RT**

4.Main Units

Centrifugal Chiller: 2,500 RT,VSD×80

In this presentation, we have considered the optimal design and operation for the three places (Tokyo, Singapore and Madinah Hajj), Makkah in KSA, Lusail in Qatar and Dubai on the basis of the following conditions

(1) Target area: Tokyo, Singapore, Madinah Hajj, Makkah, Lusail, Dubai

(2) Climate condition: Outside air temperature of 3 hours on behalf every month

(3) Cooling capacity of DC plant: 30,000 RT

(4) Chiller select: 5,000 RT, PL unit.

1) https://www.thebig5hub.com/news/2016/january/in-pictures-top-10-projects-in-makkah-and-madinah/ 2)http://www.nna.jp/articles/show/20160401spd011A

3. Climate Condition and Characteristic of Cooling Load

3.1 Dry-Bulb Temperature

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Although GCC countries are **the highest temperature level** that we have never experienced in Japan . But the experience of Singapore must be useful, and the temperature difference throughout the year in Tokyo is able to take advantage for the design and method of operation

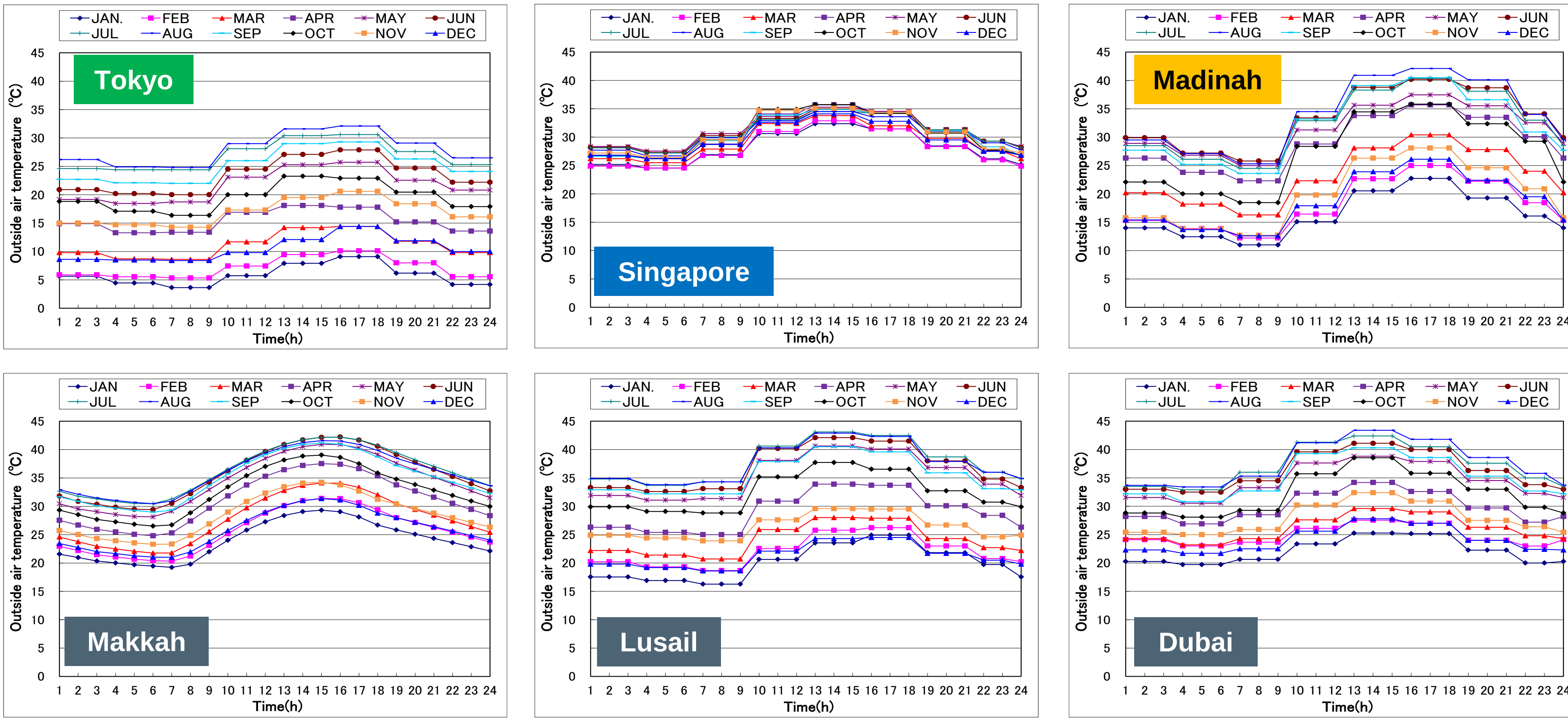

Fig.6 Dry - Bulb Temperature

※Weather data source ： World Weather Online Using the Outside air temperature of 3 hours on behalf every month. Number of statistics: 8 per month×12＝96

3.2 Wet-Bulb Temperature

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Wet-bulb temperature of GCC countries is less than that of Singapore.
the fluctuation range is small enough.

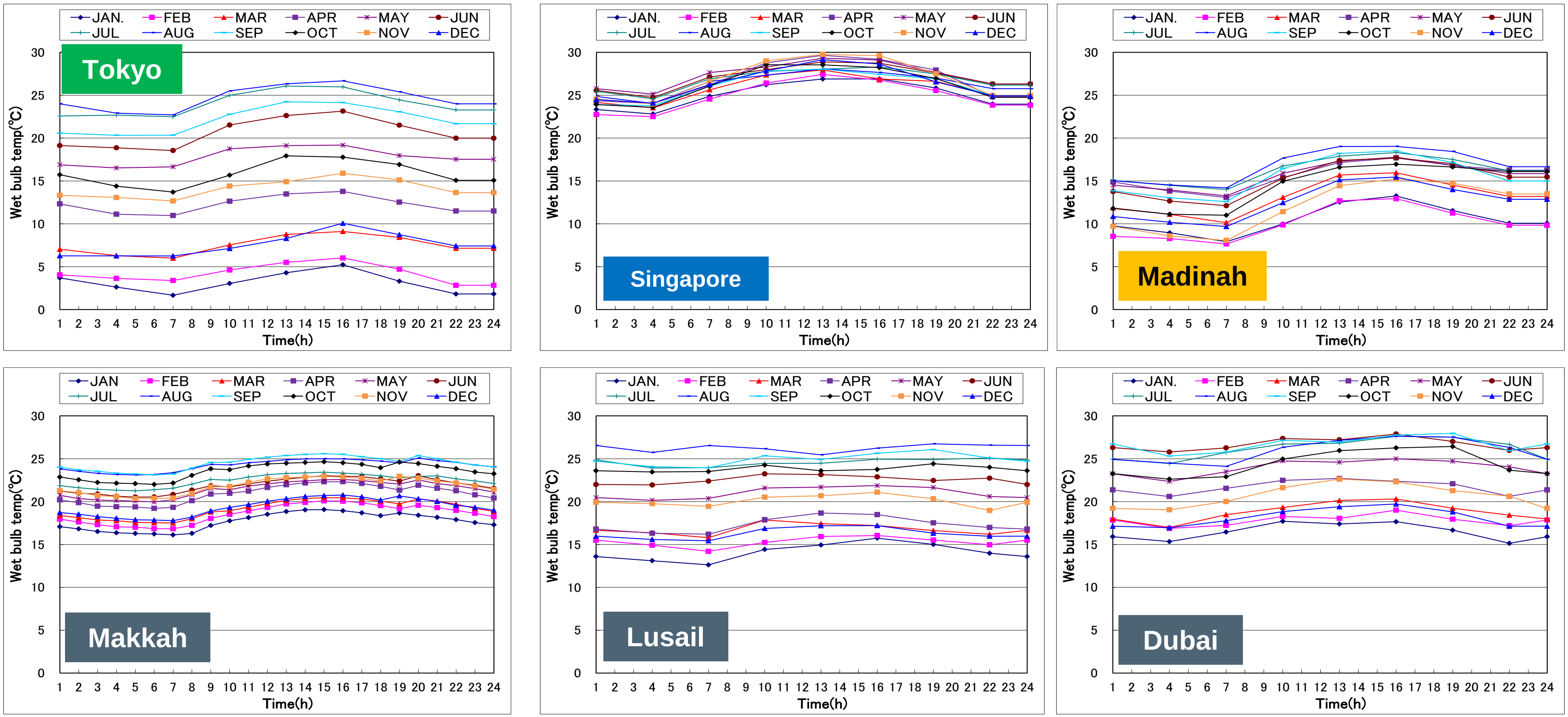

Fig.7 Wet-Bulb Temperature

※Weather data source : World Weather Online Using the Wet-bulb temperature of 3 hours on behalf every month. Number of statistics: 8 per month×12＝96

3.3 Cooling Water Temperature

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Cooling water temperature changes widely in Japan through a year.

In Singapore it is almost constant.

In Madinah, Makkah, Lusail and Dubai it is narrow.

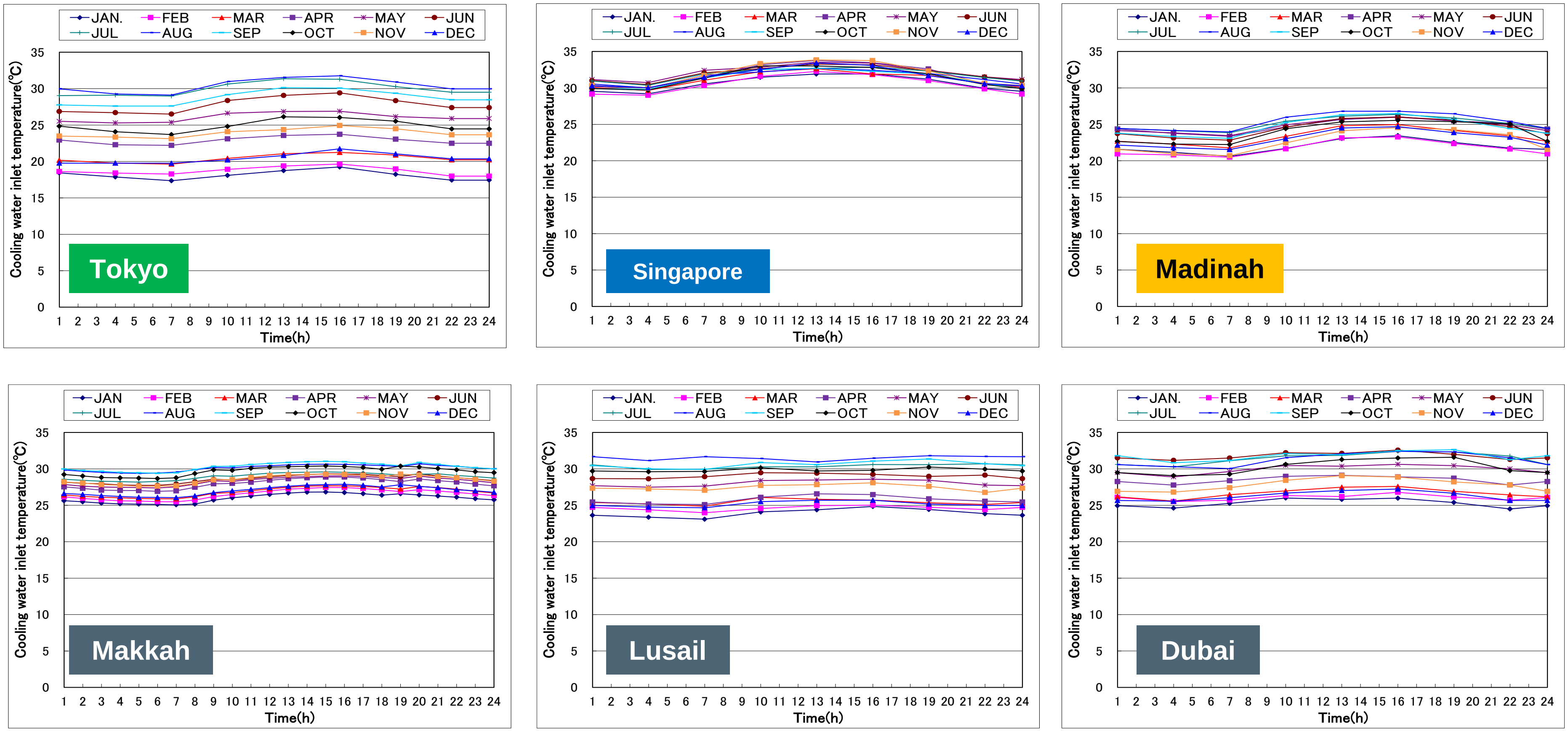

Fig.8 Cooling Water Temperature

※Weather data source ： World Weather Online　　Using the Cooling water inlet temperature of 3 hours on behalf every month. Number of statistics: 8 per month×12＝96

3.4 Cooling Load

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In Japan, Load fluctuation is a large at daytime and small at night time.

In Singapore, Medina, Mecca, Lusail and Dubai, these load characteristics are similar

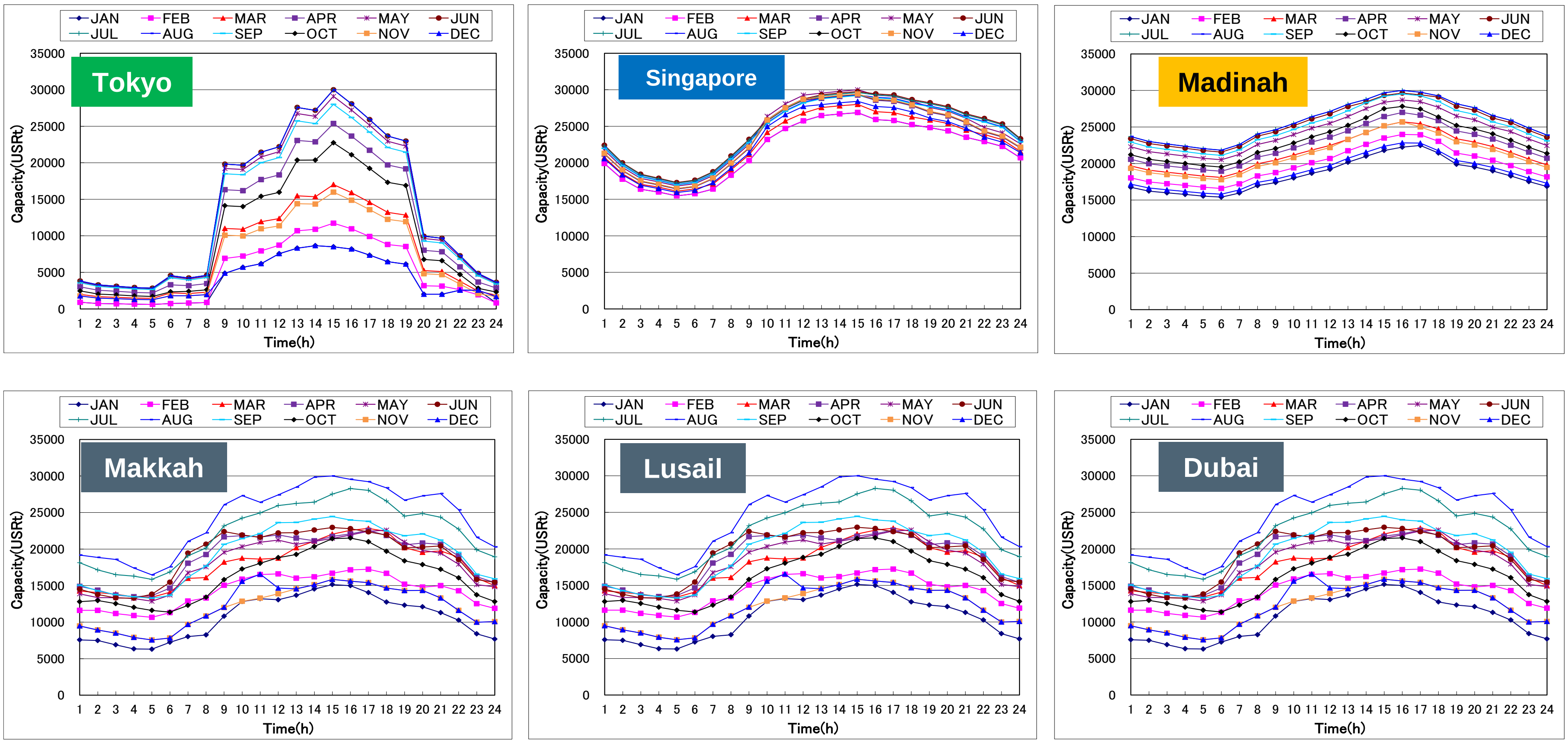

Fig.9 Cooling Load (24h×12month)

※Using the Cooling load of 3 hours on behalf every month. Peak load:30,000USRt

4. Basic design for DC plant in GCC

4.1 Chiller design for DC plant in GCC

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1.We suggest **3 concepts** of chiller design for DC plant in GCC to reduce capital expenditure.

(1). Large capacity, more than 3,000 RT

(2). Small footprint with the large capacity chiller

(3). High performance chiller even under the GCC condition

2.We suggest **3 solutions** in order to meet the above concepts.

(1). Big capacity compressor apply for the chiller

(2). Dabble compressors on one chiller, Parallel unit.

(3). Series-Counter flow configuration by one Parallel unit or two units.

Larger capacity chillers and the smaller footprint should be selected to be less the plant building cost.

3. Optimal control system

The optimal operation system controls the number of chiller, chilled water flow and cooling water flow to reduce the operation expenditure in accordance with the cooling water temperature and the cooling load. Reduction of the operation cost will be huge by using the optimal operation.

4.2 Plant specification

4.2.1 Chiller Specifications for 30kRT Plant

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Following table shows specifications of chillers with FSD and VSD

Table.1 Specifications of chiller

Model No.	FSD ※1	VSD※1
DC plant capacity(USRt)	30,000	30,000
Capacity(USRt)	5,000	5,000
Unit nuber	6	6
Power Input(kW)	3,498	3,498
Rated COP	5.0	5.0
Chilled water(℃)	13/4.4	13/4.4
Cold water flow rate(m^3/h)	1,655	1,655
Evaporator pressure drop(kPa)	53.4 ※2	53.4 ※2
Pump head(mAq)	13.0	13.0
Chilled water pump power(kW)	90	90
Cooling water(℃)	35/43.5	35/43.5
Cooling water flow rate(m^3/h)	2,107.8	2,107.8
Condenser pressure drop(kPa)	31.0 ※3	31.0 ※3
Pump head(mAq)	20.0	20.0
Cooling water pump power(kW)	200	200

Large capacity

High performance

Large temperature difference

Low pressure drop

Low pressure drop

※1 FSD：Fixed Speed Drive chiller, VSD：Variable Speed Drive chiller

※2 Chilled water pump head=Head loss of straight pipe+Piping fittings, valves and others+Strainer(3mAq)+Control valve(3mAq)+Head loss and flow rate of Evaporator

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

4.2.2 Part Load Performances

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High performance characteristic in actual operation range

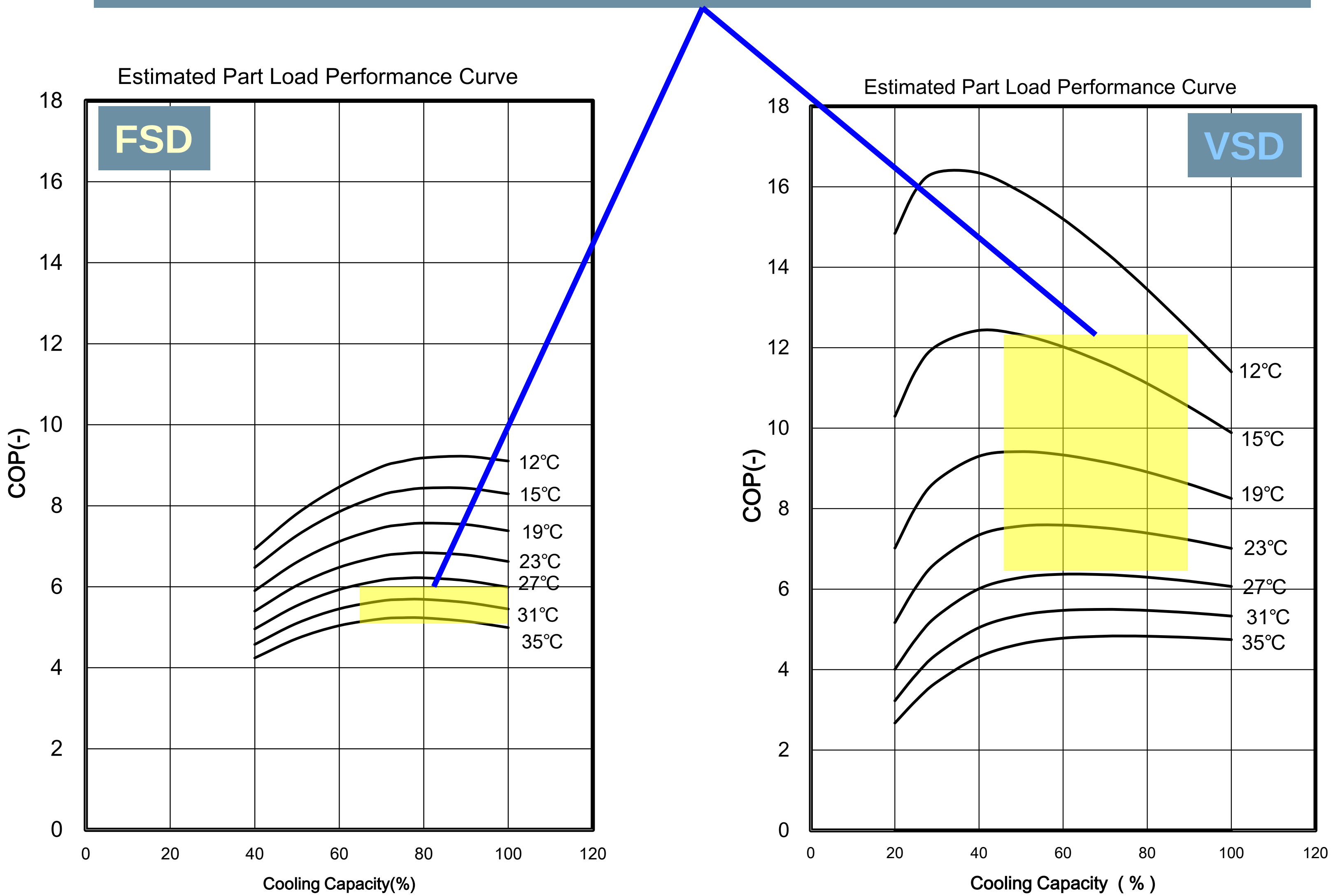

Fig.10 Part load performance curve

4.2.3 Optimal control for PL type

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Higher COP value is shown at each condition, cooling load and cooling water temperature in Fig.11, comparing with performance between FSD and VSD.

VSD is better performance in low cooling water temperature.

FSD is better performance in high cooling water temperature and high cooling load

Singapore

FSD / VSD

Cooling water inlet temp.(℃) \ Cooling 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

Tokyo

Madinah

Dubai, Makkah, Lusail

Cooling load.(%)

Fig.11 COP Comparison between VSD and FSD

※1 FSD：Fixed Speed Drive chiller, VSD：Variable Speed Drive chiller

4.2.4 Comparison of the Unit Layout

Footprint of 2 single units is about the same of a parallel unit in the case of our chillers.

Series counter flow by 2 single units
5000RT

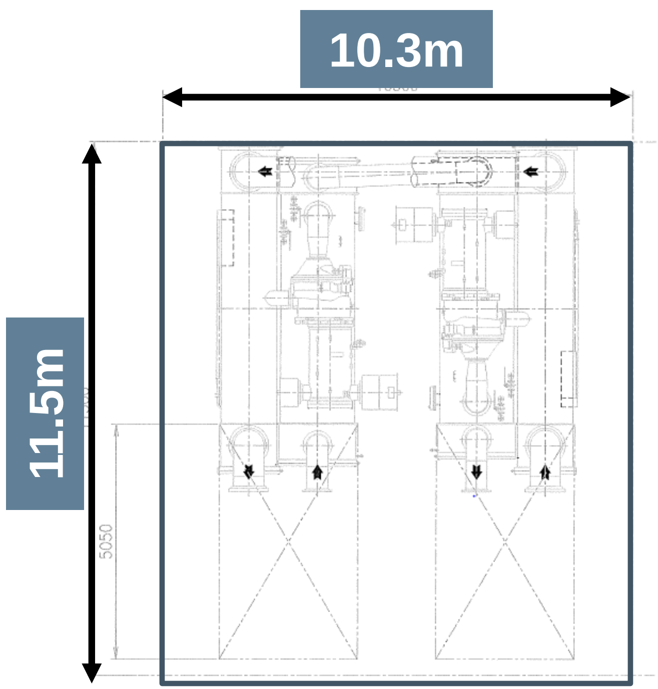

Fig.12 Installation Area 118m^2

Series counter flow by a parallel unit
5000RT

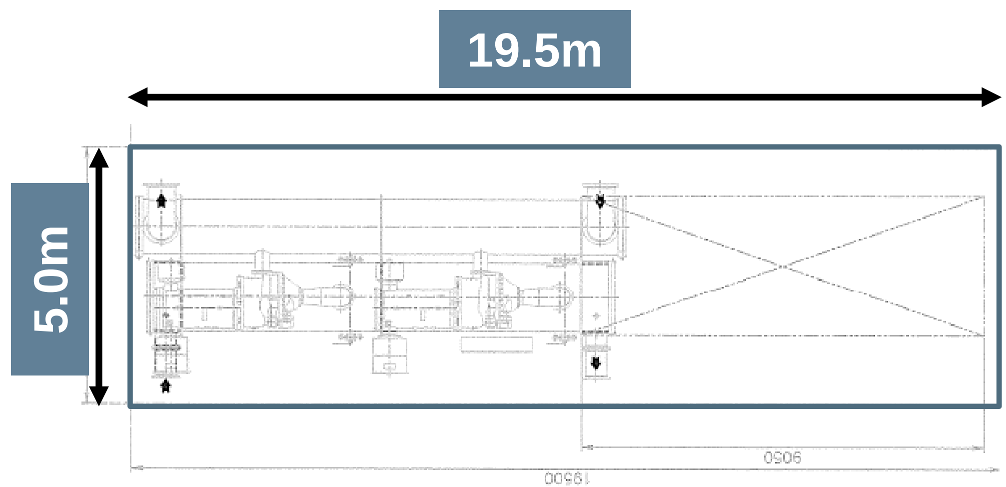

Fig.13 Installation Area 117m^2

4.2.5 Plant Layout

The layout shows the minimum area for 30kRT plant with 6 parallel centrifugal chillers.

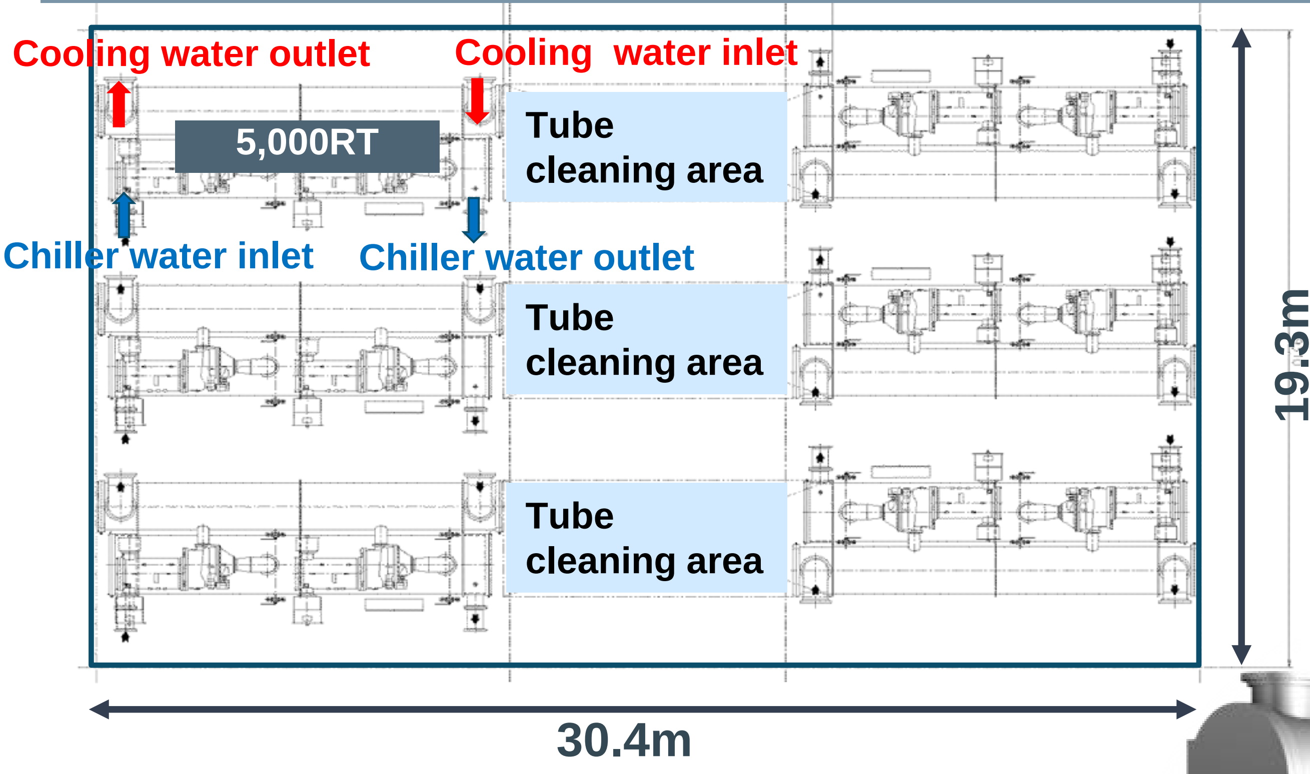

Fig.14 Plant Layout

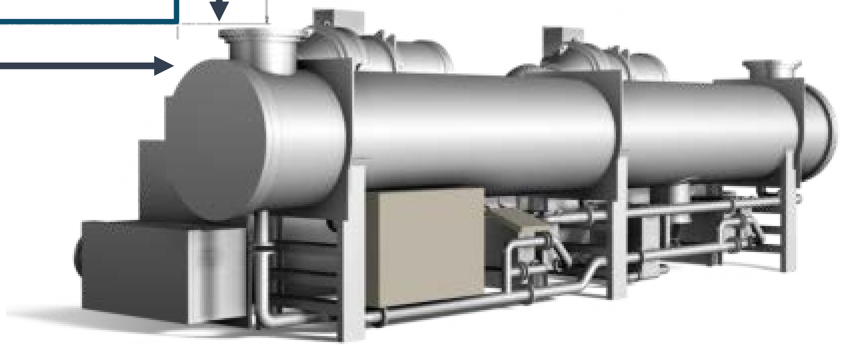

Fig.15 Outline of 5kRT chiller

4.3 Optimal control system

4.3.1 Outline of control items

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The optimal control system is able to control six items of following (1) –(6) in Fig.16 show the system diagram.

The In this presentation, COP and system COP were calculated in consideration of

(1) Multiple chiller control, (2) Chilled water variable flow control and (3) Cooling water variable flow control.

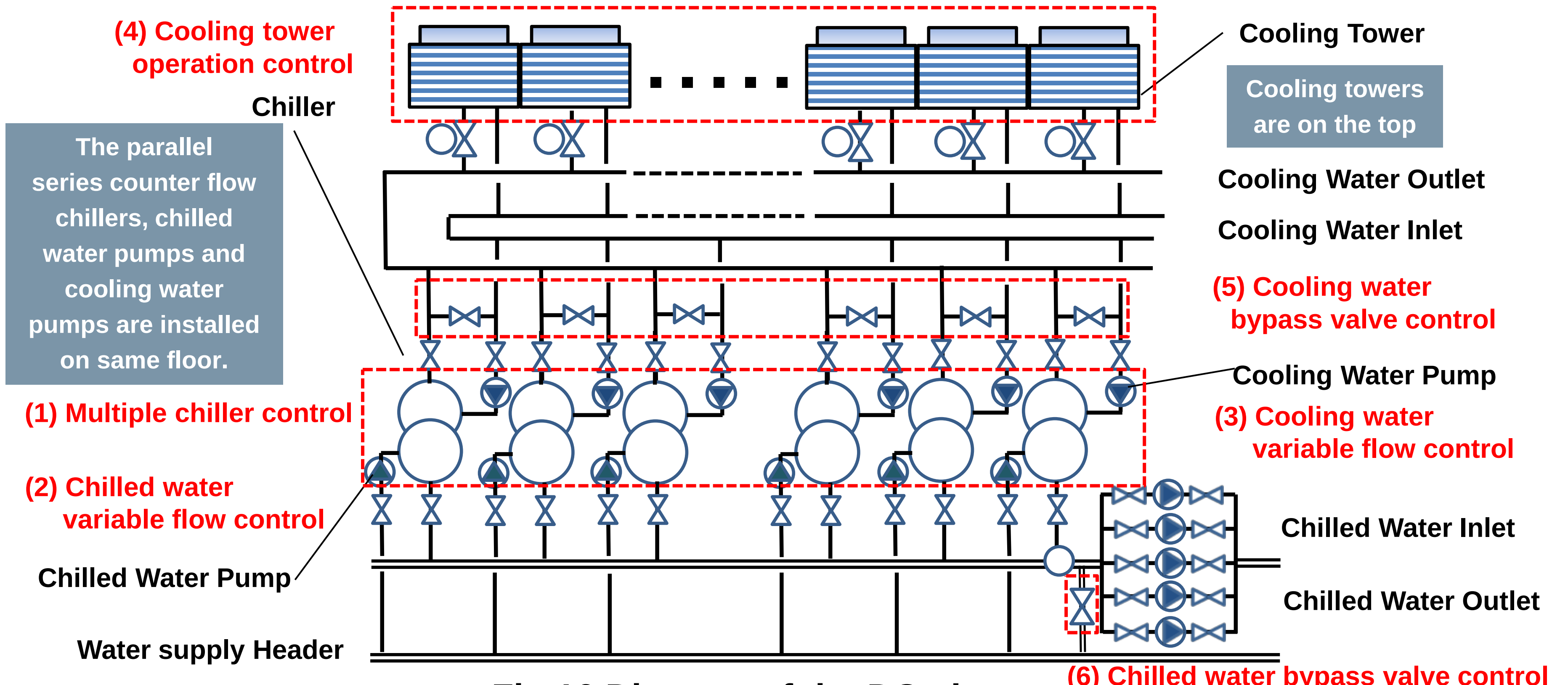

Fig.16 Diagram of the DC plant

4.3.2 Multiple Chiller Control

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(1) An Optimal load range is unique to each cooling water temperature in case of VSD, and to each chiller. The range is able to be calculated and transmitted to the control system via the operating box of the chiller. An Optimal range is around maximum load for FSD.

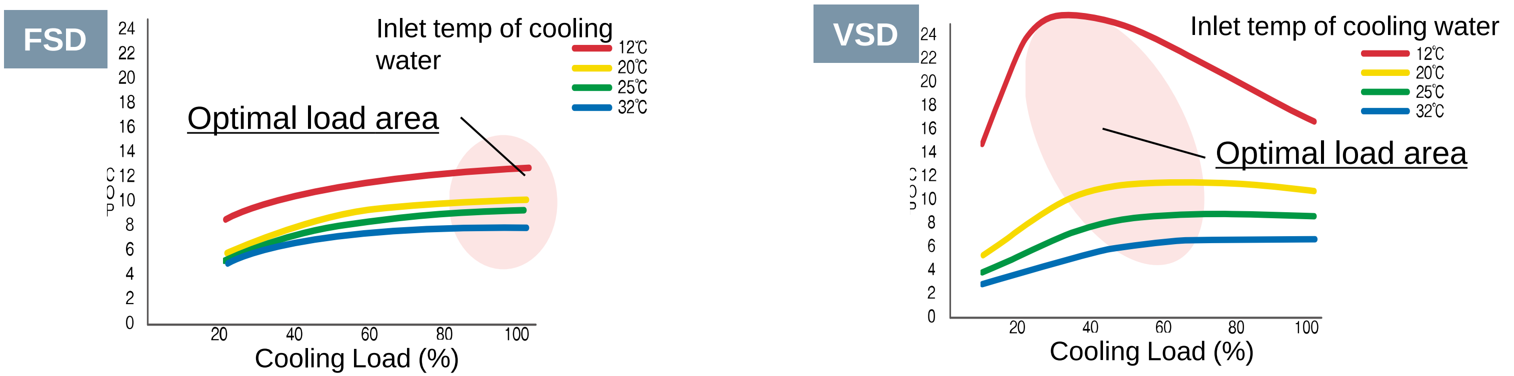

Fig.17 Optimal load range of FSD and VSD

(2)Adequate chilled water flow minimizes (6) bypass flow between the inlet and outlet header.

(3)An Optimal flow range of cooling water is decided by the cooling load in Fig.18-a, and ,minimize the energy consumption (Fig.18-b)

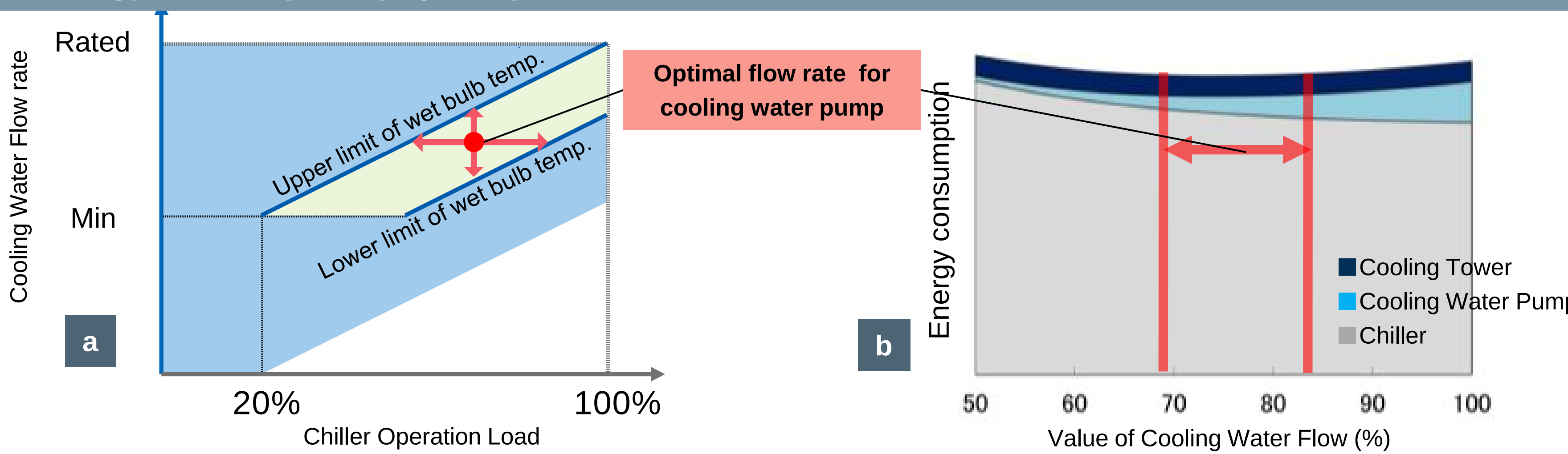

Fig.18 Cooling water variable flow control

4.4 Annual energy consumption and consideration

4.4.1 Tokyo and Singapore

The VSD is better than the FSD by more than 6% in Tokyo at the view of Annual energy consumption. The Optimal control system has a reliable advantage in spite of the drive unit. Both VSD and Optimal control system are useful in the region has fluctuation of cooling water temp and cooling load.

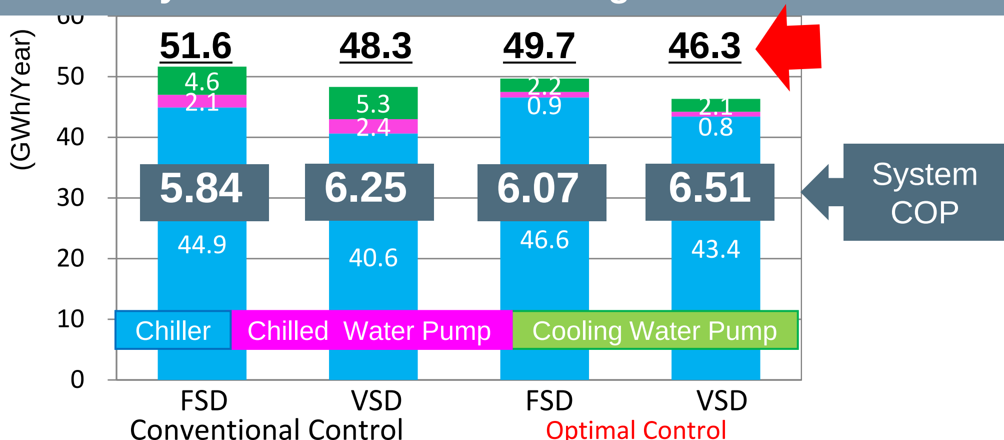

Fig19-(a)Annual energy consumption in Tokyo

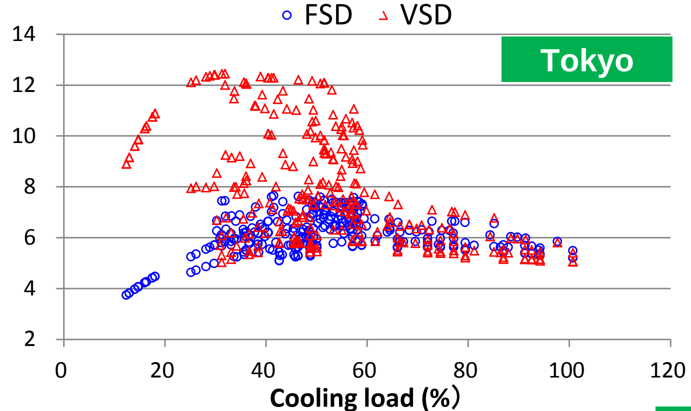

Fig19-(b) COPsys through the year in Tokyo

The VSD is worse than the FSD by about 3% due to electrical loss. High performance FSD chillers should be applied for Singapore site.

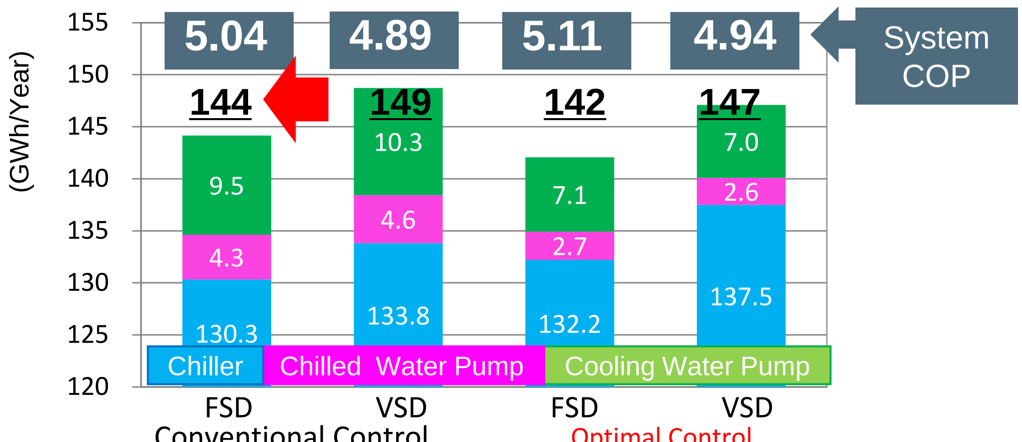

Fig20-(a)Annual energy consumption in Singapore

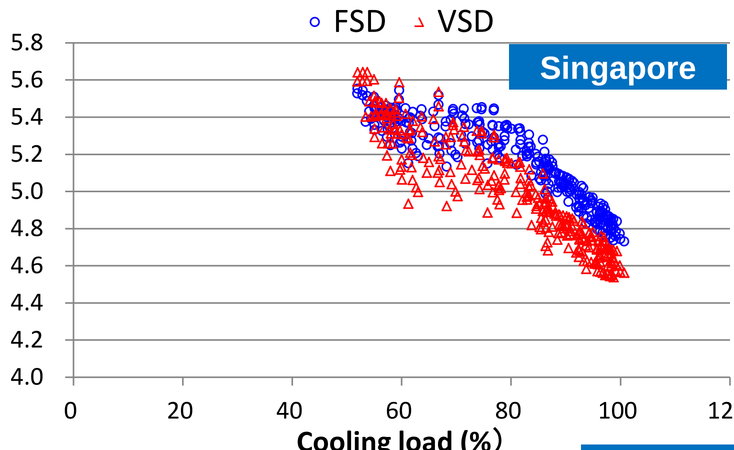

Fig20-(b) COPsys through the year in Singapore

4.4.2 GCC region

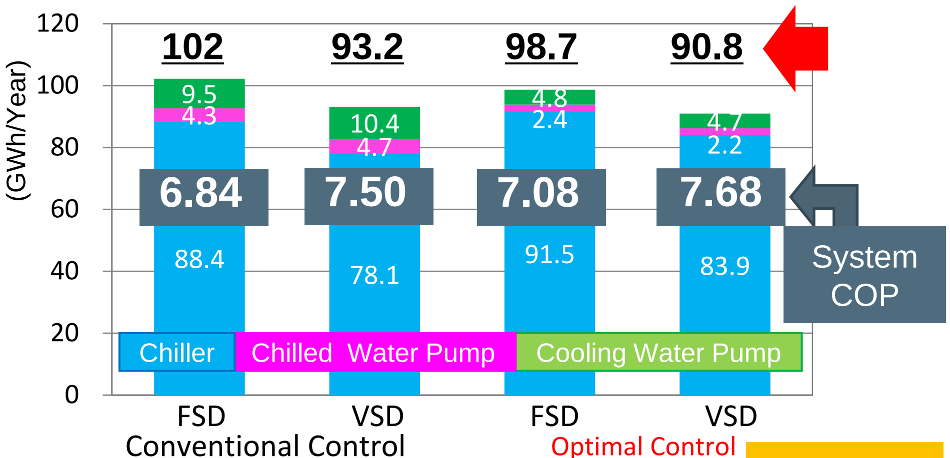

Fig20 Annual energy consumption in **Madinah**

In **Madinah,** the VSD is better than the FSD by about 9% at the view of annual energy consumption due to low cooling water temperature. The Optimal control system reduces additionally about 3% energy consumption.

The combination FSD & Optimal control system is better suited to typical GCC region, Makkah Dubai and Lusail, due to high cooling water temperature.

High performance FSD chiller, are suitable for typical GCC region, Makkah Dubai and Lusail.
The Series counter flow parallel unit is one of best ways for DC plant in GCC region.

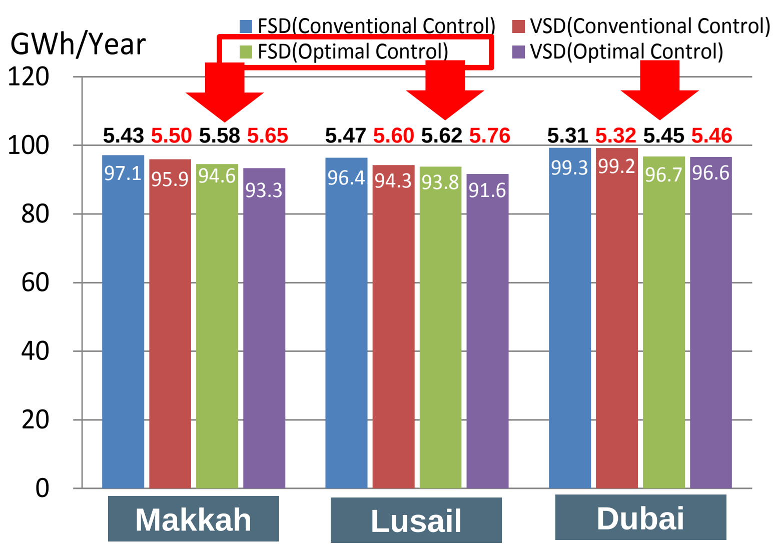

Fig22-(a) Annual energy consumptions of GCC region

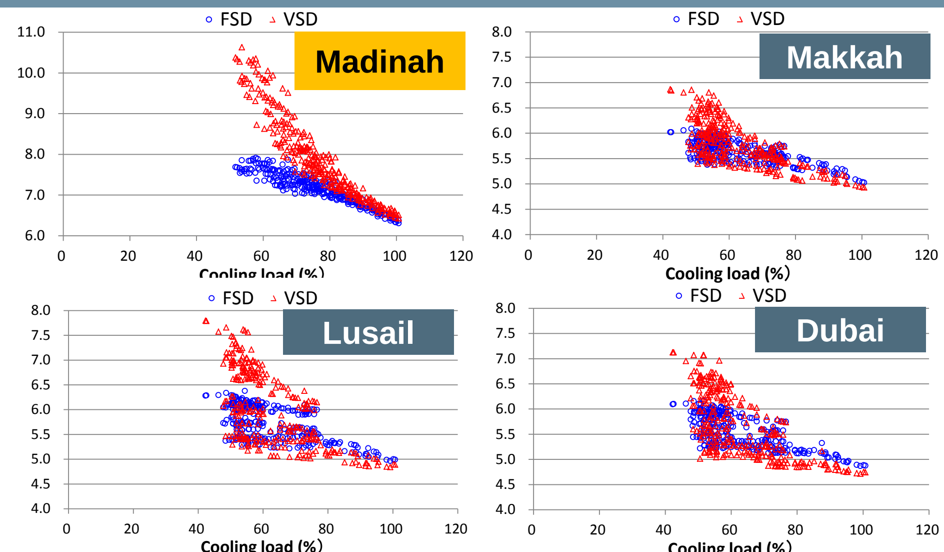

Fig22-(b) COPsys through the year in GCC region

5. Conclusion

5. Conclusion

1. High performance FSD centrifugal chiller is suited to DC plant in GCC region, due to high temperature cooling water.

2. The Optimal control system is reduce the energy consumption of the DC plant by approx. 3% in any case.

3. If temperature difference through a year is large, the combination VSD chillers and Optimal control system is best. It improves the performance of the DC plant by 10%

4. The series counter flow parallel unit with double compressors is ideally suited to DC plant in GCC region, due to large capacity, high performance and small footprint.

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