ACTUAL CONDITION INVESTIGATION OF HIGH-EFFICIENCY LARGE-CAPACITY ELECTRIC HEAT PUMP MODULAR CHILLING UNITS INSTALLED AT LARGE COMMERCIAL FACILITIES

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Abstract: Direct fired absorption chiller heater has been used regularly in the market for large scale air-conditioners. We have developed high efficiency large capacity electric heat pump modular chilling units (hereinafter "modular heat pump") employing the highly efficient refrigerant R410A, in 2006. Since then, by considering a low carbon society, we have been promoting the development of high efficiency electric heat pump chillers utilizing our heat pump technology. This modular heat pump is now widely accepted than the conventional absorption chillers from the viewpoint of greenhouse gas emission reductions. From seven months of investigation for actual condition at large commercial facilities in Yamanashi prefecture of Japan, we verified the performance of modular heat pump. We remotely monitored the energy measurement and surveyed the air-conditioning load and electric power consumption with various types of measurement devices installed around the chiller plant. This investigation demonstrated that the modular heat pump was operated under very light load and it was proven to operate efficiently especially in the low load condition. Additionally, the water spray system that is installed for using vaporized heat to obtain further high efficiency performance under high temperature environment achieved a desired result. In this paper we will introduce our findings.

Key Words: modular heat pump, Super Flex Modular Chiller, Large Commercial Facility

1 INTRODUCTION

One of the effective energy-saving methods for large commercial facility which requires higher energy consumption is to introduce high efficiency chillers. "Lazawalk Kai Futaba" is a suburban large commercial facility completed in April 2009 and is employing the economically efficient air-cooled heat pump chillers as air-conditioning heat source. This chiller is the first for large air-cooled chiller industry to adopt high efficiency refrigerant R410A, which is used regularly for the light commercial air-conditioners, and have better energy-saving efficiency. Furthermore, from the viewpoint of law regulation, dispersion of failure risk, and power saving, the chiller can respond to large-scale facilities with multiple chiller installation of compact module chillers and also have benefit of maintaining the performance regardless of the number of connected units.
In this document, we will introduce our field survey of air-conditioning load characteristics and chiller efficiency at operating phase as we measured the energy of chiller itself after completion.

2 GENERAL INFORMATION

Building Name : Lazawalk Kai Futaba
Location : 645-1 Shidaaza Kakiki Kofu-city, Yamanashi
Building Use : Commercial facility (food, department store, restaurant, amusement facility)
Structure : Steel Gymnasium
Number of floors : 1 basement floor below ground, 4 floors above ground
Building area 31,000 sqm, Gross area 82,700 sqm (Shopping floor area 36,700 sqm)



Figure 1: Lazawalk Kai Futaba (left) and Super Flex Module Chiller (right)

3 CHILLER OUTLINE

Air-Conditioning System : FCU and Air-Cooled Heat Pump
Water System : 1st floor Secondary Pump system
2nd floor Primary Pump system
Air-conditioning Load : 1st floor Cooling load 2520kW Heating load 600kW
2nd floor Cooling 3240kW
Specifications for each chiller are shown in Table 1.

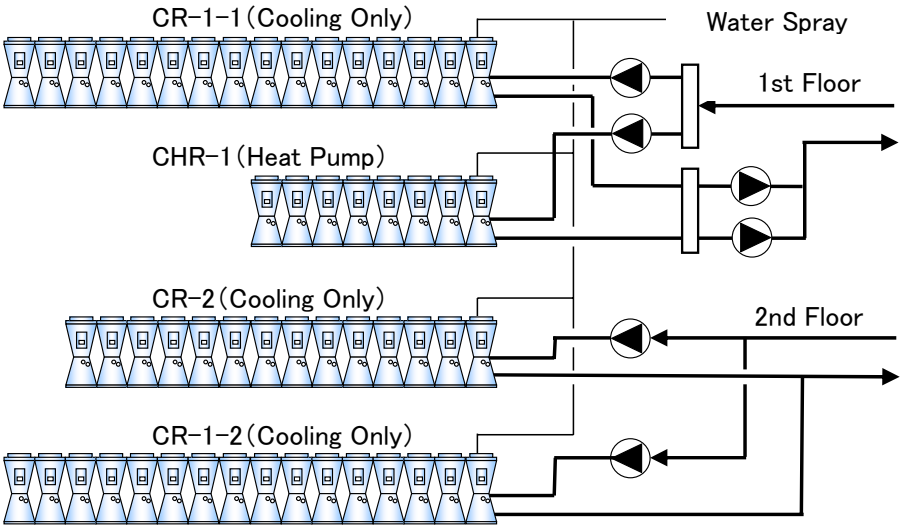


Figure 2: Chiller System

Super Flex Module Chiller is adopted as heat source, which large capacity can be obtained by modularizing and connecting 25 tons air-cooled heat pump chillers (see Figure 1). Every

floor systems are consisted of two sets of chillers; only one set on 1st floor system is heat pump and the rest are cooling-only (see Figure 2).
Also, the specification for all chillers are large temperature difference (DT=10 Deg C) to reduce the pump power input.

Table 1: General Information of Chillers

Unit	System	Cooling Capacity	Heating Capacity	EWT/LWT	Rated COP
CR-1-1(Cooling Only)	1F	1728kW	—	17⇒7℃	5.05(C)
CHR-1(Heat Pump)		792kW	600kW	43.3⇒50℃	4.96(C),2.91(H)
CR-1-2(Cooling Only)	2F	1728kW	—	17⇒7℃	5.05(C)
CR-2(Cooling Only)		1512kW	—		5.05(C)

4 OUTLINE OF MEASURING DEVICES

To determine the performance and energy efficiency of each chiller, we installed measuring instrument on the points shown in Table 2, and automatically measured the time-series data of one-minute interval with remote control system for seven month continuously.

Table 2: Measuring / Weighing Points around Chillers

Unit	Water Temp		Flow Rate	kWh	Spray Volume	OAT DB
	Ent	Lev				
CR-1-1(Cooling Only)	○	○	○	○	○	○
CHR-1(Heat Pump)	○	○	○	○		
CR-1-2(Cooling Only)	○	○	○	○	○	
CR-2(Cooling Only)	○	○	○	○		

Figure 3 shows the basic concept of remote monitoring system. The analog data measured with measuring instrument is converted to digital signal via measuring device and is sent to local server. From here, it is automatically saved in the data server of the remote monitoring center via internet through ADSL modem. We collected the saved data periodically with PC. The operating data for each chiller was also saved into the compact flash memory integrated in the group controller(GC) of chiller, and we collected them later at field. The data was utilized to confirm the consistencies with data of remote monitoring center.

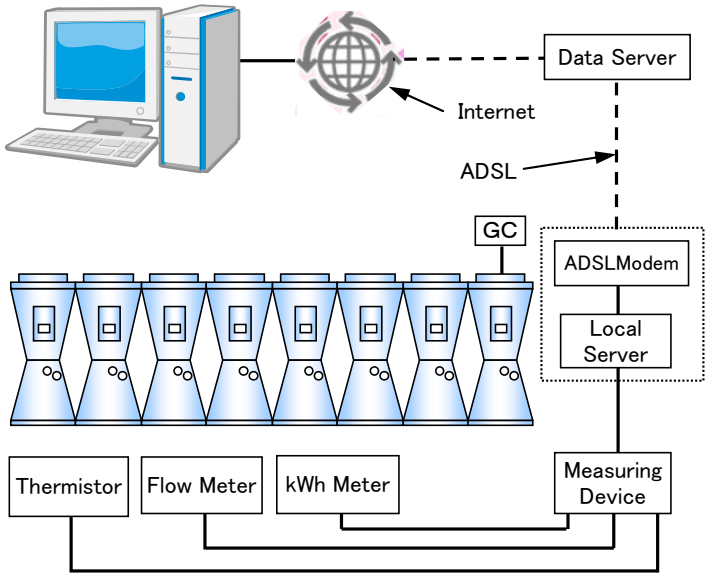


Figure 3: Remote Monitoring System's Basic Concept

5 PRODUCTION ENERGY (COOLING AND HEATING LOAD CHARACTERISTICS)

Figure 4 shows the monthly variation of produced energy as chilled water. Air-conditioning load of this building is affected by outdoor air temperature and customer traffic, and produced energy will be changed accordingly. The amount of produced energy has recorded maximum value of 3100GJ in August, and decreased from interim period to winter season along with the decreased outdoor air temperature. Meanwhile, the monthly average outdoor air temperature is approximately 7 Deg C and it switches into the hot heat production-centered operation while keeping the slight cold heat production. The heat production balance during the measuring period shows that the cold heat production is approximately 6700GJ while hot heat production is 1/7 of the cold heat. It is obvious that cold heat is high in demand.

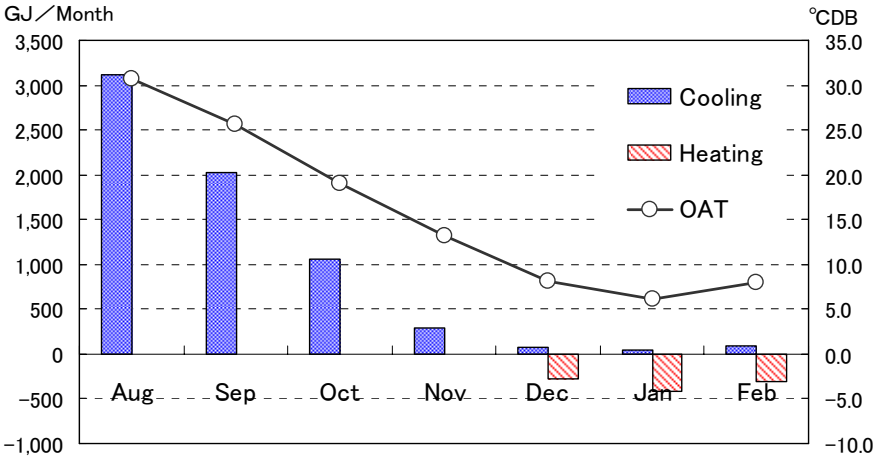


Figure 4: Monthly Variation of Produced Energy

6 CHILLER OPERATING STATUS AT MAX. LOAD

Figure 5 shows the chiller operating status on August 11 when the daily cooling calorie reached to the maximum. Due to the preparation for opening stores, capacity changing into high load operation was observed for 20 minutes after starting, but it soon calmed down and recorded stable operation all day. It is considered there are less load changes because the internal load ratio has higher percentage under cooling load.

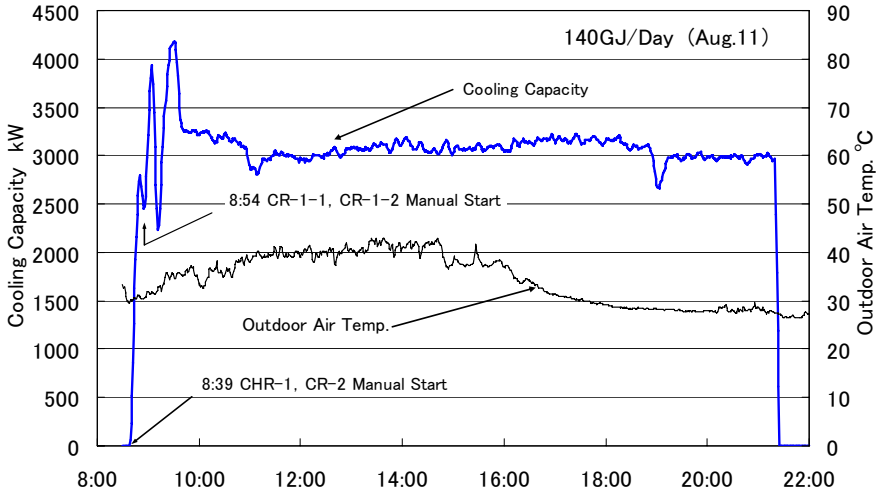


Figure 5: Chiller operating status (cooling)

Also figure 6 shows that the chiller operating status on January 18 when heating calorie for winter season reached maximum. During winter season, heating operation is performed as to prevent the outdoor air into the entrance door only for 1st floor system. Though the impact of the outdoor air load is large, there is less daily variation with stable internal load. Several defrosting operation was observed during morning, but the level should not be a problem.

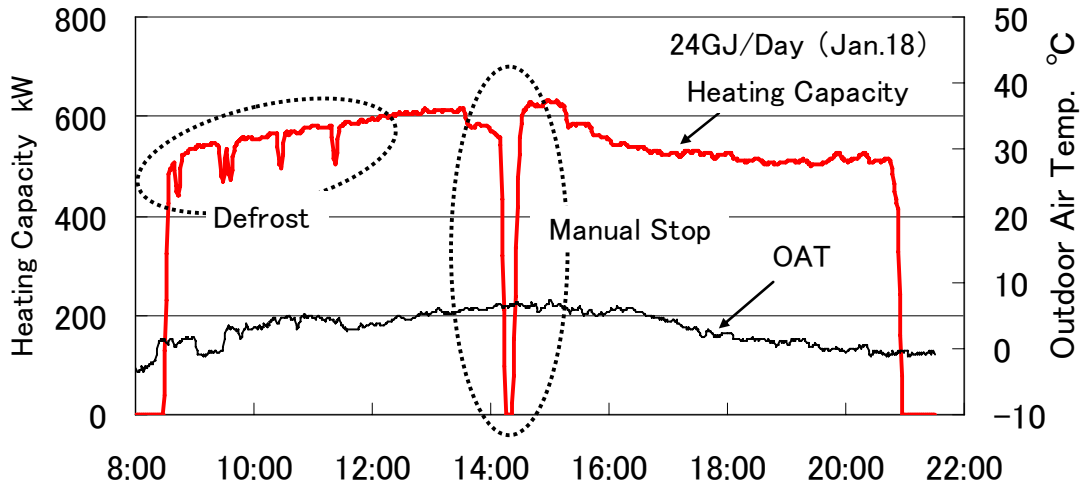


Figure 6: Chiller operating status (heating)

7 POWER CONSUMPTION AND MAXIMUM POWER INPUT

Figure 7 shows the status in electric power consumption and maximum power input by month. The maximum integral power consumption was occurred in August for cooling period and in January for heating period. Because of the building characteristics, heating load is so low that there is less power demand for winter season. Thus, the power demand for summer season is high and the instantaneous maximum power input recorded 1327kW (AM8:59) on August 14. Depending on the seasons, the power demand varies greatly and the maximum power for most of the year is much lower than that in August. Because the maximum power input occurs in short time at startup in every morning, it is necessary to review the operational procedure of chillers to reduce the power input.

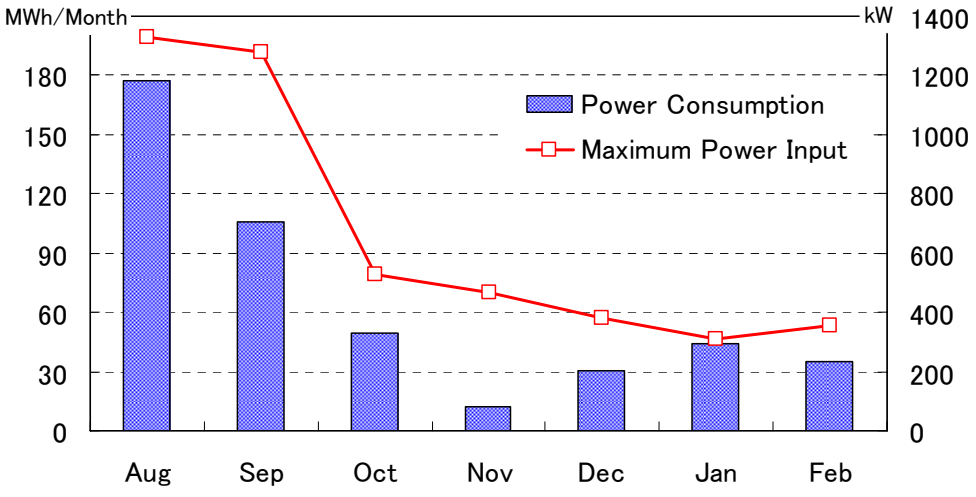


Figure 7: Power Consumption and Maximum Power Input

8 PERFORMANCE EVALUATION BY COP

8.1 Monthly Average COP

The Correlation between monthly average COP of chiller and outdoor air temperature is shown in Figure 8. The heat pump chiller on the 1st floor system from December to February is switched into heating operation (heat mode) which is easy to be affected by fresh air load while 2nd floor system is year-round cooling.
As chiller energy efficiency is highly affected by outdoor air temperature, COP will coordinate with outdoor air temperature. Unlike common building, this building has cooling demand throughout the year, and the cooling operation efficiency from mid-season to winter season provided fairly-high result as an average value.

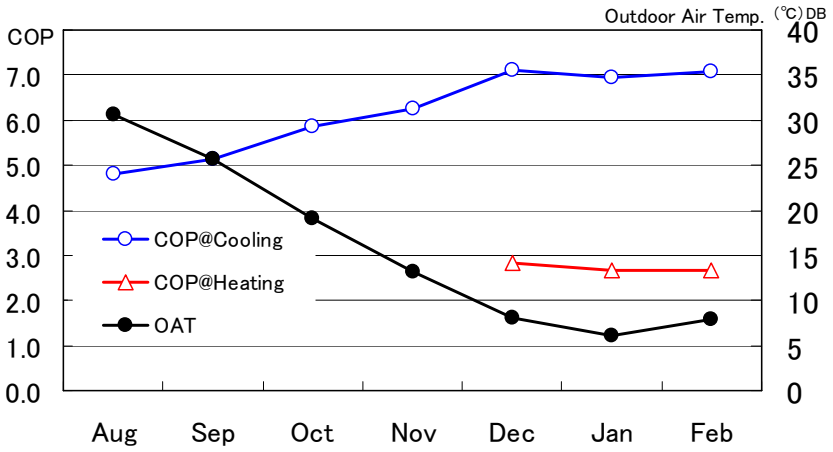


Figure 8: Monthly Average COP

8.2 Scattergram of COP for Summer-only

Figure 9 shows the COP scattergram for three sets of cooling-only chiller in August only. We used a data describing the relation between daily average load rate and COP, and graphically-illustrated the actual value by outdoor air temperature into air heat exchanger. The outdoor air temperature is identified at every 5 Deg C, and plotted display is changed for every temperature range. Average COP of actual value is 4.8 which is about same as the value on the product specification. In addition, it is operated at nearly 50% of load rate on average. We could confirm that the benefit of module type chillers excellent in part load efficiency is utilized.

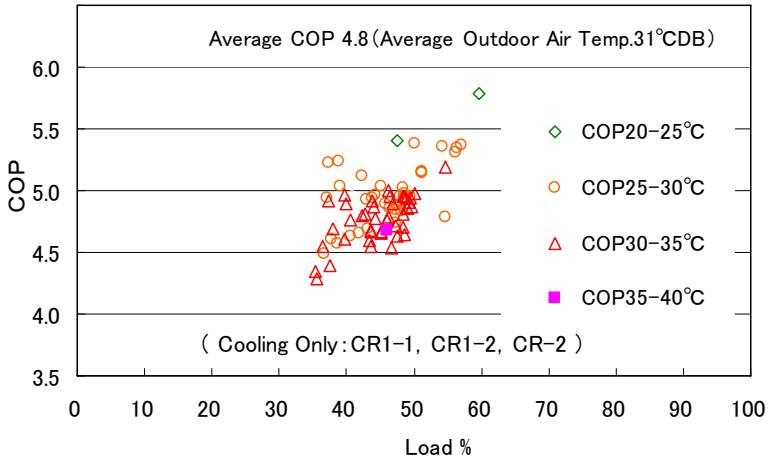


Figure 9: COP Scattergram for August

8.3 Correlation between COP and Outdoor Air Temperature

The correlation between COP and outdoor air temperature for cooling-only chiller is shown in Figure 10. We created a data showing the correlation between daily average COP and average outdoor air temperature for each chiller, and we plotted the actual value from August to February. The reference straight line of the chiller (CR-1-2) on 2nd floor system which has longer operating hour throughout the year is also shown. When air-cooled chiller performs cooling operation, chiller performance will vary in response to the outdoor air dry bulb temperature to air heat exchanger. On the reference straight line, COP grew one as outdoor air temperature decreased by 10 Deg C. While COP on the product specification is 5.05 when spraying water with 35 Deg C DB of outdoor air temperature, the actual value was about 4.7 for 3.97 at air-cooling. From actual operating condition, which evap-cooled and air-cooled was mixed by the load rate, we can say this is positive result.

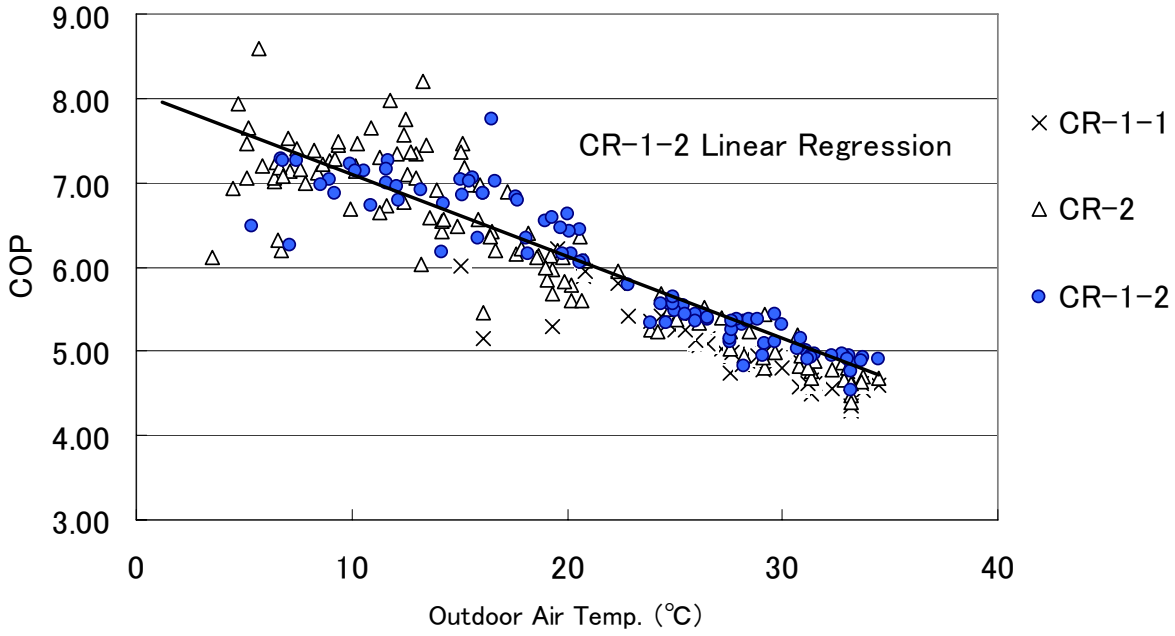


Figure 10: COP and Outdoor Air Temperature

9 COMPARISON OF ACTUAL MEASURED-PERFORMANCE WITH DESIGN SPECIFICATION

9.1 Max. Load Day of Summer Season

Figure 11 shows the correlation between cooling capacity and power consumption for the cooling-only chiller (CR-1-2), which the produced energy recorded the maximum on August 11. By putting the design cooling capacity and design power consumption at 100% load for the air-cooled operation (non-spraying water) with 35 Deg C DB of outdoor air temperature as 100% standard, we plotted the actual measured value every one minute to the standard value. The design specification at air-cooled and evap-cooled operation is also displayed with sold and dotted line.
For 34.9 Deg C DB of average outdoor air temperature of the day, the actual value distribution was within the range air-cooled (solid line) and evap-cooled (dotted line) operation with 35 Deg C of outdoor air temperature and showed satisfied result.

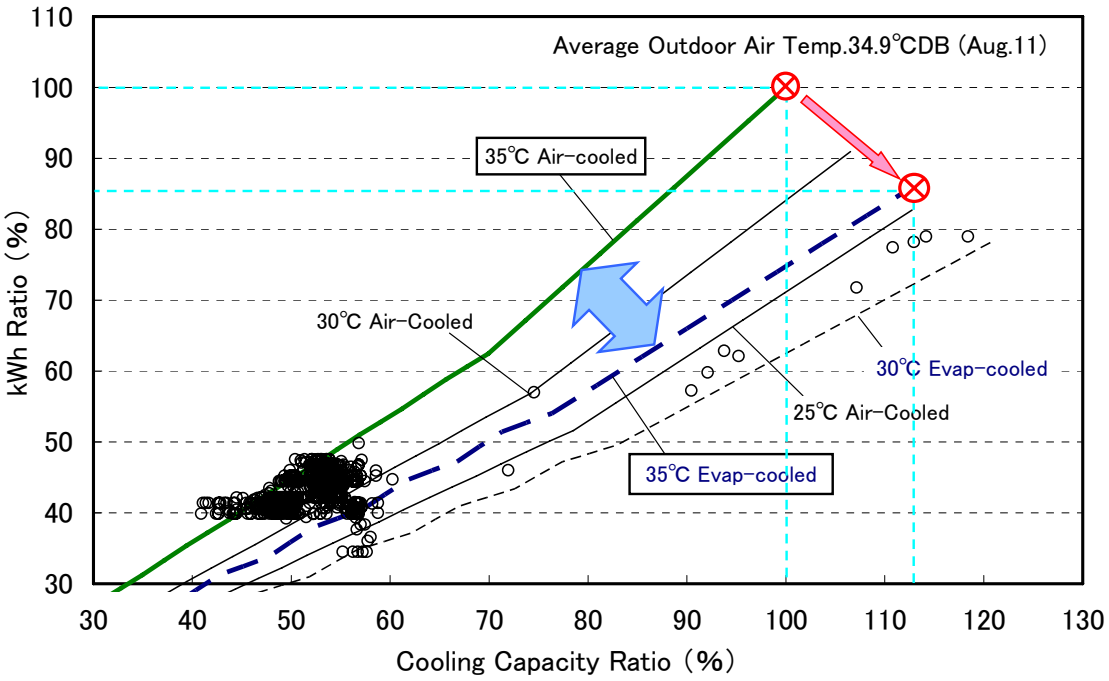


Figure 11: Correlation between Cooling Capacity and Power Consumption (summer season)

9.2 Designated Day of Interim Period

Correlation of cooling-only chiller (CR-1-2) on October 13 is shown in Figure 12 as interim period. For the 20.6 Deg C DB of average outdoor air temperature of the day, most of the actual measured results were plotted in the area below the air-cooled operation (solid) with 25 Deg C of outdoor air temperature, which is positive outcomes.

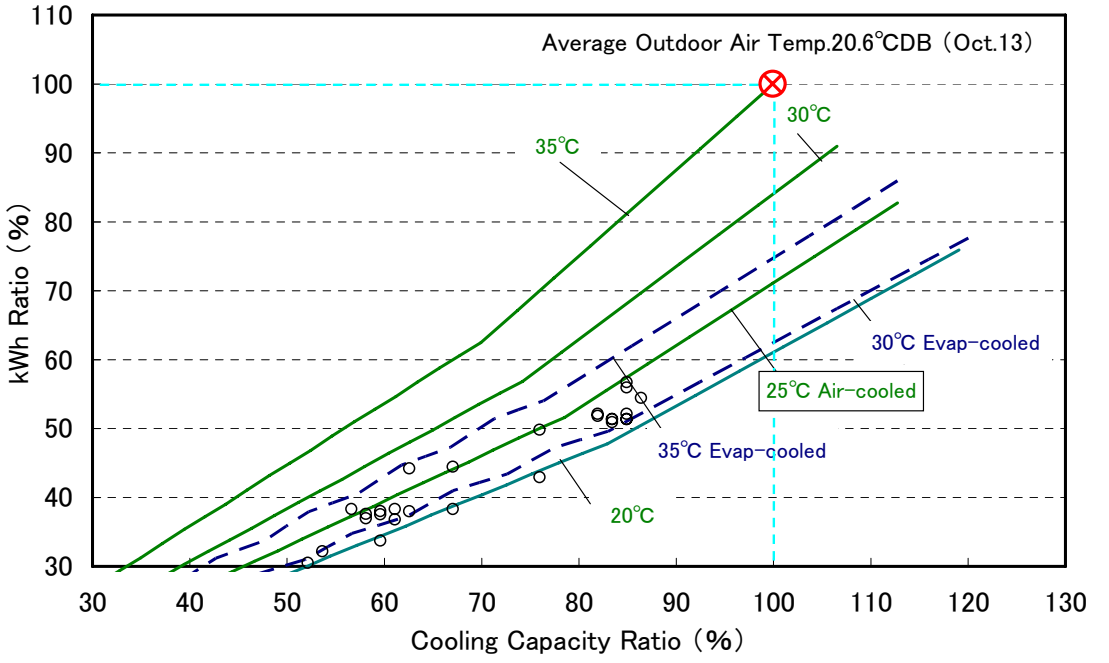


Figure 12: Correlation between Cooling Capacity and Power Consumption (interim period)

9.3 Max. Load Day of Winter Season

Figure 13 shows the correlation of heat pump chiller on January 18 when it recorded maximum produced energy during heating period. The actual measured result to the 3.3 Deg C DB of average outdoor air temperature of the day was plotted around the heating operation (solid line) with 5 Deg C DB of outdoor air temperature. The effect of defrost operation (decreased in statistical heating capacity) and outdoor air wet-bulb temperature were compensated for the used heating capacity diagram based on engineering data. Because the defrost operation did not reduce the capacity so much, actual operation provided better result than the compensating diagram.

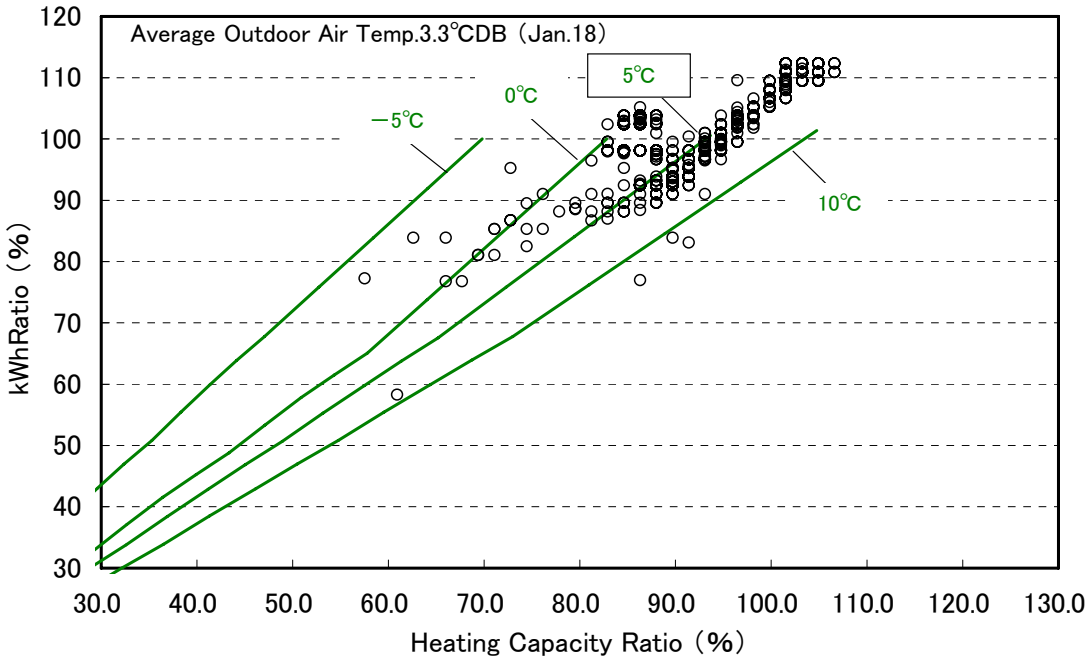


Figure 13: Correlation between Statistical Heating Capacity and Power Consumption (winter season)

10 EVAPORATIVELY COOLED CONDENSER

Figure 14 shows the result that we analyzed the correlation between COP and outdoor air temperature on August 11 (maximum load) for every module of cooling-only chiller. In addition, the cooling capacity and compressor power consumption is calculated according to the compressor performance, and the power consumption includes fan motor and heater. Spray equipment is installed on each module as standard, and evap-cooled condenser of each module is controlled by considering the outdoor air temperature (setpoint is changeable) and load ratio. Though the increased COP with spraying was affected by outdoor air temperature, it showed increase in COP by approximately 28% when the outdoor air temperature is 35 Deg C (wet-bulb temperature showed 25.5 Deg C by AMEDAS at this time). This virtually corresponds with the rated value.

Spraying to air-cooled condenser tend to be avoided because of the heat exchanger or chassis corrosion and scale adhesion. However, by installing it as standard at factory with measures, we could confirm the great energy-saving effect.

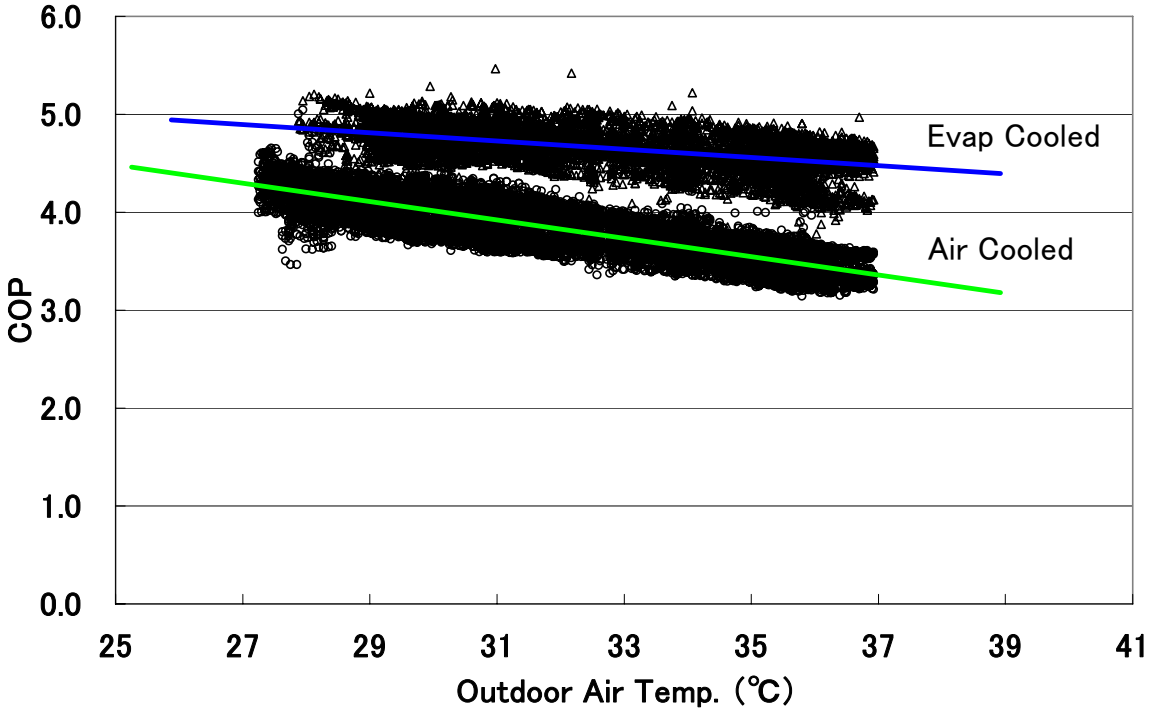


Figure 14. COP per Module at Evap-Cooled and Air-Cooled

11 CONCLUSION

For the energy efficiency of the chiller, the measuring result meeting product rated value was achieved and higher energy efficiency was also confirmed at operation phase after completion. Especially for the cooling load during interim period and winter season, the chillers which are suitable for building use were adopted because of high part load efficiency. We would like to consider the practical use of the easy way to determine the chiller operating efficiency and the characteristics under various air-conditioning load, including industrial process cooling, by utilizing the control information on chiller side in the future.

12 REFERENCES

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