PERFORMANCE COMPARISON OF TEMPERATURE AND HUMIDITY INDEPENDENT CONTROL AIR-CONDITIONING SYSTEM AND THE CONVENTIONAL AIR-CONDITIONING SYSTEM

Haiqiang Zhang[1], Xiaohua Liu[2], and Yi Jiang[3]
Department of Building Science, Tsinghua University, Beijing, 100084, China

ABSTRACT

This article introduces two system models to simulate the energy performance of the temperature and humidity independent control air-conditioning system (THICS) and the conventional air-conditioning system (CAS). The energy performance comparison includes three parts of cooling resource, transportation system and terminal devices. A typical office building with these two different systems is numerically analyzed. Beijing and Guangzhou, two major cities in China, are chosen, which lay in temperate zone and tropical zone respectively. In Beijing office building, the Energy Efficient Ratio (EER) of THICS is 4.5, while which of CAS is 3.6. In Guangzhou office building, the EER of THICS is 4.5, while which of CAS is 3.4.The energy efficiency of THICS is higher than that of CAS and THICS can save 20%~30% energy consumption compared with the CAS. In detail, cooling resource accounts for the biggest part of the energy-saved.

KEY WORDS: THICS, air-conditioning, transportation, energy performance

INTRODUCTION

The temperature and humidity independent control air-conditioning system (THICS) is a new air-conditioning system, which controls the temperature and humidity independently with different equipments, while the conventional air-conditioning system (CAS) disposes the latent load and sensible load together only using conventional chiller. Compared to CAS, THICS can improve the indoor thermal comfort, energy efficiency and indoor air quality and so on (Jiang Yi, 2004). In China, the application of THICS has been extended rapidly (Heating and Refrigeration, China, 2008), contributing to high attention on the energy saving. In THICS, the humidity of the indoor air is controlled by the fresh air which is processed by the liquid desiccant outdoor air handling processor (LD), and the control of temperature relies on the higher temperature water chiller (chilled water temperature increases to 18℃). Correspondingly, the latent load and sensible load are disposed together by the common chiller (chilled water temperature is 7 ℃) in CAS.

John W Spears made a two months test of energy consumption of a THICS with desiccant system and a CAS in two supermarkets where the THICS saved 13% energy consumption (John W Spears et al, 1997). Sekhar, S.C. introduced a single-coil twin-fan air-conditioning system which involves the independent control of temperature and humidity and has a potential to save energy up to 12% (Sekhar, S.C. etc, 2004). LIU Xiaohua adopted the empirical average COP (co-efficiency of performance) to analysis the energy performance difference between THICS and CAS, and pointed out that THICS can save 20%~30% compared to CAS (Liu Xiaohua etc, 2008). These studies mainly forced on the cooling resources, and lacks hourly energy consumption data according to the hourly building load. In fact, the energy consumption of the air-conditioning system consists of cooling resource, transportation system and terminal devices. As indicated by many testing results in commercial buildings, about 30%~60% of the total energy is consumed by the transportation system and terminal devices. At the same time, energy consumption data in the whole cooling seasons calculated hourly are still demanded. Therefore more detailed performance comparison of these two systems is still required.

SIMULATION

Building and Air-conditioning type

The performance of THICS varies by different climates and different building types, so the authors choose a typical office building and Beijing and Guangzhou two cities in China, which are in two typical climate zones, temperate zone and tropical zone respectively.

The office building consists of six floors, with 16500 m^2 building area and 16000m^2 air-conditioning area. The main room types include office, meeting room, washroom, and corridor. The enclosure material properties used in the office building and typical room type data come from the building simulation tools – DeST, which is a powerful building simulation tool developed by Department of Building

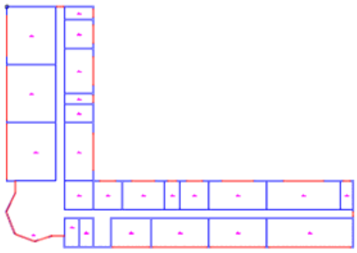


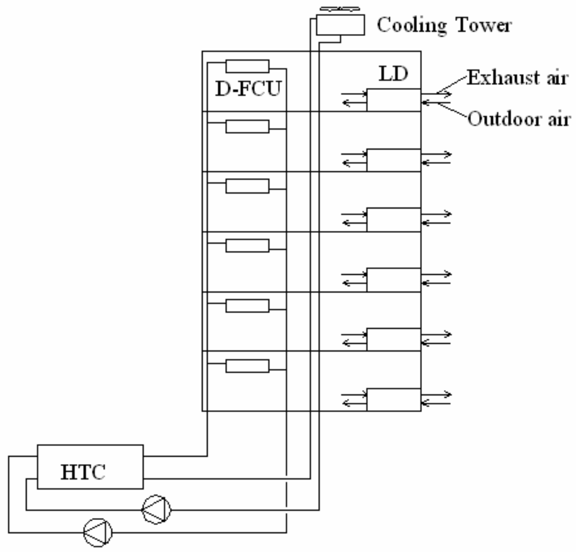
Figure 1 The floor plan of the office building

Nomenclature

THICS	temperature and humidity independent control air-conditioning system
CAS	conventional air-conditioning system
LD	liquid desiccant outdoor air handling processor
AHU	fresh air handling unit
FCU	fan-coil unit
D-FCU	dry fan-coil unit
EER	energy efficiency ratio
COP	co-efficiency of performance
TCE	total cooling energy
TEC	total electricity consumption
N	power (kW)
Q	load (kW)
G	air flow volume (m^3/h)
P	the whole pressure of fan (Pa)
S	the resistance characteristic of the air pipelines ($Pa*h^2/(m^2)$)
T_c	evaporative temperature (K)
T_e	condensing temperature (K)
t	air temperature (℃)
C_p	capacity of air (kJ/kg)
Greeks letter	
φ	relative humidity (%)
η	COP coefficient
ρ	density of air (kg/m^3)
ξ	efficiency of fan
ϕ	load ratio of FCU (D-FCU)
Subscripts	
w	outdoor air
i	hourly
b	building
htc	high temperature water chiller
cc	conventional chiller
s	sensible
set	rated by manufacturer

Science, Tsinghua University in China (Yan Da etc, 2004). DeST has been widely used in Chinese building simulation work. The typical room types' full year schedule, inner disturbance and set-point of HVAC system have been investigated in DeST. And the floor plan of the building is shown in Fig.1.

In this model, only performance for cooling seasons is considered. The operation schedules of air-conditioning system in Beijing and Guangzhou start from June to September and April to November respectively. Fan coil unit and outdoor air system is applied in the office building while the primary pump system is adopted. The cooling tower fan and pump run at constant frequency and the outdoor air volume will change as the number of persons in the building. The schematic diagrams of these two systems are shown in Fig. 2 and Fig. 3.The differences of equipment between THICS and CAS are shown in Table1.



HTC: high temperature water chiller

LD: liquid desiccant outdoor air handling processor

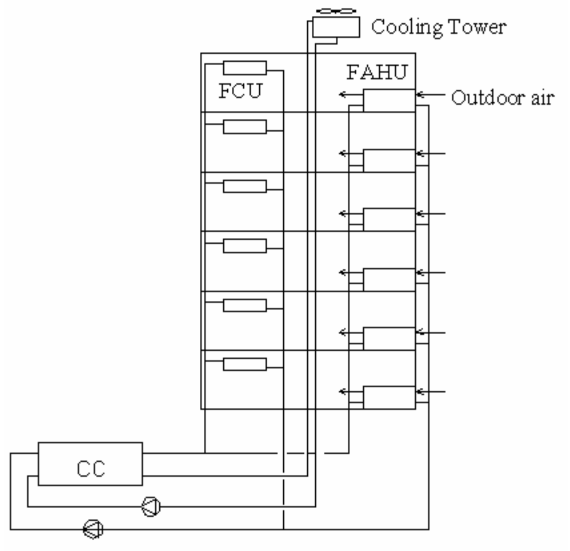
Figure 2 Schematic diagram of THICS

The energy consumption of THICS is composed of cooling resource including high temperature chiller (to control indoor temperature) and liquid desiccant outdoor air processor (LD) (to control indoor humidity), transportation system including chilled water pump, cooling water pump and cooling tower, and terminal devices including outdoor air fan and indoor FCUs. In the CAS system, the energy

Table 1 The differences of equipments between THICS and CAS

Type	FCU	Outdoor air processor	Chiller
THICS	Dry Fan-coil Unit (D-FCU)	Electricity powered liquid desiccant outdoor air handling processor (LD)	High temperature water chiller (18℃)
CAS	Fan-coil Unit (FCU)	Conventional Fresh air handling unit (FAHU)	Conventional chiller (7℃)

consumption concludes cooling resource of the common chiller (to remove the entire load), transportation system consisted of chilled water pump, cooling water pump and cooling tower, and terminal devices of outdoor air fan and indoor FCUs.



CC: conventional chiller

FAHU: fresh air handling processor

Figure 3 Schematic diagram of CAS

Building load

The building load will be simulated by using DeST software. By inputting the weather type, building type, room type and location into DeST, hourly load of the building in two cities will be simulated.

Chiller model

After calculating out the load and COP for chiller, the electricity power of chiller will be gained by the Eq. (1). For THICS, the load and COP for high temperature chiller is calculated by Eq. (2) and Eq. (3). For CAS, the load and COP for conventional chiller is calculated by Eq. (4) and Eq. (5).

$$N_i = \frac{Q_i}{COP_i} \tag{1}$$

$$Q_{htc} = Q_b - Q_{LD} \tag{2}$$

$$COP_{htc} = \frac{T_c}{T_c - T_e} \times \eta_{htc} \tag{3}$$

$$Q_{cc} = Q_b \tag{4}$$

$$COP_{cc} = \frac{T_c}{T_c - T_e} \times \eta_{cc} \tag{5}$$

First assuming that the temperate difference between evaporative temperate and chilled water temperate and temperate difference between condensing temperate and cooling water temperate are both 8℃, while temperature difference between cooling water temperate and outdoor wet bulb temperature is 3℃. So the evaporative temperates for high temperate water chiller and conventional chiller are -1℃ and 10 ℃ respectively. Based on this assumption, the COP coefficient η of many chiller product stylebooks is analyzed in Fig. 2, which shows the relationship between COP coefficient η and chilled water temperature. Thus, COP coefficient η_{htc} of 0.61 and COP coefficient η_{cc} of 0.68 are gained.

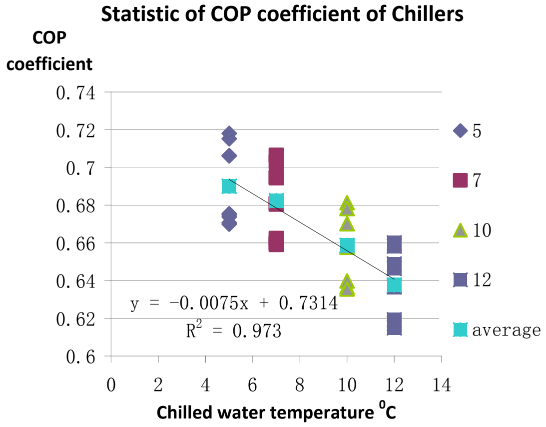


Figure 4 Statistic of COP coefficient η of chillers

Where 5, 7, 10 and 12 represent different series of chilled water temperature.

Outdoor air handling processor model

The LD is used to remove latent heat in THICS, which is powered by heat pump. So the hourly electricity power of LD can be calculated as below:

$$N_{LD} = \frac{Q_{LD}}{COP_{LD}} \tag{6}$$

In this part, the power only includes electricity power for heat pump and liquid pump. The other power consumption of the processor is air fan power, which will be discussed in Outdoor air fan and FCU model. Q_{LD} includes four parts of outdoor air sensible heat, outdoor air latent load, building latent load and part of building sensible load Q_s .The designed indoor temperate is 26℃ and the supply air temperate difference is 4℃. So:

$$Q_s = G_w \times \rho \times 4 \times C_p / 3600 \tag{7}$$

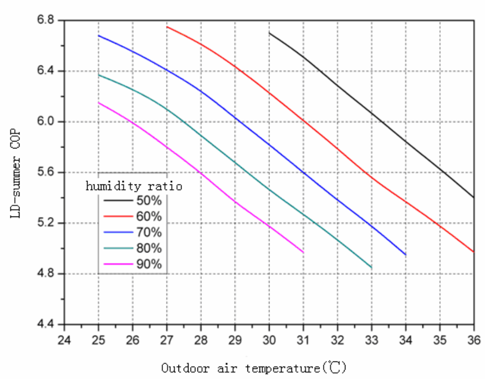


Figure 5 Summer COP of liquid desiccant outdoor air handling processor

The COP of LD is relative with the outdoor air temperate and relative humidity, and calculated by the fixed Eq. (8) of Fig. 5, which is the simulation result of the LD in the work state of summer.

$$COP_{LD} = =11.783+0.037764\times t_w-6.4233\times\varphi$$
$$-0.043733\times t_w\times\varphi-0.0034389\times t_w{}^2+2.8932\times\varphi^2 \quad (8)$$

Pump model

In THICS, the designed input and output water temperate of high temperature chiller is 22℃/18℃, while which of the conventional chiller in CAS is 12 ℃/7 ℃. In addition, the designed temperature difference of input and output temperate of cooling water is 5℃.

Outdoor air fan and FCU model

✧ The calculation procedure of the fan power

According to the air flow volume G and the whole pressure P, we choose a type of fan. With the rated power N_{Fan} of the fan, the efficiency of the fan can be gained by Eq.(9).

$$\xi=\frac{G\times P}{3600\times N_{Fan}} \quad (9)$$

Assuming that the air flow volume is changed based on the demand by changing frequency, the efficiency ξ keeps constant, and the resistance characteristic S of the air pipeline also keeps constant.

$$S=\frac{P}{G^2} \quad (10)$$

Then, the annual hourly power of the fan can be calculated by next equation:

$$N_i = S\times G_i{}^2\times G_i\frac{1}{\xi} \quad (11)$$

✧ The calculation procedure of the FCU power

Dry-FCU is used in THICS as the sensible heat removal terminal. The cooling load capacity of the Dry-FCU is 50W/W while the cooling load capacity of the FCU used in conventional system is 60W/W. The annual hourly power of the FCU (Dry-FCU) is calculated based on the load ratio ϕ_i. In THICS, Q_{FCU} is equal to the load taken by high temperature chiller, while which of CAS includes the building latent load and building sensible load.

$$\phi_i=\frac{Q_{FCU}}{Q_{set}} \quad (12)$$

Assuming that the rated power of the FCU in medial rank is N_{FCU}, then the hourly power of the FCU can be obtained by Eq. (13).

$$N_i=\phi_i\times N_{FCU} \quad (13)$$

RESULT ANALYSIS AND DISCUSSION

Building load

The cooling load of two office buildings in Beijing and Shanghai are shown in Fig. 6 and Fig. 7. The total cooling energy in cooling reasons of the office building in Beijing and Guangzhou are 66.51 kWh/m^2 and 147.93 kWh/m^2 respectively.

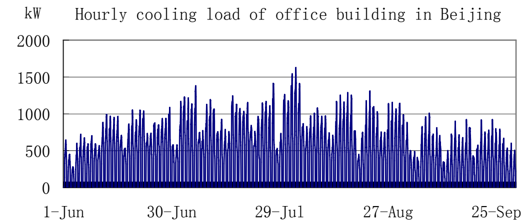


Figure 6 Hourly cooling load of office building in cooling season in Beijing

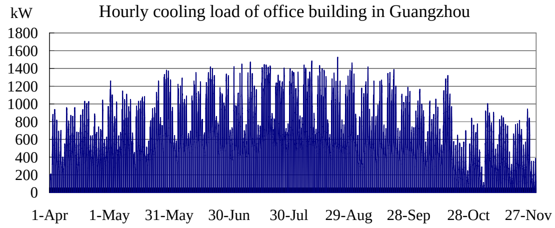


Figure 7 Hourly cooling load of office building in cooling season in Guangzhou

System parameters

The system parameters in Beijing and Guangzhou are shown in Table. 2 and Table. 3 respectively, seen in Appendix.

Energy consumption and co-efficiency

With the building load calculated in DeST and the system model, the energy consumption data of THICS and CAS in Beijing and Guangzhou office buildings are shown in Fig. 8.1~8.4. At the same time, the COP of key equipments, shown in Fig. 9.1~9.6, and the Energy Efficiency Ratio (EER) of the two systems shown in Table 4 and Table 5 are calculated. And, the data depicts the average COP of liquid desiccant outdoor air handling processor and high temperature chiller are 6.04 and 7.77 which are both higher than the average COP of conventional chiller that is 5.49 in Beijing office building. Similarly, in the Guangzhou office building, the average COP of LD and high temperature chiller are 5.81 and 6.95, which are both higher than the average COP of conventional chiller which is 5.10.

Following, the energy consumption is computed based on per building area. In Beijing office building, the electrical consumption of the THICS is 14.75kWh/m^2 p.a. and EER is 4.5, the electrical consumption of the CAS is 18.63kWh/m^2 p.a. and EER is 3.6. 20.83% energy has been saved by THICS. For the COP of cooling resource of THICS is 26.22% higher than that of CAS, and the energy consumption of cooling resource takes up more than 60% of the total energy consumption, the cooling resource saves 3.18 kWh/m^2, which contributes to the biggest part in the total energy saved. In addition, transportation system holds 25% of total energy consumption and THICS saves about 20% energy in this part, which result in transportation system saving 0.97 kWh/m^2 of the total energy saved. The leaving part of terminal devices in THICS consumes 0.26kWh/m^2 more than that of CAS.

To make the comparison more forceful, some other parameters should be included:

1) Influence of different climates

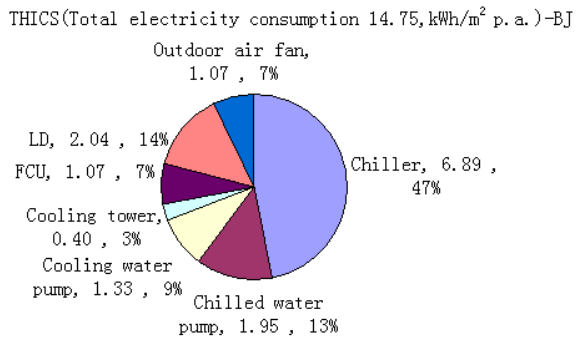


Figure 8.1 Energy consumption of THICS in Beijing

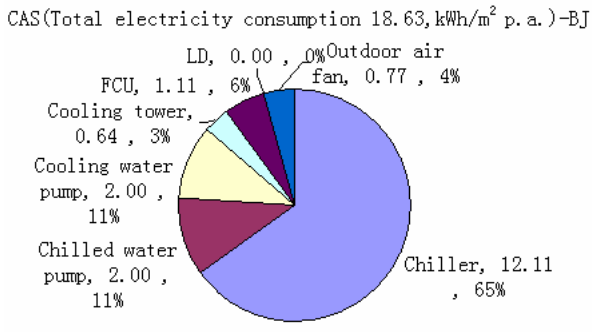


Figure 8.2 Energy consumption of CAS in Beijing

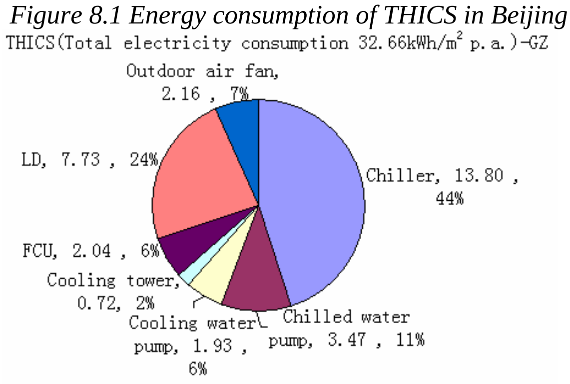


Figure 8.3 Energy consumption of THICS in Guangzhou

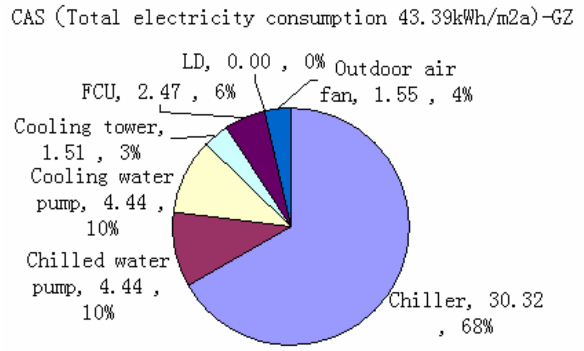


Figure 8.4 Energy consumption of CAS in Guangzhou

$$EER = \frac{TCE}{TEC} \tag{14}$$

Table 4 Performance comparison of THICS and CAS in Beijing office building

Item	CAS	THICS	Saving Ratio
TCE(kWh/m^{2}a)	66.51	66.51	
TEC(kWh/m^{2}a)	18.63	14.75	
EER	3.57	4.51	20.83%

Table 5 Performance comparison of THICS and CAS in Guangzhou office building

	CAS	THICS	Saving Ratio
TCE((kWh/m^{2}a)	147.93	147.93	
TEC(kWh/m^{2}a)	43.39	32.66	
EER	3.41	4.53	24.74%

In Guangzhou office building, the result is similar. The electrical consumption of the THICS is 32.66kWh/m^2 p.a. and EER is 4.5, the electrical consumption of the CAS is 43.39kWh/m^2 p.a. and EER is 3.4. Thus the energy efficiency of THICS is higher than that of CAS and THICS can save 20%~30% energy consumption compared with the CAS. While in the energy-saved, cooling resource accounts for the biggest part of the energy-saved.

2) Influence of different building types

3) More detailed chiller model

CONCLUSION

A system model to calculate the THICS and CAS energy consumption has been developed. A typical office building with outdoor air system and FCU has been used to analyze the energy performance of THICS and CAS in Beijing and Guangzhou, two cities in China. The data shows that the energy efficiency of THICS is higher than that of CAS and THICS can save 20%~30% energy consumption compared with the CAS. While in the energy-saved, cooling resource contributes to the biggest part of the total energy-saved.

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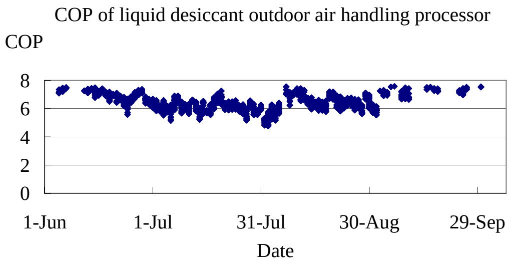

Figure 9.1 Hourly COP of THICS liquid desiccant outdoor air handling processor-BJ

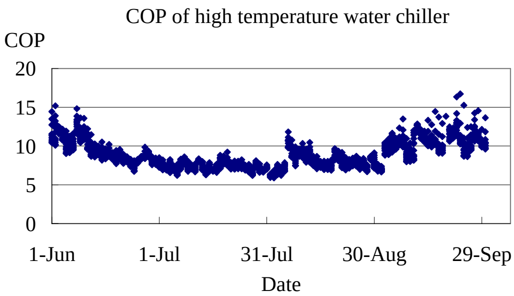

Figure 9.2 Hourly COP of THICS high temperature water chiller-BJ

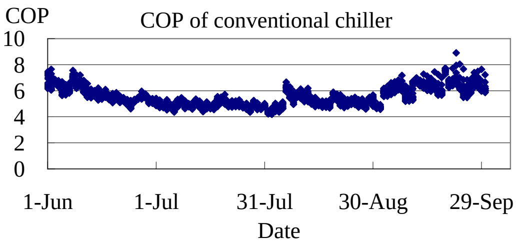

Figure9.3 Hourly COP of CAS conventional chiller-BJ

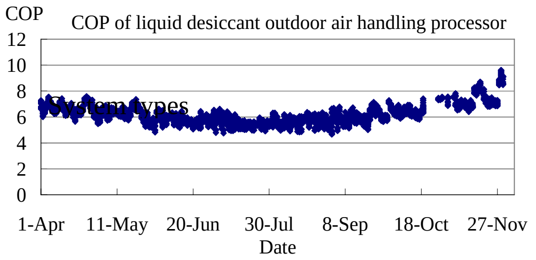

Figure 9.4 Hourly COP of THICS liquid desiccant outdoor air handling processor-GZ

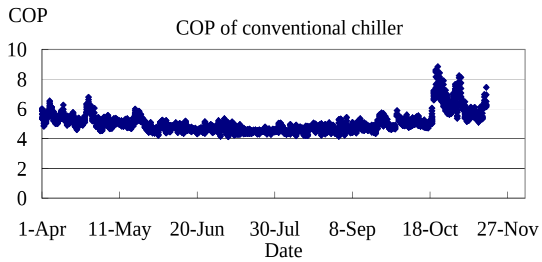

Figure 9.5 Hourly COP of THICS high temperature water chiller-GZ

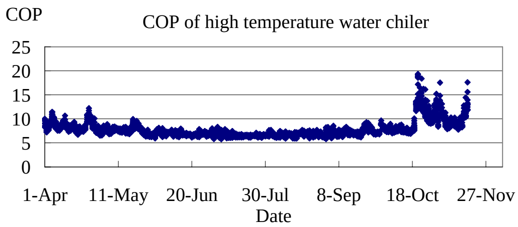

Figure 9.6Hourly COP of CAS conventional chiller-GZ

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APPENDIX

Table 2 Beijing office building system parameters

Parameters \ System Types		THICS	CAS
Beijing office Building	Capacity of Chiller (kW)	427	507
	Number of Chillers	3	3
	Power of cooling tower (kW)	2.25	3.5
	Number of cooling towers	3	3
	Power of chilled water pump (kW)	11	11
	Number of chilled water pump	3	3
	Power of cooling water pump (kW)	7.5	11
	Number of cooling water pump	3	3
	Power of FCU (kW)	23.64	23.32
	Power of outdoor air fan (kW)	28	26.4

Table 3 Guangzhou office building system parameters

Parameters \ System Types		THICS	CAS
Guangzhou office Building	Capacity of Chiller (kW)	287	496
	Number of Chillers	3	3
	Power of cooling tower (kW)	2.25	3.5
	Number of cooling towers	3	3
	Power of chilled water pump (kW)	11	11
	Number of chilled water pump	3	3
	Power of cooling water pump (kW)	7.5	11
	Number of cooling water pump	3	3
	Power of FCU (kW)	23.64	23.32
	Power of outdoor air fan (kW)	28	26.4