# Experimental Investigation on the Performance of Ground-source Heat Pump with the Refrigerant R410A

Junhao Niu
*School of Energy and Power Engineering.Xi'an Jiaotong University.P.R. China*, 824805525@qq.com

Huagen Wu
*School of Energy and Power Engineering.Xi'an Jiaotong University.P.R. China*, hgwu@mail.xjtu.edu.cn

Yunda Dong
*Waterfurnace Shenglong HVACR Climate Solutions Co., Ltd*, niujunhow@foxmail.com

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Junhao NIU[1]*, Huagen WU[1], Yunda DONG[2]

[1] Xi'an Jiaotong University, School of Energy and Power Engineering,
Xi'an, Shaanxi, P.R. China
Email: ic@mail.xjtu.edu.cn

[2] Waterfurnace Shenglong HVACR Climate Solutions Co., Ltd,
Yinzhou District, Ninbo, P.R. China
Company phone: 400-0574-026. Fax: 0086-574-88393212

* Corresponding Author

## ABSTRACT

Nowadays, in some small and medium-sized heat pumps, refrigerant R410A has been used widely because of the good thermodynamic performance and environmental protection. Firstly the principles of the system and the characteristics of refrigerant has been demonstrates. The paper has set up a heat pump system with the refrigerant R410A and the performance parameters under different working conditions were tested and analyzed. The results showed that when the condensation temperature increased from 30℃ to 60℃, the cooling capacity decreased by 33%, the input power increased by 97.8%, and COP decreased by 66%. As the evaporation temperature increased from 0℃ to 12.5℃, the refrigerating capacity increased by 55% and the input power increased by 20%. Drop in chilled water and cooling water flow rate are both harmful to the refrigeration capacity. Chilled water flow rate must be controlled higher than 35% of the rated flow rate. The inlet temperature of cooling water drops can improve the cooling capacity. When the cooling water inlet temperature increased from 18℃ to 30℃, the unit COP decreased by 40.8%. Chilled water inlet temperature rise can improve the evaporation pressure of the system, and hereby improve the cooling capacity and COP. When the chilled water inlet temperature increased from 10℃ to 25℃, COP improved by 63%.

## 1. INTRODUCTION

Based on the gradual attention to environmental issues, the research of R22 substitutes has been carried out, such as R410A, R407C, and so on. As a mixed refrigerant, R410A is recognized as one of the R22 alternatives. Not only the performance of thermal performance is good, do not destroy the ozone layer, and the operation is safe and reliable. The higher working pressure is also one of the characteristics of R410A, so the development of the refrigerant has also brought about the improvement of the heat pump system components.

The first popularity of R410A country is Japan around the world. It has a very good performance in the small and large air conditioning market, in a variety of ways to reduce the condensing temperature so that the R410A can be more efficient. Heat pump system is mainly used in residential and public facilities. Although the acceptance of R410A is late in Europe and the United States, it has made some considerable research. Copeland company in terms of R410A flexible digital scroll compressor research and manufacturing technology is leading, has already been mature market in the United States. In some countries of Europe and the United States universities and research institutions launched a theoretical and applied research, making basic research and product development of ground source heat pump (GSHP) go hand in hand, and to develop the corresponding industry standards.

Compared with foreign countries, because of national conditions and market reasons, acceptance rate improved in recent years in China about R410A. Because R410A has high working pressure, if the general application, system and its components need to be redesigned. If the compressor is equipped with domestic R410A system, four valve, selection of thermal expansion valve and other components was no more than R22, high work pressure also led to selection of tube material has some problems. At the same time, system the use of R410A is protected by patent restrictions in the process of production and sales, the cost is higher than that of R22 system. To some extent, these problems hinder the development of R410A heat pump system. However, Chinese in 2030 to stop the production and use of all R22, so to find a suitable replacement is irresistible that trend. These problems will get further overcome.

Gradually in recent years in the market penetration of R410A scroll chiller under different conditions of rated operation are mainly researched in the paper. For small and medium heat pump unit of experimental research, R410A scroll type heat pump unit test rig is built. Test method and measuring instrument is introduced. The units were tested under different conditions, and the data were recorded and processed in detail. The change trends of the unit's cooling capacity, input power, COP and other parameters were summarized, and the reasons for the emergence of some kind of trend were analyzed.

## 2. TEST RIG

In this paper, we build a test rig for testing data. It uses the improved design of the ground source / water source heat pump unit, main application features are:

1) In view of the ground source / water source conditions of the design; the use of ground source soil, such as the storage of geothermal resources as a heat source;
2) Relative to the air conditioning, the installation is simple, comfortable to use;
3) Units built in pumps, expansion tanks and other water fittings, the whole installation is simple;
4) Internal water system pipeline using PP-R material, to ensure that the user's water quality.

Its design performance indicators are shown in the following table:

**Table 1 :** Unit design performance index

| | |
|---|---|
| Refrigerating capacity/kW | 28.5 |
| Refrigerating power /kW | 6.28 |
| EER | 4.53 |
| Heating capacity /kW | 30.9 |
| Heating power/kW | 9.0 |
| COP | 3.43 |
| ACOP | ≥3.8 |

Test rig is overall layout and filling refrigerant R410A, unit is equipped with two compressors, two independent systems in common use on both sides of the heat exchanger. It is single stage compression refrigeration, variable conditions experimental study using the prototype. The system is divided into for refrigerant loop, the loop of cooling water and chilled water loop. Heating condition and cooling condition can conversion through the four-way reversing valve. The general arrangement of the experimental rig is shown in Fig. 1 and in a photograph in Fig. 2.

**Fig. 1** Photograph of the test rig

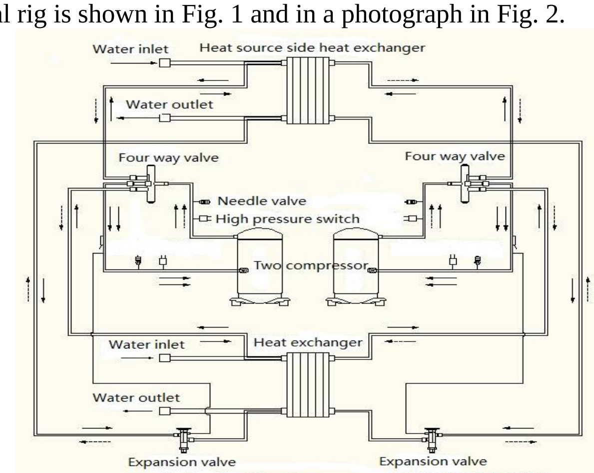



**Fig. 2** Schematic of the test rig

Firstly, R410A heat pump unit shall be the reliability experiment after the completion of the assembly. It is mainly divided into the circuit reliability and reliability test of the system test, the circuit control and the system's maximum, minimum heating / cooling system test, ensure the stable operation of the prototype and the reliability of the data.
The experiment was conducted based on the requirement of the Chinese National Standard involving GB/T 19409-2013.

1) Upon completion of the reliability experiment, at nominal operating conditions were tested unit from water loop type and ground loop type to groundwater loop type. Cooling conditions to ensure that the use-side water temperature 7 ℃, heating condition using side water temperature is 45 ℃.
2) To change the use-side water temperature, under the specified water temperature in the different forms of heat source, the unit was measured under maximum cooling / heating conditions and the minimum cooling / heating conditions. Under maximum cooling condition, use-side water temperature is 15 ℃, and when minimum cooling condition, use-side water temperature is 5 ℃. The use-side water temperature is 50 ℃ under maximum heating condition, the use-side water temperature is 40 ℃ under minimum heating condition.
3) Change the a certain conditions, other conditions according to the nominal working condition of flow and temperature conditions tested and test results collected, plotted as not less than four measuring values of a chart.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

### 3.1 Effect of Condensation Temperature Change on Performance

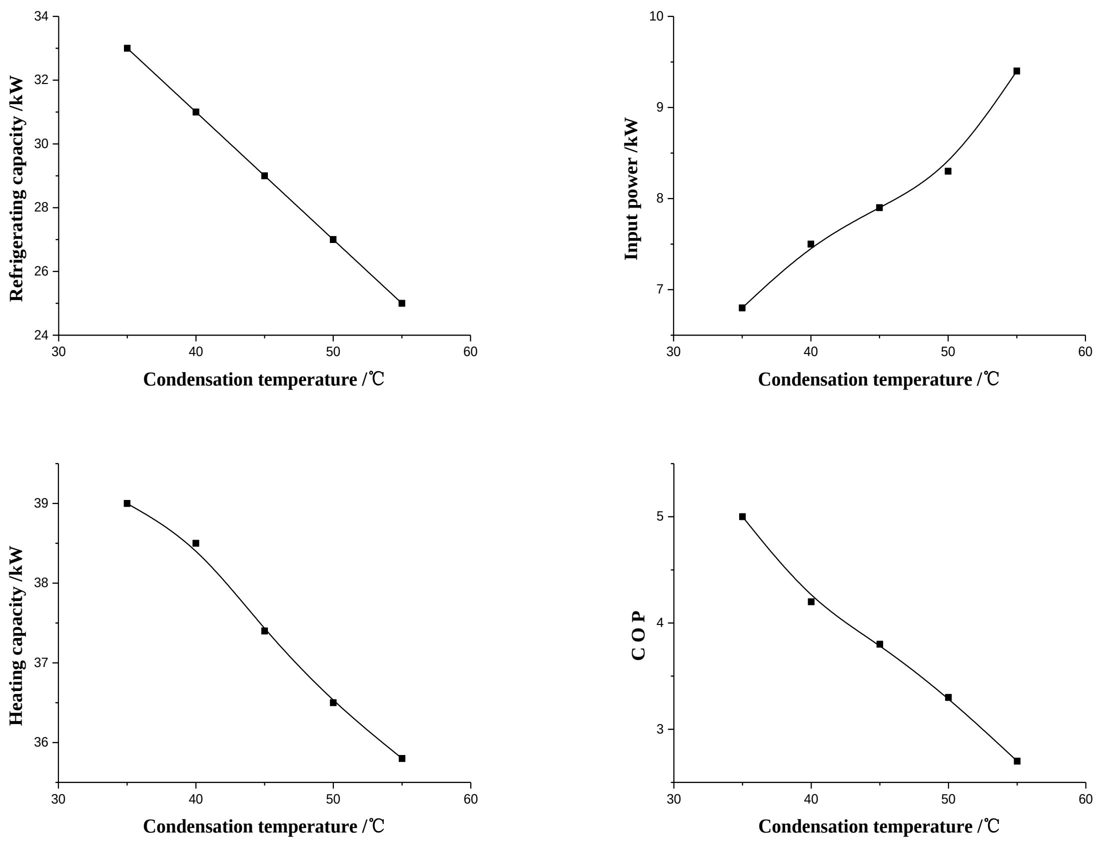



**Fig.3** Condensing temperature at various refrigerating capacity, input power, heating capacity and COP

By the process control variables, variable condition on the unit study, evaporation temperature is kept constant running. At different condensing temperature, refrigerating capacity, heating capacity, the input power and COP are measured. During the experiment, keep the evaporation side evaporation temperature of 5 ℃, condensing temperature changes from 30 ℃ to 60 ℃. Figure 3 is a line graph that refrigerating capacity, input power, heating capacity and COP varies with the condensing temperature.
As can be seen from Figure 3, when the system evaporation temperature stabilized at about 5 ℃, with the increase of the condensing temperature, the downward trend cooling capacity of the system appears. With the increase in the condensing temperature corresponding to the refrigerant condensing pressure will increase, so that the pressure ratio increases. By calculation, the condensation temperature will lead to a decline enhance volumetric efficiency, mass flow rate decrease, thereby reducing the capacity of the system. From the figure, when the condensing temperature rises from 30 ℃ to 60 ℃, the cooling capacity decreased by about 12kW, a decline of 33%.
The higher the condensing temperature, the compressor will need to spend more energy to the working fluid is compressed to a higher pressure, and therefore not only cause excessive condensing pressure heat exchange system is reduced, but also more expensive electricity, in actual operation, We should take into account the actual situation of the terminal, the condensing pressure stable within the range of both cost and energy efficiency. When the condensate temperature rises from 30 ℃ to 60 ℃, the input power is increased by about 5.5kW, rise 97.8%.
Similar trend of heat release and cooling capacity trends, are due to reduced mass flow decreased heat transfer from the figure can be seen in the condensation side heat transfer value is above the evaporation side heat exchange. Due to lower input power and cooling capacity to rise, resulting in decreased energy efficiency, energy efficiency within the test range decreased from 6.58 to 2.23, a decrease of 66%.

### 3.2 Effect of Evaporation Temperature Change on Performance

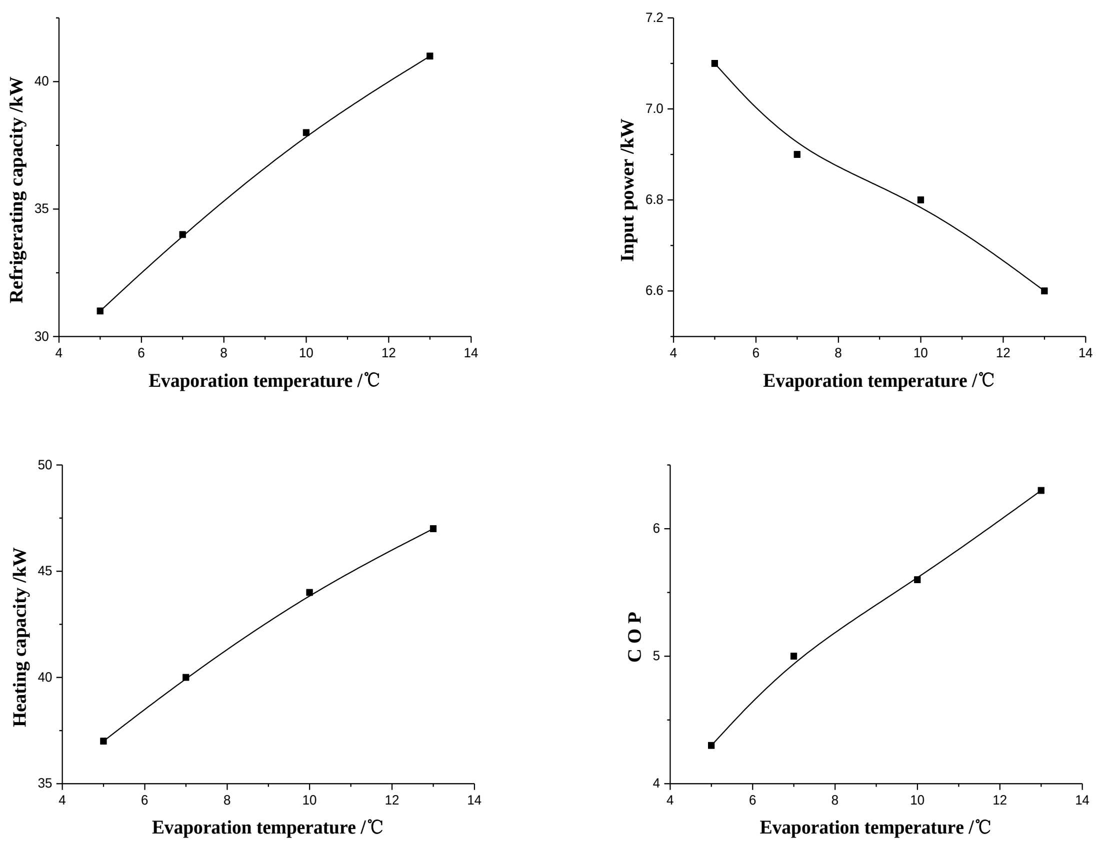



**Fig.4** Evaporation temperature at various refrigerating capacity, input power, heating capacity and COP

Holding unit high side condensing temperature at 40 ℃, it controls evaporation side temperature range 0 ℃ ~ 12.5 ℃. According to the experimental data plotted in Fig. 4, it is a line graph that refrigerating capacity, input power, heating capacity and COP varies with the evaporation temperature.

Figure 4 shows that with the evaporation temperature, the cooling capacity of the unit significantly increased, in line with the general rule. When the evaporation temperature and the evaporation pressure increase, will make the suction volume ratio is reduced, reducing the compressor pressure ratio, exhaust temperature is reduced, increasing cooling capacity per unit mass. Evaporation temperature rise will cause the compressor mass flow rate increases, so the system cooling capacity increase. The evaporation temperature from 0 ℃ to rise to 12.5 ℃, the cooling capacity increase of 15kW, an increase of 55%

Similar trends heating capacity and cooling capacity, heat from the refrigerant in the evaporator side of the absorbent increases, it cause the release of heat required to increase the condenser, heat capacity increases. Within the same range, the heating capacity increased by 43.2%, its growth rate is less than the cooling capacity of growth due to the input power is reduced.

With the evaporation temperature rises, the input power decreased from 7.08kW to 6.66kW, decreased by 5.9%. And the condensing temperature on the comparison of the input power can be seen, the impact of changing the evaporation temperature of the input power is much smaller, a greater impact on the cooling capacity.

As the mass flow rate increases, energy efficiency increased by 65%. When the system is in low vapor pressure of the situation will deteriorate unit performance. But we can’t arbitrarily increase the evaporation pressure, according to user needs and the need for heat transfer temperature difference constraints increase the evaporation pressure in the system within a reasonable range.

When the unit is running, because the system short of refrigerant and the evaporation area is too small and other reasons, it will cause a decline in the evaporation temperature. When the unit pressure ratio increases, the volumetric efficiency of the compressor is reduced. The results show that the evaporation temperature of the unit should be controlled at 2 ℃ above the unit to achieve design standards.

### 3.3 Effect of Cooling Water Inlet Temperature on the Cooling Performance

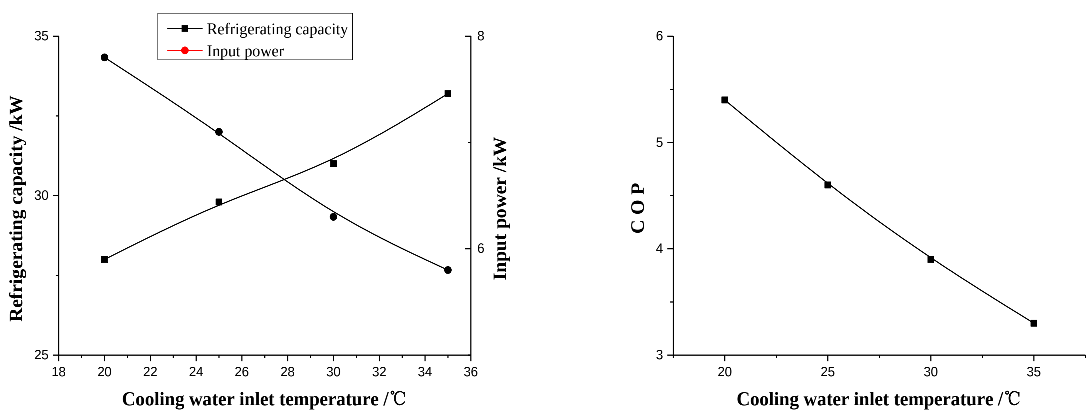



**Fig.5** Cooling water inlet temperature at various refrigerating capacity, input power, and COP

In cooling conditions, the evaporation pressure unchanged, condenser cooling water inlet temperature changes can cause condensation temperature changes, thus changing the compressor pressure ratio, respectively, will impact on the cooling capacity and compressor power consumption. Evaporator chilled water inlet temperature is 12 ℃. Chilled water flow rate is 6.4 $m^3 \cdot h^{-1}$. The condenser side cooling water flow rate is 5.1 $m^3 \cdot h^{-1}$. Condensation side inlet temperature adjustment range is 18 ℃ to 35 ℃. Figure 5 is a line graph that refrigerating capacity, input power, and COP in the operating conditions.

Analysis Figure 5 shows that, during the cooling conditions, changing the condenser cooling water inlet temperature on system performance is affected, the cooling water inlet temperature from rose 18 ℃ to 30 ℃, the system cooling capacity fell by nearly 4kW, while the compressor input power rose nearly 2kW, led to a 40.8% decline in COP. Changing the condenser side water temperature, compressor suction temperature and pressure are not affected, but leads to increased exhaust gas pressure and the exhaust gas temperature when the water temperature in the range of

18 ℃ to 25 ℃, the rise of discharge exhaust temperature and pressure is not obvious. As the water temperature continues to increase, the rate of change of temperature and pressure of the exhaust gas to accelerate, it will result in reduced gas transmission coefficient of the compressor, the compressor mass flow impact. Imports increased water temperature facilitating an increased condensing temperature and pressure of the high pressure side of the system, therefore the compressor takes more power.

Cooling water inlet temperature rise can cause condensing unit condensing pressure and temperature rise, causing the compressor pressure ratio increases. At higher condensing pressure, the liquid will be such that enthalpy of R410A decreases, the condensing pressure results in a decrease of the enthalpy outlet of the condenser, the cooling capacity per unit mass immediately affected.

When the condensation temperature rises, the compressor power consumption increases. At the same time due to the decline of the compressor volumetric efficiency, and therefore decrease the amount of gas. Condensing temperature rise will lead to mass flow is reduced, thus reducing the COP always.

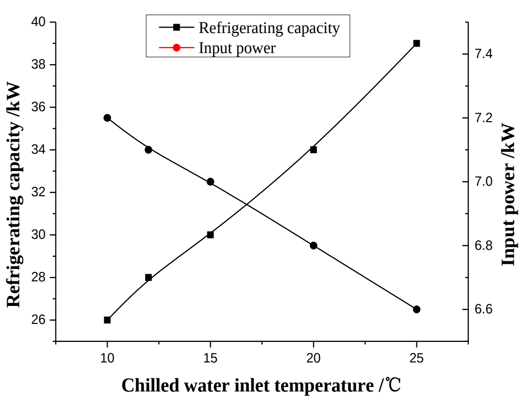
When the flow rate constant, the lower the cooling water inlet temperature, the stronger the cooling capacity. Its import value also depends on the type of heat source, ground source heat pump water generally at about 25 ℃, water source heat pump imports at about 30 ℃, inlet temperature groundwater heat pump can be as low as 18 ℃. The results show that, under conditions of water rated flow, cooling water inlet temperature is higher than 30 ℃, the cooling capacity of the unit will be less than the design value.

### 3.4 Effect of Chilled Water Inlet Temperature on the Cooling Performance

In the heating conditions, water temperature and flow of the condensation side unchanged. The evaporation side chilled water inlet temperature changes can cause changes in evaporation pressure, thereby changing the pressure ratio of the compressor, it will also affect the cooling capacity and compressor power consumption. Test conditions condenser side cooling water inlet temperature is 40 ℃, the cooling water flow rate is 5.2 $m^3 \cdot h^{-1}$; evaporator side chilled water flow rate is 6.4 $m^3 \cdot h^{-1}$, the evaporation side inlet temperature adjustment range from 10 ℃ to 25 ℃. Figure 6 is a line graph that refrigerating capacity, input power, and COP in the operating conditions.

Changes seen in Figure 6, the evaporation side chilled water inlet temperature change on system performance is influential. When chilled water inlet temperature changes from 10 ℃ to 25 ℃, cooling capacity increased by 10 kW, while the compressor input power dropped nearly 2kW, so that COP has improved in the range.

With the rise in chilled water inlet temperature, energy efficiency has increased significantly. Improve water temperature side evaporator pressure and temperature lead to lifting the suction side of the compressor, and with the increase of water temperature rises faster; changing the chilled water inlet temperature of the high-pressure side of the impact is not obvious. High pressure is maintained at about 2900kPa, the exhaust gas temperature is about 50 ℃. Reduce system pressure ratio, the compressor mass flow will increase. By the principle known to improve the evaporation temperature of the system it is advantageous, therefore reducing the compressor power consumption and improve efficiency. The results show that when the water temperature from 10 ℃ to 25 ℃, increase energy efficiency by 63%.



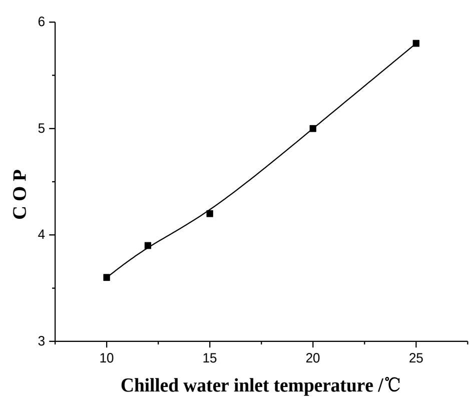




**Fig.6** Chilled water inlet temperature at various refrigerating capacity, input power, and COP

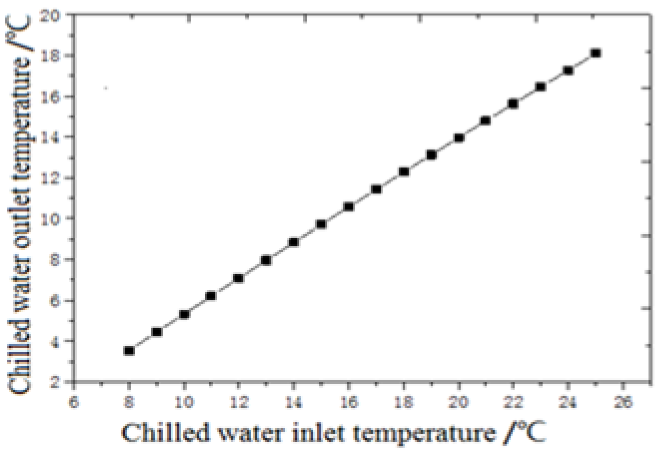



**Fig.7** Chilled water inlet temperature at various chilled water outlet temperature

In general, although an improvement in frozen water inlet temperature can bring some beneficial effect on the system, but the actual project in the user-side water temperature requirements are different. Such as air conditioning in summer conditions, human comfort zone is 25 ℃, relative humidity of 60%. Taking into account the air-conditioning cooling and dehumidification, the general design of the water temperature at 5 ~ 7 ℃. Without adjusting the flow rate, although the increase in water temperature increases the cooling capacity and COP, the water temperature increases will make the user side to decreased cooling effect.

Figure 7 is rated conditions of water, chilled water flow remains constant, chilled water outlet temperature varies with the inlet temperature. High water temperature will not reach the indoor cooling and dehumidification effect. Therefore, when considering raising the chilled water inlet temperature to bring energy savings must be considered chilled water flow changes on the system.

## 4. CONCLUSIONS

Based on the analytical and experimental investigation reported in this paper, the conclusions are as follows.

- When the system evaporation temperature stabilized at about 5 ℃, with increasing condensation temperature, cooling capacity appeared the downward trend. From the figure, when the condensing temperature rises from 30 ℃ to 60 ℃, the cooling capacity decreased by about 12kW, a decline of 33%; the input power increased by about 5.5kW, rise 97.8%, while the energy efficiency ratio decreased from 6.58 to 2.23, a decrease of 66%.
- When the evaporation temperature and pressure increase, will make the suction volume ratio is reduced, reducing the compressor pressure ratio, exhaust temperature is reduced, increasing cooling capacity per unit mass. The evaporation temperature from 0 ℃ to rise to 12.5 ℃, the cooling capacity increase of 15kW, an increase of 55%. The results show that the evaporation temperature of the unit should be controlled at 2 ℃ above the unit to achieve design standards.
- When chilled water inlet temperature changes from 10 ℃ to 25 ℃, cooling capacity increased by 10 kW, while the compressor input power dropped nearly 2kW, so that COP has improved in this range. The results show that when the water temperature from 10 ℃ to 25 ℃, increase energy efficiency by 63%. High water temperature will not reach the indoor cooling and dehumidification effect. Therefore, when considering raising the chilled water inlet temperature to bring energy savings must be considered chilled water flow changes on the system.

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## ACKNOWLEDGEMENT

The authors acknowledge the support of this work from Waterfurnace Shenglong HVACR Climate Solutions Co., Ltd.