Study on Performance of Ground Source Heat Pump System Based on Active Chilled Beam

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Abstract. This paper takes the ground source heat pump unit of a research and development centre in Beijing as the research object. This collected the operation data in the cooling condition and the heating condition respectively. Based on the measured data, this paper calculated the coefficient of performances and the energy efficiency ratio of the unit. The results show that when the active chilled beam is used as the air-conditioning terminal device, the inlet temperature of the heat pump unit is greatly improved. The ground source heat pump unit meets the standard and has a higher energy efficiency ratio; The operation of a single unit is more efficient than that of multiple units at the same time.

1. Introduction
Chilled beam is a new type of green air-conditioning system with high comfort, low energy consumption, low noise and long equipment life. It is widely used in Europe and America due to its advantages of energy saving, environmental protection, comfort and health. Especially in the office buildings with high sensible heat load and comfort requirements, the active cold beam is gradually replacing the variable air volume system. Although the chilled beam technology has just started in China, its development is very rapid and has an excellent development prospect.

As a kind of energy-saving and environmentally-friendly cold and heat source, ground source heat pump can be well combined with chilled beam system and has better energy saving effect. The active chilled beam has high requirements on the water supply temperature, and it needs a cold and heat source to provide circulating water with stable temperature. Therefore, it is necessary to optimize the chilled beam and ground source heat pump composite system.

2. Project Overview
2.1. Project status
The project is a research and development center in Beijing. The research and development center has 4 floors above ground and 3 underground floors with a total construction area of 59,726 m². The above-ground construction area is 23989 m². The underground building area is 35737 m². And the building height is 18 m. The center applied a large number of environmentally-friendly materials and energy-saving construction technologies. The ground source heat pump is used as a heat source to extract heat/cool from the soil surrounding the green lawn, reducing construction consumption and operating costs.

The air conditioning terminal device includes chilled beam, floor convector and fresh air system (temperature and humidity independent control system). The chilled beam is only used for heat/cold load in the indoor office area, while the fresh air is used for indoor humidity conditioning.
2.2. Equipment

Table 1. Heat pump unit equipment parameter table.

| Serial number | Device name               | Cooling capacity | Heating capacity | Power  | Quantity |
|---------------|---------------------------|------------------|------------------|--------|----------|
| 1             | Ground source heat pump unit | 1242 kW          | 1349 kW          | 292 kW | 3        |

Table 2. Pump parameter table.

| Serial number | Device name               | Cooling capacity | Power | Head | Quantity |
|---------------|---------------------------|------------------|-------|------|----------|
| 1             | Ground source side pump   | 1450 m³/h        | 37 kW | 32 m | 3        |
| 2             | Water pump on user side   | 1450 m³/h        | 30 kW | 30 m | 3        |

3. Testing and evaluation program

3.1. Testing equipment and content

Table 3. Test Instruments and Content.

| Test instrument               | Test content                                    |
|-------------------------------|-------------------------------------------------|
| Ultrasonic Flowmeter          | Ground source side traffic; user side traffic   |
| Clamp Power Meter             | Heat pump unit power; pump power                 |
| Platinum Resistance Thermometer | User side inlet temperature; user side outlet temperature |

3.2. Testing process

1) Install Ultrasonic Flowmeter to test flow

Determine the flow measuring point (the position where the sensor is installed). Then remove the paint and lubricate at the flow measuring point pipe. Install and secure the slide rails. Install the sensor and connect it to the monitor. When the test conditions are become stable, the number of readings is taken every 10 minutes and the average value of each reading is taken continuously for 30 minutes as the measured value of the test.
3) Test power using a clamp-type Power Meter
Open the control panel of the heat pump unit and the water pump. Connect the jaws and connectors of the clamp Power Meter to the various connections of the internal circuit of the control panel. Wait for the indicator to stabilize and read the voltage and current indication.

5) Install a Platinum Resistance Thermometer to test the temperature.
Select the appropriate test point. Disassemble the insulation material and attach the temperature sensing end of the Platinum Resistance Thermometer to the wall of the pipe. Cover it with insulation material and fix it at the test point. Record readings every 10 minutes.

4. Test results and data analysis

4.1. Test results in the cooling condition
According to the standard numbered DB11T 1639-2019[2], the energy efficiency ratio (EER) of ground source heat pump unit should be calculated according to Formula (1).

\[
EER = \frac{Q_0}{N_i}
\]

In the Formula:
- \(Q_0\) — the cooling capacity (kW) of the heat pump unit;
- \(N_i\) — the input power (kW) of the heat pump unit.
Table 4. Calculation table for test results of No. 2 heat pump unit (two units running in summer).

| Serial number | Test content                        | Test result | Average value |
|---------------|-------------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 18.4 18.6 18.6 18.5 | 18.525 |
| 2             | Return water temperature on user side (°C) | 22.1 21.8 20.7 20.9 | 21.375 |
| 3             | Water flow on user side (m³/h)          | 186.7 189.1 188.3 184.1 | 187.05 |
| 4             | Cooling capacity (kJ)                  | 618.83      |               |
| 5             | Input power (kW)                       | 131.2 131.5 131.6 131.1 | 131.35 |
| 6             | EER                                  | 4.71        |               |

Table 5. Calculation table for test results of No. 3 heat pump unit (two units running in summer).

| Serial number | Test content                        | Test result | Average value |
|---------------|-------------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 18.4 18.7 17.9 18.5 | 18.375 |
| 2             | Return water temperature on user side (°C) | 21.3 21.8 21.4 20.9 | 21.35 |
| 3             | Water flow on user side (m³/h)          | 175.0 172.8 174.2 174.3 | 174.075 |
| 4             | Cooling capacity (kJ)                  | 601.16      |               |
| 5             | Input power (kW)                       | 125.1 125.8 126.4 126.3 | 125.9 |
| 6             | EER                                  | 4.77        |               |

Table 6. Calculation table for test results of heat pump unit (single unit running in summer).

| Serial number | Test content                        | Test result | Average value |
|---------------|-------------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 17.8 18.1 18.1 17.9 | 17.975 |
| 2             | Return water temperature on user side (°C) | 21.1 20.9 21.1 21.2 | 21.075 |
| 3             | Water flow on user side (m³/h)          | 188.25 189.71 187.97 190.01 | 188.985 |
| 4             | Cooling capacity (kJ)                  | 680.08      |               |
| 5             | Input power (kW)                       | 131.1 130.9 130.7 130.7 | 130.85 |
| 6             | EER                                  | 5.20        |               |

According to Table 4-6, the EER of the two heat pump units which operate at the same time is 4.71 and 4.77 respectively; the EER of the single heat pump unit is 5.20. They all meet the national standards (EER ≥ 3.4). The chilled water greatly increases the inlet water temperature of the heat pump unit, therefore the heat pump unit has a higher energy efficiency ratio.

Comparing Tables 4-5 and Table 6, in the summer working condition, the EER of a single unit is significantly higher than that of two units. This indicate that a single unit operating has a higher efficiency than that of a plurality of units.
4.2. Test results in the heating condition

According to the standard numbered DB11T 1639-2019[2], the heating coefficient of performance (COP) of the heat pump unit should be calculated as Formula (2).

\[
COP = \frac{Q_c}{N_i}
\]  

(2)

In the Formula: \(Q_c\) — the heat supply (kW) of the heat pump unit;

\(N_i\) — the average input power (kW) of the unit.

Table 7. Calculation table of test results for No. 2 heat pump unit (two units running in winner).

| Serial number | Test content                      | Test result | Average value |
|---------------|-----------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 37.7       | 37.7          |
| 2             | Return water temperature on user side (°C) | 33.7       | 33.7          |
| 3             | Water flow on user side (m³/h)      | 176.7      | 178.3         |
| 4             | Heating capacity (kJ)               | 822.10     |               |
| 5             | Input power (kW)                    | 142.8      | 142.1         |
| 6             | COP                                | 5.77       |               |

Table 8. Calculation table of test results for No. 3 heat pump unit (two units running in winner).

| Serial number | Test content                      | Test result | Average value |
|---------------|-----------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 38.5       | 38.6          |
| 2             | Return water temperature on user side (°C) | 33.7       | 35.7          |
| 3             | Water flow on user side (m³/h)      | 175.0      | 174.3         |
| 4             | Heating capacity (kJ)               | 681.99     |               |
| 5             | Input power (kW)                    | 144.1      | 144.3         |
| 6             | COP                                | 4.73       |               |

Table 9. Calculation table for test results of heat pump unit (single unit running in winner).

| Serial number | Test content                      | Test result | Average value |
|---------------|-----------------------------------|-------------|---------------|
| 1             | Water supply temperature on user side (°C) | 37.4       | 37.2          |
| 2             | Return water temperature on user side (°C) | 33.5       | 33.4          |
| 3             | Water flow on user side (m³/h)      | 188.25     | 187.97        |
| 4             | Heating capacity (kJ)               | 861.07     |               |
| 5             | Input power (kW)                    | 141.1      | 140.7         |
| 6             | COP                                | 6.11       |               |
According to Table 7-9, the heating coefficient of performance of the two units operating at the same time is 5.77 and 4.73; When the single unit is running, the EER of the heat pump unit is 6.11. The results meet the standard (≥3.0).

Comparing Tables 7-8 and Table 9, in the winter working conditions, the COP of a single unit is significantly higher than that of two units. This indicates that a single unit operating is more efficient than that of a plurality of units.

5. Conclusion

In this project, the cooling capacity, heating capacity, energy efficiency ratio and coefficient of performance are in accordance with the standards. Since the air conditioning terminal device is the active chilled beam, the water supply temperature is higher and the inlet temperature of the heat pump unit is greatly improved. The heat pump unit has a higher energy efficiency ratio.

The active chilled beam system requires high-temperature water supply system and low temperature water supply systems. The operation of a single unit is more efficient than simultaneous operation of multiple units, so high-temperature water can be obtained from low-temperature water through a heat exchanger.

References

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