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ORIGINAL RESEARCH ARTICLE

Performance analysis of ground source heat pump system under low load rate

Yangfang Dong[1,2], Zhaotian Zeng[2*], Hui Zhu[1], Yan Liu[1], Miaomeng Liang[2]

[1] *College of Energy Engineering and Building Environment, Guilin University of Aerospace Technology, Guilin 541005, China.*

[2] *College of Civil Engineering and Architecture, Guilin University of Technology, Guilin 541005, China. E-mail: zengzhaotian@163.com.*

ABSTRACT

Taking a demonstration project of a ground source heat pump system under karst geological conditions in Guilin as the research object, based on the measured data under operating conditions in a typical season, and sorted according to the importance of influencing factors, this paper mainly studies the influence of system at very low load rate and unit load rate on the operation effect of ground source heat pump system. The research results show that the ground source heat pump system is in good operating condition when the system load rate is lower than 30.00% and the unit load rate is higher than 80.00% in typical seasons, and the proportion of power consumption of units and pumps meets the energy consumption requirements of transmission and distribution system. During the operation of the heat pump unit in July, the average refrigeration performance coefficient of the unit is 4.48, and the average refrigeration energy efficiency ratio of the system is 3.59; during the operation in January, the average heating performance coefficient of the unit is 4.26, and the average heating energy efficiency ratio of the system is 3.32; the energy saving rate in summer and winter is 30.72% and 35.93%, respectively. The energy-saving effect of the ground source heat pump system is remarkable, and it is worth popularizing and applying in Guilin.

Keywords: Ground Source Heat Pump System; System Load Rate; Unit Performance Coefficient; System Energy Efficiency Ratio; Energy Saving rate

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1. Introduction

With the development of green buildings and zero energy consumption buildings and the implementation of energy conservation and emission reduction policies, building energy conservation has become an issue to be considered in the whole life cycle of building planning, design, construction, delivery, operation and so on. The energy consumption of air conditioning system accounts for 30% to 70% of the building energy consumption. Therefore, solving the energy consumption of air conditioning system to a large extent solves the problem of building energy conservation. Ground source heat pump technology takes advantage of the fact that the soil temperature in summer is lower than the outdoor air temperature, and the soil temperature in winter is higher than the outdoor air temperature. As a natural renewable cold and heat source, it has the advantages of high efficiency and energy saving, clean and environmental protection, and low operating cost[1], which can well solve the energy problem of the air conditioning system.

Guilin is an area hot in summer and cold in winter with abundant rainfall, which is mostly concentrated in spring and summer. It is also a typical carbonate karst area with rich groundwater resources[2], which lays a foundation for the development and application of shallow geothermal energy. The ground source heat pump air conditioning system has been widely used in practical engineering projects. Guilin has also actively responded to the call for energy conservation and emission reduction policies and has built a certain scale of ground source heat pump air conditioning hot water application projects, such as the ground source heat pump system of the entrepreneurial mansion office building, the ground source heat pump system of Huayu residence community, the ground source heat pump system of public buildings of Guilin Grand Theater, Guilin Museum, Guangxi Guilin Library, and auxiliary facilities cultural square, etc. Most of the actual ground source heat pump projects in Guilin are basically under extremely low load or test conditions 2 ~ 3a before the system operation, while there are few studies on the actual operation performance, cost-effectiveness ratio, and investment payback period of the ground source heat pump system in karst areas. Most of them are based on the impact of different operation modes of the experimental platform[3,4], groundwater seepage[5], different underground pipe partitions[6], and unbalanced cooling and heating load rates[7] on the heat transfer performance of the underground pipe. Li *et al*.[8] and Wang *et al*.[9] studied the operation performance analysis of ground source heat pump and solar composite system under the energy utilization optimization strategy. Yan, Hu, Li, *et al*.[10], and Yan, Hu, Peng, *et al*.[11] studied the energy efficiency evaluation of 39 ground source heat pump demonstration projects in Wuhan and compared and analyzed the performance prediction of ground source heat pump systems based on actual monitoring geothermal data using a variety of data mining methods, Huang and Liu[12] applied random forest model to analyze the factors affecting the operation performance of geothermal system. These research results do not meet the geothermal application of Guilin because of the geological conditions or system load rate operation conditions unable to meet the use requirements in the literature. Therefore, this paper studies the actual power consumption, operating energy efficiency ratio, energy saving rate, etc. under low load rate conditions in karst areas from the measured operation data of ground source heat pump system, providing empirical data reference for subsequent geothermal application projects.

2. Project overview

The ground source heat pump project is located in the Guilin geothermal application demonstration project which is hot in summer and cold in winter, with a total construction area of 105,965 m^2, including 9,500 m^2 of the Grand Theater, 32,475 m^2 of the library, and 34,195 m^2 of the museum. The designed total cooling load of the system is 9,980.3 kW, the total heating load is 6,197.6 kW, and the domestic hot water load is 300.0 kW. The dry bulb temperature of the air conditioner in summer is 34.20 ℃, the wet bulb temperature is 27.30 ℃, and the dry bulb temperature of the air conditioner in winter is 1.10 ℃. The temperature of chilled water under refrigeration conditions in summer is 7.00/12.00 ℃, and the temperature of hot water under teating conditions in winter is 50.00/45.00 ℃. According to the “Technical code for ground-source heat pump system” GB 50366-2009[13], the design conditions in winter are selected to determine the number of buried pipe heat exchange wells. There is a total of 852 wells with a depth of 100 m, and the vertically buried pipes are made of double U-shaped PE pipes. The distance between the vertical shafts is 5 m, and the buried pipe groups are arranged in the outdoor green belt and under the road according to the function of the building.

Considering the air conditioning end load and simultaneous use coefficient, the parameters of air conditioning cold and heat source heat pump unit and water system equipment are shown in **Table 1**.

Table 1. Equipment parameters for air conditioning systems

Equipment name	Quantity/set	Parameter
Ground source heat pump unit	27	Refrigerating capacity 258.0 kW
		Heating capacity 299.0 kW
Ground source heat pump unit (waste heat recovery type)	10	Refrigerating capacity 258.0 kW
		Heating capacity 299.0 kW
Ground source side circulating pump	3 Sets (2 for use and 1 for standby)	Flow 620.00 m^3/h
		Lift 35.0 m
Circulating pump on user's side	5 Sets (4 for use and 1 for standby)	Flow 480.00 m^3/h
		Lift 32.0 m
Hot water circulating pump	2 Sets (1 for use and 1 for standby)	Flow 76.20 m^3/h
		Lift 12.8 m

Under the design conditions of the Guilin geothermal application project, in summer (June to September), the buried pipe heat exchange system is used as the main cold source of the air conditioning system, and 37 ground source heat pump units + cooling tower auxiliary air conditioning systems are operated to make domestic hot water from the recovered waste heat; in winter (January to March and December), the buried pipe heat exchange system is used as the heat source of the air conditioning system, and 20 ground source heat pump units are operated, of which 5 heat pump units are waste heat recovery type, and the recovered waste heat is used to produce domestic hot water; in the transitional season (April, May, October, and November), start five waste heat recovery ground source heat pump units, set them to the hot water priority mode, and use the recovered waste heat to produce domestic hot water.

3. Operation performance analysis method

After the completion of the construction of the ground source heat pump system project, because the library and museum have not been settled in the building, only some offices, conference rooms, and theatres (non-scheduled) have been used for a long time, so the ground source heat pump project has been operating under extremely low load rate for the first 2 ~ 3a. This paper will analyze the operating performance of the ground source heat pump system under a low load rate, and the calculation method of each parameter is:

Average refrigerating (heating) capacity during the test period:

$$W = qvc_p\rho\Delta t/3600 \tag{1}$$

Where: Δt is the average temperature difference between supply and return water at the user side of the heat pump unit, ℃; c_p is the specific constant pressure heat capacity of water supply and return, J/(kg·K); ρ is the density of water, kg/m^3; q_v is the average flow of supply and return water at the user side of the heat pump unit, m^3/s.

Load rate:

$$R = W/W_0 \tag{2}$$

Where: R is the load rate; W_0 is the refrigerating (heating) capacity under the design working condition, kW·h.

Refrigeration energy efficiency ratio of heat pump unit:

$$COP = W/\overline{W_i} \tag{3}$$

Where: the calculation formula of energy efficiency ratio of heat pump unit W is the average refrigerating (heating) capacity of the unit during the test period; $\overline{W_i}$ is the average power consumption of heat pump unit during the test period, kW·h.

Heat efficiency ratio of heat pump unit:

$$EER = W/\overline{W_i} \tag{4}$$

Accumulated refrigerating (heating) capacity during system test:

$$\sum W = \sum_{i=1}^{n} W_i \Delta t \tag{5}$$

Where: W_i is the refrigerating (heating) capacity of the heat pump system in the i^{th} period, kW·h.

Refrigerating (heating) capacity of the heat pump system in the i^{th} period:

$$W_i = \frac{q v_i \rho_i c_i \Delta t_i}{3\ 600} \tag{6}$$

Refrigeration energy efficiency ratio of heat pump system:

$$COP_{sys} = \frac{\sum W}{\sum W_i + \sum W_j} \tag{7}$$

Where: $\sum W_i$ and $\sum W_j$ are the cumulative power consumption of all heat pump units and pumps during the system test, kW·h.

Heat efficiency ratio of heat pump system:

$$EER_{sys} = \frac{\sum W}{\sum W_i + \sum W_j} \tag{8}$$

4. Analysis of operation results

Select July in summer and January in winter as typical seasons to analyze the operation performance. Under low load rate conditions, in order to meet the requirements of air conditioning system terminal and hot water supply, the system operation time is basically 8:30 ~ 16:30 on weekdays, and shutdown on weekends. In order to avoid the large fluctuation range of test data in the startup stage and facilitate the statistical analysis of measured data, the stable operation stage of ground source heat pump system is selected for data acquisition. The instantaneous temperature of water supply and return on the user side, the instantaneous temperature of water supply and return on the ground source side, the instantaneous flow, the daily cumulative power consumption of units and pumps, etc. At 4 ~ 7 hours in the working day operation period (generally 9:00, 11:00, 14:00 and 16:00, in special cases, 7 hours are collected if the daily operation time is long or the temperature fluctuation is large) are selected for data acquisition to analyze the operation effect of the ground source heat pump system.

4.1 Operating conditions in summer

Figure 1 shows the outdoor temperature, temperature and temperature difference of supply and return water at the user side. The outdoor temperature remained at 30.00 ℃ throughout the test period, and the maximum temperature amplitude from July 20 to 31 was 4.00 ℃. The water supply temperature on the user side is basically maintained at 8.50 ℃, the average return water temperature on the user side is 12.14 ℃, and the average temperature difference of the actual supply and return level on the user side is 3.40 ℃. The supply and return water temperature at the user side decreases with the increase of outdoor temperature, and the fluctuation range of the return water temperature at the user side is greater than that of the water supply temperature. Therefore, when the outdoor temperature rises, the ground source heat pump system adopts the return water temperature control strategy on the user side, which can correspondingly reduce the water supply temperature on the user side, so as to adjust the cooling capacity of the heat pump unit to adapt to the changes of the building cooling load of the air conditioning system. The ground source heat pump system adopts intermittent operation mode, and the return water temperature on the user side shows obvious periodic intermittent changes. The system adopts the return water temperature control on the user side, which causes the intermittent change of the water supply temperature on the user side to be weaker.

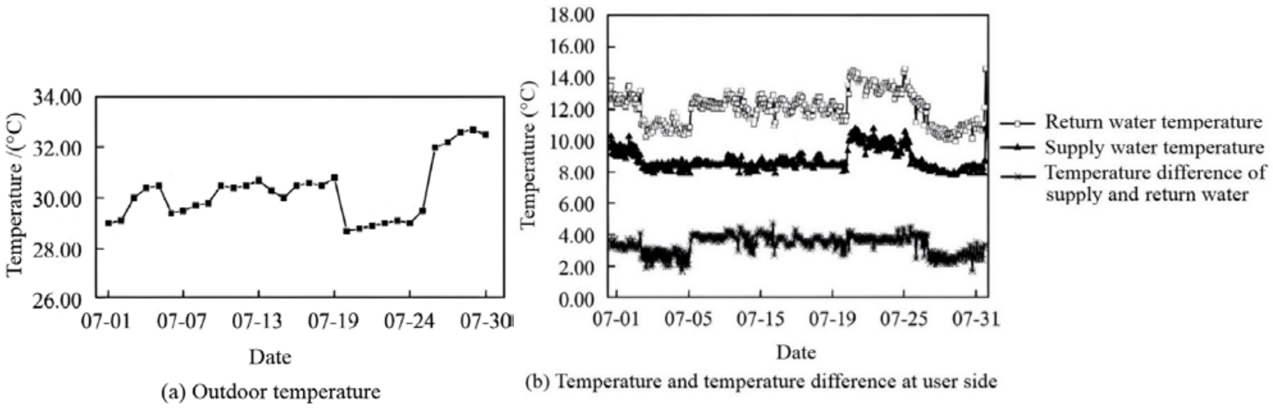

Figure 1. Summer outdoor mean temperature and temperature and temperature difference of supply and return water at user side.

Figure 2 shows the temperature and temperature difference between the supply and return water at the ground source side. The water supply temperature at the ground source side is between 31.00 and 36.00 ℃, the temperature of the return water is between 28.70 and 33.00 ℃, and the average temperature difference between supply and return levels is 3.16 ℃. The fluctuation range of outdoor temperature is small. Due to the heat storage of soil, the water supply and return temperature at the ground source side basically remains unchanged. When the outdoor temperature fluctuates greatly, such as the outdoor temperature rises to 32.00 ℃ from July 25 to 31, the building cooling load increases sharply, and the heat discharged into the soil also increases. The water supply and return temperature at the ground source side is a mirror image of the outdoor temperature. The water supply and return temperature at the ground source side shows a very obvious periodic intermittent change. During the system shutdown period, the soil temperature has a strong recovery ability, which can better alleviate the soil heat accumulation effect around the buried pipe, ensure the heat exchange capacity of the soil and the buried pipe heat exchange system, and meet the cooling capacity of the system. With the increase of operation time, the recovery ability of soil temperature decreases slightly, causing the supply and return water temperature at the source side to rise slowly.

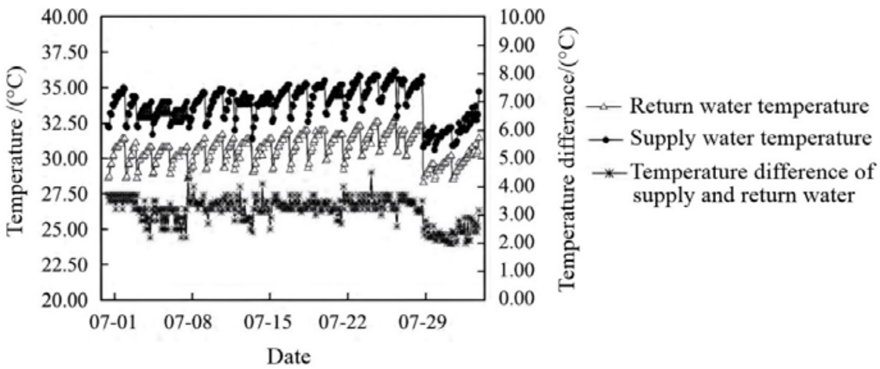

Figure 2. Temperature and temperature difference of supply and return water at source side in summer.

In areas hot in summer and cold in winter, the occupancy rate of buildings directly affects the system load rate. The operation strategy selected by the composite ground source heat pump system according to the system load rate directly affects the building energy consumption and building energy saving rate. **Figure 3** shows the load rate of the heat pump unit, system load rate, and total daily power consumption. During the whole refrigeration test of the ground source heat pump system, the system load rate is below 30.00%, but the unit load rate is 70.00% ~ 90.00%, and the total daily power consumption is between 2,800 and 5,000 kW·h. On July 16, the total daily power consumption increased due to the long operation time of the system and the increase of the system load rate on July 24.

According to the *Requirements of the Evaluation Standard for Renewable Energy Building Application Engineering*[14] and *The Guidelines for Energy Efficiency Evaluation of Renewable Energy Technology Application in Civil Buildings in Guangxi*[15], the load rate of the unit should reach more than 80.00% of the rated value, and the load rate of the system should reach more than 60.00% of the design value. The load rate of the heat pump unit meets the requirements of the evaluation guidelines. Zhu[16] studied that under the condition of extremely low occupancy (below 30.00%), the heat pump system adopts the best control strategy of single buried pipe operation, and the total energy consumption of the system is the lowest. Due to the low occupancy rate of the actual use of the building, the system load rate is below 30.00% in summer. Only the ground pipe heat pump system is operated, and the geothermal system is equipped with 37 heat pump units. 3 ~ 8 heat pump units are started and stopped according to the return water temperature at the user side, which can well meet the requirements of the unit load rate and reduce the daily power consumption of the system.

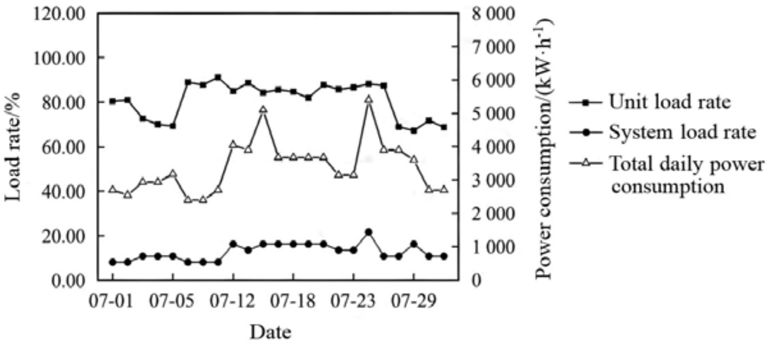

Figure 3. System load rate and heat pump unit load rate in summer.

Figure 4 shows the proportion of water pump and unit power consumption in the total daily power consumption. The daily power consumption of heat pump unit is 60.00% ~ 80.00%, basically maintained at about 65.00%, and the daily power consumption of water pump is 30.00% ~ 40.00%. According to the *Research Report on the Development of Ground Source Heat Pump in China*[17], the pump energy consumption of typical domestic ground source heat pump projects under summer conditions accounts for about 34.00% of the system energy consumption. Therefore, it can be seen that the actual energy consumption proportion of pumps in this project meets the design proportion of energy consumption of transmission and distribution system. The selection and quantity of heat pump units, circulating water pumps and hot water pumps of the ground source heat pump system are reasonable, which can choose optimal start and stop strategy of heat pump units and pumps according to the cooling capacity demand of the system, so as to improve the energy efficiency ratio of geothermal system operation under low load rate conditions.

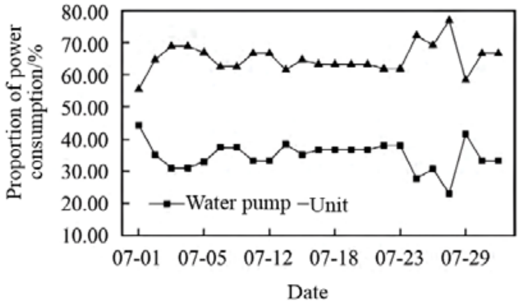

Figure 4. Power consumption ratio of water pump and unit in summer.

4.2 Operating conditions in winter

As shown in **Figure 5**, the temperature and temperature difference of water supply and return at the user's side in winter. The outdoor temperature remained at 8.00 ~ 10.00 ℃ throughout the test period, and only on January 25, the temperature suddenly fell to 5.00 ℃. The water supply temperature on the user side is 42.00 ~ 44.90 ℃, and the return water temperature is 40.00 ~ 42.50 ℃.

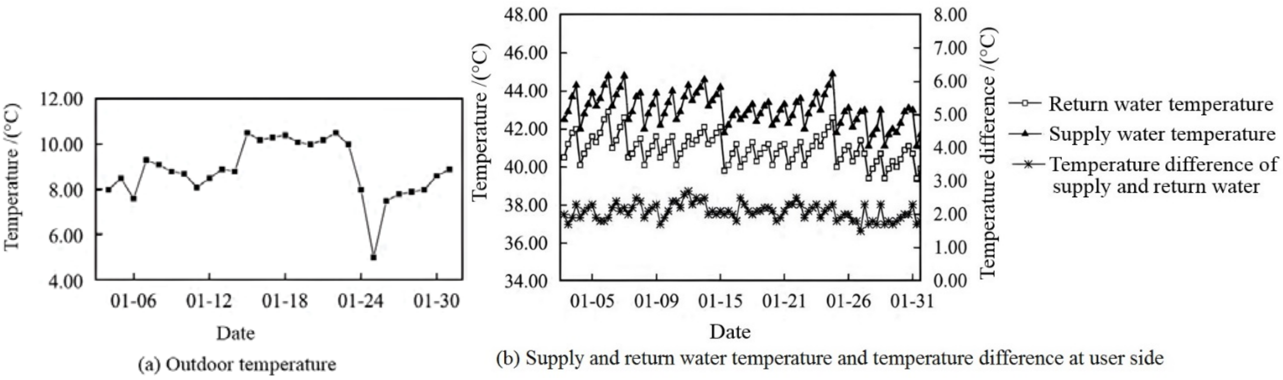

Figure 5. Outdoor temperature in winter and temperature and temperature difference of supply and return water at the user side.

The average temperature difference is 2.00 ℃. The supply and return water temperature on the user's side fluctuates in the opposite direction with the change in the outdoor average temperature. For example, the outdoor temperature drops sharply on January 24 and 25. If the return water temperature on the user's side is lower than the set value range, increasing the number of heat pump units and water pumps, adjusting the water volume of circulating water pumps by frequency conversion, and maintaining the supply and return water temperature difference at 2.00 ℃, to increase the supply and return temperature to meet the heating demand of the system. During intermittent operation under a low load rate in winter, the supply and return water temperature on the user side show obvious periodic intermittent changes.

Figure 6 shows the supply and return water temperature at the ground source side in winter. The supply water temperature at the ground source side is 14.20 ~ 16.00 ℃, the return water temperature at the ground source side is 16.50 ~ 18.00 ℃, the supply and return water temperature difference at the ground source side is 1.70 ~ 2.50 ℃, and the average supply and return water temperature difference is 2.08 ℃. Due to the small change in outdoor temperature, the building heating capacity is relatively stable. Only on January 24 and 25, the outdoor temperature plummet, the building load increased sharply, the heat absorption of buried pipe heat exchanger increased, and the water supply temperature at the ground source side increased. The ground source heat pump system operates intermittently in winter, and the supply and return water temperature at the ground source side shows periodic intermittent changes and a slow downward trend. This is mainly because the soil temperature quickly recovers to the initial value during the system shutdown, maintaining the heat exchange capacity between the soil and the buried pipe heat exchange system. With the increase of operation time, the heat absorption gradually increases, the soil around the buried pipe forms a cold accumulation, and the heat exchange capacity of the buried pipe system decreases.

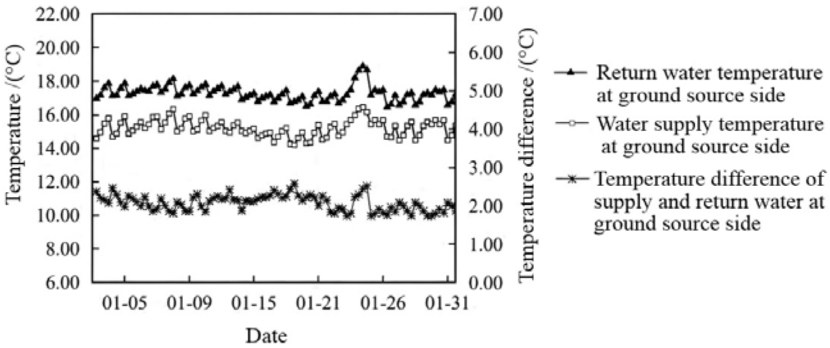

Figure 6. Temperature and temperature difference of supply and return water at source side in winter.

Figure 7 shows the unit load rate, system load rate, and total daily power consumption. When the system load rate is less than 30.00% and the unit load rate is maintained at 70.00% ~ 80.00%, the total daily power consumption in January is 2,100 ~ 5,300 kW·h. Compared with the total power consumption in July in summer, the total power consumption in winter increased by 20,670 kW·h. January was at the end of the year when the increased summary meeting and energy consumption of hot water supply cause the average total energy consumption in January to increase compared with July. **Figures 5** and **6** show that the fluctuation of outdoor temperature and supply and return water temperature difference in January is relatively small, but the range of daily total power consumption in January fluctuates significantly, which is mainly due to the increase of daily total power consumption caused by the increased performances in the grand theater, and summary meetings, the number of unit water pumps to start, the increase of system operation time and other reasons at the beginning of January, which is in line with the actual energy application.

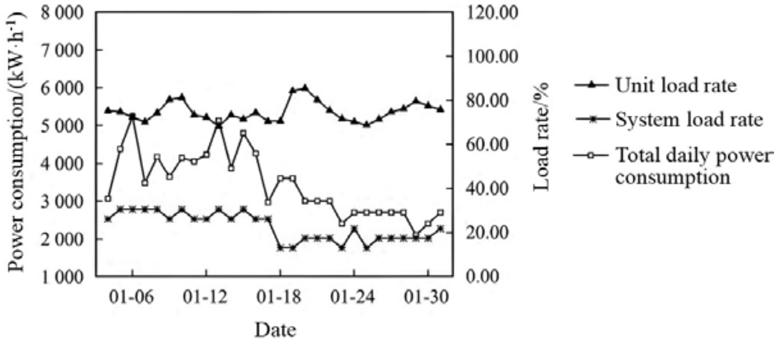

Figure 7. System load rate, heat pump unit load rate and total daily power consumption in summer.

Figure 8 shows that the power consumption of heat pump units and water pump heat pump units accounted for 55.00% ~ 75.00% and 25.00% ~ 44.00%, respectively, in January under low load operation conditions, both of which show little fluctuation. *The research report on the development of ground source heat pump in China* points out that the energy consumption of water pumps tested in the winter of domestic typical ground source heat pump system projects accounts for about 28.00% of the system energy consumption. Therefore, it can be seen that the actual proportion of water pump energy consumption under low load operating conditions meets the standard of typical demonstration projects of ground source heat pump system in Guangxi, but it is slightly higher than the requirements of the Research Report on the development of ground source heat pump. There may also be errors in the measurement of electricity due to the magnification of electric meters, leading to an error in the proportion of power consumption between the water pump and the unit.

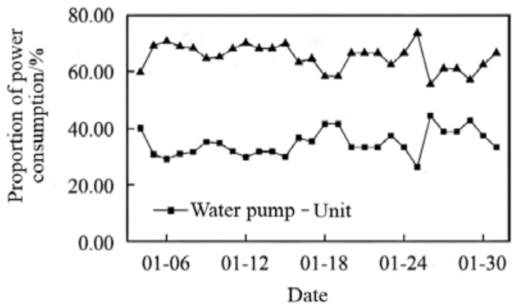

Figure 8. Power consumption ratio of water pump and unit in winter.

5. Analysis of system operation performance and energy saving rate

5.1 System operation performance analysis

It can be seen from the work of Huang and Liu[12] that with the gradual increase of the unit load rate R, the cooling performance coefficient COP of the unit increases. The random forest algorithm is used to sort the factors affecting the performance coefficient of the unit according to the importance of the mean square error Δ_{MSE} value, as shown in **Table 2**. The unit load rate R ranks first in importance, followed by the return water temperature on the ground source side under cooling conditions or the return water temperature on the user side under heating conditions, and the outdoor temperature and humidity ranks last. According to Yan *et al*.[11], with the increase of unit and system load rate, COP_{sys} increases. When the long-term system load rate is less than 30.00% based on the back-propagation network algorithm, and R > 60.00% only accounts for 30.00%, COP_{sys} and EER_{sys} are both less than 2.30. From the analysis of the influencing factors of the geothermal system, it can be seen that other influencing factors except the system load rate comply with the technical specifications of the ground source heat pump project, and only the system load rate is far from the requirements of the energy efficiency evaluation guidelines. The following will mainly study the impact of the system load rate and unit load rate on the system operation performance.

The *COP* of the local source heat pump system is 4.00 ~ 5.00, the average *COP* is 4.48, the COP_{sys} is 3.40 ~ 4.00, and the average COP_{sys} is 3.59, as shown in **Figure 9**. According to the actual *COP*, COP_{sys} and the *evaluation standard for application of renewable energy in buildings*, the ground source heat pump project can still be at level 2 energy efficiency under the conditions of system load rate <30.00% and unit load rate >80.00%. The changes of *COP* and COP_{sys} are less affected by the system load rate R_{sys}, and increase with the increase of unit load rate R.

As shown in **Figure 10**, in winter, when the system load rate is <30.00% and the unit load rate is about 70.00%, the unit heating performance coefficient *EER* is 3.78 ~ 4.70, the average *EER* is 4.26, the system heating energy efficiency ratio EER_{sys} is 3.07 ~ 3.70, the average EER_{sys} is 3.31, and the operation energy efficiency level is level 2. *EER* and EER_{sys} are less affected by the system load rate, which decreases with the decrease of unit load rate and increases with the increase of unit load rate. Therefore, when the load rate of the system in the early operation of the actual geothermal project is less than 30.00% for several years, the design scheme of the ground source heat pump system is set up so that the buried pipe heat exchange system can operate in different areas. The number of heat pump units equipped can select the appropriate number of operating units according to the actual building load, so that the load rate of the units can be maintained at around 80.00%, and the control strategy of heat pump units and water pump groups can be optimized to make the supply and return water temperature at the ground source side, the supply and return water temperature at the user side and the temperature difference, meet the requirements of engineering technical specifications and improve the system operation energy efficiency ratio of ground source heat pump system.

5.2 comparative analysis of unit and system performance

In order to better analyze the operation performance of the ground source heat pump system under low load rate, the unit performance coefficient and system performance coefficient tested by the geothermal research platform system of Guangxi Key Laboratory of energy conservation in Guilin in the work of Zeng *et al*.[4] and Zeng, Zhao, Lv, *et al*.[18] are compared with this project, as shown in **Figure 11**. Under the same climatic environment and karst geological conditions, the *COP* (4.48) of the project operating under low load rate conditions in summer is 4.28% higher than that of the geothermal experimental platform under normal operating conditions (4.30), and the *EER* (4.26) in winter is 18.99% higher than that of the geothermal experimental platform (3.58). In order to better study the feasibility, operating energy efficiency and energy saving rate of ground source heat pump system in karst areas, the average unit performance coefficient of 33 ground source heat pump demonstration projects in Wuhan where is hot in summer and cold in conducted by Yan *et al*.[10] is compared with this project, as shown in **Figure 11**. The *COP* (4.48) of the project in summer is 18.84% lower than the average value (5.52) of geothermal demonstration projects in Wuhan, and the *EER* of the two regions in winter is basically the same. Because the design of the buried pipe heat exchange system, the control mode of the air conditioning system, the operation management and maintenance of the experimental platform are quite different from the actual engineering projects, this paper will no longer compare with the experimental test data.

Table 2. Ranking of influence factors of heat pump unit

Influence factor	Refrigeration condition		Heating condition		Comprehensive ranking
	ΔMSE	Importance ranking	ΔMSE	Importance ranking	
Unit load rate	60.54	1	75.64	1	1
Return water temperature at ground source side	45.14	2	37.60	3	2
Return water temperature at user side	41.63	4	54.07	2	3
Water supply temperature at ground source side	44.65	3	24.79	5	4
Water supply temperature at user side	21.05	6	26.75	4	5
Outdoor temperature	31.30	5	16.64	6	6
Outdoor humidity	27.52	7	11.56	7	7

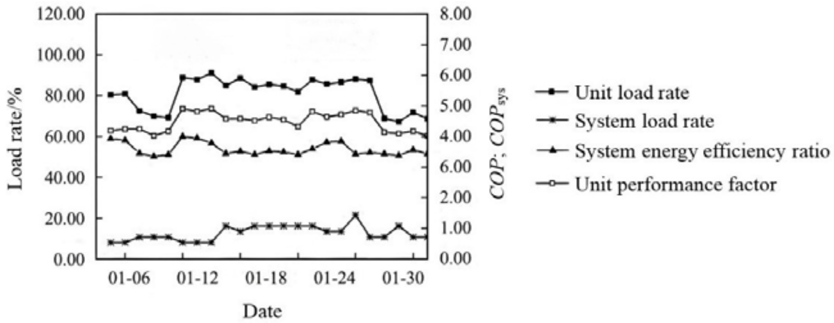

Figure 9. Load rate and performance coefficient of heat pump unit and load rate and energy efficiency ratio of system in summer.

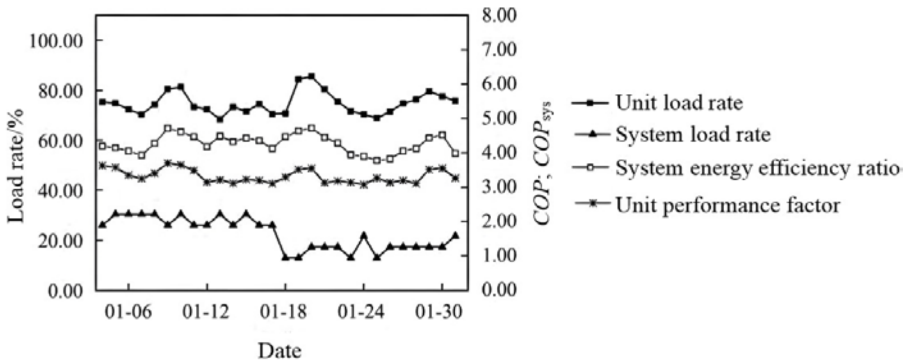

Figure 10. Load rate and performance coefficient of heat pump unit and system in winter.

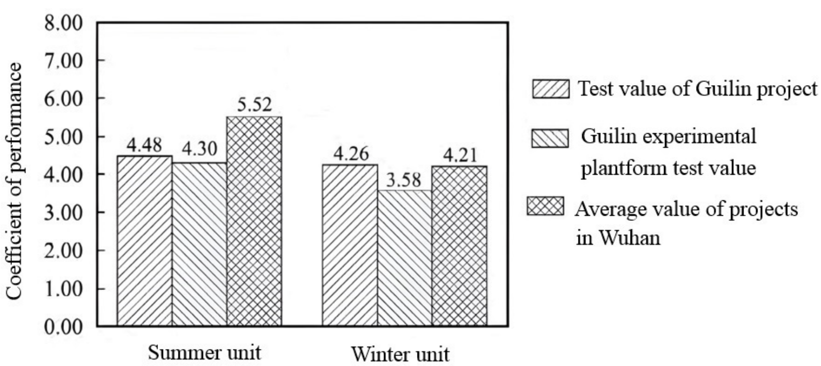

Figure 11. Comparison of unit performance coefficient.

The system energy efficiency ratio (COP_{sys}) of the project under low load rate operation in summer is 3.59, which is 8.79% higher than that of Wuhan COP_{sys} 3.30, and the system energy efficiency ratio (EER_{sys}) in winter is equal to the average EER_{sys} of Wuhan, as shown in **Figure 12**. It can be seen that the project can achieve high system energy efficiency ratio under the working condition of system load rate <30.00%, is due to the reasonable design of buried pipe heat exchange system, system equipment selection and quantity allocation, unit pump group control strategy and operation management. The karst area is particularly rich in groundwater resources, and the groundwater level is low, which can well enhance the heat exchange capacity of buried pipes and play an important role in improving the energy efficiency ratio of system operation.

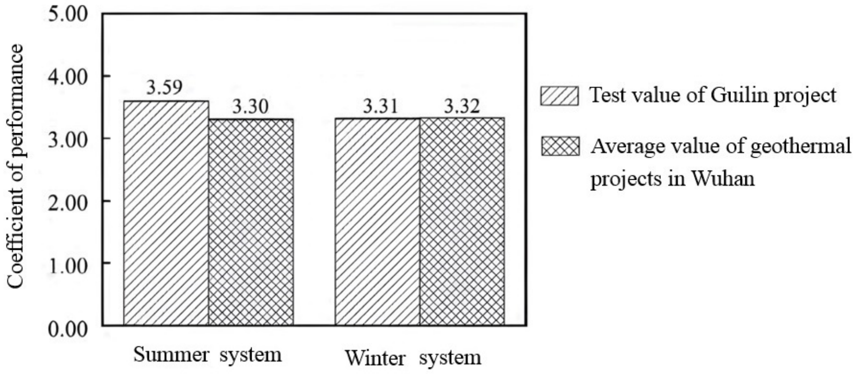

Figure 12. Comparison of system performance coefficient.

6. Conclusion

Based on the measured data of Guilin ground source heat pump demonstration project under karst geological conditions, this paper analyzes the operating parameters and effects of ground source heat pump system from the order of importance of factors affecting the operating performance of ground source heat pump system and heat pump unit, and draws conclusions.

In summer, the average water supply temperature on the user side is 8.50 ℃, the average return water temperature is 12.14 ℃, the average water supply temperature on the ground source side is 34.70 ℃, and the average return water temperature is 31.44 ℃. In winter, the average water supply temperature on the user side is 43.10 ℃, the average return water temperature is 40.99 ℃, the average water supply temperature on the ground source side is 15.14 ℃ the average return water temperature is 17.22 ℃, and the whole ground source heat pump system is in good operation.

(1) When the system load rate is <30.00% and the unit load rate is >70.00% under typical seasonal conditions, due to the reasonable system design, the total daily power consumption is less affected by the system load rate, and decreases with the increase of the unit load rate. The power consumption of the unit in summer accounts for 60.00% ~ 80.00%, the power consumption of the water pump accounts for 30.00% ~ 40.00%, the power consumption of the unit in winter accounts for 55.00% ~ 75.00%, and the power consumption of the water pump accounts for 25.00% ~ 44.00%. The proportion of power consumption of pumps and units is in line with the provisions of the *Research report* on the *Development* of *ground source heat pump in China*.

(2) The average *COP* in summer is 4.48, the average COP_{sys} is 3.59, and the average *EER* in winter is 4.26, and the average EER_{sys} is 3.31, belonging to level 2 energy efficiency. If the buried pipe heat exchange system can be operated in different areas, the selection and quantity of heat pump units and water pump equipment can be selected according to the actual building load, and the optimal pump start and stop strategy of heat pump units can be adopted to ensure that the unit load rate reaches 80.00%, the unit performance coefficient can reach more than 4.00, and the system operation energy efficiency ratio can reach more than 3.30.

(3) The *COP* of the ground source heat pump system of the project in summer is 4.28% higher than that of the experimental platform in Guilin, and the *EER* in winter is 18.99% higher; *COP* in summer is lower than that of geothermal projects in Wuhan, and *EER* in winter is basically the same; the average COP_{sys} in summer is 8.79% higher than that in Wuhan, and the average EER_{sys} in winter is

the same. The energy-saving rate of the ground source heat pump system of the project is 30.72% in summer and 35.93% in winter, which is only 9.54% lower than that of the geothermal project in Wuhan in summer and 4.14% lower than that in winter. Although the system load rate is lower than 30.00%, the energy-saving rate in typical seasons is not much different, and it still maintains a high energy-saving rate compared with the conventional air-conditioning system.

It can be seen from the conclusion that when the ground source heat pump system is under partial load condition under karst geological conditions in Guilin, the high-efficiency and energy-saving characteristics of the ground source heat pump system can still be achieved by operating part of the buried pipe heat exchange system and implementing the linkage group control strategy of the heat pump unit and the water pump to ensure that the load rate of the heat pump unit is about 80.00%. When the system load rate reaches more than 60.00%, the energy-saving effect of the system will be more significant, which is conducive to the promotion and application of ground source heat pump system in Guilin.

Conflict of interest

The authors declare that they have no conflict of interest.

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