ANALYSIS AND SIMULATION OF ECOLOGICAL ENVIRONMENT RESPONSE OF GROUND SOURCE HEAT PUMP SYSTEM UNDER THERMAL EQUILIBRIUM

by

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Original scientific paper
https://doi.org/10.2298/TSCI2402355H

This work is designed to study the thermodynamic equations of groundwater source heat pump in hot summer and cold winter, and to determine the optimal operating conditions of groundwater source heat pump by means of the thermodynamic analysis of source heat pump, flow, unit, pump power, evaporation side and condensation side. Practice has proved that the equipment runs stably and with high efficiency. By comparison, the ground source heat exchangers were compared with conventional chillers and boiler. The results showed that the underground heat pump had higher energy consumption, lower primary energy consumption, reduced CO_2 *emissions, and reduced environmental pollution during operation, proving that the underground heat pump had obvious advantages over the conventional cooling and heating system. Meanwhile, this also shows that the long-term operation of ground heating system has caused the instability of ground heating system, the accumulation of cold and heat in ground-water, and the variation of ground temperature, which not only reduces the system efficiency, but it also affects the physical properties of soil itself and the soil heat flow, and will also cause changes in soil microbial environment and vegetation ecological environment, thus affecting the whole ecological environment.*

Key words*: ground source heat pump system, thermal equilibrium, ecological environment, response analysis*

Introduction

In recent years, the ground heating equipment has developed rapidly in the global heating and cooling industry, using the shallow ground heating as the coolant and heat source for heating, air conditioning, and domestic hot water. It has become one of the most promising technologies of heating and cooling technology recognized worldwide. Figure 1 shows the combined energy supply system of soil source heat pumps [1]. Its energy-saving, environmentally friendly, land saving, and comprehensive utilization of renewable energy make it a powerful competitive way for traditional heating and air conditioning. Ground source heat pumps use underground soil as a place for heat absorption (heat source) and heat removal (heat sink).

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In summer, waste heat is removed from the ground and stored for winter use. In winter, heat is absorbed in the ground and stored in rooms for summer use. Therefore, in particular, ground pumps are underground power storage and reuse systems that use ground-water as a central power source (unless the groundwater seepage is strong, it can timely take away the cold and heat accumulated near the buried pipe), rather than a pure geothermal energy utilization technology, this is a common misconception in the industry regarding the understanding of ground source heat pumps [2, 3]. In order to ensure the long-term and efficient operation of the soil source heat pump system, it is necessary to ensure the balance between the annual heat supply and the annual heat supply of the soil, so that it can recover itself within a one-year cycle. However, with the gradual deepening of its research and application, the scope of application continues to expand, it shows the influence of the imbalance of underground energy load in areas with large annual gap between cooling and heating load demand, that is, underground thermal equilibrium. We all know that in the whole house, the air conditioner produces a lot of energy consumption, while in public buildings, HVAC has about 50-60% of the annual energy consumption [4]. Ground pumps are heat and cooling systems that use rock, groundwater, or surface water as low heat sources, and use geothermal energy for geothermal exchange. It is combined with the geothermal exchange process inside the building to produce heat and cooling. According to the types of power transformer, ground pump can be divided into three types: ground pump, ground pump, and ground pump,which is either horizontally installed in a trench or vertically installed in a *U*-shaped tube in a vertical shaft. The heat exchangers in different trenches or shafts are connected in parallel, and then enter the building through different headers to connect with the water loop inside the building. When the liquid temperature is low, it is necessary to add antifreeze or increase the liquid-flow rate in the system to prevent the liquid from freezing. Compared with conventional air conditioning, ground source heat pump technology with soil heat exchange device has more demonstration projects all over the country because of its advantages of high efficiency and environmental protection. The ground source heat pump has a 40% to 60% higher operating efficiency than traditional air conditioning systems, making it the most promising air conditioning system for development. Through engineering example, quantitative analysis has been made on the quality of geothermal heat pump compared to air-conditioning system in energy consumption, energy consumption, CO_2, SO_2 emissions, *etc*. [5, 6].

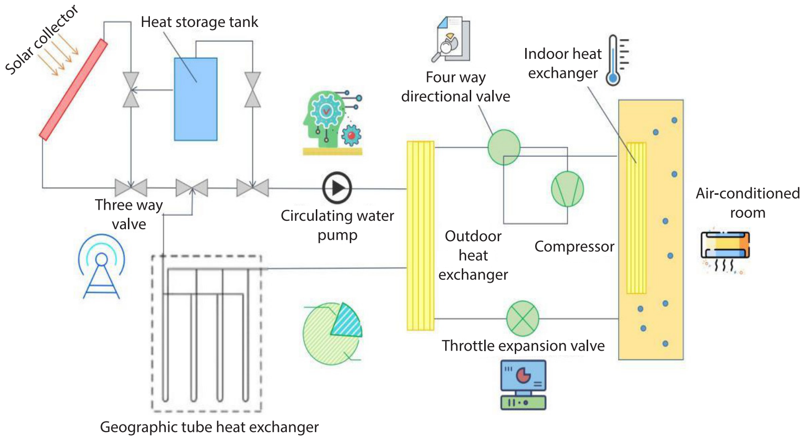

Figure 1. Ground source heat pump combined energy supply system

Methods

Project overview

The building is located on the first underground floor and five above ground floors in City A, with a height of 17.70 m. The underground floor is mainly used for equipment rooms, and the first to fifth floors are mainly used for accommodation, cafeteria, learning, and living rooms. It is a practical and functional demonstration building [7]. Its main technical and economic indicators are the land area is 13837.8 m^2. The total construction area is 11609 m^2. The energy-saving demonstration area is 11609 m^2. Based on the investigation of the geological conditions of the project site, the feasibility and economy of the underground-water source heat pump air conditioning system are analyzed. Considering that the only suitable source of sand and sandstone, the ground electrical equipment of heat exchanger in this project adopts vertical double *U*-shaped buried pipes with pipe diameter of DN32, depth of 100 m, diameter of 130 mm, hole spacing of 6 m, and horizontal connecting pipe spacing of 2.5 m from the ground. The pipes and fittings of this project are made of polyethylene, and their quality meets the various provisions of the current national standards. The nominal pressure and service temperature of the pipe meet the design requirements, with a nominal pressure greater than 1.0 MPa. The two ends of the buried pipe-line loop are, respectively connected to the supply and return water loop headers, and are arranged in the same direction.

System settings

The form of HVAC system is: pure airdual duct fan coil system. This project takes groundwater source heat pump as research object and studies the application of groundwater source heat pump in the building. Ground pipe ground source heat pump is divided into three groups, including two groups spiral air cooling heat pump and one layer spiral water heat pump. Table 1 test equipment and performance indicators of ground pump [8].

Table 1. Heat pump unit parameters

Serial number	1	2	3
Device name	Screw type ground source heat pump unit	Screw type ground source heat pump unit	Screw type ground source heat pump hot water unit
Model	30HXC130 A-HP1	30HXY050 A-HP1	30HXC130 A-HM
Parameter	Refrigeration capacity: 451 kW Power consumption: 90 kW Heating capacity: 486 kW Power consumption: 116 kW	Refrigeration capacity: 168 kW Power consumption: 35 kW Heating capacity:189 kW power consumption: 44 kW	Heating capacity: 479 kW Power consumption: 125 kW
Number	1	1	1
Refrigeration under rated operating conditions COP$_L$	4.99	4.30	–
Heating under rated operating conditions COP$_H$	4.19	4.8	3.83
Refrigeration IPLV	5.72	–	–

Air conditioning heat pump unit 30HXC130A-HP1: cooling capacity 451 kW (chilled water temperature 12.79 °C, cooling water temperature 30.35 °C), cooling power 90 kW, COP = 4.99, cooling IPLV = 5.72. Heating capacity 486 kW, heating power 116 kW, COP = 4.19. Heat pump unit 30HXY050A-HP1: cooling capacity 168 kW (chilled water temperature 12.79 °C, cooling water temperature 30.35 °C), cooling power 35 kW, COP = 4.30, heating power 189 kW, COP = 4.8. Hot water heat pump unit 30HXC130A-HM: heat 479 kW, power consumption 125 kW, heating power 125 kW, COP = 3.8. The circulating pump at the load end has a head design of 25 m, a total operation of 0.70 m, a cooling water temperature of 7 °C, a loop circulating temperature difference of 5 °C, and a supply and return water temperature of 45/40 °C for cooling water temperature. The circulating pump for its underground heat exchange device has a design head of 32 m, a performance of 0.70 °C, and a heat loop deviation of 59 °C. Its operating mode is speed regulation.

On site testing analysis

On site analysis

After the completion and operation of the ground pump, test personnel conducted two tests from August 29 to September 10, 2013 and December 23 to 24, 2013, respectively. The main parameters of this experiment are: the indoor and outdoor temperature, relative humidity, the input power and cooling capacity of ground source heat pump, ground source heat pump, and ground source heat pump*, etc.* Choose representative dates such as August 30 in summer and December 23 in winter for further analysis. During winter heating, the average inlet temperature of side condenser is 41. °C, the average outlet temperature is 44.3 °C, the average inlet temperature difference between inlet and outlet water is 3.2 °C, the average inlet temperature of side water is 17.39 °C, the average outlet temperature is 14.3 °C, and the average temperature is 3 °C. According to the temperature difference between winter and summer on shore, it can be determined that under the same conditions, the heat transfer capacity of buried pipe-lines in summer is better than that in winter.

Analysis of economic and energy-saving benefits

Comparison of initial investments

Compared with air conditioning and heating systems, air chillers, and water heaters, the main equipment and cost of ground heating equipment are listed in tab. 2. From tab. 2, it can be seen that compared to the traditional air-conditioning and heating systems, in the soil insulation effect in spring, the cooling tower is replaced by the buried heat, and the boiler is replaced by the heat pump. The addition is buried pipes, but no cooling towers. The underground-water source heat pump system mainly costs drilling, backfilling, pipe fittings, *etc.*, while the conventional water source heat pump system mainly produces refrigerants and boilers. Through the aforementioned calculation, compared with the traditional spiral cooling tower + gas boiler, the initial investment of the underground-water source heat pump system increased by 997100 Yuan.

Energy efficiency analysis

According to the *Renewable Energy Building Application Demonstration Project Evaluation Guide*, in this project, the traditional alternative energy of the project is calculated by using traditional cold and heat sources. The energy saving rate of this system is 2.4%, and the operating room temperature is selected as the heat comparison unit. Efficient power consumption of the boiler reached 68%.

Table 2. Comparison of initial investment between ground source heat pumps and conventional systems

Ground source heat pump system			Conventional cold and heat source air conditioning system		
Device name	Number	Price (10000 Yuan)	Device name	Number	Price (10000 Yuan)
No. 1 screw type ground source heat pump unit	1 unit	25.221	No.1 chiller unit	1 unit	23.681
No. 2 screw type ground source heat pump unit	1 unit	9.361	No. 2 chiller unit	1 unit	8.641
No.1 chilled water pump	1 unit	1.421	No. 1 chilled water pump	1 unit	1.421
No.2 chilled water pump	1 unit	0.681	No. 2 chilled water pump	1 unit	0.681
No.1 cooling water pump	1 unit	1.7	No. 1 cooling water pump	1 unit	2.1
No. 2 cooling water pump	1 unit	0.821	No. 2 cooling water pump	1 unit	1.021
Drilling and backfilling of wells	10000 m	100	Gas boiler and facility costs	1 unit	32.451
Buried pipe material	48.9 million m	33	Cooling tower	1 unit	2.5
Total cost	172. 491		Total cost	72.491	

Calculate the cumulative cooling load during the cooling season using the temperature frequency method. Assuming the building load equation is: Q_{SLi}, Kt_{wi}, and C, based on the average cooling load Q_{SL1} and Q_{SL2} of each day during the testing period and the corresponding outdoor average temperature t_{w1} and t_w2, the temperature related load characteristic value K [kW°C^{-1}] and load constant C [kW] of this project are solved, then, based on the annual temperature frequency data of urban Area A, the cumulative air conditioning load during the cooling season can be calculated:

$$\sum_{i=1}^{n} Q_{SL1} = \sum_{i=1}^{n} \left(Kt_{wi} + C \right) t_i \tag{1}$$

where t_{wi} [°C] is the center temperature of the i^{th} temperature frequency band and i [hour] – the hours of the i^{th} temperature frequency band. Based on the test results, the average outdoor temperatures on August 29th and August 30th were 32.4 °C and 33.59 °C, with average cooling loads of 357.5 kW and 300.6 kW, respectively. The calculated K value is –51.8 °C value is 2035.8. Then, check the specialized meteorological dataset for thermal environment analysis of Chinese buildings to obtain the temperature of each temperature frequency center and the corresponding temperature frequency number.

Ecological environment response analysis under thermal equilibrium

Change of soil temperature caused by thermal equilibrium

If the annual imbalance rate between underground heat release and extraction is within ±20%, it can be considered as reaching seasonal equilibrium. If it exceeds this range, corresponding measures should be taken to solve it. Otherwise, the temperature of the soil, rocks, the reservoirs pumped by underground pipes will increase or decrease year by year, and the cooling or heating efficiency of heat pump will decrease, leading to the system failure and changes in the underground environment after years of operation [9]. The results shown in figs. 2 and 3.

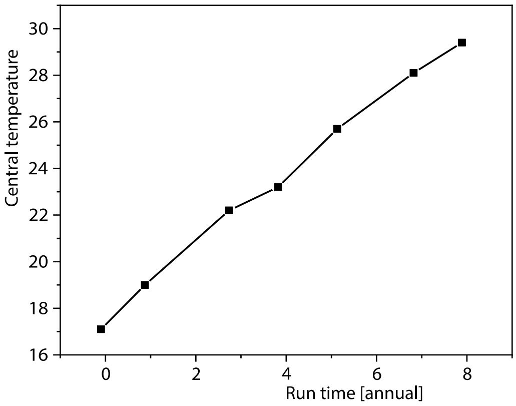

Figure 2. Heat release in summer is greater than heat absorption in winter

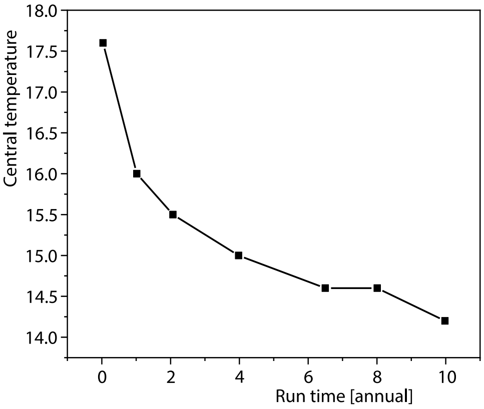

Figure 3. Heat absorption in winter is greater than heat release in summer

As shown in fig. 2, by the 10th year, the summer soil temperature has reached 31.0 °C, and as time goes on, the soil temperature will continue to rise, resulting in the accumulation of underground soil heat, which reduces the operation efficiency of the system. As shown in fig. 3, by the tenth year of operation, the soil temperature in winter has been below 14.5 °C, and as the operation time continues, the soil temperature will continue to decrease, causing cold accumulation of underground soil and a decrease in system operation efficiency. The solar hybrid ground source heat pump is adopted to solve the problem. The heat of the buried pipe is designed based on the cooling load of the building, and the equipment is used to balance the difference between the winter and summer underground cooling and heating loads when heating in winter.

Impact of underground thermal equilibrium on ecological environment

The change of soil temperature can lead to the change of the ratio of liquid-liquid two-phase moisture content in soil, thus changing the pore structure of soil and having a significant effect on the performance of soil. In order to observe the effect of ground temperature on ground penetration capacity, monitoring of continuous water conductivity from 10-20 cm obtained the relationship between ground temperature and saturated water conductivity, see fig. 4.

As shown in fig. 4, as the ground temperature increases, the saturated hydraulic conductivity also increases, and the relationship between the two is quadratic polynomial. While supporting ground heating in cold northern regions, the difference in cooling and heating loads

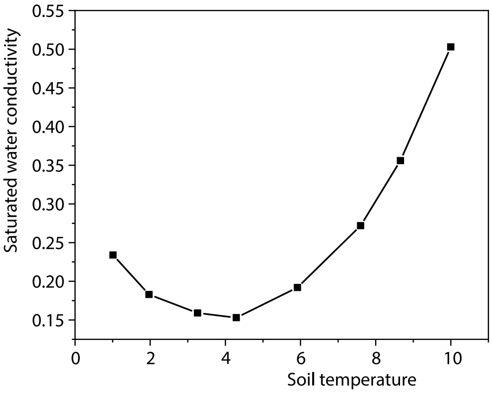

Figure 4. Relationship between soil temperature and saturated hydraulic conductivity

causes a continuous decrease in underground soil temperature, a decrease in saturated hydraulic conductivity, and a change in the corresponding physical parameters of the soil. On the contrary, in the hot regions of the south, the difference in cooling and heating loads causes a continuous increase in underground soil temperature, an increase in saturated hydraulic conductivity, and also changes in soil physical parameters. In any biological activity, every physiological and chemical process is involved in the enzyme system, and each enzyme activity has its optimal temperature. Each organism has its own temperature range, beyond which conditions can cause it to stop growing and developing, enter a dormant state, and even cause coma or death. Therefore, soil temperature is an important factor affecting the existence and evolution of ecosystems. It affects the accumulation of organic matter and N, P, K in soil, soil conductivity, soil moisture status, microbial activity and various biological Chemical process in soil. Thermal imbalance can lead to a continuous increase or decrease in soil temperature year by year. Once the temperature range required by the original biological activities is exceeded, it will inevitably lead to the extinction of certain biological communities, cause the redistribution of biological species, disrupt the biological chain, and ultimately affect the changes in the ecological environment of the entire region [10].

Conclusion

The implementation of the project requires environmental impact assessment and geological survey to solve the problem of underground heat balance of the project. Secondly, in the design stage, the dynamic calculation is carried out by year and hour to determine the hole distance and appropriately increase the buried pipe depth. In the construction stage, combined with the actual conditions and composite system, the number of soil heat exchanger is appropriately increased and optimized. At the same time, the operation and management of soil source heat pump should also be paid attention. In winter and summer, due to improper operation, the imbalance of soil heat dissipation will increase.

Acknowledgment

This work was sponsored in part by the Xingtai Science and Technology Plan Project (2022zz122).

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Paper submitted: May 23, 2023
Paper revised: July 22, 2023
Paper accepted: September 12, 2023

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