NUMERICAL SIMULATION OF GROUND TEMPERATURE FIELD CHANGE IN UNDERGROUND HEAT TRANSFER ZONE OF GROUND SOURCE HEAT PUMP UNDER DIFFERENT GROUNDWATER RUNOFF CONDITIONS

by

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The heat transfer capacity of ground and soil energy sources is the key factor that affects the performance of the ground source heat exchanger. The heat storage capacity of soil is related to various factors. The author proposes a multi-component heat pump system which combines solar energy, waste heat, and air, and designs a new type of dual channel finned tube evaporator for defrosting. Based on different weather conditions, the operation mode of the system was provided, and performance tests were conducted on the system under no light conditions and with or without waste heat utilization. The results show that the seepage speed of buried tube ground source heat pump system geographic tube heat exchanger and soil heat transfer influence is larger, the groundwater seepage speed of 15 m per annual, running 3-4 years later, the heat transfer well area of the soil temperature field will be stable, which can judge in the groundwater seepage is sufficient area, the buried tube ground source heat pump conditional soil winter and summer heat balance.

Key words: *ground source heat pump, buried pipe heat exchange zone, ground temperature field, numerical simulation, water runoff*

Introduction

The properties and variation characteristics of cold and heat sources in air conditioning systems are the basis for HVAC design. Currently, there has been extensive research on the heat transfer laws of the most widely used air-cooled air conditioning in the air, and corresponding environmental climate design indicators have been determined. The core of ground source heat pump technology is to use shallow geothermal energy to understand and master the temperature change and energy change law of underground rock and soil layer, provide basis for design, development, and implementation. At present, there is more research on ground heat transfer law of ground source heat pump, while there is little research on ground source heat transfer and energy dissipation law of ground source heat pump [1, 2]. After the operation of the groundwater surface heat pump, a power supply is generated above and below the ground, affecting the balance of the original groundwater temperature,and the ground temperature is no longer a constant value at the design time. Under the influence of injected energy, a certain underground space begins to change, this change occurs relatively quickly and violently due to the direct and rapid migration of flowing groundwater between pumping wells and recharge wells. Due

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to the significant impact of underground heat storage, thermal conductivity, diffusion, range of influence, long-term and short-term changes and balance of ground temperature on the underground environment, system energy efficiency, and sustainable operation, it is necessary to study the laws of underground energy transfer and diffusion [3]. As an important component of underground power equipment, underground power equipment plays an important role in the reliable operation of underground power equipment. The pipe-line buried heat exchanger uses the steady temperature field of ground to cool and heat the building by changing the temperature with ground-water. Therefore, during the operation of underground heat exchanger, the dynamic characteristics of underground heat exchanger in the geothermal exchanger area have an important effect on the heat transfer performance of the heat exchanger, thus affecting the power of the whole heat pump system. However, in the practical engineering application of ground source heat pump, the monitoring of the temperature field in the heat exchange area of buried pipes, especially the continuous monitoring for more than one year, is still insufficient, which is extremely incompatible with the high speed promotion and development of Ground source heat pump [4]. Many scholars at home and abroad have studied the heat transfer of underground heat pump and underground environment, provided reference for the design and operation of underground heat pump and solved many problems in design and operation. Ground pump is an efficient and energy-saving air conditioning system which can utilize low temperature ground source for air conditioning and heating treatment. Its working principle is to use ground source heat pump to extract ground heat for building heating, or release heat energy from building underground to achieve building cooling [5, 6]. In summer, the thermal energy in the building can be stored on the ground for use in winter, during winter, the additional cold and hot energy can be stored on the ground for use in summer. The thermal energy in the building can be stored on the ground for use in summer. In this way, the energy exchange between buildings and the environment is achieved by using the thermal properties of the strata themselves. Ground source heat pumps convert low temperature thermal energy to high temperature heat through small inputs of high energy sources (such as electricity). In theory, a ground source heat pump uses 1 kW of electric power, and users can get more than 4 kW of heat or cooling capacity. Compared with electric boiler heating, it saves more than 2/3. Compared to oil heater, the energy saving rate is more than 1/2. Because of the temperature of ground source heat pump throughout the year, the temperature in Changsha is generally around 16.8 °C, and its cooling and heating coefficients can reach 3.5-4.4%, which is about 40% higher than that of traditional air source heat pump. The Committee notes with appreciation that, inter alia, the Committee notes with appreciation the state party's efforts to strengthen its efforts to ensure that States parties are fully committed to the implementation of the Convention on the Privileges and Immunities for the Eli Therefore, in recent years, the Chinese government has promulgated policies to promote underground heat pumps, and underground heat pumps have achieved rapid development. Ground source heat pump is divided into ground source heat pump, ground source heat pump, and surface water pump. The development and application of ground source heat exchanger mainly depends on the accurate and reliable design methods and calculationols. The long-term research of groundwater heat exchanger is an important part of the system. The influence of groundwater source heat exchanger on groundwater temperature needs further study.

The heat transfer capacity between the ground heat exchanger and the soil is an important factor affecting the operation of the ground source heat pump system. The heat storage capacity of soil is related to many influencing factors, such as solar radiant intensity intensity, geographical location, soil thermophysical parameters (including soil thermal conductivity, *etc.*), soil porosity and groundwater seepage. Based on the numerical simulation software

FLUENT and the ground source heat pump itself of a sports venue, the author proposes a set of medium and long-term simulation scheme for the buried ground source heat pump, which is suitable for the project and can be extended, to simulate and predict the operation of the project in the future.

Long term numerical simulation methods

The underground-water supply pipe-line is responsible for the winter heating and summer cooling of the stadium. In summer, underground pipe-lines release heat to the ground, which collects heat. After a short transient period, underground pipe-lines in winter suspend heat stored in the ground during summer, providing heat to the building. After a period of summer fluctuations, the next summer will continue to release heat to the ground through underground pipe-lines. If the heat released from underground pipe-lines the ground source heat pump for soil in summer is equal to the heat absorbed by soil in winter, that is, thermal equilibrium in winter and summer, the ground heat transfer will deteriorate after the heat transfer cycle. In general, this is not the case. Because of the imbalance of heat output and absorption in winter and summer, after a thousand cycles of heat transfer, the price fluctuation of soil will lead to a decrease.

Simulation assumptions

There are many factors that affect the heat transfer mechanism of buried pipe-lines and soils. Considering the complexity of the actual situation, in order to save the calculation time and cost, the following assumptions are made for the calculation models and models, given that the accuracy of the simulated results is permitted: the accuracy, the cooling time and the heat transfer of different natural years. In order to simplify the calculation, the start and end times of the cooling season, the heating season, and the changing season in the simulation results are the cooling season is from June 1 to September 30, a total of 122 days. The heating season starts on november 15 and ends on march 15 annually, totaling 122 days [7]. The transitional seasons are from October 1st to November 14th (45 days), and from March 16th to May 31st (77 days). Due to the several years involved in this simulation calculation, in order to save computational time and cost, a time step of 1 day was set in the non-stationary simulation calculation. Due to the fact that most of the buried heat exchangers are located on both sides of the runway within the stadium, and a few are located under the podium stands, the obstruction of buildings above ground level is ignored to simplify the model. There are 312 heat exchange wells in the underground pipe ground source heat pump project. In order to simplify the model, the location of heat exchange wells is divided into three areas, fig. 1. In the numerical simulation, three internal heat sources are assumed. The direction of groundwater seepage is from east to west, and the seepage velocity is assumed to be within the range of 15-50 m per annual.

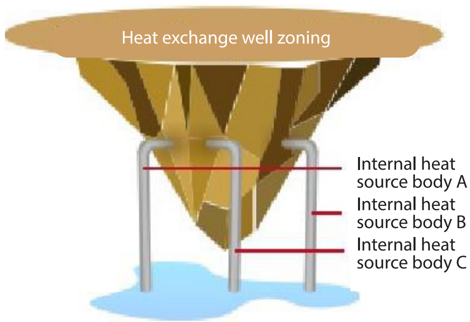

Figure 1. Schematic diagram of heat exchange well zoning

Simulation calculation method

In the selection of calculation area, in order to meet the requirements of calculation accuracy, the length and width directions are roughly set to three times the buried pipe area

(400 m × 300 m). In the height direction, considering the actual situation of the sports venue buried pipe ground source heat pump project, the horizontal pipe is buried 5 m underground, the *U*-shaped pipe is 70 m long, and the soil calculation area extends 125 m downward. The total height is 200 m. Structured grids are used in the whole calculation area. Dense grids are distributed near the internal heat source (A, B, and C areas), and sparse grids are distributed at the edge of the calculation area. According to the description of the project site thermal response test report in the project case data *Construction Scheme for Ground Source Heat Pump Air conditioning Buried Pipe Heat Exchange System of Stadium Project* described by the author, the soil static temperature in this project is 14.6 °C, and the soil thermal conductivity coefficient is 2.32 W/mK. After reviewing the relevant geological data of the city, it is determined that the soil density in this area is about 2000 kg/m^3, and the specific heat capacity is 1010 J/kJK. Based on the annual dynamic load calculation results of DeST, the unit value of the internal heat source in the heat exchange well area is calculated. The relevant geological data of the city shows that the groundwater seepage velocity in the urban area is roughly between 15 m per annual and 50 per annual, therefore, in the three working conditions of 15 m per annual, 30 m per annual, and 50 m per annual, the direction of groundwater seepage is proposed to be from east to west, and the soil porosity is 0.35.

Simulation results

Due to the fact that the total air temperature of summer parks is higher than the total heat load of winter, without considering the groundwater level, the temperature of heat field shows an increasing trend year by year. With the extension of time, the radius of internal heat resources continues to expand. After 10 years, the calculated radius of internal heat resources in the area is nearly 250 m in the east-west and nearly 300 m in the north-south. The soil temperature in the calculation area increased rapidly, and after 10 years, the soil temperature even 10 ℃ was higher than the first stage [8].

Due to the influence of groundwater seepage from east to west (the direction in the fig. 1 is from top to bottom), the heat in the three areas where the heat exchange well is located will migrate with the direction of groundwater seepage, and different seepage velocities will lead to different heat migrations. When the groundwater seepage velocity is 30 m per annual, the speed of heat transfer is significantly higher than that when the groundwater seepage velocity is 15 m per annual. After the buried pipe ground source heat pump runs to the fifth year, the temperature field in the calculation area and the thermal action radius of the internal heat source basically do not change every year. This situation also occurs under the condition of groundwater seepage velocity of 50 m per annual, and due to the higher seepage velocity, the temperature field stability is advanced to the end of the third year. After the third year, the temperature field within the calculation area will no longer change. The temperature field of soil varies significantly after several years under different seepage velocities. Under the influence of groundwater seepage at a higher velocity of 50 m per annual, the radius of thermal action of the soil's internal heat source is smaller than that of 30 m per annual. Similarly, under the influence of groundwater seepage velocity of 15 m per annual, the thermal action radius of its internal heat source is 3.2, and the temperature changes year by year.

As shown in fig. 2, the annual variation of soil temperature at running time 0 m per annual. As shown in fig. 3, the annual variation of soil temperature at the running time of 15 m per annual. As shown in fig. 4, the annual variation of soil tperature at running time 30 m per annual. As shownin fig. 5, the annual variation of soil temperature at running time 50 m per annual. As shown in fig. 6, the soil temperature changes annually at running time 0 m per annual. As shown in

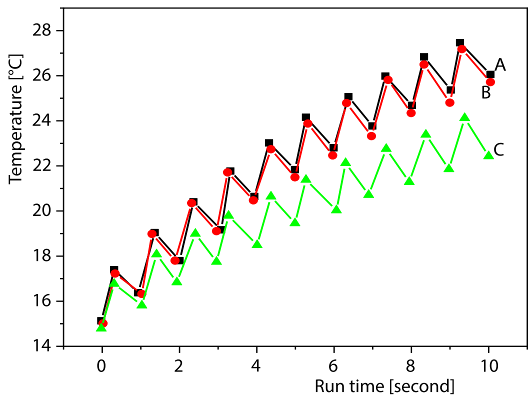

Figure 2. Yearly variation of soil temperature: 0 m per annual

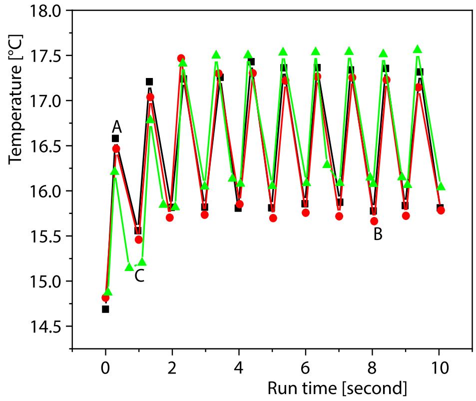

Figure 3. Yearly variation of soil temperature: 15 m per annual

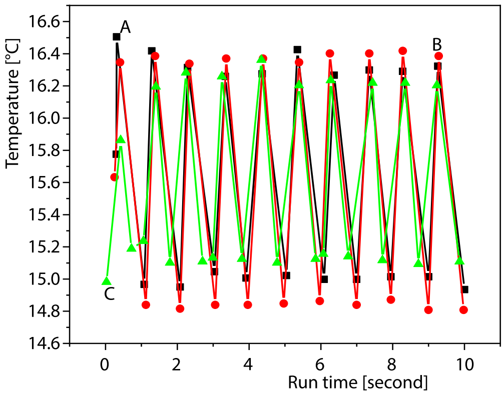

Figure 4. Yearly variation of soil temperature: 30 m per annual

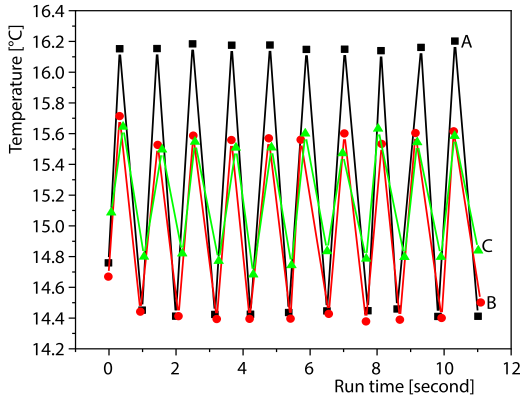

Figure 5. Yearly variation of soil temperature: 50 m per annual

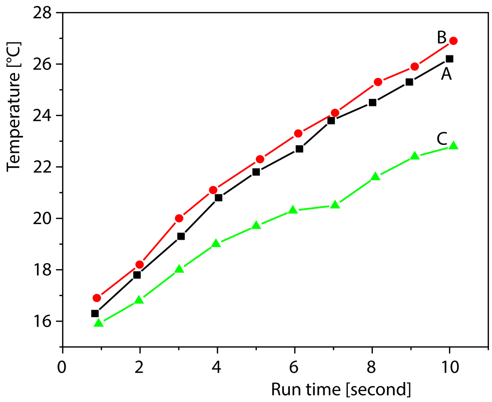

Figure 6. Annual average soil temperature in Areas A, B, and C: 0 m per annual

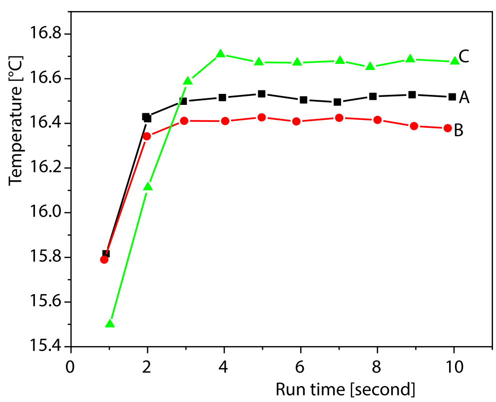

Figure 7. Annual average soil temperature in Areas A, B, and C: 15 m per annual

fig. 7, the annual variation of soil temperature at the running time of 15 m per annual. As shown in fig. 8, the annual variation of soil temperature at running time 30 m per annual. As shown in fig. 9, the annual variation of soil temperature at running time 50 m per annual, it can be seen

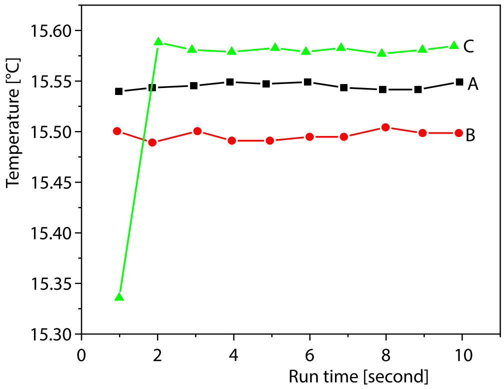

Figure 8. Annual average soil temperature in Areas A, B, and C: 30 m per annual

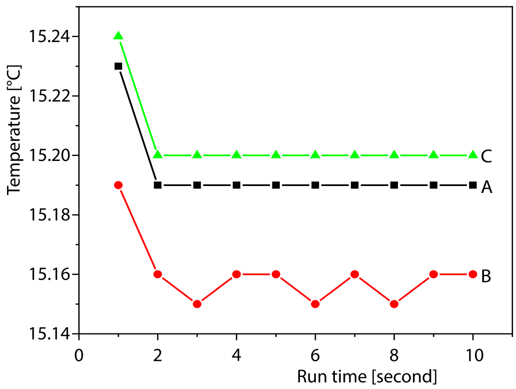

Figure 9. Annual average soil temperature in Areas A, B, and C: 50 m per annual

that, without considering the influence of groundwater seepage, due to the similar area, shape, size, and unit value of internal heat sources in Areas A and B, which are roughly symmetrically located on both sides of the east-west central axis of the stadium, the average temperature change of the temperature field is basically the same, with a temperature rise of about 1.8 °C in the first year. Due to the heat accumulation effect, the annual temperature rise decreases year by year [9]. In 10 years, the average annual soil temperature in Zones A and B will be 26-27 °C. Zone C is located on the east side of the sports stadium's podium, with a small area and a shape of approximately a long strip. The unit value of the internal heat source is slightly smaller than Zones A and B, and the temperature rise in the first year is about 1.2. In 10 years, the average annual soil temperature in Zone C will be around 23 ° C. After 10 years, the three regions have a significant temperature rise, which limits the ability of the buried pipe Ground source heat pump to continue to heat the soil in summer.

Introducing the influencing factors of groundwater seepage, when the seepage velocity is 15 m per annual, the annual average temperature in Zones A and B has been stable at 16.5 °C and 16.4 °C, respectively, since the third year, while the annual average temperature in Zone C has been stable at 16.7 °C since the fourth year. When the seepage velocity is 30 m per annual, the annual average temperatures of Zones A and B have been stable at 15.55 °C and 15.50 °C, respectively, since the second year, while the annual average temperature of Zone C has been stable at 15.6 °C since the third year [10].

Conclusion

Taking a stadium as an example, the medium and long term working models of underground pipe-lines in underground space heat exchanger were established, and the experimental work has been carried out for 10 years. The results show that the seepage velocity has great influence on the area of tube heat exchanger and the soil heat transfer of buried tube in ground source heat exchanger. When the groundwater enters the ground is 15 m per annual, the soil temperature in the area where the heat transfer is good will remain stable after 3 to 4 years of operation. Therefore, in the area with enough groundwater input, the ground pump with buried pipe-lines can achieve the soil Thermal balance in winter and summer.

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References

[1] Hu, Y., Bidirectional Analysis Model of Green Investment and Carbon Emission Based on LSTM Neural Network, *Thermal Science*, *27* (2023), 2B, pp. 1405-1415
[2] Tsuya, S., *et al*., Field Test and Numerical Simulation of Single-Tube Horizontal Ground Heatexchangers Installed Using Horizontal Directional Drilling Method, *Journal of the Geothermal Research Society of Japan*, 43 (2021), 1, pp. 7-17
[3] Hao, H., Yu, Y., Study on Solar-Ground Source Heat Pump and Combined Heating System in Severe Cold Area, IOP Conference Series, *Earth and Environmental Science*, *825* (2021), 1, 012008
[4] Bellos, E., Tzivanidis, C., Parametric Investigation of a Ground Source CO_2 Heat Pump for Space Heating, *Energie*s, *14* (2021), 12, 3563
[5] Hu, X., *et al*., Development of a High-Efficiency and Cost-Effective Ground Source Heat Pump System for Hot-Climate Applications, I*ndoor and Built Environment*, *32* (2023), 2, pp. 387-407
[6] Wang, J., *et al*., Simulation Experiment on Energy Tower Coupled with Buried Pipe System of Ground-Source Heat Pump for Cross-Season Heat Storage, *Journal of Physics: Conference Series*, *2108* (2021), 1, 012039
[7] Xiang, B., *et al.*, The 10-Year Simulation of Photovoltaic-Thermal Road Assisted Ground Source Heat Pump System for Accommodation Building Heating in Expressway Service Area, *Solar Energy*, *215* (2021), 24, pp. 459-472
[8] Ide, T., *et al*., Influences of Operational Improvement on Ground Temperature and Energy Performance in Ground Source Heat Pump System in Warm Region, *AIJ Journal of Technology and Design*, *29* (2023), 71, pp. 280-285
[9] Dong, Li, *et al*., Investigation of the Explosion Characteristics of Ethylene-Air Premixed Gas in Flameproof Enclosures by Using Numerical Simulations, *Thermal Science*, *27* (2023), 2B, pp. 1573-1586
[10] Peng, W., Enhancement Technology of Underground-water Flow Field in Coal Mine to Improve Energy Efficiency of Heat Pump System in Geothermal Energy Development, *Thermal Science*, *27* (2023), 2A, pp. 1191-1198

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