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Study on the Recovery Characteristics of Shallow Geothermal Energy

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ABSTRACT

In recent years, with the country's emphasis on resources and environment, as a clean and renewable energy source to energy conservation and emission reduction, the contribution of shallow geothermal energy has increased year by year. GSHP technology is a main way to develop and utilize shallow geothermal energy. The heat transfer between GSHP system and soil is mainly based on the heat conduction of the rock and soil during the system operation. It will change the geothermal field of the heat exchange zone to some extent in the process of operation, while the change of the geothermal field directly affects the geological environment of the heat exchange zone. This paper takes a GSHP system in Beijing as an example to carry out the monitoring and data analysis research on the geothermal field, and studies the distribution of the original geothermal field and the recovery performance of the heat pump system during operation, especially in the transitional season. It can be concluded through analysis that the change of temperature field is closely related to the operation of the system, and it changes regularly. The variation range and variation trend of temperature curve at different depths are almost the same, showing that the temperature is lower in winter, while the temperature is rising slowly in transition season and gentle in summer. According to the distribution of time and space, it analyzes the recovery situation of heat exchange holes in different periods and different regions. The recovery rate of ground temperature is introduced to illustrate the recovery extent of ground temperature in different strata, and it makes a comprehensive analysis on characteristics of geothermal field from the formation lithology and groundwater dynamic changes. Through the monitoring of the geothermal field, we can master the dynamic characteristics of the geothermal field in the heat exchange zone, and scientifically guide the system operation, so as to provide reference for the application of GSHP system, which is of great significance to achieve the optimal performance of the system and protect the geological environment.

1. INTRODUCTION

Buried pipe ground source heat pump system is a kind of high efficiency and energy saving air conditioning system that uses shallow geothermal resources. The heat transfer between soil and system during the operation of heat pump system is complicated unsteady heat transfer process, mainly by the heat conduction of rock and soil mass, the ground water seepage, thermal physical properties of rock and soil mass and soil initial temperature have a certain influence on the heat transfer process, change the characteristics of formation temperature field to a certain extent, Li Shuhong, Yang Weihua, Zhang Xiaosong(2001).

In the past the monitoring data of GSHP on ground temperature field in transition season are relatively few, which is unfavorable to studying the recovery performance of ground temperature field under different working conditions of GSHP. Many scholars have carried out research on the operation of GSHP and the temperature change of ground temperature field. Underwood and Michopoulos took the buried pipe ground source heat pump projects in Britain and Greece as examples respectively, and analyzed the monitoring data of ground temperature field during the operation period of eight and ten years, Underwood&Spitler(2007), Michopoulos& Zachariadis(2013). Pulat studied a horizontal buried pipe ground source heat pump project in Turkey, and proposed effective methods to improve the energy efficiency ratio of the system and improve the operation of system, Pulat，Coskun, Unlu(2009). Lenarduzzi in Toronto, Canada, took a ground source heat pump exchanger project as an example, the project has experienced serious system performance problems that caused by the pipe extrusion result of ground freezing and ice lens. Through the monitoring of the underground temperature field, improving the ratio of filler, it solved the problems of reduce of heat exchanger performance and system energy efficiency during system operation, Lenarduzzi, Cragg, Radhakrishna (2009).

This paper takes a buried pipe ground source heat pump system in Beijing as an example to study the distribution of original ground temperature field and the recovery performance during system operation and transition season.

2. RESEARCH OVERVIEW

The research site is about 300 m2, which is a one-story building. A total of 18 heat transfer holes are drilled, with bore diameter of 200 mm and PE100 pipe. Buried pipe ground source heat pump system is used for winter heating with a heat load of 36kw.

The lithologic structure of aquifer is composed of fine sand, medium sand, medium sand and coarse sand. The average temperature of the ground temperature field at a depth of 70 m is less than 13℃. The groundwater temperature ranges from 11℃ to 13℃. The water level is at its highest in April and October, and at its lowest in May. During the heating season, the dynamic change of underground water level is less than 1 m. The groundwater flow direction is from southeast to northwest. The trend of groundwater flow in the study site has little change.

3.MODEL DESCRIPTION CONSTRUCTION OF GROUND TEMPERATURE MONITORING SYSTEM

Among the 18 heat transfer holes, H1-H9 are the heat transfer monitoring holes, G1-G7 are the heat transfer impact monitoring holes, G8 is the normal temperature monitoring hole, and G9 is the reference monitoring hole located at a place 10 m away along the direction of groundwater flow outside the hole distribution area. The buried depth of heat transfer monitoring holes is all 120 m, except the H5 hole with 130m depth. The buried depth of heat transfer impact monitoring holes is 60 m to 120 m, and the buried depth of reference monitoring hole G9 is 150 m.

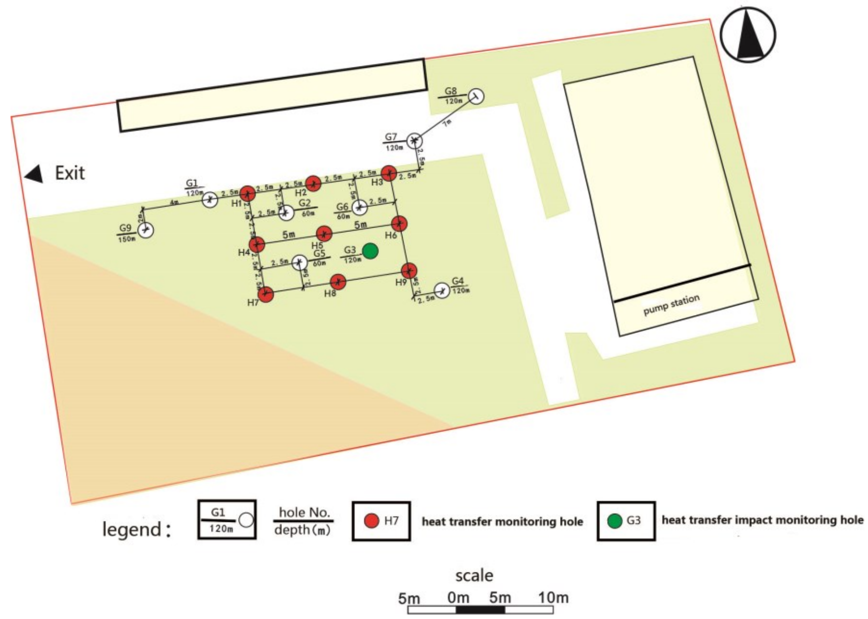

Figure 1: Location plan of monitoring holes

Temperature sensors are arranged at a certain interval in the heat exchange holes with the model of armored WZPPT1000 thermal resistance. The backfilling materials are all made of bentonite and raw slurry.

Table 1: Statistical table of the temperature sensor installed in the heat transfer monitoring holes and transfer impact monitoring holes

Depth (m)	H1	H2	H3	H4	H5	H6	H7	H8	H9	G1	G2	G3	G4	G5	G6	G7	G8	G9
3	•	•	•	•	•	•	•	•	•	•		•	•			•		
10	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
25	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
40	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
60	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
80	•	•	•	•	•	•	•	•	•	•		•	•			•		•
100	•	•	•	•	•	•	•	•	•	•		•	•			•	•	•
120	•	•	•	•	•	•	•	•	•	•		•	•			•		•
121					•													
126					•													
130					•													•
140																		•
150																		•

The special control cabinet and patrol inspection instrument installed in the machine room in combination, and the signal line of each monitoring equipment introduced from outside. It can make a real-time monitoring and recording of each monitoring data on the site. Through GPRS remote transmission equipment, the monitoring data is transmitted to the data center to realize real-time and centralized online monitoring of ground temperature data.

4.MONITORING DATA ANALYSIS

4.1 Distribution characteristics of original ground temperature field

The original temperature of the shallow soil layer is not only the background condition for calculating the heat input and output of GSHP, but also an important parameter for the optimization design and operation evaluation of GSHP system. The distribution of temperature field of underground rock and soil mass is influenced by the buried depth of rock and soil, the nature of rock and soil, and the distribution of groundwater. The original temperature of rock and soil mass is different with depth.

According to the original ground temperature measurement results, the variation range over 130 m was 13.9℃-16℃in June 2013. Except that the formation temperature of 3 m is significantly higher under the influence of weather temperature, the formation temperature gradually increases along the depth from top to bottom, and the variation range is within 1.5℃. There is no significant difference in temperature between sand, clay and silt layer.

4.2 Variation characteristics of ground temperature field during the year

From the temperature curves of H4 and H5 heat transfer holes, it can be seen that the temperature curves at different depths have roughly the same variation range and variation trend, showing a trend of low temperature in winter, slow rise in transition season and gentle temperature in summer. From vertical distribution, the temperature above 3 m is influenced by the environment temperature and has seasonal change, the more shallow depth, the more obvious influenced by environmental temperature, and with the change of season, stratum above 3 m has larger different changes in temperature and has a certain effect of latency, in general, the larger the buried depth, the longer the time lag.

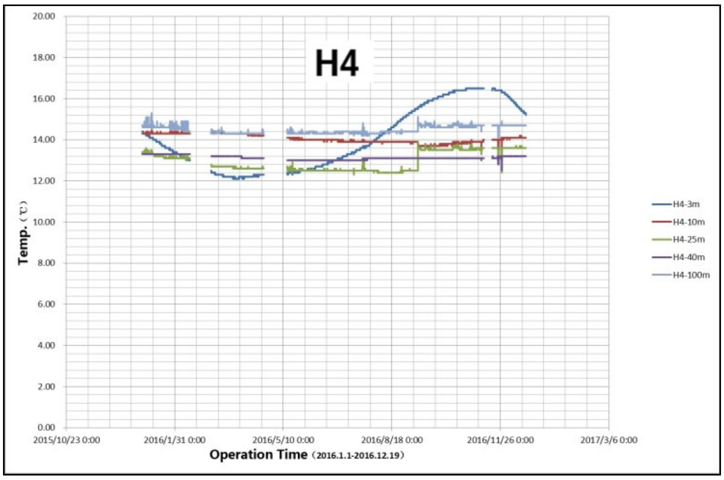

Figure 2: Temperature variation curves of typical heat transfer monitoring holes H4

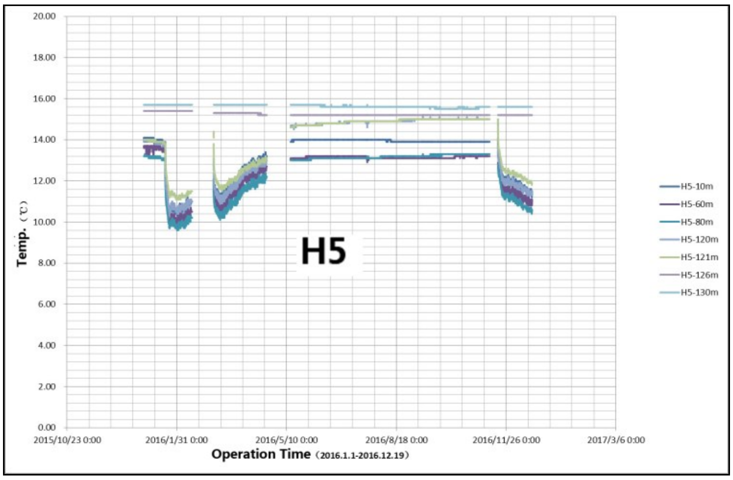

Figure 3: Temperature variation curves of typical heat transfer monitoring holes H5

The temperature of buried depth of 121m and above has obvious changes with the operation of the system. When compared with the lowest temperature in winter, the temperature of 121 m is 0.7℃ higher than that of 120 m, while the temperature of the two sensors with the buried depth of 126 m and 130 m also shows a decreasing trend, drops about 0.2℃ in the whole year.

From the perspective of heat balance, although the heating operation of the system affects the local ground temperature field, the formation temperature quickly recovers after the end of the heating season. It can be seen from the temperature curve of G8 that the temperature of buried depth above 5 m is greatly affected by the ambient temperature. In general, the deeper the burial, the longer the lag time.

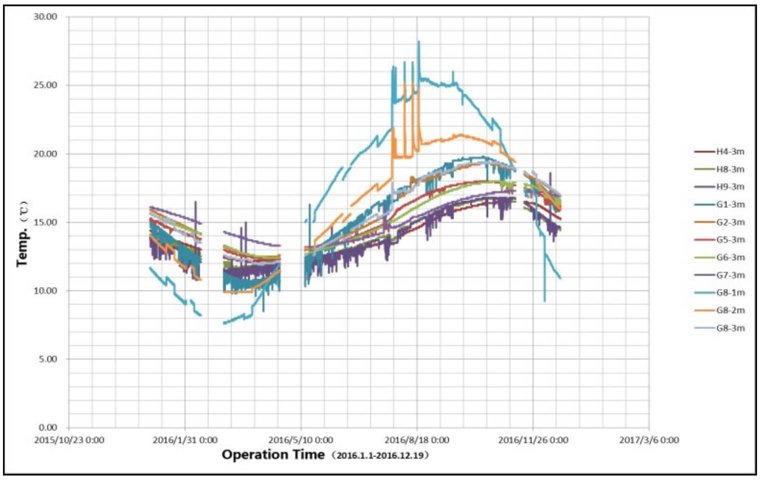

Figure 4: Temperature variation curve of monitoring hole buried depth of 1-3 m

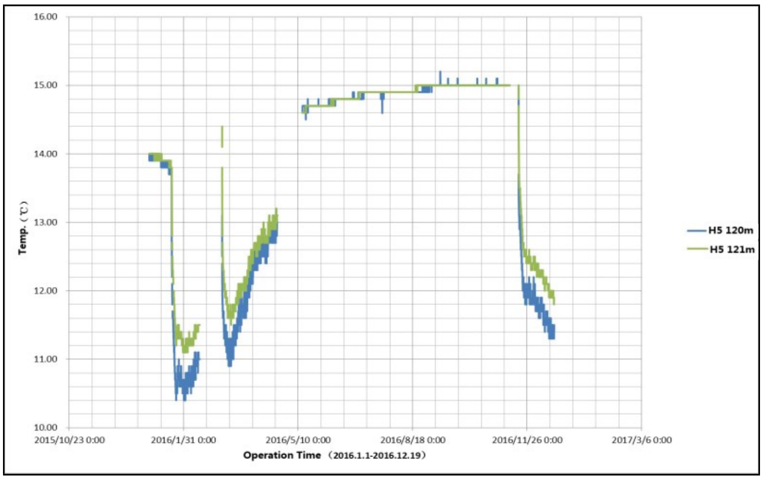

Figure 5: Temperature change curves of H5 in 120m, 121m

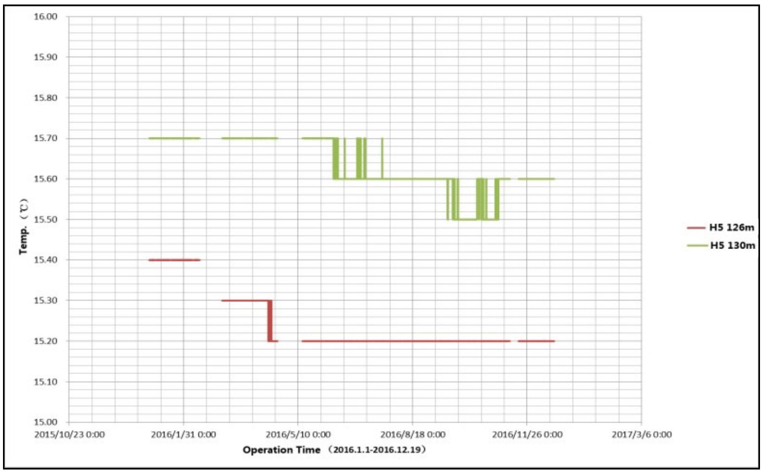

Figure 6: Temperature change curves of H5 in 126m and 130m

It can be seen from G9 temperature curve, from the transition season to the heating season, the temperature curves of buried depth of 25 m to 150 m have the same change regulation that has smooth temperature in transition season and presents a downward trend in heating season, the corresponding minimum temperature is in depth of 25 m. The temperature at a depth of 150 m is about 2.8 ℃

higher than that at a depth of 25 m, the temperatures of the rest depth are basically present the deeper the depth, the higher the temperature.

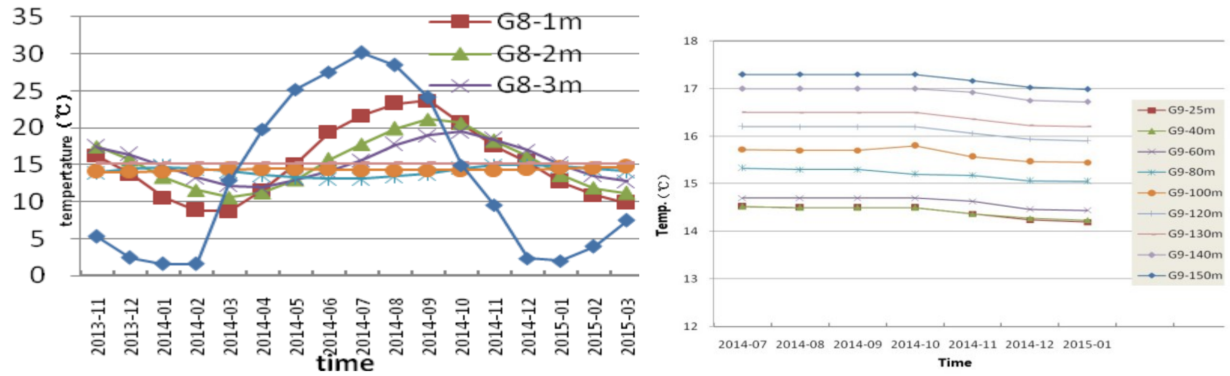

Figure 7: Temperature change curve of G8 and G9

5.RECOVERY CHARACTERISTICS OF GROUND TEMPERATURE FIELD

5.1 Ground temperature recovery characteristics of heat exchange holes

By comparing the heat transfer monitoring hole with the normal temperature observation hole, it can be seen that the rising trend of ground temperature continues until the next heating season. At this time, the ground temperature at the depth of 3 m has recovered, while the ground temperature at the other depth presents a difference in size. It can be concluded from Table 2 that the temperature drop in the first and second heating seasons is calculated by statistics of the difference between the lowest point of ground temperature at the same depth of different heat transfer holes and the same depth of G9 in the heating season.

By observing the relationship between different depths and temperature drop, it is found that the temperature drop is the smallest at the depth of 40 m, the temperature drop in the first and second heating seasons is 3.41℃ and 3.33℃ respectively, while the temperature drop is the largest at the depth of 120 m, the temperature drop of the first heating season is 4.80℃ and the second heating season is 4.83℃. From March 16, 2014 to November 14, 2014 is the recovery period of ground temperature. As can be seen from Figure 8, ground temperature gradually increases during the recovery period and recovers to the highest in early November. By comparing the ground temperature at this point with the observation hole G9, the recovery degree of the recovery season temperature can be obtained. It can be seen from Table 2 that the recovery degree of ground temperature varies in different depths. The overall trend is that the temperature drop increases with the depth, and the temperature difference between the recovery season temperature and the normal temperature hole increases. By comparing the temperature difference between the first and second recovery seasons, it can be seen that after the GSHP system stops heating, the ground temperature in the heat exchange area gradually recovers and basically recovers to the initial value.

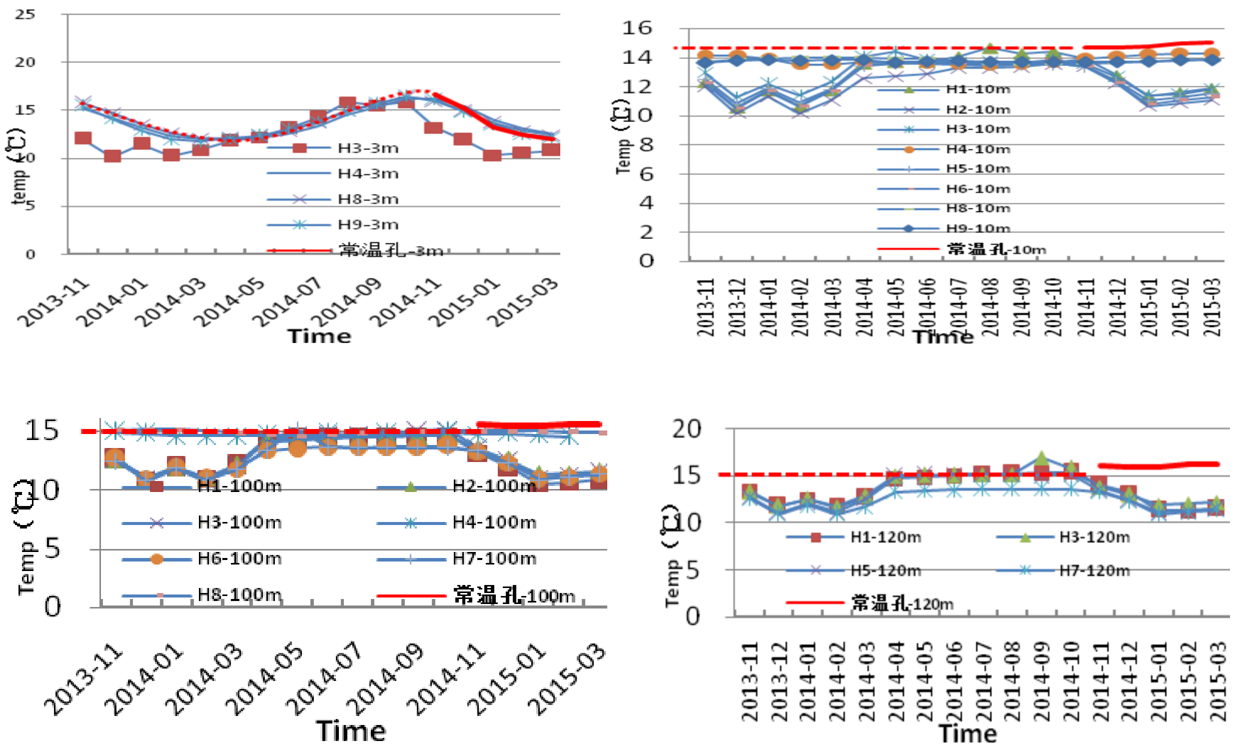

Figure 8: Temperature variation curves of H1 to H9 with buried depth of 3m, 10m, 100m and 120m

(Note: the dotted line in the figure is the presumed ground temperature extension line of G9 hole)

Table 2: Statistical table of ground temperature reduction and recovery degree at the same depth of heat exchange hole

Buried depth（m）	25	40	60	80	100	120
The1st heating season temperature drop (℃)	3.69	3.41	3.60	4.04	4.71	4.80
The 2nd heating season temperature drop (℃)	3.40	3.33	3.44	4.02	4.65	4.83
Temperature difference of restoration season and constant temperature hole(℃)	0.60	0.65	0.68	0.94	1.06	1.53
Temperature difference of first and second restoration season(℃)	0.02	0.10	0.15	0.24	-0.06	-0.23

Note: the first heating season refers to 2013, the second heating season refers to 2014, the first restoration season refers to 2013, and the second restoration season refers to 2014

5.2 Recovery characteristics of observation holes

The average monthly temperature change curve of the observation hole is generally divided into two types. One is the ground temperature curve with a buried depth of 3 m, which shows a decline-rise-fall curve with a larger range, reflecting that the ground temperature in that depth range is greatly affected by atmospheric environment temperature, and the ground temperature lags behind the season. The other type is the relatively stable variation curve of other buried depth ground temperature. The overall trend variation range of the curve is small, and the ground temperature difference is not big.

It can be seen from Table 3 that the ground temperature difference of observation points in the heat transfer area is between 0.24 ℃ and 0.50 ℃, while the temperature difference of observation holes in the periphery of the heat transfer area is between 0 ℃ and 0.36 ℃. By comparing the temperature difference inside and outside the heat transfer area, it is found that the higher the ground temperature recovery degree at the depth of the observation hole is, the greater the temperature drop amplitude in heating season inside the observation area is. The temperature difference between the recovery season and normal temperature observation hole G9 represents the maximum recovery degree of ground temperature at different observation points.

In addition, it can be seen from Figure 7 that thermal impact monitoring hole temperature variation curves, from time to time, since it began to heat transfer in the first month of first heating season in 2013, the temperature drop had been spread to the observation hole, the ground temperature of observation hole had reduced since the end of December in 2013 to April the following year the temperature fell to the lowest point, and in May, temperature began to recover, so it was speculated that ground temperature of observation holes decrease and recovery than heat holes' has about two months of delay, it reflected the rapidity of ground temperature spread in the research site. When observing the second heating season in 2014, the ground temperature continued to decrease until the end of heat exchange in March next year, it was inferred that the observed area's mainland temperature would continue to decrease after the heating season.

Table 3: Statistical table of ground temperature reduction-recovery degree at the same depth of observation holes

Buried depth（m）		25	40	60	80	100	120
The 1st heating season temperature drop (℃)	Inside of heat transfer area	0.65	0.51	0.59	0.42	0.41	0.26
	Outside of heat transfer area	0.32	0.30	~	0.49	0.58	0.55
The 2nd heating season temperature drop (℃)	Inside of heat transfer area	0.68	0.78	0.76	0.42	0.50	~
	Outside of heat transfer area	0.44	0.47	0.18	0.38	0.61	~
Temperature difference of restoration season and constant temperature hole(℃)	Inside of heat transfer area	0.24	0.50	0.30	~	0.34	0.29
	Outside of heat transfer area	0.29	0.15	0.00	0.36	0.19	0.00

Note: the first heating season refers to 2013, the second heating season refers to 2014, the restoration season refers to 2014

The spread time of funnel drop of formation temperature at different observation holes and strata is different. In order to observe the difference of temperature drop time at different strata, the difference of time point when the ground temperature begins to drop-drops to the minimum-starts to rise, statistics show different time points of G1, G6 and G7 holes located inside and outside the heat exchange area in the beginning of heating season in 2013--the ground temperature began to decline --the ground temperature dropped to the minimum -- it began to recover in this paper. The temperature drop point is calculated when the temperature drops 0.2℃ compared with the initial point, and the statistical results are shown in Figure 9. It can be seen that the temperature change velocity of each layer inside of the heat transfer area is quicker than that of the observation holes in the periphery of the heat transfer area, indicating that the further away from the heat transfer hole, the more obvious difference in thermal conductivity of the formation is. The better the thermal conductivity is, the sooner the temperature begins to decrease. From the G6 hole, the response of the formation temperature at 25m is faster than that at 40m and 60m; from the G1 and G7 hole, the response of the formation temperature at 40m and 100m is better than that at 80m.

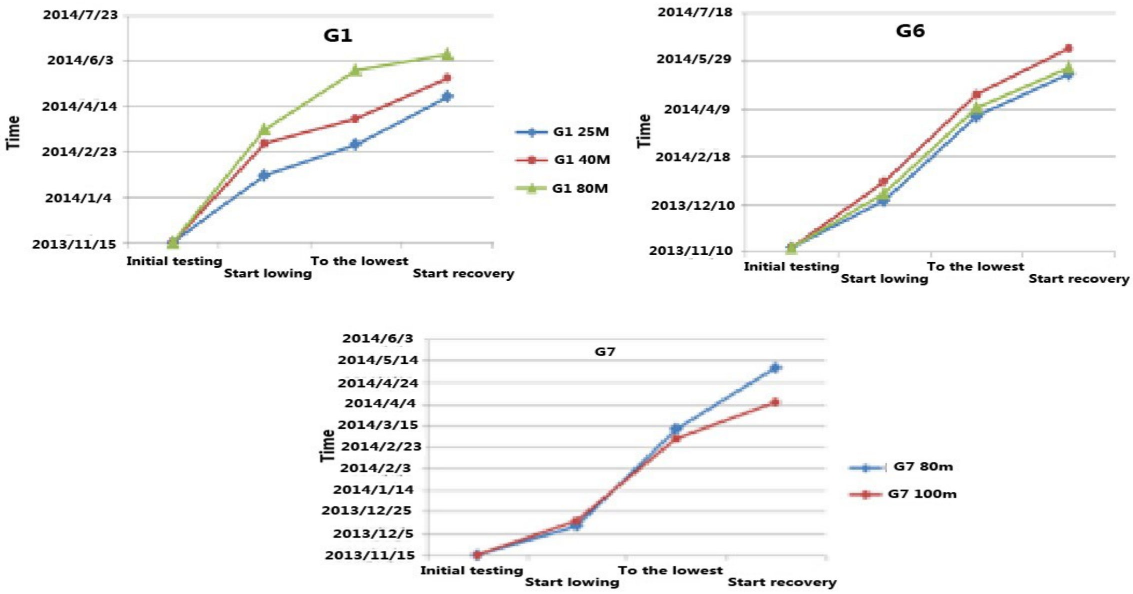

Figure 9: Comparison of time points of temperature change at different depths of G1, G6 and G7

5.3 Recovery characteristics of ground temperature in different lithologic strata

To study the recovery characteristics of ground temperature field in different lithologic strata, it is necessary to select characteristic lithologic strata. In the study site, the buried depth of 40m is fine sand, 60m is silty clay, 80m is sandy silty soil and 100m is medium sand.

The average temperature of each heat transfer holes in early November (that is, before the start of the heating season) as the initial ground temperature, select the average temperature of each month with the buried depth of 40m, 60m, 80m and 100m of each hole as a representative of corresponding time, compared with the initial temperature and obtains the variation of temperature of each strata with time, so as to eliminate temperature difference caused by the geothermal gradient change, the diversity of different heat exchanger position and inhomogeneity of rock and soil mass.

The analytical calculation formula is as follows:

$$\Delta T = T_{H11} - T_H \quad (1)$$

$\triangle T$ -- monthly average temperature difference (℃);
T_{H11} -- average temperature before heating season at the same depth of different heat transfer holes (℃);
T_{H} - monthly average temperature at the same depth of different heat transfer holes (℃).

Ground temperature recovery rate: in order to better reflect the recovery degree of ground temperature in different strata, the concept of ground temperature recovery rate is introduced, that is, the ratio of temperature reduction range to initial ground temperature, where the initial ground temperature value is taken in early November 2014. From the perspective of the ground temperature recovery rate of the average monthly ground temperature at different depths and the average monthly temperature in November (Figure 10), during the first heating season (November 2013-March 2014), the ground temperature recovery rate was the highest in the middle sand formation with buried depth of 100m, and the maximum decrease of ground temperature was 3.5℃. The ground temperature recovery rates in silty clay strata of 60 m and sandy silt layer of 80m were similar, while the fine sand strata with buried depth of 40 m was the minimum. During second heating season (November 2014 - March 2015), the ground temperature recovery rate at 100 m depth of medium sand formation is the highest, followed by sandy silt layer at 80m, the third is silty clay strata at 60m, the minimum is still fine sand strata at 40m. The ground temperature recovery rate curve is basically consistent with the trend of temperature reduction amplitude, reflecting the characteristics of fast temperature diffusion and fast ground temperature recovery in sand layer, while slow temperature diffusion and relatively slow ground temperature recovery in clay and silty layer.

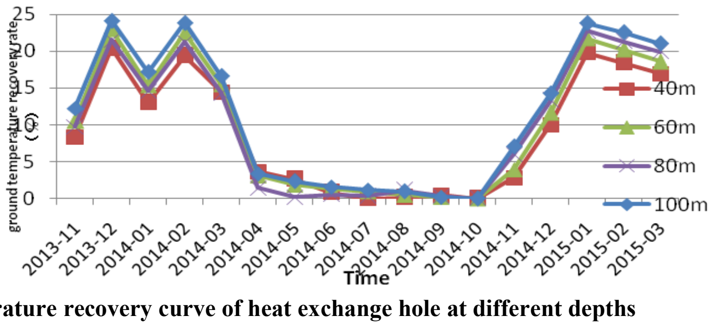

Figure 10: Ground temperature recovery curve of heat exchange hole at different depths

The average values of density, moisture content, thermal conductivity and specific heat capacity of different lithology in the research site were obtained to calculate the thermal conductivity. It can be seen from Table 4, according to thermophysical property analysis results at different depths and lithologies, the conductivity coefficient of sand stratum is slightly higher than that of clay stratum, indicating that the thermal diffusion capacity of sand stratum is better than that of clay stratum. Therefore, it is concluded that the recovery degree of ground temperature is comprehensive influenced by the original ground temperature, thermophysical property and water condition.

Table 4: Statistical table of average thermal properties of different depths of rock and soil mass

Depth,m	Lithology	Density, g/cm^3	Moisture content %	Thermal conductivity, W/(m·K)	Specific heat capacity, kJ/(kg·K）	Coefficient of conductivity, m^2/h
40	fine sand	1.97	18.59	1.28	0.75	0.87
60	silty clay	2.00	23.77	1.52	1.00	0.76
80	sandy silt	2.02	20.60	1.56	0.94	0.82
100	medium sand	1.84	21.60	0.83	0.56	0.81

6.CONCLUSION

The heating operation of the buried pipe GSHP system changes the temperature field in the heat transfer zone to some extent, and the temperature field changes are related to the operation of the system and show regular changes. After the end of the heating season, the formation temperature quickly recovered.

The monitoring data show that the temperature curve at different depths has roughly the same variation range and trend, displaying a trend of low temperature in winter, slow rise in transition season and gentle temperature in summer. During the heating season, the overall ground temperature field showed a decreasing trend, and the ground temperature of heat exchange holes decreased the most, followed by the observation holes in the heat exchange area, the temperature drops significantly inside of the heat exchange area compared with outside of the area. The above of buried depth of 5m is greatly affected by the ambient temperature which has a certain lag with the change of seasons, the greater the buried depth, the longer the lag time.

For the buried pipe GSHP project with single heating, after a running year, the ground temperature field in the heat exchange zone can basically return to the initial temperature field. In terms of time distribution, during the restore of ground temperature, the recovery amplitude of ground temperature of heat exchange hole in the first month was the largest. The start recovery time of ground temperature at the observation hole 2.5-3.5m away from the heat transfer hole was about two months later than the stop heat transfer time, and the reduction and recovery time of ground temperature at the observation holes were about two months later than that at the heat transfer holes, reflecting the fast and slow of spread speed of ground temperature at the research site. From the perspective of spatial distribution, comparing with the temperature monitoring data inside and outside of the heat transfer area, the higher the ground temperature recovery degree of the observation hole is, the greater the extent of temperature drop of the heating season in the observation area is. The more distant the formation is from the heat transfer hole, the more obvious the difference of thermal conductivity is. The better the thermal conductivity of the formation, the sooner the temperature begins to decline.

The recovery rate of ground temperature is introduced to illustrate the recovery degree of ground temperature in different strata. The recovery rate curve of ground temperature is basically consistent with the trend of temperature reduction amplitude, reflecting the characteristics of rapid temperature diffusion and fast ground recovery in sand layer, and slow temperature diffusion and relatively slow ground recovery in clay and silty layer.

From the formation lithology, the sand layer has the characteristics of rapid temperature diffusion and quick temperature recovery, while the clay and silt layer are relatively slow. The recovery degree of ground temperature is influenced by the original ground temperature, thermophysical property and water condition.

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