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Solutions to key geological problems of super large-scale ground-source heat pump underground heat exchange system

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ABSTRACT

In the past 15 years, the global ground-source heat pump industry has developed rapidly, and the large-scale trend of ground-source heat pump system has become obvious. The super large-scale ground-source heat pump systems with more than one million m^2 appears constantly. In terms of the development situation of ground-source heat pump industry, it can be described as “mingled hope and fear”. "Hope" is that the shallow geothermal energy is rapidly utilized on a large scale using ground-source heat pump, due to the government's attention, social recognition and technological advances. “Fear” is that the rapid and rough development has also brought a series of problems, especially the geological problems of the super large-scale ground-source heat pump underground heat exchange system, which has seriously restricted the large-scale, sustainable and efficient development and utilization of shallow geothermal energy by using ground-source heat pump technology, which needs high attention.

The key geological problems of super large-scale ground-source heat pump underground heat exchange system are the distribution law of shallow geothermal energy in subsurface rock-soil body, thermal response properties and the characteristics of heat exchange contribution rate. Through the research on the monitoring data of a ground-source heat pump underground heat exchange system for more than ten years, it is found that:

(1)The subsurface rock-soil body in the ground heat exchange zone is not a "homogeneous body". There are obvious differences in the original temperature of rock-soil body at different depths, and the stratification of variable temperature zone, constant temperature zone and increasing temperature zone is not obvious. The geothermal field is a relatively open system controlled by geological conditions, and its shallow geothermal energy distribution law is obviously restricted by geological conditions and is irregular.

(2)During the operation of ground-source heat pump, different parts of subsurface rock-soil body have different thermal (cold) responses to the water temperature change at the ground-source side of the system, both positive and negative response, and there are obvious differences in the response degree of the same response properties, which can be characterized by the positive and negative temperature difference of thermal (cold) response.

(3)During the operation of ground-source heat pump, the characteristics of heat (cold) exchange contribution rate of different parts of subsurface rock-soil body and different heat exchange wells are obviously different. In the heating season, about 1/7 heat exchange wells have a negative contribution rate, which means 1/7 wells "do not supply heat" in the heating season. In the cooling season, about 2/7 heat exchange wells have a negative contribution rate, which means 2/7 wells "do not provide cooling" in the cooling season.

It appears that he laying of ground heat exchanger in the form of equal spacing grid was obviously unscientific in the past and the larger the laying area of buried pipes, the more unscientific it is. Therefore, we propose a "four methods" solutions to the key geological problems of the super large-scale ground-source heat pump underground heat exchange system in order to scientifically support the efficient, sustainable and large-scale development of ground-source heat pump industry:

the “quantitative study “on the genetic mechanism of shallow geothermal energy;the "refinement" of the exploration and evaluation of shallow geothermal energy in subsurface rock-soil body;the "intellectualization" of the operation and control of ground-source heat pump system;the "scientization" of multi energy coupling.

1. QUESTIONS RAISED

General Secretary Jinping Xi proposed: "Strive to reach the peak of carbon dioxide emissions by 2030, and strive to achieve carbon neutrality by 2060." at the 75th United Nations General Assembly. In order to achieve "dual carbon" goal, it is urgent to develop and utilize renewable, high-quality, environmentally friendly, non-fossil new energy. Shallow geothermal energy is a new type of high-quality non-fossil energy which is renewable, has large reserves, can be mined locally, is clean and environmentally friendly. Vigorously developing and utilizing shallow geothermal energy is an important choice to achieve the "dual carbon" goal and the transformation of energy structure.

Ground-source heat pump technology is the key technology relying on the development and utilization of shallow geothermal energy. It is currently a new energy technology that has attracted much attention around the world. It is listed as one of the top ten cutting-edge technologies in science and technology in 2022 ("Technology Think Tank" 2022 (1)). The application of ground-source heat pump technology to develop and utilize shallow geothermal energy in energy-saving buildings can not only make the living environment more comfortable and improve energy utilization efficiency, but also promote indoor air improvement, effectively avoid greenhouse gas emissions, which play an important role in achieving carbon neutrality.

The "2050 Energy Zero Carbon Emissions Roadmap Report" issued by the International Energy Agency (IEA) proposes that under the "1.5°C" temperature control target, it is recommended that countries around the world no longer use fossil fuel boilers in 2025, and the annual use of heat pumps in global heating reaches or exceeds 50% in 2045. At present, refrigeration, lighting and electrical products have already been fully electrified, and heating equipment decarbonization has become the primary task of building energy conservation. "Energy Efficiency 2021", the annual flagship report published by the International Energy Agency (IEA), identifies heat pumps as a key technology to electrify space heating in a zero-carbon emissions scenario by 2050.

Since 2010, China has been increasing at an average annual rate of 28%. At present, China ranks first in the world in terms of development scale of shallow geothermal energy using ground-source heat pump technology. The single heating (cooling) area is getting larger and larger, and the super large ground-source heat pump system with the single heating (cooling) area greater than 1 million m2 continues to appear. In the next 10 to 15 years, there will still be a development trend of "high-speed nationwide, large-scale cities, and large-scale individual units", and it is urgent to change the development model from the scale-speed growth in the past to the quality and efficiency growth.

Quality-benefit growth requires large-scale and ultra-large-scale ground-source heat pump systems to save energy and increase efficiency, and the key geological problems of underground heat exchange systems are one of the main factors that affect their energy conservation and efficiency, and should be highly valued. Therefore, it is necessary to study the key geological problems affecting the efficient heat exchange of the ultra-large-scale ground-source heat pump underground heat exchange system, propose solutions, and scientifically support the efficient, sustainable and large-scale development of the ground-source heat pump industry.

2. RESEARCH ON KEY GEOLOGICAL PROBLEMS OF GROUND-SOURCE HEAT PUMP UNDERGROUND HEAT EXCHANGE SYSTEM

The key geological problems of the ground-source heat pump underground heat exchange system are mainly the distribution law of the shallow geothermal energy, the thermal response characteristics and the heat transfer contribution rate characteristics in the subsurface rock-soil body. The mining of shallow geothermal energy mainly realizes the heat transfer between the above-ground buildings and the subsurface rock-soil body and water through the ground-source heat pump system and heat transfer medium. It is different from other solid, liquid, and gas energy sources. The resource conditions and heat transfer process are "invisible", which requires a new research idea and method.

2.1 Research ideas and methods

Through the long-term monitoring of the ground-source heat pump project in operation, it is found that under the condition of the same inlet and outlet water temperature of the main pipe on the ground-source side of the system, the original temperature, response temperature and The heat transfer efficiency of the subsurface rock-soil body with different depths in the same heat exchange well and different heat exchange wells in the same depth are obviously different. It is inferred that the characteristics of shallow geothermal energy resources are obviously different under different geological conditions, and the heat exchange effect between the buried pipe and the subsurface rock-soil body contributes to the increase or decrease of the water temperature on the ground-source side of the system. Therefore, the concepts of initial temperature (T_o), response temperature (T_r), response temperature difference (ΔT_r) and heat transfer contribution rate ($\emptyset_Q$) are proposed.

When the ground-source heat pump mining shallow geothermal energy starts to operate, the initial temperature (T_o) is "thermally disturbed" to generate the response temperature (T_r), and the difference between the response temperature and the initial temperature is the response temperature difference (ΔT_r), and the buried pipes are replaced in different formations. The ratio of heat (Q_{sn}) to system ground-source side heat transfer (Q_g) is related to the response temperature difference (ΔT_r) of rock-soil body, which reflects the heat transfer contribution of the buried pipes in different strata. This contribution is called heat contribution rate ($\emptyset_Q$).

The theoretical basis of the heat transfer contribution rate ($\emptyset_Q$) is to assume that the buried pipe is a line heat source, and the temperature at different depths in the well is used as the temperature value of the line heat source at this point (layer). Therefore, the calculation formula of the heat transfer contribution rate ($\emptyset_Q$) of the buried pipe in different layers of rock-soil body is shown as follows:

$$\emptyset_{Qn} = \frac{Q_{sn}}{Q_g} = \frac{\int K_s \Delta T_r dL}{V \rho c \Delta T_g} = \frac{K_{sn}(T_{rn} - T_{on}) L_n}{V \rho c (T_{g1} - T_{g2})} \quad (1)$$

$\emptyset_{Qn}$- Contribution rate of heat transfer of buried pipe in the nth layer of rock-soil body;

Q_{sn}-Heat transfer of buried pipe in the nth layer of rock-soil body , kW·h;

Q_g-Heat exchange on the ground-source side of the system, kW·h;

K_{sn}-Heat transfer coefficient of the nth layer of underground rock and soil, W/(m·℃);

ΔT_r-Response temperature difference of the nth layer of rock-soil body;

T_{rn}-Response temperature of the nth layer of rock-soil body, ℃;

T_{on}-Initial temperature of the nth layer of rock-soil body, ℃;

L_n-Thickness of the nth layer of rock-soil body, m;

V -Flow rate of circulating working medium on the ground-source side of the system, m3/s;

ρ -Density of circulating working medium on the ground-source side of the system, kg/m3;

c -Specific heat of the circulating working medium on the ground-source side of the system, kJ/(kg·℃);

ΔT_g-Temperature difference between the circulating working fluid in and out of the ground-source side of the system, ℃;

T_{g1}-Outlet temperature of the circulating working fluid at the ground-source side of the system, ℃;

T_{g2}-Inlet temperature of the circulating working fluid at the source side of the system, ℃ (Fig. 1).

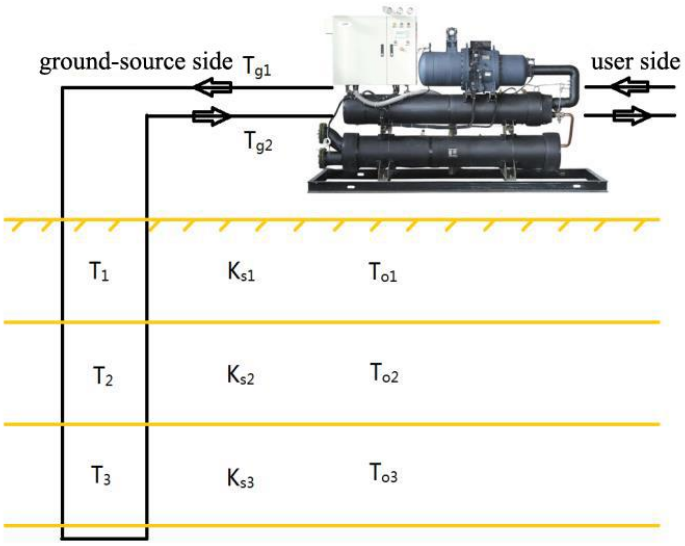


Fig.1 Temperature relation of rock-soil body between user side and ground-source side

It can be seen from (Equation 1) that the heat transfer contribution rate ($\emptyset_Q$) is positively correlated with the response temperature difference (ΔT_r), heat transfer coefficient (K_s) and thickness of rock-soil body ( ). K_s、 L 、 ρ c are constants; ΔT_r、 V 、 ΔT_g are variables, The value can be obtained by monitoring, and its variation directly affects the contribution rate of heat transfer ($\emptyset_{Qn}$). Therefore, it is necessary to study the variation characteristics of rock-soil body response to temperature difference (ΔT_r). Based on the collected monitoring data, the heat transfer contribution rate ($\emptyset_{Qn}$) can be calculated according to (Equation 1).

A ground-source heat pump project located in Haidian District, Beijing is selected as the research object. The heating (cooling) area of the project is 430,000 m2, and the buried pipe area A is a cuboid with the size of 115m×30m×120m, and the buried pipes are arranged in a grid of 5m×5m. Considering that the flow direction of groundwater in Beijing is basically from northwest to southeast, the monitoring wells are arranged in the upstream, midstream, downstream and the vertical flow direction of

groundwater (Fig. 2). Temperature sensors are arranged along the wall of each monitoring well (Fig. 3) to collect the monitoring data before and during the operation of the ground-source heat pump, and the temperature data of the inlet and outlet water of the main pipe at the ground-source side.

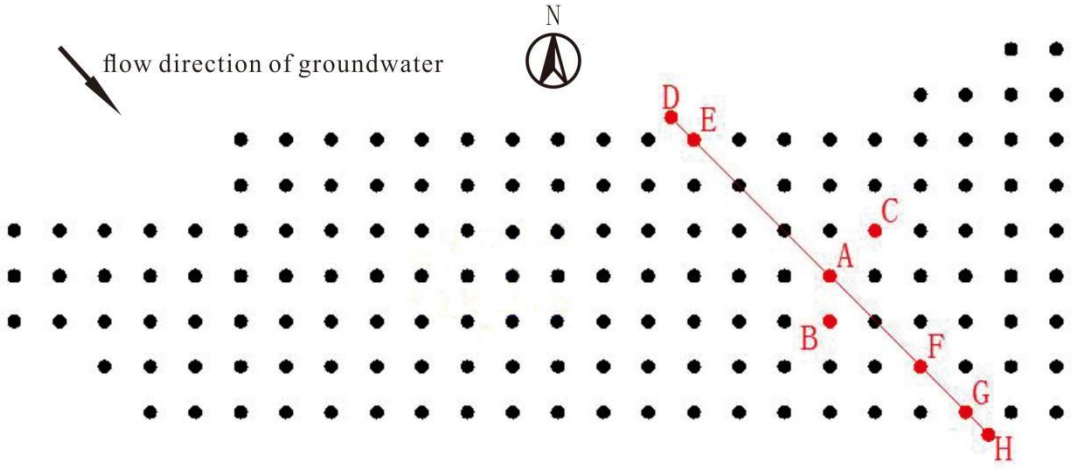


Fig.2 Schematic diagram of monitoring well layout

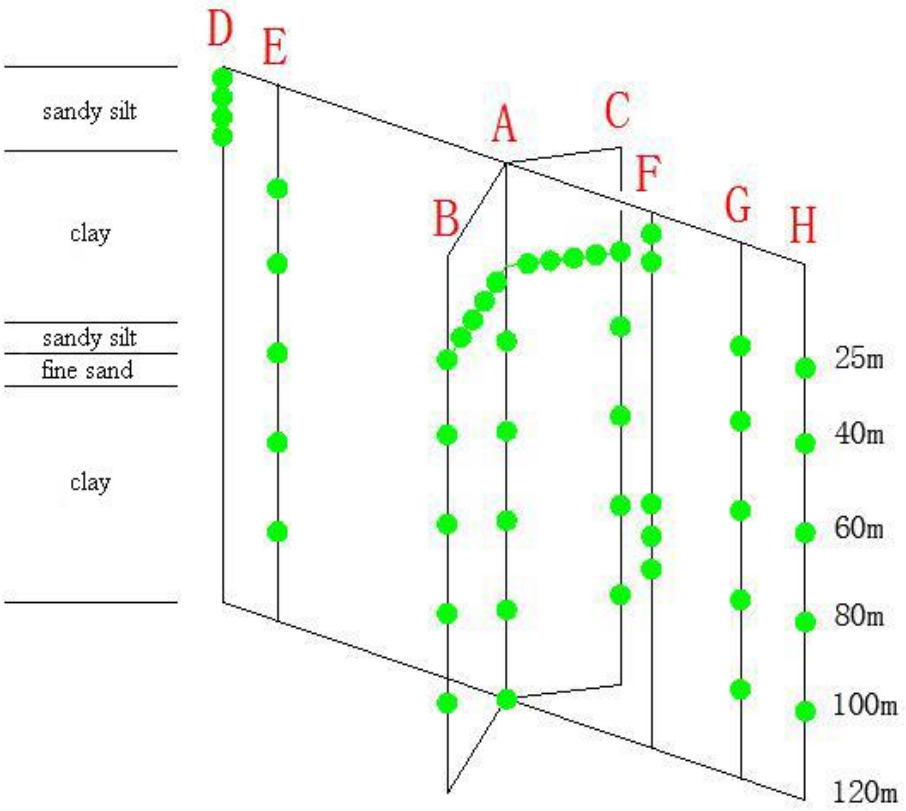


Fig.3 Schematic diagram of temperature sensor layout

2.2 Distribution feature of initial temperature(T_o)

As can be seen from Table 1 and Figure 4, the subsurface rock-soil body in the ground heat exchanger zone is not a "homogeneous body". There are obvious differences in the original temperature of rock-soil body at different depths, and the stratification of variable temperature zone, constant temperature zone and increasing temperature zone is not obvious. The geothermal field is a relatively open system controlled by geological conditions, and its shallow geothermal energy distribution law is obviously restricted by geological conditions and is irregular. It is not a simple plate-shaped "homogeneous body", indicating that there is currently no scientific basis for laying buried pipes at equal intervals.

Table 1. Comparison table of initial geothermal field characteristics of shallow geothermal energy

Depth (m)	Initial temperature (℃)							Joint Profile (℃)	E-A-H Profile (℃)	B-A-C Profile C- (℃)
	E	A	B	C	F	G	H			

2.00	5.8	5.8	5.8	5.0	5.8	5.8	5.8	5.8	5.8	5.8
25.00	13.3	12.2	12.6	12.3	12.3	14.8	13.4	13.0	13.2	12.4
40.00	13.1	10.8	9.9	12.2	12.8	13.7	14.9	12.5	13.1	11.0
60.00	11.7	8.7	12.3	12.0	12.6	14.2	13.1	12.1	12.1	11.0
80.00	8.8	11.5	9.2	-	12.7	13.3	13.0	11.4	11.8	10.3
100.00	12.3	12.3	12.0	11.9	13.7	12.6	14.9	12.8	13.1	12.0
120.00	10.2	9.3	-	11.3	-	-	-	10.3	9.8	10.3
average （℃）	10.7	10.1	10.3	10.9	11.6	12.4	12.5	11.2	11.3	10.4

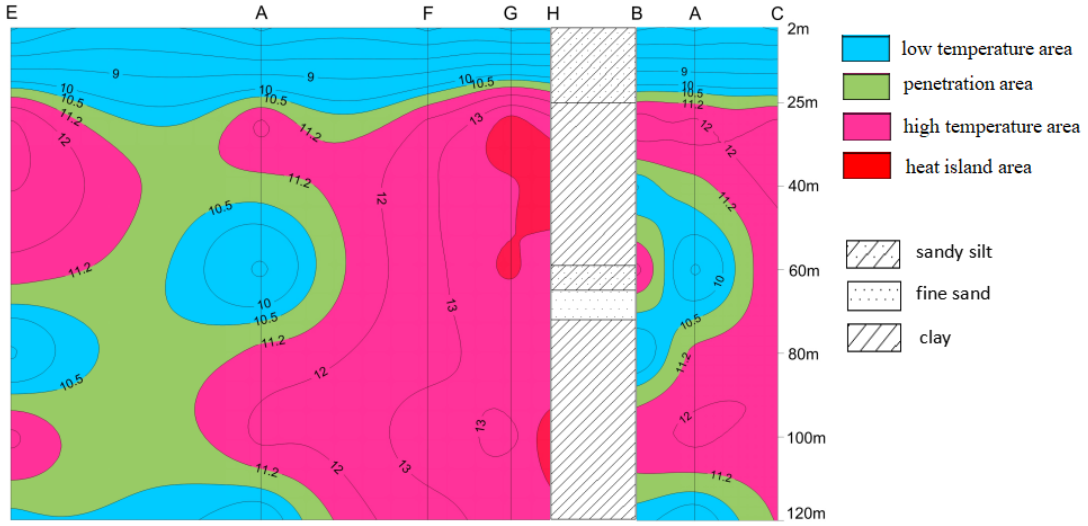


Fig. 4 Joint profile of initial temperature field distribution（3.15）

(1)The initial temperature varies greatly. It can be seen from Table 1 that the lowest initial temperature of rock-soil body is 8.7°C in the normal temperature layer (25m underground) in the mining area , which is located at -60m from well A in the midstream ; the highest initial temperature is 14.9°C, which is located at -40m from the well H in the most downstream of the mining area (5m outside the mining area); the difference between the maximum initial temperature and the minimum initial temperature of rock-soil body is 6.2 °C in the distance of only 23m , indicating that the initial geothermal field in this area has a large variation.

(2)The spatial distribution is complex. It can be seen from Figure 4 that the spatial distribution of the initial temperature of rock-soil body is complex, which is not the plate-like "homogeneous body" in the traditional concept, it is an irregular shape controlled by multiple factors. Taking the mean initial temperature of the joint profile as the boundary of 11.2 °C, it is divided into a low temperature area (light blue-emerald green) and a high temperature area (pink-red). The low temperature area is divided into the light blue low temperature area (≤10.5℃) and the emerald green thermal (structural) penetration area (10.5℃~11.2℃) with the bottom boundary temperature of the normal temperature layer at 10.5℃; The high temperature area is divided into pink high temperature area (11.2~14℃) and red heat island area (≧14℃) by the average temperature of the normal temperature layer in Beijing.

(3)The effect of multi-factorial compound control is obvious. It can be seen from Figure 4 that there is an equilibrium interface (the bottom interface of the normal temperature layer) between geothermal energy and solar energy. The temperature of the bottom interface of the normal temperature layer is 10.5℃. The area below 10.5℃ is classified as a light blue low temperature area, which is mainly distributed in the temperature-changing layer above the bottom boundary of the normal-temperature layer and the fine sand and sandy clay distribution area with better permeability in the temperature-increasing layer, reflecting that the initial temperature of fine sand and sandy clay distribution area with good permeability is relatively low. The emerald green (structural) thermal penetration area (10.5℃ ~ 11.2℃) reflects the tectonic space distribution pattern, groundwater heat energy can be transferred along this structure. The pink high temperature area (11.2~14℃) is mainly the clay distribution area with poor water permeability, and the initial temperature of the clay distribution area with poor water permeability is relatively high. The red heat island area (≧14℃) is distributed in the clay "islands" with poor water permeability, and this "heat island" has poorer heat transfer ability. It is obviously controlled by the bottom boundary temperature, structure, stratigraphic lithology and hydrogeological conditions of the normal temperature layer.

2.3 Distribution characteristics of response temperature (T_r)

(1)Two typical days of heating (2.25) and cooling (8.4) in the operating season of the system are selected to study the temperature variation characteristics of rock-soil body response. It is found that during the operation of the ground-source heat pump, different parts of subsurface rock-soil body have different thermal (cold) responses to the water temperature change at the ground-source side of the system, both positive and negative response, and there are obvious differences in the response degree of the same

response properties, which can be characterized by the positive and negative temperature difference of thermal (cold) response. (Table 2).

(2)Under heating condition, the response temperature distribution of rock-soil body is similar to the initial temperature distribution, with obvious "similarity" (Fig. 5), which reflects that the penetration area of the structure still exists, and heat energy can be transferred along the penetration area.

(3)Under cooling condition, the response temperature distribution of rock-soil body is significantly different from the initial temperature distribution (Fig. 6). Under the influence of atmospheric temperature, the response temperature of the variable temperate zone above 25m increases significantly. There is also an obvious heat transfer phenomenon inthe penetration area.

Table 2. Comparison table of rock-soil body response temperature characteristics under heating state (2.25)

Depth (m)		Temperature (℃)							Joint Profile	E-A-H Profile	B-A-C Profile
		E	A	B	C	F	G	H			
2	Initial	5.8	5.8	5.8	5.0	5.8	5.8	5.8	5.8	5.8	5.8
	Response	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Difference	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
25	Initial	13.3	12.2	12.6	12.3	12.3	14.8	13.4	13.0	13.2	12.4
	Response	13.2	11.3	12.7	12.3	12.3	14.0	13.0	12.6	12.6	11.9
	Difference	-0.1	+0.1	+0.1	0	0	-0.8	-0.4	-0.4	-0.6	-0.5
40	Initial	13.1	10.8	9.9	12.2	12.8	13.7	14.9	12.5	13.1	11.0
	Response	13.1	11.0	9.9	12.2	12.8	13.7	14.8	12.4	13.1	10.8
	Difference	0	+0.2	0	0	0	0	-0.1	-0.1	0	-0.2
60	Initial	11.7	8.7	12.3	12.0	12.6	14.2	13.1	12.1	12.1	11.0
	Response	11.7	8.7	12.3	12.0	12.5	14.2	12.9	12.0	11.9	11.6
	Difference	0	0	0	0	-0.1	0	+0.2	-0.1	-0.2	+0.6
80	Initial	8.8	11.5	9.2	-	12.7	13.3	13.0	11.4	11.8	10.3
	Response	8.7	11.4	9.1	-	12.6	13.2	13.0	11.4	11.8	10.3
	Difference	-0.1	-0.1	-0.1	-	-0.1	-0.1	0	0	0	0
100	Initial	12.3	12.3	12.0	11.9	13.7	12.6	14.9	12.8	13.1	12.0
	Response	12.2	12.3	12.0	11.8	13.4	12.6	14.8	12.8	13.2	12.0
	Difference	-0.1	0	0	-0.1	-0.3	0	-0.1	0	+0.1	0
120	Initial	10.2	9.3	-	11.3	-	-	-	10.3	9.8	10.3
	Response	10.3	9.3	11.2	-	-	-	-	11.9	12.1	10.8
	Difference	+0.1	0	-	-	-	-	-	+1.9	+2.3	+0.5
Average	Initial	10.7	10.1	10.3	10.9	11.6	12.4	12.5	11.2	11.3	10.4
	Response	10.6	9.9	10.3	10.8	11.4	12.1	12.3	11.1	11.3	10.3
	Difference	-0.1	-0.2	0	-0.1	-0.2	-0.3	-0.2	-0.1	0	-0.1
Note: Inlet temperature of main pipe is 11.4℃, outlet temperature of main pipe is 9.8℃, △T (outlet temperature - inlet temperature) =-1.6℃.											

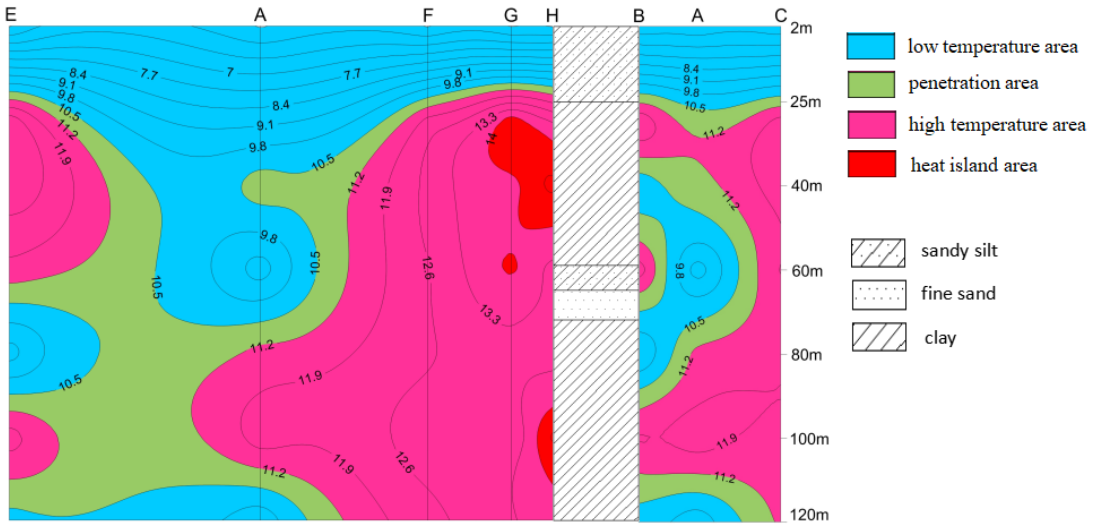


Fig. 5 Joint profile of response temperature distribution under heating condition (2.25)

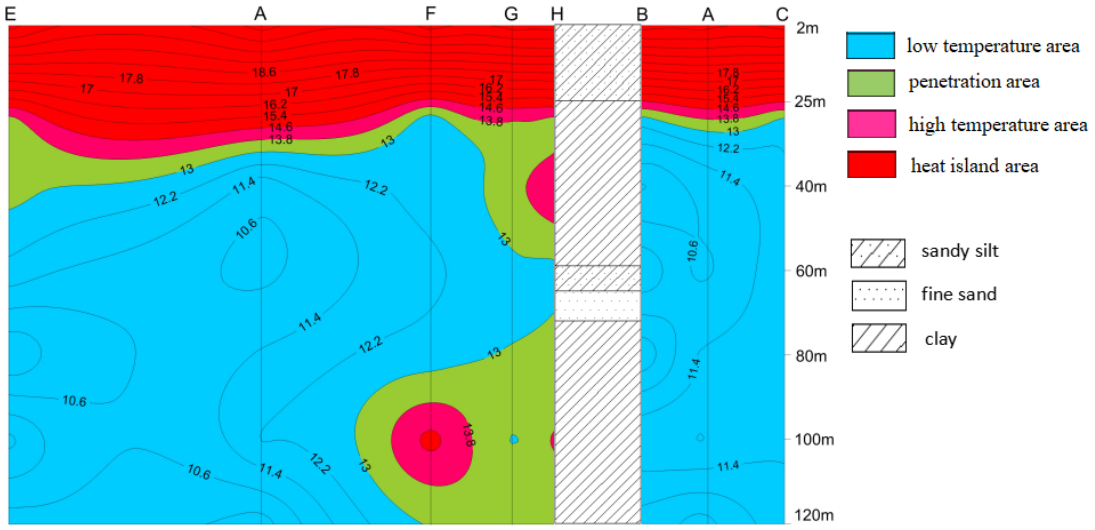


Fig. 6 Joint profile of response temperature distribution under cooling condition (8.4)

2.4 Distribution characteristics of heat transfer contribution rate ($\emptyset_Q$) of shallow geothermal energy.

During the operation of ground-source heat pump, the characteristics of heat (cold) exchange contribution rate of different parts of subsurface rock-soil body and different heat exchange wells are obviously different.

(1)Under the heating condition, the heat exchange contribution rate of rock-soil body with low initial temperature is often negative. In the heating season, about 1/7 heat exchange wells have a negative contribution rate, which means 1/7 wells "do not supply heat" in the heating season(Fig.7).

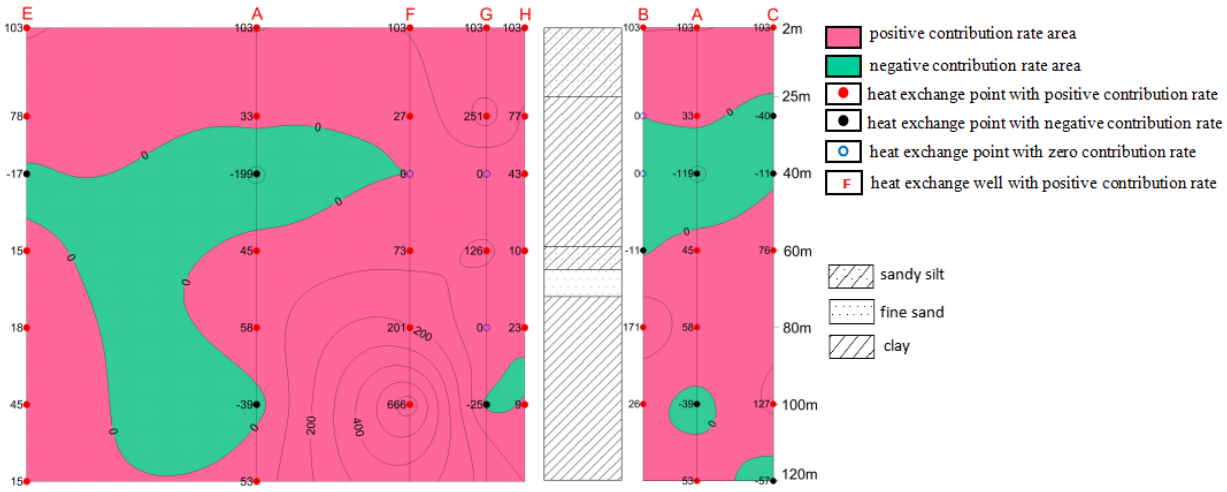


Fig. 7 Joint profile of heat exchange contribution rate distribution under heating condition (2.25)

(2)Under the cooling condition, the heat exchange contribution rate of rock-soil body with high initial temperature is often negative. In the cooling season, about 2/7 heat exchange wells have a negative contribution rate, which means 2/7 wells "do not provide cooling" in the cooling season(Fig.8).

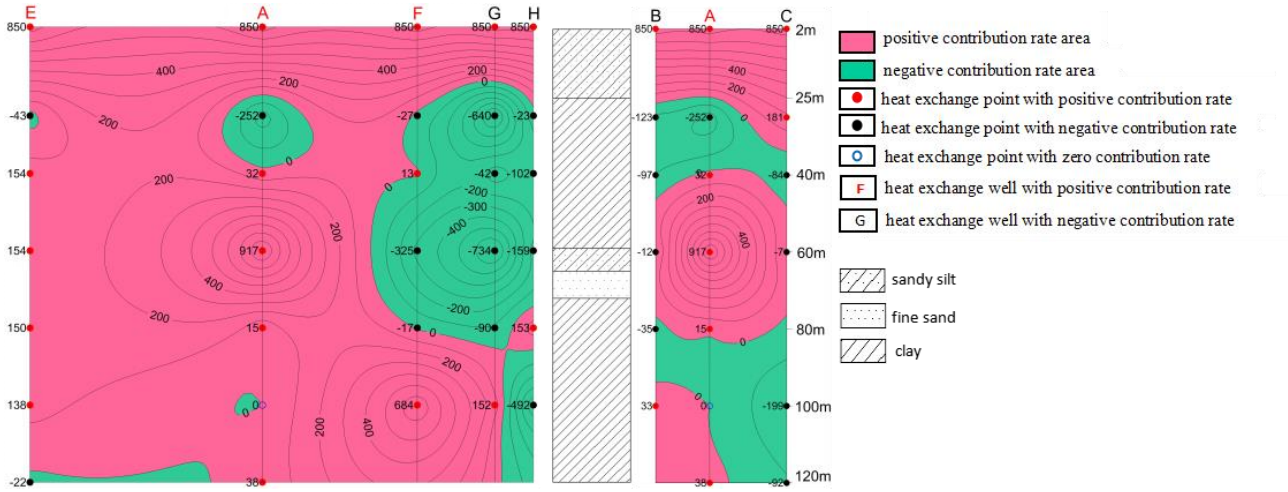


Fig. 8 Joint profile of heat exchange contribution rate distribution under cooling condition (8.4)

In the future exploration and evaluation of shallow geothermal energy, the shallow geothermal energy "resource body" with high heat transfer contribution rate under the two states of heating and cooling should be searched. The underground distribution law can reflect the actual heat exchange characteristics of buried pipes and geological bodies at different locations. Through optimized design, scientific construction and intelligent management and control, the mining efficiency of shallow geothermal energy resources can be greatly improved, and the purpose of energy saving and efficiency improvement can be achieved.

From this point of view, the larger the mining scale of a single project, the more restrictive the resource conditions will be. It is unscientific to lay buried pipes at equal intervals and depths of a certain network, which will result in low heat exchange efficiency and poor energy saving. It is necessary to study the theory of heat exchange contribution rate and carry out exploration and evaluation of shallow geothermal energy based on the evaluation of heat exchange contribution rate. According to the size and positive or negative of the heat transfer contribution rate, the network degree and depth of laying buried pipes are determined differently. It is bound to save energy and increase efficiency if the buried pipes with negative work are closed in time. An intelligent control device should be installed at the upper end of each vertical buried pipe to scientifically and intelligently control the operation of the underground heat exchange system. Therefore, it is necessary to study and propose "solutions to key geological problems of super large-scale ground-source heat pump underground heat exchange systems".

3. SOLUTIONS TO KEY GEOLOGICAL PROBLEMS IN THE UNDERGROUND HEAT EXCHANGE SYSTEM OF SUPER LARGE-SCALE GROUND-SOURCE HEAT PUMP

"Four methods" solutions to the key geological problems of the super large-scale ground-source heat pump underground heat exchange system should be propsed in order to scientifically support the efficient, sustainable and large-scale development of ground-source heat pump industry:

the “quantitative study “on the genetic mechanism of shallow geothermal energy; the "refinement" of the exploration and evaluation of shallow geothermal energy in subsurface rock-soil body; the "intellectualization" of the operation and control of ground-source heat pump system; the "scientization" of multi energy coupling.

3.1 the “quantitative study “on the genetic mechanism

The idea of "model" is used to solve the problems of the distribution law of shallow geothermal energy and the "invisibility" of heat exchange process in rock-soil body. Using the correlation between the "inlet and outlet temperature difference" of the heat pump system and the "response temperature difference" of the rock-soil body during the mining process, the distribution law and heat transfer mechanism of shallow geothermal energy resources are quantitatively analyzed to study and put forward heat contribution theory, analysis of shallow geothermal heat control factors, which provides a theoretical basis for the "refinement" exploration and evaluation of shallow geothermal energy heat exchange contribution rate. The research contents include:

(1) Analyze the genesis type of the mining area, study the suitability of the mining method, carry out high-precision ground feature rhinestones, delineate the lithology, structure and aquifer distribution of rock-soil body, carry out thermophysical property tests, determine the scope of the study area, and establish a research 3D geological model of the area.

(2) Analyze the initial temperature and response temperature distribution characteristics of shallow geothermal energy in the mining area, study the variation law of initial temperature and response temperature of different heat exchange wells and different heat exchange sections, and establish the initial temperature field model and response temperature model of the study area.

(3) Calculate the response temperature difference and heat transfer contribution rate of rock-soil body, analyze the heat (cold) response characteristics and response degree, and establish a shallow geothermal energy heat exchange contribution rate model.

(4) Delineate the target body or heat exchange well with high heat exchange contribution rate, determine the heat exchange contribution rate attribute of the borewell, delineate the range of high contribution rate "body" and negative contribution rate "body", and establish a digital twin of heat transfer contribution rate theoretical model.

3.2 the "refinement" of the exploration and evaluation

"Evaluation System and Standards for Shallow Geothermal Energy Exploration in Mining Areas" is established to carry out shallow geothermal energy exploration evaluation mainly based on the evaluation of heat transfer contribution rate, and provide a basis for determining the network degree and depth of buried pipes according to the size, positive and negative heat exchange contribution rate. The exploration and evaluation process is shown in Figure 9.

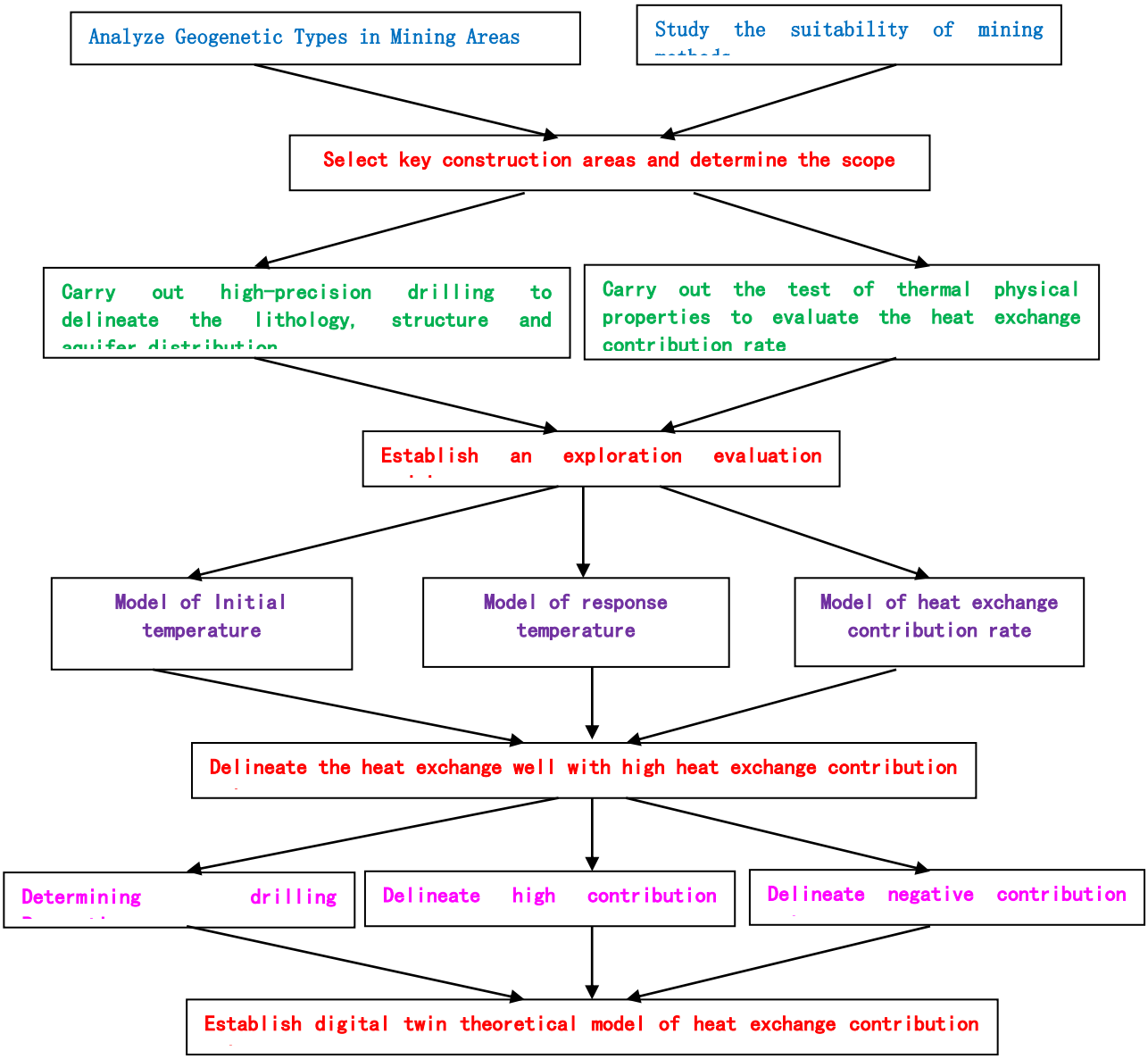


Fig. 9 Flow chart of shallow geothermal energy exploration and evaluation in mining area

3.3 the "intellectualization" of the operation and control

According to statistics, the overall energy utilization rate of most central air-conditioning systems is still very low, only 60% to 70%. By adding an intelligent control management system and matching operation strategies, management functions, and control requirements, the operating energy consumption can be reduced by 10%. ~30% (Zhang Hao et al., 2020). Especially for buried pipe ground-source heat pump systems, the control of energy consumption and heat exchange efficiency on the ground-source side is particularly important. Therefore, it is necessary to establish and use a perfect monitoring system to implement intelligent management and control of shallow geothermal energy resources and the operation of the above-ground heat pump system. According to the performance of different buried pipes, it is necessary to carry out zoning or perforation control to improve the underground heat exchange. Efficiency, rational allocation of shallow geothermal energy resources scientific development.

3.4 the "scientization" of multi energy coupling

In December 2020, the State Council Information Office released "China's Energy Development in the New Era", proposing to build a multi-source and clean energy supply system. Innovating the development and utilization mode of geothermal energy, carrying out central heating of geothermal energy in cities and towns, and building a demonstration area for the efficient development and utilization of geothermal energy (State Council Information Office, 2020).

In the future, there will be more and more large-scale shallow geothermal energy development and utilization projects in cities. A single energy source cannot meet the needs of construction. The trend of development is the composite application of multiple

energy sources and the energy regionalization. The use of scientific, ecological and environmental protection requirements is higher. The development and utilization of shallow geothermal energy should be scientifically integrated into the regional energy system, and an energy supply system should be built together with other energy forms to improve the quality and security of energy supply. For example, when the thermal energy of urban underground space or shallow strata is insufficient, heat can be obtained from deeper strata, or it can be applied in other forms of energy peak-shaving and coupled, and it can become an effective supplement to the urban heating network.

Research on basic scientific problems is the main support for innovation and development, and solving the scientific problems of shallow geothermal energy development is the only way to achieve large-scale, sustainable and high-quality development in the future. Furthermore, it will make positive and contributions to realize China's "carbon peak" and "carbon neutrality" goals as soon as possible.

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