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Shallow Geothermal Energy + Solar Power Multi-energy Complementary Household Heating (cooling) Technical Solutions and Case Studies

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ABSTRACT

The shallow geothermal energy is used to provide household heating heat source for rural buildings, and the rooftop solar power generation and commercial power are complementary to provide driving power for the heat pump system, which can realize the optimization of environmental and economic benefits. Taking the actual project of Yihepu rural in Zhangjiakou competition area of Beijing Winter Olympic Games as an example, this paper introduces the application and practical benefits of taking shallow geothermal energy + solar power generation energy complementary as household heating (cooling) in rural buildings. By 2022, the project has been stable operation for 6 years, using single well circulating heat transfer technology to collect shallow geothermal energy, centralized geothermal energy exchange and transmission, household heating,the heat pump equipment in each room is independent, successfully solved the rural family heating high energy consumption, poor thermal comfort, points room control difficulty, low distribution network capacity of rural family clean heating common problems, realize the regional heating zero carbon emissions. At the end of this paper, a new generation of low-voltage DC power supply driven multi-energy coupling household heating (cooling) system scheme is proposed, which can realize zero-carbon heating (cooling) in rural buildings.

1. INTRODUCTION

Rural areas in northern China have a large population and a wide area, belonging to severe cold or cold regions. Historical reasons cause the poor insulation performance of rural building maintenance structure, the high height, and the building area is generally large, which is 1.5-2 times higher than the heating energy consumption of urban residential buildings[1]. Rural housing needs a " intermittent heating and part of the room heating" heating mode[2]. On the other hand, the rural power supply capacity is limited, it is difficult to realize the conventional electric heating and other electric replacement of coal heating transformation. Rural households need a heating (cooling) system with low power distribution, flexible division control, energy-efficient, environmental protection and economy.

This paper proposes shallow geothermal energy as an alternative energy source for rural building heating in northern China. Solar power generation driven heat pump operation for rural household heating (cold) to provide solutions and attempt to solve the bottleneck problem of clean heating (cooling) for rural households in northern China.

2. TECHNICAL SOLUTION

2.1 Shallow geothermal energy household heating (cooling) system

Shallow geothermal energy is widely distributed and rich in reserves. The single well circulating heat transfer technology to develop and utilize this energy source for heating, cool buildings and make domestic hot water, which has a good energy saving and environmental protection effect[3]. Using single well circulation heat transfer centralized collection shallow geothermal heat energy household heating (cooling) system is referred to as single well circulation heat exchange geothermal household heating system, using centralized geothermal energy heat exchange station, the heat source water with a temperature below 25 degrees Celsius is transported to the heat pump equipment in each room through the geothermal transmission pipe network. The indoor unit of heat pump equipment is heat pump heat fan type similar to ordinary split air conditioning. The system shown in Figure 1.

The system has the advantages of flexible control and simple operation of ordinary household split air conditioning, which can realize household electric metering and separate room control for home heating (cooling), and the power distribution is lower than ordinary split air conditioning. The differences between single well circulating heat exchange geothermal energy household heating system and ordinary geothermal source heat pump system are shown in Table 1.

2.2 SYSTEM INNOVATION

2.2.1 Indoor unit configured in the sub-room

The heat pump equipment in each room is independent. Therefore, the user can adjust the temperature start and stop, and the temperature in the room can be controlled in the range of 16-32 degrees Celsius. Even if the machine is not running, it will not be frozen. Turn on the equipment when people enter the room, and turn it off when they leave the room. This design innovation avoids the energy waste caused by the heating of the entire building, and is conducive to the realization ‘intermittent heating and part of the room heating’ heating mode. Geothermal energy household heating equipment is frequency conversion control, adjusting the working frequency of the heat pump unit according to the number of indoor unit used and indoor and outdoor temperature, high efficiency and energy saving.

2.2.2 Floor-type lower air outlet structure heat dissipation design suitable for rural building heating

The indoor unit of geothermal household heating system is a Floor-type lower air outlet structure, which is installed on the ground or 0.2-0.3m wall hanging from the ground. The main air outlet is below and the secondary air outlet is up. The lower air outlet is the main air outlet,while the upper outlet can flexibly adjust the angle of the air outlet, and the warm air heating is directed in the space of the people in the room, so that the active area can quickly heat up.In the special lower outlet air supply the air can flow and spread close to the ground. As the hot wind gradually rises naturally, the temperature of the whole room rises uniformly, to achieve the comfort of floor heating, and the heating speed is fast, as shown in Figure 2.

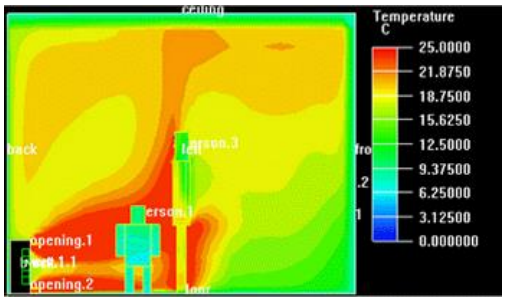

Figure 2 Floor-type lower air outlet structure heating room temperature field

The temperature of the indoor unit heating room is 3-7℃ higher than that of the roof and surrounding space and the heating energy consumption is reduced by about 15%. Floor-type lower air outlet structure heat dissipation makes the room temperature have the effect of a high temperature near the floor space, improves the room temperature and comfort, and solves the problems of large heating energy consumption and low temperature caused by the large space of rural buildings.

2.2.3 Multiple energy sources complement each other

The operation mode of the solar power generation system generate electricity given priority to own use and the rest is sold to the grid. In the transition season, solar power generation is preferentially used in household appliances, the rest electricity is sold to the grid. In the heating (cooling) period, solar power generation is preferentially applied to geothermal energy heating equipment. When the solar power generation is greater than the power consumption, the power consumption of geothermal energy heating system and household appliances is all provided by solar power, When the power is less than the power consumption, the rest is provided by the municipal power grid; The heat of the system comes mainly from shallow geothermal energy, heat pump equipment consumes only a small amount of electricity. [4]。

The power consumption of heating and cooling system is less, and the coupling with solar power generation can generate more surplus green electricity, which brings economic benefits, and well solves the demand of heating (cooling) and income generation of rural buildings.

3. DESIGN PARAMETERS AND OPERATING DATA OF THE CASE

Yihepu Rural is located in Huailai County, Zhangjiakou City, near by the the Beijing winter Olympics center. The annual average temperature is 5.5- -6.5℃, and the heating design temperature in winter is-13.6℃. It is a cold area A. The annual total radiation of solar energy is 5700-6100 MJ / ㎡, which belongs to the second class resource area.

3.1 Scheme configuration

The buildings in Yihepu Rural are all single-story buildings, with 370mm red brick wall and no insulation, and the doors and Windows are single-layer wood or single-layer aluminum alloy materials. Each household is 13.2m long from east to west and 7.8m long from north to south, with a heating area of about 100 ㎡. According to 18℃ in winter and 26℃ in summer, the annual heating heat load is 10,478 kW.h, and the annual cooling load is 3,323 kW.h.

The whole rural has 265 households, divided two areas, east and west. Each household designs two geothermal energy household heating equipment, one equipment has 7.6kW heat, input power 1.9kW, the other equipment has 3.7kW heat and input power 0.9kW. Each household solar power generation uses 20 265Wp photovoltaic modules, with a total power of 5.30kWp. The multi-energy complementary power supply system adopts a 5kW photovoltaic inverter, which is connected to the 220V line to the original indoor distribution box of the home, and then connected to the indoor low-voltage distribution network through the 220V line. Shallow geothermal energy + solar power generation multi-energy complementary household heating (cooling) system is configured as shown in Table 2.

3.2 Operating data of the case

In June 2022, the company conducted a field investigation and return visit to the project, to feedback the data of 236 households, and sorted out the system application data for 6 years. There are mainly three types of operating data. The first type is coal burning amount and indoor temperature before renovation; The second type is heating (cooling) power consumption, indoor temperature, indoor heat dissipation equipment startup time and daily living electricity consumption; and the third type is solar power generation and actual income.

3.2.1 Comparison of heating before and after renovation

Before the renovation, farmers burned coal-fired stoves for heating, and manually added coal blocks and removed coal cinders every day. Each household in one season burns is 2.5-3.5t (the calorific value of bulk coal is 5000kcal / kg), equivalent to the standard coal of 1.79-2.5t. There are 75% of the home heating room temperature is lower than 16℃, the room temperature changes greatly with the operation of coal addition, the heating temperature is not stable. After the transformation, the farmer remote control controls the indoor units start and stop, easy to operate. Winter heating power consumption is 2200-3190kW.h, 80% of the user feedback heating room temperature is about 18℃, 20% of the user feedback temperature is more than 20℃, and the geothermal energy household heating system can be used as a cooling system in summer. Users generally regard it as comfortable and convenient.

3.2.2 Use of the indoor unit

According to the field research and user feedback,most farmers use the mode of " only turning on the indoor unit of the room in use during the day, and only turning on the indoor unit of the bedroom at night" . The boot time cake chart of the indoor unit is shown in Figure 3. It can be seen that the proportion of indoor units running ≤ 6h and 7h-12h per day accounted for 32% and 48%, respectively, and the number of indoor units running continuously for 21h or more accounted for 6%. The users of continuous use are families with children or sick elderly people. Our specially designed indoor unit with room adjustment conforms to the heating mode of " intermittent heating and part of the room heating" , which meets the habit of ‘saving energy’ in rural families to the maximum extent, and behavior energy saving and reduces energy consumption.

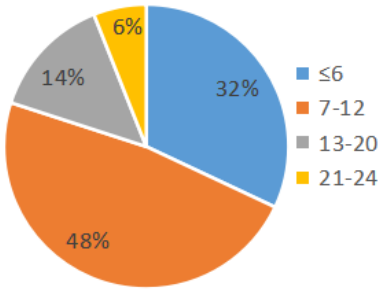

Figure 3. Table chart of the startup time of the indoor unit

3.2.3 Annual economic income of families

By 2022, the project has been in stable operation for 6 years. The total power consumption of the geothermal energy household system is 6.00 million kW.h. The total solar power generation is 12.36 million kW.h and the amount of electricity delivered to the grid is 10.26 million kW.h.

The benefits of the multi-energy complementary system from the Zhang’s home from August 1,2020 to July 31,2021 are shown in Table 3. The annual power generation is 8183kW.h, the on-grid power is 6955kW.h. Excluding heating and cooling households, the annual electricity consumption is 1,948 kW.h, and the annual power consumption of the heating and cooling households system is 4032.6kW.h. Solar power generation income is 6899.4 RMB, the electricity purchased is 2471 RMB, and the total household net income is 4428 RMB.

4. APPLICABILITY ANALYSIS

4.1 Economic analysis

In the implementation process of rural electricity replacing coal, the life span and maintenance costs of the system equipment are different due to the residents' different choices of heating methods. The annual cost value method is used to calculate the economics of each system. The formula of the annual system cost value Y is:

$$Y = C\frac{i(1+i)^n}{(1+i)^n - 1} + F$$

In: annual value of Y —— system,RMB / a;

C —— system cost,RMB;

I —— Bank interest rate, take 0.0465;

n——system lifetime;year(a);

F Annual operating expenses of the —— system, including electricity charges and maintenance and management costs, RMB / a;

On the premise of meeting the needs of rural households for heating in winter and cooling in summer, analyze the economics of geothermal energy household heating system and solar power generation coupling system and household low temperature air energy heat pump and solar power generation type coupling system, as shown in Table 4.

Heating(Cooling) system	Geothermal energy (Geothermal energy household heating) + Solar power generation	Air energy heat pump + Solar power generation

Heat pump equipment cost (RMB)	28981	18000
Solar power generation equipment (RMB)	33962	33962
Service life (years)	20	15
Annual electricity charge (RMB)	-4428	-2614.2
Maintenance and management expenses (RMB)	629.43	519.62
Annual value of cost (RMB)	1103	2793

Table 4 Cost comparison of the system

Remarks:

① Yihepu Rural shallow geothermal energy household heating (cooling) system investment of 7.68 million RMB, solar power generation system investment of 9 million RMB;

② According to the data in Table 3, the heating heating consumption is 3190.6kW.h in winter and 842kW.h in summer, which all include the shared power of the geothermal energy heat exchange station; the total income of the coupling system is 4,428RMB;

③ Air energy heat pump, the heat fan equipment costs 6000RMB / set[5], Air energy heat pump energy consumption 55.3kW.h/㎡ · heating season[6]The heating energy consumption of a household in winter is 5530kW.h; the refrigeration coefficient is calculated as 3.5, and the refrigeration power consumption is 950kW.h; According to the data of Table 3, the total annual income of the coupling system is RMB 2614.2RMB;

④ Maintenance and management expenses are estimated at 1% of the total system investment.

The annual cost of geothermal energy household heating system+ solar power system is 1252RMB / year, and the annual cost of air energy heat pump + solar power system is 2793RMB / year. The promotion of geothermal energy + solar energy multi-energy complementary system has greater economic benefits.

4.2 Environmental benefit analysis

Environmental benefits mainly come from two parts. The one part is the zero-pollution and zero-emission environmental benefits brought by the system replacing burning loose coal for heating, and the other part is the environmental benefits brought by solar power generation replacing the production and transmission of thermal power plants. Reduction of loose coal according to Technical Guide for Preparation of Air Pollutant Emission List of Civil Coal[7]Calculate the environmental benefits of solar power generation according to China Power Industry Annual Development Report (2017)[8]And the Evaluation Standards for Renewable Energy Building Application Engineering[9]Calculated data, the annual energy saving and emission reduction are shown in Table 5.

Before the transformation, the whole rural burned 567.9t standard coal of loose coal every year, the geothermal energy heating system consumed 846,000 kW.h of electricity every year, the solar energy generated 2.168 million kW.h per year, and the surplus green electricity was 1.322 million kW.h. Annual can reduce carbon dioxide emissions 3101.69t, reduce sulfur dioxide emissions 14.13t, reduce soot emissions 12.36t, with good environmental benefits.

5. NEW GENERATION OF LOW-VOLTAGE DC POWER SUPPLY DRIVEN MULTI-ENERGY COUPLING HOUSEHOLD HEATING (COOLING) SYSTEM

Tsinghua University found that most rural buildings can use their own solar photovoltaic resources to effectively solve their own energy needs and connect excess power to the grid, making rural areas significant solar photovoltaic utilization potential and expected to become an important distributed power source in future zero-carbon power system[10]. Using shallow geothermal energy DC power supply products + rooftop solar power generation + energy storage adjustment multi-energy coupling system can realize home zero carbon heating (cooling) and year-round green electricity.

Ever Source Science&Technology Development Group co,Ltd is studying the new generation of DC power supply driven shallow geothermal energy household heating (cooling) products, using 48V low-voltage full DC technology, directly combined with solar power supply. The energy efficiency ratio of 5.5, heating capacity 7500W and heating power 1500W; cooling capacity 8200W and cooling power 1360W; it can be used as a reference for the development of shallow geothermal DC heating (cooling) products.

Schematic diagram of the multi-energy coupled household heating (cooling) system of the new generation of low-voltage DC power supply drive is shown in Figure 4. The system is composed of DC power supply power system, energy storage system, solar power generation equipment, controller, inverter and other circuit supporting components. In winter heating, the geothermal energy heating system consumes 1 kW.h, transport 4kW.h shallow geothermal energy, and supplies 5 kW.h heat energy to the building . In summer, the four-way valve in the geothermal energy household heating unit can be changed to cool the building. The energy storage system can store excess electricity, which is released at night or in rainy weather to drive the geothermal household heating system, and can also be converted to the electricity power through the inverter and generate economic benefits.

The system uses underground shallow geothermal energy and solar energy; green energy saving; DC power supply without secondary conversion. higher solar power utilization rate; energy storage system makes excess electricity automatic safe storage and increase the proportion of self-use; the system can generate more economic benefits.

6. CONCLUSION

Yihepu Rural shallow geothermal energy + solar power generation complementary household heating (cooling) system, using shallow geothermal energy for rural building household heating (cooling), using room adjustment and Floor-type lower air outlet structure of geothermal energy heating equipment, with small power distribution, simple operation, separate control, temperature comfort, energy saving, solve the problems of rural building heating, combined with roof solar power generation, can increase economic income for farmers; the system innovative and practical significance of geothermal energy + multi-energy complementary.

In the future, with the listing of DC power supply products, shallow geothermal heating (cooling) + solar power + roof energy storage regulation system can realize family zero carbon heating (cooling) and green electricity, is a kind of rural family energy supply strategy, coordinate the relationship between resources, economy and environment, is conform to the requirements of the ‘carbon peaking and carbon neutrality" development of rural building new energy system.

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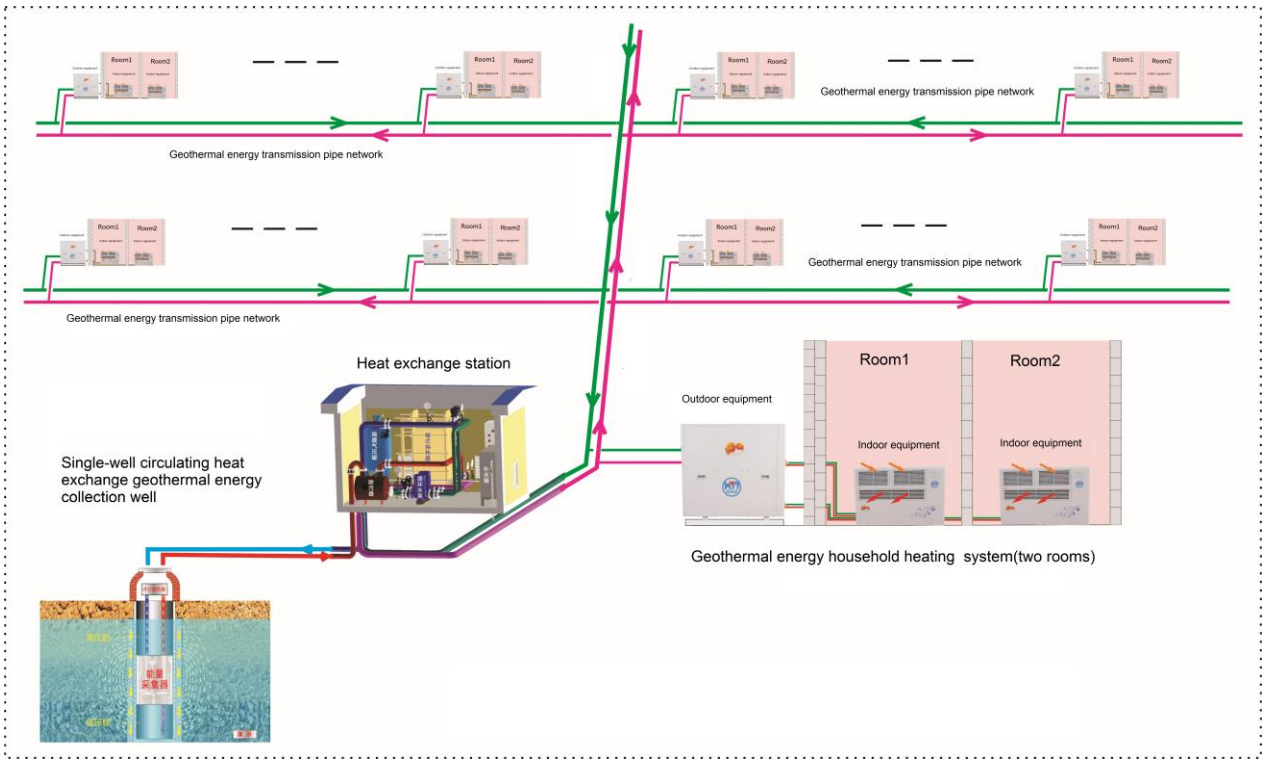

Figure1 Schematic diagram of the single-well circulating heat exchange geothermal energy household heating system

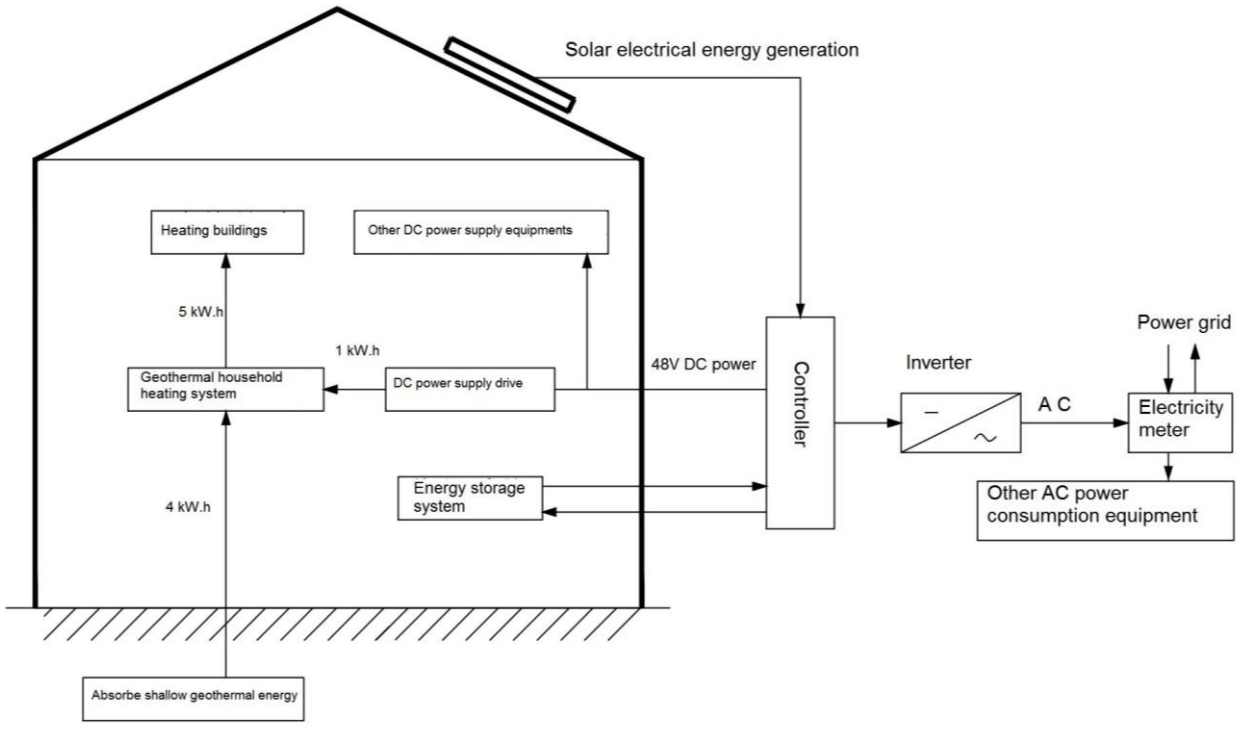

Figure4 Schematic diagram of the multi-energy coupled household heating (cooling) system

System form	Geothermal energy exchange system	Geothermal energy side transmission and distribution system	Heat pump unit	User-side heating (cooling) medium	End equipment	Characteristic
General geothermal source heat pump system for central heating	Centralized collection of geothermal energy	Centralized setting	Centralized setting	Heating (Cooling) water	Radiator; radiant floor; fan coil;	① Can consider the simultaneous use coefficient to reduce the installed capacity; ② Heat source temperature is not less than 35℃, and the transmission and distribution pipe network has heat loss; ③ Big pot rice system, which can not meet the different needs of each household.
Ordinary geothermal source heat pump system for household heating	Collect geothermal energy separately	Household Settings	Household Settings	Heating (Cooling) water	Radiator; radiant floor; fan coil;	①Individual independent, meet differentiated needs; ② Is suitable for buried pipe geothermal energy collection system, drilling area, construction cost is greatly affected by geological conditions; ③ Overall heating, difficult to achieve separate control.
Single-well circulating heat exchange geothermal energy household heating system	Centralized collection of geothermal energy	Centralized setting	Household setting, division and each room matching	Heating (Cooling) gas	Heat pump heat fan	① Geothermal energy collection can consider the same use coefficient, reduce the construction cost; ② Geothermal energy transmission and distribution system for low temperature heat source (25℃) transmission, less heat loss; ③Can achieve household measurement, separate control, behavior energy saving; ④ 2kW-3kW per household distribution, ordinary split air conditioning distribution can meet the capacity requirements.

Table 1 The differences between single well circulating heat exchange geothermal energy household heating system and ordinary geothermal source heat pump system

Subregion	Number of households (households)	Geothermal energy heat exchange station				Geothermal energy household heating equipment		Solar power generation power (kWp)
		Number of single well (individual)	Submersible water pump power (kW)	Circulation pump power of heat exchange station (kW)	Aggregate capacity (kW)	One drag, one quantity (station)	One drag and two quantity (table)	
Eastern Conference	223	5	55.2	18.5	64.5	223	223	1181.9
western conference	42	1	9.2	3	12.2	42	42	222.6

Table 2 The configuration of Shallow geothermal energy + solar power generation multi-energy complementary household heating (cooling) system

	Transition Season (03.16-06.14,09.16-11.14)		Heating Season (11.15-03.15)		Refrigeration Season (06.15-09.15)		Annual
	Municipal electricity	Solar electrical energy generation	Municipal electricity	Solar electrical energy generation	Municipal electricity	Solar electrical energy generation	
Solar Power Generation (kW.h)		3391.5		2439		2352.5	8183
Solar grid power supply (kW.h)		3319.5		1637		1998.5	6955
Household Consumption (kW.h)	786	72	550	40	470	30	1948
Winter heating and power consumption (kW.h)			1820	762			2582
Power consumption in summer refrigeration (kW.h)					168	324	492
Apalized electricity quantity of heat exchange station (kW.h)			608.6		350		958.6
Electricity income (RMB)		3292.9		1623.9		1982.5	6899.4
Municipal electricity charges (RMB)	-408.7		-1548.9		-513.8		-2471
Total income (RMB)	2884.2		75.0		1468.8		4428.0

Table 3 The benefits of the multi-energy complementary system

Remarks:

① Feed-in electricity price is 0.992RMB / kW.h (state subsidy 0.42RMB / kW.h, provincial subsidy 0.2RMB / kW.h, basic electricity price 0.372RMB / kW.h); municipal electricity price is 0.52RMB / kW.h;

② Home appliances mainly include lighting, TV, refrigerator, washing machine, electric kettle, etc.;

	Coal saving capacity (tce)	Carbon dioxide discharge (t)	Sulfur dioxide discharge (t)	Smoke emissions (t)
Reduce loose coal by 795 tons	567.85	2082.90	5.88	8.24
The surplus of green electricity is 1.322 million kW.h	412.46	1018.79	8.25	4.12
Gather	980.46	3101.69	14.13	12.36

Table 5 annual energy saving and emission reduction

Remarks:

① According to the Technical Guide for the Compilation of Civil Coal Air Pollutant emission List (Trial), the emission standards of sulfur dioxide and particulate matter are respectively: 7.4kg / t loose coal (the emission coefficient is 7.4St, d, where St, d is 1),10.36kg/t loose coal (bituminous coal dry ash-free volatilization Vdaf is 37%, the soot emission coefficient is 0.28Vdaf=10.36), and the carbon dioxide emission is calculated as 2.62t / t loose coal;

② In 2016, the national standard coal supply consumption of thermal power plants with 6,000 kW and above was 312 g / kW.h.