

Analysis and Discussion of Baoji "Shigu • Tian Xi Tai", "Shigu • Sun City" Ground Source Heat Pump Energy Station System

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Abstract: Baoji "Shigu • Tian Xi Tai", "Shigu • Sun City" ground source heat pump energy station system is an important energy supply project in Shigu. In this paper, we systematically introduce the design of green building and ground-source heat pump system, points of construction process, pre-cooling station technology, EMC economic model in detail. In addition, the ground source heat pump system of the project was tested in the field to analyze and evaluate the running performance of the system. We hope our research can provide some reference and help to the practitioners.

0 Project introduction

The project name is Baoji "Shigu • Tian Xi Tai" and "Shigu•Sun City" ground source heat pump energy station energy supply system project, which is to build the national top three-star green building group and ground source heat pump utilization building group.

Baoji Shigu•Sun City Project: It is a high-end comprehensive leisure and entertainment area, divided into three blocks: Area A, Area B and Area C. Among them: Area A (completed) has a total construction area of 89,000 m² and is divided into four functional areas: Tianshanfang, Tianbaocheng, Personal Art Center and Bar Street; The total construction area of Chencang Old Street in Area B is about 70,000 m², which is an open-type ecological and cultural tourism concentrated experience area; The total construction area of Shigu Square in Area C is about 117,000 m², which is a boutique hotel and a one-stop business experience shopping center.

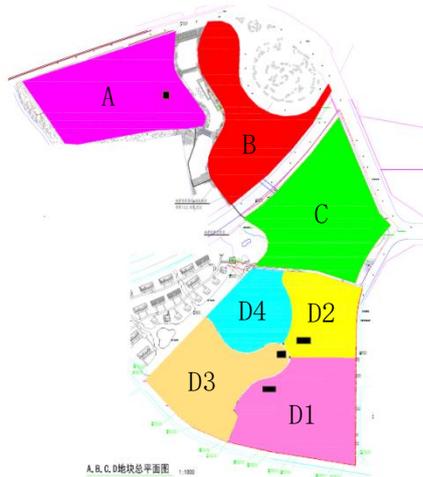
The total construction area of Baoji Shigu•Tian Xi Tai Project is about 630,000 m², and the construction industry is residential. The project is completed in four phases (D1, D2, D3, D4) and is positioned as a three-star green building. The ground source heat pump

is used to provide central air conditioning for cooling/heating, creating Baoji's top luxury residential model.

The total construction area of Shigu•Tianzhutai, Shigu•Sun City Project is about 900,000 m², and the total heating area is about 668,000 m², of which the commercial heating area is about 193,000 m², and the residential building heating area is about 474,000 m².

The total air-conditioning cooling area of the project is about 485,000 m², of which the commercial cooling area is about 193,000 m², and the residential building cooling area is about 292,000 m², some commercial hot water needs.

In the winter of the project, the heating scheme of ground source heat pump + gas boiler is planned to be adopted; in summer, the scheme of ground source heat pump cooling is proposed. The total design air conditioning cooling load of the area is 22.68MW, the total design heating load is 31.53MW, and the domestic hot water design heat load is 0.94MW. The project plans to build 5 energy stations (A, C, D1, D2, D3).



Remarks: The black squares in the figure indicate the energy station; the location of the C block energy station has not been determined.

Figure 1.1 Schematic diagram of the project plot location

1 All green building design

The residential building of this project adopts all-green building design. The first and third phases of the project obtained the three-star green building design identification certificate (certificate No.RD32702, NO.RD32703) in June 2014 and October 2015 respectively. The building area is about 500,000 m². The main innovations of the project:

(1) The outdoor green area is large, and the area ratio of the first-phase and third-phase outdoor permeable floors is more than 70%.

(2) Make full use of underground space. The ratio of underground construction area to construction area of Phase I and Phase III projects is 271.4% and 394.7%, respectively.

(3) The use of abandoned sites, rational use of abandoned brick factories for construction, saving land resources.

(4) Ground source heat pump technology, the household renewable energy utilization rate is 100%.

(5) Adopting non-traditional water source utilization technologies such as rainwater infiltration and storage and utilization.

(6) Use of high-strength steel, the ratio of use as the main rib is greater than 70%.

(7) The use of renewable recycled materials, the proportion of renewable recycled materials used in the total weight of building materials exceeds 10%.

(8) Adopt a variety of complete design plans.

2 Hole forming process

The project uses shallow geothermal energy as the main form of energy to provide heating and cooling for the buildings in the area. A total of 6600 wells are planned to be drilled. The drilling progress of the buried heat exchangers in each block is as follows:

Table 2.1 Construction progress of buried pipe heat exchangers in various blocks

Plot number	Number of buried tube heat exchangers	Drilling progress
A	Not laid out	--
B	Not laid out	--
C	2000	Completed
D1	1700	Completed
D2	1050	Completed
D3	1200	Under construction
D4	650	Unbuilt
Total	6600	

2.1 Site survey

Site survey is the first step in the construction process. Before the construction of the buried pipe heat exchanger, accurate and detailed investigation and investigation should be carried out on the site conditions and geological data.

According to the site survey, the construction plan is formulated. Careful planning will greatly reduce the time and cost of installation. To lay the foundation for the successful completion of the installation of the buried heat pipe of the geothermal heat exchanger.

2.2 Drilling equipment

In view of the geological conditions of the project and the size of the site, the borehole tube heat exchanger drilling construction uses the on-board drilling water-400 type, and the corresponding mud pump is used together to carry out the drilling construction to speed up the construction progress on schedule.

2.3 Buried pipe

After the wall of the drilling hole is solidified, the U-shaped tube which has been welded, pressed and filled with water, and the tube card is placed vertically into the drilled hole.

When the drilling depth and the groundwater (or mud) water level in the hole are shallow, artificial pipes

should be used. When the buried pipe is difficult, a mechanical auxiliary buried pipe can be used.

When burying the pipe, care should be taken to maintain the concentricity of the pipe and the borehole, and reduce the friction between the pipe, the pipe fitting and the borehole. The lower end of the U-shaped pipe should be provided with a protection device.

Immediately after the completion of the buried pipe, the pipe is pressed to confirm that there is no leakage before backfilling.

After the pressure is passed, effective temporary sealing measures should be taken for the U-tube port.

2.4 Drilling backfill

Backfilling is an important part of the construction process of the buried pipe heat exchanger. After the drilling is completed and the U-tube is laid down, the backfill material is injected into the borehole. The choice of backfill material and the correct backfilling construction are of great significance for ensuring the performance of the buried pipe heat exchanger.

2.5 Horizontal header connection

Horizontal buried pipe trench structures should take into account factors such as above-ground and underground obstacles, surface slope, ditch radius limitation, backfilling and recovery requirements.

The horizontal header connection is divided into two methods: hot melt connection and electrofusion connection. Because the hot-melt connection will cause the diameter reduction phenomenon, increase the local resistance of the pipeline, and reduce the strength of the pipe; the pipe with diameter $\Phi \leq 63\text{mm}$ is all connected by electrofusion.

2.6 Inspection and acceptance

After the installation of the buried pipe system is completed, the test shall be carried out on site by the professional testing organization in accordance with the requirements of the standard specifications [1~3], and the inspection and acceptance report shall be provided.

3 Energy bus [4]

There are 5 energy stations in the project area, which are located in Block A (for Zones A and B), Block C (for Zone C), Block D1 (for Zone D1), and Block D2 (for Zone D2), Block D3 (for Zones D3 and

D4).A total of 6600 drill holes are planned in the area, which are located in C block, D1 plot, D2 plot, D3 plot and D4 plot. The cooling load in the area is completely borne by the buried pipe, and the heat load is carried by the buried pipe and the auxiliary gas boiler; the auxiliary heat source is concentrated in the D3 energy station.

In this project, there are many underground pipe partitions. By setting up the buried pipe side sub-catchment, the different sub-catchers can be connected to each other to realize interconnection and intercommunication between the buried pipes, so as to ensure the underground cold and heat balance as much as possible. The underground pipe side communication scheme is as shown in the following figure. The ground source side sub-catchment is installed in the C energy station, the D2 energy station and the D3 energy station, and there is no ground source side sub-catchment in the A energy station and the D1 energy station.

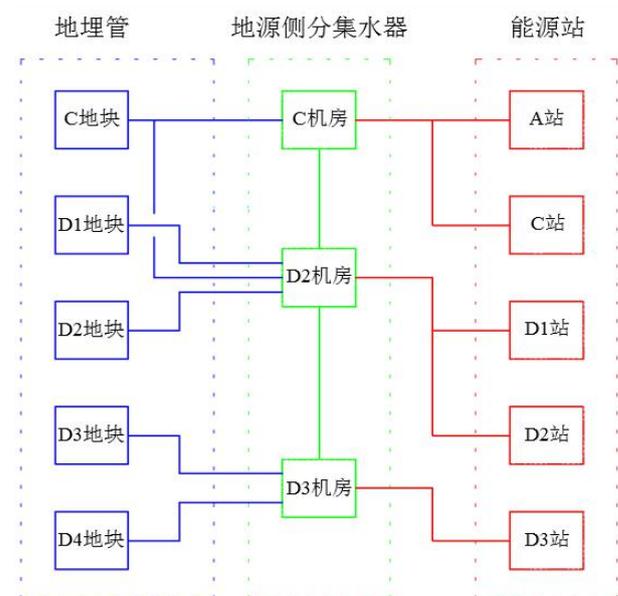


Figure 3.1 Ground-buried pipe side communication scheme in the area

The way of interconnecting the buried pipe side is as follows:

- 1) Water supply from the C-ground buried pipe to the C machine room sub-catch; C-source ground-source sub-catchment supplies cooling water to the A-energy station and the C-energy station heat pump unit.
- 2) Water supply from the ground source side of the D2 machine room by the ground pipe of the C block, the buried pipe of the D1 block, and the buried pipe of the D2 block. The D2 room sub-catch provides

cooling water to the heat pump units of the D1 energy station and the D2 energy station.

- 3) Water supply from D3 plot buried pipe and D4 plot buried pipe to D3 machine room source side sub-catch; D3 engine room sub-catchment supplies cooling water to D3 energy station heat pump unit.
- 4) The ground source side sub-catchment of the C machine room and the ground side sub-catchment of the D2 machine room are provided with a communication pipe to realize interconnection and intercommunication of the buried pipe.
- 5) The ground source side sub-catchment of the D2 machine room and the ground side sub-catchment of the D3 machine room are provided with a communication pipe to realize interconnection and intercommunication of the buried pipe.

Through the above-mentioned buried pipe side interconnection and intercommunication scheme, the 10-year dynamic simulation calculation of the underground heat transfer process of the whole project area is carried out, and the hourly inlet and outlet water temperature of the buried pipe heat exchanger and the time-dependent temperature change of the underground rock and soil are obtained. As shown below. After 10 years of continuous operation, the temperature of underground rock and soil has decreased slightly, and the balance of underground rock and soil is better. The entire system can achieve stable and efficient operation in winter and summer.

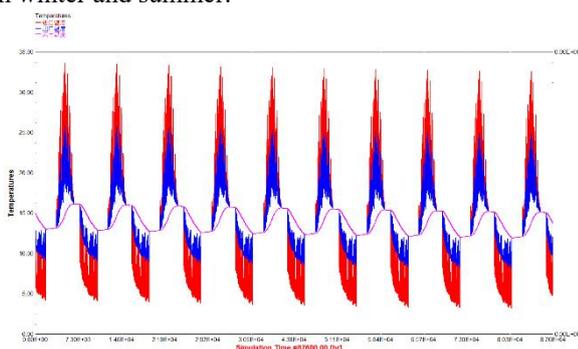


Figure 3.2 Simulation of 10-year heat balance of inlet and outlet water temperature and geotechnical temperature of buried pipe

The project has a large construction scale and a large number of drill holes, and adopts the energy bus design idea. With the progress of the project construction, energy stations will be built in phases, and through the interconnection and coordination of energy

stations, the maximum utilization of renewable energy can be realized.

In the later construction process of the energy station, comprehensive consideration will be given to the thermal and thermal load of the whole project and the configuration of the peak cooling and heat source. Through the mutual deployment of the buried pipe side, the cold and heat balance of the buried pipe side of each energy station in the entire area is realized, and the cold and heat balance of the whole project is ensured.

4 Integrated cold station

The traditional freezing station is usually a construction unit that purchases the main equipment of the freezing station according to the preliminary design of the design institute, and then installs the HVAC project on site by the electromechanical installation company. Traditional freezing stations often have the following problems:

- 1) The traditional freezing station is a decentralized engineering project. The parties are only responsible for their own project content, lack of system engineering ideas, and the overall performance cannot be guaranteed.
- 2) Due to the construction of the traditional freezing station, the construction work area is large, the cross-operation time of different professions is very long, and the coordination and management of the owner site is very difficult.
- 3) The traditional freezing station generally adopts an independent and simple control mode, and the control of each main power consuming equipment lacks correlation, and the energy saving effect is not obvious.

The integrated refrigerating station is based on the high-efficiency and energy-saving related predictive control system. Based on the preliminary design of the design institute, the second deepening design and three-dimensional simulation are carried out. It is a mechatronic system-level product that is optimized for parameters of the equipment and is formed by factory prefabrication, module transportation and on-site assembly. And multi-module integrated products are easier to disassemble, hoist and transport. Efficient, energy-saving, space-saving, easy to operate, easy to control equipment in the prefabricated production in the factory, to avoid the trouble of on-site construction.

- 1) From the decentralized responsible entity to the single responsible entity of the system integrator;
- 2) From engineering projects to system products;

- 3) From project site construction to factory prefabrication;
- 4) From independent control to associated control, the introduction of full inverter control technology.

The energy station design of this project adopts integrated refrigeration station technology. The main innovations of energy station design are as follows:

The integrated refrigeration station uses modular design technology and is integrated into manufacturing at the manufacturing facility. After the installation and commissioning is passed, the sub-modules are shipped, and after the project site, the modules are connected and paired. The on-site construction period is shortened from the traditional 5~6 months to 1 month.

- 1) The integrated refrigeration station system has a high energy efficiency ratio and can save more than 30% energy compared with the conventional refrigeration station system.
- 2) Adopting the patented technology of Taijia refrigerant side switching to avoid the cross-contamination problem between the air-conditioning side and the ground source side.
- 3) Save more than 10% of materials, save upfront investment and reduce maintenance and management costs.
- 4) Intelligent integration, unattended, remote control.
- 5) The control system automatically calculates and compares different operation strategies according to the collected data, iteratively calculates the energy efficiency of the system operation, and adaptively adjusts the water flow and temperature difference.

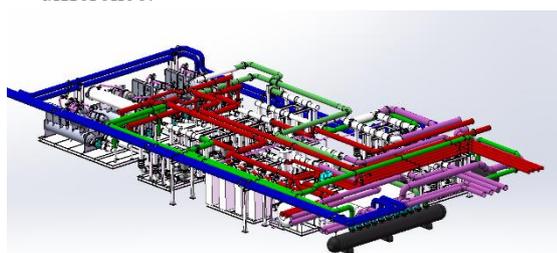


Figure 4.1 Three-dimensional design of an energy station of the project

5 Running test

The National Air Conditioning Equipment Quality Supervision and Inspection Center of China Academy of Building Research, as a commissioned evaluation agency, conducted on-site test and evaluation of the operation performance of the ground source heat pump system of the energy station in Zone A.

5.1 Outdoor buried pipe hydraulic balance test results

The outdoor side secondary sub-catchment corresponding to the A room of the project is 13#--24#, a total of 12. Divided into two groups, each group of 6 parallel operation (13#--18#, 19#--24#). In addition, each group of secondary sub-catchment outlets is connected to 10 three-stage sub-catchments, and each three-stage sub-catchment is connected with 8 holes.

Therefore, the original operating state of the outdoor side buried pipe and the hydraulic balance after commissioning were tested. The test is divided into two aspects: (1) The hydraulic balance of the secondary manifold; (2) Hydraulic balance of the three-stage sub-catch. Because of the large number of on-site three-stage sub-collectors, it is difficult to achieve one-by-one testing. This test draws a typical three-stage sub-catchment for testing and checking its hydraulic balance.

Table 5.1 Three-stage sub-catch flow

Secondary manifold number	Test condition	Secondary manifold flow(m ³ /h)	Three-stage sub-catchment flow(m ³ /h)										Flow imbalance rate
			1#	2#	3#	4#	5#	6#	7#	8#	9#	10#	
16#	Original	47.2	/	7.52	/	7.03	/	8.10	/	4.75	/	7.72	41.4%
	Debug 1	50.6	/	5.39	/	4.41	/	5.81	/	6.52	/	4.52	32.4%
	Debug 2	52.2	/	5.13	/	5.35	/	5.41	/	6.01	/	6.55	21.7%
18#	Original	54.1	7.17	/	7.22	/	5.55	/	6.32	/	5.94	/	23.1%

	Debug	/	5.70	/	5.65	/	5.50	/	6.37	/	6.10	/	13.7%
20#	Original	/	6.30	5.70	/	5.70	5.96	7.45	7.82	7.01	7.56	5.71	27.1%
	Debug	40.1	/	/	/	5.41	/	/	5.78	6.03	/	/	10.3%
21#	Original	/	6.15	5.83	7.60	6.07	6.05	6.03	7.40	8.20	7.60	7	28.9%
	Debug	33.2	/	3.54	/	/	/	/	/	3.62	3.66	/	3.3%
23#	Original	65.1	7.51	/	7.09	/	7.48	/	8.31	/	7.89	/	14.7%

Remarks: “Original” in the table refers to the initial operation of the system; “Debug” refers to the test results after debugging the valves of some three-stage sub-collectors.

In this project, each group of secondary sub-catchment (13#-24#) outlet is connected with 10-way three-stage sub-catchment, and each three-stage sub-catchment is connected with 8 holes.

Therefore, the design flow rate of each group of secondary manifolds is the same. So the flow imbalance rate of the secondary manifold can be calculated by the following formula:

$$\text{Flow imbalance rate} = (\text{Maximum flow} - \text{Minimum flow}) / \text{Maximum flow}$$

Table 5.2 Secondary Separator

Secondary Separator						
Measuring point	13#	14#	15#	16#	17#	18#
Flow (m ³ /h)	55.3	53.0	47.1	52.2	48.5	54.1
Flow imbalance rate	14.8%					

Table 5.3 Secondary Separator

Secondary Separator							
Measuring point	19#	20#	21#	22#	23#	24#	
Flow (m ³ /h)	Original	84.6	76.8	60.8	80.8	86.5	77.8
	Debug	74.0	65.8	69.3	68.8	67.9	76.6
Flow imbalance rate	14.1%						

5.2 Ground source heat pump summer working condition test results

There are three high-efficiency ground source heat pump units (DRSW-760-2F) in the A plot machine room. Since the 1# unit is in maintenance state, there is no test condition. Therefore, the performance of the 2# and 3# units was tested. During the test, in order to

ensure the unit load rate, a single unit operation was used to test one by one.

During the performance test of the heat pump unit, the cooling water primary circulation pump and the chilled water primary circulation pump are opened in one-to-one correspondence; each end branch chilled water secondary circulation pump is operated in a single frequency conversion.

During the test, the average performance coefficient of the unit under the actual operating conditions of the ground source heat pump unit was 4.93. The average performance coefficient of the system is 3.3, and the specific test results are shown in Table 5.4 below. The variation of the effluent return water temperature on the user side and heat source side of the ground source heat pump unit is shown in Figure 5.1.

Table 5.4 Refrigeration performance test results of a ground source heat pump unit under actual operating conditions

Serial number	Test items	Test Results
1	Unit user outlet water temperature (°C)	7.9
2	Unit user side return water temperature (°C)	11.0
3	Unit user side flow (m ³ /h)	382.9
4	Unit heat source side outlet water temperature (°C)	28.9
5	Unit heat source side return water temperature (°C)	24.2
6	Unit cooling capacity (kW)	1381.5
7	Unit input power (kW)	280.1
8	Unit cooling average performance coefficient (kW/kW)	4.93
9	System cooling average performance coefficient (kW/kW)	3.3
Remarks:		
1) The test time is from 15:00 to 17:30 on September 8, 2016;		
2) All test items are average values during the test period;		
3) Unit cooling average performance coefficient = Unit cooling capacity / Unit input power		

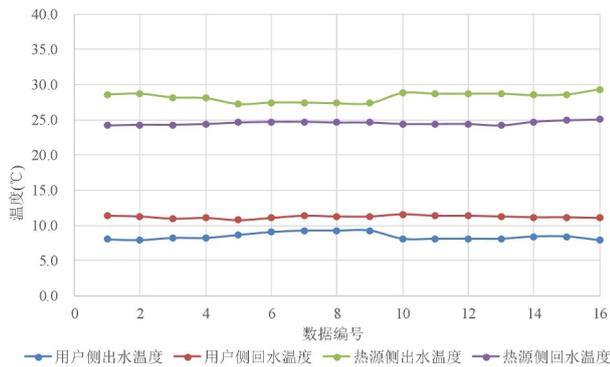


Figure 5.1 Temperature variation curve of circulating medium on the user side and heat source side of a ground source heat pump unit

5.3 Field test conclusions

Through the operation test and analysis of the ground source heat pump system of the Baoji “Tiangu•Tianzhutai” and “Shigu•Sun City” district energy supply projects, the following conclusions were obtained:

- 1) In addition to the 1# heat pump unit in this system, it can not be tested due to maintenance during the test. The other equipments are running stably during the test.
- 2) Through the test of all the secondary sub-catchments and the typical unfavorable three-stage sub-catchment: The hydraulic balance of the secondary sub-catchment can meet the requirements of the "Code for Design of Heating, Ventilation and Air Conditioning for Civil Buildings"(GB50736-2012)^[5]; The hydraulic balance of more than 80% of the three-stage sub-catchment can meet the requirements of the "Code for Design of Heating, Ventilation and Air Conditioning for Civil Buildings"(GB50736-2012) ^[5].
- 3) The outdoor ground pipe can meet the design requirements at present.
- 4) The ground source heat pump system of this project is in the test condition and the operation performance is reasonable. The refrigeration performance coefficient of the pumping test heat pump system is about 3.3.

It should be noted that the operation effect of this test system has not reached the original design goal, which is mainly caused by the following reasons:

(1) The operation of the system circulating water pump is unreasonable, and the start and stop of the water pump cannot be adjusted according to the load situation;

(2) During the test, the system load rate is low and the equipment is not in the best condition.

After the test, according to the discovered problems, the operator performed systematic debugging of the system, and adjusted and optimized the system operation strategy. After commissioning, according to the operational data, the analysis shows that the operating efficiency of the system has been greatly improved, and the average cooling coefficient of the system has been increased from 3.3 to 3.9.

For the ground source heat pump system project, due to the complicated operation on the source side and the load side, the hydraulic balance and the underground cold and heat balance have a great influence on the system operation effect. After the construction of this kind of project is completed, it is necessary to carry out systematic debugging and diagnosis, on the one hand to ensure the safe, stable and reliable operation of the system, on the other hand to give full play to the characteristics of system efficiency and energy saving.

6 Model innovation

The energy system project adopts the contract energy management model. EMC (Energy Management Contracting) is an energy-saving investment method that uses the reduced energy bill to pay for the full cost of energy-saving projects. This model allows users to upgrade their plants and equipment with future energy savings, reducing current operating costs and improving energy efficiency.

The end users of the project do not need to pay the initial installation fee (government financial subsidy ¥20/m²), non-residential heating and cooling prices are ¥28/m², residential heating price is ¥22/m², The residential cooling price is ¥12/m². The price of domestic hot water for residents is ¥13.5/t (including tax), and the price of domestic hot water for public construction is ¥16/t (including tax).

The total investment of the project is 132.178 million yuan. Under the existing price system and calculation basis, the project internal financial rate of return (after tax) of the project investment is 10.05% under the condition of the owner's yield, intensity of use and hot water supply for hot and cold, and the investment payback period (tax) After) 9.48 years.

7 Conclusion

Baoji City's “Shigu • Tian Xi Tai” and “Shigu•Sun City” ground source heat pump energy station energy

supply system project, the design of the whole green building design innovation, ground source heat pump system design, process construction points, and underground The pipe side interconnection and intercommunication scheme, the integrated cold station technology, and the EMC economic model were introduced in detail and systematically. And through field test, analyze and evaluate the operation performance of the ground source heat pump system and the hydraulic balance of the buried pipe side of the project.

Through analysis, the following conclusions are drawn:

(1)The Energy Bus Technology program can realize the interconnection and coordination between energy stations, and realize the maximization utilization of renewable energies, which is of great significance to the scale application of renewable energies.

(2)Renewable energy area for energy projects, through reasonable design, as well as subsequent commissioning and optimization, can ensure the efficient operation of the system, to achieve the design purpose of reducing emissions.

(3)Integration of BIM integrated refrigeration station technology is now more mature, can be used as a future regional energy station to implement the important technical means.

(4)Green building high-star, regional energy station centralized supply and other industry hotspots in the rational planning and design, under the premise of Such a non-one or two-line city like Baoji can also be reasonably popularized and applied.

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