ADVANCEMENT PROSPECTS OF GSHP AIR CONDITIONING SYSTEM IN HSCW ZONE OF CHINA

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ABSTRACT:

Ground-source heat pump (GSHP), originated in a patent of Sweden in 1912, is becoming a kind of energy efficiency and environmental protecting technology in 21st century. GSHP has developed rapidly in developed European countries in the recent decades, and has been applied practically in China because of emergent provision of energy and the demand of environmental protecting. The majority of China area belongs to hot summer and cold winter (HSCW) climate area, and the weather condition provides good developing feasibility of GSHP air conditioning system. Based on the analysis of climate characteristics and building factors, this paper proves that GSHP air conditioning technology has great significance and good prospects for the whole HSCW zone focusing on energy efficiency in building, operating performance, etc. For the more, the paper puts forward some feasible solutions for such problem as cooling-heating imbalance and the choice of system styles.

1 INTRODUCTION

GSHPs are being installed more frequently for space heating and cooling and hot water heating because of the high efficiency in Europe countries and the United State [1]. The earliest research of GSHP in China began in 1980's, and GSHP system not only became the hot research subject in heating, ventilation and air conditioning (HVAC) trade but also applied to the engineering practice [2] by the end of 1990's.

Especially in HSCW zone, there are normally over 200 days in a year to demand cooling or heating, the great deal of energy consumption takes building energy efficiency of these areas into important position. Terrible climate and building environment demand a highly efficient, clean and steady-operating energy source of heating/cooling to solve air conditioning problems, the qualities of GSHP system suit for climate and demand of energy efficiency in HSCW zone. GSHP also has good market competitively and developing prospects improving building environment to reach the standard of energy efficiency. However, GSHP research in China is in the exploring and experimental stage and has many unsolved problems in theory and practice. This paper discusses the advancement prospect of GSHP system in HSCW zone and puts forward the viewpoint on the base of Chinese economy and building trade development.

2 CLIMATE FACTOR AND BUILDING ENERGY CONSUMPTION IN HSCW ZONE

2.1 Climate Factor

According to *Design Standard for Energy Efficiency of Residential Buildings in HSCW Zone (JGJ 134-2001)*, HSCW zone covers 16 provinces and autonomous regions with 5 500 million population of China, and HSCW climate is the main climate style of China [3]. In these areas, summer is characterized by high temperature and solar radiant intensity as well as climate wind is rushing. The mean temperature of the hottest month can reach the point of 25℃ to 30℃ and relative humidity ratio about 80 percents in the year [4]. Climate of main cities in HSCW zone are showed in Table 1 [5].

2.2 Building Thermal Environment

The heating environment indoors is poor in HSCW zone [6]. After long time of investigation, citizens of these areas have formed the habit of ventilation and making inside air fresh, and the windows are opened even in winter. So the indoors temperature is nearly as low as outdoors with a temperature different of 1℃ to 4℃ in winter and the mean temperature of the whole winter is around 10℃.

These areas are non-central-heating area due to the economic development limits of China. In winter, small boilers are used as the main heating style and large industrial boilers are also common in some factories, which are inefficient and pollute the environment. For the neglect of heat preservation and insulation of civil building in this area, thermal characters of envelopes are worse than the northern area of China. These building would be used for as long as 50 to 70 years, so that it impossible to improve thermal characters of building immediately. On the other hand, people are eager on the improvement of their living conditions, so the improvement of HVAC system efficiency is very significant.

2.3 Developing Trends of Energy Consumption for HVAC

The main building energy consumption in HSCW zone includes heating, air conditioning, hot water heating, lighting, household electric equipments, etc. Long-term investigations show HVAC system takes up more than 60 percent of whole building energy consumption. How to reduce the energy consumption of HVAC system is an important part of building energy efficiency. And with the improvement of living conditions, civil air conditioner is common. Especially in such big cities as Shanghai and Wuhan, the diffusion ratio of air conditioner has attained 50 percent and changed from one air conditioner per household to one per room. According to the energy consumption at present, the electric consuming and annual electric consumption of HVAC system are tremendous after 2000 year in order to make the whole area comfortable if efficient measures are not taken. The electric consuming of that will attain 80 million kW in summer and 200 million kW in winter, 11 times of the capability of Sanxia electric factory; and the annual electric consumption is 224 billion kW·h, 3 times of annual electric capability of the same factory. Because such high electric energy can't be obtained, the hope of improving buildings Environment lies in the reinforcement of building energy efficiency.

2.4 Demand and Tendency of Building Energy Efficiency

China has been under tremendous pressure of insufficient energy in the recent years. On one hand, Chinese economy need to keep rapid development rate, on the other hand, the problems of environmental protecting and the sustained development have to be considered. In order to put equal emphasis on both things the energy using efficiency must be improved and energy construction must be adjusted, and the former should focus on energy efficiency and clear energy exploiting and using.

By analysis of buildings thermal characters and HVAC equipments performance, it is possible that heating load of building is reduced by 30 percents and cooling load is reduced by 70 percents, also air conditioning electric consuming of summer is reduced by 40 percents. So the electric load of annual HVAC and humidity removing is reduced by 50 percents, that means energy efficient is raised by 50 percents. *JGJ 134-2001* indicates that 25 percents of energy can be saved from envelopes, and the other 25 percents energy efficiency relies on improvement of HVAC system efficient.

It is a tough task to raise energy efficient by 50 percents. *Thermal Design Code For Civil Building* indicates distinctly [7]: Government encourages development of solar and ground energy, advocates research on energy recycle and energy efficient technology and equipments. It also proves that GHSP technology is according with government policy.

3. EFFECT OF GSHP SYSTEM IN HSCW ZONE

3.1 Environmental Protecting Effect of GSHP

Material above indicates that HSCW zone faces significant choice, and GSHP system provides a feasible solution. Considered annual mean temperature keep in 15℃ to 20℃ in these areas, cooling water temperature out of compressor is between 25℃ to 35℃. The temperature difference between outdoors and soil can attain 20℃ to 30℃ [8], which improves cooling or heating COP value of heat pump equipment, furthermore water vapor and bacteria are prevented from releasing into air environment.

The pollution that GSHP system produced is 40 percents less than air source heat pump system and 70 percents less than electric heating equipment’s. For the more, the leak of cryogen is lowering in large. Compared with air heat pump system, when the outdoor temperature in utmost condition and energy demanding is at the peak, and the GSHP system can provide high temperature of condensator and low temperature of evaporator because of soil’s character of fading and delaying inflation of outdoor temperature [9]. And there is abundant groundwater and surface-water that supplies convenience for GSHP system.

3.2 Energy Efficient Effect of GSHP

Unitary ground- and water-source heat pumps offer many performance advantages over the more common air-source heat pumps. This is a direct result of the outstanding heat transfer properties of surface-water, groundwater and soil [10].

GSHP takes advantage of large temperature difference between indoors air and soil in summer and small temperature difference in winter. And with the new type heat exchanger, the COP value is higher than other center air conditioning. Experiments of ground-coupled heat pump system by Tongji University, has tested the COP value to be 3.87～4.22 [11]. At the same time, GSHP system solves the problem that air source heat pump couldn't offer enough heat and need assistant heating source which lead to energy wasting when outdoor climate in the utmost condition in winter.

Take the ground-water central air conditioning system in Shandong province as an example [12]. The system has achieved ideal effect after a year's operating since June 2000. The detail data showed in Table 2 [12].

3.3 Operation Characteristic of GSHP

The distinct operating performance of GSHP system is steady due to the litter variation of ground temperature inflation. In HSCW zone, initial ground temperature is kept in 15℃ to 25℃, and temperature increases at the rate of 3℃ to 5℃ per 100 meters with the deepening of ground [13] . Groundwater almost has the same value as the ground. The ground temperature in January and July of Shanghai are showed in Table 3.

From table 3, the temperature at the certain depth of ground in a year is about a constant value equal with the annual mean temperature. That characteristic insures a stability of condenser and evaporator, so the unit operates relatively steady.

4. DESIGN AND OPERATION OF GSHP SYSTEM IN HSCW ZONE

4.1 Ground Temperature and Soil Thermal Performance

The operation of groundwater and surface-water system is related with ground temperature. From above, operation of GHSP is relatively steady, but the ground temperature changes after a long time of running. In summer, temperature of ground rises due to the great amount of heat rejected to underground, which makes temperature of condensator higher and unit COP value decrease; and in winter, the ground temperature drops with the heat extracted from the ground that makes evaporate temperature lower and unit COP value decrease.

For the ground-coupled heat pump system, the unit operation is closed related to soil thermal performances that affect the underground heat exchanger effect [14]. The mainly coefficient of soil characteristics are thermal conductivity, specific heat and humidity. When the location and system style is determined, such physical parameters as diameter and depth of pipes and water temperature affect the unit operation performance mainly [15].

It should be more intentioned that ground-coupled heat pump would take a few hours (8-10 hours in summer and 3-5 hours in winter, Shanghai) for heat exchanger to keep steady at the start-up of water pump for the heat obstructing of soil [11]. So if the system is to be opened, water pump must be opened first then the fun and compressor are opened after a start-up time later.

4.3 Dynamic Building Load

Building load characteristics also affect GSHP system greatly, that should be considered when developing a design method. In Japan and Denmark, GSHP system is only used to heat in winter, but in United State it is not only used to cooling in summer but also be used to heating in winter [16].

The HSCW areas of China require heating and cooling due to their climate, so the outdoor weather parameters are changing, inevitably leading to the operating performance complexity. That is the different of GSHP from other air conditioning systems. When designing a GHSP system the building load must be analyzed correctly, to make the unit control and adjustment concordant with the load-changing tendency.

Calculation of the dynamic load is important because the owner chooses GSHP system to supply cooling and heating always because of its good economic effect. The air conditioning load is a main factor in evaluation of the system and optimal design of air conditioning system. Now there are many software on energy dynamic calculation: DOE-2, BLAST and TRANSYS of America, HASP of Japan; in China, DeST has been developed by Tsinghua University for 30 years [17]. Those softwares can be used to predict the performance of the GSHP systems with various design changed, thus offering valuable insight on how design changes might impact performance and operation conditions [18].

Figure 1 and Figure 2 show the dynamic load changing state of Changsha in Hunan province that calculated by DeST.

The changing tendency of dynamic load can be showed in Figure 1 that there is a maximum load in winter and summer and there is a period of time needing both cooling and heating in the transient season (spring and winter). Figure 1 can confirm the capacity of unit, the whole building load can be calculated with the building area and the temperature frequency value in Figure 2. Figure 1 also shows that the maximum load of summer is much bigger than the maximum load of winter.

4.4 Imbalance of Cooling and Heating Load

Working principle of GSHP is rejecting the heat from building to ground in summer and extracting heat from ground to building [19]. Ground becomes a huge cumulating heat-body. If the heat extracted from the ground is almost equal with the heat rejected to ground, the balance of ground energy is kept and the system run steadily, thus can satisfying the energy demand for a long time.

How to deal with the energy balance in summer and winter and to make reasonable operation scheme is very important. When designing ground energy is always supposed to be balance. In some places of HSCW zone the supposition is reasonable, but in others that supposition is unreasonable. Table 2 and Table 3 is the annual load in Chungking and Changsha (based on the COP value equal to 3.0).

Table 2 shows that Chungking the ground energy is almost balance and sole GSHP system is suitable. But Table 3 illustrates that ground heat gained is much bigger than heat lost in Changsha. Although there is a ground temperature recovery in transient seasons, the imbalance can't be ignored. After long time running with a great deal of net heat reject into ground, the initial ground temperature maybe changed and energy balance maybe destroyed. After many theory and experimental research, can use hybrid GSHP system in that imbalance location [20, 21]. This hybrid system allows geothermal field to be sized for the smaller heating load and with a cooling tower to meet the peak cooling needs of the building. That system also can solve the problem of limited space available for geothermal wells or flux of groundwater can't meet the peak-cooling load. In the demonstrate engineering of Hangzhou, air-conditioning system is connect groundwater with a cooling tower.

4.5 Control and Adjustment of GSHP System

To make the operation simple and performance change convenient, the constitution of a suitable operating method is inevitable. The annual operation performances are often divided into several sections on the basis of dynamic energy calculation and the temperature frequency value in Figure 2. Outdoors climate is different in a year, divided-sections control is used with the consideration of the frequency of every weather state to make the sections number minimum but efficiently controllable.

On the whole, the system can be adjusted from two aspects: One is by controlling open-and-close ratio of compressor, when indoor air attains the temperature compressor closed, after a few minutes, indoor air temperature changed for heat transform the compressor opened. This method suits for small system. The other is adjustment the current of compressor that is content adjustment. This method is relatively complex and need compile control program, but the effect is better and is not harm for the life of compressor.

Water pumps, funs in the rooms and other equipments also need to operate under certain logical principle.

5. DEVELOPING GSHP AIR CONDITIONING SYSTEM IN HSCW ZONE

5.1 Conclusion on the Existing GSHP Engineering

According to literature report, only GSHP system of ground well water has been used widely in China. But this system is hard to introduce because of the government policy for groundwater using. The most early ground-coupled heat pump system is an office building in Shanghai 1987 [22]. Ground coupled heat pump system mainly stayed in research phase. At the same time that theory research mainly focuses on performance of underground heat exchanger, and the energy balance and technology economy of system are not considered. Existed ground coupled heat pump engineering projects are only for hundreds square meters, while GSHP system need great mount of geological information that must be exact. Otherwise, the whole engineering will be destroyed. There have been some painful lessons in China [2].

At 1997 China and American subscribed the agreement to develop GSHP system in China.

According to the agreement, three demonstrating engineering projects will be established in Beijing, Guangzhou and Hangzhou at 1998 to find the correct and suitable way to introduce GSHP system to China. After some engineering were put into use, much data came from reality operation, which supplied foundation for designing and operating.

As all known, China has a huge population and the proportion of per person is relatively small. It makes owner not choose the ground-coupled heat pump system because it needs large place to lay underground heat exchanger pipes. And groundwater or surface-water system is limited by the flux of water and the country's policy [23]. So although GSHP system has many advantages, there is much limit to develop sole GSHP system. To put attention on technical connection with other systems and make the performance more perfect is the main work in our future.

5.2 Prospects of Developing GSHP Air Conditioning System

On one hand develop GSHP system has a good start in China, on the other hand, there is a long way to go in introducing this technology into Chinese HVAC trade and it would meet great trouble and many problems to be solved.

GSHP system has three main styles: ground-coupled heat pumps system, groundwater heat pumps system and source-water heat pumps system [24]. Ground-coupled heat pump system more complex than the two others by the variety of geological formations and properties that affect thermal performance and need large area to lay pipes, but it not much limited by water and it is a applicable system when building area small. Groundwater system is determined by location and country's policy. In HSCW zone there is abundant ground-water source available, if the technology of returning water to ground is reliable, this system has a good prospect. And source-water system is mainly determined by water source. Connecting source-water system with cooling tower system has been proved to have good practical prospect in these areas.

5.3 Suggestions of Developing GSHP Air Conditioning System

The economic development of HSCW zone is promising and it has great potential for energy efficiency and supplies space for developing GSHP system. But in China, GSHP is a new technology and system of ground heat; the project and engineering which suit for market economy hasn't matured; standard and criterion of designing, constructing and operating of GSHP system haven't consummated. There exist many difficulties to develop GSHP air conditioning system. The work can be done from the following aspects:

1) Get people familiar with the concept of GSHP system. It is essential to set up many demonstrating engineering and collect the practice data to prove the merits of GSHP system for many people who are familiar with tradition central air conditioning system and can't accept the concept of GSHP system.

2) Develop advanced technologies [22]. Technician and engineer should try to construct the series standard and criterion about GSHP system as soon as possible.

3) Take advantage of the foreign advanced technology and set up air conditioning

production, develop GSHP productions suitable for China.

4) Adamant the government's attitude. A new technology want to develop the social, economic, and government forces will demand. Government should pay much attention on energy efficiency in building and environmental protection; enhance people's consciousness of energy efficiency in building and environmental protecting.

CONCLUSIONS

The thermal environment of buildings is too bad and the task of energy efficiency is tough in HSCW zone. Using high efficient equipments and system to improve the buildings environment is most urgent. At this critical time GSHP system with the character of energy efficiency and environmental protecting should be used abroad. GSHP system is more suitable for HSCW zone because there is needs cooling and heating in a year, the climate and building environment need this system too. In a long period, GSHP system has good prospects in HSCW zone.

But the difficulty must be fully considered. There is large range of cooling/heating load in this area, control and adjustment of GSHP is more complex than other systems. Unit capacity is determined by the maximum load and unit collocation determined by the dynamic load-changing tendency. Control schemes should be considered for operating performance is distinct difference during a year. In the place where energy is imbalance the system from system style and heating/cooling source can be considered.

In conclusion, although GSHP system has many merits, it is hard to develop sole GSHP system. To put attention on technical connection with other systems and make the performance more perfect is the main work in our future.

REFERENCES

1. Bose J. E., Parker J. D., 1983. Ground coupled heat pump Research, ASHRAE Transactions, Vol. 89, Part II, pp. 375-390.
2. Ying P., 2001, GSHP in China, Modern air conditioning, Vol. 3, pp. 1-9.
3. Design standard for energy efficiency of residential buildings in HSCW zone, JGJ 134-2001, Chinese architecture press, Beijing.
4. Zhang J., 1991,Climate of China, Climate press, Beijing.
5. Thermal design code for civil building, GB50176-93, Chinese architecture press, Beijing.
6. Fu X., 2000, Energy efficiency in buildings in HSCW zone, Energy efficiency in buildings, Vol. 29, pp. 40-46.
7. Ministry of Construction, 2000, Management stipulation on energy efficiency in civil buildings.
8. Ding L., Liu S., 2000, Economic analysis of water source heat pump system in Hunan, Fluid Machinery, Vol. 28(12), pp. 57-59.
9. Mei V. C., Baxter V. D., 1986, Performance of a ground-coupled heat pump with multiple

dissimilar coil in series. ASHRAE Transactions, Vol. 92, Part II, pp. 30-42.
10. Warren A.A, Cenk Y., Jefferey D.S., 2000, Development of an in-situ system and analysis procedure for measuring ground thermal properties. ASHRAE Transactions, Vol.106, Part I, pp.365-379.
11. Zhang X., 2001, Experimental and interrelated theoretic research on Ground- coupled heat pump system, Modern air conditioning, Vol. 3, pp. 75-87.
12. Fan X., Xie Q., and zhen H. etc., 2001,Water-source heat pump system and application, Modern air conditioning, Vol. 3, pp.101-111.
13. Mei V. C., 1986, Theoretical heat pump ground coil analysis with variable ground far-field boundary conditions, ASHRAE Journal, Vol. 28(7), pp. 11-15.
14. Ball D. A., Fischer R. D., 1983, Design methods for ground-source heat pump. ASHRAE Transactions, Vol. 89, Part II, pp.416-440.
15. Ding L., Chen J., 2002, Underground vertical single tube heat exchange affect factors by soil source heat pump, Fluid Machinery, Vol. 30(3), pp. .
16. Steve Kavanauh, 1995. A design method for commercial ground-coupled heat pumps. ASHRAE Transactions, Vol. 101, Part I, pp.1088-1094.
17. Chen F., Deng Y., and Xue Z., 1999, Building environment design simulate toolbox DeST. HV&AC, Vol. 29(4), pp. 58-63.
18. Cane P. E., 1991. Modeling of ground-source heat pump performance. ASHRAE Transactions, Vol. 97, Part I, pp. 909-925.
19. Kavanaugh S., 1992. Ground-coupled heat pumps for commercial buildings. ASHRAE Journal, Vol. 34(9), pp. 30-37.
20. Phetteplace G., 1998. Performances of a hybrid ground-coupled heat pump system. ASHRAE Transactions, Vol. 104, Part I, pp.763-770.
21. Kavanaugh S.P., 1998. Design method for hybrid ground-source heat pumps. ASHRAE Transactions, Vol. 104, Part II, pp.691-698.
22. Fleming W. S., 1998. Ground-source heat pump design and operation—experience within an Asia country. ASHRAE Transactions, Vol. 104, Part I, pp.771-774.
23. The regulation of city groundwater. Ministry of Construction.
24. Kevin P.E. A capital cost comparison of commercial ground-source heat pump systems. ASHRAE Transactions, Vol. 101, Part II, pp.1095-1100.

TABLES

Table 1 Climate of main cities of HSCW zone

Location	Wuhan	Changsha	Shanghai	Nanjing	Chungking
Annual temperature ℃	16.3	17.2	15.7	15.3	18.3
Mean temperature in hottest month ℃	28.8	29.3	27.8	28.0	28.6
Outdoor design dry-bulb temperature for winter air condition ℃	-5	-3	-4	-6	2
Outdoor design dry-bulb temperature for summer air condition ℃	35.2	35.8	34.0	35.0	36.5

Table 2 A practical GSHP engineering operate performance data

	Summer	Winter
The cooling water temperature in/out ℃	9～15	50～40
Middle water in/out ℃	18～27	11～4
Groundwater in/out ℃	15～24	15～9
Indoor temperature ℃	22～26	>20
Unit（system）COP value	4.37（3.13）	3.49（2.72）

Table 3 The ground temperature in January and July of Shanghai

Depth（centimeter）	0	5	10	20	40	80	160	320
January ℃	4.4	4.7	5.1	6.1	7.4	9.7	13.2	17.2
July ℃	30.4	29.5	29.3	28.4	26.7	24.2	20.7	16.7

Table 4 Annual civil building cool/heat load and ground losing/getting heat values of Chungking （kW·h/㎡）

	Annual cool load in summer	Annual cool load in winter	Annual ground getting heat in summer	Annual ground getting heat in winter
Civil building	26.4	62.4	35.1	41.6

Table 5 Annual civil building cool/heat load and ground losing/getting heat values of Changsha （kW·h/㎡）

	Annual cool load in summer	Annual cool load in winter	Annual ground getting heat in summer	Annual ground getting heat in winter
Ci	42.2	33.5	56.1	22.3

vil building

FIGURES

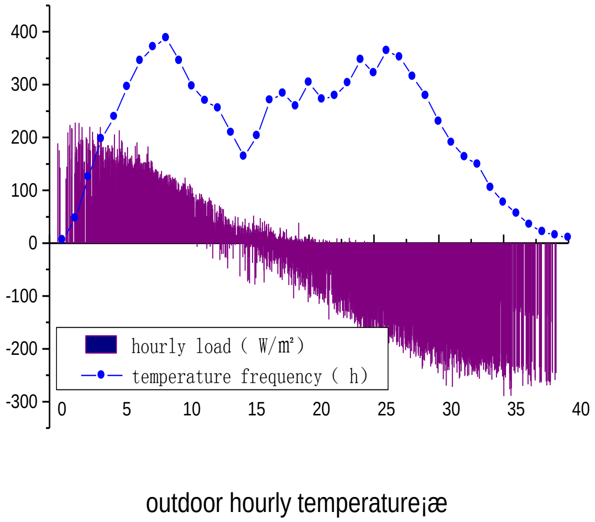

Figure 1. Hourly load and temperature frequency along with outdoor temperature in Changsha

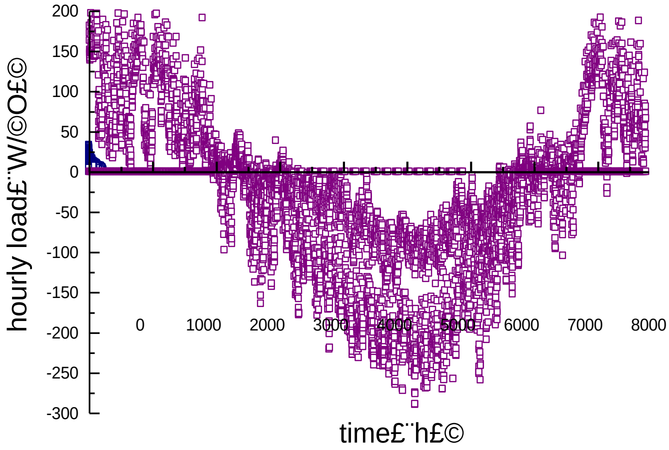

Figure 2. Hourly load of a year in Changsha