Ground Source Heat Pump System: A Review of Current Status in China

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Abstract: This paper discusses the research and the state-of-art practices on ground source heat pump systems (GSHP) in China. It introduces the Chinese patents on GSHP. The GSHP development policies of China, including incentive mechanism, relevant codes and regulations, are also introduced. In addition, this paper discusses and summarizes the shortages and imperfects of the current research of the GSHP system and gives some recommendations for future work. At last, the authors give some advice for the development of ground source heat pump. For more reliable statistics on geothermal energy use, the obligation to supply an installation report to the relevant authority should also be imposed on the rural buildings besides urban buildings. GSHP systems are suitable for heating and cooling of buildings and so could play a significant role in reducing CO_2 emissions.

Keywords: Application, China, ground source, heat pump.

1. INTRODUCTION

Global warming has generated increased international concern and the reduction of CO^2 emissions also became an emergent issue, attracting interest to many energy-saving technologies around the world. Amongst those which use natural energy are ground-source heat-pump (GSHP) systems, which utilize temperature differences under natural conditions. Currently, ground source heat pump systems have become an important energy-saving and environmental protection technology for space heating and air-conditioning of residential and commercial buildings. These systems can achieve greater energy savings than conventional air-source heat-pump systems, since they use ground or groundwater as their heat source, which maintains a relatively stable temperature. They make use of renewable energy stored in the ground, providing one of the most energy-efficient ways of heating buildings. They are suitable for a wide variety of building types and are particularly appropriate for low environmental impact projects. They do not require hot rocks (geothermal energy) and can be installed in most of the world, using a borehole or shallow trenches or by extracting heat from a pond or lake. Heat collecting pipes in a closed loop, containing water (with a little antifreeze) are used to extract this stored energy, which can then be used to provide space heating and domestic hot water and to provide an element of cooling [1].

In November 1997, the U.S. Department of Energy (DOE) and the Chinese Ministry of Science and Technology (MOST) signed a joint cooperation focused on development of the geothermal heat pump market in China. This agreement, also called Annex IV under the U.S.-China Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization (U.S.-China Protocol), demonstrated the technical and economic feasibility of ground-air GSHP technology to enhance commercialization potential for the benefit of both China and the U.S. This agreement has led to notable achievements. To date, 12 GHP demonstration projects have been developed in a joint effort by DOE, the U.S. GSHP Consortium, and Beijing Jike Energy New Technology Development Company (Beijing Jike). Based on the first three completed projects, in April 2002 Beijing Jike and a U.S. company, Jacwill Services, were awarded a $309,000 U.S. Trade and Development Agency (TDA) grant to expand the GSHP market in China and leverage $5-10 million in four additional projects in northern China. The projects demonstrated the benefits of ground-air GSHP technology over conventional heating and cooling technologies, especially in the residential setting.

This paper discusses the research and the state-of-art practices on GSHP systems in China. Then it introduces the Chinese patents on GSHP. The GSHP development policies of China, including incentive mechanism, relevant codes and regulations, are also introduced.

2. THE COMPONENT OF GSHP SYSTEM

A geothermal heat pump includes three principle components—an earth connection subsystem, heat pump subsystem, and heat distribution subsystem.

(1) The earth connection system

(2) A heat pump

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This has three main parts: the evaporator—(e.g., the squiggly thing in the cold part of the fridge) takes the heat from the water in the ground loop; the compressor—(this is what makes the noise in a fridge) moves the refrigerant round the heat pump and compresses the gaseous refrigerant to the temperature needed for the heat distribution circuit; the condenser—(the hot part at the back of the fridge) gives up heat to a hot water tank, which feeds the distribution system.

(3) Heat distribution system

Consist of under floor heating or radiators for space heating and in some cases water storage for hot water supply.

As is shown in Fig. (**1**).

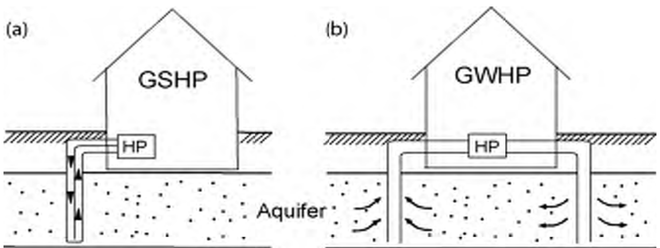

Fig. (1). (**a**). Ground source heat pump (GSHP) system and (**b**) groundwater heat pump.

3. A BRIEF UTILIZATION AND HISTORICAL DEVELOPMENT OF GSHP IN CHINA

The research and practices on GSHP in China started relatively much later than that in developed countries. The end of 1980s saw the beginning of experiments and tests on the performance of the GSHP systems. Qingdao Technological University, Tianjin University of Commerce and Tianjin University are the first three universities, which conducted relevant research on GSHP technologies. At the end of 1990s, theoretical and experimental studies in all aspects of GSHP were carried out, mainly supported by the National Natural Science Foundation of China. More and more universities and academes, such as Hunan University, Harbin Institute of Technology, Tongji University and Beijing University of Technology, joined in the research work. Some significant achievements have been attained ever since, so that the application and development of GSHP systems are being boosted greatly. The beginning of the 21st century is a period of rapid growth of the application of GSHP systems. However, due to China's vast territory and differentiated climatic zones as well as the restrictions on water resource and environmental policies, Chinese research and practices on GSHP have their own characteristics. Investigations in the characteristics of the research and application of GSHP in China become a necessity for academia and policy development [2]. Since 1990s, the Chinese market for GSHP has developed significantly. With continuous commercialization of the technology combined with Chinese and U.S. government support, GSHP could significantly contribute to China's effort to move toward more sustainable development.

4. SIMULATION MODEL AND OPERATION PERFORMANCE OF GSHP IN CHINA

4.1. Coupled Model and Simulation of Ghe and Heat Pump Unit

In China, in terms of the simulation of the GSHP system, the studies focus on the simulation of the heat pump unit or a single component, and the coupling of the building load, ground heat pump unit and GHE. Since the operating principle of the heat pump unit is similar to that of the conventional air conditioning unit, generally, based on the law of mass and energy conservation, researchers establish mathematical models of four main components of the typical heat pump unit, including the compressor, condenser, expansion valve and evaporator and then combine these models to simulate the operation performance of the heat pump unit *via* the numerical method. Zhou *et al*. [3] proposed a dynamic lumped parameter model to describe the operating characteristics, and mass and energy conservation of the refrigeration equipment. The parameters of the refrigeration unit in any operating mode are quickly simulated based on a few structural parameters and performance parameters of the working condition. Yang *et al*. [4] developed a characteristic parameter optimization prediction model, which is used to analyze the operation performance of the water-to-water heat pump with eight undetermined characteristic parameters. Wang [5] regarded the heating output of the heat pump unit as the power function of the flow temperature and flow rate of the source side and load side. By employing the neural network analyzing method, the operation feature curve of the heat pump unit is fitted to analyze the variation of its heating output and cooling output. The operation feature curve also illustrates the coupling relationship between the ground source heat pump unit and the GHE under annual dynamic load. Based on the simulation model of the GSHP system and the building load in a whole year, Yang *et al*. [6] defined the annual performance factor (APF) of the water-to-water heat pump and used it to study the optimal design and matching mode between different components for the on/off control scheme of the compressor.

At present, there are limited studies focusing on the dynamic coupled model of the GHE and the ground heat pump unit in China. Wang [7] adopted the mechanism modeling method to establish a dynamic mathematical model combining the heat pump unit and the load of the building. Besides, the fuzzy control method is applied in the system. The dynamic operating simulation is carried out with the help of Matlab/Simulink. Qu [8] built a dynamic simulation model by incorporating the ground heat pump model, GHE model and water loop model on the basis of the energy and mass conservation. The simulation model can predict the operating parameters and energy consumption profile of the GSHP system at any time. Zhao *et al*. [9] established a prediction model whose key parameters are the heat exchange rate and heat transfer coefficient by using the grey theory. The operational conditions of the unbalance of the load between winter and summer are divided into three working phases: transitional phase, steady phase and declining phase. Grey prediction can provide a quantitative basis for the stable operation and the operation optimization of the GSHP system. At the mean time, experimental investigation [10] was conducted to analyze the long-term operation performance of the GSHP. The experimental results showed that the COP of GSHP system increased in winter and decreased in summer. Ma *et al*. [11] detected the operation of an actual GSHP project for three consecutive quarters, analyzing the reasons and influence factors of the ground heat unbalance and proposing advices for the optimization.

4.2. Simulation of GSHP

To deal with the performance decline of the GSHP system which is caused by the unbalanced building load between winter and summer, the GSHP with assistant cooling devices or heating devices has appeared. At present, most studies mainly focus on the computational analysis of the operation mode, optimization and performance of the system. Wang *et al*. [12, 13] simulated and evaluated the operation performance of the assistant cooling source heat pump system in the hot summer and cold winter region, and adopted the corrected design method to maximize its performance and indicated that considering the initial investment and operating cost, the assistant cooling-source heat pump system is superior to the GSHP system without assistant cooling. Yang *et al*. [14, 15] developed a mathematic model for the solar earth source heat pump system (SESHPs) on the basis of the component models, and simulated numerically the performance of alternative SESHPs. Ma *et al*. [16-18] presented the integrated frozen soil cool storage-GSHP system. Through establishing the mathematic model of the soil charge and discharge, the operation performance of the integrated system is simulated numerically and the energy loss through the soil charge and discharge is analyzed. In addition, literatures [19, 20] have investigated the control strategies, design procedures and optimization designs of different kinds of HGSHP systems and provided general methodologies and advices for optimal design and operation of such HGSHP systems.

5. REGULATION AND POLICY ON GSHPS IN CHINA

Research on GSHP systems and their commercial use started in the 1980s [21]. In 2006 the China Renewable Energy Law and also the first technical standard for geothermal heat pump systems (GB50366-2005) was enacted. It is valid for open and closed systems and also for surface water heat pumps and it contains project investigation, general information for such systems, for example system design or backfilling material. As distance between each BHE for GSHP systems 3 and 6 m are recommended [22]. Since 2006 general documents on renewable energy have increasingly been issued by the Chinese authorities [21]. In practice a minimum distance of 4 m between individual BHEs is usually applied. However, there are not yet any regulations for temperature thresholds or minimum distances for closed and open systems.

"Technical Code for Ground Source Heat Pump System (GB50366-2005)", has been promulgated and took effect on January 1, 2006. The code plays a significant role for the development of geothermal heat pump industry. The code is composed of eight parts, including general principles, technical terms, engineering exploitation, buried pipeline heat exchange systems, groundwater heat exchange systems, surface water heat exchange systems, indoor systems, equipment operation and trial running, etc. "Main points of industry development plan in new and renewable energy resources from year 2000 to 2015" indicated that ''China will actively promote the development and utilization of geothermal and ocean energies. Geothermal energy resources will be used rationally-promoted so as to meet environmental protection and water resource protection requirements. Geothermal energy will be used for heating, hot water supply, and geothermal heat pumps. The heat pump technology will be widely promoted for space heating and cooling in regions in need of space cooling in summer and space heating in winter. The target of annual geothermal energy utilization will be 4 metric tons carbon equivalent (Mtce) by 2010 and 12 Mtce by 2020." The existing significant policy documents related to GSHP technologies is shown in Table 1.

6. PATENTS RELATED TO GSHP

There has been increasing number of patent applications related to GSHP over the past two decades. From 1985 to 2007, there are 630 in total, in which 278 of them are issued patents, 157 of the total is under examination, the other 258 has been rejected [23]. Fig. (**5**) shows the number of the patents applied from 1985 to 2007. As is shown in Fig. (**2**), the patent applications are in the rapid development phase from 1996 to 2003. Since 2003, the number of application patent is about 80 each year, which indicates that the GSHP in the maturity stage in China. Among all the 630 patents, 59%were about making use of water as heat source and sink, and 41% of the patents were related to GCHP system. As the application of SWHP (Surface Water Heat Pump) and GWHP (Ground Water Heat Pump) are restricted by environmental policy, water source, and recharge technology, the related number of patents is decreased

In recent years. Meanwhile, the number of the patent related to the GSHP is increased. These patents are mainly used for air-conditioning and hot water. The percentages of the patents usage are shown is Fig. (**2**). The market survey conducted estimated the potential sales of GSHP technology by predicting the growth of the air-conditioning market in all of China, for both commercial and non-commercial use. The survey found that between 2005 and 2010, sales of both GSHP systems and units increased at a yearly rate of about 17%.

7. THE FUTURE OF GSHP TECHNOLOGIES IN CHINA

The GSHP technologies can be useful to adjust Chinese energy structure by remarkably reducing reliance on fossil fuels. With the support of Chinese government, the research work of the GSHP technologies is recognized as one focus

Table 1. Existing significant policy documents related to GSHP technologies.

No.	Title	No.	Title
1	Energy Conservation law of People's Republic of China	7	Decision about strengthening energy efficiency tasks
2	Agenda of China 21st Century	8	Opinions on promoting application of renewable energy in buildings
3	Renewable Energy Law of People's Republic of China	9	A tentative management method of special funds for renewable energy development
4	New and renewable energy resource development outline (1996-2010)	10	China's national climate change program
5	Main points of industry development plan in new and renewable energy resources from year 2000 to 2015	11	Medium and Long-Term Development Plan for Renewable Energy in China
6	Regulation of civil building energy saving (2005)	12	Technical code for ground source heat pump system

issue in the HVAC field in China. Consequently, these technologies enjoyed a boom in China, and some achievements have been made in recent years, which promoted the application of GSHP. Though China has not yet set up a fully developed financial incentive system for GSHP, some laws, codes and regulations have been set up to promote the development of the GSHP systems. In addition, the advantages of GSHP technologies also evoked a strong attraction to the users. Therefore, as presented early, the application of GSHP systems will have an upward tendency at its primary stage in China. It is also believed that the GSHP systems will have broad prospects in China. On the other hand, the application of GSHP systems should be based on different locations and climatic zones. The GSHP systems are suggested to be mainly used in cold, cold winter& hot summer and mild zones. If the heat extraction and heat rejection cannot be balanced, the hybrid systems are suggested to be used. In the southeast and coastal areas, where there is abundant groundwater and surface water resource, the SWHP are suggested to be used while in the cold and cold winter and hot summer zone, the GWHP are suggested to be used.

Since the energy for GSHP comes from the soil and is free, the expense for GSHP-generated heating and cooling is lower than conventional sources— electricity is required only for the heat pumps and controls. As the Chinese government looks toward achieving sustainable development goals, energy consumption policy will be an important factor in promoting the use of GHP technology. Preferential pricing, tax benefits, and subsidies are all encouraged for the promotion of GHP. Thus, the development of GHP utilization depends on forward-looking government policies, and efforts to educate the public about the economical and environmental advantages of GHP technology.

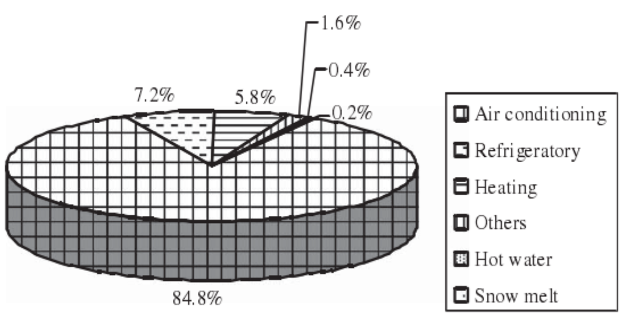

Fig. (2). Application of the patens related to GSHP [23].

8. MARKET SURVEY AND ANALYSIS OF POTENTIAL GSHP COMMERCIAL GROWTH

A recent market survey of 14 cities and provinces in China, supported by the U.S.-China Protocol, revealed that the predicted growth in sales for GSHP units and building systems is significant. Growth was predicted in two ways. The first formula of calculation, reflected in Tables **2** and **3**, combined the following values: the predicted annual growth of newly constructed buildings' floor space; the percentage of this floor space that is suitable for GSHP utilization; the price of GSHP system construction per square meter of floor space (for example, in public buildings the price of construction equals 320 Yuan [US$52.03] per m^2); and the rate of installation of GSHP technology, based on preferential policies and the increase in commercialization [24]. Table **2** shows the values obtained from this calculation for public not-for-profit buildings (such as schools and hospitals); Table **3** shows the results for commercial for-profit buildings.

China has been experiencing an electricity shortage since 2003, and much of this shortage is caused by air conditioning use during summer months—air conditioning accounts for more than 40% of total public energy consumption in China's developed cities during these months. GHP technology requires less electricity for cooling than a traditional air conditioner and presents a real solution to the need for energy conservation. Imports of GHP units (especially U.S. imports) and energy-efficient appliances have increased steadilysince 1999, while imports of household-size air conditioning units have declined. However, the price of Chinese air conditioners has decreased consistently over recent years, so the challenge for the promotion of GHP technology is to decrease its price similarly and demonstrate that the quality-price ratio is considerably higher.

The market survey conducted by a China company also estimated the potential sales of GsHP technology by predicting the growth of the air-conditioning market in all of China, for both commercial and non-commercial use. The survey found that between 2005 and 2010, sales of both GSHP systems and units should increase at a yearly rate of about 17%. Overall, the estimated sales of GSHP systems in 2010 equals 7.65 billion Yuan--a 116% total increase from the estimated sales for 2005. The future of market

Table 2. Forecasted sales of GSHP systems and units in public buildings over a five-year period in 14 provinces of China. Sales are in millions (m) or billions (bn).*

	2008	2009	2010	2011	2012	2013
GSHP system	CNY 3.93 bn	CNY 5.19 bn	CNY 7.48 bn	CNY 9.08 bn	CNY 10.50 bn	CNY 10.92 bn
	US 633.87 m	US 837.10 m	US 1206.45 m	US 1.46 bn	US 1.69 bn	US 1.76 bn
GSHP unit	CNY 1.57	CNY 2.08 bn	CNY 2.99 bn	CNY 3.63 bn	CNY 4.20 bn	CNY 4.37 bn
	US 253.22 m	US 35.48 m	US 482.26 m	US 585.48 m	US 677.42 m	US 704.84 m

* Conversion rate used: 1 USD = 6.20 CNY.

Table 3. Forecasted sales of GHP systems and units in commercial buildings over a five-year period in 14 provinces of China. Sales are in millions (m) or billions (bn). *GHP units include GHP equipment; GHP systems include closed-loop heat exchangers, pump, pipelines, etc.

	2008	2009	2010	2011	2012	2013
GSHP syste m	CNY 449.0 m	CNY 566.0 m	CNY 808.0 m	CNY 1.00 bn	CNY 1.18 bn	CNY 1.35 bn
	US 72.42 m	US 91.29 m	US 130.32 m	US 161.29 m	US 190.32 m	US 217.74 m
GSHP unit	CNY 180.0 m	CNY 226.0 m	CNY 323.0 m	CNY 402.0 m	CNY 473.0 m	CNY 541.0 m
	US 29.03 m	US 36.45 m	US 52.10 m	US 64.84 m	US 76.29 m	US 87.26 m

*Conversion rate used: 1 USD = 6.20 CNY.

development for GHP technology appears promising, since the promotion of GHP and other environmentally responsible technologies is driven primarily by government policy, which increasingly favors sustainable development and environmental protection. In fact, this forecasted growth represents a conservative viewpoint. The predicted increase in demand is based largely on a growing desire for cooling and air conditioning, and much of this will be comprised of U.S. ground-air technology.

CONCLUSION

In this paper, the current status of GSHP systems in China was presented. In China, the GSHP systems have been increasingly paid attention to. Improved use of hydrothermal resources, limitation of front-end costs and increased ground heat extraction are the keys to a steady development of conventional geothermal energy. The number of applications is growing rapidly in both residential and commercial buildings in recent years. Nowadays, China has seen great success in implementing GHP projects that have proven commercially, economically, and environmentally viable. For China, the GHP projects provide a welcome option for promoting environmental protection and energy efficiency in heating and cooling, while enjoying a low operating cost.

Despite this optimistic anticipation, there are a few barriers hindering the development and the use of geothermal energy, particularly for shallow low temperature energy. They include insufficient technical experiences (high cost of installation), societal concerns of environmental aspects related to groundwater contamination and regulations not specifically tailored to the GSHP systems. All these problems can be tackled by the cooperative work of geothermal companies, researchers and regulation authorities. In the meantime, for more reliable statistics on geothermal energy use, the obligation to supply an installation report to the relevant authority should also be imposed on the rural buildings. GSHPs are suitable for heating and cooling of buildings and so could play a significant role in reducing CO_2 emissions.

CONFLICT OF INTEREST

The authors declare that this article content has no conflict of interest.

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