

# A Comparative Study on the Status of GSHP Applications in US and China

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## Abstract

Since the ground source heat pump (GSHP) technology (also often referred as geothermal heat pump) was developed and commercialized in 1970's, more than 1.5 million GSHP units have been installed in the US. The applications of GSHP technology also grew rapidly in China since it was introduced into China in 1990's through collaboration between the Chinese and US governments. It is estimated that 227 million m<sup>2</sup> (2.44 billion ft<sup>2</sup>) building floor space in China have been heated or cooled by GSHP systems by 2009. Both Chinese and the US governments are giving strong incentive and support to promote applications of GSHP technologies.

After decades of practices, both countries have accumulated abundant experience in the application of GSHP technology, but also are confronted with various challenges to rapidly deploy this energy saving technology. Under the US-China Clean Energy Research Center for Building Energy Efficiency (CERC-BEE), researchers reviewed and compared various aspects of the current status of GSHP applications in US and China, including related policies, standards, technologies, equipment, cost of various GSHP systems, and market development.

In this paper, a comprehensive comparison of GSHP applications in the two countries is summarized in six areas: current landscape of GSHP applications, applied technologies, market development, policies and incentives, standards and certifications, and barriers preventing sustainable growth. Based on this comparison, areas where both countries can learn from each other are identified and recommendations for future collaborations are suggested.

## 1. Introduction

Ground source heat pump (GSHP), which is also equivalently referred as geothermal heat pump (GHP), is applied to a variety of systems that use the ground, groundwater, or surface water as a heat source and sink (ASHRAE, 2007). The general terms include ground-coupled heat pump (GCHP), groundwater heat pump (GWHP), and surface water heat pump (SWHP).

Since GSHP technology was developed and commercialized in 1970's, more than 1 million GSHP units have been installed in the United States (US EIA, 2010). The application of GSHP technology grows rapidly in China in recent year and it is estimated that 227 million m<sup>2</sup> (2.44 billion ft<sup>2</sup>) buildings in China have been heated and/or cooled by GSHP systems by 2012 (MoHURD 2012). Both Chinese and the US governments are giving strong incentives and supports to promote applications of GSHP technologies.

After decades of practices, both countries have accumulated abundant experience in the application of GSHP technology, but also are confronted with various challenges to rapidly deploy this energy saving technology. Under the US-China Clean Energy Research Center for Building Energy Efficiency (CERC-BEE), researchers surveyed the current status of GSHP applications in the United States and China, respectively (Liu, 2012 and LU, 2012 and Chen, 2012).

In this paper, a comprehensive comparison of GSHP applications in the two countries is summarized in six areas: current landscape of GSHP applications, applied technologies, market development, policies and incentives, standards and certifications, and barriers preventing sustainable growth. Based on this comparison, areas where both countries can learn from each other are identified and recommendations for future collaborations are suggested.

## 2. Landscape of GSHP Applications

Based on available information, the current landscape of GSHP applications in both the US and China is depicted in Table 1 by a side-by-side comparison in three categories: geographical distribution, building characteristics, and cumulative GSHP applications in the two countries.

**Table 1. Comparison of current GSHP applications in the United States and China**

	<b>Geographical Distribution</b>	<b>Building Characteristics</b>	<b>Cumulative GSHP Applications</b>
<b>US</b>	Used in all the 50 States and the District of Columbia. About 52% of domestic GSHP shipments	About 60% GSHP units are used in residential applications and 40% is used in commercial	Approximately, 1.5 million GSHP units have been installed (IGSHPA, 2009). It is roughly

	went to ten States: Florida, Illinois, Indiana, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, and Texas (US EIA, 2010).	applications (US EIA, 2010). It is estimated that 75% residential applications go to new construction and 25% to retrofits of existing homes (Hughes, 2008).	translated to 2.73 billion ft <sup>2</sup> (253 million m <sup>2</sup> ) <sup>1</sup> building floor space.
<b>China</b>	Widely applied in all climate zones. About 50% of GSHP applied areas went to 4 provinces (municipality): Shandong, Liaoning, Beijing and Jiangsu. More applications in areas with developed economy and fewer applications in western region. Mostly used in cities and rarely used in typical rural country and small towns.	All types of buildings, including residential, commercial, and industrial buildings (Xu 2008). Used more in residential buildings in northern region, while more popular in commercial/public buildings in climate zone with hot summer and cold winter.	In total, 227 million m <sup>2</sup> (2.44 billion ft <sup>2</sup> ) building floor space are conditioned with GSHP systems by 2010 (MoHURD, 2012)

As can be seen from Table 1, the cumulative GSHP application in China has almost been equal to that of the United States as a result of the rapid growth GSHP applications in China in the past 8 years.

Figures 1 and 2 graphically show the distribution of GSHP applications in the United States and China. The distribution of U.S. GSHP applications shown in Figure 1 is based on the 2009 data on the destinations of the GSHP unit shipment in the United States (US EIA, 2010) and is color-coded based on the total rated capacity (in cooling ton). The distribution of Chinese GSHP applications shown in Figure 2 is based on a survey conducted by Chinese Geological Survey (CGSB, 2010) and is color-coded by the cumulative installed building floor space. As shown in Figures 1 & 2, GSHP applications are concentrated in East-North region of the two countries, where space heating is needed. In the US, there are also many GSHP applications in Texas and Miami where the weather is hot and humid.

<sup>1</sup>It is estimated based on the average cooling capacity per GSHP unit, which is 3.5 ton (US EIA, 2010), the typical design cooling capacity (400 ft<sup>2</sup> per ton for commercial buildings and 600 ft<sup>2</sup> per ton for residential buildings), and the percentages for residential and commercial applications listed in Table 1.

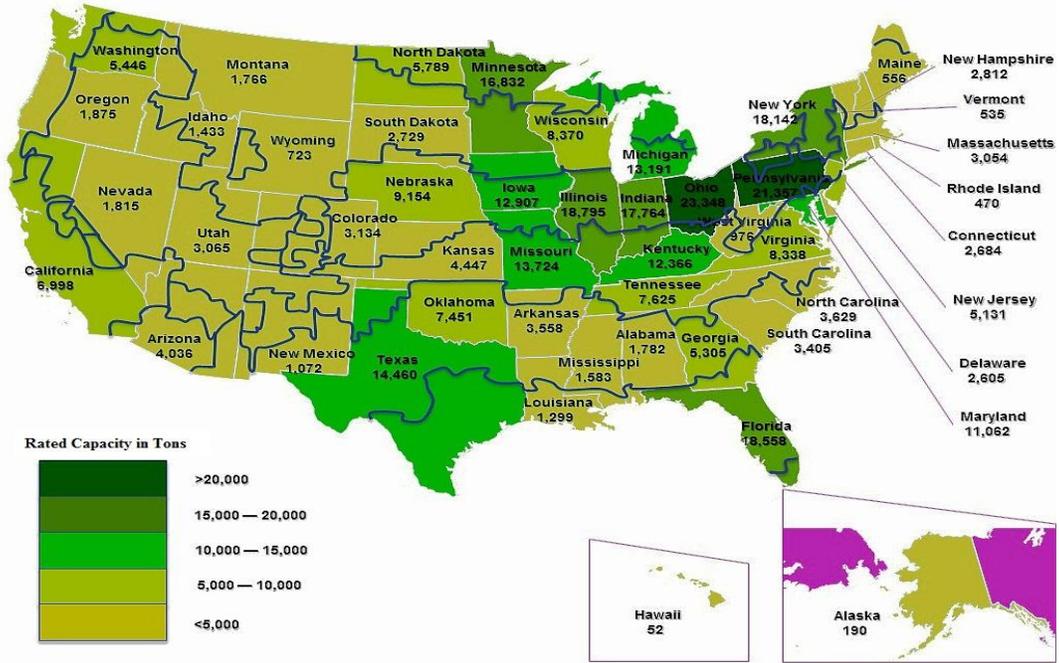


Figure 1. Distribution of GSHP unit shipments in the US in 2009

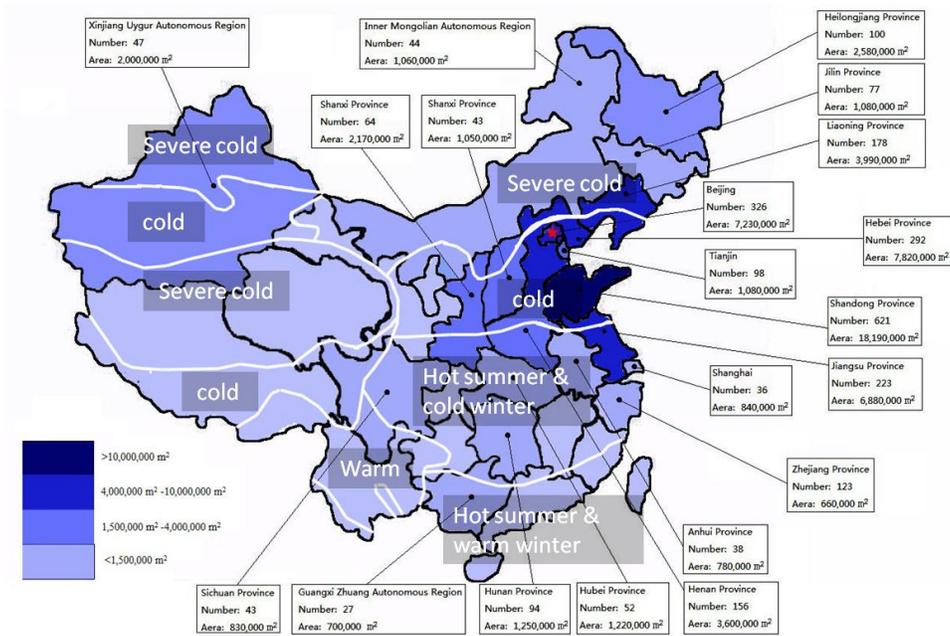


Figure 2. Distribution of cumulative GSHP applications in China

### 3. Applied Technologies

#### 3.1. Heat sinks and sources

The vast majority of GSHP systems in the United States use closed-loop ground heat exchangers (GHX) buried in the earth in either a vertical or horizontal configuration. It is estimated that vertical and horizontal closed-loop GHXs is used in 46% and 38% GSHP systems in the US, respectively. The rest 16% GSHP systems use surface water, ground water, or reclaimed grey water in an open loop or closed-loop configuration (Lund, 2001). The first, and currently also the only, heat pump system in the US that directly utilizes raw sewage water as heat sink and source was just commissioned in April 2012 (NovaThermal, 2012).

In contrast, the heat sinks/sources used in GSHP systems in China are much more diversified. Closed-loop GHXs are used in only 32% of the GSHP systems in China, ground water are the most predominant heat sink/source, which is used in nearly half (42%) of the GSHP systems in China. Other non-conventional resources (i.e. surface water and wastewater) are used in the 26% Chinese GSHP systems (Xu, 2008). Several Chinese companies have developed patented filter technologies that allow direct use of raw sewage water as the heat sink and source of GSHP systems (Pan, 2011). In a few GSHP systems, including the main building of the 2010 Shanghai World Expo, closed-loop GHXs were attached on building foundations in order to reduce drilling cost and land area requirement<sup>2</sup>.

The difference in the heat sources and sinks used in US and China is thought due to the fact that the building size and the required HVAC system capacity are larger in China but the available land for installing ground-couple GHXs is very limited. Since ground water can provide large capacity with minimal land requirement, it has been widely adopted in China, especially in East-North region. However, the usage of ground water for space conditioning is tightly regulated in the US due to concerns on its potential environmental impacts. The massive constructions ongoing in China and the strong governmental support and financial incentives for renewable energy application in buildings greatly motivated innovations in the application of GSHP technology in China, but in some cases, environment protection was not given enough consideration.

#### 3.2. Equipment

In the United States, there were 27 known domestic manufacturers of GSHP equipment (US EIA, 2010). Most of these manufacturers produce water source heat pump (WSHP) units not only for the GSHP market but also for water loop heat pump (WLHP) systems, which use more conventional cooling towers and boilers in place of ground heat exchangers. Small packaged or split water-to-air heat pump units with cooling capacity in the range from ½ to 20 tons are most commonly used in the US. Large central water-to-water heat pump chillers or modular water-to-water heat pump units have got some market share recently in large commercial GSHP systems.

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<sup>2</sup> <http://expo.newscn.com/2010-09-10/15087.html>

ClimateMaster (a unit of LSB Industries located in Oklahoma), Florida Heat Pump (a unit of Bosch located in Florida), WaterFurnace International, Inc. (located in Indiana), and Trane (a unit of Ingersoll Rand located in Texas)—are believed to produce most GSHP units in the US, supplemented by McQuay International (a unit of Daikin), Mammoth, and several regional manufacturers. Other major brands such as Carrier and Johnson Control International participate in the WLHP and GHP markets by sourcing WSHP units from other manufacturers. The direct employment in the GSHP manufacturer industry accounted for 1,832 person-years in 2009 (US EIA, 2010).

High-density polyethylene (HDPE) pipes are predominantly used in the closed-loop GHXs in the US. It is believed that Performance Pipe (a unit of Chevron–Philips), ISCO Industries, and Centennial Plastics are the largest suppliers of HDPE to the U.S. GSHP market.

Truck-mounted rotary or sonic drilling equipment, which is usually designed for water well or oil drilling, is most commonly used in the US for drilling boreholes of the vertical closed-loop GHXs. The directional drilling technology, which is primarily used for cabling in oil and natural gas industry, has been adopted lately to provide angled ground source boreholes.

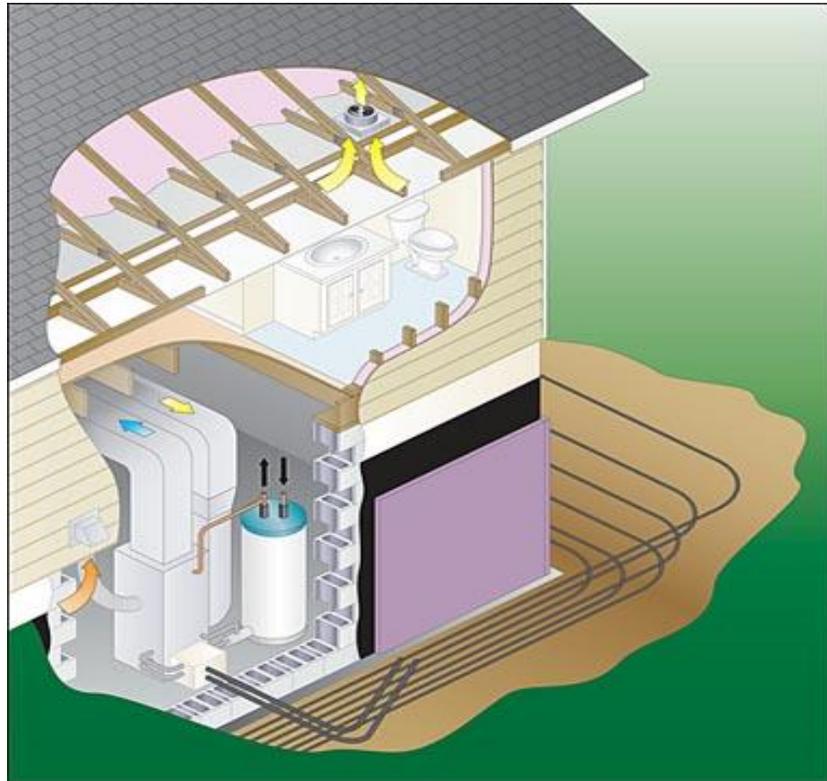
The specialty products unique to the GSHP system—such as flow centers, flush carts, purge pumps, pump stations, headers, vaults, hose kits, thermally enhanced grouts, specialty installation equipment, and surface water immersion heat exchangers—are generally made by relatively small regional firms.

In China, many GSHP equipment manufacturers have emerged in the past 10 years and now the total number is more than two hundreds. Most of these manufacturers are located in Shandong province, Beijing, Shenzhen, Dalian, Hangzhou, Suzhou, and Guangzhou. The domestically made GSHP equipment is mostly large central water-to-water heat pump using screw compressors and shell-tube heat exchangers. There are also modular GSHP unit using scroll compressor and flat-plate or shell-tube heat exchangers. The major domestic manufacturers include Qinghua Tongfang, Beijing Ever Source, Guangzhou Zhong Yu, Sichuan Deep Blue, Shandong Jigao, and Haier. The cooling capacity of the large central GSHP unit is up to 2000 – 3000 kW (500 - 900 ton) but mainly in the 50-2000 kW range (15 – 500 ton). There are also small GSHP units with 10 kW (3 ton) cooling capacity for residential applications. In addition to the domestic brands, many internationally renowned brands went into China by establishing manufacturing base or joint-adventure companies to locally serve Chinese market.

There are more than 100 other manufacturers in China that manufacture accessories of heat pump equipment and polyethylene pipe. The design and installation infrastructures of GSHP industry grow rapidly in China and it is estimated that the current workforce has exceeded 100,000 people.

### 3.3. System Configurations

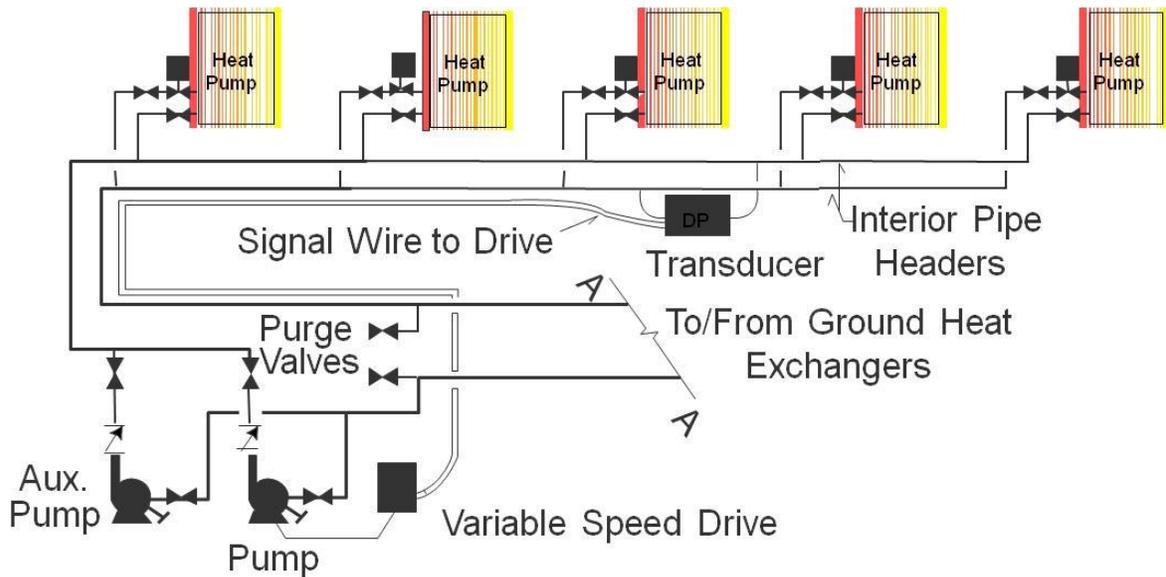
The most typical configuration of GSHP systems used in typical U.S. homes is a packaged water-to-air heat pump unit coupled with a central duct air distribution system, which conditions the entire house as illustrated in Figure 3. A combination of this forced-air system with radiant floor heating is often used in high-end homes in northern region for better thermal comfort, in which case, a water-to-water heat pump that is connected to the ground loop is used in addition to the water-to-air heat pump and a more sophisticated control strategy is needed to optimize the system performance.



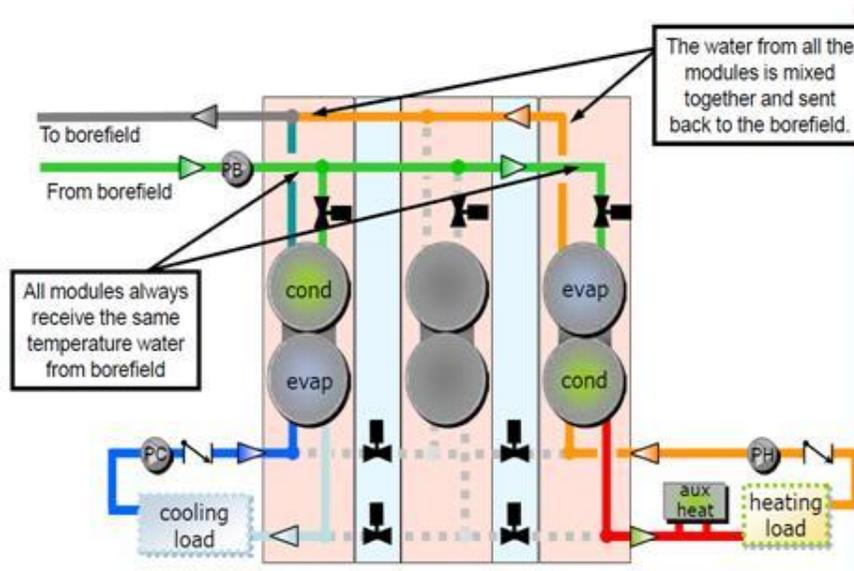
**Figure 3. Typical configuration of residential GSHP system in the US.**

For commercial buildings, such as offices, schools, or hotels, or large residential buildings with multiple dwelling units, decentralized GSHP systems are predominantly used in the US (Liu, 2012). With the decentralized GSHP system, each zone of the building is conditioned with an individual heat pump unit and all these individual heat pump units are connected through a common water loop. Traditionally, a two-pipe water loop is used with a central pump station as shown in Figure 4. To save pumping energy, the central pump is usually operated with a variable speed drive. Recently, a one-loop design has been introduced (Mescher, 2010). In this design, each individual heat pump uses a dedicated circulator to extract water from and rejected it back to the same water loop after exchanging heat with the heat pump. The central pump of the

common loop can be downsized and only operates when the loop temperature is beyond a specified range. This design reduces the piping cost and also the pumping energy without using the more expensive variable speed pump.



**Figure 4.** Typical configuration of decentralized GSHP systems (Kavanaugh and Rafferty, 1997).



**Figure 5.** Typical configuration of four-pipe central GSHP systems used in the US (Trane 2008).

Central GSHP systems, which use large heat pump chiller or modular water-to-water heat pump to generate hot and/or chilled water and then deliver it to the conditioned space, have also been used in US, especially for retrofitting existing central chiller and boiler systems (e.g. the central district GSHP system in Ball State University). As shown in Figure 5, to satisfy the simultaneous demands for heating and cooling at different zones of a building, the central GSHP systems in the United States usually have four-pipe water loop: two pipes are for the supply and return of the chiller water, and the other two pipes are for the supply and return of the hot water. Lately, Trane introduced a cascade configuration for central GSHP systems that use multiple heat pump chillers, which could improve heat pump efficiency by taking advantage of the simultaneous heating and cooling operations of different heat pump chillers (Trane, 2008).

In China, central GSHP systems are most popularly used. However, different from the four-pipe configuration used in the US, most of these central GSHP systems have two-pipe configuration (as shown in Figure 6), which can only provide heating or cooling at a given time and cannot provide simultaneous heating and cooling to different zones in the building. The application of decentralized GSHP systems is very limited in China now.

Both the central and decentralized systems have advantages and disadvantages, as summarized in Table 2. The dominance of the central system with two-pipe configuration in China is thought due to following reasons: 1) low initial investment, 2) familiar to designers, 3) energy saving compared with the four-pipe configuration (with sacrifice of thermal comfort, especially during shoulder season), and 4) convenient for retrofitting existing conventional HVAC systems that use two-pipe configuration. However, with the increasing demand for active individual indoor environment control, it is foreseeable that the decentralized GSHP systems will be adopted in China eventually.

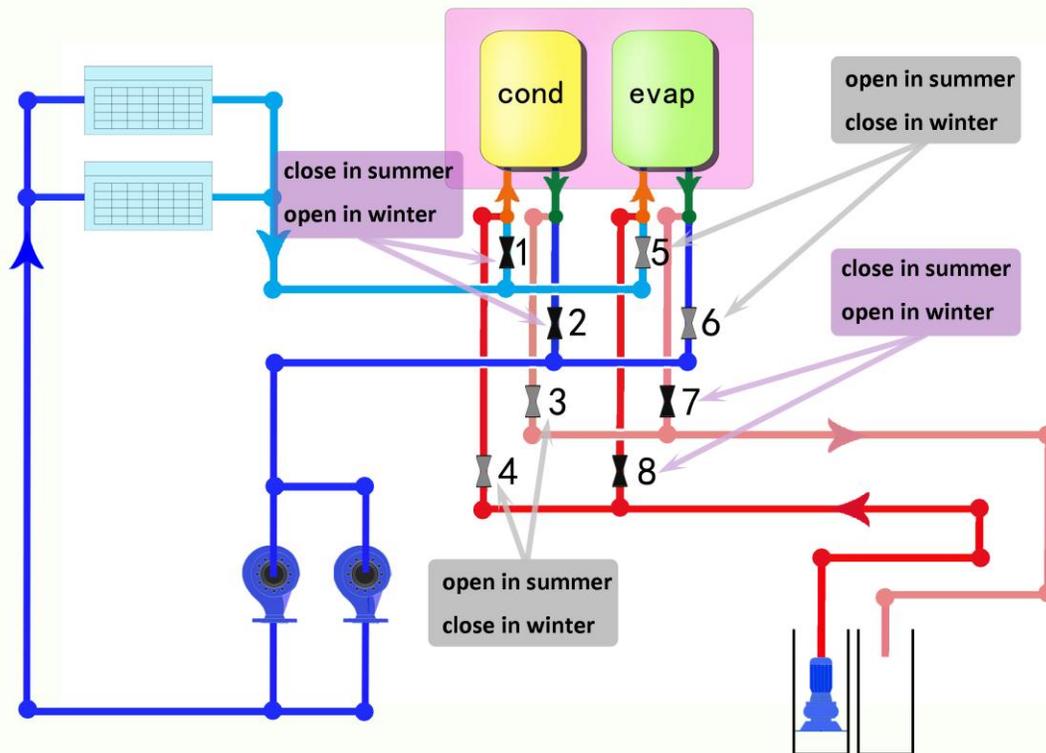


Figure 6. Typical configuration of central GSHP systems in China

Table 2. Comparison of advantages and disadvantages of central and decentralized systems

	Advantages	Disadvantages
Central System	<ul style="list-style-type: none"> <li>With central service and maintenance</li> <li>Easy for retrofitting existing conventional central HVAC systems</li> <li>Able to integrate air economizer if central air distribution is used</li> </ul>	<ul style="list-style-type: none"> <li>Mechanical room is needed and the system is more complicated</li> <li>System efficiency degrades at part load conditions</li> <li>Requires chiller technicians to service central plant</li> </ul>
Decentralized System	<ul style="list-style-type: none"> <li>Simple design and limited floor space requirement</li> <li>Isolated impact of equipment failure and easy to self-service</li> <li>Superior efficiency at part load conditions and capable of individual metering of energy consumption</li> <li>Heat recovery in the common loop</li> </ul>	<ul style="list-style-type: none"> <li>Decentralized service and maintenance</li> <li>Requires a separate dedicated outdoor air system (DOAS)</li> </ul>

#### 4. Market Development

A recent estimate (IGSHPA, 2009) indicated that there have been 1.5 million GSHP units up in operation in the US. As shown in Figure 7, the shipment of domestic GSHP units has increased rapidly since 2004. The total shipments of GSHP units increased more than 40% in 2008 to 121,243 units compared to 86,396 units in 2007. The rated capacity of the shipped units grew 43% in 2008 to 416,105 tons compared to 291,300 tons in 2007. The GSHP shipments dropped to about 100,000 units in 2010 due to the recession. It is estimated that the total revenue of domestic GSHP units was approximately \$550 million. A report issued by Priority Metrics Group (PMG 2009) estimated that the GSHP market in the US was around \$3.7 billion in 2009, including design, equipment, and installation costs.

In China, the GSHP industry has experienced an explosive growth since 2005 due to the strong promotion and financial incentives offered by Chinese central government. The GSHP application increases year by year and the cumulative application area reached 227 million m<sup>2</sup> (2.44 billion ft<sup>2</sup>) by 2010 (MoHURD, 2012). As shown in Figure 8, the growth rate of GSHP applications in China exceeded 60% in the past two years, which is much faster than the 20% average growth rate of GSHP applications in the world in the recent 5 years (Xu, 2008).

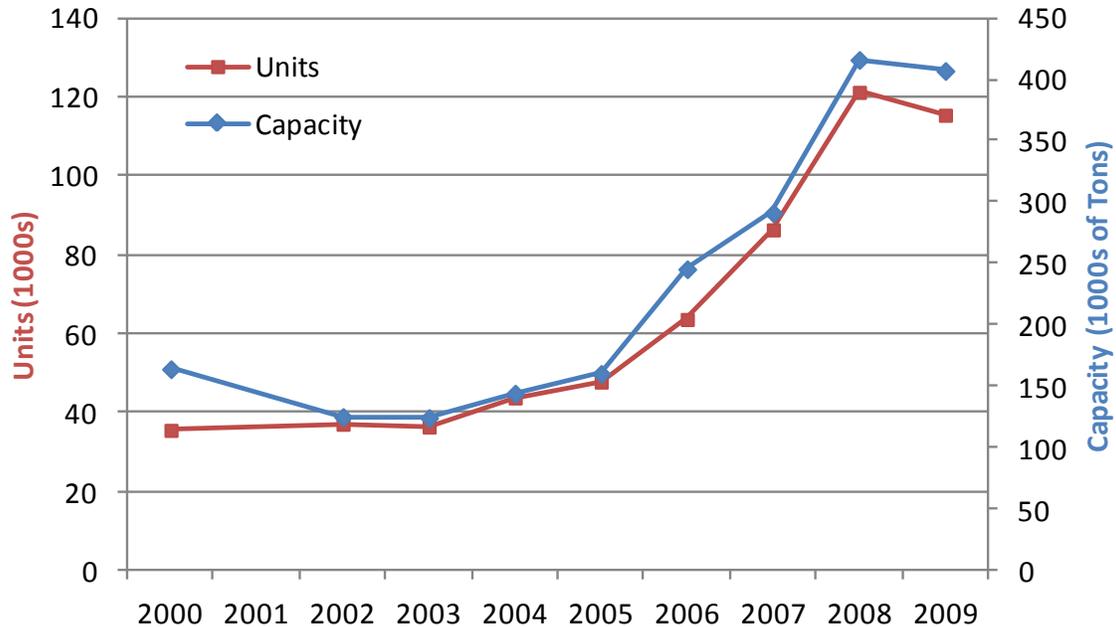
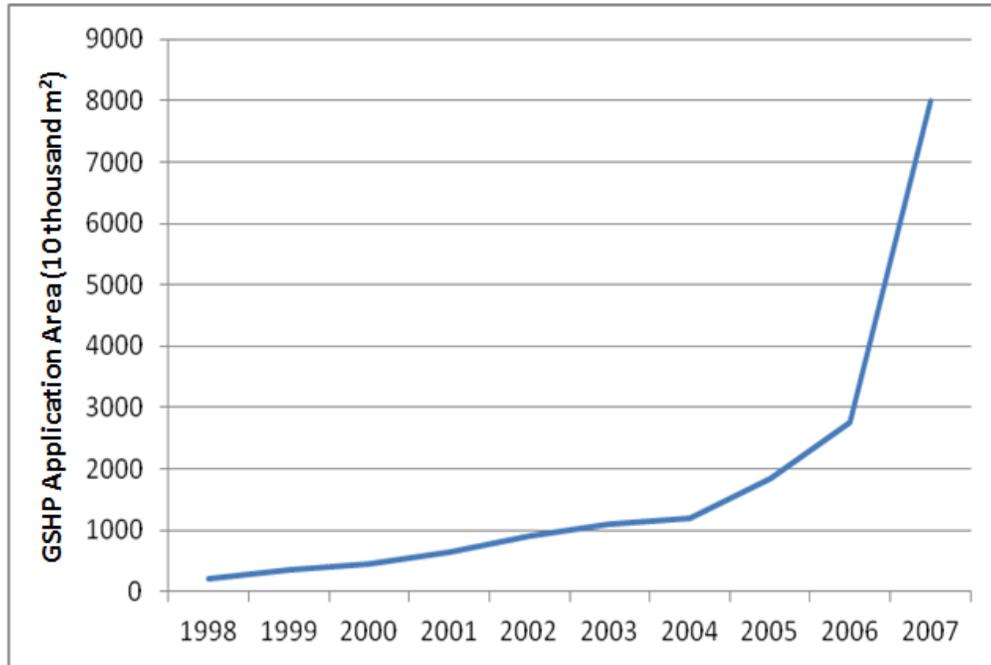


Figure 7. History of annual GSHP shipment in the US (US EIA, 2010)



**Figure 8. History of annual GSHP application areas in China**

A few surveys have been conducted in the US to collect cost information of GSHP systems. Per these surveys, the average cost of commercial GSHP systems is increased from \$9.07/ft<sup>2</sup> in 1995 to \$20.75/ft<sup>2</sup> in 2012. The cost increase (177%) of the interior portion of GSHP systems (includes heat pump and other major equipment, controls, piping and ductwork) is much more than the cost increase (52%) of the ground loop portion in the past 17 years (Kavanaugh, 2012). The typical price for GSHP systems installed in new homes is in the range of \$3000-\$5000 per ton (Ellis 2008) and the average price for retrofit is \$4,600 per ton in 2006 dollars (DOD 2007).

The simple payback period for a GSHP retrofit project in the US is usually 8-14 years (DoD, 2007 and Liu, 2010). For new construction the simple payback period is better, but larger than 5 year payback is still common (Hughes, 2008).

The cost data of GCHP and GWHP systems in China is obtained through a survey of GSHP equipment manufacturers and building owners. Table 3 summarizes the itemized costs of GCHP and GWHP systems in the US and China.

**Table 3 Itemized cost of GCHP and GWHP systems in the US and China.**

		China	USA
GCHP	Total Installed Cost	¥ 300-480/m <sup>2</sup> (\$5-8/ft <sup>2</sup> )	\$13.34 - 26.10/ft <sup>2</sup>
	Drilling	¥ 100/m <sup>2</sup> (\$1.6/ft <sup>2</sup> )	\$3.35 - 8.89/ft <sup>2</sup>

	Pipe		¥ 5~10/m (\$0.24-0.48/ft)	(or \$6.76 - 15/ft) for vertical closed-loop (including all the labor and material cost for drilling, grouting, and piping)
	Labor	Horizontal	¥ 5~10/m (\$0.24-0.48/m)	
Vertical		¥ 30~120/m (\$1.5-6/ft)		
GWHP	Total Installed Cost		¥ 250~420/m <sup>2</sup> (\$4-7/ft <sup>2</sup> )	\$7.5 – 12.5 /ft <sup>2</sup>
	Heat Pump		680~900 元/KW (\$400 – 525 per ton)	\$835 per ton (US EIA, 2010)
	Water Well		South: ¥ 1000~2000/m <sup>3</sup> (yield) \$160.5~321/m <sup>3</sup> (yield) North: ¥ 500~1000/ m (well depth) \$24~48/ft (well depth)	NA

## 5. GSHP-Specific Policies and Incentives

### United States

In December 2007, Congress directed the General Services Administration (GSA) to establish a program to accelerate the use of more cost-effective energy-saving technologies and practices in GSA facilities, starting with lighting and GSHP.

In the same year, U.S. Department of Agriculture Rural Utilities Service provides rural electric cooperatives low-interest loans with terms up to 35 years to build the outside-the-building portion of GSHP systems to customers in exchange for a tariff on the utility bill, which would be more than offset by the cost savings achieved by the installed GSHP system of the customers.

Enacted in October 2008, home and business owners investing in GSHP systems can get federal income tax credits per the law *The Energy Improvement and Extension Act of 2008*. The *American Recovery and Reinvestment Act of 2009 (ARRA)* further removed the maximum credit (\$2,000) amount for GSHP systems installed in residential buildings. Qualified GSHP systems installed in a residence<sup>3</sup> are eligible for a 30% credit of the installed cost, which includes labor costs for onsite assembly or original system installation, and for piping or wiring to interconnect

<sup>3</sup> GSHP systems must be placed in service on or after January 1, 2008, and on or before December 31, 2016; the home served by the system must be located in the US and used as a residence, although it does not have to be the taxpayer's principal residence, but not for a rental property; the heat pump must meet federal Energy Star program requirements in effect at the time the installation is completed.

a system to the home. For qualified commercial GSHP systems<sup>4</sup>, there are two options for the federal income tax credits: the first is an investment tax credit of 10% of the installed cost, which can be used to offset both regular income taxes and alternative minimum taxes (AMT), and the second option is a grant from the U.S. Treasury Department, which is only available for equipment placed in service during 2009 and 2010 and is worth 10% of the installed costs for equipment placed in service<sup>5</sup>.

In addition to the above federal income tax credits, U.S. federal government supports energy efficient mortgages (EEM) by insuring them through Federal Housing Authority (FHA) or Veterans Affairs (VA) programs. Homeowners can finance a variety of energy efficiency measures, including GSHP systems, in a new or existing home with EEM, which allows borrowers who might otherwise be denied loans to pursue energy efficiency improvements<sup>6</sup>.

In October 2009, DOE awarded a total of \$67 million in American Recovery and Reinvestment Act funds to support sustainable growth of the U.S. GSHP industry through actions in three areas:

- demonstrating innovative business and financing strategies and/or technical approaches designed to overcome barriers to the commercialization of GHPs
- gathering data, conducting analyses, and developing tools to assist consumers in determining project feasibility and achieving lowest-life-cycle-cost GHP applications
- creating a national certification standard for the GHP industry to increase consumer confidence in the technology, reduce the potential for improperly installed systems, and ensure product quality and performance

DOE selected 26 technology demonstration projects and awarded grant to these projects in the range from \$430,000 to \$5 million. The total DOE investment in technology demonstration projects is \$65 million. The individual projects range in size from 73 to 10,000 tons of cooling capacity and will be installed in a wide variety of buildings, including an ice rink, poultry barn, College campus, housing development, and shopping mall. A few innovative business models and financing approaches are proposed by the awardees, such as third-party micro-utilities where the investor owns the system and provides energy services for a monthly fee, and energy saving performance contracts. Each of the demonstration projects is required to assemble installed cost information and collect detailed performance data of the installed GSHP systems. DOE awarded \$1 million to 9 projects to improve design and simulation tools of GSHP systems, independently gather and analyze the cost and performance data of existing GSHP systems at various

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<sup>4</sup> The qualified commercial GSHP systems must serve buildings located in the US and its original use begins with the taxpayer. The credit can only be claimed on spending for equipment that is placed in service from October 4, 2008 to December 31, 2016.

<sup>5</sup> <http://energytaxincentives.org/business/renewables.php>

<sup>6</sup> [http://www.dsireusa.org/incentives/incentive.cfm?Incentive\\_Code=US36F&re=1&ee=1](http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US36F&re=1&ee=1)

climates. DOE also invested \$1 million to create the first national certification standard for primary personnel in the GSHP industry, including architects, designers, drillers, commissioning agents, etc. The standard tends to increase consumer and policymaker knowledge and confidence in the technology, reduce the potential for improper design and installation of systems, and assure GSHP systems with high quality and expected performance.

The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy administers the State Energy Program (SEP), which provides grants to states and directs funding to state energy offices. States use SEP grants to address their energy priorities and program funding to adopt emerging renewable and energy efficiency technologies. Under the American Recovery and Reinvestment Act of 2009, funding totaling \$3.1 billion is available for State Energy Programs (SEP). Many states have used this funding to support the implementation of GSHP systems in their states (Kaarsberg 2010).

In addition to the incentives from federal government, a growing number of states offer tax credits or other incentives for GSHP systems. Maryland is the first state in the US to approve GSHP eligibility for Renewable Energy Credits (RECs), which is an effort to make GSHP projects more economically viable by motivating investments from utilities, which are obligated to satisfy the Renewable Portfolio Standards (RPS) requirement of 20% of all electric productions from renewable energy by 2020. GSHP has also been recognized in six states as a qualified measure for satisfying the Energy Efficiency Resource Standards (EERS), which establish specific, long-term targets for energy savings that utilities or non-utility program administrators must meet through customer energy efficiency programs<sup>7</sup>.

## China

The financial subsidies for GSHP applications carried out by the Chinese central government in two stages: prior to 2009, the subsidies were mainly for pilot demonstration projects, and it evolved into city level pilot demonstration after 2009. In 2006, the Ministry of Construction (MOC) enacted the *Interim Measures on the Management of Special Funds for Use of Renewable Energy in Building Construction*, in which GSHP are identified as one of the key technologies qualified for the special fund. In July 2009, Ministry of Housing and Urban Rural Development (MOHURD, formerly MOC) and Ministry of Finance (MOF) jointly rolled out a program to subsidize applications of renewable energy, including GSHP and solar thermal, in buildings in competitively selected cities and rural areas. The subsidization level is 50 to 80 million RBM per city based on a few factors, such as economic development of the candidate city, types of applied technologies, potential of energy savings, etc.

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<sup>7</sup>An EERS can apply to either electricity or natural gas utilities, or both, depending on the state, and can be adopted through either legislation or regulation. An EERS is similar in concept to a Renewable Energy Standard (RES) or Renewable Portfolio Standard (RPS). While an RES requires that electric utilities generate a certain percentage of electricity from renewable sources, an EERS requires that they achieve a percentage reduction in energy sales from energy efficiency measures.

In addition to the subsidies from the central government, many local governments also have GSHP-specific policy and financial incentives. Table 4 listed a few of these policies and financial incentives.

**Table 4. GSHP-specific policy and incentives offered by a few local governments in China**

District	Policy	Incentives	Incentive level
Beijing City	Beijing city municipal government developed a plan to apply GCHP and waste water heat pump (WWHP) technologies in 18 million m <sup>2</sup> (194 million ft <sup>2</sup> ) during the 12 <sup>th</sup> 5-year development plan (issued in September, 2011)	Provide one-time subsidize to GSHP systems (issued in May, 2006)	GWHP and SWHP: ¥ 35/m <sup>2</sup> (\$0.6/ft <sup>2</sup> ) GCHP and WWHP: ¥ 50/m <sup>2</sup> (\$0.8/ft <sup>2</sup> )
Tianjin City	Tianjin city municipal government developed temporary regulations for the development, installation, and operation of GSHP systems (issued in 2006)	Issued financial support method for encouraging development of green economy and low carbon technologies (津滨政发 2011 11 号)	For GCHP and SWHP system installations with individual metering devices: ¥ 30-50/m <sup>2</sup> (\$0.5-0.8/ft <sup>2</sup> ) with a cap of ¥ 2 million (\$ 333k) per project
Liaoning Province	Shenyang city municipal government issued a management method for the development and application of GSHP systems and requested all appropriate buildings in Shenyang city shall use GSHP system (《沈阳市地源热泵建设应用管理办法》,《沈阳市民用建筑节能条例》,《沈阳市地源热泵技术推广发展规划》)	The Department of Construction of Liaoning Province issued a plan in 2008 for promoting GSHP and other renewable energy technologies (《关于推广地源热泵等可再生能源技术的意见》)	In addition to all the incentives granted to coal-firing district heating, GSHP systems are granted with discounted electricity rate and waiver of the water resource fee
Shandong Province	Provincial municipal government developed a plan to develop a group of large GSHP (especially GWHP)	Yantai City was awarded ¥ 100 million (\$ 16.7 million) grant from MoHURD and MoF for demonstrating large scale city-level application of GSHP	For GSHP: ¥ 20/m <sup>2</sup> (\$0.3/ft <sup>2</sup> ); For integrated solar thermal and GSHP:

	demonstration projects during the 12 <sup>th</sup> 5-year development plan, and increase GSHP applications in 30 million m <sup>2</sup> (322 million ft <sup>2</sup> ) building floor space by 2015 (《山东省节约能源“十二五”规划》)	technology	¥ 25/m <sup>2</sup> (\$0.4/ft <sup>2</sup> )
Henan Province	Provincial municipal government requested in 2006 that public buildings funded by government shall use GSHP systems (《关于加强节能工作决定的实施意见》,《关于加强建筑节能工作的通知》)	Hebi City announced in 2010 temporary rules for managing the city-level demonstration of renewable energy applications in buildings (《鹤壁市可再生能源建筑应用城市示范项目和资金管理暂行办法》)	For GSHP systems provide either heating or cooling: ¥ 15/m <sup>2</sup> (\$0.25/ft <sup>2</sup> ); For GSHP systems provide both heating and cooling: ¥ 19.5/m <sup>2</sup> (\$0.3/ft <sup>2</sup> )
Zhejiang Province	Provincial municipal government developed a detailed plan in 2009 for implementing GSHP systems in 1 million m <sup>2</sup> (11 million ft <sup>2</sup> ) building floor space	Ningbo city issued administration measures for the special funds used for energy conservation (《宁波节能专项资金管理办法》)	Energy conservation service companies are qualified for the financial credits from both the central government [¥ 240 per ton of coal] and Ningbo city [[¥ 60 per ton of coal] based on the achieved energy savings

## 6. Standards and Certifications

### Heat pump Efficiency Standards

#### United States

There are a few industry standards that specify the minimum energy efficiencies of GSHP units in ground water and ground loop applications, including ASHRAE standards 90.1 (2010) and 189 (2010), as well as the Energy Star standards of the Environmental Protection Agency (EPA). The heat pump efficiencies shall be measured in accordance with the ISO/AHRI/ASHRAE Standard 13256-1 (for water-to-air heat pump) and 13256-2 (for water-to-water heat pump). Federal and local governments adopted the minimum efficiencies specified in these standards in their related building energy efficiency codes, procurement requirements, or qualifications for financial incentives. For example, the Energy Star certification is a prerequisite for obtaining the federal tax credits for GSHP installations. The Energy Star minimum efficiency requirements for GSHP equipment at various applications are listed in Table 5. Currently, more than 3,600 GSHP models have been certified by ENERGY STAR standard<sup>8</sup>.

**Table 5: ENERGY STAR minimum efficiency requirements for GSHP equipment at various applications**

<b>ENERGY STAR Specifications (Effective January 1, 2012)</b>			
Product Type		EER	COP
Water-to-Air	Closed-loop	17.1	3.6
	Open-loop	21.1	4.1
Water-to-Water	Closed-loop	16.1	3.1
	Open-loop	20.1	3.5

Note: The “Closed-loop” and “Open-loop” applications in the above table refer to the “Ground loop” and “Ground water” applications defined in the ISO/AHRI/ASHRAE Standard 13256, respectively.

<sup>8</sup> ENERGY STAR certified GSHPs – List available at:  
[http://www.energystar.gov/ia/products/prod\\_lists/geothermal\\_heatpumps\\_prod\\_list.pdf](http://www.energystar.gov/ia/products/prod_lists/geothermal_heatpumps_prod_list.pdf)

## China

The government published a standard for water-source heat pump equipment in 2003 called “Water-source heat pump—Testing and rating for performance NEQ” (GB/T 19409-2003), which is based on ISO standard 13256 (1998) with some revisions and additions. One of the additions is the minimum efficiencies for the water-to-air and water-to-water heat pump equipment, which is listed in Table 6.

**Table 6: Minimum efficiency requirements for GSHP equipment at various applications specified in Chinese water source heat pump standard GB/T 19409-2003**

Water-to-air Heat Pump	Unit nominal cooling capacity Q kW (Ton)	EER		COP	
		GWHP	GCHP	GWHP	GCHP
		SWHP		SWHP	
	$Q \leq 14$ (4)	13.65	13.31	3.10	2.65
	$14$ (4) $< Q \leq 28$ (8)	13.82	13.48	3.15	2.70
	$28$ (8) $< Q \leq 50$ (14.2)	13.99	13.65	3.20	2.75
	$50$ (14.2) $< Q \leq 80$ (22.8)	14.16	13.82	3.25	2.80
	$80$ (22.8) $< Q \leq 100$ (28.4)	14.33	13.99	3.30	2.85
	$Q > 100$ (28.4)	14.51	14.16	3.35	2.90
Water-to-water Heat Pump	Unit nominal cooling capacity Q W (Ton)	EER		COP	
		GWHP	GCHP	GWHP	GCHP
		SWHP		SWHP	
	$Q \leq 14$ (4)	14.51	13.99	3.25	2.8
	$14$ (4) $< Q \leq 28$ (8)	14.68	14.16	3.3	2.85
	$28$ (8) $< Q \leq 50$ (14.2)	14.85	14.33	3.35	2.9
	$50$ (14.2) $< Q \leq 80$ (22.8)	15.02	14.51	3.4	2.95
	$80$ (22.8) $< Q \leq 100$ (28.4)	15.19	14.68	3.45	3
	$Q > 100$ (28.4)	15.36	14.85	3.5	3.05
	$150$ (42.7) $< Q \leq 230$ (65.4)	15.53	15.02	3.55	3.1
	$Q > 230$ (65.4)	15.70	15.19	3.6	3.15

Comparing the minimum efficiencies requirements in Tables 5 and 6, it is clear that the United States has much higher requirements for the minimum efficiencies. Compared with its counterpart in China, the U.S. minimum efficiency for water-to-air heat pump is 21-28% and 45-55% higher in the “ground loop” (GCHP) and “open loop” (GWHP/SWHP) applications, respectively; for water-to-water heat pump, the U.S. minimum efficiency for is 7-15% and 29-29% higher in the “ground loop” (GCHP) and “open loop” (GWHP/SWHP) applications, respectively.

## **GSHP System Design and Performance Evaluation Standards**

International Ground Source Heat Pump Association (IGSHPA), which is located at Oklahoma State University in the United States, developed and kept updating a series of manuals and tools for the design and installation of GSHP systems that use closed-loop (horizontal or vertical) GHXs and are applied in residential and light commercial buildings. American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) published a few books on the design, operation, and commissioning of commercial GSHP systems (Kavanaugh and Rafferty, 1997 and ASHRAE, 2002) and included a chapter dedicated on the application of GSHP technologies in its Handbook of Applications (ASHRAE 2011). NGWA (National Ground Water Association) published in December 2009 a revised guidelines for the construction of vertical boreholes for closed-loop GSHP systems, which covers loop field design, test holes and samples, borehole construction, piping, borehole grouting, loop field identification, and permanent loop piping decommissioning (NGWA, 2009). These publications have been widely accepted by the GSHP industry and used in guiding the design and installation of GSHP systems in the US. However, there has not been any well-established guidance for the design of GSHP systems that utilize surface water or ground water as heat sink and source.

Given the expensive cost and land area requirements, it is critical to properly size the closed-loop GHXs. The sizing needs to account for many factors, including the heat rejection and extraction loads imposed on the heat exchanger—both cumulative and peak loads, layout of the heat exchanger, thermal properties of soil and rock formations at the job site and the grouting/backfilling material used to fill the gaps between the pipes and the borehole wall. Several software programs are available in the US to size the closed-loop GHXs, including GLHEPRO, GlheCal, EES, GLD, and GeoDesigner. These software programs require user to provide building heating and cooling loads (and estimate the cumulative loads if they are not available) and usually cannot perform comprehensive energy analysis of the GSHP systems. In recent years, there have been a few integrated simulation tools available, including eQUEST (Liu, 2008), TRNSYS, and EnergyPlus. These tools can be used to evaluate and optimize GSHP system design based on the simulation-predicted performance.

China issues a national standard for GSHP systems called “Technical code for ground-source heat pump system” (GB/T 50366-2005) in 2005 and revised it in 2009. It provides guidance on the design, installation, and commissioning of GCHP, GWHP, and SWHP systems. In addition, guidance on GSHP system design is also given in other related standards, including the “Design Standard for Energy Efficiency of Residential Buildings (GB50189-2005)”, “Regulation on Energy Conservation in Public Buildings”, and “Code for Design of Heating Ventilation and Air Conditioning Systems (GB 50019-2003)”.

To evaluate the performance of GSHP systems, both the United States and China have developed protocols for collecting data and assessing the performance of GSHP demonstration projects (CABR/MoHURD, 2008 and ORNL/DOE, 2010). The two protocols are quite different in the method for evaluating the performance of heat pump equipment and the GSHP system, as well as assessing the energy, environmental, and economical benefits of the GSHP system. While the U.S. protocol requires measurements during a full year operation, the Chinese protocol only requires short-term measurements at certain conditions: one hour for equipment efficiency and 2-3 days for system efficiency. Given the varied operating condition of the ground sources over the course of a year, it is believed that the measurement of a full year operation data will better depict the real performance of a GSHP system.

### Professional Certification Standards

Proper professional licenses or certifications are usually required in the US to design and install GSHP systems, especially for commercial projects. In many states, it is required that designers of GSHP systems must be accredited by IGSHPA as Certification GeoExchange Designer (CGD), the ground loop installer must be an IGSHPA accredited installer and/or driller, and the installer of the HVAC system must be an ACCA (Air-Conditioning Contractors of America) certified HVAC technician. However, there has not been any certification for other disciplines involved in GSHP projects, such as the site evaluator, ground thermal conductivity tester and analyst, and GSHP system regulator. Currently, Geothermal Heat Pump Consortium (now renamed as Geothermal Exchange Organization) is collaborating with IGSHPA and Oak Ridge National Laboratory (ORNL) to develop the first national certification standard for all the disciplines involved in GSHP projects (GEO 2012).

In China, there has not been any certification system in place for professionals who design or install GSHP systems. It is often just referred to the qualification of related disciplines, such as geotechnical engineers and water well installers.

## 7. Barriers and Problems

A recent survey to a group of U.S. GSHP industry experts identified a few barriers preventing sustainable growth of GSHP applications in the US and prioritized these barriers into three tiers (1 being the most important) (Hughes, 2008). Table 7 listed the identified barriers in the US along with the barriers identified in China.

**Table 7 Barriers preventing sustainable growth of GSHP applications in the US and China.**

Barriers	US	China
<b>Tier one</b>	<ul style="list-style-type: none"> <li>High initial cost of GSHP systems to consumers</li> </ul>	<ul style="list-style-type: none"> <li>Lack of standards in the quality of equipment, design, installation, and</li> </ul>

		operation of GSHP systems
<b>Tier two</b>	<ul style="list-style-type: none"> <li>• Lack of consumer knowledge of and/or trust in GSHP system benefits</li> <li>• Lack of policymaker and regulator knowledge of and/or trust in GSHP system benefits</li> <li>• limitations in GSHP design and business planning infrastructure</li> <li>• limitations in GSHP installation infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>• Limitation of land area for installing closed-loop ground heat exchangers</li> <li>• Poor performance and lack of energy saving benefits</li> <li>• Lack of market entry threshold, which resulted in large variation of product quality</li> </ul>
<b>Tier three</b>	<ul style="list-style-type: none"> <li>• Lack of new technologies and techniques to improve GHP system cost or performance</li> </ul>	<ul style="list-style-type: none"> <li>• Unqualified system operator</li> <li>• Lack of performance data and cannot evaluate the long-term performance of GSHP systems</li> <li>• Lack of technologies to avoid blockage in rejection wells and properly size ground heat exchangers</li> </ul>

## 8. Conclusions and Suggestions

Based on the comparisons presented in this paper, following conclusions can be drawn with regard to the difference of GSHP applications in the United States and China.

- The GSHP technologies have been applied in all the climate zones in both countries. In the United States, GSHP systems are installed predominantly in residential (e.g., single family homes) and light commercial buildings, but in China they are used mostly in high rise multi-family buildings and large commercial/public buildings.
- The vast majority of GSHP systems (84%) in the US use closed-loop ground heat exchangers (GHX) buried in the earth in either a vertical or horizontal configuration. In the contrast, the heat sinks/sources used in GSHP systems in China are much more diversified: closed-loop GHXs are used in only 32% of the GSHP systems and ground

water are the most predominant heat sink/source, which is used in 42% of the GSHP systems. Other non-conventional resources (i.e. surface water and wastewater) also have significant share (26%).

- Decentralized GSHP systems are widely used in the US due to its superior part load performance and the capability of enabling individual metering and thermal comfort control in each zone of a building (in lieu of the four-pipe configuration). However, the decentralized system is rarely used in China, where central GSHP systems with two-pipe configuration are dominant. Given the merits of the decentralized system, it could be a better choice in some applications over the central system, especially when better part-load performance and/or thermal comfort control in each individual zone of a building is desired.
- The United State has established vigorous standards for GSHP equipment and corresponding enforcement mechanisms to ensure the quality of GSHP equipment. It also has a well-established program for training and certifying professionals involved in GSHP projects. However, the GSHP market in China is not strictly regulated, which results in large variation in the quality, energy efficiency, and cost of GSHP systems.
- The United State has developed several advanced design and simulation tools for GSHP systems, which have been widely used in the GSHP system design. However, the usage of these tools is still limited in China.
- In contrast to the modest growth of GSHP applications in the US, the Chinese GSHP industry has been experiencing an explosive growth since 2005 due to the strong supportive policies and financial incentives from both the central and local governments. Based on available information, it is believed that the cumulative building floor space conditioned by GSHP systems in China has almost been the same as that in the United States.
- The GSHP industry in the United States and China are confronting with different challenges for sustainable growth. The biggest barrier that prevents sustainable growth of GSHP applications in the US is the high initial cost to consumers, but in China, it is the quality of the equipment, design, installation, and operation of GSHP systems. The Chinese GSHP industry has not yet established an effective mechanism to regulate the quality of the GSHP equipment and the professionals who design and install the GSHP systems.
- The methods for evaluating the performance of GSHP systems in the two countries are quite different: while it is required in the US to measure the performance during a full year operation, only short-term measurements (one hour for equipment efficiency and 2-3 days for system efficiency) are required in China. Given the varied operating condition of the ground sources over the course of a year, it is believed that the measurement of a full year operation data will better depict the real performance of a particular GSHP system.

The above comparisons indicated that there are some areas that both countries can learn from each other. US has vigorous standards for GSHP equipment, advanced design and simulation tools for facilitating GSHP system design, and established successful program for training and certifying professionals involved in GSHP projects. Chinese government has implemented very effective policies and financial incentives that have resulted in explosive growth of GSHP applications in China within the past 8 years. The Chinese GSHP industry has been motivated to invest and apply various innovative GSHP technologies.

In order to ensure sustainable growth of GSHP applications and realize its huge energy saving potential in the United States and China, it is suggested that the two countries should collaborate in following areas: development and implementation of GSHP related standards, improvement in the quality of the GSHP equipment as well as system design and installation, training and certification of practitioners, and research, development, and deployment of advanced GSHP technologies.

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