RESEARCH AND DEVELOPMENT OF LARGE SCALE AND CITY LEVEL GROUND SOURCE HEAT PUMP SYSTEM

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Abstract: A large number of ground-source heat pumps (GSHP) systems have been used in residential and commercial buildings in different climate zones in China because it was considered as an environmentally-friendly and cost-effective alternative with potential to replace fossil fuels and help mitigate global warming by the central government since 2006. The total floor area that uses this technology is nearly 10 times at the end of 2012 compared with 2006. Ground heat exchanger heat pump system in China are always used for large scale residential and commercial building with the floor area more than 20,000 m2 and some surface water and sea water heat pump system could reach to city level, such as provide heating and cooling with several large GSHP energy station for an new district with the building floor area more than 5 million m2. At the same time, how to planning, design and operation such large system correctly to achieve higher COP is still needed to be answered. With latest research and development information of large scale and city level GSHP collected from EU, USA and Japan, this paper raise a series of questions that needed to be solved in China in the future to keep promoting this technology, such as simultaneity usage coefficient of different buildings selection in one district, more accurate TRT and ground water flow consideration during the load calculation, heat extraction and rejection point selection and control strategy for hybrid system..

Key Words: large scale, city level, GSHP

1 INTRODUCTION

Since 2000, GSHP started to be used in few small pilot projects, the total floor area that uses this technology reach to 240 million m2 at the end of 2012, which is nearly 10 times compared with 2006. Technical Code for Ground Source Heat Pump System GB50366-2005 made a clear definition of GSHP for China, which let the government much easier to provide policies and subsidies for this technology. But, due to the China's fast development in urbanization and its own building form, GSHP always use for large building more than 20,000m2 and even for district with total building floor area reach to 5 million m2. As the system goes larger, the COP of the system couldn't reach the design requirement and some problems raise up. By latest research and development information collection of large scale and city level GSHP of EU, USA and Japan, the future research area that should be paid attention to in China are discussed..

2 RESEARCH AND DEMOSTRATION OF LARGE SCALE GSHP

Ground-source heat pumps (GSHP) systems have been used in residential、commercial and industry buildings throughout the world because of the highly energy saving and greenhouse gas emissions reduction potential. The GSHP technology can be used both in

cold and hot weather areas and the energy saving potential is significant. During the past few decades, Due to the renewable energy policies and financial subsidy, GSHP systems have been applied in larger and larger scale around the world, some systems even reached community and city level. (Ioan, 2014).

2.1 EU large scale GSHP utilization

On 2008, the European Parliament adopted the Renewable Energy Directive , which establishes a common framework for the promotion of energy from renewable sources. This directive opens up a new opportunity for widely use of heat pumps for heating and cooling of new and existing buildings. Also, EU set up three key objectives for 2020, known as the "20-20-20" targets, which including Raising the share of EU energy consumption produced from renewable resources to 20%.

With the promotion from the EU and member countries, GSHP had been promoted by different programs, such as The GEO.POWER project etc. The GEO.POWER project ("Geothermal energy to address energy performance strategies in residential and industrial buildings ") (B.M.S. Giambastiani.,2014) was co-financed by the European Regional Development Fund in the frame of the INTERREG IVC Programme. The general project objective was to exchange the partners' own experiences on heating and cooling supply mainly through GSHP and from low enthalpy geothermal energy. After a SWOT technical and cost–benefit assessment, Participants evaluated the reproducibility and transferability of the best practices currently exists in Europe. It could find out that the most transferable example of technology is the TELENOR building in Hungary. The TELENOR building is a new industrial building with 180 Borehole Heat Exchangers (BHE) drilled 100m deep for cold and hot water, it also has 168 m2 solar collectors to meet 60–70% of the hot water demand. The CO2 emission saving could reach to 800–850t/year and the energy saving is 2.1 million kWh; the payback time is 8–10 years.

The core results achieved by the GEO.POWER project focused on the elaboration of action plans to encourage the GSHP market development and through the use of the EU Structural Funds in the current and in the future Programming Period 2014–2020. All documents contain a set of potential flanking measures to be implemented in the concerned areas to address strategies for GSHP large scale introduction and subsidy schemes to support geothermal energy investments.

Most large cities use tunnels to provide transportation and utility networks and some of the tunnels need to be cooled to meet operational requirements. Nicholson D. P. discusses the use of system-wide thermal tunnels with closed loops embedded in the tunnel segments to extract heat from the tunnel and then used with GSHP systems to heat adjacent buildings via a district heating system. After the detailed analysis of the system, Nicholson D. P. point out that this kind of large scale GSHP system requires a city scale investment in long term heat supply because the thermal tunnel system requires an early investment when the tunnels are being built to provide pipe work for heating adjacent buildings (Nicholson D. P.2013). The author carried out a preliminary study for the buildings in a corridor extending 100m beyond the tunnels for CROSSRAIL project, which including 34 hotels, large residential, hospitals, 4 schools, colleges, libraries, museums and 327 offices, leisure centers, retailers, with the conclusion that based on header pipe access points connecting to 500m of twin tunnels, the heat output would be about 200 to 600kW for 10 to 30 W/m2 of tunnel surface heat extraction.

A. Sciacovelli (A. Sciacovelli,2013) investigated the impact of a ground source heat pump installation for a public building in Italy through a thermo-fluid dynamic model of the subsurface which considers fluid flow in the saturated unit and heat transfer in both the saturated and unsaturated units. The building is 160m high and its volume is about 240,000m3. The groundwater flows in the south-east direction toward PO River, which is about 2 km far from the building. The groundwater system is composed of four wells, two for the water extraction and two for the re-injection. The distance between re-injection and

extraction wells is 150m, while the transversal distance between the wells is 80 m. The cooling season lasts for about 6000 h with a peak request of 7MW and the heating period is of about 2800 h with a peak heating load of 2.5MW for the building. The author made analysis of two possible scenarios, one is constant heat pump mass flow rate case and the other is variable heat pump mass flow rate case. The result shows that at 1.8 km downstream the wells the difference between the unperturbed temperature and thermal plume temperature is about 3K when the heat pump operates with a variable mass flow rate and the wells thermal plume temperature is 5K higher than the unperturbed one when the heat pump operates with a constant mass flow rate.

2.2 USA large scale GSHP utilization

Justin Mahlmann considered that the only way to achieve California's stringent policies and emission goals that set a minimum for emissions reductions is strategic planning of the energy system on the community scale. Technologies such as geothermal heat pump systems (GHPS) can be implemented to heat and cool an entire community, reducing energy consumption, emissions and water consumption, while also serving as a backbone for carbon neutrality and zero net energy. Justin Mahlmann introduced Ball State University GSHP system, which have a capacity of approximately 5000 tons, and will serve the heating and cooling purposes for 47 buildings over 731 acres. The underground heat exchanger consists of 3600 boreholes with depths ranging from 400-500 ft and diameters of 5-6 inches. Capital expenditures for the project cost upwards of $70 – 75 million, which is only $15 million more than that for a conventional HVAC, resulting in a payback period of 7.5 years. The system will reduce the campus's CO2 an estimated 85,000 tons annually (Justin Mahlmann,2012).

Alaska Sea Life Center demonstrates a seawater heat pump system with the funding from Denali Commission Emerging Energy Technology Grant (EETG) program. Two 90-ton heat pumps were installed to provide heating and hot water. Since February 2013 the project was successfully commission, over the course of three months of monitoring since that time (1,900 hours of system operation), the average COP was 2.90, displacing a total equivalent of 20,000 gallons of heating oil while consuming 300,000 kWh of electricity. Years to payback the investment is 8.5(ACEP,2013).

2.3 Japan large scale GSHP utilization

Hikari Fujii developed a mass and heat transport model to simulate the long-term performance behavior of large-scale GSHP systems with the consideration of well-to-well interference in the presence of groundwater flow for a public building. The GSHP system was installed in the basement of a gymnasium of a public school in the central part of the Akita Plain with 75 cast-in-place, one-meter diameter and 50m deep piles in the foundation of the building. All of the piles were equipped with two 2.5 cm i.d, 50m long U-tubes to be used as GHEs.With the set up and analysis of the field wide numerical model of Akita Plain on the basis of groundwater levels and temperatures measured in the field. Groundwater velocity at the GCHP system location was estimated to be 1.4×10-4m/day. Four simulation run cases all with 120 days of heat extraction and different heat storage periods (none, 30 days, 60days, 120days) were carried out, the author find that more heat storage operations should be implemented in the downstream GHEs than in the upstream GHEs to maintain heat extraction rates and wider GHE spacing is preferable in cases without heat storage operations (Hikari,2005).

Li Huai used both field data and a numerical simulation to examine the long term performance and environmental effects of a large GSHP (ground source heat pump) system installed in the city of Akabira in the north of Hokkaido, Japan. The heat exchange system of the GSHP consists of 78 boreholes, each with a depth of 85 m, that could provide a maximum capacity of 640 and 648 kW for heating and cooling for 12 greenhouses, each greenhouse comprises a total area of 450 m2.The system was monitored and analyzed from

Oct 2010 through May 2011. The system had a COP of 3.0 and the average heat extraction rate of the system was approximately 27.7 W/m. Six wells were drilled in the borehole field to monitor the soil temperature and groundwater level, the author found the ground temperature at a depth of 40 m decreased from approximately 7.8℃ to 0 ℃after 8 months of operation and the operation of system with unbalanced heating and cooling loads (less than two times) is available with an average groundwater flow velocity around 10-15 m/y (Huai,2013).

Table 1 Typical large scale and city level GSHP projects

Country	Location	Building Type	Installed year	Collector Type	Collector Index	Load/Heat Pump(kW)	COP	Payback Period (years)	CO_2 reduction
Hungary	Torokbalint	industrial building	-	Vertical Borehole	180*100m		-	8 to 10	800–850 t/year
Italy	Turin	240,000m^3	-	Underground Water	2 extraction wells, 2 injection wells	peak heating load=2.5MW	-	-	-
USA	Indiana	47 buildings	2012	Vertical Borehole	3600*120 m	5000 tons		7.5	85,000 t/year
USA	Alaska	-	2013	Seawater	-	2 90-ton heat pumps	2.9	8.5	-
Japan	Akita	public building	2003	Vertical Borehole	75*50m	-	-	-	-
Japan	Akabira	12 greenhouses	2010	Vertical Borehole	78*85m	640kW for heating;	3		291t/year

3 CURRENT STATUS OF GSHP IN CHINA

The last decade of the 20th century was the infant phase of GSHP application in China. During that period, policymakers and the real estate developers started to realize the advantages of GSHP through some pilot projects.

3.1 Technical Code

One technical code set the concrete foundation for the fast development of GSHP after 2005 because it gave the financial incentive mechanism from the central and local government a technical reference. The technical code is ‘‘Technical Code for Ground Source Heat Pump System (GB50366-2005)’’, which was promulgated and took effect on January 1, 2006. The code plays a significant role for the development of geothermal heat pump industry as it is first time made the clear definition of Ground-Source Heat Pump System of China, which including three major types, that are Ground Heat Exchanger Heat Pump System (same as ASHRAE ground-coupled heat pump (GCHP) systems), Groundwater Heat Pump System, Surface Water Heat Pump System (sea water, lake water, river water and sewage water). 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 (CABR, 2005).

3.2 Government Policies and Subsidies

On September 2006, ‘‘Opinions on promoting application of renewable energy in buildings’’ and ‘‘A tentative management method of special funds for renewable energy development’’ were promulgated by the Ministry of Construction (now called Ministry of Housing and Urban-Rural Development, MOHURD) cooperating with the Ministry of Finance. In these two documents, 4 of the 8 technologies which are subsidies by the state are GSHP system:
Ground source heat pump system and shallow groundwater source heat pump system.

- Water source heat pump system.
- Seawater source heat pump system.
- Sewage source heat pump system.

After that, a series of policies came out to promote GSHP on the city level and town level, at the end of 2010, 47 cities and 98 towns got the funding from the central government to promote GSHP, each city got 50 to 80 million RMB and each town got 15 to 20 million RMB to promote this technology. Based on the information from The State Council Information Office of P.R.China, at the end of 2006, the total floor area of GSHP application is just 26.5 million m2, by the end of 2007, the number reach to 80 million m2, till the end of 2012, the total project number use GSHP is 23,000 with the floor area reach to 227 million m2 and the number of GSHP system integration companies reach to 4,000. The increasing rate of GSHP in China from 2000 to 2012 could be found in Figure 1 (Xu, 2013).

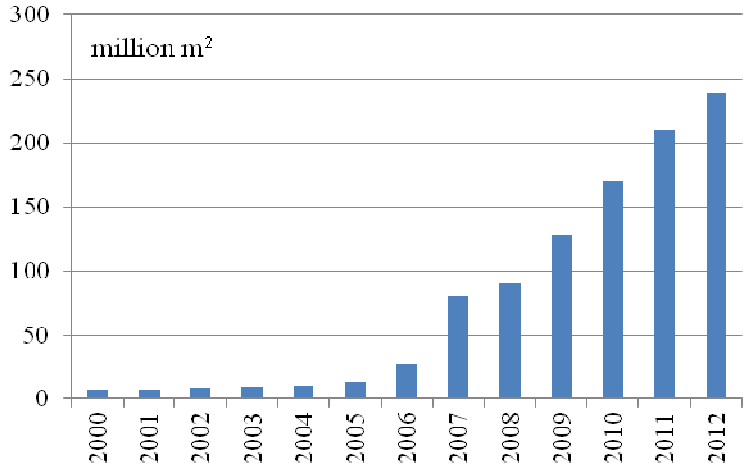


Figure 1 Increasing of GSHP in China

3.3 Project Type Distribution

Based on the analysis of 291 projects that funded by the Ministry of Construction and the Ministry of Finance, which the total floor area is about 32.72 million m2, we could find out that: 259 projects use GHSP at the only heating and cooling source while 32 projects use hybrid system. In the GSHP only projects, 110 projects use Ground Heat Exchanger Heat Pump System with the total floor area of 11.19 million m2 which accounts for 33.70% of all the projects, 78 projects use Groundwater Heat Pump System with the total floor area of 8.84 million m2 which accounts for 26.63% of all the projects, 32 projects use Surface Water Heat Pump System (heat source are river and lake water) with the total floor area of 3.63 million m2 which accounts for 10.92% of all the projects, 16 projects use Surface Water Heat Pump System (heat source is sea water) with the total floor area of 1.82 million m2 which accounts for 5.46% of all the projects, 23 projects use Surface Water Heat Pump System (heat source are civil sewage water, cooling water in Refinery, coal mine tunnel water and circulating cooling water from thermal power plant)with the total floor area of 4.52 million m2 which accounts for 13.61% of all the projects (Xu, 2013).

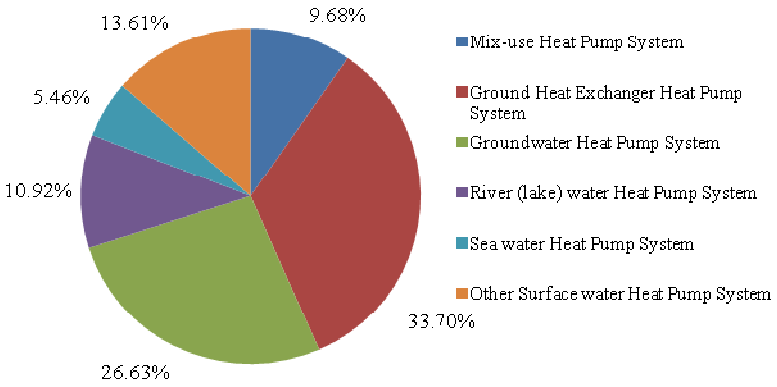


Figure 2 Percentage of different type GSHP system in China

4 LARGE SCALE AND CITY LEVEL GSHP APPLICATION IN CHINA

Due to China's different climatic zones, each type of GSHP have their own characteristics and suitable location, The Ground Heat Exchanger Heat Pump System are suggested to be mainly used in cold, cold winter & hot summer and temperate zones. In the southeast and coastal areas, where there is abundant groundwater and surface water resource, the Ground and Surface Water Heat Pump System are suggested to be used while in the cold and cold winter and hot summer zone. If the heat extraction and heat rejection cannot be balanced, the hybrid systems are suggested. Because the average single building in China is always bigger than the western style and with a much more quantity, the GSHP system is usually larger. Also, China now is going through a fast increasing period of urbanization, there are lots of new cities, new towns, new districts and new communities, from the beginning of the planning, GSHP was considered as the main heating and cooling source, that makes this technology goes to city-level in China recently. Following are some pilot projects in large-scale and city level.

4.1 Ground Heat Exchanger Heat Pump System Project

Beijing Zhongguancun International Mall is located in Beijing Zhongguancun Technology District, the total floor area is 1.56 million m2. Based on the system simulation, the total cooling load is 17MW, and the total heating load is 7.39MW.



Figure 3 Beijing Zhongguancun International Mall

Table 2 Heating and Cooling load of the Mall

Building floor area (m2)	Cooling Load Index (W/m^2)	Cooling Load (MW)	Heating Load Index (W/m^2)	Heating Load (kW)
156000	108.9	17	47.4	7.39

Based on the TRT, the geological condition is as follow:

Table 3 Geological condition of the Project

Depth （m）	thermal conductivity W/(m.K)
0~19m	1.4
19~32m	2.0
32~35m	1.6
35~38m	2.2
38~44m	1.4
40~52m	1.7
52~57m	1.6
57~70m	2.2
70~75m	1.6
75~100m	1.4

According to the on-site condition and the TRT result, 1,060 vertical boreholes with 123 m depth and distance as 4.5 are drilled under the parking lot. Double-U ground heat exchanger with diameter as DN32 is used.

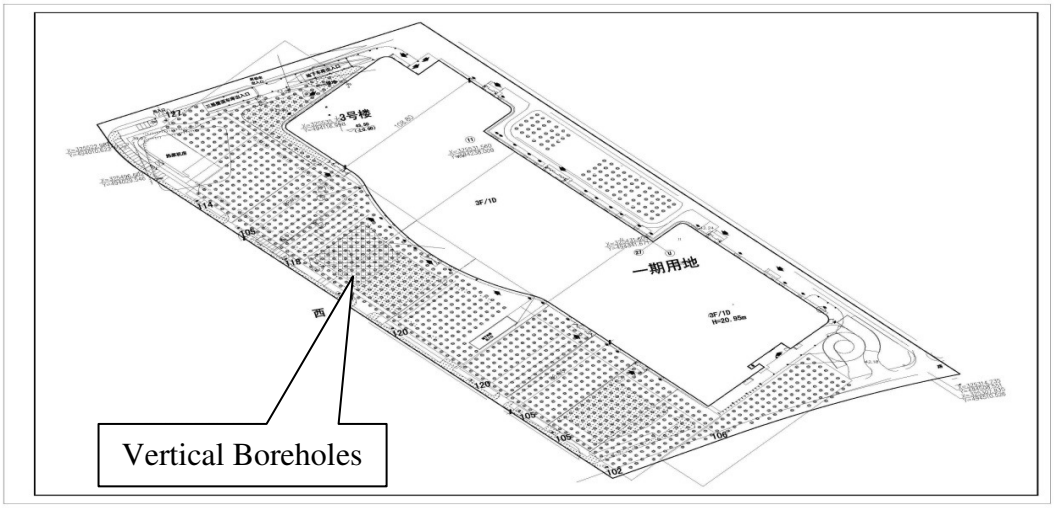


Figure 4 Vertical boreholes map of the projects

3 LSBLGR-M2800 heat pumps are selected, the heating capacity of single heat pump is 2.32MW, and the cooling capacity is 2.28MW. The system heating COP could reach 3.0 according to the system testing result during 120 days in the 2008 winter.

4.2 Groundwater Heat Pump System Project

Qindao Yinshengtai International Center and Business Center are two buildings in one district near each other. The total floor area of International Center is 58,000m2 and the total floor area of Business Center is 26,400 m2. The water extracted from underground from one well is 80t/h and the rejection data is 67t/h.

According to the calculation, 464tons of water per hour with the inlet/outlet temperature as 16℃/31℃in summer and 348t/h tons of water per hour with the inlet/outlet temperature as 15℃/7℃in winter is needed. 14 wells with the minimum distance as 40m are drilled; other 3 spare wells are also constructed. Cost of the GSHP system is 350 RMB/m^2.

4.3 Surface Water Heat Pump System Project

(1) Wuxi T-Park Energy Center

WUXI T-Park is a new district on the south of the urban area, the total construction floor area will be 8 million m2, and the first phase is just finished with the total floor area of 4 million m2. Across the district, there is a river with stable flow rate, the temperature is 6.8-12.4℃in winter and 23.6-32.4℃ in summer, also there is a sewage plant, the temperature of the sewage is 9-14℃in winter and 25-28℃ in summer. Two energy stations B and G that use the energy from the river water and sewage water are built to supply energy for the entire district.
4 water source heat pump with cooling (heating) capacity as 7.8MW（9.2MW）and 4 water source heat pump with cooling (heating) capacity as 5.9MW（10.6MW）are installed in the energy center B. 1 water source heat pump with cooling (heating) capacity as 6MW(6.5MW) and 1 water source heat pump with cooling (heating) capacity as 6MW（6.4MW）are installed in the energy center G. 860,000Mwh electricity and 900,000tons of CO_2 will be saved each year after the whole district completed.
(2) Thaizhou Medical City Energy Center
Thaizhou is a city near Yangtse River, the water average temperature and the flow rate is suitable to use in a heat pump system to provide energy for the whole district. So the new core city areas with the total floor area of 5 million m2 use the river water heat pump system for energy service. The total cost of the energy station in the first phase is 1.84 billion RMB with the cooling load of 55MW and heating load of 38.5MW. 3 water source heat pumps with cooling (heating) capacity as 7.9MW（8.4MW）and 3 water source heat pumps with cooling (heating) capacity as 6.0MW（9.5MW）were selected for the system.

Table 4 average water temperature and flow rate

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Auf	Sep	Oct	Nov	Dec
Ave Temp（℃）	9.2	10.6	13.1	17.9	22.3	25.5	28.1	29.1	26.2	22.4	17.4	12.6
Flow Rate（m^3/s）	6.5	8.3	9.4	15.0	22.2	24.1	18.4	19.4	18.9	22.4	13.7	6.7

4.4 Hybrid Heat Pump System Project

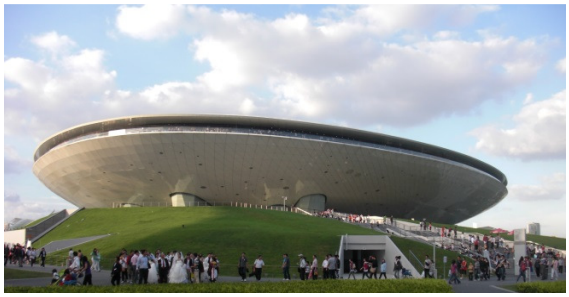


Figure 5 Shanghai World Expo Culture Center

Shanghai World Expo Culture Center is a mix-use building, above the ground is a theatre with 18,000 seats and the six floor building circulated the theatre, 2 floors are under the ground. Peak cooling load in summer is 14.95MW and peaking heating load is 9.2MW in winter. The center is very close to the Shanghai Huangpu River, the hydrological data shows that the water temperature is 26~32℃ in the upper level and 15~22℃ in the lower level in summer, in winter, the water temperature is 3~8℃ in the upper level and 10~15℃ in the lower level. As in the summer the river water temperature is relatively high and in winter cold, besides the heat pump system, ice storage system and boiler are also installed for summer and winter. According to the test, the river water heat pump system could cover 40% cooling load with COP 5.1 in summer and 55% heating load with COP 4.1 in winter.

5 FUTURE RESEARCH DIRECTION OF LARGE SCALE AND CITY LEVEL GSHP IN CHINA

From the general data of GSHP developments in China we could find that GSHP in China are always in a large scale and even reach to city level. According to the Ministry of Science and Technology of China, the total area adopting the GSHP systems will be up to 350 million square meters by the end of 2015. From the operation COP of the pilot projects, there are still big potential for the large scale and city-level GSHP system to enhance the energy efficiency in the future. Compare with the research of large GSHP system internationally, there are still several problems that needs to be resolved in China

5.1 Simultaneity usage coefficient

When use GSHP system to provide heating and cooling for a city level system, which including lots of residential buildings and commercial buildings, some of them are mix-use, the simultaneity usage coefficient between different function area in the same between and between different buildings should be considered, especially the coefficient between different buildings. Because for large central heating system with boilers in the northern part of China, this coefficient should be 1 to secure the heating supply. For the mix-use building, according to the China National Standard <Design code for heating ventilation and air conditioning of civil buildings> GB50736-2012, the coefficient could be 0.7-0.9. But In the GSHP system, heating and cooling are both supply within the GSHP system, usually, the GSHP provide cooling only for commercial buildings in summer but for heating for all the buildings, including residential buildings in winter, how to calculate the simultaneity usage coefficient of the large scale GSHP system is a key question.

5.2 TRT and ground water flow

For the Ground Heat Exchanger Heat Pump System, accuracy of the TRT result to calculate the thermal conductivity will contribute significantly to the total costs of system planning. The TRT equipment is commonly built in a few portable boxes or mounted on a car trailer for easy transportation to test sites. The mobile TRT method is becoming more and more important in the rapid spreading of Ground Heat Exchanger Heat Pump System. In the future, how to make the mobile TRT box smaller while more accurate will be put more effort. Groundwater flow is normally present and could enhance the heat exchanger rate and balance the heat extraction and injection to increase the COP of GSHP systems. But nowadays, the underground flow rate is not taking consideration during the design of Ground Heat Exchanger Heat Pump System; the engineer took it as a safety factor for the system. From the international experience, if the underground water flow is carefully calculated, the underground heat exchanger system could be 10-20% smaller to save cost; so the impact of groundwater flow on the performance of ground heat exchangers will be a future research area in China.

6 CONCLUSION

More and more large scale and city level GSHP system and GSHP energy station are used in China for buildings and districts, GSHP have a bright future in China as an environmentally-friendly and cost-effective technology to help mitigate global warming. As the system grow larger and hybrid, some technical problems that will not affect the COP of small GSHP system obviously became a hot topic to save cost for the large scale and city level project, such as more accurate TRT and ground water flow consideration during the system calculation, heat extraction and rejection point selection and control strategy for

hybrid system and so on. Compare with the latest research and development information collection of large scale and city level GSHP of EU, USA and Japan, the future research area of GSHP in China are discussed.

7 ACKONWLEDGEMENTS

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