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Analysis of test results for the operation of some ground coupled heat pump systems in Wuhan

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ABSTRACT

Based on the test results of some ground source heat pump systems in Wuhan, China, the energy efficiency, operation parameters and indoor thermal environment are studied. Indirect method was used to measure energy efficiency of the heat pump unit and system. The operation characteristics of the systems, the comparison and the difference between the system performance and the standard are analyzed. It is showed that most systems meet the standard of energy efficiency and all systems have a certain energy saving effect. Some systems have shortage in system performance, which includes small value of system COP, the relatively small temperature difference of supply and return water, higher energy consumption of pump, etc.

1. INTRODUCTION

Due to the outstanding advantage of energy saving and environment protection and renewability, ground source heat pump systems (GSHPs) have been well developed in many countries in the world, including China. The design, construction and operation are research focuses which are very important for the application and development of GSHPs. A large number of projects of GSHPs have been constructed and put into operation in China. The test and analysis for the operation effect of the projects are beneficial for the summary of the technology, which can be used to guide the development and application of the technology.

Some experts and technicians made tests and analysis on the operation of GSHPs. Montagudet al (2011) made evaluation of the performance of a ground source heat pump system, providing heating/cooling to an office building. The analysis of the experimental results shows that the system energy performance is maintained through the years. Hwang et al (2009) analyzed the cooling performance of a water-to-refrigerant type ground heat source heat pump system (GSHP) installed in a school building in Korea. The evaluation of the cooling performance had been conducted under the actual operation of GSHP system in the summer of year 2007.Man et al (2012) carried out detailed on-site experiments on a GCHP experimental test rig, and the GCHP system for both cooling provision and heating provision were investigated with intermittent mode and continuous mode. Wang et al (2017) tested some demonstration project of GSHPs in winter (summer) condition on a typical heating day (cooling day) for not less than 2 days, and summarized and analyzed the performance of the systems. Some scholars made measurements on the experimental set-up of GSHPs (Yang, 2018; Fuentes,2016). Pen et al (2020) measured 10 projects of GSHPs in commercial and residential buildings in Changsha, China (including ground coupled heat pump, underground water source pump, surface water heat pump), and analyzed the system performance, energy saving and emission reduction. Even so, the research and measurement on the operation of GSHPs are limited and still expected further carried on.

In order to strength the post-evaluation for the application of renewable energy, some projects of GSHPs were tested by the administration department in Wuhan, China. In this paper, 10 projects were selected to analyze in which ground coupled heat pump systems were installed in commercial buildings, and the shortcomings and problems of the systems were discussed.

2. SYSTEM OVERVIEW

The projects are all located in Wuhan, China, which is in the area of hot in summer and cold in winter. Both cooling and heating are needed here. The general information of the projects and systems are shown in Table 1.Vertical borehole heat exchanger were used in each system. Energy pile, in which multiple branches of U-shaped polyethylene pipe have been tied up on the reinforcement cage of the pile, combined with vertical borehole heat exchanger (VBHE) were used in 3 systems (A,H,I). Ice storage is used in H and J system. In Table 1, double U pipe are all in parallel. The depth of borehole are generally 80-100 m.

In Wuhan, the cooling load is much higher than heating load and the heat exhaust to the ground is higher than heat extract from the ground. So the capacity of system was generally designed based on the heating load and an auxiliary cooling tower system was combined with the GSHPs.

The heating load and extracted heat taken on one meter of borehole depth are shown in Table 2.All the systems are installed in office buildings. The average value of extracted heat on one meter of borehole depth is 38.0W/m.The reason of the difference between each value could be related on the different geological conditions, design parameters of the system, accuracy of the thermal response test, etc.

Table 1: General information of systems.

Project (System)	Area /m^2	Cooling/ heating load/kW	Borehole depth/m diameter/mm	Single/double U pipe	Pipe diameter/ mm	Number of borehole
A*	8588	960/560	90/150	Single U	32	72
			30/800	Double U	32	140
B	10592	1048 /838	80/110	Single U	32	155
C	14533	1400/830	60/150	Double U	32	270
D	8500	560/350	100/150	Double U	25	56
E	100000	9360/5400	90/150	Double U	32	1200
F	19871	1600/960 /460 #	100/150	Double U	25	571
G	17871	970/730	75/150	Double U	32	288
H*	100523	7820/4600	90/150	Double U	32	546
			19/800	Double U	32	290
I*	30048	6240/4380	65/133	Single U	25	1177
			40/1200	Double U	32	612
J	59351	5665/4472	95/150	Double U	25	810

Notes: *: VBHE (parameters are listed in upper column）+ Energy pile (parameters are listed in lower column) are used in project A, H and I.

#: Domestic hot water load.

Table 2: Ability of heat transfer of the VBHE in seven systems.

Item	System						
	B	C	D	E	F	G	J
Single/double U	Single U	Double U	Double U	Double U	Single U	Double U	Double U
Heating load(kW)/per meter of depth/m	67.6	51.2	47.4	62.5	50.0	24.9	58.1
Extracted heat (kW)/per meter of depth/m	47.4	38.7	35.8	43.4	37.1	18.8	44.6

3. TEST RESULTS AND ANALYSIS

The test results of the 10 systems are shown in Table 3.

3.1 Test method

Indirect method was used to measure energy efficiency of the heat pump unit and system.

Some representative rooms were chosen, and the temperature and humidity in these rooms were tested and the results were averaged. The outdoor temperature and humidity were recorded by two meters. The measuring point for the flow of heat pump unit in on the main pipe of return water in machine room. The portable ultrasonic meter was used to monitor and record data. The temperature of the cooling or heating water was measured on the main pipe of supply and return water in users' side. The wattmeter was installed on the air switch outlet of the control cabinet in corresponding equipments, and the data was recorded and analyzed bya harmonic analysis device. The energy efficiency can be calculated by the temperature and flow of the supply and return water in users' side and power consumption of the heat pump unit and pump. The testes were conducted in typical summer or winter in recent years and lasted for 2 days in general.

3.2 Indoor thermal environment

As shown in Table 3, the temperature and relative humidity in the buildings is 22.8-27.4℃and 43.5- 84.4% respectively in summer, and 18.2-20.7℃ and 37.5-52.6% respectively in winter. The design standard requirement in thermal comfort in the projects are met.

Table 3: Parameters of system performance.

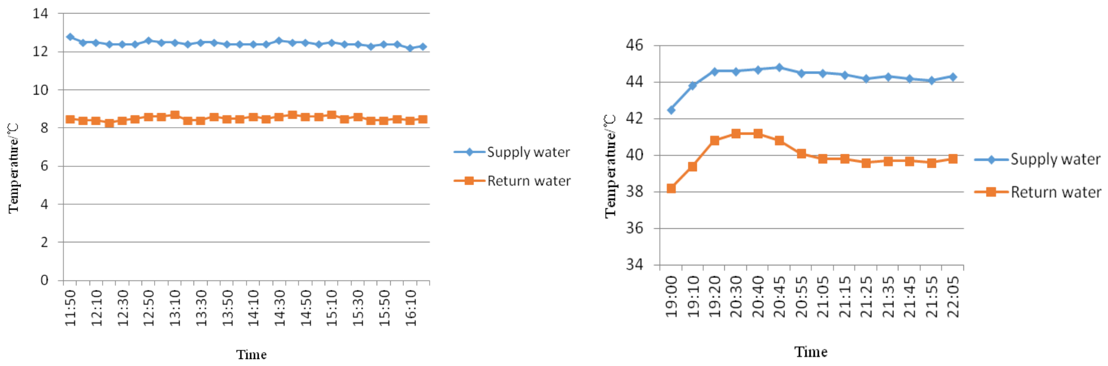
Project (System)	Average Indoor temperature/ ℃ /relative humidity/ %	Average supply/return water temperature/℃	Load rate /%	COP/EER of heat pump unit in a season	COP/EER of system in a season
A	22.8/ 43.5	8.9/11.6	59.0	4.00 (summer)	2.94 (summer)
B	18.2/51.6	44.2/41.3	79.5	3.34（winter）	2.39（winter）
C	27.4℃79.4	14.6/17.3	87.5	3.96 (summer)	2.70 (summer)
D	25℃/67.2	8.2/10.0	47.0	4.58 (summer)	2.92 (summer)
E	20.7℃/37.5	44.3/40.0	47.2	3.28（winter）	2.78（winter）
F	19.7℃/52.6	44.1/39.6	94.6	3.89（winter）	3.11（winter）
G	25.8℃/69.3	8.5/12.4	101.1	5.09 (summer)	3.76 (summer)
H	25.1℃/84.4	12.2/18.7	107.2	5.67 (summer)	5.86 (summer)
I	29.7℃/72.9	11.0/16.1	102.6	5.63 (summer)	3.52 (summer)
J	20.1℃/35.0	42.3/39.1	81.8	5.87 (winter)	4.30（winter）

3.3 Energy efficiency of heat pump unit and system

As shown in Table 3, the EER of heat pump unit are 3.64-5.67, and system EER are 2.6-5.86 in summer. The COP of heat pump unit are 3.28-3.89, and system COP are 2.39-3.11 in winter. Six GSHP systems meet the standard of COP/EER in "Evaluation standard for application of renewable energy in buildings"(GB/T 50801-2013, 2012). Three systems (Project A、C and D) in summer and one system (Project B) in winter are below the value in standard, which is 3.0 in summer and 2.6 in winter. It should be noted that the load rates of the4 systems are all less than 60%, which is the recommended value of load rate in the test. The results of the four systems could be affected by the reason.

3.4 Temperature and temperature difference of supply water and return water

The average temperature of supply water and return water of the projects are shown in Table 3. The temperature variation of supply water and return water of the project D and F are shown in Fig. 1. The water temperature in these projects are generally stable and the water temperature difference are also basically constant. Some temperature difference are near 5 ℃ and most are less than 5℃ obviously. Small temperature difference of supply water and return water is a convention problem, and reason for this may include improper selection of heat pump unit or pump, system status which is not working at the optimal point, poor hydraulic balance, etc.



(a) (b)

Figure1： Temperature of supply water and return water ((a) System D in summer.(b) System E in winter).

3.5 Energy consumption of pump

The ratio of the energy consumption of air conditioning unit and pump is shown in Fig. 2. In central air conditioning system, energy consumption of pump generally accounts for 20-23% of the total energy consumption of the system (Xu, et al, 2019). As shown in Fig.2, half of the systems are in this range. Some systems are out of range. The maximum value of ratio is 36.24% in system E. The average ratio of the systems is 24.0% in winter and 29.1% in summer. The ration is less than that of some systems in reference (Xu, et al, 2019), but a little higher than the configuration value in design (Xu, et al, 2019). One of the reason could be related to the pump design, in which the optimized configuration is not considered based on the pump performance at part load. And it is unfavorable for system energy consumption.

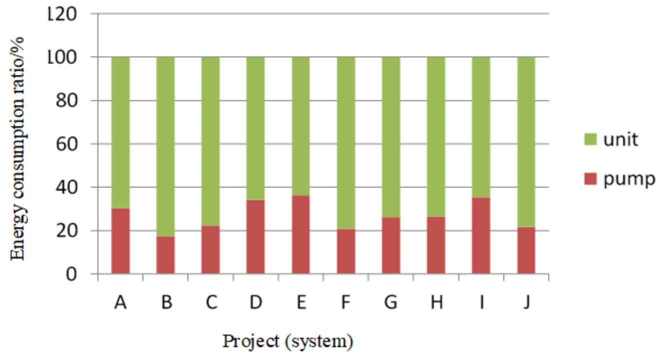


Figure 2: Energy consumption ratio of the system.

Table 4: Comparison of energy consumption ratio.

Item	Energy consumption ratio in winter		Energy consumption ratio in summer	
	Pump	Unit	Pump	Unit
Average value of some system in reference*	25%	75%	32%	68%
Average value in this paper	24.0%	76.0%	29.1%	70.9%

*Notes: Xu et al (2019)

3.6 Energy saving performance and economic efficiency

Energy saving rate of the GSHPs is defined as reduced proportion of energy consumption compared with convention central air conditioning system. According to" Evaluation standard for application of renewable energy in building"(GB/T 50801-

2013,2012),air conditioning system with chiller and gas boil were used as a reference mode of conversional system. Energy efficiency ratio of air conditioning system with chiller is 2.4 and gas boil efficiency is 80%. Energy saving rate is given by:

$$C = \frac{N_c - N_g}{N_g} \times 100\% (1)$$

where, C is energy saving rate of the GSHPs, N_c is the energy consumption of conventional central air conditioning system, N_g is energy consumption of GSHPs.

Energy saving rate and payback period of the ten projects are shown in Fig. 3 and 4.The energy saving rates are 27.00 -49.89%. The average value is 38.7% and the energy saving level is relatively better. The payback period is 3.9-8.8 years and six projects exceed 6 years. The average value is 6.5 years. Overall the payback period is slightly long.

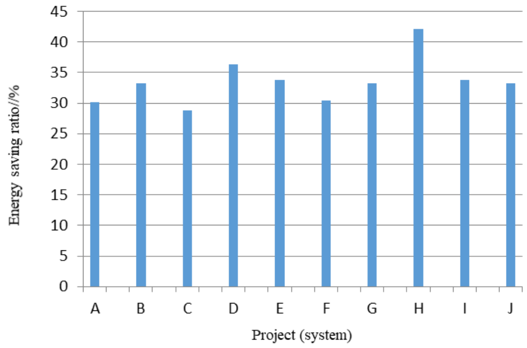


Figure 3: Energy saving ratio of the system

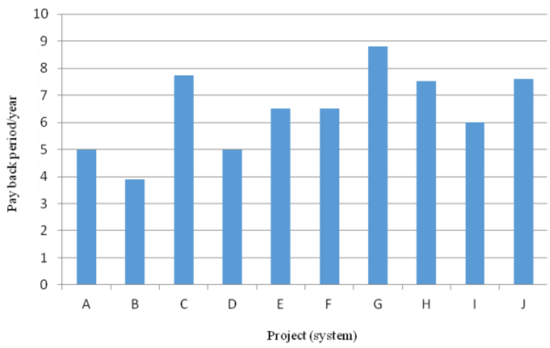


Figure 4: Payback period of the system

4. CONCLUSION

The test results of 10 ground coupled heat pump systems in commercial buildings were analyzed. The comparison between the results and other systems in reference and value in standard were made. Following conclusions are obtained.

Most GSHPs operates normally and the COP and EER meet the standard requirement. COP or EER are lower in some systems. It may be partly related to the lower load rate during the test period and the temperature differences of supply water and return water which are generally smaller than 5℃ in these systems. Energy consumption ratio of pumps in some systems are a litter bit higher. All the systems have a certain energy saving rate compared with convention central air conditioning system. The payback period is basically rational, and a litter longer in some projects.

The conclusions are beneficial for us to know more about the current situation of GSHPs operation and the effect of design and construction in Wuhan, China.

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