Energy and Buildings 119 (2016) 153–163

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Operation analysis and performance prediction for a GSHP system compounded with domestic hot water (DHW) system

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ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 8 March 2016
Accepted 9 March 2016
Available online 16 March 2016

Keywords:
Ground source heat pump
System performance
Heat accumulation
Domestic hot water
TRNSYS

ABSTRACT

A ground-source heat pump (GSHP) system located in Chongqing, a cooling dominated region in China, was taken as an experimental system. In order to explore the operating characteristics of the GSHP system, the GSHP system was monitored with a data acquisition system. The measured data were analyzed, including the inlet/outlet water temperatures, power consumptions, *EER*/*COP* and also the ground temperature variations. The measured system *EER* of 2013 and 2014 are 3.01 and 2.91, respectively, while the system *COP* of 2013 is 2.59. A TRNSYS model was established based on the studied GSHP system. The accuracy of the model was validated by the comparison between the measured and the simulated outlet water temperatures, and also the ground temperatures. The model was then used to predict the long-term performance of the GSHP system. It has been found that after 20-years running of the system, the heat accumulation under the ground and the deterioration of system efficiency aggravate: the ground temperature would rise up to 30.5 °C from the initial value of 20 °C, while the ASPF value would descend to 2.72 from the initial value of 3.12. As a remedy for the problem, the domestic hot water (DHW) system was supposed to be operated in the following years, and the simulation showed that the operation of DHW system could effectively reduce the ground temperature and improve the system performance.

1. Introduction

Ground source heat pump (GSHP) has been regarded as a highly efficient, renewable energy technology for space heating and cooling [1,2]. This technology has gained international attention as a mean of energy conservation in the residential and commercial air conditioning of indoor spaces, and then it has been widely used in the world [3,4]. Specifically, in China, the GSHP system has been developed rapidly in recent years [5,6].

The GSHP system has a more stable heat source comparing with other air conditioning systems, for the reason that the ground temperature variation during a whole year is far less than that of ambient temperature, especially in the deeper ground. For example, in Chongqing, China, the ground temperature is stabilized around 20 °C below the depth of about 11m, while the annual highest air temperature and the annual lowest air temperature reach 41.9 °C and −0.7 °C, respectively [7,8]. The good stability characteristics of the ground temperature that lower than the air temperature in cooling season and higher than that in heating season make the GSHP system perform better than other air conditioning systems [4].

A number of papers have covered GSHP technology, including researches on the system performance measurement. For example, Yu et al. [9] tested a constant temperature and humidity air-conditioning system driven by GSHP. Compared with air source heat pump system and water cooled unit combined with boiler system, they concluded that the operating cost of GSHP decreased by 55.8% and 48.4%, respectively. They also developed an operation mode that one heat pump ran in heating mode and the other one ran in cooling mode, which could reduce the heat absorbed from the soil by 20% [10]. Hwang et al. [11] evaluated the cooling performance of a GSHP system installed in a school building. The averaged energy efficiency ratio (*EER*) of the GSHP system was found to be 5.9 at 65% partial load condition. Bakirci [12] investigated the heating performance of a GSHP system. The experimental results indicated that the average coefficient of performance (*COP*) of heat pump unit (HPU) and heat pump system (HPS) were 3.0 and 2.6 in the coldest month, respectively. Peng et al. [13] analyzed the actual operation performances and energy efficiencies of 39 GSHP systems based on site tests in Wuhan, China. The results showed that the *EER*/*COP* values of these GSHP systems varied from 2.6 to 4.85, which were generally higher than that of conventional

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http://dx.doi.org/10.1016/j.enbuild.2016.03.024
0378-7788/

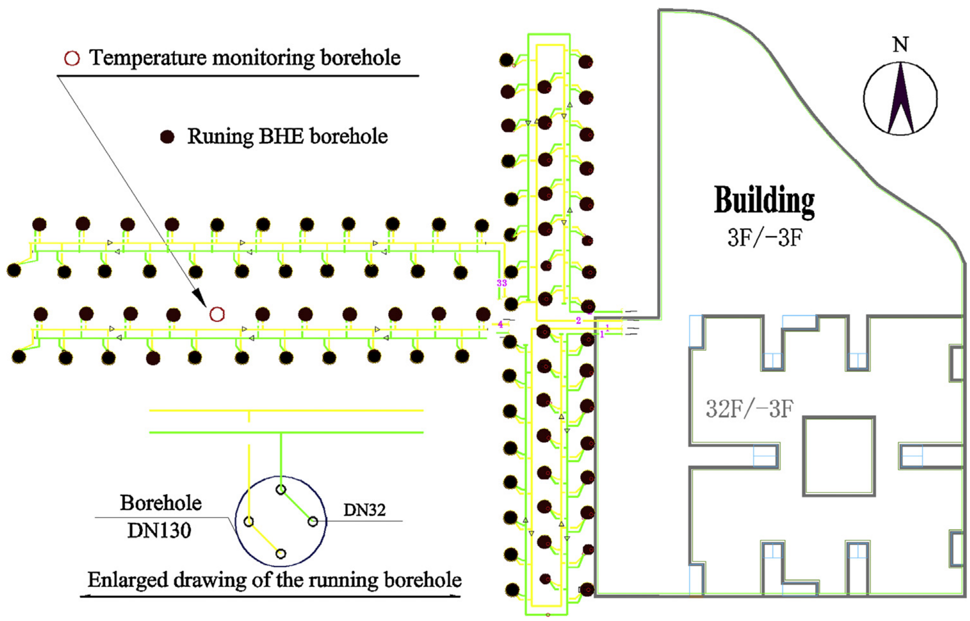

Fig. 1. Layout of the building and BHE system.

air-conditioning systems. Michopoulos et al. [14] reported the performance of a GSHP system over an operation period of 8 years. It was found that the seasonal *EER* and *COP* values of HPU were between 4.5 ~ 5.5 in heating mode and 3.6 ~ 4.5 in cooling mode, respectively.

Besides, there are also a series of articles about the prediction of system long-term performance that usually be accomplished with TRNSYS software. Huang et al. [15] simulated the 20 years' performances of two GSHP cases. The results showed that, benefiting from the proposed multi-objective design optimization strategy, the total system cost in 20 years decreased by 9.5% and 5.2% for the two cases, respectively, comparing with a single-objective design optimization strategy. Chen et al. [16] performed a 20 years' numerical simulation for a solar-assisted GSHP system. The simulation results showed that the long-term yearly average space heating efficiency was improved by 26.3% comparing with a traditional GSHP system. Fan et al. [17] simulated the long term (50 years) performance of a practical hybrid GSHP (HGSHP) system assisted with cooling tower. The results showed that the hybrid GSHP system could effectively solve the heat accumulation problem and the decrease of system performance in the long run. Wang et al. [18] developed a simulation model in TRNSYS to predict the multi-years' performance of a hybrid GSHP system assisted with solar energy. The simulation results showed that the system was reasonably designed to resolve the thermal imbalance problem. Cui et al. [19] constructed models of the parallel and serial hybrid GSHP systems assisted with cooling tower in TRNSYS software. They studied the performances of the two systems in 20 years' running period and the optimum auxiliary cooling ratio was found to be 50%.

It can be summarized from the above statements that most of the system measurements were usually too short to reflect the system performance in the long run. Therefore, simulation software was generally adopted to predict the long-term performance of the GSHP system. However, few GSHP models for simulation were effectively validated against to the measured data. Hence, the prediction results were mostly lack of persuasion. In addition, in cooling dominated areas, few studies about the hybrid GSHP compounded with DHW system have been covered. In this paper, the running performance of a GSHP system in two successive years was analyzed with the measured data. And then, a TRNSYS model was constructed according to the practical parameters of the GSHP system, and also validated against to the measured data. Based on the model, the 20-years' performances of the GSHP system, together with GSHP compounded with DHW system were predicted.

2. Description of the GSHP system

2.1. GSHP system

The research object is a multi-storied building with 32F on the ground and 3F under the ground. The building's footprint size is 2123 m^2 and its orientation can be seen in Fig. 1. The first three floors of 6368 m^2 on the ground are office area and the stories that above 3F are residential rooms. Therefore, there is not only air-conditioning demand in office floors but also domestic hot water (DHW) demand in residential floors for this building. Since the building is located in Chongqing where the climate is characterized by hot summer and cold winter, there is a load imbalance between the cooling and heating. A hybrid GSHP system compounded with DHW system was applied to this building.

The designed cooling and heating loads of the office part were 605 kW and 298 kW, respectively. There were two heat pump units (HPUs) installed, which were used for domestic water-heating and air-conditioning, respectively, as shown in Fig. 2. Table 1 shows the main parameters of the GSHP system.

2.2. Data acquisition system

The data acquisition system includes two separate monitoring systems, i.e, a GSHP performance monitoring system and a ground temperature monitoring system. The data acquisition system ran automatically by the control of computers. For the GSHP performance monitoring system, the temperatures were measured by thermocouples (±0.5 °C accuracy), which were distributed at some specific points at the inlets and outlets of the pipes. The flow rates of water in the source and load side pipes were measured by ultrasonic flow meters (1–5% accuracy). The locations of the thermocouples and ultrasonic flow meters can be found in Fig. 2.

The ground temperature monitoring system was set up in an idle borehole which was surrounded by other running boreholes, as shown in Fig. 1. The resistance temperature detectors (RTDs, ±0.1 °C accuracy) were installed on the legs of the U-pipe at spec-