Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Ground Source Heat Pump Application in Tropical Countries

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Keywords: Ground Source Heat Pump (GSHP), Tropical Countries

ABSTRACT

In this paper we discuss the performance data of Ground Source Heat Pumps (GSHPs) installed in Tropical countries, in this case South East Asia (Thailand). Unlike the application of GSHP in four-seasons countries in which rejection (cooling) and heat extraction (heating) are balance, the use of GSHP in tropical country is predominatly for cooling only (heat rejection). Also, the difference between ground and atmospheric temperature is essentially low. The results show possible electricity reduction over the conventional Air Source Heat Pump (ASHP). Local production of heat pumps and heat exchangers, as well as rapid regional economic growth, can be positive factors for future ground-source heat pump application, not only in Thailand but also southeast Asian countries.

1. INTRODUCTION

Ground Source Heat Pump (GSHP) has been widely used in many subtropical countries in which seasonal heating and cooling are required. The GSHP system takes advantage of the relatively constant ground temperature against seasonal temperature variations. The tropical countries, however, have limited temperature variations, besides, the underground temperatures in some location may significantly high to the extend the use of GSHP may not provide better efficiency compared to normal ASHP. Moreover, the intensive use of GSHP merely for heat rejection may create underground heat island problem. Figure 1 shows the average ground temperature in comparison with atmospheric temperature.

2. BACKGROUND AND OBJECTIVES

(Yasukawa et al. 2009) provided important information on general groundwater condition in Chao-Phraya plain, Thailand and Red river plain, Vietnam by conducting ground water temperature surveys. The study identified several locations in Thailand where the use of GSHP as cooling may have greater advantages. Southeast Asian countries have experienced rapid economic growth, at an average rate of 5.2% per year since 2000. The rapid growth has been followed by an increase in the energy demand. In 2016, the total primary energy consumption in the region reached 643 million tons of oil equivalent (MTOe). While Southeast Asian countries may not be considered a major global CO_2 contributor, the CO_2 emissions of those countries rose from 711 million tons in 2000 to 1288 million tons in 2015 (IEA 2017; Ministry of Energy of The Kingdom of Thailand 2018). The total generation of electricity in the region increased from 370 TWh in 2000 to 868 TWh in 2015. By 2015, 83.4% of electricity was generated by burning fossil fuels (i.e., coal, natural gas, and oil). Serious action must therefore be taken immediately, in order to reduce the fossil fuel dependency (Lee et al. 2013). Thailand accounts for 21.7% of the primary energy demand in Southeast Asia (IEA 2017). By 2015, the national primary energy consumption and total electricity generation were respectively 135 million tons of oil equivalent and 178 TWh, with fossil fuel accounting for 80.7% and 91.6%, respectively. In 2017, the generation of electricity emitted 96.035 million tons of CO_2 (Ministry of Energy of The Kingdom of Thailand 2018). Air conditioners consume much of a household's electricity demand. According to a report published by The Japan Refrigeration and Air Conditioning Industry Association, Thailand's domestic total air conditioner demand in 2016 was 1.56 million units, the third largest demand in southeast Asia after Indonesia and Vietnam [4]. Data published by the Ministry of Energy of Thailand suggest that the residential sector consumed 20.4% of national electricity, 46% and 17% of which were used for air conditioning and refrigeration, respectively. These sectors have high potential energy savings.

Based on the report World Air Conditioner Demand by Region, published by The Japan Refrigeration and Air Conditioning Industry Association (JRAIA), national total air conditioner demand in 2016 was 1.56 million units, the third largest in southeast Asia after Indonesia and Vietnam (Japan Refrigeration and Air Conditioning Industry Association (JRAIA) 2018)

South east Asian countries, as one of the region with the fastest economic growth rate where most of its countries are in tropical regions, are among the major contributor to global (Green House Gasses) GHG emissions. At the 2015 United Nations Climate Change Conference (COP21) held in Paris, the panel of 190 countries agreed upon a framework for global warming countermeasures from 2020 onward. It implies that, reducing the emission of CO_2 into the atmosphere become the main issue that requires immediate action.

The application of GSHP in the tropical countries can potentially be applied to reduces GHG emission reduction. The application of GSHP in the tropical countries can potentially be applied to reduces GHG emission reduction.

This research is carried out mainly to study the applicability of GSHP system in tropical countries. From the installed GSHP systems, important heat pump's thermal performance utilizing both vertical and shallow-horizontal heat exchanger can be evaluated. Also, the installed systems served as educational purpose for public awareness on the GSHP technology and renewable energy technology application.

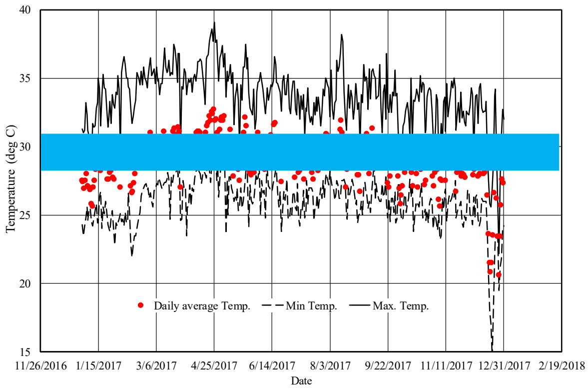

Figure 1. Average atmospheric temperature and average underground temperature in Bangkok; blue shaded area represents average daily air temperature range.

3. INSTALLATION SITES

We have installed four GSHP systems in total. All of those have 4kW and 5kW capacity of cooling and heating respectively. Currently, we have three installed GSHP systems in Thailand.

3.1 Chulalongkon University Bangkok Campus

The Chulalongkorn University GSHP at Bangkok campus has two vertical boreholes with single u-tube arrangement. Both boreholes were supposed to have 50m depth, however, due to one of the borehole collapsed; only one borehole can be installed as planned while the other one has only 20m depth. The Fan Coil Unit (FCU) of the system is used for cooling purpose in one of the room of Parot Racha building.

3.2 Chulalongkon University Saraburi Campus

The Saraburi system installed at Chulalongkorn University Saraburi campus is using horizontal heat exchangers (carpet type and slinky coils). The FCU is used to provide room cooling in one of the laboratory offices. In this site,two GSHP were installed. One of which is an original GSHP with heating and cooling modes while another one is locally modified ASHP, by changing its refrigerant-air heat exchanger to refrigerant-fluid heat exchanger. For energy saving comparison, a normal ASHP was also installed. Figure 2 shows the installation of heat exchangers in this site. Schematic diagram of installed Saraburi system is depicted in figure 3. The upper soil comprises of mainly volcanic-derived, clayey-sandy soil. There were four groups of heat exchangers, as shown in Figure 3. Two types of heat exchanger were used, namely sheet-type (carpet-type) and high-density polyethylene (HDPE) pipe GHEs. The carpet-type heat exchanger had overall dimensions of 5.6 m x 0.9 m and is comprised of 117 small HDPE tubes (with an outer diameter of 6 mm). The HDPE pipes with a diameter of 3.2 cm and thickness of 2.4 mm were used in both slinky and helical arrangements. In total, 500 m of HDPE pipe and two carpet-type heat exchangers were installed over a footprint of 73.8 m^2.

Figure 2. Installation of horizontal ground heat exchangers in Saraburi campus, Chulalongkorn University, Thailand.

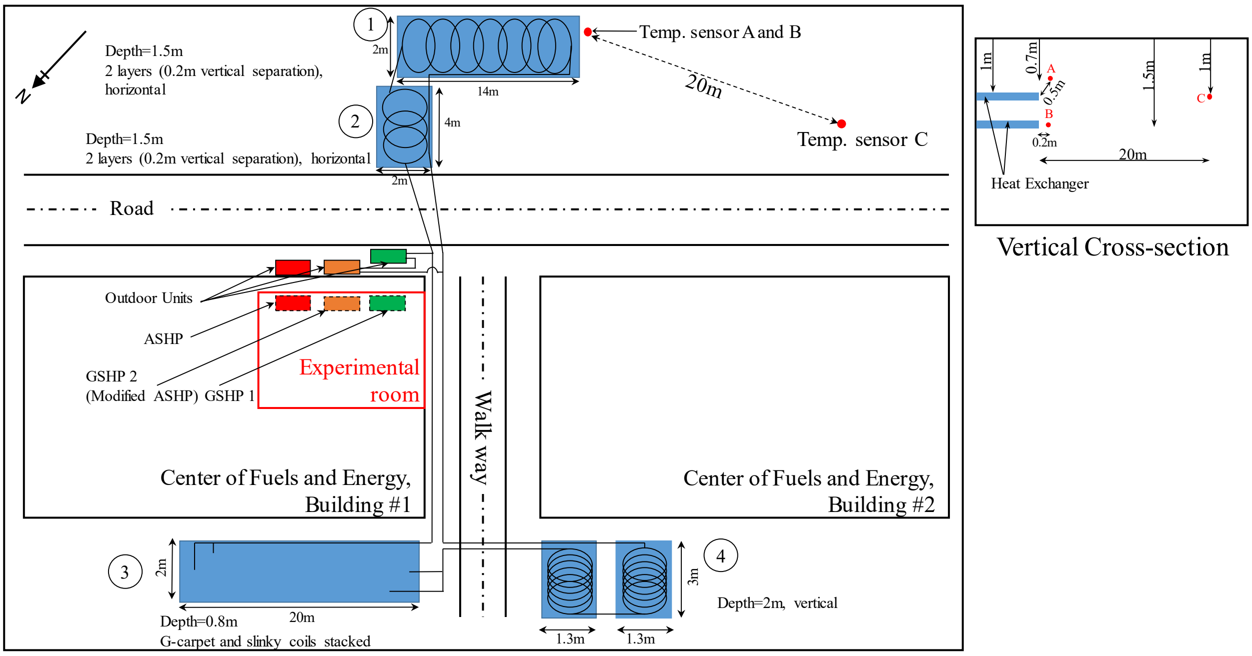

Figure 3. Schematic diagram of the connection of heat pumps and GHEs; the number in the circle represents the grouping of the ground heat exchangers.

<u>3.3 Department of Mineral Resources (DMR) of Thailand</u>

The Department of Mineral Resources (DMR) GSHP at Pathum-Thani Province has two vertical 50m boreholes with double u-tube arrangement. The fan coil unit is used for cooling purpose of the museum's souvenir shop. Figure 4 shows the installation of GSHP at DMR geological museum, Thailand.

Figure 4. Installation of ground heat exchangers in Geological Museum, Department of Mineral Resources of Thailand

4. RESULTS AND DISCUSSIONS

<u>4.1 Test data</u>

Figure 5 shows the recorded CoP of GSHP installed in Bangkok campus, Chulalongkorn University. The CoP are presented for both 20^{0}C and 25^{0}C temperature setting. Detail of the experimental result of this site can be further found in other published paper (Chokchai et al. 2018).

Figure 6 compares the performances of all heat pumps. Each error bar represents the standard deviation of data. The standard deviations of the power consumptions of GSHP 1 and the ASHP were larger, indicating larger variations, while the temperature data of GSHP 1 and the ASHP had smaller standard deviations in comparison with the standard deviations for GSHP 2. A comparison of the average electrical consumption shows that the GSHPs required less electrical input than the ASHP. The average electrical consumptions of GSHP 1 and GSHP 2 were 658.7 and 648.6 W, respectively, being 17.1% and 18.4% less, respectively, than the electrical consumption of 795.5 W for the ASHP. More detailed investigation, including the cost analysis can be found in (Widiatmojo et al. 2019).

Figure 7 shows one of the observation data and calculated System-CoP of Thai DMR museum from March to September 2017. The recorded temperatures were outside, room, heat exchange fluid inlet-outlet temperatures as well as electricity consumption and heat exchanger fluid flowrate. The average temperature difference between outside and room temperature were 9.7^{0}C while average temperature difference between outlet and inlet were 4.5^{0}C. The temperature setting for the indoor unit was set to the minimum level

(17^{O}C). The results also show the declining daily system-CoP due to high cooling load. However, the CoPs return to initial value on the following day, implying that although there was temperature built-up inside the borehole heat exchangers, it returned to the initial value after system was switched off overnight. This phenomena can also be seen from the increasing inlet-outlet temperatures during daily operation. The analysis also indicated that the system run at its maximum cooling load.

The accuracy of the recorded data has been one of the major issues in the experiment. It includes the use of standard thermocouples, sensors and proper installations. The standard power logger was just installed this year to ensure the precision of the power consumption.

4.2 Thermal Response Test

Additionally, in February 2018, we also carried out the Thermal Response Test (TRT) in Bangkok site. It was the first TRT to be carried out in South-east Asia. The thermal conductivity of Bangkok site is surprisingly higher, 1.82 W/mK due to the fact that most of ground layer in upper 50m are consist of high permeability sandstones as a part of Bangkok upper aquifers. Furthermore, the existence of pumping wells in Bangkok city have possibly increase the groundwater flow that enhance the effective thermal conductivity. Figure 8 shows the TRT measurements and results in Bangkok

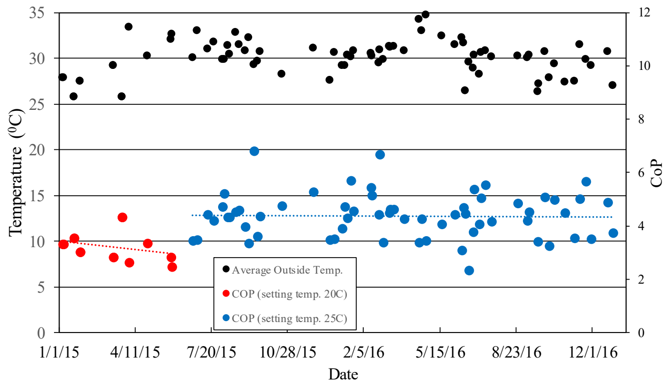

Figure 5. Cooling performances of GSHP system installed at Chulalongkorn University, Bangkok Campus

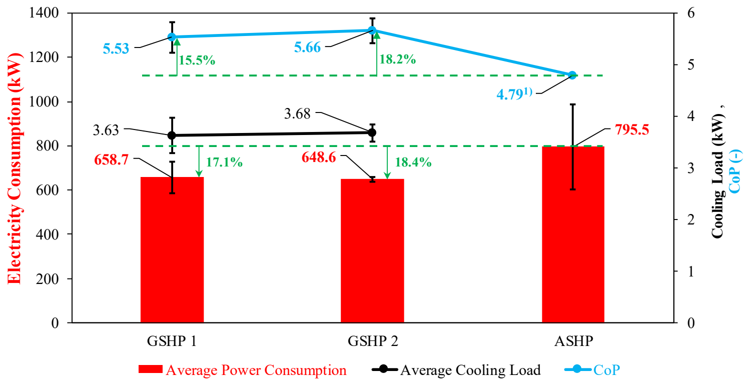

Figure 6. Performance comparison of the GSHPs and ASHP, for Saraburi systems; the coefficient of performance (CoP) of the ASHP is calculated assuming an average cooling load similar to that of GSHP 1 and GSHP 2.

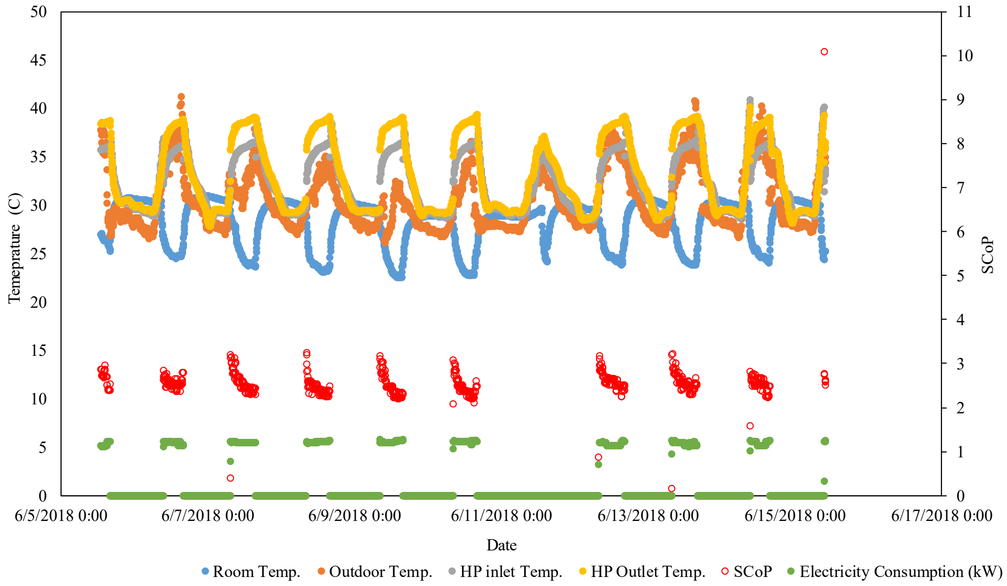

Figure 7. Cooling performances of GSHP system installed at DMR museum

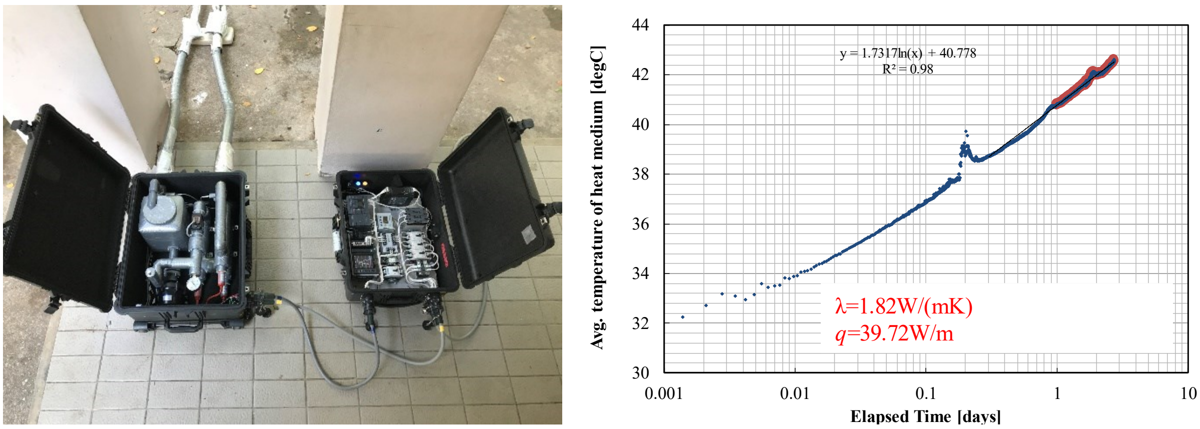

Figure 8. TRT measurement in Bangkok GSHP site

5. CONCLUDING REMARKS

The GSHP systems have been installed in Thailand (3 sites). These systems were used to obtain important thermal parameters that are required to assess the potential applicability of GSHP in tropical countries, especially South-east Asian countries. Furthermore, TRT measurements have been also carried out in two sites. The results signify the importance of groundwater flow as advective heat transport that could enhance the thermal performance of heat pump, despite in fact the temperature differences between ground and air is significantly low. For Bangkok site and Saraburi site, the GSHPs require less electrical power to run the relatively similar cooling load as those of normal AC (ASHP). This result indicated that in hot tropical climate, cheaper shallow heat exchanger can still provide higher thermal efficiencies in comparison to the conventional ASHP. The installed GSHP also serve for educational purpose for local people. Further study will focus on long-term performance while upgrading data acquisition, so that other crucial data can be obtained for advance analyses.

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