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A Pilot Study on Geothermal Heat Pump (GHP) Use for Cooling Operations, and on GHP Site Selection in Tropical Regions Based on a Case Study in Thailand

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Received: 1 August 2018; Accepted: 3 September 2018; Published: 6 September 2018

Abstract: In order to reduce electricity consumption, the vertical loop geothermal heat pump (GHP) system coupled with a normal air conditioner was installed in an experimental room in the Parot Racha Building, Chulalongkorn University, Bangkok, Thailand for a comparative, long-term measurement program. The decrease in electricity consumption was approximately 30%. On the basis of the data derived from our measurements, the underground temperature seemed to be consistent and lower than the average outside air temperature, over two years. The underground system consisted mainly of two 50-m-long drilling wells and pipes with a total length of 170 m. The well performance was not examined, but both soil and groundwater aquifer (Bangkok aquifer) at 25 to 50 m. could be utilized for the cooling operation. Moreover, the major controlling factors of electricity consumption were found to be the outside air temperatures and the underground water circulation temperatures. In addition, we considered the geology, underground temperature, and aquifer of Bangkok concluding that almost all Bangkok areas are suitable for GHP installation, except for those where the subsurface temperature is too high compared with the outside air temperature.

Keywords: Bangkok aquifer; electrical saving; geothermal heat pump (GHP); groundwater; subsurface temperature; tropical regions

1. Introduction

Geothermal heat pumps (GHP) or ground source heat pumps (GSHP) [1] have been used as one of the alternative ways [2,3] to reduce electricity consumption [4] and the high price of energy in many countries in Europe [5,6], as well as in the USA [7], South Africa [8], China [9–11], and Japan [12,13]. A GHP utilizes the subsurface energy associated with temperature as an energy source. Although shallow (<100 m) subsurface temperatures fluctuate with the seasons, that fluctuation is moderated by heat flow from the Earth's interior. The temperature at the site of interest usually will be appropriate for heat exchange for cooling and/or heating, depending upon local conditions.

A GHP is applied on the principle that low or high temperatures exist under the ground surface, and cooling or heating energies are transferred by circulating water through a sealed loop, so as to control the room temperature in a building. The employment of energy exchanges based on temperature differences has been considerably useful to control the room temperature, especially by replacing a heater in the winter and a conventional air conditioner in the summer [14]. For this reason, the GHP is an environmentally friendly system [15] and it can be used in nearly zero energy building (building energy conservation) projects [16].

In the tropical zone, the GHP system is only applied as a cooling system. However, the air temperature is relatively high or close to the subsurface temperature [17,18]. Even though, the first trial was conducted in central Thailand in 2006 and obtained promising results [17]. After this study, some application studies were carried out in Thailand [19,20]. However, such studies did not use suitable and highly efficient GHP units. Recently, a small, high-efficiency GHP machine was commercially produced. This GHP system together with a normal air conditioner was installed in the same experimental room in the Parot Racha Building, Chulalongkorn University, Bangkok, Thailand. The underground piping system of the building is a U-tube, vertical design, with two 50-m-deep wells. The GHP used is specialized for room cooling and the operation was optimized with inverter control. All necessary data, as temperature, humidity, flow rate, electric consumption, were recorded by data loggers. Therefore, this study is the first case in the world in which the efficiency of the GHP in cooling operation only was investigated in detail.

From a previous study by Yasukawa et al. [21] that surveyed the subsurface temperatures from wells in the central plain of Chao-Phraya Basin, it was concluded that Bangkok is one of the places whose subsurface temperatures are lower than average maximum atmospheric temperature, so this area is suitable for the installation of the GHP system. Moreover, the subsurface thermal regime of the Chao-Phraya Basin was examined by Uchida et al. [18].

In this current study, we present GHP operation data and a potential map for GHP installation based on lithostratigraphic information derived from drilling two boreholes and on reported well information. Figure 1 shows a location map of the experimental site.

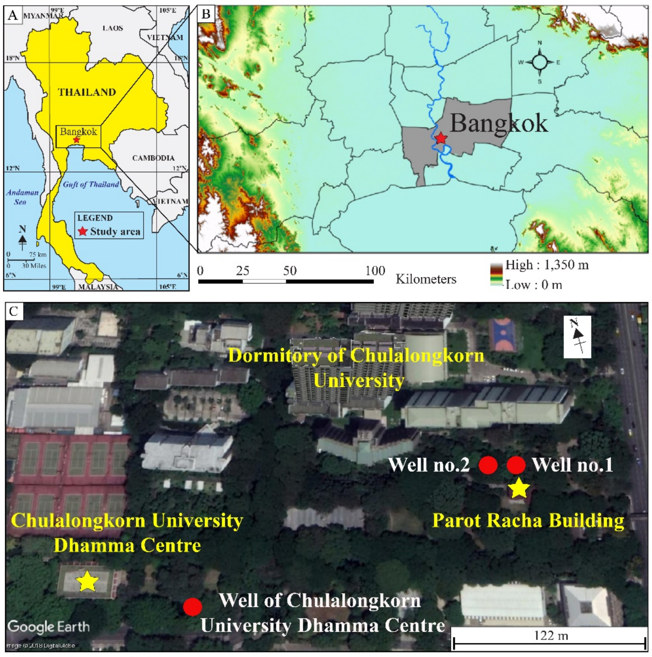

Figure 1. The location of installed GHP system: Index map of Thailand (**A**) and Chulalongkorn University (star) in Bangkok (**B**). Google Earth Map showing the location of Paraot Racha, well no. 1 and no. 2 in Chulalongkorn University and the nearest artesian well (Chulalongkorn University Dharma Centre) (**C**).

2. Materials and Methods

2.1. Geology and Underground Temperature of Bangkok Area

The installation of the GHP system was conducted in a vertical loop field in the central plain of Thailand where the experimental room is situated, in the Parot Racha Building, Chulalongkorn University about 200 m from the Phayathai Road (the main street) (see Figure 1). The subsurface temperature of the site itself is suitable for the installation of the GHP system because the average subsurface temperature is lower than that of the atmospheric air throughout a year. In addition, there is groundwater flow in the Bangkok aquifer underneath the study area, which is one of the important factor for subsurface heat transfer. For this reason, GHP should be suitable for Bangkok area [21]. A specific site reconnaissance was first performed for finding the best location to drill the boreholes. Two boreholes were drilled in the backyard of the Parot Racha Building at 50 m depth to place High-Density Polyethylene (HDPE) pipes for water circulation. The pipes were also equipped with thermistors for subsurface temperature measurement. Furthermore, lithostratigraphy of both boreholes was recorded and photographed (see Figure 2).

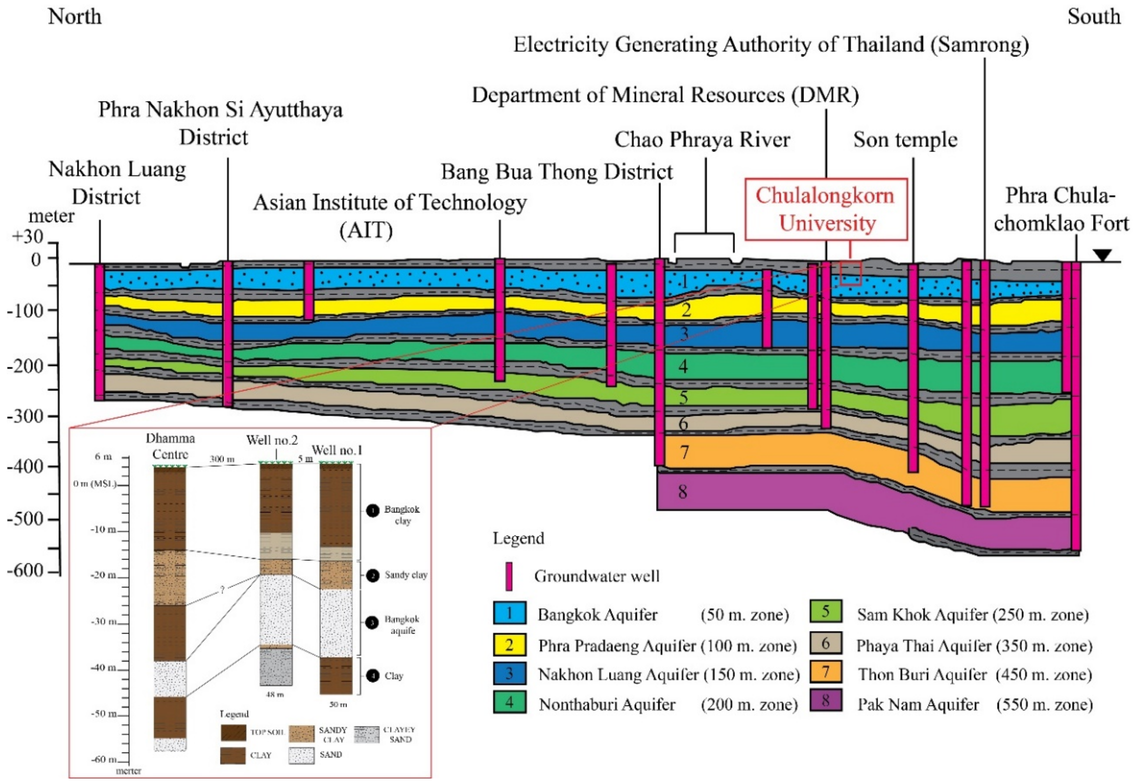

Figure 2. Subsurface stratigraphy and aquifer of the Lower Chao Phraya Plain (modified after Department of Mineral Resources [22]).

Figure 3 shows a comparison between the subsurface temperature of the previous study area and that of this study area at a depth from 1.5 to 50 m.

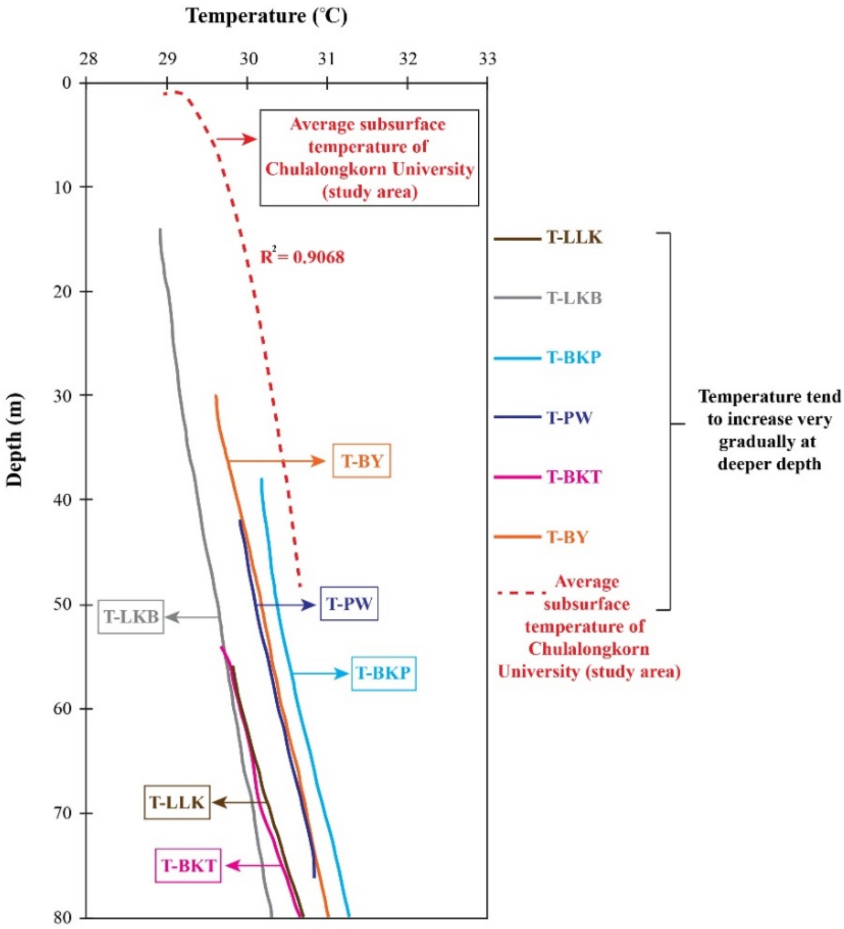

Figure 3. Comparison between well temperature profiles around Bangkok including the study area (data from Uchida et al. [18]).

It was observed that all subsurface temperatures followed the same trend, i.e., when the depth increased, the subsurface temperatures also increased within the limit of ≤1 °C). By correlating the lithostratigraphic logs of the study area wells (well no. 1 and no. 2) with those of the Department of Groundwater Resources (DGR) located at Chulalongkorn University Dhamma Centre as shown the stratigraphic columns in Figure 2, four layers could be described, as indicated below.

- The 1st layer has a thickness of up to 20 m and consists mainly of clay with high plasticity and homogeneity.
- The 2nd layer has an average thickness of 6 m and consists principally of pale brown to yellowish brown sandy clay. It is composed of 60% clay with moderate plasticity and heterogeneity and 40% sand with fine to medium grain sizes, relatively poorly sorted grains, and sub-angular shapes. Mineralogically, it is comprised essentially of quartz with subordinate feldspar and rock fragments.
- The 3rd layer has an average thickness of 15 m and consists of pale brown sand with fine to medium grain sizes, good sorted grains, and sub-angular shapes. It is mostly composed of quartz with subordinate feldspar, rock fragments, and clay minerals.
- The 4th layer has an average thickness of 9 m and comprises yellowish brown clay with moderate plasticity and a heterogeneous mixture of medium sand and silt.

It is clear, as depicted in Figure 2, that the lithostratigraphy in this study shows both similarities and differences compared with that of a near site described in a previous work (Chulalongkorn University Dhamma Center). Bangkok area is divided into three parts, i.e., central, eastern, and the western parts. In the current study, only the topmost aquifer (or the sand layer of Bangkok aquifer) was considered for installing the GHP system with the referenced wells based on the data of the DGR. In order to establish a cross section from southwest to northeast of Bangkok, we used the lithostratigraphic data from seven wells, including TLC-1, TLC-2 (in the western part of Bangkok), LKB-1, LKB-2 (in the eastern part of Bangkok), HK, PKN, BKP, and that in the study area (in the central part of Bangkok) (see Figure 4).

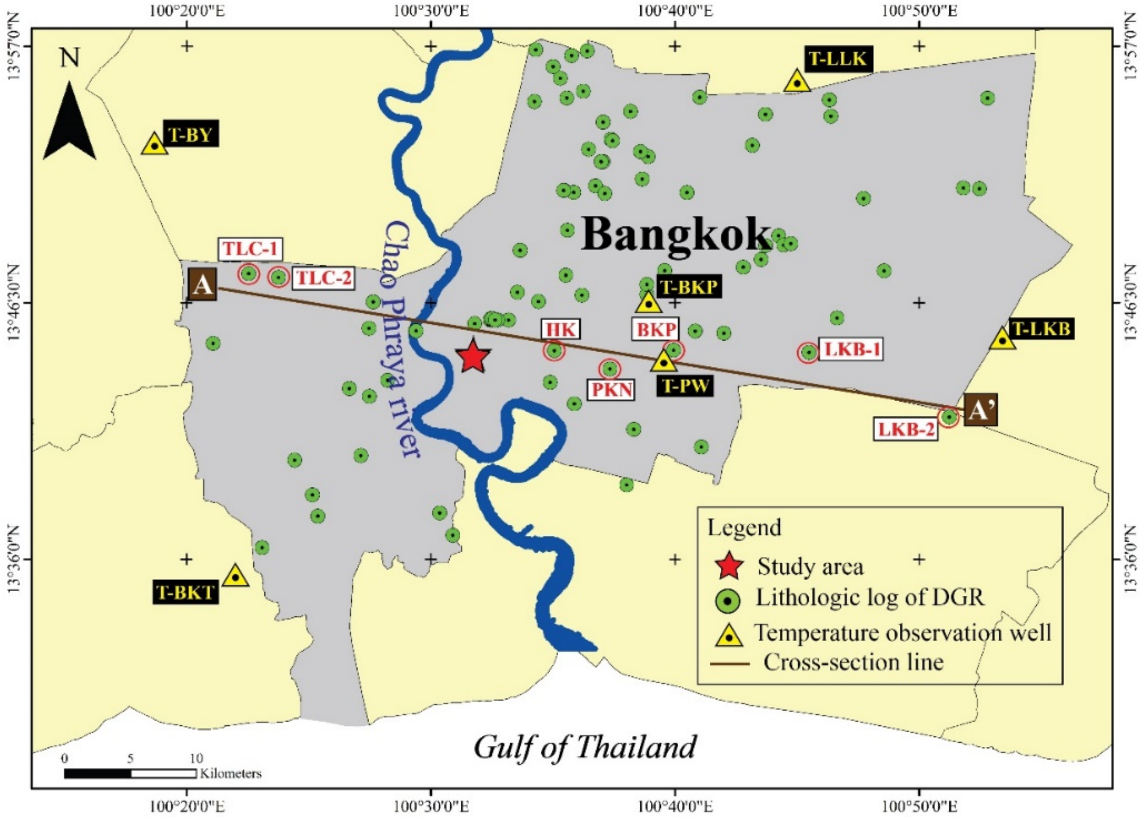

Figure 4. Index map of the Lower Chao Phraya Plain showing the locations of the study area (red star) and lithologic log (green circle) with A-A′ cross section line (data from Department of Groundwater Resources (DGR) and Index map of Lower Chao Phraya Plain showing the locations of temperature observation wells around Bangkok (yellow triangle). The eastern part of Bangkok includes T-LLK and T-LKB. The central part of Bangkok includes T-BKP and T-PW. The western part of Bangkok includes T-BKT and T-BY.

On the basis of Figure 2, the southwest to northeast cross section line (A to A′) was constructed by using a total of seven groundwater well logs, including those of TLC-1, TLC-2, HK, PKN, BKP, LKB-1, and LKB-2 together with the well logs in this study. The sand layer in the Bangkok aquifer was used as a diagnostic key layer. The wells TLC-1 and TLC-2 are located in western Bangkok and consist of sandy gravel at the depths of 28 to 60 m and 17 to 67 m, while a sand layer was observed (well no. 1 and no. 2) in this study at the depth of 23 to 41 m. In addition, sand layers in HK, PKN, and BKP in central Bangkok were observed at the depth of 27 to 36 m, 20 to 30 m, and 18 to 31 m, respectively. Also, in eastern Bangkok area (LKB-1 and LKB-2) two sand layers appear located at depths between 22 and 30 m and between 21 and 50 m, respectively. Therefore, it can be summarized that the GHP system is recommended to be installed in the Bangkok aquifer, so heat can be transferred by the groundwater flowing through the sand layer. It is implied that the GHP system should be installed at the depths of 25 to 50 m and of 30 to 50 m in the eastern part and western part of Bangkok, respectively. Moreover, in the central part of Bangkok, groundwater wells should be drilled at depths of 25–30 m, but how deep they should be depend on the convex of minor clay lens [23]. Bangkok is located in the lower

Chao Phraya basin in the central plain basin of Thailand (see Figure 4). In late Quaternary, the Chao Phraya basin is formed by complicated sequence of fluvial, alluvial, deltaic and tidal flat environment more than 2000 m-thickness. Because rapid sedimentary deposit is occurred by deceleration of river flow which is interacted with sea water [24,25]. However, in order to assure long-term performance of GHP systems, it is important to investigate flow rates and directions. This allows calculations to be performed of heat transfer properties over time, to monitor whether or not long-term temperature increases might slowly occur.

2.2. System Setting for GHP Experiment

The equipment used in the GHP system comprises five components including: (i) equipment for water circulation system; (ii) geothermal heat pump (GHP) air conditioner and normal air conditioner (AC); (iii) thermistors with humidity sensor and T-type thermocouples for measuring temperature and humidity; (iv) flow meter data logger; and (v) electricity meter. High-density polyethylene (HDPE) pipes with a 32 mm outer diameter that are light, flexible, long-lasting, and non-brittle were used. They were connected in the pattern of a U-shape with a submersible pump with a flow rate in the pumping test as illustrated in Figure 5.

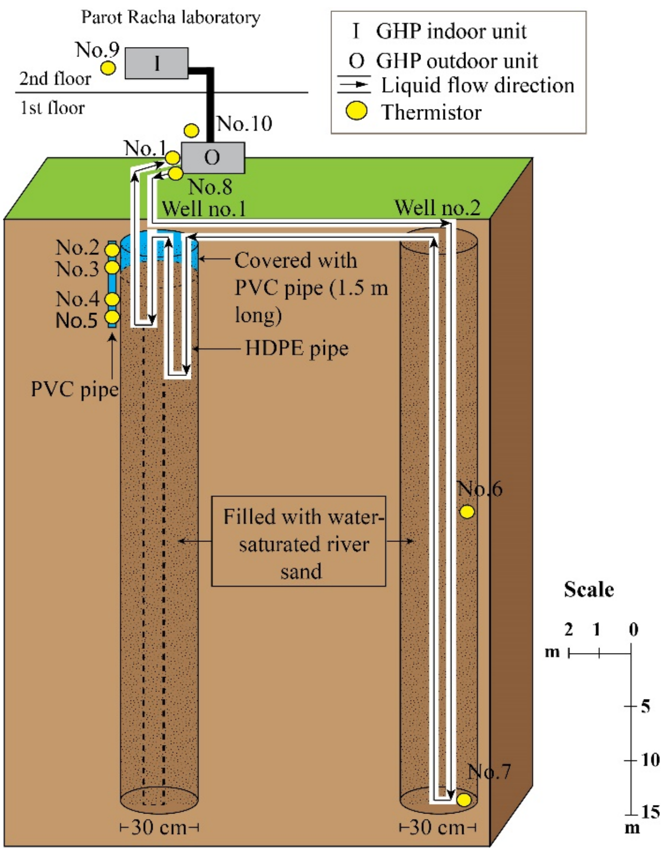

Figure 5. Schematic installation of geothermal heat pump system at Parot Racha laboratory room. Note: HDPE pipe in well no. 1 was broken. Therefore two new HDPE pipes with the lengths of 10 and 15 m were inserted and connected to the well no. 2.

A wall-mounted GHP and normal air conditioners were installed in the same room in order to compare energy saving. The CORONA brand (Japan), CSH-C4000G model with 4000 W, which used a plate type heat exchanger, was selected for the GHP. The GHP indoor and outdoor units were set in different places, i.e., the GHP indoor unit was set up in an experimental room (on the second floor of the Parot Racha Building), while the GHP outdoor unit was set up on the first floor. Also, the indoor and outdoor units of the GHP air conditioner were connected with the HDPE pipes in well no. 1 and no. 2. Similarly, for the normal air conditioner, the CS-PC12QKT model (Panasonic, Japan) with 3600 W and fan coil was used since its specifications are similar to those of the GHP air conditioner. The indoor and outdoor units of the normal air conditioner were set in the same location as the units of the GHP air conditioner, and the thermistors attached to the HDPE pipes were linked to the data logger system present in the experimental room for measuring and recording subsurface temperatures. An anti-corrosion solution (special liquid for preventing engine corrosion, CORONA brand, UPF-L20N) and water were added in the pipes for water circulation. The connection between the HDPE pipes and the GHP outdoor unit was performed in well no. 1 and well no. 2 to allow the liquid to flow into and out the machine and the experimental room.

Thermistors and thermocouples were applied to measure the room temperature (no. 9), outside air temperatures (no. 10), inlet liquid temperatures (no. 1), and outlet temperatures (no. 8). Moreover, the subsurface temperatures at 1.5 (no. 2), 3 (no. 3), 8 (no. 4), 10 (no. 5), 25 (no. 6), and 50 m depth (no. 7) were also measured. A flow meter (FD-M series model L/min, Keyence, Osaka, Japan) was also used to measure water circulation. In terms of data logging, the data obtained from the thermistors and flow meter were automatically recorded every 20 min for 24 h. A Graphtec mini Logger GL220 model (Graphtec Corporation, Yokohama, Japan) was used for logging room temperature, atmospheric (outside air) temperature, inlet and outlet liquid temperature, and subsurface temperatures at 1.5, 3, 8, 10, 25 and 50 m depth. The data logger comprises a total of nine channels that show the recorded temperatures. Additionally, the electricity consumption was measured for both the GHP and the normal air conditioners in kilowatt/hour (kWh) by using an electricity meter (Sankomec, Jakarta, Indonesia).

3. Results

3.1. Stratigraphy of Wells for System Setting

The depth of both wells (no. 1 and no. 2) is approximately 50 m and the distance of both wells is 6 m apart (Figure 2). During drilling, cuttings (large sediment samples) were collected at an interval of 1 m starting from 2 m to the bottom of the wells. The examination of the sediments' characteristics and physical properties was performed. The lithologic logs of both wells were recorded. Generally, wells no. 1 and no. 2 yielded similar Quaternary lithologic characteristics, with quartz, feldspar, and rock fragments as the major composition of this sand layer. Nevertheless, the lithologic logs of well no. 1 and no. 2 (50 m) can primarily be classified into four layers (1 to 4) as follows. The 1st layer is 20 m thick (0–20 m) and contains gray clay with a highly plastic and homogeneous texture. The 2nd layer is about 6 m thick and is present at the depth of 20 to 26 m. It contains pale brown to yellowish brown sandy clay. It consists of 40% sand with fine to medium grain sizes, poorly sorted grains, and sub-angular shapes. The major compositions of the sand are quartz, feldspar, and rock fragments. The rest (60%) is clay with moderate plasticity and heterogeneity. The 3rd layer consists of pale brown to yellowish brown sand occurring at the depth of 27 to 41 m (about 15-m-thick). The sand is characterized by fine-to-medium-size sediments, well-sorted, and sub-angular. Quartz, feldspar, and rock fragments are present as major compositions. The bottom layer, i.e., the 4th layer, is a 9-m-thick clay layer at the depth between 41 to 50 m with moderate plasticity and heterogeneity. Medium sands were also observed in well no.2 with a different in composition, that is, 20% clay and 80% medium, well-sorted, and sub-angular sand at depths of 40 to 48 m.

3.2. Operation and Data Acquisition

Subsurface temperature data gathered from four thermistors installed at different depths, i.e., at 8 m, 10 m, 25 m and 50 m were recorded on 15 and 27 May 2014 and on 4, 10, 19, 24 June 2014. The primary results indicate the stability of the subsurface temperature at the same depth for 45 days and a tendency to increase progressively at a greater depth (Table 1 and Figure 6).

Moreover, a data logger was installed in August 2014 in conjunction with thermistors at 1.5 m and 3 m depths. The main objective of the data logger installation is the long-term recording of the subsurface temperature. On average, the subsurface temperatures recorded from May 2014 to September 2016 at all depths showed stable values. However, the temperature at 1.5 m depth displayed high fluctuation, resulting from the atmospheric temperature. Additionally, it was noted that the thermistors at the depths of 10, 25 and 50 m were broken before installing the data logger in August 2014, so no data were recorded after that date.

Table 1. Subsurface temperature measurement at depths of 8, 10, 25 and 50 m in 6 days measurement (short-time measurements).

Date	Time	Subsurface Temperature (°C)			
		8 m	10 m	25 m	50 m
15 May 2014	10.00 a.m.	29.6	29.6	30.0	30.5
27 May 2014	10.00 a.m	29.7	29.8	29.9	30.7
4 June 2014	10.36 a.m.	29.7	29.7	29.8	30.7
10 June 2014	10.05 a.m.	29.8	29.7	29.9	30.7
19 June 2014	10.00 a.m.	29.7	29.8	30.0	30.7
24 June 2014	10.00 a.m.	29.8	29.8	30.0	30.7

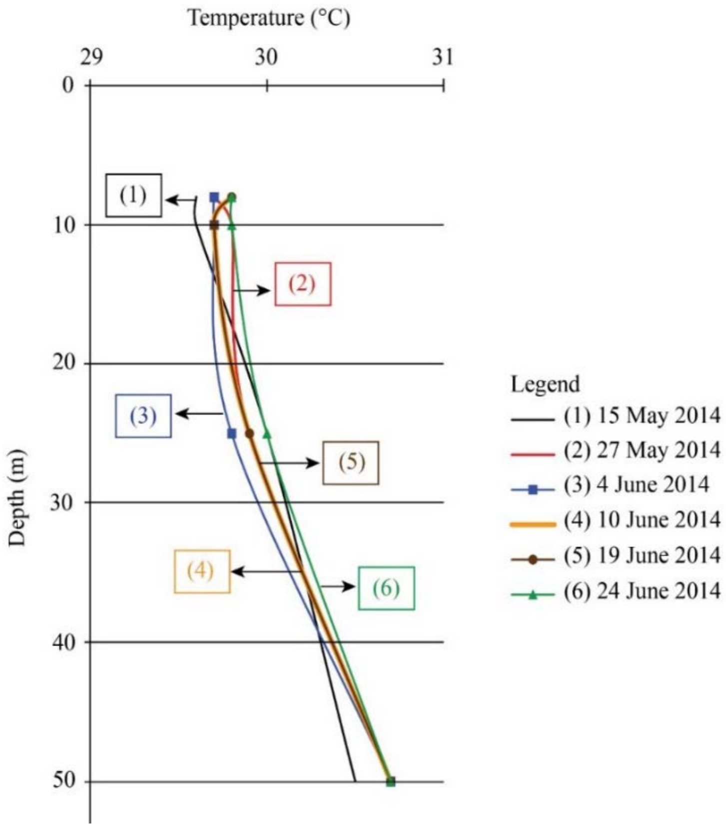

Figure 6. Temperature profiles of the observation well no. 1 and no. 2 at depths of 8, 10, 25 and 50 m at the Parot Racha Building, Chulalongkorn University. Noted that the data logger was installed in August 2014 together with thermistor at depth of 1.5 m (thermistor no. 2) and 3 m (thermistor no. 3). However thermistors at depths of 10, 25 and 50 m were broken so they were not able to use after that.

Long-term comparisons between outside air and subsurface temperatures were performed, and the values were averaged monthly. In terms of maximum temperatures, the highest monthly averaged atmospheric value was 34.6 °C in April 2016 and the lowest monthly averaged atmospheric value was 28.6 °C in December 2014. In terms of minimum temperatures, the highest monthly averaged atmospheric value was 30.9 °C in May 2015 and the lowest monthly average atmospheric value was 24.9 °C in January 2015 (Figure 7). The subsurface temperatures appeared more stable within the approximate range of 29 to 30 °C. Moreover, the subsurface temperatures were lower than the monthly mean maximum of the outside air temperatures almost throughout the year (Figure 7).

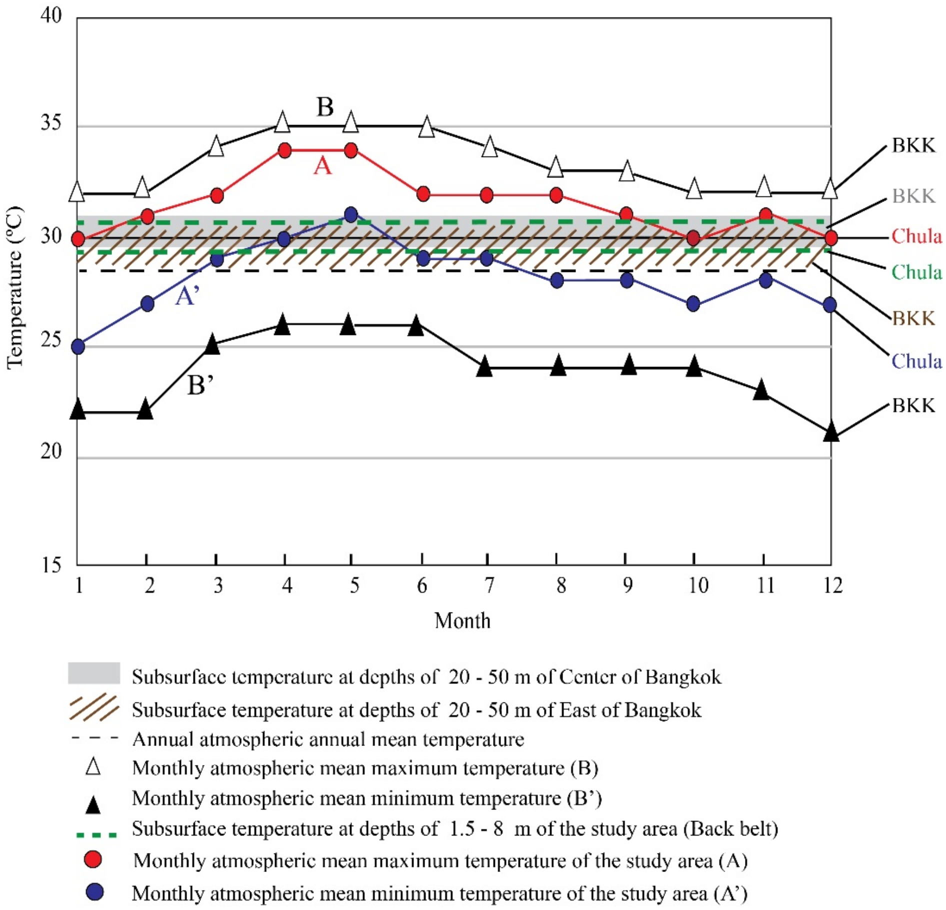

Figure 7. Comparison of atmospheric and subsurface temperatures of Bangkok area (modified after Yasukawa et al. [21]) and this study.

The room temperature set on the GHP air conditioner (GHP) and the normal air conditioner (AC) was 25 °C, and temperature data were recorded (Figure 8). The long-term record was conducted from June 2015 to September 2016. In the long-term measurement, the average room temperatures recorded using the GHP and normal air conditioners (AC) were 24.9 °C and 24.5 °C, respectively. Based on the thermodynamic sense, this result shows that GHP unit has significantly greater efficiency (degree change per unit of energy consumed) (Figure 8). The operation time was generally from 9:00 to 16:00, which was the base period for data averaging.

In addition, the inlet and outlet liquid temperatures of the underground circulation piping unit of the GHP air conditioner were recorded at the thermistors. The inlet fluid was cooled in the underground towards the GHP and the outlet fluid while moving from the GHP. The highest average inlet liquid temperature was 34.2 °C in April 2016 and the lowest average inlet liquid temperature was 30.1 °C in December 2015. Besides, the highest average outlet liquid temperature was 36.0 °C in April 2016 and the lowest average outlet liquid temperature was 31.6 °C in October and December 2015.

The flow rates of the GHP air conditioner were recorded during operation each month. On average, the highest flow rate was 24.0 L/min, recorded in April 2016 and the lowest flow rate was 9.5 L/min recorded in December 2015. All data gathered in each month showed that the highest average flow rate normally corresponded to the highest inlet and outlet liquid temperatures. On the other hand, the lowest average flow rate corresponded to the lowest inlet and outlet liquid temperatures. This phenomenon is due to the inverter operation of the GHP machine.

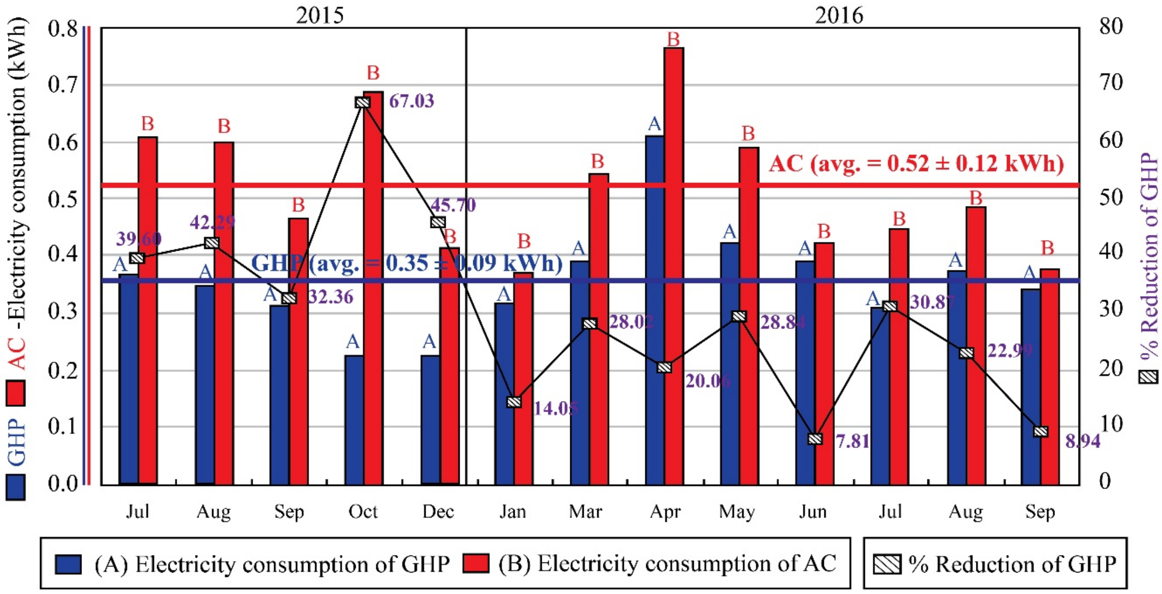

Figure 8. The comparison of electricity consumption of GHP- and normal air-conditioners (AC) when operating at 25 °C in a long-term measurement (July 2015 to September 2016) at the experimental room, Parot Racha Building, Chulalongkorn University.

Room humidity data were recorded monthly in the experimental room during operation. On average, the highest average humidity was 72.2%, recorded in October 2015 and the lowest average humidity was 45.9%, recorded in April 2016. It is inferred that humidity depends essentially on seasonal variations. Moreover, in this research, we measured only in-room humidity when the GHP and AC were operating. According to *t*-test result, it showed that the averages of humidity between the day that GHP and normal air-conditioner (AC) were operated, were not significantly different ($p < 0.05$).

3.3. Electricity Consumption

Electricity consumption can be divided into two parts: the electricity consumption of the GHP and that of the normal air conditioner (AC). The electricity consumption of the GHP in kWh at 25 °C was averaged each month (Figure 9). The highest electricity consumption by the GHP was 0.61 kWh, recorded in April 2016 and the lowest electricity consumption was 0.22 kWh, recorded in December 2015. The average electricity consumption of the GHP was 0.35 kWh. In the long-term analysis, the electricity consumption of the GHP air conditioner and the average flow rate were determined from the data recorded at 25 °C in individual months. The results showed that the highest average flow rate yielded the highest electricity consumption. In contrast, the lowest average flow rate yielded the lowest electricity consumption. The electricity consumption of the normal air conditioner (AC) was recorded each month in kWh at 25 °C. The highest electricity consumption of the AC was to 0.76 kWh, recorded in April 2016, and the lowest electricity consumption was 0.37 kWh, recorded in January 2015 and September 2016. Additionally, the average electricity consumption of the AC was 0.52 kWh.

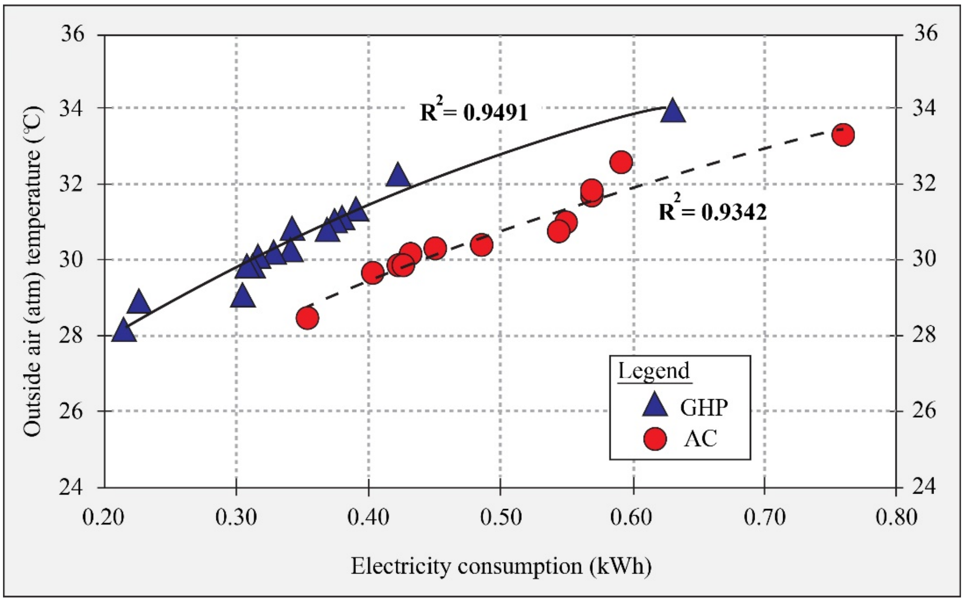

Figure 9. Comparison of electricity consumption and outside air temperatures (ATM) when operating at 25 °C in long-term measurement (July 2015 to September 2016) at the experimental room, Parot Racha Building, Chulalongkorn University.

A comparison was made for the GHP and the normal air conditioner (AC). The parameters in the formula below were expressed in kWh at 25 °C for both air conditioners. The electricity consumption from both air conditioners was recorded.

The formula to determine the reduction of electricity consumption by the GHP is represented in Equation (1):

$$\text{Reduction of electricity consumption} = 100 - \frac{\text{Electricity consumption of GHP} \times 100}{\text{Electricity consumption of AC}} \quad (1)$$

The highest reduction in electricity consumption using GHP was about 67.03%, which was recorded in October 2015 while the lowest reduction in electricity consumption was 7.81%, recorded in June 2016. The result indicates that the GHP and normal air conditioners consumed an average electricity of about 0.35 and 0.52 kWh, respectively. Therefore, on average, the GHP could allow about a 30% reduction of electricity consumption.

The average of two population groups can be statistically compared by the *t*-Test method. The statistical *t*-Test can be applied if there are less than 30 samples in each sample set. In general, the statistical *t*-Test includes two methods: the independent *t*-Test and the paired *t*-Test [26]. In the analysis, the samples in each set were randomized independently and were not controlled by other factors possible to affect the dependent variables. Therefore, these conditions were appropriate for the application of the independent *t*-Test method.

4. Discussion

4.1. Comparisons between Subsurface Temperatures and Outside Air Temperatures

The subsurface temperatures of our experimental site appeared stable within the approximate range of 29 to 30 °C. Moreover, the subsurface temperatures were lower than the monthly mean maximum outside air temperatures almost throughout the year (Figure 7).

As shown in Figure 4, we selected six temperature observation well locations around Bangkok (Lower Chao Phraya Basin) to compare the lithostratigraphy of Bangkok with that reported by the Department of Groundwater Resources (DGR). A total of six logs including the Central part of Bangkok

(T-BKP and T-PW logs), the Eastern part of Bangkok (T-LLK and T-LKB logs), and the Western part of Bangkok (T-BKT and T-BY logs) were collected. On the basis of the temperatures of these observation wells around the Lower Chao Phraya Basin, the obtained subsurface temperature can be grouped in to three areas including the central part of Bangkok, the eastern part of Bangkok, and the western part of Bangkok. The data of western Bangkok, recorded at 54 to 80 m depth in the T-BKT log, showed that the subsurface temperatures were within the ranges of 29.7 to 30.7 °C and became higher at a greater depth. At 30 to 80 m depth, the subsurface temperature of the T-BY log was in the range of 29.6 to 31.0 °C and gently increased with the depth. In eastern Bangkok, T-LLK was at a temperature in the range of 29.8 to 30.7 °C at the depth of 56 to 80 m, and T-LKB was at a temperature in the range of 28.9 to 30.3 °C at the depth of 14 to 80 m. Both T-LLK and T-LKB showed a moderate increase in the temperature with a greater vertical depth. In the Central Bangkok, the T-BKP log recorded a subsurface temperature of 30.2 to 31.3 °C at the depth of 38 to 80 m, and the T-PW log displayed a subsurface temperature in the range of 29.2 to 30.8 °C at 42 to 76 m depth. The subsurface temperatures of both logs rose gradually.

In eastern Bangkok, the subsurface temperatures were sparsely about 1 °C higher, maybe because of the effect of the groundwater flow [27,28]. Consequently, the GHP exploited the groundwater temperature to provide space heating and cooling for efficient energy use [29]. Similarly, Galgaro et al. [30] found that in areas where the subsurface temperature is higher than the normal air temperature, the subsoil is considered to be the energy source, and GHP systems are used in heating-mode efficiently.

From the foregoing description, GHP system installation is presumably more effective in the western and the eastern part of Bangkok than in the central part of Bangkok. According to the comparison between the subsurface and the outside air temperature in this study, the subsurface temperatures appeared to be constant throughout the year of 2014–2016. Considering the underground data, we will start to select suitable locations to install GHP system.

4.2. Suitable Depth for Heat Exchange Wells

As shown in Figure 2, the first layer from the ground surface is Bangkok clay at the depth of 0 to 20 m. The second layer comprises sandy clay at the depth of 19 to 30 m from the ground surface, while sandy clay is located between 20 and 29 m depth. Furthermore, in the vicinity, clay at the depth of 30 to 41 m was observed in another study, whereas it was absent in this study. The possible explanation of this difference is that in the past sedimentation seems to have occurred according to the characteristic of convex or concave lenses. The third layer is a sand layer. This sand layer is located at the depth of 23 to 41 m, whereas, in the vicinity, the sedimentation is around 41 to 49 m. It is possible that this is the effect of the convex or concave lens overlaying on the top. Also, this can have a negative effect on the GHP system because this system needs to exploit the groundwater to cool the heat flowing through the sand layer. Hence, if sand layer is present in deep layers, drilling must be conducted deeper as well. The groundwater utilized in this study is located in the first confined aquifer (Bangkok aquifer) at a depth around 25 to 50 m. A simple selection of a GHP well depth is based on the groundwater level related to hydrogeological units. However, factors as water flow rates, temperatures, costs, etc. have also to be considered to construct a potential map for GHP installment in the very near future.

4.3. Factors of Energy Saving

4.3.1. Outside Air Temperatures

It is clear, as shown in Figure 10, that higher outside air temperatures can significantly induce a higher electricity consumption. Notably, the electricity consumption of the normal air conditioner and of the GHP was compared, and this study concluded that the electricity consumption of the GHP was lower because the GHP system exchanged the heat of flowing water with the lower and stable subsurface temperature, while the normal air conditioner used the outside air temperatures to reduce the heat, which are influenced by the daily fluctuations of the weather. Consequently, the main affecting factor for both systems is the outside air temperatures, that is, the warmer the outside air temperature, the higher the electricity consumption.

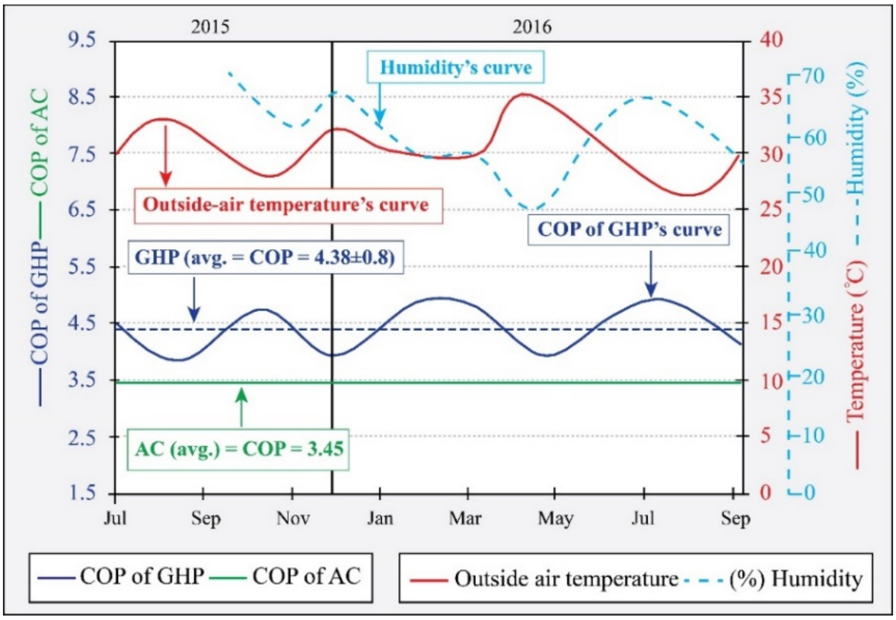

Figure 10. The comparison between COP value of GHP, AC and outside air temperature (ATM) when operating at 25 °C in long-term measurement (July 2015 to October 2016) and the comparison between value of COP of GHP and humidity when operating at 25 °C in long-term measurement (October 2015 to September 2016) at Parot Racha Building, Chulalongkorn University.

4.3.2. Humidity

As mentioned in the previous section, the outside air temperature is one of the important factors that influence the energy-saving performance of both the GHP and the normal air conditioner. However, humidity showed a clear tendency in the cooling operation from April 2016, being high for low outside temperatures and low for high outside temperatures (Figure 10). This tendency can be explained by the fact that the high-power operation to reduce the day high temperatures reduced both room temperature and humidity. The operation in low-temperature days caused the opposite phenomenon. We need further observations to evaluate the contribution of humidity.

4.4. Coefficient of Performance (COP)

The coefficient of performance (COP) is the performance of the cooling system, measured as the heat output (kWh) and divided by the electrical input (kWh). In the case of our system, the true heat output cannot be defined.

Then, a rough COP can be determined according to the definition below [31] in Equation (2):

$$\begin{aligned} \text{COP} &= \frac{Cooling\ capacity}{Power\ input} \\ &= \frac{Q_H - W}{W} \end{aligned} \tag{2}$$

where:

Q_H refers to heat transferred to the ground (kW);

W refers to the heat output or total electricity consumption = E_E (kWh);

Q_H is calculated from the flow rate of the circulation fluid, fluid density and specific heat, and fluid temperature difference of inlet and outlet.

In contrast, in this study, the electricity consumption is the total daily consumption, so the COP of GHP in the real time cannot be calculated. For this reason, we calculated the daily COP value by averaging the whole 20 min data. The calculated day average was in the range from 4 to 5 (long-term average was 4.38), as shown in Figure 10. For COP of the normal air conditioner (AC) it was 3.45, as shown in the EER (the energy efficiency ratio) value that is indicated in the manual book. It was also different from true COP, but useful for performance evaluation. In conclusion, the COP of the GHP was higher than that of the AC. Generally, the coefficient of performance (COP) of the GHP system was between 3 and 4, which is approx. 20–30% higher than that of the conventional air conditioner which generally uses an air source system [32–34]. Since the manufacturer's manual for determining an EER sets a certain condition which usually gives overly optimistic value for COP of their air-conditioner, the real advantage of GHP could be higher than this calculation results.

Moreover, we found that the average COP of GHP in this study is approximately 4.38 with a standard deviation of 0.80 during the monitoring periods from July 2015 to September 2016. However, the main factor on the GHP's COP seemed to be affected from the ambient temperature and humidity variations (see Figure 10). Moreover, as compared the temperature during the GHP operation at depth of 1.5 and 8 m between August 2015 and August 2016, the temperatures were not significantly different ($p < 0.05$). As mentioned, this implies that the warming of the soil due to the heat rejected into the ground does not decline the GHP's COP.

4.5. Interpretation of the Results and Importance of This Study

This study shows that the GHP system is not only useful for energy savings but also for the reduction of urban heat islands [21], which are a serious problem in metropolitan cities in Asia. In addition, energy savings in tropical region is very important because most of the cities in which significant energy consumption is expected in the 21st century are located in tropical or semi-tropical regions of the world, especially in Asia. Energy saving in these areas has a quite large impact on the world environment. Thus, the impact of this study is not regional but worldwide.

5. Conclusions

A vertical loop geothermal heat pump system (GHP) was installed in an experimental room at Chulalongkorn University and equipped with two drilled holes (of a total length of about 170 m) to evaluate electricity reduction. Long-term operation and geological data from the heat exchanger wells were obtained and compared with existing information. According to previous and our results, the average outside air temperature (ATM) were about 30.5 °C and the underground temperatures were about 29–30 °C at the depth of 0 to 50 m. It was also found that these underground temperatures have been quite consistent for almost the two whole years and invariably lower than the average outside air temperatures. Therefore, a range of underground temperatures of the whole Bangkok area are similar to those of our experimental site, although the data are relatively limited at present. On the basis of our results, it is apparent that GHP for cooling should be used widely in tropical areas in the world.

(1) The suitable depth of GHP piping should be lower than that of the water table (25 to 50 m in eastern Bangkok, 30 to 50 m in the western part of Bangkok, and 25 to 30 m in central Bangkok). However, for the actual site selection other factors must be considered.
(2) The underground temperatures of Bangkok area range between 29 to 31 °C at the depth of 0 to 50 m. These temperatures are 1 to 1.5 °C different depending on the location. Our GHP experiment indicates good electricity saving even when the site is located on a relatively high underground temperature area.
(3) A comparison was made between the GHP and the normal air conditioner (AC) in the same room with similar specifications, and it was found that the electricity consumption was reduced by about 30% when using of the GHP system.
(4) The electricity consumption showed clear a relation to the atmospheric temperature, namely, high electric consumption was recorded in high-temperature days and vice versa. The COP

was in the range between 6.7 and 2.3 with an average of 4.38 showed also the same tendency. For humidity, we could not directly show relation with the power consumption of the cooling system.

(5) The inlet and outlet temperature was 34.2 °C and 36.0 °C in April 2015. Even with such high temperatures of the circulating cooling water, the energy saving was very good. It is further recommended that the horizontal-loop GHP system should be compared with the vertical-loop system.

(6) In economic point of view, the installation cost of GHP system was higher than normal air conditioner. There was an advantage of GHP system after operating for 14 years [35].

(7) In the future research, it would be interesting to perform a building model validation for precise prediction of energy saving in building [36].

Author Contributions: Perspective, I.T. and Y.U.; Methodology, S.C. (Sasimook Chokchai), S.C. (Srilert Chotpantarat), I.T., Y.U. and P.C.; Analysis, S.C. (Sasimook Chokchai), S.C. (Srilert Chotpantarat), I.T., and A.W.; Investigation, S.C. (Sasimook Chokchai); Resources, K.Y.; Writing-Original Draft Preparation, S.C. (Sasimook Chokchai); Writing-Review & Editing, I.T., S.C. (Srilert Chotpantarat), and P.C.; Supervision, S.C. (Srilert Chotpantarat) and P.C.; Project Administration, S.C. (Srilert Chotpantarat) and P.C.

Funding: This research was funded by the Food and Water Cluster, Ratchadaphiseksomphot Endowment Fund of Chulalongkorn University, National Research University Project, Office of Higher Education Commission grant number NRU59-052-EN & WCU-58-017-EN and the S&T Postgraduate Education and Research Development Office (PERDO) for the financial support of the Research Program.

Acknowledgments: The author gives sincerely thanks to Stapana Kongsen for providing language help. A special thank also goes to the Department of Groundwater Resources (DGR) for providing all the subsurface data.

Conflicts of Interest: The authors declare no conflict of interest.

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