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Review

A Review of Ground Source Heat Pump Application for Space Cooling in Southeast Asia

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Abstract: Ground source heat pump (GSHP) systems have been used worldwide in buildings because of their advantages of highly efficient performance in terms of energy and environment for space cooling and heating; however, cooling demand is predominant in tropical climates. This paper reviews of the GSHP systems applications in Southeast Asia; several applications of GSHP in Thailand, Indonesia, Malaysia, Singapore, and Vietnam have been addressed. Experiments were initiated in 2006 in Kamphaengphet; the latest experiment found in the Scopus searching tool is the GSHP simulation in Kuantan in 2019 using EnergyPlus using the ground loop design software. GSHP systems have the potential to be used in Southeast Asia despite the dominance of cooling demand, leading to a thermal imbalance within the subsurface. This imbalance can reduce the performance of the system; however, groundwater flow is considered as a key factor in preventing the effect of thermal distribution owing to GSHP operation. These results suggest that the GSHP has the potential to reduce emissions and electricity consumption within areas having tropical climates, such as Southeast Asia, for sustainability and future generation.

Keywords: energy saving; ground source heat pump; Southeast Asia; space cooling; subsurface temperature; coefficient of performance

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1. Introduction

Climate change disrupts natural systems and decreases the environmental quality [1,2]. Natural hazards, such as heatwaves, extreme weather, and food system disruption, influence human health [3] as well as transportation, infrastructure, and global trade [4]. According to the previous report, the CO_2 emissions of Southeast Asian countries increased from 711 MT in 2000 to 1288 MT in 2015; they constitute the world's most developing regions in terms of electricity consumption [5]. Urbanization is generally a crucial factor affecting total energy consumption because the residential sector is considered as the second highest consumer of electricity after the industrial sector [6–8]. Studies have showed that a strong relation exists between gross domestic product growth and electricity demand; therefore, serious actions are required for environmental protection and energy conservation as they are important topics for ensuring sustainability [9,10].

The research field of climate change mitigation has evolved over the last few decades owing to public concern, the development of innovative technology, and improved computational and analytical power for sustainability and future generation [11–13]. Among various energy-saving and environmental-friendly technologies, the ground source heat pump (GSHP) has been widely applied for space cooling and heating in several countries because it can reduce electricity consumption [14–23]. This air-conditioning system transfers heat to/from underground by circulating water to control the room temperature in buildings. The GSHP mainly uses the subsurface as a heat sink or a heat source with its operating system comprising a heat pump, a ground-coupled heat exchanger, and a conditioned air distribution system [24,25]. The GSHP is generally divided into two types: open- and closed-loop systems with multiple possible configurations [26]. The open-loop system uses groundwater or a pond water to exchange heat between an indoor area and subsurface. Typically, existing domestic groundwater wells are used for transferring heat. In addition to the open-loop system, the closed-loop system is installed with buried high-density polyethylene pipes that transfer heat via the circulating fluid. These pipes can generally be buried in narrow boreholes (vertical closed-loop) or trenches (horizontal closed-loop) near a building. Compared with the open-loop system, the closed-loop system is cheaper in terms of operation and maintenance; moreover, the vertical closed-loop system has a lower risk of environmental contamination [27,28].

The GSHP with heat exchange based on temperature difference is suitable for replacing a conventional air conditioner (AC) in summer and a heater in winter [24]. Further, it can be applied in a nearly zero-energy building projects. However, the GSHP is only applied for space cooling in tropical regions owing to their high atmospheric temperatures throughout the year [29,30]. Despite its numerous benefits, the extensive application of the GSHP is still limited to tropical regions. First, there are technical problems with GSHP applications in the Southeast Asian region. The GSHP system is mainly used for space cooling in tropical climates, leading to a thermal imbalance between heat rejection and extraction; this phenomenon may also decrease the efficiency of the system. Temperature differences between the underground areas and the atmosphere are mostly quite small for GSHP application [5,31]; thus, data on GSHP performance in tropical climate conditions are limited. Second, financial and market problems are considered; the initial cost of a GSHP is higher than that of a conventional AC resulting in the absence of a GSHP market in Southeast Asia. Finally, government regulations on renewable energy usage remain limited. However, a subsurface cooling system can still be applied under tropical climates if supplementary measurements are applied to prevent an increase in the ground temperature [32]. The application of GSHP systems in various climate zones was investigated in China [33]. GSHP systems can be used for cooling and heating domestic water in summer and winter, respectively, in China throughout the year. Further, the use of a GSHP coupled with a cooling tower as a supplemental heat rejecter was studied in Greece [34]. The use of the similar type of system can be observed in Hong Kong under a subtropical climate [35–37]. The Renewable Research Center of National Institute of Advanced Industrial Science and Technology, Chulalongkorn University, the Department of Mineral Resources of Thailand, and the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) have set up a team to study the possibility of GSHP application in Southeast Asia in a tropical climate based on these mentioned barriers. This collaboration enables the GSHP performance analysis in high-temperature conditions throughout the year. Notably, the cost of the GSHP was evaluated in comparison with a conventional AC. Moreover, a framework for system optimization was developed to assess the sustainability and the best GSHP application method in Southeast Asia. The information of each experiment was collected using the Scopus search tool with the keywords “ground source heat pump” and the names of countries in Southeast Asia. In this field, from 2006 to 2021, eight articles were found to be published in seven journals in Thailand, Vietnam, Malaysia, Indonesia, and Singapore. Figure 1 presents the locations of the GSHP project.

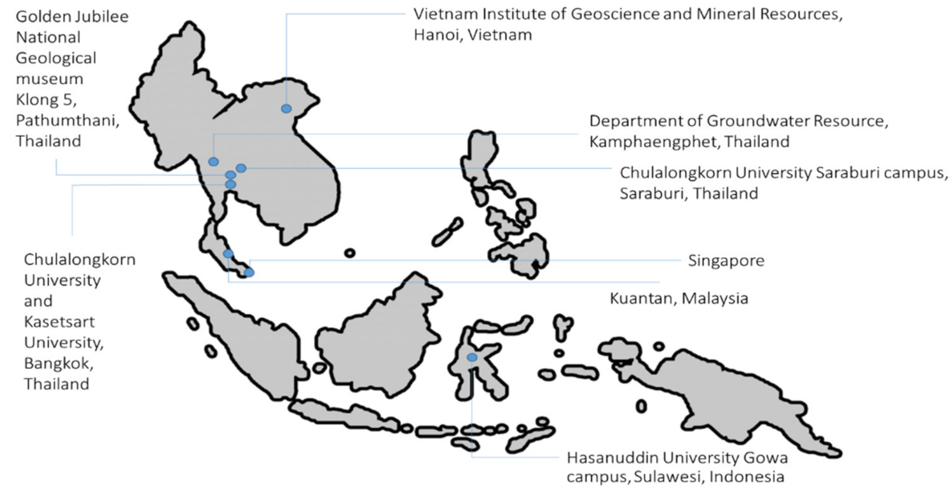

Figure 1. Locations of GSHP experiments within the Southeast Asia countries in a tropical climate.

Currently, GSHP applications have been reported for various purposes in Southeast Asian countries; however, space cooling has not been mentioned or reviewed. Better investigation regarding the potential and performance of such a system is required in tropical regions where operational problems may occur owing to the dominant cooling requirement. To solve these problems, a comprehensive evaluation of GSHP performance under tropical climates is required; therefore, this paper reviews previous studies on GSHP systems in Southeast Asian countries for space cooling. This paper mainly comprises subsurface-temperature surveys and experimental performances of the GSHP system at each study site. Finally, a discussion of the GSHP application is provided in the last section.

2. Subsurface Characteristics and Temperature Survey

Information on groundwater flow and temperature is crucial for GSHP system design because the advective effect caused by groundwater flow can reduce the temperature fluctuation during heat exchange around the borehole, which can decrease the efficiency of the GSHP [38]. Shallow groundwater is dominant in Southeast Asian countries, and thermal conductivity and GSHP performance are largely affected by groundwater flow. The natural subsurface temperature is generally stable at the depth of 20 m throughout the year round and is moderately higher than the annual average atmospheric temperature [39]. The GSHP in tropical regions is advantageous for space cooling and heating because the subsurface temperature is lower than the atmospheric temperature in summer and higher in winter. By contrast, cooling demand is dominant in tropical regions, and the subsurface temperature is equal to or higher than the atmospheric temperature, revealing a disadvantage of GSHP application. Yasukawa and Uchida [40] suggested that applying GSHP in the tropical regions can maximize advective heat transfer owing to groundwater flow in a natural state and during an operational period.

A groundwater survey was conducted throughout the Chao Phraya plain from 2003 to 2005 using observation wells constructed and maintained by the Department of Groundwater Resources (DGR), Thailand [40]; Figure 2 presents the locations of the observation wells. The Chao Phraya plain comprises the lower and upper plains; in addition, groundwater in this region is divided into two systems, with a border at 15°40′ N″ (Nakhon Sawan Province). However, natural groundwater flow, controlled by the topography and subsurface boundaries with permeability changes, may affect the subsurface thermal regime and divide it into recharge and discharge zones. Infiltration at the recharge zone generally disturbs heat transfer vertically, indicating a reduction in the heat transfer from shallow groundwater, whereas precipitation encourages heat transfer vertically at the discharge zone. Therefore, the subsurface temperature at the recharge zone is less than that at the discharge zone at an identical elevation. Subsurface temperatures in Phitsanulok and

Nakhon Sawan Provinces for over four months are less than the monthly average maximum atmospheric temperatures with more than a 5-K difference. Further, the subsurface temperature in Kanchanaburi Province is lower than the monthly mean maximum atmospheric temperature by 4 K over four months with the largest difference of 10 K in April. Therefore, GSHP application for space cooling might be effective in these areas. The GSHP is also useful in Bangkok and Ayutthaya Provinces, where the subsurface temperature is less than the monthly average maximum atmospheric temperature throughout round. However, the difference is small, indicating that although the GSHP performance is not as good as in the previous areas but it is still effective. By contrast, the subsurface temperature in Sukhothai Province is higher than its monthly mean maximum atmospheric temperature; thus, this area is unsuitable for GSHP application.

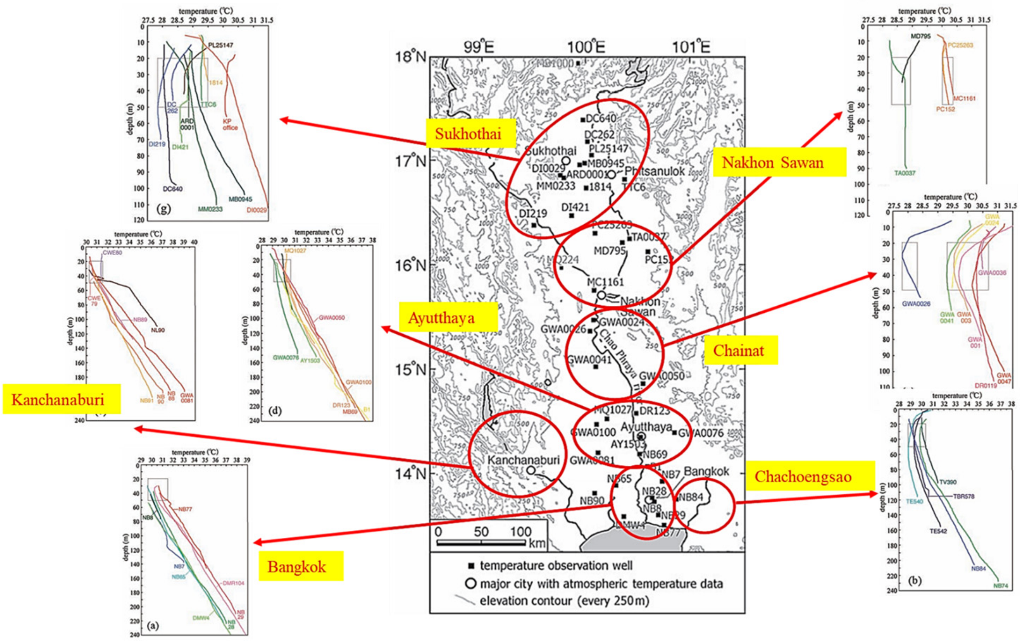

Figure 2. Temperature profiles measured at each observation well around the Chao Phraya Basin (modified based on the report by Yasukawa et al. [40]).

In this case, the average atmospheric temperature was around 30.5 °C, while the mean subsurface temperatures at a 50-m depth were approximately 29–30 °C. The subsurface temperature of this area is considered to be appropriate for the GSHP application in the cooling mode because the average underground temperature is less than the atmospheric temperature throughout the year. Moreover, groundwater flow is observed in the Bangkok aquifer underneath the study area, which is considered as one of the most important factors for subsurface heat transfer; therefore, the GSHP can be operated in the Bangkok aquifer. Notably, heat can be transferred within the sand layer through groundwater flow, which is considered a diagnostic key layer; this layer is found at a depth of 25–50 m.

Further, groundwater temperature was measured in the Red River plain using the observation wells owned by the Department of Geology and Minerals of Vietnam from 2005 to 2006. Results showed that the wells located in the southern part of the plain indicated a higher temperature gradient than those located in Hanoi, revealing that the wells near the sea are in the discharge zone. However, the wells in Hanoi are in the intermediate zone of the groundwater system. Additionally, the subsurface temperature in Hanoi is lower than the monthly average maximum atmospheric temperature from May to October, as shown in Figure 3. This result indicates the potential of GSHP application in the cooling mode in summer.

The result of the subsurface-temperature survey revealed that the probability of GSHP application for space cooling was found at the places in Thailand and Vietnam, where subsurface temperatures was less than the atmospheric temperature. Moreover, three other countries (i.e., Malaysia, Indonesia, and Singapore) have the potential for GSHP application despite the absence of subsurface-temperature measurement in the experiments.

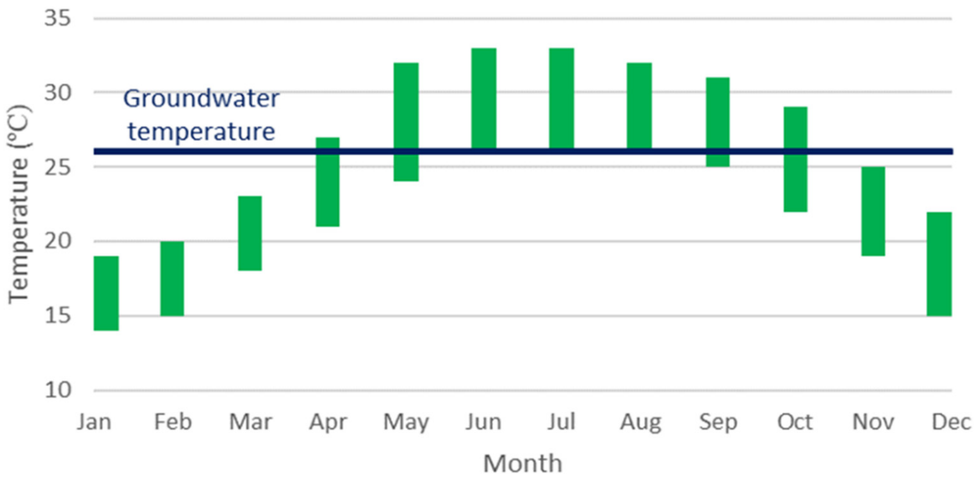

Figure 3. Comparison of atmospheric and subsurface temperatures in Hanoi (modified based on the report by Yasukawa et al. [40]).

3. GSHP Application for Other Purposes

Because the subsurface environment indicates a low temperature for cooling and a high temperature for heating as well as less temperature fluctuation than ambient temperature change, the GSHP is selected as it can achieve higher energy efficiency for air conditioning compared with conventional air-conditioning systems. The GSHP is applied with various systems that use the ground, groundwater, or surface water as a heat source or sink, including ground-coupled, groundwater, and surface water heat pumps [41,42]. Indonesia is reported to have the highest annual AC demand in Southeast Asia (2.3 million units in 2016), followed by Vietnam (1.98 million units), and Thailand (1.56 million units) [43]. However, as shown in Figure 4, geothermal heat pumps have mostly been used for other purposes than space cooling in this region.

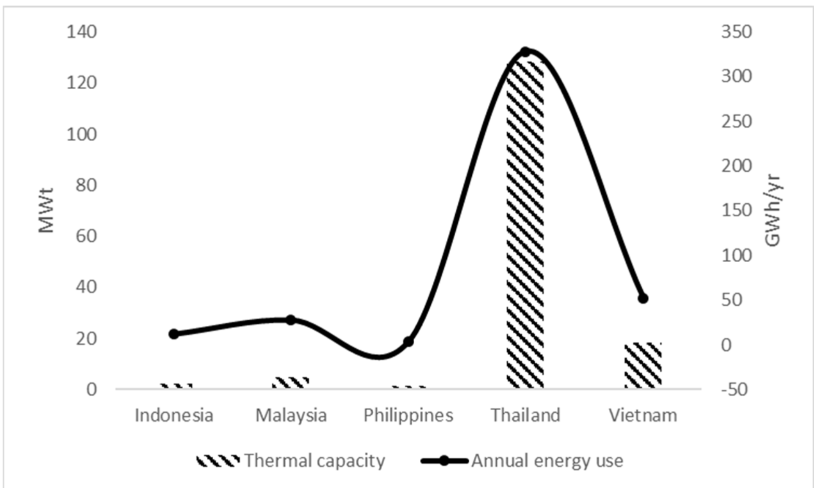

Figure 4. Comparison of thermal capacity and annual energy use in the countries of Southeast Asia.

Natural hot springs in Indonesia have been directly used over the years for several purposes, including the filling for swimming pools, spas, and also for cooking, bathing, washing, fish farming, pasteurizing techniques in mushroom farming, tea leaf and coffee bean weathering, and brown sugar processing [44]. In addition, their indirect use for electricity generation was reported. Currently, power plants with 1948.5-MW-power generated via geothermal energy have been installed; this power is approximately 510 MW more than its installed capacity in 2015 and almost double of that in 2009. The installed geothermal power plants are located in 13 geothermal areas.

In Malaysia, the largest group of hot springs, which originating owing to tectonic rather than volcanic process, possesses at least 15 bathing facilities using natural hot water. They are mainly in the Malaysian Peninsula with one in Sabah Province on the large island of Borneo (Sarawak). A high-temperature geothermal project known as Tawau or Apas Kiri has been identified in Sabah Province. The total thermal energy usage for bathing and swimming is assumed to be approximately 100 TJ/yr and 5MWt [45], respectively.

In the Philippines, the Department of Energy is currently conducting "Philippine Geothermal Resource Inventory and Assessment" project to find geothermal resources for both power generation and direct applications. Therefore, the foot of Mount Makiling in Laguna has been used as a geothermal resource providing hot water to hot spring resorts and pools. Notably, the capacities for direct application, i.e., bathing and swimming, are 12.65 TJ/yr and 1.87 MWt [46].

In Thailand, more than 1800 spring manifestations have been found, with subsurface temperatures of 40°C–100°C. A pilot house was constructed in the Sankamphaeng geothermal field for drying and preserving agricultural products, such as bananas, garlic, chili, maize, and tobacco. A similar drying facility was constructed in the Fang geothermal field using water from an operating power plant [47,48]. Additionally, hot spring baths operated by the private sector and local communities have been very popular in the country. Interestingly, geothermal energy has been directly used for swimming and (127.470 MWt and 1168.898 TJ/yr) and crop drying (0.04 MWt and 0.3 TJ/yr). This gives the country total geothermal energy of 128.510 MWt and 1181.198 TJ/yr [49].

In Vietnam, geothermal sources have been mostly used directly utilization, for example, in bathing, spas, and hot-water swimming pools. However, in the Quynh Phu and Hung Ha districts of Thai Binh province, geothermal energy has been applied for chicken and pig farming in winter and for warm-water fish breeding [50,51]. In conclusion, annual energy consumption values for various forms of direct use and capacity are 185.32 TJ/yr and 17.64 MWt for bathing and swimming, 1.66 TJ/yr and 0.53 MWt for fish farming, and 0.08 TJ/yr and 0.03 MWt for other animal farming.

However, the potential of GSHP application for space cooling has also been investigated in this region. Permchart and Tanatvanit conducted field experiments in Thailand to investigate the potential of GSHP application and payback of the system operation within four years [52]. Moreover, Khedari and Permchart [53] studied the possibility of using ground-couple ACs in Thailand. The major disadvantage in their study was the ground circulation loop, where high-pressure refrigerant directly flowed through the loops of ground circulation. This could reduce the ground-loop lifetime and increase leakage potential, which is difficult to maintain. In Singapore, Bruelisauer and Meggers [54] reviewed potential technologies to replace conventional ACs. They discovered that the conventional technology produced the worst thermal performance, whereas cooling tower using wet-bulb temperature performed the best, followed by the use of a water body as a heat sink, such as a lake or a river, and the GSHP. Moreover, an energy performance evaluation was conducted in Hanoi through five high-story buildings. Interestingly, the air-conditioning systems of these buildings consumed 78% and 38% of the total electricity use in winter and summer, respectively [55]. Thus, this study reviews the previous experiments of the GSHP for space cooling in Southeast Asian countries.

4. Experimental Performance

The results of subsurface-temperature measurements conducted in Thailand and Vietnam indicated that the GSHP cooling mode is probably used across most of the Southeast Asia region, where subsurface-temperatures are lower than atmospheric temperatures.

GSHP systems have been installed in several locations in Southeast Asian countries, where cooling demand is dominant. Some of these GSHP systems were installed in Thailand and operated by Chulalongkorn University at the Saraburi and Bangkok campuses. The heat pump was additionally established in the Geological Museum of Thailand under joint research with the Department of Mineral Resources, Ministry of Natural Resources and Environment of Thailand. These systems are of closed-loop type because they are easier to install and less expensive than the open-loop systems. Table 1 and Figure 1 show the experiments of the GSHP at several locations in Southeast Asia.

Table 1. Experimental sites of GSHP in Southeast Asia in tropical climates (modified after Yasukawa and Uchida [39]).

Locations	Operational Period	Subsurface Heat Exchanger	Average Subsurface Temperature (°C)	Performance	Reference
Kamphaengphet, Thailand	October 2006–March 2008	57-m deep borehole with double U-tube	30.1–30.6	CoP of 3	[56]
Kasetsart University, Bangkok, Thailand	July 2010–2012	200-m horizontal tube	26–29	CoP of 3–4	[57]
Singapore	2013	Simulation mode: 1. Open loop with a cooling tower 2. Open loop without a cooling tower 3. A surface water cooling system	27	Approximately 25% energy saving compared with the conventional AC	[58]
Chulalongkorn University (Bangkok, Thailand)	May 2014–2019	Two 50-m deep borehole with a single U-tubes	29–30	CoP of 3.45	[27,59]
Chulalongkorn University (Saraburi, Thailand)	November 2016–present	300-m carpet style and 300-m coil style	30–32	CoP of 5.53–5.66	[5]
Geology Museum (Pathumthani, Thailand)	March 2015–present	50-m deep borehole with double U-tube × 2 (400 m)	N/A	The average CoP of series-parallel configuration was 2.30; the average CoP of parallel-series configuration was 2.54	[60]
Vietnam Institute of Geosciences and Mineral Resources, VIGMR (Hanoi, Vietnam)	October 2016–present	50-m deep borehole with double U-tube × 2 (400 m)	27.2	CoP of 3.1 for cooling and 3.6 for heating	[60]
Hasanuddin University Gowa campus, Indonesia	2018	3-m deep borehole with shallow spiral-tube ground heat exchanger × 3	27–28	An average heat exchange rate of series configuration was 86.2 W/m, while that of parallel configuration was 122.4 W/m	[61]
Kuantan, Malaysia	2019	Simulated vertical GHE	27.6	CoP of 3.3 achieved via simulation	[62]

4.1. Indonesia

Ground heat exchangers (GHEs) have gained interest owing to their better performance than other types of heat exchangers [63–70]. Each spiral-tube GHE includes a spiral-tube and a straight pipe as inlet and outlet tubes, respectively. Miyara and Tarakka [61] presented their findings from an experimental investigation of the thermal performance of three shallow spiral-tube GHEs installed in a 3-m deep borehole at the Hasanuddin University Gowa campus, Indonesia. All three GHEs were installed at a 1-m depth to prevent atmospheric temperature effects. The average subsurface temperature at a 3-m depth was approximately 27–28 °C. They compared the series and parallel configurations of GHEs based on the heat-exchange rate. Their results demonstrated that the average rate of heat exchange of series configuration was 86.2 W/m with a temperature of inlet and outlet flows of 40 °C and 35.6 °C while that of parallel configuration was 122.4 W/m with inlet and outlet flow temperatures of 41 °C and 37 °C, respectively. Overall, the high heat-exchange rate of the shallow spiral-tube GHE indicates that the application of this GHE type is possible for the cooling mode of the GSHP, especially in tropical climates.

4.2. Malaysia

The potential of vertical GSHP installation was assessed in ten cities in tropical and subtropical climates, including Kuantan, Malaysia, via EnergyPlus and the ground loop design software packages for a 30-year operation [62]. Results suggested that GSHP might not be an economically suitable alternative for areas with tropical climates, such as Kuantan, owing to inefficient performance and high cooling demand; however, a coefficient of performance (CoP) of 3.3 was achieved through this simulation. Subsurface temperature is one of the factors affecting the performance of GSHP systems; the subsurface temperature of this study area was 27.6 °C [71–73]. Interestingly, the cost of borehole installation in this area is higher than that in other countries because of its low ground thermal conductivity (1.1 W/m°C). Notably, the performance and possibility of GSHP application depend on several other factors, such as geological conditions, groundwater conditions, operating duration, pattern usage, and heat-pump information, which are not specifically investigated in the aforementioned assessment.

4.3. Singapore

The government of Singapore has a sustainable development plan using a Sustainable Development Blueprint [74]; this plan aims to improve resource utilization efficiency and the urban environment. The GSHP system is required to achieve the aforementioned goals because this system uses renewable and clean energy resources to reduce energy consumption and pollution emissions. Hence, the study by Liu and Qin [58] indicated the investigation of the potential application of the GSHP in Singapore with three heat-rejection modes. Modes 1 and 2 refer to the open-loop groundwater cooling systems with and the system without a cooling tower, respectively, while Mode 3 involves a surface water cooling system. Several successful examples of using Modes 2 and 3 have been demonstrated for other countries [75,76]. However, these two modes were used only for cooling in this study. Notably, the groundwater temperature was considerably higher than that in other study areas [77]. The water consumption, thermal effects, and economic benefits were theoretically evaluated using the software EnergyPlus. Notably, the groundwater level was assumed to be 10 to 30 m in an unconfined aquifer with a thickness of 30 m. In Singapore, the shallow subsurface temperature is approximately 27 °C, which is close to the average air temperature [78]. The result showed that all the three proposed modes of GSHP application demonstrated better performance than a conventional air-conditioning system in the country. Modes 2 and 3 were more economical than Mode 1, with minimal water and electricity consumption; however, they highly depend on geotechnical conditions. Mode 1 may be the superior choice for the places with insufficient groundwater and lack of available surface water.

4.4. Thailand

The use of energy-efficient products is an important way to reduce CO_2 emissions. However, the price of such products, e.g., five-star-rated ACs, is still higher than that of regular products [79,80]. Among various alternative clean technologies, four experimental sites of GSHP installation have been investigated in Thailand. Vertical and horizontal closed-loop systems were found within the Chao Phraya plain owing to the potential of GSHP application in this area. Details of each study area are described in the following subsections.

4.4.1. Bangkok Province

A vertical-loop GSHP was installed and connected to an experimental room with dimensions of $3 \times 4.75 \times 3.5$ m^3 on the second floor of the Parot Racha building, Chulalongkorn University, as shown in Figure 5 [27,59]. The system included two 50-m deep boreholes with a single U-tube. The GSHP was operated from May 2014 to 2019 in a cooling mode optimized with inverter control. In this case, the average atmospheric temperature was around 30.5 °C, while the subsurface temperature at 50-m depth was approximately 29–30 °C. In addition, the underground temperatures remained consistent throughout the study period, which was over two years, and the underground temperatures were lower than the average atmospheric temperature during the operational period. The vertical GSHP was compared with a conventional AC under similar conditions. The room temperature was set as 25 °C on GSHP and a normal air conditioner, and the electricity consumption data were recorded as shown in Figure 6. The results showed that the average electricity consumption reduction was approximately 30% owing to the application of the GSHP system. The highest recorded reduction was approximately 67.03% in October 2015, whereas the lowest recorded reduction was 7.81% in June 2016. Interestingly, humidity also plays an important role in energy saving; the atmospheric temperature and humidity were low in October 2015, leading to low electricity demand for the GSHP and causing high energy reduction. By contrast, a low atmospheric temperature was observed in June 2016, while the humidity was high, leading to reduced energy savings. The average electricity consumption of the GSHP and the conventional AC were 0.35 and 0.52 kWh, respectively. Additionally, the CoP of the AC was 3.45; however, the Cop of the GSHP was generally between 3 and 4, which is approximately 20%–30% higher as shown in Figure 7 [81–83].

According to Chokchai et al. [27], high atmospheric temperature can cause high electricity consumption. The GSHP consumed less electricity compared with the conventional AC because of the small temperature difference between stable subsurface temperature and the temperature of the experimental room, while the AC exchanged heat between the room and the atmosphere, causing a larger temperature difference owing to weather fluctuation. Overall, the heat sink temperature is the main factor affecting AC systems; a high atmospheric temperature leads to additional electricity consumption. The GSHP system saves energy and reduces urban heat islands [40]. These serious problems are observed in metropolitan cities in most Asian countries. Moreover, energy saving in tropical regions is crucial because it provides considerable environmental benefits. Notably, the Parot Racha building, Chulalongkorn University, is located in the central part of Bangkok Province. Interestingly, this study discovered that the western and eastern parts of Bangkok Province can provide effective performance conditions for GSHP application owing to the thinner sand layers and slightly higher subsurface temperature in the central part. As previously mentioned, the GSHP must transfer heat through the groundwater and send it to surrounding environment via the sand layer [84–86]; therefore, if the sand layer exists in a deeper layer, deep drilling must be conducted. This issue should also be considered for GSHP installation in other locations.

Another experimental site was discovered at Kasetsart University. The GSHP in this location was coupled with a heat exchanger pipe system arranged in a horizontal loop [57]. The results showed that the GSHP in the study consumed approximately 600 W/h of electricity with a CoP of 3–4, demonstrating the possibility of using this system in the experimental site.

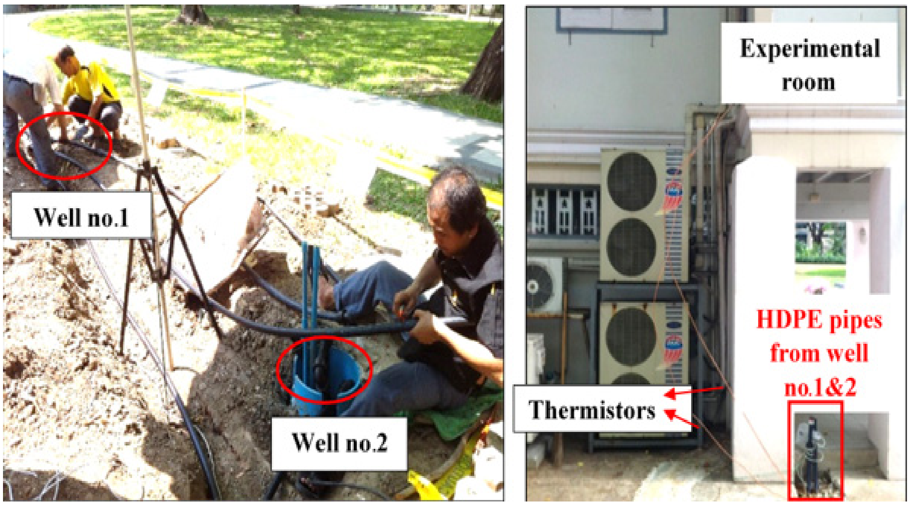

Figure 5. Installation of the GSHP connected to the second floor of the Parot Racha building, Bangkok, Thailand (obtained from the report by Chokchai et al. [27]).

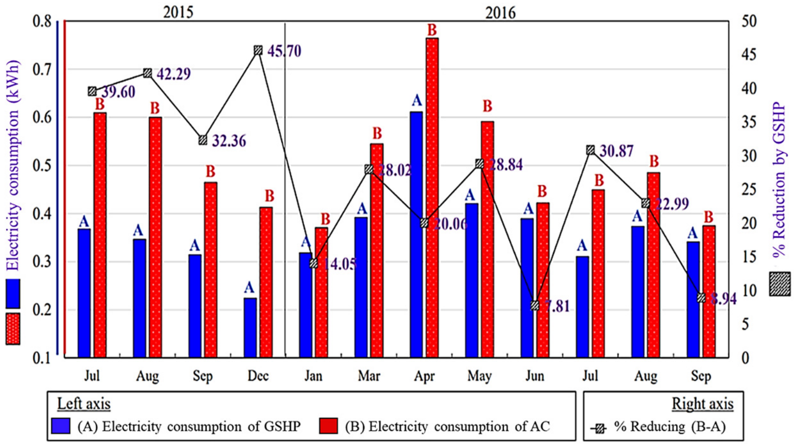

Figure 6. Electricity consumption comparison between the GSHP and the conventional AC when operating at 25 °C recorded from July 2015 to September 2016 in the experimental room (obtained from the report by Chokchai et al. [27]).

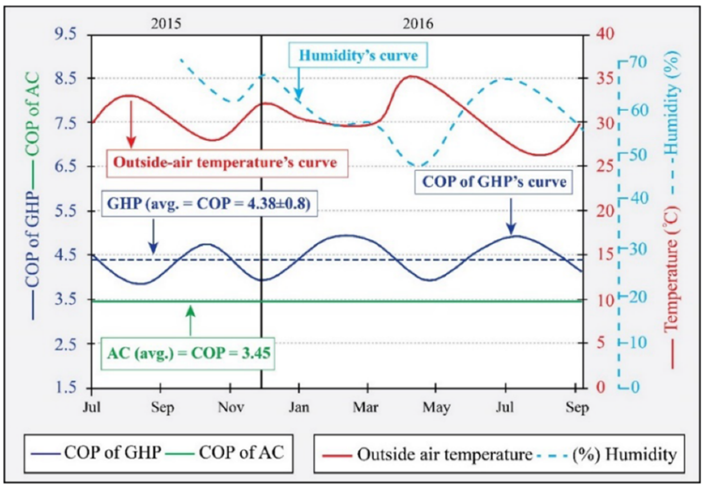

Figure 7. Comparison of the CoP values between the GSHP and conventional AC after one year of operation at 25 °C (July 2015 to September 2016) (obtained from the report by Chokchai et al. [27]).

4.4.2. Kamphaengphet Province

In 2006, an experimental GSHP was installed in the DGR (Department of Groundwater Resource of Thailand) building for space cooling in Kamphaengphet Province and was used for 17 months till March 2008 [56,87]. The heat-energy storage, of approximately 40 W/m, was simulated using a numerical solution to define the thermal influence of such a GSHP operation on space cooling [88]. Some parameters are ascertained from previous model studies [89,90]. Notably, the subsurface layers of this location are clayey and sandy. With the proper setting of operation, the room temperature was maintained at 23–28 °C, while the outside temperature was 30–35 °C during the operational period. The temperature changes at several points (i.e., boreholes and surrounding, heat-pump inlet and outlet, room, and atmosphere) and electricity consumption were measured in this experiment to assess the performance of the GSHP. The results of this experiment are summarized as follows.

- 85% of the temperature increase in borehole heat exchangers due to the operation was recovered within 10 days after the operation was stopped.
- Subsurface temperature did not increase considerably over a year of operation.
- A suitable setting for heat-pump operation was required for an effective cooling operation and for electricity consumption reduction (around 0.6 kW). The difference between the minimum and maximum temperatures of the inlet fluid should not be larger than 5 K. Additionally, the recommended minimum setting temperature should not be less than 14 °C.
- CoP value for the stable operation period was approximately 3. The stable operation may continue if the heat-exchange rate is not above 80 W/m.

4.4.3. Pathumthani Province

The study area is located at the Golden Jubilee National Geological Museum Klong 5 in Pathumthani Province, which is 50 km away from Bangkok and is situated in the lower Chao Phraya Basin with a relatively flat topography and 1–5-m above the mean sea level. The GSHP system was installed in March 2016 at a souvenir shop with two 50-m borehole heat exchangers and a double U-tube configuration [60]. Initially, such an installation was called a parallel–series configuration, where two boreholes were connected in parallel, while a double U-tube was connected in series. The heat-exchange fluid was divided into two lines of flow, with each line passing through every borehole twice in a parallel–series configuration. Then, the systems were adjusted in March 2019, which is now called the series–parallel configuration; two boreholes are currently connected in series, whereas the double U-tube is different. The heat-exchange fluid was divided as per two flows and went through both boreholes in each parallel flow, as shown in Figure 8. This rearrangement determines the most appropriate piping configuration for the system in Pathumthani Province.

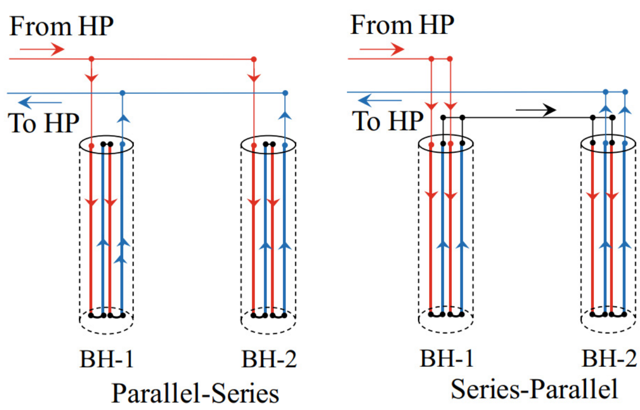

Figure 8. Configurations of heat exchangers in the National Geological Museum in Pathumthani Province, Thailand (modified based on the report by Widiatmojo et al. [60]).

The parallel–series configuration generally provided a high CoP with an average difference of 0.3, thus yielding improved thermal performance. The mean CoP of the series–parallel configuration was 2.30, indicating that it was 9.40% lower than that of the parallel–series configuration. Moreover, the average temperature difference between the inlet and outlet fluids of the series–parallel configuration was 2.44 °C, which was lower than that of the other configuration. Overall, a low CoP corresponds to a reduction in the temperature difference. Therefore, the parallel–series configuration is considered the most suitable configuration for the GSHP system based on a short-term evaluation.

4.4.4. Saraburi Province

Widiatmojo et al. [5] studied the application of the shallow horizontal GSHP in Saraburi Province and performed a performance comparison between the two GSHPs and the AC based on a two-month experiment. This type of GSHP has been considered in several studies because it requires only shallow trenches, resulting in relatively inexpensive cost [91–96]. GSHP 1 was imported from Japan with a reversible function between the cooling and heating modes, whereas GSHP 2 was the AC modified using a plate heat exchanger (Kaori-K050 × 22, 7.03 kW); in GSHP 2 operation, R410A refrigerant fluid was used as the heat exchange media via ground-loop-circulation. Moreover, GSHP 1 and 2 were connected in series to the ground heat exchanger.

The results showed that GSHPs consumed less electricity than the conventional AC during summer. GSHP 1 could reduce 17.1% of electricity consumption, while GSHP 2 could reduce the electricity consumption by 18.4% compared with the conventional AC; the emission of CO_2 could also be reduced at the same rate. Additionally, the CoP provided by GSHP 2 (CoP = 5.66) was higher than those of GSHP 1 (CoP = 5.53) and the AC (CoP = 4.79). Notably, GSHP 2 achieved a smaller electricity consumption reduction during the low-temperature period compared with that during the higher-temperature period. However, GSHP 1 indicated a drastic electricity consumption reduction in the low-temperature season. This result is achieved owing to the inverter, which controls the rate of the compressor motor during low thermal load during the low-temperature period, for regulating the temperature continuously. Moreover, for a two-month GSHP operation, the rise of the daily final inlet temperature was not observed after 37 days of GSHP operation. Therefore, the background temperature was unaffected by the long-term operation of these systems after the experiment; inlet and outlet temperature fluctuations during GSHP operation were caused by variations in atmospheric temperatures, leading to different cooling loads.

The subsurface temperature is a crucial factor that affects the GSHP performance. The variation in the underground temperature is due to the heat transfer from the surrounding environment and heat exchangers [97–99]. Three underground temperature sensors were set up in the area of this study [5]. Sensors A and B were installed in a single borehole at 0.7- and 1.5-m depth, respectively, as indicated in Figure 9; both sensors were positioned near the heat exchanger and operated with a 60-min sampling interval. By contrast, sensor C was installed at 1-m depth and 20 m away from the heat exchangers for measuring the background temperature. The results showed that all sensors could record temperature fluctuations with an average subsurface temperature of 31 °C. Sensor A provided a sharp fluctuation pattern owing to a subsurface temperature increase followed by a temperature drop during the operational period. Additionally, the subsurface-temperature fluctuation at the 1-m depth was caused by the daily atmospheric temperature variations, displayed by sensor B. However, the minimal fluctuation was indicated by sensor C because it was positioned further away from the heat exchanger. The temperature pattern recorded by sensor B was attributed to the intermittent use of GSHP systems and the conventional AC, providing sufficient time for recovering subsurface temperature and preventing the temperature increase, reducing the efficiency of GSHP systems. Overall, the intermittent use of GSHP systems with the conventional AC could provide better thermal performance than the operations performed using only the GSHP.

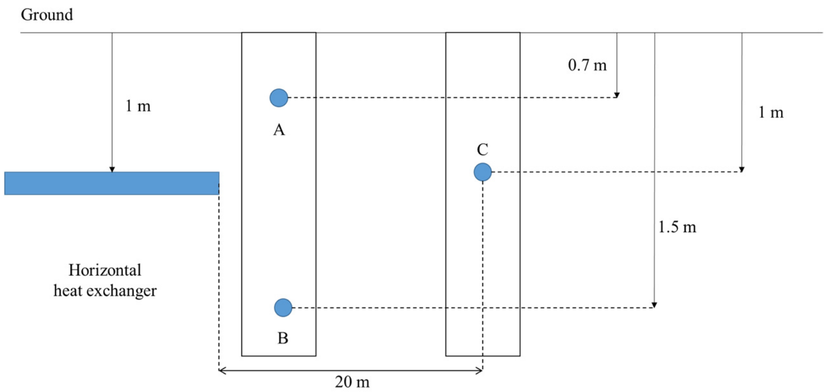

Figure 9. Vertical cross-section of sensors A, B, and C installation in Saraburi campus.

Indicating the economic benefits of the GSHP application is crucial for increasing the attractiveness of the system. The comparison of both the GSHP systems shows that the heat pump is the main reason for the cost difference because both systems use similar heat exchangers. The costs of installation and heat exchanger accounted for 10% and 60% for GSHP 1 and 2, respectively. Notably, the underground temperatures were higher than the average daily atmospheric temperature during the operation in Saraburi province. Moreover, the heat rejection raised the subsurface temperature near the heat exchanger during the operational period. However, the intermittent use of a GSHP and the conventional AC provided sufficient time to reduce the long-term effect of the operation regarding the system performance. The cost evaluation revealed no economic advantage of the GSHP investment over the conventional AC during their lifetime of 15 years. Thus, local manufacturing of GSHP systems is an alternative to increase their economic benefit.

4.5. Vietnam

Hanoi has a humid subtropical climate with a high precipitation rate. This city has a lower average atmospheric temperature than Bangkok; moreover, the atmospheric temperature range of Hanoi is broader than that of other regions in Southeast Asia (25–31 °C) because the city is located at a higher latitude [100]. Interestingly, thermal comfort in most buildings in Hanoi during November and March can be achieved using natural ventilation and electric fans [101]. The GSHP was completely installed in October 2016 in the director's room of the VIGMR with dimensions of 25 m^2. The closed-loop system was connected in series with two vertical 50-m boreholes and a double U-tube configuration [60]. Sensors for measuring atmospheric, room, inlet and outlet fluid temperatures were installed, and power consumption was measured to evaluate the GSHP performance.

The results indicated that the CoP was 3.1 and 3.6 for cooling and heating via heat exchanging fluid, respectively. Notably, Hanoi exhibited lower thermal conductivity (λ = 1.42 Wm^{-1} K^{-1}) compared with that of Bangkok (λ = 1.82 Wm^{-1} K^{-1}), leading to lower CoP achieved from the GSHP in Hanoi.

5. Conclusions

Undoubtedly, the GSHP system is an alternative technology for a renewable energy, which applies the subsurface temperature for transferring heat instead of using the conventional AC or heater, which transfers heat into the atmosphere. Additionally, the GSHP system is considered to be environmentally friendly and widely used in several countries. However, using this system in a tropical zone is still challenging because of the hot climate conditions and the high subsurface temperatures, and cooling demand is predominant in Southeast Asia due to the prevalence high temperatures throughout the year. Currently, a GSHP application for various purposes in Southeast Asian countries has already been reported, but information on space cooling is limited. Therefore, this paper reviews GSHP applications in the Southeast Asian region; several applications of GSHP systems in Thailand, Indonesia, Malaysia, Singapore, and Vietnam were conducted. The experiment in Kamphaengphet, the first GSHP trial in Southeast Asia, indicated the potential of GSHP application at the experimental site, as reflected by thermal recovery within 10 days after the operation was stopped.

GSHP systems may be used in this region despite the dominance of cooling demand, causing a thermal imbalance in the subsurface. Groundwater flow and subsurface temperature are expected to be the key factors in thermal distribution owing to the GSHP operation. These results suggest that the GSHP has the potential to reduce CO_2 emissions and electricity consumption within areas with tropical climates, such as Southeast Asia, for sustainability. However, previous studies indicated that a short operational period results in limited field data for the critical evaluation of sustainable GSHP application and possible system improvement. Thus, the future research will aim to improve the amount of the collected data, analyze long-term performance and socio-economic impact, evaluate the regional groundwater flow effect on the performance of the system, and achieve system modeling and optimization for providing a comprehensive analysis.

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