Chapter

Space Cooling by Ground Source Heat Pump in Tropical Asia

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Abstract

In Southeastern Asia, where energy demand is expanding to meet the increasing population and industry needs, energy saving by use of ground source heat pump (GSHP) could be one of the solutions. There are several concerns on GSHP installation in this region. The biggest concern is the subsurface temperature in tropical Asia. Although space cooling is needed in tropical regions, underground is slightly warmer than average atmospheric temperature and may not be used as "cold" source. However, groundwater temperature survey results in Thailand and Vietnam show the applicability of GSHPs in this region. Also, experimental GSHP systems for cooling have been installed in Thailand, Indonesia, and Vietnam, and studies have been done to improve cost performance of these systems. As results, the following things are found: 30% of energy saving compared to normal air-conditioner has been confirmed at a test site in Bangkok. Systems with local manufacturing would be a key for cost reduction. Cost performance may be optimized by selection of horizontal and/or vertical heat exchangers depending on the local subsurface condition. Drilling technology for no-cementing and no-casing completion is a key for higher heat exchange rate in vertical heat exchangers.

Keywords: ground source heat pump (GSHP), tropical Asia, space cooling, groundwater flow, temperature survey, advection effect, apparent thermal conductivity, drilling, no cementing, polymer

1. Introduction

Ground source heat pump (GSHP) system for heating and cooling purposes may be a powerful alternative to reduce energy consumption and to contribute to environmental issues. Its intensive utilization for heating may reduce emissions of CO_2 and other toxic gases by replacing fossil fuel boilers.

It may also greatly contribute to mitigate the urban heat island (UHI) phenomenon, since GSHP operation for cooling does not emit waste heat to atmosphere. UHI is a matter of great concern in megacities [1] because it triggers bad circulation of energy consumption. The higher the atmospheric temperature, the more energy is consumed for space cooling, resulting in even higher atmospheric temperature in urban areas (**Figure 1**). Expansive population growth and urbanization in Asia would make the problem of UHI more serious. In such a situation, intensive use of GSHP may largely contribute to cut the bad circulation of UHI. An estimation [2] shows that full installation of GSHP in the central part of Tokyo may reduce the daily maximum atmospheric temperature in the summer by 1.2 K through combined effects of high efficiency of GSHP and reduction of UHI.

However, in Southeastern Asian countries, where significant economic growth is expected so that energy saving and environmental protection will be major matters of importance for sustainable growth, the current number of GSHP installations is quite limited and rapid growth of GSHP installation is desirable.

GSHP has been considered not appropriate in tropical regions where only space cooling is needed. Since seasonal change of atmospheric temperature is quite limited in tropics and subsurface temperature is generally higher than year-average atmospheric temperature, underground may not be appropriate as a "cold heat-source" (**Figure 2**). Nevertheless, there still exist advantages of GSHP use in tropical regions if (1) daily changes of atmospheric temperature exist and (2) subsurface temperature is rather low and/or the advection effect of groundwater flow in shallow aquifer raises heat exchange rate.

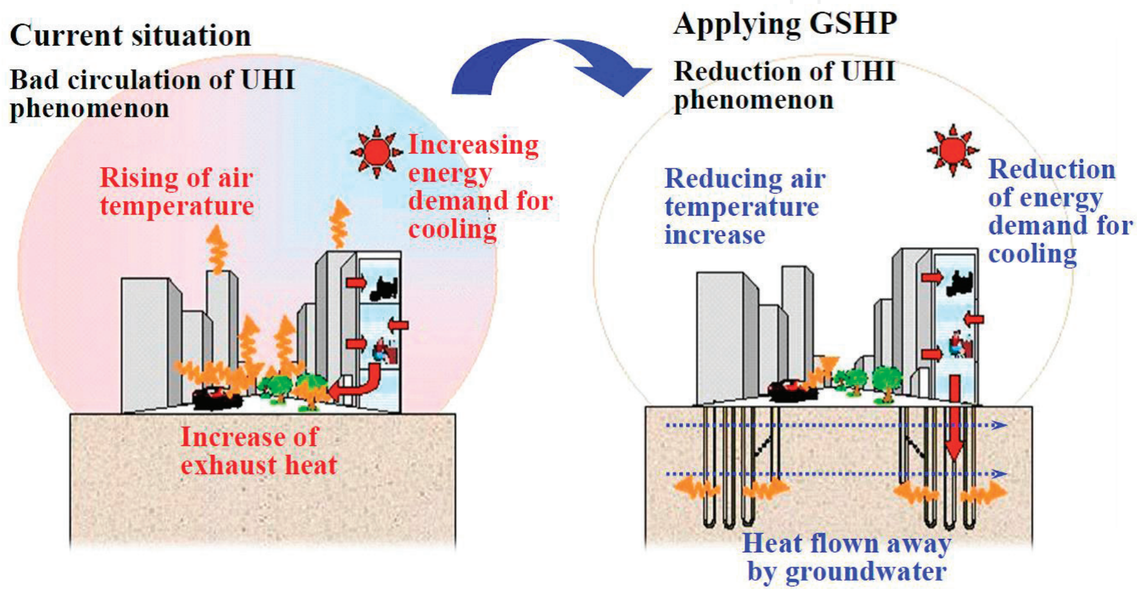

Figure 1.
Reduction of UHI phenomenon by intensive installation of GSHP systems.

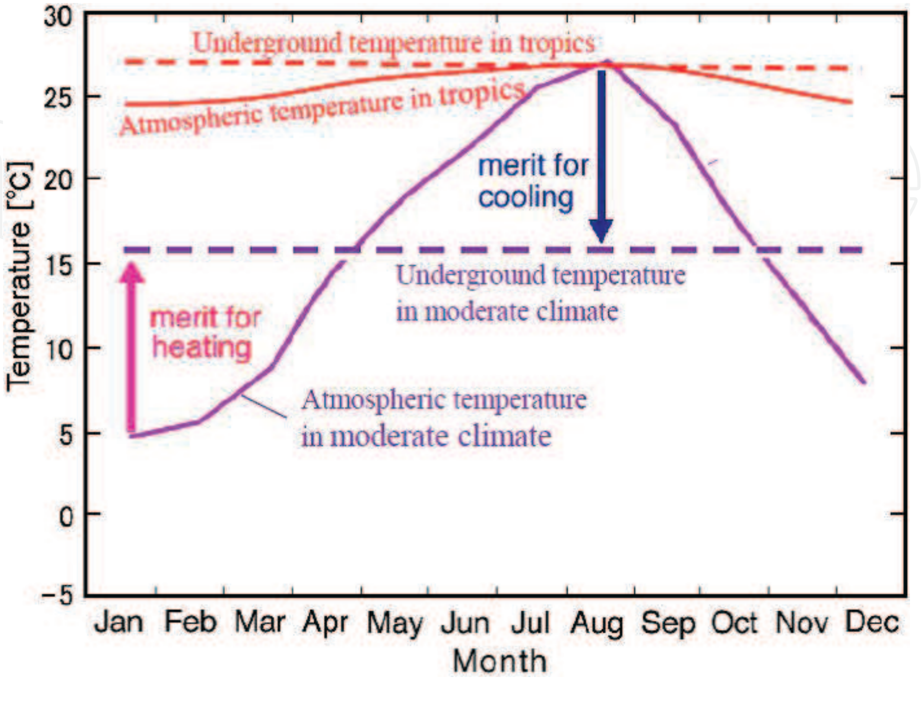

Figure 2.
Comparison of monthly average atmospheric temperature and underground temperature in moderate climate and tropical regions (conceptual figure).

According to a result of groundwater temperature survey conducted in the Chao Phraya plain, Thailand, subsurface temperature is lower than daytime atmospheric temperature throughout the year in most cities [3]. Considering that the major consumers of cooling systems in these areas are offices and shops, higher performance only in daytime would still have advantage to normal air-conditioners. It suggests that underground may be used as a cold heat-source even in parts of tropical regions.

Thus, to verify the applicability of GSHP in tropical regions, mapping of subsurface temperature is essential. Then, demonstration of the GSHP system is important to understand a possible performance of GSHP systems in the region and to make practical guidelines on system design and installation procedure. Therefore, in the following sections, subsurface temperature survey and results of experimental installations of the GSHP system in Thailand and in Vietnam are presented.

2. Subsurface temperature survey in tropical regions

2.1 Effects of natural subsurface temperature and groundwater flow on GSHP systems

For a GSHP system design, information on groundwater is quite important. For open-loop systems, in which groundwater is extracted for heat exchange at ground surface and re-injected afterward, information of aquifer on depth, temperature, and flow rate is important. For closed-loop systems in which heat exchange is conducted by circulating fluid in a heat exchange tube buried underground, information on subsurface temperature and apparent thermal conductivity is important (see **Table 1**). In monsoon Asia, where shallow groundwater flow is dominant, apparent thermal conductivity is largely affected by advection effects of groundwater flow. Therefore, information on subsurface temperature and groundwater flow is essential for both closed and open systems. Thus, in this subsection, effects of groundwater flow on subsurface temperature distribution and its implication on GSHP systems will be explained.

Subsurface temperature in natural state at a depth of 20 m or deeper is normally stable throughout the year and generally slightly higher than year-average atmospheric temperature of the place. **Figure 2** schematically shows the seasonal variation of atmospheric and subsurface temperature at a depth of about 50 m. In moderate climate regions, where subsurface temperature is higher than atmospheric temperature in the winter and lower in the summer, the GSHP system is useful for both space heating and cooling. On the other hand, in tropics where

Term	Measurement method	Affecting matters	Notes
Thermal conductivity σ	Thermal conductivity of a dried rock sample	Rock property	Unconsolidated sediments have lower σ than hard rocks
Effective thermal conductivity σ_e	Thermal conductivity of a water-saturated rock sample	Rock and water properties	$\sigma < \sigma_e$
Apparent thermal conductivity σ_a	Thermal conductivity measured at a site	Rock and water properties and flow rate	$\sigma < \sigma_e < \sigma_a$ for saturated zone, higher for higher flow rate

Table 1.
Terms of thermal conductivity in this chapter.

space cooling is needed, subsurface temperature is higher or approximately equal to atmospheric one and no advantage of GSHP systems can be seen.

Nevertheless, there exist temperature variations at the same depth of a plain or a basin. Natural groundwater flow, controlled by the topography of the ground surface and subsurface boundaries of rock permeability, may perturb the subsurface thermal regime. At recharge zones, infiltration of precipitation disturbs heat conduction from a depth that lowers the shallow subsurface temperature, while upward groundwater flow encourages heat transfer from a depth at discharge zones. Therefore, within an identical groundwater system, subsurface temperature at recharge zone is generally lower than that at discharge zone as shown in **Figure 3**. Thus, temperature difference of a few Kelvins may be achieved by groundwater flow. Another aspect of groundwater flow is that recharge zones have higher flowing velocity because of their non-flat topography. In the central flat region of a plane, groundwater flows more slowly.

Groundwater flow has another important effect on subsurface heat exchange using a closed-loop GSHP system. Advection effect of groundwater flow reduces temperature rise/drop around the borehole during heat exchange, which otherwise degrades the system performance. Thus, groundwater flow contributes to sustainable operation of GSHP systems. Therefore, if subsurface layers are effectively cooled by groundwater flow, GSHP systems may be useful in tropical regions.

2.2 Temperature survey at the Chao Phraya plain, Thailand

The authors conducted groundwater temperature measurements in the Chao Phraya plain in numerous observation wells belonging to the Department of Groundwater Resources (DGR), Thailand, from 2003 to 2005 [3]. Locations of the observation wells are shown as red dots in **Figure 4**. It should be noted that temperature profile should be taken in observation wells, in which water temperature reaches equilibrium with subsurface temperature. Topographically, the Chao Phraya plain consists of upper plain and lower plain, and the groundwater system is separated into two flow systems as well at a border around N15°40'. Nakhon Sawan is a discharge zone of the upper plain where groundwater discharges into a lake and flows away as river water while Chai Nat is a recharge zone of the lower plain.

Figure 4 shows the observed temperature profiles in these wells for each region. Wells in the same region have similar temperature profiles. Temperature inversions, in which shallow subsurface temperature is lower than surface temperature, are commonly seen in profiles in Chai Nat and Chachoengsao regions probably because

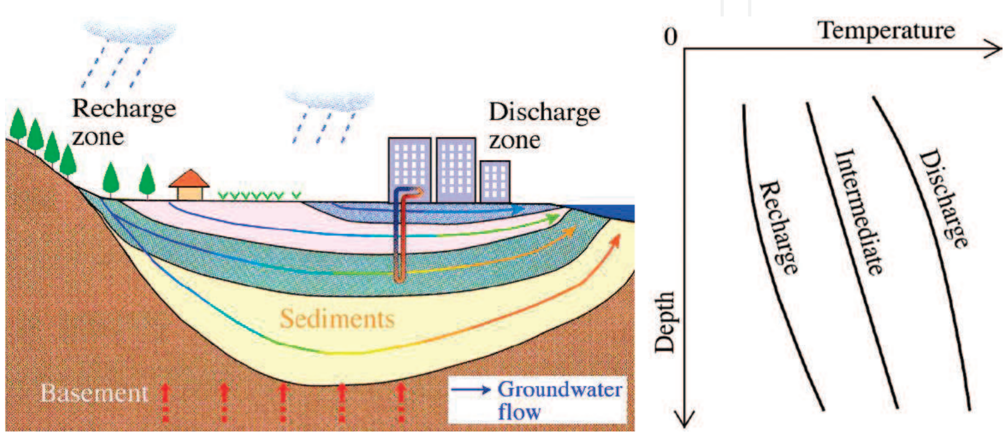

Figure 3.
Schematic image of groundwater flow in a plain and vertical temperature profiles in hydrologically different zones.

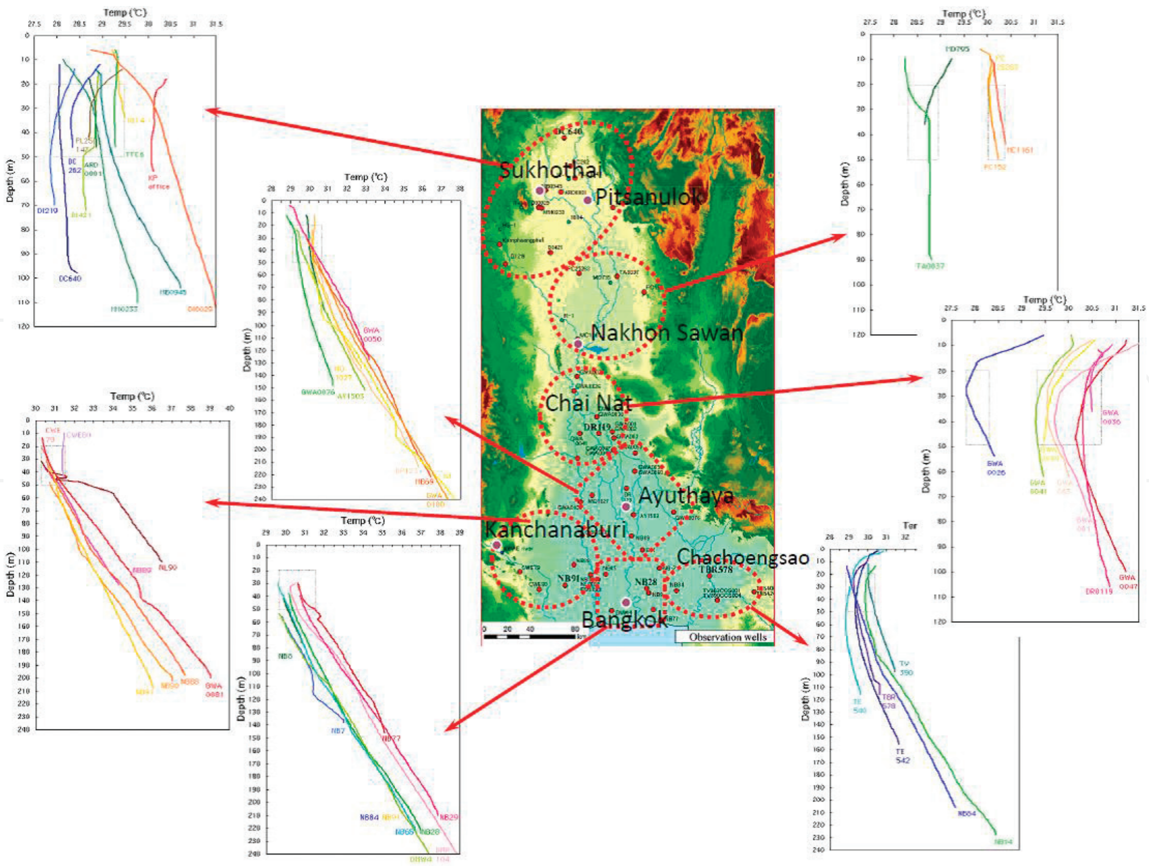

Figure 4.
Temperature profiles widely measured at observation wells in the Chao Phraya basin [3]. Red dots in the map show the locations of observation wells.

of global warming. Since surface temperature has risen in recent decades, it becomes higher than subsurface temperature that remains at the past level. This temperature inversion caused by global warming is typically observed in recharge zones [4, 5].

The proper depth of borehole heat exchanger for space cooling may be around 50 m or less, because subsurface temperature increases with depth and deeper parts are not appropriate as "cold" heat-source. For this reason, temperature range at depths between 20 and 50 m in each area is indicated in **Figure 5**. Temperature at a depth of 20 m or shallower is ignored because it may be affected by daily and seasonal changes so that observed values may not represent the statistical mean.

Figure 5 compares atmospheric and subsurface temperature at Bangkok, Ayutthaya, Nakhon Sawan, Phitsanulok, Sukhothai, and Kanchanaburi regions, respectively. For Phitsanulok and Sukhothai, an identical set of subsurface temperature data was used, while the atmospheric ones are different. At four regions out of six, Bangkok, Ayutthaya, Phitsanulok, and Nakhon Sawan, subsurface temperature is lower than monthly mean maximum atmospheric temperature throughout the year. The GSHP system may be effective in these areas for space cooling especially in daytime.

2.3 Temperature survey at the Red River plain, Vietnam

Groundwater temperature survey in the Red River plain, Vietnam, in observation wells belonging to the Department of Geology and Minerals of Vietnam (DGMV) was conducted in 2005 and 2006 [3]. Note that this region is not a tropical but semi-tropical area, but the knowledge obtained from this survey would be applied to tropical parts of the nation.

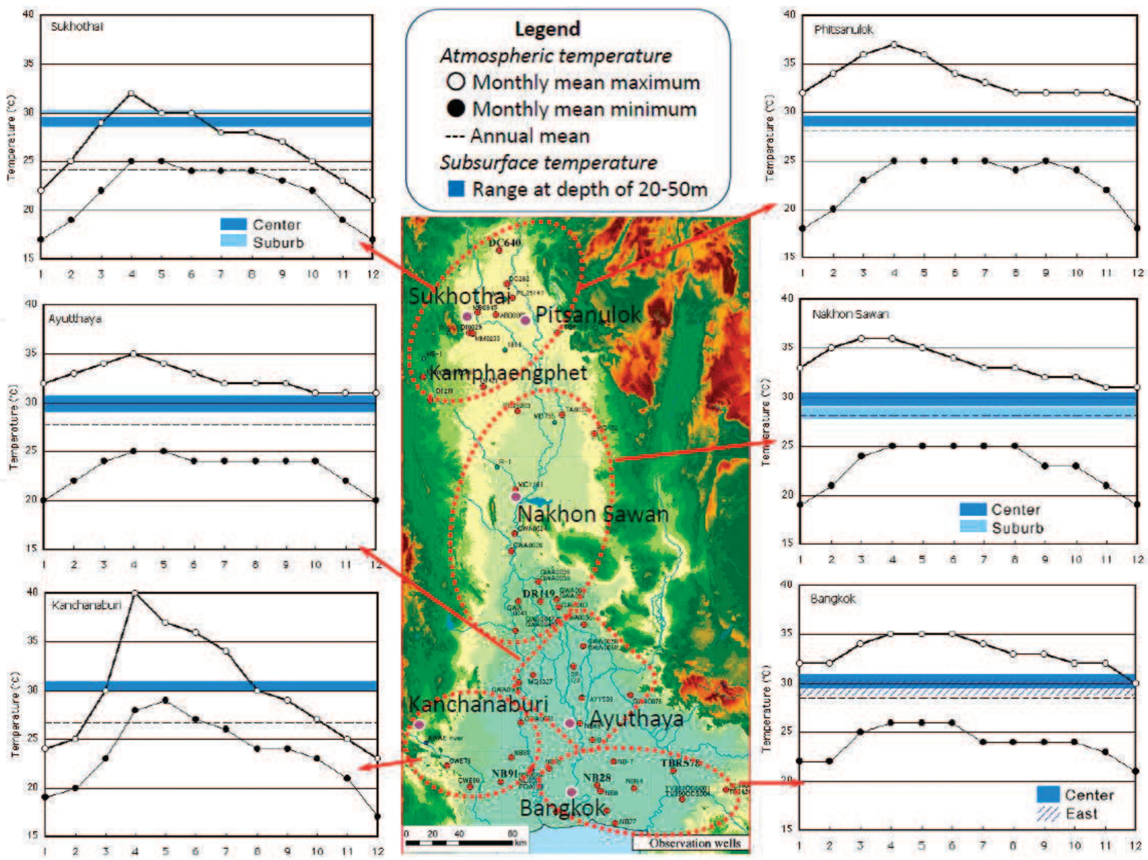

Figure 5.
Comparison of atmospheric and subsurface temperature at depths between 20 and 50 m at each region [3].

Location of observation wells in this area and their temperature profiles are shown in **Figure 6**. The color of each profile in **Figure 6** (right) corresponds to that of wells in **Figure 6** (left).

In the south of the Red River, the wells near the sea (Q108, Q109, and Q110) show higher temperature and temperature gradient than those in Hanoi, suggesting that the coast is a discharge zone while Hanoi is an intermediate zone of a groundwater system. The wells in the north of the Red River (Q131, Q159, Q158, and Q156) show lower temperature than those in Hanoi although they are nearer to the sea. But still, their temperature decreases with the distance from the sea. The groundwater system in the north must have a different origin from that in the south.

Figure 7 shows the monthly change of atmospheric temperature and subsurface temperature in Hanoi area. The subsurface temperature range is obtained from wells shown by circle in **Figure 6**, for depths of 20–50 m. In Hanoi, subsurface temperature is lower than monthly mean maximum atmospheric temperature from May to October by 2–7 K. Therefore, the underground may be used as a "cold heat-source" in the summer season.

2.4 Discussion on possibility of GSHP application

Based on the temperature observation results in Thailand and in Vietnam, the possibility of GSHP application for space cooling was identified for most places where subsurface temperature becomes lower than atmospheric temperature in daytime.

Generally, in a same source temperature condition, a water-source heat pump such as GSHP has higher performance than an air-source heat pump such as conventional air-conditioner because of its high heat exchange rate. A literature review [6] shows that their open GSHP gives higher coefficient of performance

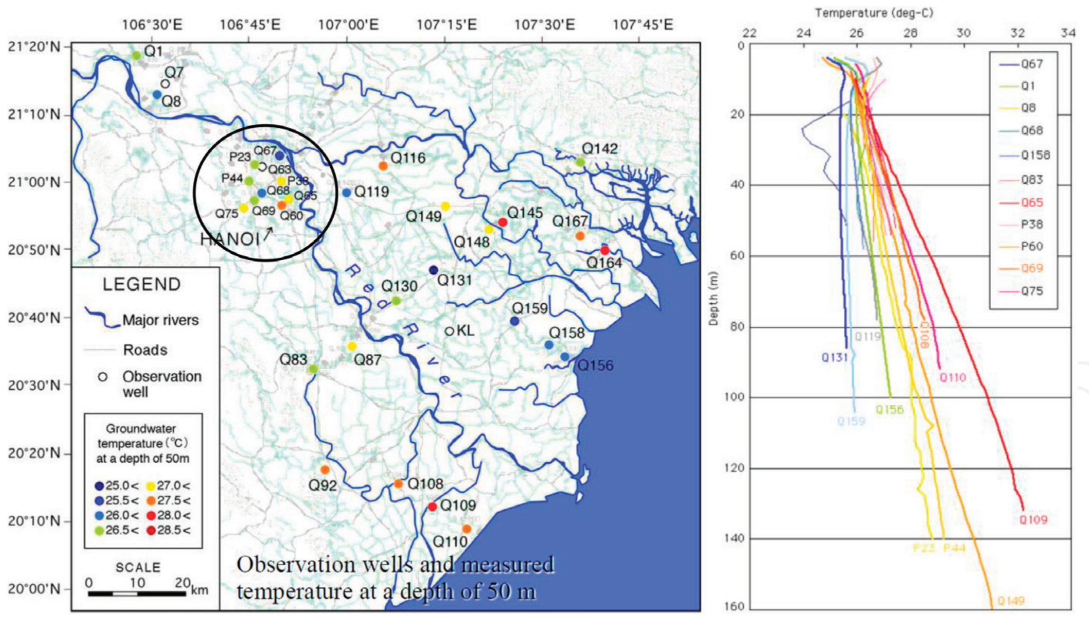

Figure 6.
Location of observation wells around the Red River, Vietnam, (left) and their temperature profiles (right) [3].

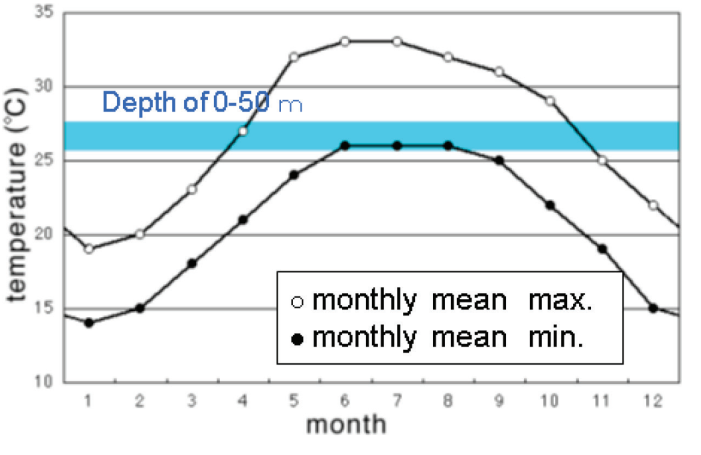

Figure 7.
Comparison of atmospheric and subsurface temperature at depths between 20 and 50 m at Hanoi area [3].

[COP, (generated heat)/(electricity consumption of heat pump)] than an air-source heat pump for cooling even when the atmospheric temperature is lower than ground temperature by 3 K. They suggest that, in their case, the COP of GSHP and air-source heat pump may be equivalent when the atmospheric temperature is lower than ground temperature by 5 K. Applying this result to **Figure 5**, a GSHP may have higher COP than an air-source heat pump in most places for most seasons in day time.

3. Demonstrations in Thailand and in Vietnam

3.1 Introduction

The authors installed and operated several experimental and demonstrational GSHP systems in tropical Asia. All these systems are closed-loop systems aiming at easier installation at lower cost. **Table 2** shows the essence of these experiments and demonstrations. The earlier systems are only experimental and removed after a year or more of operation. The later ones are demonstrational systems that have been continuously used by the people working at the site. Improvements have been done through these installations for better cost performance, which include drilling and well completion technology to achieve higher heat exchange rate, a combination of horizontal and vertical heat exchangers, and a controlling system for the heat pump operation. Details of the first experiment will be described in the next subsection and improvements in the other installations will be explained in the following subsection.

No., Place	Period	Subsurface heat exchanger	Surface system	Note
1. Kamphaengphet (DGR), Thailand	October 2006 to March 2008	57-m deep borehole with double U-tube	Water-water chiller, fan coil	First experiment in tropics. Mostly made in Japan.
2. Chiang Mai (DGR), Thailand	March 2008 to July 2010	80-m deep borehole with single U-tube + 60-m horizontal tube	Same as above	Moving the above system to another site.
3. Bangkok (Kasetsart Univ.), Thailand	July 2010 to 2012	200-m horizontal tube	Same as above	Moving the above system to another site.
4. Bandung (ITB), Indonesia	July 2013 to 2015	200-m horizontal tube	Remodel from air-conditioner	Cooling efficiency 25% up. Done by Akita University.
5. Bangkok (Chulalongkorn Univ.), Thailand	May 2014 to present	50-m deep borehole with single U-tube × 3 (150 m)	Combined chiller and fan unit	Cooling efficiency 30% higher than normal air-conditioner.
6. Bandung (Western Java Energy Mineral Institute), Indonesia	(pending: planned in 2015)	100-m deep borehole with single U-tube (installed in 2017)	Remodel from air-conditioner (planned)	Heat pump made in Indonesia is expected.
7. Saraburi (Chulalongkorn Univ.), Thailand	June 2015 to present November 2016 to present	300-m carpet style (horizontal) 300-m coil style (horizontal)	Combined chiller and fan unit	Machine made in Thailand Remodel from air-conditioner.
8. Pathumthani (Geology Museum, DMR) Thailand	March 2015 to present	50-m deep borehole with double U-tube × 2 (400 m)	Combined chiller and fan unit	Mostly made in Japan. No cementing borehole for higher heat exchange.
9. Hanoi (VIGMR), Vietnam	October 2016 to present	50-m deep borehole with double U-tube × 2 (400 m)	Combined chiller and fan unit	Mostly made in Japan. No cementing borehole for higher heat exchange.

Table 2.
Experiments and demonstration of GSHP cooling in tropical region by AIST and/or Akita University in collaboration with local institute.

3.2 Kamphaengphet experiment

An experimental GSHP system for space cooling was installed in DGR Kamphaengphet office, Thailand, in 2006 and operated for 17 months. Kamphaengphet is located at the edge of the Chao Phraya basin where groundwater flow is rather high (**Figure 5**). **Figure 8** (left) shows the temperature profile of an observation well in Kamphaengphet office measured before the installation of the GSHP system. The temperature range below water level is 30.1–30.6°C. A comparison of atmospheric and subsurface temperature at this place is shown in **Figure 8** (right). Except for December, subsurface temperature is lower than monthly mean maximum atmospheric temperature.

Figures 9 and **10** show the installed system. A heat exchange borehole (well) was drilled to a depth of 56 m and completed by normal cementing and a screen at the bottom. Then, a double U-tube (heat exchange pipe) was inserted and the borehole was filled with pebbles so that the water level in the borehole may keep equilibrium with the water-head of the bottom hole. The circulation fluid of both primary and secondary loops is just water because no brine is needed in tropical regions.

All major materials such as heat pump, fan-coil, and U-tube were exported from Japan although they are costly. Thus, the purpose of this project is to confirm genuine technical feasibility of GSHP in tropical regions, and the feasibility analysis of local material and cost was not included in this project scheme. Surface piping was made by normal PVC pipes which were purchased in local shops.

Temperatures in the subsurface heat exchanger, the room for cooling, and atmosphere were monitored in this project. The electricity consumption of the whole system and temperatures and flow rates of primary and secondary fluids were measured as well to calculate the system coefficient of performance (SCOP). For more details of this experiment, literatures are available [7, 8].

The system was operated in working hours of the office, approximately 8 hours a day in daytime, 5 days a week. Several times, the system operation was stopped for a week or longer for maintenance and the temperature data during these periods were effectively used to evaluate short-term and long-term effects of this system operation on subsurface temperature.

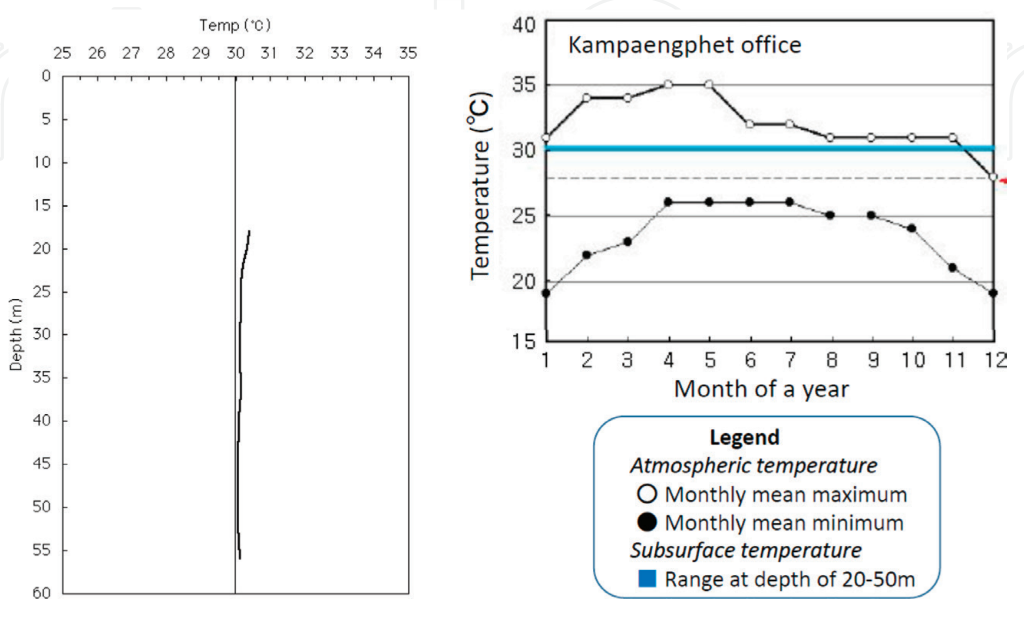

Figure 8.
Temperature profile of an observation well in Kamphaengphet office measured in December 2005 (left) and comparison of atmospheric and subsurface temperature (right) [7].

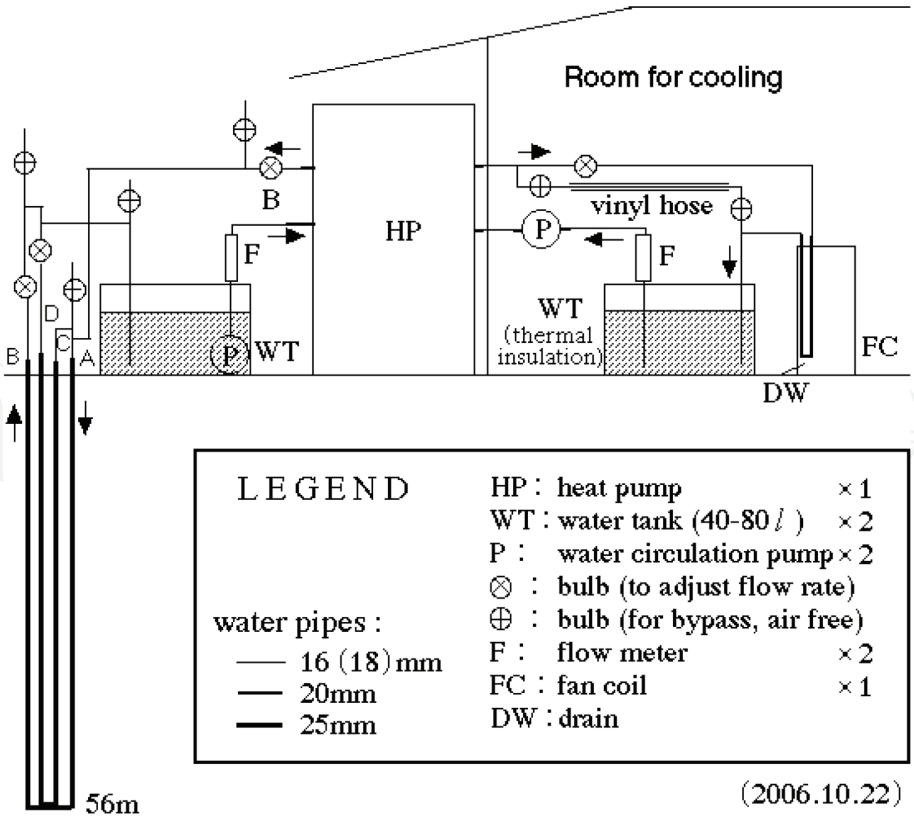

Figure 9.
Schematic figure of the Kamphaengphet GSHP system.

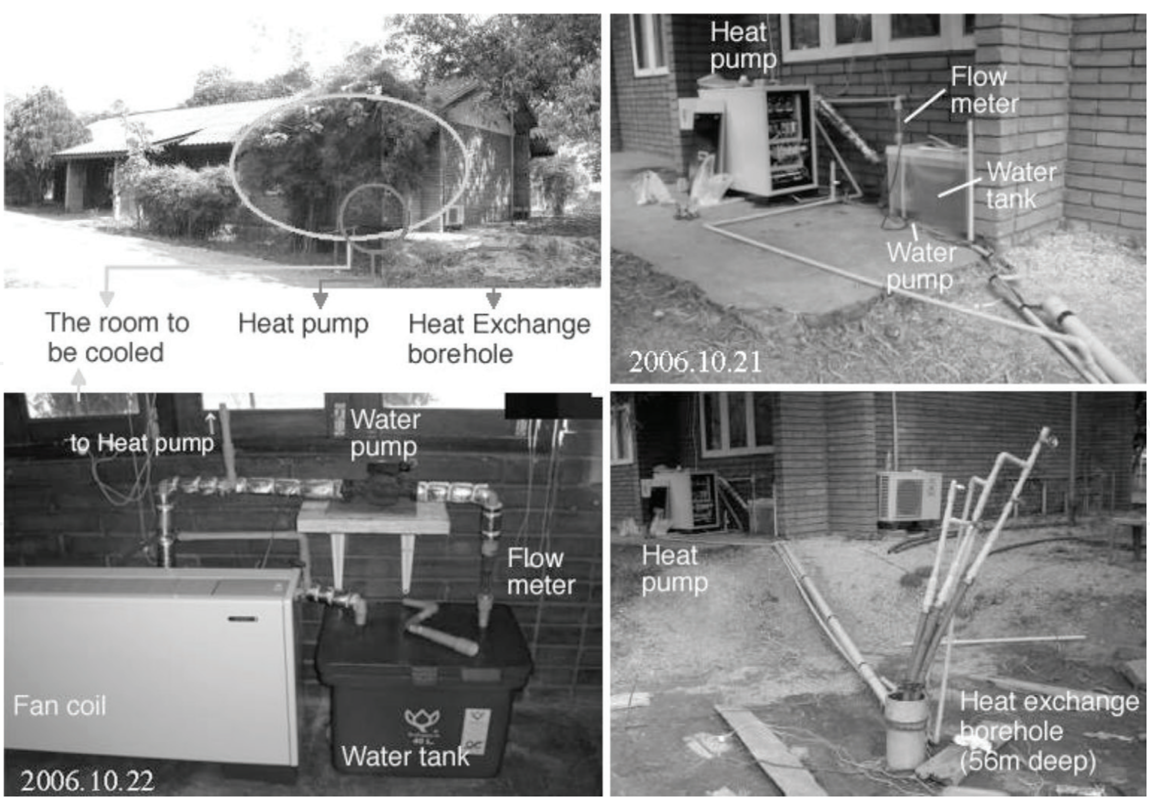

Figure 10.
Outlook of Kamphaengphet GSHP system. Down-left: inside the room, the others: outside.

Figure 11 shows temperature recovery at the bottom of the heat exchange borehole after stopping GSHP operation. During operation of the GSHP system, the subsurface temperature has risen to 33.5°C. It is because the length of the heat exchange pipe is shorter than necessary, and the temperature of circulation water reaches 42°C. However, after stopping system operation (at day 0 of x-axis in **Figure 11**), temperature rapidly drops and recovers to 30.5°C or lower in a week. Even after 15 months of operation in January 2008 (green dashed line), no long-term effect was observed. It may be because of its location near the edge of the basin, where groundwater flow rapidly releases exhaust heat by its advection effect.

In this first experiment, the on-off controlling system of the heat pump was a very basic thermostat, controlled simply by outlet fluid temperature of the heat pump. **Figure 12** shows outlet fluid temperature (light purple, shown as "HP operation temperature"), SCOP (blue-green), outside temperature (green), and room temperature (yellow and blue) during the experiment period. For the first few months (October 19, 2006 to March 7, 2007), the difference between maximum and minimum outlet temperatures was experimentally set to 8 K. However, by this setting, the interval between operation periods of the heat pump was too long, thus the room was not effectively cooled by this system and SCOP was quite low. Then, after trial and error, effective cooling and an SCOP of 3 were achieved with outlet temperature difference of 5 K when outside temperature in daytime was 30–35°C (August 20, 2007 to October 20, 2007).

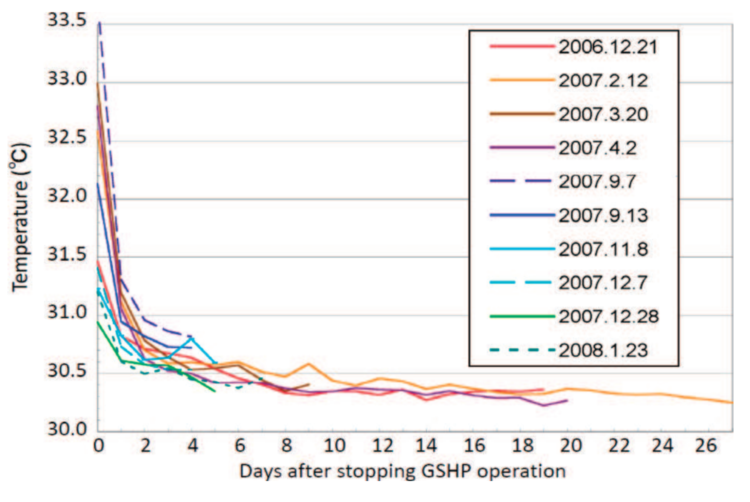

Figure 11.
Temperature recovery at the bottom of heat exchange borehole after stopping GSHP operation [7].

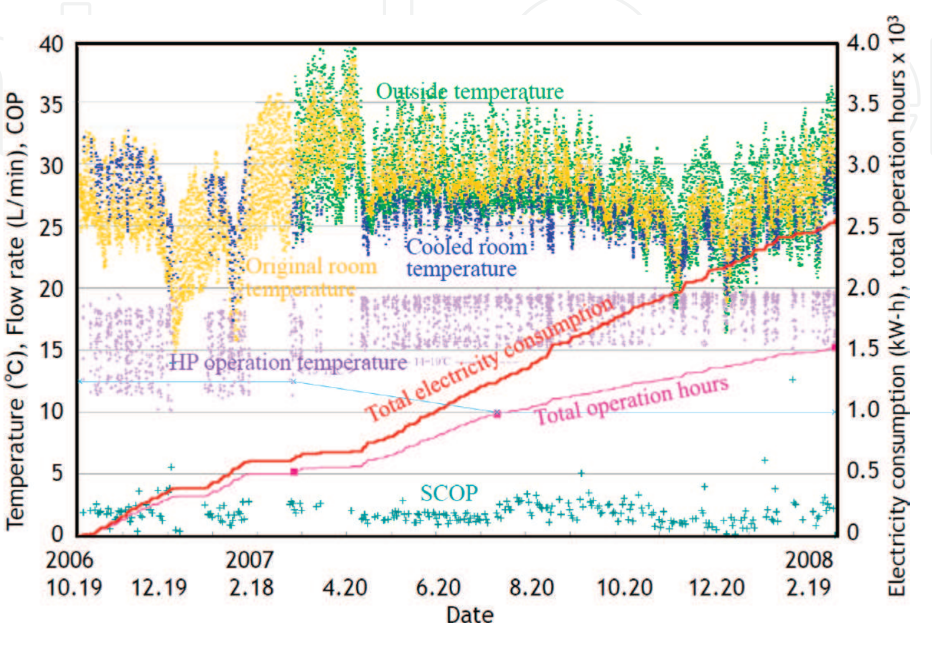

Figure 12.
Temperature monitoring result [7].

It is interesting that atmospheric temperature is not very different from original subsurface temperature, but higher performance is obtained by GSHP as was described by [6]. However, in a season when outside temperature in daytime dropped to 23–32°C (November 19, 2007 to February 19, 2008), SCOP dropped to 2 or lower. Here, SCOP was calculated as follows:

$$\text{SCOP} = \text{provided heat/total electricity consumption} = (T_{outlet} - T_{inlet}) \times Q_2/W_e,$$

where

T_{outlet} is the fan-coil outlet temperature (= heat pump inlet temperature from fan coil);

T_{inlet} is the fan-coil inlet temperature (= heat pump outlet temperature to fan coil);

Q_2 is the flow rate of the secondary fluid (= flow rate from heat pump to fan-coil);

W_e is the total electricity consumption per unit time (= electricity for heat pump and water circulation pump).

In summary, the following results were obtained:

- A continuous operation of the system causes temperature increase in the heat exchange borehole, but it recovers in a week after operation has stopped.

- No long-term subsurface temperature increase occurred even after a year of operation may be because of advection effects of groundwater flow in this region.

- Proper setting of heat pump operation and system design is essential for effective cooling with higher SCOP. Otherwise, its performance may be lower than regular air-conditioner.

- With a proper setting of heat pump operation, SCOP of around 3 was achieved when outside temperature in daytime was 30°C or higher, which is equivalent to original subsurface temperature.

Thus, the applicability of GSHP in tropical regions was confirmed by this experiment. For more effective utilization with better cost performance and SCOP, some adjustment of the system is recommended.

3.3 Demonstration projects in other places

Table 2 shows experiments and demonstrations of GSHP cooling in tropical region conducted by now. Since the applicability has been already confirmed in Kamphaengphet, the following experiments are aiming at higher SCOP and/or better cost performance. Study for better cost performance includes applicability of local material, local technology, and local human resources.

One method to reduce installation cost is the application of horizontal heat exchanger (Nos. 3, 4, and 7 of **Table 2**). The installation costs of simple tubes horizontally buried at a depth of 2 m in Nos. 3 and 4 were lower than that of vertical ones in an order. When burying a tube, it is important not to bend it to keep a high flow rate with a modest water circulation pump. It is also important to make surface piping as short as possible and cover with thermal insulation material to avoid influence of surface heat. In case of No. 7, more sophisticated heat exchangers were used. **Figure 13** shows two types of horizontal heat exchangers, carpet style and

Figure 13.
Installation of horizontal heat exchangers in Saraburi campus, Chulalongkorn University, Thailand (No. 7).

coil style, applied in No. 7. Although a shallow horizontal system may be affected by surface temperature change, its cost performance may be better especially if a large area is available to bury longer heat exchangers. Combination of horizontal and vertical heat exchangers may be a solution if wide area is not available (No. 2). The circulation fluid will be roughly cooled by horizontal pipe and it will be cooled further by the vertical heat exchanger.

Another method to reduce installation cost is to use local material. Nos. 6 and 7 in **Table 2** were planned to use heat pump by local manufacture and No. 7 was successfully operated. For Nos. 5, 8, and 9, electrofusion welding was used to connect the head part of U-tube with local tubes. Since U-tube is not sold in the countries where GSHP is not common yet and importing whole U-tube of 50 m or longer from other country is so costly, electrofusion welding is quite effective to use local material with imported U-tube head.

For higher performance of vertical heat exchanger, well completion without cementing is essential to efficiently raise heat exchange rate per length by the advection effect of groundwater. This method was applied for Nos. 8 and 9; since drilling without cementing was not common in Thailand and Vietnam, technology transfer was needed. In case of No. 8, drilling with normal bentonite mud was done and mud-cake inside the wellbore was washed away after drilling. However, this washing work was quite hard and time-consuming so that the whole process took a week for full drilling crews. Therefore for No. 9, synthetic polymer was applied as drill mud. In this case, drilling and installation of U-tube took only 3 days for an identical system as in No. 8 because polymer mud does not need washing. The local crews were able to conduct polymer drilling without problem using local drilling machine (upper left of **Figure 14**) with an instruction of an expert from Japan.

Nowadays, more sophisticated heat pumps and their controlling systems, which can be used just like normal air-conditioner, are available for GSHP systems. They automatically turn on and off the heat pump for a certain room temperature setting with energy saving. Such systems are used for Nos. 5–9. As result of such a control system and proper design of subsurface heat exchanger, system No. 5 achieved 30% of electricity saving compared to a latest normal air-conditioner [9].

In summary, the following results were obtained through these projects:

- Application of horizontal subsurface heat exchanger is effective to reduce installation cost of heat exchanger. Combination of horizontal and vertical ones is effective to keep higher heat exchange rate and reduce installation cost.

- Shorter piping and thermal insulation of surface pipe is important for effective cooling. Subsurface pipe for horizontal system should not be bended to keep high fluid circulation with a small water pump.

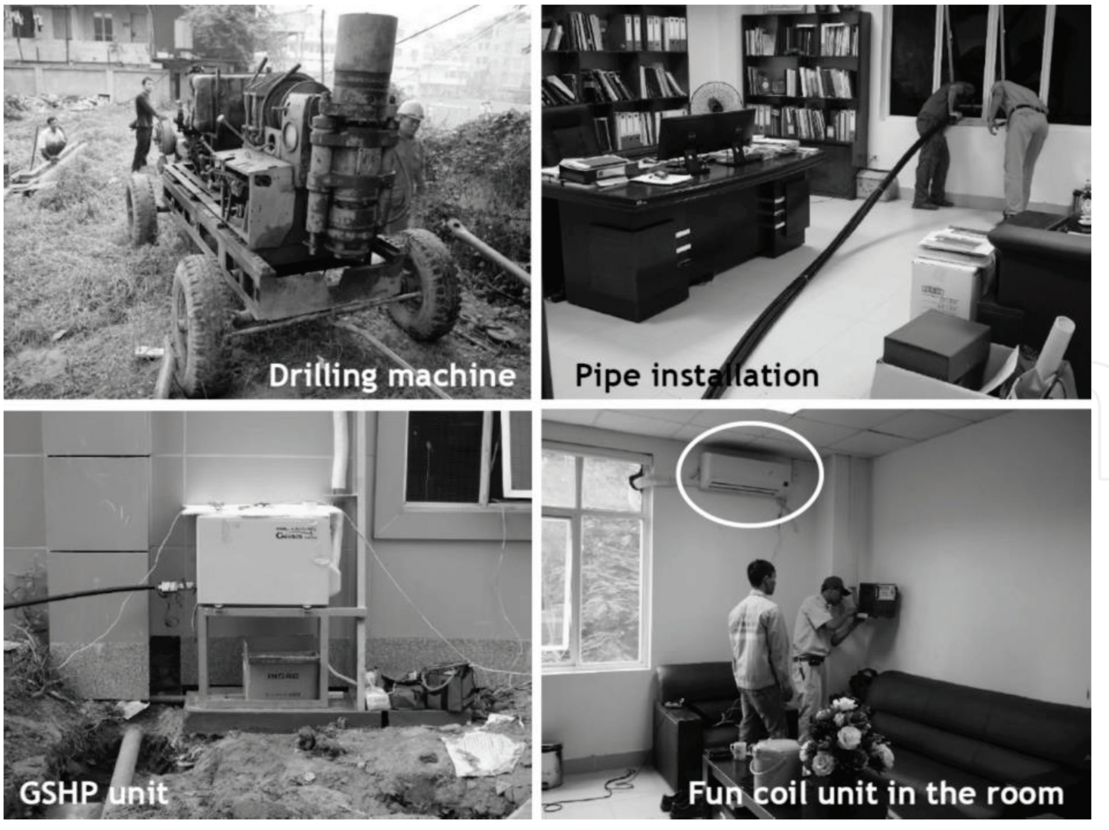

Figure 14.
Installation of a GSHP system in Vietnam Institute of Geology and Mineral Resources (VIGMR), Hanoi, Vietnam (No. 9).

- Application of local material, such as domestic heat pump and domestic tube is effective to reduce total cost. Electrofusion welding is useful to connect the head part of U-tube and local tubes so that import of whole U-tube is not necessary.

- For higher performance and cost reduction of vertical heat exchanger, well completion without cementing is essential. Polymer mud is quite effective for such drilling and local crew may handle it without problem.

- A sophisticated heat pump control system with a proper of heat exchanger achieved 30% of electricity saving compared to a latest normal air-conditioner.

4. Discussion

4.1 Numerical modeling for heat exchange simulation

Higher performance and appropriate design of heat exchange system (length and the number of borehole heat exchangers) may be achieved by numerical simulation prior to GSHP installation. In monsoon Asia, the advection effect of shallow groundwater on heat exchange rate is so dominant that measurement or estimation of groundwater flow rate is essential to perform such a numerical simulation for each region. Literatures describe methods to develop regional potential maps of GSHP installation based on groundwater flow modeling in a plain and simulation of heat exchange rate at any installation location [10–12]. Groundwater temperature surveys or thermal response tests in the region are essential for such modeling.

4.2 Application of open-loop systems

Only closed-loop systems are introduced in these demonstrations, but open-loop systems should also be considered for future application. Normally, open-loop system has higher installation cost because it needs at least two wells, production well and injection well, and its system design is order-made. However, open-loop systems may achieve higher heat exchange rate and lower running cost [13–15]. Therefore, open-loop systems may have higher cost performance if the following conditions are satisfied:

- Water production from a well is allowed in the area (in many urban areas, water production is prohibited by regulations to avoid land subsidence);
- Shallow aquifer is available so that drilling cost may not be high;
- Large system is planned so that high initial cost may be recovered by low running cost in few years; and
- Enough spacing between production well and injection well is available to avoid temperature interference.

In addition, some new ideas of heat exchange systems, so-called "semi-open "systems, which have benefits of both open- and closed-loop systems, are introduced by several authors [16, 17].

4.3 Consideration on subsurface temperature change

Contamination of subsurface temperature by exhaust heat would be a matter of concern. In all cases shown in this chapter, no long-term effects on subsurface temperature at the site were observed. That means exhaust heat was flown away by advection of groundwater and heat concentration was diluted. However, if an intensive installation of GSHP system would be done in the future, it might raise subsurface temperature in some extent and finally the heat may be released to surface water or atmosphere. Note that, however, effect of such heat release on UHI phenomenon should still be lower than that by normal air-conditioner because GSHP may save electricity for cooling, which means the amount of exhaust heat is smaller. Utilization of hot water from heat pump may be a solution to avoid subsurface temperature increase. Also, to avoid local subsurface temperature increase, numerical simulation prior to the installation and temperature monitoring after installation is recommended.

4.4 Heating operation in semi-tropical region

Hanoi, Vietnam, is not a tropical region but semi-tropical. In the winter season in Hanoi, underground temperature is higher than atmospheric temperature and GSHP can be used as a heater. Atmospheric temperature in the winter of Hanoi is not so low that people normally do not use heater. However, since humidity is quite high, heating systems may provide more comfortable life. As a fact, system No. 9 has been used as heater in the winter, and the visitors of this room have been quite impressed by the comfort of the heat by GSHP that they have never experienced. It may be used for drying as well. Thus, GSHP for both cooling and heating might get a new market in semi-tropical regions.

4.5 Application to other regions

GSHP for cooling may be applied for other tropical regions in the world. It is known that GSHP has higher performance than normal air-conditioner even when subsurface temperature is slightly higher than atmospheric ones [6]. In addition, existence of shallow groundwater may give higher performance of GSHP in tropical regions. As shown in **Table 1**, rock's heat conductivity σ, effective heat conductivity σ_e, and apparent heat conductivity σ_a have a relation of $\sigma < \sigma_e < \sigma_a$ in the saturated zone. Therefore, high heat exchange rate in the subsurface heat exchanger may be achieved with the existence of groundwater flow. Collection of long-term operational data is necessary to show the real value of GSHP for both heating and cooling as pointed out by [18].

5. Conclusions

Possibility of GSHP application in tropical Asia is studied based on groundwater temperature survey data in the Chao Phraya plain, Thailand, and in the Red River plain in Vietnam to be compared with atmospheric temperature data. As a result, in most cities in these areas, subsurface temperature is lower than atmospheric temperature in daytime for most months. Thus, it is suggested that shallow underground may be used as a "cold" heat-source at least in daytime. Therefore, experimental operations of GSHP have been conducted in Thailand, Indonesia, and Vietnam to confirm its applicability. In the first experiment in Thailand, SCOP of 3 was achieved. Aiming at higher performance at low cost, several technical improvements were conducted through the experiments. Use of local material, local technology, and local human resources is a key for better cost performance. Well completion without cementing is one of the key technologies to raise the heat exchange rate of a vertical system and polymer drilling is quite useful for its drilling. Horizontal heat exchangers may reduce the installation cost drastically. Combination of horizontal and vertical systems would be effective when enough space for horizontal system is not available. For better designing of GSHP system in monsoon Asia, numerical modeling of the regional groundwater flow and heat exchange simulation at the target location is recommended to know the proper length and depth of the borehole heat exchanger. In the case of semi-tropical region, heating by GSHP may create a new market for comfortable lives. The studies shown here may be applied to other tropical and semi-tropical regions in the world.

Acknowledgements

The temperature measurement in Thailand and Vietnam was conducted by AIST in cooperation with Department of Groundwater Resources (DGR), Thailand, and Department of Geology and Minerals of Vietnam (DGMV), respectively. GSHP experiments were conducted by AIST and Akita University, Japan, in collaboration with DGR, Department of Mineral Resources (DMR), Kasetsart University, and Chulalongkorn University, Vietnam Institute of Geology and Mineral Resources (VIGMR), Bandung Institute of Technology (ITB), and Western Java Energy Mineral Institute. These international collaborations have been done under CCOP Groundwater Water Sub-Project "Development of Renewable Energy for Ground-Source Heat Pump System in CCOP Regions." Special thanks should be given to Prof. Isao Takashima, Akita University, who designed all these systems and installed them with the authors.

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