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Groundwater Temperature Survey for Geothermal Heat Pump Application in Tropical Asia

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Abstact: In east Asia, where significant economical growth in this century is expected, intensive installation of geothermal heat pump (GHP) system may be important from both energy security and environmental protection aspects. Detailed underground temperature survey is essential for its promotion. Possibility of geothermal heat-pump application in tropical Asia is studied based on groundwater temperature data. Although generally geothermal heat-pump system may not have thermal merit for space cooling in tropics because subsurface temperature is generally higher than average atmospheric temperature, there may be some places in tropical regions where underground can be used as “cold heat-source”. In order to confirm this possibility, groundwater temperature surveys were widely conducted in the Chao-Phraya plain, Thailand and Red-river plain, Vietnam to compare with atmospheric temperature data. As a result, regional variation of subsurface temperature at depths from 20 to 50 m of 3.4 K was observed in the whole Chao-Phraya plain while that of 2.0 K was observed in the Red-river plain. In some cities, subsurface temperature lower than monthly mean maximum atmospheric temperature for 5 K or more over four months was identified. Thus underground may be used as cold heat-source even in parts of tropical regions.

Keywords: groundwater, subsurface temperature, geothermal heat pump, Chao-Phraya plain, Thailand, Red-river plain, Vietnam

1. Introduction

Worldwide use of geothermal heat-pump (GHP) has extensively grown in recent two decades. In this century, the energy use of GHP increased 3.6 times in five years, reaching to 87,503 TJ/year in 2005 (Lund, 2005). GHP may achieve higher coefficient of performance (COP, thermal output / power input) than conventional air-source heat pumps that may contribute to energy savings and environmental protection. Intensive use of GHP system may:

(a) Save energy and reduce CO_2 gas emission
(b) Reduce urban heat-island (UHI) phenomenon
(c) Normalize electricity consumption through a day

Among these three effects, (a) is common for anywhere. Replacing fossil fuels for heating to GHP may drastically reduce CO_2 emission. Replacing conventional air-conditioner to GHP may save electricity by its high COP and also reduce CO_2 emission if the energy source of electricity is fossil fuel. Several authors show high COP of around 5 for both heating and cooling by GHP systems, which means GHP can produce heat energy 5 times higher than electricity input. By combination with the effect of (b), total electricity saving for space cooling in central Tokyo may amount to 10 % with the maximum installation of GHP in the area (Genchi, 2001).

Effect of (b) is peculiar in urban areas. UHI phenomenon, an endless bad-circulation of air temperature increase, is a common severe problem in densely populated cities in east Asia. Human activities with energy consumption raise atmospheric temperature, which induces more intentional use of air conditioner, resulting in even higher outside air temperature. Use of GHP may reduce UHI by releasing heat into underground but not to the atmosphere. Genchi (2001) estimated that full installation of GHP in the central part of Tokyo may reduce the daily maximum atmospheric temperature in

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the summer by 1.2 K.

(c) is an issue for industrial areas where electricity consumption is considerably high in daytime. In addition to industrial uses, electricity demand for air conditioning is significant in daytime in hot climates. Use of GHP may contribute to decrease peak load by its high COP, by reducing UHI, and by cold/hot water storage at night for daytime use. Normalization of electricity consumption through a day may reduce the required capacity of the power plants for the same economical activity. It may also reduce CO_2 emission because peak load electricity is normally supplied from thermal plants, that emmit CO_2, since their output variations are easily controlled.

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

Although subsurface heat can be directly used without heat-pump, application of a heat-pump enables us to increase heat exchange rate with underground. It also allows us to control output temperature (ex, room temperature). Therefore in most cases, a heat exchange system with underground includes a heat pump and is called as a “GHP system”.

GHP systems have been used for space heating only or for both heating and cooling. Since it is applicable in non-geothermal regions, the system is known as “direct use of geothermal energy applicable anywhere”. But it may not be true for tropical regions where the atmospheric temperature is stable through a year. Although cooling system is needed there, subsurface temperature may always be higher than atmospheric one because of geothermal gradient. Therefore underground is not suitable as “cold heat-source” and there is no advantage of subsurface heat exchange. High COP may not be expected in such cases.

However, still there is a possibility of GHP use in tropical regions if 1) seasonal and/or daily changes of atmospheric temperature exist, and 2) cooling effect of downward infiltration of precipitation is locally dominant in shallow subsurface. Operational devices, such as reverse operation of GHP (making hot water for shower, etc.) at night, may be another option. In this case, underground is used as a heat storage tank and balance of hot and cold water uses is important.

To verify the cooling effect of groundwater flow, the second condition, mapping of subsurface temperature is essential. Therefore, results of temperature measurements in observation wells in Thailand and in Vietnam are shown in this paper. The other papers in this special issue are also on topics of GHP utilization in tropical Asia including experimental installation of GHP system in Thailand. The final aim of our studies is to make an East Asian map, indicating availability of GHP systems at any arbitrary location based on surface and subsurface temperature and hydrological conditions.

2. Natural subsurface temperature and groundwater flow -in application of GHP systems-

For designing a GHP system, information on groundwater is quite important. In case of open GHP system, in which groundwater is pumped up for heat exchange at ground surface and re-injected after heat exchange, information on depth, temperature and flow rate of the aquifer is important. In case of closed GHP system, in which heat exchange is conducted by circulating fluid in a heat exchange tube buried in underground, information on subsurface temperature and effective thermal conductivity is important. Since effective thermal conductivity is largely affected by existence of groundwater flow, as a consequence, information on subsurface temperature and groundwater flow is essential for both closed and open systems. Therefore in this section, effects of groundwater flow on GHP system will be explained.

Subsurface temperature in natural state at a depth of 20 m or deeper is generally stable through a year and generally higher than year-average atmospheric temperature at the place. Fig. 1 schematically shows seasonal variation of atmospheric and subsurface temperature at a depth of about 50 m. In cold climate regions, where subsurface temperature is mostly higher than atmospheric one, GHP system is quite suitable for space heating. In moderate (temperate) climate regions, where subsurface temperature is higher in the winter and lower in the summer, GHP system is useful for both space heating and cooling. In tropics, where space cooling is preferred, subsurface temperature is higher or approximately equal to atmospheric one and no advantage of GHP system can be seen.

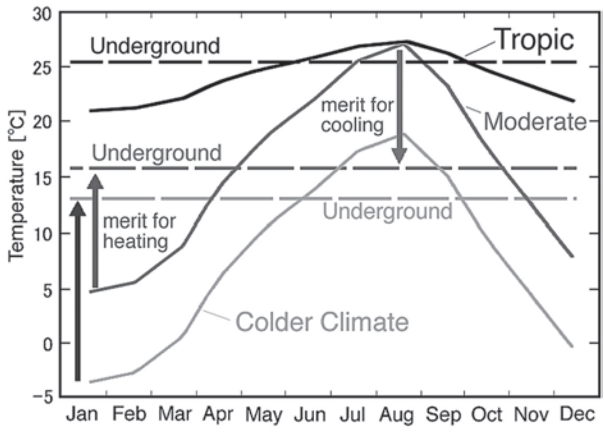

Fig. 1 Seasonal variation of subsurface and atmospheric temperature for different climates
Solid lines: atmospheric, broken lines: subsurface

However natural groundwater flow, which is controlled by topography of the ground surface and the subsurface boundaries with permeability changes, may perturb the subsurface thermal regime. At recharge zones, infiltration of precipitation disturb heat conduction from a depth, which lowers the shallow subsurface temperature while upward groundwater flow encourage the heat transfer from a depth at discharge zones. Therefore in an identical groundwater system, subsurface temperature at recharge zone is generally lower than that at discharge zone at the same depth as shown in Fig. 2. Thus temperature difference of few Kelvin may be achieved by groundwater flow.

Groundwater flow has another important affect on subsurface heat exchange around a closed GHP 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 GHP system. Therefore, if subsurface layers are effectively cooled by groundwater flow in both natural state and operational period of a GHP system, GHP systems may be useful in tropical regions.

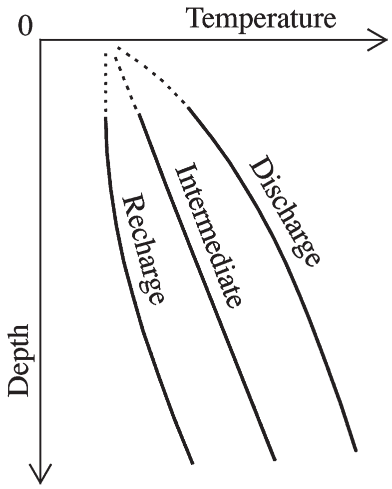

Fig. 2 Schematic temperature profiles for different zones of a groundwater system

Fig. 3 Locations of Chao-Phraya river and Red river

3. Temperature survey at the Chao-Phraya Plain, Thailand

Authors widely conducted groundwater temperature measurements in the Chao-Phraya plain in numerous observation wells settled by Department of Groundwater Resources (DGR), Thailand from 2003 to 2005. Topographically the Chao-Phraya plain consists of upper plain (north of Nakhon Sawan) and lower plain (south of Nakhon Sawan) with a border around N15°40'.Locations of the observation wells are shown in Fig. 4.

Fig. 5 shows the observed temperature profiles

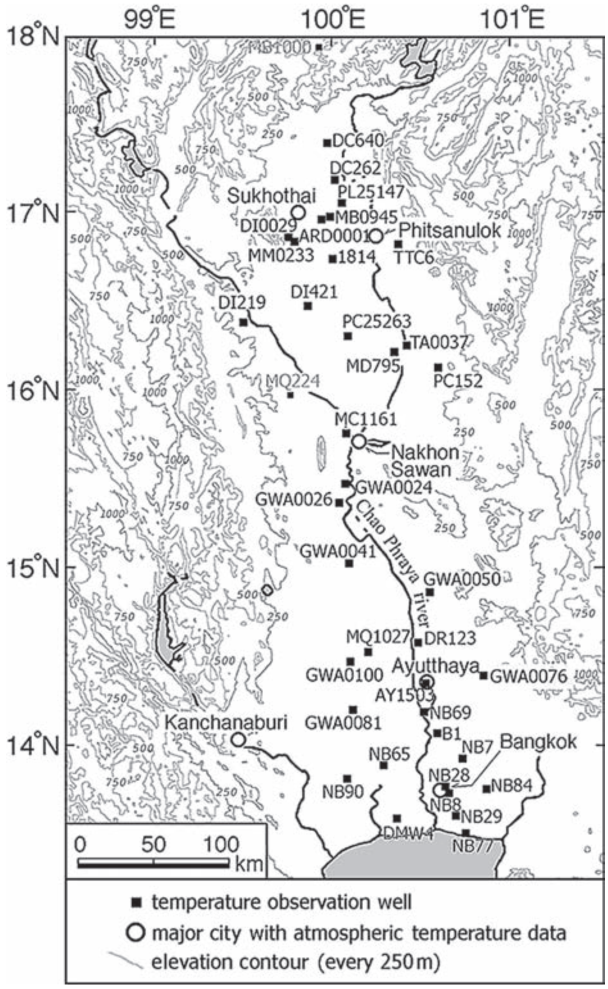

Fig. 4 Temperature observation wells in the Chao-Phraya Plain

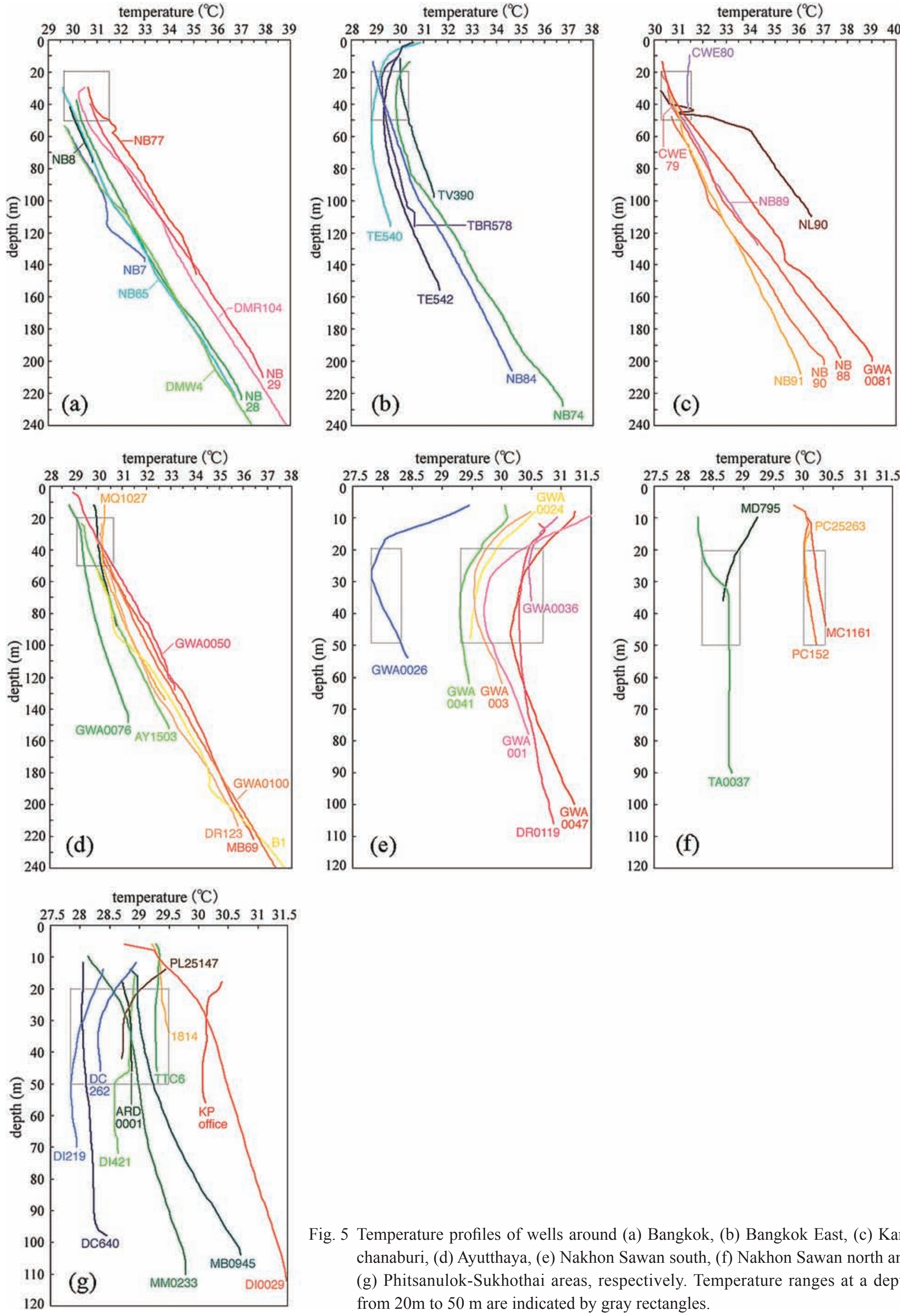

Fig. 5 Temperature profiles of wells around (a) Bangkok, (b) Bangkok East, (c) Kanchanaburi, (d) Ayutthaya, (e) Nakhon Sawan south, (f) Nakhon Sawan north and (g) Phitsanulok-Sukhothai areas, respectively. Temperature ranges at a depth from 20m to 50 m are indicated by gray rectangles.

in these wells for each area. Temperature anomalies at certain depths in NB7 and NB77 in Fig. 5(a) and in NL90 in Fig. 5(c) may be due to artificial pumping of groundwater. Temperature inversions commonly seen in profiles in Fig. 5(b), (e), (f), and (g) may be because of global warming that is typically observed in recharge zones as pointed by authors such as Cermak (1971) and Jessop (1990).

For GHP systems for cooling, proper depth of heat exchange wells may be around 50 m or less, since subsurface temperature increases with depth and deep wells are not appropriate as “cool” heat source. Therefore temperature range at depths between 20 to 50 m in each area is indicated in Fig.5. Temperature at depth shallower than 20 m is ignored because it may be affected by daily and seasonal changes so that observed value may not represent the statistical mean. In the whole Chao Phraya plain, temperature at depths between 20 to 50 m ranges from 27.8 ^{o}C (GWA0026, DI219) to 31.5 ^{o}C (NB77, GWA0081).

Fig. 6 shows a contour map of maximum temperature in these depths. An elevation contour line of 250

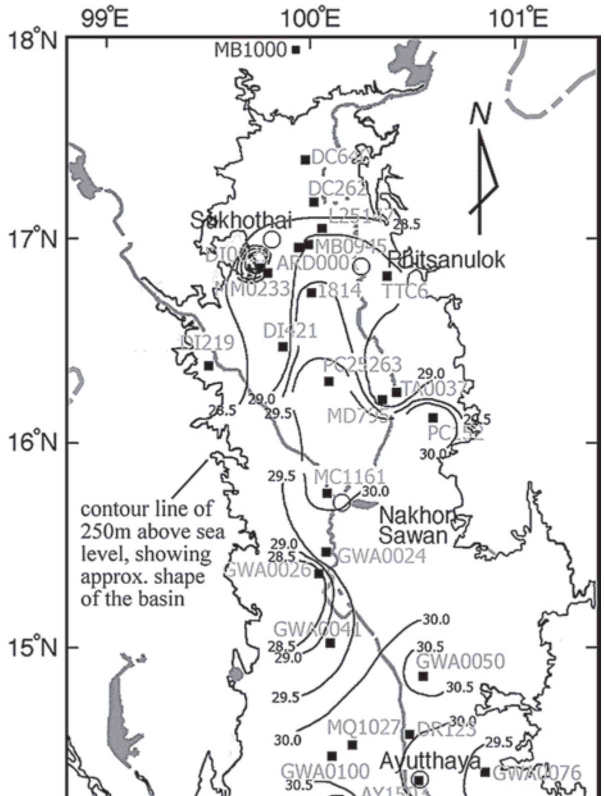

Fig. 6 Contour map of maximum temperature at depths between 20 - 50 m (^{o}C)

m in this figure shows the approximate shape of the Chao-Phraya plain. Generally the wells in the upper basin have lower subsurface temperature than those in the lower basin. However, GWA0041 (Fig. 5(e)) and GWA0076 (Fig. 5(d)) in the lower basin have rather low temperatures with profiles characteristic of recharge zone. These wells are considered to be located in local recharge zones of the lower basin for groundwater flow. Local flow systems may exist in upper and lower basins, respectively.

Fig. 7 compares atmospheric and subsurface temperature in depths between 20 to 50 m at (a) Bangkok, (b) Ayutthaya, (c) Nakhon Sawan, (d) Phitsanulok, (e) Sukhothai and (f) Kanchanaburi regions, respectively. Subsurface temperature data from the wells NB29 and NB77, both located near the sea, with extremely high temperature, are eliminated for Fig. 7(a). Subsurface temperatures shown in 7(d) and 7(e) are identical because they are based on data from the same region, while the atmospheric temperatures are different.

At Pitsanulok and Nakhon Sawan, subsurface temperature is lower than monthly mean maximum atmospheric temperature (MMMAT) through a year. Its difference is bigger than 5 K over four months. Also at Kanchanaburi, subsurface temperature is lower by 4 K or more over four months with a largest difference of 10 K in April. GHP system may be effective in these areas for space cooling especially in daytime. In Bangkok and Ayutthaya, subsurface temperature is lower than MMMAT for almost through a year, but the difference is smaller, so the performance of a GHP system may be lower than the other three areas. In Sukhothai, where subsurface temperature is higher than MMMAT for most of the year, underground may not be used as “cold heat-source”.

4. Temperature survey at the Red-river plain, Vietnam

The authors conducted groundwater temperature survey in the Red-river plain in observation wells operated by Department of Geology and Minerals of Vietnam (DGMV) in 2005 and 2006. Although this region is not a tropical area, it is important to know the subsurface temperature distribution around this area in order to compare with southern part of the country later.

Location of observation wells in this area, for which temperature profiles are obtained, are shown in Fig. 8. Fig. 9 shows the observed temperature profiles for these wells.

In the south of the Red River, the wells near the sea (Q108, Q109, Q110) show higher temperature gradient than those at Hanoi (inner land), suggesting that the wells near the sea are located at discharge zone while those in Hanoi are at intermediate zone of a groundwater system as shown in Fig. 2. However in the North

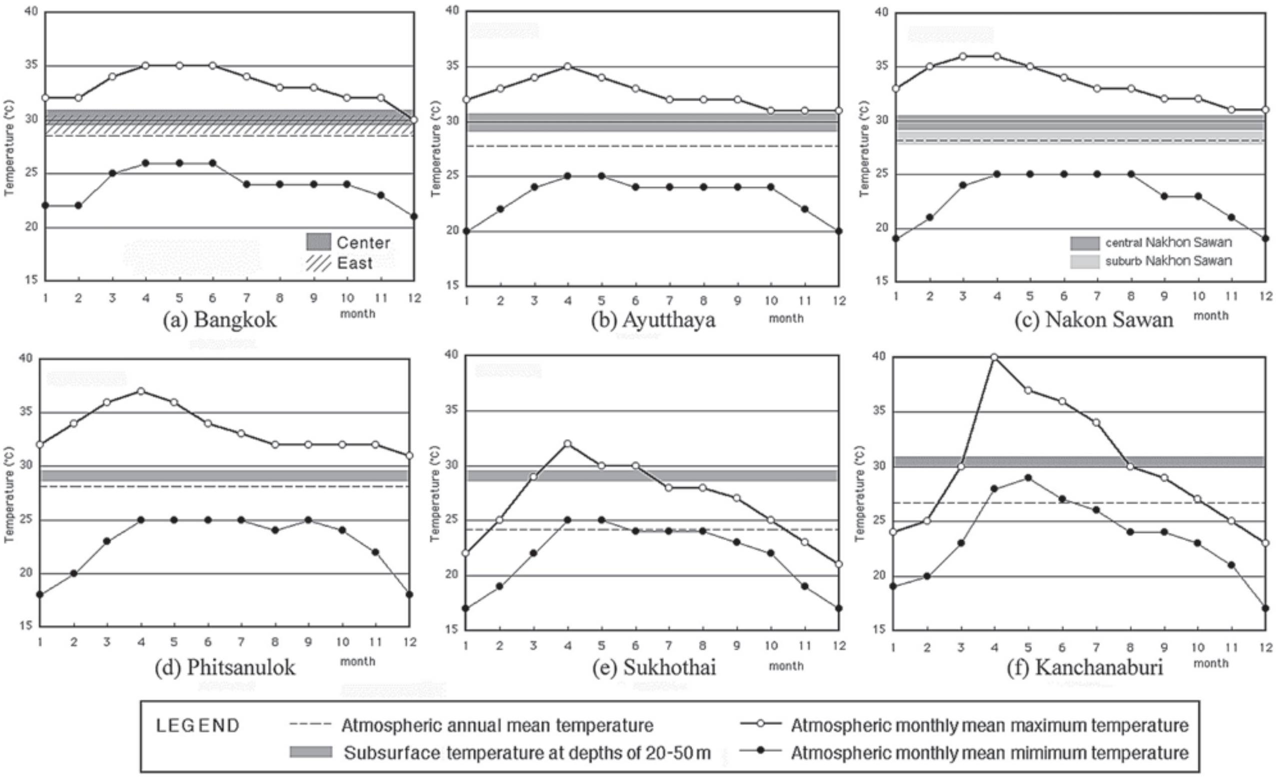

Fig. 7 Comparison of atmospheric and subsurface temperature at each region

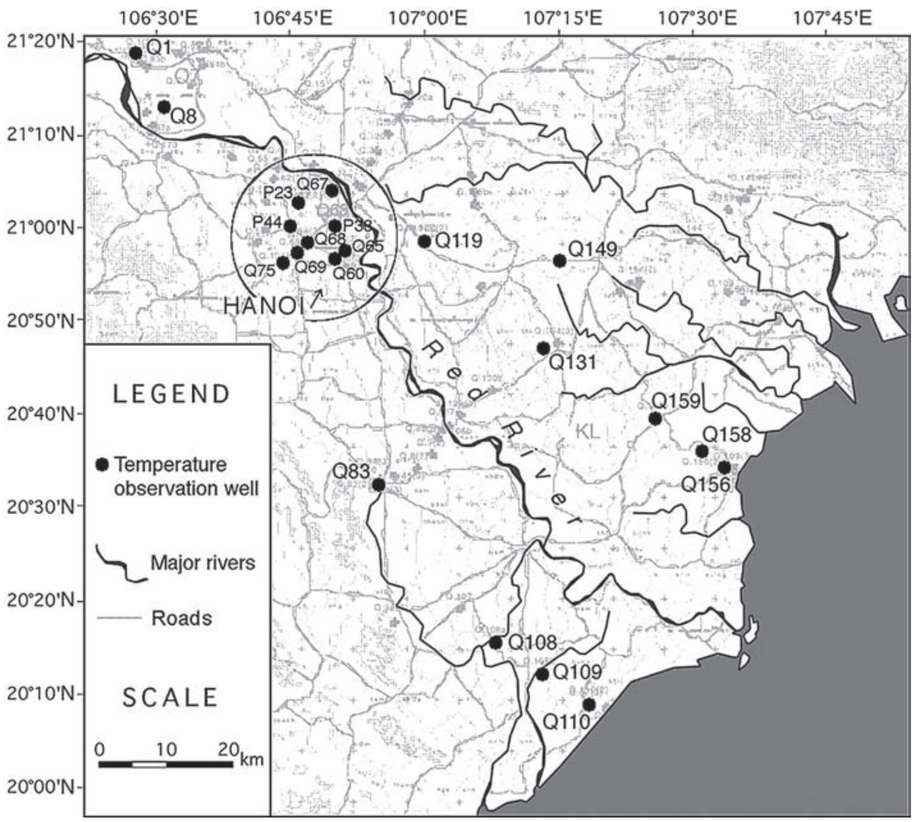

Fig. 8 Locations of temperature observation wells in the Red-river plain

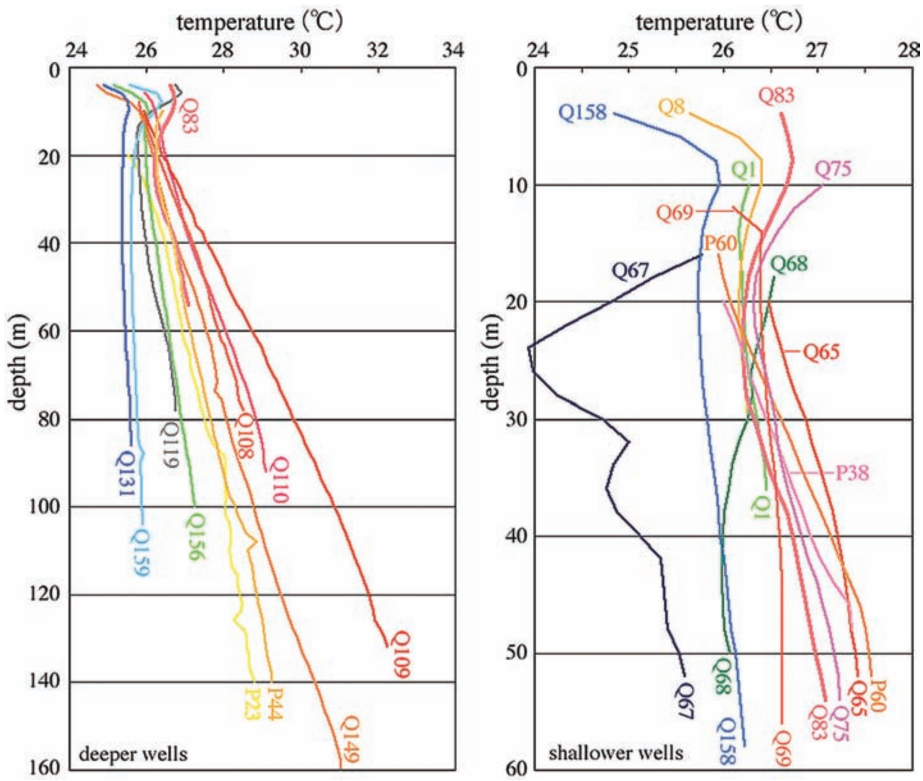

Fig. 9 Temperature profiles of the wells around Hanoi area
Left graph is for deeper wells while right is for shallower ones. Q83 is shown in both graphs as reference.

of the Red River, the wells near the sea (Q156, Q158, Q159) have lower temperature gradient than those in Hanoi. It suggests that the groundwater system in the north is different from that in the south of the Red river. Among the wells in the north of the river, those near the sea have higher temperature gradient than those at inner land such as Q119 and Q131. Q149 has exceptionally high temperature gradient.

Fig. 10 shows monthly change of atmospheric temperature at Hanoi and groundwater temperature at depths of 20-50m, observed at wells shown in a gray circle in Fig. 8. In Hanoi, subsurface temperature is lower than MMMAT from May to October by 2 to 7 K. Therefore, underground may be used as a “cold heat source” in the summer season.

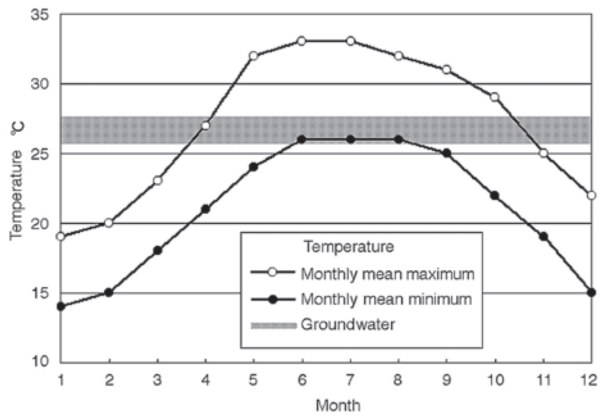

Fig.10 Comparison of atmospheric and subsurface temperature around Hanoi

5. Discussions

Based on the temperature observation results in Thailand and in Vietnam, possibility of geothermal heat pump application for space cooling was identified in some places where subsurface temperature becomes lower than atmospheric temperature in some season or time of a day. For real applications of air-conditioners, operation plans will be important to get higher COP, such as operation hours a day, humidity control and combination with hot water supply. These elements may change the performance of the system.

Generally in a same source temperature condition, a water-source heat pump such as GHP has higher performance than an air-source heat pump such as conventional air-conditioner because of its high heat exchange rate. Nam and Ooka (2008) shows that their open GHP gives higher COP 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, COP of GHP and air-source heat pump may be equivalent when the atmospheric temperature is lower than ground temperature by 5 K. Applying this result onto Figs 7 and 10, a GHP may have higher COP than an air-source heat pump in most places for most seasons in day time.

Hanoi, Vietnam is not a tropical region. However, the observation results obtained in this study would be valuable as base data for potential mapping of GHP applications in this country. On the other hand in the winter season in Hanoi, underground temperature is higher than atmospheric temperature and it can be used as hot heat source. Although winter atmospheric temperature in Hanoi is not very low, humidity is so high that GHP as heating system would be useful for drying. Thus new application of GHP may be found through climatic and subsurface data.

6. Conclusions

Possibility of ground-coupled (geothermal) heat-pump application in tropical Asia is studied based on groundwater temperature data. Groundwater temperature was widely measured in wells in the Chao-Phraya plain, Thailand and in the Red-river plain in Vietnam to be compared with atmospheric temperature data. As a result, regional variation of subsurface temperature of 3.4 K was observed in the whole Chao-Phraya plain and 2.0 K in the Red-river plain at depths from 20 to 50 m. In Nakhon Sawan, Pitsanulok, and Kanchanaburi in Thailand and in Hanoi, Vietnam, subsurface temperature lower than monthly mean maximum temperature for 5 K or more over four months was identified. Also in Bangkok and Ayutthaya, subsurface temperature is lower than monthly mean maximum temperature almost through a year. Thus underground may be used as cold heat-source even in parts of tropical regions. Detailed underground temperature survey is essential for promotion of geothermal heat pump system.

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熱帯アジアにおける地中熱利用のための地下温度調査

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要　旨

今世紀の多大な経済的発展が見込まれる東アジアでは，エネルギーセキュリティと環境保護が大きな課題となると見られる．地中熱ヒートポンプ（GHP）システムの普及は，その両方の問題解決に貢献すると考えられる．GHP 普及のためには，詳細な地下温度分布情報が必要である．そのため，地下水温度データに基づいて，熱帯アジアにおいてのGHP 利用可能性の研究を行った．地下温度は一般的に地表の平均気温よりも高いため，熱帯では一般的に地中熱を冷房に利用することの熱的メリットはないが，場所によっては，地下を「冷たい熱源」として利用できる可能性がある．この可能性を探るため，タイのチャオプラヤ平野およびベトナムのホン川平野において，広く地下水温度調査を行い，気温データとの比較をおこなった．その結果，チャオプラヤ平野では，場所により深度20 ～ 50m の温度範囲が3.4K，ホン川平野では2.0K も変化することが明らかになった．またいくつかの都市では，この深度の地下温度が月平均最高気温より5K 以上低い月が4ケ月以上あることが確認された．従って，熱帯でも場所によっては，地下を冷熱源としてGHP に利用できる可能性が出てきた．