Bulletin of the Geological Survey of Japan, vol.60 (9/10), p.503-509, 2009

Subsurface thermal influence of experimental geothermal heat pump system operation for space cooling in Kamphaengphet, Thailand

Norio Tenma[1], Kasumi Yasukawa[1], Isao Takashima[2], Youhei Uchida[1],
Oranuj Lorphensri[3] and George Zyvoloski[4]

Norio Tenma, Kasumi Yasukawa, Isao Takashima, Youhei Uchida, Oranuj Lorphensri and George Zyvoloski (2009) Subsurface thermal influence of experimental geothermal heat pump system operation for space cooling in Kamphaengphet, Thailand. *Bull. Geol. Surv. Japan*, vol. 60(9/10), p. 503-509, 7 figs, 1 table.

Abstact: An experimental geothermal heat pump (GHP) system operation for space cooling was conducted in Kamphaengphet, Thailand from October, 2006 to March, 2008. Temperature sensors were installed in the heat exchange tube to monitor underground temperature for this test. Using this measured data, numerical simulation was performed in order to estimate subsurface thermal influence of the GHP system operation for space cooling. As the results of this calculation, the authors consider that the thermal influence of the GHP system operation at this test site is quite limited.

Keywords: environmental impact, heat energy storage, closed system, heat pumps, Kamphaengphet, Thailand

1. Introduction

Using natural sources of energy (solar, wind, biomass etc.) may potentially help to mitigate global warming. Low-temperature geothermal resources are among the more abundant natural energy sources. Methods of utilizing low-temperature geothermal resources include both direct use of warm groundwater and geothermal heat pump (GHP) systems.

GHP systems may be subdivided into two basic types. One uses water circulated through a subsurface pipe without direct mass exchange between the pipe and the local groundwater aquifer (“closed system”). The other involves direct withdrawal of heated groundwater (“open system”). GHP systems are popularly used worldwide (Rybach et al., 2000; Fridleifson, 2001; Lund, 2005). In Sweden, the number of GHP system installation per 100 people in 2005 is about two (Curtis et al., 2005).

It is generally considered that GHP systems may be utilized everywhere because of stable temperature of the underground. However, the applicability of the GHP system is not clear for space cooling in tropical region where sufficient temperature difference between underground and atmosphere may not be expected.

Aiming at grasping the applicability of GHP systems for space cooling in tropical region, an experimental operation of a GHP system was conducted at Kamphaengphet, Thailand from October, 2006 to March, 2008 (Yasukawa et al., 2009). The depth of the heat exchange borehole, in which U-tube was installed, was 56m. The authors set temperature sensors every ten meters inside the U-tube (at depths of 0, 6, 16, 26, 36, 46 and 56 meters, respectively). As the detail of the GHP system, the results of temperature measurements and calculation of system performances are presented in Yasukawa et al. (2009) in this issue, we attempted to estimate subsurface thermal influence of the GHP system for space cooling by acquiring temperature data of the underground from this test.

2. Analysis

2.1 The heat energy storage in the underground

In the case of the GHP system for space cooling, heat energy is stored in the underground. The purpose of this study is the estimation of subsurface thermal influence of the GHP system for space cooling in Kamphaengphet. At first, we calculate the heat energy storage at each depth, using temperature monitoring data from temperature sensors installed in the heat exchange tube.

Temperature sensors were set every ten meters inside the U-tube. Inlet/outlet temperatures were measured

---

[1] AIST Institute for Geo-Resources and Environment

[2] Akita University, 1-1 Tegata-gakuen-machi, Akita, 010-8502 Japan

[3] Department of Groundwater Resources (DGR), Rama VI Rd., Ratchathewi Dist., Bangkok 10400 Thailand

[4] Los Alamos National Laboratory, Earth and Environmental Science Division, Los Alamos, NM 87545, USA

at the surface and at depths of 6, 16, 26, 36, 46, and 56 meters, respectively. The differences between inlet and outlet temperatures at the surface and at a depth of 16 m are shown in Figure 1(a) – (b), respectively. As inlet temperature at the ground surface was sometimes lower than the outlet temperature because of mutual effects of daily change of atmospheric temperature and raised subsurface temperature by the GHP system operation, it is difficult to estimate the heat energy storage in the underground from the inlet/outlet temperatures at the surface. Therefore inlet/outlet temperatures at the water saturation zone in the U-tube were used for the calculation. The saturation depth at this test site is around 16 m. Thus the value of heat energy storage is calculated by using the water circulation rate of the primary fluid of the GHP system (circulating between the heat pump and the U-tube) and measured inlet/outlet temperatures at saturation zone. The heat energy E is given by the enthalpy of the water $E_w(t_{inlet})$ and $E_w(t_{outlet})$.

$$E=\{E_w(t_{inlet})-E_w(t_{outlet})\}\cdot q \qquad (1)$$

In this equation, the circulation rate of the primary fluid is $q$kg/s, temperature at the inlet of U-tube is t_{inlet} ^{o}C, and that at the outlet is t_{outlet} ^{o}C. The result of the calculation for 16m deep is shown in Figure 2. The heat energy storage in the underground was about 40 W/m during the term of the GHP system operation. The ratio of heat energy storage between 26m deep and 16m deep, 36m deep and 16m deep, and 46m deep and 16m deep during the term of the GHP system operation are shown in Figure 3. The ratio of heat energy storage between 26m deep and 16m deep are about 70 % in the first half period. But the ratio changes to about 40 % at the second half period. We change the operation condition of the GHP system, such as the temperature range and mode of fluid circulation (continuous or intermittent), in order to estimate the performance of GHP system during the experiment (Yasukawa et al.,2009). Thus, it may be because of influences of a long term operation and heat energy storage by different temperature settings of heat pump operations.

2.2 The step from the modeling to the estimation of environmental impact

The heat energy storage calculated from the measured data was about 40 W/m. Aiming at estimation of the thermal influence by such a GHP system operation for space cooling, a numerical simulation of heat storage was performed. During temperature measurements of the underground since October 2006 to March 2008, the GHP system operation was temporally stopped several times. Therefore, we consider these breaks as temperature recovery periods. Thus, we optimize the physical properties of the simulation model by using the measured data during the stopping period of the system. Steps for the environmental impact evaluation are as follows.

1) Assume that the break periods of the GHP operation are those of thermal recovery tests
2) Construct a 3D numerical model including the U-tube as shown in Figure 4
3) Compare calculated temperatures with measured temperatures during the test
4) Investigate model properties (groundwater flow rate, thermal conductivity, etc) to obtain a reasonable match of measured and calculated temperatures
5) Evaluate subsurface thermal influence of the GHP system for space cooling from October 2006 to March 2008, using the optimum properties for modeling

Subsurface layers of this place are clayey and sandy. Thus, some property values are referred from previous model studies (Tenma et. al., 2003, Tago et. al., 2004). For the simulation, a numerical code FEHM (Finite Element Heat and Mass transfer) was used (Zyvoloski et al., 1997). In FEHM code, the conservation equations of heat and mass in a porous media are solved by the control volume finite element method.

2.3 The results of temperature recovery

Examples of the temperature recovery at sensors inside the U-tube are shown in Figure 5. The upper figure shows the temperature at a depth of 46m, and the lower does of 36m. The period of this thermal recovery test was from February 9, 2007. Also, we assume the fluid flow at this site is steady flow. To investigate the effect of groundwater flow, three different conditions for groundwater flow rate (high, low and zero) were introduced in the simulation as shown in Table 1. For both cases at a depth of 36m and 46m, calculated temperatures for all conditions get good matches with the observed data. Condition 3 (no flow model) particularly is a best match of measured and calculated temperature in earlier period of the thermal recovery test. Because the effect of groundwater flow is small as shown in the result of this calculation, the authors assume that the thermal advection effect of the groundwater flow is small at this site.

3. Estimation of the thermal influence

As Condition 3 is no thermal advection effect of the groundwater flow at this test site, the thermal influence by the heat energy storage in the underground is larger than other conditions. Using the model and simulation condition 3 (Table 1) in order to estimate the thermal influence, which was developed on the basis of the results of thermal recovery test, the temperature of underground at this test site was calculated for 1.5 years. The temperature changes at depth of 36m measured

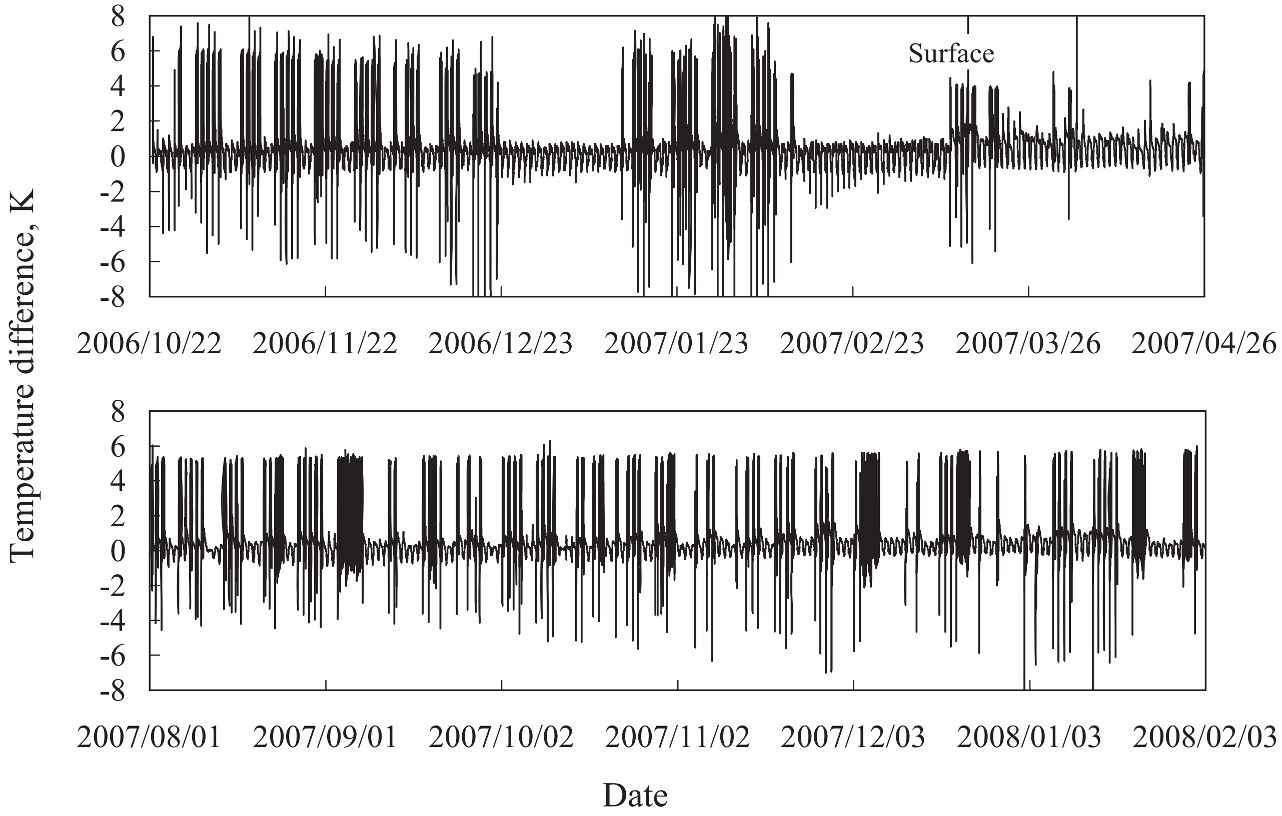

Fig. 1(a) Difference between inlet and outlet temperature at the ground surface

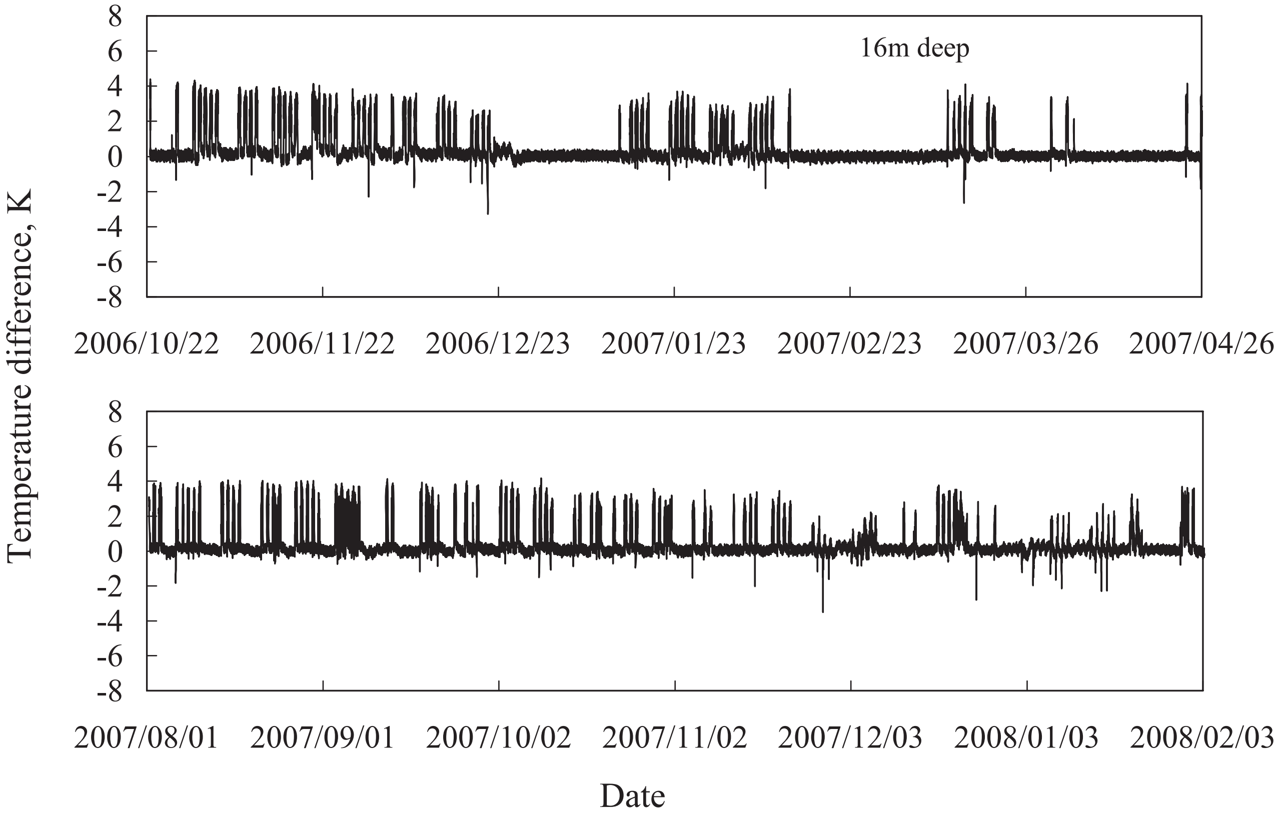

Fig. 1(b) Difference between inlet and outlet temperature at depth 16m

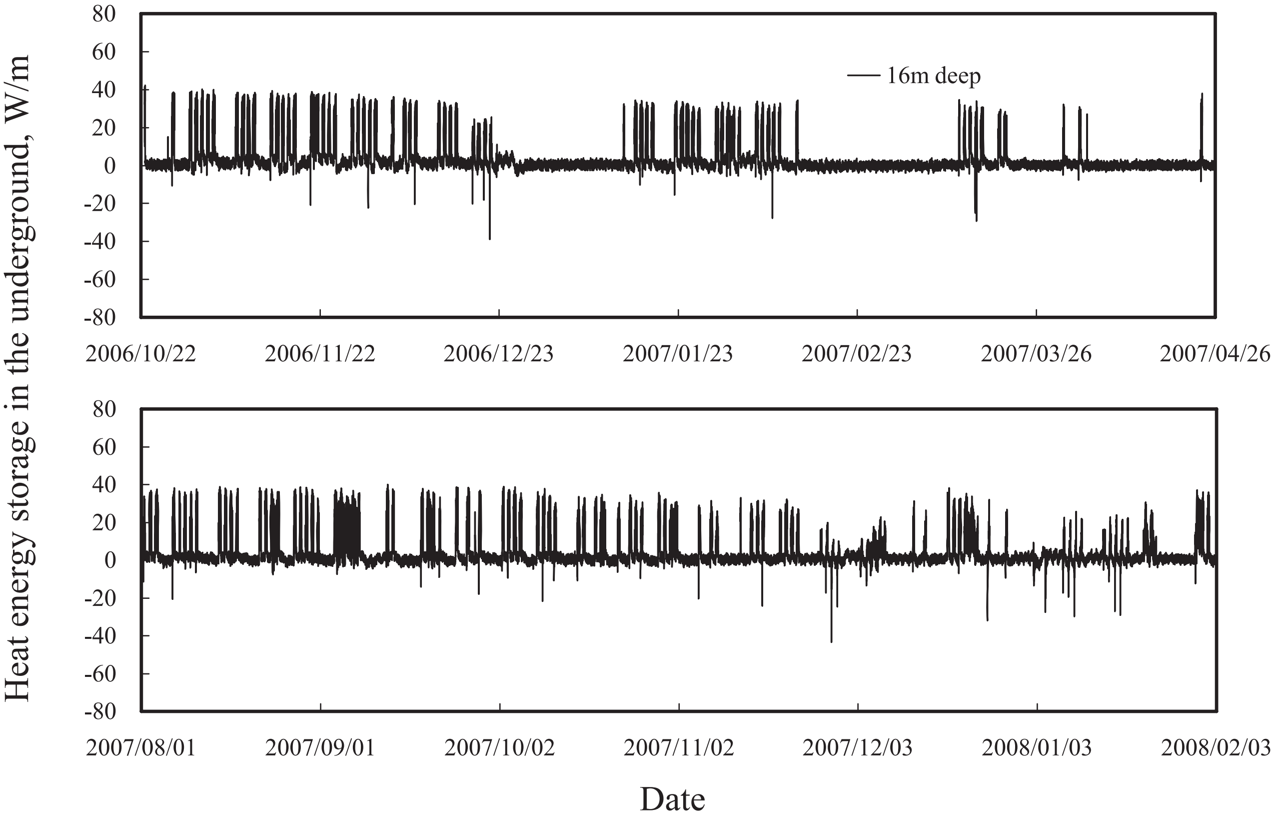

Fig. 2 Heat energy storage from heat exchange tube at a depth of 16m

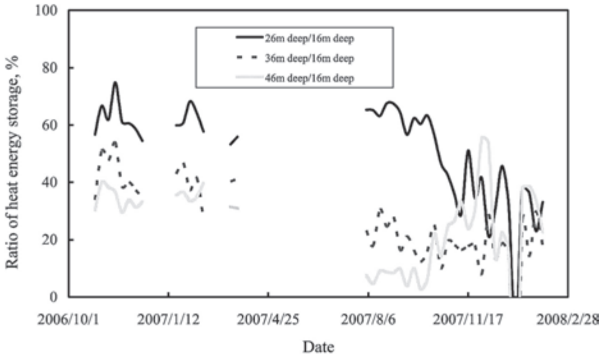

Fig. 3 Ratios of heat energy storage

inside the U-tube and calculated for its surroundings at 0.5m and 2.0m apart, respectively, are shown in Figure 6. Since no remarkable temperature variation in the U-tube was observed for 1.5 years, it was assumed that the increase of calculated temperature at 0.5 m apart from the U-tube might be small. Variation of the temperature at a point 0.5 m apart from the U-tube is approximately 1 K for 1.5 years. Similarly, temperature at a point 2.0 m is almost constant. As the results of this calculation, the authors consider that the thermal influence of the GHP system operation at this test site is quite small.

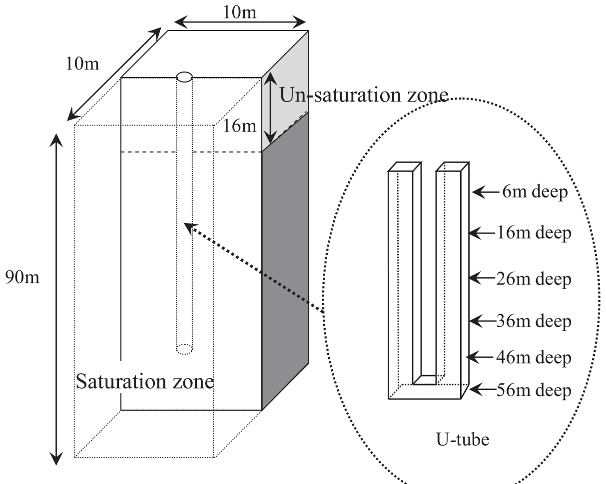

Fig. 4 Simulation model of the GHP system for space cooling Temperature sensors were set every ten meters inside the U-tube

4. Future task

A 3D numerical model including the U-tube was constructed in this study. The calculation results show that the subsurface thermal influence of the GHP system operation at the test site is quite limited. In the future, we plan to study the sensitivity analysis for different operation conditions of the GHP system for space cool-

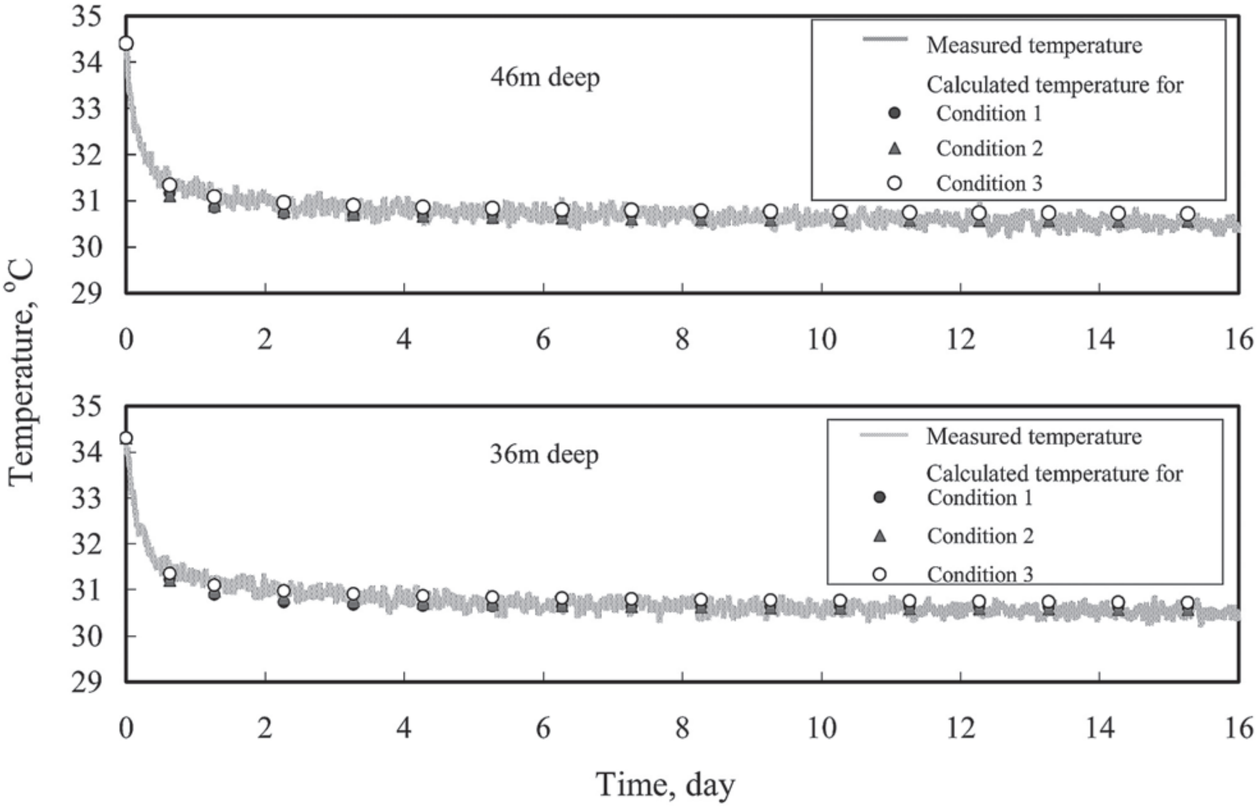

Fig. 5 Comparison between calculated and measured temperatures inside the U-tube. The upper is of 46m deep and the lower is of 36m

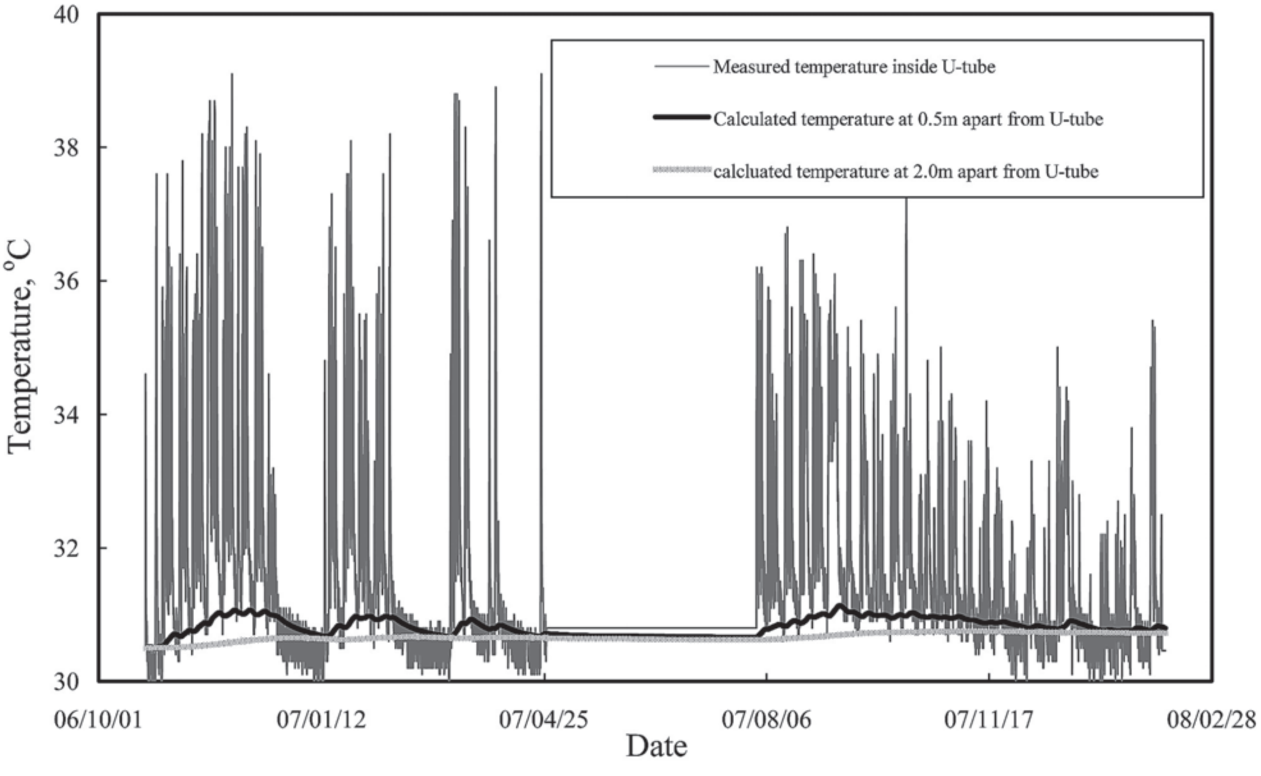

Fig. 6 Temperature histories at a depth of 36m: measured inside the U-tube and calculated by FEHM for surrounding points

Table 1 Simulation conditions for thermal recovery test

	Groundwater flow rate	Thermal Conductivity	Specific heat
Condition 1	10^{-5} m/s	1.1 W/(m/K)	1230 kJ/kg K
Condition 2	10^{-6} m/s		
Condition 3	Zero		

ing, and evaluate the subsurface thermal influence at the test site for each condition.

Acknowledgments: This study has been conducted by international collaboration of AIST Japan and DGR (Department of Groundwater Resources), Thailand. The authors wish to thank Mr. Tetuya Ishizuka and other members of this project for their kind advice and cooperation during this study.

References

Curtis, R., Lund, J., Sannar, B., Rybach, L. and Hellstrom, G. (2005) Ground source heat pumps-Geothermal energy for anyone, anywhere: Current worldwide activity. *Proc. WGC2005*, 3456-3464.

Fridleifson, I.G (2001) Geothermal energy for the benefit of the people. Renewable and Sustainable Energy Reviews 5, 299-312.

Lund J.W. (2005) Worldwide utilization of geothermal energy–2005. *Geothermal Resources Council Transactions*, 29, 831-836.

Niibori, Y., Iwata, Y., Mori F. and Fukaya, G. (2002) A study on relation between groundwater flow and design of ground-coupled HP system with borehole, *Journal of Geothermal Research Society of Japan*, pp.339-348, 24, No.4 (in Japanese with English abstract)

Rybach L., Brunner M. and Gorhan H.(2000) Swiss geothermal update 1995 – *2000. Proc. WGC 2000 Kyushu – Tohoku, Japan*, May 28 – June 10, 413-426.

Tenma, N., Yasukawa K. and Zyvoloski, G. (2003) Model study of the thermal storage system by FEHM code , *Geothermics*, 32, 603-607

Tago, M., Morita, K., Sugawara, M., Fujita, T. and Iwasashi, T. (2004) Heat extraction characteristics of a double U-Tube downhole heat exchanger, *Journal of Geothermal Research Society of Japan*, pp.317-331, 26, No.4

Yasukawa, K., Takashima, I., Uchida, Y., Tenma, N. and Oranuj L. (2009), Geothermal heat pump application for space cooling at Kamphaengphet, Thailand, *Bull. Geol. Surv. Japan*, 60, 491-501.

Zyvoloski, G. Dash Z. and Kelkar S. (1992) FEHMN1.0: Finite Element Heat and Mass Transfer Code : LA-12062-MS, Rev.1, Los Alamos

Received March, 04, 2009
Accepted May, 28, 2009

カンペンペット（タイ）における地中熱ヒートポンプ冷房利用の実証試験における地下環境評価について

天満則夫・安川香澄・高島　勲・内田洋平・オラニュー ロルペンスリ・ジョージ ジボロスキー

要　旨

地中熱利用ヒートポンプシステムの冷房利用の実証試験がカンペンペット（タイ）にて2006年10月から2008年3月まで実施された．熱交換井に13の温度センサーを設置して地下温度の温度計測が行われた．そこで，この実験データを用いて，周辺の温度影響に関する数値計算を行った．その結果，運転実績に伴う地下温度場への影響はほとんどないことがわかった．