SYSTEM PERFORMANCE OF A GEOTHERMAL HEAT PUMP FOR SPACE COOLING AT KAMPHAENGPHET, THAILAND

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ABSTRACT

An experimental geothermal heat pump system for space cooling was installed in Kamphaengphet, Thailand, in October 2006 and was operated for 17 months. Temeprature changes in the heat exchange borehole were measured through the period to evaluate the subsurface thermal properties and effects of short and long term operation of the system onto subsurface thermal environment. Temperatures of secondary fluid, room and atmosphare, were also measured through the period. The electricity comsumption and flow rate of secondary fluid were also measured to evaluate coefficient of performance (COP) of the system. The results of temperature measurements and calculation of system performances will be presented in this paper.

Keywords: geothermal heat pump, Coefficient of performance (COP), space cooling, Kamphaengphet, Thailand

1. INTRODUCTION

Geothermal heat pump (GHP) system may be a powerful alternative to reduce energy consumption and to contribute to environmental issues. Its intensive utilization may reduce emissions of CO_2 and other toxic gases by replacing fossil fuel boiler into GHP. It may also greatly contribute to solve the problem of urban heat island (UHI) phenomenon. Combination of high performance of GHP and reduction of UHI may result in a few percent of saving electricity for air conditioner in highly populated cities.

GHP is generally not appropriate for space cooling in tropical regions: since subsurface temperature is generally higher than year-average atmospheric temperature and atmospheric temperature is almost constant through a year in tropics, underground may not be appropriate as “cold heat-source”. However, according to the result of groundwater temperature survey in the Chao-Phraya plain, Thailand, subsurface temperature is lower than daytime atmospheric temperature for 5K or more over four months in several cities (Yasukawa et al., 2006). Thus underground may be used as cold heat-source even in parts of tropical regions, which have seasonal temperature changes.

A GHP system, a borehole heat exchanger, a heat pump and a fan-coil, was installed for room cooling in Kamphaengphet in October 2006 and operated for 17 months. Temperatures at a various depths in the heat exchange well, those of secondary fluid, room, and atmosphare, were monitored during operation. The results of temperature measurements and calculation of system performances will be introduced in this paper. Although shallow subsurface temperature in Kamphaengphet is rather high and not quite suitable for a cooling system, the experimental results can be applied for other regions. Thus places more suitable for GHP system will be found as a result of this experiment and regional groundwater survey.

2. THE GHP SYSTEM AND THE TEMPERATURE MEASUREMENT SYSTEM

Fig. 1 shows the installed GHP system. A heat exchange borehole was drilled to a depth of 56 m. Two sets of plastic heat exchange tubes, called double U-tubes were installed into the borehole. Grouting with bentonite was performed as water table exists at a depth of 17 m and no thermal contact between U-tubes and surrounding soil at shallower part.

The capacity of the heat pump is 1.5 HP (Horse Power). The GHP system consists of two closed fluid (water) circulation systems: primary fluid circulation between borehole and heat pump and secondary fluid circulation between heat pump and fan coil, respectively. During cooling operation of the room, the primary fluid pushed by a water pump from an outside

water tank goes into the heat pump, gains heat from the secondary fluid, then goes down into the borehole through

U-tube. Releasing heat into the soil, it finally comes back to the outside water tank. The secondary fluid pushed by another water pump from inside water tank goes into the heat pump, releases heat into the primary fluid, and goes into fan coil to cool the room. So it gains heat and finally comes back to the inside water tank. Diameter of the pipes is 2.0 cm.

Through the experiment period, the GHP system was manually switched on in the morning and off in the evening on weekdays. Only a few times it was continuously operated for several days. During operation, its thermostat switch was controlled by inlet fluid temperature of the fan-coil (= outlet fluid from the heat pump). The range of fan-coil inlet temperature was controlled by operational settings of the heat pump, as maximum and minimum temperatures: the heat-pump began cooling when the inlet temperature reached the max., and stopped if it reached the min. temperature. These settings in each period will be shown in Fig. 6.

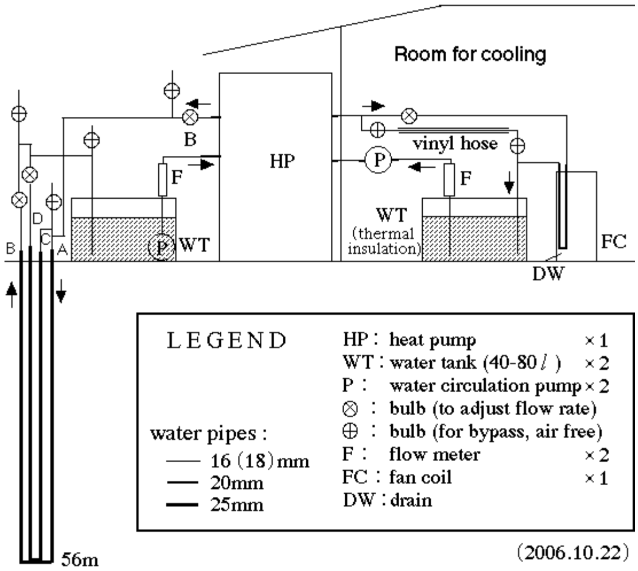

Fig. 1. Kamphaengphet GHP system

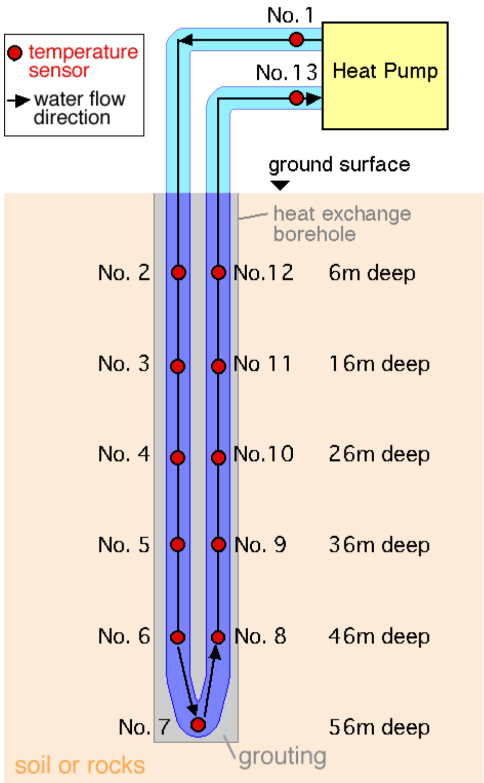

Fig. 2 Cross-sectional view of temperature sensors in the heat exchange tube

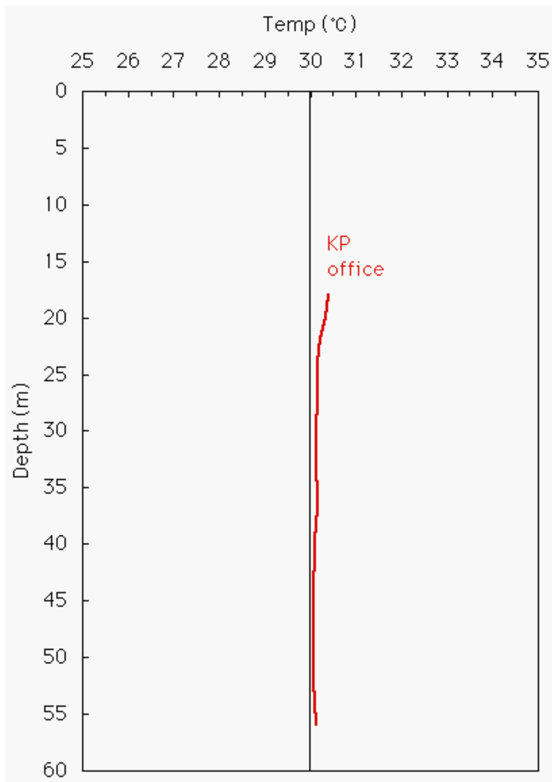

Fig. 3 Temperature profile in a well at Kamphaengphet office

Fig. 2 shows cross-sectional (vertical) image of the heat exchange U-tube, indicating locations of temperature sensors, which are set every 10 m inside the tube. For simplicity, only single U-tube is shown in this figure although double U-tubes were installed into the borehole. Therefore, fluid circulates into another U-tube between sensors No. 12 and No. 13. No temperature measurement was conducted in the second U-tube. Despite sensors for inlet/outlet of fan-coil are covered by thermal insulation material and No. 1 and No. 13 are installed inside the pipe, temperature values of these sensors may be affected by atmospheric temperature, especially when the heat-pump operation is stopped (no fluid circulation).

Note that the subsurface temperature in natural state at this site is quite homogeneous. It is between 30.0 and 30.5 ^{o}C from a depth of 17 to 56 m, as shown in Fig. 3.

3. TEMPERATURE MONITORING RESULTS

3.1 Subsurface Temperature

Fig. 4 shows all temperature monitoring results. Operation hours of the heat pump can be identified by temperature increase at Nos. 1 - 13. The temperature change at No. 1 (red) is most prominent because it is of the primary fluid immediately after receiving heat from the secondary fluid in the heat pump. Such temperature increases are higher in the first period (from the beginning to March 2007) because of the settings of thermostat with wider temperature range. It causes a longer running period and larger temperature increase for both primary and secondary fluids.
Temperature at No. 7 (green color) is lowest among those in U-tube because it is of the bottom hole where the heat from the secondary fluid has been already reduced by the heat conduction to the soil. Temperatures at Nos. 8-12 are higher than that at No. 7, although the heat has been already reduced. It is because the tubes in the borehole are so close each other that the heat from another pipe may affect. For example, temperature of No. 4 affects on No. 10.

Higher temperature at shallower part of the borehole may be caused by fluid circulation in the U-tube. Temperatures at Nos. 1 and 13 are largely affected by atmospheric temperature when the system operation is stopped. Those at Nos. 2 and 12 are also affected by atmospheric temperature.

In order to investigate the effect of long-term operation on subsurface temperature, the result for No. 13, the deepest sensor is used. Fig. 5 shows the temperature recovery at No. 13 after stopping GHP operation in different periods. Since No. 13 has bigger drift because of it's longer wire-cable, 24-hour average is used to represent the temperature value of a day. Day 0 is the final day of successive operation of the system (repeat of switch on in the morning and switch off in the evening).

Data with the symbol of * show the case in which operation was continued (no switch off in the evening) for longer than 3 days. For the case of 12 February 2007 (red), which has the longest recovery period, temperature at the beginning of 33.0 ^{o}C decreased to 30.5 ^{o}C in ten days. Assuming the original temperature was 30 ^{o}C (cf., Fig.6), 85% of temperature increase was recovered in ten days.

No significant difference is identified between temperature recoveries on 21 December 2006 (pink) and on 28 December 2007 (green), which are in the same season of different years. It suggests that no clear effect of long-term GHP operation occurred.
In case of 7 September 2007 (purple), temperature level is higher because of continuous operation for five days. However, its successive period after one-day operation (13 September 2007, blue), temperature recovered to a level equivalent to the other period.

3.2 Surface Temperature and COP

Fig. 6 shows surface temperature monitoring results, flow rate of the secondary fluid, cumulative electricity consumption, total operation hours, and COP. Since the temperature sensor was attached to the outside inlet pipe but not inserted into the pipe, range of measured temperature values for fan-coil inlet (light purple dot in Fig. 6) is slightly higher than that of temperature settings, affected by the higher air temperature of the room.

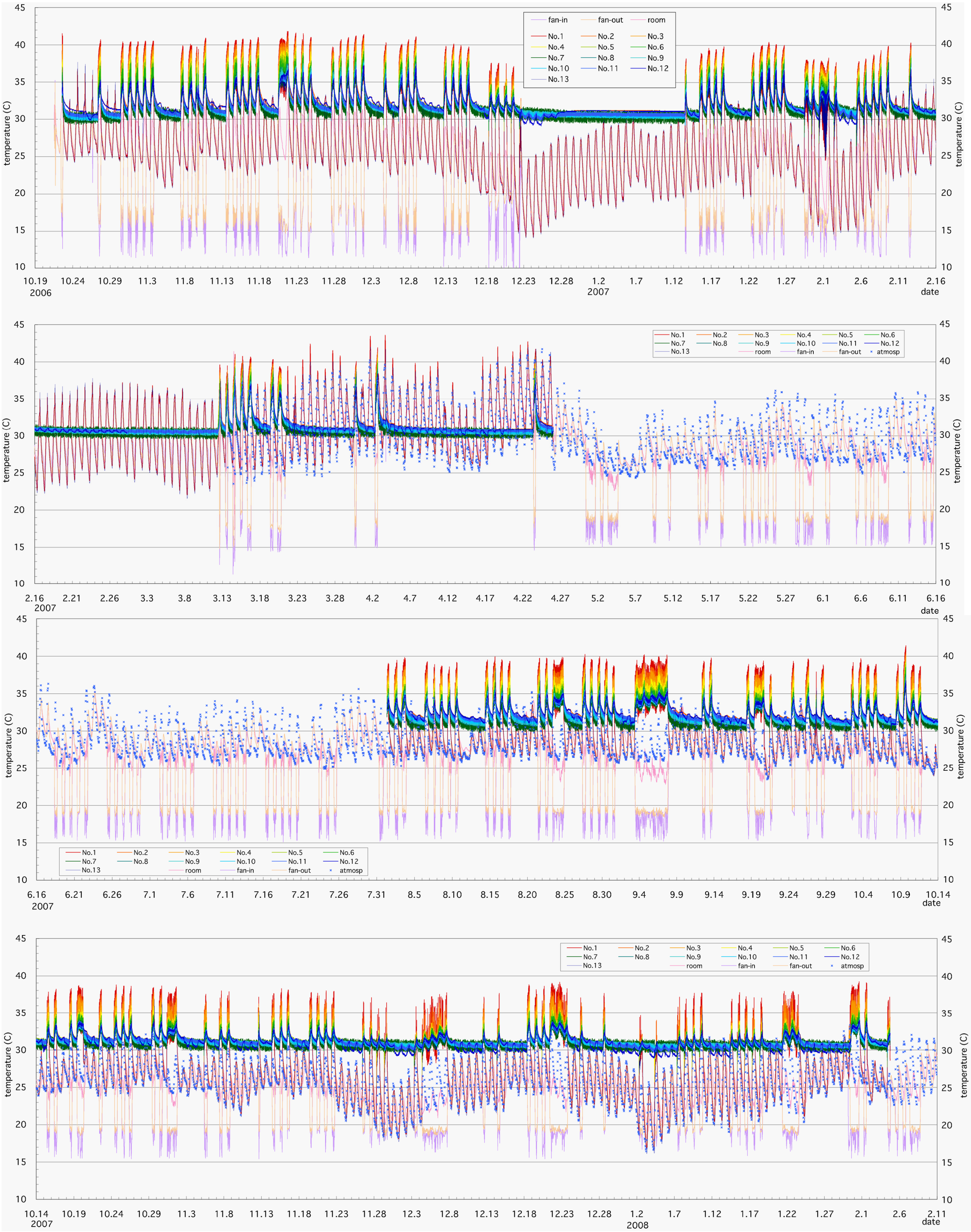

Fig. 4 Results of temperature monitoring

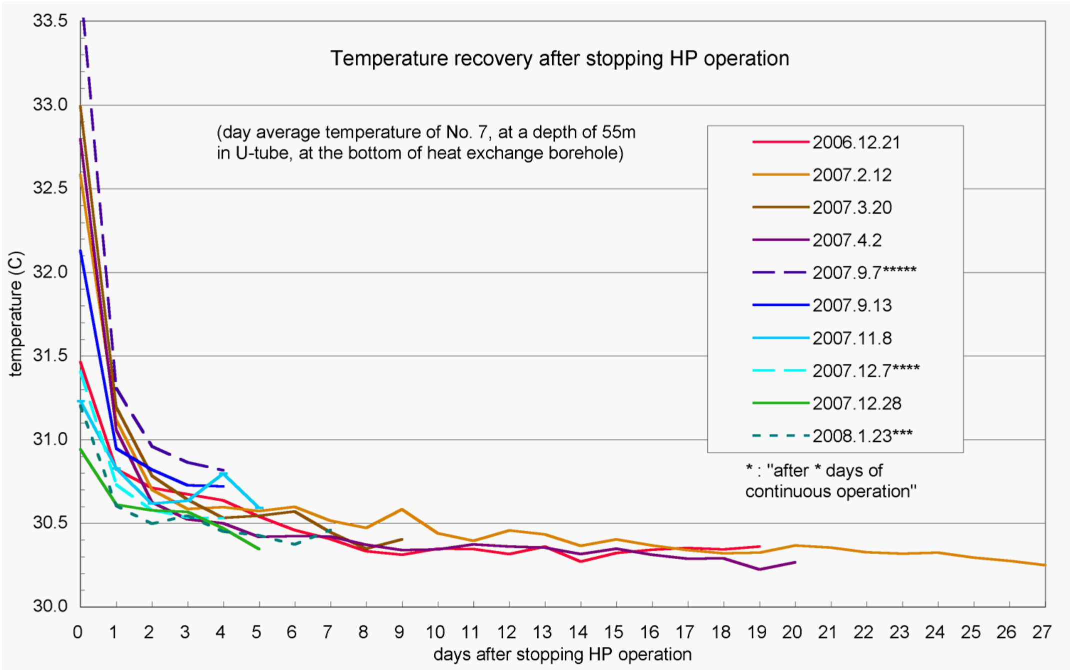

Fig. 5 Temperature recovery at No. 13 sensor after stopping GHP operation

Air temperature of the room, in which the fan-coil was installed, is shown by yellow and blue dots: yellow is for the period when the heat pump was switch-off while blue is for switch-on. For the first five months, the room temperature during heat-pump operation (blue) stays in higher level than that without operation (yellow) because it was operated only in daytime when the atmospheric temperature is high and its corresponding room temperature is also high. That indicates the room was not cooled by the system effectively. A large difference between maximum and minimum temperatures caused long stand-by periods during operation, which made room temperature increase. After the settings have been changed on 21 March 2007, the room temperature during operation stays in lower level, indicating that the room was cooled by the system effectively. In this period, room temperature was kept from 23 to 28 ^{o}C, while outside temperature was from 30 to 35 ^{o}C.

Atmospheric (outside) temperature is shown by green dot in Fig. 6. The temperature sensor was hanged outside near the window of the room under a shade. This measurement has started only on 21 March 2007. Generally its value is higher than room temperature during daytime and lower in nighttime. Daytime temperature under sunshine must be higher than this observed temperature.

Flow rates of primary and secondary fluids, Q_1, Q_2, respectively, were measured four times. Q_1=14.5 and Q_2=12.5 L/min on 19 October 2006 and 15 March 2007, Q_1=11.0 and Q_2=10 L/min on 1 August, 2007 and 18 March 2008. The flow rates decreased probably because of degradation of water pumps after 6 months of use. For calculation of COP, missing values of Q_2 was linearly interpolated with time as shown in Fig. 8 as light blue line.

The red line in Fig. 6 shows the total operation hours of the system. The pink squares show the cumulative electricity consumption on 20 March 2007, 1 August 2007 and 17 March 2008, respectively. Pink line shows the estimated value from operation hours linearly interpolated for each period between squares. Comparing the inclinations of red and pink lines, the rate of electricity consumption is lower in the later period. It may be because the proper settings of inlet temperature of the fan-coil reduced the electricity consumption. In Fig.5, temperature at No. 1 often rises over 40 ^{o}C in the first six months while it stays under 40 ^{o}C in the later period. High temperature of the primary fluid may reduce the efficiency of heat pump,

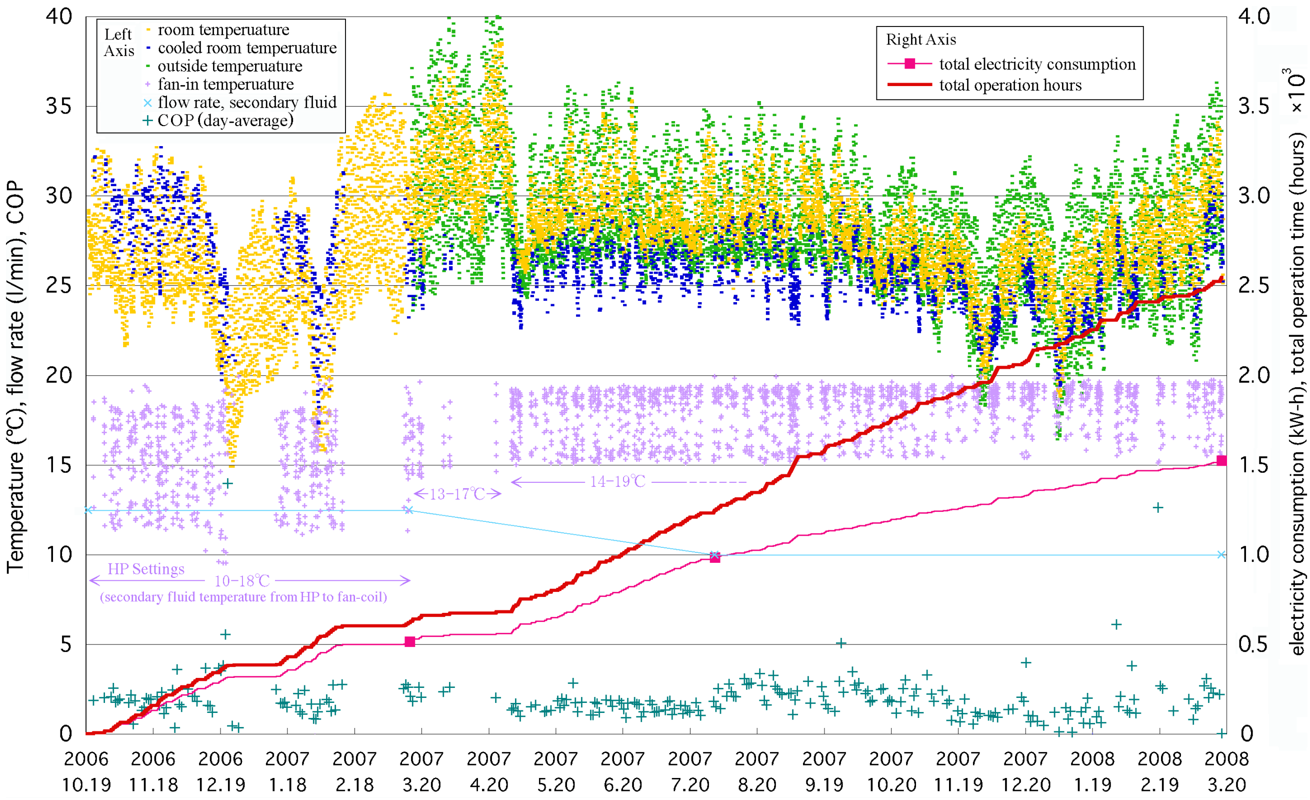

Fig. 6 Observed temperatures, electricity consumption, and COP

This phenomenon is clearly shown in Fig. 7, which shows electricity consumption on days from 13-15 March and 1-2 August, 2007. In March, when the fan-coil temperature setting was 10-18 ^{o}C, the electricity consumption rate was around 1.2 kW, while that was around 0.6 kW in August with temperature setting of 14-19 ^{o}C. Since atmospheric temperature is in the same level in these periods (28–37 ^{o}C on 13-15 March and 26–35 ^{o}C on 1-2 August), this difference may be simply caused by the different settings.

Considering this effect of temperature settings, linear interpolation of electricity consumption with operation hours would not be appropriate for the period between 20 Match and 1 August 2007 because the temperature setting has been changed since 30 April 2007. Electricity consumption rate from 30 April to 1 August 2007 may be the same level as that from 1 August 2007 to 18 March 2008, while that from 20 March 2007 to 30 April 2007 may be higher than what was shown in Fig. 6. It may affect on COP values.

The blue-green "+" symbol in Fig. 6 shows the coefficient of performance (COP) of the system. COP was calculated as follows;

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

where,

T_{outlet} : fan-coil outlet temperature

T_{inlet}: fan-coil inlet temperature

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

W_e : electricity consumption per unit time.

Change of T_{outlet} is shown in Fig. 5, while T_{inlet} is shown in both Fig. 5 and Fig. 6. Flow rate of the secondary fluid, Q_2 is shown as light blue line, and W_e is shown as pink line in Fig. 8, respectively.

COP values around 2 are obtained for period from 30 April 2007 to 1 August 2007 and around 3 are for period from 1 August 2007 to 19 November 2007. Considering the uncertainty of electricity consumption rate in the former period, rather stable atmospheric temperature and constant inlet temperature settings for these periods, COP in the former period may be higher, if the electricity consumption rate is lower. Thus the COP value for a stable operation period may be around 3.

COP is quite low from 19 November 2007 to 19 January 2008 when the atmospheric temperature is lower than 30 even in daytime. Considering that the recommended temperature setting for an air-conditioner for energy saving is 28^{o}C, it may better not use the cooling system when the atmospheric temperature is lower than 30 ^{o}C.

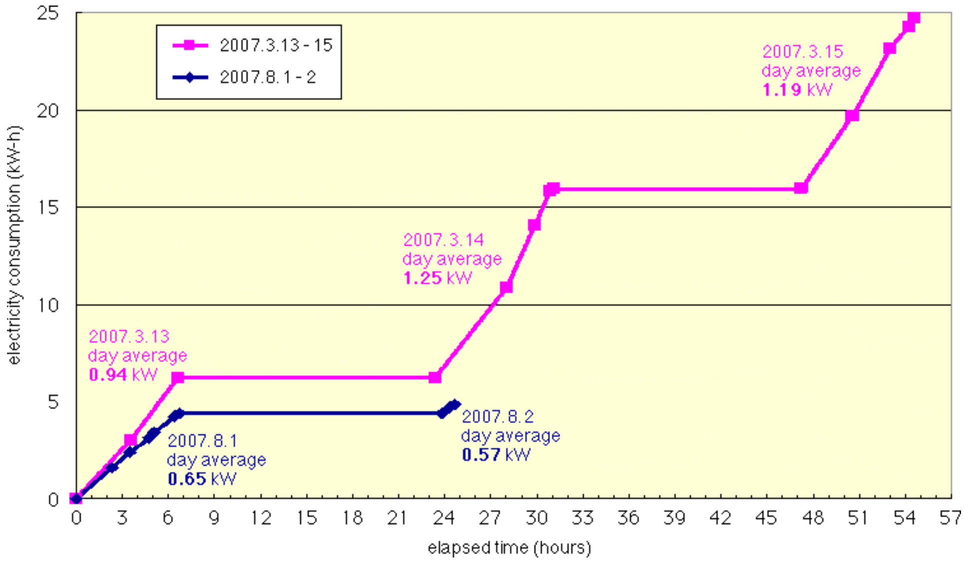

Fig. 7 Electricity consumption during cooling operation

4. DISCUSSIONS FOR BETTER SYSTEM PERFORMANCE

This experiment in Kamphaengphet proved that such a system can be continuously used in tropical region for space cooling only. However, for more practical application, higher efficiency may be required to make the system cost and performance competitive. For higher performance, following improvement may be done.

- Length of heat exchange pipe may be extended for further release of heat into the ground to keep the temperature of primary fluid lower. Lower temperature of the primary fluid may allow higher performance for different temperature settings of the secondary fluid. To reduce the drilling cost for a longer heat exchange pipe, combination of horizontal and vertical geometries of pipes may be applied.

- Diameter of the pipes for both primary and secondary fluid circulations may be enlarged to reduce inside friction and increase flow rates. Higher flow rate may encourage heat transfer from fan-coil to secondary fluid, from secondary fluid to primary fluid, and from primary fluid to soil, which may result in higher performance of the system,

- Different operational settings may change the system performance as we have seen for inlet temperature of the secondary fluid. The system may better shut down when the outside temperature is lower than 28 ^{o}C. Operational devises, such as using heat from primary fluid for hot water supply will reduce the temperature increase of primary fluid, which may lead to higher efficiency.

- Choice of the place is another factor. Lower subsurface temperature and existence of ground water flow may allow higher heat exchange rate in the borehole. For promotion of GHP system, places which are more suitable for GHP system should be selected based on subsurface temperature and hydro-geological information.

5. CONCLUSIONS

A GHP system was installed to a building at Kamphaengphet, in October 2006. This system was experimentally used as a space cooling system for 17 months, till March 2008. Temeprature changes in the heat exchange borehole, at inlet and outlet of heat pump, and of room and atmosphare, and electricity comsumption were measured. The results of this experiment are summarized as follows;

- 85% of temperature increase in heat exchange well was recovered in ten days after stopping operation.
- A successive operation of the system causes temperature increase in the heat exchange well even at the bottom hole, but it recovers in a week after operation has stopped.
- No long term subsurface temperature increase occurred over a year of operation.
- For effective cooling of the room, proper setting of heat pump operation is necessary. Difference between maximum and minimum temperatures of the inlet fluid should not be bigger than 5K.
- With a proper setting of operation, room temperature was kept from 23 to 28 ^{o}C, while outside temperature was from 30 to 35 ^{o}C during the period.
- The electricity consumption rate was around 0.6 kW with proper settings of operation.
- The COP value for this stable operation period was around 3.

Thus applicability of GHP in Thailand is confirmed by this experiment. For more effective utilization with better cost performance and COP, some adjustment of the system would be necessary.

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