Geothermal heat pump application for space cooling
in Kamphaengphet, Thailand

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Abstact: An experimental geothermal heat pump system for space cooling was installed in Kamphaengphet, Thailand in 2006 and used for 17 months. Temeprature changes in the subsurface heat exchange tube and its surroundings were monitored to evaluate subsurface thermal properties and short- and long-term effects of operation of the system. Subsurface temperuatre increase due to the system operation recovered in few days and no long-term effect was observed after a year of operation. Room and atmospheric temperatures and electricity consumprion of the system were also measured through the period. Temperatures and flow rates of primary and secondary fluids were measured as well. As a result, a system COP (coefficient of performance) of around 3 was obtained for its stable operation period. The results of temperature measurements and calculation of system performances is presented in this paper.

1. Introduction

Geothermal heat pump (GHP) system for heating and cooling purposes may be 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 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., 2009, in this issue). Thus underground may be used as cold heat-source even in parts of tropical regions.

A GHP system, borehole heat exchanger, heatpump and fan-coil, was installed for room cooling in Kam-phaengphet, Thailand. Temperatures in the subsurface heat exchange tube and of secondary fluid, etc., were monitored during operation of the system. The results of temperature measurements and calculation of system performances are introduced in this paper. Capacity of the subsurface heat exchange system is presented in Tenma et al. (2009) in this issue.

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 its operation

A GHP system was installed at a building of DGR in Kamphaengphet, in October 2006. This system was experimentally used as a room cooling system for 17 months, till March 2008. Figs. 1 and 2 show the installed GHP system. A heat exchange borehole was drilled to a depth of 56 m. Two sets of plastic heat exchange tubes, so called double U-tubes were installed to the borehole, as shown in the down-right of Fig. 2 as dark pipes. Since water table in this borehole is at a depth of 17 m and no thermal contact between U-tubes

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and surrounding soil exists at shallower part, grouting of the borehole with bentonite was performed.

The capacity of heat pump in this system is 1.5 HP (horsepower). The GHP system consists of two fluid (water) circulation systems: primary fluid circulation between borehole and heat pump, and secondary fluid circulation between heat pump and fan coil, both closed systems in pipes with a diameter of 2.0 cm. During cooling operation of the room, the primary fluid pushed by a water pump in an outside water tank goes into the heat pump, gains heat from the secondary fluid, then

goes down into the borehole through U-tubes. Releasing heat into the soil, it finally comes back to the outside water tank. The secondary fluid pushed by another water pump beside an 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.

Through the experiment period, the GHP system was manually switched on in the morning and off in the evening on weekdays. Only sometimes 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). This controlling temperature will be described in chapter 6 and shown in Fig. 8.
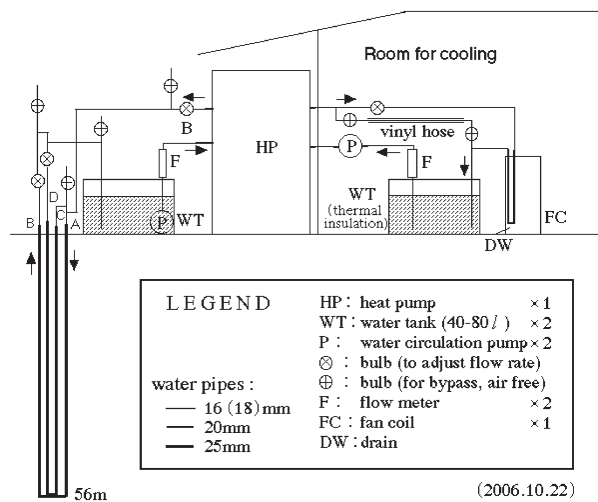
3. Temperature monitoring during operation

Figs. 3 and 4 show the geometry of temperature sensors. Fig. 3 shows plan view of temperature sensors buried in the soil around the heat exchange borehole. Horizontal distances from the borehole to sensors N1, E1, S1, W1, NE, NW, SE, and SW are all 1 m. Those between N1 to N2, E1 to E2, S1 to S2, and W1 to W2 are also 1 m. Distance from S2 to S3 is 2 m. NE, NW, SE, and SW are buried at a depth of 2 m, while the others are at 1 m. Locations of surface temperature sensors are also shown in Fig. 3. Temperature sensors for inlet and outlet of the fan-coil are attached at outer surface of

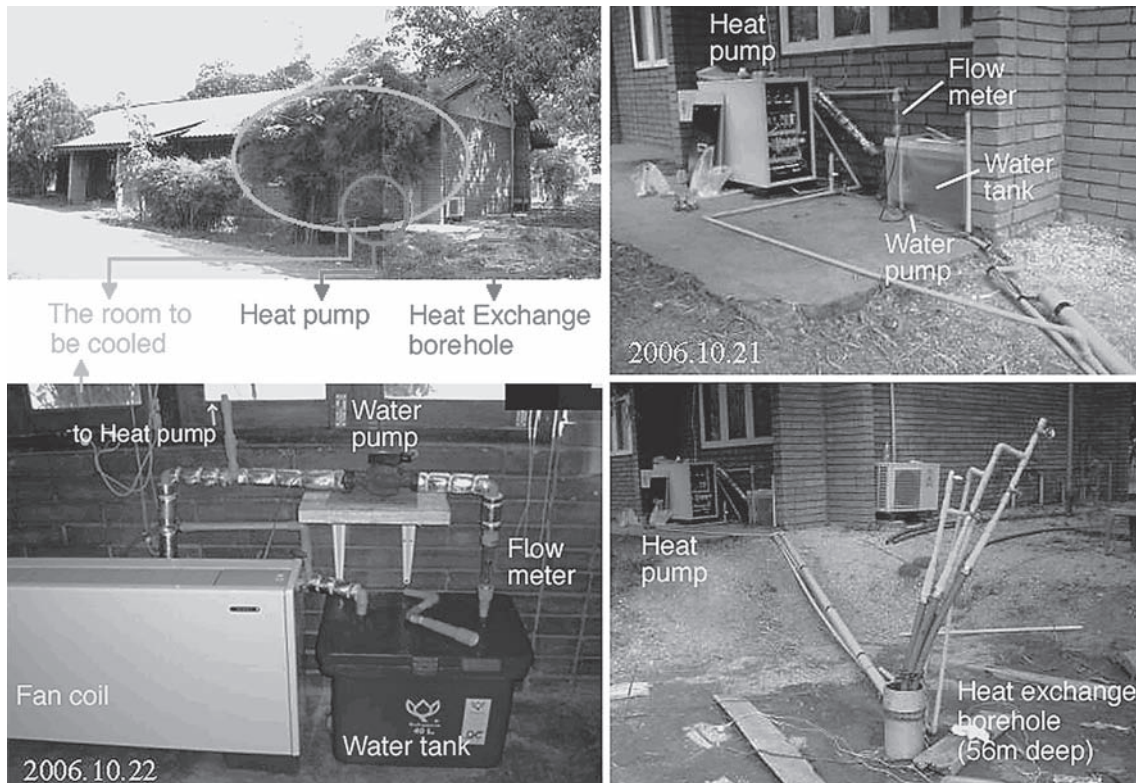Fig. 1 Kamphaengphet GHP system

Fig. 2 Outlook of Kamphaengphet GHP system. Down-left: inside room, the others: outside

the pipes for secondary fluid circulating inside the room, and wrapped by thermal insulation material. Those for room and atmosphere are hung in the air under a roof.

Fig. 4 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
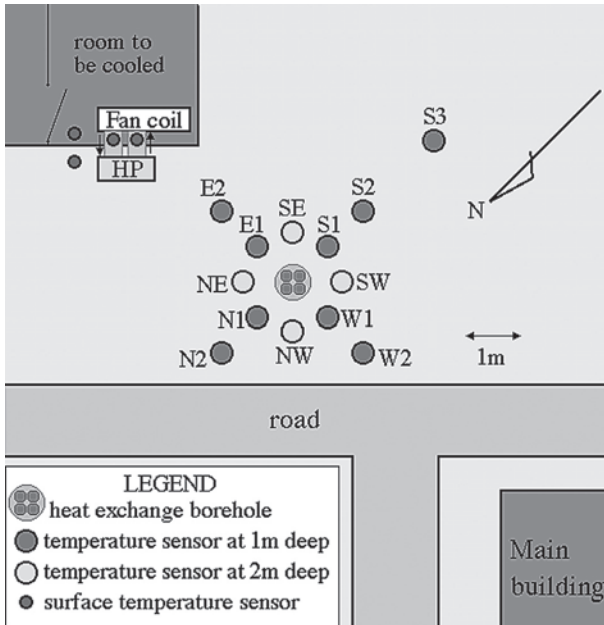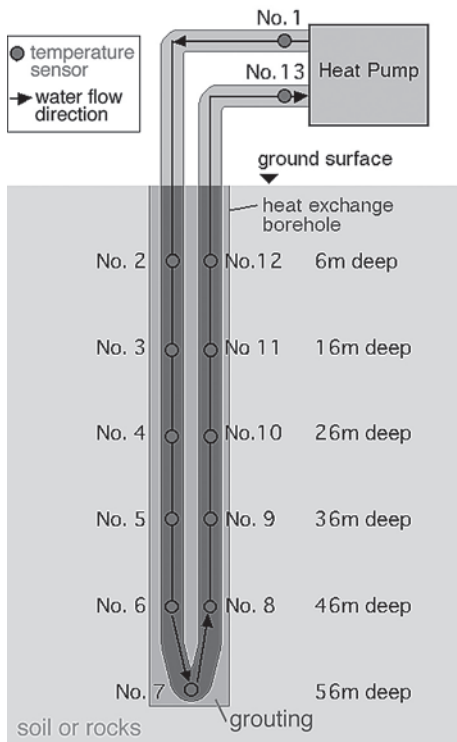

Fig. 3 Plan view of temperature sensors

Fig. 4 Cross-sectional view of temperature sensors in the heat exchange tube

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).

4. Results of temperature monitoring

Fig. 5 shows overall temperature monitoring results except for those of the sensors buried in the soil at a depth of 2 m: they have similar tendency as those at 1 m, but with smaller changes and with time lags (delay).

Operation hours of the GHP system can be identified by temperature increase at Nos. 1-13. The temperature change at No. 1 (red line in Fig. 5) is most prominent because it is of the primary fluid right 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 of the primary fluid.

During system operation, temperature rise is highest at No.1 and lowest at No. 13 in the U-tube. It is because heat from the secondary fluid was released into the ground during circulation of the primary fluid. However during non-operation, temperature at No. 7 at the bottom hole reaches to the lowest values because heat dispersion occurs three dimensionally at the bottom while that does two dimensionally at other points.

Note that the subsurface temperature in natural state at this site is quite homogeneous. It is between 30.0 and 30.5 $^{\circ}$C from a depth of 17 to 56 m, as shown in Fig. 6. Therefore, higher temperature observed in the monitoring period might 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 slightly affected by atmospheric temperature.

Temperatures at inlet and outlet of fan-coil ("fan-in" and "fan-out" in Fig. 5, respectively) also indicate operation hours since these values are lower than 20 $^{\circ}$C during operation. Therefore these data are especially valuable for periods in which temperature measurement in the U-tube was failed. The number of days on which GHP system was operated was counted as 234 days from inlet temperature data throughout the period.

For subsurface sensors around the heat exchange borehole, only the results of shallow ones, 1 m apart
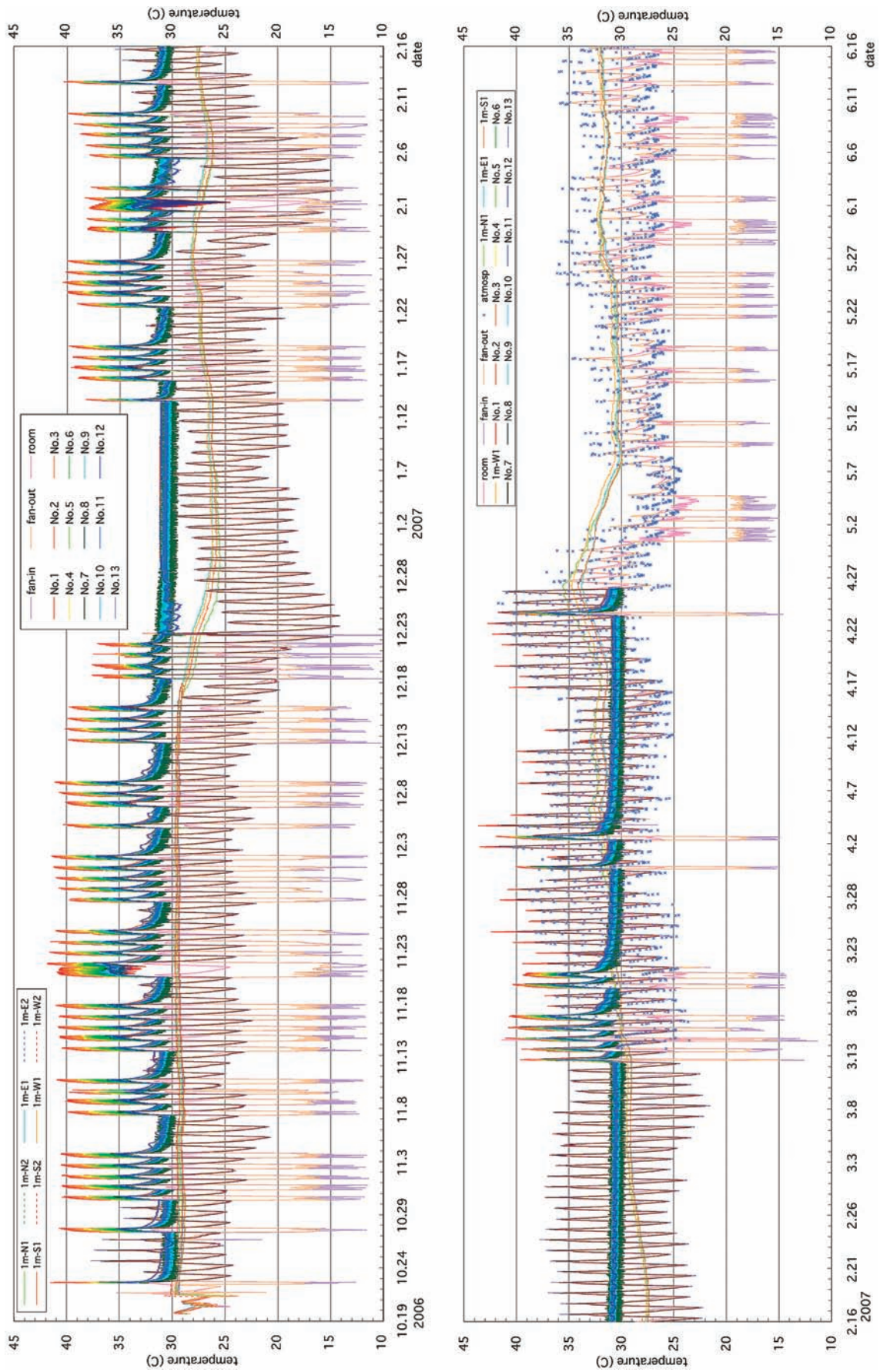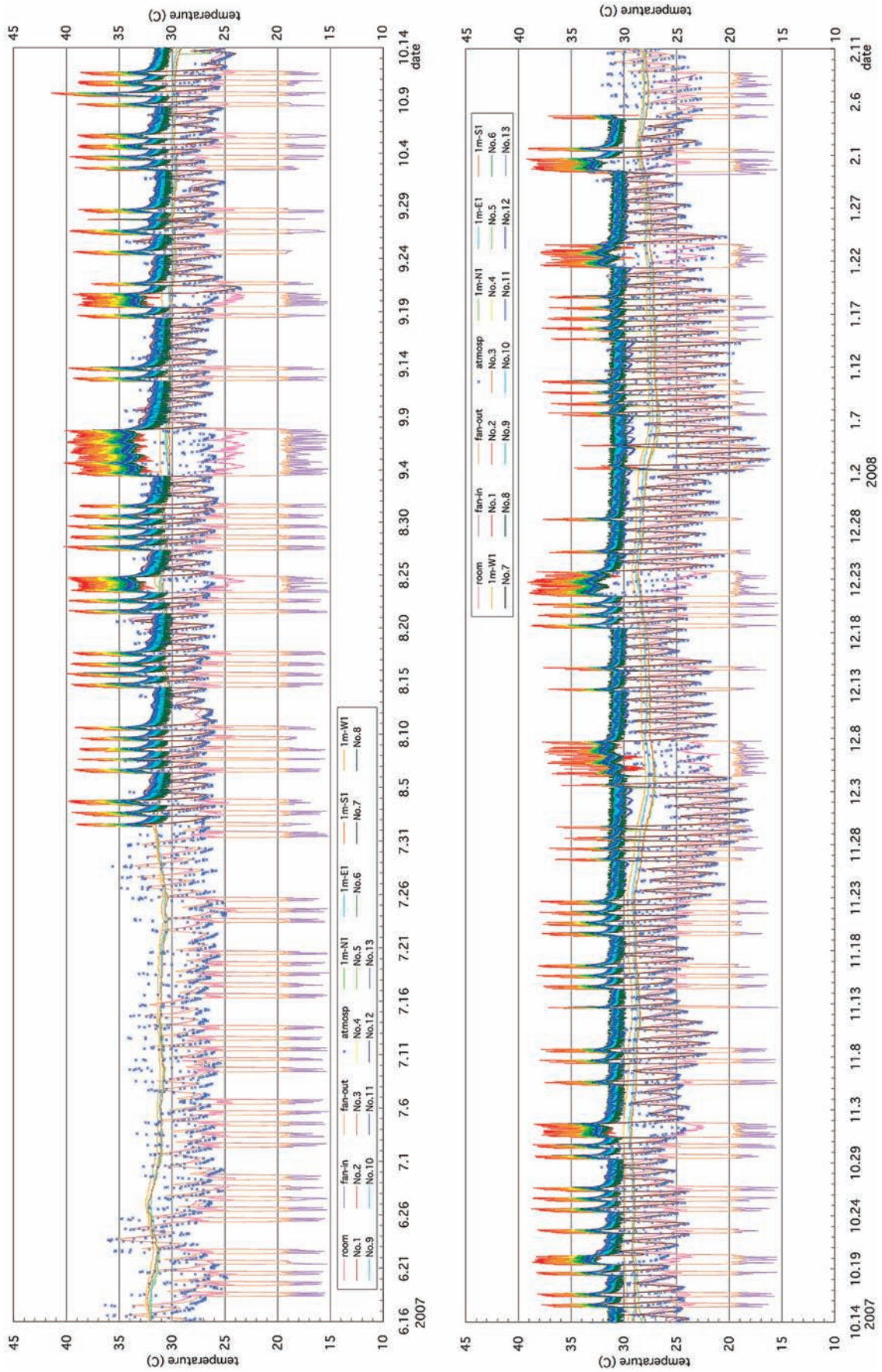
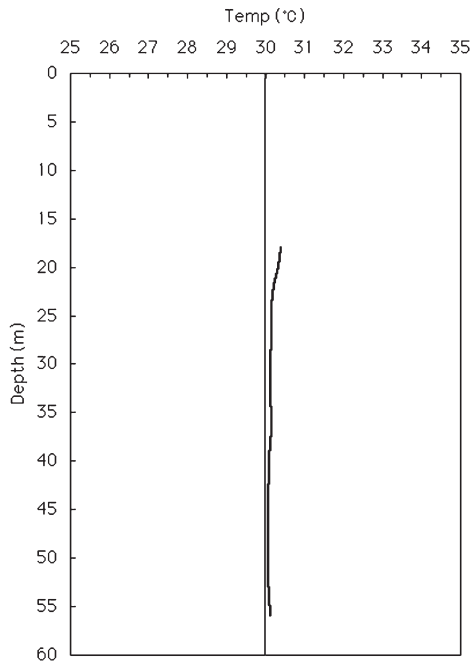Fig. 5 Temperature monitoring results

Fig. 5 Continued

Fig. 6 Temperature profile of an observation well in Kamphaengphet office (2005. 12. 9)

from the borehole, are shown in Fig. 5. General tendency of temperature change, slowly following the atmospheric temperature, is common for all these observation points including the ones not shown here. Differences among points are larger when temperature variation in time is larger. To detect the effects of shallow subsurface water flow in unsaturated zones, more detailed analysis is required. No clear difference is identified between these temperatures in the first and second years in the same season (ex., October 2006 and 2007). It suggests that no effect of long-term GHP operation remains at least at this shallow part.

5. The effect of long-term operation

Fig. 7 shows the temperature recovery at No. 7 after stopping GHP operation in different periods. Since data from No. 7 have bigger drifts due to its longer wire-cable, 24-hour average is used to represent the temperature value of a day. No. 7, the deepest sensor, is chosen to investigate the effect of long-term operation on subsurface temperature because it is less interfered by other pipes of double U-tube or ground surface.

Day 0 is the final day of successive operation (switch on in the morning and off in the evening). Asterisks (*) show cases in which operation was continued (no switch off in the evening) for three days or longer. The number of asterisks indicates the number of days of continuous operation.

For the case of 12 February 2007, which has the longest recovery period, temperature at the beginning of 33.0 $^{\circ}$C decreased to 30.5 $^{\circ}$C in ten days. Assuming

the original temperature was 30 $^{\circ}$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 and on 28 December 2007, which are in the same season of different years. It suggests that no detectable temperature increase occurred as a long-term effect. Heat may be released by groundwater flows.

Temperature level is higher for the case of 7 September 2007 due to continuous operation for five days. However, its successive period after one-day operation (13 September 2007), temperature recovered to a level equivalent to the other periods.

6. Electricity consumption and COP

Fig. 8 shows surface temperature monitoring results, cumulative electricity consumption, total operation hours and coefficient of performance (COP). Each of following subsections explains about an item of these monitorings.

6.1 Fan-coil inlet (heat-pump outlet) temperature

The range of fan-coil inlet temperature was controlled by operational settings of the heat pump, as maximum and minimum temperatures (T_{max} and T_{min}). The heat-pump began cooling when the inlet temperature reached to T_{max}, and stopped if it reached to T_{min}. These settings in each period are shown in Fig. 8 with purple letters. Range of measured temperature values is slightly higher than that of temperature settings, affected by high room temperature because the temperature sensor was attached to outside the inlet pipe but not inserted into the pipe.

6.2 Air temperature of the room

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 system was off and blue is for on. For the first five months, the room temperature during operation (blue) stays in higher level than no-operation period (yellow). This means the room was not cooled by the system effectively in this period. Since the system was operated only in daytime when the atmospheric temperature is high, its corresponding room temperature was also high. Big difference between T_{max} and T_{min} caused long stand by period during operation that allowed increase of room temperature. After the setting was changed on 21 March 2007, the room temperature during operation stayed in lower level, showing that the room was cooled by the system effectively. In this later period, room temperature was kept from 23 to 28 $^{\circ}$C, while outside temperature was from 30 to 35 $^{\circ}$C.
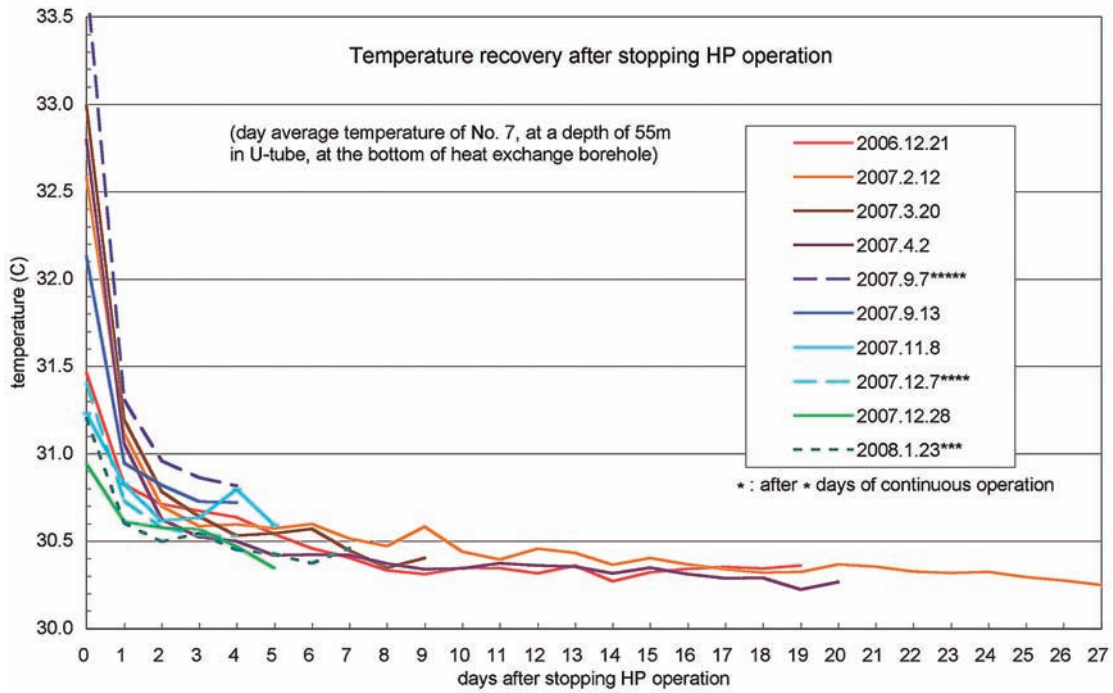
Fig. 7 Temperature recovery at No. 7 sensor after stopping GHP operation
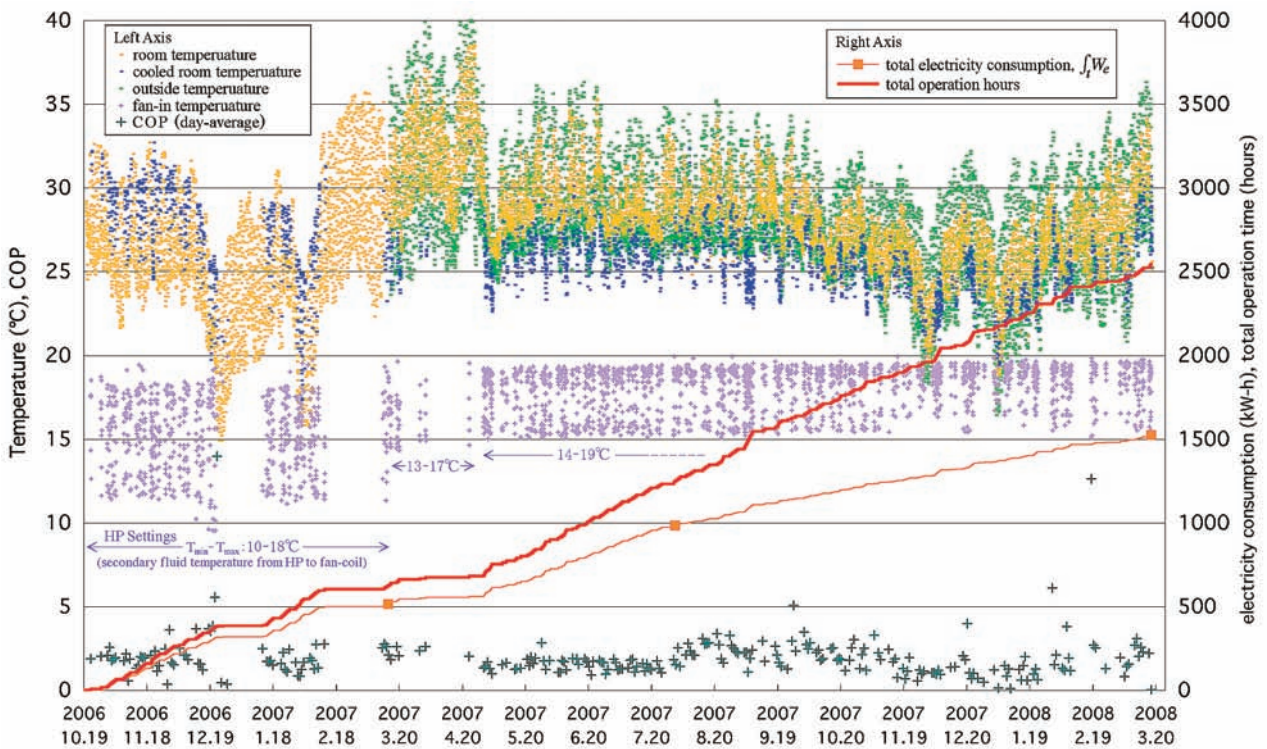

Fig. 8 Observed temperatures, electricity consumption, and COP

6.3 Atmospheric (outside) temperature

Outside atmospheric temperature is shown by green dot in Fig. 8. The temperature sensor was hung 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.

6.4 Flow rates of primary and secondary fluids

Flow rates of primary and secondary fluids, Q_1, Q_2, respectively, were measured four times in the whole period. Q_1=14.5 and Q_2=12.5 L/min on 19 October 2006 and 15 March 2007 and 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 six months of use. For COP calculation, missing values of Q_1 and Q_2 were linearly interpolated with time as shown in Fig. 10 as thick lines.

6.5 Operation hours and electricity consumption

The red line in Fig. 8 shows the total operation hours of the system. The orange squares show the cumulative electricity consumption by 20 March 2007, 1 August 2007 and 17 March 2008, respectively. The orange line shows the estimated value from operation hours linearly interpolated for each period between squares. Comparing the inclinations of red and orange lines, the electricity consumption rate is lower in the later period. It may be because the proper settings of T_{min} and T_{max} reduced the electricity consumption. In Fig. 5, temperature of the primary fluid at No. 1 often rises over 40 °C in the first six months while it stays under 40 °C in the later period. Its high temperature may have reduced the efficiency of the system in the first period.

This phenomenon is clearly shown in Fig. 9, which shows electricity consumption on days from 13-15 March and 1-2 August, 2007. In March, when settings of T_{min} and T_{max} were 10-18 °C, the electricity consumption rate was around 1.2 kW, while that was around 0.6 kW in August when the settings were 14-19 °C. Since both atmospheric temperature of around 25–35 °C and cooled room temperature of around 24-27 °C are common in these two periods, the difference in efficiency may be caused simply by the different settings of T_{min} and T_{max}.

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 T_{min} and T_{max} was changed on 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 is shown in Fig. 8. It may affect on the calculation of COP, described in the next paragraph.

6.6 System COP

In Fig. 8, the blue-green "+" symbol shows day average COP of the system. COP was calculated as follows;

COP = 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.

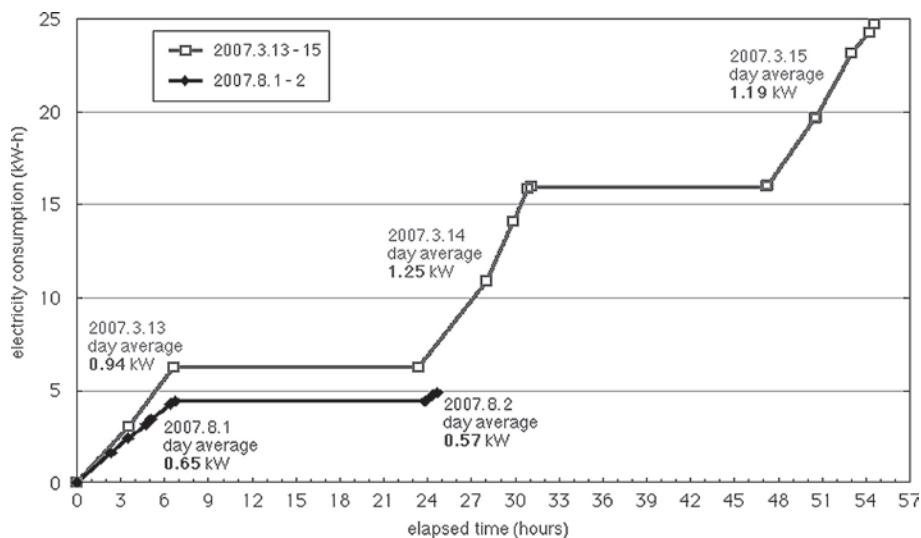Change of T_{outle} is shown in Fig. 5, while that of T_{inlet} is

Fig. 9 Electricity consumption during cooling operation

shown in both Figs. 5 and 8. Flow rate of the secondary fluid, Q_2 is shown in Fig. 10. Time integral of W_e (total electricity consumption) is shown in Figs. 8 and 10.

COP values around 2 are obtained for a period from 30 April 2007 to 1 August 2007 and around 3 for a period from 1 August 2007 to 19 November 2007. Different values are obtained although settings of T_{min} and T_{max} are common for these periods and atmospheric temperature is rather stable in both periods. Considering the uncertainty of electricity consumption in the former period (as described in 6.5), COP in this period may be higher than 2. 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 °C even in daytime. The cooled room temperature is as low as 20 °C in this period. It may better not use the cooling system when the atmospheric temperature is lower than 30 °C.

6.7 Waste heat released to the underground

Fig. 10 shows waste heat released to the underground, calculated from the inlet/outlet temperature and flow rate of the primary fluid (wh_1). Waste heat calculated from those of the secondary fluid (wh_2) is also shown as a reference. The value obtained from primary fluid is the true value because it directly shows the heat exchange rate into the underground, while that from secondary fluid is sum of heat exchange at fan-coil and

electricity consumption. The difference between these two results may be mainly due to the efficiency of the heat pump.

The clear cluster of dots in high values, ex.,110 -120 W/m for wh_1 and 80-90 W/m for wh_2 at the beginning, are obtained during operation of the system. Those in low values, ex., 20-30 W/m for both wh_1 and wh_2, are of the period when heat pump stops but only water circulation continues. The dots between them are obtained when heat pump stops but the effect of heat pump still remains in the fluid temperature.

At the beginning, the amount of released heat is quite high because longer interval of GHP operation (due to the big difference of T_{min} and T_{max}) requires intensive heat exchange during operation. Extremely high heat exchange rate beyond its heat conductivity reduces the efficiency because it raises temperature of the borehole and its surroundings. Therefore, the heat exchange rate during operation drastically decreases with time in the first few months (October 2006-April 2007). In later period (August 2007 to the end), heat exchange rate is constant around 65-80 W/m due to a stable operation with appropriate settings.

In the later part (August 2007 to the end), there is no clear high cluster for wh_2. It is because the interval of heat pump operation in this period is shorter than sampling interval. Data sampling interval for secondary fluid is one hour while that of primary fluid is ten minutes.
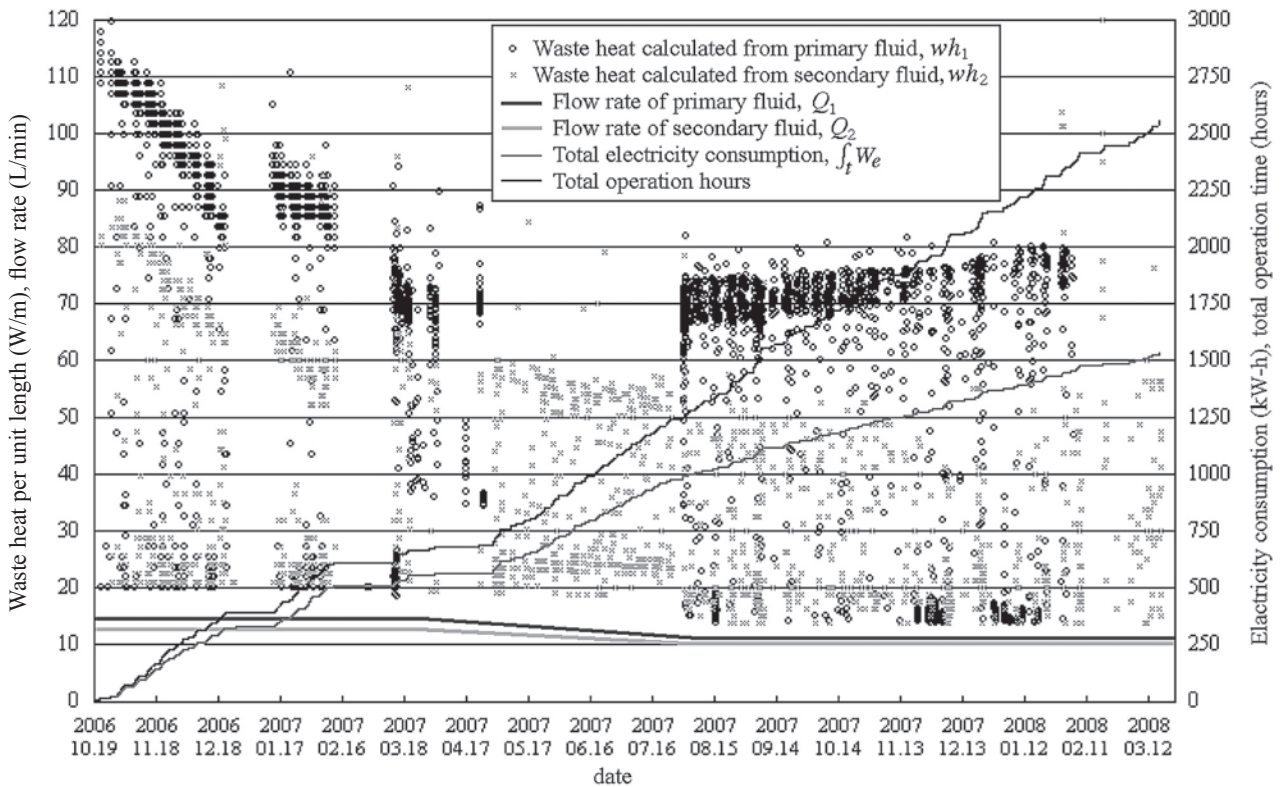

Fig. 10 Waste heat released to the underground

7. Discussions for better system performance

This experiment in Kamphaengphet proved that such a system can be continuously used in tropical region for space cooling. 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 and reduce the increase of primary fluid temperature. It 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 exchange between primary fluid and soil, primary fluid and secondary fluid, and secondary fluid and fan-coil, 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 °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 that are more suitable for GHP system should be selected based on subsurface temperature and hydro-geological information.

8. Conclusions

A GHP system was installed to a building of Kamphaengphet office, DGR, in October 2006. This system was experimentally used as a space cooling system for 17 months, till March 2008. Temperature changes in the heat exchange borehole and its surroundings, at inlet and outlet of heat pump, and of room and atmosphere, and electricity consumption were measured. The results of this experiment may be summarized as follows;

- 85% of temperature increase in heat exchange borehole was recovered in ten days after stopping operation.
- A successive operation of the system causes temperature increase in the heat exchange borehole even at the bottom hole, but it recovers in a week if 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 °C, while outside temperature was from 30 to 35 °C during the period.
- To save electricity consumption, proper setting of heat pump operation is necessary. Smaller difference between maximum and minimum temperatures, and minimum temperature no less then 14 °C is recommended.
- 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.
- A stable operation may be continued if the heat exchange rate is no higher than 80 W/m.

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.

References

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タイ・カンペンペットにおける地中熱冷房利用実証運転

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要　旨

　冷房用地中熱ヒートポンプシステムをタイのカンペンペットに設置し，2006年から17ケ月の試験運転を行った．地下の熱特性および短期－長期のシステム運転影響を評価する目的で，地下の熱交換パイプ内およびその周辺の温度を連続観測した．システム運転による地下温度上昇は数日で回復し，1年間の運転後でも長期的影響は見られなかった．この期間中，室温，気温，システムの電力消費量，1次流体および2次流体の流量と出入口温度も観測した．その結果，安定した運転が行われていた期間には，成績係数 COP はほぼ3という値が得られた．本論文では，温度観測結果およびシステム成績について記す．