Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Evaluation of Thermal Interference between Horizontal Ground Heat Exchangers

Takahiro Ogawa[1]*, Hikari Fujii[1], Retsu Harada[2], Hiroyuki Kosukegawa[1], Saeid Mohammadzadeh Bina[1]
Akita University, 1-1 Tegatagakuen-machi, Akita, 010-8502, Japan[1], Biotex Inc., 1853-3 Tokuman, Kubota-cho, 849-0201, Saga, Japan[2]
takahiro20021128@gmail.com

Keywords: ground source heat pump, horizontal ground heat exchangers, horizontal directional drilling, numerical simulation, thermal response test, thermal interference

ABSTRACT

Ground Source Heat Pump (GSHP) systems using vertical Ground Heat Exchangers (GHEs) are costly to install in Japan due to complex geological conditions. As a cost-effective alternative, Horizontal GHEs (HGHEs) can be installed at shallow depths using Horizontal Directional Drilling (HDD). However, HGHEs require large land areas, which limits their feasibility in land-scarce regions. HDD offers a viable solution for installing HGHEs in space-constrained environments. Nevertheless, thermal interference between adjacent GHEs can reduce system performance, making its investigation important for optimal design. In this study, field experiments were conducted in Saga City, Japan, to examine thermal interference between HDD-installed HGHEs spaced at 1 m, 2 m, and 4 m intervals. Thermal Response Tests (TRTs) were performed for each spacing scenario, confirming that greater distance between GHEs reduced thermal interference and improved heat exchange performance. A numerical model was then developed using FEFLOW based on geological conditions and was validated using measured temperatures at the turning and outlet points of the GHEs. The validated model was used to conduct long-term cooling simulations at GHE distances of 1 m, 2 m, and 4 m, respectively. As a result, thermal interference was observed on the 12th and 40th day after the start of the simulation at 1 m and 2 m spacing. Additionally, the predicted temperature difference between 1 m and 4 m spacing was only 0.6°C after 4 months, indicating that in GSHP systems with two HGHEs, the influence of thermal interference on overall energy efficiency is relatively small.

1 INTRODUCTION

Due to the complex geological formations, the installation cost of conventional vertical Ground Heat Exchangers (GHEs) in Japan is significantly higher than that of many Asian, European and North American countries. Horizontal GHEs (HGHEs), which can be installed using standard power shovels, offer a more affordable alternative. HGHEs are installed horizontally in shallow ground. However, they typically require large land areas, making them less feasible in countries like Japan, where available land is limited. To address this limitation, Horizontal Directional Drilling (HDD) (Figure 1) offers a viable solution for installing HGHEs in space-constrained environments. In addition, it is important to consider potential thermal interference between multiple adjacent GHEs. Thermal interference can degrade the overall performance of the system over time.

Several studies have investigated the performance of HGHEs through field tests or numerical simulations. Bina et al. (2020) reported that the installation cost of Ground Source Heat Pump (GSHP) systems using HDD can be reduced by up to 78% compared to conventional systems. Pu et al. (2018) found that the thermal efficiency of HGHEs is strongly affected by the thermal interference between adjacent buried pipes. Asgari et al. (2020) examined the thermal behavior of various HGHEs configurations including linear, spiral and slinky. Fujii et al. (2013) conducted sensitivity studies of both single-layer and double-layer slinky-coil HGHEs.

To date, there have been no field-based studies specifically focusing on thermal interference in HDD-installed HGHEs. Therefore, this research will investigate how the spacing between GHEs influences thermal interference and heat exchange performance.

In this study, field experiments were conducted in Saga City, located in western Japan, where HGHEs were installed using HDD technology. Thermal Response Tests (TRTs), numerical modeling, and case studies were performed to evaluate the extent of thermal interference and the overall heat exchange performance.

2 METHODS

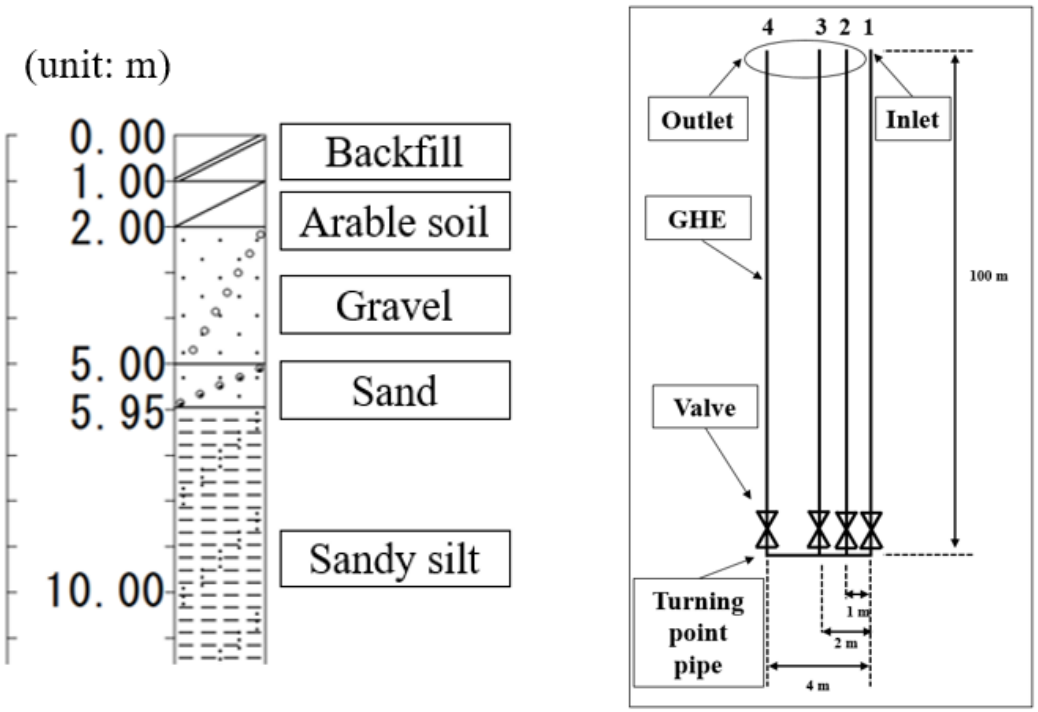
2.1 Information about GHEs

This section describes how our experiments were conducted. In Saga City, Japan, four single-loop pipes of 100 m in length were installed using HDD for testing purposes. The shallow ground of the test site, covered with the Ariake clay layer of Quaternary age, consists mainly of gravel and sand (Figure 2(a)). The groundwater level was observed at a depth of approximately 2.0 m below the ground surface.

The pipes were installed in parallel at a depth of 6 m, with separation distances of 1 m, 2 m, and 4 m, as shown in Figure 2(b) and 3(a). In each test, GHE-1 served as the inlet, while the others (GHE-2, GHE-3 and GHE-4) were used as the outlets, resulting in a total active GHE length of 200 m for each TRT. The polyethylene pipes with inner and outer diameters of 50 mm and 63 mm, respectively, were used as GHE (Figure 3(b)).

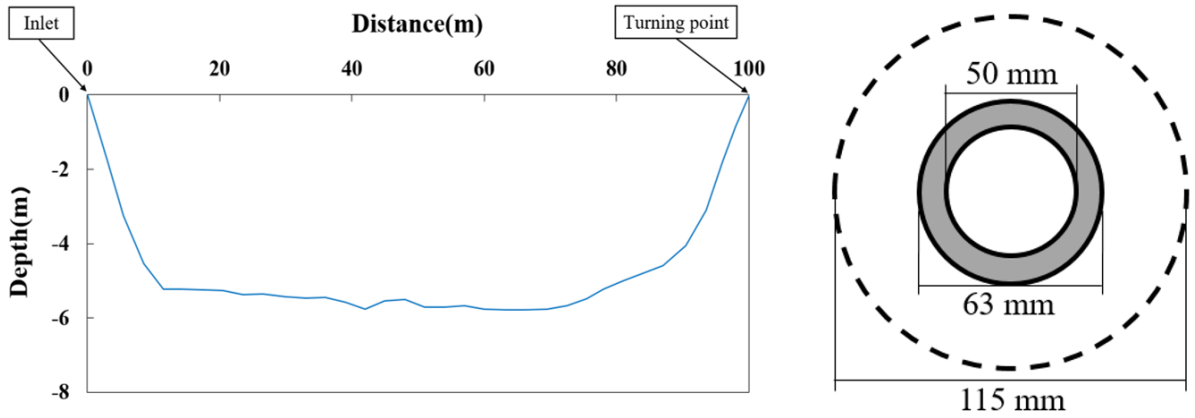


Figure 1. Scene of construction using an HDD machine



(a) (b)

Figure 2. (a) Geological column (b) Schematic diagram of the GHEs

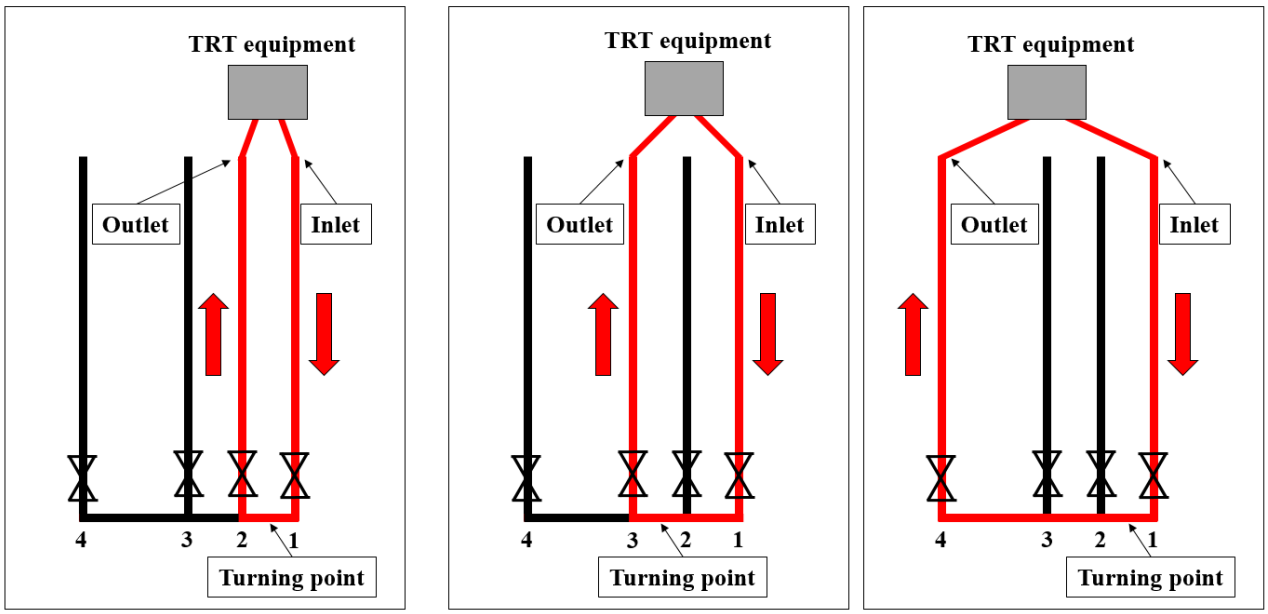


(a) Well path (b) Cross-section of well

Figure 3. Information of well

2.2 Field tests

TRTs were conducted as shown in Figure 4 and 5. In each test, GHE-1 was connected to the inlet side of the TRT device, while GHE-2, GHE-3 and GHE-4 were connected to the outlet side. To change the separation distance between the GHEs, the flow of the circulating fluid was controlled by opening or closing valves at the ends of the GHEs. The circulating fluid was water, which is shown in red (Figure 4). The tests were performed under three different conditions: TRT-1, TRT-2 and TRT-4 (Table 1). The heating tests lasted for 11days, 31days, and 20days for each case. For TRT-1 and TRT-2, the circulation tests were stopped once thermal interference was observed during the heating test. In TRT-4, the temperature of the heat medium at the turning point was measured during the heating period. Additionally, a recovery test using Distributed Temperature Sensor (DTS) was carried out in TRT-4 with a duration of 7days.



(a) TRT-1 (b) TRT-2 (c) TRT-4

Figure 4. Schematic diagram of TRTs

Table 1. Conditions for the TRTs

TRT name	GHE distance	GHE length	Heating period		Recovery period		Heat Load		Flow Rate
		(m)	(Days)	(Date)	(Days)	(Date)	(kW)	(W/m)	(L/min)
TRT-1	1 m	205.17	11	2024/11/1-2024/11/12	-	-	4.13	20.12	19.83
TRT-2	2 m	204.68	31	2024/12/4-2025/1/4	-	-	4.25	20.75	19.84
TRT-4	4 m	204.74	20	2024/8/6-2024/8/26	7	2024/8/26-2024/9/2	3.92	19.15	19.83

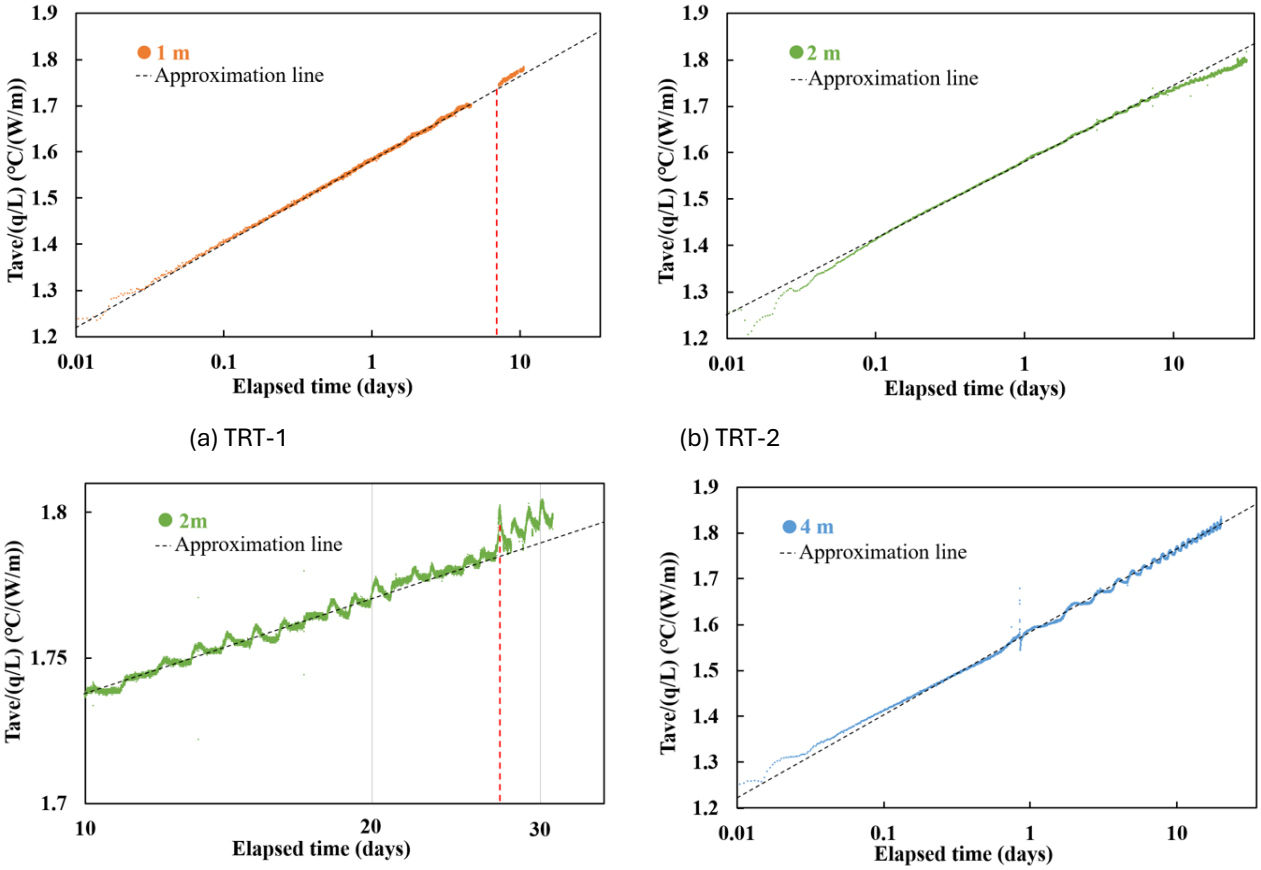


Figure 5. View during TRT

3 RESULTS AND DISCUSSION

The temperature changes in each TRT are presented in Figure 6. The vertical axis shows the average temperature at the inlet and outlet of the GHE divided by the heat exchange rate per GHE length, and the horizontal axis shows the elapsed time. In the graphs, the data overlaps with the approximation line until thermal interference occurs. After thermal interference occurs, the average temperature start to shift from the approximation lines. Using these evaluation methods, we compared the timing when the thermal interference occurred.

From Figure 6(a), due to a malfunction of the measuring device, the data from the 5th to the 7th day were missing. It was confirmed that the thermal interference occurred around the 5th to 7th day by comparing the data with the approximation line. From Figure 6(b), the temperature trend started to shift from around the 3rd day. Then, the data was positioned in the opposite direction to the direction indicating thermal interference. This was thought to be due to the influence of the outside temperature. TRT-2 was conducted in colder season than the other tests. As a result, the outside temperature was significantly lower and affected the heat medium temperature. Figure 6(c) is an enlarged diagram of Figure 6(b) after 10 days. The approximation line was drawn using data from the 10th day, when the data slope had stabilized, to the 20th day, before thermal interference occurred. Comparing the data with the approximation line, signs of thermal interference appeared from the 22nd day, and noticeable thermal interference could be confirmed from the 27th day. Finally, in Figure 6(d), no thermal interference was observed. From these three tests, it was found that the required heating time until thermal interference was observed increased as the spacing between GHEs increased.



(a) TRT-1 (b) TRT-2

(c) TRT-2(enlarged diagram) (d) TRT-4

Figure 6. Temperature changes in each TRT

4 DESCRIPTION OF THE NUMERICAL MODEL

In this study, the numerical model of a single-pipe GHE was constructed using FEFLOW ver. 7.1. FEFLOW enables the input of actual GHE paths and various geological conditions. Since HGHEs often exhibited complex geometries, the trace maps were created using Autodesk AutoCAD 2025 and then imported into FEFLOW.

The constructed model is shown in Figure 7. The dimensions of the numerical model were set as 110 m, 10 m, and 10 m in the x, y, and z directions, respectively. The distance between the model boundaries and the GHEs were assigned as 5 m in the x-direction, 3 m in the y-direction, and 4 m in the z-direction to avoid the effect of outer boundaries. In Figure 7(b), the width of grids between the GHEs was divided into 0.1 m to allow detailed analysis of thermal interference, with the others being 0.5 m. Figure 7(c) shows a cross-sectional slice of the model that includes the GHE. The red line indicates the location of the GHE. The mesh near land surface was refined to improve accuracy in the shallow zone, which is affected by the weather condition. To consider this, we used the sol-air temperature (SAT) as the surface boundary condition of the model. The SAT is defined as Equation (1):

$$\mathrm{SAT} = \theta_0 + 1/\alpha_0\left((1-\alpha_s)J - \varepsilon J_{eh}\right) \quad (1)$$

Where θ_0 and J are the ambient temperature and the solar radiation, respectively. Both were derived from the local weather station in Saga City. α_0 and α_s represent the coefficient for heat transfer between air and soil ($W/m^2/K$) and the Albedo (set as 0.12 for asphalt pavement), respectively. Lastly, ε and J_{eh} are the dimensionless factor of longwave emissivity and effective emission (W/m^2), respectively.

As an initial condition, the formation temperature was uniformly set as 21.0°C. This value was considered reasonable, as the annual average air temperature in Saga City in 2024 is 18.8°C, and the temperature at shallow

subsurface depths is typically 1-2°C higher than the air temperature. During the simulation, SAT data obtained from the Saga District Meteorological Observatory was applied to the top boundary, while a constant temperature of 21°C was applied to the bottom boundary. The side boundaries were set as adiabatic conditions, as they were placed far enough from the GHEs. Table 2 summarizes the physical properties used in the numerical model. The thermal conductivity value of 0.75 W/m/K was applied for the grout based on trial and error.

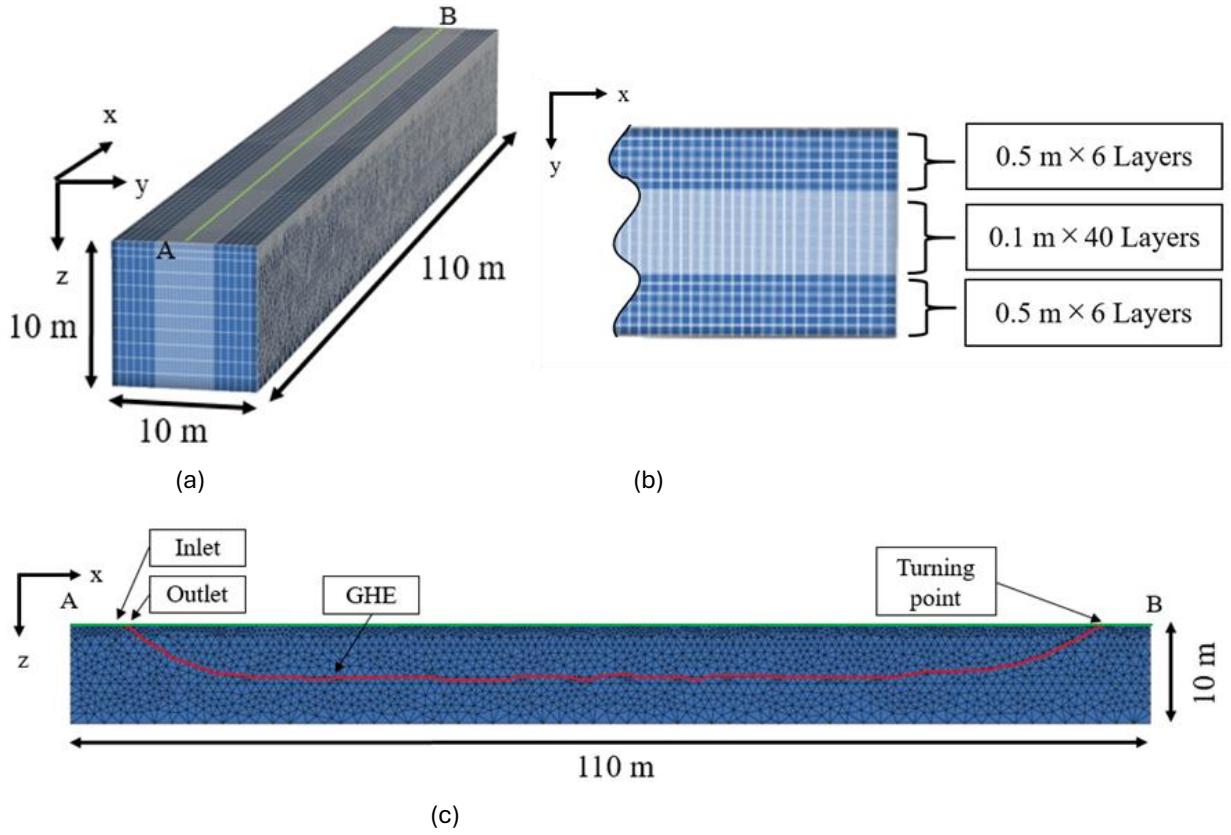


Figure 7. Simulation grid of the HGHE model (a) 3D view, (b) cross sectional view of the layers(x-y), and (c) cross sectional view of the HGHE(x-z)

Table 2. Physical properties used in the numerical model

Thermal conductivity (solid) (W/(m·K))	Thermal conductivity (grout) (W/(m·K))	Volumetric heat capacity (solid) (MJ/(m^3·K))
0.90	0.75	1.80

5 MODEL VALIDATION

This section shows the results of history matching. Figure 8(a) shows the results of history matching using outlet temperatures in TRT-1 and TRT-2 in the field. In TRT-1, the missing inlet temperature data were interpolated to obtain continuous input values. Through the entire period of the TRTs, reasonably good agreements were obtained. Figure 8(b) shows the results of history matching of outlet and turning point temperature in the heating period of TRT-4. Although a temperature difference of about 0.3°C was observed between the measured and calculated outlet temperatures, the temperature difference was considered within the acceptable range, and a good agreement was obtained. Figure 8(c) shows the results of history matching for temperature of DTS in the recovery period of TRT-4. The legends indicates the measured and calculated values at each elapsed time of the recovery tests. Good agreement was observed on Days 1, 3, and 6 in each recovery test. From these results, the validity of the model was demonstrated.

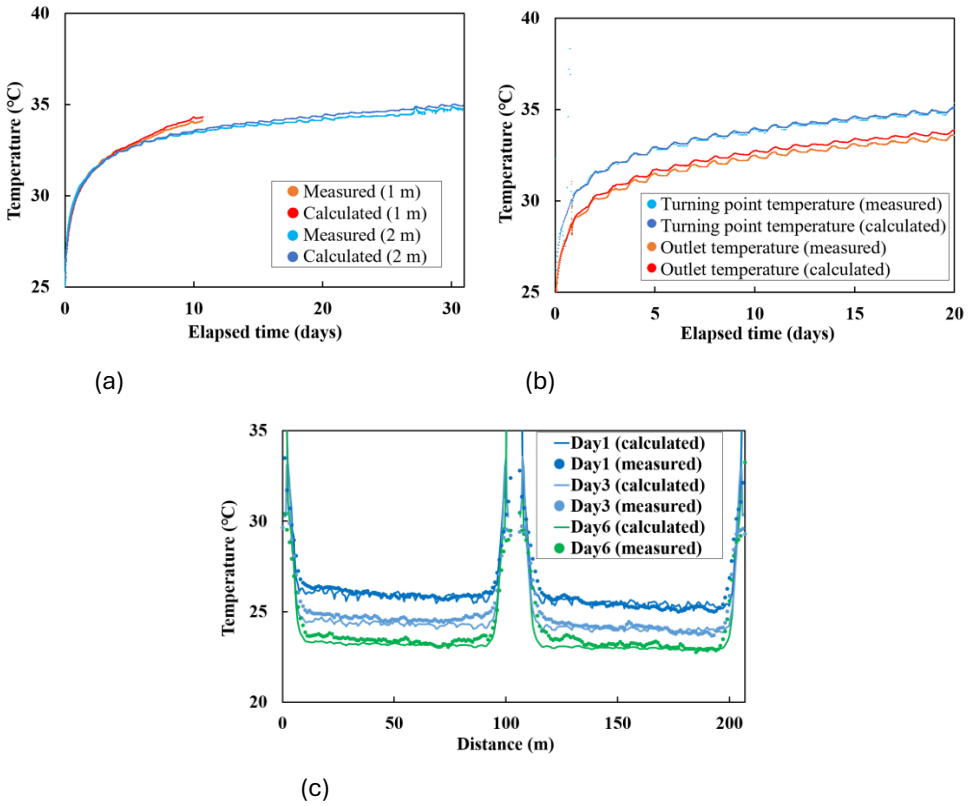


Figure 8. Results of history matching (a) Outlet temperature in TRT-1 and TRT-2 (b) Outlet and turning point temperature in TRT-4(heating test) (c) Temperature of DTS in TRT-4(recovery test)

6 CASE STUDY

6.1 History matching on the thermal interference

As a case study, a numerical model was developed in which the thermal load was set as an input parameter to reproduce the timing of thermal interference observed in the field results. The same initial temperature and physical properties as those in Table 2 were used. Schematic diagram of the numerical model is shown in Figure 9. The dimensions of the model were set as 120 m, 24 m, and 16 m in the x, y, and z-directions, respectively (Figure 9(a)). The width of grids between the GHEs was divided into 0.1 m, while the others were set as 0.2 m, 0.4 m, and 0.8 m which increased as the distance from the GHE increased(Figure 9(b)). The distance between the model boundaries and the GHEs were assigned as 10 m in the x, y, and z-directions (Figure 9(c)).

History matching was performed in the GHE distance of 1 m and 2 m. Figure 10 shows the results of history matching in each scenario. The vertical axis shows the average temperature between inlet and outlet of the GHE, and the horizontal axis shows the elapsed time. The approximate line was calculated in the same way as in Figure 6. Figure 9(a) shows the results of history matching in GHE distances of 1 m. Both the measured and calculated values indicated that thermal interference began to occur around the 7th day. Figure 9(b) and Figure 9(c) show the results of history matching in GHE distances of 2 m. Both the measured and calculated values indicate that, although the changes were slight, thermal interference started to occur around 27th day. As a result, the timing of thermal interference showed good agreement. Thus, the validity of the numerical model was demonstrated.

Table 3. Numerical model input values

GHE distance	Heat load (kW)	Flow rate (L/min)
1 m	4.13	19.83
2 m	4.25	19.84

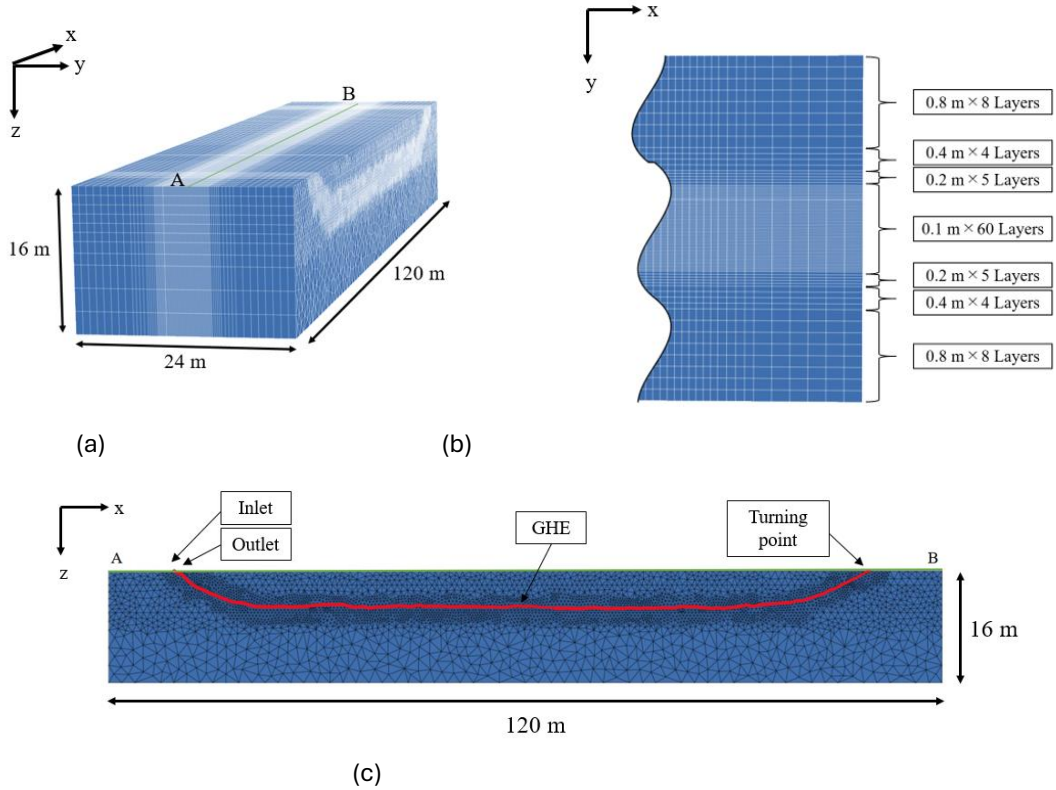


Figure 9. Simulation grid of the modified HGHE model (a) 3D view, (b) cross sectional view of the layers(x-y), and (c) cross sectional view of the HGHE(x-z)

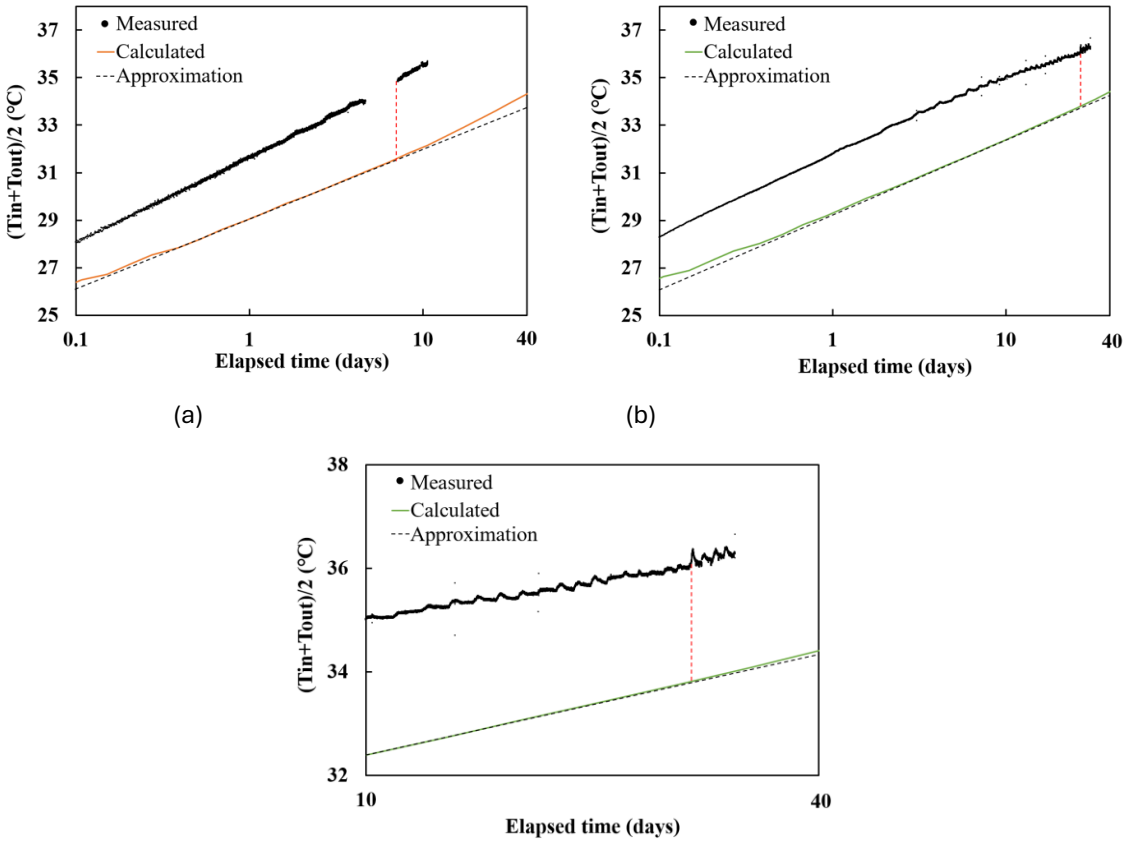


Figure 10. Results of history matching in GHE distances of (a) 1 m (b) 2 m (c) 2 m(enlarged diagram)

6.2 Long-term prediction

Using the model in Figure 9, long-term simulations on the thermal interference were performed for GHE distances of 1 m, 2 m, and 4 m. The conditions are shown in Table 4. The simulations were run for 120 days, 24 hours per day. The heat load and the circulation flow rate were set as 20.0 W/m and 20.0 L/min, respectively. The results are shown in Figure 11. The vertical axis shows the average temperature at the inlet and outlet of the GHE, and the horizontal axis shows the elapsed time. At a separation of 1 m and 2 m, significant thermal interference was observed on the 12th and 40th day after the start of the simulation, respectively. On the other hand, at a separation of 4 m, almost no thermal interference was observed throughout the 120 days. It was found that on the 120th day, the temperature difference between the 1 m and 4 m spacing was 0.6°C, and the difference between the 2 m and 4 m spacing was 0.2°C. From these results, it is considered that the impact of thermal interference between GHEs on energy efficiency is small, since the temperature difference was less than 1.0°C even after long-term operation in cooling system assuming two horizontal GHEs. Yet, in the case of installing more GHEs, greater thermal interference is expected. Therefore, case studies need to be conducted for accurate design of GSHP systems.

Table 4. Conditions for long-term simulations

Period	Operation time	Heat load		Flow rate
(days)	(hours/day)	(kW)	(W/m)	(L/min)
120	24	4.0	20.0	20.0

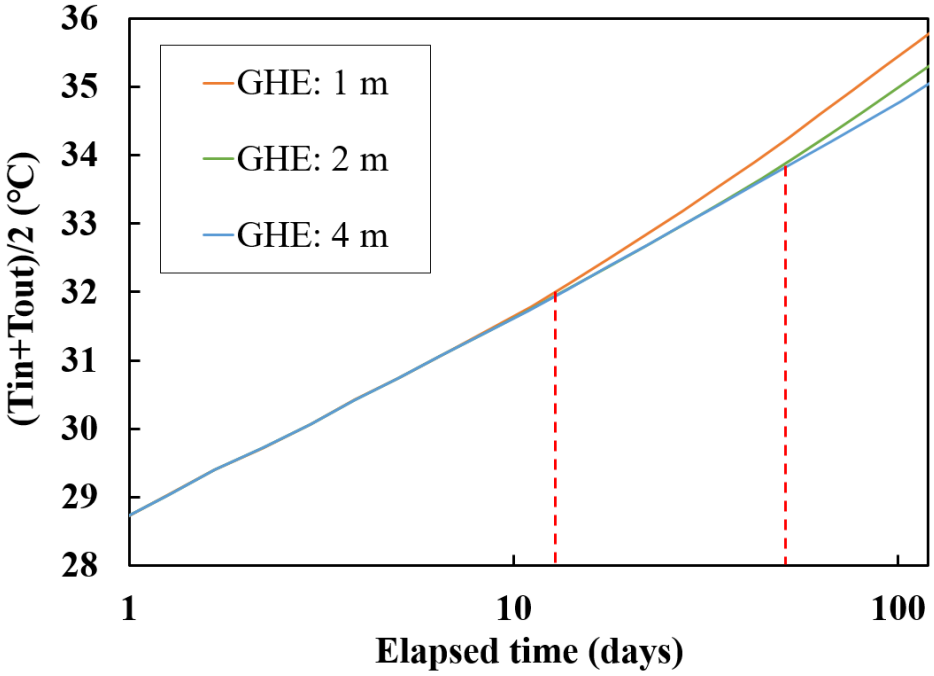


Figure 11. Long-term simulations at GHE distances of 1 m, 2 m, and 4 m

7 CONCLUSIONS

In this study, TRTs on HGHEs installed using HDD were performed to evaluate the thermal interference between HGHEs in Saga City, Japan. Then, a numerical model was constructed using FEFLOW ver. 7.1 based on geological conditions and its validity was verified through history matching with TRT results. In addition, long-term simulations were conducted at GHE distances of 1 m, 2 m, and 4 m to assess heat exchange capacity of GHEs in each case. The following findings were obtained in the course of the study:

1. From the TRT results, thermal interference started to appear from about 7th and 27th day in GHE distances of 1 m and 2 m, respectively, and was not observed in GHE distance of 4 m during the heating of 20days. These results indicate that the wider the GHE installation separation, the smaller the effect of thermal interference between the HGHEs, and the higher the heat exchange capacity of GHEs.

2. At GHE distances of 1 m, 2 m, and 4 m, a numerical model was constructed based on the geological conditions and SAT in the field, and history matching was performed for the GHE outlet temperature and temperature profile of DTS setting the GHE inlet temperature as input. The measured and the calculated values were in good agreement.

3. Long-term cooling simulations were performed using a verified numerical model to investigate the temperature rise due to thermal interference. The results showed that significant thermal interference was confirmed on the 12th and 40th day after the start of the simulation at GHE distances of 1 m and 2 m, respectively. However, almost no thermal interference was confirmed at distance of 4 m throughout the 120 days.

4. Prediction calculations showed that the temperature difference between GHE distance of 1 m and 4 m was 0.6℃, and the difference between distance of 2 m and 4 m was 0.2℃ after 4 months. This indicates that in GSHP systems assuming two horizontal GHEs, the impact of thermal interference between the GHEs on energy efficiency was relatively small.

REFERENCES

Bina, S. M., Fujii, H., Tsuya, S., and Kosukegawa, H.: Evaluation of utilizing horizontal directional drilling technology for ground source heat pumps, *Geothermics*, 85, (2020), 101769.

Pu, liang, Xu, L., Qi, D., and li, Y.: Structure optimization for horizontal ground heat exchanger, *Applied Thermal Engineering*, 136, (2018), 131–140.

Asgari, behrad, Habibi, M., and Hakkaki-fard, A.: Assessment and comparison of different arrangements of horizontal ground heat exchangers for high energy required applications, *Applied Thermal Engineering*, 167, (2020), 114770.

Fujii, H., Yamasaki, S., Maehara, T., Ishikami, T., and Chou, N.: Numerical simulation and sensitivity study of double-layer slinky-coil horizontal ground heat exchangers, *Geothermics*, 47, (2013), 61–68.