Well Path Optimization and Long Term Simulation of Water Injection into Horizontal Directional Drilled Ground Heat Exchangers

DIPL.-ING. RICHARD LEIN

AKITA UNIVERSITY

DER GEOTHERMIEKONGRESS 2024, POTSDAM

Outline

1. Introduction
2. Field Test and Numerical Model
3. Case studies for Well Path Optimization
4. Long Term Simulations
5. Conclusions
6. References

Introduction

Conventional Horizontal Ground Heat Exchangers (HGHE) are installed in trenches 1-2m deep

Commonly they are installed as straight loops or slinky coil loops

Compared to vertical ground heat exchangers:

- Lower installation cost
- Larger land requirement

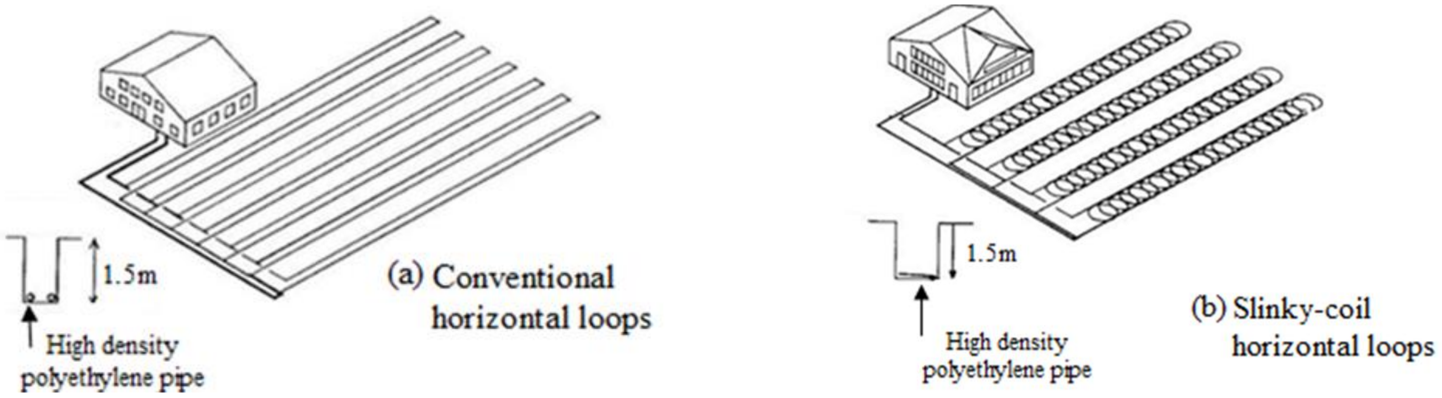

Fig.1 Conventional Installation Methods of HGHE [1]

Horizontal Directional Drilling

Horizontal Directional Drilling (HDD) is a non dig drilling method commonly used to install pipelines or infrastructure in cities, without the need to disturb the surface

It can also be used to install ground heat exchangers, allowing for a flexible installation path

Fig.2 Drilling equipment in Japan

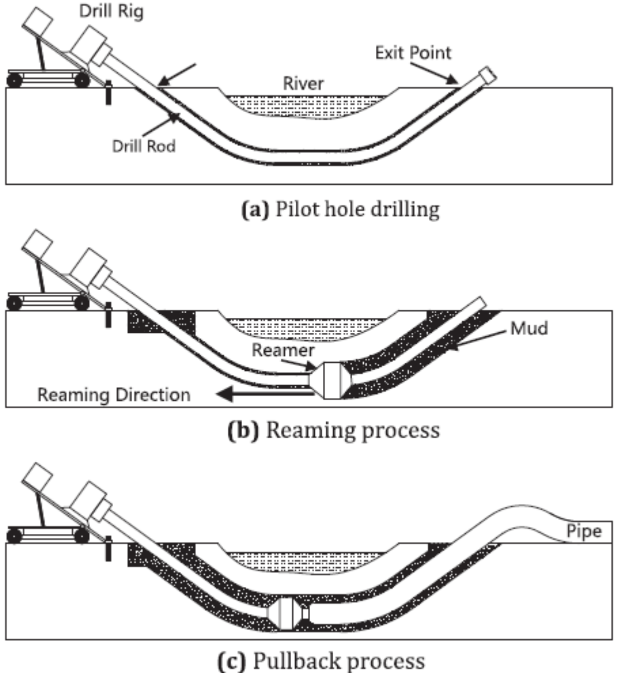

Fig. 3 Process of HDD drilling [2]

Field Test and Numerical Model

秋田大学
Akita University

A double layered HDD drilled ground heat exchanger was installed in Saga City, Japan

In March 2022, a two day thermal response test (TRT) was conducted on the system

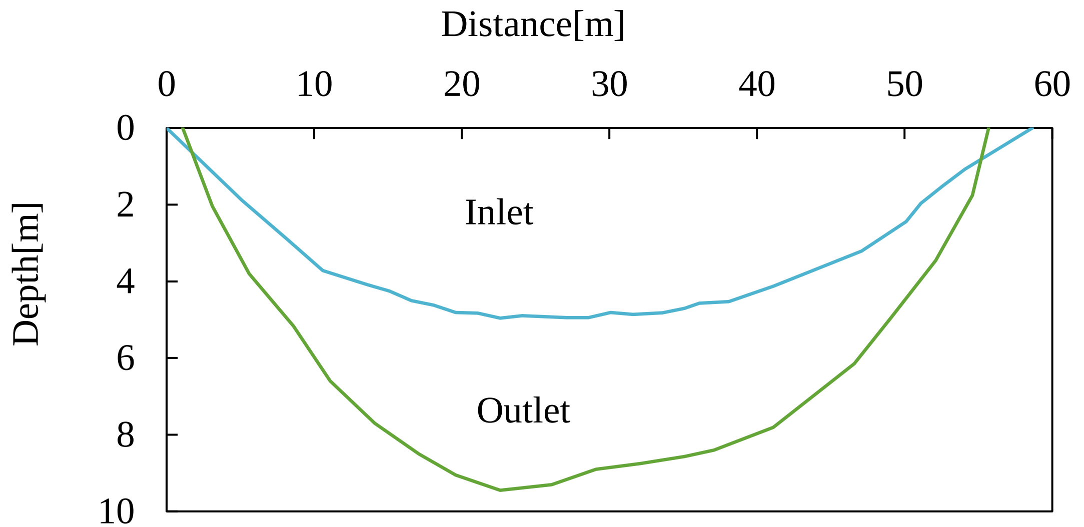

Fig. 4 Borehole path of the project in Saga

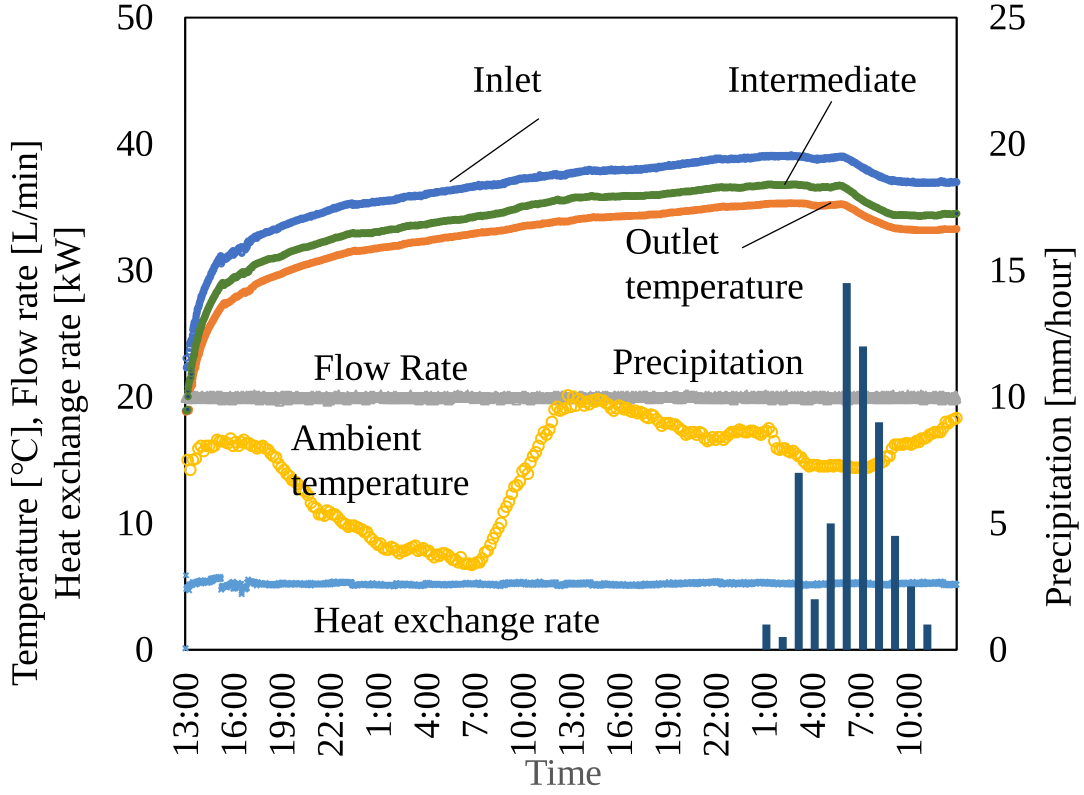

Fig. 5 Results of the TRT

Numerical Model

Based on the field test a numerical model was created in FEFLOW ver8.1

The model was validated with the measured data from the TRT

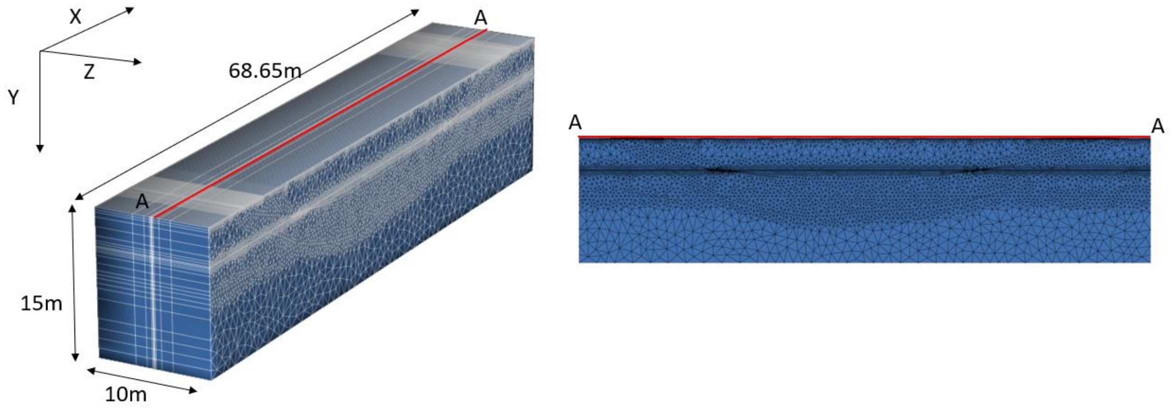

Fig. 6 Dimensions of the model in 3D and 2D

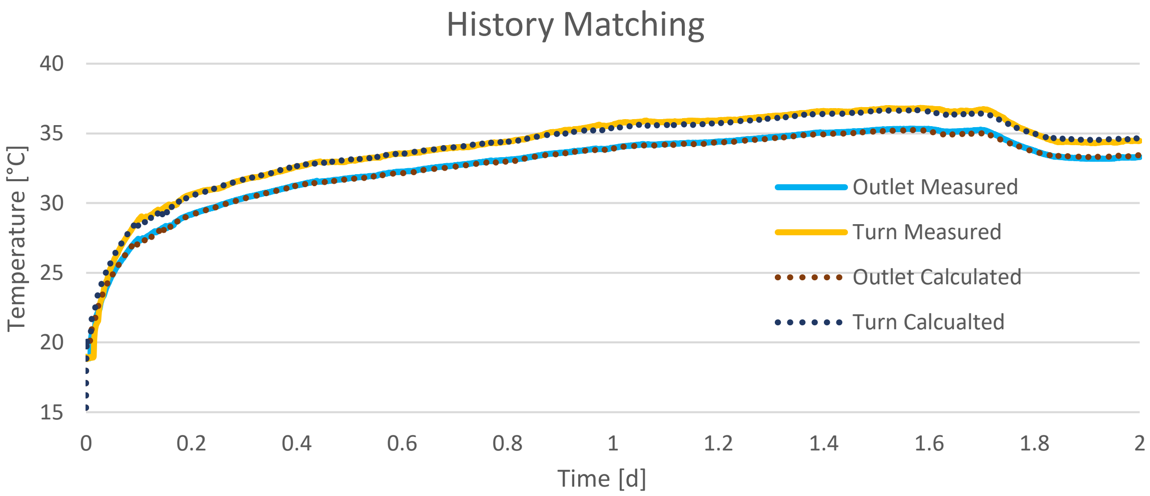

Fig. 7 Results of the history matching

Previous Research

Based on the observations from the TRT, the effect of various parameters of water injection into the borehole of HDD drilled ground heat exchangers was investigated by Lein et al. 2024.

One of the results showed that the geology, especially the permeability of the location is an important factor on the effectiveness of water injection.

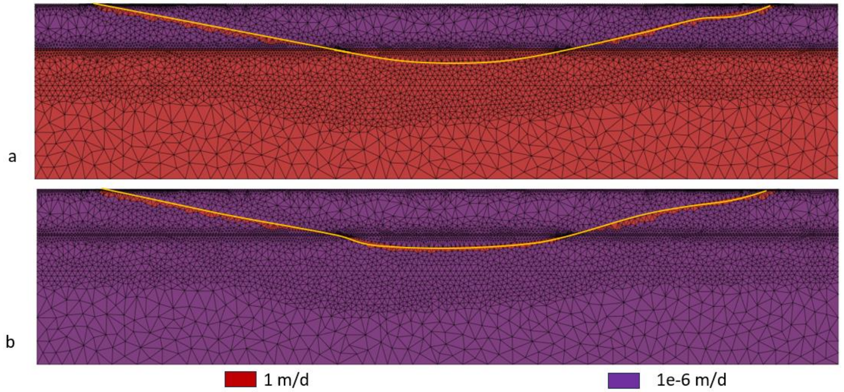

Fig. 8 Borehole path of the project in Saga

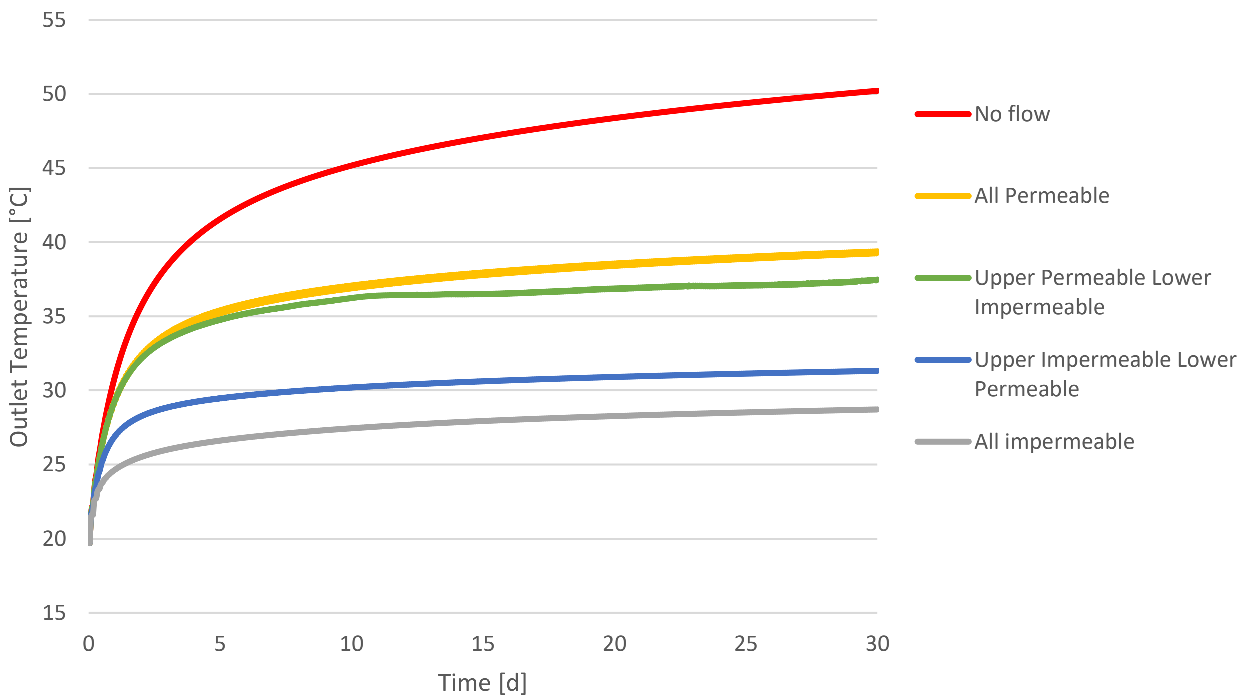

Fig. 9 Effect of Permeability of the ground on the performance of water injection [3]

Case Studies – Goals and Operation Conditions

Based on the previous research, for the location in Saga the influence of several parameters of the well path will be investigated.

These parameters include:

- Percentage of the pipe in the impermeable layer
- Well angle
- Vertical distance between pipes
- Depth of the pipe

For comparability, the following operation conditions have been applied:

- Heat Load: 5 kW
- Injection Point: Each Borehole
- Injection Temperature: 25°C
- Injection Rate: 1 L/min
- Simulation Time: 30 Days
- Heat Medium: Water

Case Studies - Results

First parameter investigated was the percentage of the pipe in the impermeable layer.

Take aways:

- Pipe should be mainly installed in the impermeable layer
- Non linear behavior
- Large steps until about 30%, afterwards smaller steps

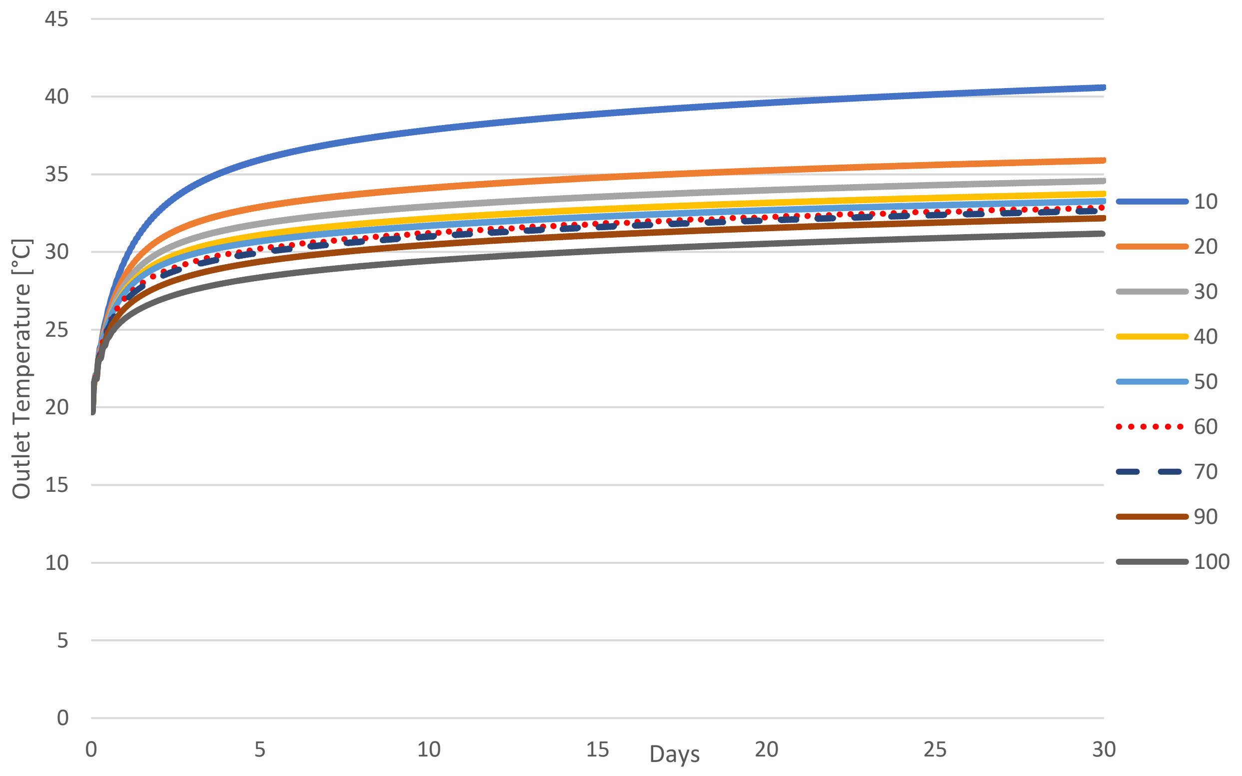

Fig. 9 Percentage of Pipe in the impermeable layer

Case Study – Well angle

When compared in the original geological setting, flat angles show a better performance for water injection.

This is behavior is caused by more pipe being in the impermeable layer when drilling in an lower angle.

To eliminate this influence the case study has been repeated with an uniform geology.

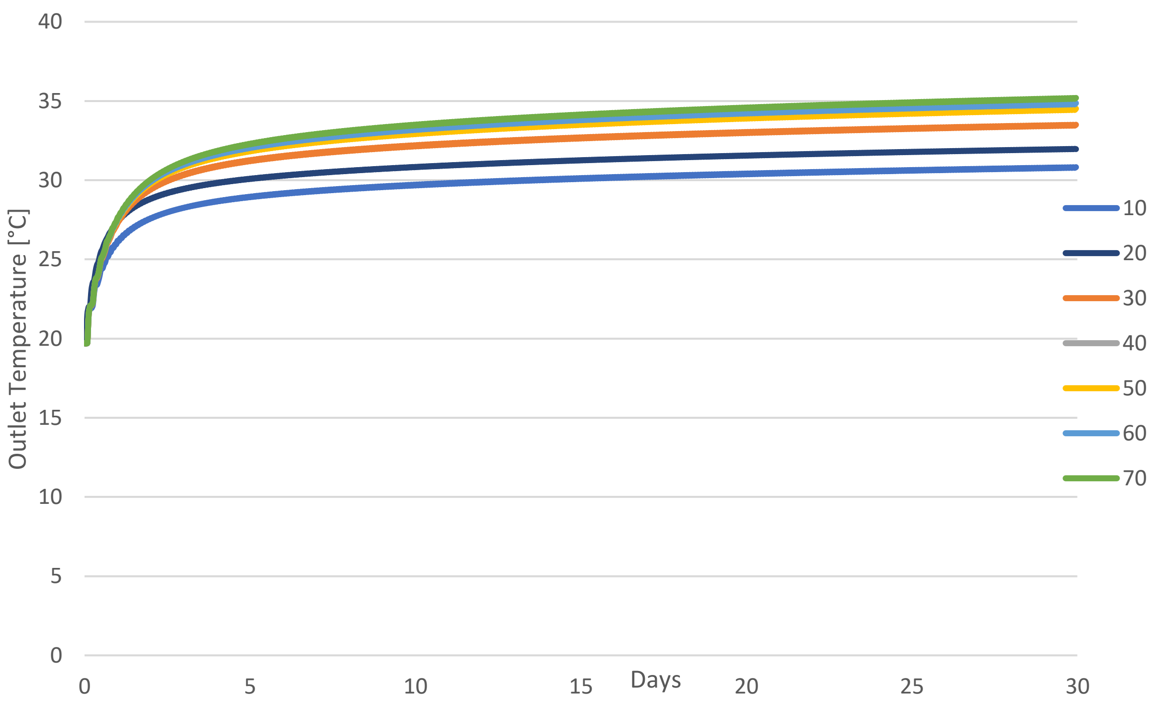

Fig. 10 Effect of the pipe angle with the test sites geology

Case Study – Well angle

With an complete impermeable geology, influence of the well angle is much smaller.

Shallower angles still have a slightly better performance, the difference however being very small.

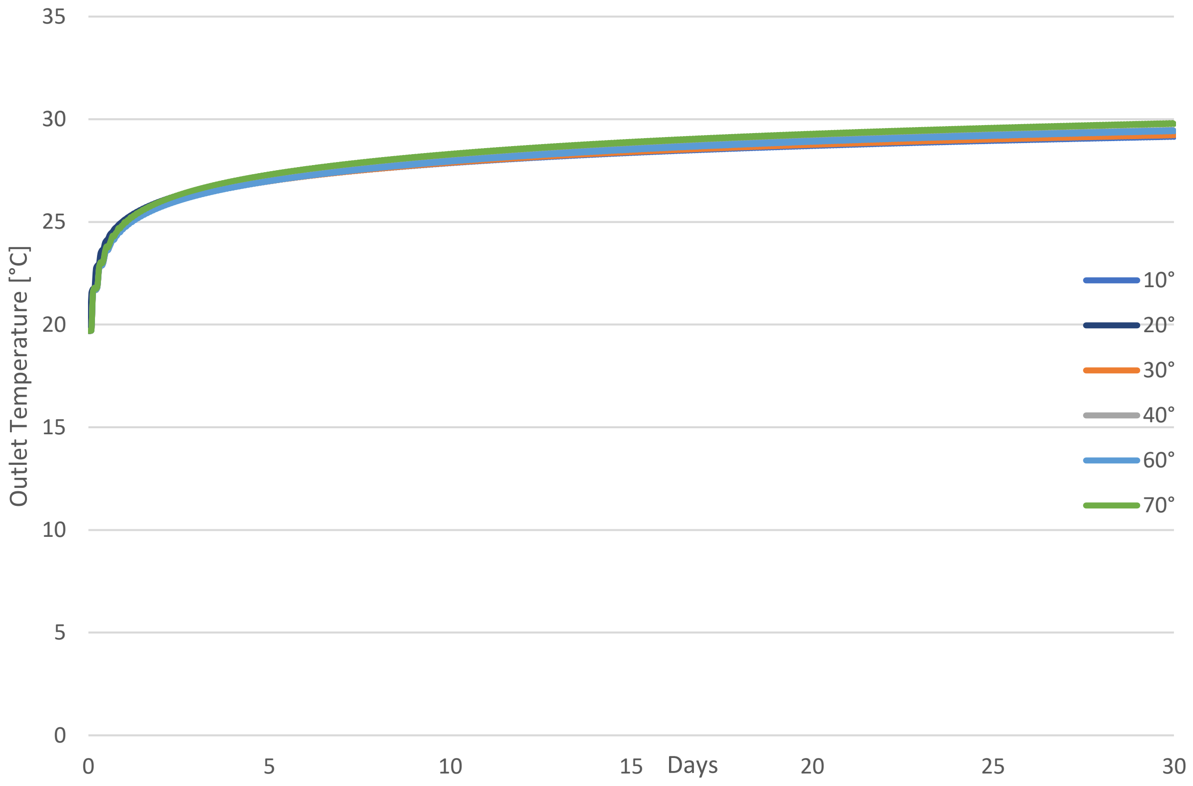

Fig. 11 Effect of the pipe angle in an uniform impermeable permeability

Case Study – Vertical Distance between Pipes

Thermal interference between the pipes reduces performance.

With water injection, even small spacings of only 1m between pipes only perform slightly worse then the original distance of 4m.

This shows that water injection can greatly reduce the effect of thermal interference between pipes.

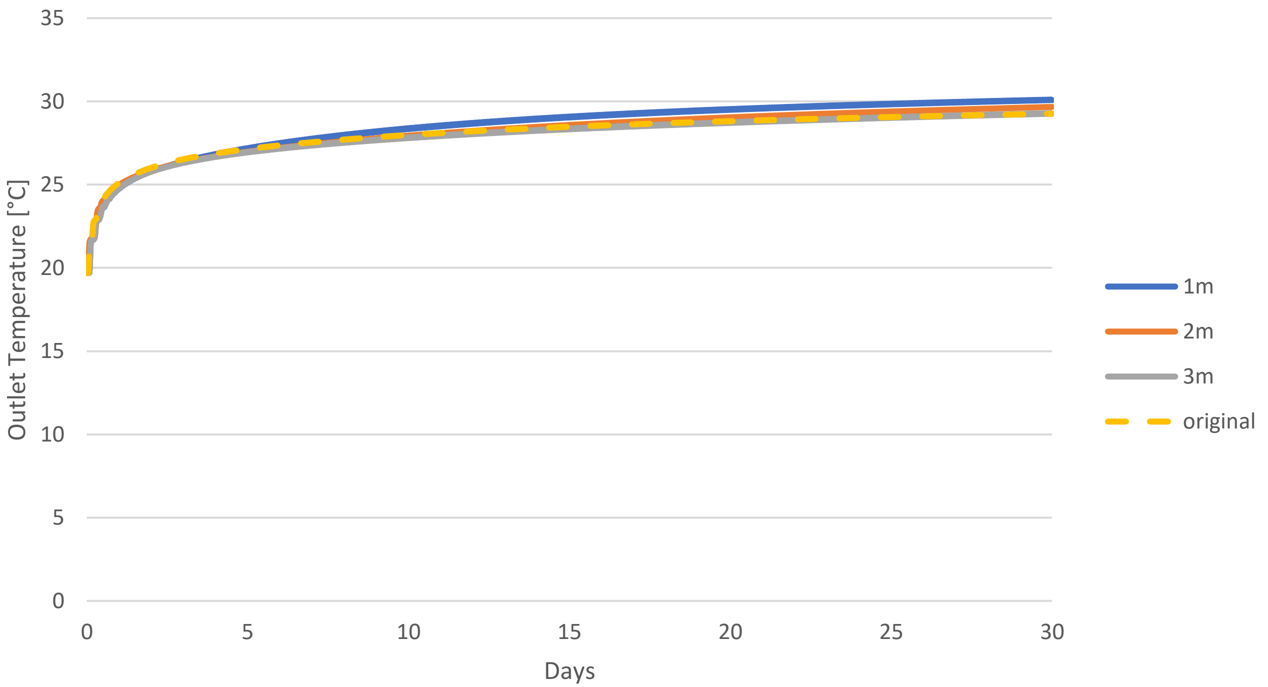

Fig. 12 Influence on water injection on the vertical distance between pipes

Case Study – Shallower Pipe

A shallower well at the location is placed completely in the impermeable layer (depth at about 3 m)

Shallower installation usually are influenced more by atmospheric conditions.

Benefits from placing the well in the impermeable layer outweigh disadvantages of shallower installation.

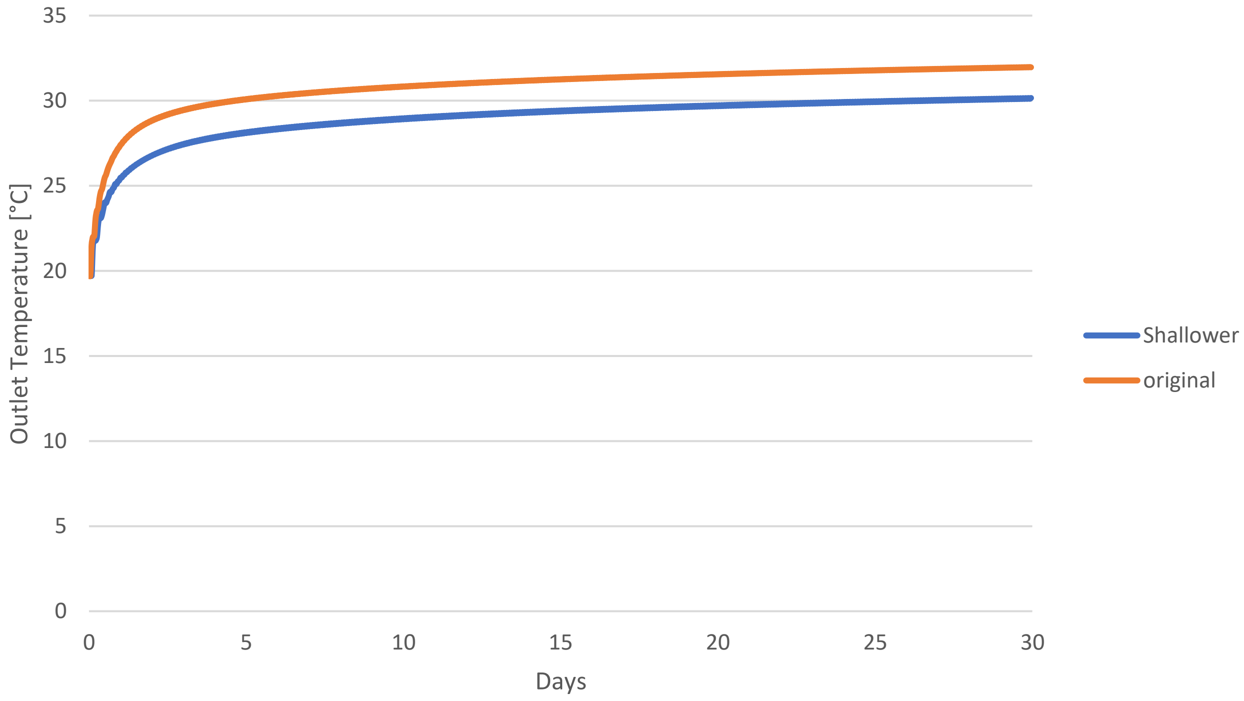

Fig. 13 Effect of water injection on shallower wells at the test location

Long Term Simulation – Operation Conditions

Long term simulations will be conducted based on the heat loads of a gym adjacent to the ground heat exchanger.

The following operation conditions have been applied:

- Heating: Dec. to Mar.
- Cooling: Jun. to Sep.
- Operation Time: 15:00 to 21:00
- Boundary Temperature:
  - Heating: 14°C
  - Cooling: 26°C

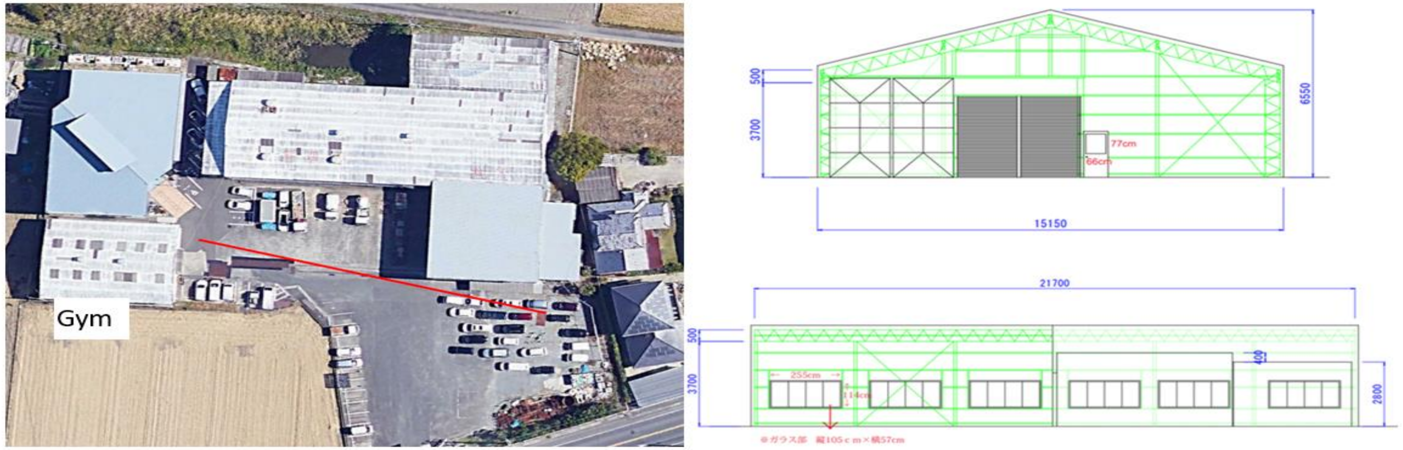

Fig. 14 Location and outline of the gym

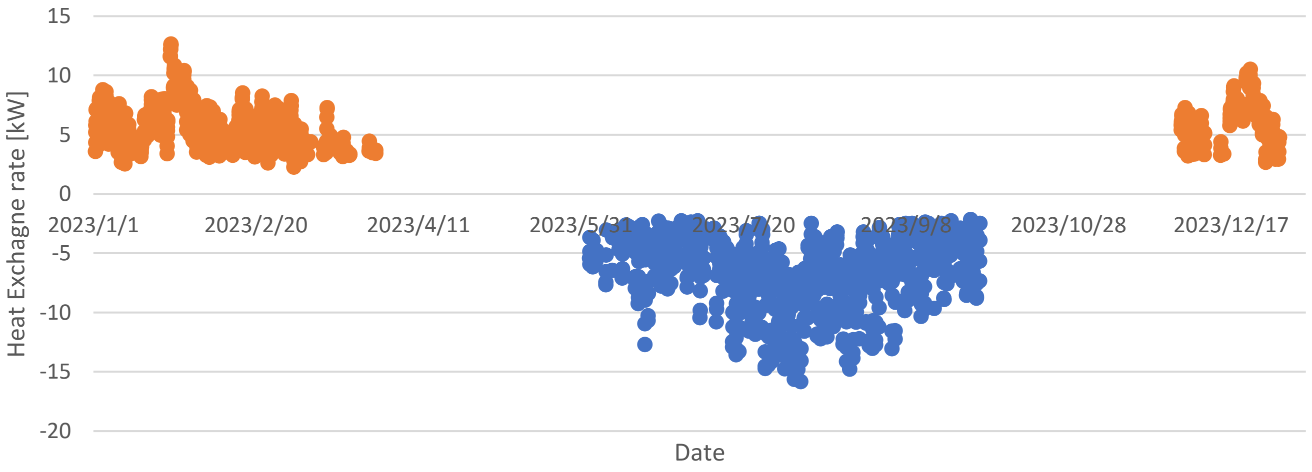

Fig. 15 Required heat exchange rate for the year 2023

Long Term Simulation – 1 year

It was shown that water injection can improve the performance throughout the year.

On average the outlet temperature was decreased by 2°C for cooling and 1.4°C for heating.

This also reflects in an improvement of the coefficient of performance (COP) by about 0.4 in both cases.

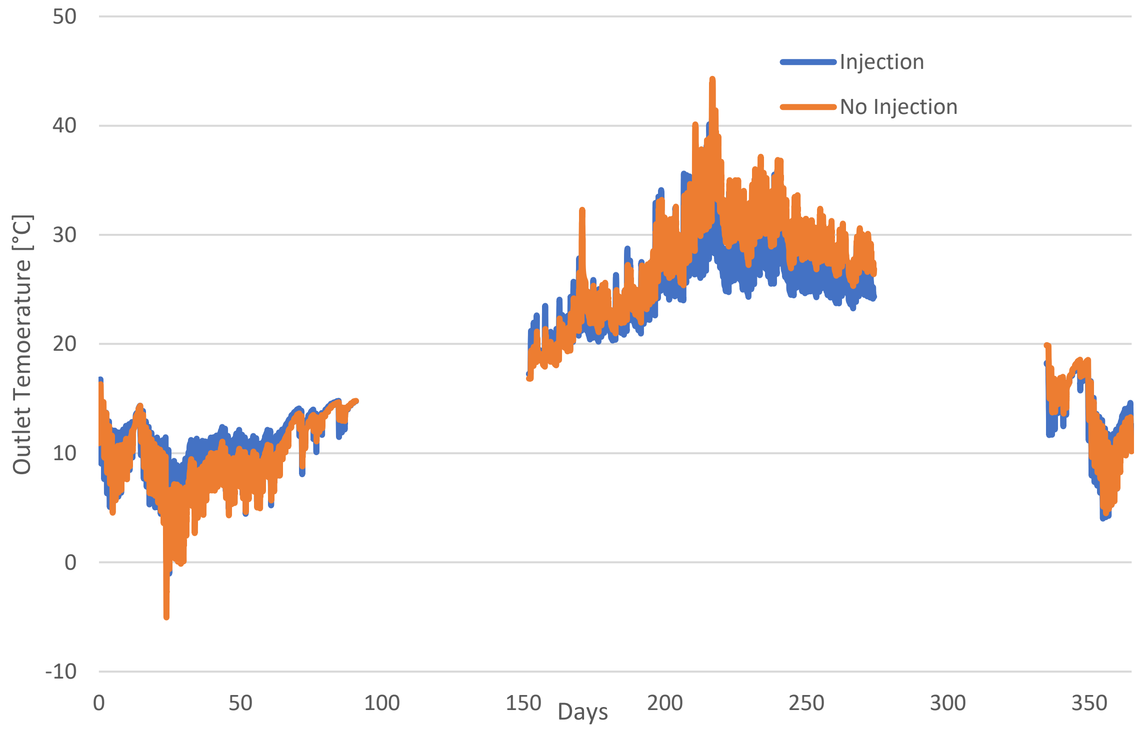

Fig. 16 1-year comparison of water injection and no injection

Long Term Simulation – 10 years

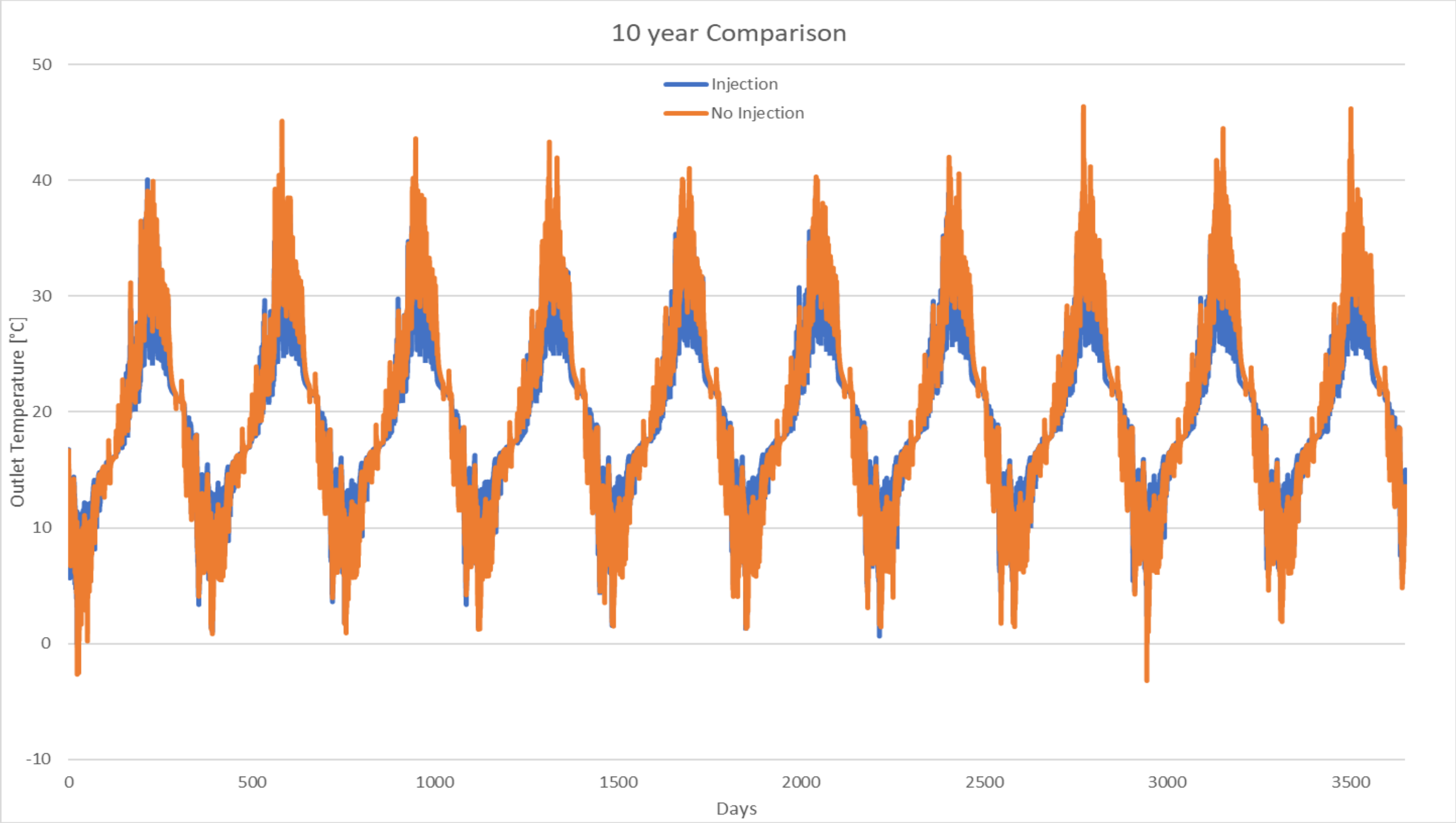

Fig. 17 10-year comparison

Water injection was shown to continuously improve performance over 10 years.

However a slight upwards trend is visible caused by a heat load imbalance imposed by the gym that was used for calculations.

COP calculations showed an similar decrease in average COP for cooling and increase for average COP in heating in both cases.

Conclusions

- The effect of several parameters of the well have been shown
- It was shown that the well should be placed in an impermeable layer, providing a defined flow path for the water
- The results also showed only a small influence of the drilling angle of the well in a uniform geology
- Water injection can eliminate the thermal interference between the pipes, allowing for less distance between the pipes and can negate influences of a shallower installation
- Based on the heat loads of a gym it was shown that water injection can increase the average outlet temperature by 1.4°C for heating and decrease the average outlet temperature by 2°C for cooling operations
- The long term stability of the system was shown, however water injection could not eliminate the effect of a thermal imbalance imposed by the heat loads calculated

References

[1] Fujii, H., et al. (2012). "Numerical modeling of slinky-coil horizontal ground heat exchangers." Geothermics **41**: 55-62.

[2] Yan, X., et al. (2018). "Horizontal directional drilling: State-of-the-art review of theory and applications." Tunnelling and Underground Space Technology **72**: 162-173.

[3] Lein, R., et al. (2024). "Optimization of double layered horizontal directional drilled ground heat exchangers by water injection into the borehole." Geothermics **118**: 102913.

Thank you for your attention!

QUESTIONS?