Assessing the Shallow Geothermal Laboratory at Universitat Politècnica de Valéncia

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ABSTRACT

As part of the Cheap-GSHPs project, an innovative laboratory for shallow geothermal research has been designed and built at the Universitat Politècnica de València (Spain). The laboratory consists of three borehole heat exchangers, each having different geometry and deep, and a common control and monitoring system. The laboratory has been designed for Thermal Response Test purposes, but the final facility is flexible enough to develop other typologies of experiments. The control system allows the researchers to define different tests and download the logged measurements through a web interface. The laboratory can be used, on the one hand, to compare the operating characteristics of different boreholes using the same experiment setup and, on the other hand, to compare different mechanisms and/or models used to obtain the operating parameters for a specific borehole. This article details the characteristics of the laboratory, its operating methodology and the first tests carried out.

1. INTRODUCTION

Thermal Response Test (TRT) was designed as a tool for investigate the ground parameters before a full design of air-conditioning systems based on ground source heat pump (GSHP) (Sauer et al. 2012) (Sanner et al. 2013). Although its wide use, the improvement of TRT evaluation techniques is still an active area of research. Our research group in the Universitat Politècnica de València (UPV) have a wide and long expertise on this area (Bandos et al. 2009) (Montero et al. 2013)(Badenes et al. 2016)(Badenes et al. 2017).

As a member of the European Union's Horizon 2020 project "Cheap and Efficient Application of Reliable Ground Source Heat Exchangers and Pumps (Cheaps-GSHPs)", one of tasks of our research group has been the design, construction and exploitation of an installation able to evaluate the developed technologies. This installation will serve as a demo site for result and technology dissemination. In fact, there is a total of six demo sites in Cheaps-GSHP:

i. the UPV test site at Valencia (Spain),
ii. a test site at Erlangen-Eltersdorf (Germany),
iii. a residential home at Putte (Belgium),
iv. an office building at Pikermi (Greece),
v. an office building at Dublin (Ireland) and
vi. the Nikola Tesla Technical Museum at Zagreb (Croatia).

The Valencia and Erlangen sites are experimental test laboratories, while the other are demonstrators of geothermal technologies by means of monitored air-conditioning systems. The Nicola Tesla Technical Museum site have been designed with special attention to improve the visibility of geothermal green energy use, because both the number of visitors and the popularity of the museum.

The UPV test site has been designed as a TRT and shallow geothermal research facility, but also for use in popularizing geothermal energy, educational purposes and training specialists. For this reason, the final installation was performed to make the more visible possible all components, arranging them in a wall ot the room to easier the explanation of their function (Figure 1).

The geothermal laboratory at UPV allows a very precise comparative study of the thermal performance between different boreholes heat exchangers (BHEs), as well very detailed studies of the thermal behaviour of BHE in different operation modes (heating and cooling). A special operation mode is added to allow the simulation of any thermal load of a building (thermal profiles). For doing so, an Air Source Heat Pump system will operate as heating and cooling source under controlled conditions.

Figure 1. General view of the test site room

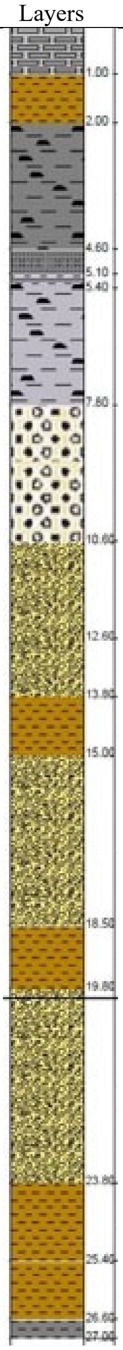
This paper begins with the detailed description of the UPV geothermal laboratory . Then, methodology and results of traditional TRT experiments are presented. These results will be used to perform a first comparison of the three BHE that has been installed in the UPV test site. Finally, we will analyse the weak points of the UPV test site and further planned improvements.

2. MATERIAL AND METHODS

2.1. Site Environment

The geographical location of the test site is at 39°29' north and 0°20' west, inside the campus of the Universitat Politècnica de València at the city of Valencia, in the spanish mediterranean coast.

Table 1. Lithological column and layers description



Layers	Description
	Stuffing
	Brown Clay Silt
	Clays – Silty Clays
	Gray Sand
	Light Grey Slime
	Clays – Silty Clays
	Sand and Gravels (<3cm)
	Gravels (<5cm)
	Clay and Gravel
	Gravel and Thick Sand
	Brown Clay
	Gravels and Thick Sand
	Brown Clay
	Dark Grey Clay

The geology of the site is an estuarine-deltaic sedimentary environment related to the river Turia and other minor ravines. It is not expected to find a real “bedrock” at least in the first 150-200 meters; therefore, the stratigraphy can be assumed as mainly composed of fine unconsolidated deposits from ground level to 100 meters of depth.

Table 1 presents the vertical section of the ground with the description of the different layers. These descriptions are based on the samples obtained while drilling the BHE. Table 5 shows the results of the analysis of the samples, detailing the geological and geothermal properties of each of those levels.

Groundwater table is observed at shallow depth, around 2 m. The area has a high groundwater affection, mostly from irrigation of the surroundings orchards.

2.2. BHEs Description

The geothermal elements of our test site are three different typologies of boreholes: one helicoidal BHE, one coaxial BHE and one single-U BHE. The last one is used as a reference of the conventional technology. Although it was planned a fourth BHE, a coaxial BHE drilled by a penetrometer technique, there were drilling problems that result in severe fluid leakages that made it useless.

The installed BHEs are separated 6m from each one. The pipe path from the control cabin to each BHE was designed with the same length in order to balance hydraulic losses (Figure 2).

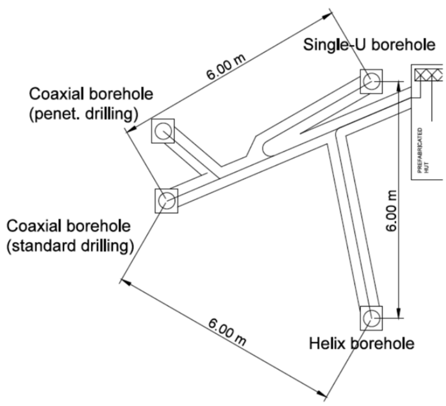


Figure 2. Connection layout scheme

The installed probe in the single-U BHE is the RAUGEO PE-Xa from REHAU (see Figure 3). The cross-linked polyethylene (PE-Xa) type probe is a continuous pipe. The ‘U’ bend at the probe tip is achieved by innovative bending technology with no joint, and a glass fibre reinforced polyester resin protects this tip.

The main reason for the choice of this area is due to valuable information on the geotechnical and geological characteristics of the ground available from other projects at that location (De Groot et al. 2013) or nearby (Badenes et al. 2016). That information was very useful during the drilling planning of the geothermal heat exchangers.

The main geometric characteristics of the single-u BHE are:

- External diameter of the pipe: 32 mm
- Internal diameter of the pipe: 26.2 mm
- Drilling depth: 15m
- BHE effective depth: 14.6 m

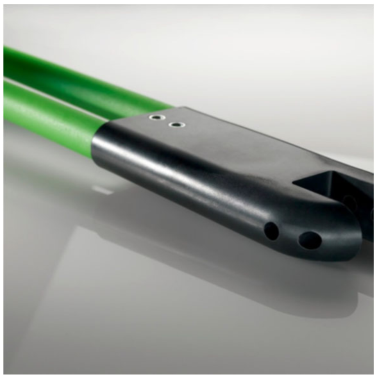


Figure 3. RAUGEO PE-Xa Single-U Probe

The helix heat exchanger is a technology improved within the project. These systems with spiral piping have considerable advantages both from a technical and economical point of view; in fact, for an equal heat exchange surface, they can be installed at depths of a few tens of meters, meaning lower depth than the classical U-tubes. The installed probe is the REHAU Helix PE-Xa. An additional unconnected single-U probe was installed aiming at using it later with the GeoSniff (EnOware 2017).

The main geometric characteristics of the helix BHE are:

- External diameter of the pipe: 25 mm
- Internal diameter of the pipe: 20.4 mm
- Drilling depth: 10 m
- Drilling diameter (casing): 450 mm
- BHE effective depth: 9.4 m
- Helix diameter: 360 mm
- Pitch helix: 63 cm

The working coaxial BHE were installed using the traditional method: rotopercussion drilling and grouted. It is composed of an external stainless-steel case and an internal plastic pipe. Its main geometric characteristics of the coaxial BHE are:

- Int. diameter external pipe: 68.1 mm;
- Ext. diameter internal pipe: 40 mm;
- Drilling depth: 15 m;
- Drilling diameter: 126 mm;
- Effective borehole depth: 14.2 m;

The grouting used for single-u and coaxial BHE was the high thermal conductivity grouting EnerGrout HD 2.1. For the helix BHE, silica sand was used for grouting.

2.3. Demo Site Layout and Specification

Figure 13 shows the hydraulic system and components of the test site. The different sensors and actuators are already shown in the same figure.

To better explain the sensors, we have divided them in seven subsystems. Table 2 describes these subsystems , the signal names and the description of the physical magnitudes that each sensor measures.

Table 2. Subsystems and names of signals to measure

Subsystem	Signal Names	Description
3-way valve	3V1 3V2 3V3 3V4	The three input temperatures to the 3.-way valve and the internal temperature of the storage tank.
Borehole **n**	BHE**n**.1 BHE**n**.2 BHE**n**.3 BHE**n**.4	**n** can be 1, 2, 3 or 4 depending on the borehole: BHE**n**.2 and BH**n**.3 are the inlet and outlet temperatures for the borehole BHE**n**.1 and BHE**n**.4 are the manifolds temperatures.
Main Pipes	FLOW.1	Flow in the collector pipe. The sensor is installed after the circulating pump.
Main Pipes	PRES.1	Pressure in the system. The sensor is installed in inlet collector.
Heat Pump	T_HP.1 T_HP.2	Temperatures in inlet (T_HP.1) and return (T_HP.2) of hydraulic circuit between Heat Pump and storage tank
Ambient	T_AMB.1	External temperature.
Soil	T_GR.1	Ground temperature. This sensor was buried equidistant to boreholes 1, 2 and 3 at a 100 cm deep.

In addition to the sensors, there are the following actuators to control the system:

1. Heat Pump. A heating and cooling air-water heat pump that will be used to generate the power used in the TRT experiments.
2. Auxiliary Resistance. There is an auxiliary heating resistance inside the tank. This resistance is 1.8kW and allows performing TRT with heat injection without the need to use the heat pump.
3. K-Flows. There is one K-Flow valve for each of the BHE (4 in the current configuration). Each k-flow valve has an associated control signal. In this way, the BHE selection can be done remotely. Experiments on several BHEs could be performed by activating more than one of these valves. They also work to balance the flow through each pipe
4. Circulating Pump. A Modbus interface connects the integrated controller of the circulating pump to PLC. Multiple operating parameters can be read and written using this interface. This allows the flow rate to be regulated.

5. 3-way valve. The 3-way valve includes an opening/closing motor and a position control system. The “close” position is the one that makes that the output is not connected at with the energy tank. The “open” position is when all the output comes from the thank.

A Siemens S7-1200 PLC is being used to implement the control algorithms, the user interface and the data acquisition and logging. The PLC implements specific control algorithm for the 3-way valve, the circulating pump and the auxiliary resistance.

The test site operating modes are:

1. STOPPED. The water pump is off and the 3-way valve is closed.
2. RECIRCULATING CLOSED. The water pump is ON, with a PID controlling the flow, and the valve is in closed position.
3. RECIRCULATING OPEN. The circulating pump is ON, with a PID controlling the flow, and the valve is in open position.
4. HEAT INJECTION. The water pump and the 3-way valve are controlled. The reference is thermal injection constant. The main objective is to control the 3-way valve in order to maintain constant the temperature jump in BHE head with inlet borehole temperature higher than outlet temperature.
5. HEAT EXTRACTION. The water pump and the 3-way valve are controlled. The reference is thermal extraction constant. The main objective is to control the 3-way valve in order to maintain the temperature jump in BHE head constant with inlet borehole temperature lower than outlet temperature.
6. THERMAL PROFILE (Heating mode). A version of (5) with parameters for power and flow taken from a table describing the 24-hour profile of a building.
7. THERMAL PROFILE (Cooling mode). A version of (4) with parameters for power and flow taken from a table describing the 24-hour profile of a building.

The most complex control algorithm is the one responsible for constant power injection at BHE by controlling the 3-way valve position (see Figure 14). The main difficulties solved in the design of this control have been the great delay of the system and the non-linearity issues that the 3-way valve introduces.

2.4. Experiment setup

This section presents the results of Thermal Response Test carried out with constant and controlled thermal power injection at each of the borehole heat exchangers.

The main purpose of any TRT is to perform an analysis of the obtained data in order to derive the main parameters that characterized the ground (ground thermal conductivity or λ and the undisturbed underground temperature or T_0) and the borehole (BHE thermal resistance or R_b)(Urchueguía et al. 2018). These parameters are necessary when designing a shallow geothermal installation in order to properly size the length of buried heat exchanger.

The data obtained from these tests has been analysed with three different BHE analytical models: Infinite Line Source Model (ILSM), Cylindrical Source Model (CSM) and Finite Line Source Model (FLSM). For these analysis the methodology used is described in (Badenes et al. 2017).

In order to compare the results from different BHEs, the parameters of the TRT were fixed with the values presented in Table 3. The Reynolds values were selected to ensure turbulent flow but low enough to minimize pressure losses from the circulation pump.

Therefore, according to these guidelines, the parameters of each of the tests performed are presented in Table 4. In this table, ΔT represents the calculated temperature jump in BHE head.

Table 3. Parameters used to perform all TRT

Parameter	Value
Injected Heat Rate	80 W/m
Reynolds	~ 2300
Duration of TRT	5 days
Logging interval	180 s

Table 4. The TRT parameters for each borehole

	Single-U	Helix	Coaxial
Depth (m)	14.6	9.4	14.2
Heat Ratio	80	80	80
Heat Injected	1168	752	1136
Flow (l/h)	187	146	680
Reynolds	2294	2391	2022
ΔT (ºC)	5.4	4.4	1.4

3. RESULTS

The measured typical parameters during a TRT are the fluid flow and the temperatures in the inlet and outlet of the borehole (Tin and Tout). In some cases, the ambient temperature is also monitored in order to detect malfunctions or thermal interference.

Although our system can monitor more variables, in this article we are focused in evaluate and compare the three boreholes as if a standard TRT has been used.

Figure 4 shows the results of the TRT on the single-u BHE. The thermal power injected (yellow line in the figure) was calculated using the measures from the flow sensor and the two temperatures sensors located in the head of the borehole. The showed values are raw data values, no filter was used. The error between the set point (see Table 4) and the measured value is always inside a 5-10% tolerance and it seems not related to ambient temperature, which is a common problem during a TRT. Figure 5 and Figure 6 show the data plots for the TRTs performed on coaxial and helicoidal BHEs.

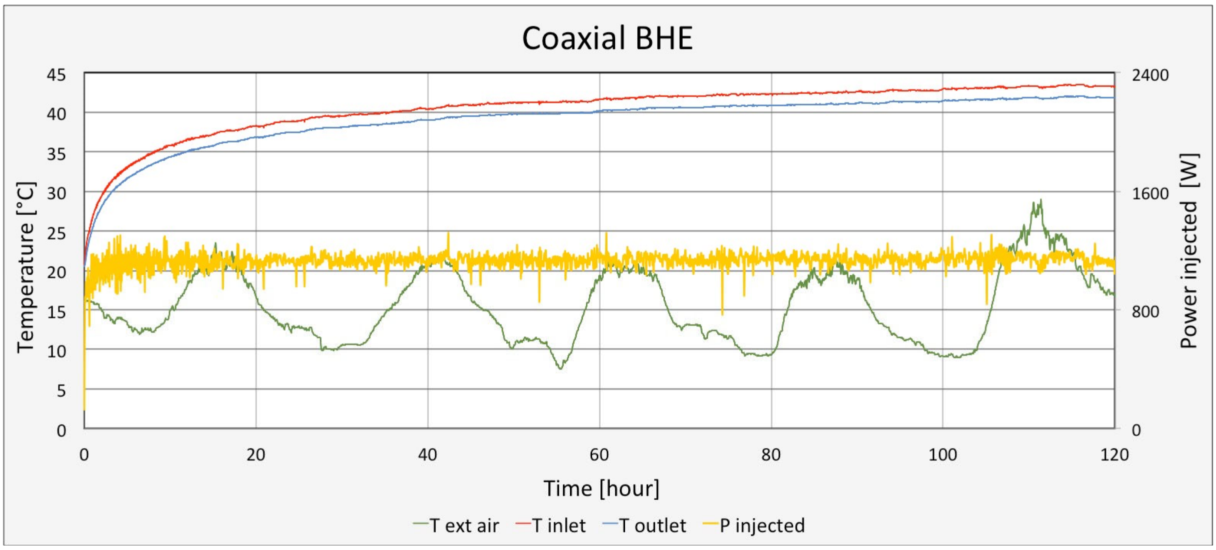


Figure 4. TRT measurements of the Single U BHE

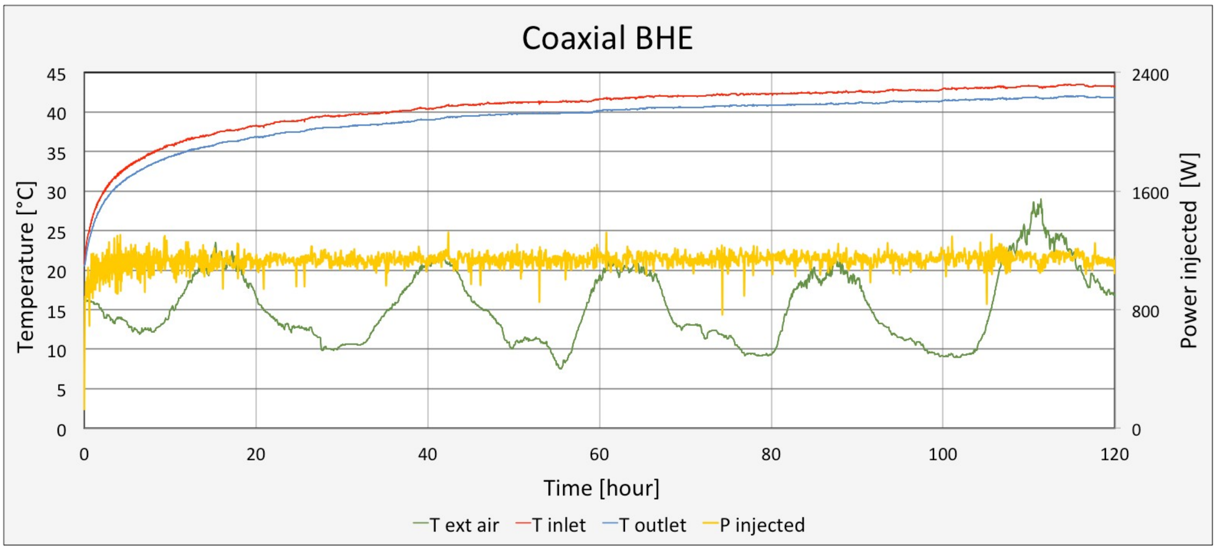


Figure 5. TRT measurements of the Coaxial BHE

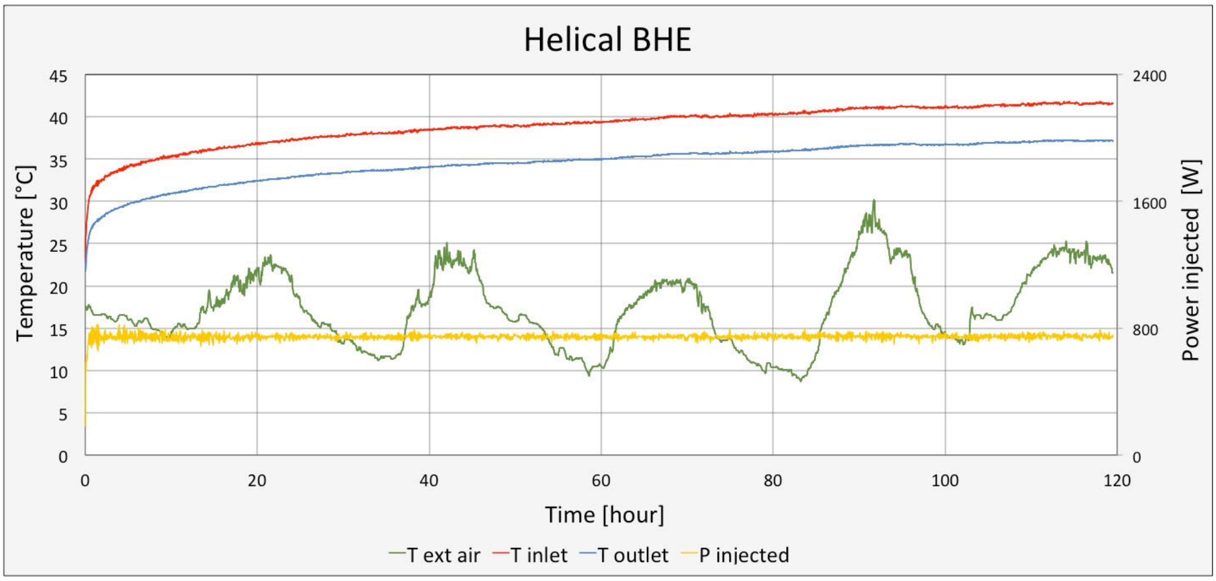


Figure 6. TRT measurements of the Helicoidal BHE

In these figures, it can be seen that in the TRT experiments with thermal power injection the typical influence of ambient temperature is not observed.

From these data, the mean temperature of the BHE is defined by equation 1. Figure 7 shows the Tm for each BHE for the five days of the test.

$$T_m = \frac{\text{Tin+Tout}}{2} \qquad [1]$$

With the values of T_m, time and flow, there are different models that can be used to determine the thermal characteristics of the ground and the borehole.

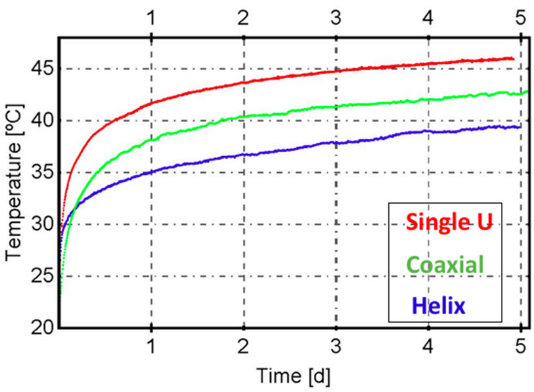


Figure 7. T_m evolution in each type of BHE

The most common estimated parameters are λ and R_b. Other parameters, as the undisturbed underground temperature (T_0) and the soil thermal diffusivity (α), are estimated. For example, a value of 6E−7 $m^2\ s^{-1}$ for the thermal diffusivity and, for T_0, the average temperature in the borehole obtained during a test without thermal injection and without thermal effect from the circulation pump.

Using a modified version of the analytical methods discussed on (Urchueguía et al. 2018) we can calculate the borehole thermal resistance fixing the other parameters of the model, including ground thermal conductivity.

As the three BHE been studied are installed in the same location, we can suppose that their surrounding soil will present the same characteristics. Taking this into account, a study was performed about how the soil thermal conductivity influences the calculated borehole resistance using three analytical models. The ground thermal conductivity values were 1.5 to 3 W/mK. These values comes from of our knowledge of the geology of the UPV test site and from previous experiments where it was an outcome of the fitting algorithms (Badenes et al. 2017).

Figures from Figure 8 to Figure 10 show the results of this study. The R_b obtained in the nine plots are around 0.1 to 0.2 mK/W, which are values inside the expected range. The coaxial BHE gets the minimum value and the single-u BHE is the one with higher values.

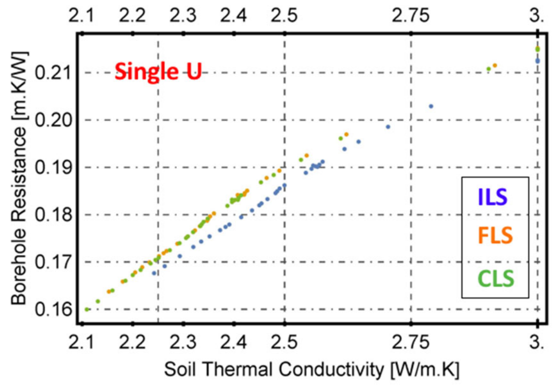


Figure 8. R_b model parameter identification for Single U

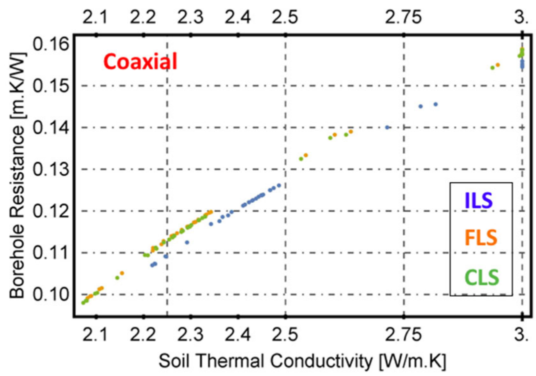


Figure 9. R_b model parameter identification for Coaxial BHE

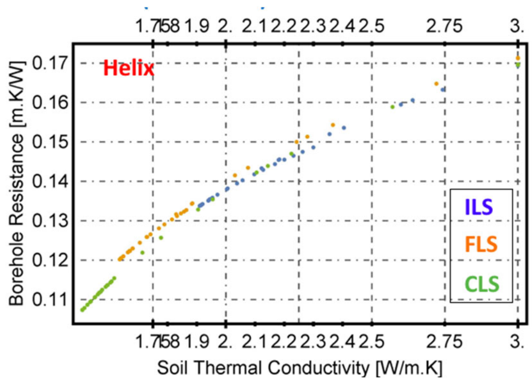


Figure 10. R_b model parameter identification for Helicoidal BHE

4. DISCUSSION

The main objective these experiments carried out in the UPV geothermal laboratory is the comparison of BHE on the same soil and using the methodology.

Talking about the comparison between BHE, after applying numerical methods to fit different model, we can get a picture of the R_b of three BHE. Figure 11 summarizes the results showed in Figures 8, 9 and 10 using only the ILS model.

Figure 11 shows that, after a five-day TRT, the coaxial BHE tested presents the better R_b, independently of the λ of the ground. Single-U, the most standard typology for BHE presents the worst value.

These results are only valid from the point of view of thermal performance. Taking into account the costs, the Figure 12 shows the cost of drilling (vertical axis in euros) related to the length of the BHE.

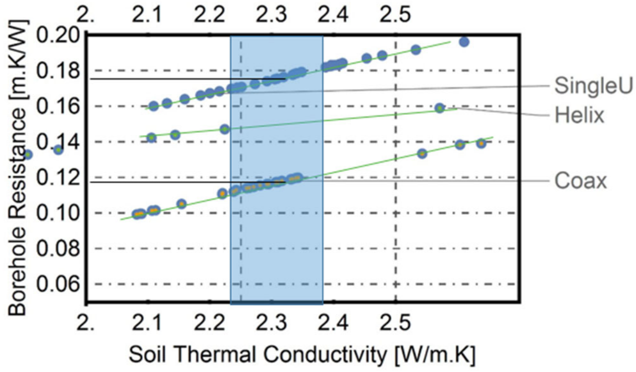


Figure 11. R_b model parameter identification for ILSM

Single-U BHE are the cheapest one but is the technology that presents the higher R_b. Un other hand, helicoidal BHE are the most expensive to install and our tests also shows that its R_b is higher than R_b of coaxial BHE.

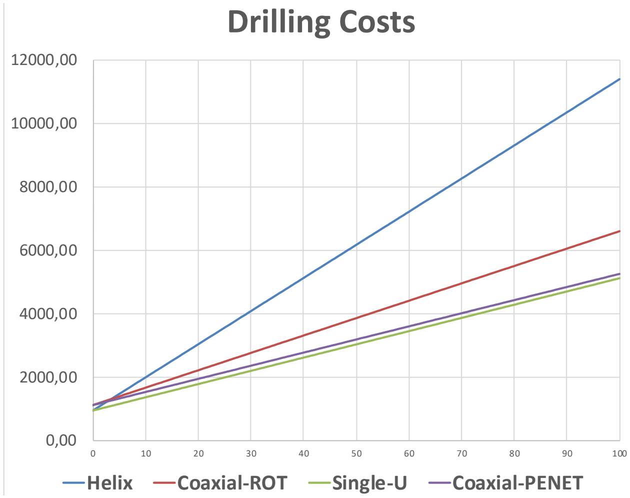


Figure 12. Drilling costs (€) vs BHE depth (m)

The coaxial BHE installed with standard drilling and grouting has showed the better R_b in our test site, but it is a bit more expensive to install than single-U.

5. CONCLUSIONS

The UPV geothermal test site has been described in this paper. This installations wants to be a reference in shallow geothermal research and it has been initially developed as part of CHEAP-GSHPs project.

The presented results are based on standard TRT performed to the three installed BHE. The results show that coaxial BHE presents the better borehole thermal resistance. Single-U, the cheaper and most popular type of BHE, show a R_b higher than the other two types.

New technologies, like penetrometer-type installed coaxial, promises that we will able to get the performance of coaxial at the installing cost of single-U (see Figure 12). Unfortunately, we can only talk about installation costs of this kind of system after the unsuccessful attempt to install a coaxial BHE with the piling method developed in the CHEAP-GSHPs project. This was due to the nature of the ground of Valencia, with the presence of unconsolidated gravels at different depths.

Regarding to the laboratory facility, there are multiple experiment configurations that can be evaluated. Among them, cooling thermal tests (heat extraction), thermal load profile evaluation and longer length of time experiments. In fact, the geothermal laboratory is flexible enough to implement new experiment setups.

But there also some points for improvement. First of all, the control algorithm is sensitive to reference noise and to the lack of linearity of the 3-way valve actuator. More thorough controls have to be designed and validated.

Another restriction of the actual facility is that switching from cooling to heating injection is not possible due to the thermal inertia of storage tank. The installation of a second storage tank will solve this problem, as one can be used for storing cold water while the other stores hot water.

In fact, the installation will be expanded in the next months as part of the H2020 European project GEOCOND. At least 6 new BHEs will be added to the test site in order to evaluate the new products developed in the project.

6. REFERENCES

Badenes, B. et al., 2016. Experimental facility to perform Thermal Response Tests and study the thermal behaviour of the ground. In *European Geothermal Congress 2016*. Strasbourg, France, pp. 19–24.

Badenes, B. et al., 2017. On the influence of operational and control parameters in thermal response testing of borehole heat exchangers. *Energies*, 10(9). Available at: http://www.mdpi.com/1996-1073/10/9/1328.

Bandos, T. V et al., 2009. Finite line-source model for borehole heat exchangers: effect of vertical temperature variations. *Geothermics*, 38(2), pp.263–270.

EnOware, 2017. GEOsniff® - enOware GmbH Karlsruhe. Available at: https://www.enoware.de [Accessed March 10, 2019].

De Groot, M. et al., 2013. Heating and cooling an energy pile under working load in Valencia. In *European geothermal Congress 2013*. Pisa, Italy, p. 8.

Montero, A. et al., 2013. Ground temperature profile while thermal response testing. In *European Geothermal Congress 2013*. Pisa, Italy, pp. 1–6.

Sanner, B. et al., 2013. More than 15 years of mobile Thermal Response Test – a summary of experiences and prospects. In *European Geothermal Congress 2013*. Pisa, Italy.

Sauer, M. et al., 2012. Thermal Response Test: Practical experience and extended range of application. In *Innostock 2012: The 12th International Conference on Energy Storage*. Lleida, Spain.

Urchueguía, J. et al., 2018. How Reliable Are Standard Thermal Response Tests? An Assessment Based on Long-Term Thermal Response Tests Under Different Operational Conditions. *Energies*, 11(12), p.3347.

7. ACKNOWLEDGEMENTS

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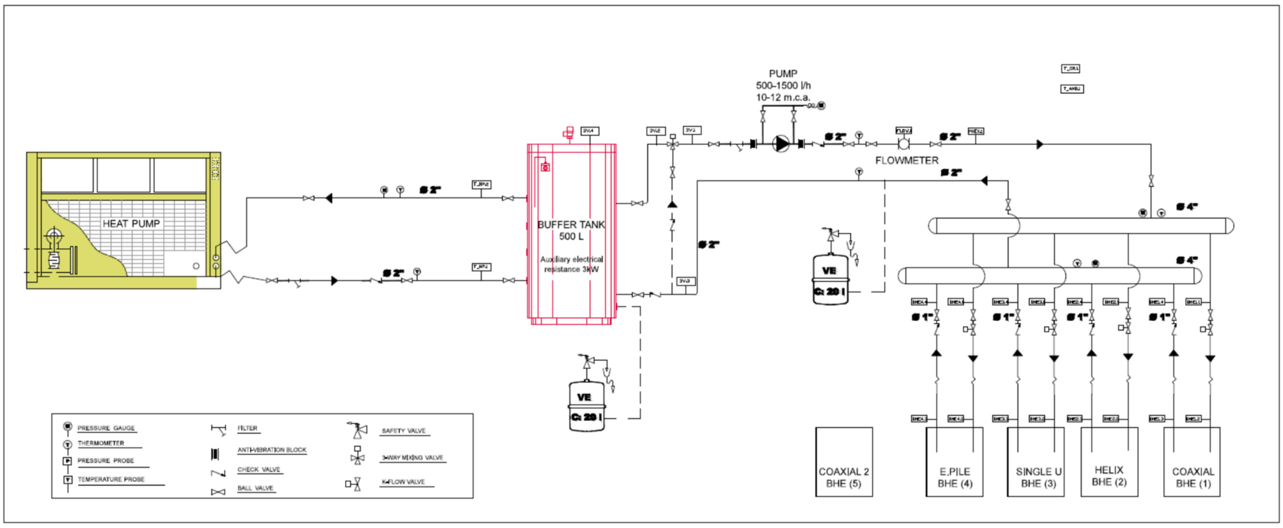

Figure 13. Hydraulic system diagram

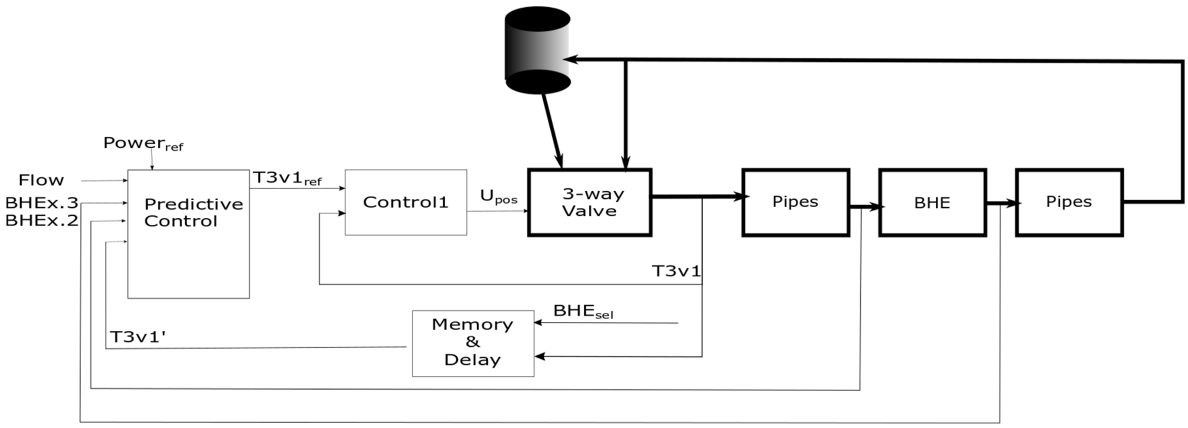

Figure 14. Control system blocks and signals

Table 5. Geotechnical and Geothermal properties of the different levels

Deep	Lithology	Geotechnical properties	Thermal properties
0 – 1,00	**Stuffing**	ρ ap 1,80 t/m^3 C' = 0 kPa φ= 28º	--
1,00 – 2,00 N.F. ∇	**Brown clayey silt** dried	ρ ap natural 2,0 t/m^3 ρ ap dried 1,70 t/m^3 Cohesion: C' = 1 kPa Internal friction angle: φ= 26º Simple compression: q_u = 60 kPa Non-drainage shear strength: c_u = 30 kPa Elastic modulus E = 5000 kPa Poisson's coefficient ν = 0,30 Permeability: K = 10^{-5} m/s Bearing resistance σ_{fh} – Shaft resistance: τ_{fh} = 25 kPa	**λ = 0,59 – 1,86 (1,60) W/m·K** **Cv = 1,27 – 2,97 (2,42) MJ/(m^3·K)** **Dif. = 0,46 – 0,82 (0,65) mm^2/s**
2,00 – 7,80	**Clays – silty clays** saturated	ρ ap natural 1,90 t/m^3 ρ ap dried 1,50 t/m^3 C' = 5 kPa φ= 26º q_u = 40 kPa c_u = 20 kPa E = 3000 kPa ν = 0,30 K = 10^{-5} m/s σ_{fh} – τ_{fh} = 15 kPa	**λ = 0,55 – 1,86 (1,43) W/m·K** **Cv = 0,64 – 3,34 (2,30) MJ/(m^3·K)** **Dif. = 0,45 – 0,82 (0,63) mm^2/s**
7,80 – 26,0	**Gravel and sand** (sandstone, variable matrix)	ρ ap natural 2,20 t/m^3 ρ ap dried 2,00 t/m^3 Cohesion: 0 - 20 kPa (depending on the matrix) φ= 35º q_u = 100 kPa c_u = 30 - 50 kPa E = 50.000 – 100.000 kPa ν = 0,25 - 0,30 K = 10^{-4} m/s σ_{fh} : 5500 kPa τ_{fh} = 75 kPa	**λ = 0,44 – 2,94 (1,29) W/m·K** **Cv = 0,92 – 2,15 (1,59) MJ/(m^3·K)** **Dif. = 0,21 – 1,91 (0,84) mm^2/s**
Levels 13,80 – 15,00 18,50 – 19,80 23,80 – 26,60	**Silty clays** firm consistency	ρ ap natural 1,90 t/m^3 ρ ap dried1,65 t/m^3 Cohesion: C' = 28 kPa φ= 26º q_u: 60 kPa c_u = 20 – 30 kPa E = 5000 kPa ν = 0,30 K = 10^{-6} m/s σ_{fh} : 450 kPa τ_{fh} = 20 - 35 kPa	**λ = 0,68 – 2,35 (1,77) W/m·K** **Cv = 1,37 – 3,50 (2,37) MJ/(m^3·K)** **Dif. = 0,46 – 1,14 (0,75) mm^2/s**