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# Ground temperature recovery time after BHE insertion

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## ABSTRACT

Thermal response tests to characterise ground thermal properties are an almost standard procedure for the design of large size ground coupled heat pump air conditioning systems. The purpose of this test is the measurement at site of three main parameters used for the design of a ground coupled heat pump system: ground thermal conductivity, borehole thermal resistance and undisturbed ground temperature. The test is usually performed a few days after borehole insertion. This contribution presents the experimental measurements of ground temperature recovery time after borehole heat exchanger insertion and its implications in the estimation of ground coupled heat pump design parameters. A 40 meters borehole heat exchanger with two independent U-pipes has been monitored after borehole insertion. Ground temperatures as a function of depth have been regularly measured. This contribution presents the evolution of the temperature profile from the date of U-pipe insertion until six months after. Main conclusion of this contribution is that the ground temperature profile achieves a stable profile at a time around five months after borehole insertion. This time scale is quite relevant for interpreting data extracted from a standard thermal response test performed, usually, a few days after borehole heat exchanger insertion. Ground temperature is biased by the heating effect produced by the drilling procedure, and the heating effect produced by the concrete setting. Then, ground thermal properties estimated by performing a TRT just a few days after borehole insertion may not be describing actual ground properties.

## 1. INTRODUCTION

Standard procedures to design ground source heat pump HVAC systems are based in the knowledge of two input parameters, first, the thermal loads that the air-conditioned area demands and, second, ground thermal properties. The capacity of the ground source system is estimated from a proper calculation of the building thermal loads. Once the needed capacity is estimated, the design procedure looks for the ground thermal properties to determine the characteristics of the water to water heat pump and the required length and layout of the borehole heat exchangers.

A proper estimation of ground thermal properties is crucial for an accurate design of the ground source system. In situ thermal response tests (Austin, 1998; Eklöf and Gehlin 1996) are carried out to have a measurement at site of the three main parameters characterizing the heat transfer process between the borehole heat exchanger and the ground: ground thermal conductivity, borehole thermal resistance and undisturbed ground temperature. An in situ thermal response test studies the thermal response of the borehole heat exchanger to a constant injection or extraction of thermal power to the ground. Main outputs of this test are the inlet and outlet temperature of the heat carrier fluid as a function of time. With these experimental data and with an appropriate model describing the heat transfer process between the fluid and the ground, thermal conductivity of the ground and borehole thermal resistance are inferred. The infinite line source (ILS) model is the most widely used method for evaluation of response test data because of its simplicity and speed (Hellström, 1991; Witte et al, 2002).

Several years ago, the research group on shallow geothermal energy at Universitat Politècnica de València started a research line with the purpose of improving the estimation of ground thermal properties needed to design ground coupled heat pump systems. Improvements of the thermal response test technique can be pursued in different ways. One approach consists in refining the model describing the borehole heat exchanger to include effects not taken into account. Finite length effects can be incorporated in the analysis procedure of test in situ outputs as shown in Bandos et al, 2009. A filtering technique of the undesired effect produced in fluid temperature measurements by the ambient temperature can be used to improve the estimating of ground thermal properties (Bandos et al 2011). Other approach to improve the in situ technique is the design of new instruments able to measure the evolution of the fluid temperature along its way through the borehole heat exchanger. A measurement device embedded in a 25 mm diameter sphere, including a temperature sensor, an acquisition system, temporary storage and wireless communication was developed to obtain these measures (Martos, 2011). With this new information it will be possible to infer some properties about the ground structure relevant for the design of the ground coupled system.

To verify the new developments achieved by our research group to improve in situ procedures to characterize ground thermal properties, an experimental facility was built to evaluate the validity of the developed models, as well as to improve the measurement of ground thermal properties in Mediterranean areas, characterized by the significant presence of ground water flows. This facility was built along 2010 year at Universidad Politécnica de Valencia, and funded by the Spanish Ministry of Science and Innovation (project ENE2008-00599).

This contribution is focused on the static characterization of the borehole heat exchanger after borehole insertion. In situ tests are usually performed a few days after borehole heat exchanger insertion. During these waiting days ground temperature recovers from the effects produced by the drilling procedure, the U-pipe insertion and the filling material setting. This paper investigates the ground temperature recovery after BHE insertion through the measurement of the ground temperature profile evolution from the date of U-pipe insertion until six months after. Main conclusion of this contribution is that the ground temperature profile achieves stability at a time around five months after borehole heat exchanger insertion.

## 2. THE BOREHOLE HEAT EXCHANGER FACILITY

The borehole heat exchanger facility was built on the first days of May 2010, inserting two independents U-pipes the 12th of May and, then, filling the borehole with a mixture of one part of bentonite and twelve parts of cement (CEMEX 32.5 raff). This mixture and the type of cement was chosen because is particularly appropriate for grounds with a considerable amount of ground water flows, as is the case of the coastal Valencia area.

First idea for this installation was inserting two independent U-pipes, both with 40 m. depth. Nevertheless, after executing the drilling and inserting metallic cylinders with 160 mm diameter, a narrowing of the diameter was observed at 30 m. depth. Metallic cylinders were 3 m. long, introduced while drilling and weld between them. The diameter narrowing could be explained by a fracture of one of the joints, reducing a few mm the diameter. There was not enough space for inserting both U-pipes from the 30 to 40 m. depth, so it was decided to introduce a shorter U-pipe (30 m. depth) and a 40 m. U-pipe.

Samples of ground components were stored while drilling, giving a first idea of ground layer structure. Figure 1 shows this layer structure.

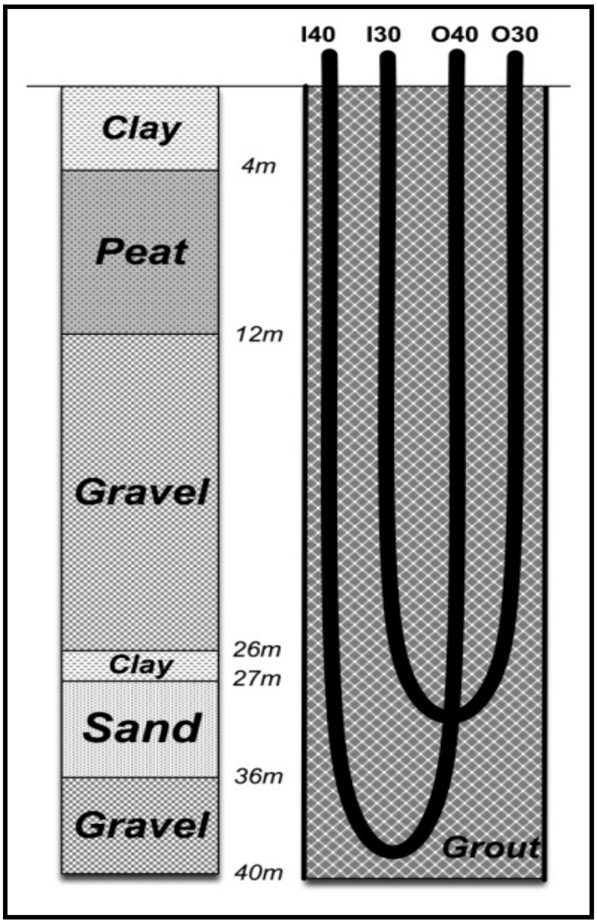


**Figure 1: diagram showing the vertical layout of the borehole, indicating the different strata of the ground.**

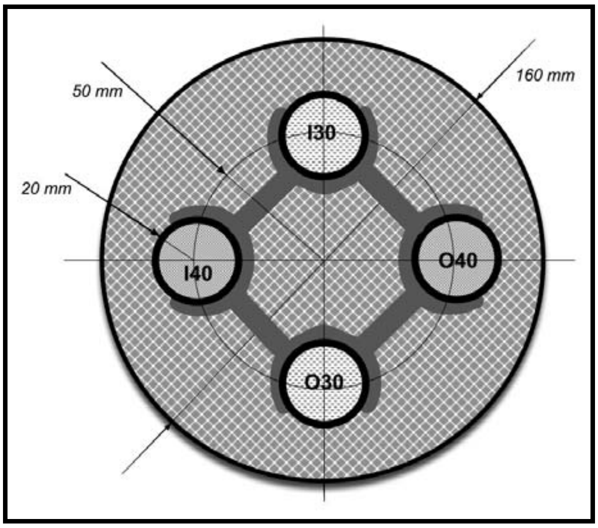


**Figure 2: diagram showing the horizontal structure layout of the borehole.**

**Figure 3: picture of the facility while inserting the heat exchanger.**

From ground samples, six layers can be identified along the 40 meters drilled. First one, from 0 to 4 m., is a clay layer. Second one, from 4 to 12 m., is a peat layer. Third one, from 12 to 26 m., is a gravel layer, with many small round stones. Fourth one is another clay layer; from 26 to 27 meters. Fifth one is a sand layer, from 27 to 36 meters. And sixth one is another gravel layer, from 36 to 40 meters, also with many small round stones. During drilling a considerable amount of ground water was observed. Figure 1 shows this vertical layer structure together with the vertical layout of both independent U-pipes. After finishing the construction of this facility a measurement of the actual depth of each U-pipe was measured with a calibrated string. Actual depth is 29.5 meters for the shorter U-pipe and 39.5 meters for the longer U-pipe.

Figure 2 shows the horizontal structure layout of the borehole heat exchanger. U-pipes are in the middle of metallic cylinders with diameter 160 mm. The diameter of each U-pipe is 40 mm, being its centre 50 mm distance from the centre of the metallic cylinder. To maintain this horizontal layout structure spacers are located every meter along the whole length of the U-pipes.

Figure 3 shows a picture of the facility while inserting the whole heat exchanger, composed of both independent U-pipes. In the centre of the borehole there is one more pipe, used to inject the filling material to the borehole. After inserting the heat exchanger a mixture of one part of bentonite and twelve parts of cement was injected to the borehole through this pipe. This process was completed in one working day.

**Figure 4: picture of the facility after finishing construction.**

After finishing the BHE facility construction, a period of six months were dedicated to measure the ground temperature profile evolution, to investigate the time that the ground needs to recover a stable temperature profile after BHE insertion.

During this measurement period, a thermal response test unit was constructed and located in the borehole heat exchanger facility. A picture of the facility after finishing construction is shown in figure 4.

## 3. EXPERIMENTAL RESULTS

Main results achieved are shown in figure 5 and 6 in which the evolution of the temperature profile from the date of U-pipe insertion until six months after is shown.

Figure 5 shows the temperature profile measured with a calibrated temperature sensor inserted in the U-pipe. Measures are taken every meter and the procedure is repeated at least once a month during next six months after borehole insertion. Main conclusion from this figure is that a stable ground temperature is achieved around 5-6 months after U-pipe insertion and grouting, decreasing the average temperature around 2 ºC during this period. The origin of this temperature behaviour is due to the heating effect produced by the concrete setting. In fact, this could be also the explanation of the temperature peak observed at 30 m. depth. As we mention previously a fracture at this depth was observed in the metallic cover, so a part of the inserted cement escape through this fracture and, then, a higher heating effect was produced during setting by this exceeding amount of cement located at this depth.

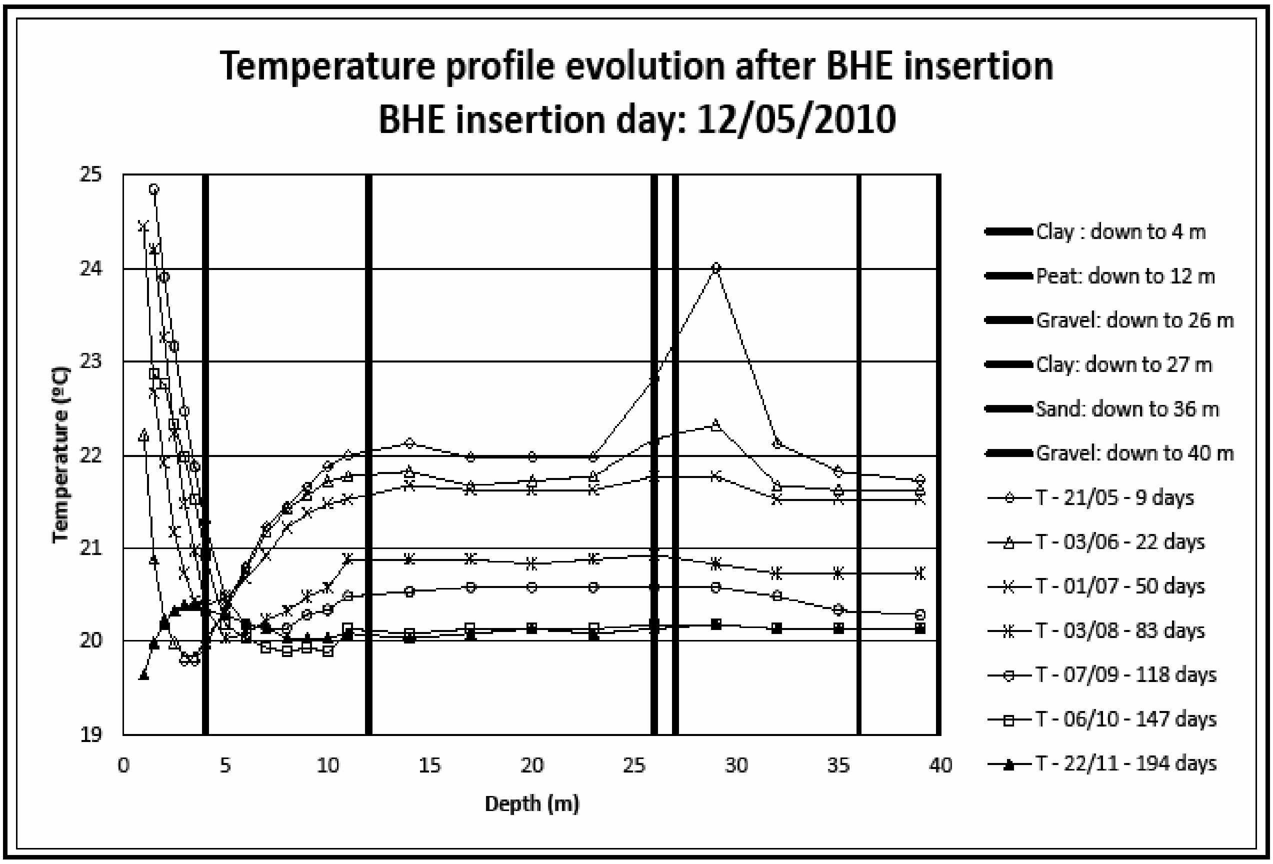


**Figure 5: Ground temperature profile is presented as a function of depth. Measures are given for the following 2010 dates: 21/05, 03/06, 01/07, 03/08, 07/09, 06/10 and 22/11. Separated with bold vertical lines are the different strata observed in the ground while drilling.**

Figure 6 shows the temperature evolution at fixed depth during first 200 days after U-pipe insertion and grouting. Five depths are shown, 2, 7, 14, 29 and 39 meters. Measures taken at 2 meters depth are highly affected by ambient temperature and show a similar evolution to ambient temperature from May to November. Measures taken at 7, 14 29 and 39 meters show very similar behaviour, converging after around 150 days to a value of 20.1 ºC, which represents the undisturbed ground temperature. As it can be observed in figure 5, from 7 to 40 meters temperature measurements are very independent of the depth and of the ambient temperature, after achieving thermal equilibrium between the borehole and the ground.

A thermal response test performed a few days after U-pipe insertion and grouting will be biased by this heating effect. The standard TRT analysis based in the infinite line source model compares the average fluid temperature, $T_{ave}$, with the model prediction:

$$T_{ave} = T_0 + R_b Q_Z + \frac{Q_z}{4\pi\lambda}\left( Ln\left(\frac{t}{t_0}\right) - \gamma \right) \quad (1)$$

Where $T_0$ is the undisturbed ground temperature, $R_b$ is the borehole thermal resistance, $Q_z$ is the average thermal power per length unit transferred to the ground and $\lambda$ is the ground thermal conductivity. The number $\gamma$ is the Euler constant and $t_0$ is a time constant equal $r_b^2/4\alpha$, where $r_b$ is the radius of the exchanger (80 mm) and $\alpha$ the diffusivity of the ground. To estimate borehole thermal resistance and ground thermal conductivity, average fluid temperature is represented against the logarithm of time. Rewriting equation (1) as:

$$T_{ave} = T_0 + R_b Q_Z + \frac{Q_z}{4\pi\lambda}\left( Ln\left(\frac{t}{t_0}\right) - \gamma \right) = a + bLn(t)$$
$$a = T_0 + R_b Q_Z - \frac{Q_z}{4\pi\lambda}\left(Ln(t_0) + \gamma\right) \quad (2)$$
$$b = \frac{Q_z}{4\pi\lambda}$$

is clear that the graph plotting $T_{ave}$ against $Ln(t)$ must show a line with a slope, $b$, inversely proportional to the ground thermal conductivity. Ground thermal conductivity will be estimated as:

$$\lambda = \frac{Q_z}{4\pi b} \quad (3)$$

So, at first sight, an error in the measurement of the undisturbed ground temperature will not affect the estimation of the effective ground thermal conductivity. Nevertheless, the heating effect produced by the concrete setting will have an impact in the value estimated for this parameter.

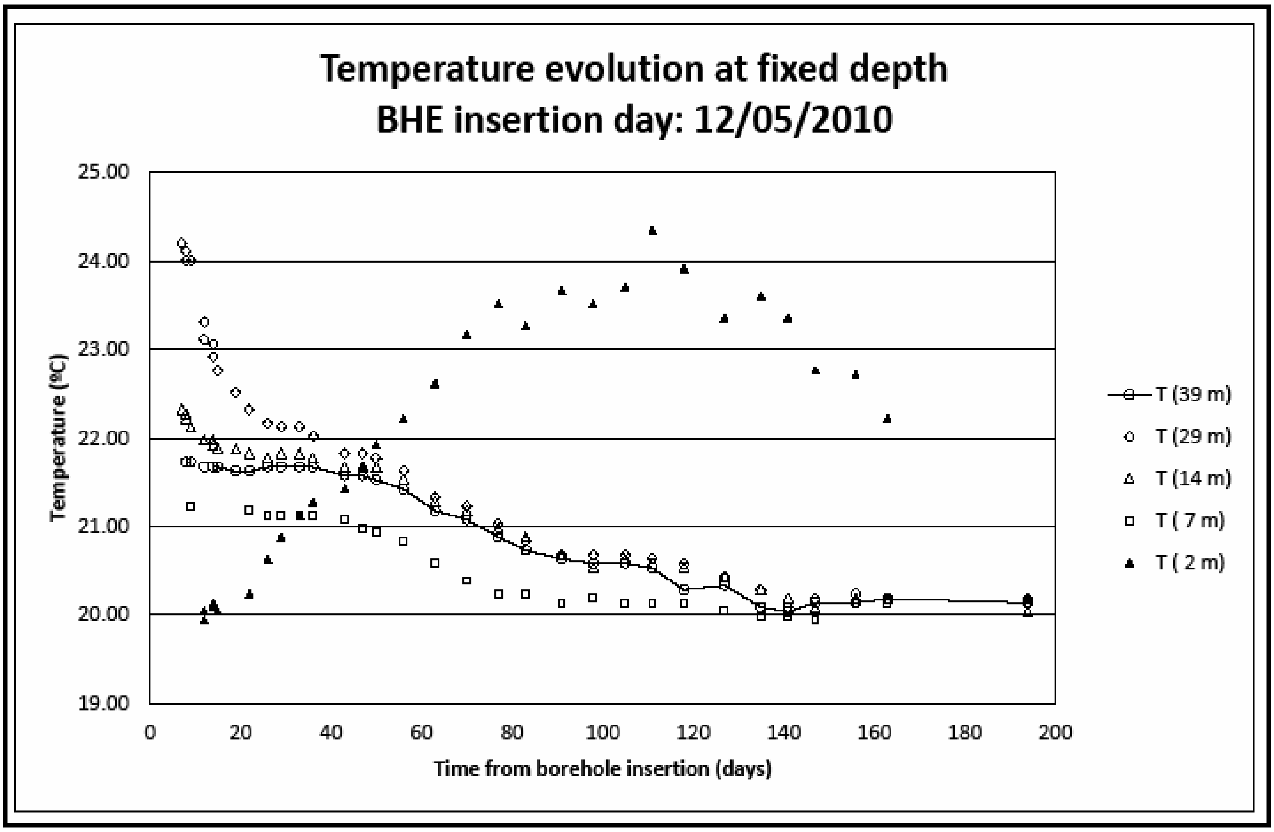


**Figure 6: temperature evolution at fixed depth.**

If a heat injection thermal response test is performed when the heating effect produced by the concrete setting is still significant, the heat transfer fluid will face with a ground with lower capacity of heat absorption than its actual one. Then ground thermal conductivity will be underestimated. The opposite effect will be produced in a heat extraction thermal response test. The heat transfer fluid will face with a ground with a higher heating capacity, coming from the additional heating source the concrete setting produces. Then, ground thermal conductivity will be overestimated in a heat extraction test.

Borehole thermal resistance is estimated from the value of the intercept *a*, using the following equation*:*

$$R_b = \frac{a - T_0}{Q_z} + \frac{(Ln(t_0) + \gamma)}{4\pi\lambda} \tag{4}$$

To evaluate $R_b$ several quantities are needed. A measurement of the average thermal power injected to the ground, $Q_z$ , is needed as well as an estimation of the ground thermal conductivity, $\lambda$. First quantity is an experimental measurement and second one is estimated with equation (3). The time $t_0=r_b^2/(4\alpha)$ is known given the thermal diffusivity $\alpha$. Finally, $T_0$ is the undisturbed ground temperature, measured just before test execution. It can be seen in equation (4) that the value used for this temperature will have a direct impact in the estimation of the borehole thermal resistance. An overestimation of the ground temperature will produce a lower value of the borehole thermal resistance and an underestimation of this quantity will produce a higher value.

Then, in our case, in which the concrete setting drives to a higher value of the undisturbed ground temperature, a standard TRT analysis done using this measurement for the ground temperature will produce a smaller borehole thermal resistance than the actual one.

## 4. CONCLUSIONS

Main conclusion of this contribution is that the ground temperature profile achieves a stable profile at a time around five months after borehole insertion. This time scale is quite relevant for interpreting data extracted from a standard thermal response test performed, usually, a few days after borehole insertion. Ground temperature is biased by the heating effect produced by the drilling procedure, and the heating effect produced by the concrete setting.

Then ground thermal properties estimated by performing a thermal response test just a few days after borehole insertion and grouting may not be describing actual ground thermal properties. Ground thermal conductivity will be affected by the additional heating source the concrete setting produces, driving to conductivity values depending on the kind of test being performed. Borehole thermal resistance will be underestimated due to the impact of a ground temperature value higher than the actual undisturbed ground temperature.

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