

# THERMAL RESPONSE TESTS

**Luis Coelho, Rita Cerdeira, João Garcia**

**Polytechnic Institute of Setúbal, ESTSetúbal, Portugal**

***GroundMed Seminar, Madrid, 24 June 2010***

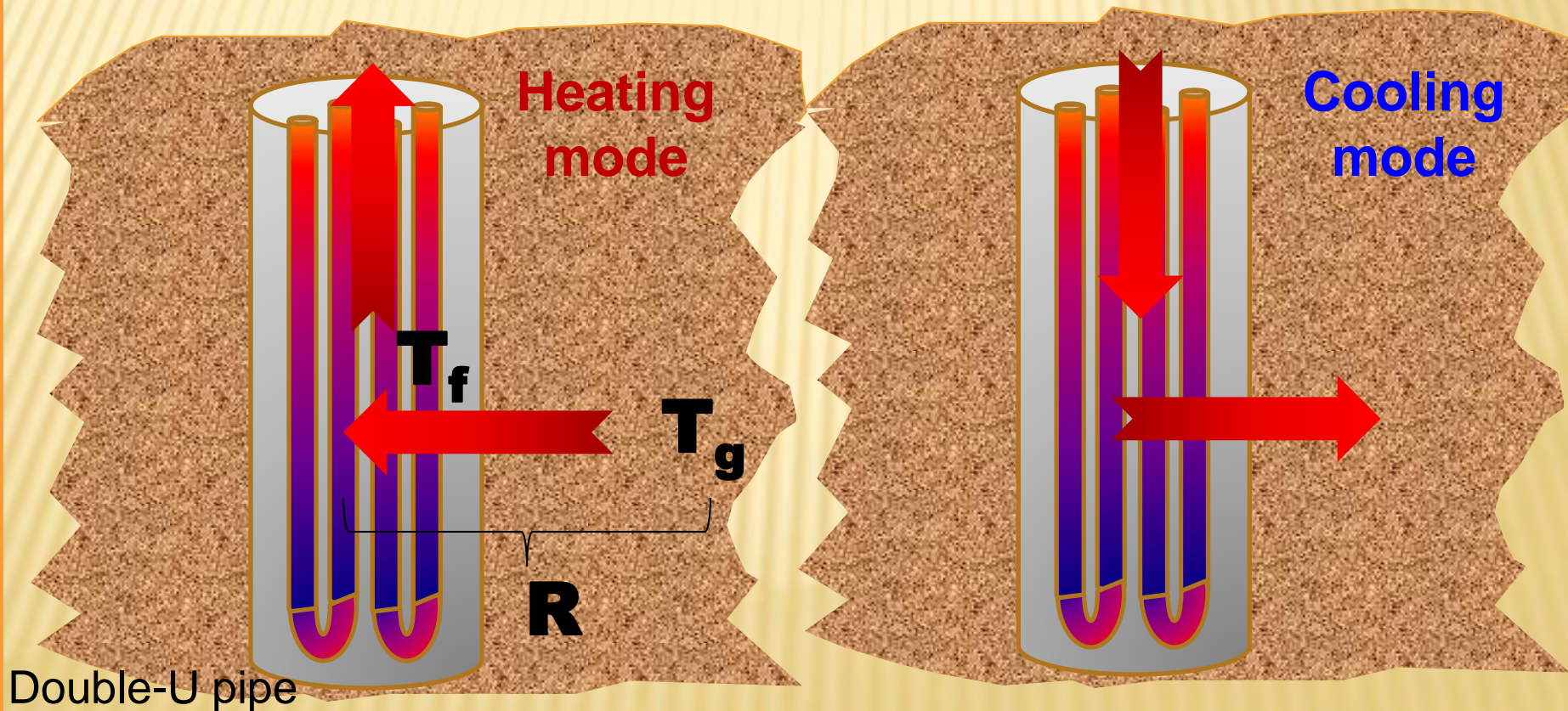
## OBJECTIVES:

- To demonstrate the importance of the Thermal Response Tests (TRT) on GSHP installations:
- To present the theory of TRT;
- To present some applications.

- ✘ The critical point of the GSHP in terms of economical viability it is the cost of the boreholes and ground HEX.
- ✘ There are numerical models to predict the performance of the boreholes based in the borehole thermal resistance.
- ✘ A good prediction needs a good model and a good knowledge of the soil properties. However could be have local deviations of the soil properties comparing with the typically soil properties in the region.
- ✘ Therefore to have a effective solutions it is necessary to complement the numerical predictions with in-local tests (Thermal Response Tests)

$T_{bw}$

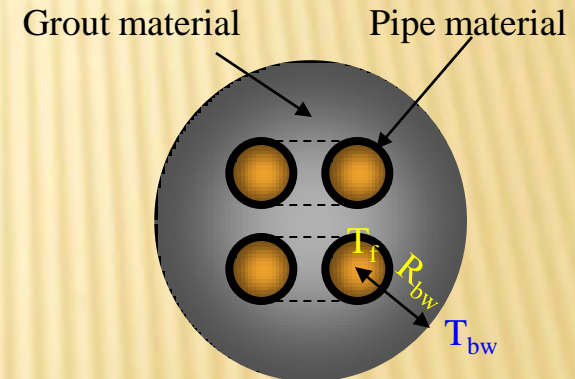
- × Main parameter for the boreholes performance:
- × Thermal resistance between the heat transportation fluid and ground.



- × **Main parameter of the boreholes performance: Borehole Thermal Resistance**
  
- × **The global thermal resistance can be divided in two contributions:**
  
- × **Thermal resistance between the heat transportation fluid and the borehole wall:**
  - × **Depends on the borehole solutions.**
  
- × **Thermal resistance trough the ground until to reach the undisturbed ground temperature:**
  - × **Depends of the soil characteristics.**

- ✘ Thermal resistance between the heat transportation fluid and the borehole wall.
- ✘ The specific heat flux transferred between the fluid and the borehole wall can be obtained by:

$$q = \frac{(T_f - T_{bw})}{R_b} \quad (W / m)$$



Double-U pipe

- ✘ Borehole thermal resistance depend on the: grout material; pipe material, borehole diameter; fluid flow characteristics (turbulent, laminar, pipe configuration).

- × Some difficulties in the model prediction:
- × Some deviations of the soil properties can appear locally, comparing with typically soil region properties;
- × The presence of ground water flow can increase significantly the conductivity (between 10% to 25%).
- × Fluid temperature and ground temperature are not constant along the borehole and along the time:
  - × Fluid temperatures vary due to heat exchange;
  - × Fluid temperatures vary during the start up and shut down of the refrigeration or heat pump cycle;
  - × Ground temperature increases with depth (0,5 to 3 K per 100 m);
  - × Could have influence on ground temperature of the others surrounding boreholes;
  - × Long term temperature modification if the annual energy balance in the ground is not neutral (ground cooling or heating).

- × An error of the boreholes length can have drastic consequences:
  - × Under-estimation: there are not enough available energy in the HVAC system to satisfy the building heating and cooling needs;
  - × Over-estimation: it wastes money, decreasing the economic viability of the system;

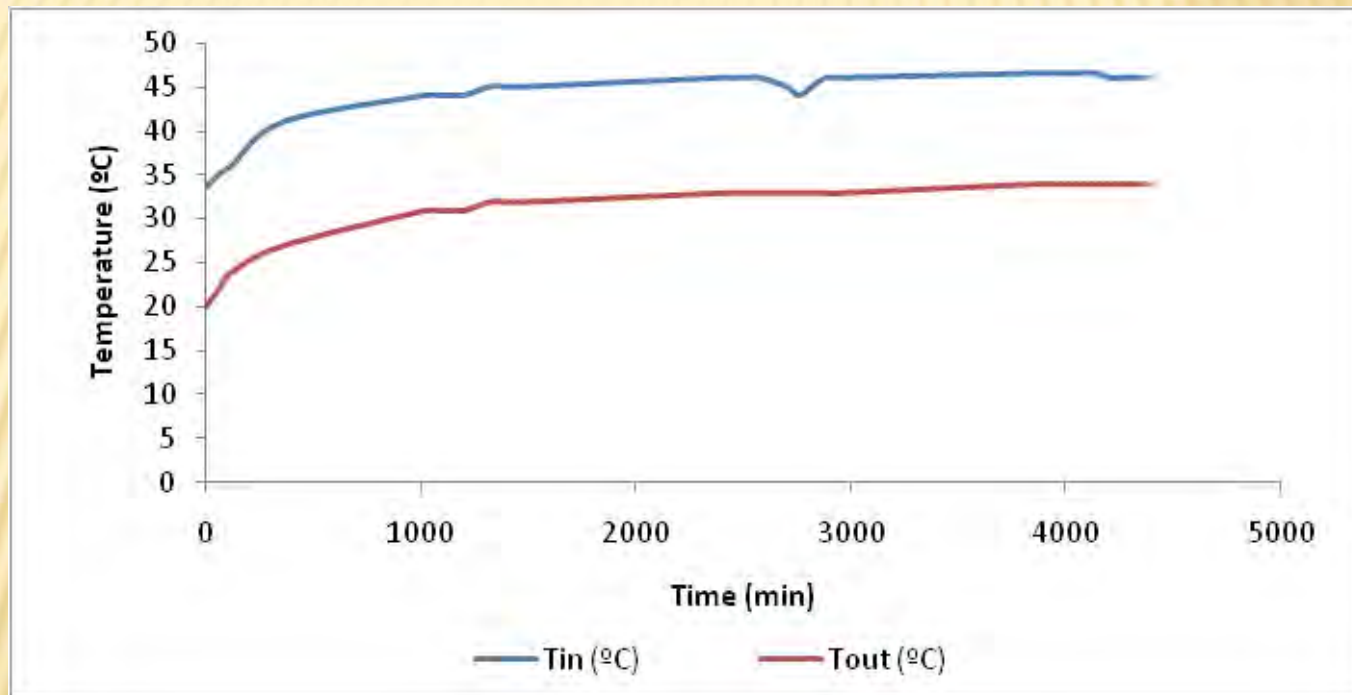
## × Thermal Response Test:

- × Thermal response of the borehole correspond to the temperature evolution of the heating transportation fluid inside the borehole, along the time, when it is fixed a heating load;
- × Thermal Response Test allow knowing the thermal properties of the borehole and surrounding ground;
- × With the knowledge of the exact values of the thermal properties it is possible to obtain the exact number of borehole length to satisfy the energy needs of the heat pumps.

## × Thermal Response Test:

- × After the beginning of the test , the fluid transportation temperature and the borehole wall temperature increases due the thermal resistance of the system;
- × However after a very short period (some minutes) the temperature difference between the transportation fluid and the borehole wall temperature rest constant along the time, (steady flux state);
- × Under this condition the temperature difference is proportional to the injected heat power per length of the borehole( $q$ ; W/m). The constant is the thermal resistance.

× Fluid temperature evolution (example):



- ✘ Thermal Response Test:
- ✘ With the Thermal Response Tests it is possible to estimate the effective thermal conductivity.
  - ✘ To estimate the effective thermal conductivity and the borehole thermal resistance it can be used the liner source theory .
  - ✘ The variation of the mean fluid temperature along the time  $[T_f(t)]$  can be represented by:

$$T_f(t) = \frac{\dot{Q}}{4 \cdot \pi \cdot H \cdot \lambda} \ln(t) + \frac{\dot{Q}}{4 \cdot \pi \cdot H \cdot \lambda} \cdot \left( \ln\left(\frac{4a}{r_b^2} - \gamma\right) \right) + \frac{\dot{Q}}{H} R_b + T_{0,m}$$

Where:

H (m) - borehole deep;  $\lambda$  (W/(m.K))- effective thermal conductivity; Q (W) – heating power; a (m<sup>2</sup>/s) – ground thermal diffusivity;  $r_b$  (m) – Borehole radius;  $T_{0,m}$  (K) – average undistributed ground temperature;  $R_b$  ([K/(W/m)] borehole thermal resistance;  $\gamma = 0,5772$ , Euler constant.

- ✘ Thermal Response Test:
- ✘ The variation of the mean fluid temperature along the time [ $T_f(t)$ ] can be represented by a generic equation:

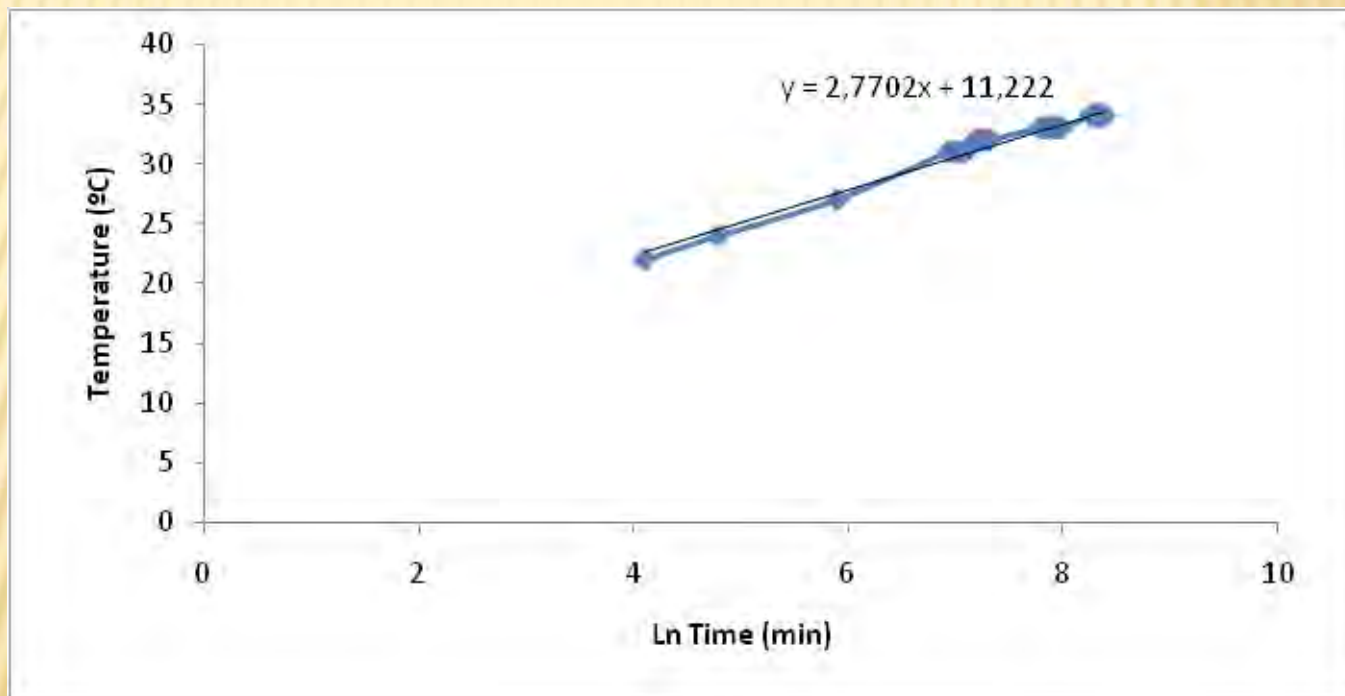
$$T_f(t) = k \ln(t) + m$$

- ✘ Comparing both equation it is possible to obtain the effective borehole thermal conductivity:

$$\lambda_{eff} = \frac{\dot{Q}}{4 \cdot \pi \cdot H \cdot k} \quad W / (m.K)$$

- ✘ Where:
- ✘  $k$  is the slope of the curve of temperature versus logarithmic time .
- ✘ With a similar analysis ( $m$ ) it is also possible to obtain the specific borehole thermal resistance,

× Fluid temperature evolution (example):



$k = 2,77$

- × Thermal Response Test (example):
  - × Estimation of the effective thermal conductivity:
    - × Borehole deep,  $H = 80$  m;
    - × Injected heating power:  $Q = 9050$  W
    - ×  $K = 2,77$

$$\lambda_{eff} = \frac{9050}{4 \cdot \pi \cdot 80 \cdot 2,77} = 3,25 \quad W / (m.K)$$

- × **Thermal Response Test conditions:**
- × **To obtain a confident results from TRT it is necessary:**
  - × **To have a very stable heating source. This is a crucial point to obtain true results;**
  - × **The TRT equipments should be well tested before using to assure that the production of heat is very stable.**
  - × **It is necessary to have a minimum period of test. Typically commercial period, 50 hours;**
  - × **It is necessary to wait at least 24 hours after drilling to the undisturbed ground temperature return to normal values.**

- ✘ For the same borehole configuration it is possible to obtain a very large range of values for the effective borehole thermal conductivity.
- ✘ Also some differences can be found between predictions and measurements.

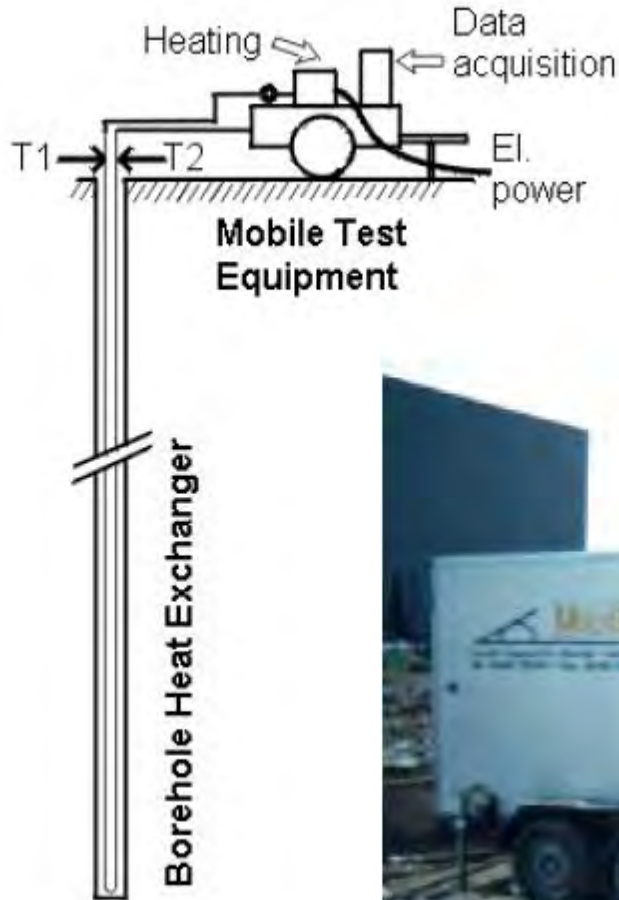
## Some tests done by UBeG

Nr	Geology	estimated $\lambda_{\text{eff}}$	Messured $\lambda_{\text{eff}}$	$r_b$
1	Limestone	2,4 W/m/K	2,7 W/m/K	0,10 K/(W/m)
2	Gravel / Sand wet	2,2 W/m/K	3,1 W/m/K	0,10 K/(W/m)
3	Mergel („Emschermergel“, Cretacious)	2,0 W/m/K	2,0 W/m/K	0,12 K/(W/m)
4	Sand/Mudstone, (Cretacios)	2,1 W/m/K	2,3 W/m/K	* 0,08 K/(W/m)
5	Sand and Clay (Quartary/Tertiary)	2,3 W/m/K	2,8 W/m/K	0,11 K/(W/m)
6	Sand and Clay (Quartary/Tertiary)	2,3 W/m/K	2,3 W/m/K	* 0,08 K/(W/m)
7	Sand and Clay (Quartary/Tertiary)	2,3 W/m/K	2,2 W/m/K	* 0,07 K/(W/m)
8	Marl, Clay	2,2 W/m/k	2,5 W/m/K	0,12 K/(W/m)
9	Sand (Quartary)	2,4 W/m/k	2,5 W/m/K	0,13 K/(W/m)
9	Sandstone	2,3 W/m/K	3,2 W/mK	0,09K/(W/m)
10	Schluff, sandig (Quartär/Tertiär)	2,4 W/mK	3,4 W/m/K	* 0,06 K/(W/m)

**Courtesy: UBeG**

- × Example:
- × GSHP capacity:
  - × Heating capacity: 520 kW (COP = 4);
  - × Evaporator load: 390 kW (520 – 520/4)
  - × Prediction: effective thermal conductivity – 2,6 W/(m.K) => 50 W/m (for the application conditions)
    - × Total of boreholes length: 7800 m
    - × Total cost of boreholes: 390.000 Euros (50 Euros/m)
    - × A error of 15% in the model prediction: 57,5 W/m (instead 50/m)
    - × Total of boreholes length: 6780 m
    - × Total cost of boreholes: 339.000 Euros (**less 51.000 Euros**)

× TRT equipment (example):



Courtesy: UBeG

- × The strategy:
- × To make a preliminary modeling calculations to estimate a number of boreholes:
- × Drilling a pilot borehole, wait at least 24 hours and test during about 50 hours;
- × Refine the calculations of the number of boreholes using TRT data, namely the effective borehole conductivity and borehole thermal resistance.

- × **Conclutions:**
- × **The critical point of the GSHP in terms of economical viability it is the cost of the boreholes and ground HEX;**
- × **There are some models that can be used to predict the number of boreholes, however there are some uncertainties that can produce wrong predictions;**
- × **The best way to have a correct value it to use a TRT in a pilot borehole, before drilling the rest of the boreholes;**
- × **An adequate TRT equipment should be used because the test conditions should be very precise.**

**Thank you very much  
for your attention**