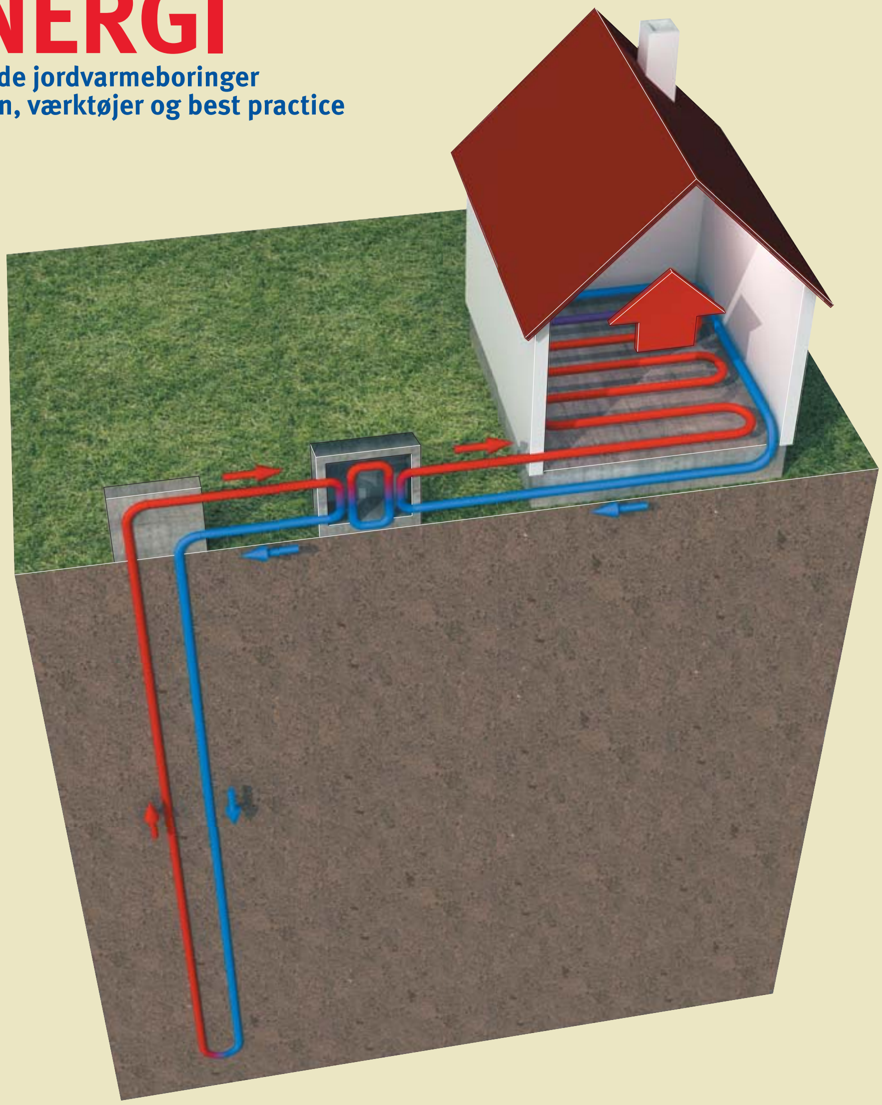
Lukkede jordvarmeboringer
– viden, værktøjer og best practice



Energianlæg baseret på jordvarmeboringer
- udvikling af markedsfremmende værktøjer og best practice

Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Område: Energieffektivisering
Program: EUDP 10-II
J.nr.: 64011-0003

D8 Guidelines for equipment, methods and calibration
Part 2. Thermal Response Test

GeoEnergy

Tools for ground source heating and cooling based on closed loop boreholes

Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Theme: Energieffektivisering
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D8 Guidelines for equipment, methods and calibration Part 2. Thermal Response Test

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Lead partner for this deliverable:
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FOREWORD

Heat-pump systems based on closed-loop, geothermal boreholes, has a potential for CO_2 reduction and energy efficiency. The application in Denmark, however, is limited compared to our neighbouring countries and we still lack know-how and experience. The objective of the project “GeoEnergy, Tools for ground-source heating and cooling based on closed-loop boreholes” is to pave the way for a wider use of the technology by acquiring know-how and developing tools and best practice for the design and installation of plants as well as providing training and dissemination.

The project is co-financed by the partners and the EUDP programme of the Danish Energy Agency (Energistyrelsen) and the duration is 3 years starting from 2011-03-11. The partners are:

- De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS)
- VIA University College, Horsens (VIA UC)
- Geologisk Institut, Aarhus Universitet (GIAU)
- Den Jydske Håndværkerskole (DjH)
- Dansk Miljø- & Energistyring A/S (DME)
- GeoDrilling A/S (GeoD)
- Brædstrup Fjernvarme AMBA (BrFj)
- DONG Energy Power A/S (DONG)
- Robert Bosch A/S IVT Naturvarme (BOSCH)

The work in GeoEnergy is structured in 8 work packages:

- WP1 Database and dissemination
- WP2 Equipment and measurements
- WP3 Temperature gradients and surface temperatures
- WP4 Drilling methods and grout techniques
- WP5 System design and energy balance
- WP6 Training and education
- WP7 Interaction with ambient groundwater system
- WP8 Guidelines and final dissemination

This document is Part 2 of deliverable D8 *Guidelines for equipment, methods and calibration* dealing with guidelines for use of equipment for thermal response test of boreholes. Part 1 contains guidelines for measurement of thermal conductivity in soil samples in the laboratory with the Thermal Needle Probe Method.

ACKNOWLEDGEMENTS

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Besides, acknowledgement goes to Hans Erik Hansen and Carl Johan Runge Andersen, who are the ones that have continuously developed and improved the equipment.

ACRONYMS

BHE	Borehole Heat Exchanger
TRT	Thermal Response Test

1 INTRODUKTION

Nærværende rapport er en vejledning til den måleprocedure, der er udviklet på VIA UC ved udførelse af en termisk respons test. Princippet i en termisk responstest er, at en væske, der cirkulerer i en jordvarmeborings lukkede rørsystem påføres en kendt energimængde i form af varme i et givet tidsrum. Ved at måle responsen fås et udtryk for afsætningen af varme i jorden. Gennem analyse af data, kan jordens varmeledningsevne beregnes. Figur 2.1 viser princippet i opstilling og måling.

Vejledningen er del 2 af EUDP-projektets "Deliverable 8" *Guidelines for equipment, methods and calibration.* Medens introduktionen til rapporten her er skrevet på dansk, er sproget i de følgende kapitler engelsk, da vejledningen anvendes både af VIA's danske og internationale studerende. Rapporten er derfor samtidig en del af projektets Deliverable 18.

Udstyr til thermal respons test er bygget op fra grunden i VIA's værksted i løbet af 2011 og 2012. Det består af en række komponenter, der er nærmere gennemgået i rapportens kap. 2. På figur 1.1 ses det sammenbyggede udstyr. Udover det hjemmebyggede udstyr, råder VIA nu også over et kommercielt tilgængeligt udstyr produceret af UBeG, Wetzlar, Tyskland. Dette udstyr har været brugt til ca. 400 tests i Tyskland.

Fig. 1.1. Thermal Response Test udstyr bygget på VIA University College.

2 DESCRIPTION OF THE EQUIPMENT

This is a user manual for the Thermal Response Test equipment assembled at VIA University College's GeoLab. It is not, therefore, a report describing the theoretical background of the analysis methodologies for the interpretation of the data obtained from the TRT.

The main components in the system are the following and they are shown in the scheme in Fig. 2.1:

- Temperature sensors
- Flow meter
- Heater
- Circulation pump
- Expansion vessel
- Air vent valves
- Data loggers
- Connection hoses

The software required for the data loggers are described later.

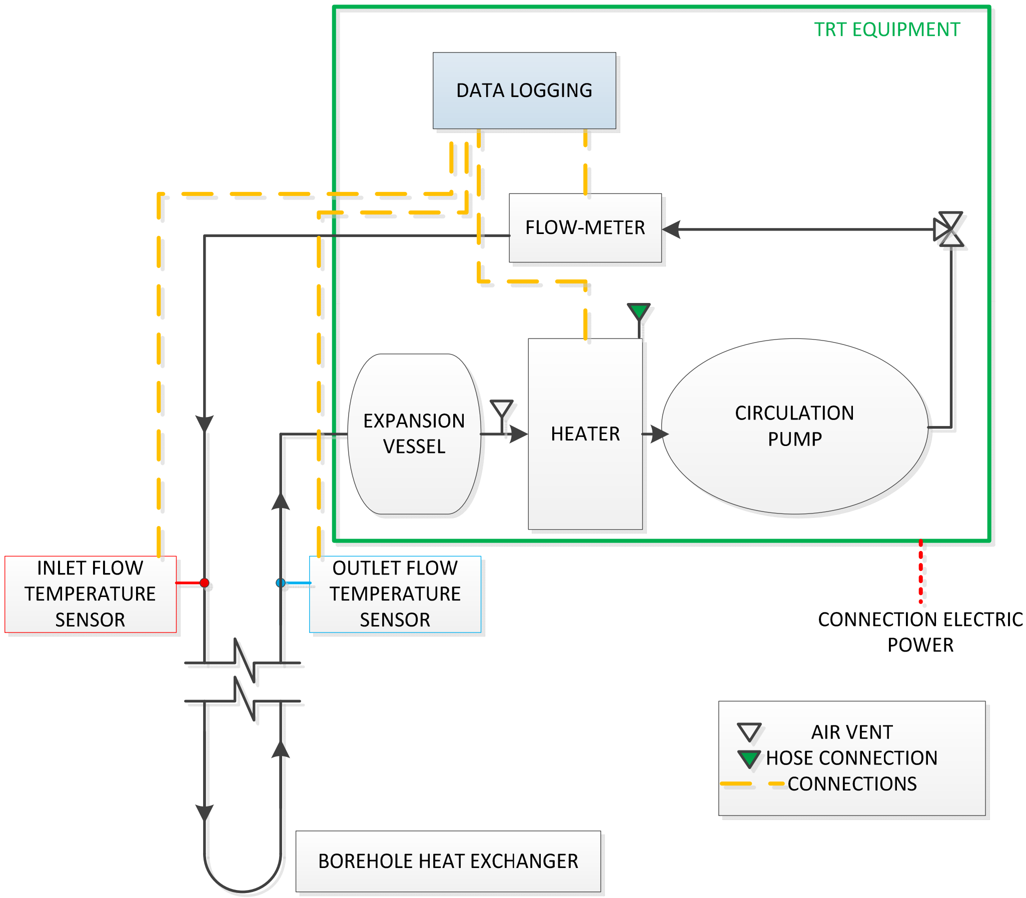

Fig. 2.1. Scheme of the main components of the TRT equipment.

The two temperature sensors that measure the fluid temperature in the inlet and outlet pipes are thermocouple sensors connected to a data logger. The ultrasonic flow meter has a +/- 0.001 m^3/h accuracy and there is a consumption meter as well in the electric frame. The data is recorded each 10 s. The heater has a nominal power of 3kW and generates a supply of constant warm water. The amount of energy injected to the ground is a function of the measured flow, the temperature difference and the heat capacity of the liquid.

The equipment can be divided in 3 sections: the hydraulic section, the controllers and data loggers and the electric frame. In the following figures (from Fig. 2.2 to 2.4) the specific parts of each section are named:

<u>Hydraulic part of the equipment (Fig. 2.2):</u>

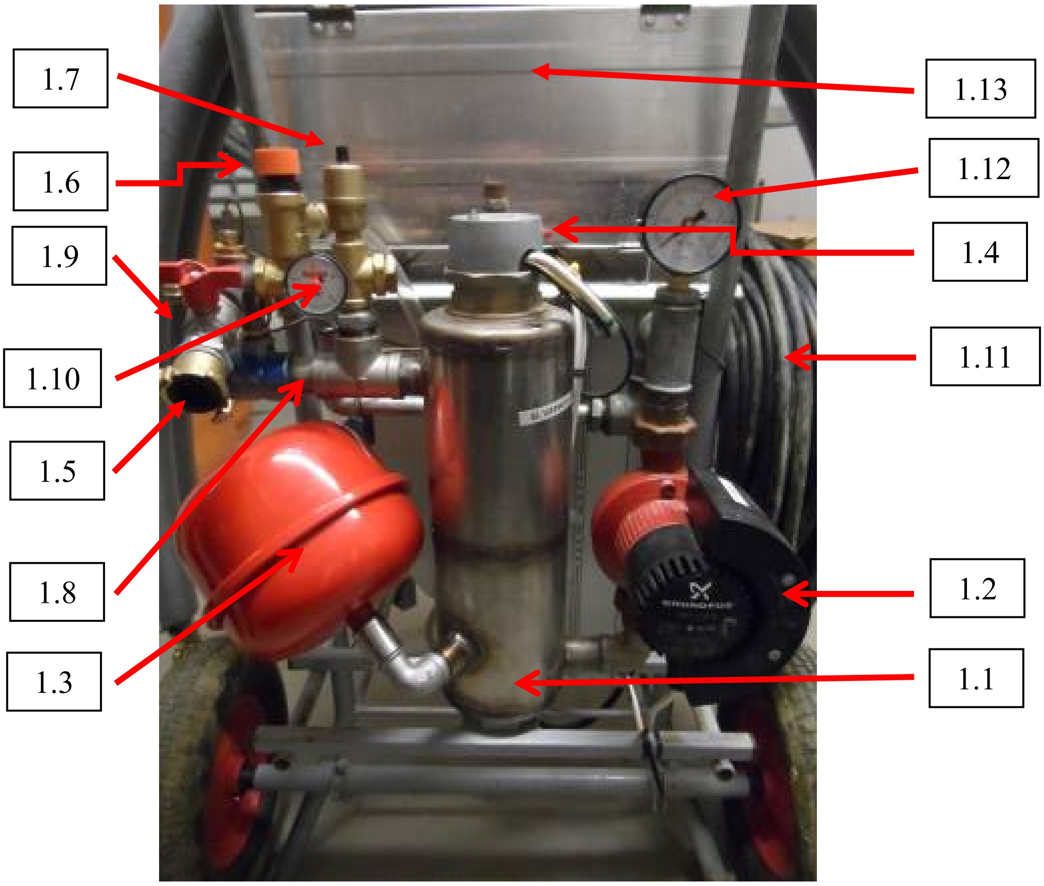

Fig. 2.2. Hydraulic section of the TRT equipment.

1.1:	Heater connected to the controller, TLZ 11.
1.2:	Circulation pump, Grundfos MAGNA 25-100.
1.3:	Expansion vessel.
1.4:	Flow-meter, 8081, connected to multiCELL 8619 for monitoring the flow and collecting the data. Both from Bürkert.
1.5:	Connection for water pump to fill and pressurize the circuit.
1.6:	Valve to release air and water from the system.
1.7:	Valve to release air from the system.
1.8 – 1.9:	Connections to BHE (red: inlet to BHE; blue: outlet from BHE).
1.10 – 1.12:	Manometers.

1.11: Power cable.
1.13: Metallic box for controllers and data loggers.

Controllers and data loggers (Fig. 2.3):

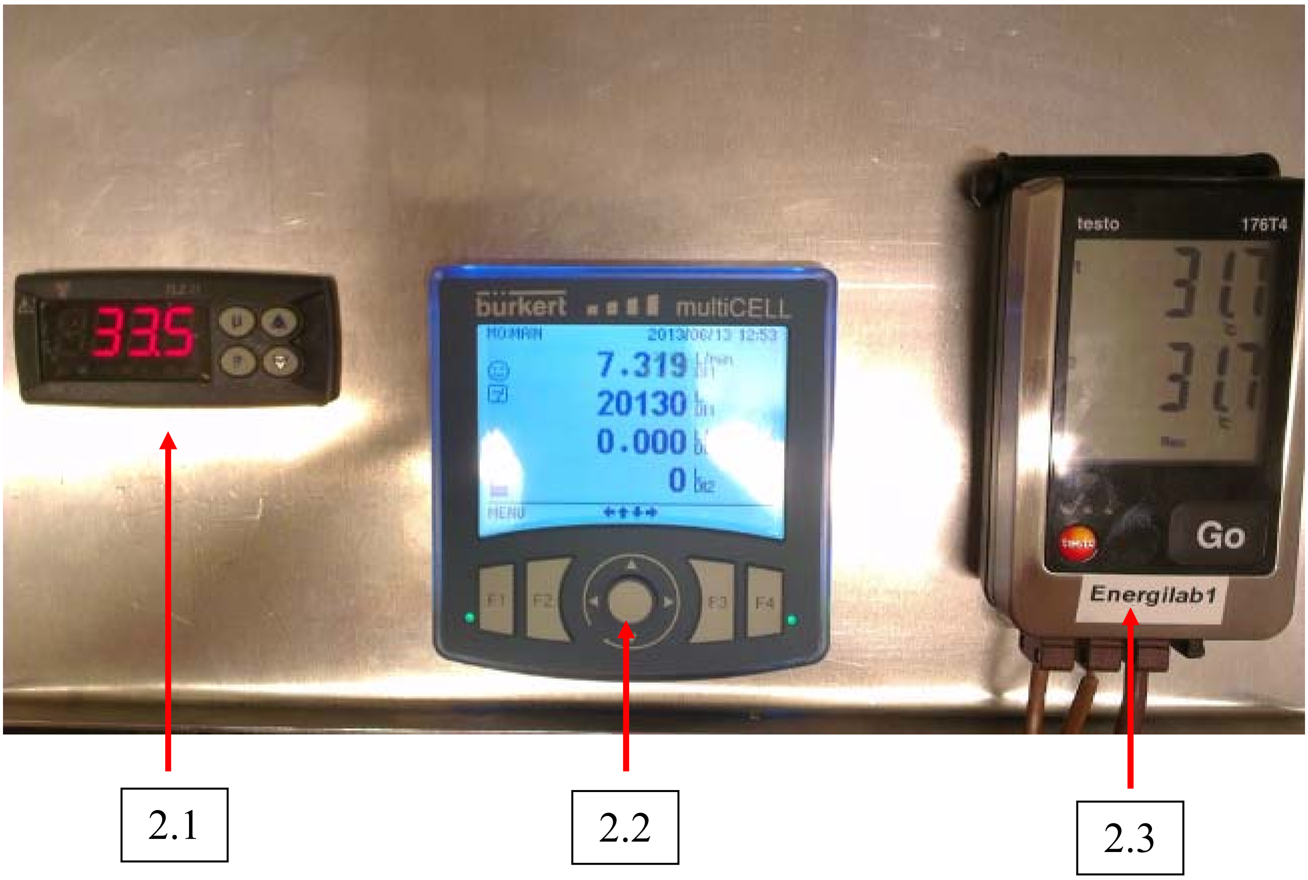

Fig. 2.3. Data Loggers and heater controllers of the TRT equipment.

2.1: TLZ 11, heater controller.
2.2: MultiCELL, type 8619, flow-meter data logger.
2.3: TESTO 176T4, temperature logger.

<u>Electric frame of the TRT equipment (Fig. 2.4):</u>

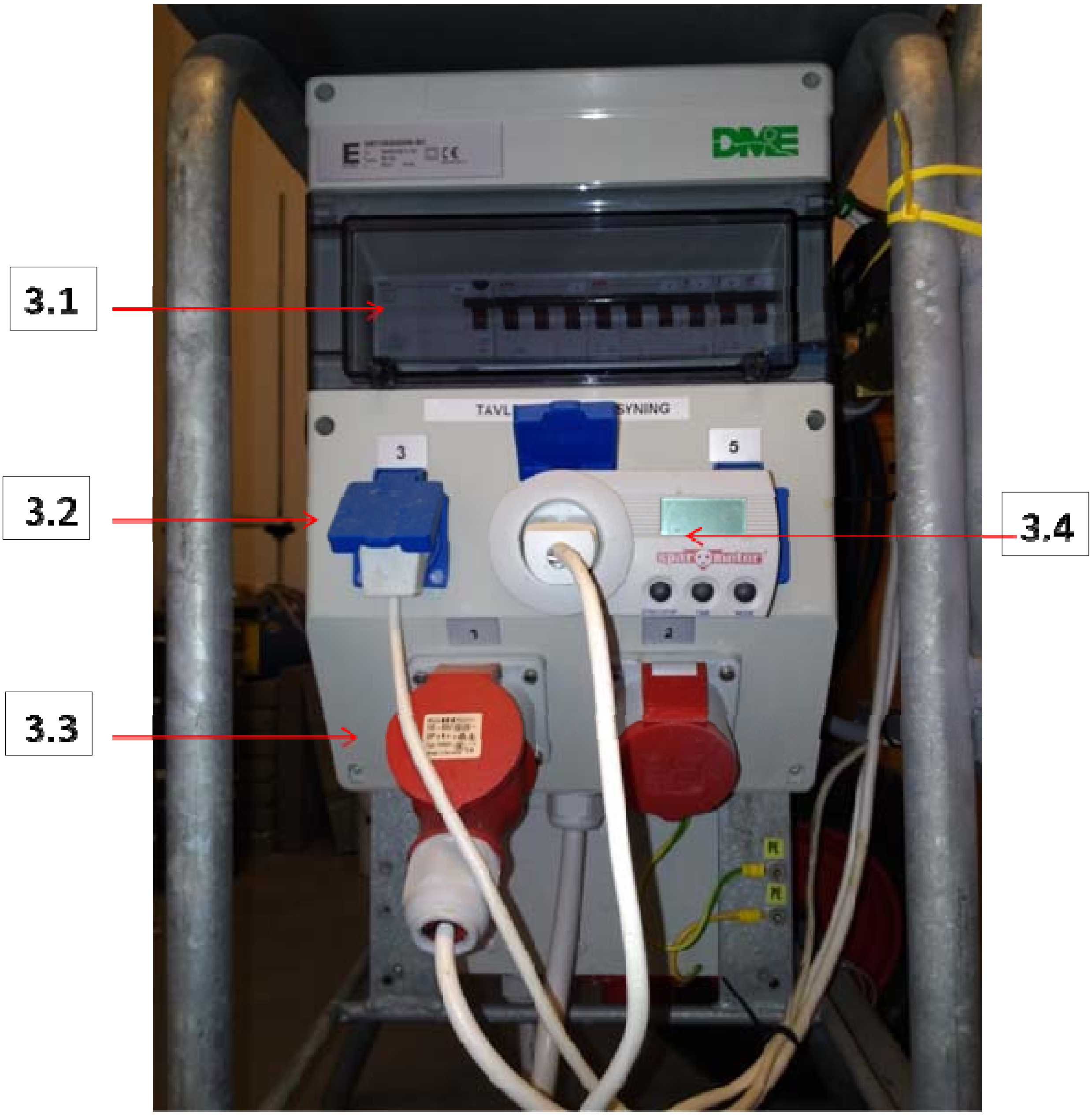

Fig. 2.4. TRT Electric Frame.

3.1: Automatic fuses.
3.2: 3 Power outlets: 240 Vac 13 Amp.
3.3: 2 Power outlets: 3 x 400 Vac 16 Amp.
On the opposite side of the equipment, a primary meter to measure the total power consumption has been placed.
3.4: A secondary portable energy meter, in one of the outlets, to measure the power consumption of the electronics.

3 PROCEDURE TO EXECUTE A TRT

A common TRT follows the subsequent process proposed for the boreholes in VIA Energy Park:

i) Measurement of the undisturbed ground temperature before the TRT.
ii) Cleaning the borehole heat exchanger before starting the TRT (24 hours before).
iii) TRT: Injection of a constant heat power during the test, at least, 48 hours.
iv) (Optional) Observation of the recovery of the ground allowing the water circulation without heating during 48 hours more.
v) (Optional) Logging of temperature profiles after the execution of the TRT (without executing step iv).

For the determination of the soil thermal properties, just the data logged in phases i) and iii) can be taken into consideration. The recovery test can be analysed in the same way as the heating process is evaluated.

From now on, the process will be described step by step.

3.1 Measurement of Undisturbed Ground Temperature

It is important to consider that before taking the undisturbed ground temperature measurements, the borehole must be filled with water (or brine) at least one day before the measurements are taken so that the liquid takes the temperature of the ground. Note that the drilling process will change the temperature in and around the borehole. It is recommended /1/ to wait at least 5 days between installing the BHE and the measurement.

The devices used for this type of measurements could be different but they are produced to do measurements in liquids. VIA University College owns two equipments in its Energy Lab:

3.1.1 Equipment 1 (thermometer with taped cable):

The equipment is shown in Fig. 3.1 and consists of:

- **Thermal sensor** or thermometer connected in the free end of the graduated cable.
- **Data logger (ALMENO 2590-2/-3S/-4S by AHLBORN)**, which requires electric connection to the grid and it is connected to the thermometer.
- **Graduated cable** with marks each meter and which is connected to the data logger.
- **Cable extension** to connect the data logger to the electric grid.

Fig. 3.1. a) Data Logger for the thermal probe placed in the free end of the taped cable; b) Rolled taped cable, 125 m length; c) Cable extension.

The temperature logging of the borehole is recorded each meter along the pipe through all the BHE depth using a temperature sensor linked on a graduated cable, and taking an average of all the executed measurements. This way, the readings are used to calculate the arithmetic mean of the undisturbed borehole temperature.

In Fig. 3.2 the measurement process is shown:

Fig. 3.2. a) Connection of all the devices and probe insertion into the BHE; b) Undisturbed temperature measurement in progress.

The first step is to prepare a sheet of paper to note the starting date and time, the initial ambient temperature, the depth of the BHE and the temperature measurement each meter (or what it is considered).

In order to take an accurate measurement, a 4 minute period has to be waited per each meter, so as to leave the thermometer stabilize. Note that there will be no problem in the first few meters, but as more meters are measured, the cable will be heavier so the cable must be held.

Notice that if the BHE is 100 m depth, 100 m multiplied by 4 min per measurement, makes 400 minutes, which means more than 6 hours of test. This requires a good planning of the works. Besides, consider that 1 day before the measurement, the BHE should be filled with water.

In addition, take care of dirt and be careful that no soil or any kind of particles are inserted into the BHE. This could lead into the breaking of the circulation pump in the TRT equipment. Moreover, while enrolling the cable again, try to clean in the process.

3.1.2 Equipment 2 (Hydrotechnik Water Meter):

A new equipment has just been received at VIA University College but just one BHE has been measured with it. As Equipment 1 has been used during all the GeoEnergy project, it has also been described in this report.

The new device is a Hydrotechnik GmbH Water Meter Type 110 (Fig. 3.3) for level and temperature measurements (150 meter depth and with a bottom sensor).

Fig. 3.3. Well Temperature logger.

This equipment allows a lower measurement period, so time is saved.

The measurement process is the same as for Equipment 1. However, it does not require any connection to the grid and the temperatures are displayed in the small screen placed on the frame.

Another way to calculate directly the average undisturbed temperature is making circulate the carrier fluid through the borehole for about 30 minutes before starting the heating for the TRT.

3.2 Cleaning the BHE before the TRT

After the Undisturbed Ground Temperature measurement, a cleaning of the BHE must be carried out in order to extract all the possible dirtiness. For this, the following equipment is proposed, which is available in the GeoLab (Fig. 3.4):

- A **submersible pressure pump** to make the water circulate through the borehole.
- A **bucket** for water, to put the pump inside.
- A **hose** to link one of the pipes of the borehole to the pump.

Fig. 3.4. a) Submersible pressure pump; b) Water buckets; c) Hose with stortz connections.

After filling one of the buckets with water, the pump must be placed inside. Then, one of the pipes of the BHE must be linked to the water pump with the hose (Fig. 3.5). After, the water pump must be connected to the electric grid.

Fig. 3.5. Connection of the pump to the BHE.

Before the pump runs, the keys of the BHE must be opened (Fig 3.6.a). In order to make the pump work, the floating switch has to be elevated. This way, the pump takes the water from the bucket and circulates it through the BHE, going out from the opposite free end (Fig. 3.6.b).

Fig. 3.6. a) Closed connection keys to a Single-U BHE; b) Water flowing out of the BHE in order to clean it.

Make sure that the water level never goes completely down. For that, try to have a hose close to the working place so that the continuous filling of the bucket is possible. The whole process must be repeated until the water going out of the BHE is totally clean (15-20 min approx.).

3.3 Preparing parameters for the TRT

Before going on site and run the TRT, some initial decisions and assumptions need to be done. Besides, information about the BHE (length, pipe diameter…) to be tested is required:

Power supply

It has been considered, taking onto account previous tests, that the heater at 30ºC is able to produce heat injection rates around 25 W/m for 100 m depth BHE. In some situations the 25 W/m has turned to be too little. The up to 50-80 W/m mentioned in /1/ is therefore advised.

Flow

The flow has to be turbulent for the execution of a TRT. Hence, the Reynolds number *Re* had to be higher than 4000 in order to ensure the turbulence inside the pipes.

$$Re = \frac{\rho \cdot v \cdot \varnothing}{\mu}$$

Where ρ is the density of the carrier fluid [kg/m^3], v is the speed of the carrier fluid inside the pipes [m/s], $\varnothing$ is the inner diameter of the pipe [m] and μ is the dynamic viscosity of the carrier fluid [Pa·s] for the temperature we are going to deal with (around 20 ºC).

For the calculations could be considered: ρ = 1000 kg/m^3, $v = Q/A$, being *A* the surface of the pipe section, μ = 0,001002 Pa·s (at 20 ºC).

Test length

Following the international guidelines established in Geotrainet [1] and the advices by Gehlin [2], at least, 48 - 50 hours long tests must be performed.

Considered borehole depth

Realize that corrections are required to consider the depth affected by the ambient conditions or the superficial layers. However, in order to simplify the calculations, all the borehole length could be considered.

Preparing for data collection

The measurement devices need to be configured following the user manuals:

Testo 176T4

This is the device for the temperature data logs. The software "Testo Comfort Basic 5.0" should be downloaded for the computer, from http://www.testo.com/download-center. The program is used to configure and retrieve the data from the 176T4.

The input canals are set: channel 1: T_{in} (inlet temperature to the BHE – warm water); channel 2: T_{out} (outlet temperature from the BHE – colder water); channel 3: T_{heater} (temperature of the heater) and channel 4: $T_{ambient}$ (ambient temperature).

In order to connect the data logger to the computer for the parameter set up, an ordinary USB connection cable will be required.

Bürkert 8619

This is the unit for the flow-data logs. The multiCELL has a SD-card to store the data. The card is inserted at the back of the unit. The slot is just above the orange terminal bar, at the left hand side. The data is stored in a .csv-file which can be transferred to an excel worksheet. To transfer the data, remove the SD – remember to stop data storing before removing the card – and insert it into the PC, in a compatible card reader. Before starting the test, the SD-card must be empty.

Be aware to set the data logging interval the same in both, for example, 10 seconds. By default, the Bürkert 8619 it is configured that way.

Later, the data can be processed in order to reduce the data quantity making mean values for each 10 minutes.

3.4 Setting up and starting the TRT

The following steps must be followed in order to execute a correct TRT with the VIA UC equipment:

3.4.1 Check list

Before we go to the site, we should remember to take all the required tools and make the necessary checks:

- Tools for connections: keys, screwdrivers, bridles…
- Water Buckets
- Hoses + connections for the hoses
- Power cable + extension
- SD card for flow meter
- Testo temperature data logger + cable
- Thermocouple cables well placed
- Laptop
- Notebook + pencil
- Parameters prepared: temperature for heating + flow in litres / min
- Insulation for the pipes
- Yellow tent
- Submersible pump
- Check the place where the test is going to be done: Is there enough space to place the equipment? Do we have a tri-phasic connection?

3.4.2 Place the equipment

The TRT equipment has to be placed as close as possible to the BHE in order to reduce the length of the connection pipes. Either these connection pipes or the pipes coming out from the BHE have to be insulated with insulating foam. Besides, in order to protect the equipment, an impermeable tent is recommended to be mounted covering the test rig (Fig. 3.7). Be aware that the borehole is full of water before the equipment is connected.

Fig. 3.7 a) TRT equipment and insulated connection pipes; b) TRT equipment already connected and placed inside the protection tent.

3.4.3 Connect the hoses to the BHE

Consider the direction of the water flow and do the connection using the appropriate tools. Be aware that the borehole is closed to ease the filling of the hydraulic circuit corresponding to the device (heater, pump) and the connection pipes.

This filling process could be done as follows: use the submersible water pump to introduce water into the system by connecting the pump to the specific connection in the equipment (number 1.5 in Fig. 2.2).

3.4.4 Connect to the power and start the pump

Unroll the cable gathered in the side of the equipment, find a power outlet "3 x 400 + N + earth; 16 A" and plug it in. In VIA Energy Park, the connection to the grid must be taken from the EcoLab.

It has to be ensured that no air is trapped in the system. So, the BHE is opened and once the circuit is filled and closed, the same connection could be used to release air, together with the valves placed for this aim. The circulation pump can start running and it will help in the process of getting rid of the air.

Once all the trapped air has been released, the circuit has to be pressurized up to 2 bars by means of the submersible water pump (same procedure as for filling the circuit). The manometers will ensure the control of this parameter and it can be checked that the pressure is the same in the input and output sides.

The starting of the pump is simple, since once the system is connected to the grid, it is about pressing the arrows and choosing the required position/flow.

Notice that if an exact flow, which cannot be achieved by the pump adjustment, is desired, it is possible to insert a valve into the circuit, to adjust the flow.

3.4.5 Start recording data

The first value to note is the initial total energy consumption [kWh] readable from the primary meter. After the test is done, the final consumption data has to be noted as well.

The logging of the flow and the temperature is done by two different devices. The clocks in the devices have to be synchronized.

- Start 176T4 (temperature logger) as it has been configured.
- To start the multiCELL you need to access the *Parameters* menu and choose *Datalogger*. Now there are 5 choices: *Status* and *Period* are the only ones that have to be modified.
  Status provides the choice between turning the data logger "ON" and "OFF".
  Period provides the opportunity to decide how often the data should be stored. It is possible to change the period when the data logging is on, it just creates a new file, while storing the first.
  The multiCELL remembers how many files has created and it numbers them continuously. The maximum logging capacity is 15.000 rows.
  Notice that the multiCELL gathers data just if the flow-meter is measuring.

Before the heater is turned on, the water should be circulating at least during 30 minutes with the data loggers on and the flow-meter measuring.

3.4.6 Set the heater temperature and start the TRT

Adjust the temperature of the heater, on the TLZ 11 controller. The display normally shows the current temperature in the heater. Once it is modified, the heater starts working.

A short push < 1 sec. to the button marked "P" will make "SP" flash in the display, alternating with a value. The value is the Set Point temperature, which can be changed by pressing the arrows up (increase) or down (decrease).

When no button it is touched for a period of 15 to 20 seconds, the display will return to the initial display, showing the temperature.

DO NOT UNDER ANY CIRCUMSTANCES HOLD THE BUTTON, IT WILL CHANGE THE FUNDAMENTAL CONFIGURATION OF THE CONTROLLER.

The manual of the controller is placed in the GeoLab.

The TRT has already started. The test procedure is automatic and works by itself once it starts.

3.5 During the TRT

Whereas the test is being performed along the 48 – 50 hours, the following data will be logged:

- Circulating water flow
- Temperature of the input flow
- Temperature of the output flow
- Temperature of the heater
- Ambient temperature

It is recommended a periodic visit to the site while taking measurements in order to be sure that the flow-meter is measuring, all the data is being recorded and there has not been any pressure drop (working pressure: 2 bars).

3.6 Once the TRT is finished

When the TRT has been running for the required period of time, turn off first the multiCELL datalogger, second the heater and finally the pump. The temperature data loggers are turned off when the data is downloaded into the computer. Besides, as it has already been stated, the final energy consumption has to be noted as well.

Then, take the pipes apart, let the water out of the equipment and close the keys of the BHE. Roll up the power cable and clean it if it is necessary. Pick up the equipment and the tent, clean them and store them in the GeoLab.

Once the test has been executed, collect the data from the multiCELL (SD card) and the 176T4 and store them on your own PC or laptop for further processing. It is recommended to gather them all in the same excel file in order to analyse the TRT.

3.7 Interpretation of data

For the interpretation of the TRT data the Infinite Line Source ILS approach is the most widely used method due to its simplicity. The basic assumptions of the Infinite Line Source approach are (Signorelli et al., 2007):

- Infinite constant-strength line-source
- Homogeneous, isotropic and infinite medium
- Negligible vertical heat flow along the BHE
- Constant lateral heat flow
- Temperature field around the BHE is dependent on time t and radial distance r

From the consideration of a line source of heat in an infinite homogeneous medium with constant thermal properties and an initial ground temperature, the temperature variation around the line source in space and time can be described as (Banks, 2008):

(1):

$$T(r,t) = T_0 + \left(\frac{-q}{4\pi\lambda} Ei\left(\frac{-r_b^2}{4\alpha t}\right)\right)$$

Where T_0 indicates the initial undisturbed ground temperature and r_b the borehole radius. It is assumed that the grouting material around the borehole pipes is infinitely conductive.
For a time range of several hours, a simplification of the previous equation (1) can be done. This time period is called “minimum time criteria” t_b. This time criteria sets the length of the initial period of data that must be discarded – it involves the short time data affected by the borehole heat exchanger. I.e., the time criteria allows the study of the optimum data where steady state situation can be assumed (Gehlin, 2002):

(2):

$$\frac{5r_b^2 S_{VC}}{\lambda} < t_b$$

Applying the time criteria, the formulation for a line source of length z can be simplified. Therefore, the average BHE temperature T_f in a borehole with a radius of r_b provoked by a specific radial heat flow rate q and considering the effect of the borehole thermal resistance R_b between the circulating fluid and the BHE wall is (Gehlin, 2002):

(3):

$$T_f(t) = \frac{q}{4\pi\lambda}\left(\ln\left(\frac{4\alpha}{r_b{}^2}\right) - \gamma\right) + qR_b + T_0$$

Where T_f corresponds to the average of inlet and outlet temperatures of the carrier fluid:

(4):

$$T_f = \frac{T_{in} + T_{out}}{2}$$

From equation (3) it can be deduced that:

(5):

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

Being k the slope of the function along the horizontal axis as logarithm of time t. Hence, the soil thermal conductivity can be derived from the slope k of the linear relation:

(6):

$$\lambda = \frac{q}{4\pi}\cdot\frac{\ln(t_2) - \ln(t_1)}{T(t_2) - T(t_1)} = \frac{q}{4\pi k}$$

Once the thermal conductivity has been estimated, the thermal borehole resistance R_b can be calculated using the next equation:

(7):

$$Rb = \frac{T_f(t) - T_0}{q} - \frac{1}{4\pi\lambda}\cdot\left[ln\left(\frac{4\lambda t}{r_b^2 S_{VC}}\right) - 0{,}5772\right]$$

The undisturbed soil temperature T_0 has been measured previously and for the calculation of the trend line, the least squares method is followed.

The following algorithm/steps should be followed in order to obtain the thermal conductivity and the borehole resistance (Monzó, 2011):

1. Calculate the average fluid temperature T_f [Equation (4)].
2. Calculate the minimum time criteria t_b [Equation (2)].
3. Discard the initial data and plot T_f in a log scale of time.
4. Use least-square method to calculate the trend line [Equation (5)].
5. Calculate λ [Equation (6)].
6. Calculate R_b over time [Equation (7)].
7. Determine the average value of R_b.
8. Plot the calculated mean temperature [Equation (3)] together with the measured one and determine the error.

In the following, an example corresponding to a TRT in a 100 m depth BHE is given. The measured temperatures are provided in Figure 1 and parameters about the test are available in table 1:

Heat Exchanger Type	Single U
Borehole Diameter (mm)	160
Active Length (m)	100
External Pipe Material	Polyethylene
Average Undisturbed Soil Temperature (ºC)	9.63
Expected Soil Volumetric Heat Capacity from literature (MJ m^{-3} K^{-1})	2.16
Average Water Volumetric Flow (m^3/h)	1.554
TRT Duration (h)	49.83
Average Heat Input Rate (W/m)	57.19

Table 1. TRT main parameters.

The following figure 1 shows the measured inlet, outlet and average temperatures over the TRT.

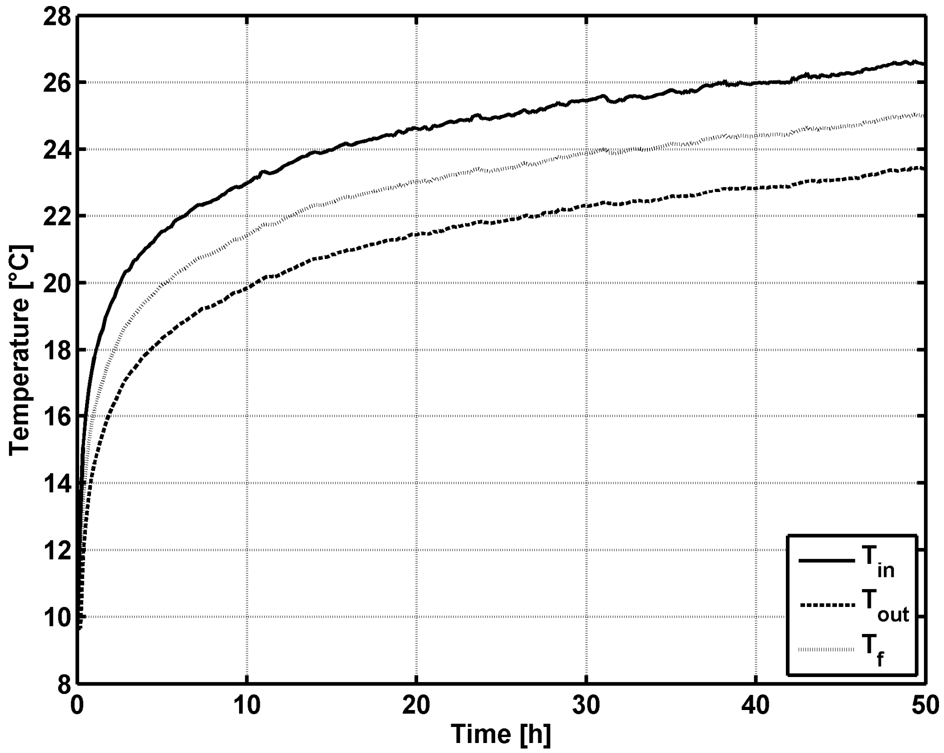

Figure 1. Measured input and output temperatures over the TRT.

For the time criteria calculation an approximation for the thermal conductivity and the volumetric heat capacity of the soil has to be done from the literature. In this case, the data before 9 hours has to be discarded. Steps 3 and 4 are shown in Figure 2:

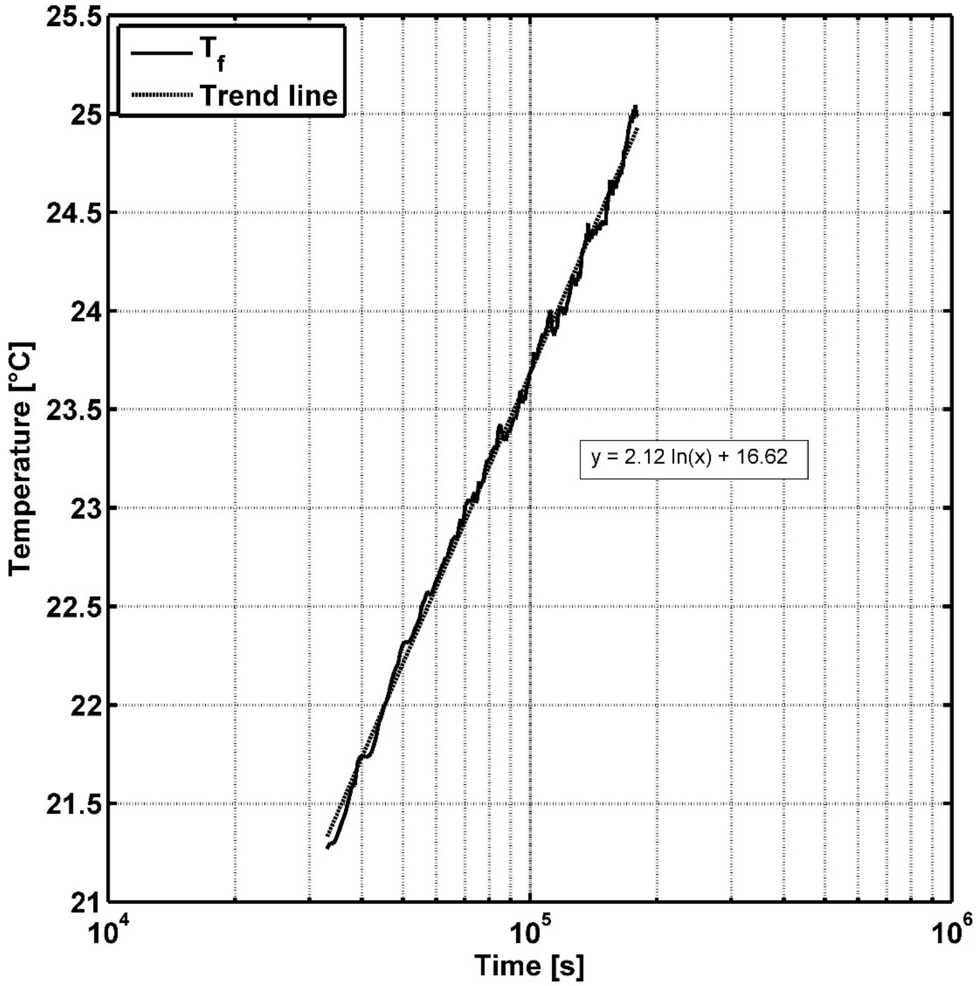

Figure 2. Least-square trend line calculation for the TRT data.

Applying the provided equations:
λ = 57.19 [W/m] / (4 · π · 2.12) [K] = 2.14 W/m/K
R_b = 0.114 Km/W

Finally, figure 3 shows the fit between the calculated and the measured values. This way, comparing the values along the time, the deviations can be calculated and subsequently the error estimated.

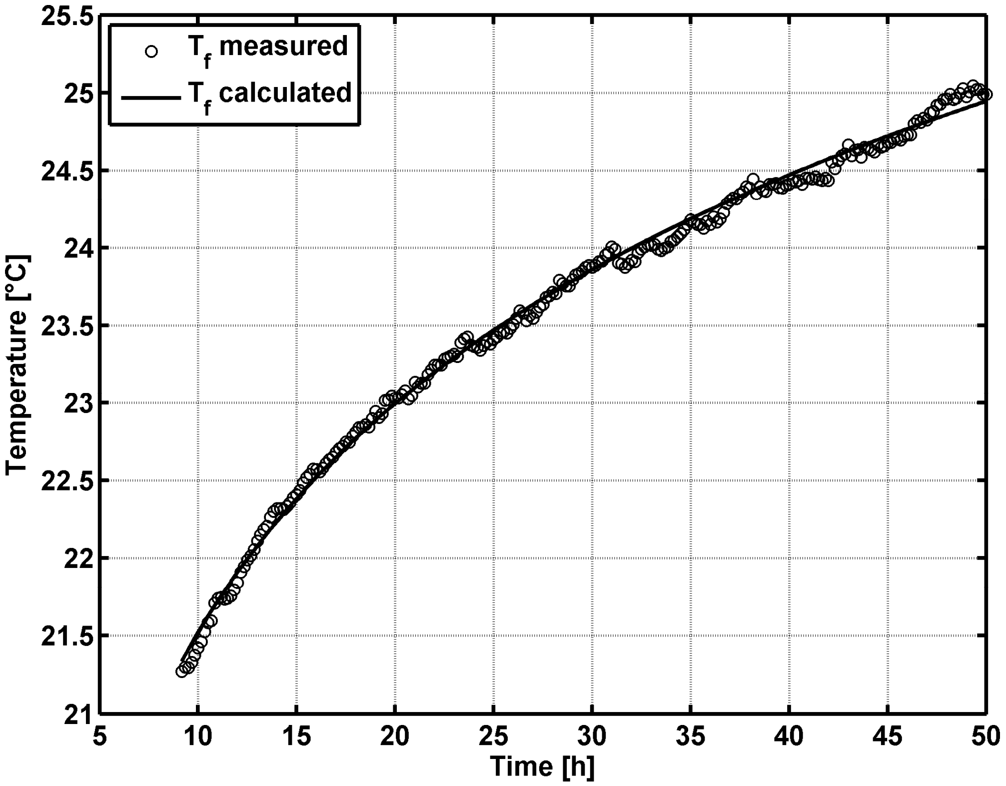

Figure 3. Measured average temperatures VS calculated average temperatures.

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