TEMPERATURE PROFILES AND THERMAL PROPERTIES OF THE GROUND IN CYPRUS, FOR USE IN THE DESIGN OF GROUND HEAT EXCHANGERS

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Abstract

The objective of this project is to investigate and determine the geothermal parameters of the ground in Cyprus, for use in the design of ground heat exchanger applications and ground thermal storage. Especially for the case of Cyprus, warm climate and the mild weather conditions in relation to other countries, provide a valuable set of conditions for the development of such energy systems.

One of the specific objectives of the project is to investigate and accurately define the ground thermal properties in Cyprus so as to provide all interested in this technology, with actual ground data. Such information is currently unavailable. Different kinds of geological structures are being investigated as well. Subsequently, neural networks will be used for the generation of geothermal maps that will show the temperature distribution at 3 different depths. In this way and for the first time, the geographical area of Cyprus will be covered and valid data will be available. The purpose of this paper is to report the information collected at six representative sites of Cyprus and prepare a map depicting the thermal characteristics of the ground in Cyprus.

Keywords: Ground thermal behaviour, Ground temperature, Ground heat exchangers, Ground thermal applications

1. Introduction

Renewable technologies are nowadays widely used in many parts of the world. The geothermal or ground source heat pumps are such systems and are used for the air-conditioning of buildings. Geothermal heat pumps save energy and reduce CO_2 emissions because they are more efficient than the usual type of heat pumps but they are still not as popular as the air source heat pumps [1]. The reason for this is that the geothermal heat pumps have high initial cost because they require the installation of ground heat exchangers (GHE). For an efficient design of a GHE the geological and thermal conditions of the installation area need to be known and therefore a survey needs to be contacted in that area.

To facilitate the determination of the geological and thermal characteristics of the ground at various areas in Cyprus, a project funded by the Research Promotion Foundation of Cyprus was undertaken by the Cyprus University of Technology in collaboration with other governmental and non-governmental organizations.

The climate of an area affects the subsurface temperature. The thermal regime at the earth's surface and in the near-surface shallow depths is controlled entirely by the solar radiation and the resultant mean surface temperature depends on the long term budget of the incoming and reflecting radiation. The amount of received solar radiation characterizes the climate varying the temperature, precipitation and wind. For the state under the surface, the temperature is increasing with depth, with the rate proportional to the outflow of the thermal energy from the earth's interior (geothermal gradient). Typical terrestrial geothermal heat flow equals to 50-60 mW/m^2 but even this relatively low geothermal outflow can provide significant geothermal gradients corresponding to 20-30K growth per Km [2]. Because of the climatic and geothermal energy flows the ground temperature varies with the location and its thermal characteristics. For instance, in northern Germany the soil temperature averaged for 137 stations varies between 8°C to 6°C at a depth of 20m to 100m [3] whilst in southern Portugal for the same change in depth the temperature varies from 18 to 19.5°C [4].

2. Geothermal investigation in Cyprus

To investigate the geothermal properties of the ground in Cyprus, six borehole sites were selected based on their geological layers, prevailing weather conditions and population density in order to include seaside, inland, semi-mountain and mountainous locations. The drilling sites are located in: Lakatamia, Kivides, Meneou, Agia Napa, Geroskipou and Prodromi near Polis Chrysochous as shown in figure 1.

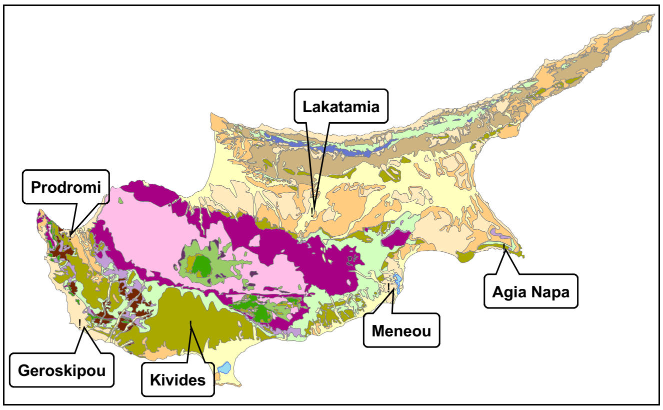


Fig. 1. Geological map of Cyprus with the six borehole locations.

A number of U-tube heat exchangers made of polyethylene pipe were installed in the boreholes. The Cyprus University of Technology (CUT) group manufactured most of the GHEs using local and imported components. The heat exchangers were also fitted with thermocouple wires at various depths for measuring the ground temperature. These combinations enabled the researchers to collect accurate data and conduct a greater number of tests leading to more results and conclusions regarding the earth-heat exchangers. All boreholes where filled with bentonitic clay.

2.1 Thermal conductivity test

Rock samples were collected from individual borehole lithologies during drilling. The samples collected were analysed by the Geological Survey Department (GSD) of the Ministry of Agriculture and Natural Resources of the Republic of Cyprus. The ground conditions mostly include sandy marls, chalk, limestones and sandstones. Figure 2 depicts the borehole lithology at the six selected locations as prepared by the GSD. Additionally, samples representing the formation of the boreholes were collected from the nearby areas for analysis. For every sample, a number of thermal conductivity measurements were made using the Hukseflux thermal sensor device.

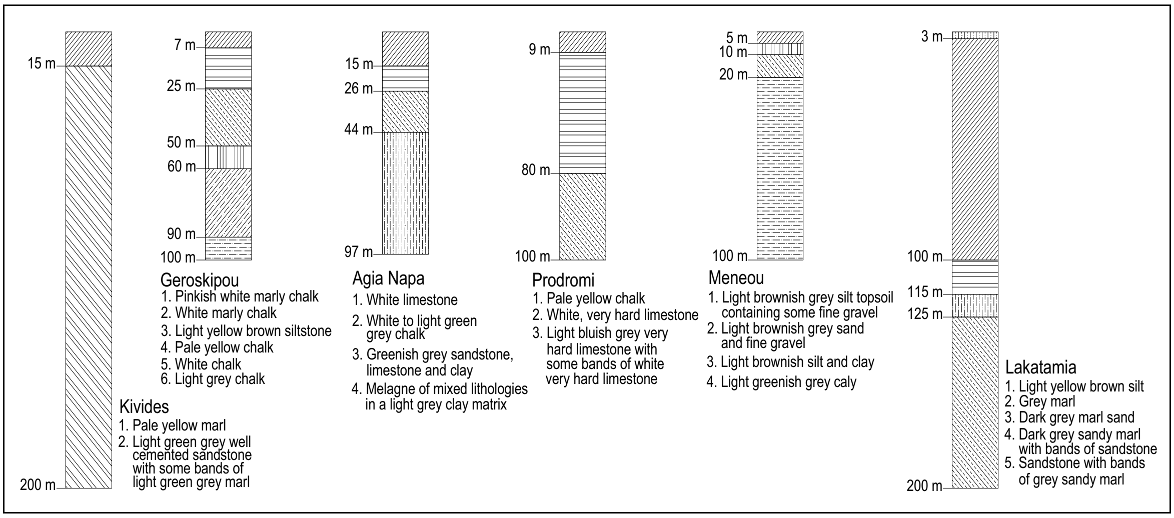


Fig. 2. Borehole lithology at the three selected locations.

For measuring the thermal conductivity a non-steady-state (hot wire, needle) probe was used. The thermal conductivity of a medium was determined from the temperature response to heating. After an initial transition period, the temperature rise close to the heater depends only on the thermal conductivity of the surrounding medium, and no longer on heat capacity. Generally, this method avoids the necessity of reaching a real thermal equilibrium with constant temperatures and therefore the method is suitable for quick experiments and also for field use. The central equation governing these probes is determined by the temperature field around a heating wire that is switched on at t = 0 supplying constant power from that moment on hence the probe of the unit is fitted with sensors measuring the temperature rise of the heater itself.

Table 1 lists the measured thermal conductivity values of the collected samples. As it is seen, the thermal conductivity of every type of the samples is not constant but it varies. This is due to the fact that the specific weight of the collected rocks also varies. Samples collected from the surface appear to be less dense than the ones collected from deeper in the ground. Also the amount of saturation with water of every sample in the actual layer of the borehole is another factor for the variation. Therefore estimating the thermal conductivity of the borehole from individual values measured on specimens does not give an accurate result. An in situ measurement of the borehole thermal conductivity is therefore necessary. This can be done by using the borehole thermal response test.

2.2 Borehole thermal response test (TRT)

For every borehole a number of TRTs were carried out in order to determine the average thermal conductivity of the ground (λ) and the average temperature of undisturbed ground.

For typical ground conditions and a single borehole heat exchanger, the borehole length is sized for a heat injection/extraction rate per meter of borehole of about 25-50 W/m. For accurately sizing the borehole heat exchanger its thermal properties must be estimated. The line source model is a method of evaluating the characteristics of the borehole. This method is the most widely used at this time. The data analysis is based on the theory describing the response of an infinite line source model. Although this model is a simplification of the actual experiment, accurate data for the design of borehole heat exchangers can be obtained on site.

Table 1. Thermal conductivity results for the collected samples.

Specimen	**State**	**λ-value (W/mK)**	**Specific weight (gr/cm^3)**
Bentonitic clay	Dry	0.6 – 0.78	1.2
	Saturated	1.1 – 1.16	1.55
Bentonitic clay + cement	Dry	0.63 – 0.68	1.2
	Saturated	0.90 – 0.94	1.55
Marl	Dry	-	1.78 – 2.13
	Saturated	2.01 -2.15	1.72 – 1.85
Chalk	Dry	1.36 – 1.38	2.13
	Saturated	-	2.27

The change in ground temperature at a distance (r) from the line source after a time duration (t) of constant heat injection rate per active length of borehole, q_c, may be used as an approximation of the heat injection from the borehole heat exchanger and:

$$T_{(r,t)} - T_{(t=0)} = \frac{q_c}{4\pi\lambda}\int_{\frac{r^2}{4\alpha t}}^{\infty}\frac{e^{-u}}{u}du = \frac{q_c}{4\pi\lambda}E_1\left(\frac{r^2}{4\alpha t}\right) \quad (1)$$

where u is an independent variable, α is the thermal diffusivity and E_1 is the so-called exponential integral. For the above expression the maximum error is 2.5% when $\alpha t/r^2 \geq 20$ and 10% when $\alpha t/r^2 \geq 5$. This condition means that the accuracy increases as the thermal front reaches further beyond the borehole wall and the velocity of the thermal front is dependent on the ratio between thermal conductivity and heat capacity of the ground, i.e., the ground thermal diffusivity [5].

Hence the thermal conductivity can be determined from the slope of the line resulting by plotting the fluid temperature against ln(t).

The tests were carried out by injecting a constant heat power into a borehole with known depth and known diameter. The recorded data include the inlet and outlet temperatures of the heat carrier fluid, the flow and the input energy over a certain period, etc. It should be noted that in some boreholes two types of GHE with different diameters were tested. Table 2 lists the obtained results from the TRTs carried out at five of the six data collection locations. As it is observed, although theoretically, the thermal conductivity of a borehole is constant and independent of the pipe diameter and heat injection rate, actually it is affected by both of these factors.

Figure 3 shows the mean fluid temperature against ln (t) used for calculating the borehole thermal conductivity (λ). As it is obvious, the mean fluid temperature is higher when greater power per unit length is used during the test but the important aspect of the graph is only the calculated slope of the line that is used in the evaluation of λ.

2.3 Ground temperature data collection

In all boreholes thermocouples were installed at various depths, to record the ground and ambient air temperatures. The Omega thermocouples used are of the K type and are twisted/shielded thermocouple wires ideal for systems sensitive to induced voltages and electrical noise. They are also moisture, abrasion, chemicals and UV light resistant [6]. All the data were recorded using DaqPRO data loggers that recorded data at 30 minute intervals.

Table 2. Thermal Response Tests results for various locations with a fluid flow of about 14-16 l/min.

Place	Pipe Diam. and length	Injected Power W/m	Initial fluid temp. °C	Tin at 50 hours °C	Tout at 50 hours °C	ΔT at 50 hours °C	Tin at 80 hours °C	Tout at 80 hours °C	Thermal conduc. (λ) W/mk
Agia Napa	32mm x100m	28.1	23.5	35.1	31	4.1	36.2	31.9	1.58
Lakatamia	32mm x160m	35.7	23	37	31.2	5.8	-	-	1.68
Geroskipou	25mm x100m	27.5	24	35	31.8	3.2	35.5	32.5	1.42
Geroskipou	32mm x100m	28.2	21.5	32	27.5	4.5	32.5	28	1.97
Meneou	32mm x100m	58.75	22	35.5	32.8	2.7	37.2	34.4	1.72
Meneou	40mm x100m	25.05	22.3	32	28	4	33	28.5	1.40
Prodromi	32mm x100m	26.78	24	32.5	30.6	1.9	-	-	1.87

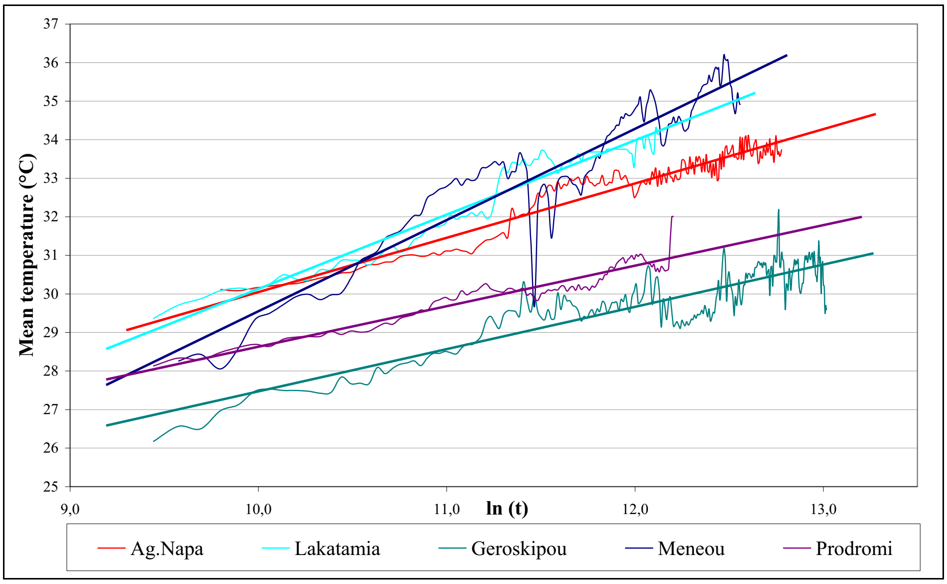
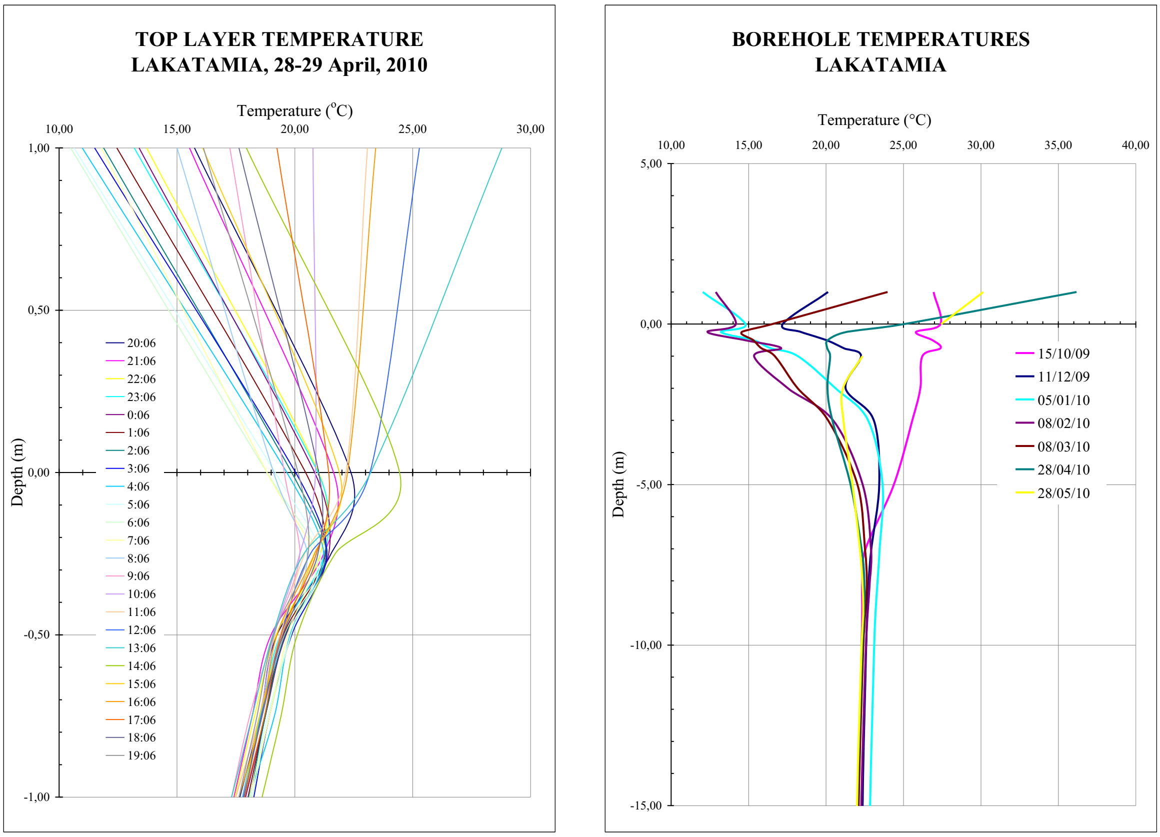


Fig. 3. Mean fluid temperature against ln (t) used for calculating λ.

DaqPRO is an eight-channel, compact, stand-alone, portable data acquisition and logging system with built-in analysis functions. It is capable for measuring voltage, current, temperature and pulses and it has a variety of selectable ranges for each input. Also, it can be connected to a PC through the DaqLAB software [7].

In figures 4a and 4b the 3 zones, surface, shallow and deep, can be distinguished. The surface zone reaching a depth of about 0.5m is obviously affected by the ambient air temperature and its fluctuations (figure 4a). The shallow zone, reaching a depth of up to 8m (figure 4b), follows a similar pattern with the surface zone but in this case the temperature variation is seasonal and is not affected by the daily ambient air variations. Usually, in the warm months of the year, the temperature in the shallow zone is lower than the temperature of the deep zone. On the other hand, in the cold months, the temperature in the shallow zone is higher than the temperatures in the deep zone. This phenomenon can be observed in figures 5a and 5b as well. The change in the temperature of the ground in the shallow zone in respect to the change of the ambient air temperature occurs with a time lag that in the depth of 3m exceeds 2.5 months.



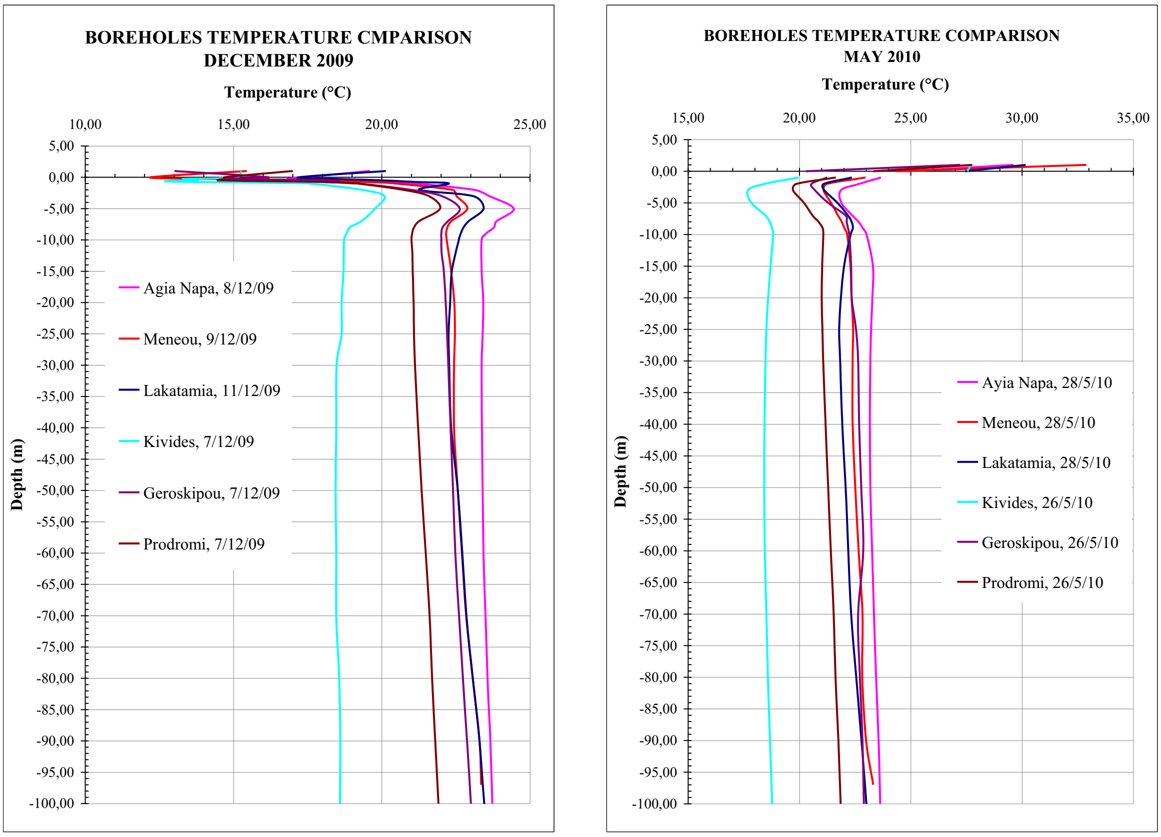
(a) (b)

Fig. 4. (a) Borehole temperatures at Lakatamia for the period of October, 2009 to May, 2010 and (b) top layer temperature distribution at Lakatamia, 28-29 April, 2010.

Figures 5a and 5b depict the ground temperature distribution at the borehole locations for the months December 2009 and May 2010, respectively. The ground temperature range of the shallow zone at the depth of 3m during the period December 2009 to May 2010 varies between 15.5°C and 23.6°C. The deep zone that starts from 8m is not affected by the climatic fluctuations and the temperature is constant throughout the year, between 18.4°C and 23.9°C.

The highest ground temperature in the deep zone was measured at Agia Napa and is 22°C-23°C, while the lowest was measured at Kivides and is 18°C-19°C. The borehole at Agia Napa represents a seaside location while the one at Kivides represents a semi-mountainous one. Usually the mean ambient air temperature in seaside areas is lower than that of the inland's during the summer period and slightly higher during the winter period. Irrespective of this, the temperature of the ground at Lakatamia, that represents an inland location with higher altitude than the seaside locations, is closer to the one measured at Agia Napa. The deep zone temperature distribution of the Island proves that the lithology of the ground is the most important factor affecting its geothermal characteristics and not the location (near the sea or inland).

It can also be observed from figures 5a and 5b that the geothermal gradient of the boreholes is about 1°C to 1.5°C per 100m. Geothermal gradient is a measure of how rapidly the temperature increases at constant heat flow and is a function of the ground thermal conductivity as well.



(a) (b)

Fig. 5. Ground temperature distribution at the borehole locations for (a) December 2009 and (b) May 2010.

2.4 Geothermal map

The ultimate objective of this work is the creation of the geothermal map of Cyprus. For this purpose artificial neural networks will be used. These will be trained using the data measured for the boreholes presented here. The data base will be enriched by the Geological Department of Cyprus which will provide data for some more boreholes used in other projects. The parameters needed for the training of the network are a) the x and y coordinates for each borehole, measured from some reference point, b) the borehole area elevation, c) the mean annual ambient temperature of the site d) the type of ground at the area of the site and e) the temperature of the ground at 20m, 50m and 100m depths. Subsequently, a grid of 10x10 km will be drawn over a detailed topographic map of Cyprus and the elevation of each grid-point will be recorded together with the other input parameters. This information will be then supplied to the network, which will produce an estimate of the mean ground temperature at the three depths indicated above for each grid-point. The x and y coordinates and the measured and estimated mean ground temperatures will then be used as input to a specialized contour drawing software in order to draw the iso-temperature lines at the three depths indicated above.

3. Conclusions

The results for the locations investigated in this study show that the undisturbed ground temperature in Cyprus is constant throughout the year and are within the range of 18.4°C to 23.9°C.

Also it is calculated that the thermal conductivity for Geroskipou is between 1.42 to 1.97 W/mK, for Lakatamia 1.68 W/mK, Agia Napa 1.58 W/mK, Meneou 1.4 to 1.72 W/mK and Prodromi 1.87 W/mK.

When the thermal conductivity of a borehole is low, using standard heat exchangers could result in long borehole lengths. Therefore one should investigate the possibility of using heat exchangers that will minimize the resistance of the thermal flow between the ground and the heat carrier fluid.

Also, it must be said that individual rocks collected from the area, similar in lithology to the rocks penetrated by the borehole, are not representative of the in situ geological layers. This is due to the fact that the rock conductivities increase with pressure and change according to their, porosity, grain size amount of water saturation etc. For these reasons the in situ measurements of the thermal conductivity with a specific heat exchanger is the only reliable test.

Knowledge of the thermal behaviour of the ground at various locations and depths is valuable for improving the design of geothermal applications in Cyprus and especially the efficiency of the ground coupled heat pumps used for the acclimatisation of buildings. The data collected until now clearly indicate that there is a potential for the efficient use of GCHPs in Cyprus leading to significant savings in power.

More precise conclusions will be extracted after October 2010 when the data collection period will end and all the data will be analysed (including the thermal conductivity tests of the collected rock samples and the boreholes thermal response tests).

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