Comparison of the thermal characteristics and temperature profile of the ground in Cyprus with other Mediterranean countries

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Abstract

The purpose of this study is to record and compare the ground temperatures and other thermal characteristics of the ground at eight representative sites in Cyprus with other studies both in the island and the nearby Mediterranean countries. Paul Morgan in the 1970s measured the geothermal gradient in 33 boreholes in Cyprus. Since then, the thermal behaviour of the ground has not been sufficiently studied and recorded, especially in inhabited areas, resulting in limited information for the design of ground heat exchangers and its effect on the efficiency of Ground Coupled Heat Pumps (GCHPs). As simulation studies indicate the ground temperature is one of the main system parameters that affect the performance of GCHPs. Measurements carried out on the representative locations in Cyprus show that the surface zone reaches a depth of 0.5m. The shallow zone penetrates to 7-8 m and there after the deep zone follows. Also the temperature of the ground at the deep zone has a range between 18-23 °C and is usually higher than that of the ambient air during the cold months of the year and lower during the warm months, showing suitable temperatures for the efficient use of GCHPs. Ground temperatures in Cyprus are lower than those examined in Jordan and higher than the ones in Portugal.

Keywords: Geothermal, ground temperatures, ground thermal properties

1. Introduction

Studies show that the ground temperature varies with depth. At the surface, the ground is affected by short term weather variations, changing to seasonal variations as the depth increases. At the deeper layers, the ground temperature remains almost constant throughout the seasons and years and is usually higher than that of the ambient air during the cold months of the year and lower during the warm months [1-2]. The ground therefore is divided into: a) the surface zone where hourly variations occur, b) the shallow zone, with monthly variations and c) the deep zone, where the temperature is almost constant.

The structure and physical properties of the soil are factors affecting the temperature, at all zones. The temperature of the ground is a function of its thermal conductivity, density and specific heat, the geothermal gradient and water contend and flow. Studies carried out in several locations in Cyprus show that according to the formation of the ground the surface zone reaches a depth of about 0.5m. The shallow zone penetrates to 7-8 m and there after the deep zone follows. Also the temperature of the ground at the deep zone has a range between 18-23 °C [2-5].

Ground Heat Exchangers (GHE) are heat exchangers used for the exploitation of the ground thermal capacity and the difference in temperature between ambient air and ground. They use the ground as a heat source when operating in the heating mode and as a heat sink when operating in the cooling mode, with a fluid, usually air, water or a water–antifreeze mixture, to transfer the heat from or to the ground [5].

It is expected that data collected from areas with climatic and soil characteristics similar to those of Cyprus would be applicable and show similar trends for the case of Cyprus as well. Other Mediterranean countries like south Greece, south Turkey, south Italy and the western areas of Middle East would be expected to be comparable with Cyprus.

As stated by Andritsos et. al. [6] the capacity of geothermal applications installed in Greece in 2000, was 57.13 MW_{th} while by the end of 2008 this number was doubled reaching 115.5 MW_{th}. The main reason for this is the increase in use of GCHPs. From the 0.4 MW_{th} installed capacity in 2000 it increased to 40 MW_{th} by the end of 2008. This is due to the fact that GCHPs are also used for cooling. The cooling load in Southern Mediterranean countries is much higher compared to countries of the Central or Northern Europe. This makes the GCHP systems more efficient than the common air cooled heat pumps since they operate in extreme weather conditions during winter and summer period.

However, the thermal behaviour of the ground in Cyprus has not been sufficiently studied. Therefore the information available so far for the design of ground heat exchangers is not representative for the whole of the island and it cannot be compared yet with other countries.

2. Geothermal investigation in Cyprus

Morgan's experiment

In a geological study, Paul Morgan in the 1970s [7] measured the geothermal gradient of 33 boreholes in Cyprus. The locations of the boreholes are shown in figure 1. A temperature measuring thermistor was mounted in a probe on the end of a four conductor cable and a Wheatstone bridge circuit with 1:1 ratio arms was used to measure the thermistor resistances. The four conductor cable was used to provide automatic compensation for the lead series and insulation leakage resistance contributions from the cable to the measured resistances. In order to measure the borehole temperature two different cables were used. The first one was a 4.5 mm outside diameter and 600 m long cable comprised of six pvc insulated 0.5 mm diameter tinned copper conductors laid around a 7/0.5 mm stainless steel strain member. The second one was a 2.8 mm outside diameter and 600 m long cable comprised of four high density polythene insulated 7/0.5 mm stainless steel cores. When both cables were used to measure a temperature at the same depth in a stable borehole, the results agreed to within 0.01 °C. The temperature measurements were made in air filled and water filled boreholes, the air and water movement was taken into account in the calculations made to compensate possible errors.

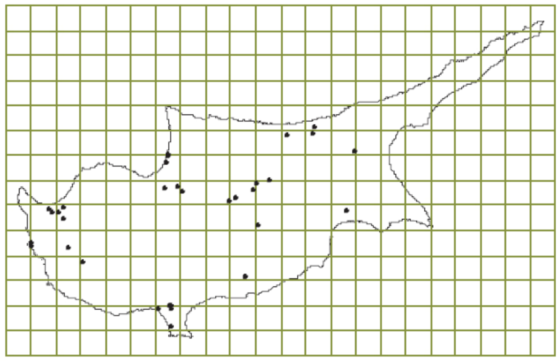

Figure 1: Geological map of Cyprus depicting Morgan's (1973) borehole locations. The map was prepared by the Geological Survey Department of The Ministry of Agriculture and Natural Resources of Cyprus on a 10x10 km grid.

New project, recent measurements

Since then, a limited number of studies were carried out in order to investigate the geothermal properties of the ground in Cyprus resulting in almost no further information. A Project funded by the Research Promotion Foundation of Cyprus was undertaken by the Cyprus University of Technology and other collaborators in order to gather and publish such information. Six borehole sites were selected based on their geologic 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 2. In addition to that, two more existing boreholes drilled in Saittas, representing a mountainous location and Limassol, representing a populated sea-side location, were used for data collection of the project.

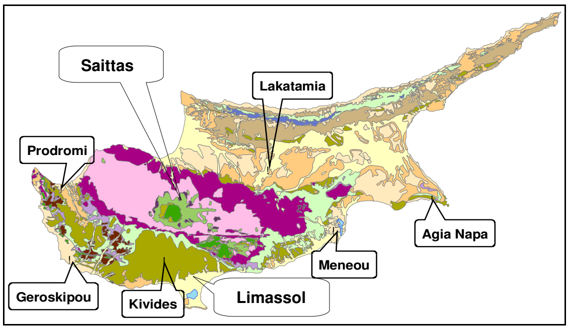

Figure 2: Geological map of Cyprus with borehole locations

A number of U-tube heat exchangers made of polyethylene pipe were installed in the boreholes and were fitted with thermocouple wires at various depths for measuring the ground temperature. All boreholes where filled with bentonitic clay. 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.

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 [8]. All the data were recorded using DaqPRO data loggers which were set to record data at 30 minute intervals.

DaqPRO is an eight-channel, compact, stand-alone, portable data acquisition and logging system with built-in analysis functions such as minimum/maximum graph values, the graph average, etc. 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 [9].

To check and increase the accuracy of the measurements, the ground temperature at various depths was also measured by using an immersible thermocouple wire connected to an Omega HH41 digital thermometer. The 500 m long thermocouple wire was winded on a small portable spool and immersed in one of the legs of the U-tube heat exchanger which was kept continuously filled with water. While lowering the thermocouple wire the temperature of the water in the tube (and therefore the ground temperature) was recorded at the step intervals were the K-type thermocouple wires were installed. This procedure was done slowly so as to prevent as much as possible the water movement in the GHE.

The results for Lakatamia borehole show that the shallow zone, reaching a depth of up to 8 m, presents seasonal variation and is not affected by the daily ambient air variations as indicated in figure 3. The yearly ground temperature variation at the depth of 0.5 m is within the range of 13.7 °C and 25.8 °C. The temperature presents a lower variation range as the depth increases and at 8 m it varies only slightly in the range of 20.8 °C to 21.3 °C

The rate of how rapidly the temperature in the ground increases at constant heat flow is called the geothermal gradient and is a function of the ground thermal conductivity. The slope of the curves representing the temperature distribution in the ground for that period indicates that the geothermal gradient of the locations under study is between 1 °C to 1.5 °C per 100 m.

Rock samples were collected from individual borehole lithologies during drilling. The collected samples were examined by the Geological Survey Department (GSD) of the Ministry of Agriculture and Natural Resources of the Republic of Cyprus. The ground layers mostly include sandy marls, chalk, limestones and sandstones.

Figure 4 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.

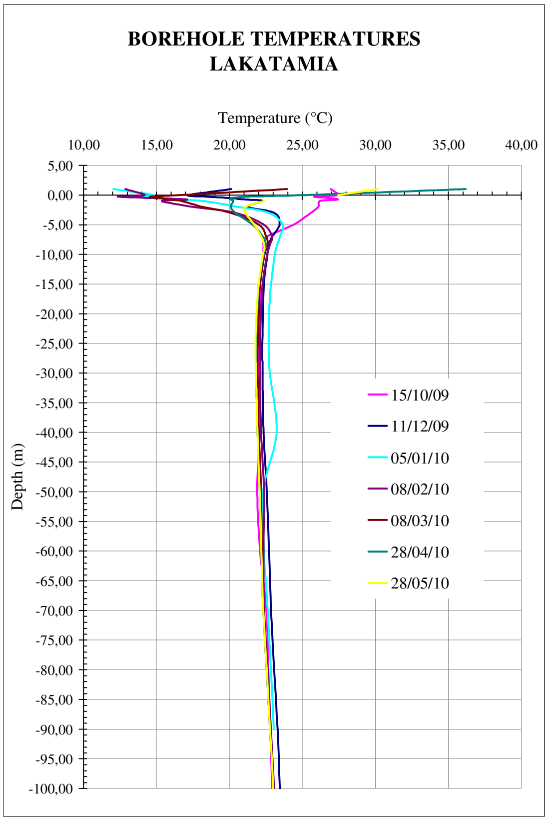

Figure 3: Borehole temperature distribution in Lakatamia for the period of October, 2009 to May, 2010.

The thermal conductivity of every type of the samples is not constant but it varies. The samples examined gave a range of thermal conductivities between 0.6–1.38 W/mK when dry and 0.9–2.15 W/mK when saturated. 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.

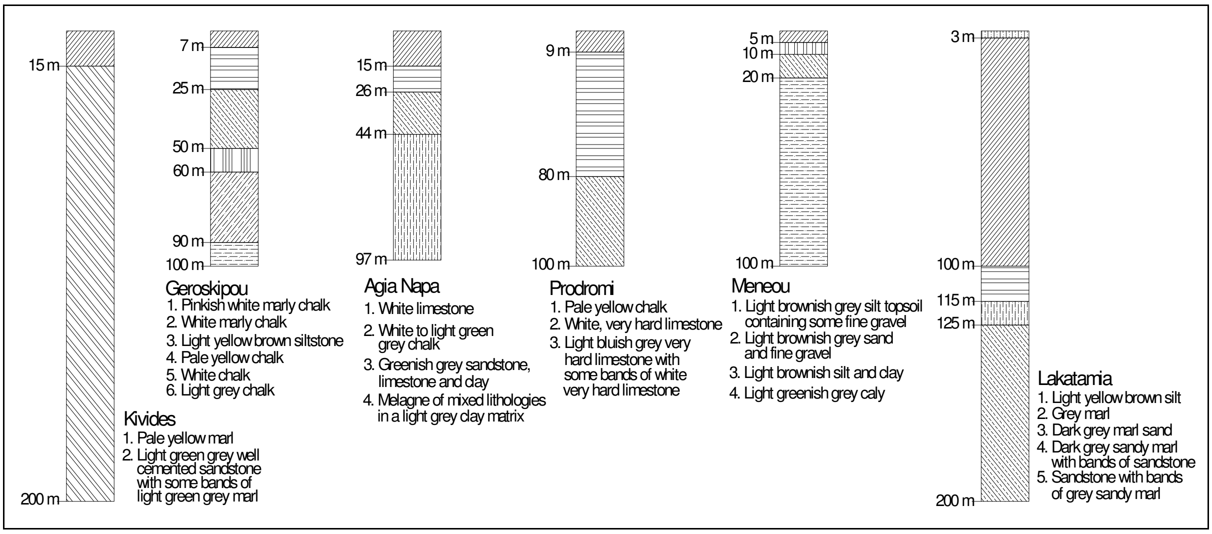

Figure 4: Borehole lithology at the six selected locations.

For every borehole a number of Thermal Response Tests (TRT) were carried out in order to determine the average thermal conductivity of the ground (λ) and the average temperature of undisturbed ground. The line source model, which was used for the analysis of the results, is a method of evaluating the characteristics of the borehole and is the most widely used nowadays [2]. This model is based on the theory describing the response of an infinite line source model and although this model is a simplification of the actual experiment, accurate data for the design of borehole heat exchangers can be obtained on site. The tests were carried out by injecting a constant heat energy into a borehole with known depth and known diameter. The recorded data included 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 1 lists the obtained results from the TRTs carried out at five of the six data collection locations. Although the lithology of the ground in the eight locations differs, the TRT results showed similarity in the boreholes thermal conductivity. The differences obtained in the results of the TRTs in Geroskipou (1.42 and 1.97 W/mk) and Meneou (1.72 and 1.4 W/mk) is due to the fact that GHEs with different diameter were used. The effect of the diameter of the GHEs on the TRT results is subject to further investigation.

3. Comparison of data within Cyprus and other Mediterranean countries

A comparison on the ground temperature distribution recorded in Saittas and Agia Napa against the ground temperature distribution recorded by Morgan in Polemi and Pigi, which are nearby areas to the above two sites, are presented in figure 5. Polemi is a mountainous location in the west site of the island and can be compared to the Saittas borehole. Polemi is also the site where the lower temperatures in the Island were recorded by Morgan. Pigi represents a coastal to inland location in the east site of the island and is the place that Morgan recorded the highest ground temperatures. According to the depicted curve profiles, the ground temperatures recorded by Morgan 39 years ago are very close to the ones recorded recently.

Table 1: Thermal Response Tests results for various locations with a fluid flow of about 14-16 l/min.

Location	Initial fluid temperature °C	Thermal conductivity λ, W/mk
Agia Napa	23.5	1.58
Lakatamia	23	1.68
Geroskipou	24	1.42
Geroskipou	21.5	1.97
Meneou	22	1.72
Meneou	22.3	1.40
Prodromi	24	1.87

Correira and Safanda [10] reported the ground surface temperature history reconstructed from borehole temperatures. In their study they recorded the temperature distribution and the thermal conductivity of the ground in a 200 m deep borehole located 5 km northwest of the town of Evora in southern Portugal. The place is located in an old cork tree forest with hercynian rock, porphyric granite with about 60% of feldspar and 15% of quartz and muscovite. A non-productive borehole drilled for water supply was cased with a 6.3 cm diameter PVC pipe, grouted at the bottom and filled with water. In this way the convection effects were limited to 0.001 °C resulting to reliable temperature recordings.

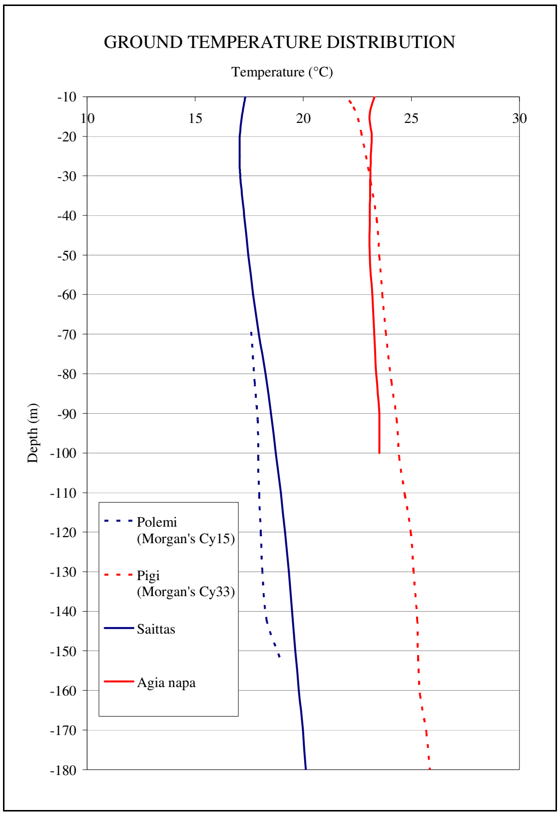

Figure 5: Comparison of the ground temperature range recorded in this project and the study carried out by Morgan for Cyprus.

Similarly, Forster et, al., [11] studied the surface heat flow of the Arabian Shield in southern Jordan (the western part of the Arabian plate). Five non-productive boreholes of up to 900 m deep drilled for the exploration of groundwater were used in the study. The area, also named the Southern Desert, is characterized by a relatively flat land surface and is mainly formed by Paleozoic sediments. The distribution of the ground temperature was recorded in spring 2002 and 2003. The accuracy of the recording process in the liquid filled part was limited to ~0.1 °C while the logs of the air filled parts above the water level in the boreholes were not used.

Table 2 lists the ground temperature range and the thermal conductivity range recorded by the above studies in three countries of the Mediterranean region i.e. Cyprus (two different studies), Portugal and Jordan. In the borehole in Evora, Portugal, the lowest ground temperatures were recorded with about 1 °C difference between highest and lowest values. In the case of Cyprus the lowest ground temperature records are almost the same with the ones recorded in Portugal. The difference is in the highest temperature records that reach the values of 23.2 °C (or 24.2 °C according to Morgan), 4 °C or 5 °C higher than the ones recorded in Portugal. In the case of Jordan, ground temperatures start at about 24.5 °C and reach 31°C, significantly higher than Cyprus.

The mean ambient air temperature in the locations of the boreholes is such so as to urge to the conclusion that the ground temperature distribution in the boreholes would be similar. Actually, it was expected to find lower ground temperatures in Portugal than Cyprus. Similarly higher ground temperatures were expected in Jordan compared to the other two locations. On the contrast, the differences in the ground temperature distribution were lower than the expected ones. The temperatures and thermal conductivities recorded in the boreholes strengthen the statement that the temperature of the ground is affected mostly by the lithology of the ground than the mean ambient air temperature in the area.

Table 2: Thermal properties of the ground up to the depth of 100 m reported in Cyprus, Portugal and Jordan

Location	**Deep zone Temperature range °C**	**Thermal conductivity range λ, W/mk**
Cyprus	≈ 18.3 - 23.2	≈ 1.40 - 1.97
Cyprus (Morgan's study)	≈ 18 - 24.2	≈ 1.3 - 2.3
Portugal (Town of Evora)	≈ 18.2 - 19.3	≈ 2.8 ± 0.2
Jordan (BH5)	≈ 26 - 31	≈ 1.55 - 5.67

Jordan (BH9)	≈ 24.5 - 26	≈ 1.55 - 5.67

4. Further work

One of the main objectives of the project undertaken by the Cyprus University of Technology 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 studied. The data base will be enriched by the Geological Department of Cyprus which will provide data for some more boreholes used in other projects. Some of the parameters needed for the training of the network are the mean annual ambient temperature, the type of ground and the temperature of the ground at several depths in the locations. The output will then be used as input to a specialized contour drawing software in order to draw iso-temperature lines.

Detailed information of the geothermal conditions in different locations in the Mediterranean area with similar weather conditions to that of Cyprus might be useful for the evaluation of the artificial neural networks to be developed. Unfortunately, such information is still limited compared to the available information concerning northern countries or areas with cold climates.

5. Results and Conclusions

The following results and conclusion can be drawn from the above presentation:

- The deep zone temperature of the ground in Cyprus is constant throughout the year and is within the range of 18.3 °C - 23.2 °C, 5 °C difference between lower and higher recorded temperature. The warmer site is the one in Agia Napa, sea-side area on the southeast of Cyprus, while the coldest is the one in Saittas, mountainous area on the mainland.
- The results of the project undertaken by the Cyprus University of Technology agree with the results of the project carried out by Morgan in 1970's.
- Ground temperatures in the boreholes examined in Jordan are higher than the ones in Cyprus and those in Portugal, as expected.
- The ground temperature distribution in the borehole examined in Portugal has the lowest range than those in Cyprus and Jordan and is about 1 °C. The ground temperature range in Cyprus and Jordan is almost the same and is about 5 °C.
- The lithology of the ground is the most important factor affecting its geothermal characteristics.
- Limited information is available regarding the thermal characteristics of the ground in warm climates and especially the area of the Mediterranean Sea.

6. Aknowledgments

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