The temperature profile of the ground in Cyprus

1. Introduction

The determination of the temperature profile of the ground is very important for heat exchanger applications. In this paper, the recorded ground temperatures in Cyprus at selected sites, in relation to depth, time of year, geology and altitude are presented and discussed. The effect of the ground temperature on the efficiency of Ground Coupled Heat Pumps (GCHP) is also examined.

The ground is divided in zones depending on its temperature variation in relation to depth and time. At the surface zone, the ground is affected by short term weather variations (hourly variations), changing to seasonal variations (monthly) in the shallow zone. At the deeper layers (deep zone) the ground temperature is not affected by weather variations. The temperature of the ground in the deep zone is 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.

2 Ground zones in Cyprus

The structure and physical properties of the ground are factors affecting the temperature, in all zones. The temperature of the ground is a function of the thermal conductivity, geothermal gradient, water content and water flow rate through the borehole. In Cyprus, Florides and Kalogirou (2005) studied the fluctuations of the ground temperature with depth in the borehole drilled in Athalassa region in Nicosia. It was found that the temperature variations in the surface zone in winter reached the depth of approximately 0.5 m. For our study, we have also measured the ground temperature for the period of May 2006 to May 2007, at Athalassa region and found that the ground temperature in the surface zone varied in phase with the ambient air temperature while as the depth increased the maximum or minimum temperatures occurred with a time delay, Pouloupatis *et al.* (2011). In the deep zone the ground temperature remains unaffected by the ambient air temperature variations. Figure 1 below depicts the recorded ground temperatures in various depths against time for the certain period. The three zones of the ground can be distinguished as well as the time delay of the minimum or maximum in the ground temperature at various depths.

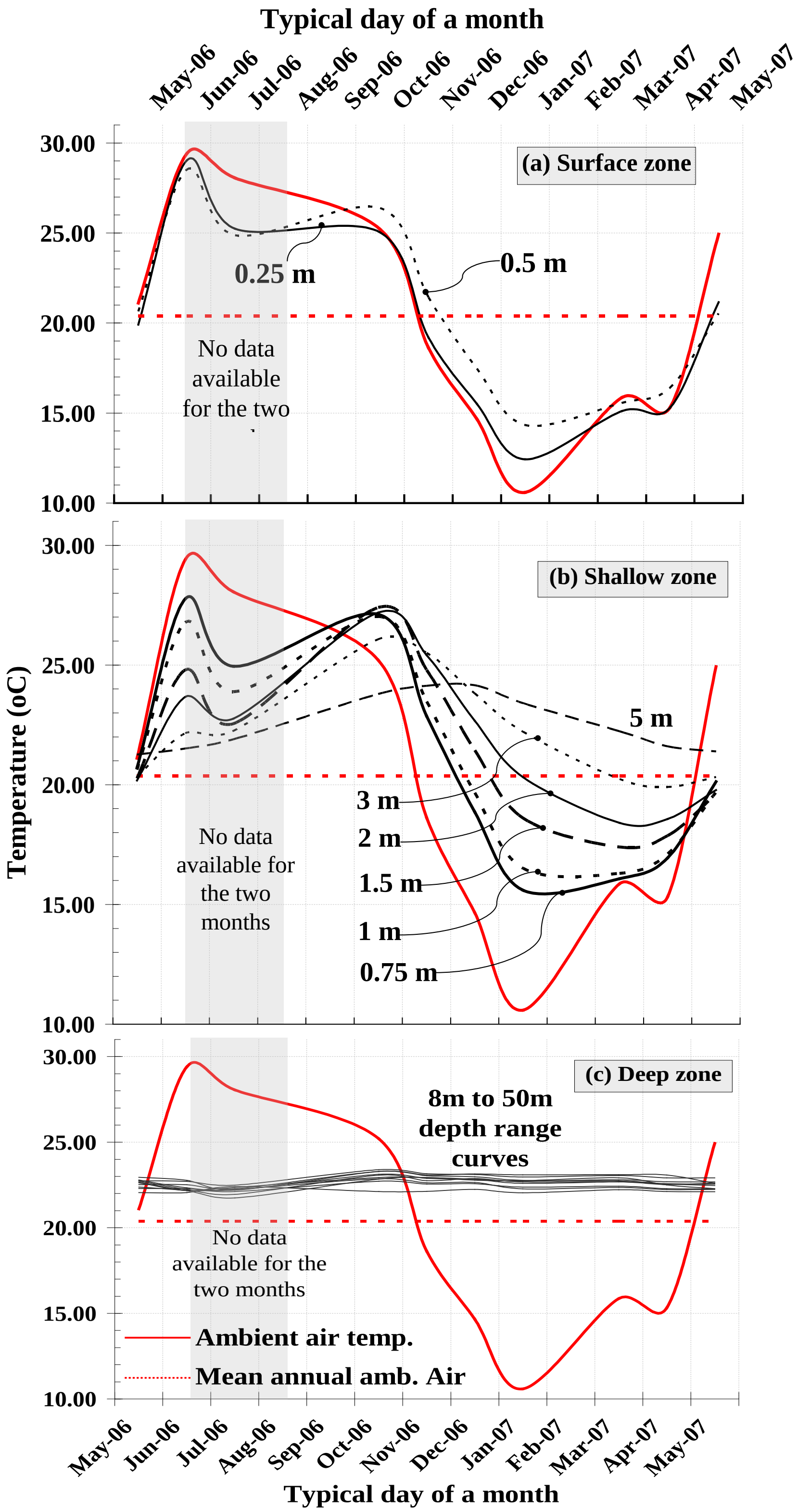


Figure 1: Mean monthly ground temperature at the (a) Surface zone, (b) Shallow zone and (c) Deep zone in the Athalassa region in Nicosia for the period May 2006 to May 2007

In Figure 1(a) the curves representing the depths of 0.25 m and 0.5 m follow the path of the ambient air fluctuation very closely stating clearly the surface zone that reaches approximately the depth of 0.5 m. The curves in Figure 1(b) representing the depths from 0.75 m to 5 m indicate the shallow zone in which longer time is needed for these layers to be affected by the ambient temperature. The shallow zone extends up to the depth of 8 m. From the depth of 8 m and deeper, Figure 1(c), the ground temperature is almost constant showing negligible fluctuations as happens typically in deep zones.

3 Ground Coupled Heat Pumps

The exploitation of the ground thermal capacity and the difference in temperature between ambient air and ground can be accomplished via Ground Heat Exchangers (GHE). A GHE is usually an array of buried pipes installed either horizontally or vertically into the ground. They are either open or closed type systems with air, water or a water–antifreeze mixture, acting as the heat carrier fluid exchanging heat with the ground. The ground acts as a heat source when heating is required while when cooling is required the ground acts as a heat sink. GHEs can contribute to the air conditioning of a space, for water heating purposes and also for improving the efficiency of heat pumps coupled to them, called Ground Coupled Heat Pumps (GCHP).

The main operation of single-stage vapour compression cycle heat pumps is to extract heat from a source and transfer it at a higher temperature to the sink. Air, water and ground are the main sources that heat can be extracted from and transferred to as well. Heat pumps are classified mainly based on their heat source and sink and their thermodynamic cycle. The most popular type of heat pump is the common air-to-air heat pump or air-cooled heat pump. These heat pumps use the atmosphere as heat source and/or sink and they exchange heat with ambient air. All refrigeration equipment, including air conditioners, used for heating and cooling purposes are considered as heat pumps.

Air-cooled heat pumps use refrigerants as heat carrier fluids for the heat exchange process. The refrigerants have the ability to change state, from liquid to gas when heated and usually they boil at low temperature. In the heating mode of an air-cooled heat pump, the refrigerant flowing in the evaporator absorbs heat from the environment and evaporates (changes state from liquid to gas) at low pressure. Then, an electrically driven compressor is used for the compression of the refrigerant aiming to the increase of its temperature. Therefore, the refrigerant at this stage is at high pressure and temperature and flows through a condenser and exchanges heat with a lower temperature medium. Having its temperature dropped the refrigerant returns to the liquid stage and after passing through an expansion valve, it becomes liquid at low temperature and pressure. The process described above is depicted in Figure 2. Most commonly, heat pumps are designed to reverse their cycles to deliver heating and cooling as well.

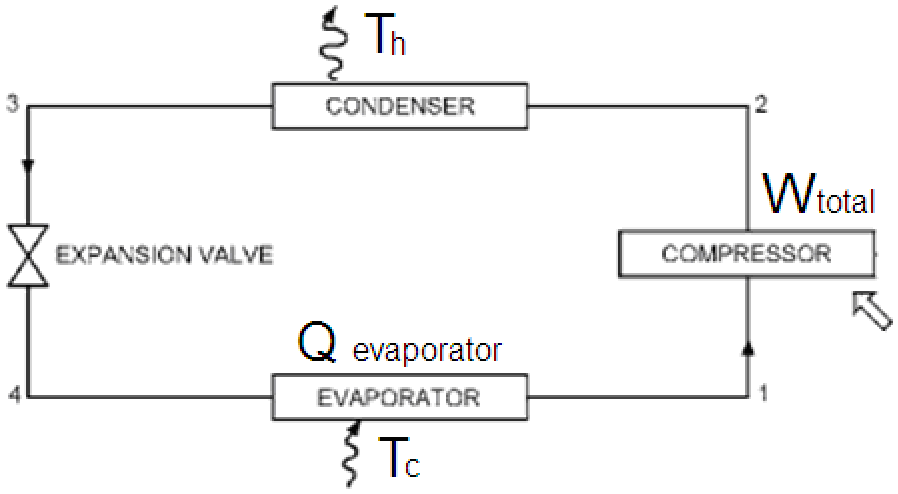


Figure 2: Theoretical single-stage vapour compression refrigeration cycle, ASHRAE Handbook (2009).

The efficiency of heat pumps is defined by the Coefficient of Performance (COP) in the heating mode and the Energy Efficiency Ratio (EER) in the cooling mode. As stated in the ASHRAE handbooks (2001), COP or EER ‘*is the ratio of the rate of net heat output to the total energy input expressed in consistent units and under designated rating conditions or is the ratio of the refrigerating capacity to the work absorbed by the compressor per unit time*’.

$$COP = \frac{\text{Rate of net heat output}}{\text{Total energy input}} = \frac{\text{Refrigerating capacity}}{\text{Work absorbed by the compressor}} \quad (1)$$

Sometimes the efficiency is described by the Seasonal Performance Factor, which is the average efficiency of the pump over the heating and cooling period, or the Seasonal Energy Efficiency Ratio for cooling (SEER), which is the total cooling output of an air conditioner during its normal annual usage period for cooling divided by the total electric energy input during the same period.

Most heat pumps use a vapour compression or an absorption thermodynamic cycle. For a mechanical vapour compression system as described above, the total energy input is usually in the form of work to the electrically driven compressor and fans. Similarly, the rate of net heat output can be expressed by the total heat delivered by the evaporator. Therefore, Eq. (1) can be expressed as:

$$COP = \frac{Q_{evaporator}}{W_{total}} \tag{2}$$

The Carnot cycle usually expresses the ideal reversible refrigeration cycle. It consists of two isothermal processes, heat exchange at constant temperature in the evaporator and condenser and two adiabatic processes, temperature increase during compression and temperature drop during expansion. By reversing the entire cycle the heat engine is converted into a refrigerator with the maximum possible efficiency. The Theoretical Coefficient of Performance of the Carnot refrigeration cycle is given by:

$$\text{Theoretical COP} = \frac{T_c}{T_h - T_c} \tag{3}$$

where:

T_c - is the temperature of the cold reservoir (room to be cooled)

T_h - is the temperature of the hot reservoir (ambient air)

Eq. (3) shows that the smaller the difference between T_h and T_c, the greater the performance coefficient.

Heat pumps actually differ from the ideal cycles in many respects. Pressure drops occur everywhere in the system except in the compression process and heat transfers occur between the refrigerant and its environment in all components. All of these cause irreversibilities within the system, each one requiring additional power into the compressor. For a non idealised refrigerator the actual thermodynamic Coefficient of Performance is always less than that of the Carnot cycle and at the best cases is 0.8 to 0.9 of the Carnot Coefficient of Performance, Vrachopoulos (2000).

GCHPs, or Ground Source Heat Pumps (GSHP) or Geothermal Heat Pumps (GHP), are heat pumps coupled to GHEs. The difference of GCHPs with common air-cooled heat pumps lies in the way they exchange heat in the evaporator. GCHPs exchange heat with the ground instead of the atmosphere. The rest of the process remains the same. Because of the difference mentioned above, it is expected that GCHPs would have some additional parts that comprise the ground loop system. Besides the GHE which is considered as part of the system, a heat carrier fluid circulator and an additional heat exchanger are required. The additional heat exchanger is responsible for the heat exchange process between the refrigerant in the main system and the heat carrier fluid in the ground loop system while the heat carrier fluid circulator is responsible for the circulation of the heat carrier fluid in the GHE and therefore for the heat exchange process in the ground, Healy and Ugursal (1997), Christofides et al. (2009). Figure 3 depicts a typical GCHP system.

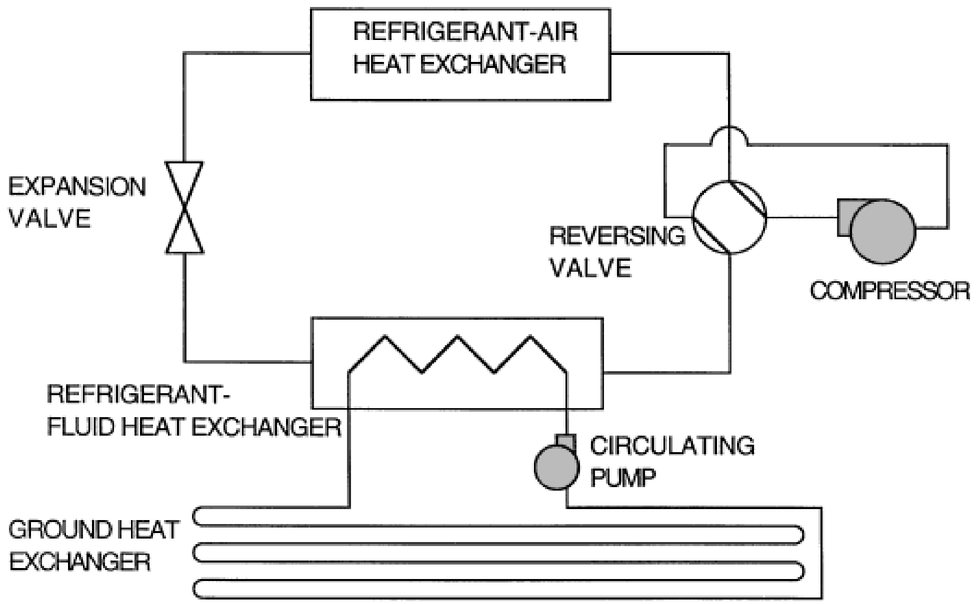


Figure 3: Schematic diagram of a Ground Coupled Heat Pump,
Healy and Ugursal (2009)

As mentioned above and also shown in Figure 1, the temperature of the ground provides a more steady and reliable source than the ambient air for the heat exchange process. Because of that, GCHPs could have improved efficiencies compared with common air-cooled heat pumps. Researches proved that the use of GCHPs could result in CO_2 reductions up to 54% in relation to common water to air heat pumps Healy and Ugursal (1997), Christofides et al. (2009).

4 Ground temperature determination in Cyprus

Morgan (1973) in his PhD study was the first known researcher who measured and reported the geothermal gradient for 33 boreholes in Cyprus, Appendix 1. For this study, the ground temperatures were recorded for 8 locations and are presented in Appendix 2.

For the temperature recording, two methods were used. Firstly, thermocouples were fitted at the various depths in each of the boreholes as shown in Table 1. The Omega thermocouples used were of the K type and were twisted/shielded thermocouple wires ideal for systems sensitive to induced voltages and electrical noise. They were also moisture, abrasion, chemicals and UV light resistant, Omega Engineering Inc. All the data were recorded using DaqPRO data loggers at 30 minute intervals.

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. Moreover, it can be connected to a PC through the DaqLAB software. The above instrument has an accuracy of 0.5°C, Fourier systems Ltd (2007).

Table 1: Borehole and equipment installation details

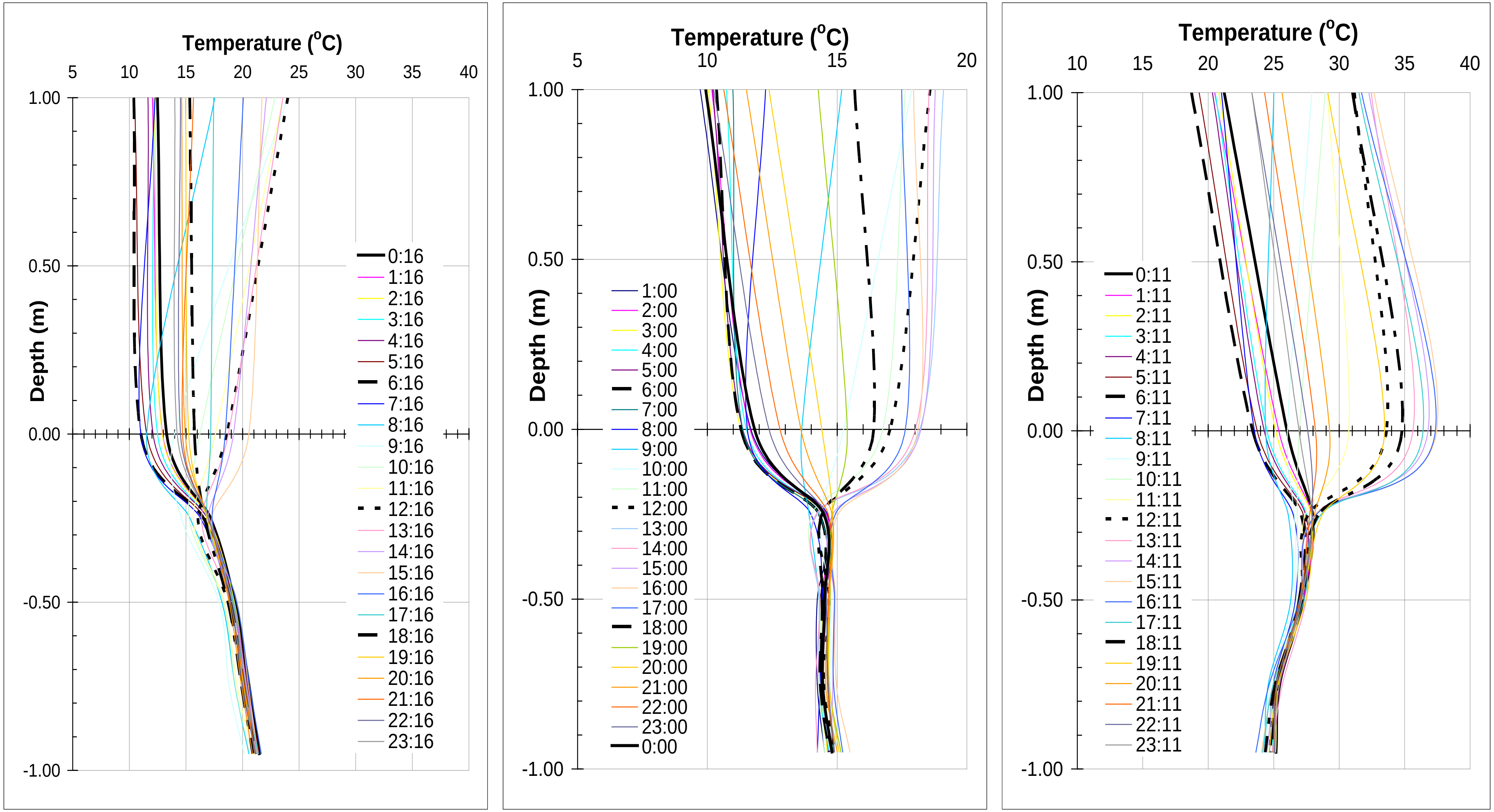
Location	Depth /Diam (m)	Thermocouple positions (m)
Agia Napa Famagusta	100.5/0.2	Ambient, 0, 0.25, 0.5, 0.75, 1, 3, 5, 7, 8, 9, 10, 11, 15, 20, 40, 60, 80, 100
Meneou Larnaca	97/0.2	Ambient, 0, 0.25, 0.5, 0.75, 1, 3, 5, 7, 8, 9, 10, 11, 15, 17, 37, 57, 77, 97
Lakatamia Nicosia	160/0.23	Ambient, 0, 0.25, 0.5, 0.75, 1, 3, 5, 7, 8, 9, 10, 11, 15, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160.
Kivides Limassol	196/0.15	Ambient, 0, 0.25, 0.42, 0.67, 0.92, 3, 5, 7, 8, 9, 10, 15, 26, 46, 76, 96, 126, 146, 176, 196.
Geroskipou Pafos	100/0.2	Ambient, 0, 0.25, 0.5, 0.75, 1, 3, 5, 7, 8, 9, 10, 20, 40, 60, 80, 100.
Prodromi Paphos	100/0.2	Ambient, 0, 0.25, 0.5, 0.75, 0.95, 3, 5, 7, 8, 9, 10, 15, 20, 40, 60, 80, 90, 100.
Limassol	127/0.152	N/A
Saittas Limassol	178/0.152	Ambient, 0, 0.25, 0.5, 0.75, 1, 3, 5, 7, 10, 50, 100, 150, 185.

A second method was used for checking and increasing the accuracy of measurements. An immersible thermocouple wire connected to an Omega HH41 digital thermometer was used. The 500 m long thermocouple wire was wound on a small portable spool and immersed in one of the legs of the U-tube heat exchanger installed in each borehole which was permanently 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 same depths where the K-type thermocouple wires were installed. This procedure was done slowly so as to prevent water movement in the GHE. The small PVC pipe diameter used for the GHE also prevented water movement due to temperature differences caused by small density variations. The measured temperature with the HH41 thermometer was corrected by using a formula provided by the manufacturer and giving an accuracy of 0.2°C for the temperature range of 10°C - 30°C. By using the same instrument and thermocouple wire all data were directly comparable with the same inherent errors.

The borehole drilled in Prodromi region in Pafos was selected as a reference borehole for the analysis of the recorded data that follows. The main reason for this was because this borehole was close to another 2 boreholes used by Morgan in his study and comparison is possible.

As expected the surface zone was affected by the ambient air temperature and the solar radiation and it reached the depth of about 0.25 m as clearly shown in Figures 4(a), (b) and (c). The hourly fluctuations of the ground temperature were more prevalent at depths closer to the surface and followed the ambient air temperature pattern. In the winter period the ambient air temperatures and the temperatures of the surface zone were colder than in the spring period. Therefore the curves of Figure 4(a) were shifted to the left in relation to the ones of Figure 4(b). Similarly, the curves shifted to the right in the summer period as shown in Figure 4(c), because of warmer ambient air and surface zone temperatures. The impact of the weather conditions on the ground temperature was diminishing with the increase in depth and this was proved by the tendency of the curves to join at a depth of about 0.25 m.

From the 0.25 m depth and downwards to about 8 m depth is the shallow zone. Only seasonal variations were observed with the daily weather variations not being of any importance. As shown in Figure 5, the ground temperature range at the depth of 0.5 m was within the range of 13.7°C to 25.8°C and reduces as the depth increases, reaching to



(a) winter (b) spring (c) summer

Figure 4: Top layer temperature distribution at Prodromi for (a) 6 November, 2009 [winter], (b) 13 March, 2010 [spring] and (c) 15 July, 2010 [summer]

the range of 20.8°C to 21.3°C at the depth of 8 m. Finally, the ground temperature in the deep zone remained almost constant throughout the year as expected with 21.77°C being the minimum temperature recorded at 100 m depth while the maximum one was 21.91°C, a difference that lies in the accuracy range of the instrument which is 0.2°C.

The geothermal gradient is a function of the ground thermal conductivity is indicated by the slope of the curves representing the temperature distribution in the ground. Based on the collected data, the geothermal gradients of the 8 boreholes examined were between 1°C to 1.5°C per 100 m. This is clearly shown in the graphs of the ground temperature plotted against depth of each borehole in Appendix 2.

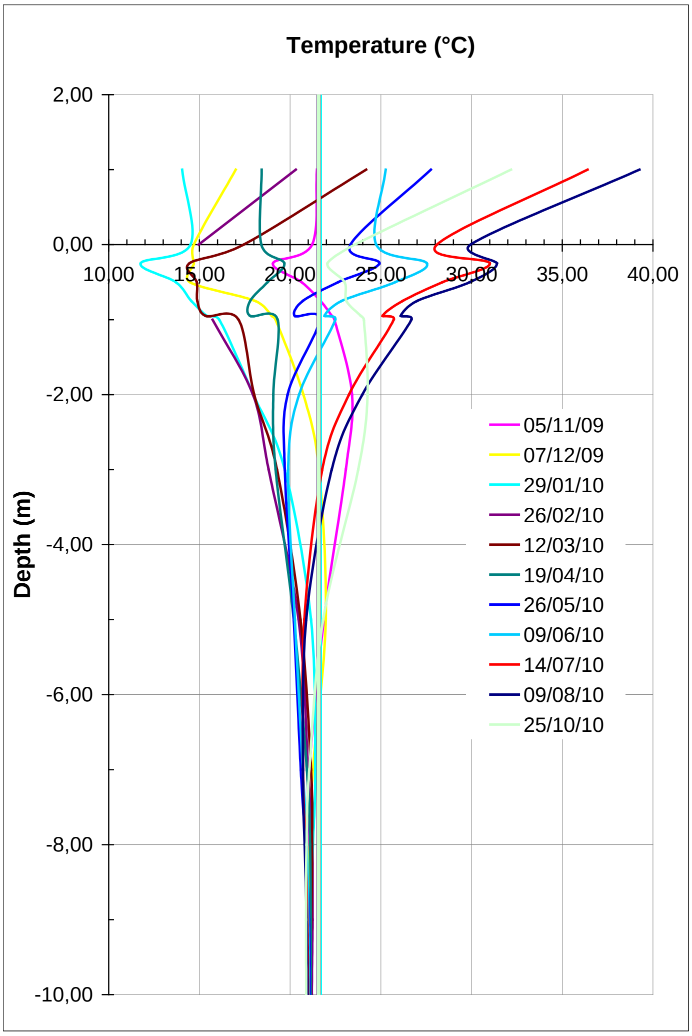


Figure 5: Borehole temperature distribution at Prodromi
for the period of January, 2009 to May, 2010

Figure 6 depicts the minimum and maximum ground temperatures recorded at the eight borehole locations for the period between October 2009 and 2010. As can be seen, the ground temperature in the deep zone was constant throughout the year. Agia Napa was the warmest of the examined locations and Saittas the coldest. The mean minimum ground temperature in the deep zone in Agia Napa region was 23.1°C and the mean maximum 23.6°C. Similarly, the mean ground temperature in the deep zone in Saittas region was 18.3°C. The semi-mountainous location represented by the borehole in Kivides region was on average 0.5°C warmer than the one in Saittas region (18.6°C – 18.8°C). The deep zone temperature distribution in the rest of the data collection locations lay between the ones in Agia Napa and Saittas regions. The deep zone temperature distribution of the boreholes examined proved that the lithology of the ground was the most important factor affecting the geothermal characteristics of the boreholes and not their location (near the sea or inland).

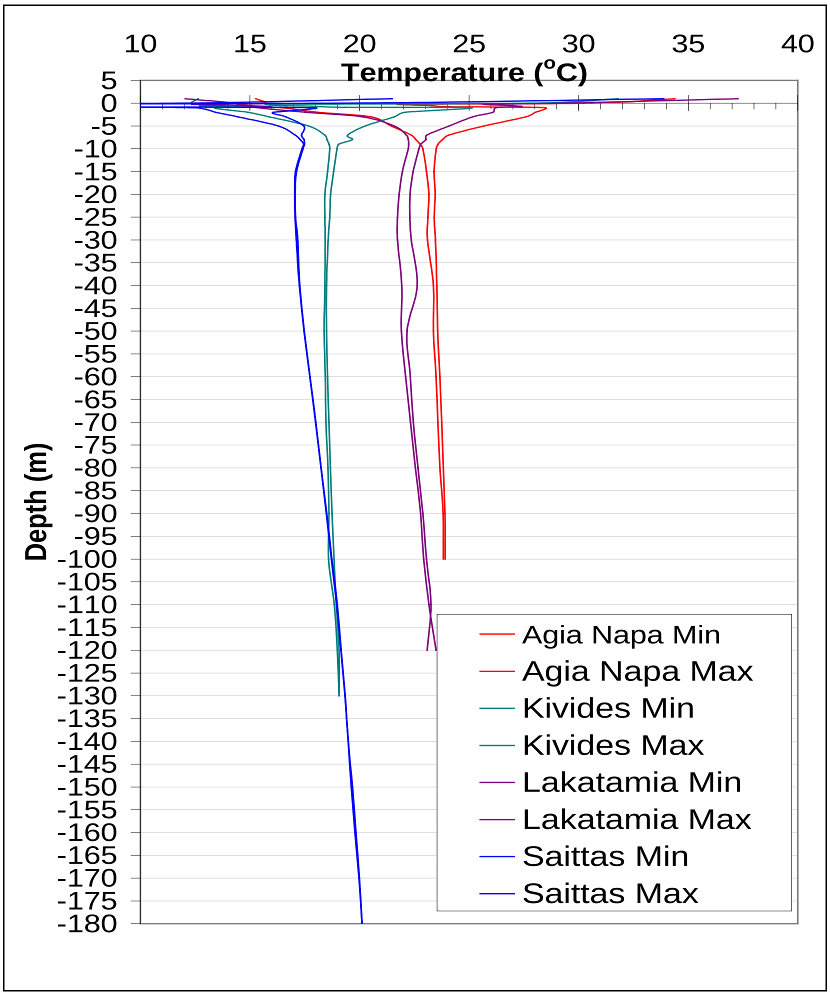


Figure 6: Minimum and maximum ground temperature distribution at Saittas, Kivides, Lakatamia and Agia Napa locations for the period between October, 2009 and 2010

A comparison of the ground temperatures recorded at Prodromi in May, 2010 against the ground temperatures recorded by Morgan in May, 1971, in three nearby locations, is presented in Figure 7. According to the depicted curves, the ground temperatures recorded by Morgan 39 years ago are very close to the ones recorded today. This proves that the lithology of the ground is the most important factor affecting the geothermal characteristics of a location and not the weather.

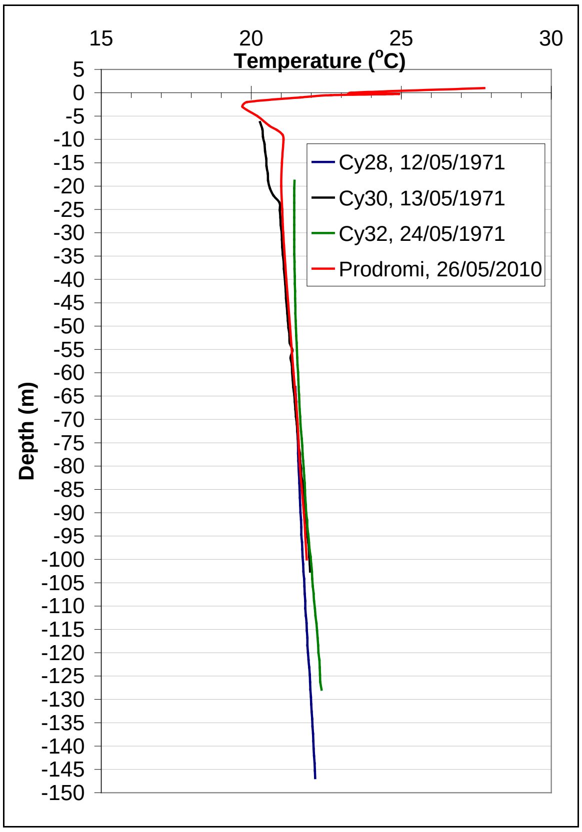


Figure 7: Comparison between the ground temperature distribution at Prodromi and the three nearby locations recorded by Morgan in May, 1971

5 Testing of a GCHP in Cyprus

As mentioned above, GCHPs exchange heat with the ground instead of the atmosphere resulting to a higher COP and EER than those of the common air-cooled heat pumps. In order to investigate the efficiency of a GCHP in relation to the ground characteristics, the GHE fitted in the borehole in the Athalassa region in Nicosia was coupled to a water to air GCHP. K-type thermocouples were placed in the middle of the 20 cm of diameter and 50 m deep borehole to record the temperature of the ground at several depths. A k-type thermocouple was also used to record the ambient air temperature. The GHE was made of polyethylene pipe, 32 mm external diameter. More details of the borehole were presented in Chapter 3. All data were recorded at 15 minute intervals, using an Omega OMB-DAQ

55/65 USB data acquisition module. The deep zone temperature was at 22.6°C while the mean annual ambient air temperature of the region was 19.5°C.

A typical office of 27.65 m^2 floor area next to the borehole was used for testing the water to air GCHP. The heating and cooling needs of the office were calculated to be 2.5 kW and 4.3 kW respectively. During the experiment, in the summer period, the room temperature was kept between 22°C and 24°C with a relative humidity of about 38%. The latent heat of the room was negligible since there were no occupants in the room and therefore it was ignored in the calculations. During the winter period the room temperature was kept at about 23°C.

The experiment was carried out during typical days early in October, 2008 and by the end of January, 2009. Figure 8 depicts the temperature variation of the water at the inlet and outlet of the GHE, the intake and delivered air temperature of the GCHP, the temperature variation of the ground at the depth of 50 m and the recorded ambient air temperature variation in October.

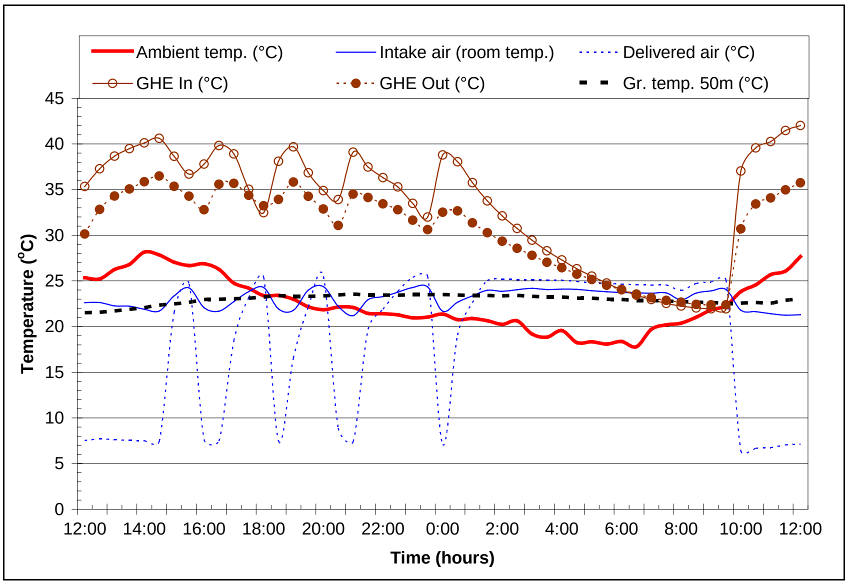


Figure 8: Temperature data during a typical day early in October of 2008

The air handling unit of the GCHP was continuously re-circulating the room air therefore the intake to the GCHP air temperature coincided with the room temperature. During the measurements the range of the room temperature was between 21.5°C and 24°C and the average room temperature was 23.0°C. The compressor of the GCHP was working continuously between 10:00 and 15:00 and intermittently between 15:00 and midnight to satisfy the cooling load. From 0:00 of the next day till 10:00 the compressor was not in operation. When the compressor of the GCHP was on the delivered air temperature was between 6°C – 8°C. Also, depending on the operation of the compressor of the GCHP the temperature of the fluid entering the GHE varied between 22°C – 42.0°C. Similarly, the return temperature of the fluid varied between 22.4°C – 36.5°C. The temperature difference between the inlet and return fluid of the GHE was about 6°C while the difference was almost zero when the compressor was not in operation.

Figure 9 depicts the variations in the sensible capacity of the GCHP, the rejected heat to the ground by the ground heat exchanger and the input power to the GCHP when the entering air temperature to the GCHP was 23°C and the entering fluid temperature varied between 10°C – 40°C. These values were calculated using the data collected during the experiment in October. It also shows the calculated sensible capacity over the input power ratio and the trend of the curves when the entering fluid temperature rises to 50°C. Under these circumstances the calculated sensible capacity over the power input ratio was between 2.52 and 2. On average, the entering fluid temperature was calculated to be 30.7°C with the sensible capacity over the power input ratio being close to 2.2. In the case that the capacity of the GHE was higher so that the entering fluid temperature to the GCHP was lower and close to that of the ground, about 25°C, the sensible capacity over the power input ratio of the GCHP would improve and reach 2.4.

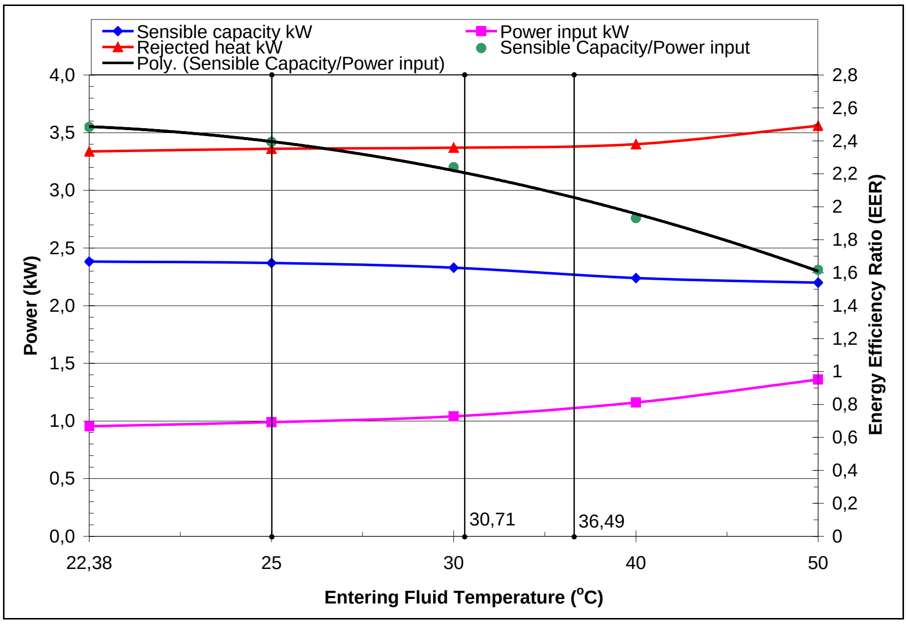


Figure 9: GCHP results for a room temperature of 23°C for a typical day early in October of 2008

Similar were the operating conditions during the experiment carried out in January. The GCHP was working periodically to satisfy the heating load, continuously during the night-time when the load was high and intermittently during the daytime where the heating requirements were less. The room temperature was about 23.0°C. When the compressor of the GCHP was in operation, the delivered air temperature was about 35°C. The temperature difference between the inlet and return fluid of the GHE was about 4°C. Figure 10, depicts the variations in the total capacity of the GCHP, the heat absorbed by the ground through the GHE and the input power to the GCHP when the range of the entering fluid temperature was between 10°C – 25°C and the entering air temperature was 23°C (room temperature). These values were calculated using the data collected during the experiments carried out in January. It also shows the calculated COP.

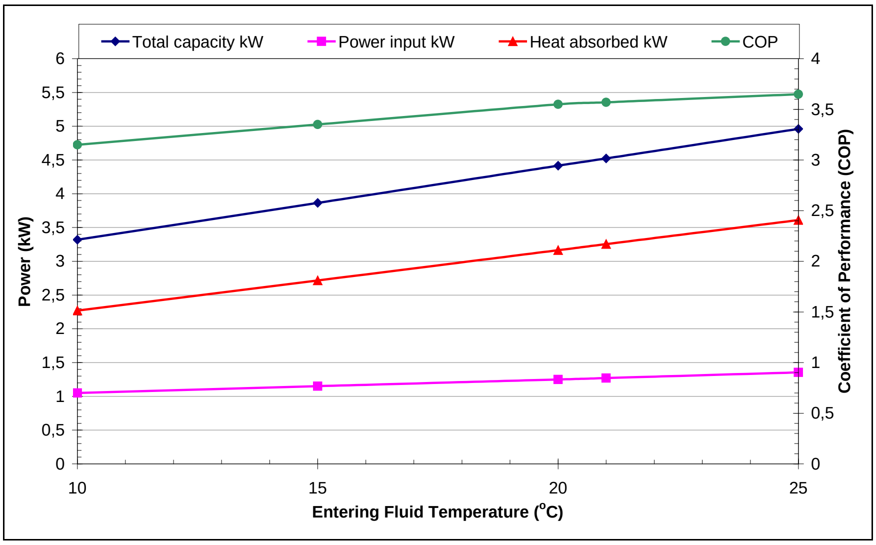
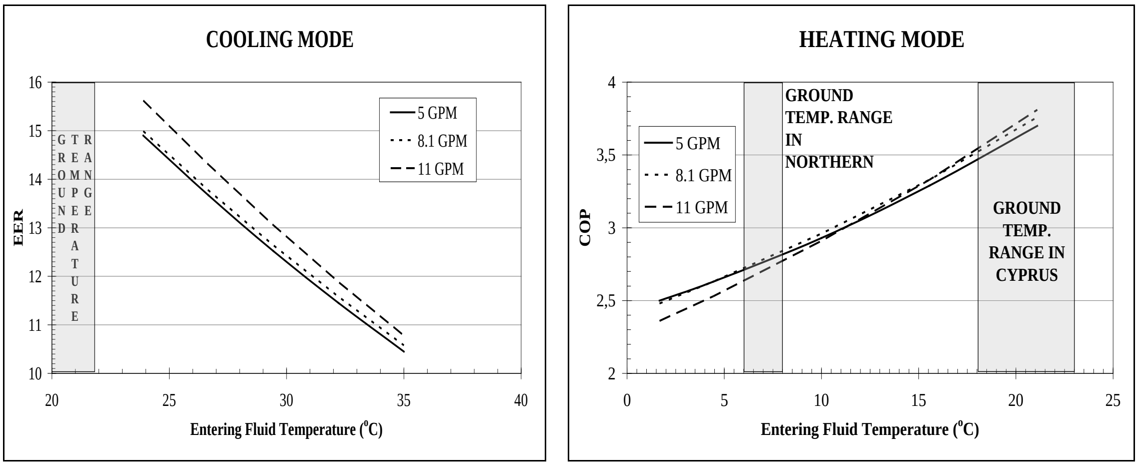


Figure 10: Heat pump results for a room temperature of 23°C for a typical day by the end of January of 2009

According to the data collected, the entering fluid temperature to the GCHP was almost constant and close to 20°C. At those conditions, the calculated COP was 3.55. According to the plot above, the COP of the GCHP would be slightly improved and reach 3.6 when the entering fluid temperature to the GCHP was close to that of the ground, about 22°C. This would occur in the case that the capacity of the GHE was higher. As shown on the graph, the COP of the pump had a small variation range of only 0.5 for an entering fluid temperature range between 10°C to 25°C.

The results of the tests showed that in summer, when the demand is for cooling load, the lower the ground temperature the higher the GCHP efficiency. Similarly in winter, when the demand is for heating load, the efficiency of the GCHP is higher when the ground temperature is as high as possible.

The effect of the ground temperature and the capacity of the GHE on the efficiency of a GCHP were further investigated. The theoretical efficiencies of three typical GCHPs with different capacities were plotted in respect to the entering fluid temperature as shown in Figure 11(a) and (b). It is clearly shown that in the cooling mode, the EER of the GCHP increases as the entering fluid temperature decreases. In this case, the lower the ground temperature, the higher the EER is. In the heating mode, the COP of the GCHP increases as the entering fluid temperature increases. It can also be seen that higher ground temperature improves the COP. Figure 11(a) and (b) also depict the range of the ground temperature measured in Cyprus and the ground temperature measured in northern Germany, Mahfouf and Viterbo, (2001).



(a) (b)

Figure 11: GCHP efficiencies in respect to the entering fluid temperature for (a) cooling mode and (b) heating mode

It is clearly shown that, provided that the same kind of heat pump is used, the ground temperature in Cyprus would ensure a higher COP for heating that the ground temperature in northern Germany. Also, the ground temperature in Cyprus is lower than the required ground temperature when cooling is needed ensuring high EER of the GCHPs. In Cyprus, steady ground temperatures unaffected by weather conditions are achieved only in the deep zone, at depths below 8 m from the ground surface. As described above, the temperature of the ground in the shallow zone is affected by seasonal variations. Therefore, vertical GHEs are expected to be more efficient and more reliable when coupled to GCHPs than the horizontal ones.

6 Summary

According to the results obtained in the 8 borehole locations in Cyprus the surface zone reaches a depth of 0.25m. The shallow zone penetrates to 7 - 8 m and there after the deep zone follows. The deep zone temperature is constant throughout the year and based on the data recorded from the 8 borehole locations is within the range of 18.3°C - 23.6°C. A temperature difference of about 5°C was recorded.

The data collected can be used by the Engineers in sizing the GHEs and clearly indicate that there is a potential for the efficient use of GCHPs in Cyprus leading to significant savings in power and in some cases in money, depending on the initial and running cost.

References

Christofides, A.C. Ksanthopoulos, S & Spyrou, S. 2009, "Εφαρμογή γεωθερμικής αντλίας θερμότητας μεταβλητης παροχής ψυκτικού μέσου (VRV) με οριζόντιο γεωεναλλάκτη" [Variable Refrigerant Volume (VRV) geothermal heat pump coupled to a horizontal ground heat exchanger] *Proceedings of the 9th National Conference for Renewable Energy Sources, Geroskipou, Cyprus*, pp. 525-532.

Florides, G. & Kalogirou, S. 2005, "Annual ground temperature measurements at various depths", 8th REHVA World Congress.

Healy, R.F. & Ugursal, V.L. 1997, "Performance and economic feasibility of ground source heat pumps in cold inmate", International Journal of Energy Research, vol. 21, no. 10, pp. 857-870.

Mahfouf, J.-. & Viterbo, P. 2001, "Land surface assimilation", ECMWF Meteorological Training Course Lecture Series, pp. 1-23.

Morgan P, 1973, "Terrestrial heat flow studies in Cyprus and Kenya", PhD thesis, Geology department, Imperial College, University of London.
Fourier Technologies Ltd. 2007, "DaqPRO user guide, 8th edition".

Pouloupatis, P.D., Florides, G. & Tassou, S. 2011, "Measurements of ground temperatures in Cyprus for ground thermal applications", *Renewable Energy*, vol. 36, no. 2, pp. 804-814

Vrachopoulos, M. 2000, *Ψυκτικές διατάξεις*, [Refrigeration configurations], ION Publishers, ISBN: 960-411-094-2.