ANNUAL GROUND TEMPERATURE MEASUREMENTS AT VARIOUS DEPTHS

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ABSTRACT

The earth temperature beyond a depth of 1 meter is usually insensitive to the diurnal cycle of air temperature and solar radiation and the annual fluctuation of the earth temperature extends to a depth of about 10 meters. In order to study the fluctuations of the ground temperature with depth we have installed a 50m deep U-tube in the ground equipped with thermocouples at various depths. The measured temperatures indicate that the short-period temperature variations are prominent to a depth of approximately 0.5 m. Because of the high thermal inertia of the soil, the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases. The annual temperature variation of the ground at a depth of 3m is between 15 to 25°C while at a depth of 25m is negligible and the temperature remains constant at about 22°C. The temperature measurements are compared to the calculated values resulting from simulations performed with TRNSYS.

KEYWORDS: Ground temperature, measurement, Kasuda formula

INTRODUCTION

Information on ground temperatures is necessary for many construction projects in Cyprus. These include the determination of the depth at which service pipes to buildings should he laid to avoid excessive heating, energy calculations such as those for determining heat losses from floors and basements and the possible use of the ground as a source for heat pump applications. Knowledge of the factors that determine ground temperatures as well as understanding of how these temperatures vary with time and depth from the surface is essential for accurate sizing of air conditioning equipment.

The ground temperature is affected by meteorological, terrain and subsurface variables. Meteorological elements such as solar radiation and air temperature influence the surface and subsurface temperature by affecting the rate at which heat is exchanged between the atmosphere and the ground. Solar radiation is probably the single most important factor. Seasonal and daily changes in solar radiation impose a cyclical variation on both air temperature and ground surface temperature. Other meteorological factors such as wind and rain can cause significant local variations.

Vegetation can provide an insulating effect, shielding the underlying ground from weather extremes that cause high rates of heat transfer to and from the atmosphere. Other terrain features such as slope orientation, can have considerable effects. In general, slopes with a southern exposure have a higher average ground temperature than north-facing slopes.

The properties of the ground that determine its response to temperature changes at the surface are volumetric heat capacity, C, thermal conductivity, K, soil latent heat and water content.

The ratio, K/Cv, known as thermal diffusivity, is important in calculating the rate of heat flow in the ground. Heat capacity, thermal conductivity and soil latent heat depend on the soil water content which is a variable property. The larger the water content, the larger the heat capacity, thermal conductivity, and latent heat. [1].

The temperature of the ground surface remains almost in phase with that of the air. Below the surface, however, the maximum or minimum occurs later than the corresponding values at the surface, the time lag increasing with depth.

In addition to an annual cycle, ground temperature undergoes both a daily cycle and a cycle associated with changes in the weather. These variations are confined to the near surface region, daily cycles penetrating about 0.5 m and weather cycles about 1 m below the surface. Daily variations are particularly important to agriculturists and are of some interest with respect to building problems.

Popiel et al. [2] presented the temperature distributions measured in the ground in Poland, for summer 1999 to spring 2001. Mihalakakou et al. [3] presented a complete model for the prediction of the daily and annual variation of ground surface temperature. The model is validated against 10 years of hourly measured temperatures for bare and short-grass covered soil in Athens and Dublin.

NUMERICAL SIMULATION

The vertical temperature distribution of the ground can be modeled based on the method developed by Kasuda who found that the temperature of the ground is a function of the time of year and the depth below the surface that can be described by the following correlation [4]:

$$T_{soil(D,tyear)} = T_{mean} - T_{amp} * \exp\left(-D\sqrt{\frac{\pi}{365*\alpha}}\right) * \cos\left(\frac{2\pi}{365}\left(t_{year} - t_{shift} - \frac{D}{2}\sqrt{\frac{365}{\pi*\alpha}}\right)\right) \quad \ldots(1)$$

where:

$T_{soil(D,tyear)}$	= Soil Temperature at depth D and Time of year
T_{mean}	= Mean surface temperature (average air temperature). The temperature of the ground at an infinite depth will be this temperature
T_{amp}	= Amplitude of surface temperature [(maximum air temperature - minimum air temperature)/2]
D	= Depth below the surface (surface=0)
α	= Thermal diffusivity of the ground (soil)
t_{year}	= current time (day)
t_{shift}	= day of the year of the minimum surface temperature

For applying the above equation for the Nicosia-Cyprus environment, the Typical Meteorological Year (TMY) data for Nicosia, developed by Petrakis et al. [5] were used. These have been generated from hourly measurements, for a seven-year period, from 1986 to 1992. The data were collected by the Meteorological Service of the Ministry of Agriculture and Natural Resources of Cyprus, at the Athalassa region, where the borehole was drilled. According to these data the time shift is 35 days, the mean surface temperature is 18.5 °C, the amplitude of the surface temperature is 21 °C with the maximum air temperature being 42 °C and a minimum 0 °C. The mean surface temperature which by definition should correspond to the temperature of the ground at an infinite depth shows a discrepancy and although it should be about 22°C as indicated by actual measurements, is only 18.5 °C as calculated from the data of the TMY.

Adjusting these variables to fit the experimental results the graph of figure 1 is obtained. As it is observed the temperature of the ground surface remains almost in phase with that of the air temperature. Below the surface, however, the maximum or minimum occurs later than the corresponding values at the surface, the time lag increasing with the depth as shown by the cosine term in Equation 1.

At a depth of 2 to 3 m the maximum ground temperature occurs about 6 months later than the average maximum temperature of the surface in summer and at a depth of about 20m the temperature is insensitive to any surface variations.

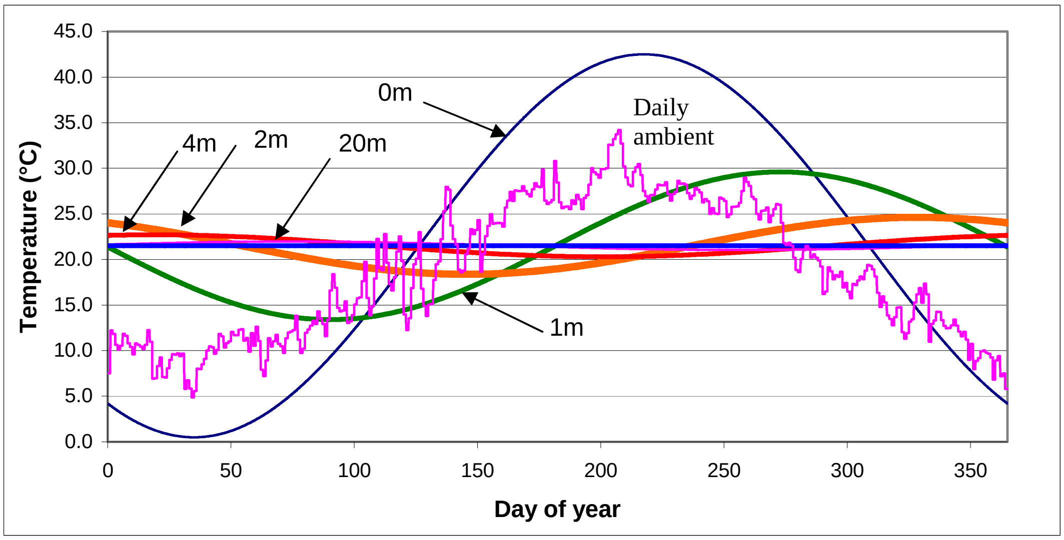

Figure 1. Temperature distribution with respect to time for various depths, calculated with the Kasuda formula for Nicosia, Cyprus.

In Cyprus, there are no studies undertaken so far related to the efficiency and cost estimation of ground heat exchanger systems and it is of interest to examine such systems in this environment. For this purpose we have installed a 50m deep U-tube, 40mm polyethylene heat exchanger, equipped with 20 thermocouples at various depths, for recording the ground temperature and exploiting the possibility for using this type of systems.

LITHOLOGY OF THE BOREHOLE AREA

The lithology prevailing over the site of the borehole is the Nicosia-Athalassa formation is represented by the calcareous sandstone and the in situ mari. In detail the geological formation is presented in [6]. The water level is about 15 meters. The discharge rate is estimated between 2 to 3 m^3/h. The water conductivity is about 2250 ms/cm.

RESULTS

Temperature measurements for the whole depth of the borehole have shown that the annual temperature cycle penetrates to a depth of 12-15 meters as shown in Fig. 2. The temperature measurements were taken on 23 December, 2004 at 12:00 noon. The temperature between 15 and 50 meters remains relatively constant at about 22°C.

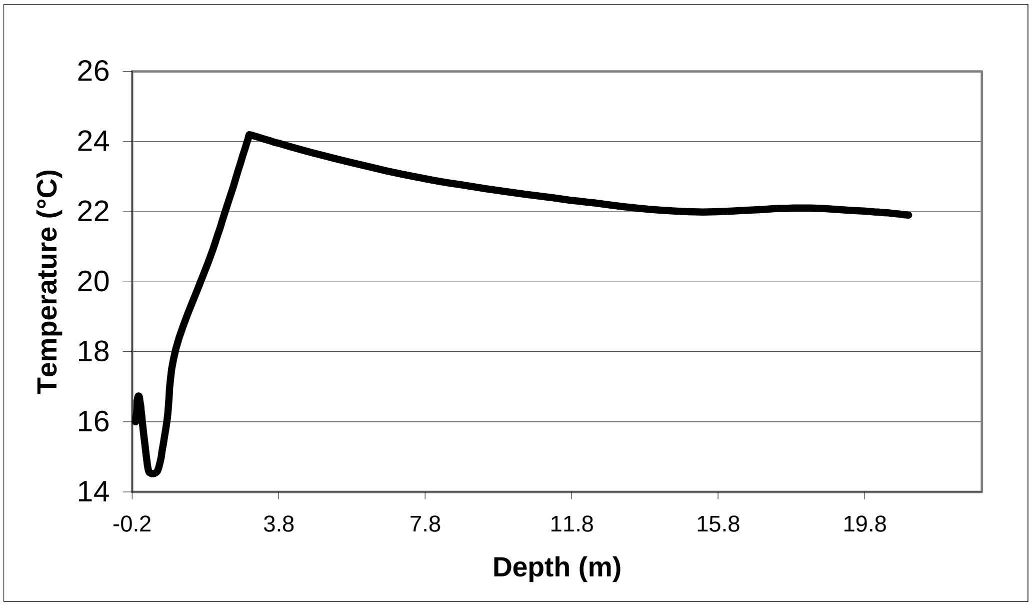

Figure 2. Temperature variation with depth for the 23 December 2004

Measurements taken during 2004, show that to a depth of 3 meters, the ground attains its lowest temperature in February and its highest in August. This is indicated in Fig. 3, where it is also observed that the soil between 2 to 3 meters starts heating up in June and starts cooling down in November ie about five to six months later that the corresponding surface changes, as predicted by the Kasuda formula (Fig. 1).

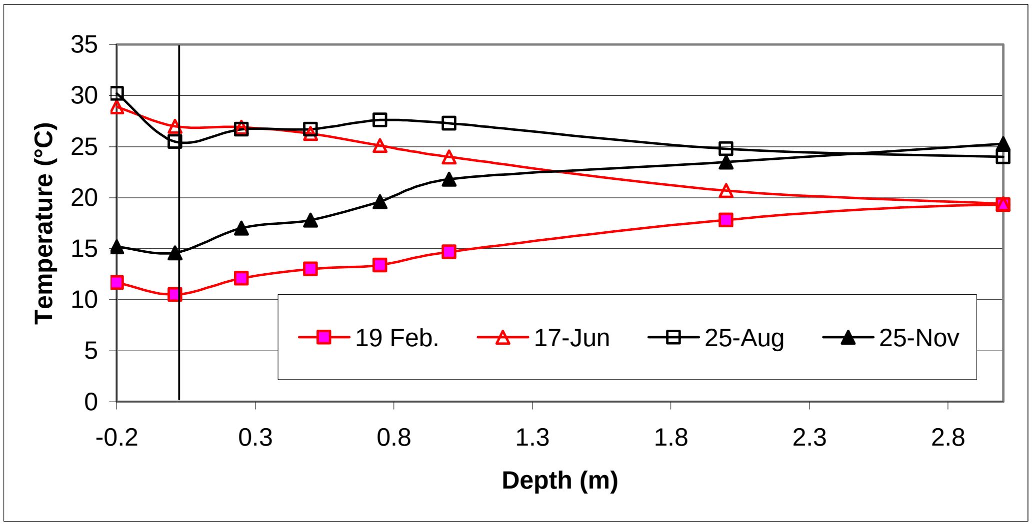

Figure 3. Temperature variation with depth for various dates at 6 am.

By plotting the measured temperatures at various depths for a whole year (Fig. 4), it is seen that at 6:00 hours, the temperature at 10 cm in the ground is between 10°C and 27°C. At a depth of three meters is obvious that there is a lag of about 160 days (5 to 6 months) between the highest surface temperature and the highest temperature at this depth. This measurement is also in alignment with the values calculated with the Kasuda formula.

Temperature variation with depth for a continuous time span, from 0:00 to24:00 on the 26 May 2004, (Fig. 5), shows that the heat penetration of the daily cycle is prominent to a depth of about 0.5 meters. This depth depends greatly on the thermal conductivity of the top soil which in this case is low therefore the depth is not expected to be large.

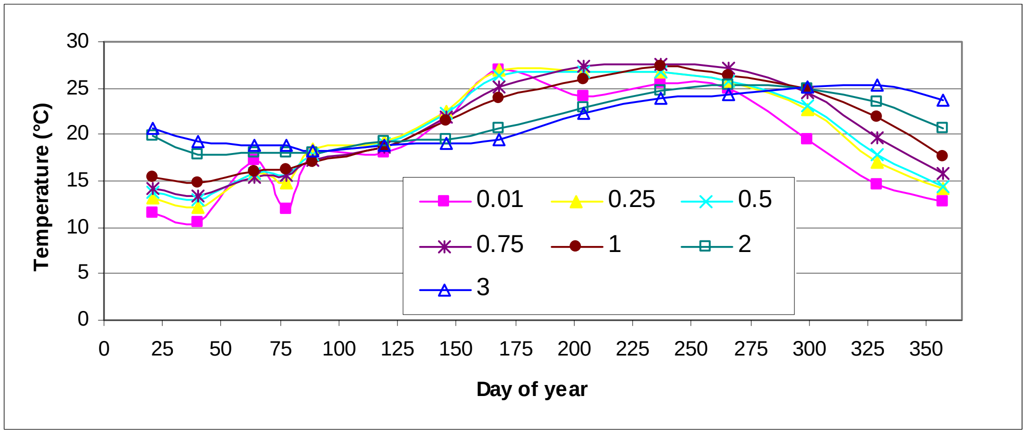

Figure 4. Ground temperature (°C) at various depths at 6:00 hours, during the year 2004

Finally, a time lag is observed between the temperature fluctuations at the surface and in the ground (Fig. 6) during a sunny day. Because of the solar radiation falling on the ground and the higher capacity of the soil relative to the ambient air, the temperature of the soil just below the surface starts getting hot at about 8 a.m. and is heated at a higher temperature (about 33°C) than the ambient air. Because of the high thermal inertia of the soil, the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases and the temperature at 0.25 m depth gets its highest value of the day at about 22:00, with a time lag of five hours compared to the maximum temperature at the depth of 0.1 meters. The daily variation below the depth of 0.25 meters is nearly negligible in this case.

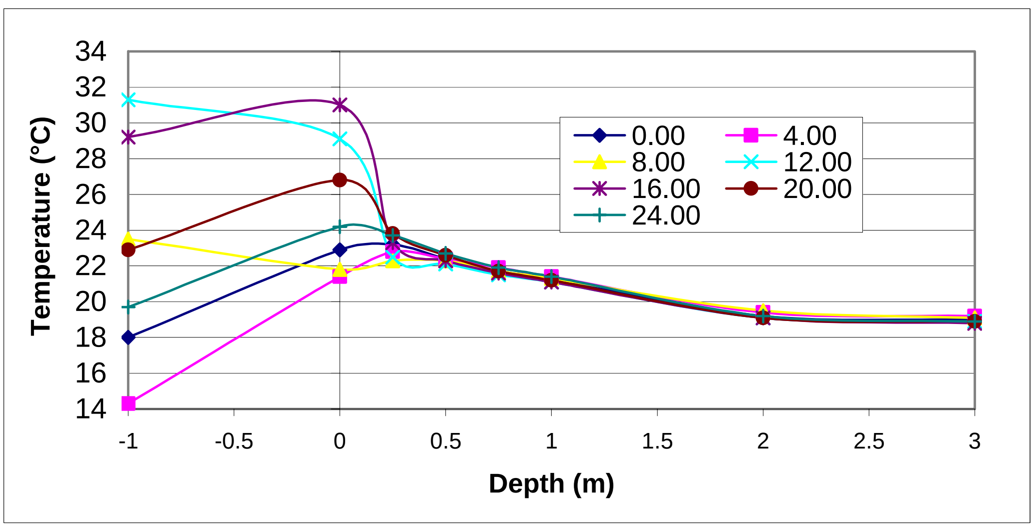

Figure 5. Temperature variation with depth and time on 26 May 2004

CONCLUSIONS

This study discusses the factors affecting ground temperature and the temperature variation with depth. It was found that the short-period temperature variations in winter are prominent to a depth of approximately 0.5 m. Because of the high thermal inertia of the soil, the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases and the temperature at 0.25 m depth gets its highest value of the day with a time lag of five hours compared to the maximum temperature at the depth of 0.1 m. The daily variation below the depth of 0.25 m is small and cannot be observed below the depth of one meter.

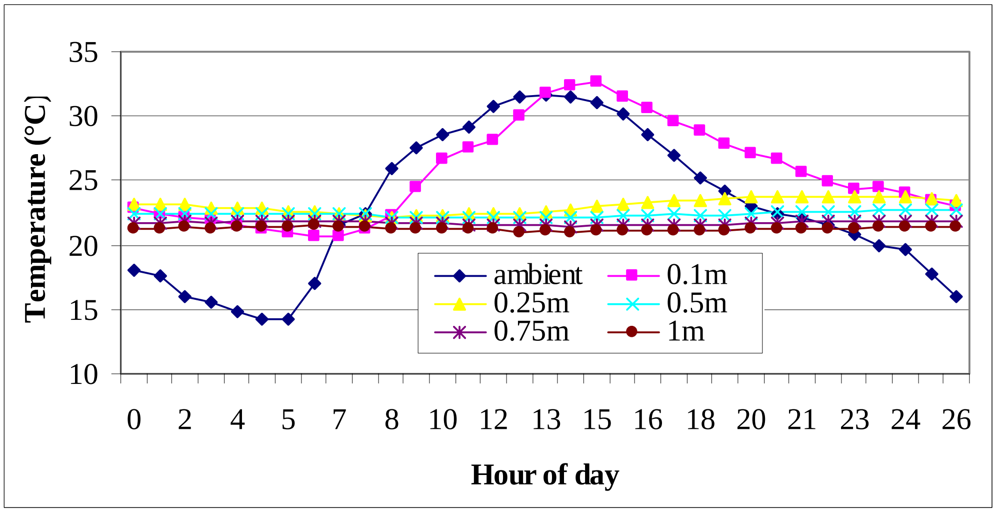

Figure 6. Time lag observed in temperature penetration for 26 May 2004.

The temperature measurements are compared to the calculated values resulting from the use of the Kasuda formula adopted by the TRNSYS program, type 501, with the results showing general agreement. The results of the numerical simulation of the ground temperature distributions may not be reliable, mainly because of difficulties of the precise determination of the physical properties of the undisturbed ground and the fact that the variation of the temperature depends greatly on the actual weather conditions and is affected by the diurnal cycle.

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