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INFLUENCE OF UPPER LAYER PROPERTIES ON THE GROUND TEMPERATURE DISTRIBUTION

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Abstract: Ground temperature distribution is crucially important for ground source heat pump applications. Ground can be composed of one or multi-layers. In this study, one and multi-layer ground temperatures were calculated numerically considering the climatic conditions of Adana-Turkey. The accuracy of the results obtained from numerical method was controlled using the ones analytically obtained for exactly the same simplifying assumptions. It was shown that the simplifying assumptions for analytical calculations were not realistic. In the numerical calculations, daily values of solar energy, relative humidity, wind velocity and ambient temperature were used for yearly calculations of ground temperature distribution. Variation of ground surface properties with the months in a year has significant effects upon temperature distribution. The depths for maximum and minimum temperatures in the ground were very different in case of multi-layered grounds existing naturally or built artificially. Above mentioned effects can be used to control ground temperature distributions in winter and summer.
Keywords: Ground temperature distribution; Ground surface properties; Multi-layer ground; Maximum-minimum temperature; Ground temperature control.

ÜST KATMAN ÖZELLİKLERİNİN TOPRAK SICAKLIĞINA ETKİSİ

Özet: Toprak sıcaklığının bilinmesi toprak kaynaklı ısı pompası uygulamaları için çok önemlidir. Toprak tek veya çoklu katmandan oluşabilir. Bu çalışmada, Adana'nın iklim verileri dikkate alınarak tek ve çok katmanlı toprak sıcaklıkları nümerik olarak hesaplanmıştır. Nümerik metottan elde edilen sonuçların doğruluğu analitik hesaplarda kullanılan basitleştirilmiş kabullerin aynısı kullanılarak elde edilen sonuçlarla kontrol edilmiştir. Analitik hesaplamalarda kullanılan basitleştirilmiş kabullerin gerçekçi olmadığı gösterilmiştir. Nümerik hesaplamalarda güneş enerjisi, bağıl nem, rüzgar hızı ve ortam sıcaklığının günlük değerleri toprak sıcaklığının yıllık hesaplamaları için kullanılmıştır. Yıl içinde aylarla toprak yüzey özelliklerini değiştirmenin toprak sıcaklık dağılımına önemli etkisi olmaktadır. Toprak içindeki maksimum ve minimum sıcaklıkların oluştuğu derinlikler doğal olarak oluşan veya suni olarak oluşturulan çok katmanlı topraklarda büyük farklılık göstermektedir. Yukarıda sözü edilen etkiler ile kış ve yaz aylarında toprak sıcaklık dağılımı kontrol edilebilmektedir.
Anahtar Kelimeler: Toprak sıcaklık dağılımı; Toprak yüzey özellikleri; Çok katmanlı toprak; Maksimum-minimum sıcaklık; Toprak sıcaklık kontrolü.

NOMENCLATURE

a_i	thermal diffusivity [m^2/s]
a_1	thermal diffusivity of the upper layer [m^2/s]
a_2	thermal diffusivity of the lower layer [m^2/s]
a_s	absorption coefficient of ground surface
f	evaporation fraction, Eq.(14)
h	heat transfer coefficient [W/m^{2}K]
h_{gl}	latent heat of evaporation [J/kg]
k_1	thermal conductivity of upper layer [W/mK]
k_2	thermal conductivity of lower layer [W/mK]
L1	upper layer depth [m]
L2	lower layer depth [m]
L	total ground depth [m]
p_a	ambient partial water vapor pressure [Pa]
p_s	surface partial water vapor pressure [Pa]
p_{sa}	saturation pressure of water vapor at ambient temperature [Pa]
p_{ss}	saturation pressure of water vapor at ground surface temperature [Pa]
$\dot{q}$	solar radiation heat flux [W/m^2]
$\dot{q}_{lw}$	long wave radiation heat flux [W/m^2]
$\dot{q}_v$	heat flux due to the water vapor evaporation, Eq.(7) [W/m^2]
R	gas constant [Pa m^3/kgK]
t	time [day]
T	temperature [^{o}C]
T_a	ambient temperature [^{o}C]
T_{end}	ground temperature at depth L [^{o}C]

T_{max} maximum temperature [^oC]
T_{min} minimum temperature [^oC]
T_s ground surface temperature [^oC]
T_{se} solar-equivalent temperature, Eq.(17) [^oC]
T_{sem} mean solar-equivalent temperature [^oC]
T_{sm} mean ground surface temperature [^oC]
u wind speed [m/s]
x soil depth [m]
β mass transfer coefficient [m/s]
φ relative humidity
ρ_a ambient partial density of water vapor [kg/m^3]
ρ_s surface partial density of water vapor [kg/m^3]

INTRODUCTION

Determination of ground surface temperature and ground temperature at different depths are very important for agricultural and ground source heat pump applications and for the calculation of heat losses from the parts of buildings that are buried in the ground. Therefore, many researches have been carried out studies for the determination of ground temperatures using analytical, numerical and experimental methods.

A simple analytical model was developed to predict annual variation of the ground temperature at the soil surface and at various depths by using long time measurements of the ground temperature values (Mihalakakou et al., 1992). A mathematical model based on heat conduction equations and the energy balance at the ground surface to predict the variation of the ground surface temperature for bare and short-grass covered soil was developed by Mihalakakou et al. (1997). Two estimation methods for modeling and estimating the daily and annual variation of soil surface temperature were presented by Mihalakakou (2002). Mathematical models based on the energy balance equation at the ground surface were developed by El-Din (1999) to predict the hourly and daily variations of the ground temperature and heat flux into the ground with depth.

In the above studies, the models were based on the energy balance equation at the ground surface and the assumption that the temperature variation at the ground surface is in the form of a Fourier series or a sine-wave. Evaporation and long wave radiation were taken into consideration. However, water saturation pressure was assumed to vary linearly with temperature and yearly mean values were used for the wind velocity.

In analytical methods, use of non-steady state ground surface properties is not possible; instead mean values are used. Therefore, numerical methods to determine ground temperatures have been applied by different researchers. A numerical model for horizontal type ground heat exchanger was developed by Piechowski (1999). A numerical model of heat conduction in order to estimate the magnitude of the heat released by freezing during the winter months was used by Beltrami (2001). A two-dimensional numerical simulation of ground-heat transfer adjacent to an experimental earth–contact structure was presented by Rees et al. (2007). A numerical model to predict the temperature of different surfaces was described by Best (1998). Crank–Nicolson implicit method was used in a surface energy balance model which is presented by Qin et al. (2002). They have then compared the simulated soil temperature with the micrometeorological measurements. Only one-layer was considered and the surface conditions were assumed to be constant in the numerical studies given above.

In this work, a numerical model was developed to predict the annual variation of ground surface temperature and ground temperatures at various depths. In the model, water saturation pressures were determined without linearization using appropriate methods. Wind velocities were taken into consideration for every single day. Numerical calculations were then carried out to determine the influence of different and non-steady state upper layer properties of two-layer ground on the temperature distribution. The variation of ground temperatures with soil surface properties can be very important for earth temperature distribution which is very important for earth coupled heat pump applications.

MATHEMATICAL MODELING

The ground was assumed to consist of two different homogeneous layers as shown in Fig. 1.

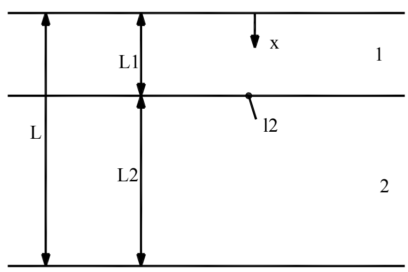

Figure 1. Two-layer ground.

Fourier differential equation is valid for the first and the second layers:

$$\frac{\partial T}{\partial t} = a_i \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where a_i is the thermal diffusivity of the upper and lower layers (a_1 and a_2).

The boundary conditions at x=L1 and x=L are:

$$x=L1 \quad : \quad k_1\left(\frac{dT}{dx}\right)_1 = k_2\left(\frac{dT}{dx}\right)_2 \tag{2}$$

$$x=L \quad : \quad \frac{dT}{dx} = 0 \tag{3}$$

L was chosen so deep, that Eq. (3) is valid. k_1 and k_2 are thermal conductivities of the upper and lower layers, respectively. The following equation can be written at the surface of the ground (Mihalakakou et al., 1997; Mihalakakou, 2002 and El-Din, 1999):

$$x = 0 \quad : \; -k_1\left(\frac{\partial T}{\partial x}\right) = h\,(T_a - T_s) + a_s\dot{q} - \dot{q}_{lw} - \dot{q}_v \qquad (4)$$

Here, h is the heat transfer coefficient between ground surface and ambient. T_a and T_s are ambient air and ground surface temperatures, respectively. a_s is the surface absorption coefficient and $\dot{q}$ is solar radiation heat flux. $\dot{q}_{lw}$ is long wave radiation heat flux and $\dot{q}_v$ is the heat flux due to the water vapor evaporation from the ground surface.

Convective heat transfer coefficient can be determined with El-Din (1999):

$$h = 2.8 + 3\,u \qquad (5)$$

where u is wind velocity.

According to ASHRAE (2003) one can assume:

$$\dot{q}_{lw} = 63\ \mathrm{W/m^2} \qquad (6)$$

For the determination of $\dot{q}_v$, the following equation can be used:

$$\dot{q}_v = \beta\, h_{gl}\,(\rho_s - \rho_a) = \frac{\beta\, h_{gl}\,(p_s - p_a)}{R\,T} \qquad (7)$$

where β is mass transfer coefficient. ρ_s and ρ_a are surface and ambient partial densities of water vapor, respectively. p_s and p_a are partial water vapor pressures at the surface and ambient, respectively. h_{gl} is latent heat of evaporation and R is gas constant.

Because mass transfer coefficient can be assumed proportional to heat transfer coefficient, the following equation is given for $\dot{q}_v$ (Mihalakakou et al., 1997):

$$\dot{q}_v = 0.0168\,f\ h\,(p_{ss} - \varphi\, p_{sa}) \qquad (8)$$

where p_{ss} and p_{sa} are saturation pressures of water vapor at the ground surface and at ambient conditions, respectively. f is a factor for water evaporation at the ground surface and it is dependent on climatic conditions and ground properties (Mihalakakou et al., 1997).

The saturation pressure data given in ASHRAE (2003) can be described by the following equations (First Development Report, 2008) for different temperature ranges:

$$0\text{-}30\ °C \;:\quad p_s = 288.68\left(1.098 + \frac{T_s}{100}\right)^{8.024} \qquad (9)$$

$$30\text{-}60\ °C \;:\quad p_s = 975.29\left(0.9303 + \frac{T_s}{100}\right)^{7.094} \qquad (10)$$

For the linearization of the relationships (9) and (10), the following linear equation was used in the numerical calculations;

$$p_s = A_p T + B_p \qquad (11)$$

where A_p and B_p were determined from the following equations:

$$A_p = \frac{p_{sa} - p_{ss}}{T_a - T_s} \qquad (12)$$

$$B_p = p_{sa} - A_p\,T_a \qquad (13)$$

In the numerical calculations carried out in this study, A_p and B_p were determined for each day. In analytical calculations A_p and B_p are taken constant for the whole year. Using above equations and the equation

$$C_v = 0.0168\ f \qquad (14)$$

Eq. (15) is yielded from Eq. (8):

$$\dot{q}_v = C_v\,h\,\left[A_p\,T_s - \varphi A_p\,T_a + B_p(1-\varphi)\right] \qquad (15)$$

In Eq.(15), φ is the relative humidity of the ambient air. Eq.(4) can be rewritten then as:

$$x{=}0 \quad : \quad -k_1\left(\frac{\partial T}{\partial x}\right) = h_c\,(T_{se} - T_s) \qquad (16)$$

where

$$h_c = h\,(1 + C_v\,A_p)$$

$$T_{se} = \frac{\left[h\,(1 + C_v\,A_p\,\varphi)\,T_a + a_s\dot{q} - \dot{q}_{lw} - C_v\,B_p\,h\,(1-\varphi)\right]}{h_c} \qquad (17)$$

Periodic solution of the temperature was used as initial boundary condition.

ANALYTICAL METHOD

When the ambient temperature is defined as sinus function; Eqs. (1), (3) and (4) can be solved analytically. Such a solution was obtained by El-Din (1999).

Temperature distribution in the soil can be expressed as a function of time and x axis as follows:

$$T(T,x) = T_{sm} + \Delta T_s \exp(-x^*)\,\mathrm{Sin}\left(2\pi t^* - x^* + \phi_s\right) \qquad (18)$$

Soil surface temperature can be written:

$$T_s(T) = T_{sm} + \Delta T_s \, \mathrm{Sin}\left(2\pi \, t^* + \phi_s\right) \quad (19)$$

In the above equations, t* and x* are defined as follows;

$$t^* = \frac{t}{t_o} \qquad x^* = \frac{x}{x_o} \quad (20)$$

where t_o is 365 days and x_o can be written in the form of

$$x_o = \left(\frac{a_i \, t_o}{\pi}\right)^{1/2} \quad (21)$$

Solar-equivalent temperature must be expressed as follows:

$$T_{se}(T) = T_{sem} + \Delta T_{se} \, \mathrm{Sin}\left(2\pi \, t^* + \phi_{se}\right) \quad (22)$$

T_{sem}, ΔT_{se} and ϕ_{se} coefficients in the above equation must be determined with a suitable curve-fitting method by using daily T_{se} values calculated from Eq. (17).

Different curve-fitting methods were tested in this study, and it was found that the Rosenbrock method is the most suitable method in obtaining T_{sem}, ΔT_{se} and ϕ_{se} coefficients.

T_{sm} , ΔT_s and ϕ_s values in Eq. (18) should be calculated from the equations below, respectively;

$$T_{sm} = T_{sem} \quad (23)$$

$$\Delta T_s = \Delta T_{se}\left[(1+\mu)^2 + \mu^2\right]^{-1/2} \quad (24)$$

$$\phi_s = \tan^{-1}\left[\frac{(1+\mu)^2 \tan\phi_{se} - \mu}{(1+\mu) + \mu \tan\phi_{se}}\right] \quad (25)$$

where μ is defined as:

$$\mu = \frac{k}{h \, x_o} \quad (26)$$

It is clear that, the annual average value of h must be used in the analytical method. h was calculated from Eq.(5) by using annual average value of wind velocity.

NUMERICAL METHOD

Finite difference method was applied for the numerical calculations. Because the values of A_p and B_p in Eqs. (12) and (13) are dependent on the surface temperature, the temperatures should be calculated iteratively. Yearly periodic solutions were obtained after approximately 12 years. Using yearly mean velocities and assuming yearly constant A_p and B_p values, numerically obtained results for one layer ground can be compared with the analytical ones to check the accuracy of the numerical values. Under this simplified conditions, it was found that the numerically obtained values are very close to the analytical ones. Therefore, it can be concluded that the numerical results obtained without utilizing simplifying assumptions are also correct. The numerical method and its comparisons were described in detail elsewhere First and Second Development Reports (2008). Table 1 shows the parameters used in the analytical and the numerical calculations.

RESULTS

The results given in this work were obtained using 20 years daily mean values of T_a, $\dot{q}$, φ and u for Adana/Turkey. Daily mean values were calculated using the data measured during 20 years by The State Meteorological Affairs General Directorate (DMİ).

Comparison of Numerical and Analytical Results

To check the accuracy of the numerical approach developed in this study, numerical calculations were first carried out with the same simplifying assumptions as made for analytical solutions, such as yearly constant values for wind velocity and yearly constant values of A_p and B_p in Eq. (17). When the results of the analytical (a) and the numerical (b) solutions are compared, it is seen that both methods produce the same results as can be seen from Fig. 2. From this figure, it can be concluded that the numerical method utilized is capable of producing accurate results for the prediction of ground temperatures. For the whole year A_p=103 Pa/^{o}C, B_p=609 Pa and u=1.29 m/s were used both in analytical and numerical calculations. Curve c in Fig. 2 was obtained numerically with constant A_p and B_p values; however, daily values of the velocity were used. When obtaining curve d, daily values were used for A_p, B_p and u. As can be seen from the comparison of the curves a, b, c and d, variation of the parameters A_p, B_p and u has considerable affects on ground surface temperatures,

Table 1. Parameters used in analytical and numerical calculations.

Parameters used in analytical calculations	Parameters used in numerical calculations
- Yearly mean value of h was used by using yearly mean value of u from Eq. (5)	- Daily value of h was used by using daily mean value of u from Eq. (5)
- A_p and B_p values in Eq. (17) were taken constant for the whole year	- A_p and B_p values in Eq. (17) were determined from Eqs. (12,13) for each day
- T_{se} values calculated from Eq. (17) were defined as sinus function in Eq. (22)	- T_{se} values calculated from Eq. (17) were used directly in the calculations

especially between the days 120 and 270. Therefore, it is clear that numerical calculations performed till 5 °C which allow daily use of variables A_p, B_p and u, should be carried out in order to predict ground temperatures accurately. Detailed information for the accuracy of the numerical calculations is given elsewhere First Development Report (2008).

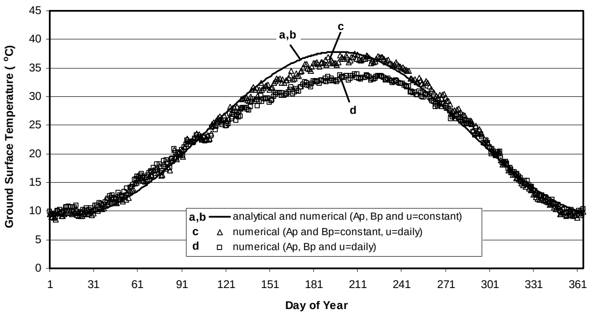

Figure 2. Comparison of analytical and numerical results, (k=1.142 W/mK, a=0.02186 m^2/day, a_s=0.9, f=0.45, L=10 m).

Results for Non-Steady State Absorption Coefficient

In this part of the study, the effect of absorption coefficient was analyzed. For the variation of the absorption coefficient, the upper layer was assumed only 5 mm thick. The upper layer has the same properties with the lower layer, but the absorption coefficient a_s varies. Different values of a_s were assumed for heating and cooling seasons. The upper layer is considered as an artificial cover for the control of ground temperature.

Heating season in Adana lasts approximately 5 months between November 10 and April 10. Cooling season can be assumed between May 10 and October 10. One month period between heating and cooling seasons is the time with no needs for either heating or cooling.

In Figs. 3 and 4, numerical results for temperature distribution for the days January 01 and July 01 are shown respectively. In these figures, the only varied parameter is a_s. The value of a_s was varied between 0.6 to 0.9 in the cooling season and it was taken constant (0.9) in the remaining time which is the time between October 10 and May 10. The ground temperature decreases with the decrease of a_s at a certain depth. As can be seen from the figures, ground temperature varies with the depth. The maximum and the minimum ground temperature occur at the same depth (3.34 m) for all cases in January 01 and July 01, respectively. After this depth, the variation is trivial. The end temperature can be considered as to be arrived at 7 m below ground surface.

The value of a_s affects the ground temperature at all depths both in heating and cooling seasons. With the increase of a_s, ground temperatures at all levels increase. This is because of the fact that more heat is absorbed by the ground surface from the solar energy.

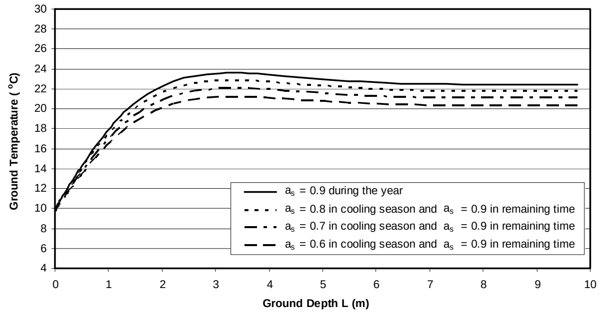

Figure 3. Variation of ground temperature with ground depth for different absorption coefficients for January 01, (k_1=k_2= 1.142 W/mK, a_1=a_2=0.02186 m^2/day, f=0.45, L1=0.005 m, L2=10 m).

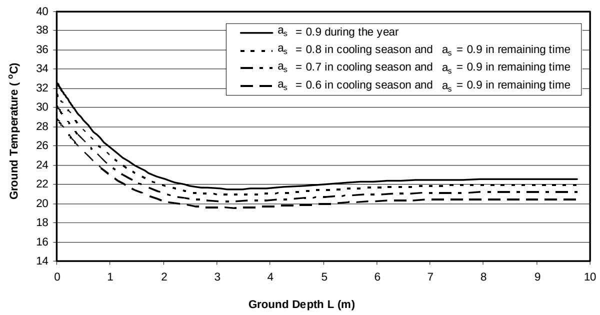

Figure 4. Variation of ground temperature with ground depth for different absorption coefficients for July 01, (k_1=k_2=1.142 W/mK, a_1=a_2=0.02186 m^2/day, f=0.45, L1=0.005 m, L2=10 m).

The variation of the maximum (T_{max}), minimum (T_{min}), end (T_{end}) and surface (T_s) temperatures were derived from Figs. 3 and 4 and shown in Tables 2 and 3. In the tables, the results obtained with the constant a_s values during the year are also included. T_{end} is defined as the temperature 10 m below from the ground surface. Variation of T_s and T_{end} with a_s are shown in Figs. 5-6, respectively.

Maximum and minimum temperatures can approximately be considered as the working temperatures for ground heat exchangers in heating and cooling seasons, respectively. It can be seen from Tables 2 and 3 that by increasing a_s value from 0.6 to 0.9, maximum temperature can be increased from 21.2°C to 23.6°C. However, in cooling season a low a_s value should be preferred. Decreasing a_s value from 0.9 down to 0.6, minimum temperature decreases from 21.5 °C down to 19.6°C. The maximum effect of varying a_s between 0.6 and 0.9 is 2.4 °C on the maximum temperature (Table 2) and 1.9 °C on the minimum temperature (Table 3), if a_s is variable in cooling season and a_s=0.9 in the remaining time. From these explanations one can conclude that maximum and minimum temperatures are sensitive to the seasonal variations of a_s values.

Table 2. Surface, maximum and end temperatures for January 01.

	a_s values in cooling season (a_s = 0.9 in remaining time)				a_s is constant during the year			
	0.9	**0.8**	**0.7**	**0.6**	**0.9**	**0.8**	**0.7**	**0.6**
Maximum Temperature, T_{max} (°C)	23.59	22.87	22.07	21.24	23.59	22,53	21.38	20.19
The depth of maximum temperature, (m)	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
Temperature at L=L1+L2, T_{end} (°C)	22.41	21.82	21.10	20.35	22.41	21.41	20.27	19.09
Surface Temperature, T_s (°C)	9.88	9.83	9.77	9.72	9.88	9.13	8.37	7.59

Table 3. Surface, minimum and end temperatures for July 01.

	a_s values in cooling season (a_s = 0.9 in remaining time)				a_s is constant during the year			
	0.9	**0.8**	**0.7**	**0.6**	**0.9**	**0.8**	**0.7**	**0.6**
Minimum Temperature, T_{min} (°C)	21.50	20.91	20.25	19.56	21.50	20.44	19.30	18.11
The depth of minimum temperature (m)	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
Temperature at L=L1+L2, T_{end} (°C)	22.52	21.90	21.18	20.42	22.52	21.50	20.36	19.18
Surface Temperature, T_s (°C)	32.59	31.40	30.16	28.86	32.59	31.39	30.13	28.81

As can be seen from Fig. 5, ground surface temperatures increase as expected with increasing a_s for the case of constant a_s (0.9) during the year for January 01. However, variation is negligible in the case of different a_s in cooling season. It is seen that for the surface temperature on January 01, the a_s values in heating season is important, whereas a_s values in cooling season are not important.

The same ground surface temperatures were obtained for July 01 in Fig. 5, since a_s values are the same (0.9) for the cooling season.

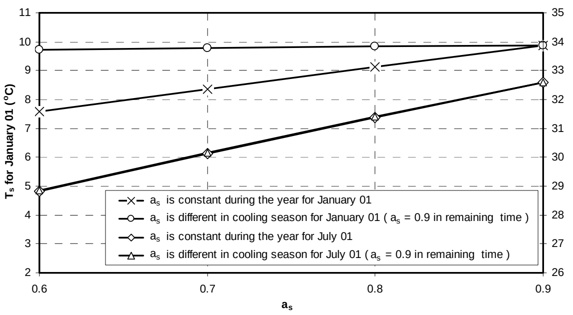

Figure 5. Variation of ground surface temperature with absorption coefficient for January 01 and July 01, (k_1=k_2=1.142 W/mK, a_1=a_2=0.02186 m^2/day, f=0.45, L1=0.005 m, L2=10 m).

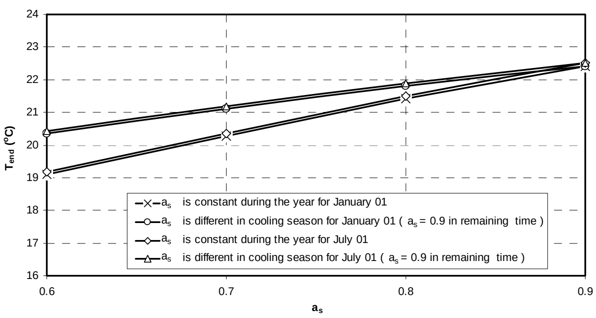

Figure 6. Variation of end temperature with absorption coefficient for January 01 and July 01, (k_1=k_2=1.142 W/mK, a_1=a_2=0.02186 m^2/day, f=0.45, L1=0.005 m, L2=10 m).

It can be seen from Fig. 6 that increase of a_s value results in higher end temperatures both for constant a_s during the year and for variable a_s in cooling season. Comparison of end temperatures in January 01 and July 01 reveals that they are very close to each other. As seen in this figure and in Table 2 and 3, the end temperatures can be influenced by seasonal variation of a_s values.

Results for Different Soil Types

In Table 4, some properties are given for commonly encountered soil types. In this part of the study, influence of different soil types on temperature distributions is given. The analysis was carried out for f=0.45, which can be considered as the average soil condition for the Çukurova Region of Turkey.

Table 4. Thermal properties of some soil types.

Soil Type	a [mm^2/s]	k [W/m°C]
Siliceous ground	0.139	0.52
Humid-heavy ground	0.648	1.3
Dry-heavy ground	0.521	0.95
Humid-light ground	0.555	0.87

In Figs. 7 and 8, temperature distributions for different types of upper layers and humid-heavy lower layer for January 01 and July 01 are demonstrated, respectively. One can see from these figures that, properties of 0.5 m thick upper layer have slight influence on the temperature distributions. However, siliceous upper layer differs slightly from the others. The maximum temperature difference between the siliceous and the others is approximately 3 °C. A kink point is noticeable at the interface between the upper and lower layers. The kink point is obtained the temperature gradient at the interface between upper and lower layer must be different from each other according to the boundary condition given in Eq.(2).

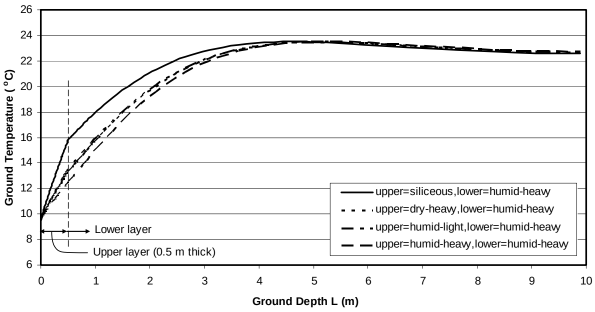

Figure 7. Variation of ground temperature with ground depth for different upper layers for January 01, (f=0.45, as=0.9, L1=0.5 m, L2=10 m).

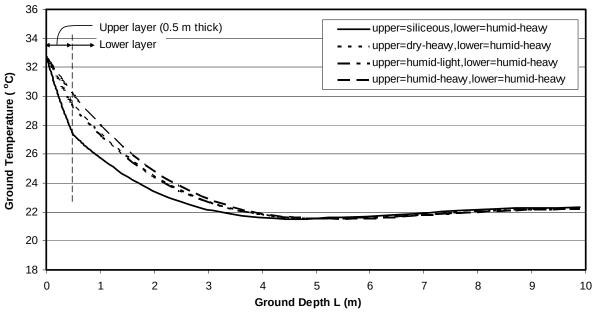

Figure 8. Variation of ground temperature with ground depth for different types of upper layers for July 01, (f=0.45, as=0.9, L1=0.5 m, L2=10 m).

In Figs. 9 and 10, temperature distributions for different types of lower layers and humid-heavy upper layer are demonstrated. The arguments made for Figs. 7-8 are also valid. It is seen from the figures that, temperature distribution for siliceous lower layer ground is very different than the other three ground types. The depths of maximum and minimum temperatures are decreased considerably. The temperature difference between different upper and lower layers but humid-heavy siliceous layer is not more than 0.1 ^{o}C. The temperature difference between humid-heavy and other layers can be as high as 3.98 ^{o}C in January 01 (Fig. 9) and 2.91 ^{o}C in July 01 (Fig. 10).

Location of siliceous layer (upper or lower) changes usual temperature distribution in the ground considerably. As can be seen from Table 4, both thermal diffusivity a and thermal conductivity k of the siliceous layer are much less than those of other soil types.

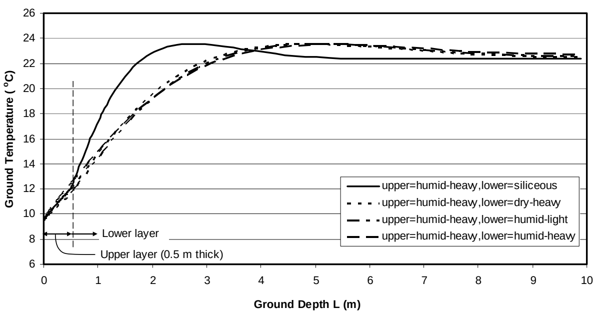

Figure 9. Variation of ground temperature with ground depth for different types of lower layers for January 01, (f=0.45, as=0.9, L1=0.5 m, L2=10 m).

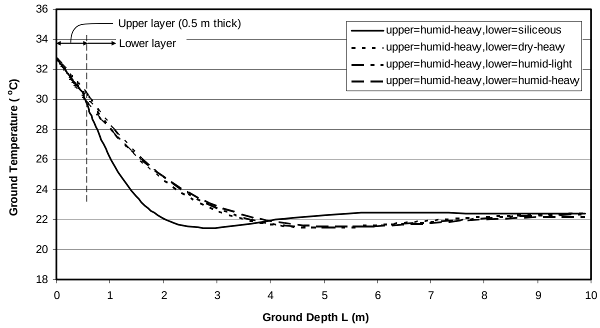

Figure 10. Variation of ground temperature with ground depth for different types of lower layers for July 01, (f=0.45, as=0.9, L1=0.5 m, L2=10 m).

Results for No Evaporation Condition

If the ground surface is covered with a thin impermeable layer such as linoleum, there will be no evaporation from the ground surface and the value of f will be zero. Temperature distributions for different types of upper layers and humid-heavy lower layer are demonstrated in Figs. 11 and 12. Since there is no water evaporation from ground to the atmosphere, surface and ground temperatures will be higher than f=0.45 case (Figs.7-10) as seen in these figures.

The difference between the surface temperatures for f=0.0 and f=0.45 is 3.12 ^{o}C for January 01 (Fig. 7 and Fig. 11) and 17.83 ^{o}C for July 01 (Fig. 8 and Fig. 12). The end temperature differences are 11.12 ^{o}C in for both January 01 and July 01. These values show the strong influence of f on the temperatures.

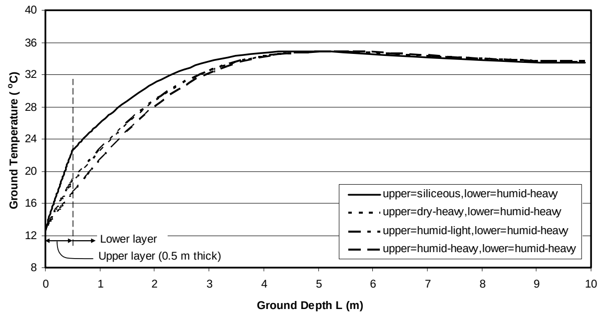

Figure 11. Variation of ground temperature with ground depth for different types of upper layers for January 01, (f=0.0, as=0.9, L1=0.5 m, L2=10 m).

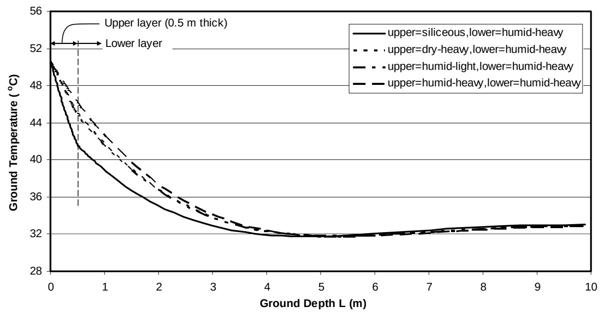

Figure 12. Variation of ground temperature with ground depth for different types of upper layers for July 01, (f=0.0, as=0.9, L1=0.5 m, L2=10 m).

Temperature distributions for different types of lower layers and humid-heavy upper layer are demonstrated in Figs. 13 and 14. Similar to the previous cases given in Figs.11 and 12, surface and ground temperatures are also higher than f=0.45 case (Figs. 7-10). The depths for minimum and maximum temperatures are considerably different than the others for lower siliceous ground layer.

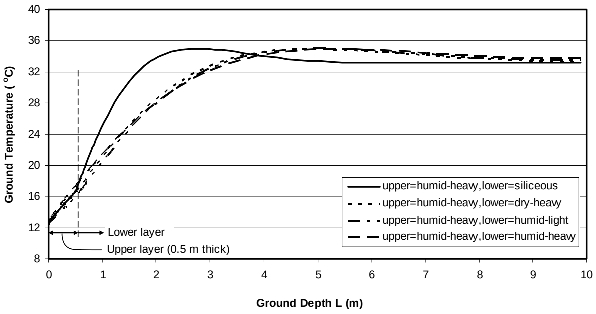

Figure 13. Variation of ground temperature with ground depth for different types of lower layers for January 01, (f=0.0, a_s=0.9, L1=0.5 m, L2=10 m).

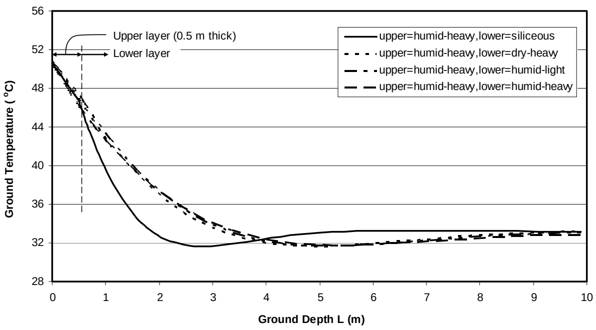

Figure 14. Variation of ground temperature with ground depth for different types of lower layers for July 01, (f=0.0, as=0.9, L1=0.5 m, L2=10 m).

Analysis of Figs. 7-14 shows that ground temperature can be artificially changed for different applications such as agricultural and ground source heat pump applications by alteration of upper/lower layers and controlling the evaporation from the surface.

CONCLUSIONS

Temperature distribution in the ground can only be calculated accurately using numerical methods. The seasonal change in surface properties can influence considerably the maximum and minimum temperatures in the ground. The alterations of the properties of the upper and lower layers of the ground change the depth below the ground surface at which maximum and minimum temperatures occur which are seen in winter and in summer period, respectively. The calculations prove that the ground temperatures can be influenced through artificial alteration of surface properties and/or upper/lower layer properties of the ground as a heat storage means for heating and cooling. Soil temperature distribution can be altered by the upper or lower layers such as siliceous soil.

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