

**ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES**

PhD THESIS

Arif ÖZBEK

**DETERMINATION OF SOIL TEMPERATURES FOR ONE OR MULTI
LAYER SOILS**

DEPARTMENT OF MECHANICAL ENGINEERING

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DEPARTMENT OF MECHANICAL ENGINEERING

We certify that the thesis titled above was reviewed and approved for the award of degree of the Doctor of Philosophy by the board of jury on 06/05/2011.

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ABSTRACT

PhD THESIS

DETERMINATION OF SOIL TEMPERATURES FOR ONE OR MULTI LAYER SOILS

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**ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF MECHANICAL ENGINEERING**

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Ground surface temperatures and ground temperatures at different depths are required for the design of Ground-Source Heat Pump (GSHP) systems. The State Meteorological Affairs General Directorate (DMİ) measures the ground temperatures at certain depths at some stations in Turkey. However, these measurements are valid only for the ground structures and properties at the measurement locations and, therefore, can not be used for other ground types.

In this study, ground surface temperatures and ground temperatures at certain depths were calculated numerically using implicit alternating directions method for multi layered and different types of ground structures and properties by utilizing the climatic parameters such as ambient air temperature, relative humidity, solar radiation and wind speed that are measured by DMİ.

Key Words: Ground temperature distribution; Ground surface properties; Multi-layer Ground; Ground temperature control

ÖZ

DOKTORA TEZİ

**TEK VE ÇOK KATMANDAN OLUŞAN TOPRAKLARDA
TOPRAK SICAKLIĞININ BELİRLENMESİ**

Arif ÖZBEK

**ÇUKUROVA ÜNİVERSİTESİ
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Toprak yüzeyi ve farklı derinliklerdeki toprak sıcaklıkları toprak kaynaklı ısı pompalarının (TKIP) tasarımında çok önemlidir. Devlet Meteoroloji İşleri Genel Müdürlüğü (DMİ) Türkiye’deki bazı istasyonlarda ve belirli toprak derinliklerinde ölçüm yapmaktadır. Bu ölçümler ölçüm yapılan yerdeki toprağın yapısı ve fiziksel özellikleri için geçerlidir ve diğer toprak türleri için kullanılamazlar.

Bu çalışmada, çok katmanlı toprak için toprak yüzeyi ve belirli derinliklerdeki toprak sıcaklıkları implisit değişken yönler yöntemi kullanarak nümerik olarak hesaplanmıştır. Hesaplamalarda DMİ tarafından ölçülen hava sıcaklığı, bağıl nem, güneş radyasyonu ve rüzgar hızı gibi iklim verileri kullanılmıştır.

Anahtar Kelimeler: Toprak sıcaklık dağılımı; Toprak yüzey özellikleri; Çok katmanlı toprak; Toprak sıcaklık kontrolü

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NOMENCLATURE

a, 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
h	: Heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
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]
L_1	: Upper layer depth [m]
L_2	: 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 [W/m^2]
R	: Gas constant [$\text{Pa m}^3/\text{kgK}$]
t	: Time [day]
T	: Temperature [$^{\circ}\text{C}$]
T_a	: Ambient temperature [$^{\circ}\text{C}$]
T_{end}	: Ground temperature at depth L [$^{\circ}\text{C}$]
T_{max}	: Maximum temperature [$^{\circ}\text{C}$]
T_{min}	: Minimum temperature [$^{\circ}\text{C}$]
T_s	: Ground surface temperature [$^{\circ}\text{C}$]
T_{se}	: Solar-equivalent temperature [$^{\circ}\text{C}$]

T_{sem} : Mean solar-equivalent temperature [$^{\circ}\text{C}$]
 T_{sm} : Mean ground surface temperature [$^{\circ}\text{C}$]
 u : Wind speed [m/s]
 x : Ground depth [m]

Greek letters

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]

1. INTRODUCTION

Ground surface temperatures and ground temperatures at different depths are required for the design of Ground-Source Heat Pump (GSHP) systems. The State Meteorological Affairs General Directorate (DMI) measures the ground temperatures at certain depths at some stations in Turkey. However, these measurements are valid only for the ground structures and properties at the measurement locations and, therefore, can not be used for other ground and ground surface properties.

Ground temperatures at certain depths can be calculated analytically for one layer homogenous ground type. But in this case assumptions must be made which are not very realistic. In Turkey, ground surface temperatures are neither measured nor calculated although there are places that these measurements and calculations are performed in the world.

There has been no study for the multi-layer ground structures in the open literature.

In this study, ground surface temperatures and ground temperatures at certain depths were calculated numerically using implicit alternating directions method for multi layered and different types of ground structures and properties by utilizing the climatic parameters such as ambient air temperature, relative humidity, solar radiation and wind speed that are measured by DMI.

2. LITERATURE REVIEW

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 for the determination of ground temperatures using analytical, numerical and experimental methods.

2.1. Literature Review for Analytical Studies

A number of analytic studies have been carried out about ground temperature. Some selected studies are given below.

El-Din (1999) has developed mathematical models based on the energy balance equation at the ground surface to predict the hourly and daily variations of the ground temperature and heat flux into the ground with depth. The energy balance equation involves the periodic variation of solar radiation, atmospheric temperature and the latent heat flux due to evaporation. He has derived the heat flux into the ground and calculated the damping depth and the corresponding ground temperature. Furthermore, the depth at which the temperature fluctuations damped has been calculated. He has performed the all calculations for hourly and monthly variations.

Mihalakakou et al. (1997) have used a mathematical model based on heat conduction equations and on the energy balance at the ground surface to predict the variation of the ground surface temperature for bare and short-grass covered ground. Their model has been compared with models using Fourier analysis for the prediction of ground temperature at the surface and at various depths. A sensitivity investigation of the ground surface temperature to different energy balance factors has been performed for both bare and short-grass covered ground.

Mihalakakou et al. (1992) have developed a simple model for the prediction of the annual and diurnal variation of the surface temperature of bare and short-grass-covered grounds. They have also analyzed the variation of the ground temperature

with depth as well as the corresponding time lag and the ratio of the temperature range at a certain depth to the temperature range at the ground surface and proposed appropriate algorithms. Finally, the results of the analysis have been compared with the corresponding data from other known measurements.

Ghosal et al. (2004) have presented a model to predict daily and monthly variations of ground temperature with depths under greenhouse and bare surface conditions. They have compared the recorded experimental ground temperature data with the predicted values.

Kang et al. (2000) have developed a robust and easily parameterized model for estimating spatial ground temperature by taking into account thermal damping ratio and solar radiation interception by forest canopy and ground litter.

Camillo (1989) has presented a model for temperature and heat flux profiles in a homogeneous ground. He has designed the model to predict diurnal ground surface temperature and heat flux from data measured below the surface. He has used a surface ground heat flux model to derive analytical expressions and tested his model on two bare grounds and one vegetated ground.

Thorn et al. (1999) have developed a statistical relationship between daily and monthly air and shallow-ground temperatures in Sweden.

Alvenas and Jansson (1997) have presented a model for predicting ground surface temperature and ground evaporation. They have compared the measured and simulated temperatures.

Elimoel et al. (2004) have designed the exponential-sinusoidal one-dimensional analytical model to describe ground temperature profile. They have compared the temperature predictions obtained from the novel and from the usual analytical solution.

Dardo et al. (2001) have developed a model based on an electrical analogy between a ground column and an electrical transmission line to predict temperature and heat flow as functions of depth and time in a sandy ground. They have defined a simple transfer function between solar radiation and ground temperature at depth of 1 cm used to calculate hourly ground temperature profiles. They have compared the modeled data with experimental data.

Padron et al. (2002) have improved a model to predict surface temperatures in both the dry sand case and wet sand case. Thus, they have found the heat and moisture transfer mechanism above a buried object in sand and the changes in surface temperature during drying process of the sand.

Spichak (2006) have proposed a method for predicting the distribution of temperatures in geothermal areas by using the neuronet approach. They have tested the method against the results of an analytical model.

Karam (2003) has developed a force–restore method that predicts exact values for ground surface temperature under a multifrequency surface forcing. In this method, he has expanded the ground surface temperature into a Fourier series. A force–restore equation has been proposed for each term in the series in terms of two unknown coefficients: forcing coefficient and restoring coefficient. Each force–restore equation has been employed in deriving explicit expressions for those coefficients. He has also developed a microwave radiometry model used in modeling the brightness temperature of a ground surface. This model replaces the ground temperature and moisture profiles by their average values over a surface ground layer. Force–restore method has been used in evaluating the performance of a surface heat flux model and in investigating the validity range of a ground microwave radiometry model.

Mihalakakou (2002) has presented and compared two estimation methods for modeling and estimating the daily and annual variation of ground surface temperature. His two estimation models have been deterministic model and intelligent data-driven approach such as neural networks. Analytic deterministic model based on the transient heat conduction differential equation has been used to estimate the ground surface temperature. He has used neural network approach in order to estimate the ground surface temperature by using the climatic parameters such as the ambient air temperature, the relative humidity and solar radiation. He has tested these two methods against extensive sets of measurements for bare and short grass covered grounds.

Saastamoinen (2007) has presented an analytical solution for the temperature distributions and heat transfer in steady state from a single pipe or several pipes in a slab or semi-infinite solid.

Gülser and Ekberli (2004) have estimated diurnal ground temperature fluctuation through a clay ground depth with respect to time using a measured data set in a cosinusoidal harmonic equation. They have determined some ground thermal properties, such as amplitude, heat diffusivity, damping depth and retardation time at some ground depths.

Al-Anzi and Krarti (2003) have developed a new local/global analysis technique to solve multi-dimensional ground-coupled heat transfer problems. They have applied a novel method in their analysis to determine foundation heat transfer for buildings with slab-on-grade floors.

2.2. Literature Review for Numerical Studies

Some models about ground temperature have been solved by using numerical methods. Some selected studies about numerical ones are given below.

Beltrami (2001) has found that ground temperatures tracked surface air temperatures with amplitude attenuation and phase lag with depth confirming that heat conduction adequately describe the ground thermal field at the Pomquet site. He has used a numerical model of heat conduction in order to estimate the magnitude of the heat released by freezing during the winter months.

Best (1998) has described a model to predict the surface temperature of a variety of surfaces. He has solved the surface energy balance equation with the model iteratively, using only standard meteorological data. Because, his model has not needed surface and ground temperature information for initialization, he has used it for any surface and location. His model has been designed to use only the following standard forecast variables: air temperature, dew-point temperature, wind speed, low, medium and high cloud amounts, and an indication of periods of precipitation.

Qin et al. (2002) have presented a complete surface energy balance model to develop a methodology for the numerical approximation to the model. Ground heat and latent heat fluxes in the model have been determined according to both ground temperature change and ground moisture movement, which have been described as two differential equations. They have used the Crank–Nicolson implicit method to expand the differential equations into two sets of simultaneous linear equations, which have been then solved by applying Gauss’s elimination method. Latent heat flux has been determined at the balance when evaporation from the surface has been equal to the ground water loss. They have compared the simulated ground temperature with the micrometeorological measurements.

Mihalakakou et al. (1995) have developed transient and implicit numerical model for the prediction of the ground temperature at various depths below buildings. They have developed the proposed model based on finite volume method by calculating the heat flow to the ground from a building, which depends on the complicated three-dimensional thermal process in the ground. Then the proposed model has been compared against experimental data.

Mihalakakou et al. (1994) have developed a transient and implicit numerical model based on coupled heat and mass transfer for the prediction of thermal performance of the earth-tube heat exchangers. The model has been compared with a set of experimental data. Their model has predicted the temperature and the humidity of the circulating air as well as the distribution of the temperature and humidity into the ground.

Stathers et al. (1988) have developed a numerical model to estimate the ground surface energy flux densities and the ground temperatures in dry and wet bare grounds. A finite-difference solution to describe one dimensional heat transfer has been used to calculate the surface ground heat flux density and ground temperatures. They have compared numerically and experimentally obtained data.

Esen et al. (2007) have developed a numerical model of heat transfer in the ground for determining the temperature distribution in the vicinity of the pipe. The results obtained from the numerical model have been compared with the experimental ones.

Rees et al. (2007) have presented a two-dimensional numerical simulation of ground-heat transfer adjacent to an experimental earth–contact structure. They have compared the obtained numerical and experimental results.

Li et al. (2005) have presented a model of underground heat exchanger based on the heat and mass transfer theory in ground. They have taken into account in the model a number of factors such as moisture movement in ground, ground type, and ground property.

Piechowski (1999) has developed a mathematical model for horizontal type ground heat exchanger. Results obtained by using the implicit and explicit methods of solving the set of governing equations have been compared.

Chacko and Renuka (2002) have calculated the thermal diffusivity of the ground by different methods. They have predicted the ground heat flux and temperature of the ground at various depths. Thermal diffusivity of the ground at different depths has been calculated by range and lag methods using the three hourly measured ground temperatures of a wet and dry day. They have modeled and found diurnal ground heat flux and ground temperatures at different depths.

Suzuki et al. (1996) have presented bang-bang control theory to control of the ground temperature. They have compared the computed results with the results obtained by the experiments and measurements.

Mihailovic et al. (1999) have used the force-restore equation in order to calculate the changes of ground heat flux, variations of deep ground temperature and changes in ground water evaporation. They have compared the calculated values of the surface temperature with the micrometeorological measurements.

2.3. Literature Review for Experimental Studies

Experimental studies about ground temperature and ground heat flux are summarized below.

Wang and Bras (1999) have developed a method that allows the diurnal variation of ground heat flux to be computed from the corresponding time series measurement of surface ground temperature. They have presented that ground

temperature and ground heat flux over time at one location has been uniquely related through a half-order derivative/integral operator when heat transfer in a ground matrix has been described by a one-dimensional diffusion equation with a constant diffusivity parameter. They have used both simulated and observed data to test the method.

Yu Qiu et al. (1999) have developed a method to estimate daily ground evaporation using differential measurements of temperature. With this approach, they could be replaced measurements of sensible heat flux by those of surface temperature. They have determined an empirical coefficient from integrated energy fluxes over daytime hours and mean daytime temperatures. Their method has been led to a new ground evaporation transfer coefficient that could be replacing the aerodynamic resistance to calculate sensible heat flux. Estimation of actual evaporation from bare ground has been explored by using the energy balance method. They have compared ground evaporation measured by this method with evaporation estimated by the proposed differential model.

Paul et al. (2004) have described an empirical model for predicting the seasonal variation of daily average temperature within surface ground layers under a different forest types.

Guglielmin (2006) has investigated active layer and permafrost monitoring experimentally in Continental Antarctica. He has showed air temperature, ground surface temperature at 2 cm and ground temperature at 30 cm depth at Boulder clay in Antarctica. He has also showed the permafrost thermal regime at different ground depths for the same location.

Popirl et al. (2001) have measured the ground temperatures with thermocouples distributed in ground at a depth from 0 to 7 m (bare surface) and from 0 to 17 m (lawn). They have found that the short-period temperature variations reached a depth of approximately 1 m and then compared their experimental data with Buggs's formula.

Plauborg (2002) has presented empirical and simple models for ground temperature at 10 cm depth in grass-covered grounds. The predictions from station specific models have been compared to the global model.

Signorelli and Kohl (2004) have defined a relationship between ground surface temperature and surface air temperature based on the data taken from the meteorological stations. They have established three different altitude zones that require individual consideration by applying nonlinear approaches. By further processing, an existing surface air temperature map was converted into the first ground surface temperature map of Switzerland.

Al-Kayssi (2002) has investigated the variation of ground surface temperature in greenhouses.

2.4. Literature Review for Ground Heat Exchangers

Ground heat exchangers utilize the ground temperature. Some selected studies are given below.

Gauthier et al. (1997) have presented a numerical study for the thermal behavior of ground heat exchanger-storage systems. The results obtained from the numerical model have been compared with the experimental data.

Piechowski (1998) has presented a ground heat exchanger model. The modeled and experimental temperature profiles have been then compared.

Hamada et al. (2007) have improved a method where underground heat exchanger is placed without drilling the ground. Experiments on a space heating and cooling system have been carried out.

Esen and Balbay (2003) have calculated the ground heat exchanger length for a ground source heat pump system installed experimentally by using different measurement values.

Philippacopoulos and Berndt (2001) have investigated the influence of gaps (debonding) on the heat transfer in ground heat exchangers of ground source heat pumps. They have used an analytical one-dimensional radial flow models to examine continuous circumferential gaps. They have then solved the two-dimensional heat conduction by finite element analysis to evaluate the spatial distribution of potential interfacial gaps.

Kyoungbin et al. (2007) have performed the thermal response test using a vertical borehole heat exchanger and measured the thermal performance of the borehole heat exchanger.

Zeng et al. (2003) have presented a quasi-three-dimensional model of the borehole heat transfer and derived analytical solutions of the fluid temperature profiles for single and double U-tube boreholes.

Leonga et al. (1998) have presented a computer program for horizontal ground heat exchanger analysis, design and simulation. They have used three different grounds (sand, silty loam and silty clay) with five different constant values of ground moisture content corresponding to 0, 12.5, 25, 50 and 100% of saturation in their simulation.

Koyun and Demir (2003) have developed a mathematical model for horizontal buried pipe and described its numerical solution techniques.

Stevens (2004) has derived an optimal depth for the ground heat exchanger to maximize the square of the difference between the surface temperature and the ground temperature.

Raab et al. (2005) have developed a model for the calculation of the thermal behavior of ground buried hot water heat stores. They have then compared measured and calculated temperatures. They have also developed another model to calculate the thermal behavior of the solar assisted district heating system. They have compared measured and calculated heat quantities.

2.5. Literature Review for Ground Source Heat Pump Systems

One of the most important reasons of investigation of the ground temperatures is to need the ground temperatures in the design of ground source heat pump systems. Studies about ground source heat pump systems are given below.

Petit and Meyer (2003) have compared the economic viability of vertical ground source and air source heat pump systems. They have determined capital costs and optimum borehole length of the ground system and evaluated heating and cooling capacities and COP's to determine running costs.

Kyriakis et al. (2006) have developed a calculation algorithm to define the maximum thermal load allowable in vertical ground heat exchangers. They have showed that the ground heat exchanger thermal load as a function of the load duration.

Hepbaşlı et al. (2003) have investigated the performance characteristics of a ground source heat pump system with a 50 m vertical U-bend ground heat exchanger. Vertical U-bend type ground source heat pump system has been designed and constructed. They have compared the overall COP of the system with other heat pumps operating under conditions at or near design values.

Li et al. (2006) have presented both the numerical simulations and experiments on the thermal performance of U-vertical ground coupled heat exchanger. They have analyzed the variation of the ground temperature and heat balance of the system.

Kıncay and Temir (2002) have presented performance and cost comparison between heating and cooling of a building with a ground source heat pump system with vertical ground heat exchanger and heating and cooling of the same building with air-source heat pump system.

Lamarche and Beauchamp (2006) have proposed a new analytical approach to analyze the thermal response of vertical heat exchangers which have been used in ground coupled heat pump systems.

Li et al. (2006) have set up an experimental system with different types of U-vertical ground coupled heat exchanger to obtain its thermal performance in various conditions. They have also developed a numerical stimulation to show the underground temperature field.

Hepbaşlı and Akdemir (2004) have investigated energy and exergy analysis of a vertical ground source heat pump system theoretically and experimentally. They have used the first and second laws to analyze the whole heat pump system and its individual components.

Özgener and Hepbaşlı (2007) have presented energetic and exergetic aspects of solar assisted vertical ground source heat pump systems and horizontal ground

source heat pump systems for the system analysis and performance assessment. They have utilized experimental and assumed values in their analysis.

Esen et al. (2003) have determined the ground source heat pump system performance with a horizontal heat exchanger for heating an experimental test room.

Esen et al. (2006) have performed the performance experiments and economic analysis of a horizontal ground source heat pump system. They have presented a detailed cost analysis and have compared to conventional heating methods in the economical analysis using an annualized life cycle cost method.

Healy and Ugursal (1997) have developed a computer model to study the effect of various system parameters on ground source heat pump system performance. They have carried out a comparative economic evaluation to assess the feasibility of using a ground source heat pump in a place of conventional heating and cooling systems and an air source heat pump.

Hepbaşlı and Balta (2007) have carried out the modeling and performance evaluation of a heat pump system utilizing a low temperature geothermal resource approximated to a geothermal reservoir. They have designed, constructed and tested the heat pump system. Energy and exergy analysis methods have been used to assess the system performance based on the experimental data.

İnallı and Esen (2005) have presented an analysis of performance evaluation of a ground-coupled heat pump for a cooling mode with R-22 as the refrigerant. They have designed and constructed such a system for an academic study. They have determined the seasonal cooling performance of the system from the experimental measurements.

Hepbaşlı (2002) has investigated the cooling performance of a ground-source heat pump system experimentally. He has compared the coefficient of performance for cooling of the heat pump and the whole system with other heat pumps operating under conditions at or near design values.

Bakırcı et al. (2007) have investigated situation of the solar and ground source heat pump systems in Turkey. They have shown applicability of these systems in our country.

Dikici et al. (2005) have investigated the performance characteristics and exergy analysis of a ground source and air source heat pump system experimentally.

İnallı (2000) has investigated the performance values for different ground types and design principle of the ground coupled heat pumps.

Hepbaşlı (2002) has investigated the Turkish market status of the ground source heat pump systems in residential and commercial buildings. In addition, he has investigated energy efficiency and cost analysis of the installed ground source heat pump system.

De Swardt and Meyer (2001) have compared the performance of a ground-source heat pump with the performance of an air-source heat pump experimentally. The comparison has been conducted in cooling and heating cycles.

Esen et al. (2007) have determined the performances of a ground -coupled heat pump system and an air-coupled heat pump system experimentally. They have achieved a techno-economic comparison between the experimental results.

Karlsson and Fahlen (2007) have investigated the energy-saving potential of applying variable-speed capacity control to brine-to-water heat pump systems.

3. MATERIAL AND METHOD

Theoretical expressions which are necessary for calculating the ground and ground surface temperatures were presented. Firstly, one layer ground was considered and then multi-layer ground was investigated.

3.1. One Layer Ground Model

3.1.1. Differential Equations and Boundary Conditions

Heat transfer in one layer homogeneous ground can be written by one dimensional time depended differential equation as follows by assuming constant ground physical properties;

$$\frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial x^2} \quad (3.1)$$

where T is temperature, t is time, x is vertical coordinate in the ground, a is the thermal diffusivity. Eq.(3.1) can be solved by writing two boundary conditions at the ground surface and ground depth.

Locations of two boundary conditions for one layer homogeneous ground are shown in figure 3.1.

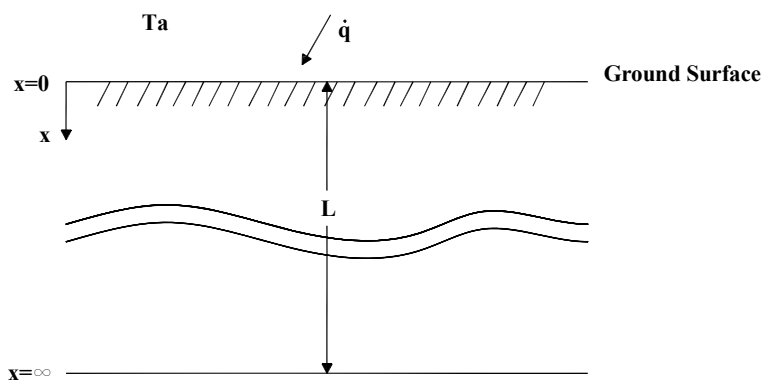


Figure 3.1. Locations of two boundary conditions

General boundary condition at the ground surface can be written as:

$$x = 0 \quad : \quad -k \left(\frac{\partial T}{\partial x} \right)_s = h(T_a - T_s) + a_s \dot{q} - \varepsilon_e \Delta R - \dot{q}_v \quad (3.2)$$

Left hand-side of eq.(3.2) shows conductive heat transfer to the ground. First term of the right hand-side of eq.(3.2) shows convective heat transfer between air and ground, second term shows short wave solar radiation absorbed from the ground surface, third term shows heat transferred from ground surface with long wave-length radiation and last term shows heat loss due to evaporation from the surface.

In eq.(3.2); k is thermal conductivity of the ground, h is convective heat transfer coefficient between ground surface and ambient air, T_a is ambient temperature, T_s is ground surface temperature, a_s is absorption coefficient of ground surface, $\dot{q}$ is total solar heat flux, ε_e is emission coefficient of ground surface, ΔR is long wave-length radiation and $\dot{q}_v$ is latent heat flux from the ground surface due to water evaporation.

Convective heat transfer coefficient h can be found by using the wind speed u (El Din, 1999).

$$h = 2.8 + 3u \quad (3.3)$$

The following values can be used according to Ashrae (2003):

$$\varepsilon_e = 1 \quad ; \quad \Delta R = 63 \quad (3.4)$$

Mihalakakou et al. (1997) have been recommended 0.8 value for a_s . Patrick E. A. F. (1983) has been given the value of a_s between 0.85 and 0.95 for dark ground. The last term of eq.(3.2) is heat transfer due to evaporation. Latent heat of evaporation can be written as follows:

$$\dot{q}_v = \beta (\rho_s - \rho_a) h_{gl} = \frac{\beta h_{gl} (P_s - P_a)}{R T} \quad (3.5)$$

where R is gas constant of water vapor, T is an average absolute temperature between ground surface and ambient air, h_{gl} is latent heat of evaporation. ρ_s and ρ_a are the partial pressures of water vapor at the ground surface and ambient air, respectively.

Because mass transfer coefficient β can be taken proportional to h , Mihalakakou et al. (1997) suggested the following equation:

$$\dot{q}_v = 0.0168 f h (P_{ss} - \phi P_{sa}) \quad (3.6)$$

In this equation, P_{ss} and P_{sa} are the water vapor saturation pressures at surface and ambient temperatures, respectively.

In TS 825, the following equation for saturated partial pressures can be written between 0-30 °C:

$$P_s = 288.68 \left(1.098 + \frac{T_s}{100} \right)^{8.024} \quad (3.7)$$

The following equation is obtained according to the values between 30-60 °C in Ashrae Handbook (2003):

$$P_s = 975.29 \left(0.9303 + \frac{T_s}{100} \right)^{7.094} \quad (3.8)$$

f value in eq.(3.6) is a parameter which depends on different ground surfaces and moisture content of the ground. For bare ground, f value can be estimated as follows:

$f=1.0$	saturated ground	
$f=0.6-0.8$	humid ground	
$f=0.4-0.5$	dry ground	(3.9)
$f=0.1-0.2$	arid ground	

For grass covered grounds, 70% of the above given f values are recommended by El Din (1999).

For very low temperature ranges between T_s and T_a , one can write:

$$P_s = A_p T + B_p \quad (3.10)$$

P_{ss} and P_{sa} in eq.(3.6) must be calculated using eq.(3.10). A_p and B_p can be obtained from the values calculated from eqs.(3.7) and (3.8).

$$A_p = \frac{P_{sa} - P_{ss}}{T_a - T_s} \quad (3.11)$$

$$B_p = P_{sa} - A_p T_a \quad (3.12)$$

From these values and with the abbreviation

$$C_v = 0.0168 f \quad (3.13)$$

We can write eq.(3.6), in the following form:

$$\dot{q}_v = C_v h [A_p T_s - \phi A_p T_a + B_p (1 - \phi)] \quad (3.14)$$

From eqs.(3.2), (3.6) and (3.10), boundary condition at the ground surface can be written as follows:

$$\begin{aligned}
-k \left(\frac{\partial T}{\partial x} \right) = & h(T_a - T_s) + a_s \dot{q} - \varepsilon_e \Delta R - C_v A_p h T_s \\
& + C_v A_p h T_a - C_v B_p h (1 - \phi)
\end{aligned} \quad (3.15)$$

With the following abbreviations;

$$h_c = h (1 + C_v A_p) \quad (3.16)$$

$$T_{se} = \frac{[h (1 + C_v A_p \phi) T_a + a_s \dot{q} - \varepsilon_e \Delta R - C_v B_p h (1 - \phi)]}{h_c} \quad (3.17)$$

Eq.(3.15) can be simplified as follows:

$$-k \left(\frac{\partial T}{\partial x} \right) = h_c (T_{se} - T_s) \quad (3.18)$$

Because there is no temperature gradient in very deep ground levels ($x \rightarrow \infty$), the following boundary condition can be written:

$$x \rightarrow \infty : \frac{\partial T}{\partial x} = 0 \quad (3.19)$$

3.1.2. Analytical Method

When the ambient temperature can be defined as sinus function, eqs.(3.1), (3.18) and (3.19) can be solved analytically. With this assumption, the problem was solved by El Din (1999). Temperature distribution in the ground can be expressed as a function of time and x axis as follows:

$$T = T_{sm} + \Delta T_s \exp(-x^*) \sin(2\pi t^* - x^* + \phi_s) \quad (3.20)$$

Ground surface temperature can be written:

$$T_s = T_{sm} + \Delta T_s \sin(2\pi t^* + \phi_s) \quad (3.21)$$

t^* and x^* are defined as follows:

$$t^* = \frac{t}{t_o} \quad (3.22)$$

$$x^* = \frac{x}{x_o} \quad (3.23)$$

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

$$x_o = \left(\frac{at_o}{\pi} \right)^{1/2} \quad (3.24)$$

Solar-equivalent temperature must be expressed as follows:

$$T_{se} = T_{sem} + \Delta T_{se} \sin(2\pi t^* + \phi_{se}) \quad (3.25)$$

In annual calculations, actual data for T_{se} must be used to determine the parameters in eq.(3.25). The coefficients of T_{sem} , ΔT_{se} and ϕ_{se} must be determined by using different curve-fitting methods.

There are various curve-fitting methods. Different methods were used in this study and Rosenbrock method was determined as the most suitable method in obtaining the T_{sem} , ΔT_{se} and ϕ_{se} coefficients.

T_{sm} , ΔT_s and ϕ_s coefficients must be calculated from the equations below, respectively:

$$T_{sm} = T_{sem} \quad (3.26)$$

$$\Delta T_s = \Delta T_{se} \left[(1 + \mu)^2 + \mu^2 \right]^{-1/2} \quad (3.27)$$

$$\phi_s = \tan^{-1} \left[\frac{(1 + \mu)^2 \tan \phi_{se} - \mu}{(1 + \mu) + \mu \tan \phi_{se}} \right] \quad (3.28)$$

μ is defined as follows:

$$\mu = \frac{k}{hx_o} \quad (3.29)$$

It is clear that, the annual average value of h value must be used in analytical method. h was calculated from eq.(3.3) by using annual average value of wind velocity.

3.1.3. Numerical Method

In this study, finite difference method is used for numerical calculations. Firstly finite different method will be applied for the one dimensional eq.(3.1) and eqs.(3.18) and (3.19) boundary conditions.

3.1.3.1. Finite Difference with Variable Step Size

Finite difference is written for the most general form for variable step sizes. In figure 3.2, variable step sizes are shown in finite difference net.

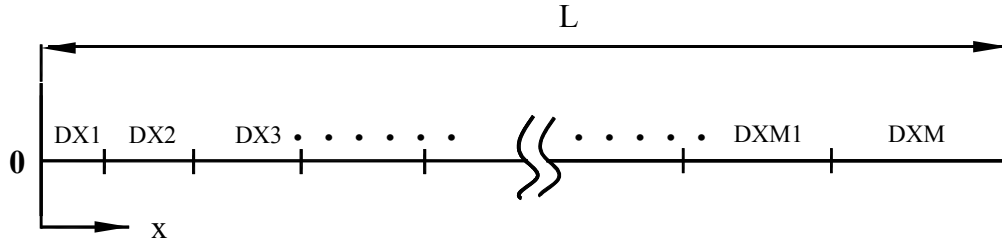


Figure 3.2. Finite difference net with variable step size

It is not possible that the solution net is infinite length. Therefore, a solution net which has the length L is assumed in the direction of x ground depth.

When $DX1$ is the first step length and step sizes multiply with a coefficient b greater than 1, the following equation can be written:

$$DX1 + b DX1 + b^2 DX1 + \dots + b^{M-1} DX1 = L \quad (3.30)$$

From this equation, following equation for $DX1$ is yielded:

$$DX1 = \frac{L}{1 + \sum_{j=1}^{M-1} b^j} \quad (3.31)$$

First step length $DX1$ is determined from eq.(3.31) according to b and M values. M is total step sizes in the solution net which has the length L .

3.1.3.2. Writing of Differential Equations with Finite Difference

In this method, first step size is determined for a certain step size M and solution net L by changing the value of step increment coefficient b . Second order derivation in eq.(3.1) can be written with variable step size for (i, j) point as follows:

$$\left(\frac{\partial^2 T}{\partial x^2} \right)_{i,j} = A_1 T_{i,j-1} + A_2 T_{i,j} + A_3 T_{i,j+1} \quad (3.32)$$

for $(i+1, j)$ point:

$$\left(\frac{\partial^2 T}{\partial x^2} \right)_{i+1,j} = A_1 T_{i+1,j-1} + A_2 T_{i+1,j} + A_3 T_{i+1,j+1} \quad (3.33)$$

Subscripts i and j in eqs.(3.33) and (3.34) show the direction of t and x in figure 3.3, respectively.

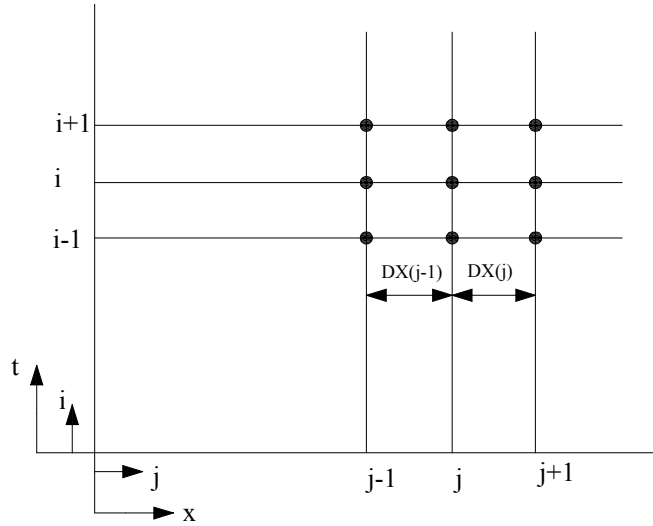


Figure 3.3. Finite differences net

The equations given below are valid for A_1 , A_2 and A_3 coefficients in eqs.(3.32) and (3.33).

$$A_1 = \frac{2}{DX(j-1) (DX(j-1) + DX(j))} \quad (3.34)$$

$$A_2 = -\frac{2}{DX(j-1) DX(j)} \quad (3.35)$$

$$A_3 = \frac{2}{DX(j) (DX(j-1) + DX(j))} \quad (3.36)$$

Finite difference at t direction can be written as follows:

$$\frac{\partial T}{\partial t} = \frac{T_{i+1,j} - T_{i,j}}{\Delta T} \quad (3.37)$$

Derivation at x direction can be written as average second order derivation between the points of i and i+1.

$$\frac{\partial^2 T}{\partial x^2} = \beta \left(\frac{\partial^2 T}{\partial x^2} \right)_{i+1,j} + (1-\beta) \left(\frac{\partial^2 T}{\partial x^2} \right)_{i,j} \quad (3.38)$$

with eq.(3.1);

$$\frac{T_{i+1,j} - T_{i,j}}{\Delta T} = a \left[\beta \left(\frac{\partial^2 T}{\partial x^2} \right)_{i+1,j} + (1-\beta) \left(\frac{\partial^2 T}{\partial x^2} \right)_{i,j} \right] \quad (3.39)$$

$$\begin{aligned} \frac{T_{i+1,j} - T_{i,j}}{\Delta T} = a \left[\beta (A_1 T_{i+1,j-1} + A_2 T_{i+1,j} + A_3 T_{i+1,j+1}) \right. \\ \left. + (1-\beta) (A_1 T_{i,j-1} + A_2 T_{i,j} + A_3 T_{i,j+1}) \right] \end{aligned} \quad (3.40)$$

and with assuming $C=a.\Delta t$;

$$\begin{aligned} -C\beta A_1 T_{i+1,j-1} + (1-C\beta A_2) T_{i+1,j} - C\beta A_3 T_{i+1,j+1} \\ = C(1-\beta) A_1 T_{i,j-1} + (1+C(1-\beta) A_2) T_{i,j} + C(1-\beta) A_3 T_{i,j+1} \end{aligned} \quad (3.41)$$

$$\begin{aligned} CN_1 T_{i+1,j-1} + CN_2 T_{i+1,j} + CN_3 T_{i+1,j+1} \\ = CA_1 T_{i,j-1} + CA_2 T_{i,j} + CA_3 T_{i,j+1} \end{aligned} \quad (3.42)$$

The following equations are valid for the coefficients in eq.(3.42):

$$\begin{aligned}
 CN1 &= -C \beta A1 \\
 CN2 &= 1 - C \beta A2 \\
 CN3 &= -C \beta A3 \\
 CA1 &= C (1 - \beta) A1 \\
 CA2 &= 1 + C (1 - \beta) A2 \\
 CA3 &= C (1 - \beta) A3
 \end{aligned} \tag{3.43}$$

In the equations above, $\beta=0.5$ is named as Crank-Nicolson method. Furthermore;

$$D_{i,j} = CA1 T_{i,j-1} + CA2 T_{i,j} + CA3 T_{i,j+1} \tag{3.44}$$

With the definition of eq.(3.44):

$$CN3 T_{i+1,j+1} + CN2 T_{i+1,j} + CN1 T_{i+1,j-1} = D_{i,j} \tag{3.45}$$

This is an equation with three unknowns.

When eq.(3.45) is written from the points of $j=2$ to $j=M$, $M-1$ equation is yielded. Because there is $M+1$ unknown, two more equations are needed. These equations are supplied from boundary conditions at $j=1$ and $j=M+1$ points.

3.1.3.3. Writing of Boundary Conditions with Finite Difference

It is seen from eq.(3.19), there is symmetry condition at $x=L$. This equation can be written at $x=L$ for variable step size as follows:

$$ELM1 T_{i+1,M-1} + ELM T_{i+1,M} + ELMP1 T_{i+1,M+1} = 0 \tag{3.46}$$

The coefficients are given below:

$$ELM1 = \frac{1}{b(1+b)} \frac{1}{DX(M-1)} \quad (3.47)$$

$$ELM = -\frac{1+b}{b} \frac{1}{DX(M-1)} \quad (3.48)$$

$$ELMP1 = \frac{2+b}{1+b} \frac{1}{DX(M-1)} \quad (3.49)$$

Derivation at $x=0$ can be written in variable step size as follows:

$$\left. \frac{\partial T}{\partial x} \right|_{x=0} = ES1 T_{i+1,1} + ES2 T_{i+1,2} + ES3 T_{i+1,3} \quad (3.50)$$

In this equation; ES1, ES2 and ES3 coefficients must be calculated as follows:

$$ES1 = -\frac{2+b}{1+b} \frac{1}{DX(1)} \quad (3.51)$$

$$ES2 = \frac{1+b}{b} \frac{1}{DX(1)} \quad (3.52)$$

$$ES3 = -\frac{1}{b(1+b)} \frac{1}{DX(1)} \quad (3.53)$$

Substituting eq.(3.50) into eq.(3.18), the following equation is obtained:

$$ESN1 T_{i+1,1} + ESN2 T_{i+1,2} + ESN3 T_{i+1,3} = ELD \quad (3.54)$$

The coefficients in eq.(3.54) can be written as follows:

$$\begin{aligned}
 \text{ESN1} &= -k \text{ ES1} + h_c \\
 \text{ESN2} &= -k \text{ ES2} \\
 \text{ESN3} &= -k \text{ ES3} \\
 \text{ELD} &= h_c T_{se}
 \end{aligned}
 \tag{3.55}$$

Thus, needed M+2 equations are obtained.

3.1.3.4. Solution of Equation System

The matrix form shown in figure 3.4 is obtained from the equations given above.

1	2	3		...j...		M-1	M	M+1
X	X	X						
X	X	X						
	X	X	X					
		X	X	X				
				... X X X ...				
					X X X			
						X X X		
							X X X	
								X X X

Figure 3.4. Matrix form of equations

The first and the last equations are the equations obtained from eqs.(3.54) and (3.46), respectively. Gauss-Seidel method was applied in the solution of these equations.

In applying the numerical method, there is no necessity for using the annual average value of h . T_{se} needs not to be described as sinus function.

3.2. Two Horizontal Layer Ground Model

3.2.1. Differential Equations and Boundary Conditions

The ground was assumed to consist of two different homogeneous layers as shown in figure 3.5.

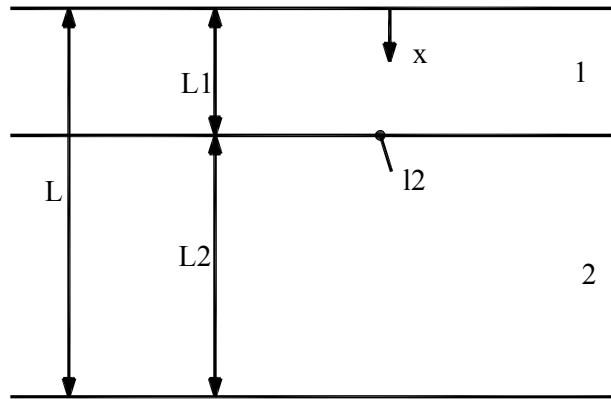


Figure 3.5. Two horizontal layer ground

Fourier differential equation given below is valid for the first and the second layers as in the one layer ground model:

$$\frac{\partial T}{\partial t} = a_i \frac{\partial^2 T}{\partial x^2} \quad (3.56)$$

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

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

$$x=L1 : \quad k_1 \left(\frac{dT}{dx} \right)_1 = k_2 \left(\frac{dT}{dx} \right)_2 \quad (3.57)$$

$$x=L \quad : \quad \frac{dT}{dx} = 0 \quad (3.58)$$

L was chosen so deep, that eq.(3.58) is valid. k_1 and k_2 are the thermal conductivities of upper and lower layers, respectively.

The general boundary condition at the ground surface for two layer ground is the same with that of one layer ground (eq.(3.2)).

3.2.2. Numerical Method

Ground thicknesses were assumed as L_1 and L_2 in two layer ground as shown in figure 3.6. The thickness of L_1+L_2 was assumed as 10 meter as in one layer ground model. Numerical program was prepared based on changing of step increment coefficient in both of L_1 and L_2 layers.

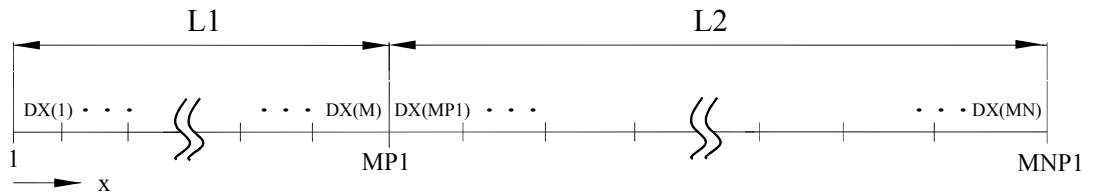


Figure 3.6. Two layer ground

L_1 and L_2 layers were divided into M and N parts, respectively. The coefficients of b_1 and b_2 are assumed for L_1 and L_2 sections as in eq.(3.31) which is given for the one layer ground model. First step for L_1 layer is $DX(1)$, last step is $DX(M)$ and first step for L_2 section is $DX(MP1)$ and last step is $DX(MN)$.
where,

$$MP1=M+1 \quad (3.59)$$

$$MN=M+N \quad (3.60)$$

$$MNP1=MN+1 \quad (3.61)$$

Previous and next step lengths of MP1 were taken equal to each other (figure 3.7).

$$DX(M) = DX(MP1) \quad (3.62)$$

Because, heat fluxes at MP1 point are the same for both grounds, one can write;

$$k_1 \left(\frac{dT}{dx} \right)_1 = k_2 \left(\frac{dT}{dx} \right)_2 \quad (3.63)$$

Subscripts 1 and 2 in eq.(3.63) show L1 and L2 sections, respectively. These equations can be written in the form of finite difference equations as follows:

$$k_{12}^* (T_{MP1} - T_M) = (T_{MP2} - T_{MP1}) \quad (3.64)$$

Re-arranging of this equation yields:

$$T_{MP2} - (1 + k_{12}^*) T_{MP1} + k_{12}^* T_M = 0 \quad (3.65)$$

Intersection point of two layer is shown in figure 3.7.

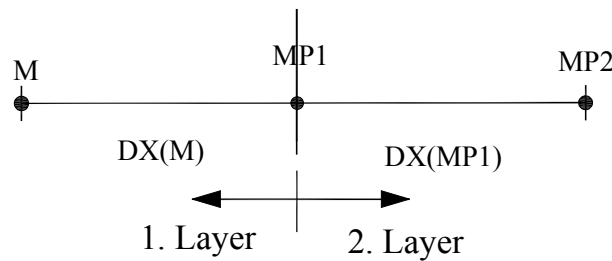


Figure 3.7. Intersection point of two layer point (MP1)

k_{12}^* and MP2 in eq.(3.65) define as follows:

$$k_{12}^* = \frac{k_1}{k_2} \quad (3.66)$$

$$MP2=M+2 \quad (3.67)$$

Equations for 1st and 2nd layers were written as in one layer ground model. Boundary conditions were also written separately for 1st and MNP1st points.

Thus, M-1 equations in first section and N-1 equations in second section were written. Three equations were obtained from 1st, MP1st and MNP1st points.

3.3. Two Vertical Layer Ground Model

3.3.1. Differential Equations and Boundary Conditions

Two vertical layer ground is shown in figure 3.8.

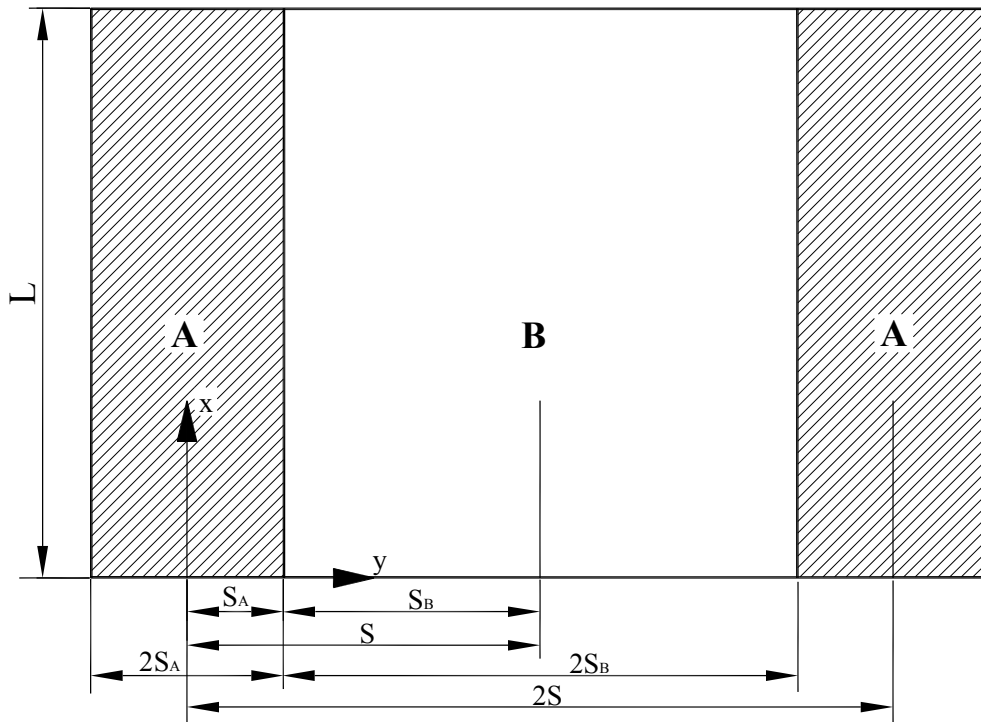


Figure 3.8. Two vertical layer ground

In this case, 2SA thickness and L length of ground which has different physical properties are located in to the ground. Normal ground is defined as B and different ground is defined as A. Because heat transfer in vertical layer ground is depended on x and y coordinates, Fourier differential equations can be written as follows:

$$\frac{\partial T}{\partial t} = a_i \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (3.68)$$

where, a_i is the thermal diffusivity which is valid for A and B layers.

Eqs.(3.2) and (3.19) in one layer ground are valid for the boundary conditions at $x=0$ and $x=L$. Furthermore, the following boundary conditions are also valid;

$$\begin{aligned} y = 0 \\ \text{and} \quad : \quad \frac{\partial T}{\partial y} = 0 \\ y = S \end{aligned} \quad (3.69)$$

$$y = S_A \quad : \quad k_A \left(\frac{dT}{dy} \right)_A = k_B \left(\frac{dT}{dy} \right)_B \quad (3.70)$$

The differential equations in eq.(3.68) were solved numerically with above boundary conditions.

3.3.2. Numerical Method

In this part of the study Alternating Direction Implicit (ADI) method was used as numerical method. [Clavero et al. (2000); Peaceman and Rachford (1955); Roache (1976)].

$$\frac{\partial T}{\partial t} = a_i \frac{\partial^2 T}{\partial x^2} + a_i \frac{\partial^2 T}{\partial y^2} \Big|_n \quad (3.71)$$

$$\frac{\partial T}{\partial t} = a_i \frac{\partial^2 T}{\partial y^2} + a_i \frac{\partial^2 T}{\partial x^2} \Big|_n \quad (3.72)$$

where n values in eqs.(3.71) and (3.72) include the last calculated values. The values of $(n+1)^{st}$ iteration are calculated by using n^{th} values. The iterations in x and y directions were continued until the results were the same in both directions (until 0.01°C temperature difference is arrived).

The differential equations in eqs.(3.71) and (3.72) can be written for old and new times as follows:

$$\frac{1}{a_i} \frac{T_{t+\Delta t, x, y} - T_{t, x, y}}{\Delta t} = \beta \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial x^2} \right)_{t+\Delta t} + (1-\beta) \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial x^2} \right)_t \quad (3.73)$$

The temperatures in t are firstly taken from initial condition. Then, they are taken as calculated values. The values in $t+\Delta t$ are determined by being hold constant the values in y -direction and then by using the values in previous iterations for them. The values in $t+\Delta t$ can be written as follows:

$$\frac{1}{a_i} \frac{T_{t+\Delta t, x, y} - T_{t, x, y}}{\Delta t} = \beta \frac{\partial^2 T}{\partial x^2} \Big|_{t+\Delta t, n+1} + \beta \frac{\partial^2 T}{\partial y^2} \Big|_{t+\Delta t, n} + (1-\beta) \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial x^2} \right)_{\Delta t} \quad (3.74)$$

The values in t are accepted as known in accordance with above equation. Furthermore, second derivatives in y -direction are calculated by determining it from the previous iteration (n^{th} iteration) and $t+\Delta t$ from already calculated temperatures. Thus, calculations are set to three band matrix explained in the one layer ground model. Calculations are repeated by using different a_i and k_i values for both vertical

layers. Temperatures are calculated except for the values in conjunction line. The values in conjunction line are calculated from eq.(3.70).

After temperature calculations in x-direction, the following equation is written for y-direction.

$$\frac{1}{a_i} \frac{T_{t+\Delta t,x,y} - T_{t,x,y}}{\Delta t} = \beta \left. \frac{\partial^2 T}{\partial y^2} \right|_{t+\Delta t,n+1} + \beta \left. \frac{\partial^2 T}{\partial x^2} \right|_{t+\Delta t,n} + (1-\beta) \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial x^2} \right)_t \quad (3.75)$$

where n is the calculated values in previous iteration and it means the obtained results in the x-direction.

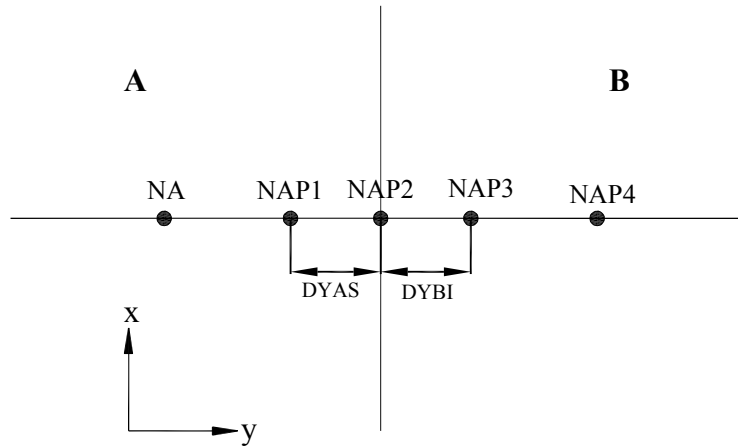


Figure 3.9. Boundary conditions in A and B layers

Because boundary condition in eq.(3.70) is written in the form of finite difference solution, calculations are done as in figure 3.9. Last step in A layer and first step in B layer are denominated as DYAS and DYBI, respectively. According to figure 3.9, boundary condition in eq.(3.70) is written in y-direction as follows:

$$\begin{aligned} & 3 \text{ TN}(\text{NAP2}) - 4 \text{ TN}(\text{NAP1}) + \text{TN}(\text{NA}) \\ & = - \text{AKAB} (3 \text{ TN}(\text{NAP2}) - 4 \text{ TN}(\text{NAP3}) + \text{TN}(\text{NAP4})) \end{aligned} \quad (3.76)$$

The ratio of the thermal conductivities of A and B layers (AKAB) is defined as follows:

$$AKAB = \frac{k_B}{k_A} \frac{DYAS}{DYBI} \quad (3.77)$$

The equation which is going to be added in triple band matrix in eq.(3.75) is written from eq.(3.76) as follows:

$$\begin{aligned} -4 AKAB TN(NAP3) + 3 (1+AKAB) TN(NAP2) - 4 TN(NAP1) \\ = - TN(NA) - AKAB TN(NAP4) \end{aligned} \quad (3.78)$$

In the calculations in y-directions, the values used in the last iteration were taken for the temperature values of TN(NA) and TN(NAP4) which are given in eq.(3.78).

In the calculations in x-directions, the temperatures in NAP2 (at the boundary) were calculated as follows by using the temperature values in the points of NA, NAP1, NAP3, NAP4.

$$\begin{aligned} TN(NAP2) = (4 TN(NAP1) - TN(NA) + \\ 4 AKAB TN(NAP3) - AKAB TN(NAP4)) / 3 (1+AKAB) \end{aligned} \quad (3.79)$$

It is required that, DYAS equal to DYBI for more accurate calculations. Firstly, a step increment coefficient for A layer b_A was defined. After that the value of DYAS was determined according to step number (NA) as given in eq.(3.31). NB step number for B layer was given and b_B value which must be taken was calculated with iteration in order to get DYBI=DYAS.

3.4. Trench-Filled Two Vertical Layer Ground Model

3.4.1. Differential Equations and Boundary Conditions

Pipes are located in trenches which have $2S$ distance and $2S_A$ thickness for horizontal pipe heat pump applications and then these trenches can be filled with same ground or various filling materials. Such a condition is given in figure 3.10.

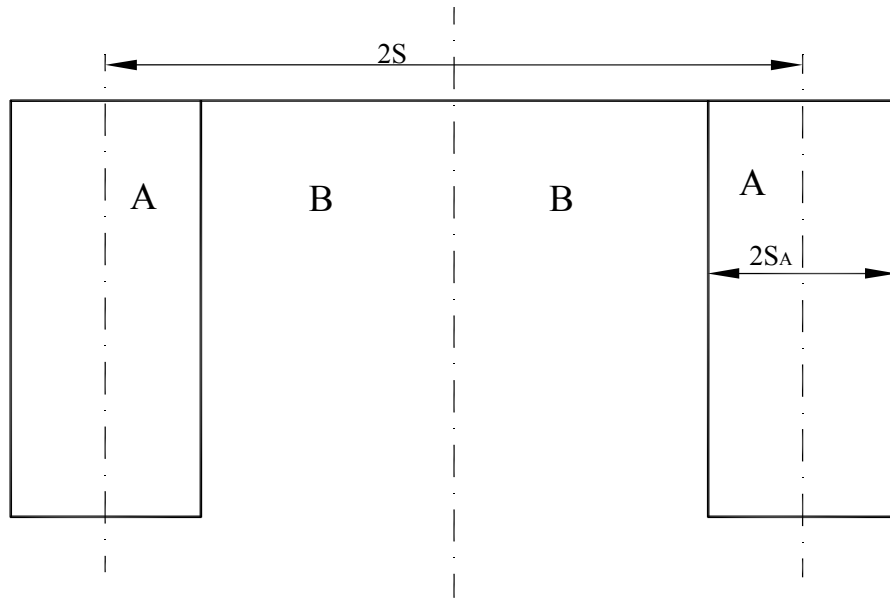


Figure 3.10. Trenches for horizontal pipe heat pump applications

This condition in figure 3.10 is shown according to numerical calculation in the figure below (Figure 3.11). A and B grounds might have different physical properties.

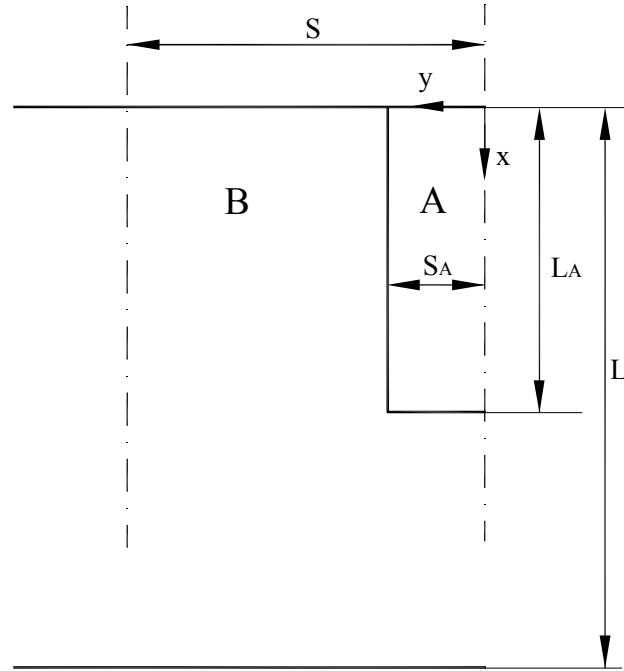


Figure 3.11. Trench-filled two vertical layer grounds for numerical modeling

When the physical properties of A filling material and B ground are different from each other, the following equations are valid for A and B layers respectively:

for A layer,

$$\frac{\partial T}{\partial t} = a_A \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (3.80)$$

and B layer,

$$\frac{\partial T}{\partial t} = a_B \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (3.81)$$

where a_A and a_B are the thermal diffusivities of A and B materials, respectively.

The boundary condition in $x=0$ for the differential equations in eqs.(3.80) and (3.81) for all y values can be described again with eq.(3.18).

Furthermore, following boundary conditions are valid:

$$x = L_A \quad : \quad 0 < y < S_A \quad : \quad k_A \left(\frac{dT}{dy} \right)_A = k_B \left(\frac{dT}{dy} \right)_B \quad (3.82)$$

$$x = L \quad : \quad 0 < y < S \quad : \quad \frac{\partial T}{\partial x} = 0 \quad (3.83)$$

The boundary conditions in y-direction are given as follows:

$$\begin{aligned} y = 0 \\ \text{and} \quad : \quad \frac{\partial T}{\partial y} = 0 \\ y = S \end{aligned} \quad (3.84)$$

$$y = S_A \quad : \quad 0 < x < L_A \quad : \quad k_A \left(\frac{dT}{dy} \right)_A = k_B \left(\frac{dT}{dy} \right)_B \quad (3.85)$$

Boundary conditions in eqs.(3.83) and (3.84) can be written in the form of finite difference solution similar to eq.(3.46).

Boundary conditions in eqs.(3.82) and (3.85) can be written in the form of finite difference solution similar to eqs.(3.65) and (3.70) that are determined before for two horizontal and two vertical layer ground.

3.4.2. Numerical Method

The differential equations (3.80) and (3.81) valid for A and B layers are solved by using the boundary conditions as explained in chapter 3.3.2. Implicit alternating directions method is used in the numerical calculations.

3.5. Physical Properties of Ground

Thermal conductivity k and thermal diffusivity a exist in boundary conditions and in differential equation. k and a values for various ground types are given in tables 3.1 and 3.2 (Yılmaz T. 2004). There are also k and a values of air and water in these tables. As can be observed from the table 3.1 that k and a values may be change according to ground type 5 and 10 times approximately.

3.5.1. Thermal Conductivity

Since ground is a granular medium consisting of solid, liquid, and gaseous phases, the thermal conductivity will depend on the volumetric proportions of these components, the size and arrangement of the solid particles, and the interfacial contact between the solid and liquid phases. The thermal conductivity for water and air are 0.59 and 0.026 W/mK, respectively. Thus, the ratio of the thermal conductivities for quartz, water, and air is 333:23:1. Because of this huge difference, it is obvious that the thermal conductivity of a granular ground will depend on the intimacy of the contact of the solid particles and the extent to which air is displaced by water in the pore spaces between the particles (Jury W. and Horton R., 2004).

Table 3.1. Thermal properties of various ground types (Yılmaz T. 2004)

Material	a [mm ² /s]	k (W/m°C)
Ground, siliceous	0.139	0.52
Ground, sandy	-	1.07
Ground, humid-heavy	0.648	1.3
Ground, dry, heavy	0.521	0.95
Ground, dry light	0.278	-
Ground, humid, light	0.555	0.87
Stone, granite	1.134	2.93
Stone, marble	1.331	2.8
Water	0.139	0.59
Air	21.47	0.026

Table 3.2. Thermal properties of ground constituents, in 10°C (Ice: 0°C) (Yılmaz T., 2004)

Ground Constituents	Density (ρ)	Specific Heat (c)	Thermal Conductivity (k)
	kg/m ³	J/kg°C	W/mK
Quartz	2660	755.4	8.5
Other minerals (Average)	2650	758.2	2.9
Organic Material	1300	1932	0.25
Water (liquid)	1000	4186	0.59
Ice	920	2047.5	2.2
Air	1.25	10046.4	0.026

The relative size of the thermal conductivity of different grounds follows the order sand>loam>clay>peat. Since the thermal conductivities of the mineral components of the solid phase are all of the same order of magnitude, thermal conductivity differences between grounds at the same dryness are related to their packing and porosity (Jury W. and Horton R., 2004).

Increasing the bulk density of grounds lowers the porosity and improves the thermal contact between the solid particles as well as reduces the volume of low-conducting air. The impact of ground porosity on thermal conductivity is shown in figures 3.12 and 3.13 (Jury W. and Horton R., 2004).

The increase in thermal conductivity as a result of raising the ground bulk density within normal ranges is small compared with the impact of adding water to the ground. The presence of water films at the points of contact between particles not only improves the thermal contact between adjacent solids but also replaces air in the ground pore space with water, which has over 20 times the thermal conductivity of air. The curves in figures 3.12 and 3.13 point out quite clearly the rapid increases in thermal conductivity and diffusivity as the percentage of water in the ground pore space rises. The greatest rate of increase in conductivity occurs at the lower moisture contents. When the water saturation values rise to 50%, the ratios range from 6.7 to 8.6, showing that the effect of bulk density on thermal conductivity is greater at higher moisture contents (Jury W. and Horton R., 2004).

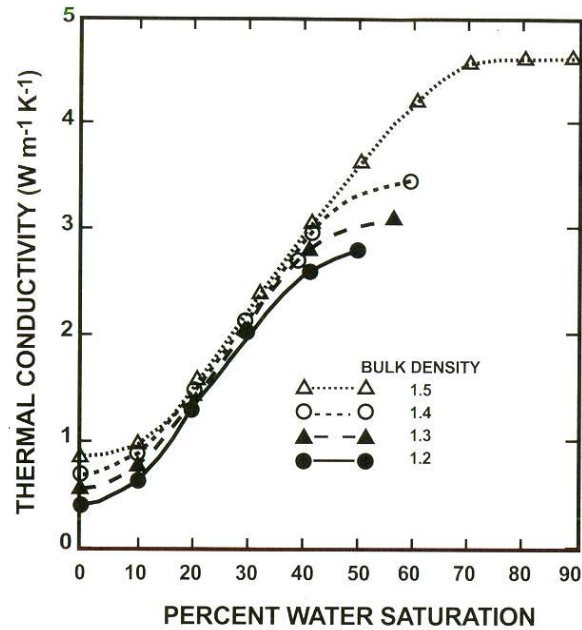


Figure 3.12. Ground thermal conductivity-water content relation as affected bulk density (Jury W. and Horton R., 2004)

3.5.2. Thermal Diffusivity

Thermal diffusivity (Figure 3.13b) increases rapidly with increasing water content to a maximum and then decreases with further increases in water content. This is explained by the fact that heat capacity rises linearly with water content. The thermal conductivity of several grounds is related linearly to volumetric air content (Figure 3.14) (Jury W. and Horton R., 2004).

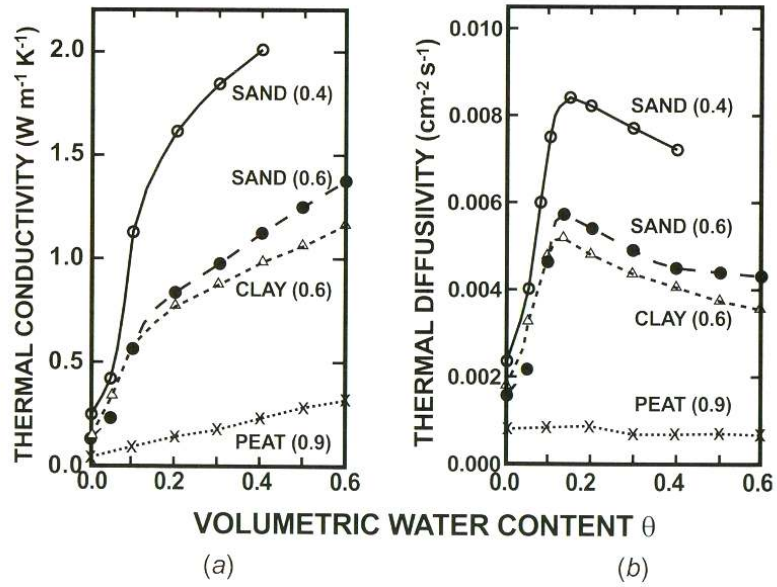


Figure 3.13. Ground thermal conductivity (a) and thermal diffusivity (b) as a function of water content for various ground types (Jury W. and Horton R., 2004)

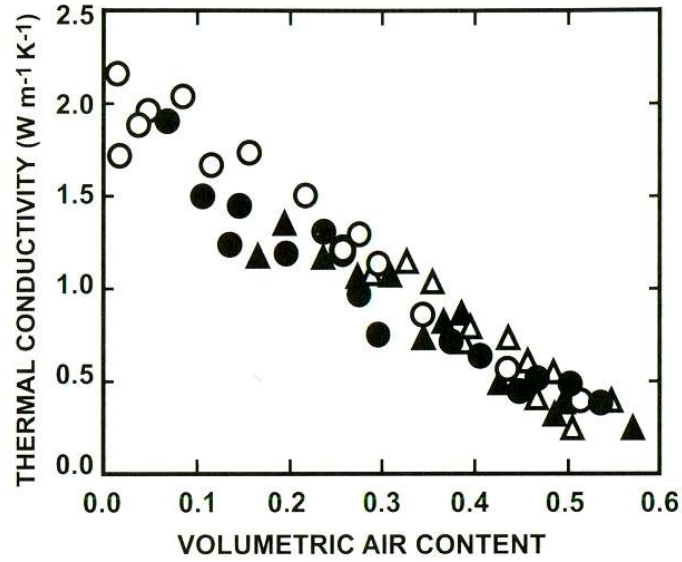


Figure 3.14. Thermal conductivity versus volumetric air content for four different ground types (Jury W. and Horton R., 2004).

3.6. Calculations for One Layer Ground Model

3.6.1. Calculation of Solar-Equivalent Temperature (T_{se})

Figures 3.15, 3.16, 3.17 and 3.18 show yearly variation of daily mean solar radiation, ambient temperature, relative humidity and wind velocity for the year 2000 in Adana. 20 years daily mean values of solar radiation ($\dot{q}$), ambient temperature (T_a), relative humidity (ϕ) and wind velocity (u) which are measured by The State Meteorological Affairs General Directorate (DMI) for Adana are used in numerical calculations. The yearly variation of 20 years daily mean values of $\dot{q}$, T_a , ϕ and u for Adana are demonstrated in figures 3.19, 3.20, 3.21 and 3.22. Fluctuation of 20 years daily values is less than that of the year 2000.

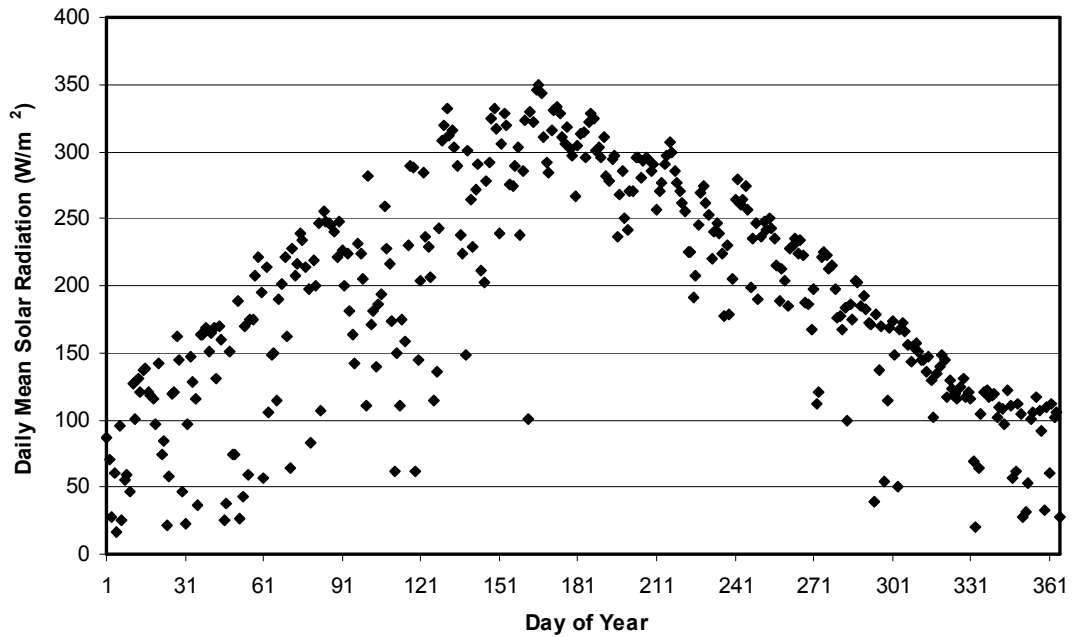


Figure 3.15. Yearly variation of daily mean solar radiation for the year 2000 for Adana

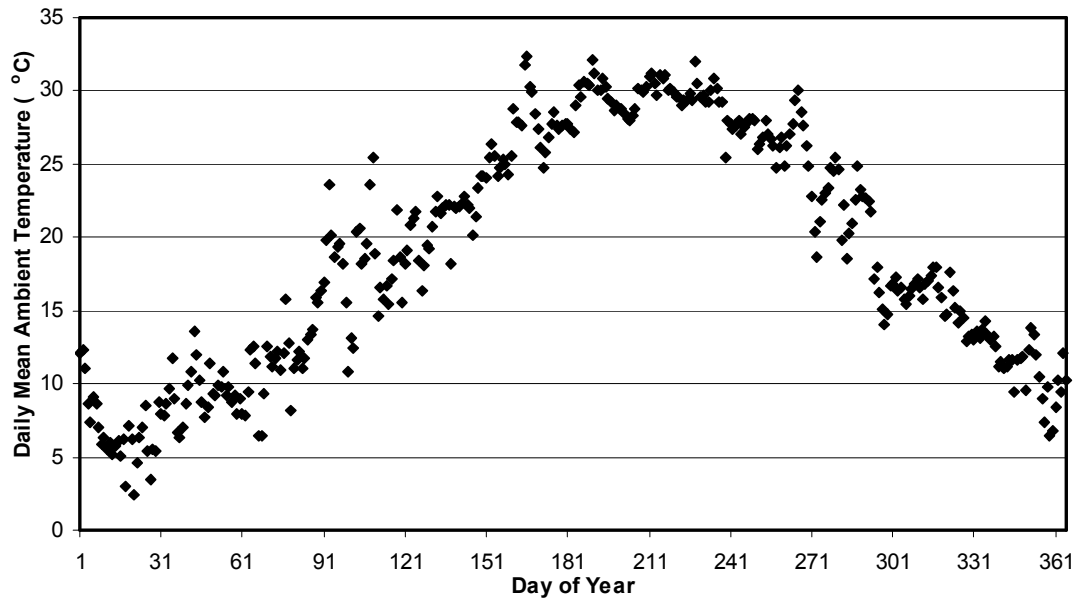


Figure 3.16. Yearly variation of daily mean ambient temperature for the year 2000 for Adana

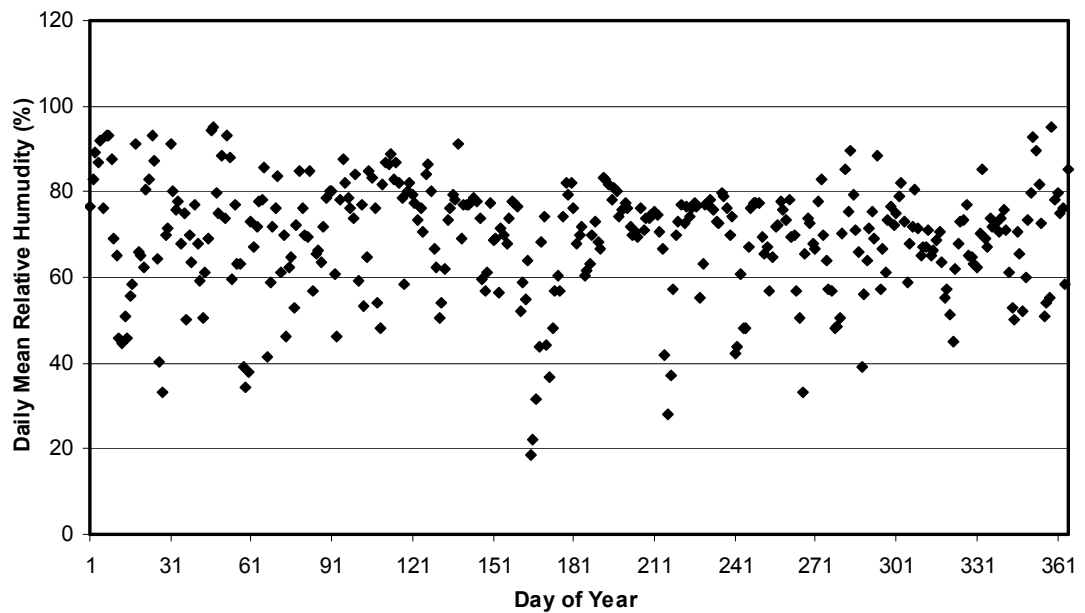


Figure 3.17. Yearly variation of daily mean relative humidity for the year 2000 for Adana

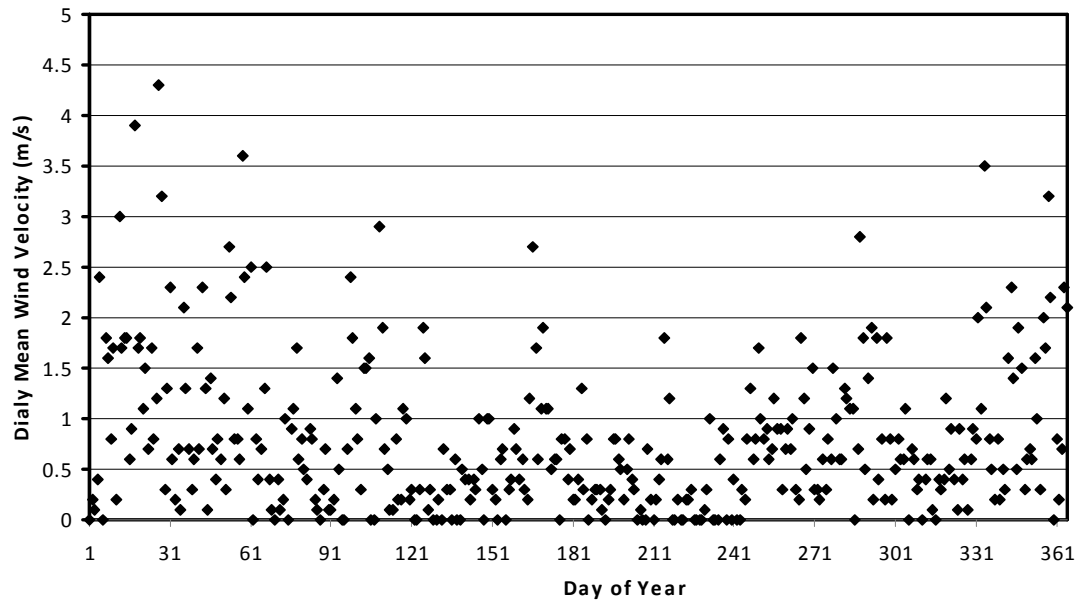


Figure 3.18. Yearly variation of daily mean wind velocity for the year 2000 for Adana

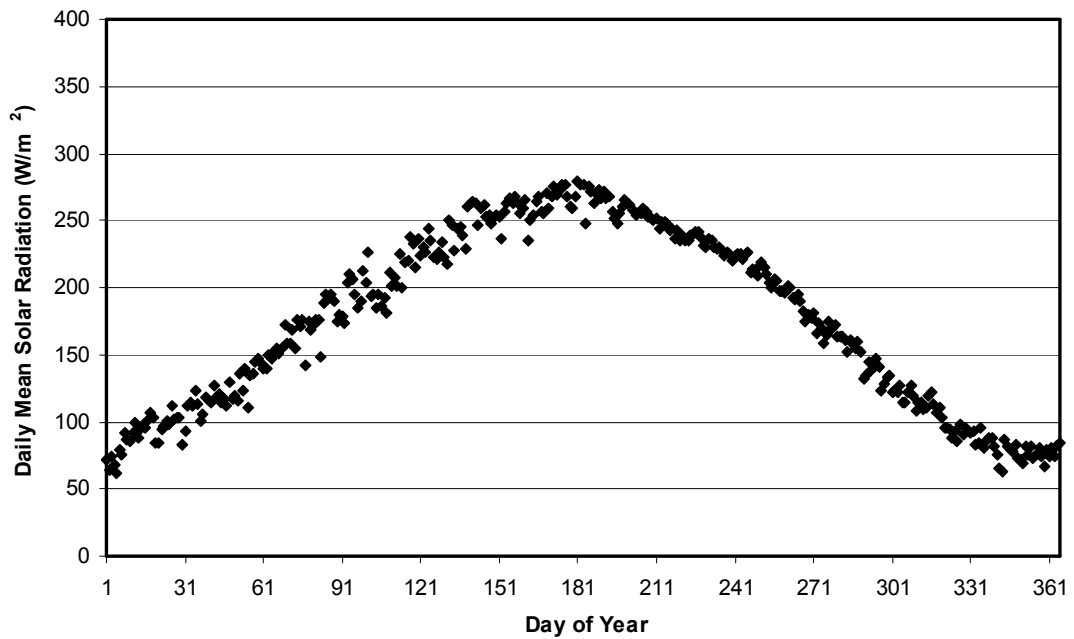


Figure 3.19. Yearly variation of 20 years daily mean solar radiation for Adana

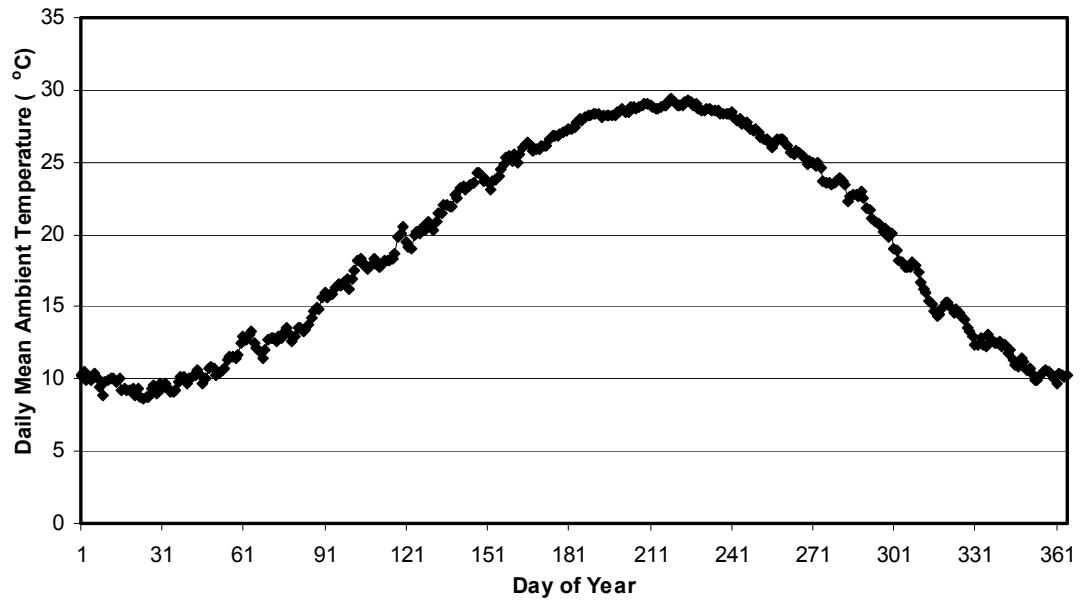


Figure 3.20. Yearly variation of 20 years daily mean ambient temperature for Adana

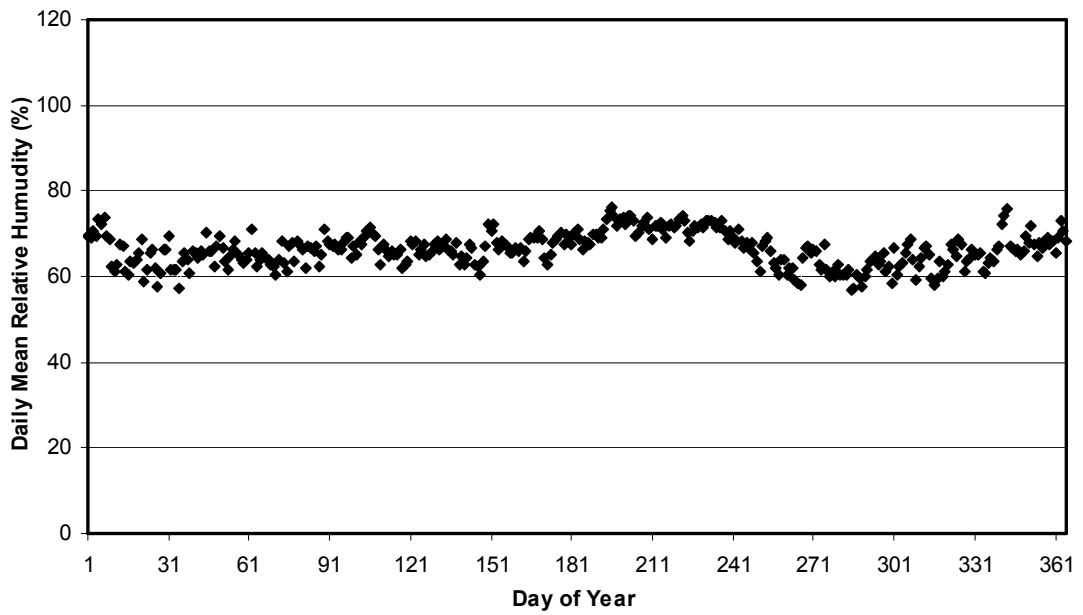


Figure 3.21. Yearly variation of 20 years daily mean relative humidity for Adana

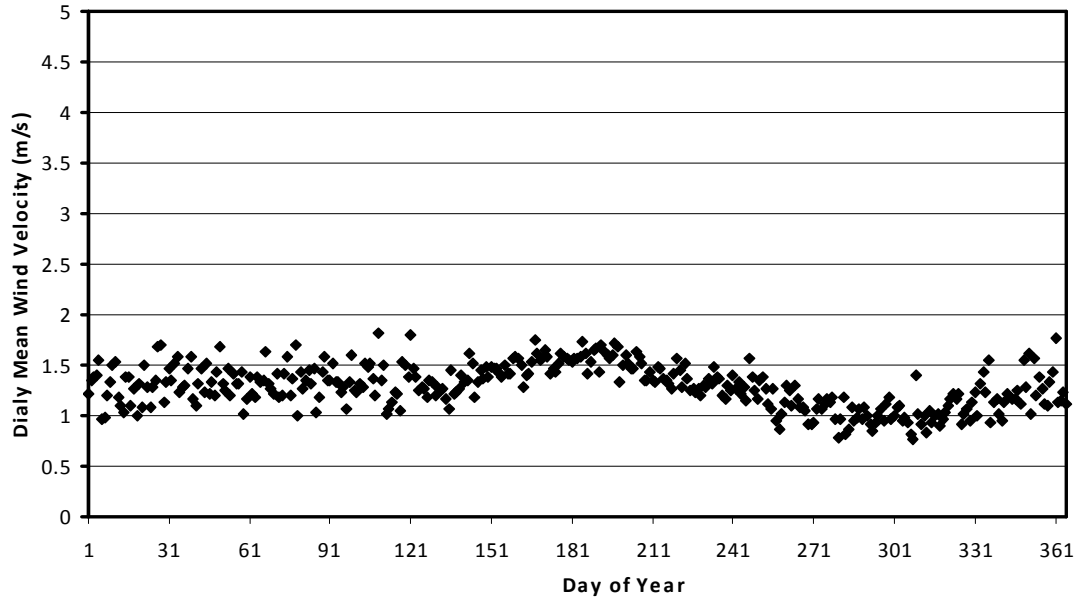


Figure 3.22. Yearly variation of 20 years daily mean wind velocity for Adana

Figure 3.23 shows the values of T_{se} for Adana by using 20 years daily mean values and the values given in eq.(3.4). T_{se} values calculated by using the value of a_s 0.8 instead of 0.9 are shown in figure 3.24. The temperature difference between figures 3.19 and 3.20 is up to 2.7 °C. It is clear that a_s value affects the T_{se} .

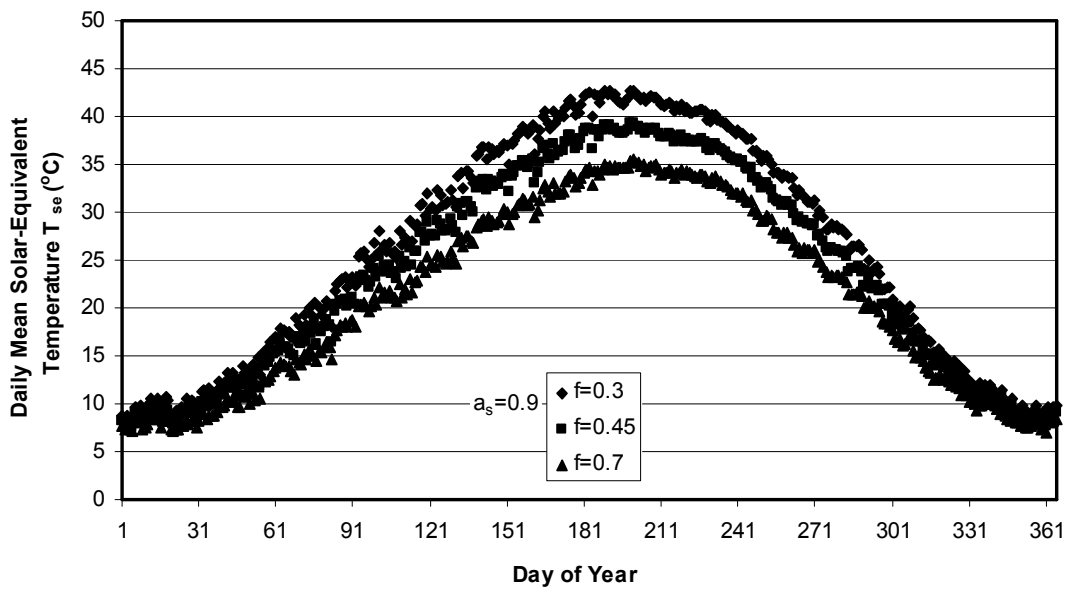


Figure 3.23. Yearly variation of daily mean solar equivalent temperature for different f values for Adana ($k=1.142$ W/mK, $a=0.02186$ m²/day, $a_s=0.9$)

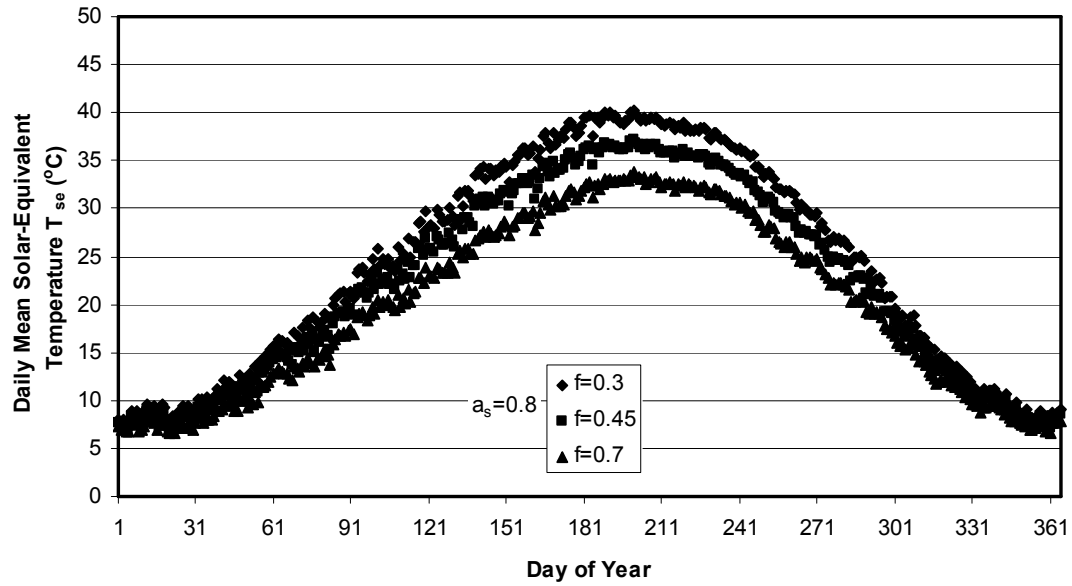


Figure 3.24. Yearly variation of daily mean solar equivalent temperature for different f values for Adana ($k=1.142$ W/mK, $a=0.02186$ m²/day, $a_s=0.8$)

3.6.2. Analytical Calculations

Analytically obtained results are used to test the accuracy of the results obtained numerically from one layer ground model. In this way, the accuracy of the results obtained numerically from multi-layered ground model will be used.

Yearly mean value of wind velocity ($u_{wv}=1.29$ m/s) must be used in analytical calculations for the whole year. Yearly variation of T_{se} values calculated by using yearly mean wind velocity is shown in figure 3.23.

This sinusoidal curve in figure 3.23 was calculated according to Statistica program and T_{sem} , ΔT_{se} and ϕ_{se} coefficients in eq.(3.25) are given for 20 years daily mean T_{se} values and 0.3, 0.45 and 0.7 values of f . 0.3 and 0.45 values of f are valid for dry and humid grounds which is covered with grass, and 0.45 and 0.7 values of f are valid for dry and humid bare grounds, respectively.

T_{sem} , ΔT_{se} and ϕ_{se} coefficients calculated for 0.3, 0.45 and 0.7 values of f are shown in table 3.3. There are temperature differences of 1 °C in winter months and 4 °C in summer months in solar-equivalent temperature (T_{se}) for dry and humid bare grounds. Also there are temperature differences of 1 °C in winter months and 3 °C in

summer months in solar-equivalent temperature (T_{se}) of covered, humid and bare grounds. It is seen that ground moisture and surface cover affect the solar-equivalent temperature.

In table 3.3 besides the coefficients about T_{se} , there are the coefficients of T_{sm} , ΔT_{sm} , ϕ_s and $t_{min,s}^*$ related to ground surface temperature (T_s). Ground physical properties k and a must be known in the calculation of ground surface temperatures. The results in table 3.3 are valid for the following values of k and a :

$$\begin{aligned} k &= 1.142 \text{ W/mK} \\ a &= 2.53 \times 10^{-7} \text{ m}^2/\text{s} \end{aligned} \quad (3.86)$$

Table 3.3. Variation of the parameters of solar-equivalent and ground surface temperatures with f values. ($a_s=0.9$, $\varepsilon_e=1.0$, $k=1.142$, $a=2.53 \times 10^{-7}$)

		T_{sem} and T_{sm}	ΔT_{se} and ΔT_s	ϕ_{se} and ϕ_s	$t_{min,se}^*$ and $t_{min,s}$	$t_{min,se}$ and $t_{min,s}$
f=0.3	T_{se}	25.7636	-16.5113	1.3789	0.0305	11.13
	T_s	25.7636	-15.3882	1.3130	0.0410	14.97
f=0.45	T_{se}	23.5850	-15.1180	1.3638	0.0329	12.01
	T_s	23.5850	-14.2346	1.3069	0.0420	15.33
f=0.7	T_{se}	21.0914	-13.5246	1.3428	0.0363	13.25
	T_s	21.0914	-12.8847	1.2965	0.0437	15.95

3.6.3. Numerical Calculations

Before giving the numerical results, accuracy of the numerical method must be demonstrated. The results are examined by changing of numerical method parameters and they were compared with analytical ones which are shown in chapter 3.6.2.

3.6.3.1. Determining of Numerical Parameters

M , b , β and ground depth L values are the numerical parameters and they are used in numerical calculations. Daily mean values of heat transfer coefficient h are

used in numerical calculations. These calculations are valid for following parameters:
(Prepared computer program for one layer ground model is given in Appendix-1).

$$\begin{array}{lll} a_s=0.9 & \varepsilon_e=1.0 & \Delta R=63 \\ f=0.45 & k=1.142 & a=2.53 \times 10^{-7} \end{array} \quad (3.87)$$

Ground temperatures for first days of the months in a year were given in figures 3.25, 3.26 and 3.27 for different L values depending on x-direction (ground depth). It is shown from these figures that total ground depth in the x-direction (L) must be chosen 10 meters for reliable calculations.

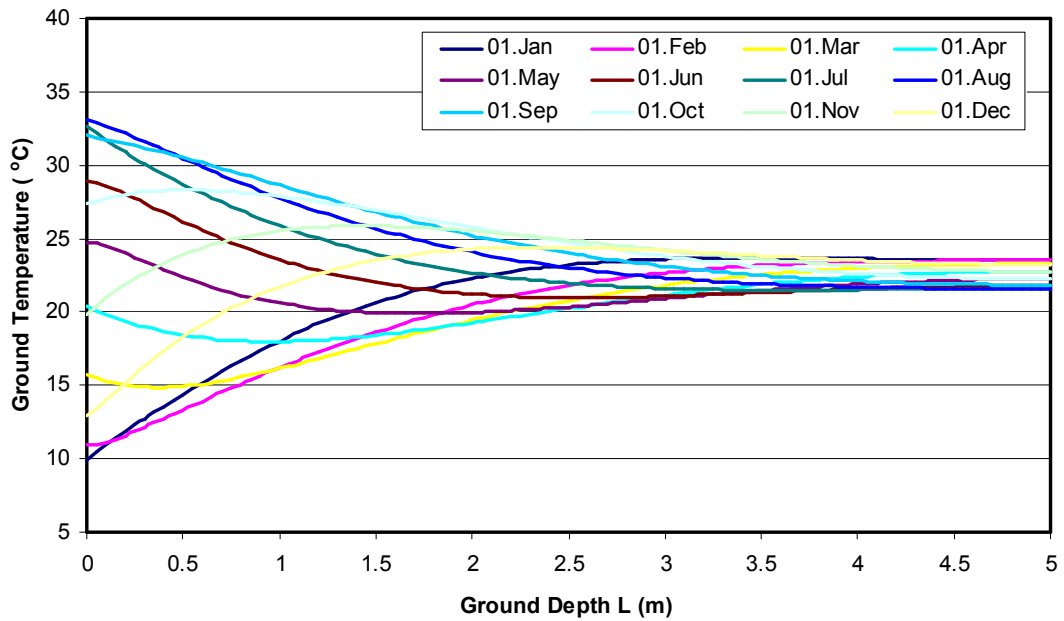


Figure 3.25. Variation of ground temperature with ground depth for L=5.0 m, (k=1.142 W/mK, a=0.02186 m²/day, b=1.0, M=100, a_s=0.9, f=0.45)

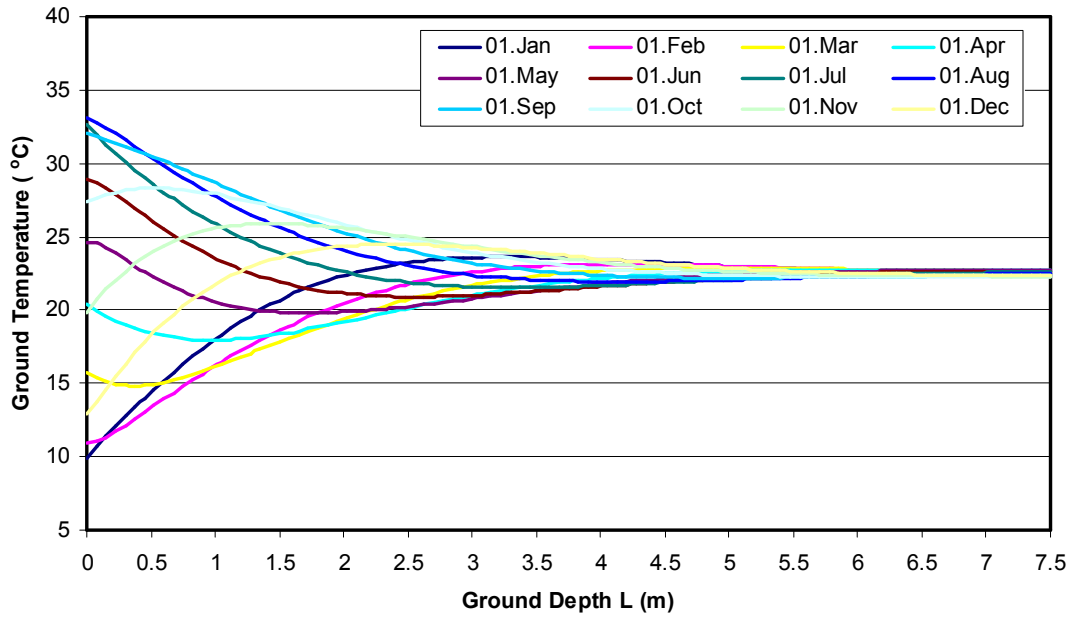


Figure 3.26. Variation of ground temperature with ground depth for $L=7.5$ m, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $M=100$, $a_s=0.9$, $f=0.45$)

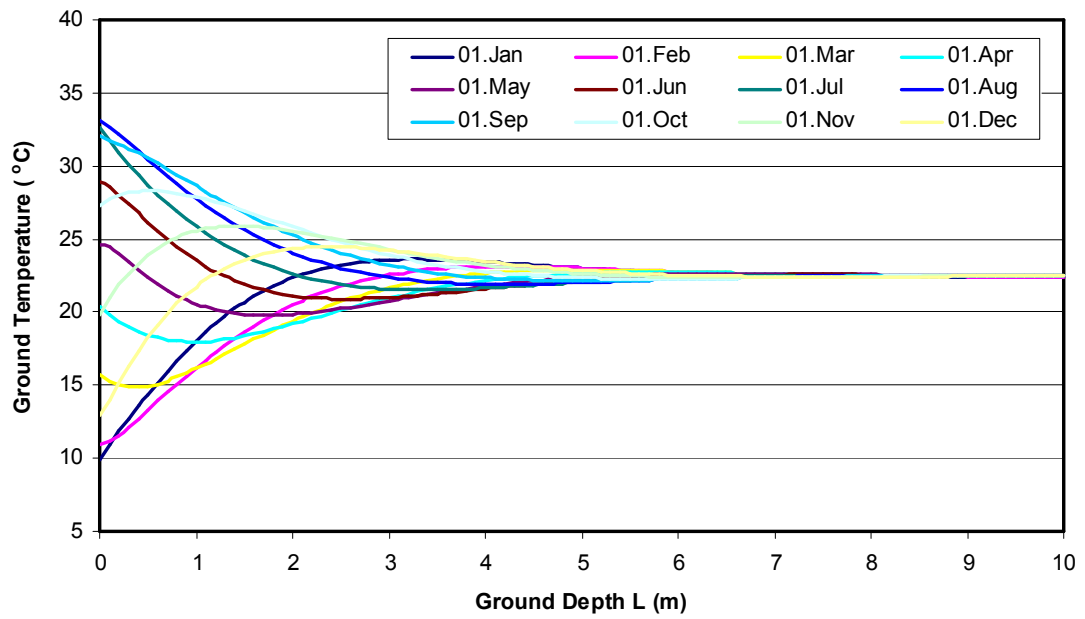


Figure 3.27. Variation of ground temperature with ground depth for $L=10.0$ m, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $M=100$, $a_s=0.9$, $f=0.45$)

Ground temperatures are shown for different step numbers (M) in figures 3.28, 3.29 and 3.30 for January 01 and July 01. In numerical calculations, $M=40$ can be considered as sufficient.

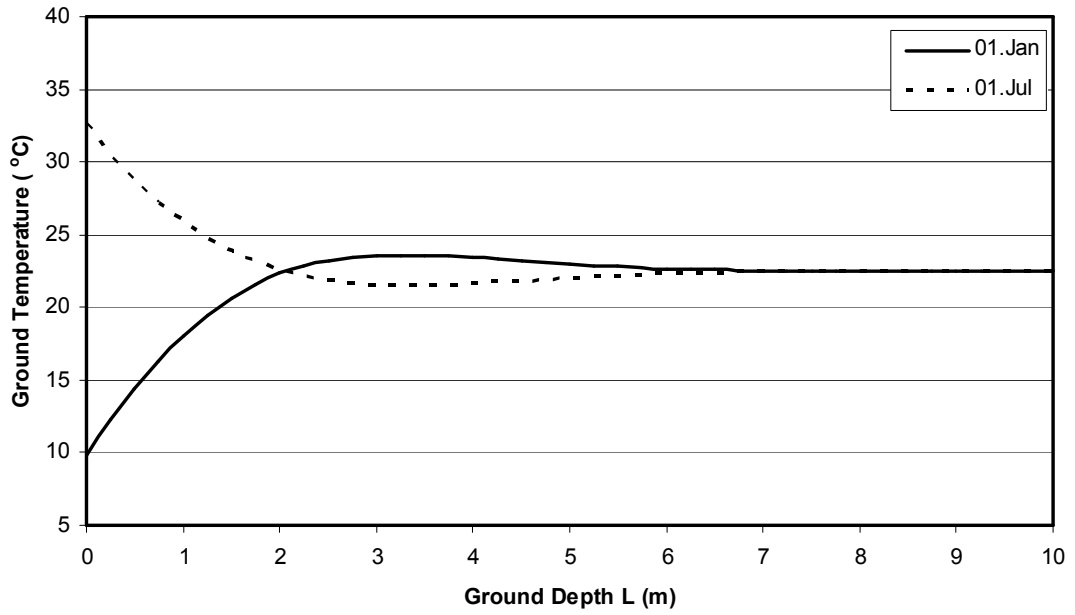


Figure 3.28. Variation of ground temperature with ground depth for $M=40$, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m)

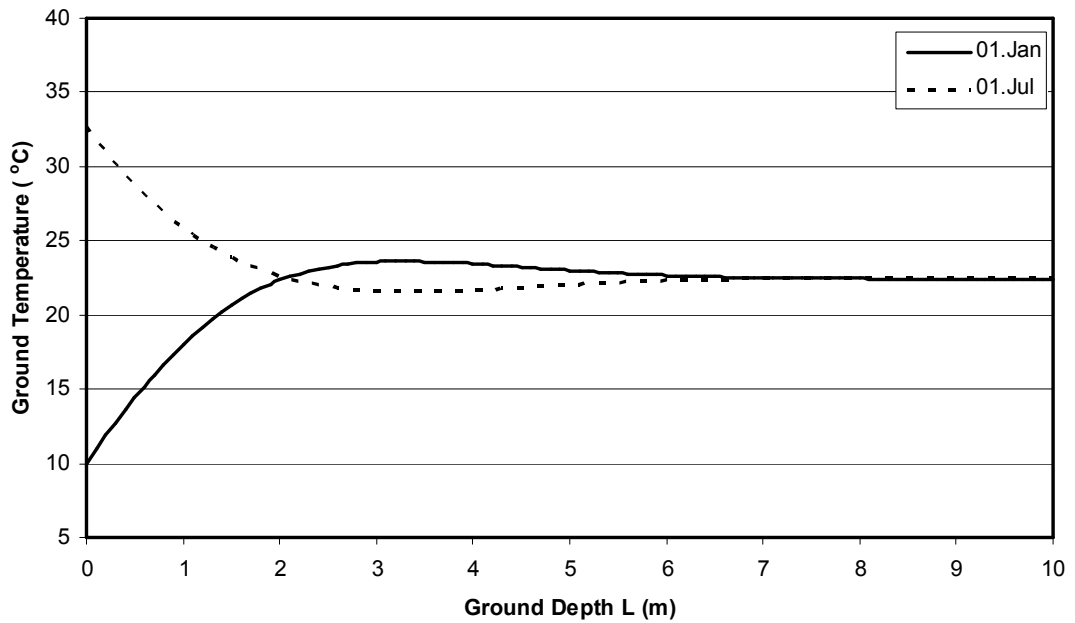


Figure 3.29. Variation of ground temperature with ground depth for $M=100$, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m)

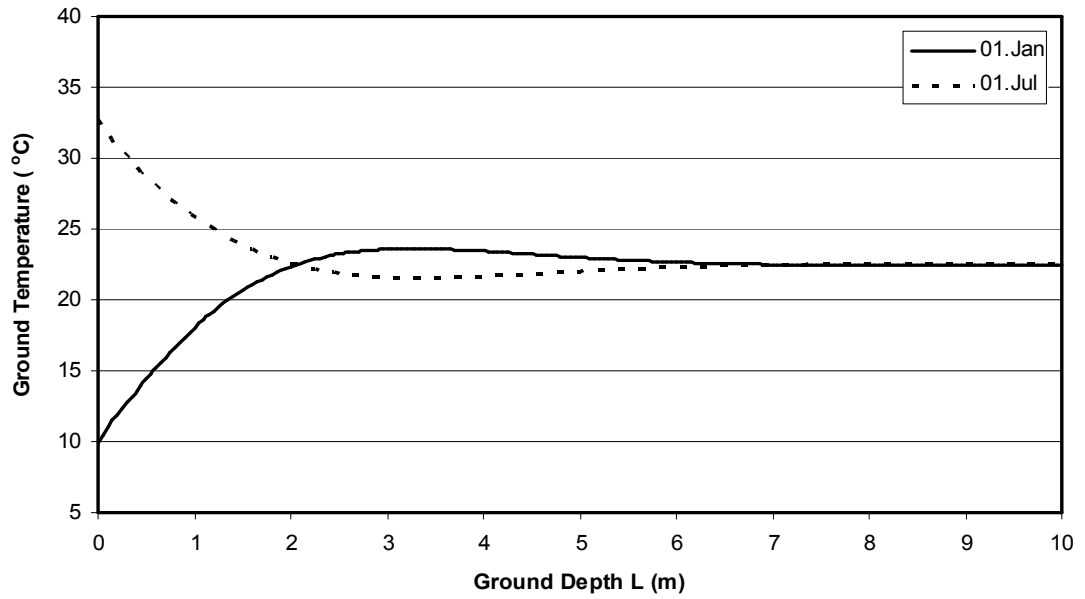


Figure 3.30. Variation of ground temperature with ground depth for $M=200$, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m)

Step increment coefficient (b) is changed in figures 3.31 and 3.32 for January 01 and July 01. It is seen that the results do not change for different b values. Therefore, constant step increment coefficient was used in numerical calculations for one layer ground.

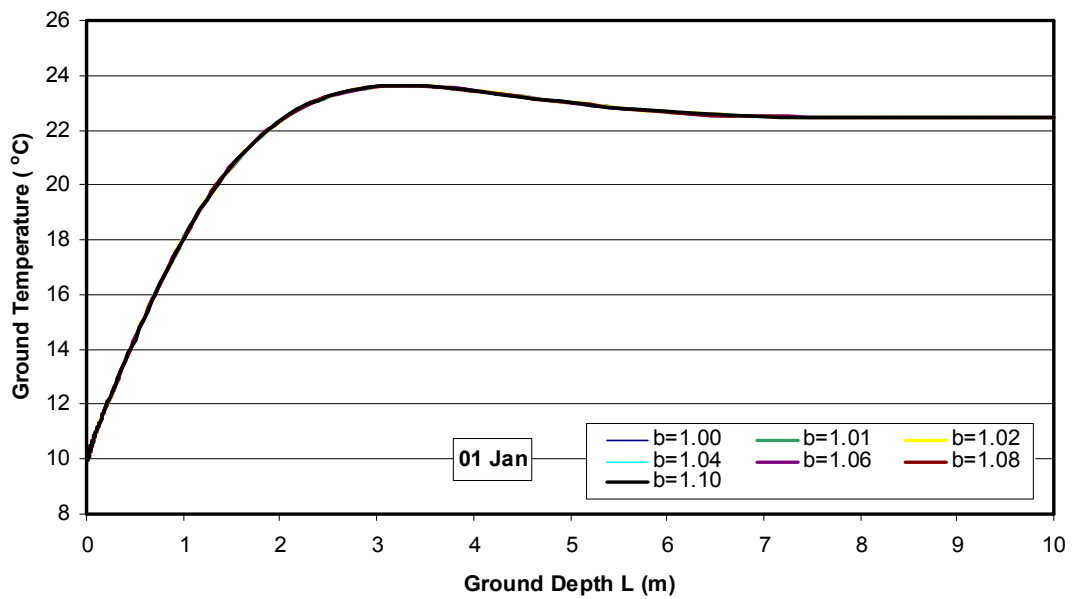


Figure 3.31. Variation of ground temperature with ground depth for different b values for January 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $M=100$, $a_s=0.9$, $f=0.45$, $L=10$ m)

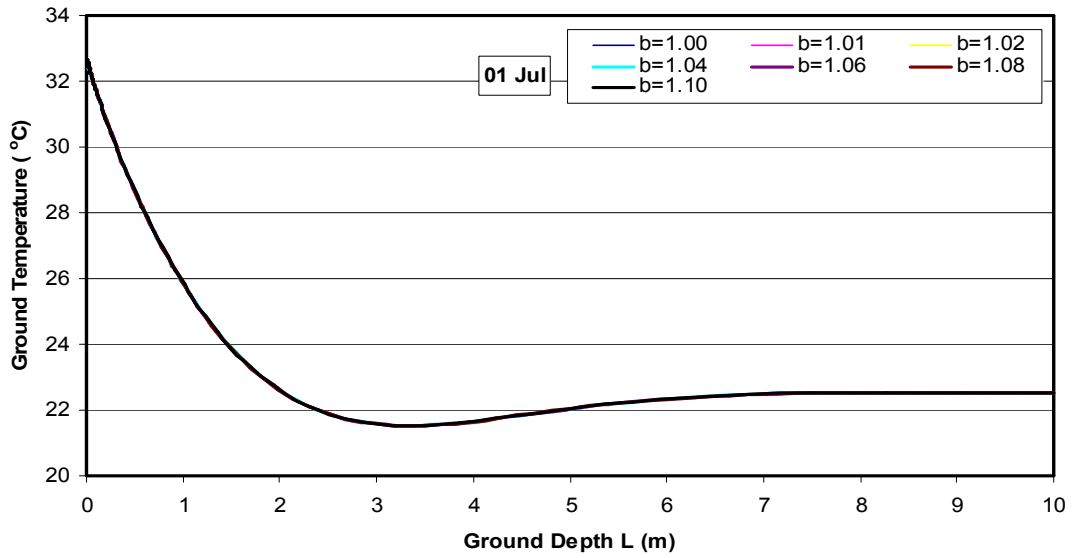


Figure 3.32. Variation of ground temperature with ground depth for different b values for July 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $M=100$, $a_s=0.9$, $f=0.45$, $L=10$ m)

β was changed in figures 3.33 and 3.34 for January 01 and July 01. There was no change in the ground temperatures in different depths for different β values (curves are overlapping). The value of β can be selected between 0.5 and 1.0 in numerical calculations. The value of β is accepted as 0.50 (Crank-Nicolson method) in the calculations.

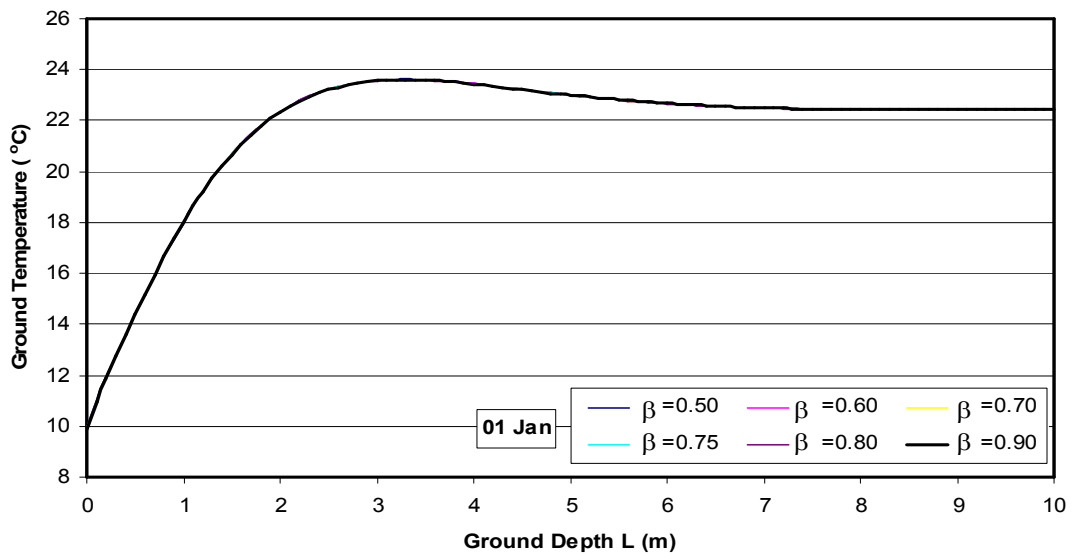


Figure 3.33. Variation of ground temperature with ground depth for different β values for January 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $M=100$, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m)

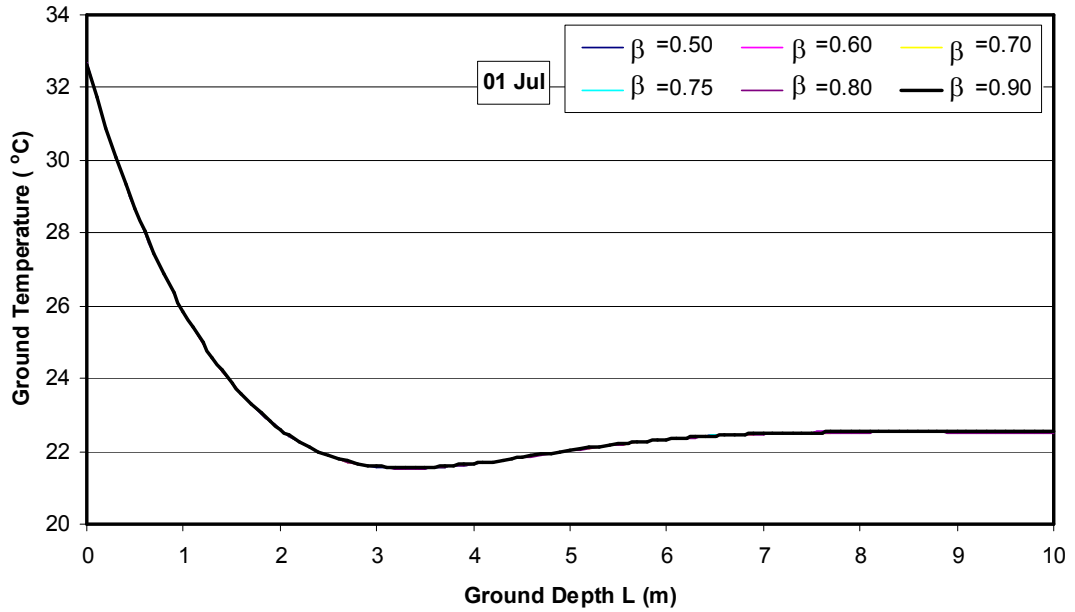


Figure 3.34. Variation of ground temperature with ground depth for different β values for July 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $M=100$, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m)

3.6.3.2. Comparison of Analytical and Numerical Calculations

3.6.3.2.(1). All Input Values are the Same

In comparison of analytical results with numerical ones, heat transfer coefficient was calculated from the annual mean wind speed in the numerical calculations. Daily average wind speeds were entered in to the prepared program as yearly mean wind speed and constant throughout the year.

Ground and ground surface temperatures obtained analytically and numerically for January 01 and July 01 are compared in figures 3.35, 3.36 and 3.37 for $f=0.45$. The differences between the results obtained from the two methods can be neglected. There is a comparison of ground and ground surface temperatures obtained analytically and numerically for January 01 and July 01 in tables 3.4 and 3.5 for 20 years daily mean values of Adana. The highest temperature differences occur near the ground surface. These results show the reliability of the numerical method.

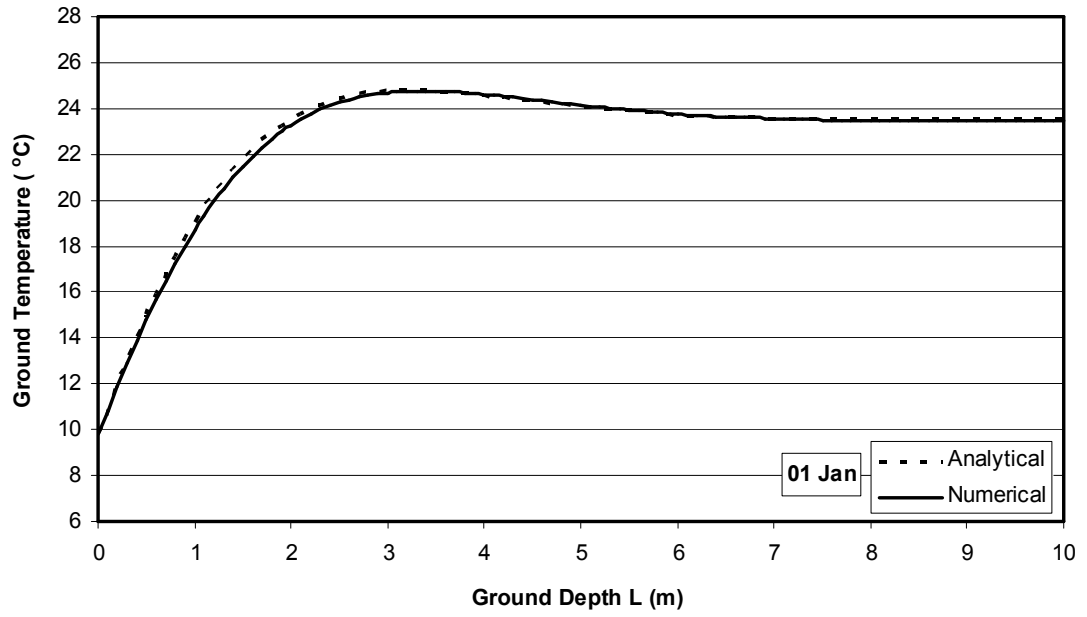


Figure 3.35. Comparison of analytical and numerical results for January 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m).

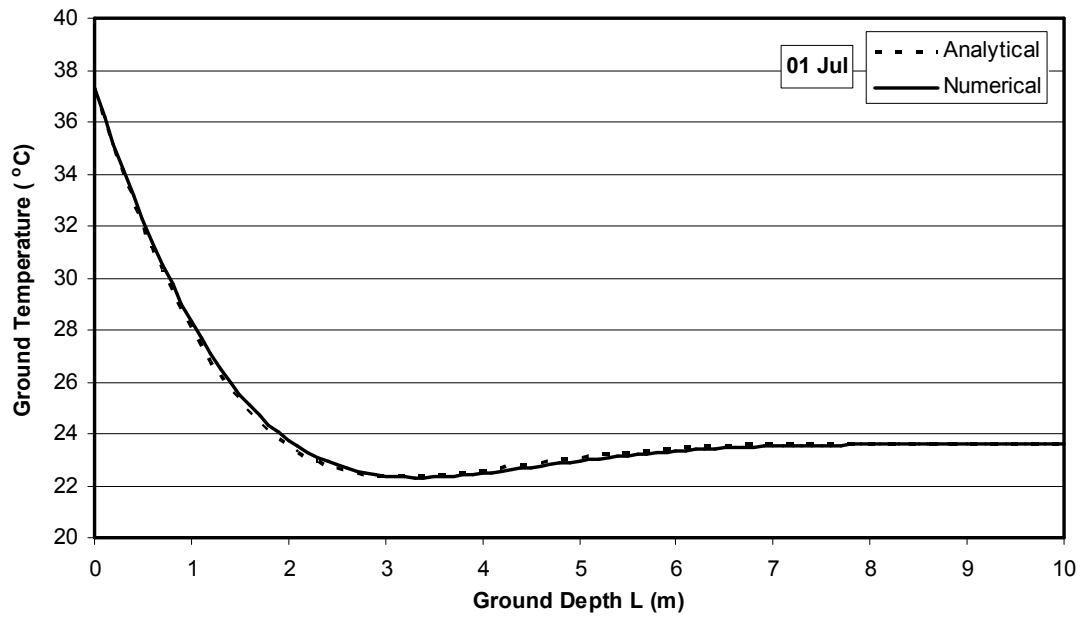


Figure 3.36. Comparison of analytical and numerical results for July 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m).

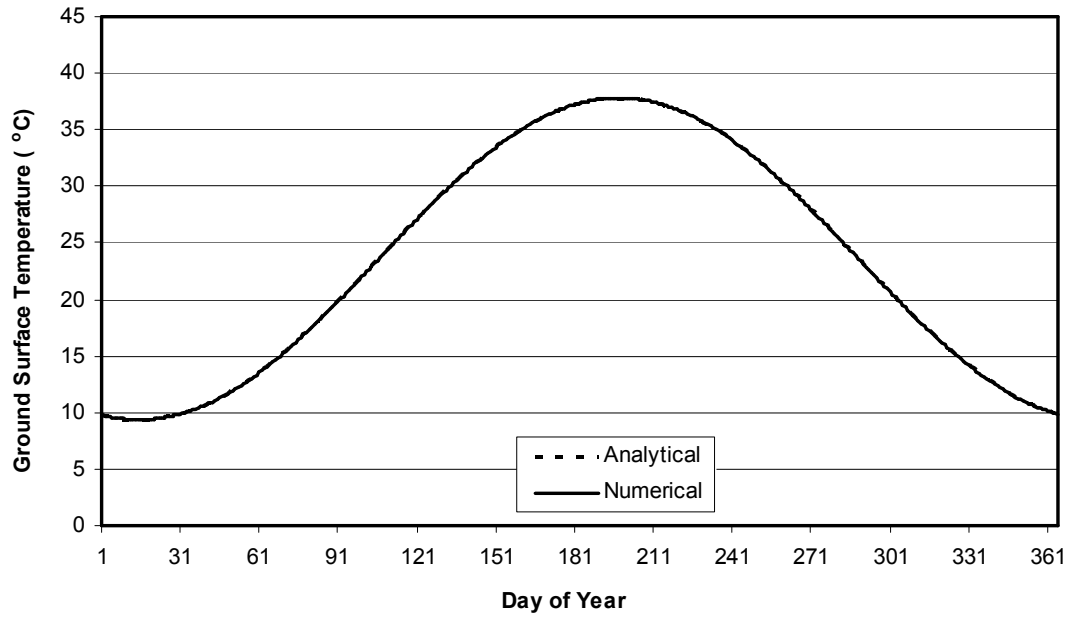


Figure 3.37. Comparison of yearly analytical and numerical results, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $b=1.0$, $a_s=0.9$, $f=0.45$, $L=10$ m).

Table 3.4. Comparison of analytical and numerical ground temperatures with depth for January 01 and July 01 in Adana

Ground Depth L (m)	01 Jan, (°C) Analytical	01 Jan, (°C) Numerical	01 Jul, (°C) Analytical	01 Jul, (°C) Numerical
0.00	9.78	9.78	37.29	37.29
0.10	10.90	10.85	36.16	36.20
0.20	11.98	11.89	35.07	35.15
0.30	13.02	12.89	34.01	34.14
0.40	14.02	13.85	33.00	33.17
0.50	14.98	14.77	32.05	32.24
0.60	15.88	15.65	31.14	31.36
0.70	16.74	16.48	30.28	30.52
0.80	17.55	17.26	29.47	29.74
0.90	18.30	18.00	28.71	29.00
1.00	19.01	18.70	28.01	28.30
1.10	19.66	19.34	27.36	27.66
1.20	20.27	19.94	26.75	27.06
1.30	20.83	20.50	26.20	26.50
1.40	21.34	21.02	25.69	25.99
1.50	21.81	21.49	25.23	25.52
1.60	22.23	21.92	24.81	25.09
1.70	22.62	22.31	24.43	24.70
1.80	22.96	22.67	24.10	24.35
1.90	23.27	22.99	23.80	24.04
2.00	23.54	23.27	23.53	23.76
2.10	23.78	23.53	23.30	23.51
2.20	23.98	23.75	23.10	23.29
2.30	24.16	23.95	22.93	23.09
2.40	24.32	24.12	22.78	22.93
2.50	24.44	24.26	22.66	22.79
2.60	24.55	24.39	22.56	22.67
2.70	24.63	24.49	22.48	22.57
2.80	24.70	24.57	22.42	22.49
2.90	24.75	24.64	22.38	22.43
3.00	24.78	24.69	22.35	22.38
3.10	24.80	24.73	22.34	22.35
3.20	24.81	24.75	22.33	22.33
3.30	24.80	24.76	22.34	22.32
3.40	24.79	24.76	22.36	22.32
3.50	24.77	24.75	22.38	22.33
3.60	24.74	24.74	22.41	22.35
3.70	24.71	24.71	22.45	22.37
3.80	24.67	24.68	22.49	22.40
3.90	24.63	24.65	22.54	22.44
4.00	24.58	24.61	22.58	22.48
4.10	24.53	24.57	22.63	22.52
4.20	24.48	24.53	22.69	22.57
4.30	24.43	24.48	22.74	22.61
4.40	24.38	24.43	22.79	22.66

Table 3.4. (Continued) Comparison of analytical and numerical ground temperatures with depth for January 01 and July 01 in Adana

Ground Depth L (m)	01 Jan, (°C) Analytical	01 Jan, (°C) Numerical	01 Jul, (°C) Analytical	01 Jul, (°C) Numerical
4.50	24.33	24.38	22.84	22.71
4.60	24.28	24.33	22.90	22.76
4.70	24.23	24.28	22.95	22.81
4.80	24.18	24.24	23.00	22.86
4.90	24.13	24.19	23.05	22.91
5.00	24.08	24.14	23.09	22.95
5.10	24.04	24.09	23.14	23.00
5.20	23.99	24.05	23.18	23.04
5.30	23.95	24.00	23.22	23.09
5.40	23.91	23.96	23.26	23.13
5.50	23.88	23.92	23.30	23.17
5.60	23.84	23.88	23.33	23.20
5.70	23.81	23.85	23.37	23.24
5.80	23.78	23.81	23.40	23.27
5.90	23.75	23.78	23.43	23.30
6.00	23.73	23.75	23.45	23.33
6.10	23.70	23.72	23.47	23.36
6.20	23.68	23.70	23.50	23.38
6.30	23.66	23.67	23.52	23.41
6.40	23.64	23.65	23.53	23.43
6.50	23.63	23.63	23.55	23.45
6.60	23.61	23.61	23.56	23.47
6.70	23.60	23.59	23.58	23.48
6.80	23.59	23.58	23.59	23.50
6.90	23.58	23.56	23.60	23.51
7.00	23.57	23.55	23.61	23.52
7.10	23.56	23.54	23.61	23.53
7.20	23.55	23.53	23.62	23.54
7.30	23.55	23.52	23.63	23.55
7.40	23.54	23.51	23.63	23.56
7.50	23.54	23.50	23.63	23.56
7.60	23.54	23.50	23.64	23.57
7.70	23.53	23.49	23.64	23.57
7.80	23.53	23.49	23.64	23.58
7.90	23.53	23.48	23.64	23.58
8.00	23.53	23.48	23.64	23.58
8.10	23.53	23.48	23.64	23.59
8.20	23.53	23.48	23.64	23.59
8.30	23.53	23.47	23.64	23.59
8.40	23.54	23.47	23.64	23.59
8.50	23.54	23.47	23.63	23.59
8.60	23.54	23.47	23.63	23.59
8.70	23.54	23.47	23.63	23.59
8.80	23.54	23.47	23.63	23.59
8.90	23.54	23.47	23.63	23.59
9.00	23.55	23.47	23.62	23.59

Table 3.4. (Continued) Comparison of analytical and numerical ground temperatures with depth for January 01 and July 01 in Adana

Ground Depth L (m)	01 Jan, (°C) Analytical	01 Jan, (°C) Numerical	01 Jul, (°C) Analytical	01 Jul, (°C) Numerical
9.10	23.55	23.47	23.62	23.59
9.20	23.55	23.47	23.62	23.58
9.30	23.55	23.47	23.62	23.58
9.40	23.56	23.47	23.61	23.58
9.50	23.56	23.47	23.61	23.58
9.60	23.56	23.47	23.61	23.58
9.70	23.56	23.47	23.61	23.58
9.80	23.56	23.47	23.61	23.58
9.90	23.57	23.47	23.60	23.58
10.00	23.57	23.47	23.60	23.58

Table 3.5. Comparison of yearly analytical and numerical ground surface temperatures in Adana

Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)	Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)
1	9.78	9.78	41	10.72	10.72
2	9.72	9.73	42	10.82	10.83
3	9.67	9.67	43	10.94	10.94
4	9.62	9.62	44	11.05	11.05
5	9.57	9.58	45	11.17	11.17
6	9.53	9.54	46	11.29	11.29
7	9.50	9.50	47	11.41	11.42
8	9.46	9.47	48	11.54	11.55
9	9.43	9.44	49	11.68	11.68
10	9.41	9.41	50	11.81	11.82
11	9.39	9.39	51	11.95	11.96
12	9.37	9.38	52	12.09	12.10
13	9.36	9.36	53	12.24	12.24
14	9.35	9.36	54	12.39	12.39
15	9.35	9.35	55	12.54	12.55
16	9.35	9.35	56	12.70	12.70
17	9.36	9.36	57	12.86	12.86
18	9.37	9.37	58	13.02	13.03
19	9.38	9.38	59	13.19	13.19
20	9.40	9.40	60	13.36	13.36
21	9.42	9.42	61	13.53	13.53
22	9.44	9.45	62	13.70	13.71
23	9.47	9.48	63	13.88	13.89
24	9.51	9.51	64	14.06	14.07
25	9.55	9.55	65	14.24	14.25
26	9.59	9.59	66	14.43	14.44
27	9.64	9.64	67	14.62	14.62
28	9.69	9.69	68	14.81	14.82
29	9.74	9.75	69	15.01	15.01
30	9.80	9.81	70	15.20	15.21
31	9.87	9.87	71	15.40	15.41
32	9.93	9.94	72	15.60	15.61
33	10.00	10.01	73	15.81	15.81
34	10.08	10.08	74	16.01	16.02
35	10.16	10.16	75	16.22	16.23
36	10.24	10.25	76	16.43	16.44
37	10.33	10.33	77	16.65	16.65
38	10.42	10.42	78	16.86	16.87
39	10.52	10.52	79	17.08	17.08
40	10.61	10.62	80	17.30	17.30

Table 3.5. (Continued) Comparison of yearly analytical and numerical ground surface temperatures in Adana

Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)	Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)
81	17.52	17.52	121	27.08	27.09
82	17.74	17.75	122	27.32	27.32
83	17.96	17.97	123	27.56	27.56
84	18.19	18.20	124	27.79	27.79
85	18.42	18.42	125	28.02	28.03
86	18.65	18.65	126	28.26	28.26
87	18.88	18.88	127	28.49	28.49
88	19.11	19.11	128	28.72	28.72
89	19.34	19.35	129	28.94	28.95
90	19.58	19.58	130	29.17	29.17
91	19.81	19.82	131	29.39	29.40
92	20.05	20.05	132	29.62	29.62
93	20.29	20.29	133	29.84	29.84
94	20.53	20.53	134	30.06	30.06
95	20.77	20.77	135	30.27	30.28
96	21.01	21.01	136	30.49	30.49
97	21.25	21.25	137	30.70	30.70
98	21.49	21.49	138	30.91	30.92
99	21.73	21.74	139	31.12	31.12
100	21.98	21.98	140	31.33	31.33
101	22.22	22.22	141	31.53	31.54
102	22.46	22.47	142	31.74	31.74
103	22.71	22.71	143	31.94	31.94
104	22.95	22.96	144	32.13	32.13
105	23.20	23.20	145	32.33	32.33
106	23.44	23.45	146	32.52	32.52
107	23.69	23.69	147	32.71	32.71
108	23.93	23.94	148	32.90	32.90
109	24.18	24.18	149	33.08	33.08
110	24.42	24.43	150	33.26	33.26
111	24.67	24.67	151	33.44	33.44
112	24.91	24.91	152	33.62	33.61
113	25.16	25.16	153	33.79	33.79
114	25.40	25.40	154	33.96	33.96
115	25.64	25.64	155	34.12	34.12
116	25.88	25.89	156	34.29	34.29
117	26.12	26.13	157	34.45	34.45
118	26.37	26.37	158	34.60	34.60
119	26.61	26.61	159	34.76	34.76
120	26.84	26.85	160	34.91	34.91

Table 3.5. (Continued) Comparison of yearly analytical and numerical ground surface temperatures in Adana

Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)	Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)
161	35.05	35.05	201	37.80	37.79
162	35.20	35.20	202	37.78	37.78
163	35.34	35.34	203	37.76	37.76
164	35.47	35.47	204	37.74	37.73
165	35.61	35.60	205	37.71	37.71
166	35.74	35.73	206	37.68	37.67
167	35.86	35.86	207	37.64	37.64
168	35.98	35.98	208	37.60	37.60
169	36.10	36.10	209	37.56	37.55
170	36.22	36.22	210	37.51	37.50
171	36.33	36.33	211	37.46	37.45
172	36.44	36.43	212	37.40	37.39
173	36.54	36.54	213	37.34	37.33
174	36.64	36.64	214	37.27	37.27
175	36.73	36.73	215	37.20	37.20
176	36.83	36.82	216	37.13	37.12
177	36.91	36.91	217	37.05	37.05
178	37.00	37.00	218	36.97	36.96
179	37.08	37.08	219	36.88	36.88
180	37.15	37.15	220	36.80	36.79
181	37.23	37.22	221	36.70	36.70
182	37.29	37.29	222	36.61	36.60
183	37.36	37.36	223	36.50	36.50
184	37.42	37.41	224	36.40	36.39
185	37.47	37.47	225	36.29	36.28
186	37.53	37.52	226	36.18	36.17
187	37.57	37.57	227	36.06	36.06
188	37.62	37.61	228	35.94	35.94
189	37.66	37.65	229	35.82	35.81
190	37.69	37.69	230	35.69	35.69
191	37.72	37.72	231	35.56	35.56
192	37.75	37.74	232	35.43	35.42
193	37.77	37.77	233	35.29	35.28
194	37.79	37.78	234	35.15	35.14
195	37.80	37.80	235	35.00	35.00
196	37.81	37.81	236	34.86	34.85
197	37.82	37.81	237	34.70	34.70
198	37.82	37.82	238	34.55	34.54
199	37.82	37.81	239	34.39	34.39
200	37.81	37.81	240	34.23	34.22

Table 3.5. (Continued) Comparison of yearly analytical and numerical ground surface temperatures in Adana

Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)	Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)
241	34.07	34.06	283	25.07	25.07
242	33.90	33.89	284	24.83	24.82
243	33.73	33.72	285	24.58	24.58
244	33.56	33.55	286	24.34	24.33
245	33.38	33.37	287	24.09	24.09
246	33.20	33.19	288	23.85	23.84
247	33.02	33.01	289	23.60	23.60
248	32.83	32.83	290	23.36	23.35
249	32.64	32.64	291	23.11	23.11
250	32.45	32.45	292	22.87	22.86
251	32.26	32.26	293	22.62	22.62
252	32.07	32.06	294	22.38	22.38
253	31.87	31.86	295	22.14	22.13
254	31.67	31.66	296	21.89	21.89
255	31.46	31.46	297	21.65	21.65
256	31.26	31.25	298	21.41	21.40
257	31.05	31.05	299	21.17	21.16
258	30.84	30.84	300	20.92	20.92
259	30.63	30.62	301	20.68	20.68
260	30.42	30.41	302	20.44	20.44
261	30.20	30.19	303	20.21	20.20
262	29.98	29.98	304	19.97	19.96
263	29.76	29.76	305	19.73	19.73
264	29.54	29.53	306	19.50	19.49
265	29.32	29.31	307	19.26	19.26
266	29.09	29.09	308	19.03	19.03
267	28.87	28.86	309	18.80	18.79
268	28.64	28.63	310	18.57	18.56
269	28.41	28.40	311	18.34	18.34
270	28.18	28.17	312	18.11	18.11
271	27.94	27.94	313	17.89	17.88
272	27.71	27.70	314	17.66	17.66
273	27.47	27.47	315	17.44	17.44
274	27.24	27.23	316	17.22	17.22
275	27.00	27.00	317	17.00	17.00
276	26.76	26.76	318	16.79	16.78
277	26.52	26.52	319	16.57	16.57
278	26.28	26.28	320	16.36	16.36
279	26.04	26.04	321	16.15	16.15
280	25.80	25.79	322	15.94	15.94
281	25.56	25.55	323	15.74	15.73
282	25.32	25.31	324	15.53	15.53

Table 3.5. (Continued) Comparison of yearly analytical and numerical ground surface temperatures in Adana

Day of Year	Analytical, T_s (°C)	Numerical, T_s (°C)
325	15.33	15.33
326	15.13	15.13
327	14.94	14.94
328	14.75	14.74
329	14.55	14.55
330	14.37	14.36
331	14.18	14.18
332	14.00	14.00
333	13.82	13.82
334	13.64	13.64
335	13.47	13.47
336	13.30	13.30
337	13.13	13.13
338	12.96	12.96
339	12.80	12.80
340	12.65	12.64
341	12.49	12.49
342	12.34	12.34
343	12.19	12.19
344	12.04	12.04
345	11.90	11.90
346	11.76	11.76
347	11.63	11.63
348	11.50	11.50
349	11.37	11.37
350	11.25	11.25
351	11.13	11.13
352	11.01	11.01
353	10.90	10.90
354	10.79	10.79
355	10.68	10.68
356	10.58	10.58
357	10.48	10.48
358	10.39	10.39
359	10.30	10.30
360	10.21	10.21
361	10.13	10.13
362	10.05	10.05
363	9.98	9.98
364	9.91	9.91
365	9.84	9.84

3.6.3.2.(2). Using of Real Saturation Pressures

Figures 3.38, 3.39 and 3.40 demonstrate the comparison of ground and ground surface temperatures obtained by using the equation used in literature (linear) and the equations given real values in numerical calculations (nonlinear-curvefit) for water vapor partial pressures for 20 years daily mean values of Adana. Moreover, there is a clear difference between the temperatures which are obtained by using of real (nonlinear-real) and curvefitted (nonlinear-curvefit) T_{se} values. Obviously, these results showed the difference between the analytical and numerical ones.

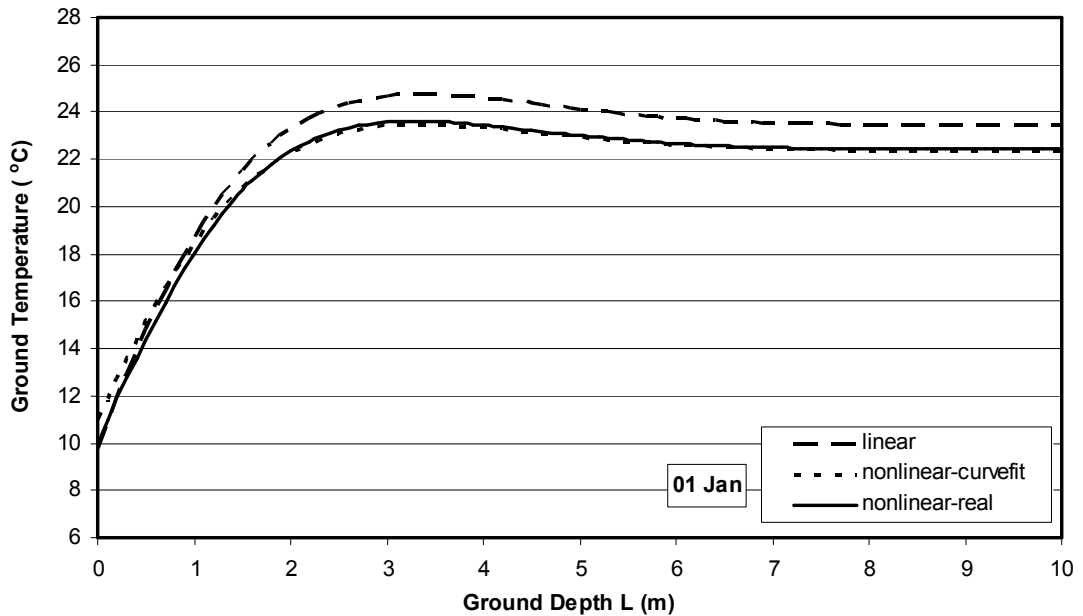


Figure 3.38. Comparison of numerical results for 20 years daily mean values of Adana for January 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $a_s=0.9$, $f=0.45$, $L=10$ m).

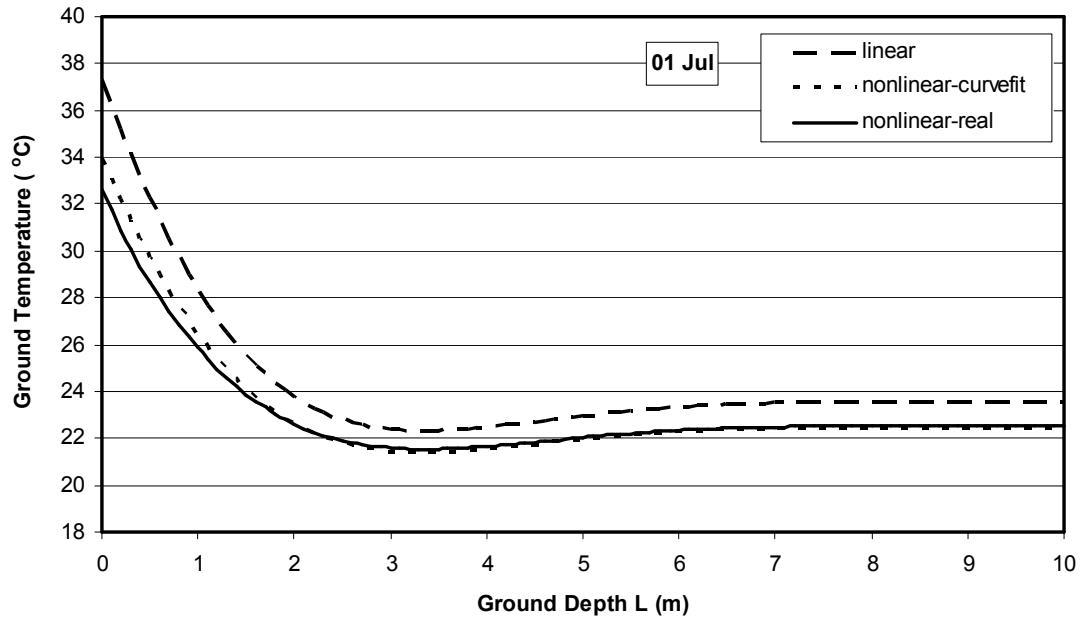


Figure 3.39. Comparison of numerical results for 20 years daily mean values of Adana for July 01, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $a_s=0.9$, $f=0.45$, $L=10$ m).

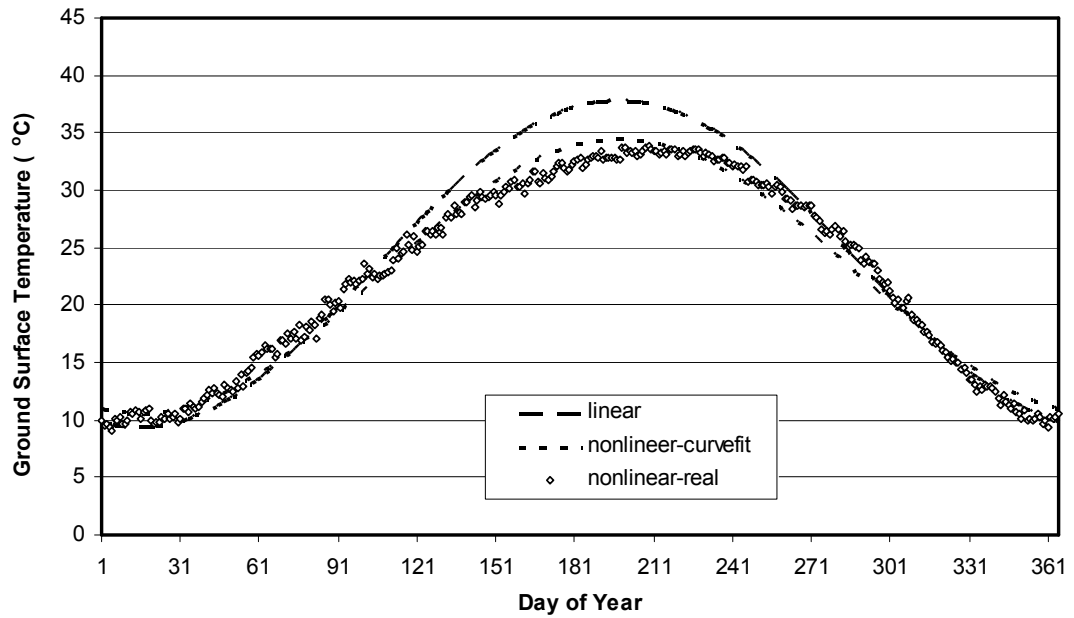


Figure 3.40. Comparison of numerical results for 20 years daily mean values of Adana, ($k=1.142$ W/mK, $a=0.02186$ m²/day, $a_s=0.9$, $f=0.45$, $L=10$ m).

3.7. Calculations for Two Horizontal Layer Ground Model

Firstly, the physical properties of upper and lower layers were assumed as the same and the results were then compared with that of the one layer ground model. (Prepared computer program for two horizontal layer ground model is given in Appendix-2).

Step increment coefficient of upper layer b_1 was changed in figures 3.41 and 3.42. L_1 and L_2 depths were selected as 1 m and 9 m, respectively. It is seen that results don't change for different b_1 values.

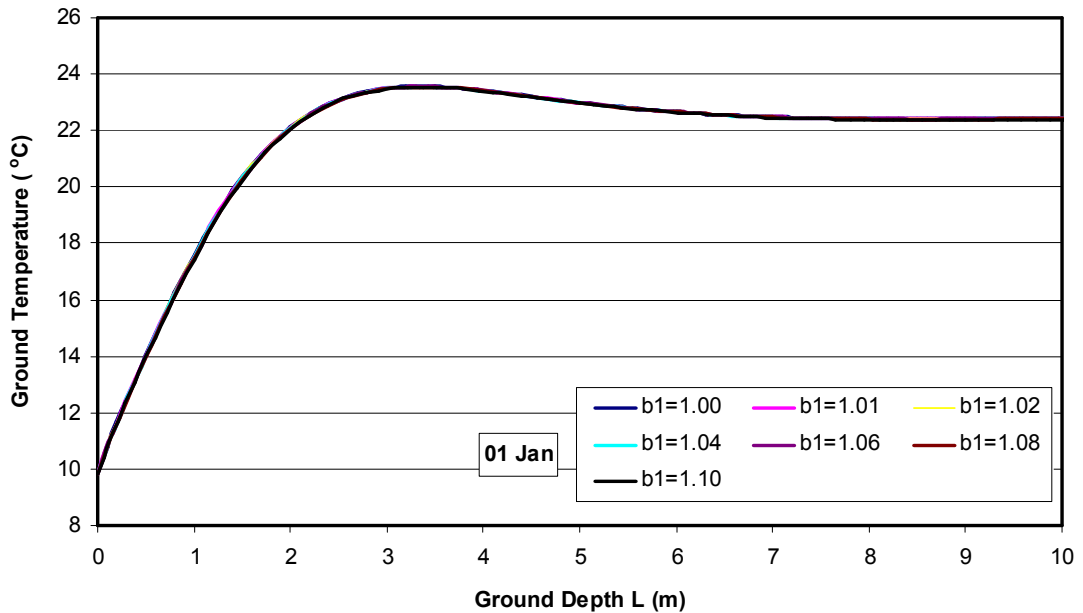


Figure 3.41. Variation of ground temperature with ground depth for different b_1 values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=10$, $N=90$, $a_s=0.9$, $f=0.45$, $L_1=1$ m, $L_2=9$ m).

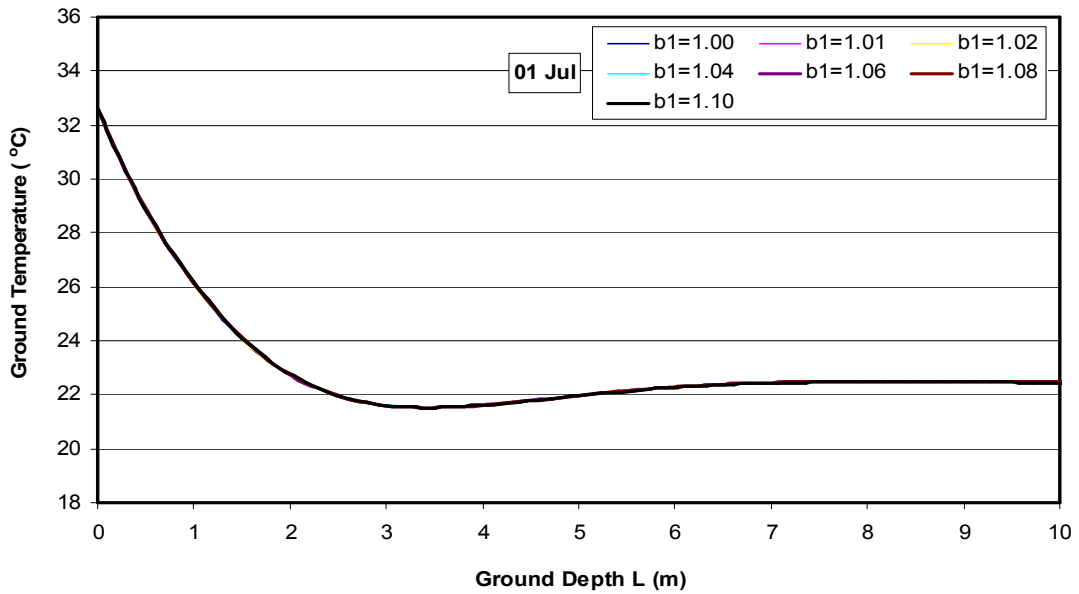


Figure 3.42. Variation of ground temperature with ground depth for different b_1 values for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=10$, $N=90$, $a_s=0.9$, $f=0.45$, $L_1=1$ m, $L_2=9$ m).

The variations of ground temperature with depth are illustrated in figures 3.43 and 3.44 for $L_1=0.5$ m and $L_2=9.5$ m for January 01 and July 01. Lower layer step number was changed between $N=50$ to $N=150$ versus constant upper layer step number ($M=50$) and the same results were obtained.

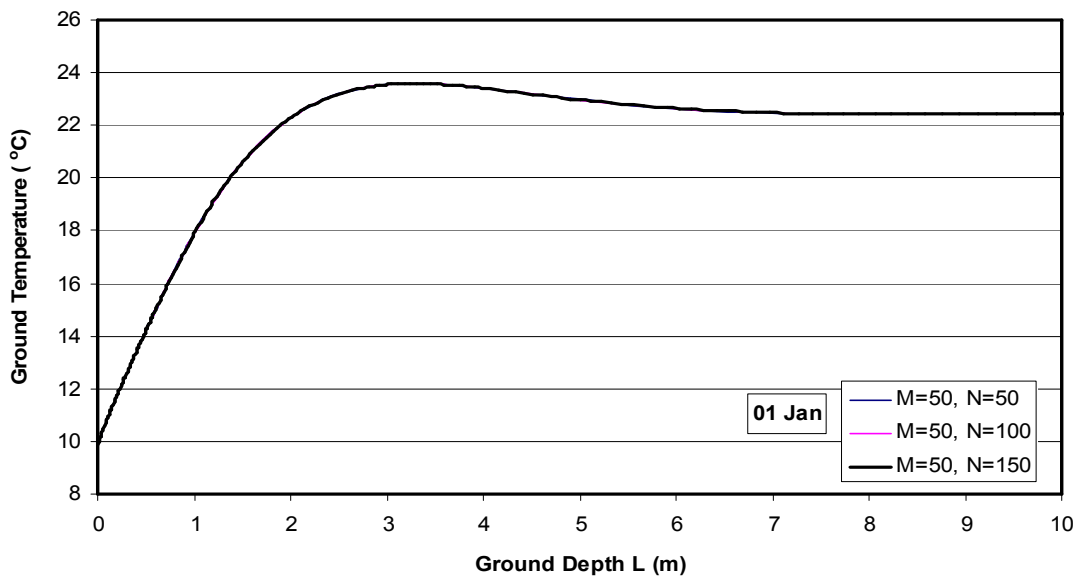


Figure 3.43. Variation of ground temperature with ground depth for different N values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $M=50$, $a_s=0.9$, $f=0.45$, $L_1=0.5$ m, $L_2=9.5$ m).

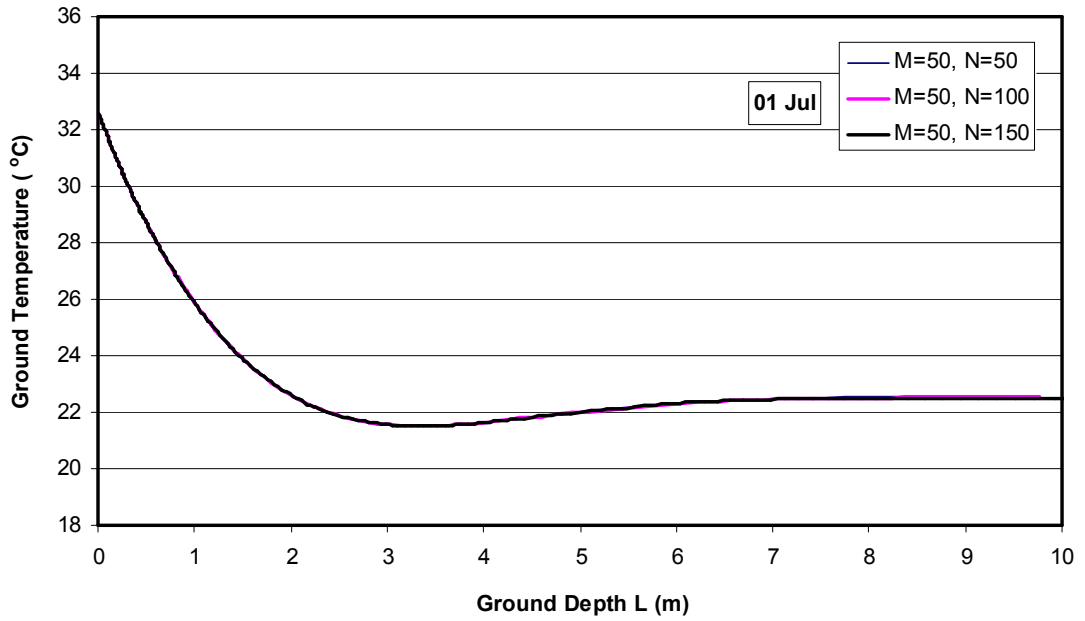


Figure 3.44. Variation of ground temperature with ground depth for different N values for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $M=50$, $a_s=0.9$, $f=0.45$, $L_1=0.5$ m, $L_2=9.5$ m).

Upper layer step number was changed between $M=10$ to $M=60$ versus constant lower layer step number ($N=50$) for $L_1=0.5$ m and $L_2=10$ m in figures 3.45 and 3.46 and the results did not change as well.

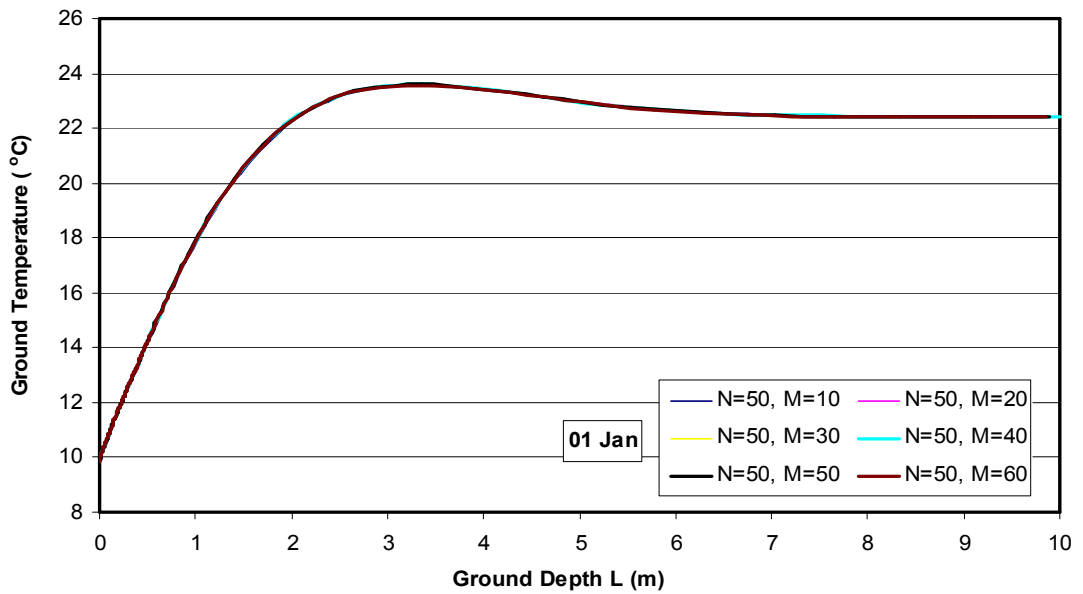


Figure 3.45. Variation of ground temperature with ground depth for different M values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $N=50$, $a_s=0.9$, $f=0.45$, $L_1=0.5$ m, $L_2=10$ m).

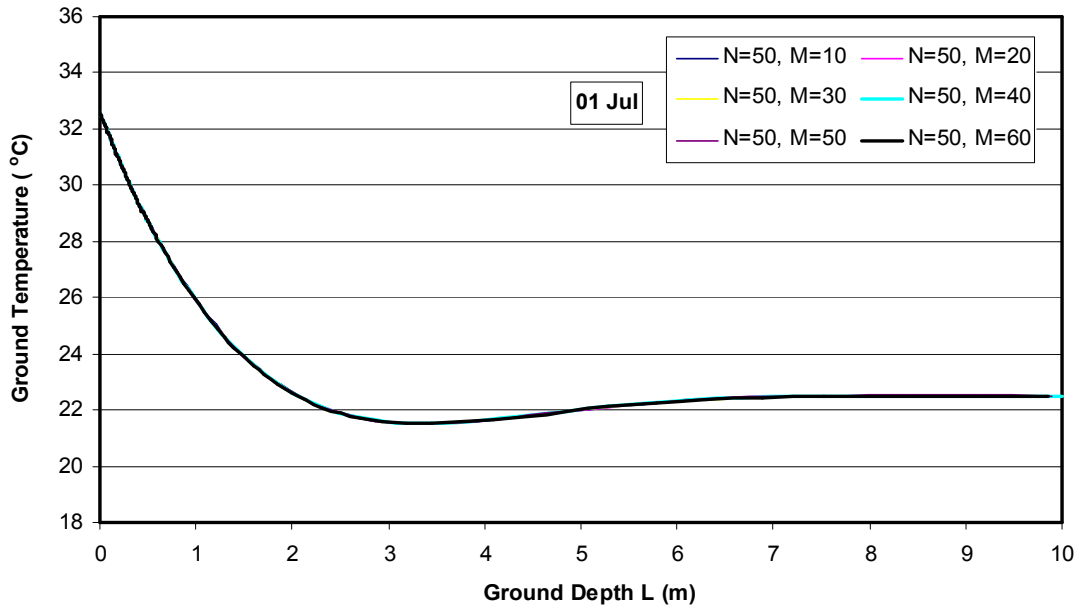


Figure 3.46. Variation of ground temperature with ground depth for different M values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $N=50$, $a_s=0.9$, $f=0.45$, $L_1=0.5$ m, $L_2=10$ m).

Upper and lower layer step numbers were changed simultaneously in figures 3.47 and 3.48. While M was changing between 10 to 50, N changed between 90 to 50 and the results were almost close to each other.

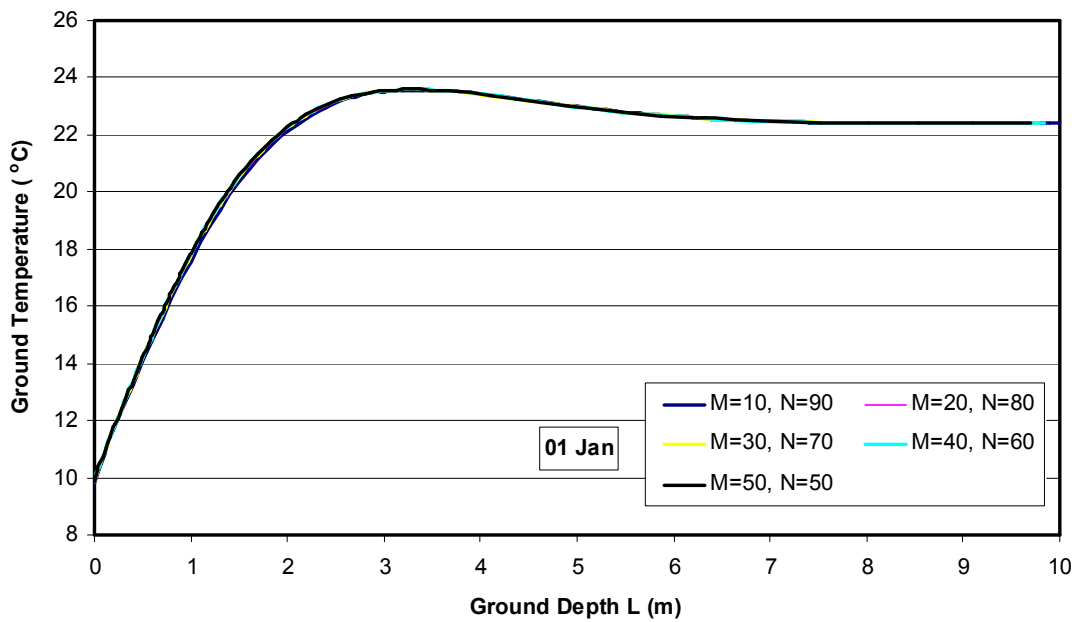


Figure 3.47. Variation of ground temperature with ground depth for different M and N values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $a_s=0.9$, $f=0.45$, $L_1=1.0$ m, $L_2=9$ m).

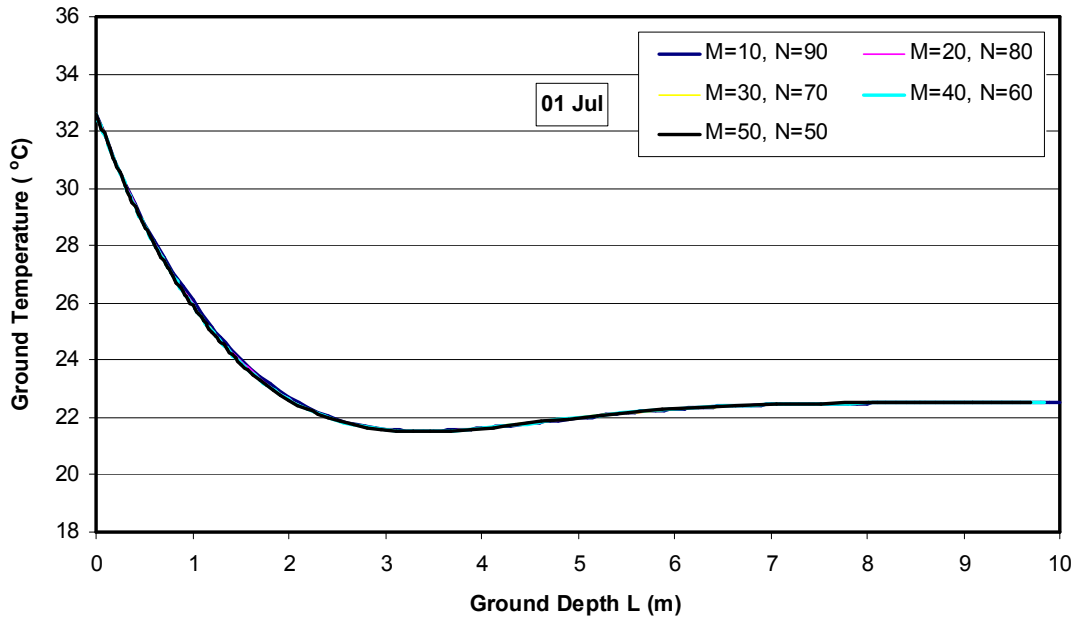
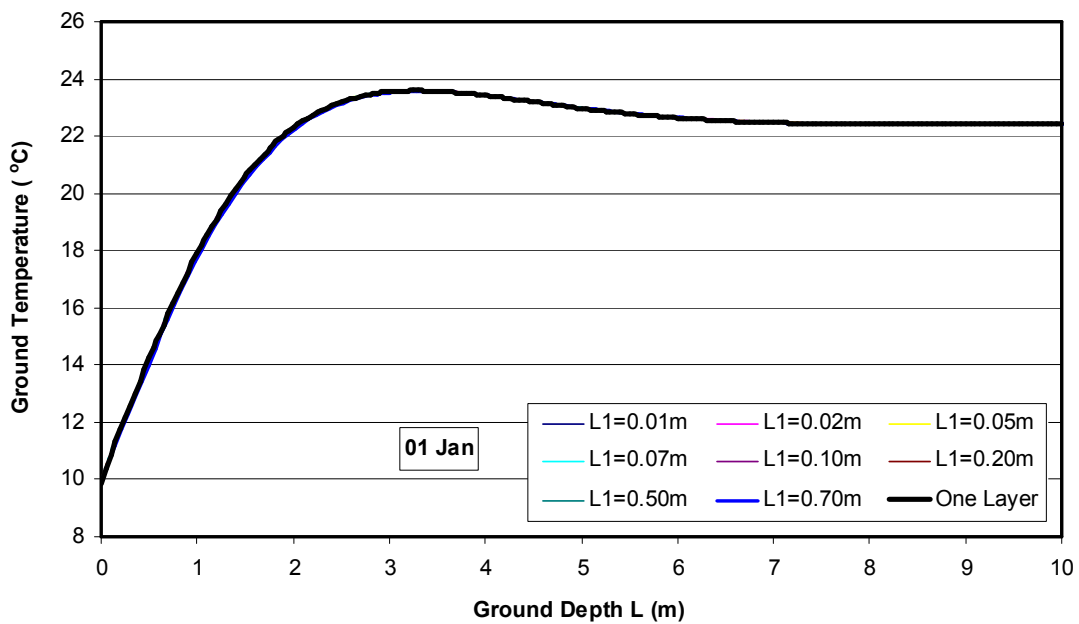


Figure 3.48. Variation of ground temperature with ground depth for different M and N values for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $b_1=1.0$, $a_s=0.9$, $f=0.45$, $L_1=1.0$ m, $L_2=9$ m).

Comparison of ground temperatures with depth are demonstrated in figures 3.49(a)-(b) and 3.50(a)-(b) for different upper layer thickness versus constant lower layer thickness ($L_2=10$ m). Furthermore, the results obtained from the one layer ground model are added to these figures. It is observed from these figures that numerical results are very acceptable.



(a)

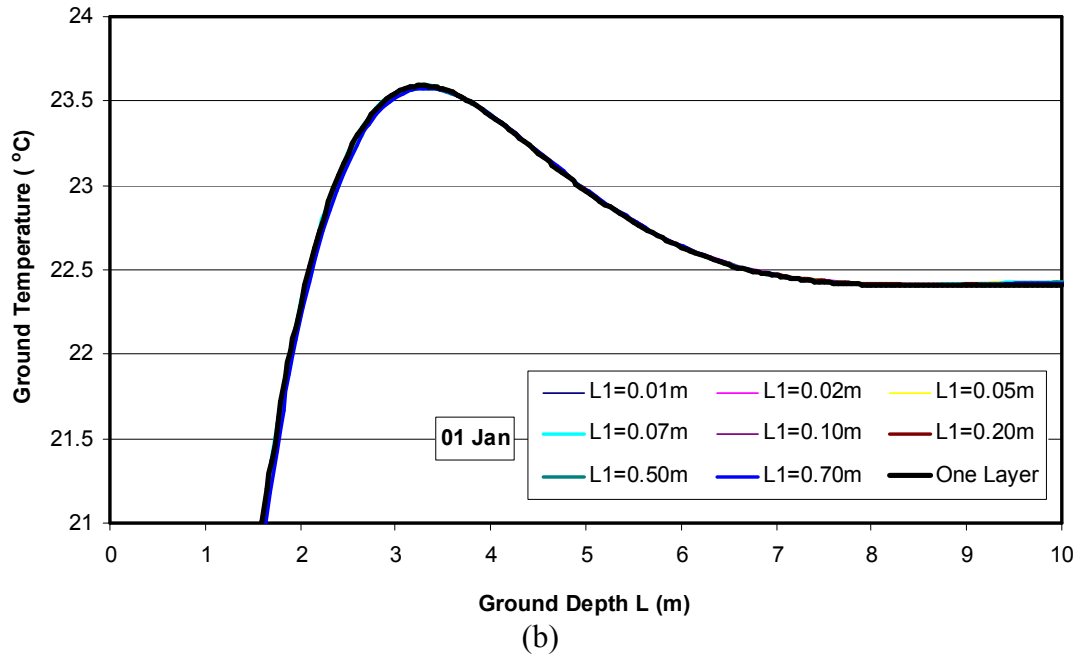
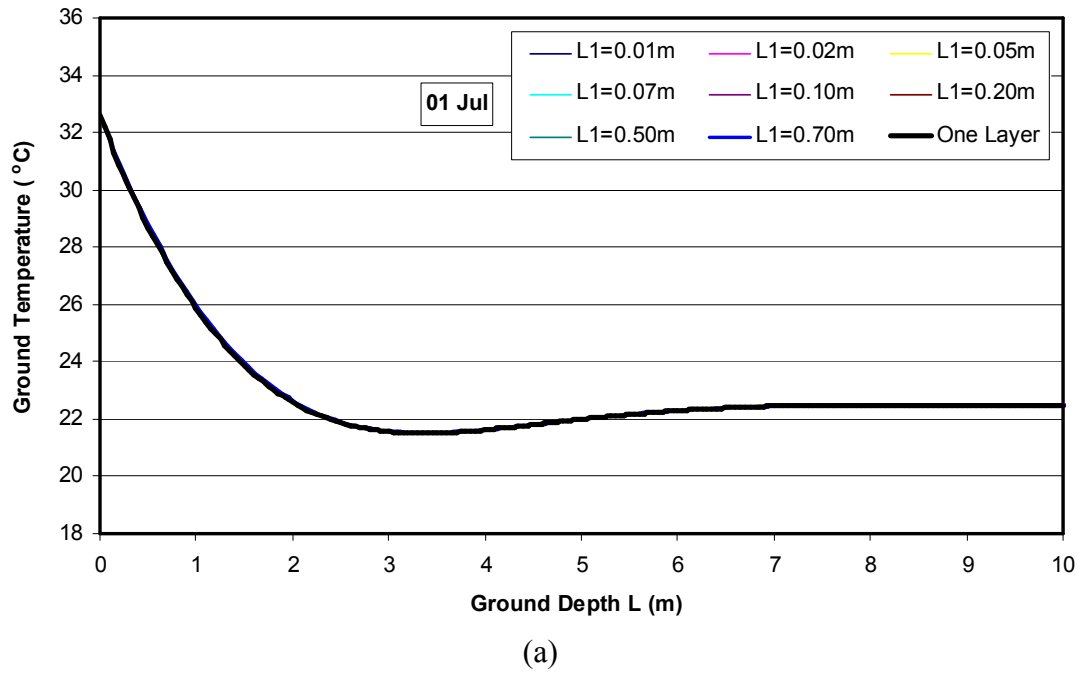


Figure 3.49. Variation of ground temperature with ground depth for different $L1$ values for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=10$, $N=190$, $b_1=1.0$, $a_s=0.9$, $f=0.45$, $L2=10$ m).



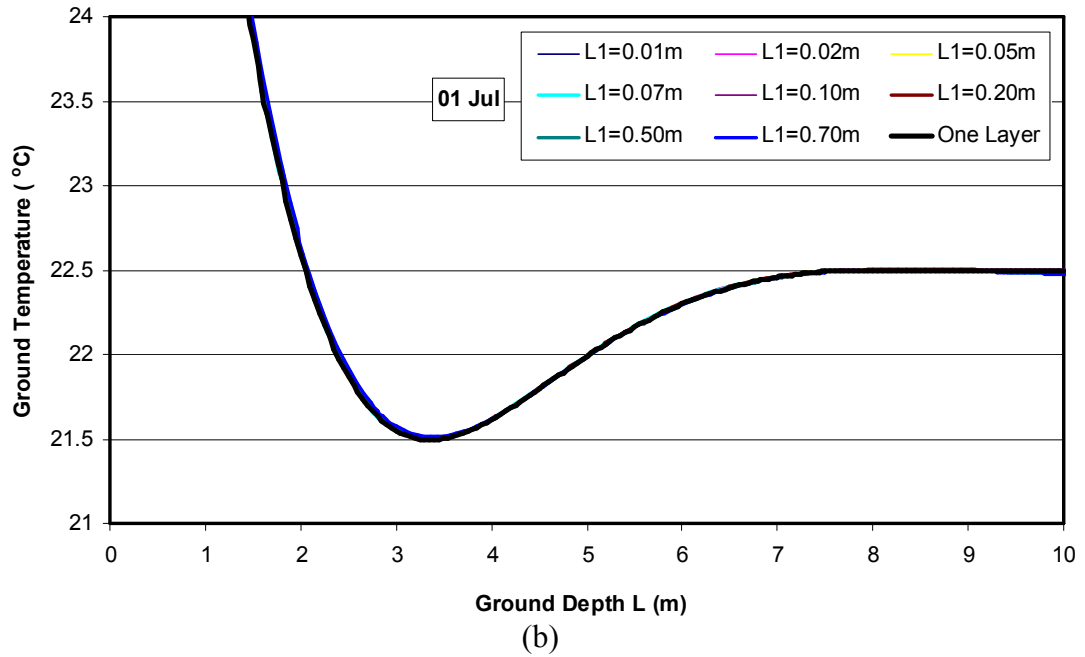


Figure 3.50. Variation of ground temperature with ground depth for different L1 values for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=10$, $N=190$, $b_1=1.0$, $a_s=0.9$, $f=0.45$, $L_2=10$ m).

In tables 3.6 and 3.7, there are ground surface temperature, the temperature at the end of the upper layer, maximum or minimum temperatures and the depth of maximum or minimum temperatures for January 01 and July 01. The reliability of calculated results can be seen clearly from these tables.

Table 3.6. Surface, maximum and end temperatures for January 01

	January 01								
L1 (m)	0.01	0.02	0.05	0.07	0.10	0.20	0.50	0.70	One Layer
Max. temp. (°C)	23.59	23.59	23.59	23.59	23.59	23.59	23.57	23.57	23.59
The depth of max. temp. (m)	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
Temp. at $L=L_1+L_2$ (°C)	22.43	22.42	22.43	22.44	22.43	22.42	22.43	22.44	22.41
Surface temp. (°C)	9.87	9.87	9.87	9.87	9.87	9.87	9.84	9.82	9.86

Table 3.7. Surface, minimum and end temperatures for July 01

	July 01								
L1 (m)	0.01	0.02	0.05	0.07	0.10	0.20	0.50	0.70	One Layer
Min. temp. (°C)	21.50	21.51	21.51	21.50	21.50	21.51	21.51	21.52	21.50
The depth of min. temp. (m)	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
Temp. at L=L1+L2 (°C)	22.48	22.51	22.49	22.47	22.48	22.50	22.47	22.44	22.50
Surface temp. (°C)	32.59	32.59	32.59	32.59	32.60	32.60	32.60	32.59	32.59

3.8. Calculations for Two Vertical Layer Ground Model

The physical properties of two vertical layers were assumed as the same firstly and the results were then compared with that of the one layer ground model. Various numerical parameters were used in the calculations. (Prepared computer program for two vertical layer ground model is given in Appendix-3).

Figures 3.51 and 3.52 show the variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step increment coefficient for January 01 and July 01. Step increment coefficients are AKX in x-direction and AKYA for layer A and AKYB for layer B in y-direction. The same step increment coefficient was determined for both vertical layers. The variation of the ground temperatures at y=0 m and y=4 m with ground depth in the vertical direction were illustrated in figures 3.53 and 3.54 for different step increment coefficients.

Since the same results were obtained by using various step increment coefficients, the numerical method and step sizes can be considered as appropriate.

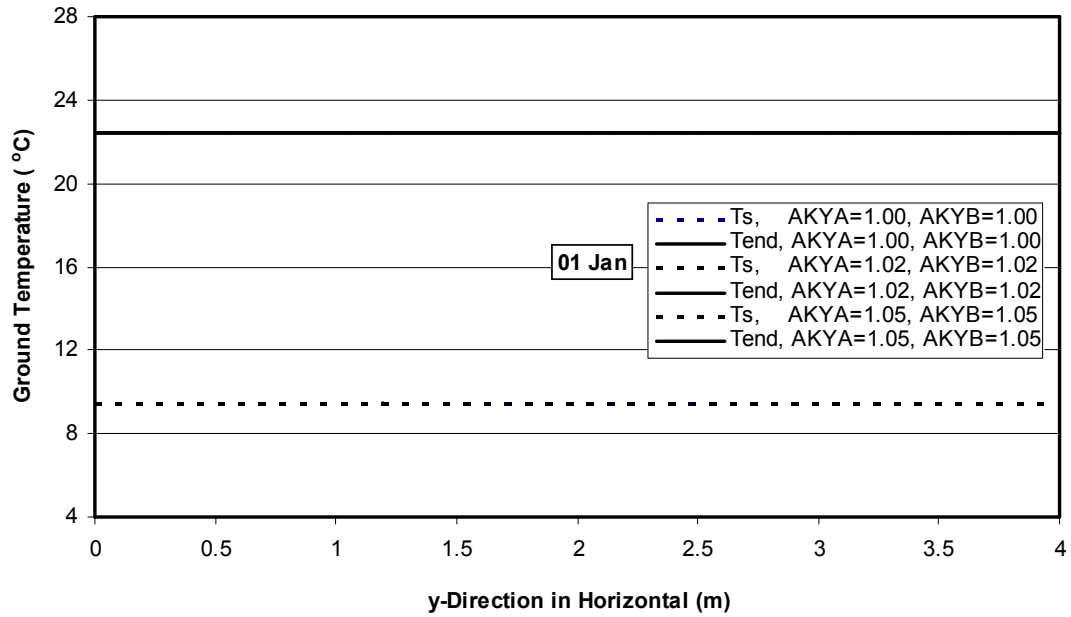


Figure 3.51. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

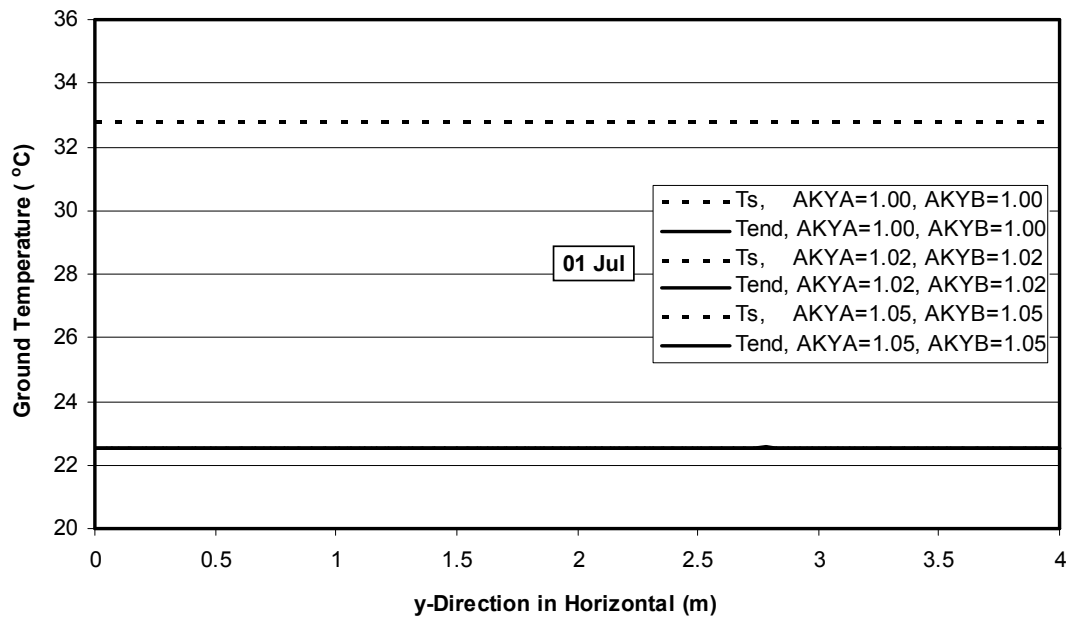


Figure 3.52. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

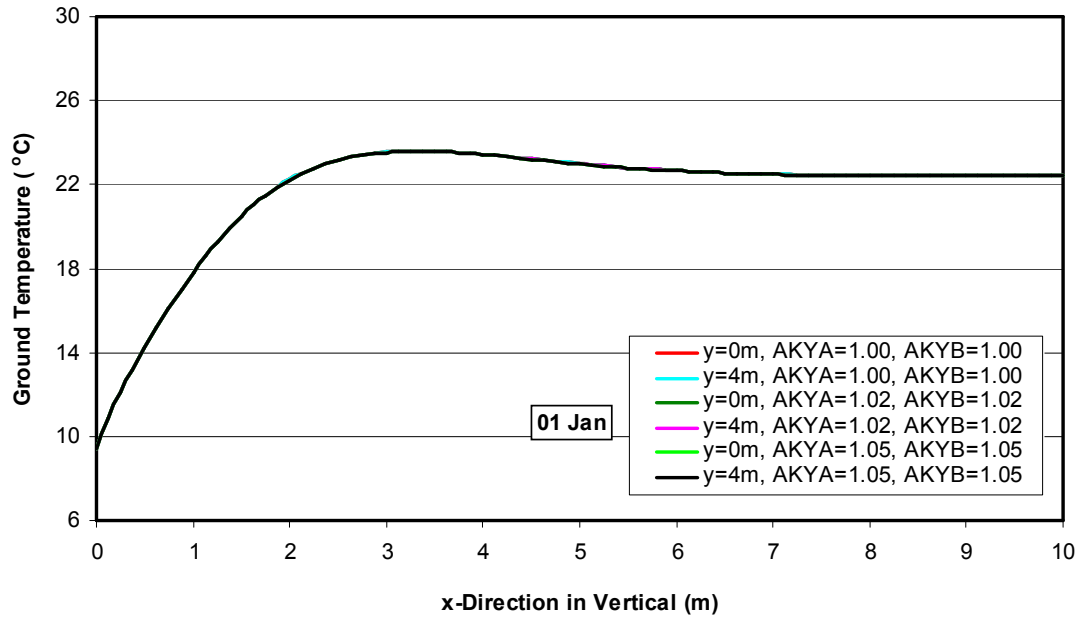


Figure 3.53. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

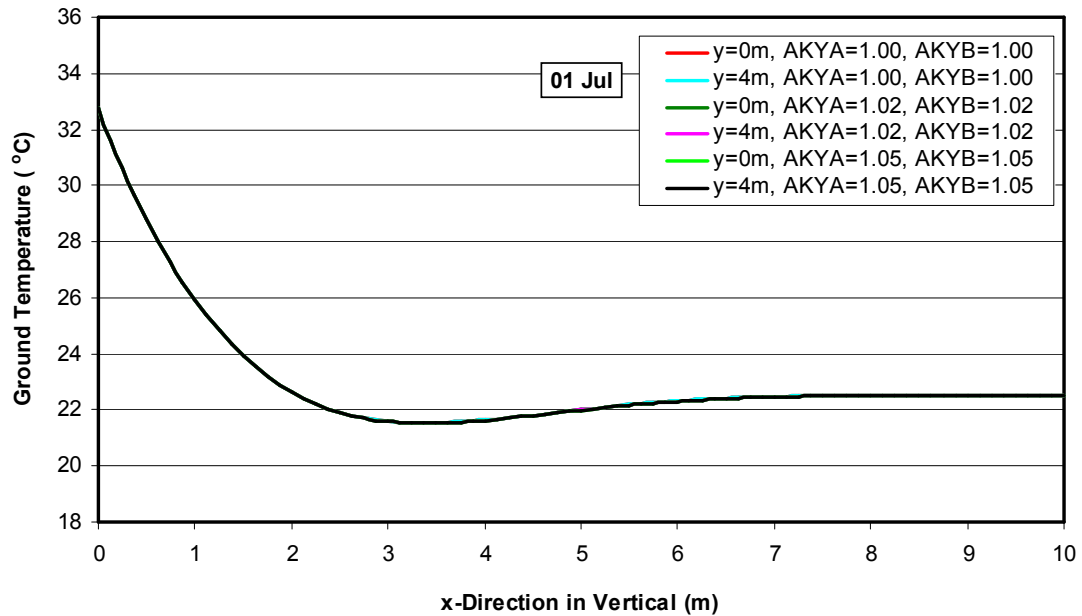


Figure 3.54. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

Figures 3.55 and 3.56 demonstrate the variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step numbers for January 01 and July 01. The variation of the ground temperatures at y=0 m and y=4 m with ground depth in the vertical direction for different step numbers are shown in figures 3.57 and 3.58.

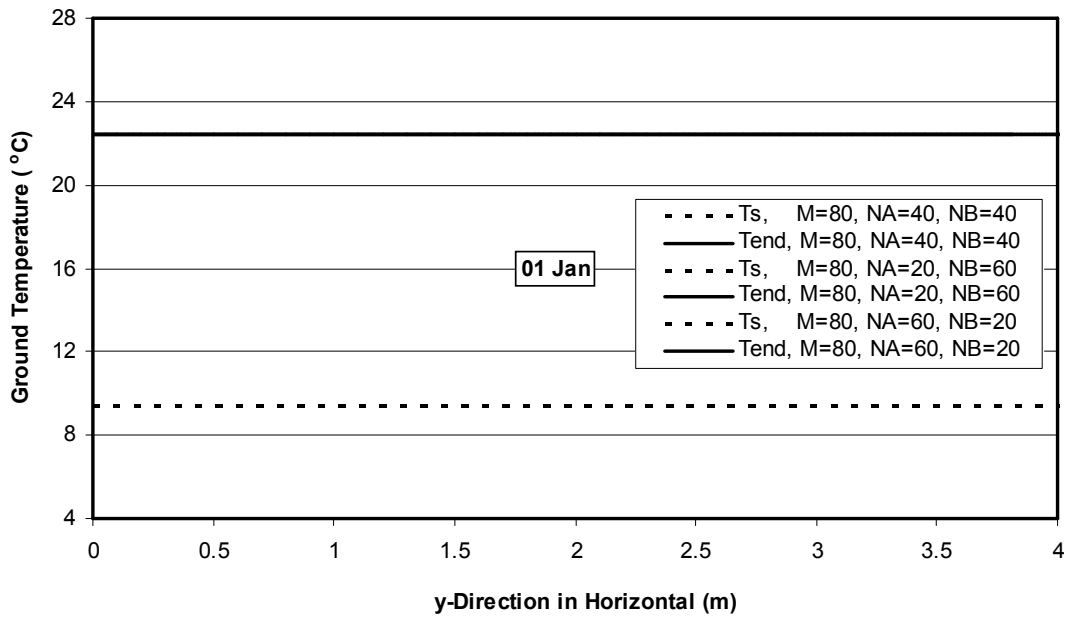


Figure 3.55. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step numbers for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

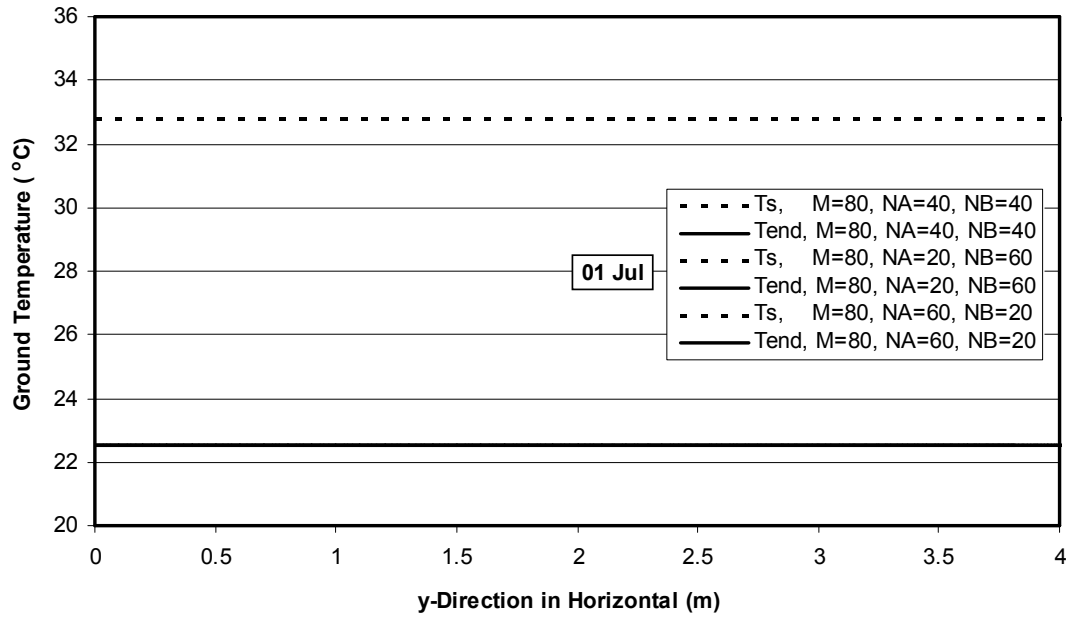


Figure 3.56. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different step numbers for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

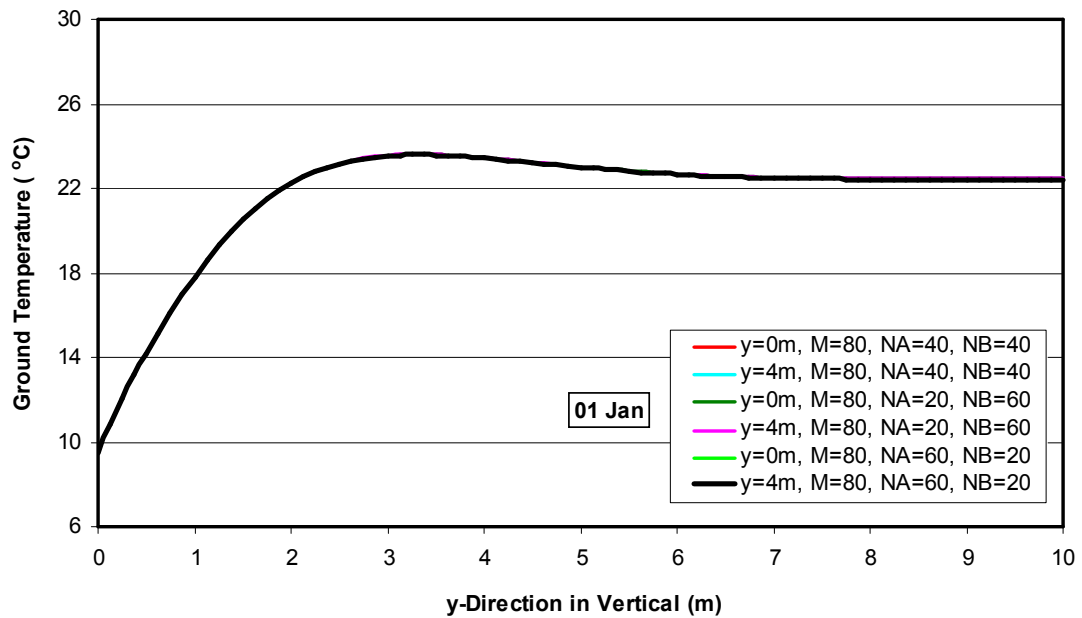


Figure 3.57. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

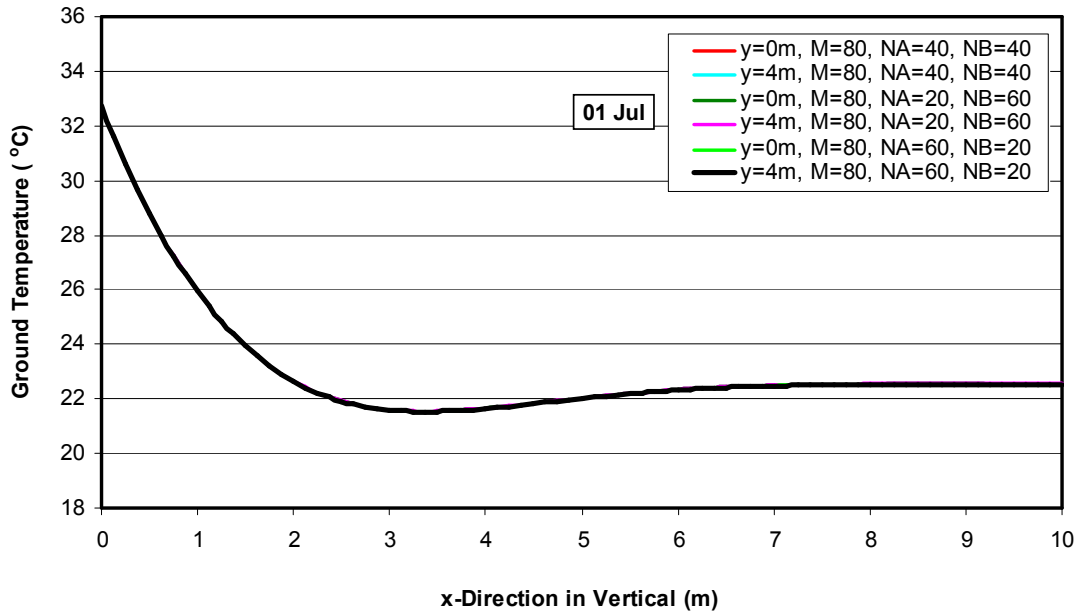


Figure 3.58. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALYA=2.0$ m, $ALYB=2.0$ m)

Figures 3.59 and 3.60 illustrate the variation of ground surface and end temperatures with horizontal y -direction in the 1st and 2nd vertical layers for different layer thick for January 01 and July 01. The variation of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction are shown in figures 3.61 and 3.62 for different layer thickness. Because the physical properties of A and B layers were assumed as the same, there were not any differences between the results. Furthermore, the numerical method yields acceptable results.

It is observed from the figures between 3.51 and 3.62 that, the results obtained from the prepared numerical program for two vertical layers ground are the same as one layer ground model's.

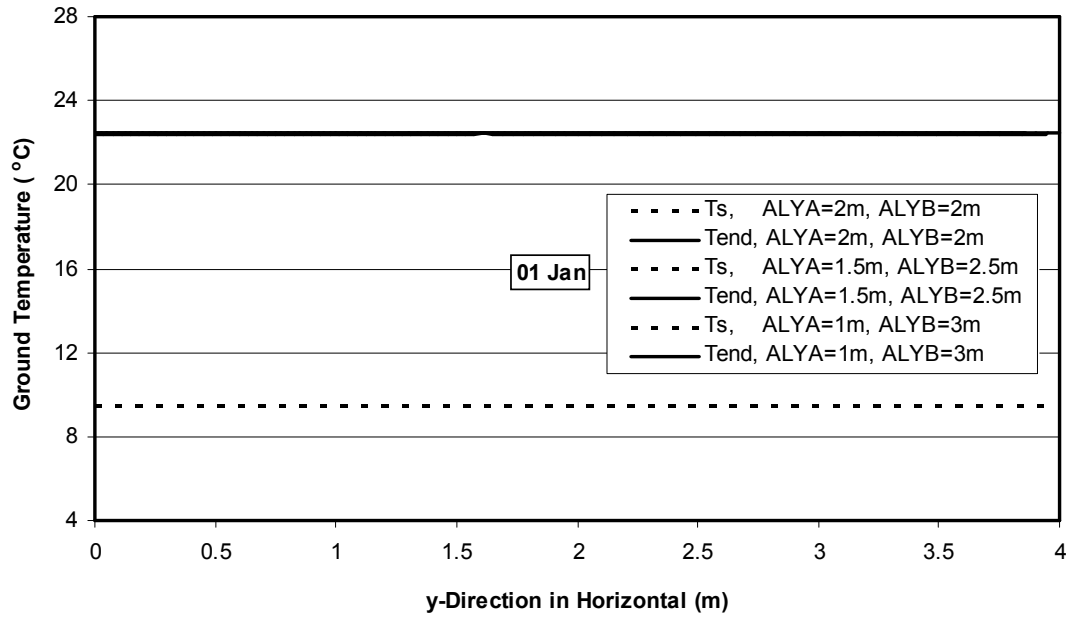


Figure 3.59. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different layer thickness for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

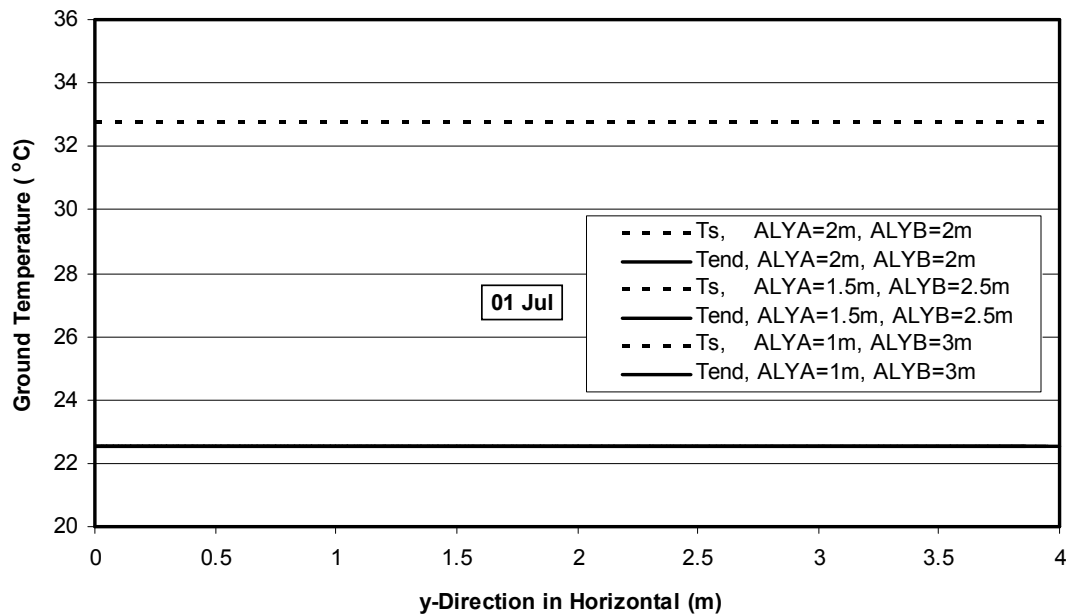


Figure 3.60. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for different layer thickness for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

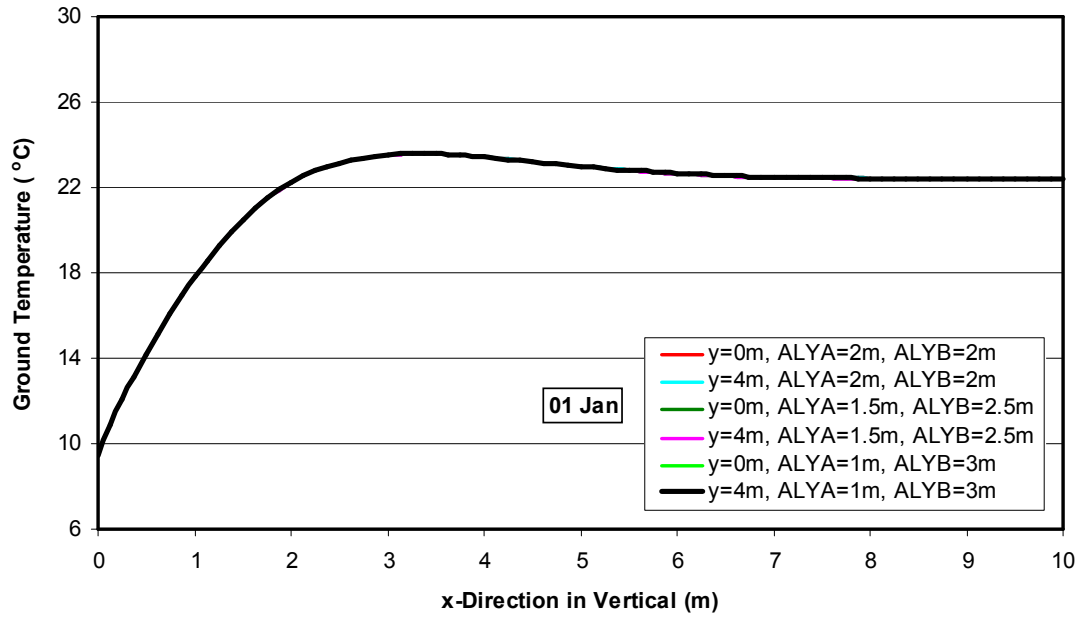


Figure 3.61. Variation of ground temperatures in $y=0$ m and $y=4$ m with ground depth in the vertical direction for different layer thickness for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

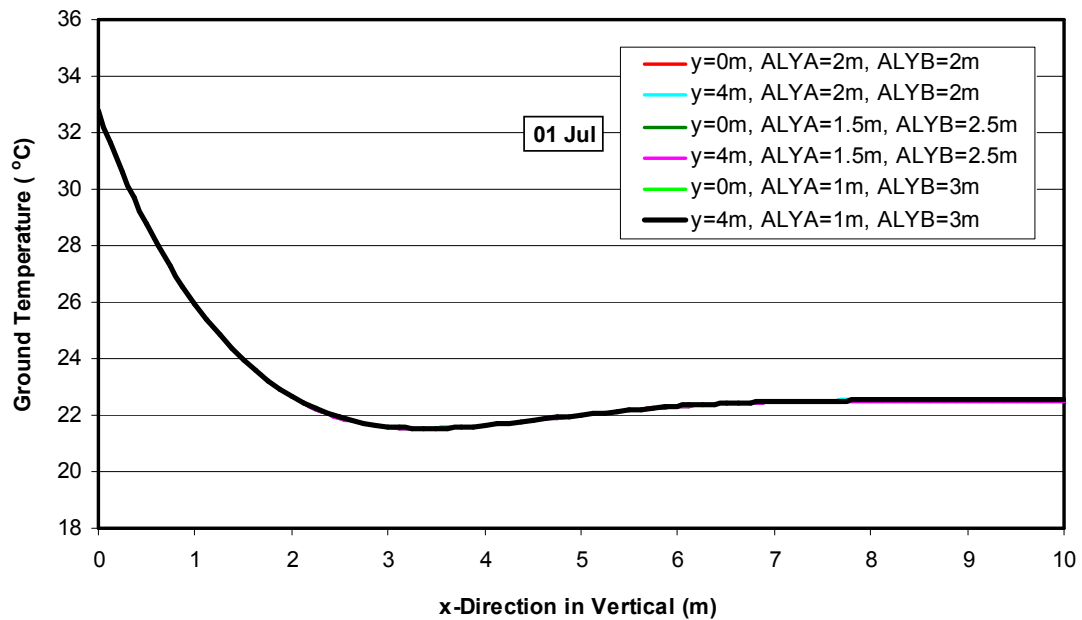


Figure 3.62. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different layer thickness for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $M=80$, $NA=40$, $NB=40$, $AKX=1.0$, $AKYA=1.0$, $AKYB=1.0$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

3.9. Calculations for Trench-Filled Two Vertical Layer Ground Model

The accordance of the prepared numerical program for trench-filled two vertical layer ground was investigated by assuming firstly physical properties of the trench layer and ground layer were the same and the results were then compared with that of one layer ground model. Various numerical parameters were used in the calculations. (Prepared computer program for trench-filled two vertical layer model is given in Appendix-4).

Figures 3.63 and 3.64 show the variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the horizontal direction and constant step increment coefficient for January 01 and July 01. Figures 3.65 and 3.66 demonstrate the variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers in the horizontal direction and constant step increment coefficient for January 01 and July 01. NA and NB show the step numbers for trench and ground layers in the horizontal direction, respectively.

Since the same results were obtained by using various step numbers in the horizontal direction, the accordance of the numerical method is considered as good.

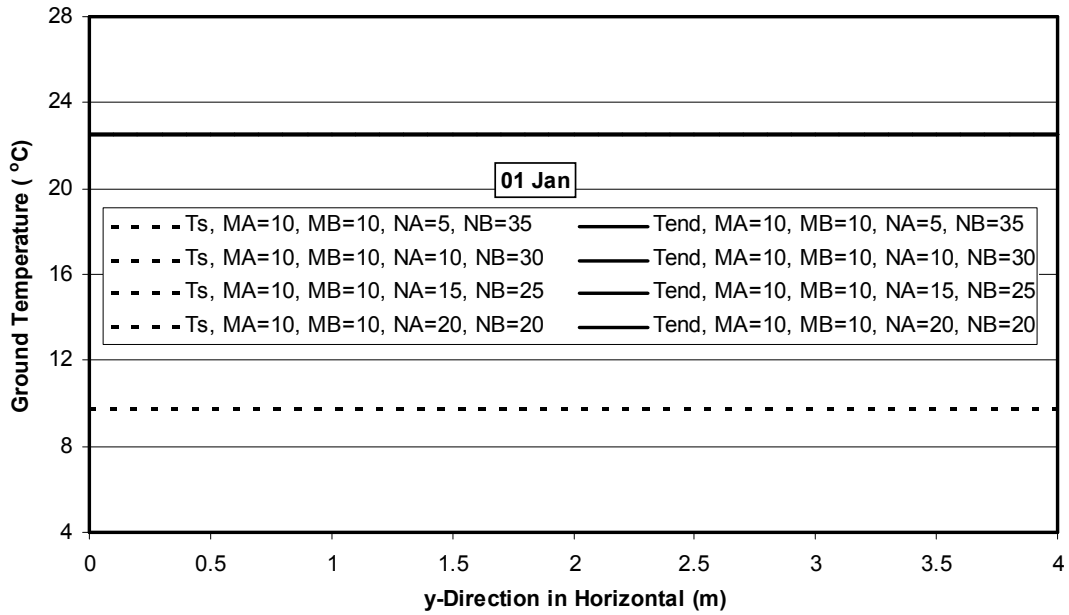


Figure 3.63. Variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the horizontal direction and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=10, MB=10, NA=40, NB=40, $a_s=0.9$, $f=0.45$, ALX=10.0 m, ALA=2.0 m, ALB=2.0 m)

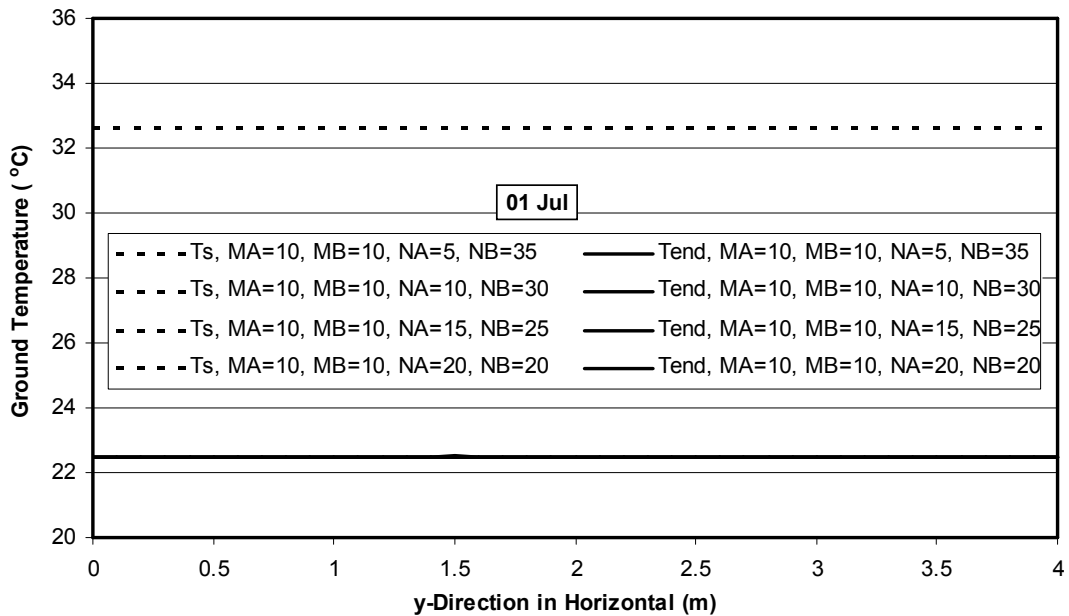


Figure 3.64. Variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the horizontal direction and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=10, MB=10, NA=40, NB=40, $a_s=0.9$, $f=0.45$, ALX=10.0 m, ALA=2.0 m, ALB=2.0 m)

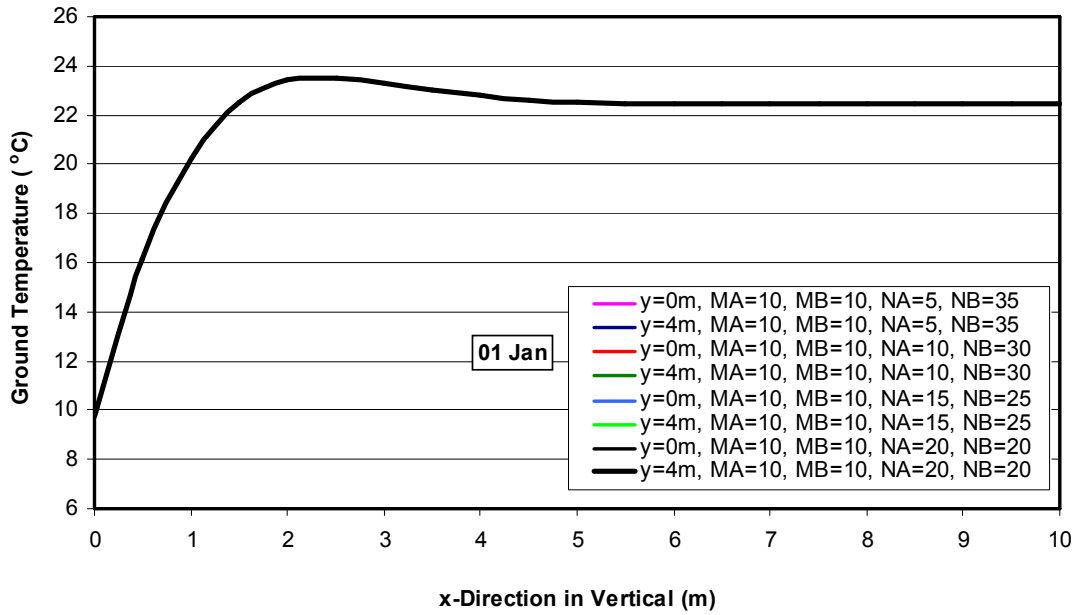


Figure 3.65. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers in the horizontal direction and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=10, MB=10, NA=40, NB=40, $a_s=0.9$, $f=0.45$, ALX=10.0 m, ALA=2.0 m, ALB=2.0 m)

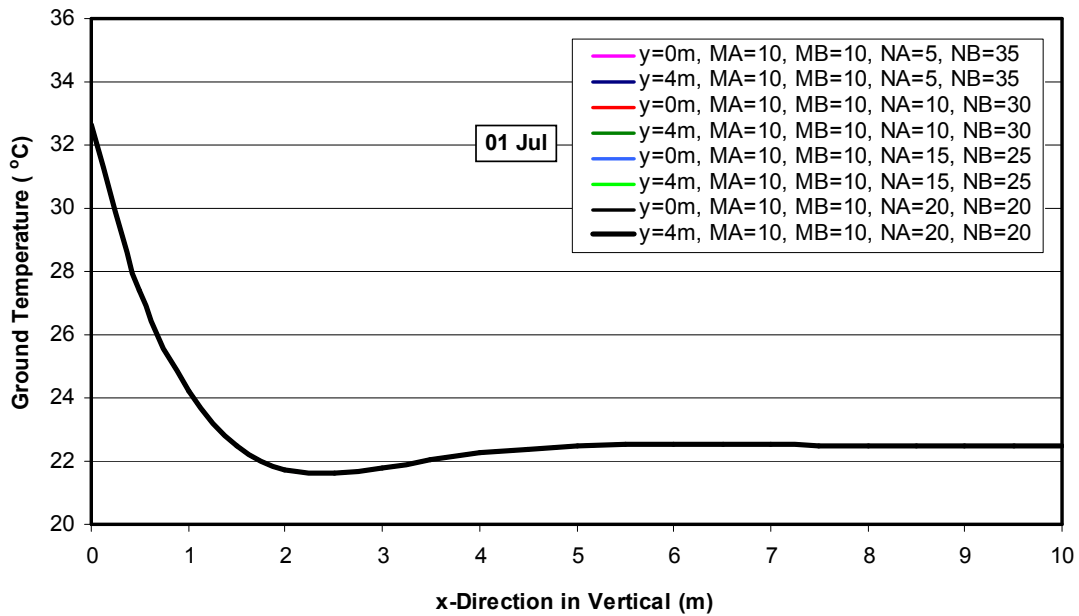


Figure 3.66. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers in the horizontal direction and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=10, MB=10, NA=40, NB=40, $a_s=0.9$, $f=0.45$, ALX=10.0 m, ALA=2.0 m, ALB=2.0 m)

Figures 3.67 and 3.68 demonstrate the variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the vertical direction and constant step increment coefficient for January 01 and July 01. Figures 3.69 and 3.70 illustrate the variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth for different step numbers in the vertical direction and constant step increment coefficient for January 01 and July 01. MA and MB show the step numbers for trench and ground layers in the vertical direction, respectively.

Since the same results were obtained by using various step numbers in vertical direction, the accordance of the numerical method was seen.

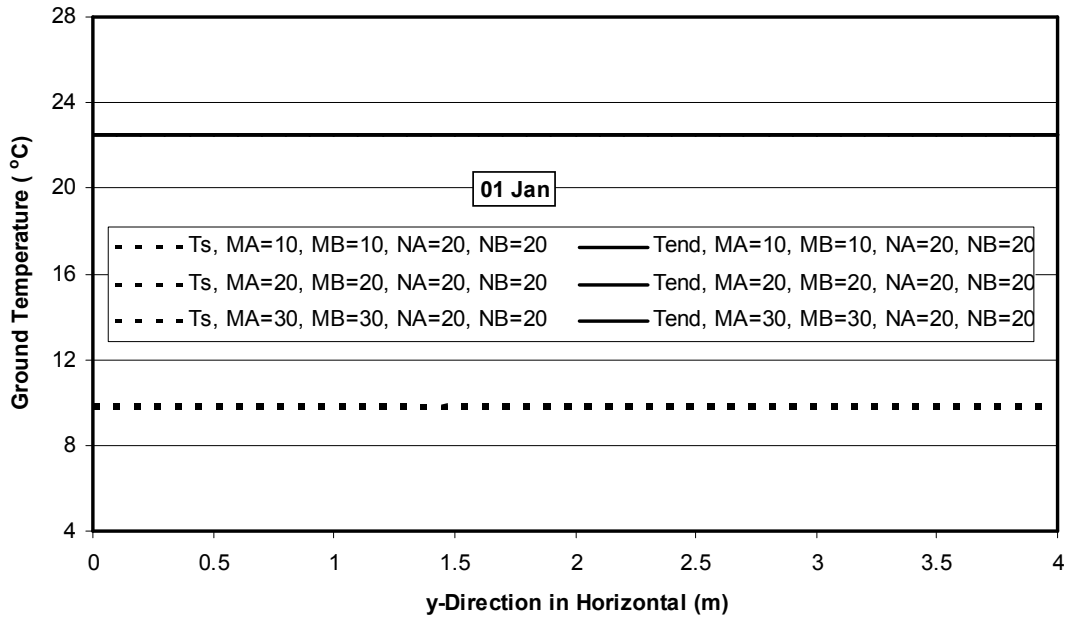


Figure 3.67. Variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the vertical direction and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, NA=20, NB=20, $a_s=0.9$, $f=0.45$, ALX=10.0 m, ALA=2.0 m, ALB=2.0 m)

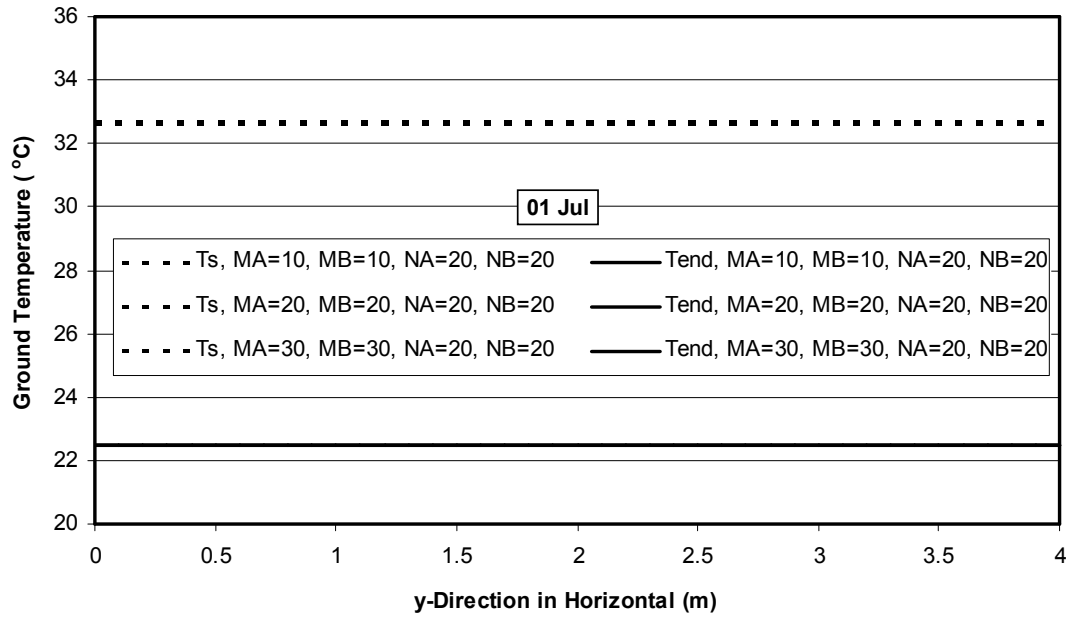


Figure 3.68. Variation of ground surface and end temperatures with horizontal y-direction for different step numbers in the vertical direction and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $NA=20$, $NB=20$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALA=2.0$ m, $ALB=2.0$ m)

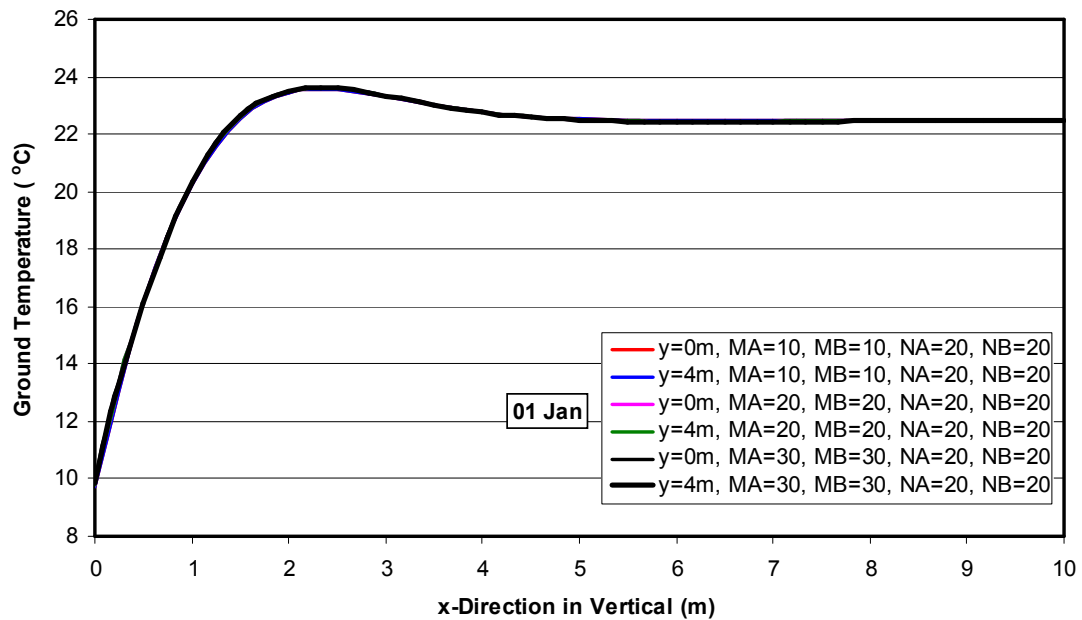


Figure 3.69. Variation of ground temperatures at y=0 m and y=4 m with ground depth in the vertical direction for different step numbers in the vertical direction and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $NA=20$, $NB=20$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALA=2.0$ m, $ALB=2.0$ m)

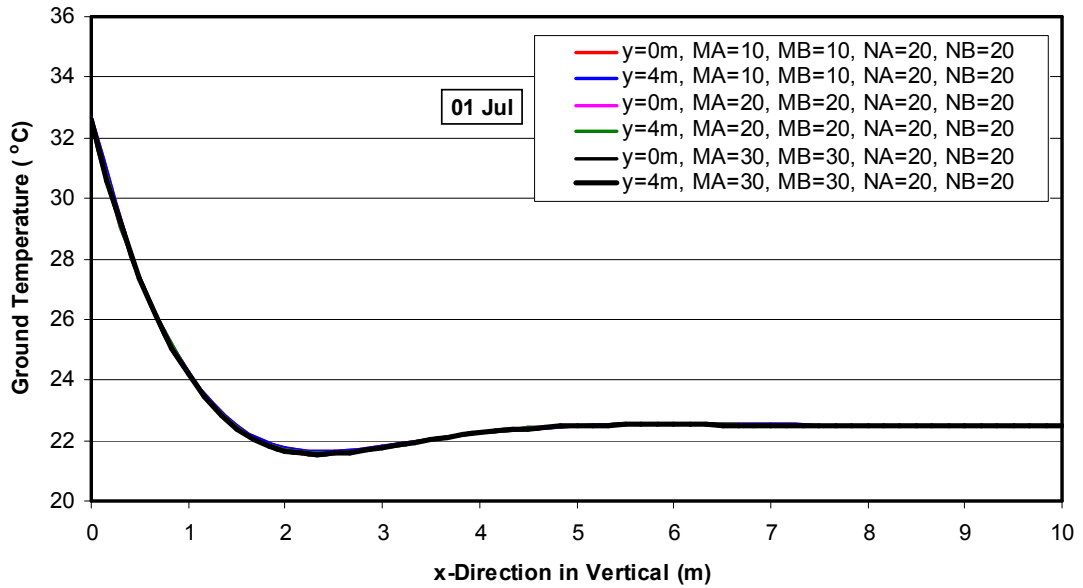


Figure 3.70. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different step numbers in the vertical direction and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $NA=20$, $NB=20$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m, $ALA=2.0$ m, $ALB=2.0$ m)

Figures 3.71 and 3.72 show the variation of ground surface and end temperatures with horizontal y -direction for different trench thickness and constant step increment coefficient for January 01 and July 01. Figures 3.73 and 3.74 demonstrate the variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different trench thickness and constant step increment coefficient for January 01 and July 01. ALA shows the trench thickness in the horizontal direction.

It is observed from the figures between 3.63 and 3.74 that, the results obtained from the prepared numerical program for trench-filled two vertical layer ground are the same with that of one layer ground model.

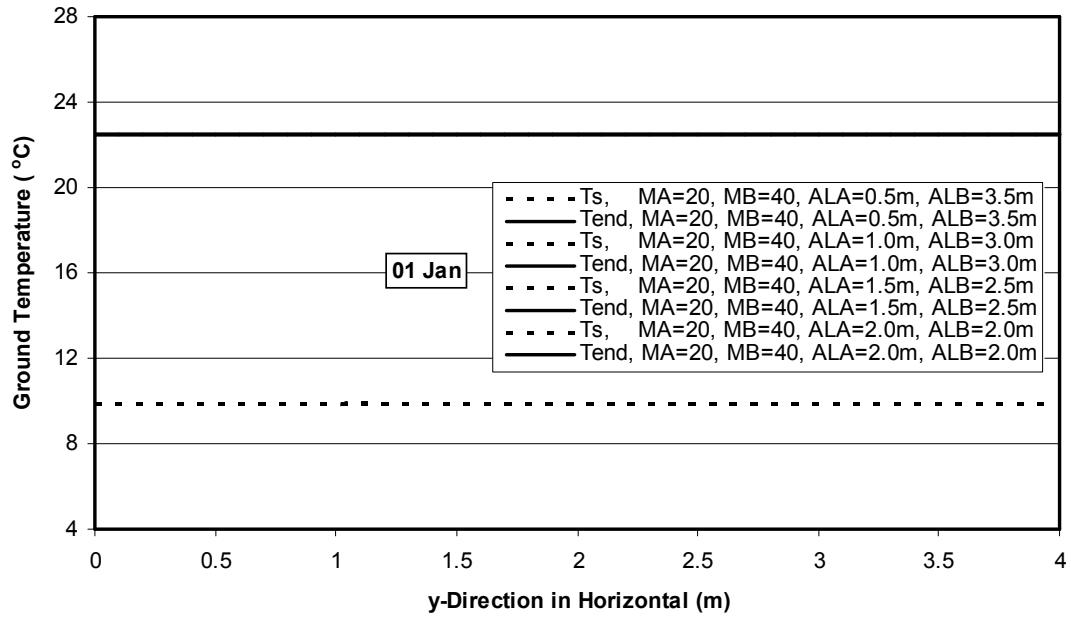


Figure 3.71. Variation of ground surface and end temperatures with horizontal y-direction for different trench thickness and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=20, MB=20, NA=20, NB=20, $a_s=0.9$, $f=0.45$, ALX=10.0 m)

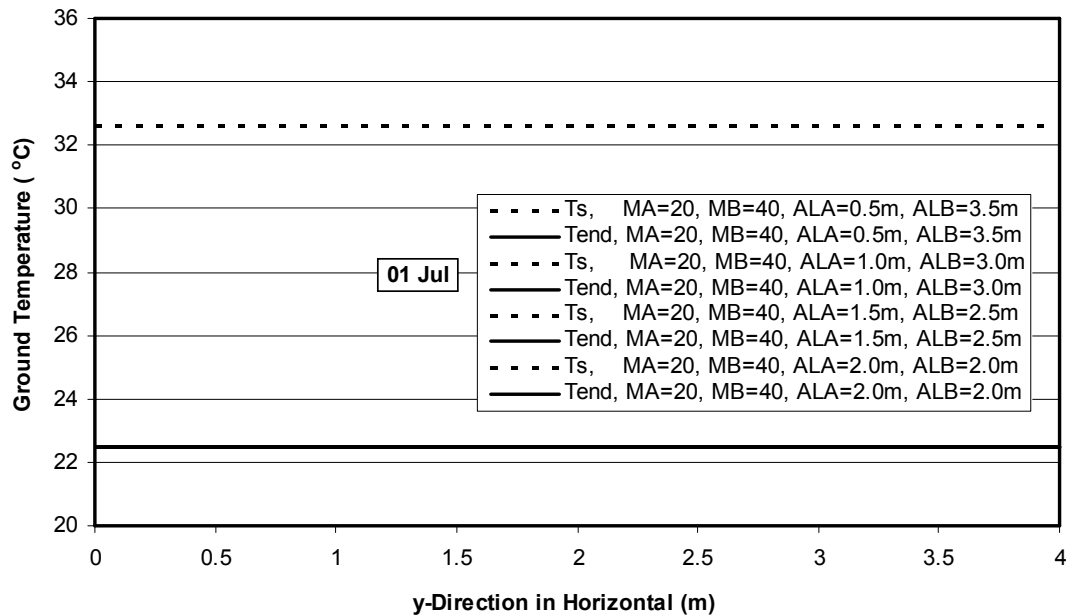


Figure 3.72. Variation of ground surface and end temperatures with horizontal y-direction for different trench thickness and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, MA=20, MB=20, NA=20, NB=20, $a_s=0.9$, $f=0.45$, ALX=10.0 m)

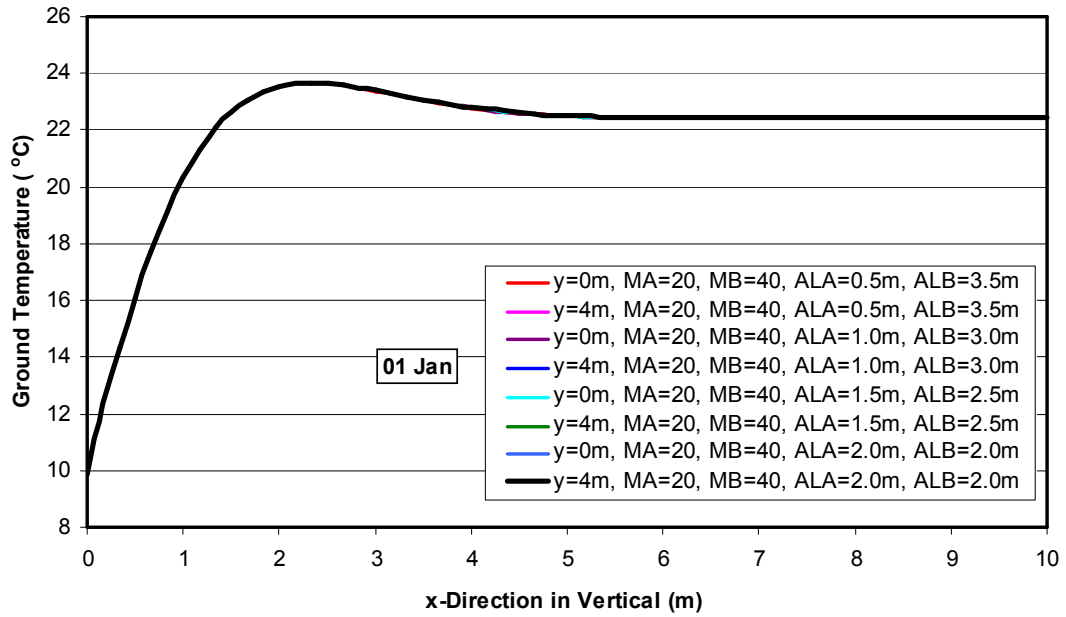


Figure 3.73. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different trench thickness and constant step increment coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $MA=20$, $MB=20$, $NA=20$, $NB=20$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

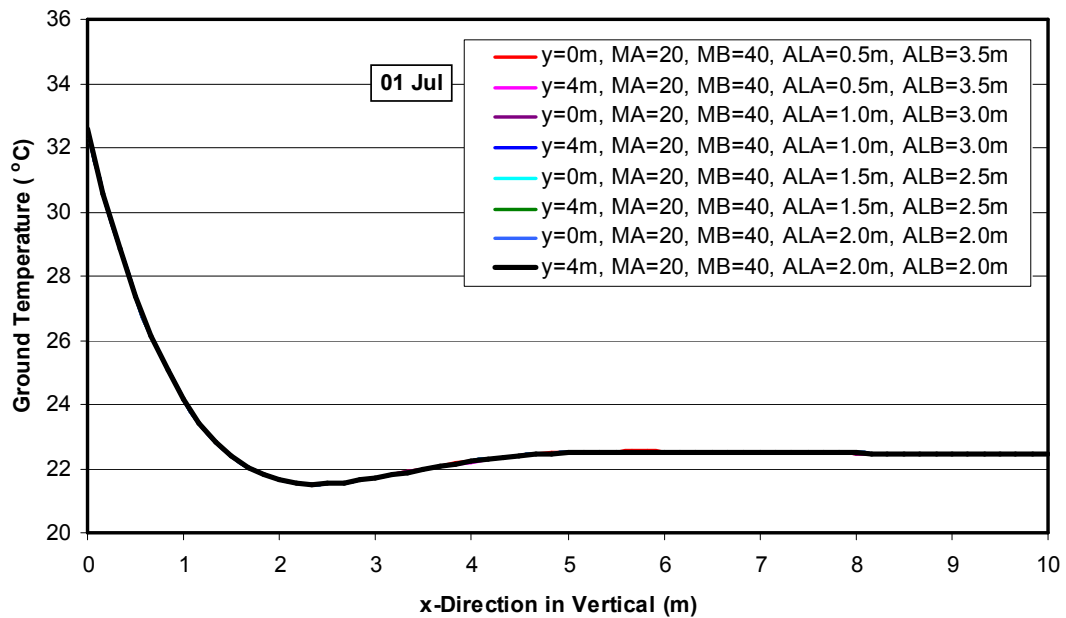


Figure 3.74. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction for different trench thickness and constant step increment coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $MA=20$, $MB=20$, $NA=20$, $NB=20$, $a_s=0.9$, $f=0.45$, $ALX=10.0$ m)

4. RESULTS AND DISCUSSION

4.1. The Effect of Ground Surface Absorption Coefficient (a_s) in Ground Surface and Ground Temperatures

It is known from agricultural applications that, the changing of ground surface cover affects the ground temperatures (Olasantan F. O., 1999, Ramakrishna A. et al., 2006). In this part of the study, the effect of absorption coefficient is analyzed. For the variation of the absorption coefficient, the upper layer is 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 are 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 figures 4.1 and 4.2, 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 is varied between 0.6 to 0.9 in the cooling season and it is 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 observed 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. Increase of ground temperature with a_s value is given clearly in figures 4.3 and 4.4. Yearly variation of ground surface temperature is shown in figure 4.5.

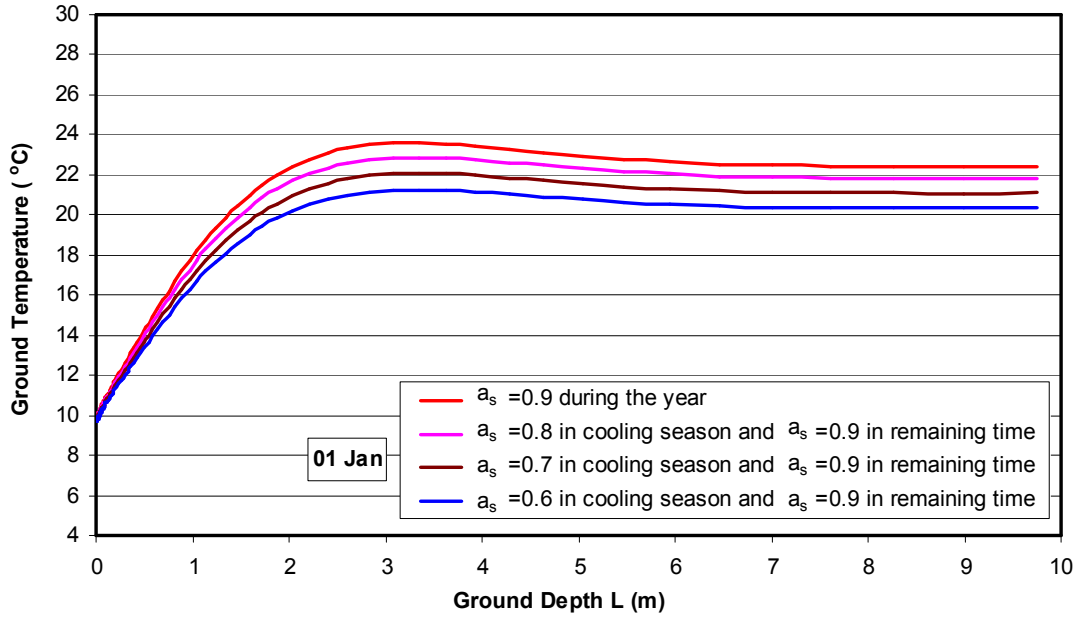


Figure 4.1. Variation of ground temperature with ground depth for different absorption coefficients for January 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

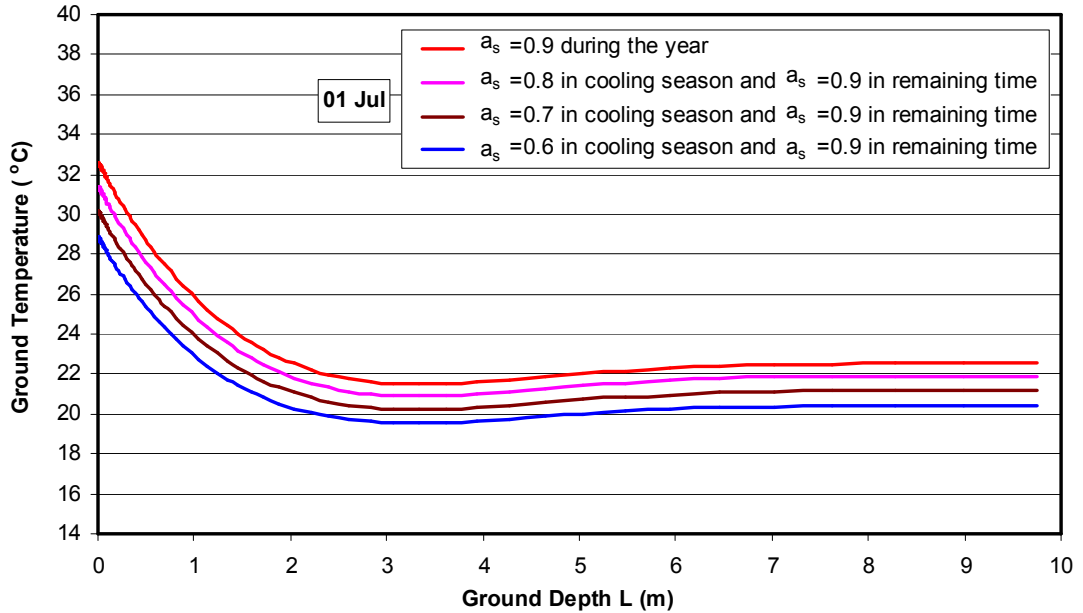


Figure 4.2. Variation of ground temperature with ground depth for different absorption coefficients for July 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

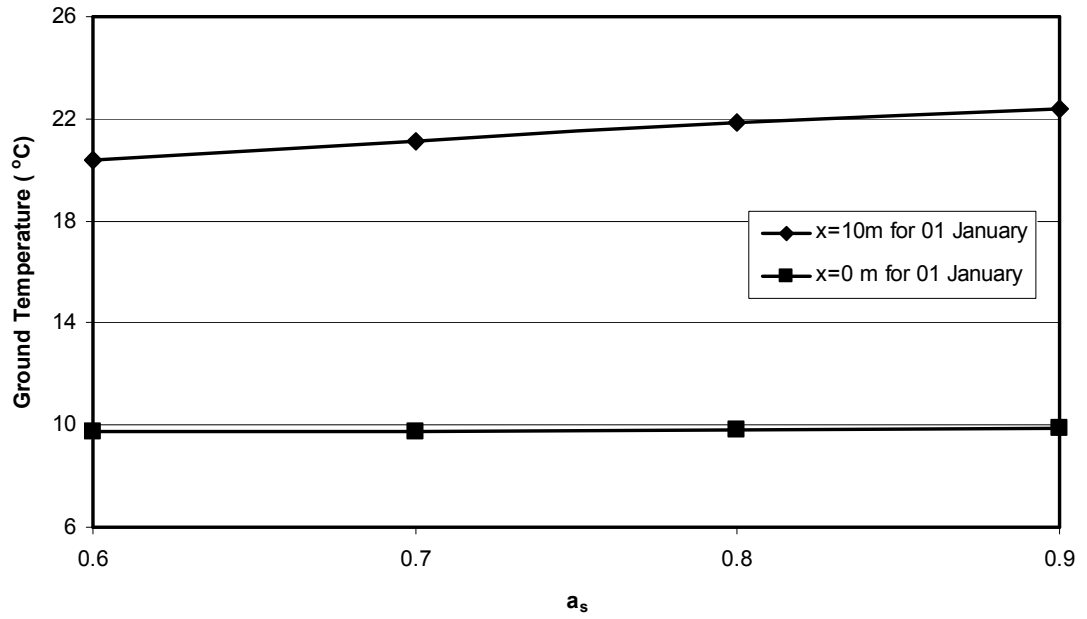


Figure 4.3. Variation of ground temperature at surface and end point with absorption coefficient for January 01, ($k_1=k_2= 1.142\text{ W/mK}$, $a_1=a_2=0.02186\text{ m}^2/\text{day}$, $f=0.45$, $L1=0.005\text{ m}$, $L2=10\text{ m}$).

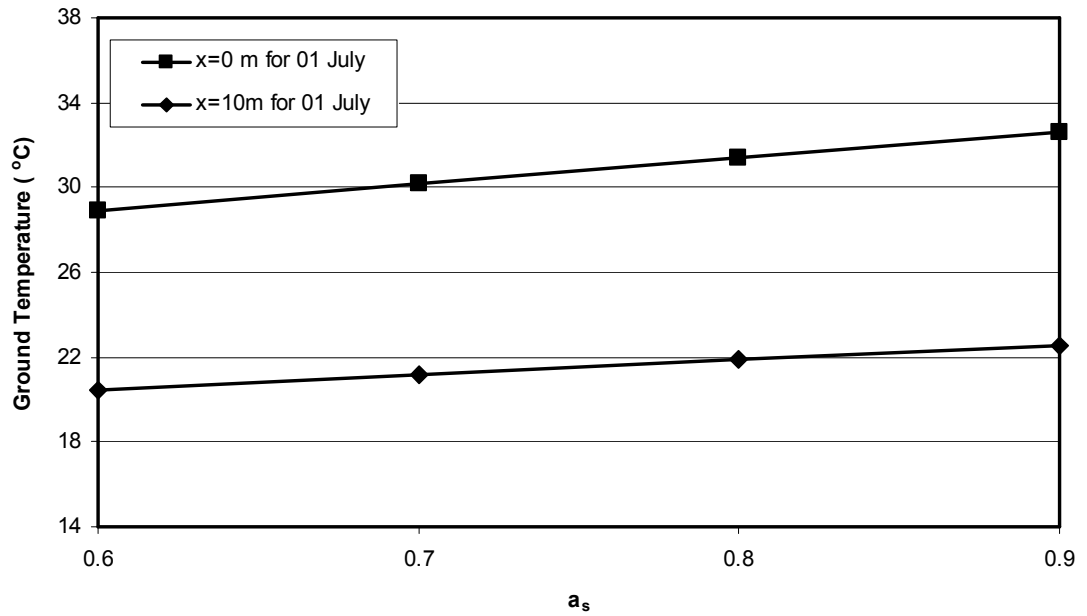


Figure 4.4. Variation of ground temperature at surface and end point with absorption coefficient for July 01, ($k_1=k_2= 1.142\text{ W/mK}$, $a_1=a_2=0.02186\text{ m}^2/\text{day}$, $f=0.45$, $L1=0.005\text{ m}$, $L2=10\text{ m}$).

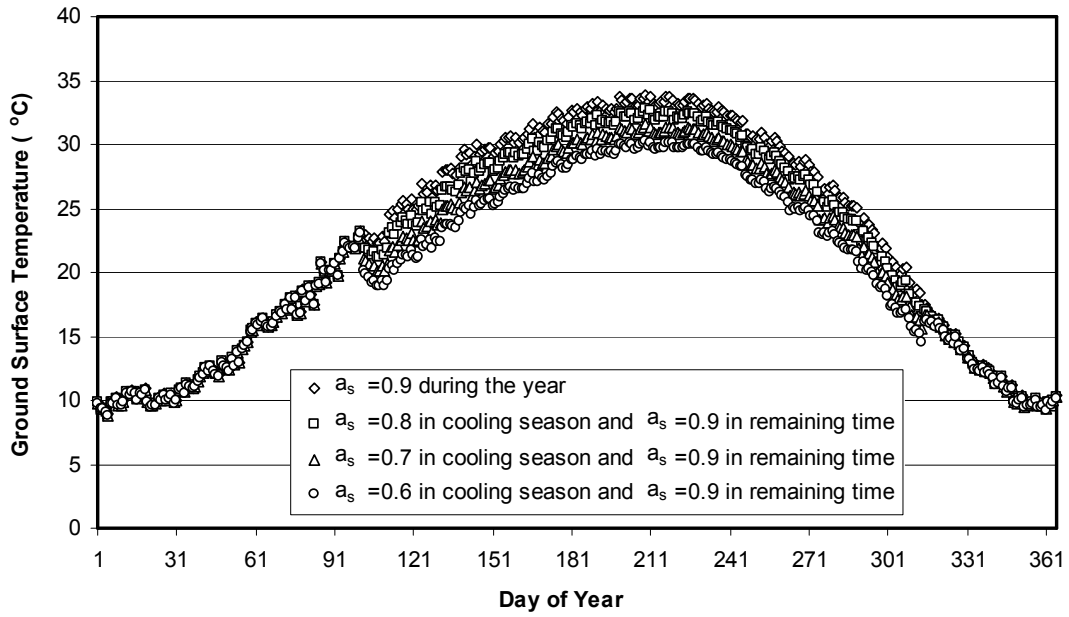


Figure 4.5. Yearly variation of ground surface temperature for different absorption coefficients, ($k_1=k_2= 1.142 \text{ W/mK}$, $a_1=a_2=0.02186 \text{ m}^2/\text{day}$, $f=0.45$, $L1=0.005 \text{ m}$, $L2=10 \text{ m}$).

Figures 4.6 and 4.7 show the variation of ground temperature with ground depth as opposite of the previous state (Adana: 10 November-10 April). In these figures the value of a_s is varied between 0.6 to 0.9 in the heating season and it was taken constant (0.9) in the remaining time which is the time between November 10 and April 10. Yearly variation of ground surface temperature is shown in figure 4.8.

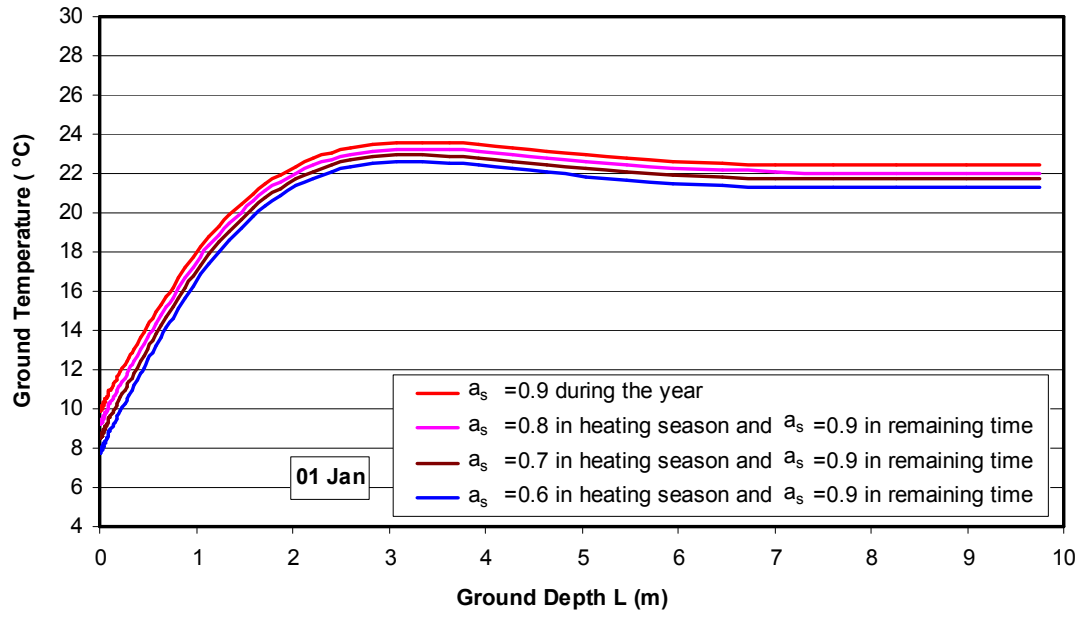


Figure 4.6. Variation of ground temperature with ground depth for different absorption coefficients for January 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

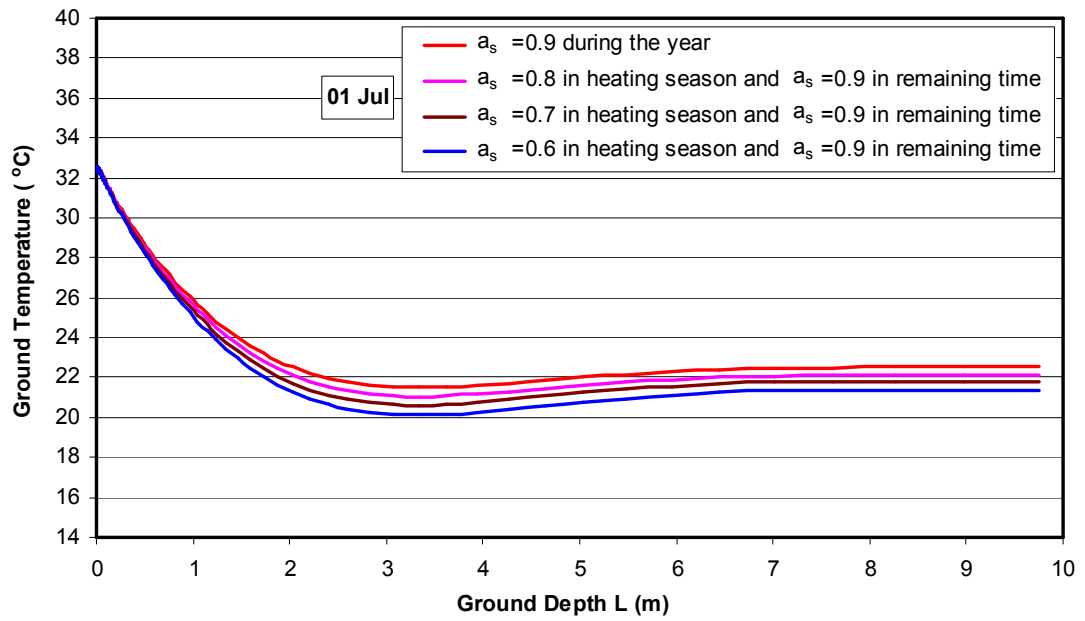


Figure 4.7. Variation of ground temperature with ground depth for different absorption coefficients for July 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

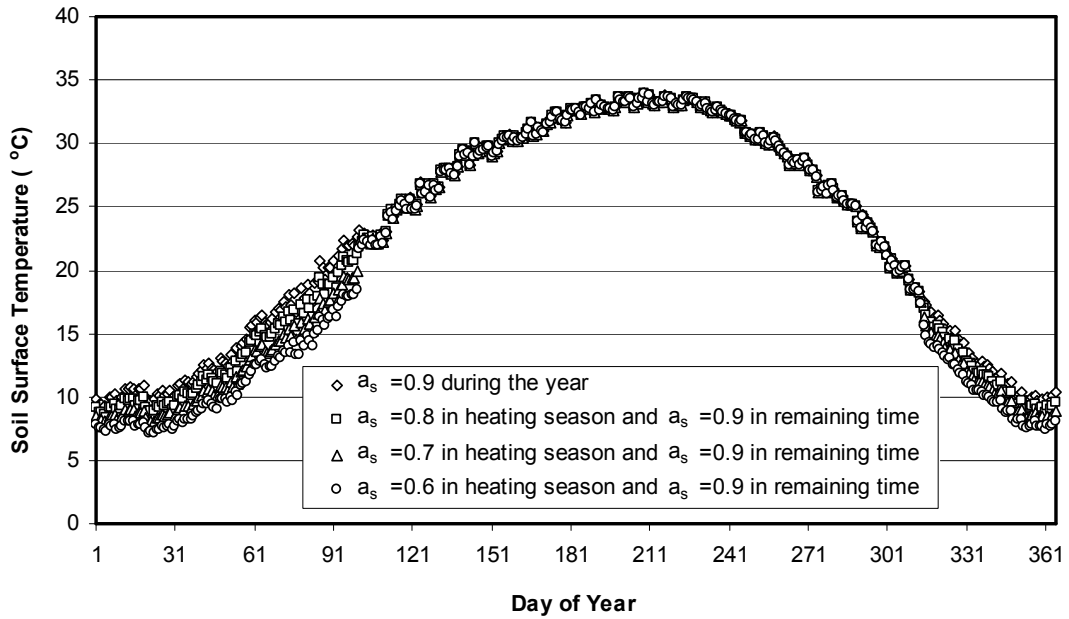


Figure 4.8. Yearly variation of ground surface temperature for different absorption coefficients, ($k_1=k_2= 1.142 \text{ W/mK}$, $a_1=a_2=0.02186 \text{ m}^2/\text{day}$, $f=0.45$, $L1=0.005 \text{ m}$, $L2=10 \text{ m}$).

Figures 4.9 and 4.10 demonstrate the variation of ground temperature with ground depth for the case of constant a_s during the year for January 01 and July 01. In these figures a_s values are varied between 0.6 to 0.9 during the year. The temperature differences for constant a_s during the year (Figures 4.9 and 4.10) are a little higher than that of the seasonal variation of a_s (Figures 4.1, 4.2, 4.6, 4.7). Yearly variation of ground surface temperature for different absorption coefficients is shown in figure 4.11.

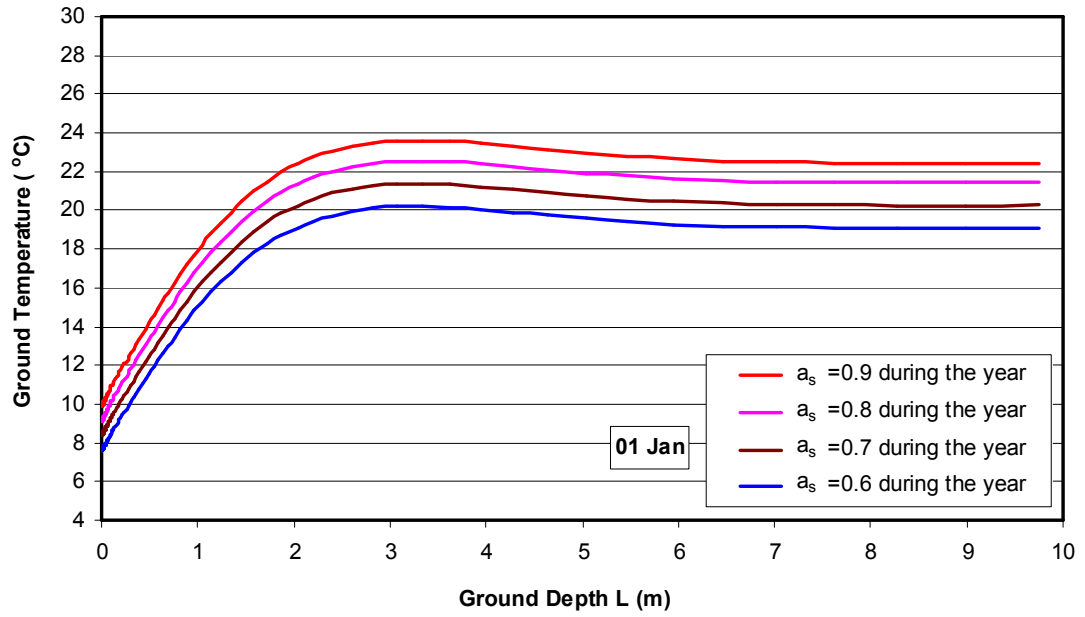


Figure 4.9. Variation of ground temperature with ground depth for different absorption coefficients for January 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

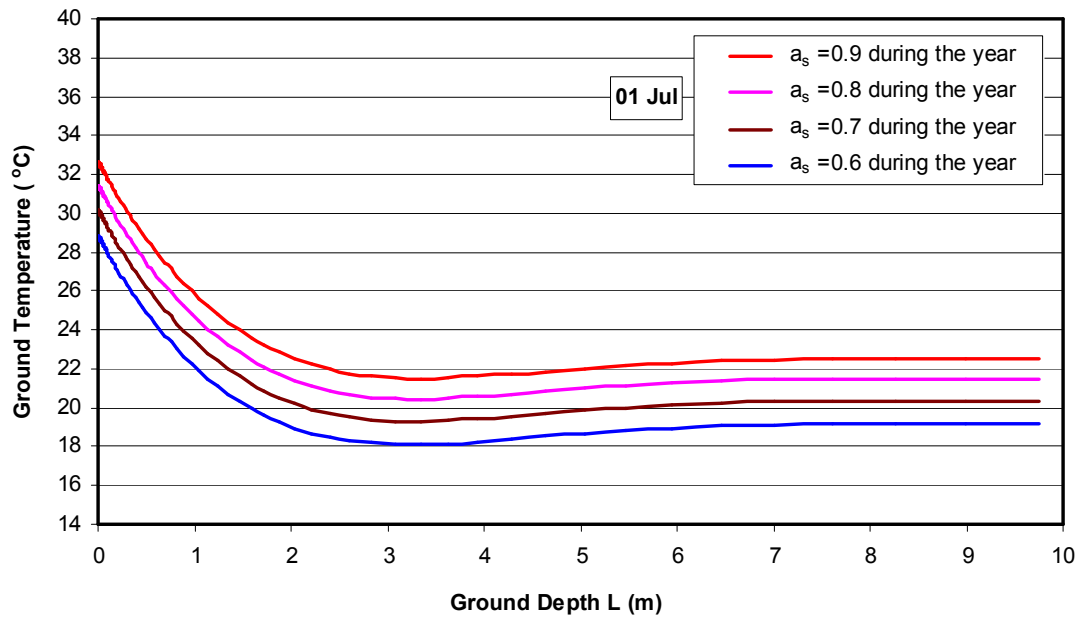


Figure 4.10. Variation of ground temperature with ground depth for different absorption coefficients for July 01, ($k_1=k_2= 1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

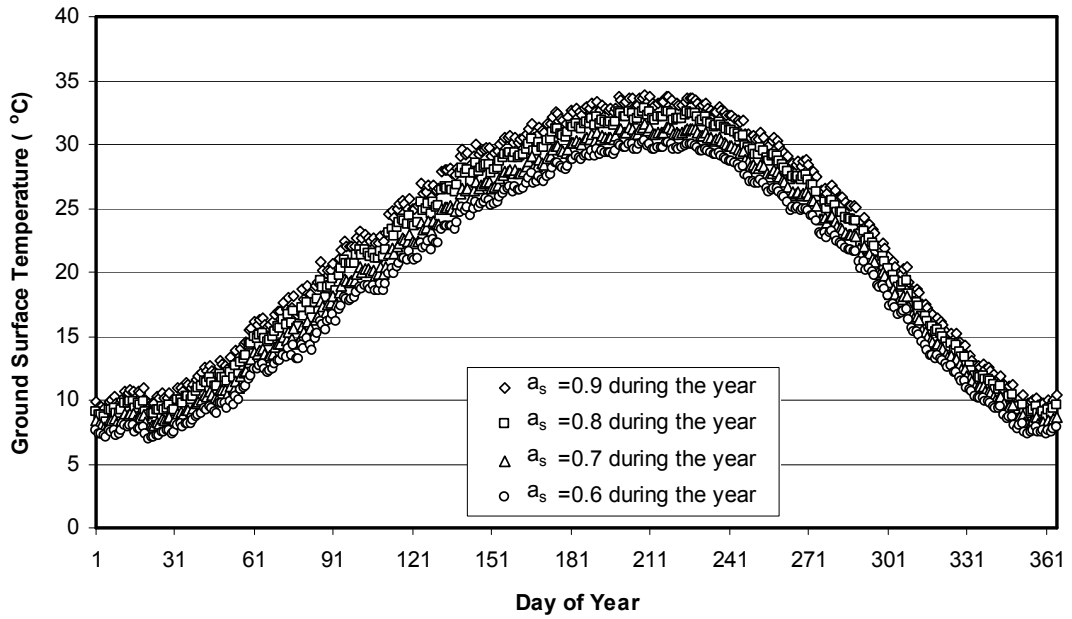


Figure 4.11. Yearly variation of ground surface temperature for different absorption coefficients, ($k_1=k_2= 1.142 \text{ W/mK}$, $a_1=a_2=0.02186 \text{ m}^2/\text{day}$, $f=0.45$, $L1=0.005 \text{ m}$, $L2=10 \text{ m}$).

As can be seen from figures between 4.1 and 4.11, 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.

The variation of the maximum ($T_{\max}$), minimum ($T_{\min}$), end (T_{end}) and surface (T_s) temperatures are obtained from figures 4.1 - 4.11 and shown in tables 4.1 and 4.2. 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 the ground surface. Variation of $T_{\max}$, $T_{\min}$, T_s , T_{end} , $AL_{\max}$ and $AL_{\min}$ with a_s are shown in figures 4.12-4.19, respectively.

Table 4.1. Surface, maximum and end temperatures for January 01

	January 01			
a_s is varying in cooling season and constant in remaining time	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Maximum Temperature, T_{max} (°C)	23.59	22.87	22.07	21.24
The depth of maximum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.41	21.82	21.10	20.35
Surface Temperature, T_s (°C)	9.88	9.83	9.77	9.72
a_s is varying in heating season and constant in remaining time	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Maximum Temperature, T_{max} (°C)	23.59	23.25	22.97	22.61
The depth of maximum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.41	22.01	21.71	21.28
Surface Temperature, T_s (°C)	9.88	9.18	8.48	7.76
a_s is constant during the year	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Maximum Temperature, T_{max} (°C)	23.59	22.53	21.38	20.19
The depth of maximum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.41	21.41	20.27	19.09
Surface Temperature, T_s (°C)	9.88	9.13	8.37	7.59

Table 4.2. Surface, minimum and end temperatures for July 01

	July 01			
a_s is varying in cooling season and constant in remaining time	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Minimum Temperature, T_{min} (°C)	21.50	20.91	20.25	19.56
The depth of minimum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.52	21.9	21.18	20.42
Surface Temperature, T_s (°C)	32.59	31.4	30.16	28.86
a_s is varying in heating season and constant in remaining time	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Minimum Temperature, T_{min} (°C)	21.50	21.04	20.62	20.14
The depth of minimum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.52	22.12	21.81	21.38
Surface Temperature, T_s (°C)	32.59	32.58	32.57	32.55
a_s is constant during the year	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Minimum Temperature, T_{min} (°C)	21.50	20.44	19.3	18.11
The depth of minimum temperature, (m)	3.34	3.34	3.34	3.34
Temperature at $L=L1+L2$, T_{end} (°C)	22.52	21.50	20.36	19.18
Surface Temperature, T_s (°C)	32.59	31.39	30.13	28.81

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 observed from the above tables 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 (Figure 4.12). 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 (Figure 4.13). The maximum effect of varying a_s between 0.6 and 0.9 is 2.4 °C on the maximum temperature (Table 4.1) and 1.9 °C on the minimum temperature (Table 4.2), 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.

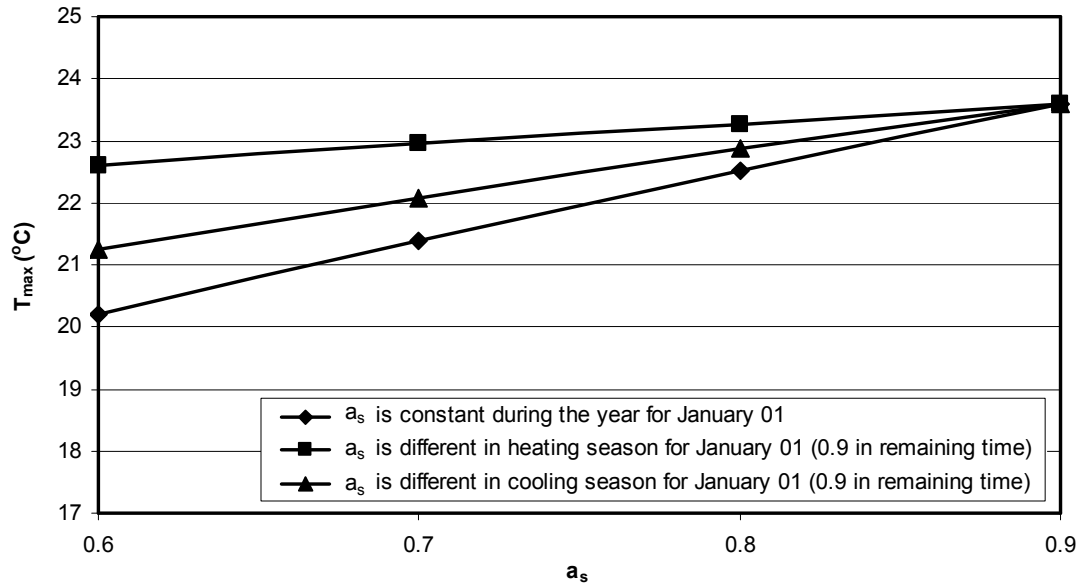


Figure 4.12. Variation of maximum temperature with absorption coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

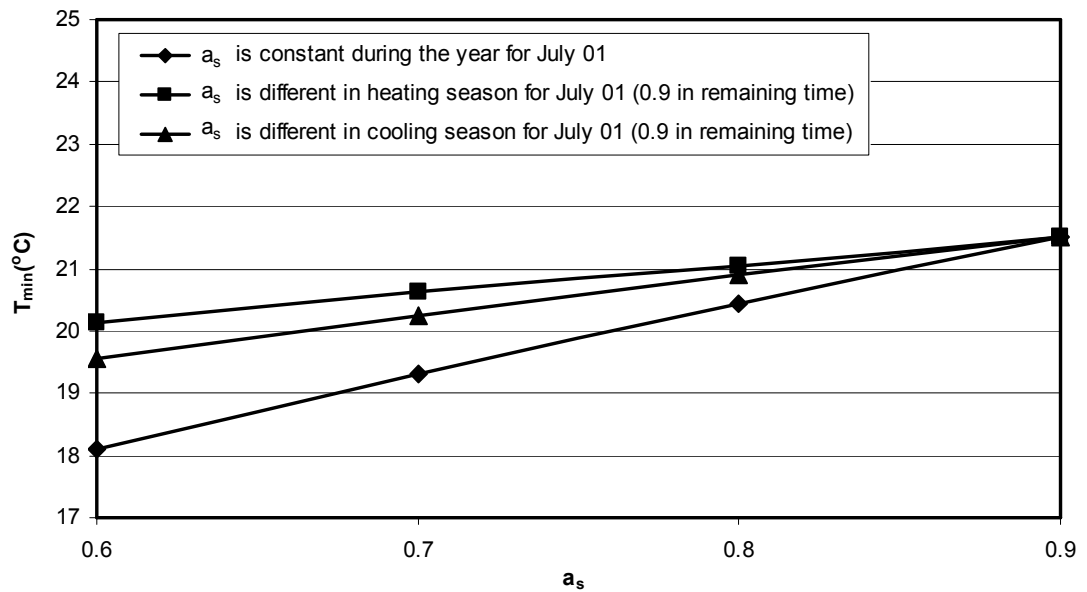


Figure 4.13. Variation of minimum temperature with absorption coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

As can be seen from figure 4.14, 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 figure 4.15, since a_s values are the same (0.9) for the cooling season.

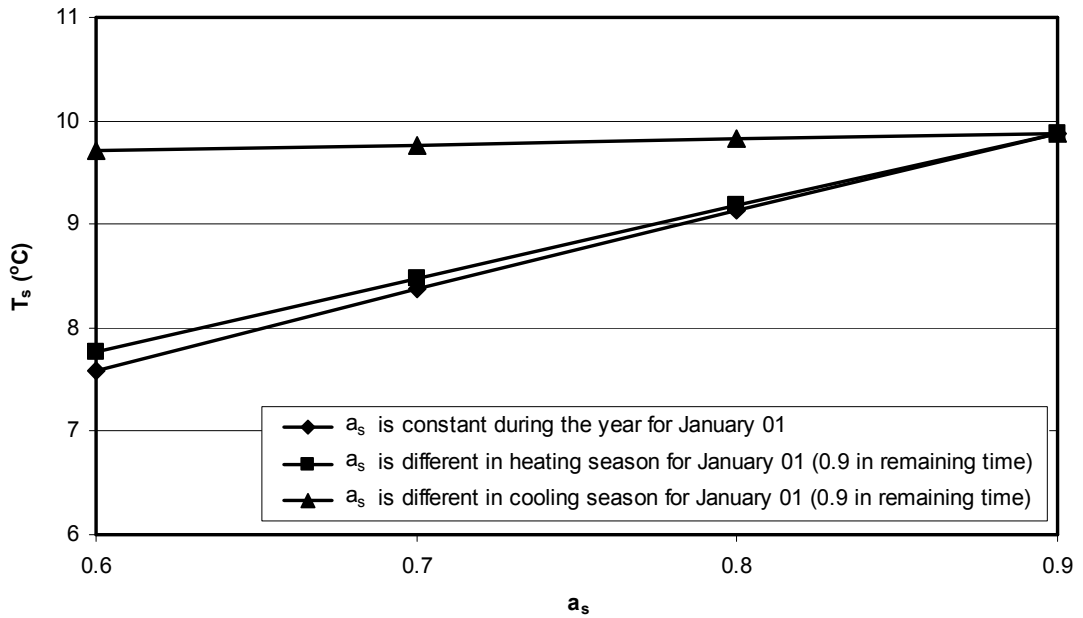


Figure 4.14. Variation of ground surface temperature with absorption coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L1=0.005$ m, $L2=10$ m).

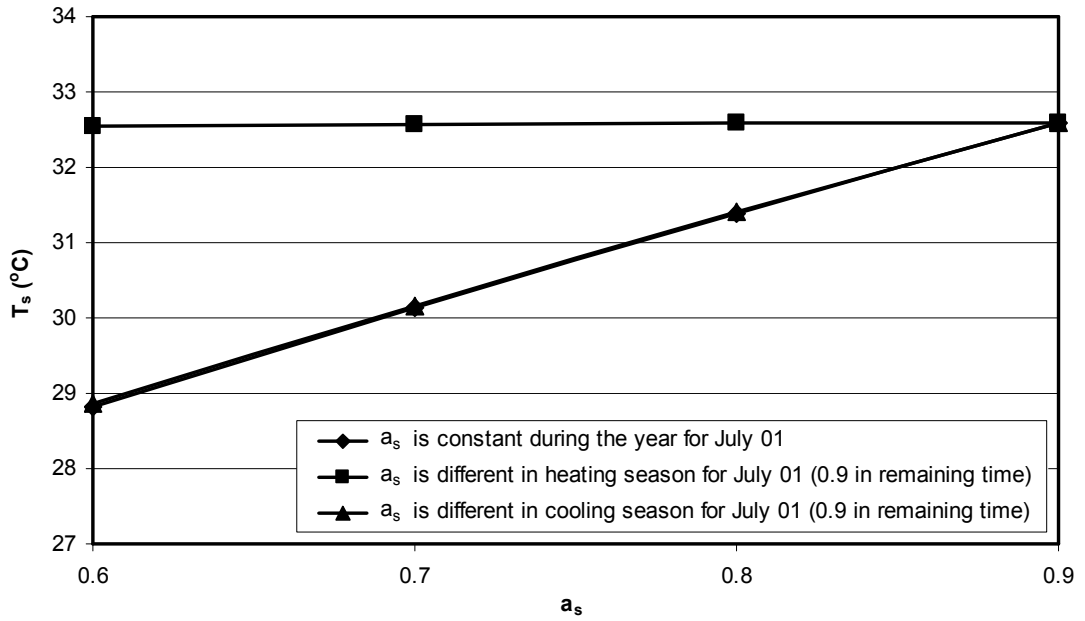


Figure 4.15. Variation of ground surface temperature with absorption coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L1=0.005$ m, $L2=10$ m).

It can be observed from figures 4.16 and 4.17 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 these figures and in tables 4.1 and 4.2, the end temperatures can be influenced by seasonal variation of a_s values.

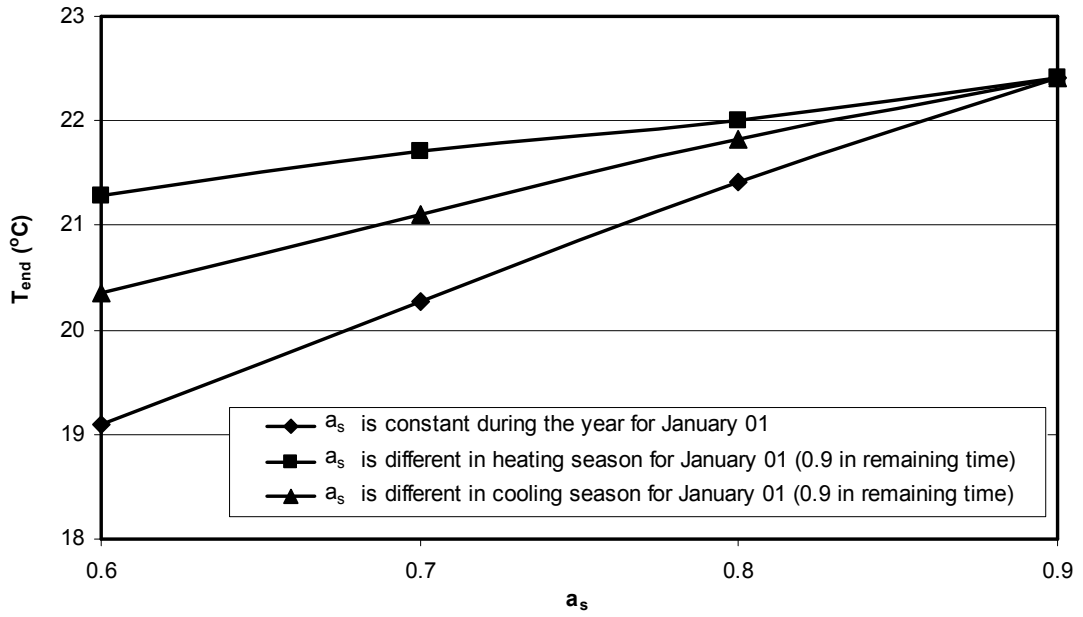


Figure 4.16. Variation of end temperature with absorption coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L1=0.005$ m, $L2=10$ m).

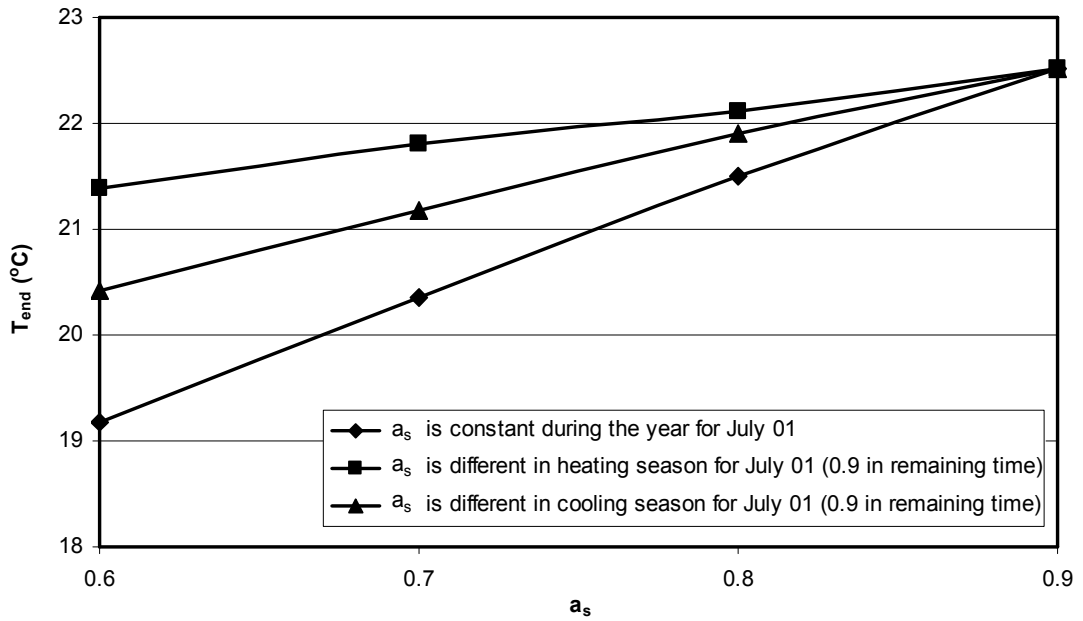


Figure 4.17. Variation of end temperature with absorption coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L1=0.005$ m, $L2=10$ m).

The depths of maximum and minimum temperatures for different a_s values for January 01 and July 01 were shown in figures 4.18 and 4.19, respectively. As can be observed in these figures, the variation of a_s values do not affect the depths of maximum and minimum temperatures.

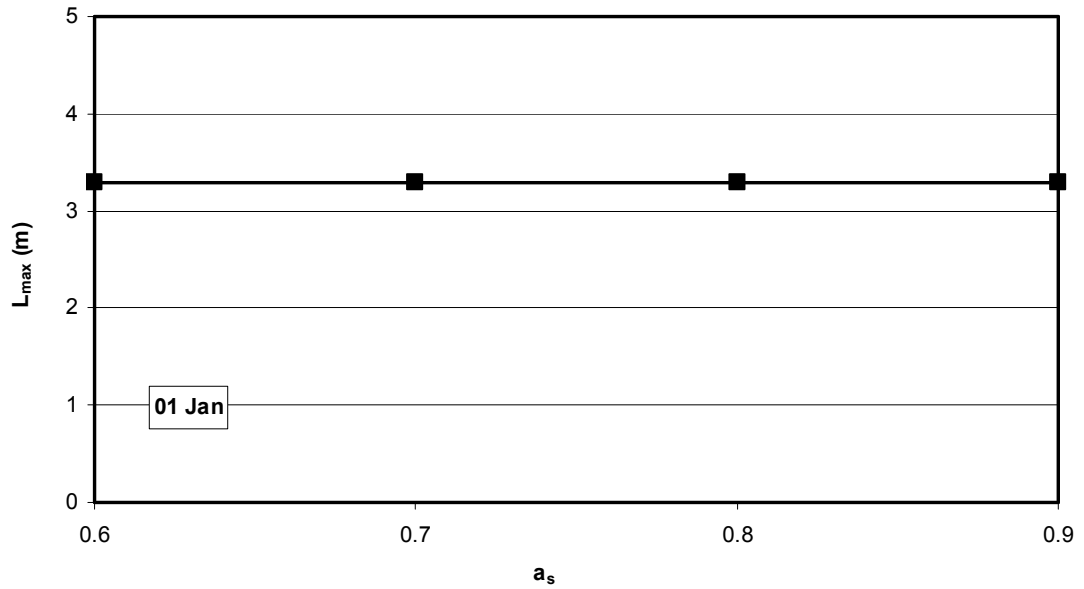


Figure 4.18. Variation of the depth of maximum temperature with absorption coefficient for January 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

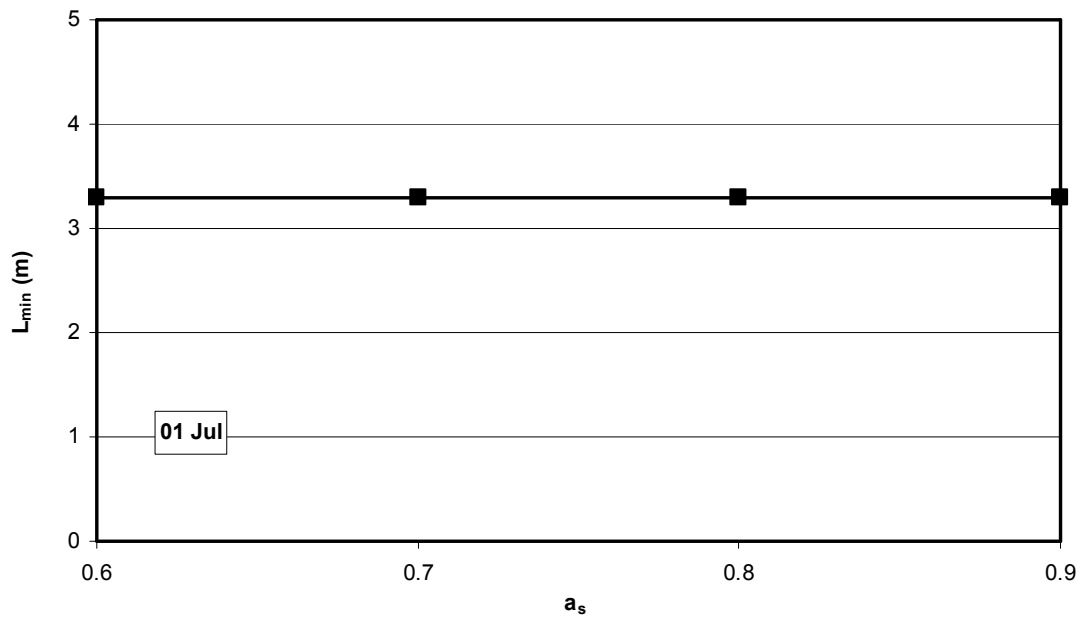


Figure 4.19. Variation of the depth of minimum temperature with absorption coefficient for July 01, ($k_1=k_2=1.142$ W/mK, $a_1=a_2=0.02186$ m²/day, $f=0.45$, $L_1=0.005$ m, $L_2=10$ m).

4.2. Ground Temperatures in Different Upper and Lower Layer Grounds

4.2.1. Results for Ground Evaporation Condition

In table 4.3, some properties are given for commonly encountered ground types. In this part, influence of different ground types on temperature distributions is given. The analysis is carried out for $f=0.45$, which can be considered as the average ground condition for the Çukurova Region of Turkey (Yılmaz T. 2004).

Table 4.3. Thermal properties of some ground types (Yılmaz T. 2004).

Ground Type	a [mm^2/s]	k [$\text{W}/\text{m}^\circ\text{C}$]
Siliceous ground	0.139	0.52
Dry-heavy ground	0.521	0.95
Humid-light ground	0.555	0.87
Humid-heavy ground	0.648	1.30

In figures 4.20 and 4.21, 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 because 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.(3.57). Figure 4.22 shows yearly variation of ground surface temperature for different types of upper layers. As can be seen from this figure, different upper layers do not affect the ground surface temperatures.

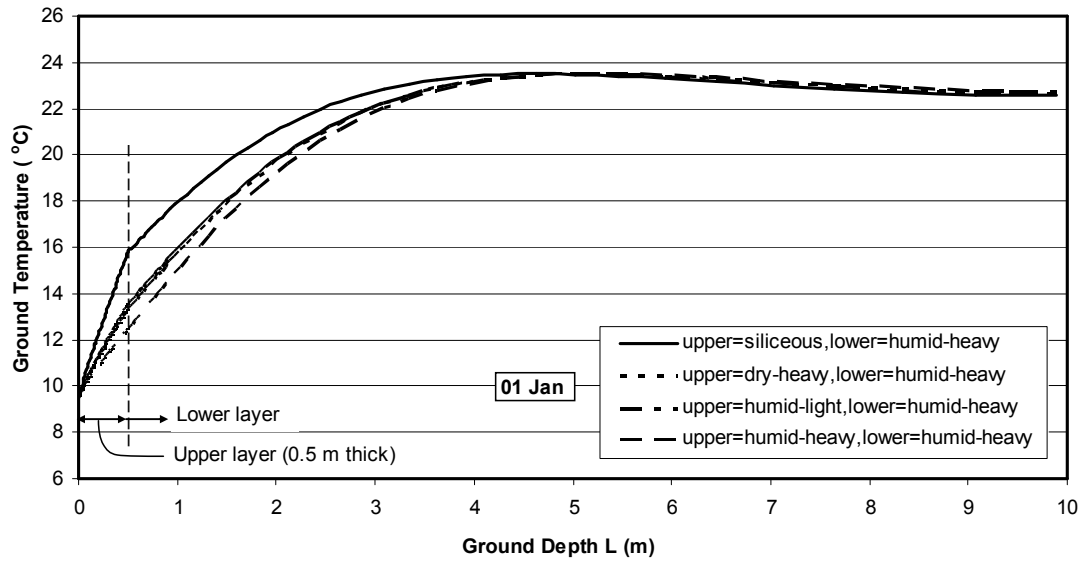


Figure 4.20. Variation of ground temperature with ground depth for different types of upper layers for January 01, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

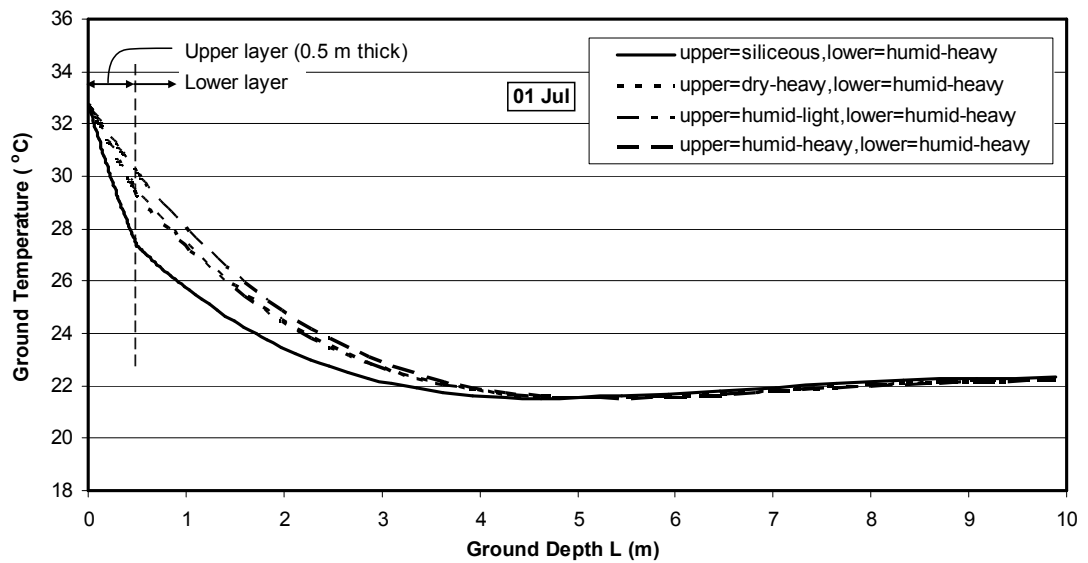


Figure 4.21. Variation of ground temperature with ground depth for different types of upper layers for July 01, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

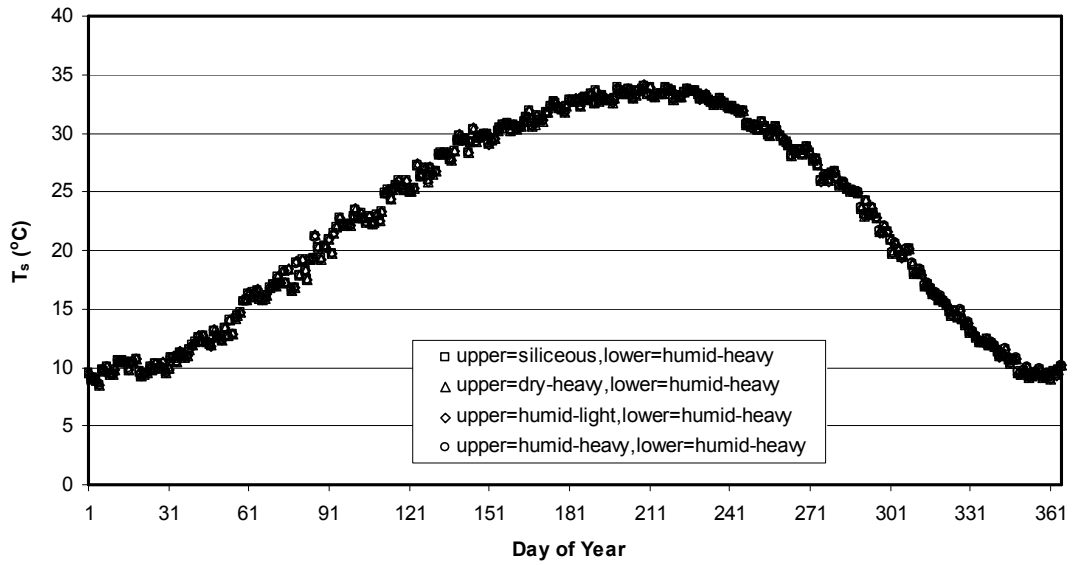


Figure 4.22. Yearly variation of ground surface temperature for different types of upper layers, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

In figures 4.23 and 4.24, temperature distributions for different types of lower layers and humid-heavy upper layer are demonstrated. The arguments made for figures 4.18 and 4.19 are also valid. It is observed 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 °C. The temperature difference between humid-heavy and other layers can be as high as 3.98 °C in January 01 (figure 4.23) and 2.91 °C in July 01 (figure 4.24). Figure 4.25 shows yearly variation of ground surface temperature for different types of lower layers. As can be seen from this figure, different lower layers do not affect the ground surface temperatures.

Location of siliceous layer (upper or lower) changes usual temperature distribution in the ground considerably. As can be seen from table 4.3, both thermal diffusivity a and thermal conductivity k of the siliceous layer are much less than those of other ground types.

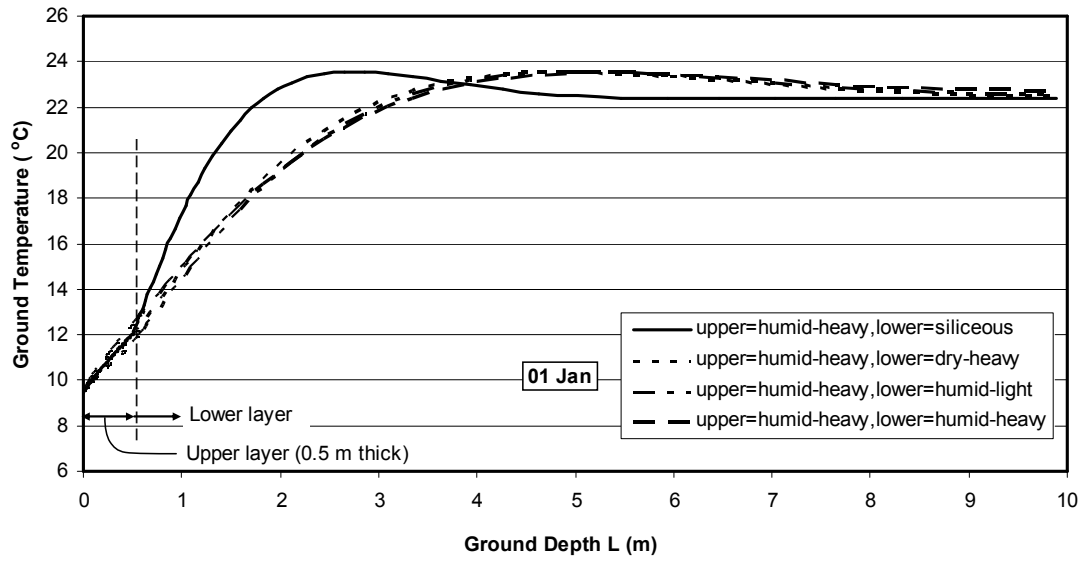


Figure 4.23. Variation of ground temperature with ground depth for different types of lower layers for January 01, ($f=0.45$, $a_s=0.9$, $L_1=0.5$ m, $L_2=10$ m).

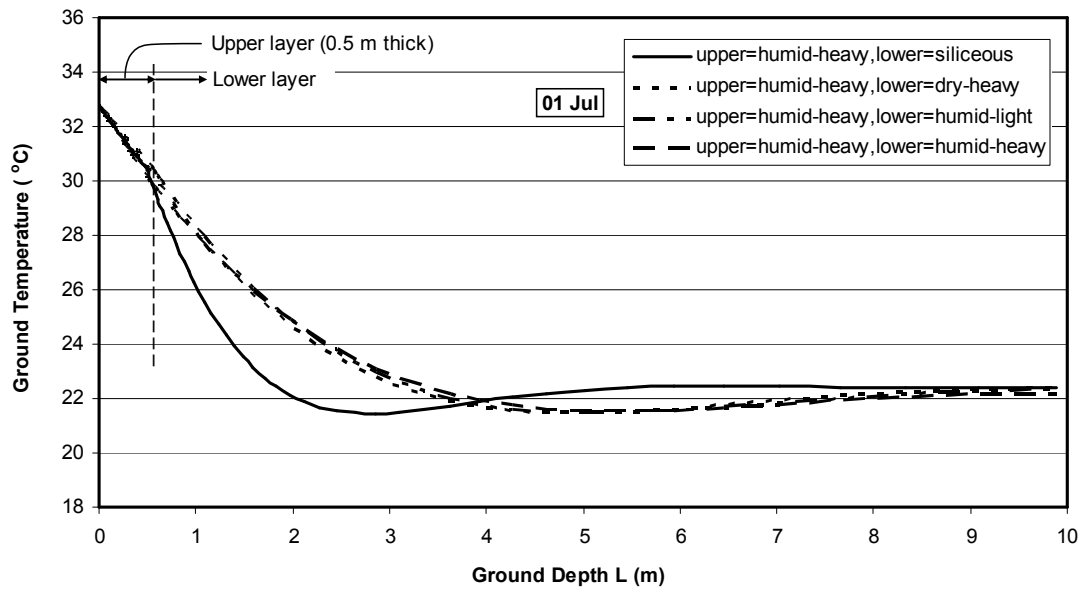


Figure 4.24. Variation of ground temperature with ground depth for different types of lower layers for July 01, ($f=0.45$, $a_s=0.9$, $L_1=0.5$ m, $L_2=10$ m).

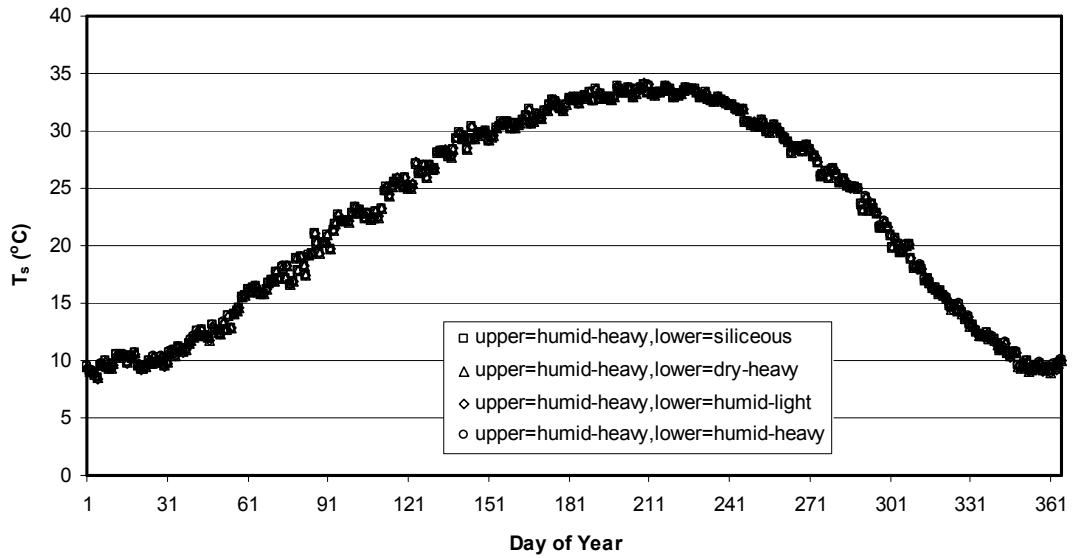


Figure 4.25. Yearly variation of ground surface temperature for different types of lower layers, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

4.2.2. Results for no Ground 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 and ground surface temperatures for different types of upper layers and humid-heavy lower layer are demonstrated in figures 4.26, 4.27 and 4.28, respectively. Since there is no water evaporation from ground to the atmosphere, surface and ground temperatures will be higher than $f=0.45$ case (figures 4.20-4.25) as seen in these figures.

The difference between the surface temperatures for $f=0.0$ and $f=0.45$ is 3.12 °C for January 01 (figure 4.20 and figure 4.26) and 17.83 °C for July 01 (figure 4.21 and figure 4.27). The end temperature differences are 11.12 °C in for both January 01 and July 01. These values show the strong influence of f on the temperatures.

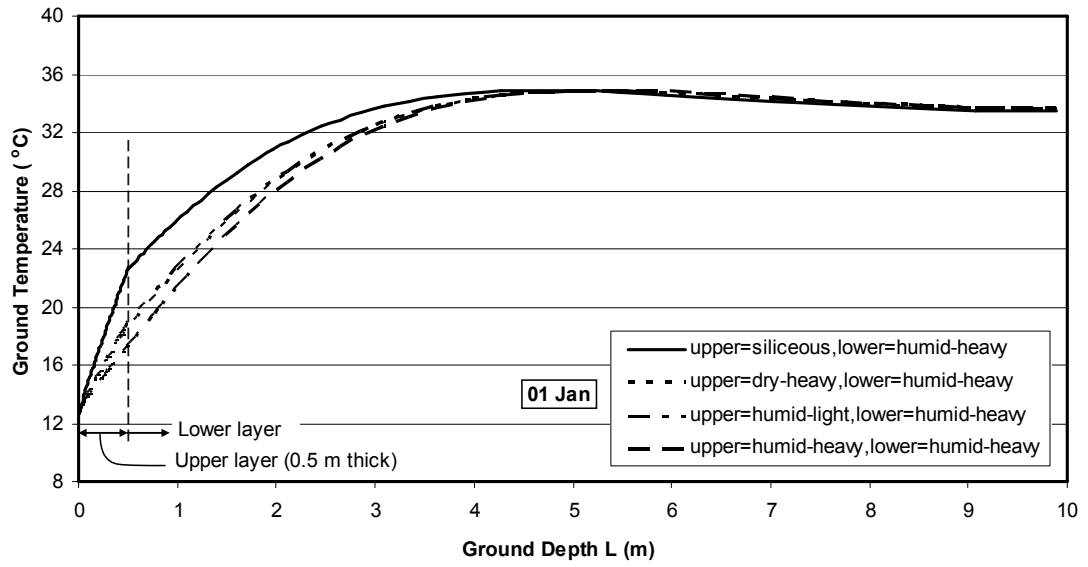


Figure 4.26. Variation of ground temperature with ground depth for different types of upper layers for January 01, ($f=0.0$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

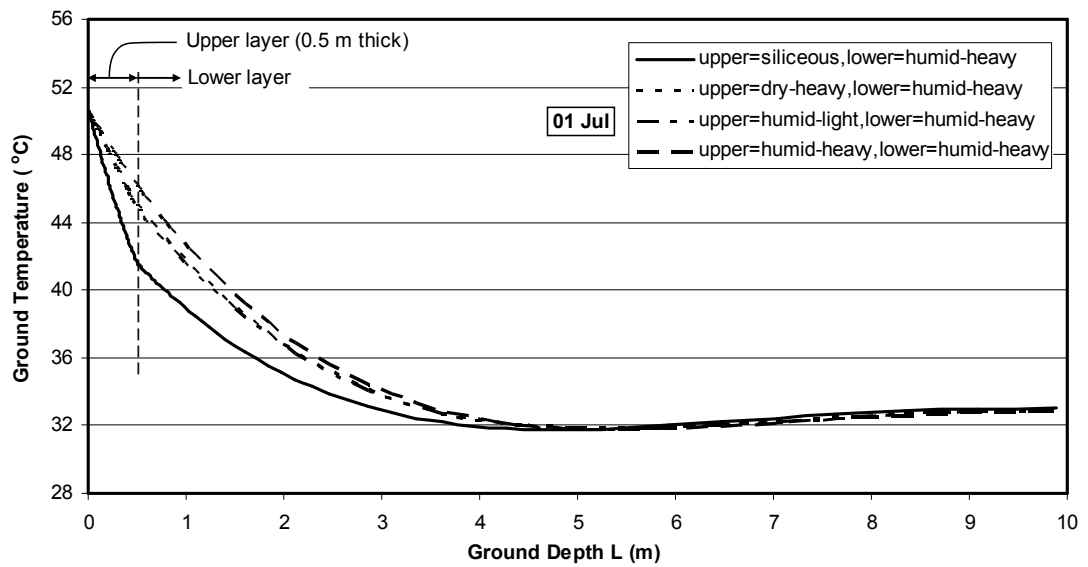


Figure 4.27. Variation of ground temperature with ground depth for different types of upper layers for July 01, ($f=0.0$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

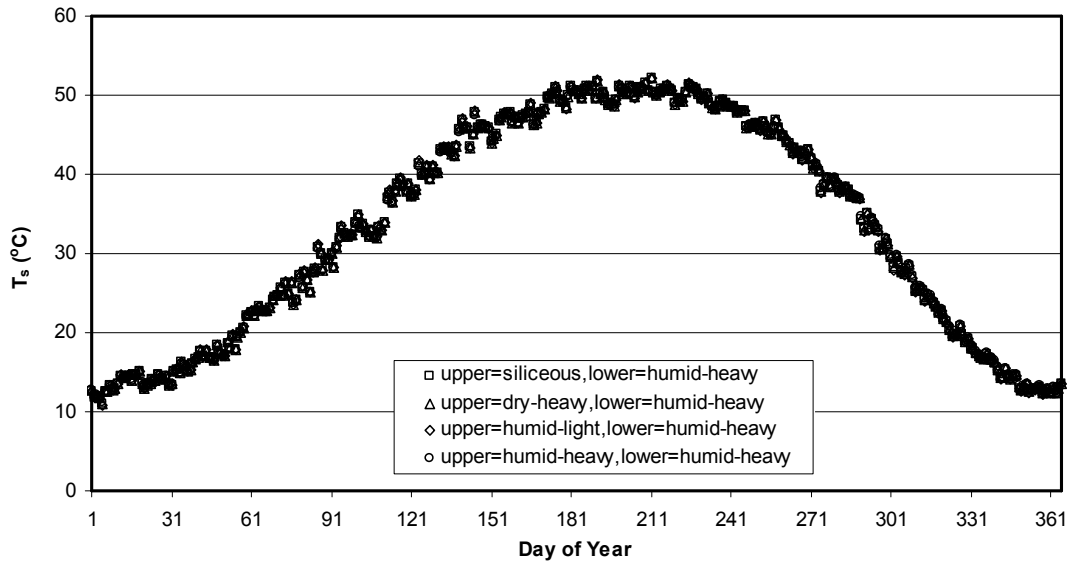


Figure 4.28. Yearly variation of ground surface temperature for different types of upper layers, ($f=0.0$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

Temperature distributions and ground surface temperatures for different types of lower layers and humid-heavy upper layer are demonstrated in figures 4.29, 4.30 and 4.31, respectively. Similar to the previous cases given in figures 4.26, 4.27 and 4.28, surface and ground temperatures are also higher than $f=0.45$ case (figures 4.20-4.25). The depths for minimum and maximum temperatures are considerably different than the others for lower siliceous ground layer.

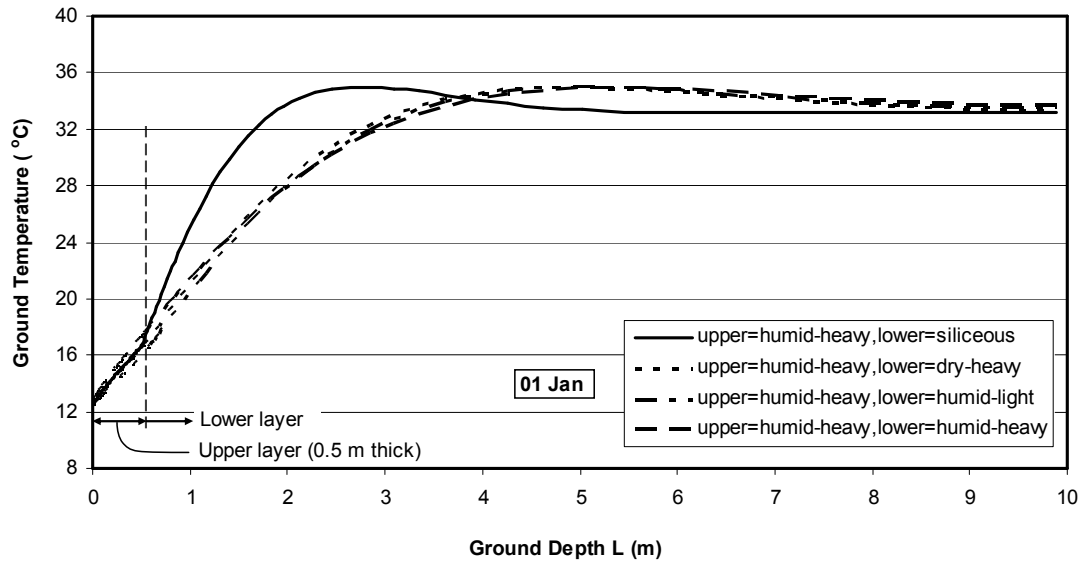


Figure 4.29. Variation of ground temperature with ground depth for different types of lower layers for January 01, ($f=0.0$, $a_s=0.9$, $L_1=0.5$ m, $L_2=10$ m).

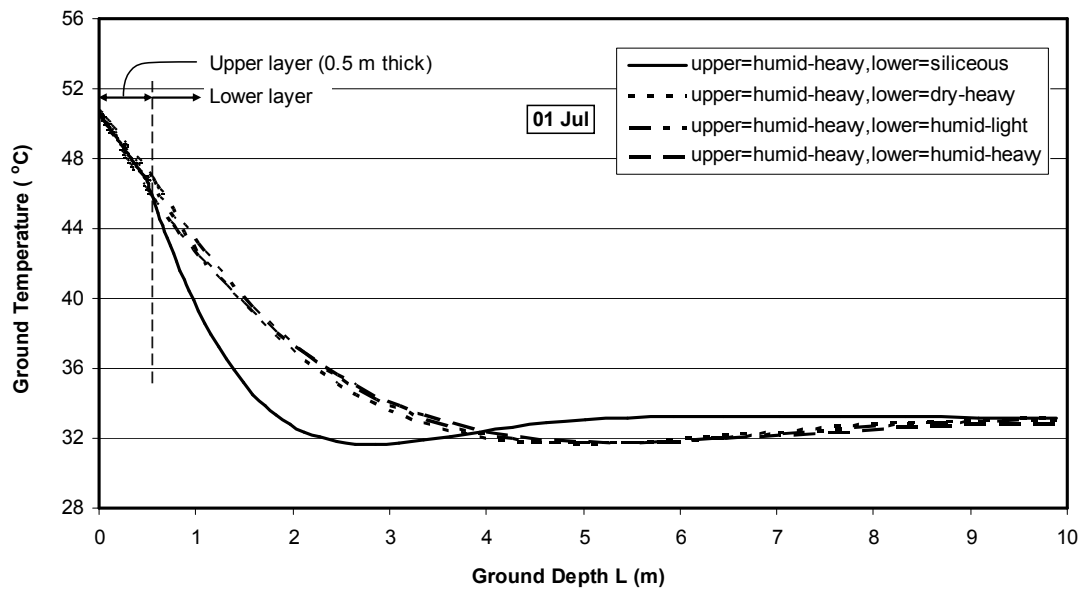


Figure 4.30. Variation of ground temperature with ground depth for different types of lower layers for July 01, ($f=0.0$, $a_s=0.9$, $L_1=0.5$ m, $L_2=10$ m).

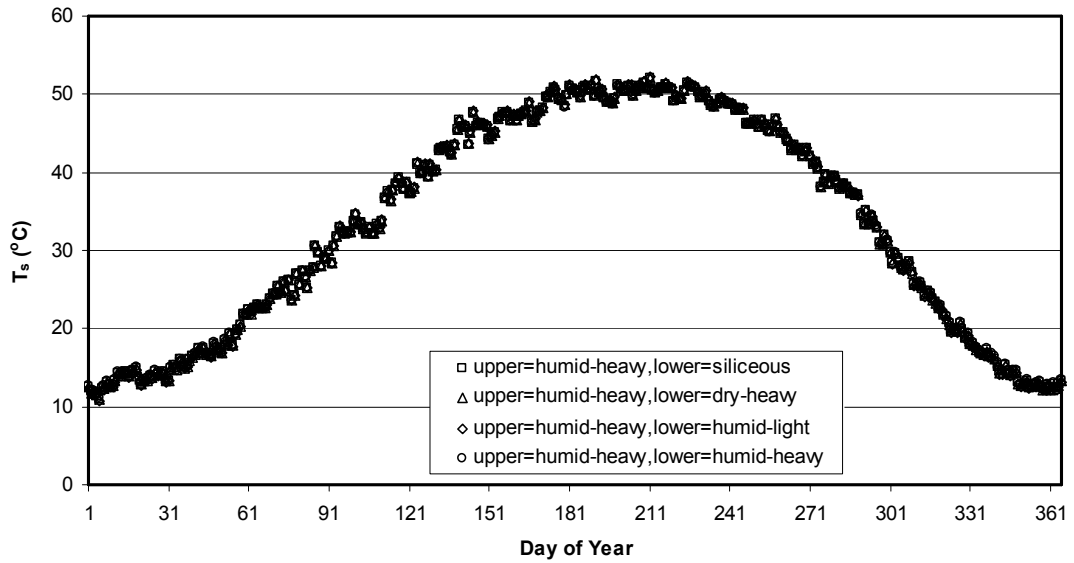


Figure 4.31. Yearly variation of ground surface temperature for different types of lower layers, ($f=0.0$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

Analysis of figures between 4.20 and 4.31 illustrates 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.

20 years average measured ground temperatures taken from The State Meteorological Affairs General Directorate (DMİ) are shown in tables 4.4 and 4.5 for January 01 and July 01 for Adana.

Table 4.4. Ground temperatures measured by DMİ in Adana for January 01

January 01	Time: 07.00	Time: 14.00	Time: 21.00	Arithmetic average
Temperature at 0.05 m (°C)	6.81	12.16	9.44	9.47
Temperature at 0.1 m (°C)	8.24	10.45	10.04	9.58
Temperature at 0.2 m (°C)	9.91	9.90	10.47	10.09
Temperature at 0.5 m (°C)	11.90	11.88	11.85	11.88
Temperature at 1.0 m (°C)	Measured once a day			14.51

Table 4.5. Ground temperatures measured by the DMİ in Adana for July 01

July 01	Time: 07.00	Time: 14.00	Time: 21.00	Arithmetic average
Temperature at 0.05 m (°C)	27.84	41.56	32.62	34.01
Temperature at 0.1 m (°C)	28.54	34.34	33.14	32.00
Temperature at 0.2 m (°C)	29.62	30.32	31.62	30.52
Temperature at 0.5 m (°C)	28.32	28.33	28.33	28.33
Temperature at 1.0 m (°C)	Measured once a day			25.38

The variation of ground temperatures obtained from numerical calculations and DMİ with ground depth for different upper layers for January 01 in Adana are shown in figure 4.32. It is observed that there is a good accordance between the calculated and measured temperatures. Figure 4.33 shows the variation of ground temperatures obtained from numerical calculations and DMİ with ground depth for different upper layers for July 01 in Adana. There is about 2 °C temperature difference between the calculated and measured temperatures.

One of the reasons for these temperature differences is that arithmetic average value of ground temperatures measured for three times in a day (07.00, 14.00 and 21.00) is given by DMİ as a daily average ground temperature. But this method can give wrong mean values especially in summer months and near the ground surface.

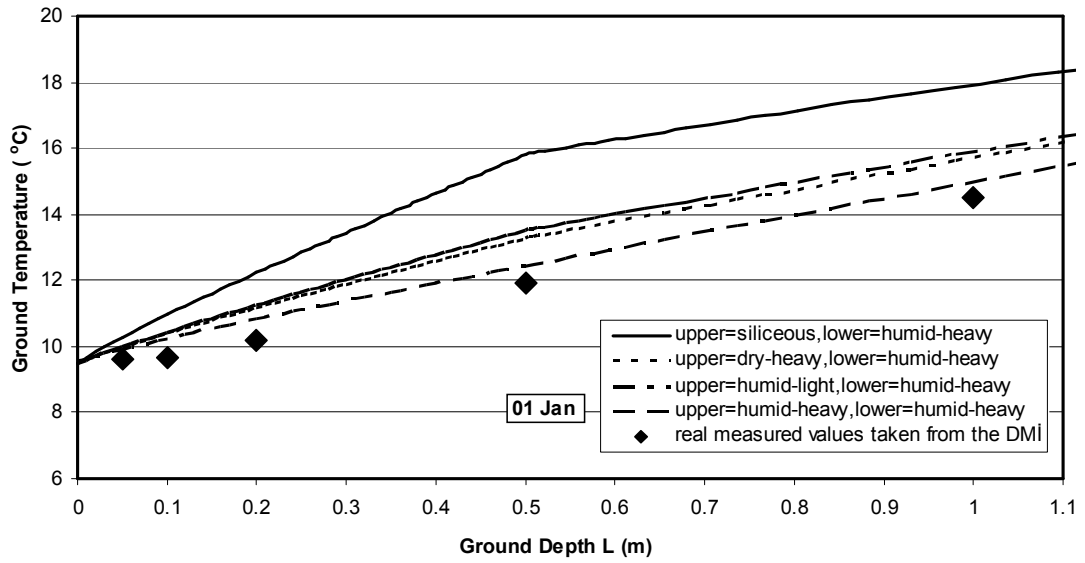


Figure 4.32. Variation of ground temperatures obtained from numerical calculations and DMI with ground depth for different upper layers for January 01 in Adana, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

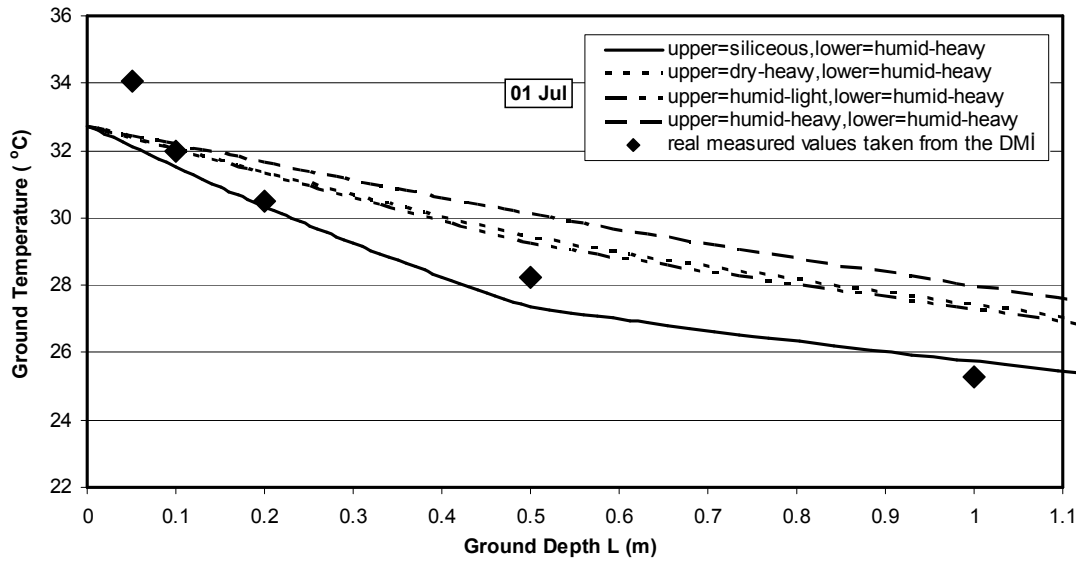


Figure 4.33. Variation of ground temperatures obtained from numerical calculations and DMI with ground depth for different upper layers for July 01 in Adana, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

The variation of ground temperatures obtained from numerical calculations and DMI with ground depth for different lower layers for January 01 and July 01 in Adana are demonstrated in figures 4.34 and 4.35. While calculated values for winter months (except for lower layer siliceous ground) are in a good accordance with

measured values, there is till 4 °C temperature difference between calculated mean measured values for summer months.

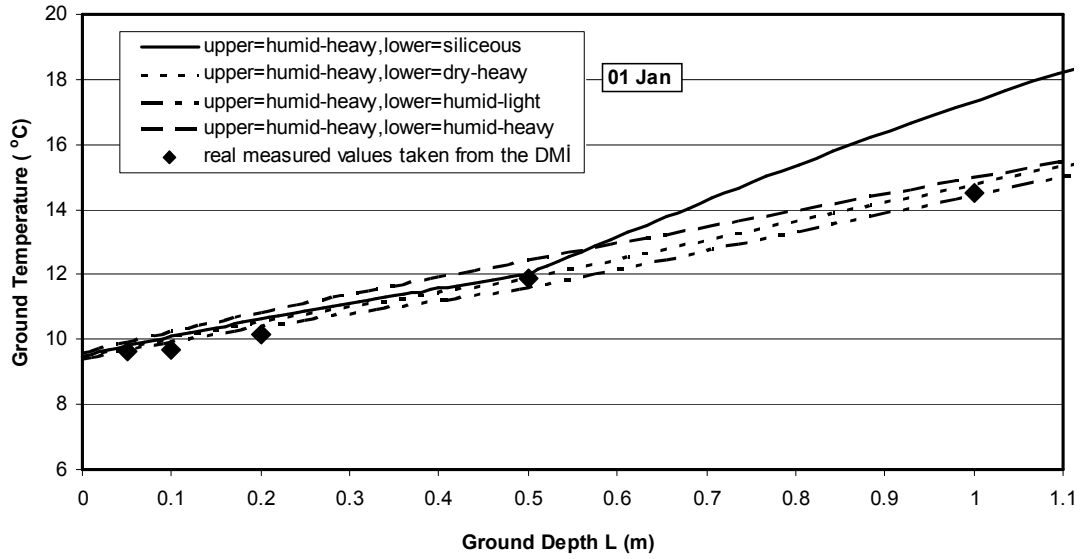


Figure 4.34. Variation of ground temperatures obtained from numerical calculations and DMI with ground depth for different lower layers for January 01 in Adana, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

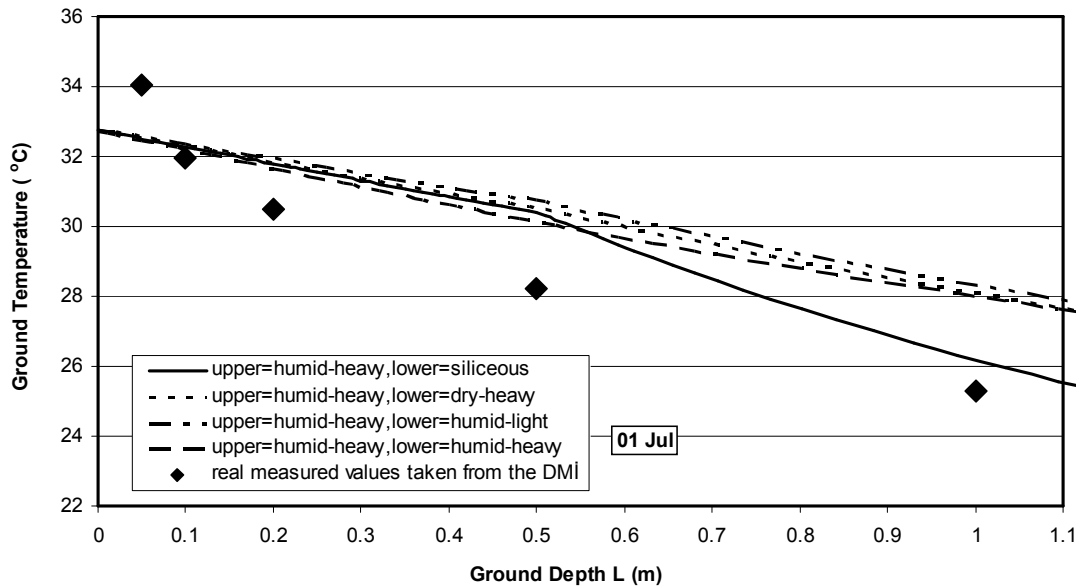


Figure 4.35. Variation of ground temperatures obtained from numerical calculations and DMI with ground depth for different lower layers for July 01 in Adana, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m).

4.3. Correction of Mean Ground Temperatures Taken from DMİ

There are some problems in ground temperatures taken from DMİ. Because arithmetic average value of ground temperatures measured for three times in a day (07.00, 14.00 and 21.00) by DMİ, the average ground temperatures must be found with integration method of daily ground temperature variation. Thus, ground temperature values taken from DMİ at 07.00, 14.00 and 21.00 for $x=0.05$ m depth are shown in figures 4.36 and 4.37 for January 01 and July 01 and then curves were fit to these values. The value at 07.00 for next day is shown as 31.00 in these figures. Similar results were obtained for 0.1 m, 0.2 m and 0.5 m depths in figures between 4.38 and 4.43.

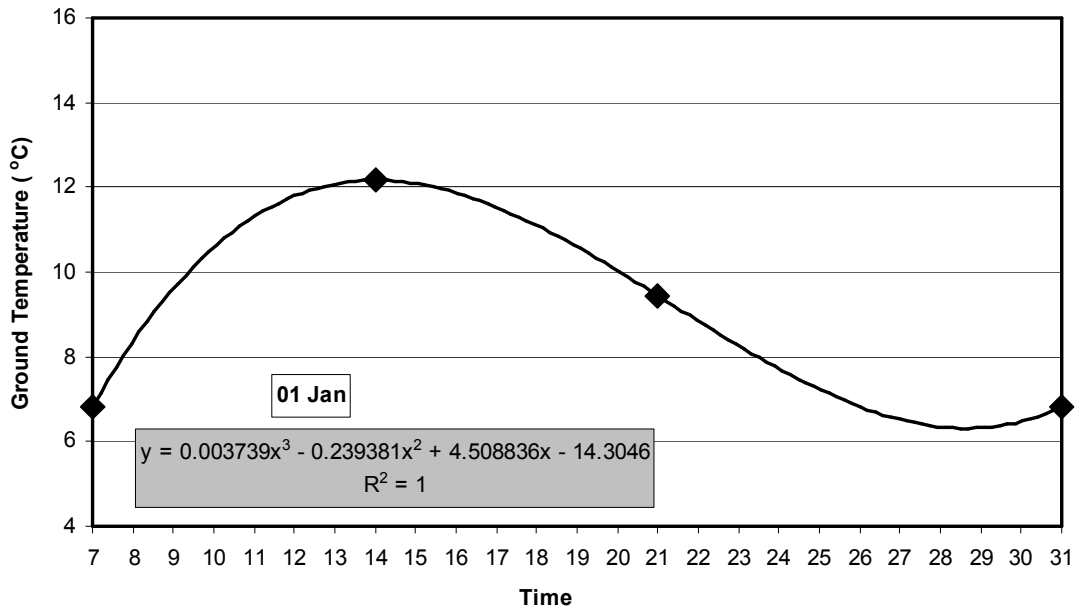


Figure 4.36. Curve-fit to the ground temperatures measured for three times in a day for 0.05 m ground depth for January 01 in Adana.

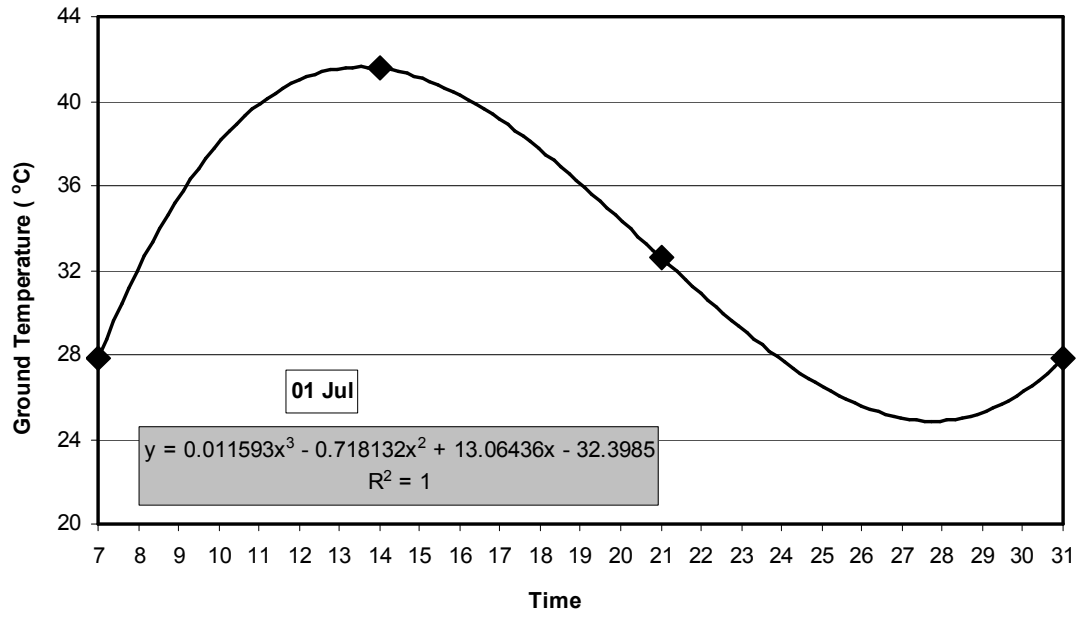


Figure 4.37. Curve-fit to the ground temperatures measured for three times in a day for 0.05 m ground depth for July 01 in Adana.

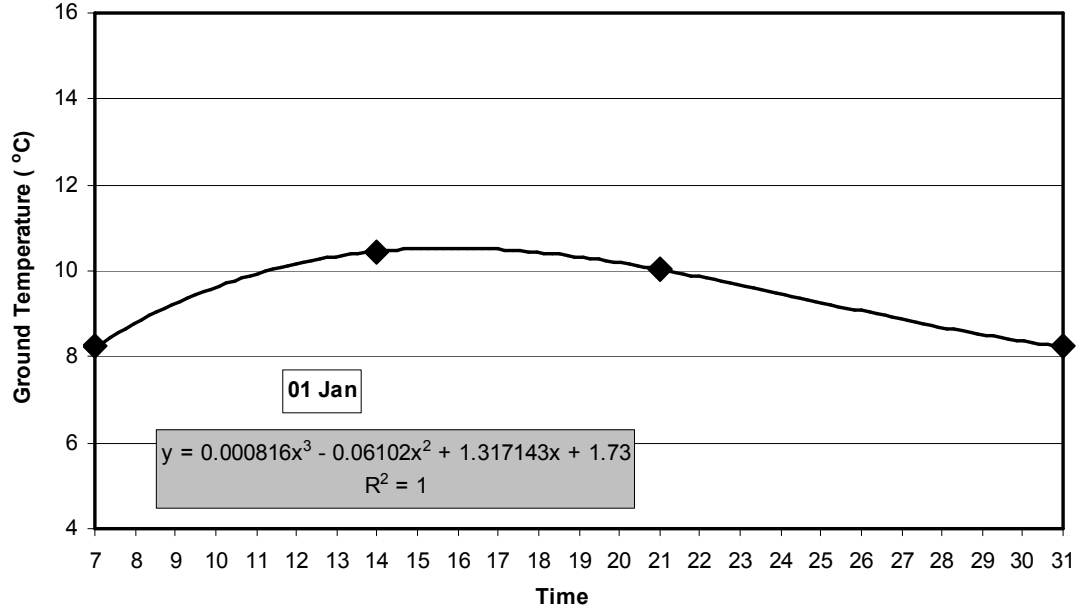


Figure 4.38. Curve-fit to the ground temperatures measured for three times in a day for 0.1 m ground depth for January 01 in Adana.

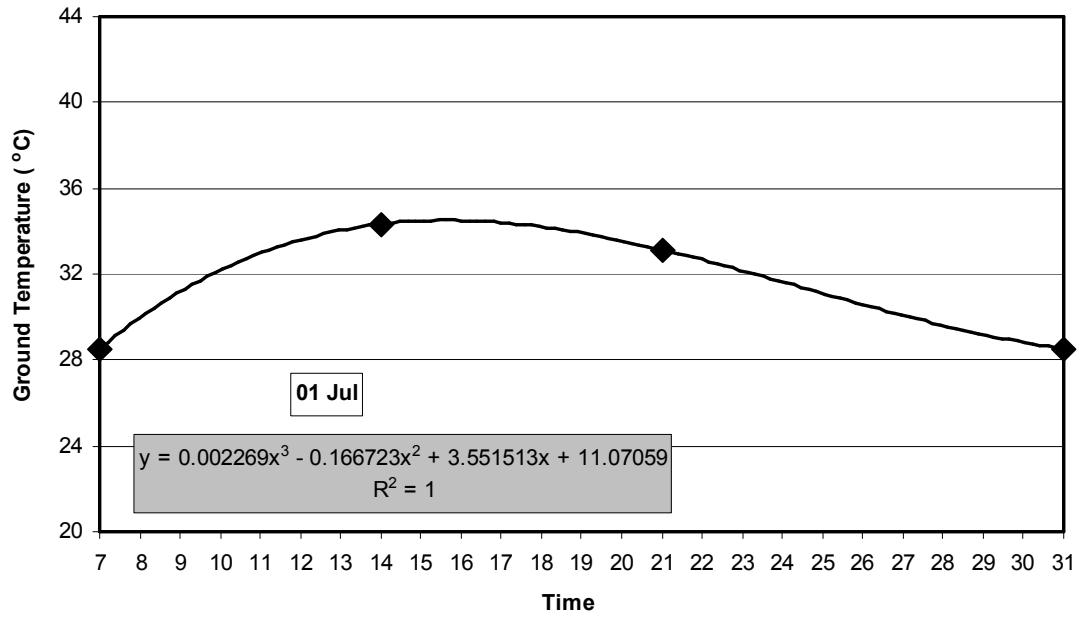


Figure 4.39. Curve-fit to the ground temperatures measured for three times in a day for 0.1 m ground depth for July 01 in Adana.

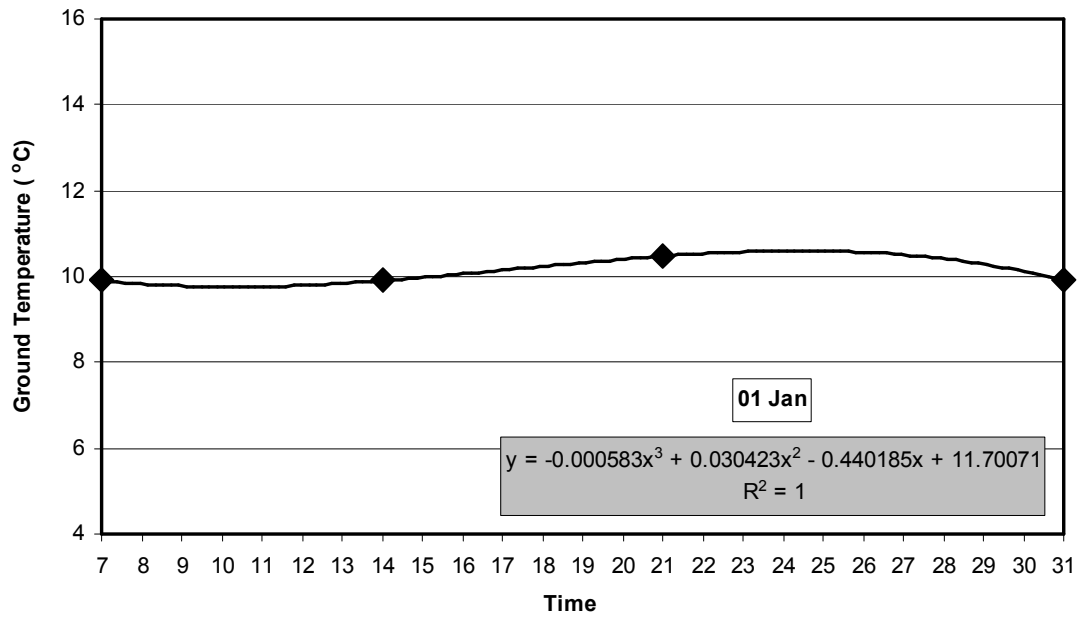


Figure 4.40. Curve-fit to the ground temperatures measured for three times in a day for 0.2 m ground depth for January 01 in Adana.

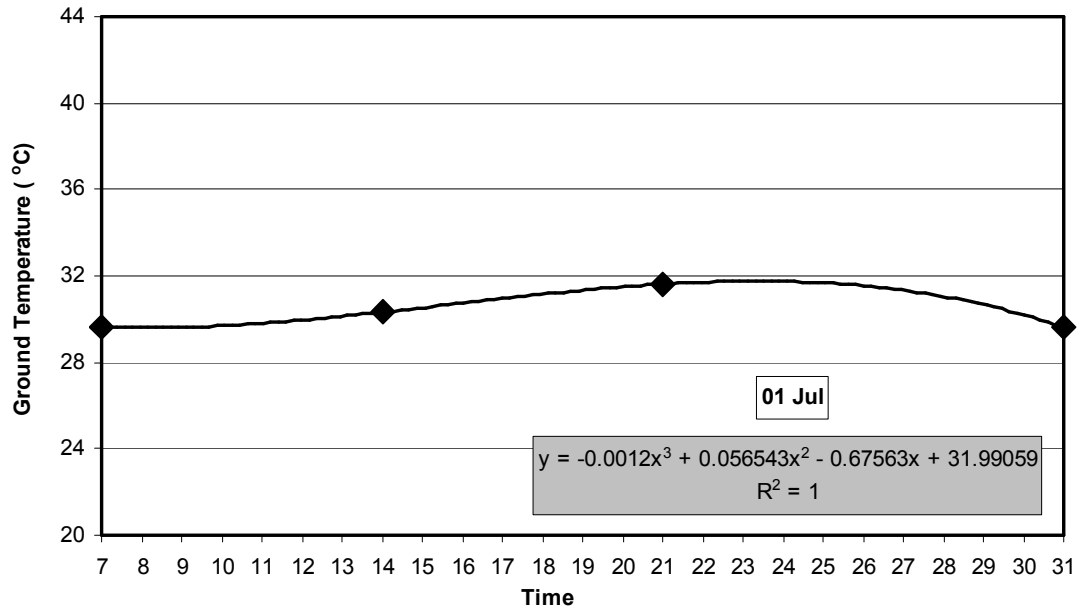


Figure 4.41. Curve-fit to the ground temperatures measured for three times in a day for 0.2 m ground depth for July 01 in Adana.

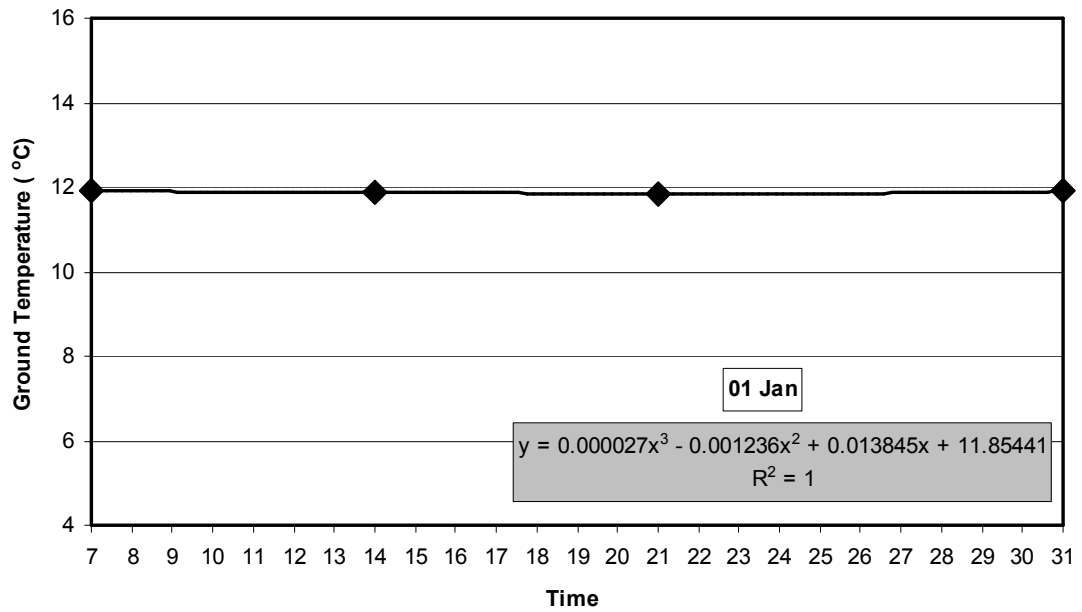


Figure 4.42. Curve-fit to the ground temperatures measured for three times in a day for 0.5 m ground depth for January 01 in Adana.

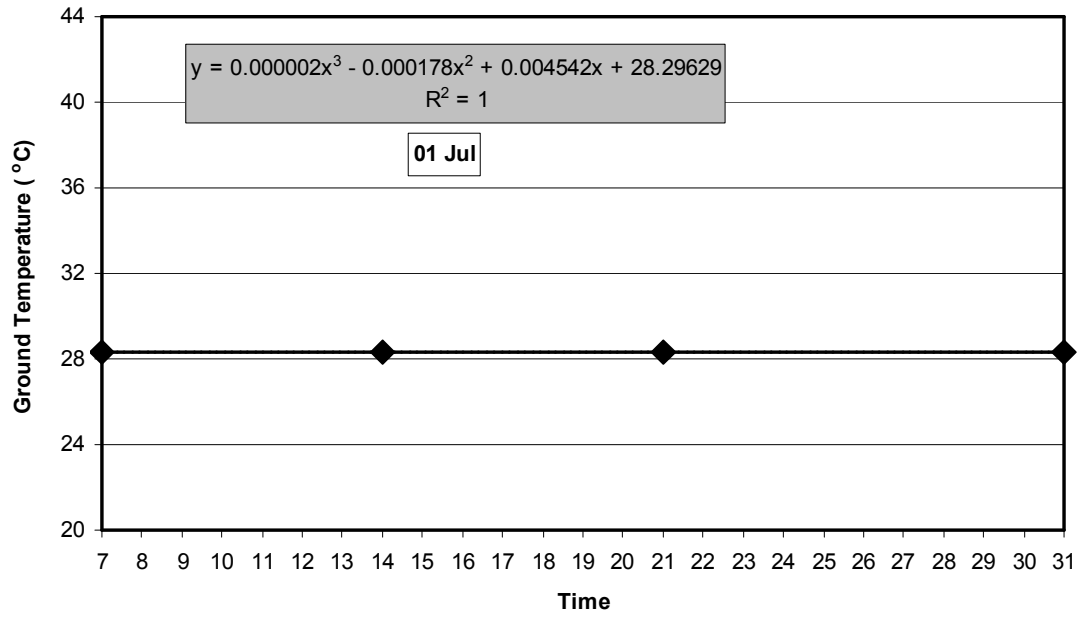


Figure 4.43. Curve-fit to the ground temperatures measured for three times in a day for 0.5 m ground depth for July 01 in Adana.

With the help of these equations, real mean ground temperatures shown in table 4.6 were determined as a result of the integration method. Mean ground temperatures taken from the DMI and the results found from the integration method were compared in table 4.7. It can be seen from this table that there is 0.9 K temperature difference near the ground surface between the mean ground temperatures in summer months.

Table 4.6. Hourly real mean ground temperatures obtained from curve-fit equations for January 01 and July 01

Ground Depth	0.05 m		0.1 m		0.2 m		0.5 m		1.0 m	
	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul
7	6.81	27.84	8.24	28.54	9.91	29.62	11.90	28.32	14.51	25.38
8	8.36	32.09	8.78	29.97	9.83	29.59	11.90	28.32	14.51	25.38
9	9.61	35.46	9.24	31.18	9.78	29.62	11.90	28.32	14.51	25.38
10	10.58	38.02	9.62	32.18	9.76	29.69	11.90	28.33	14.51	25.38
11	11.30	39.85	9.92	32.98	9.76	29.80	11.89	28.33	14.51	25.38
12	11.79	41.00	10.16	33.60	9.79	29.95	11.89	28.33	14.51	25.38
13	12.07	41.54	10.33	34.05	9.84	30.13	11.88	28.33	14.51	25.38
14	12.16	41.56	10.45	34.34	9.90	30.32	11.88	28.33	14.51	25.38
15	12.09	41.11	10.51	34.49	9.98	30.53	11.88	28.33	14.51	25.38
16	11.87	40.27	10.53	34.51	10.06	30.74	11.87	28.33	14.51	25.38
17	11.53	39.11	10.50	34.41	10.15	30.95	11.87	28.33	14.51	25.38
18	11.10	37.70	10.43	34.21	10.23	31.15	11.86	28.33	14.51	25.38
19	10.59	36.10	10.32	33.93	10.32	31.33	11.86	28.33	14.51	25.38
20	10.03	34.38	10.19	33.56	10.40	31.50	11.85	28.33	14.51	25.38
21	9.44	32.62	10.04	33.14	10.47	31.62	11.85	28.33	14.51	25.38
22	8.84	30.88	9.86	32.67	10.53	31.72	11.85	28.33	14.51	25.38
23	8.26	29.24	9.67	32.17	10.58	31.76	11.85	28.33	14.51	25.38
24	7.71	27.76	9.47	31.64	10.60	31.76	11.85	28.33	14.51	25.38
25	7.23	26.52	9.27	31.11	10.60	31.69	11.85	28.33	14.51	25.38
26	6.82	25.58	9.07	30.59	10.58	31.56	11.85	28.33	14.51	25.38
27	6.52	25.01	8.87	30.08	10.52	31.35	11.86	28.33	14.51	25.38
28	6.35	24.88	8.68	29.61	10.43	31.06	11.87	28.33	14.51	25.38
29	6.32	25.26	8.51	29.19	10.30	30.68	11.87	28.33	14.51	25.38
30	6.47	26.22	8.36	28.83	10.13	30.21	11.89	28.33	14.51	25.38
31	6.81	27.84	8.23	28.54	9.92	29.63	11.90	28.33	14.51	25.38
Average	9.23	33.11	9.57	31.98	10.18	30.72	11.87	28.33	14.51	25.38

Table 4.7. Mean of the values taken from DMİ and obtained from curve-fit for January 01 and July 01

	0.05m		0.1m		0.2m		0.5m		1.0m	
	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul	01 Jan	01 Jul
Aritmetic mean values of the data taken from the DMİ	9.47	34.01	9.58	32.00	10.09	30.52	11.88	28.33	14.51	25.38
Mean of the values obtained from curve-fit	9.23	33.11	9.57	31.98	10.18	30.72	11.87	28.33	14.51	25.38

In figures 4.44 and 4.45, the ground temperatures with ground depth for mean values taken from DMI and obtained from curve-fit are demonstrated for January 01 and July 01.

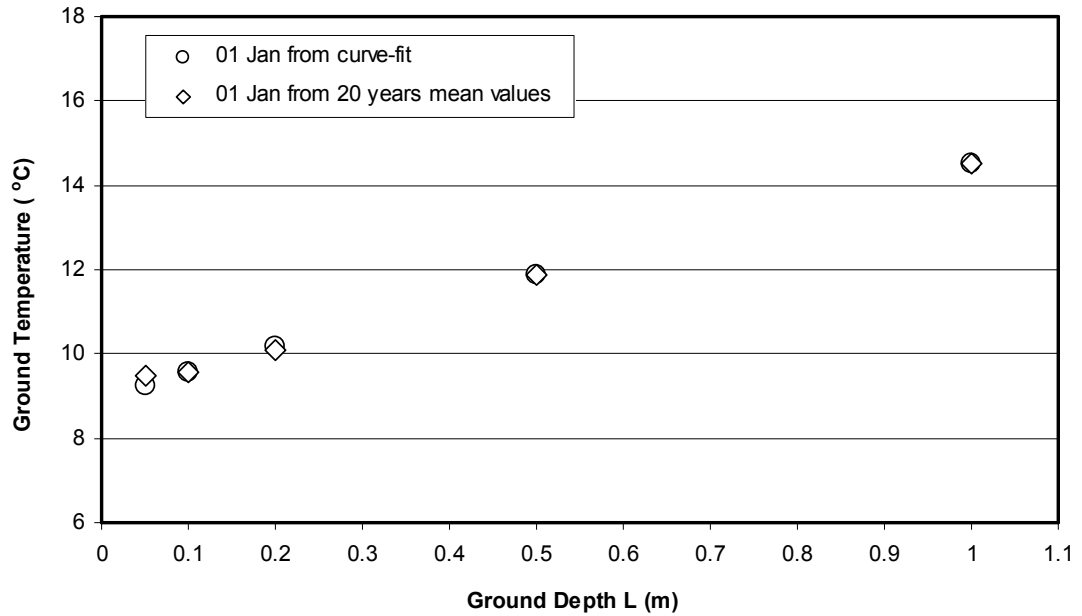


Figure 4.44. Comparison of ground temperature with ground depth for mean values taken from DMI and obtained from curve-fit for January 01

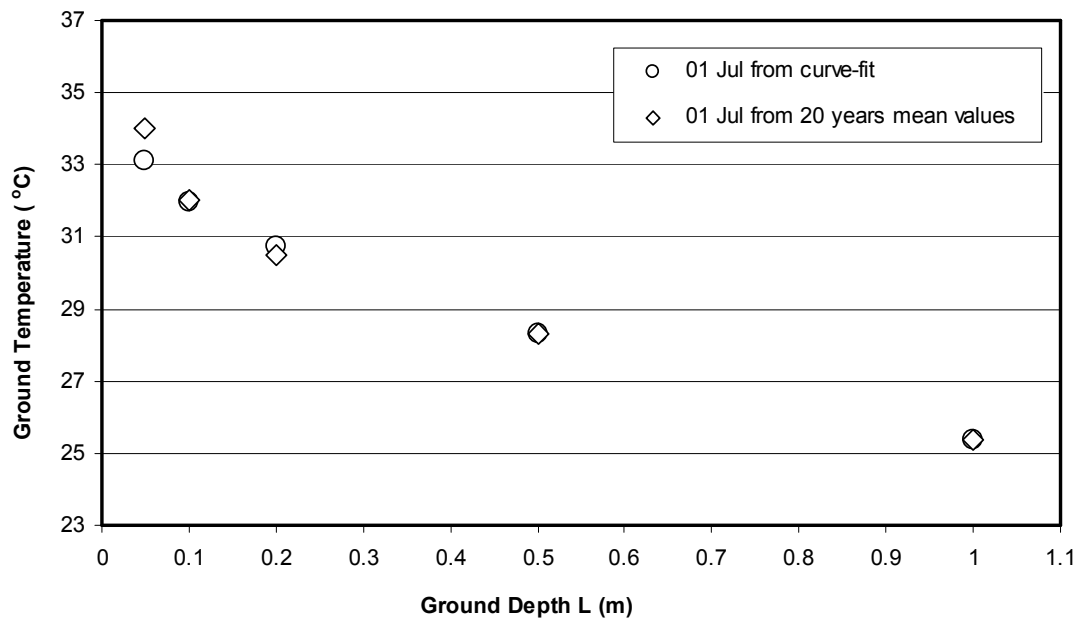


Figure 4.45. Comparison of ground temperature with ground depth for mean values taken from DMI and obtained from curve-fit for July 01

4.4. Ground Temperatures in Horizontal Two Layer Ground which has Different Physical Properties of Lower Layers and Various Thickness of Upper Layers

In this part of the study, calculations were performed using two horizontal layer ground model for Adana. Surface, maximum, minimum and end temperatures were calculated using various physical properties of lower layer grounds for constant ground evaporation fraction ($f=0.45$) and varying of ground surface absorption coefficient ($a_s=0.6-0.9$) and then tables and figures were obtained using these values.

Firstly, 5 mm thick ground cover for upper layer was used for the variation of the ground surface absorption coefficient and 10 m thickness of different physical properties of ground layer are assumed in the calculations. Then, the calculations are carried out by assuming for 50 cm thickness of humid-light ground cover for upper layer and 10 m thickness of different physical properties of ground for lower layer. These calculations are realized for Adana, İstanbul, Ankara and Kars provinces selected from 4 different climatic regions in Turkey.

4.4.1. Results for Adana

4.4.1.1. Thickness of Upper Layer is 5 mm

The calculations were realized for Adana for two horizontal layer ground model taking the values of thermal conductivity k and thermal diffusivity a ($k=1.142$ W/mK, $a=0.02186$ m²/day) which were used in one layer ground model in chapter 3.6.3. In this part, the calculations are carried out using real ground physical properties (Table 3.1).

The values of ground surface, maximum, minimum and end temperatures are shown in tables 4.8, 4.9 and 4.10 for Adana for January 01 and July 01 when different physical properties of ground layers are used.

Table 4.8. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	23.54 (Max.)	22.49 (Max.)	21.34 (Max.)	20.16 (Max.)	21.46 (Min.)	20.41 (Min.)	19.26 (Min.)	18.07 (Min.)
The depth, (m)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
End temp., T_{end} (°C)	22.38	21.45	20.31	19.13	22.38	21.44	20.30	19.12
Surface temp., T_s (°C)	9.45	8.72	7.97	7.20	32.75	31.55	30.31	29.00

Table 4.9. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	23.53 (Max.)	22.46 (Max.)	21.31 (Max.)	20.12 (Max.)	21.49 (Min.)	20.40 (Min.)	19.25 (Min.)	18.07 (Min.)
The depth, (m)	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
End temp., T_{end} (°C)	22.50	21.44	20.29	19.11	22.37	21.32	20.18	19.00
Surface temp., T_s (°C)	9.41	8.68	7.93	7.17	32.76	31.57	30.32	29.02

Table 4.10. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	23.52 (Max.)	22.44 (Max.)	21.29 (Max.)	20.10 (Max.)	21.52 (Min.)	20.44 (Min.)	19.30 (Min.)	18.11 (Min.)
The depth, (m)	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
End temp., T_{end} (°C)	22.76	21.68	20.54	19.34	22.16	21.09	19.97	18.80
Surface temp., T_s (°C)	9.56	8.82	8.07	7.30	32.71	31.51	30.26	28.95

In figures 4.46 and 4.47, variation of maximum and minimum ground temperatures with ground surface absorption coefficient are demonstrated for January 01 and July 01 for Adana. It is observed from these figures that maximum and minimum temperatures do not depend on the ground type.

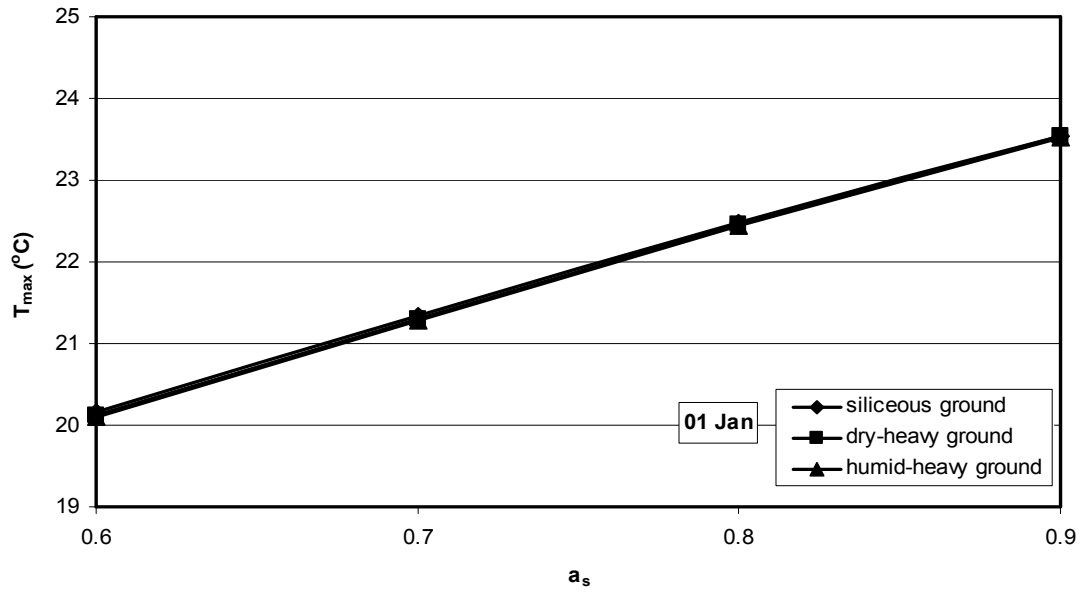


Figure 4.46. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

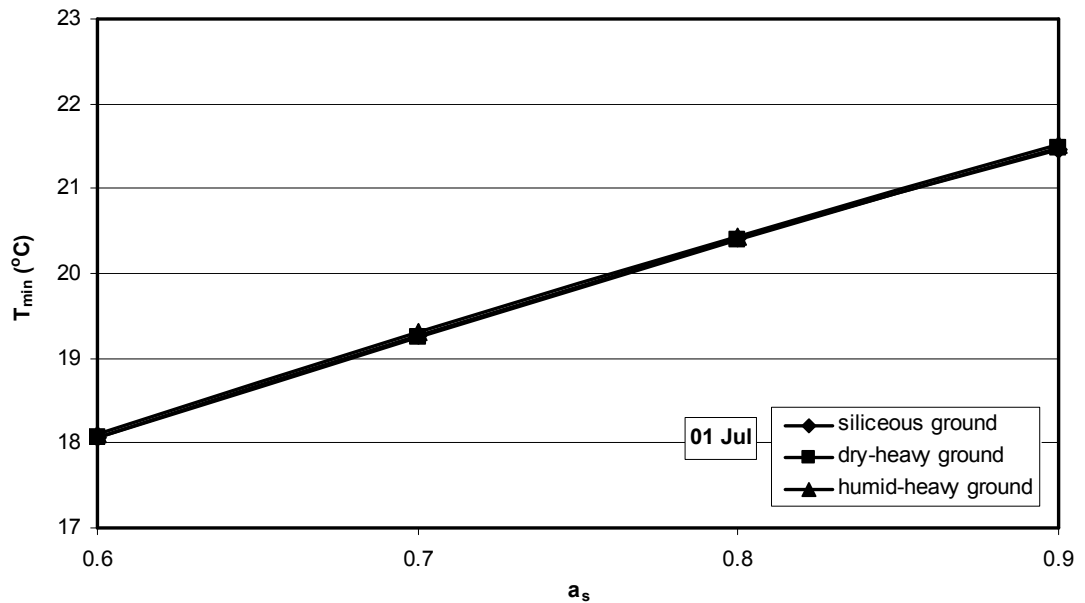


Figure 4.47. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

The variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 for Adana are illustrated in figures 4.48 and 4.49. It is seen from these figures that end temperatures do not vary annually and do not depend on the ground type. But it is clear that the ground surface absorption coefficient affects the end temperatures.

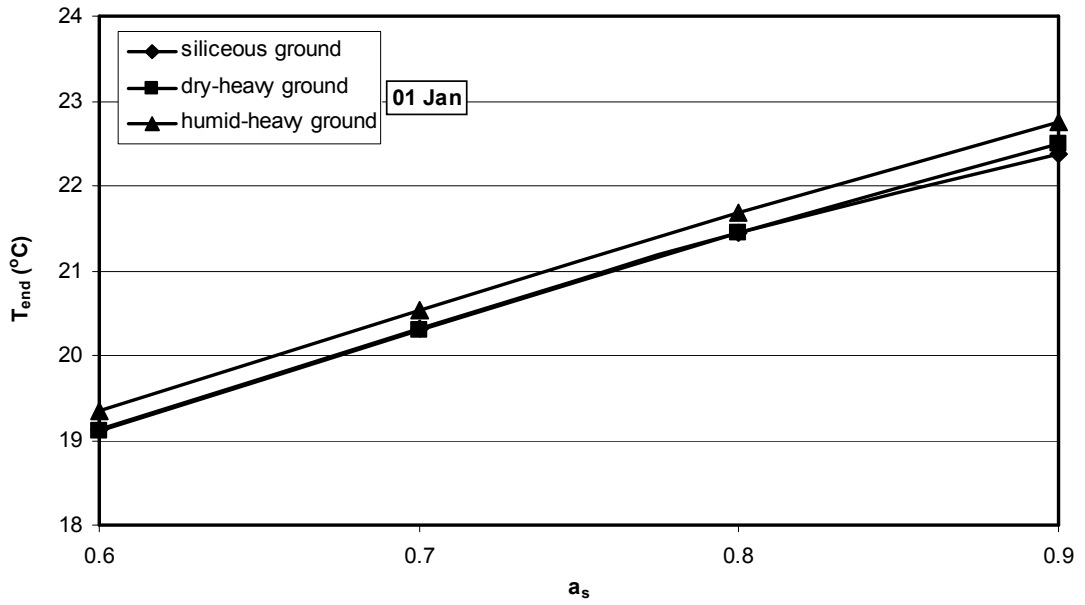


Figure 4.48. Variation of end temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

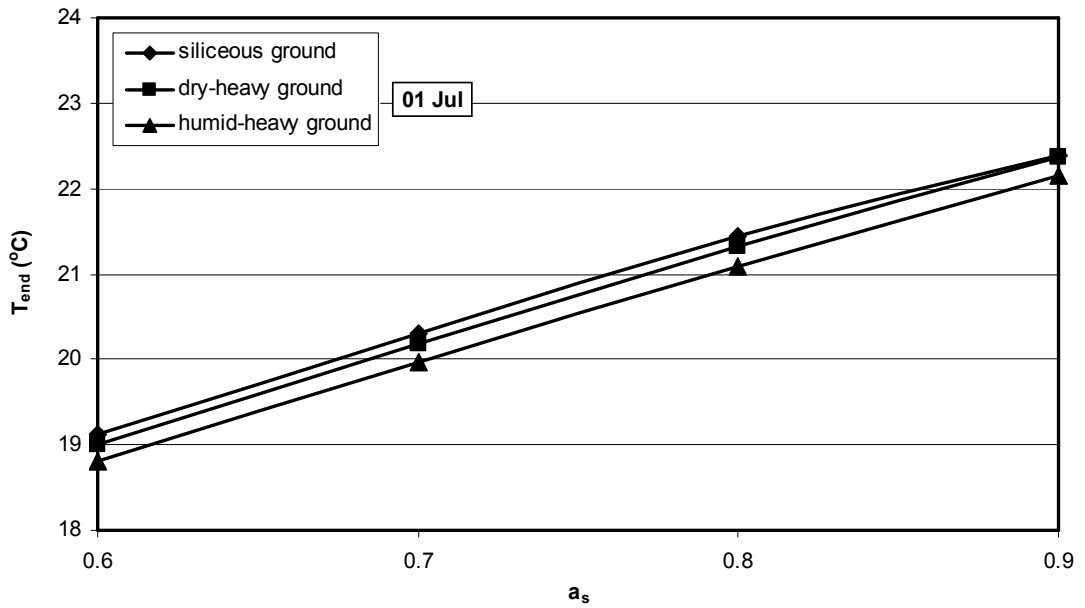


Figure 4.49. Variation of end temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

Figures 4.50 and 4.51 show the variation of ground surface temperatures with ground surface absorption coefficient for various ground types for January 01 and July 01 in Adana. There is not a noticeable effect of ground physical properties on the ground surface temperatures.

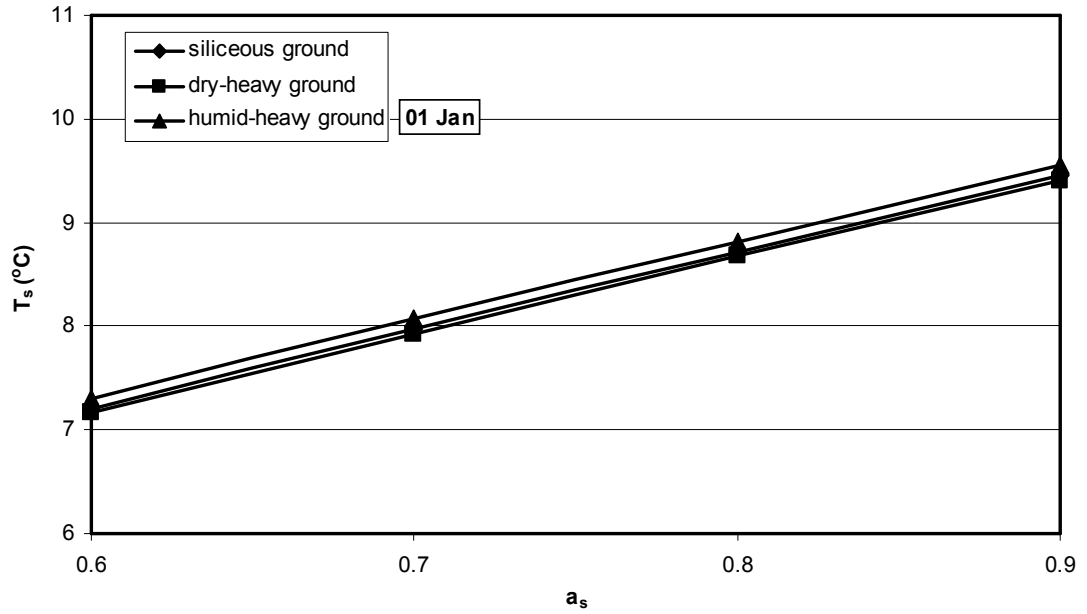


Figure 4.50. Variation of ground surface temperature with ground surface absorption coefficient for January 01 in Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

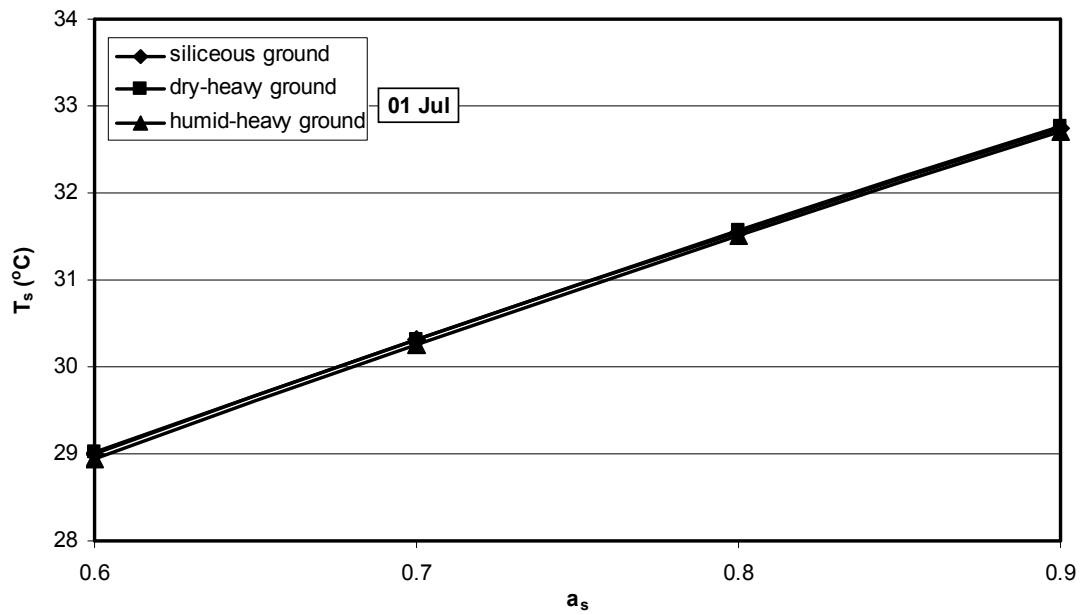


Figure 4.51. Variation of ground surface temperature with ground surface absorption coefficient for July 01 in Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

The variations of depth of maximum and minimum temperatures with ground surface absorption coefficient are demonstrated in figures 4.52 and 4.53 for January 01 and July 01 for Adana. These figures show that the values of $L_{\max}$ and $L_{\min}$ do not vary with ground surface absorption coefficient but it is a function of ground physical properties.

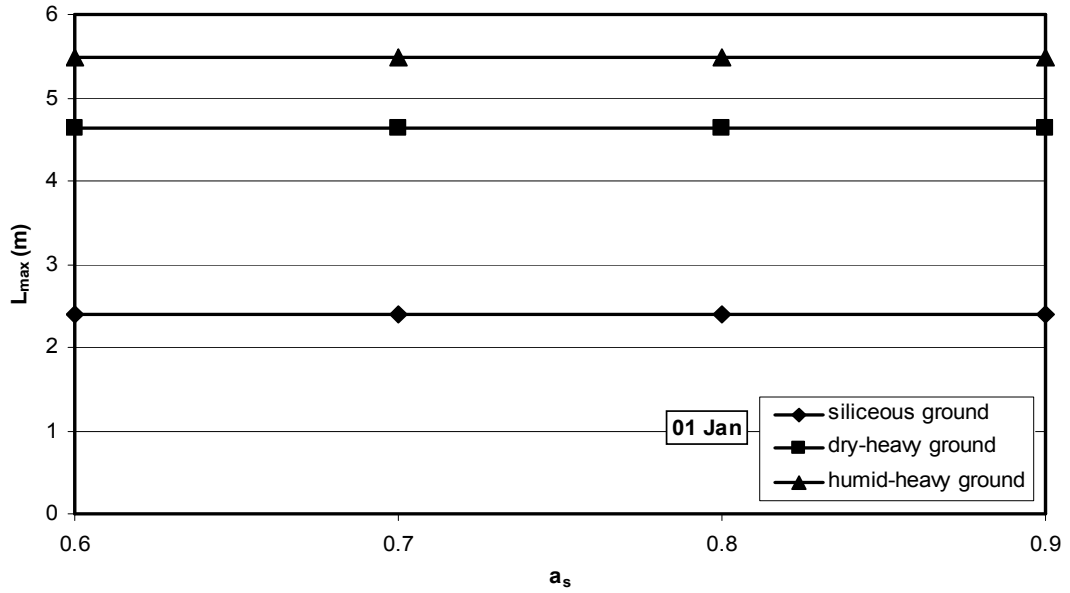


Figure 4.52. Variation of the depth of maximum temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

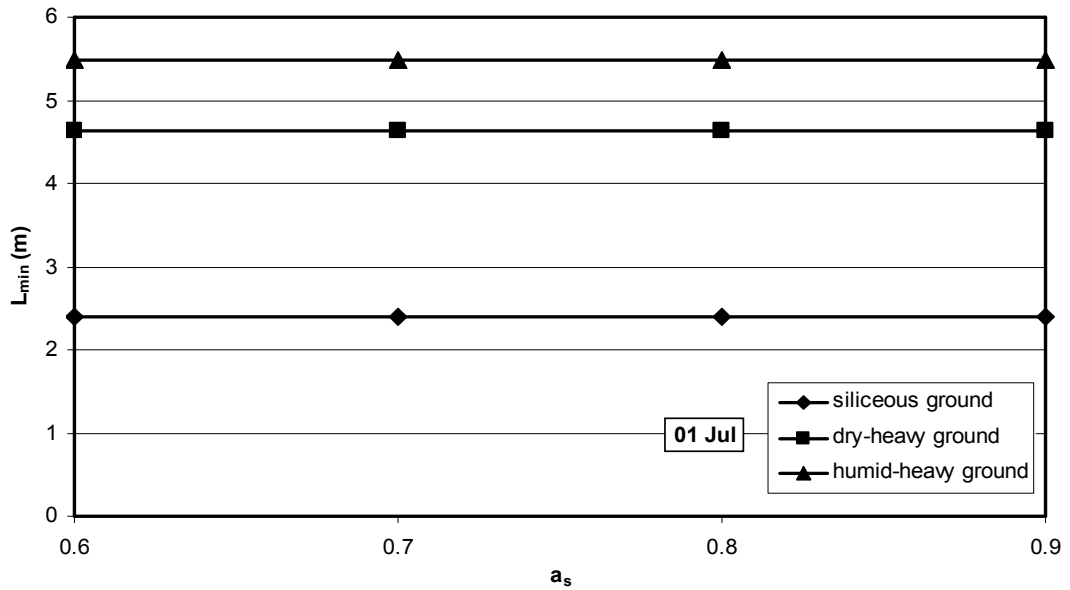


Figure 4.53. Variation of the depth of minimum temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

Figures 4.54, 4.55, 4.56 and 4.57 demonstrate yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients for Adana.

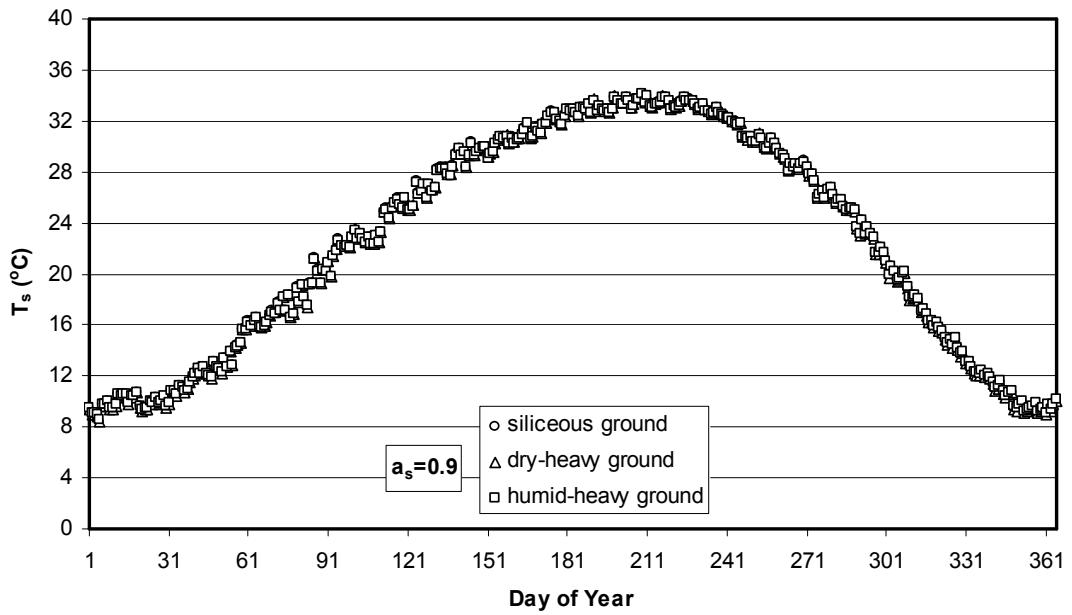


Figure 4.54. Yearly variation of ground surface temperatures for various ground types for Adana, ($f=0.45$, $a_s=0.9$, $L1=0.005$ m, $L2=10$ m)

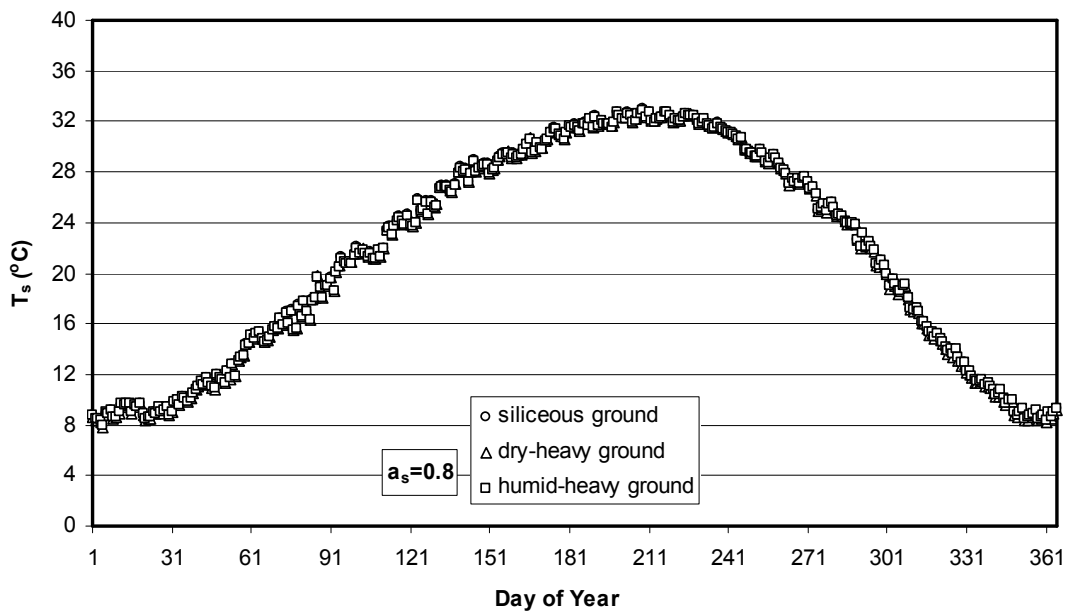


Figure 4.55. Yearly variation of ground surface temperatures for various ground types for Adana, ($f=0.45$, $a_s=0.8$, $L1=0.005$ m, $L2=10$ m)

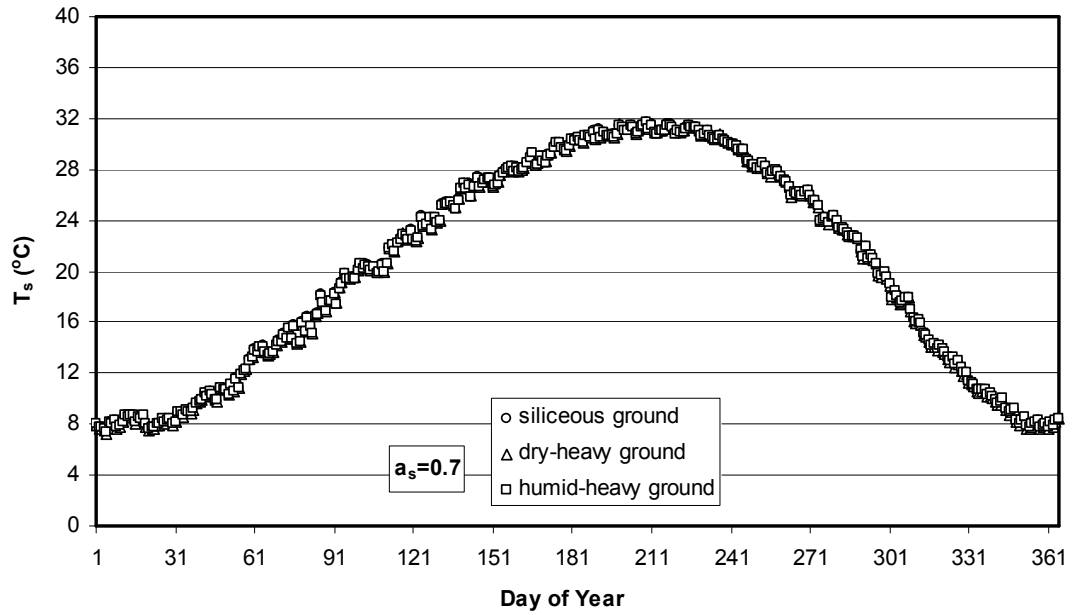


Figure 4.56. Yearly variation of ground surface temperatures for various ground types for Adana, ($f=0.45$, $a_s=0.7$, $L1=0.005$ m, $L2=10$ m)

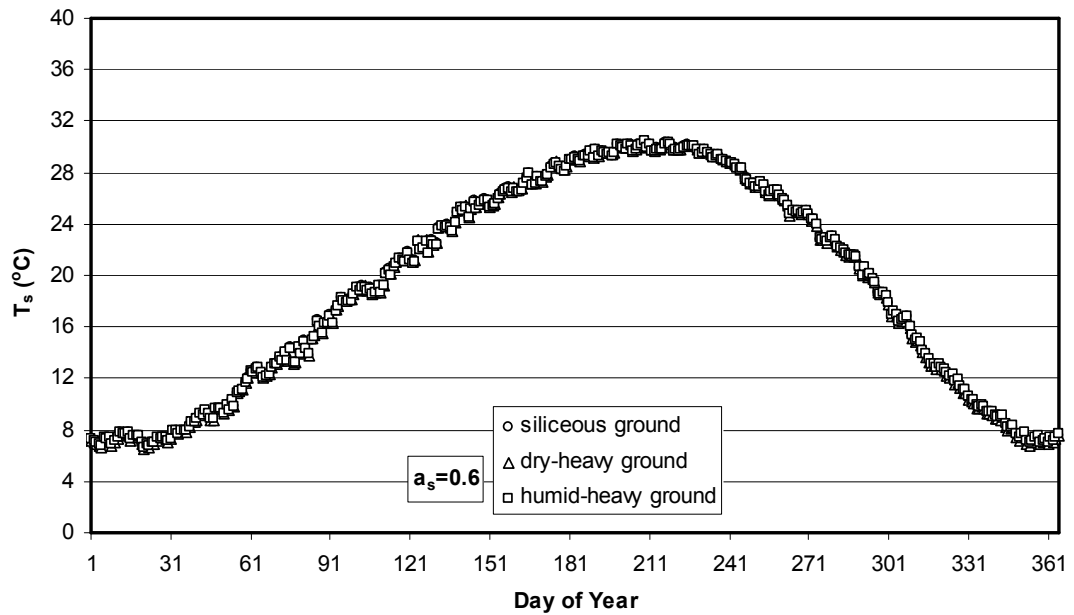


Figure 4.57. Yearly variation of ground surface temperatures for various ground types for Adana, ($f=0.45$, $a_s=0.6$, $L1=0.005$ m, $L2=10$ m)

Figure 4.58 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous lower layer ground for Adana.

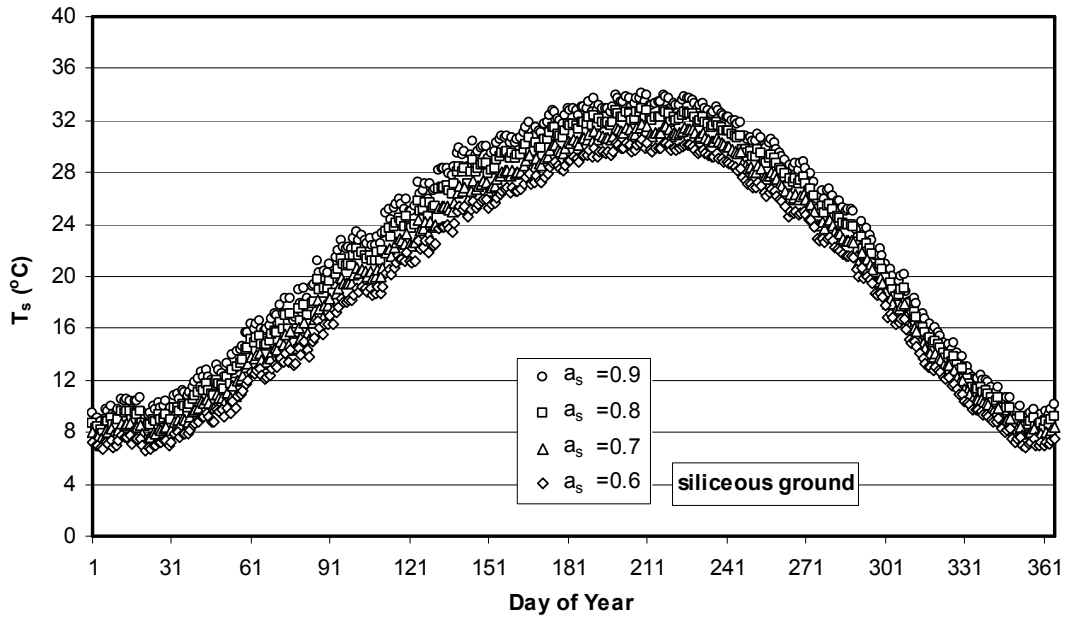


Figure 4.58. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous ground for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figure 4.59 illustrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy ground layer for Adana.

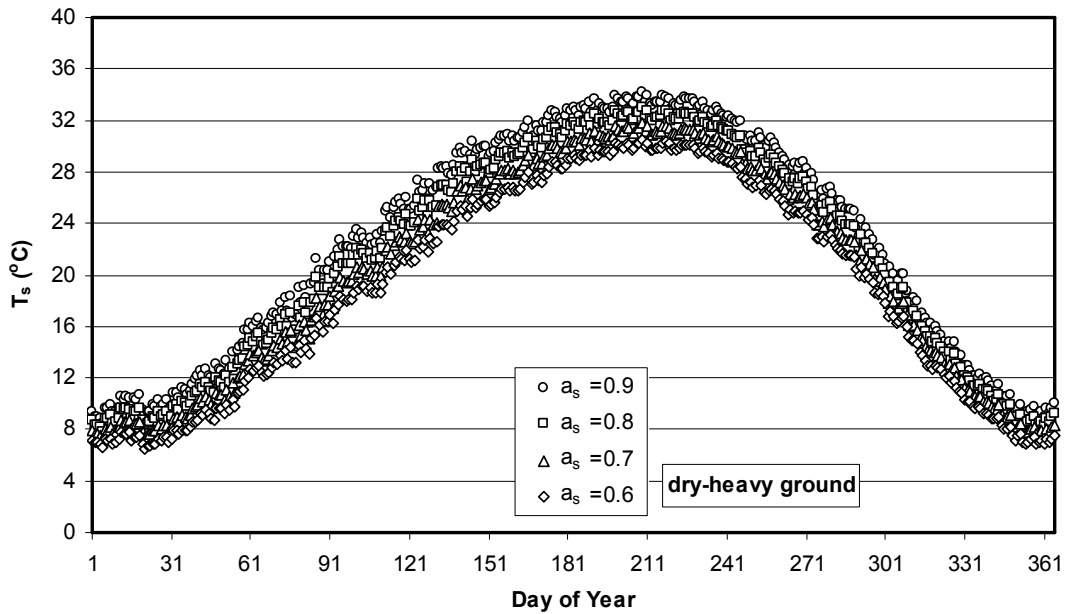


Figure 4.59. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy ground layer for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figure 4.60 demonstrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy ground layer for Adana.

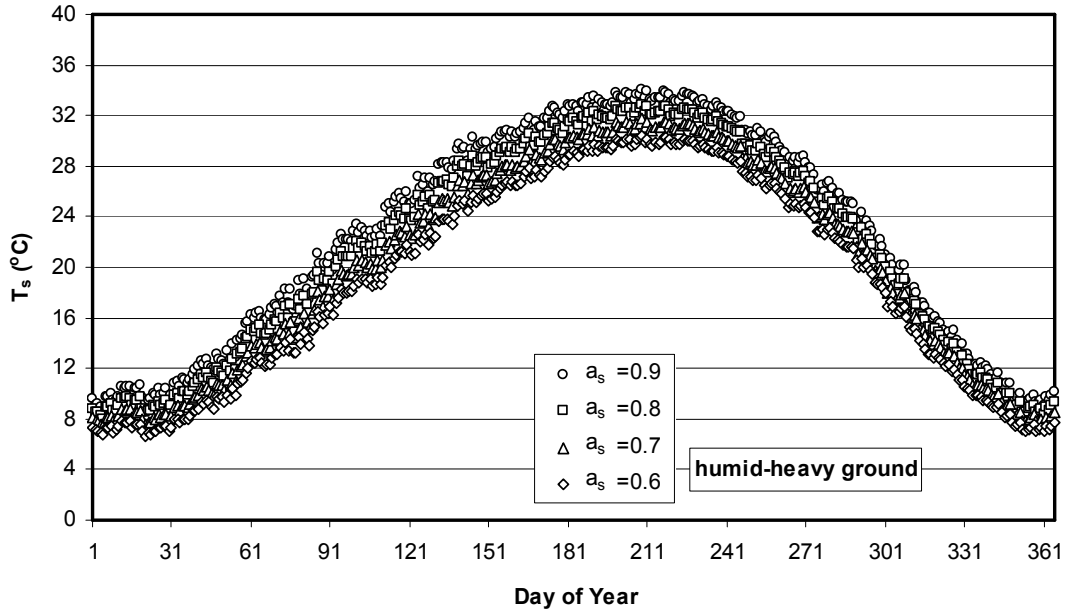


Figure 4.60. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy ground layer for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

As can be seen from these figures given for Adana, ground surface temperatures change with ground surface absorption coefficient considerably.

4.4.1.2. Thickness of Upper Layer is 50 cm

In tables 4.11, 4.12 and 4.13, ground surface, maximum, minimum and end temperatures are demonstrated for January 01 and July 01 in Adana when 50 cm thick humid-light upper layer and different physical properties of lower layers are used.

Table 4.11. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid-Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	23.51 (Max.)	22.47 (Max.)	21.32 (Max.)	20.13 (Max.)	21.47 (Min.)	20.42 (Min.)	19.28 (Min.)	18.09 (Min.)
The depth, (m)	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
End temp., T_{end} ($^{\circ}\text{C}$)	22.37	21.45	20.31	19.12	22.37	21.44	20.30	19.11
Surface temp., T_s ($^{\circ}\text{C}$)	9.42	8.69	7.94	7.18	32.76	31.57	30.32	29.02

Table 4.12. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	23.52 (Max.)	22.45 (Max.)	21.3 (Max.)	20.11 (Max.)	21.49 (Min.)	20.41 (Min.)	19.26 (Min.)	18.07 (Min.)
The depth, (m)	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63
End temp., T_{end} ($^{\circ}\text{C}$)	22.47	21.41	20.27	19.09	22.39	21.34	20.20	19.03
Surface temp., T_s ($^{\circ}\text{C}$)	9.39	8.66	7.91	7.15	32.77	31.58	30.33	29.03

Table 4.13. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Adana (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	23.49 (Max.)	22.41 (Max.)	21.26 (Max.)	20.07 (Max.)	21.54 (Min.)	20.46 (Min.)	19.31 (Min.)	18.12 (Min.)
The depth, (m)	5.02	5.02	5.02	5.02	5.02	5.02	5.02	5.02
End temp., T_{end} ($^{\circ}\text{C}$)	22.66	21.6	20.45	19.26	22.23	21.17	20.03	18.86
Surface temp., T_s ($^{\circ}\text{C}$)	9.49	8.76	8.01	7.25	32.74	31.54	30.30	28.99

The variation of maximum and minimum ground temperatures with ground surface absorption coefficient are shown in figures 4.61 and 4.62 for January 01 and July 01 for Adana. When these values are compared with the values given in figures 4.46 and 4.47; the effect of 50 cm thick upper layer ground on the maximum and minimum temperatures can be neglected.

Figures 4.63 and 4.64 demonstrate the variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 for Adana. When these values are compared with the values given in figures 4.48 and 4.49; the effect of 50 cm thick upper layer ground on the end temperatures can be neglected.

Variations of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 in Adana are illustrated in figures 4.65 and 4.66. When these values are compared with the values given in figures 4.50 and 4.51, the effect of upper layer on these temperatures can be neglected.

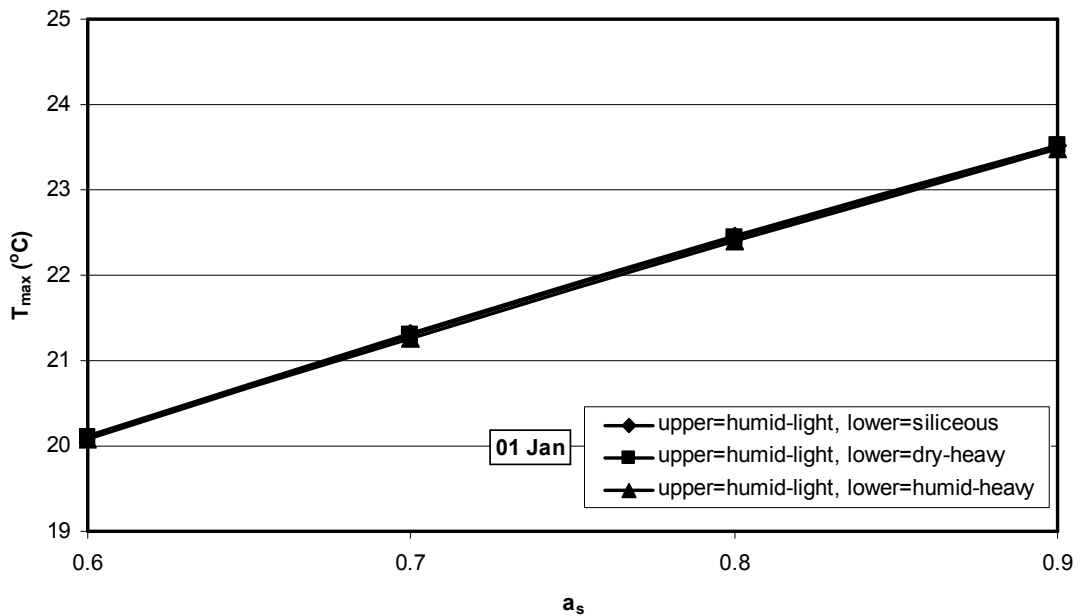


Figure 4.61. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

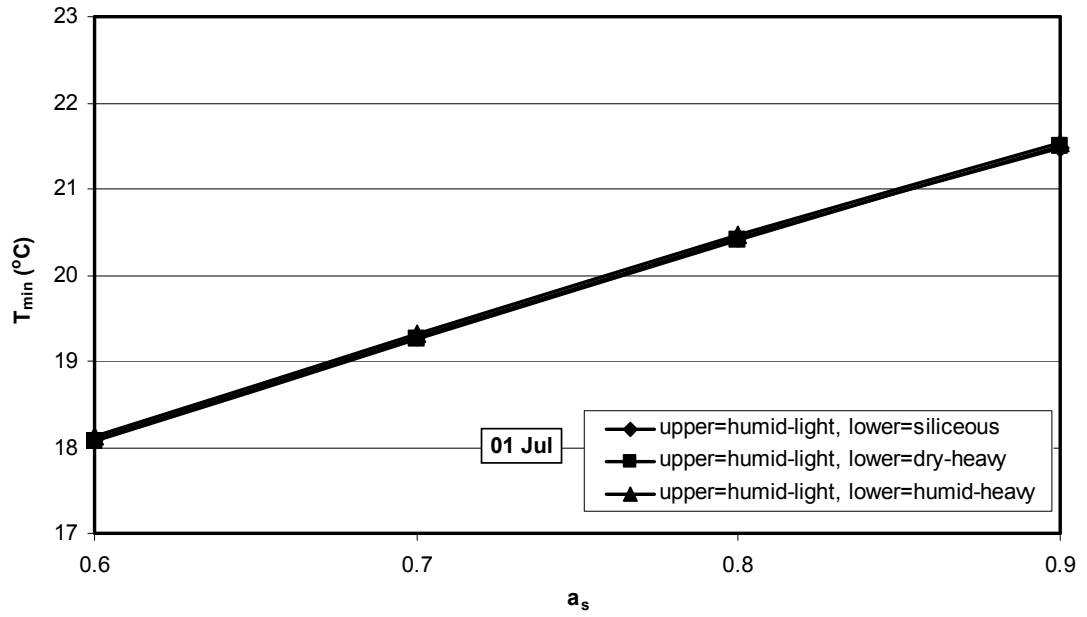


Figure 4.62. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

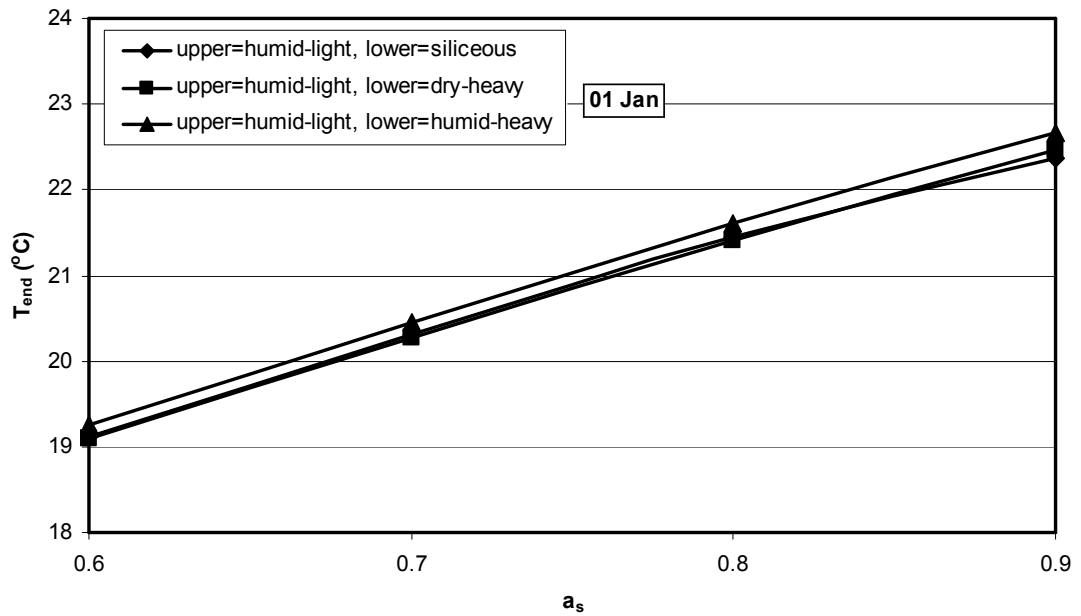


Figure 4.63. Variation of end temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

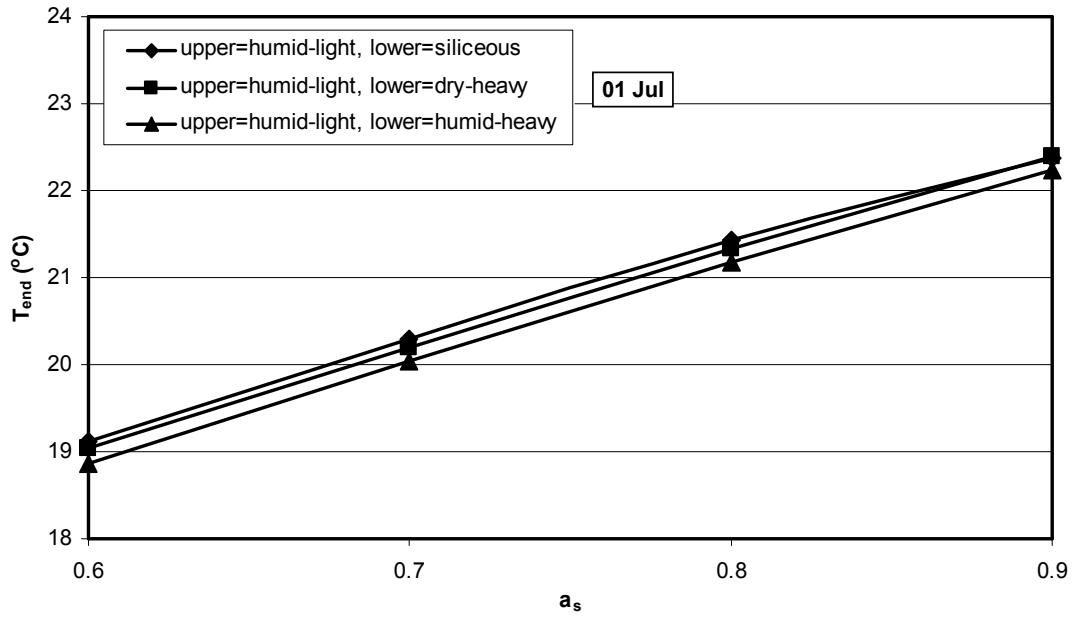


Figure 4.64. Variation of end temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

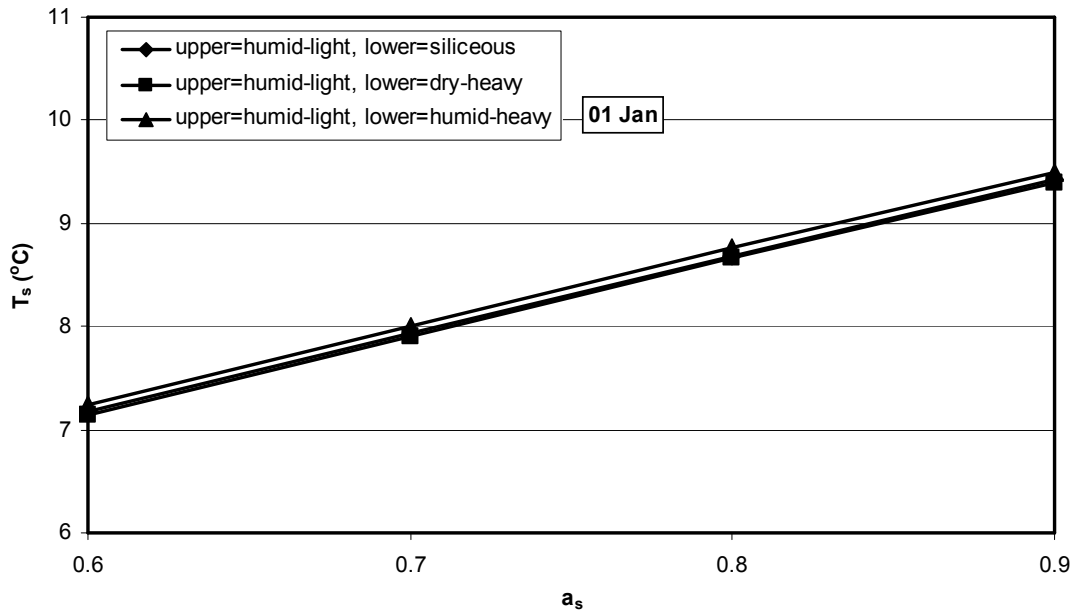


Figure 4.65. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

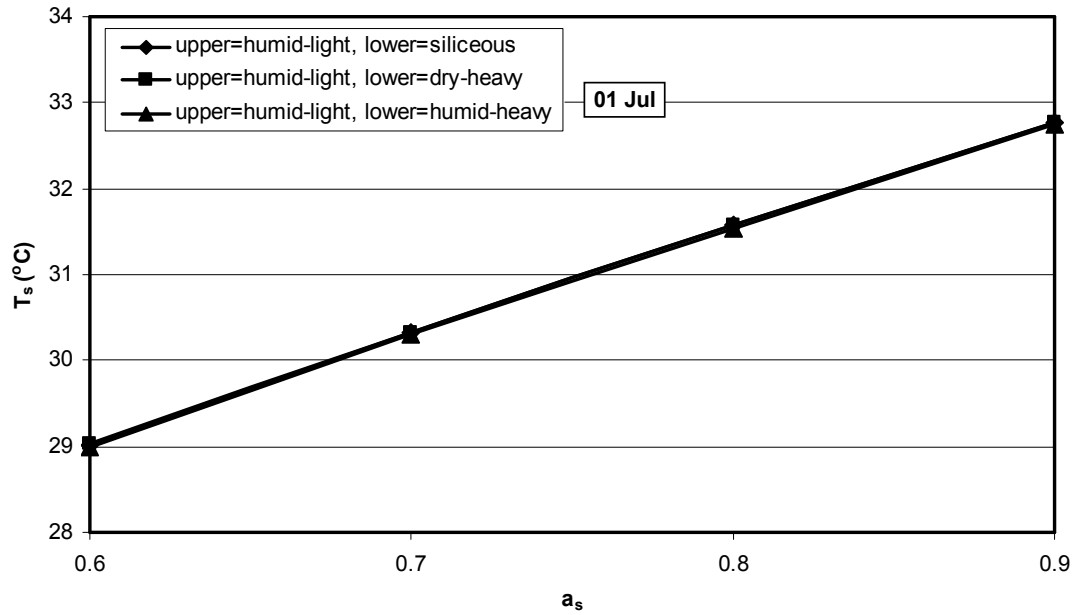


Figure 4.66. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figures 4.67 and 4.68 show the variations of the depth of maximum and minimum temperatures with ground surface absorption coefficient for January 01 and July 01 for Adana. When 50 cm thick humid-light upper layer ground is located on the siliceous lower layer ground; the depths of maximum and minimum temperatures increase from 240 cm to 265 cm compared to 10 m thick ground layer.

When 50 cm thick humid-light ground is located on the dry-heavy ground; the depth of maximum and minimum temperatures did not vary with a_s . But, when 50 cm thick humid-light ground is located on the humid-heavy ground; the depths of maximum and minimum temperatures decrease from 548 cm to 502 cm compared to 10 m thick ground layer.

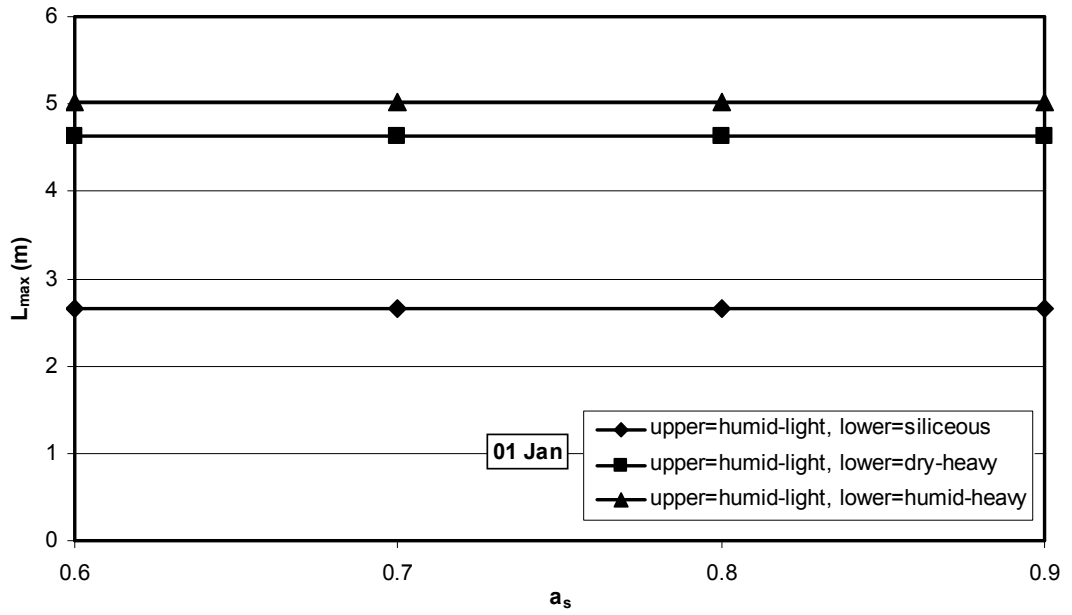


Figure 4.67. Variation of depth of maximum temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

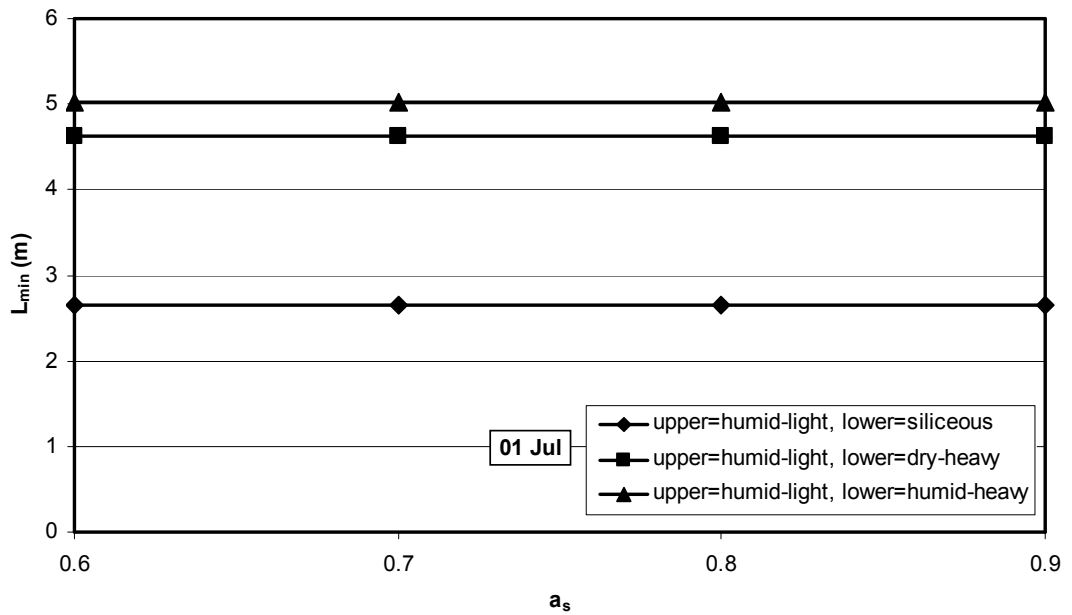


Figure 4.68. Variation of depth of minimum temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients are illustrated in figures 4.69, 4.70, 4.71 and 4.72 for Adana.

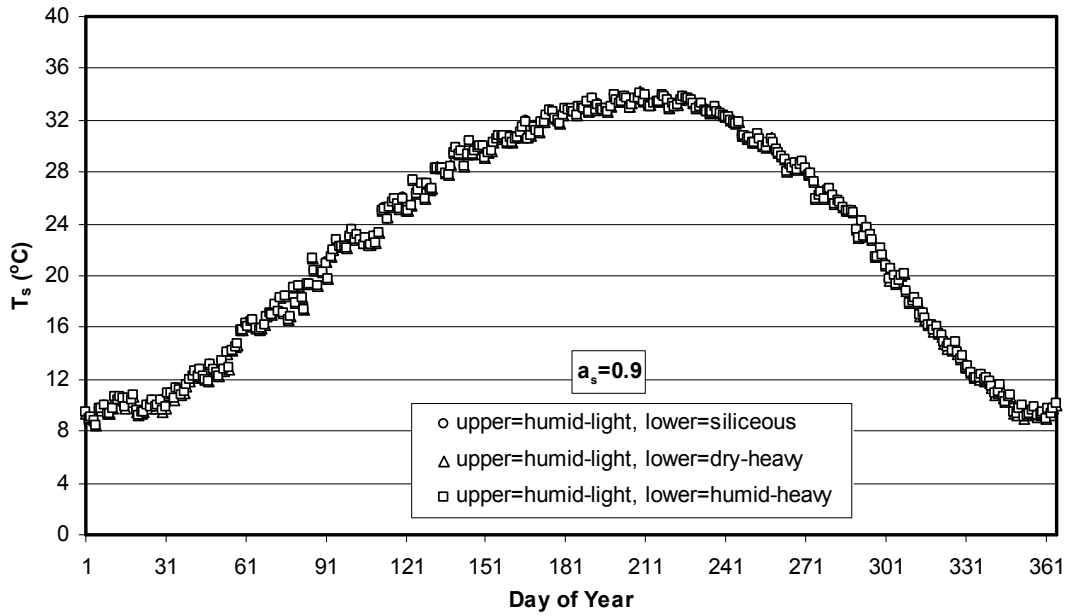


Figure 4.69. Yearly variation of ground surface temperatures for various lower layer ground types for Adana, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m)

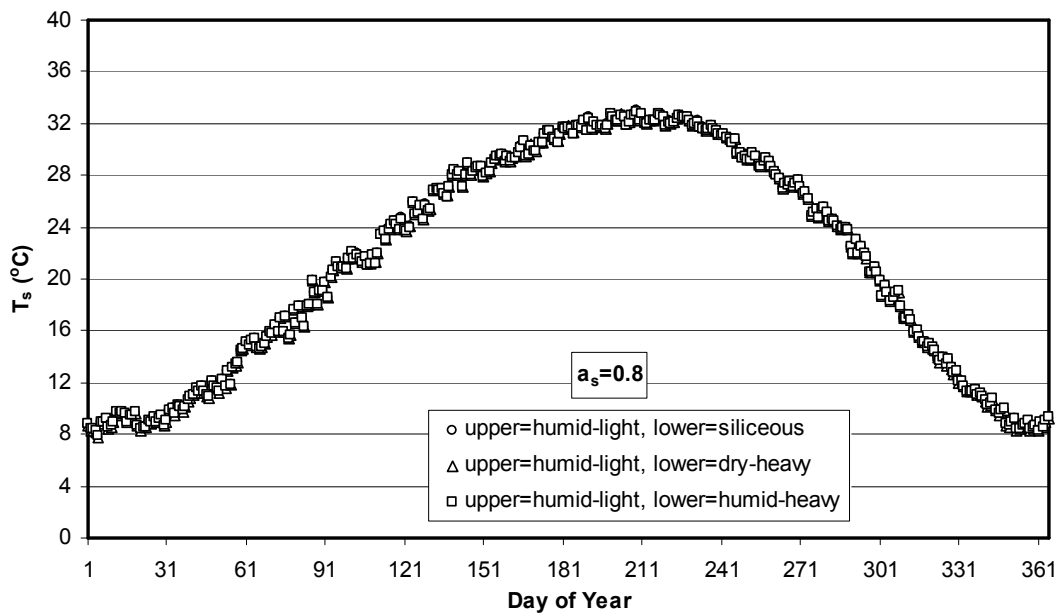


Figure 4.70. Yearly variation of ground surface temperatures for various lower layer ground types for Adana, ($f=0.45$, $a_s=0.8$, $L1=0.5$ m, $L2=10$ m)

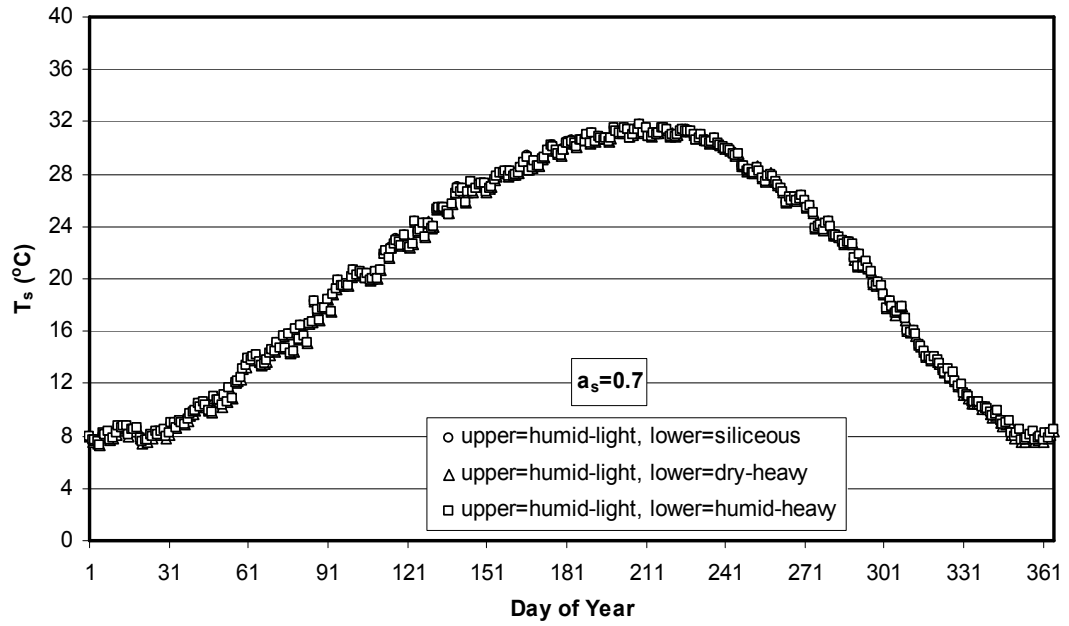


Figure 4.71. Yearly variation of ground surface temperatures for various lower layer ground types for Adana, ($f=0.45$, $a_s=0.7$, $L1=0.5$ m, $L2=10$ m)

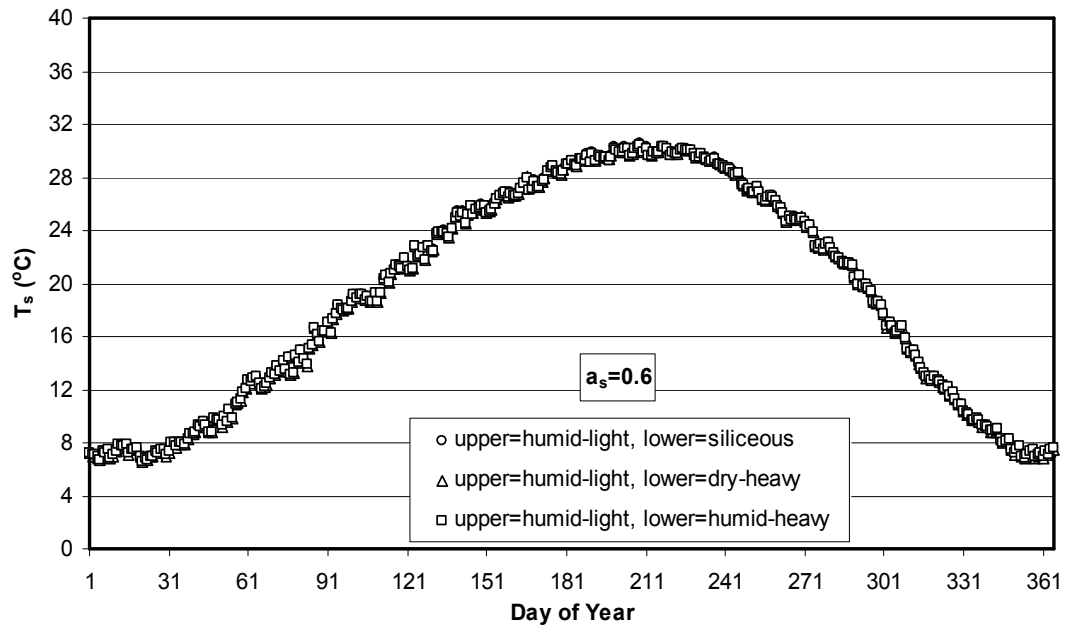


Figure 4.72. Yearly variation of ground surface temperatures for various lower layer ground types for Adana, ($f=0.45$, $a_s=0.6$, $L1=0.5$ m, $L2=10$ m)

Figure 4.73 demonstrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous lower layer ground for Adana.

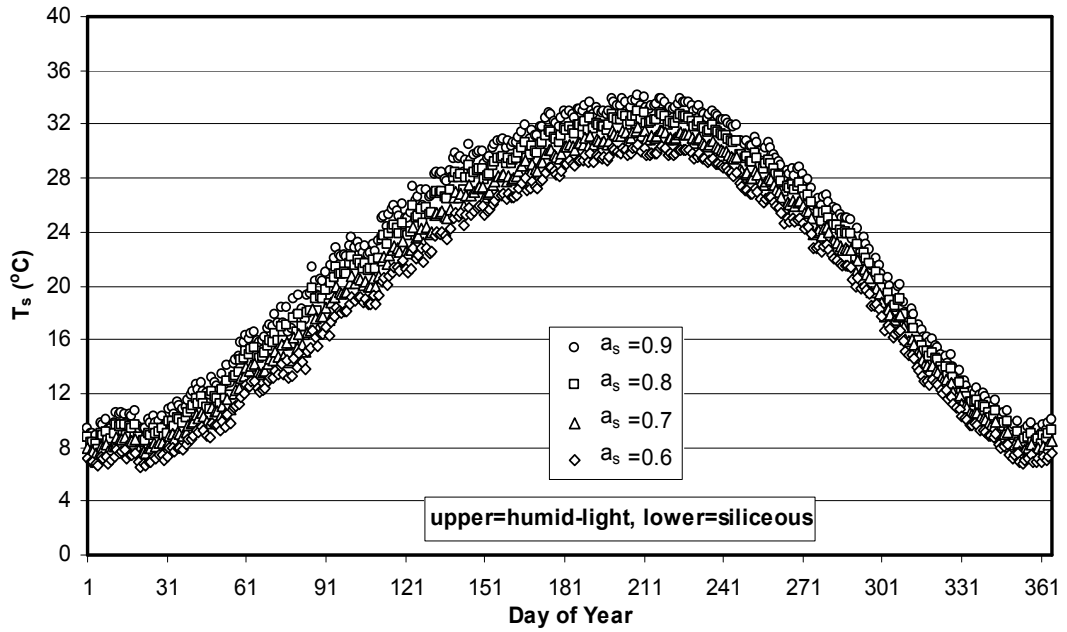


Figure 4.73. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous lower layer ground for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy lower layer ground is shown in figure 4.74 for Adana.

Figure 4.75 illustrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy lower layer ground for Adana.

It is clearly understood from these figures that ground surface temperatures vary with ground surface absorption coefficient for 50 cm thick upper layer ground.

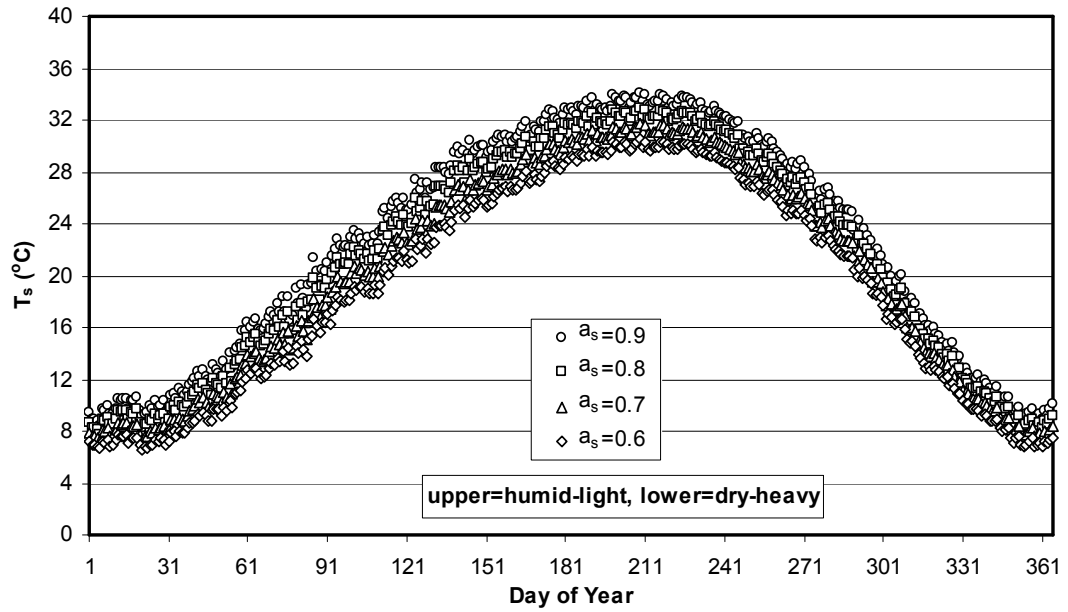


Figure 4.74. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy lower layer ground for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

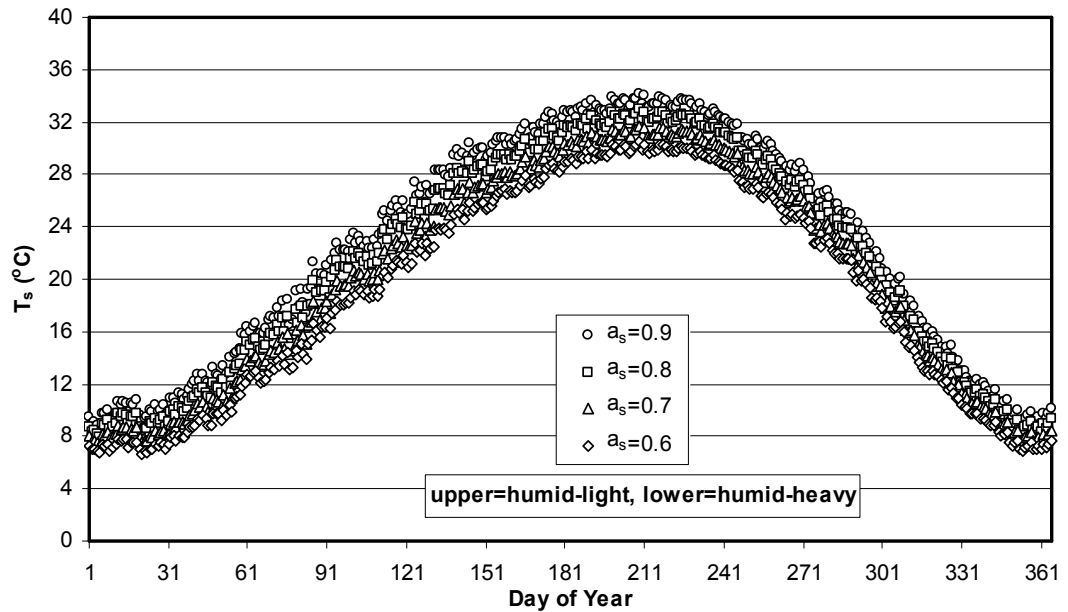


Figure 4.75. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy lower layer ground for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.4.2. Results for İstanbul

4.4.2.1. Thickness of Upper Layer is 5 mm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.14, 4.15 and 4.16 for January 01 and July 01 for İstanbul when different physical properties of ground layers are used.

Table 4.14. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	17.27 (Max.)	16.53 (Max.)	15.77 (Max.)	14.99 (Max.)	15.21 (Min.)	14.48 (Min.)	13.73 (Min.)	12.97 (Min.)
The depth, (m)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
End temp., T_{end} (°C)	16.30	15.57	14.82	14.05	16.29	15.56	14.81	14.04
Surface temp., T_s (°C)	5.44	5.11	4.78	4.45	27.19	26.24	25.25	24.24

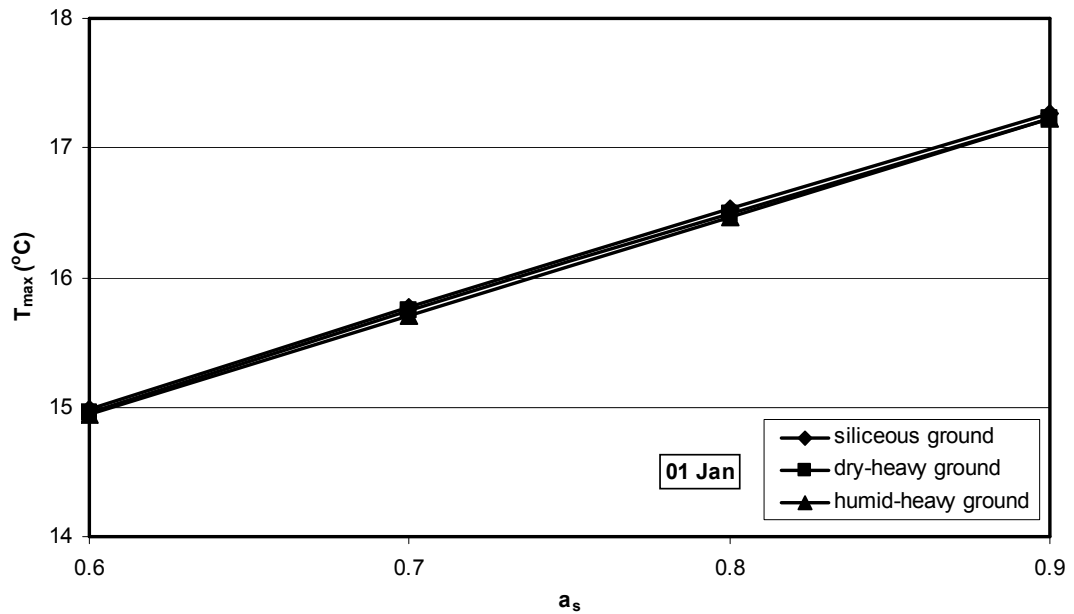
Table 4.15. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	17.23 (Max.)	16.49 (Max.)	15.74 (Max.)	14.96 (Max.)	15.20 (Min.)	14.47 (Min.)	13.73 (Min.)	12.96 (Min.)
The depth, (m)	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
End temp., T_{end} (°C)	16.28	15.55	14.80	14.03	16.16	15.44	14.71	13.95
Surface temp., T_s (°C)	5.41	5.09	4.76	4.42	27.21	26.25	25.27	24.26

Table 4.16. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	17.22 (Max.)	16.47 (Max.)	15.71 (Max.)	14.94 (Max.)	15.24 (Min.)	14.50 (Min.)	13.75 (Min.)	12.99 (Min.)
The depth, (m)	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04
End temp., T_{end} ($^{\circ}\text{C}$)	16.53	15.78	15.02	14.24	15.94	15.22	14.49	13.74
Surface temp., T_s ($^{\circ}\text{C}$)	5.51	5.18	4.84	4.51	27.15	26.20	25.21	24.20

In figures 4.76 and 4.77, variation of maximum and minimum ground temperatures with ground surface absorption coefficient are shown for January 01 and July 01 for İstanbul. It is observed from these figures; these values are much smaller than the values given for Adana.

Figure 4.76. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

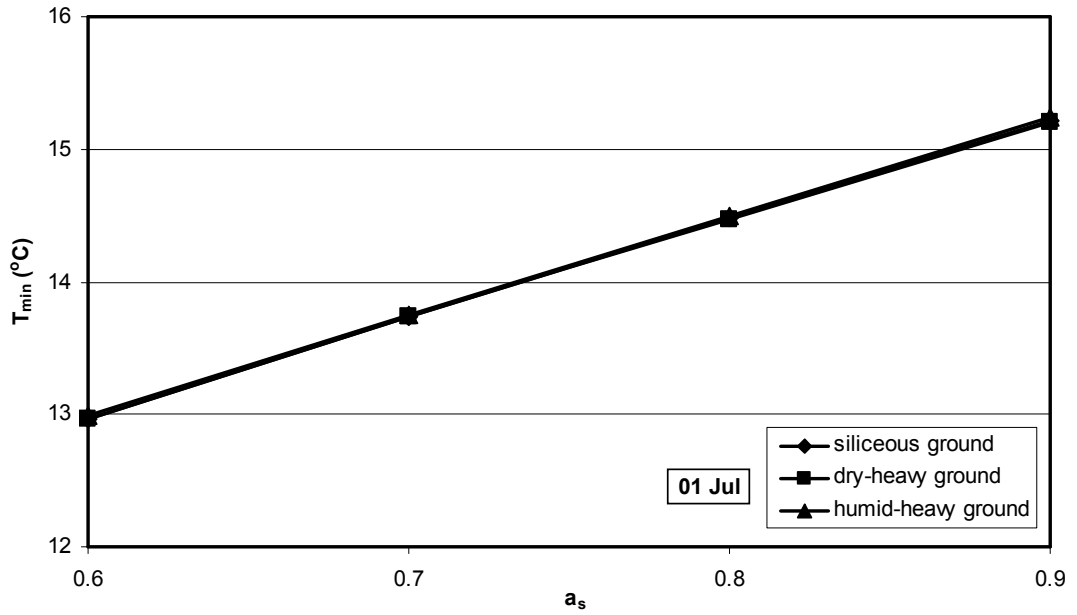


Figure 4.77. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figures 4.78 and 4.79 show the variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 for İstanbul. It is seen from these figures that these values are much smaller than the values given for Adana.

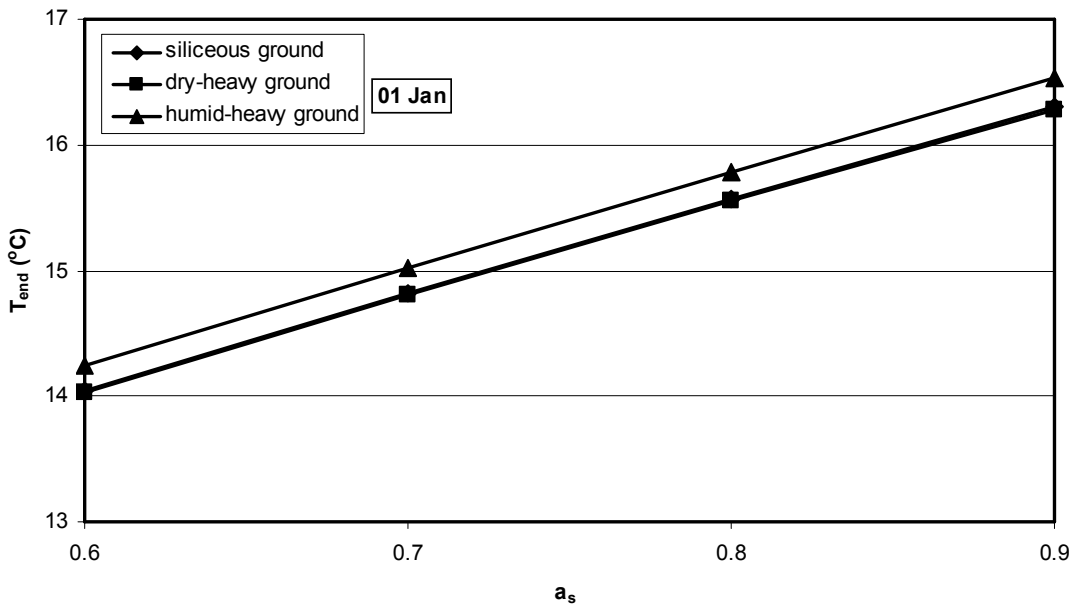


Figure 4.78. Variation of end temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

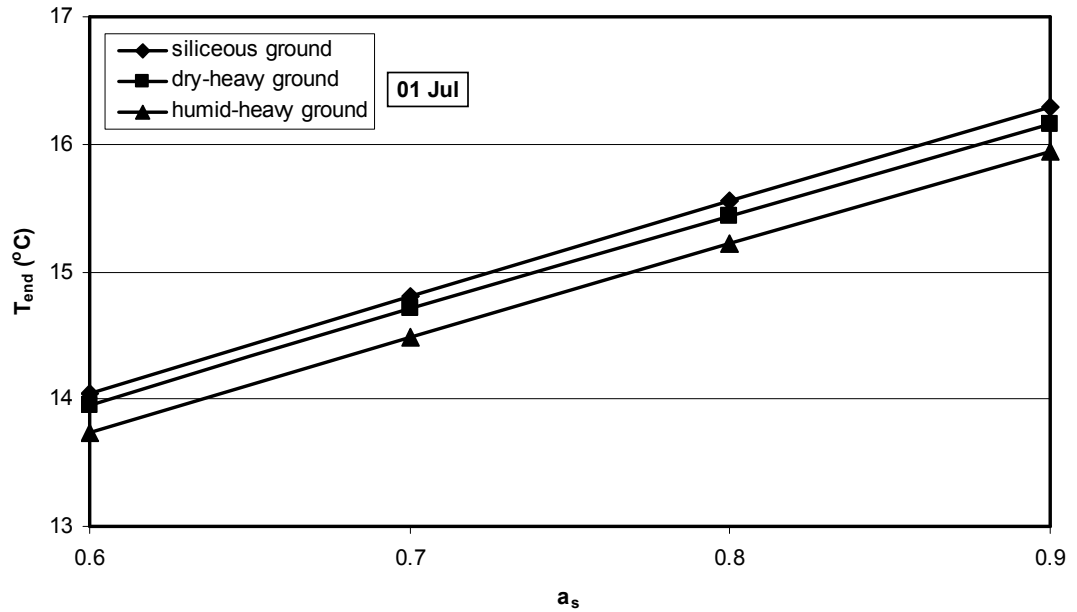


Figure 4.79. Variation of end temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

In figures 4.80 and 4.81, the variations of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 in İstanbul are illustrated. There is a significant decrease in ground surface temperatures according to the values given for Adana.

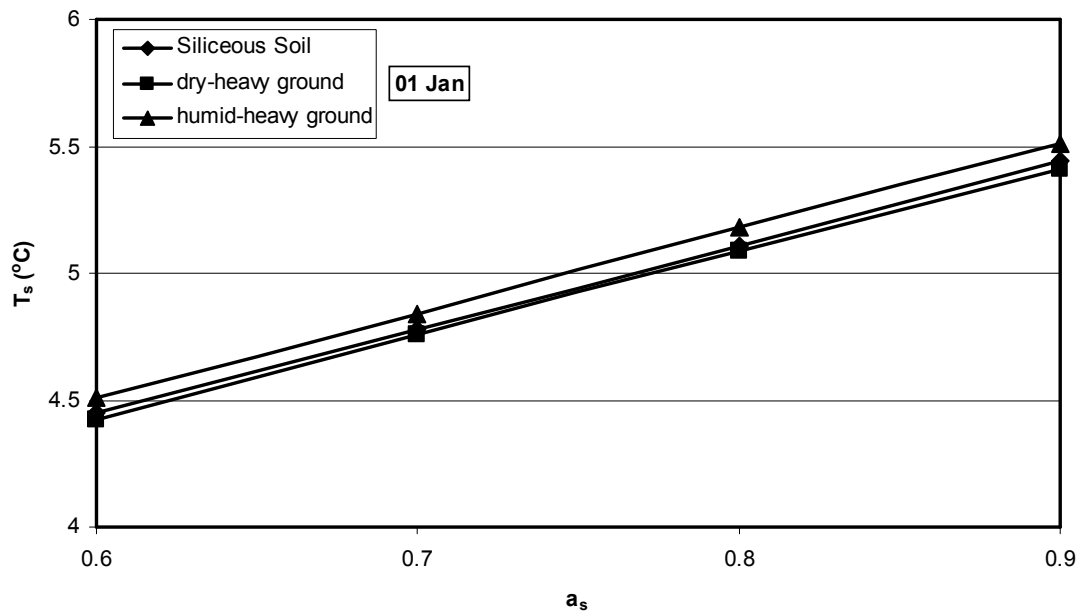


Figure 4.80. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

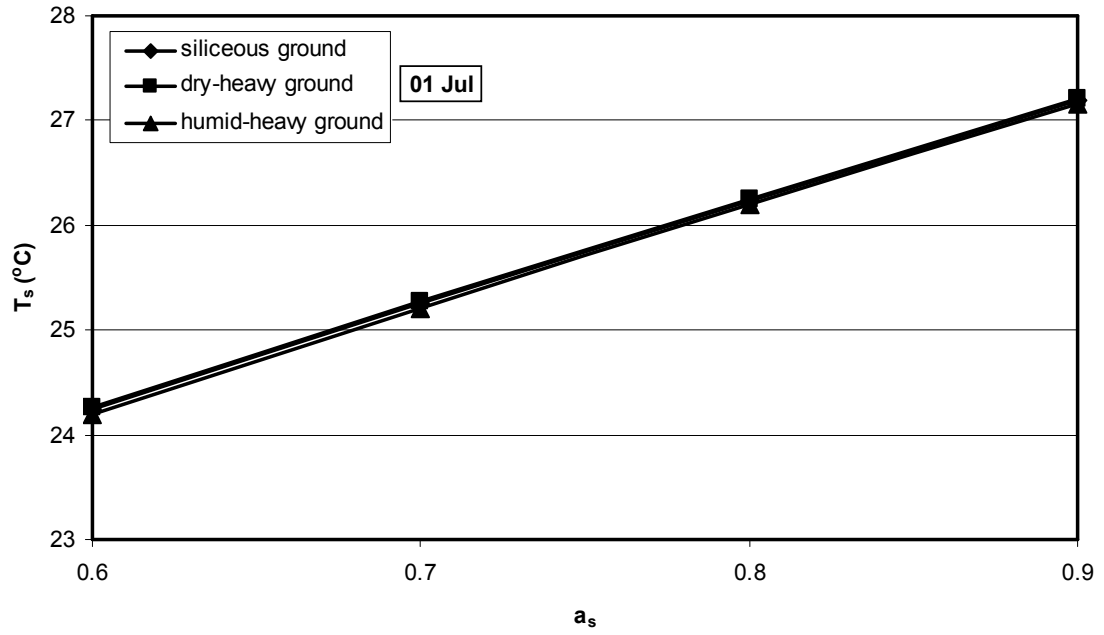


Figure 4.81. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Variations of the depth of maximum and minimum temperatures with ground surface absorption coefficient are shown in figures 4.82 and 4.83 for January 01 and July 01 for İstanbul.

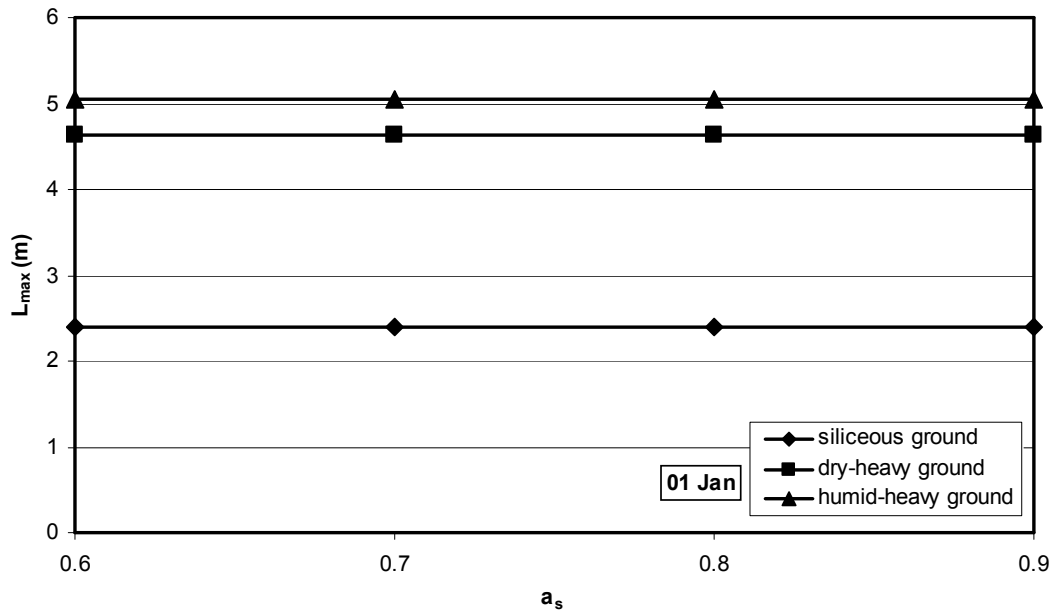


Figure 4.82. Variation of the depth of maximum temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

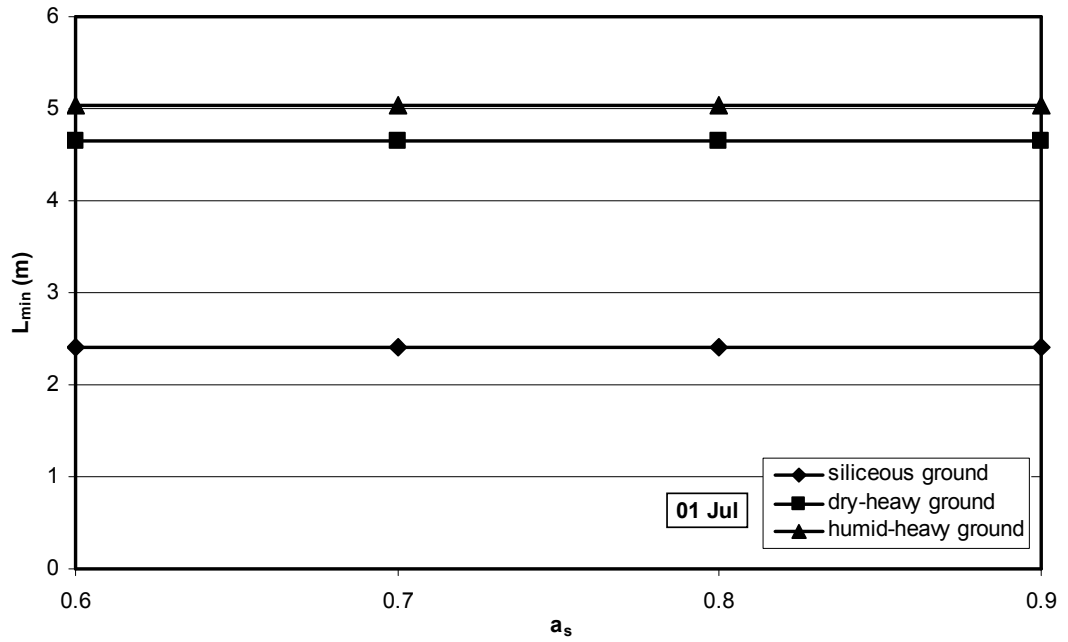


Figure 4.83. Variation of the depth of minimum temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figures 4.84, 4.85, 4.86 and 4.87 illustrate yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients for İstanbul.

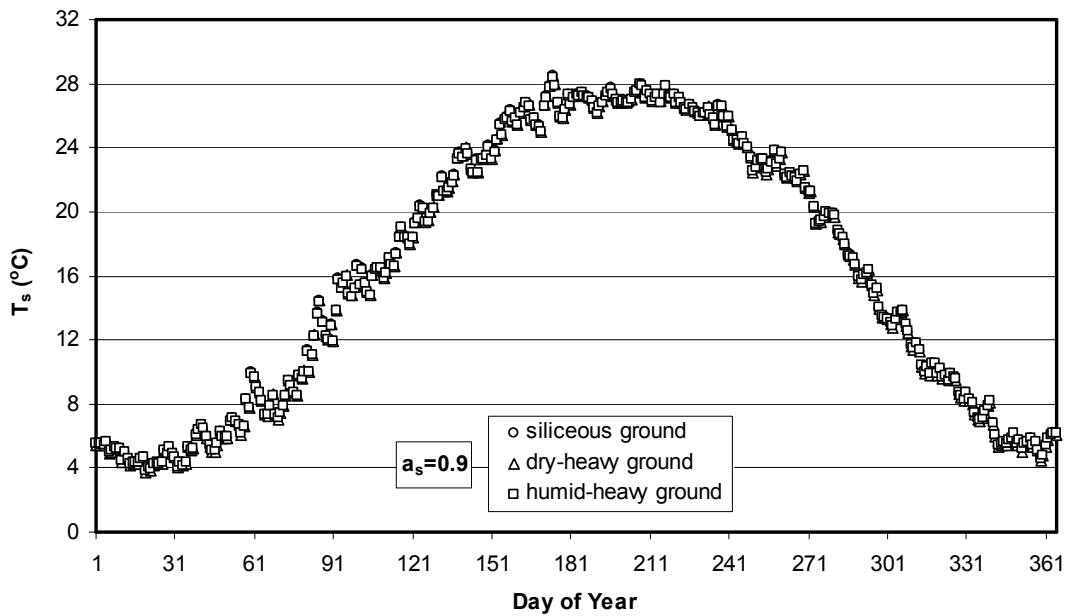


Figure 4.84. Yearly variation of ground surface temperatures for various ground types for İstanbul, ($f=0.45$, $a_s=0.9$, $L1=0.005$ m, $L2=10$ m)

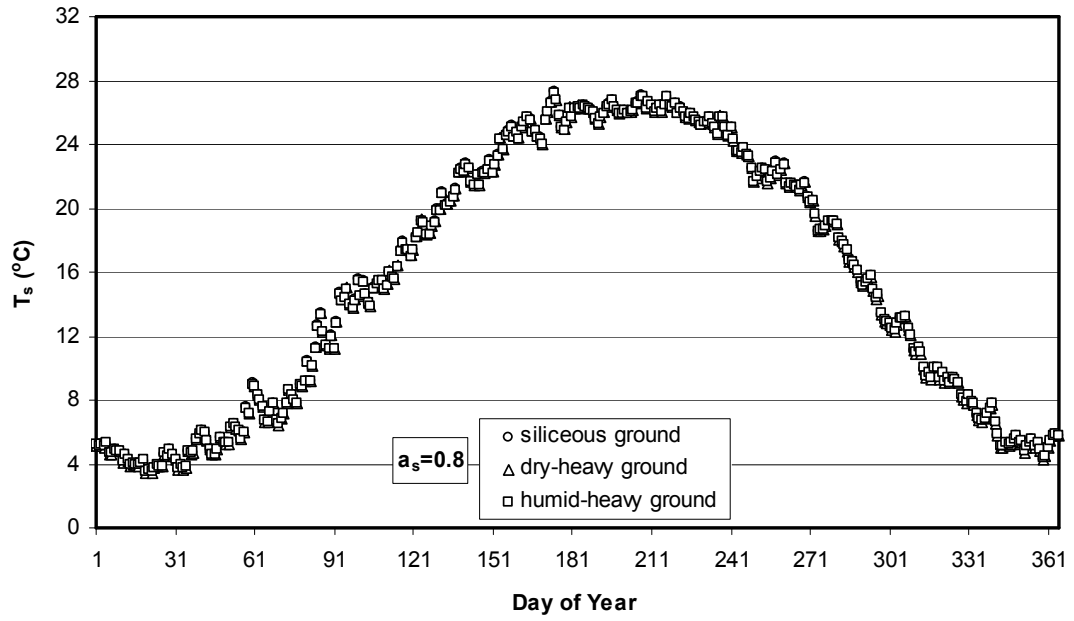


Figure 4.85. Yearly variation of ground surface temperatures for various ground types for İstanbul, ($f=0.45$, $a_s=0.8$, $L1=0.005$ m, $L2=10$ m)

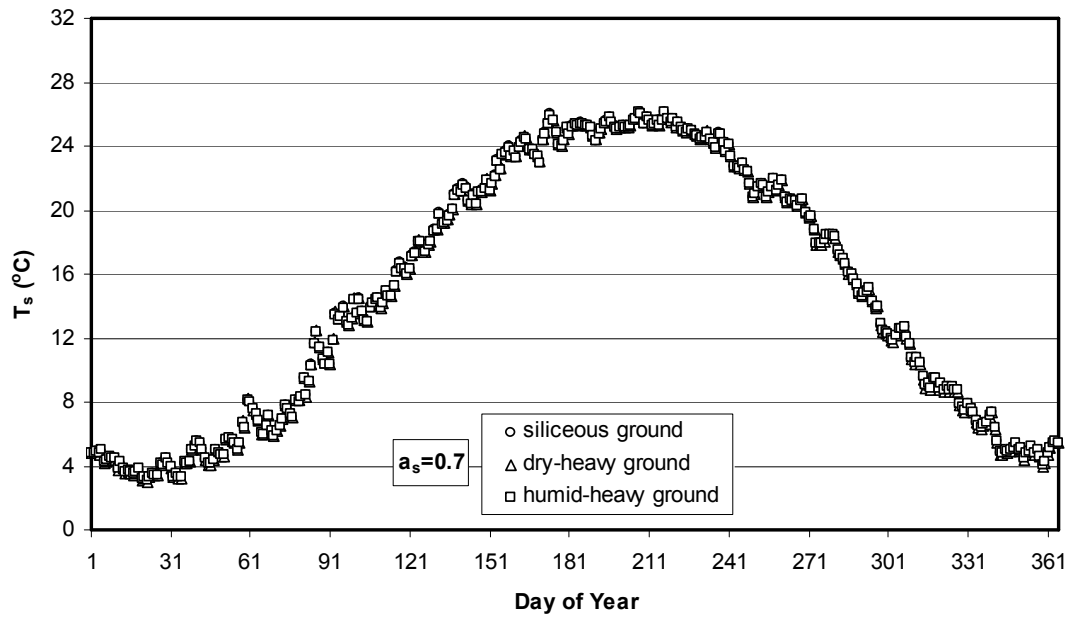


Figure 4.86. Yearly variation of ground surface temperatures for various ground types for İstanbul, ($f=0.45$, $a_s=0.7$, $L1=0.005$ m, $L2=10$ m)

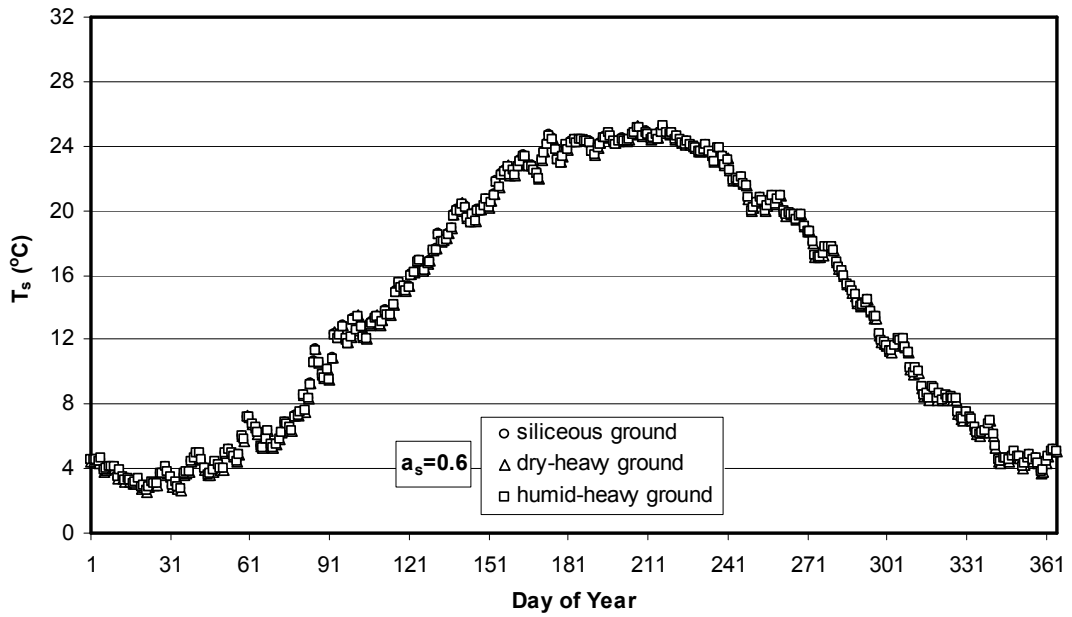


Figure 4.87. Yearly variation of ground surface temperatures for various ground types for İstanbul, ($f=0.45$, $a_s=0.6$, $L1=0.005$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous ground layer for İstanbul are demonstrated in figure 4.88.

Figure 4.89 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy ground layer for İstanbul.

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy ground layer for İstanbul are illustrated in figure 4.90.

It is clearly observed from these figures that the value of ground surface absorption coefficient affects the ground surface temperatures.

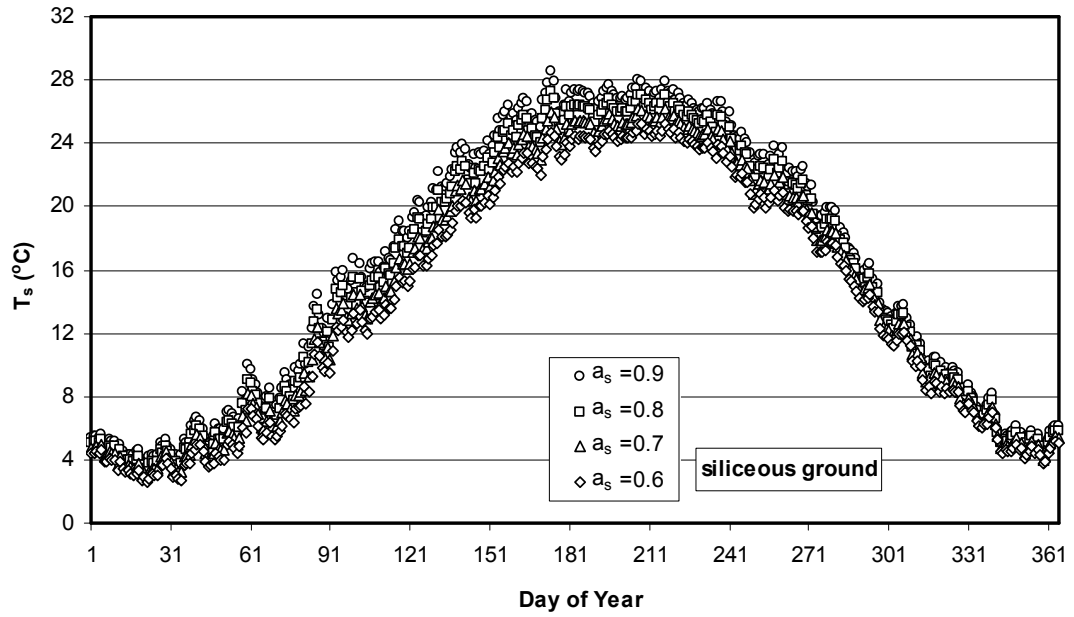


Figure 4.88. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous ground layer for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

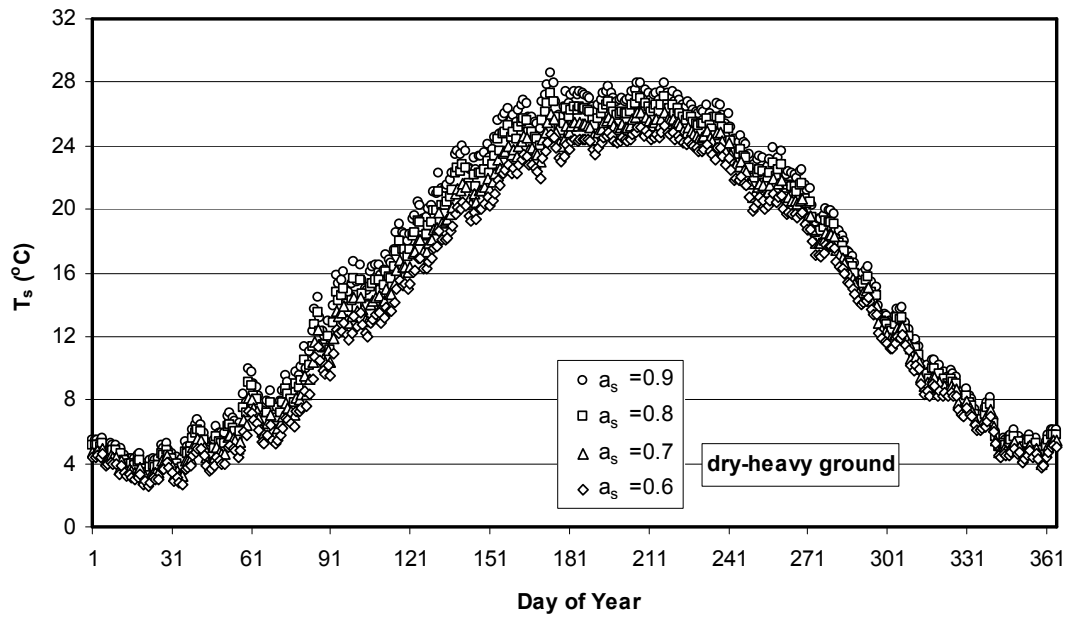


Figure 4.89. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy ground layer for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

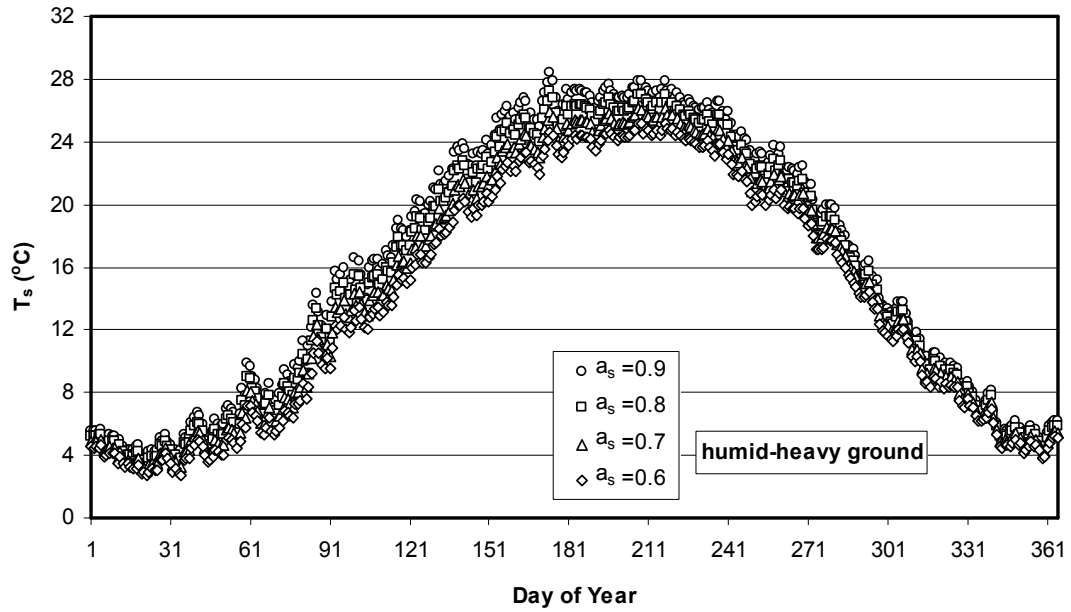


Figure 4.90. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy ground layer for İstanbul, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

4.4.2.2. Thickness of Upper Layer is 50 cm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.17, 4.18 and 4.19 for January 01 and July 01 for İstanbul when 50 cm thick of a humid-light upper layer and different physical properties of lower layers are used.

Table 4.17. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid-Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	17.25 (Max.)	16.51 (Max.)	15.75 (Max.)	14.97 (Max.)	15.22 (Min.)	14.49 (Min.)	13.75 (Min.)	12.99 (Min.)
The depth, (m)	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
End temp., T_{end} ($^{\circ}\text{C}$)	16.29	15.56	14.81	14.05	16.28	15.55	14.80	14.04
Surface temp., T_s ($^{\circ}\text{C}$)	5.41	5.08	4.75	4.42	27.21	26.26	25.27	24.26

Table 4.18. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	17.22 (Max.)	16.49 (Max.)	15.72 (Max.)	14.95 (Max.)	15.21 (Min.)	14.48 (Min.)	13.73 (Min.)	12.97 (Min.)
The depth, (m)	4.63	4.63	4.63	4.63	4.63	4.63	4.63	4.63
End temp., T_{end} (°C)	16.26	15.53	14.77	14.00	16.19	15.47	14.72	13.97
Surface temp., T_s (°C)	5.39	5.07	4.74	4.41	27.22	26.26	25.28	24.27

Table 4.19. Surface, maximum, minimum and end temperatures for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	17.19 (Max.)	16.45 (Max.)	15.69 (Max.)	14.91 (Max.)	15.26 (Min.)	14.53 (Min.)	13.78 (Min.)	13.01 (Min.)
The depth, (m)	5.02	5.02	5.02	5.02	5.02	5.02	5.02	5.02
End temp., T_{end} (°C)	16.44	15.70	14.94	14.16	16.02	15.30	14.56	13.81
Surface temp., T_s (°C)	5.45	5.12	4.79	4.46	27.19	26.23	25.25	24.24

Figures 4.91 and 4.92 demonstrate the variation of maximum and minimum ground temperatures with ground surface absorption coefficient for January 01 and July 01 for İstanbul. The effect of 50 cm thick upper layer ground on maximum and minimum temperatures compared with Adana values can be neglected.

Variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient are illustrated in figures 4.93 and 4.94 for January 01 and July 01 for İstanbul. The effect of physical properties of upper layer ground on end temperatures compared with Adana values can be neglected.

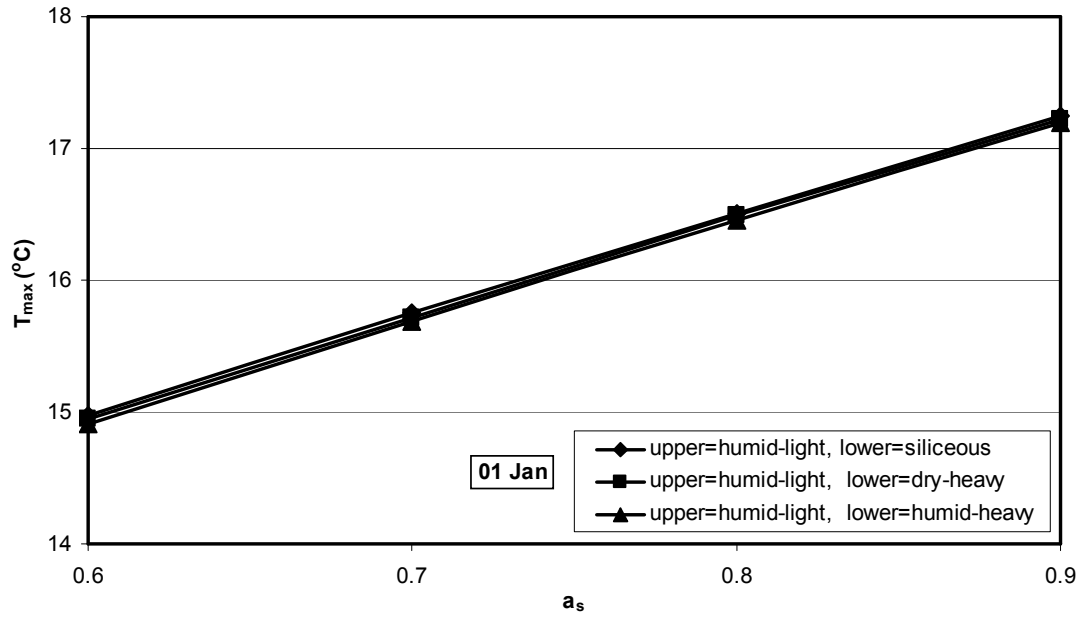


Figure 4.91. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

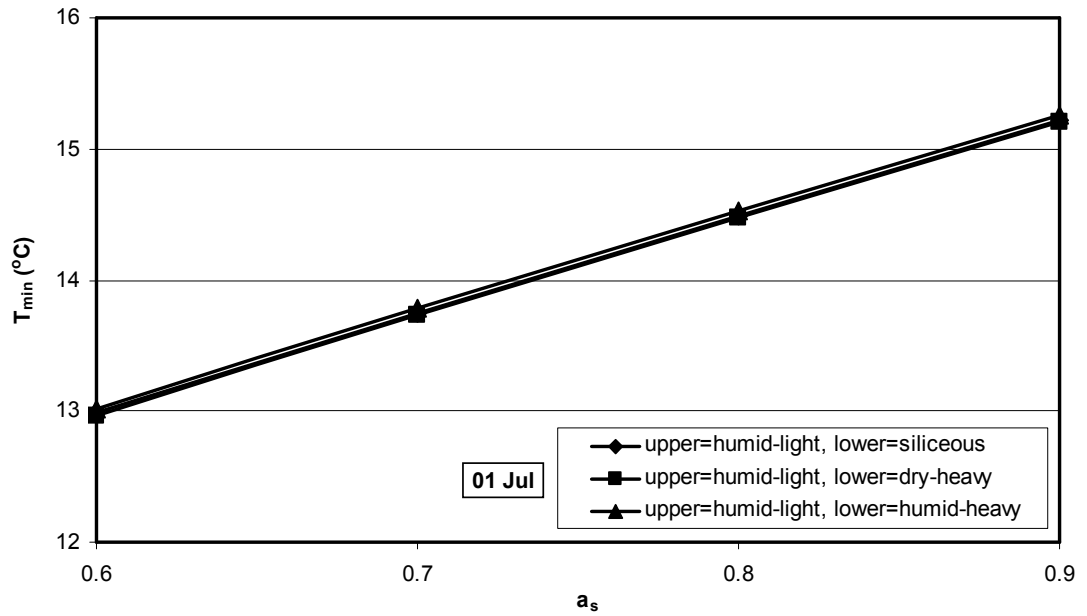


Figure 4.92. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

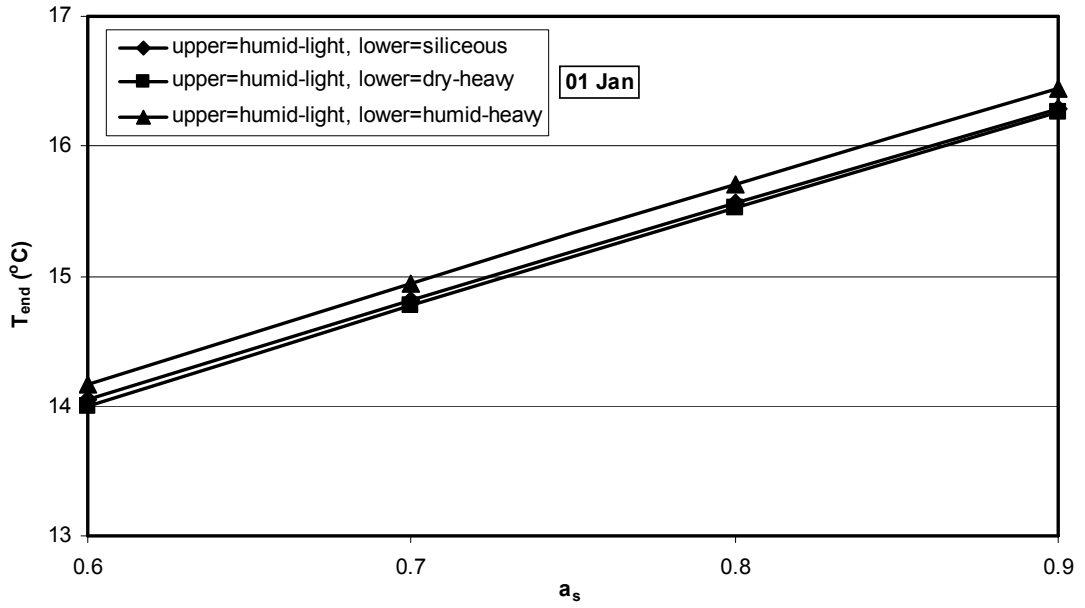


Figure 4.93. Variation of end temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

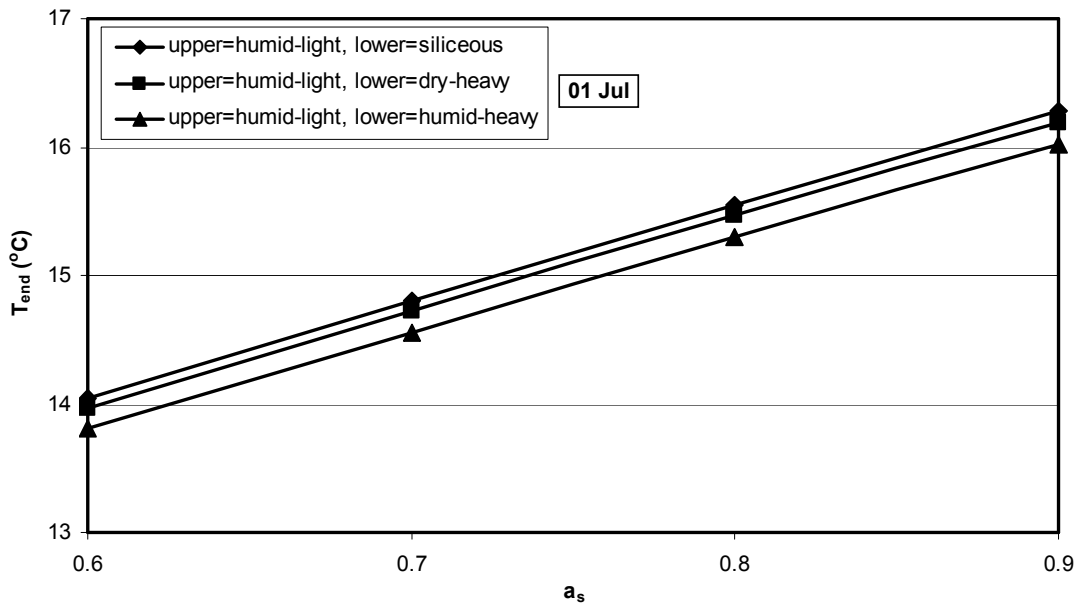


Figure 4.94. Variation of end temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figures 4.95 and 4.96 show the variation of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 for İstanbul. It is shown from these figures that upper layer does not affect ground surface temperatures.

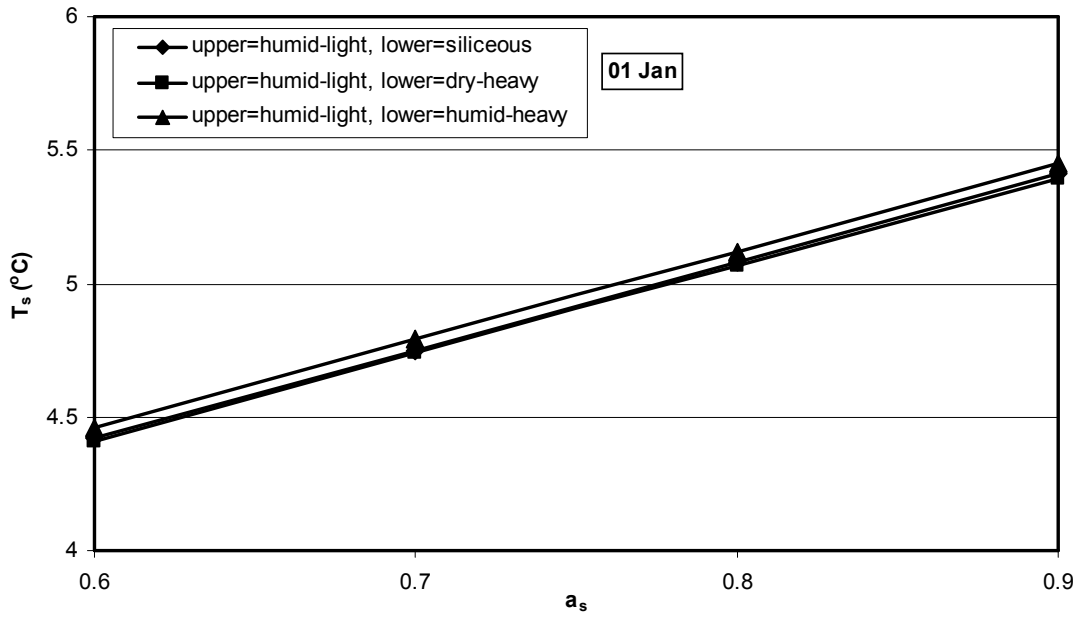


Figure 4.95. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

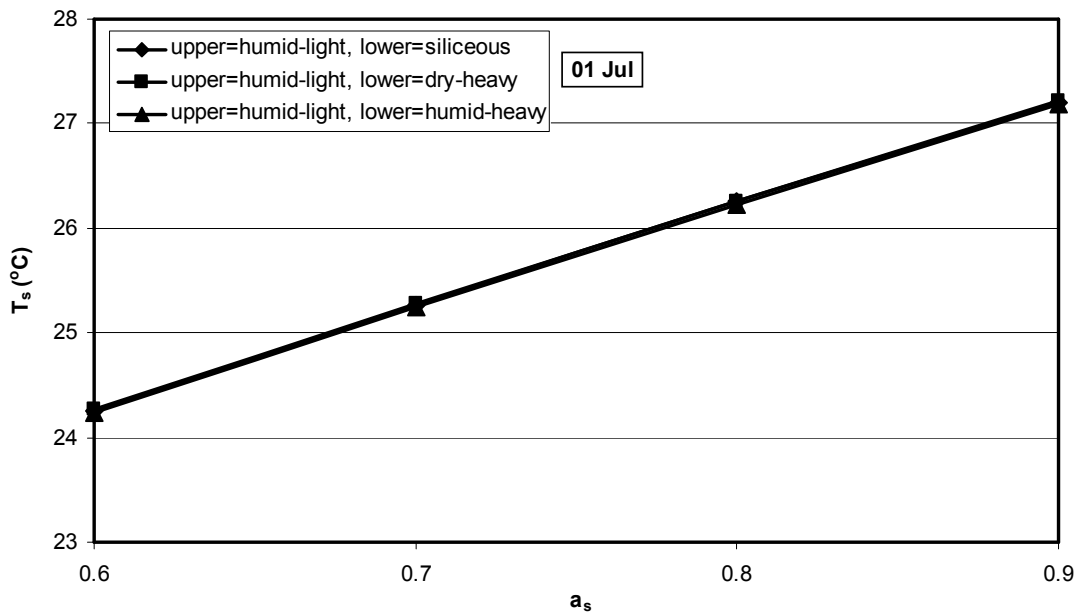


Figure 4.96. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figures 4.97 and 4.98 demonstrate variation of the depth of maximum and minimum temperatures with ground surface absorption coefficient for January 01 and July 01 for İstanbul. When 50 cm thick humid-light upper layer ground is located

on the siliceous lower layer ground; the depths of maximum and minimum temperatures increase but decrease when humid-heavy lower layer used compared to 10 m thick ground layer.

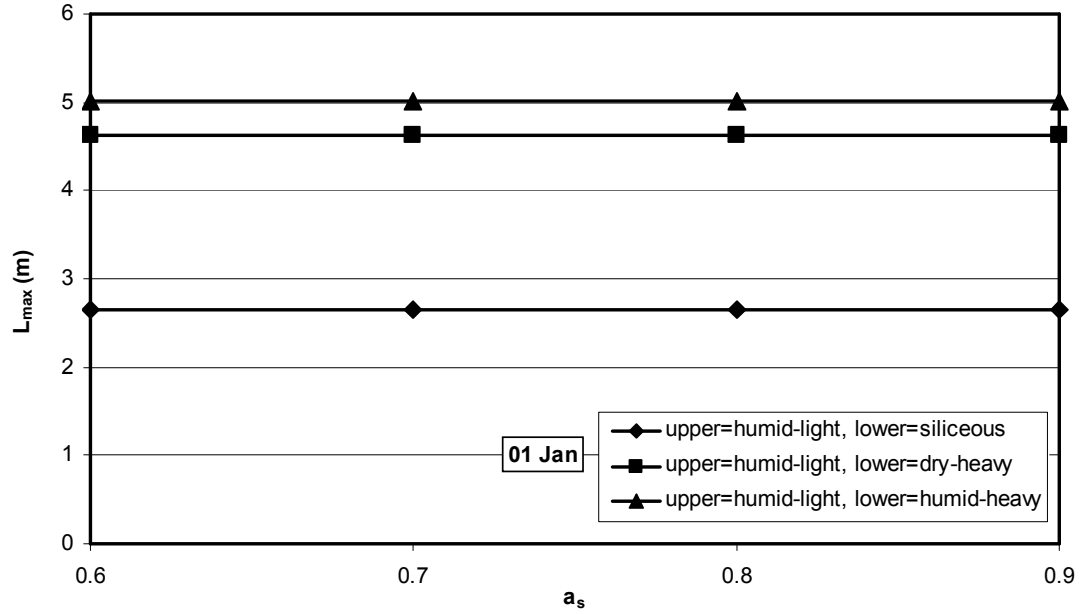


Figure 4.97. Variation of the depth of maximum temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L_1=0.5$ m, $L_2=10$ m)

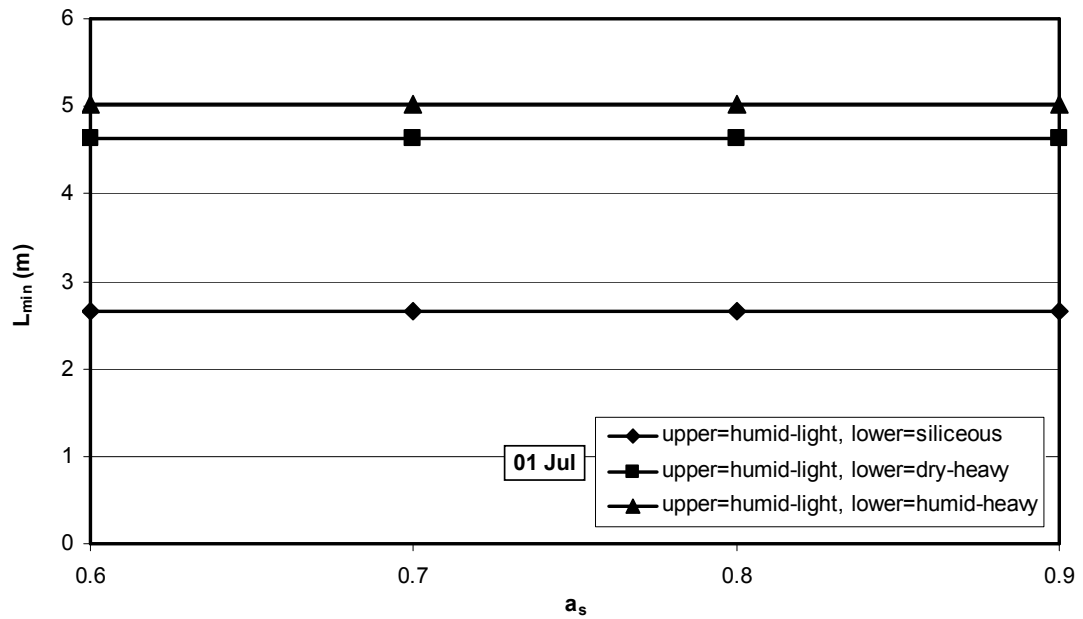


Figure 4.98. Variation of the depth of minimum temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L_1=0.5$ m, $L_2=10$ m)

Yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients for İstanbul are shown in figures 4.99, 4.100, 4.101 and 4.102.

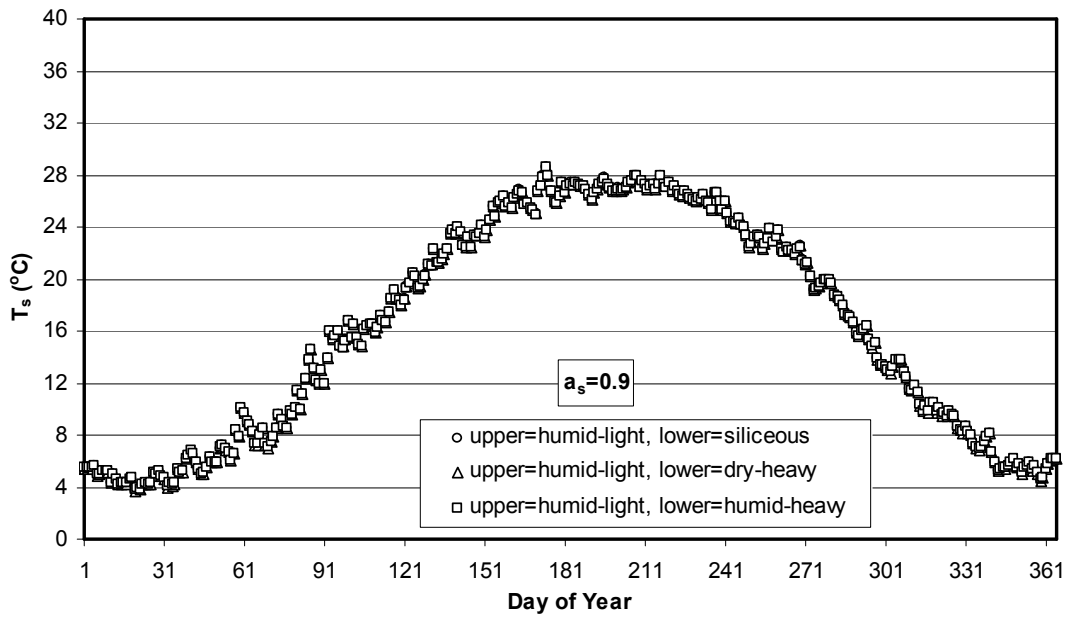


Figure 4.99. Yearly variation of ground surface temperatures for various lower layer ground types for İstanbul, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m)

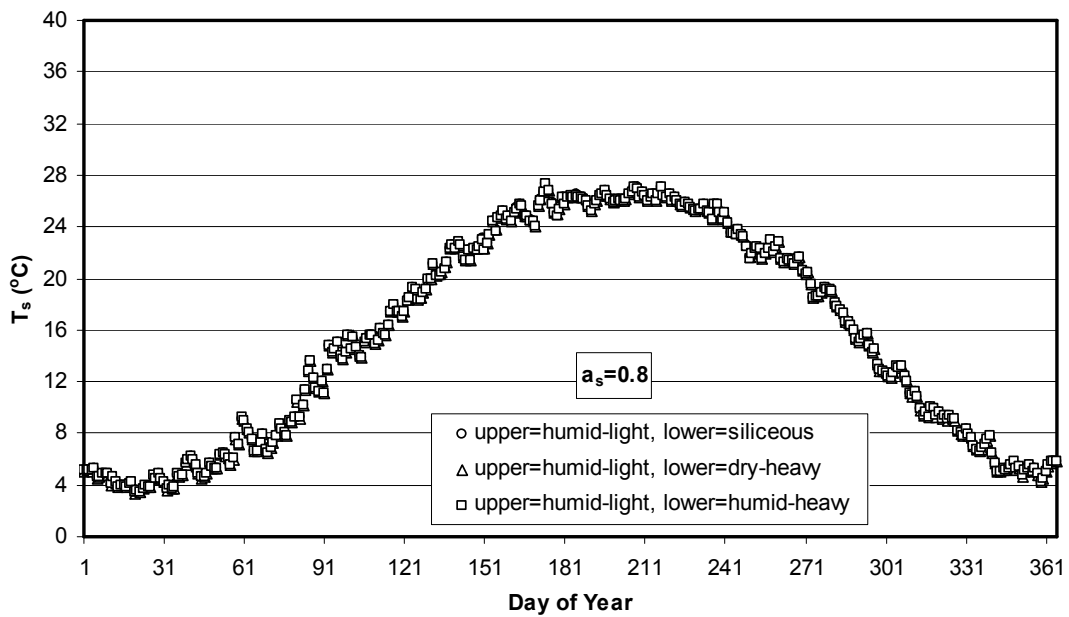


Figure 4.100. Yearly variation of ground surface temperatures for various lower layer ground types for İstanbul, ($f=0.45$, $a_s=0.8$, $L1=0.5$ m, $L2=10$ m)

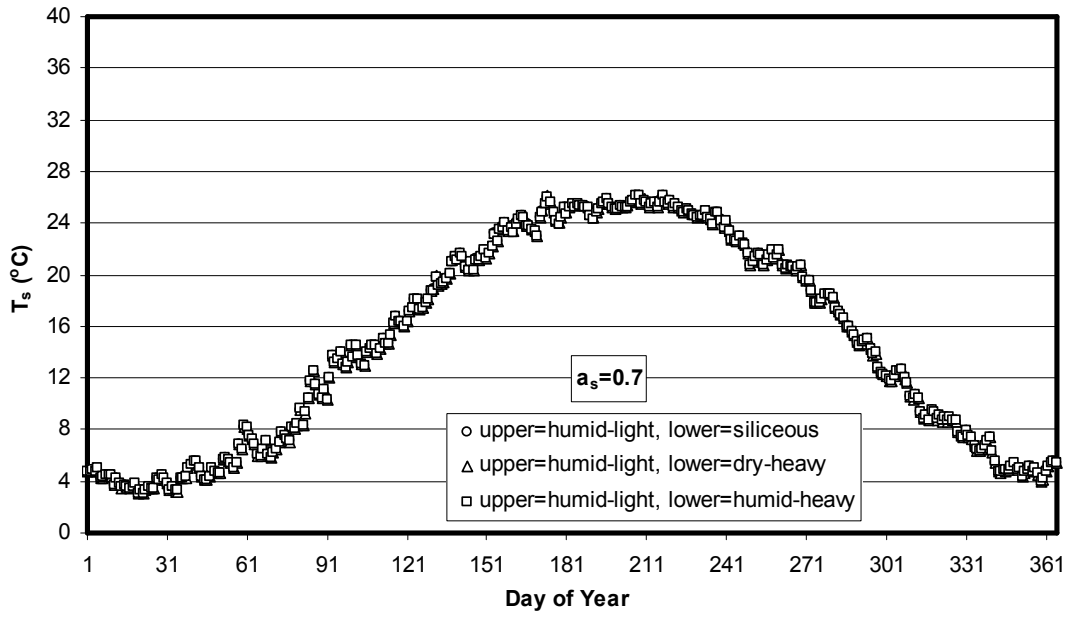


Figure 4.101. Yearly variation of ground surface temperatures for various lower layer ground types for İstanbul, ($f=0.45$, $a_s=0.7$, $L1=0.5$ m, $L2=10$ m)

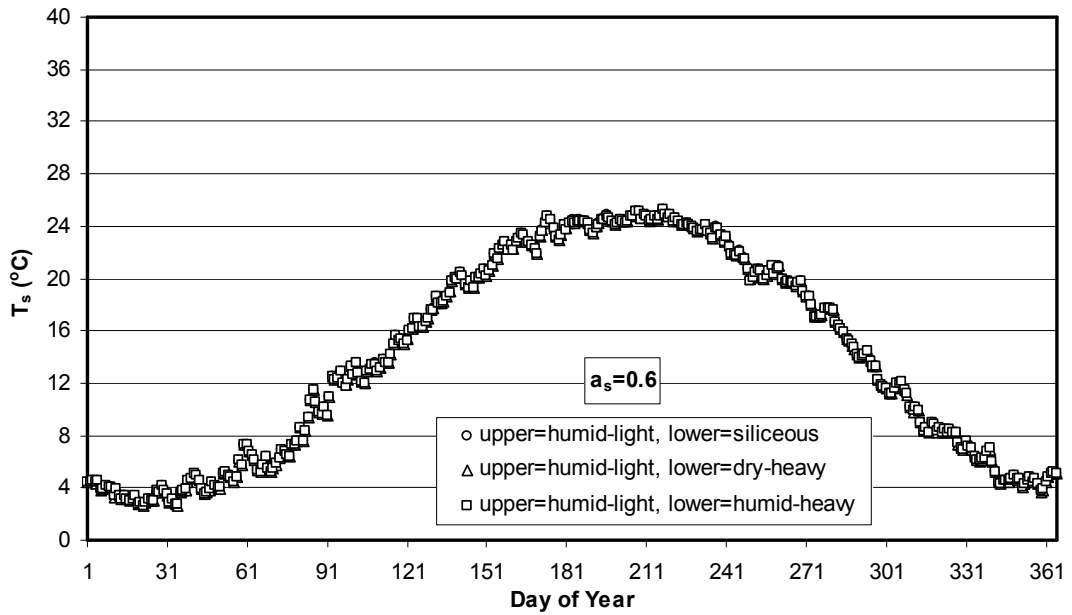


Figure 4.102. Yearly variation of ground surface temperatures for various lower layer ground types for İstanbul, ($f=0.45$, $a_s=0.6$, $L1=0.5$ m, $L2=10$ m)

Figure 4.103 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous lower layer ground for İstanbul.

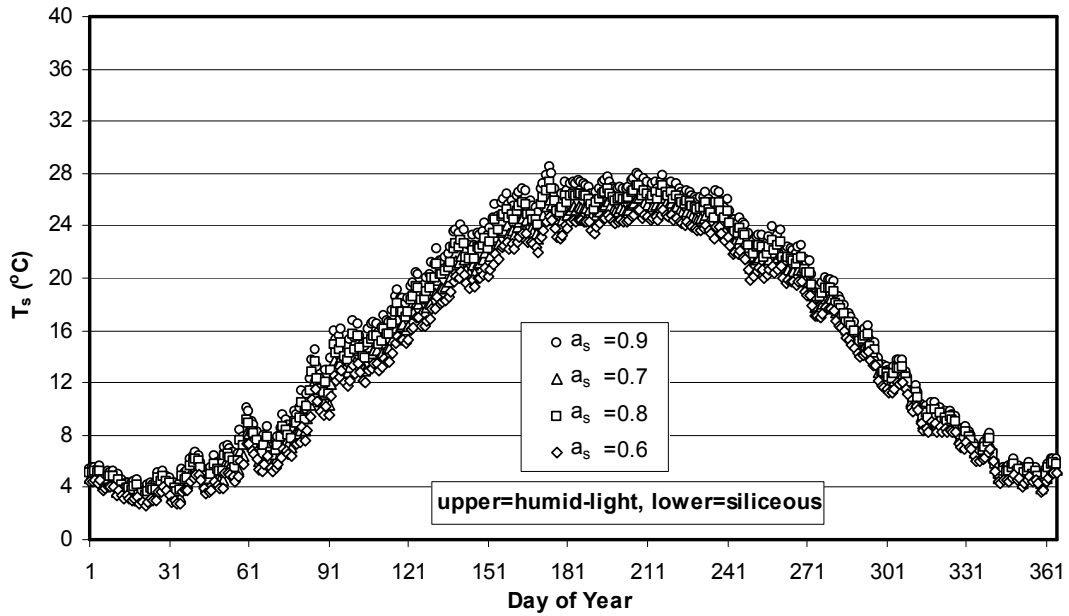


Figure 4.103. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous lower layer ground for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figure 4.104 demonstrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy lower layer ground for İstanbul. Figure 4.105 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy lower layer ground for İstanbul.

It is seen from these figures that the value of ground surface absorption coefficient affects ground surface temperatures.

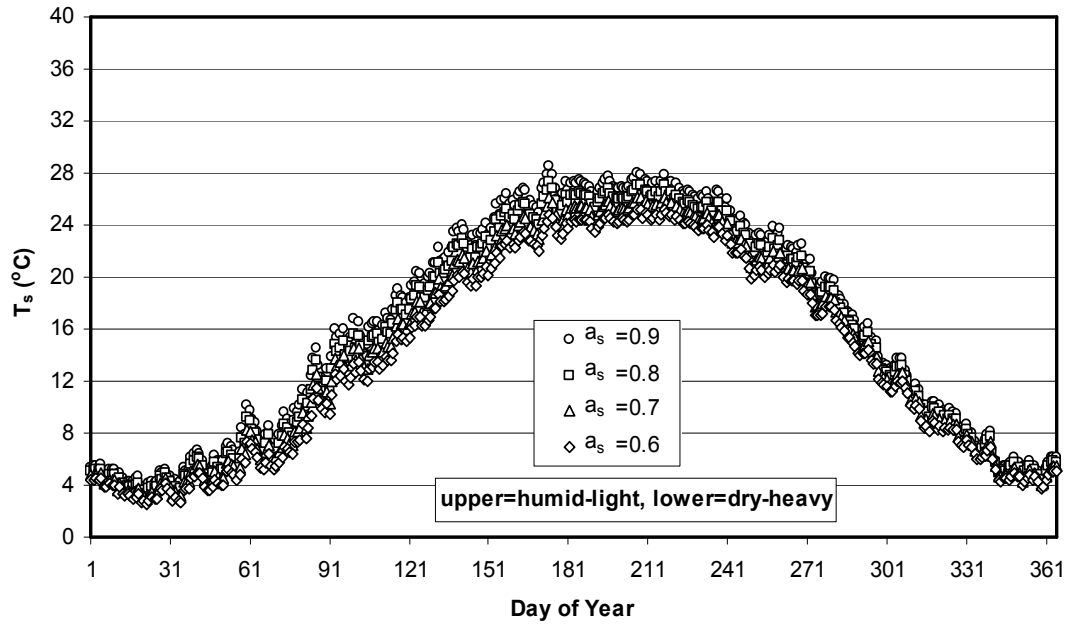


Figure 4.104. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy lower layer ground for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

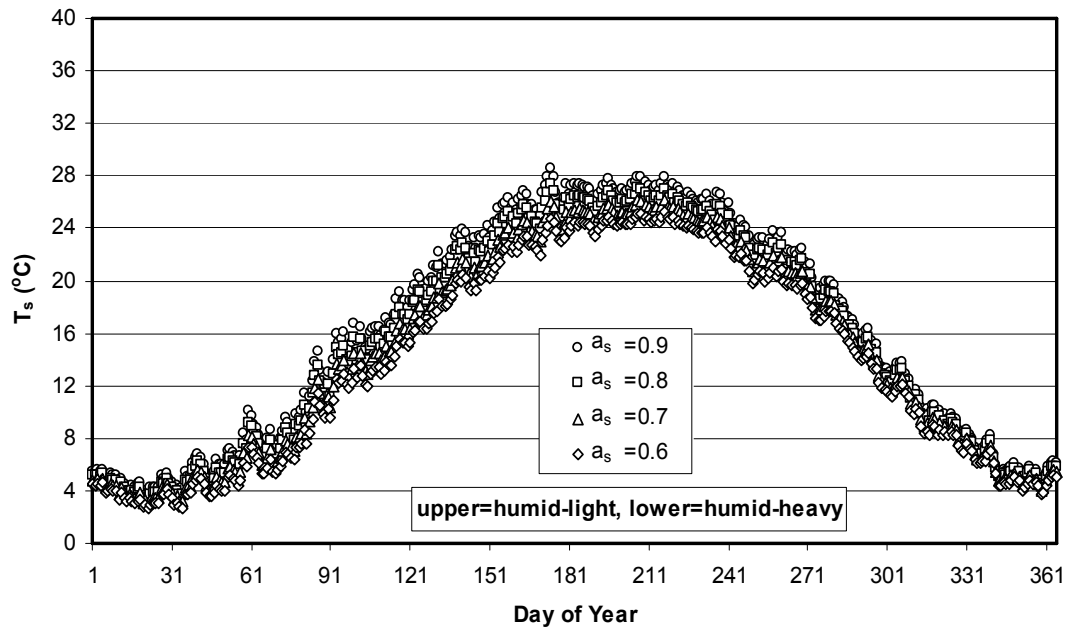


Figure 4.105. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy lower layer ground for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.4.3. Results for Ankara

4.4.3.1. Thickness of Upper Layer is 5 mm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.20, 4.21 and 4.22 for January 01 and July 01 for Ankara when different physical properties of ground layers are used.

Table 4.20. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	15.55 (Max.)	14.54 (Max.)	13.50 (Max.)	12.43 (Max.)	13.37 (Min.)	12.38 (Min.)	11.37 (Min.)	10.32 (Min.)
The depth, (m)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
End temp., T_{end} (°C)	14.46	13.47	12.44	11.39	14.45	13.46	12.43	11.38
Surface temp., T_s (°C)	1.12	0.51	-0.10	-0.72	25.83	24.70	23.53	22.31

Table 4.21. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	15.51 (Max.)	14.49 (Max.)	13.46 (Max.)	12.40 (Max.)	13.37 (Min.)	12.38 (Min.)	11.36 (Min.)	10.32 (Min.)
The depth, (m)	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
End temp., T_{end} (°C)	14.48	13.48	12.45	11.40	14.30	13.30	12.29	11.25
Surface temp., T_s (°C)	1.09	0.48	-0.13	-0.75	25.84	24.71	23.54	22.33

Table 4.22. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	15.50 (Max.)	14.50 (Max.)	13.46 (Max.)	12.39 (Max.)	13.40 (Min.)	12.42 (Min.)	11.40 (Min.)	10.35 (Min.)
The depth, (m)	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
End temp., T_{end} ($^{\circ}\text{C}$)	14.76	13.76	12.73	11.65	14.04	13.06	12.05	11.01
Surface temp., T_s ($^{\circ}\text{C}$)	1.19	0.59	-0.03	-0.65	25.80	24.67	23.49	22.27

Figures 4.106 and 4.107 demonstrate the variation of maximum and minimum ground temperatures with ground surface absorption coefficient for January 01 and July 01 for Ankara. It is seen from these figures that maximum and minimum temperatures do not depend on the ground type as in Adana and İstanbul.

In figures 4.108 and 4.109, variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 are shown for Ankara. It is observed from these figures that end temperatures do not vary annually and do not depend on the ground type. But it is clear that the ground surface absorption coefficient affects the end temperatures.

The variations of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 in Ankara are shown in figures 4.110 and 4.111. There is not a noticeable effect of ground physical properties on the ground surface temperatures.

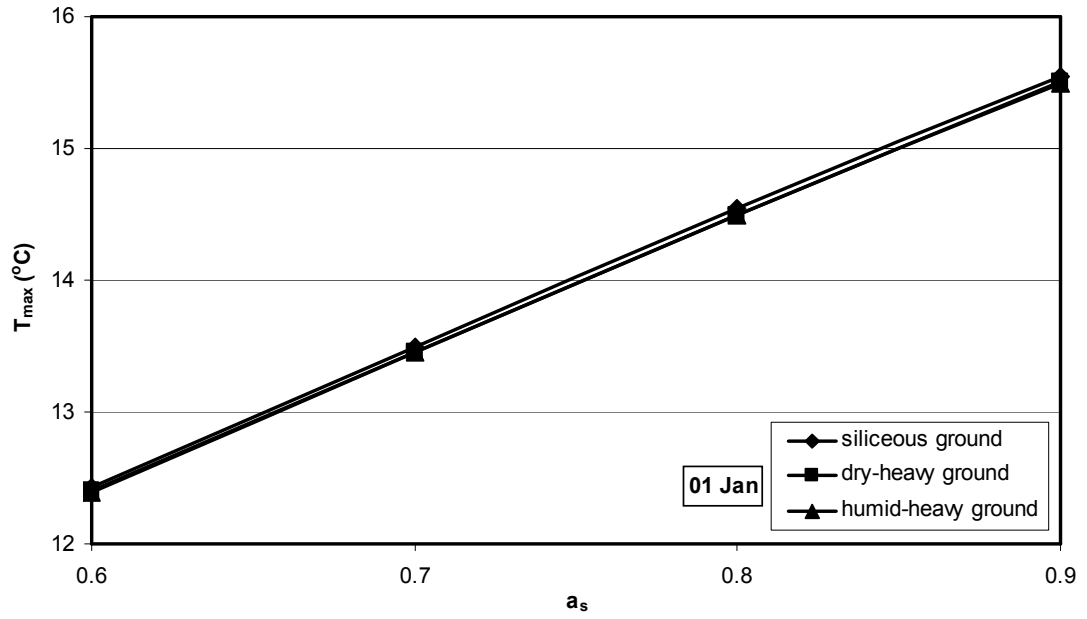


Figure 4.106. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

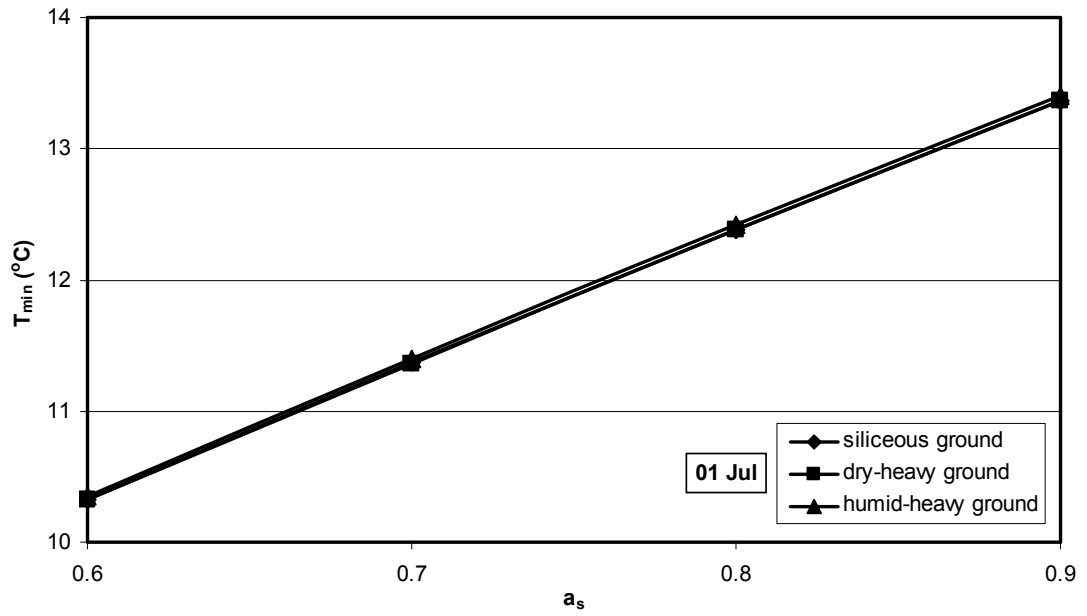


Figure 4.107. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

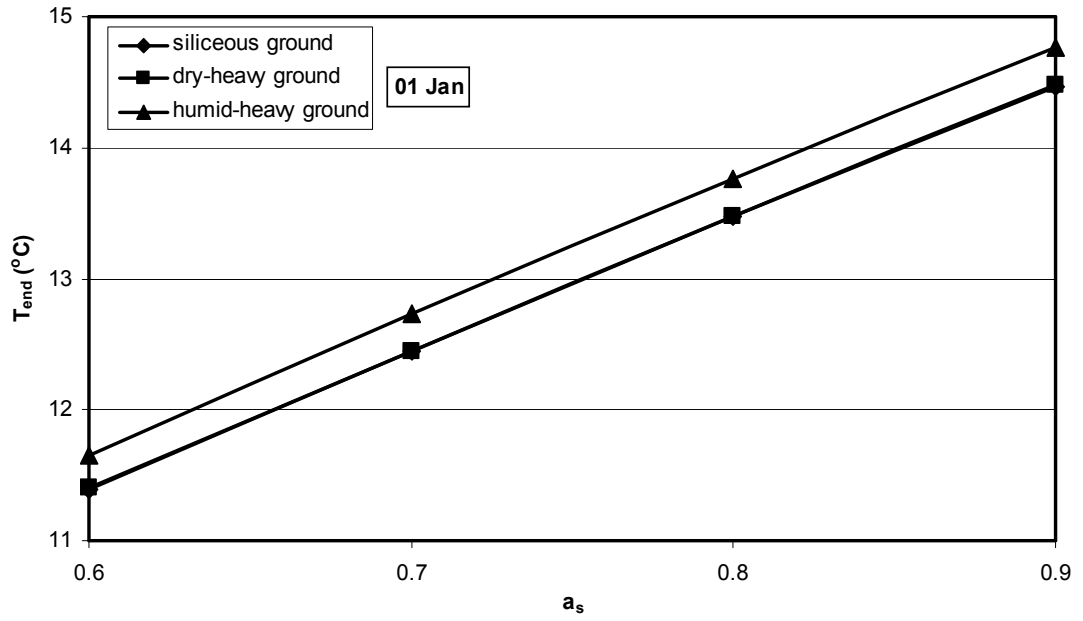


Figure 4.108. Variation of end temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

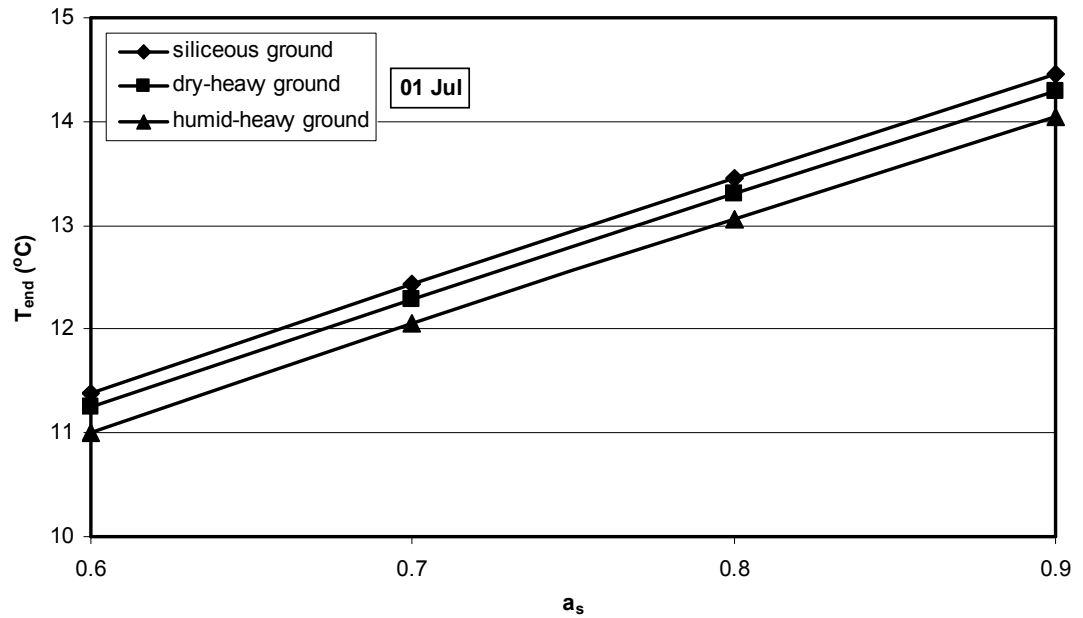


Figure 4.109. Variation of end temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

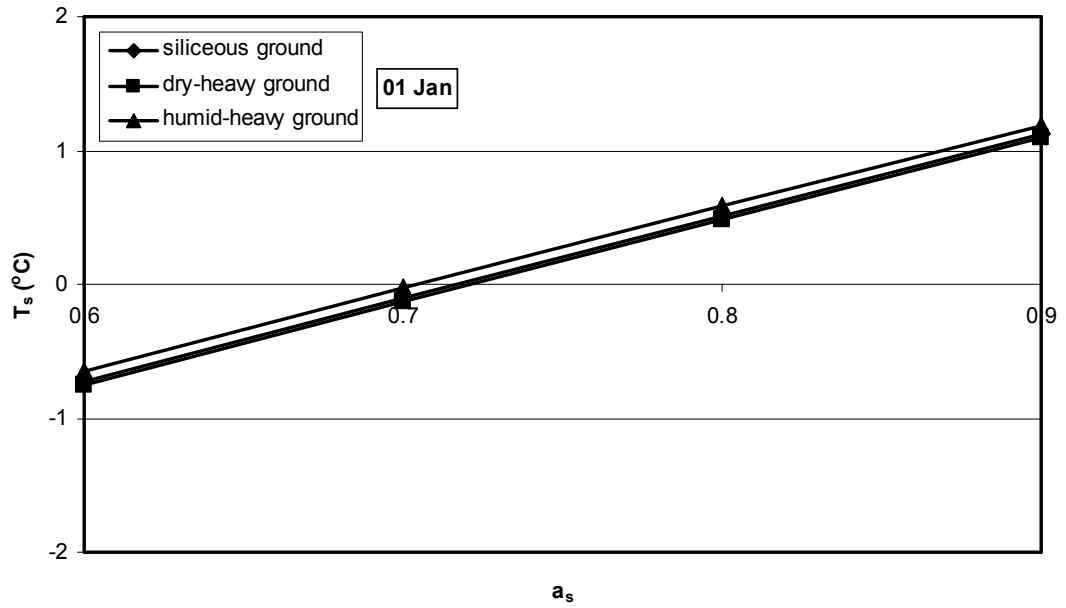


Figure 4.110. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

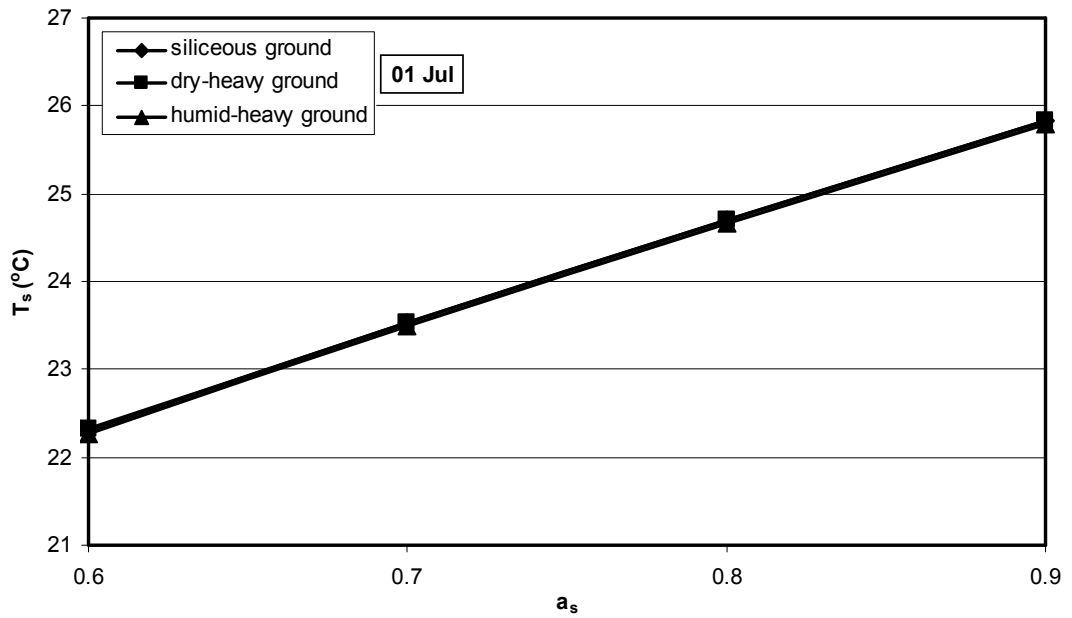


Figure 4.111. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

In figures 4.112 and 4.113, the variations of the depth of maximum and minimum temperatures with ground surface absorption coefficient are illustrated for January 01 and July 01 in Ankara.

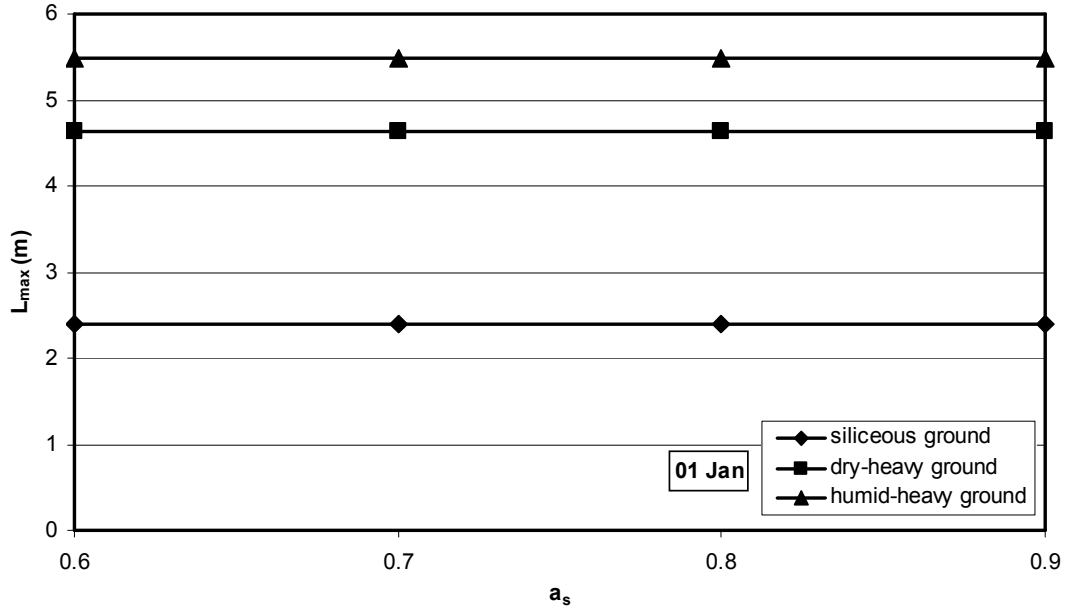


Figure 4.112. Variation of the depth of maximum temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

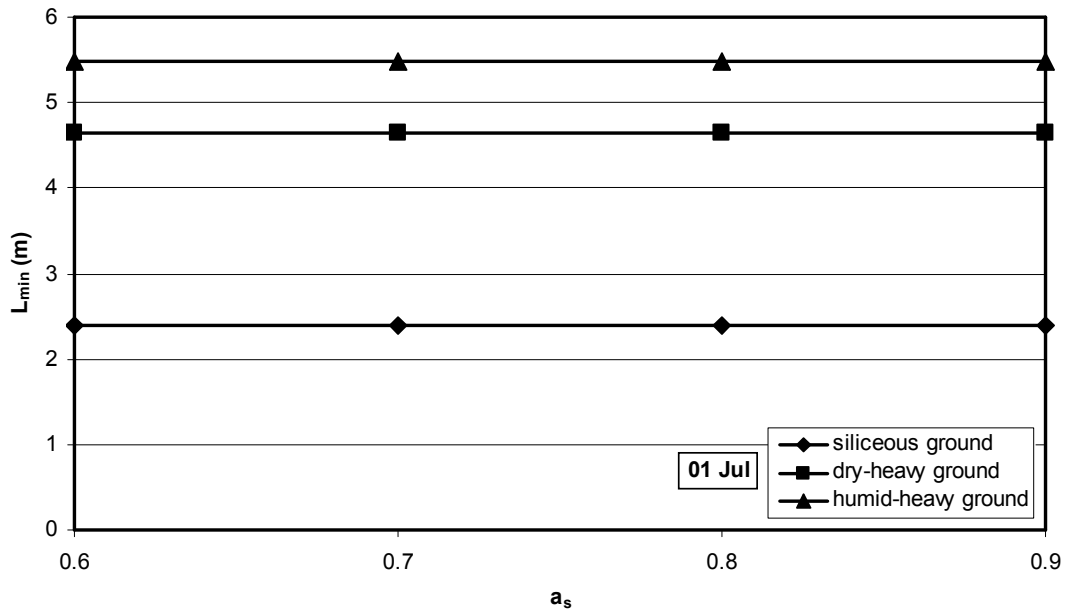


Figure 4.113. Variation of the depth of minimum temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

In figures 4.114, 4.115, 4.116 and 4.117, yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients are demonstrated for Ankara.

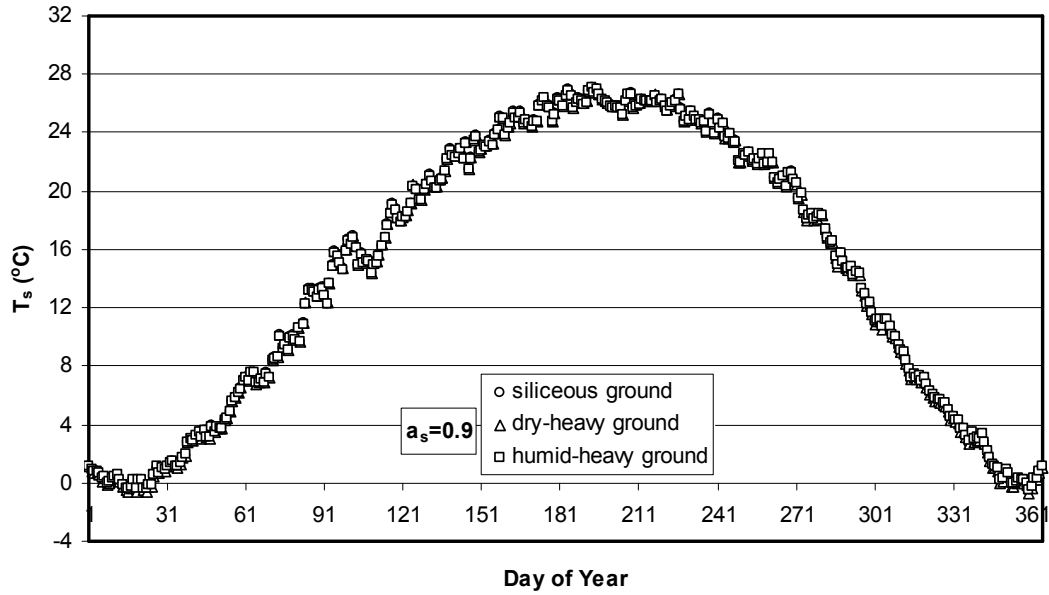


Figure 4.114. Yearly variation of ground surface temperatures for various ground types for Ankara, ($f=0.45$, $a_s=0.9$, $L1=0.005$ m, $L2=10$ m)

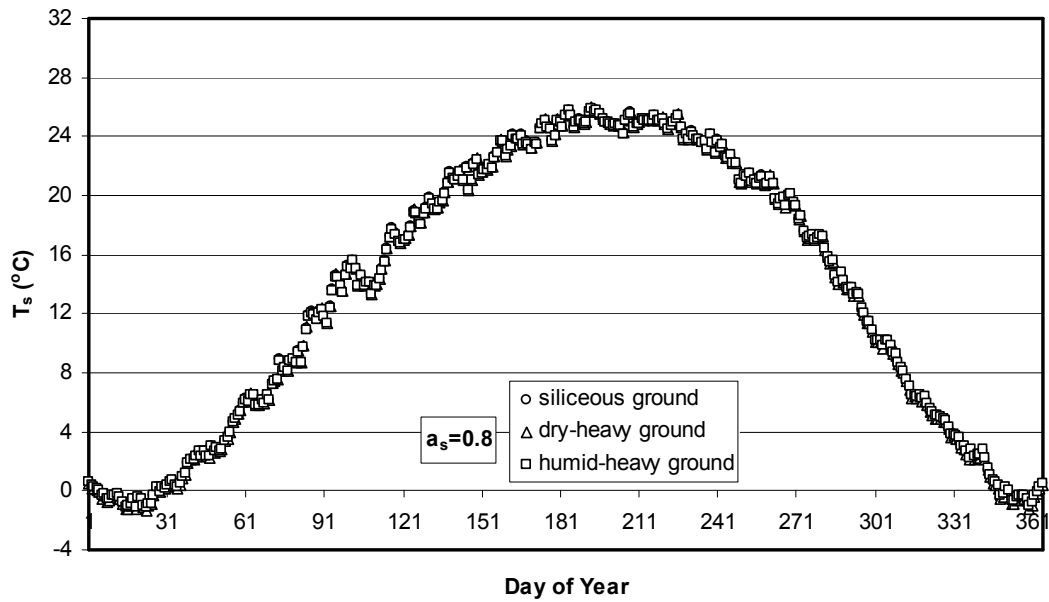


Figure 4.115. Yearly variation of ground surface temperatures for various ground types for Ankara, ($f=0.45$, $a_s=0.8$, $L1=0.005$ m, $L2=10$ m)

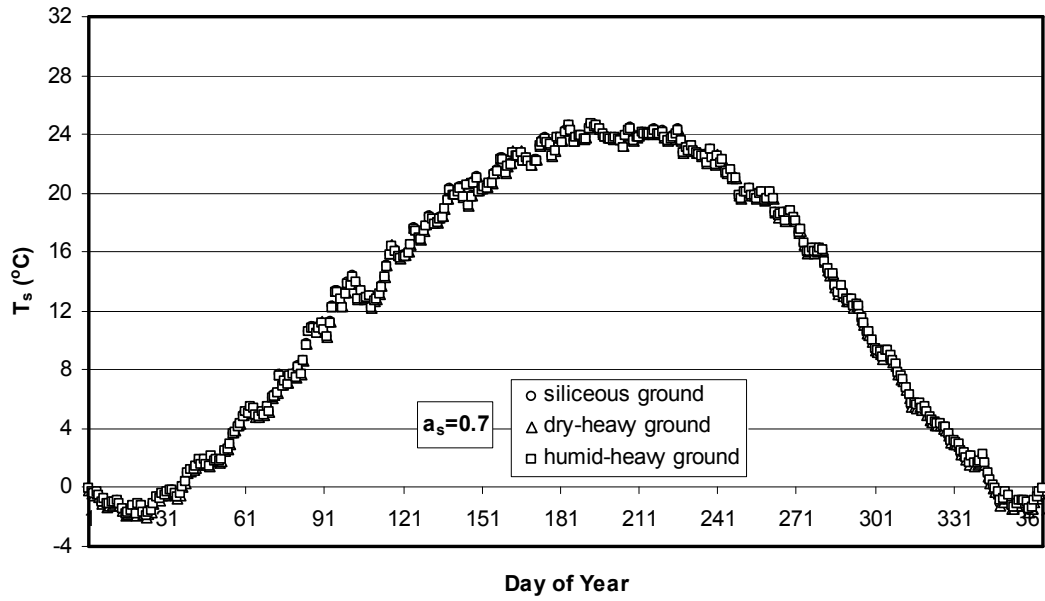


Figure 4.116. Yearly variation of ground surface temperatures for various ground types for Ankara, ($f=0.45$, $a_s=0.7$, $L1=0.005$ m, $L2=10$ m)

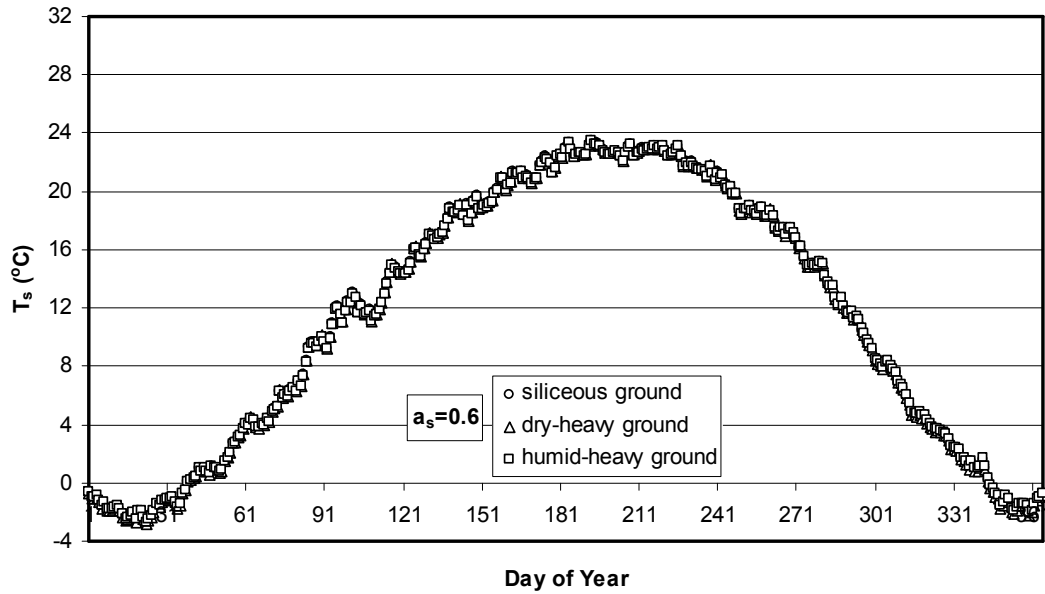


Figure 4.117. Yearly variation of ground surface temperatures for various ground types for Ankara, ($f=0.45$, $a_s=0.6$, $L1=0.005$ m, $L2=10$ m)

Figure 4.118 demonstrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous ground layer for Ankara.

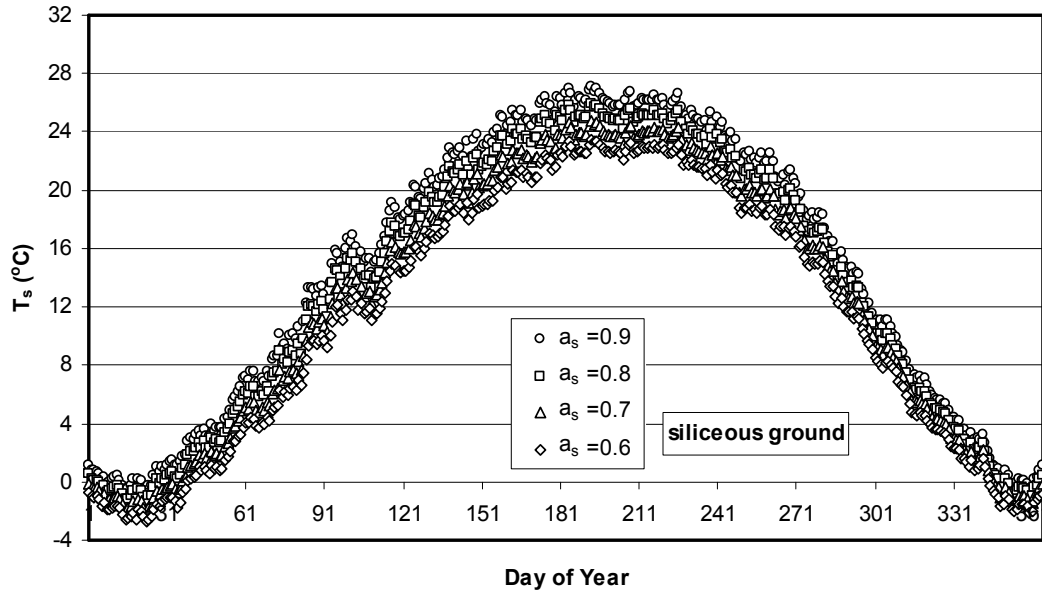


Figure 4.118. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous ground layer for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy ground layer are illustrated in figure 4.119 for Ankara.

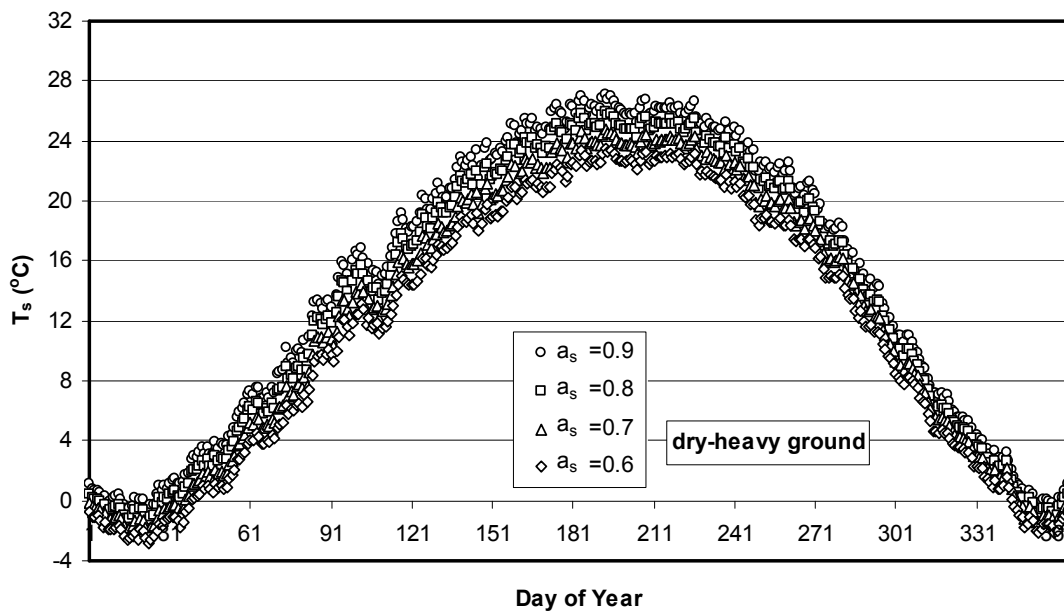


Figure 4.119. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy ground layer for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figure 4.120 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy ground layer for Ankara.

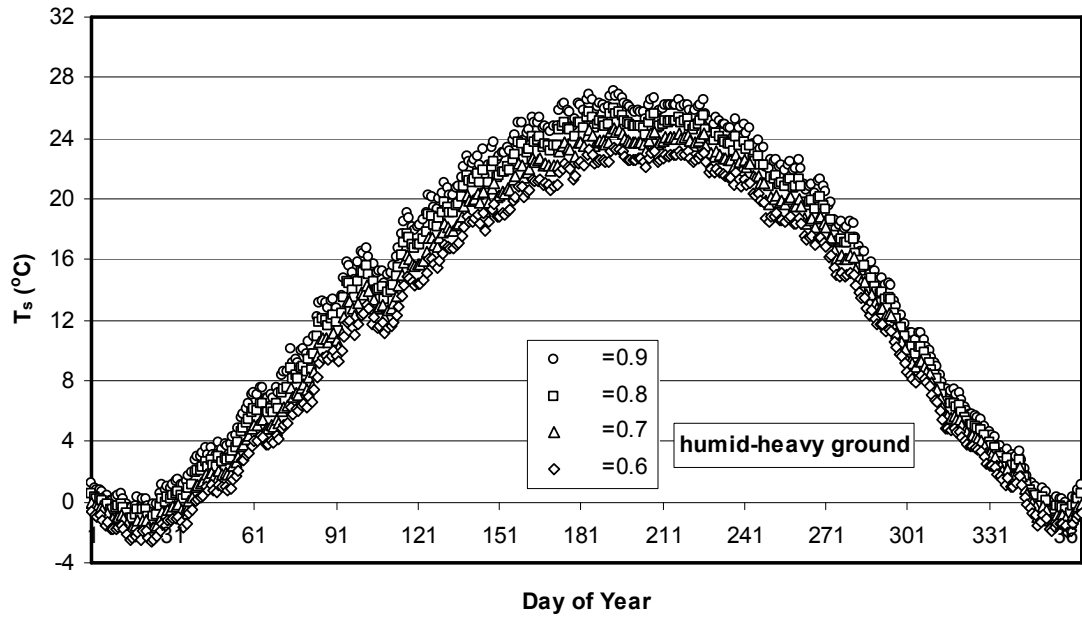


Figure 4.120. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy ground layer for Ankara, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

As can be seen from these figures, ground surface temperatures change with ground surface absorption coefficients considerably.

4.4.3.2. Thickness of Upper Layer is 50 cm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.23, 4.24 and 4.25 for January 01 and July 01 for Ankara when 50 cm thick humid-light upper layer and different physical properties of lower layers are used.

Table 4.23. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid- Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	15.53 (Max.)	14.52 (Max.)	13.48 (Max.)	12.41 (Max.)	13.39 (Min.)	12.40 (Min.)	11.39 (Min.)	10.34 (Min.)
The depth, (m)	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
End temp., T_{end} ($^{\circ}\text{C}$)	14.46	13.47	12.45	11.39	14.45	13.46	12.43	11.38
Surface temp., T_s ($^{\circ}\text{C}$)	1.12	0.52	-0.10	-0.72	25.83	24.70	23.54	22.32

Table 4.24. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	15.49 (Max.)	14.49 (Max.)	13.45 (Max.)	12.38 (Max.)	13.37 (Min.)	12.39 (Min.)	11.37 (Min.)	10.32 (Min.)
The depth, (m)	5.02	5.02	5.02	5.02	5.02	5.02	5.02	5.02
End temp., T_{end} ($^{\circ}\text{C}$)	14.45	13.45	12.43	11.36	14.32	13.33	12.32	11.27
Surface temp., T_s ($^{\circ}\text{C}$)	1.10	0.49	-0.12	-0.74	25.84	24.71	23.55	22.33

Table 4.25. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Ankara (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	15.46 (Max.)	14.45 (Max.)	13.42 (Max.)	12.35 (Max.)	13.43 (Min.)	12.44 (Min.)	11.43 (Min.)	10.38 (Min.)
The depth, (m)	5.46	5.46	5.46	5.46	5.46	5.46	5.46	5.46
End temp., T_{end} ($^{\circ}\text{C}$)	14.66	13.66	12.63	11.57	14.13	13.14	12.13	11.09
Surface temp., T_s ($^{\circ}\text{C}$)	1.20	0.59	-0.02	-0.64	25.81	24.68	23.51	22.30

In figures 4.121 and 4.122, variation of maximum and minimum ground temperatures with ground surface absorption coefficient are shown for January 01 and July 01 for Ankara. When these values are compared with the values given in figures 4.106 and 4.107, the effect of 50 cm thick upper layer ground on the maximum and minimum temperatures can be neglected.

The variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 are demonstrated in figures 4.123 and 4.124 for Ankara. When these values are compared with the values given in figures 4.108 and 4.109, the effect of 50 cm thick upper layer ground on the end temperatures can be neglected.

In figures 4.125 and 4.126, the variations of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 in Ankara are illustrated. When these values are compared with the values given in figures 4.110 and 4.111, the effect of upper layer on these temperatures can be neglected.

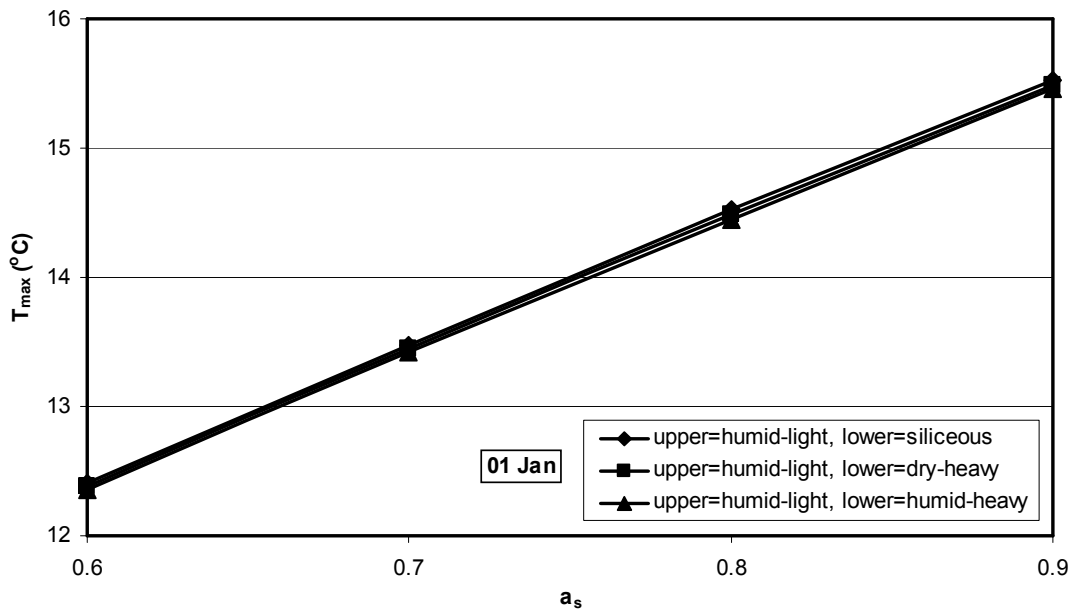


Figure 4.121. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

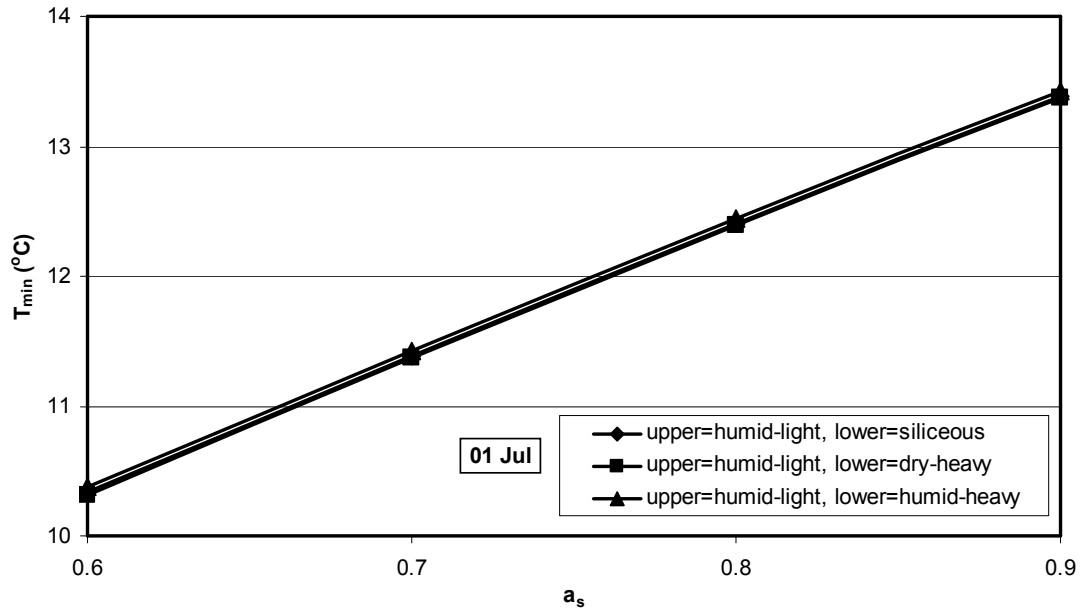


Figure 4.122. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

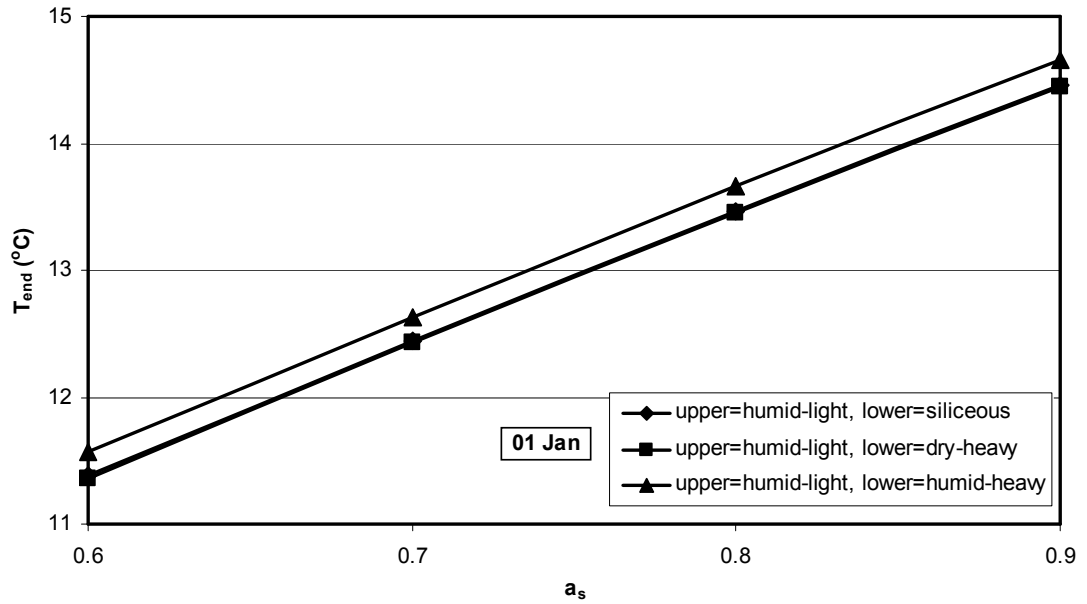


Figure 4.123. Variation of end temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

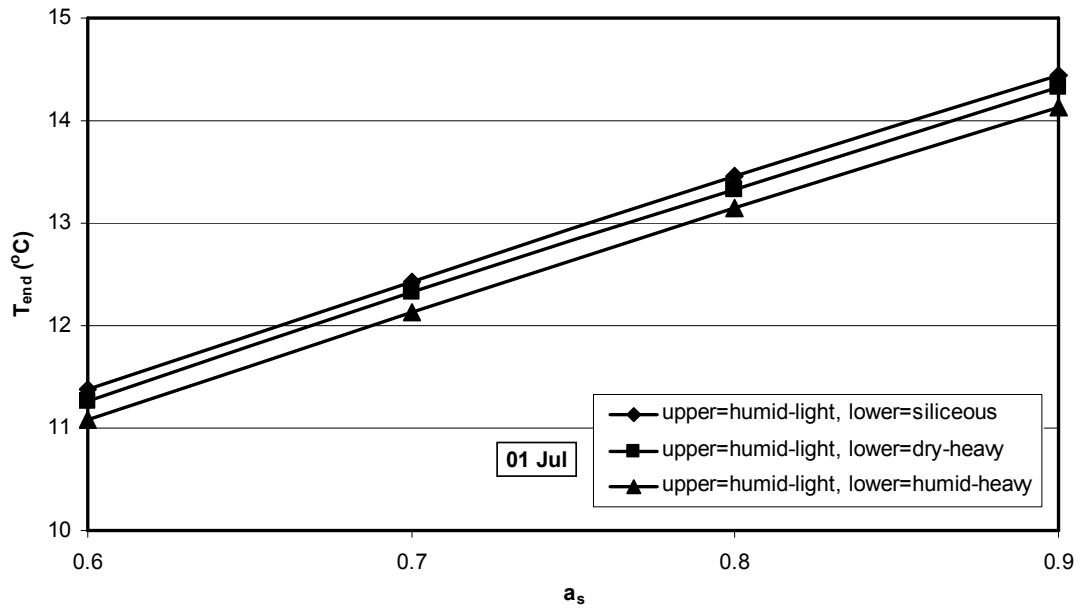


Figure 4.124. Variation of end temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

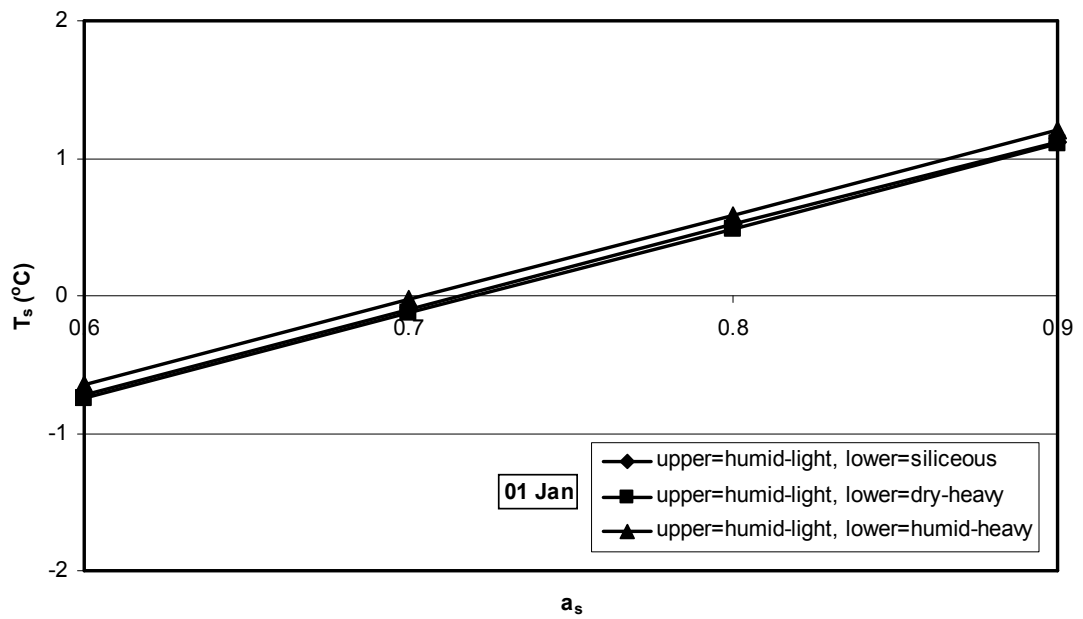


Figure 4.125. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

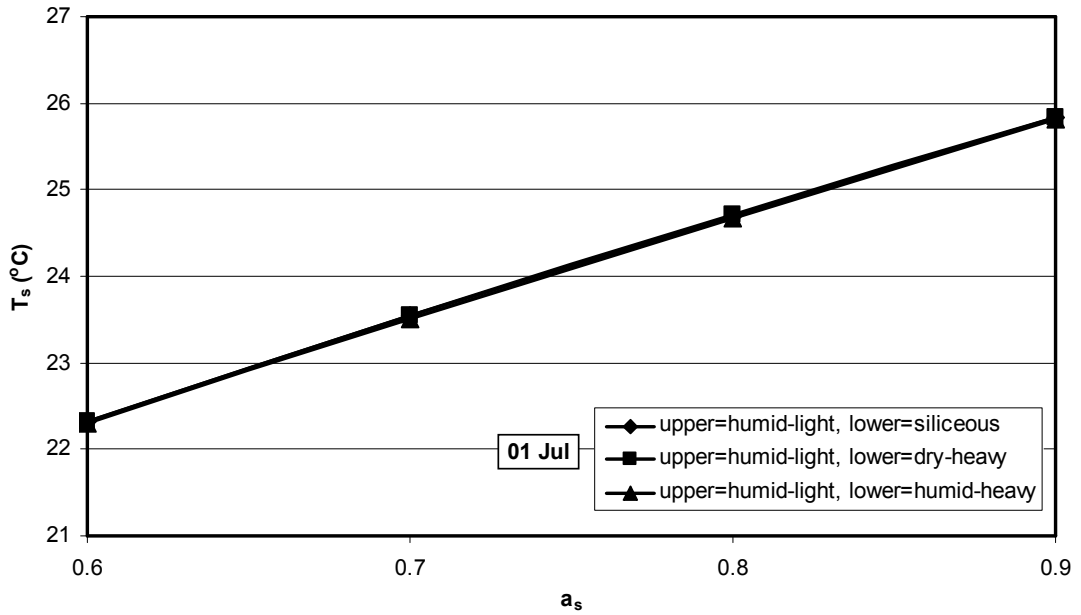


Figure 4.126. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Variations of depth of maximum and minimum temperatures with ground surface absorption coefficient are shown for January 01 and July 01 for Ankara in figures 4.127 and 4.128. When 50 cm thick humid-light upper layer ground is located on the siliceous lower layer ground; the depths of maximum and minimum temperatures increase from 240 cm to 265 cm compared to 10 m thick ground layer.

When 50 cm thick humid-light ground is located on the humid-heavy ground; the depths of maximum and minimum temperatures does not vary with a_s . But, when 50 cm thick of humid-light ground is located on the dry-heavy ground; the depths of maximum and minimum temperatures increase from 464 cm to 502 compared to 10 m thick ground layer.

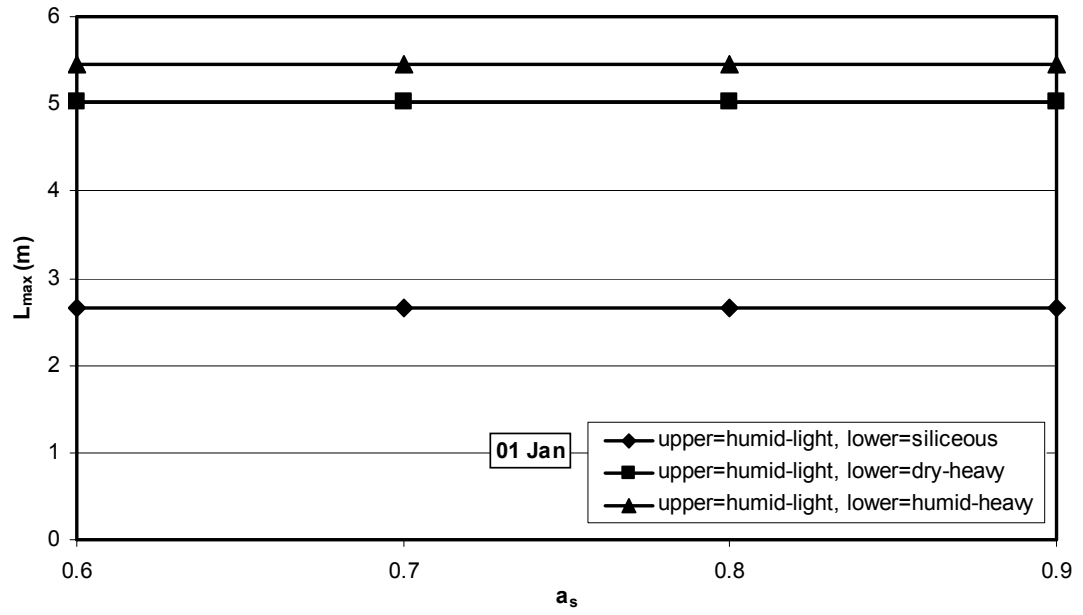


Figure 4.127. Variation of depth of maximum temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L_1=0.5$ m, $L_2=10$ m)

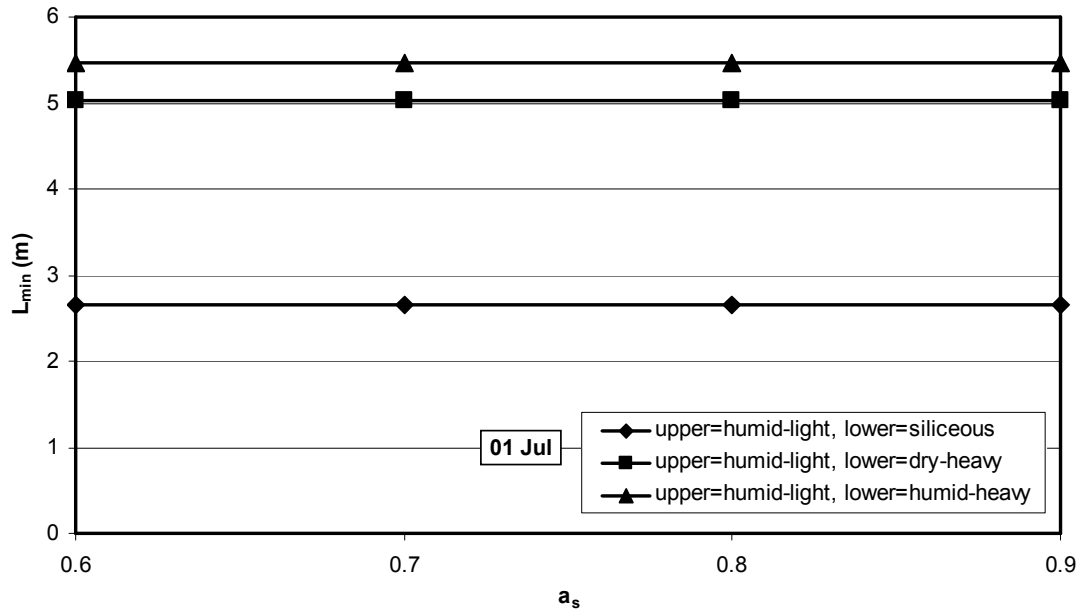


Figure 4.128. Variation of depth of minimum temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L_1=0.5$ m, $L_2=10$ m)

Figures 4.129, 4.130, 4.131 and 4.132 illustrate yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients for Ankara.

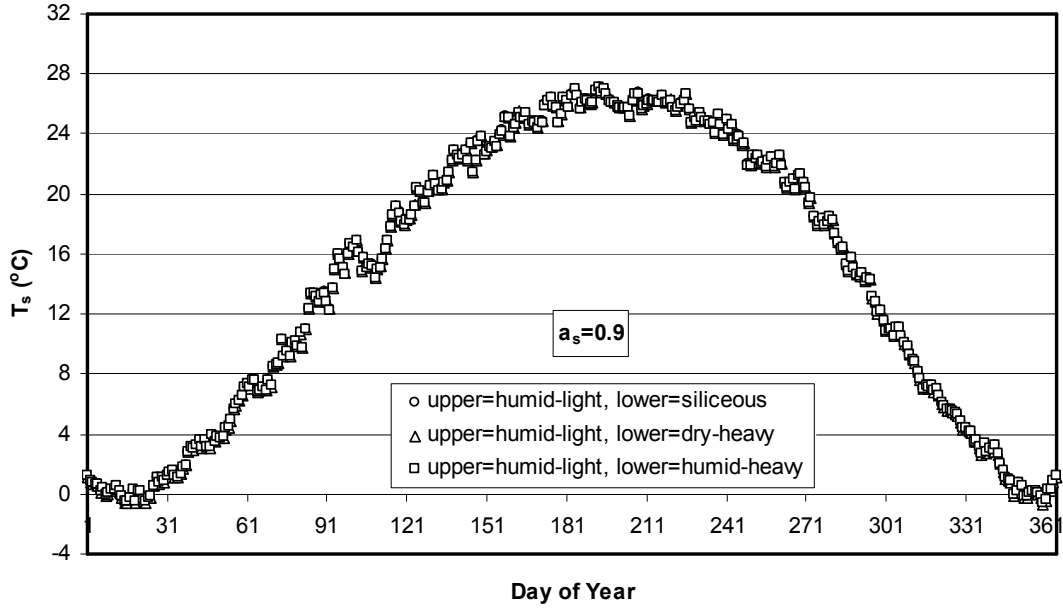


Figure 4.129. Yearly variation of ground surface temperatures for various lower layer ground types for Ankara, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m)

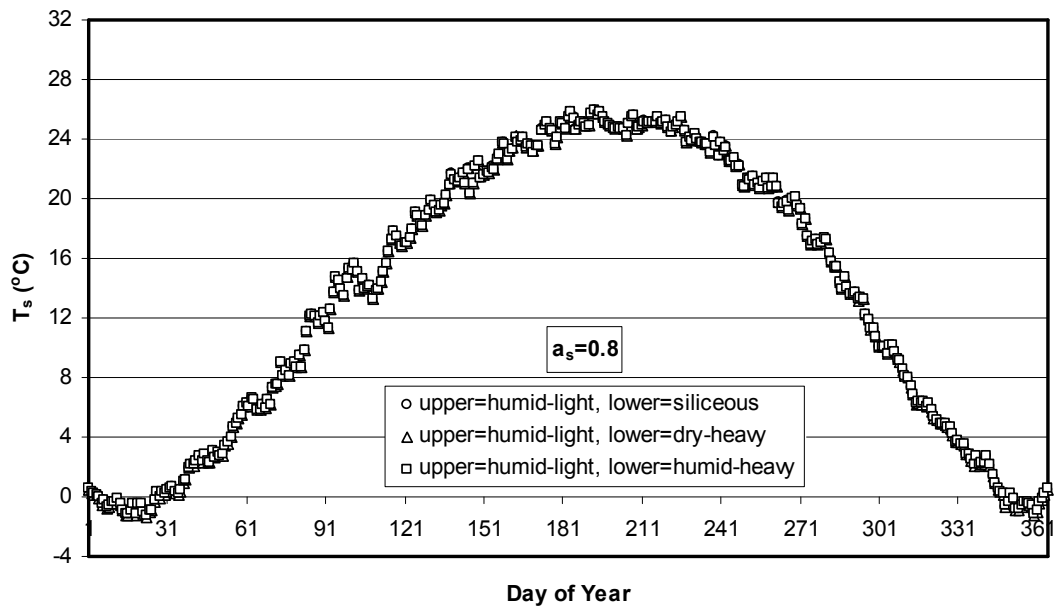


Figure 4.130. Yearly variation of ground surface temperatures for various lower layer ground types for Ankara, ($f=0.45$, $a_s=0.8$, $L1=0.5$ m, $L2=10$ m)

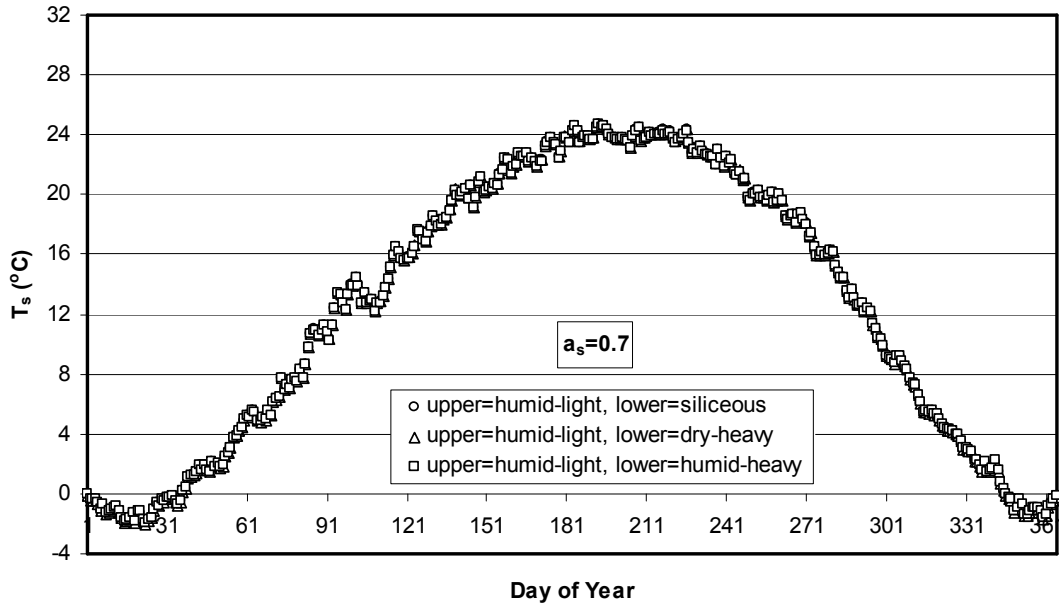


Figure 4.131. Yearly variation of ground surface temperatures for various lower layer ground types for Ankara, ($f=0.45$, $a_s=0.7$, $L1=0.5$ m, $L2=10$ m)

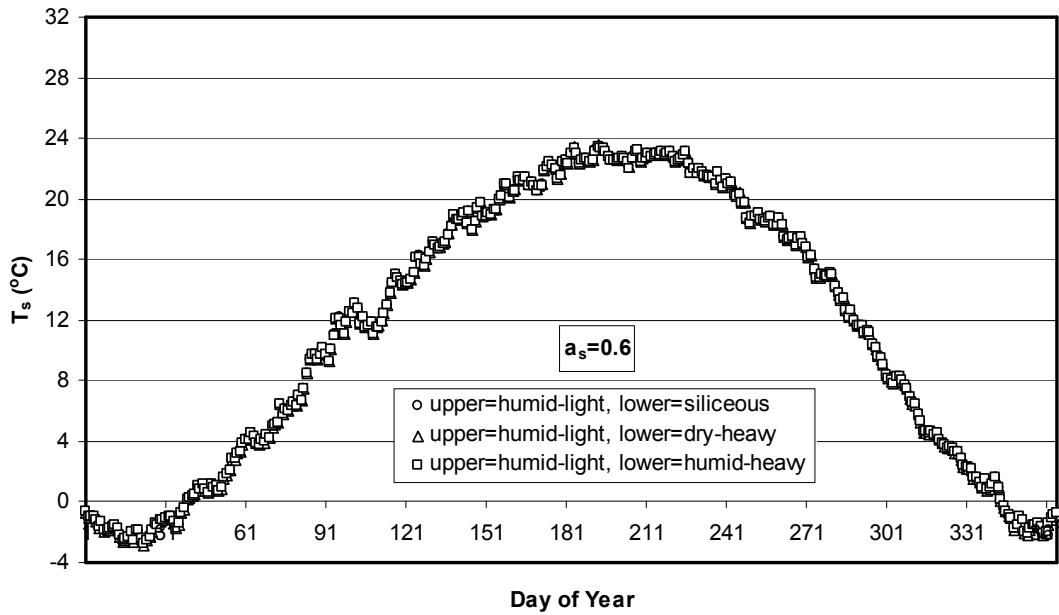


Figure 4.132. Yearly variation of ground surface temperatures for various lower layer ground types for Ankara, ($f=0.45$, $a_s=0.6$, $L1=0.5$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous lower layer ground for Ankara are demonstrated in figure 4.133.

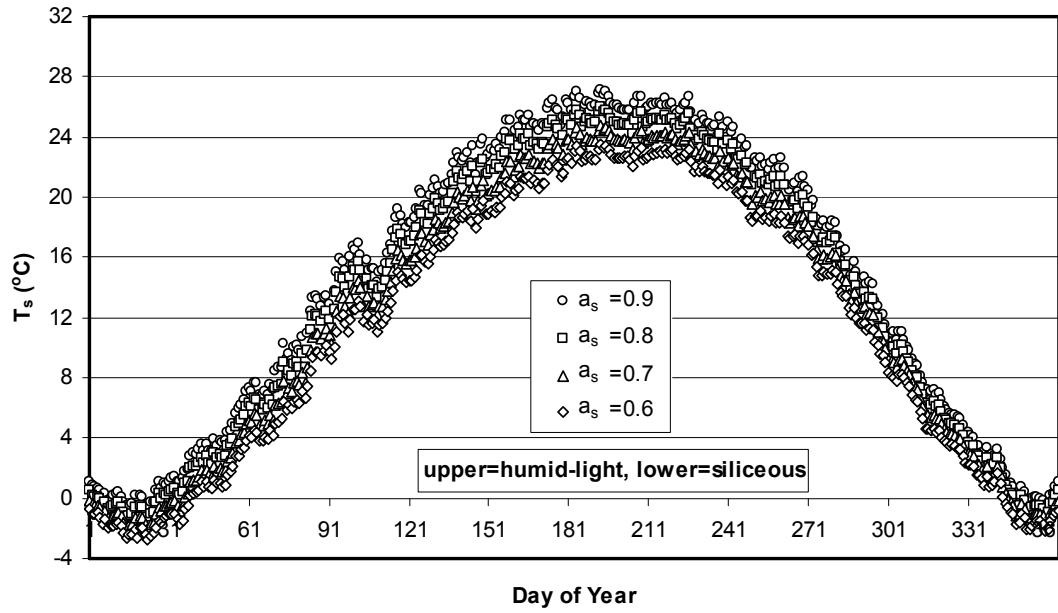


Figure 4.133. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous lower layer ground for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figure 4.134 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy lower layer ground for Ankara.

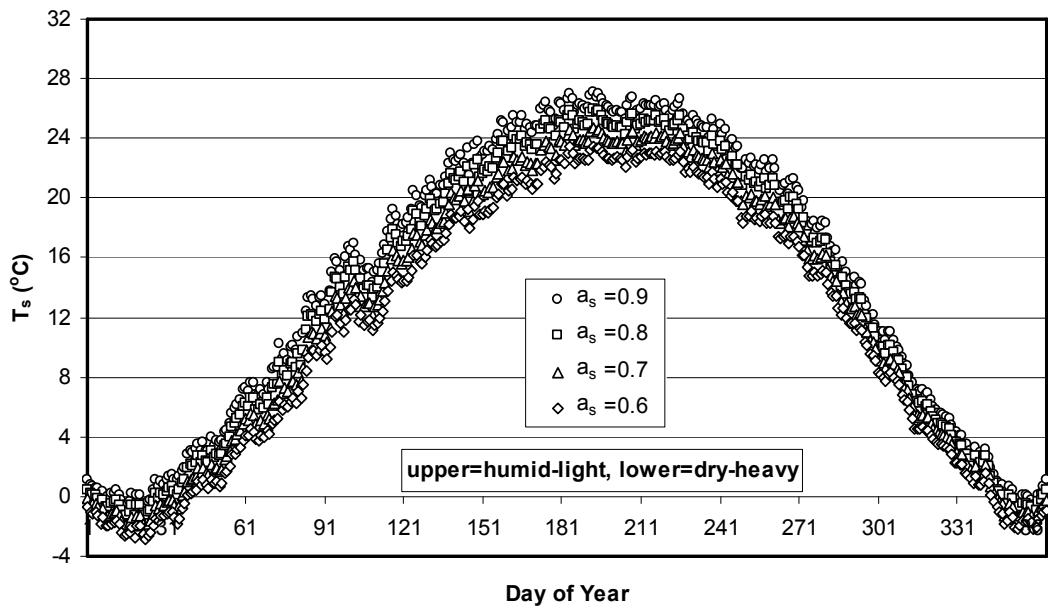


Figure 4.134. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy lower layer ground for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

In figure 4.135, yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy lower layer ground for Ankara is illustrated.

It is clearly understood from these figures that ground surface temperatures vary with ground surface absorption coefficient for 50 cm thick upper layer ground.

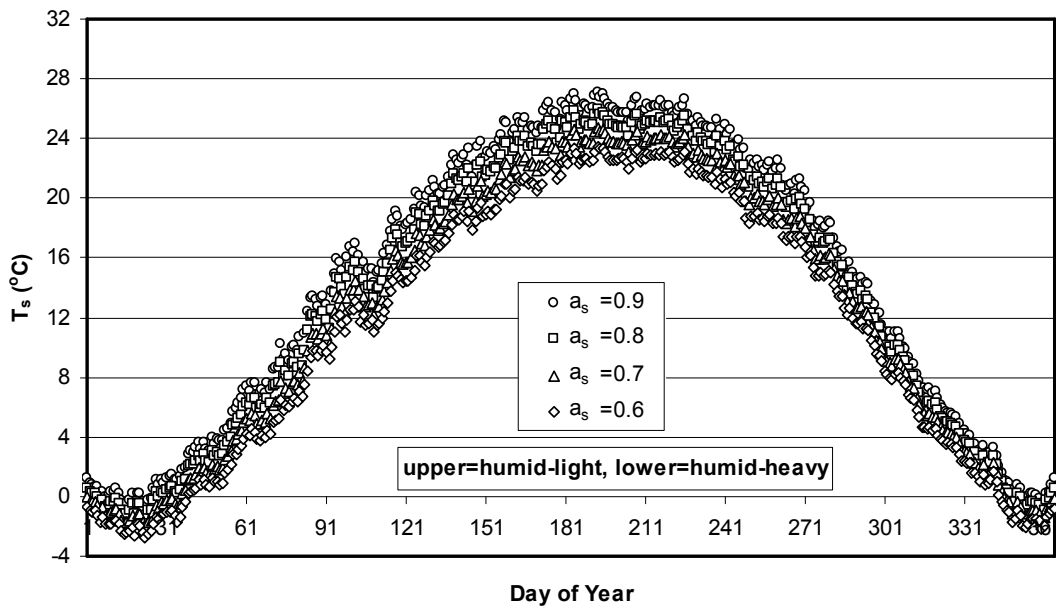


Figure 4.135. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy lower layer ground for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.4.4. Results for Kars

4.4.4.1. Thickness of Upper Layer is 5 mm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.26, 4.27 and 4.28 for January 01 and July 01 for Kars when different physical properties of ground layers are used.

Table 4.26. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	10.00 (Max.)	9.07 (Max.)	8.13 (Max.)	7.16 (Max.)	7.51 (Min.)	6.57 (Min.)	5.61 (Min.)	4.63 (Min.)
The depth, (m)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
End temp., T_{end} (°C)	8.74	7.81	6.86	5.89	8.73	7.80	6.84	5.88
Surface temp., T_s (°C)	-6.32	-7.06	-7.80	-8.56	20.38	19.35	18.29	17.19

Table 4.27. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	9.96 (Max.)	9.03 (Max.)	8.08 (Max.)	7.12 (Max.)	7.51 (Min.)	6.56 (Min.)	5.60 (Min.)	4.62 (Min.)
The depth, (m)	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
End temp., T_{end} (°C)	8.74	7.81	6.85	5.87	8.58	7.66	6.71	5.74
Surface temp., T_s (°C)	-6.35	-7.09	-7.84	-8.59	20.39	19.36	18.30	17.21

Table 4.28. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	9.94 (Max.)	9.02 (Max.)	8.07 (Max.)	7.11 (Max.)	7.55 (Min.)	6.61 (Min.)	5.66 (Min.)	4.68 (Min.)
The depth, (m)	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
End temp., T_{end} (°C)	9.05	8.11	7.15	6.17	8.32	7.39	6.45	5.48
Surface temp., T_s (°C)	-6.23	-6.97	-7.71	-8.47	20.35	19.31	18.25	17.15

The variation of maximum and minimum ground temperatures with ground surface absorption coefficient are shown in figures 4.136 and 4.137 for January 01 and July 01 for Kars. It is seen from these figures, these values are much smaller than the values given for Adana, Ankara and İstanbul.

In figures 4.138 and 4.139, variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient for January 01 and July 01 for Kars are illustrated. It is observed from these figures that these values are much smaller than the values given for Adana, Ankara and İstanbul.

Figures 4.140 and 4.141 illustrate variation of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 in Kars. There is a significant decrease in ground surface temperatures according to the values of Adana, Ankara and İstanbul.

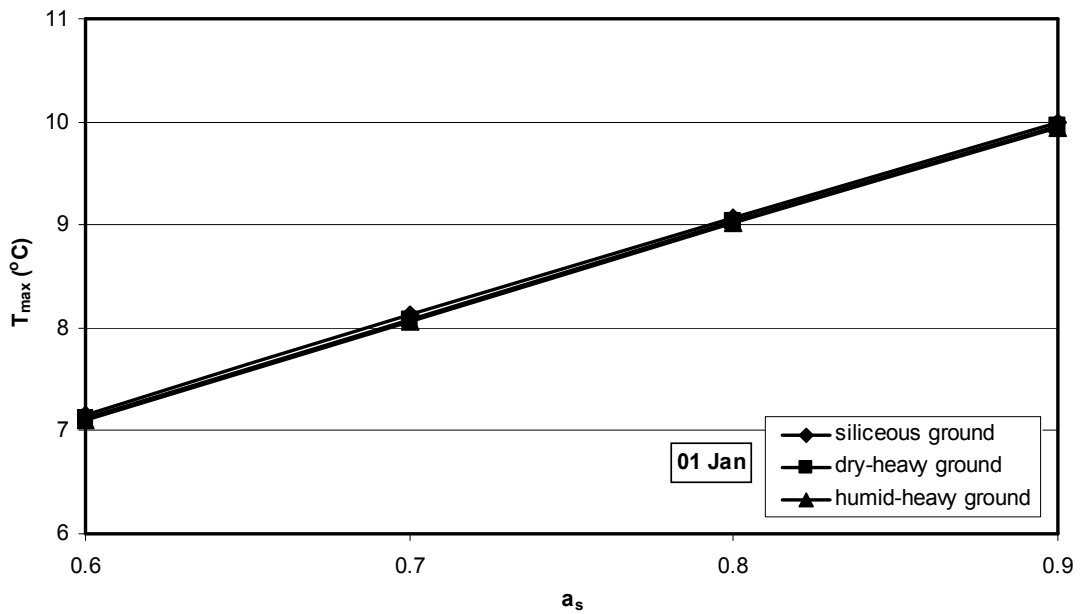


Figure 4.136. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

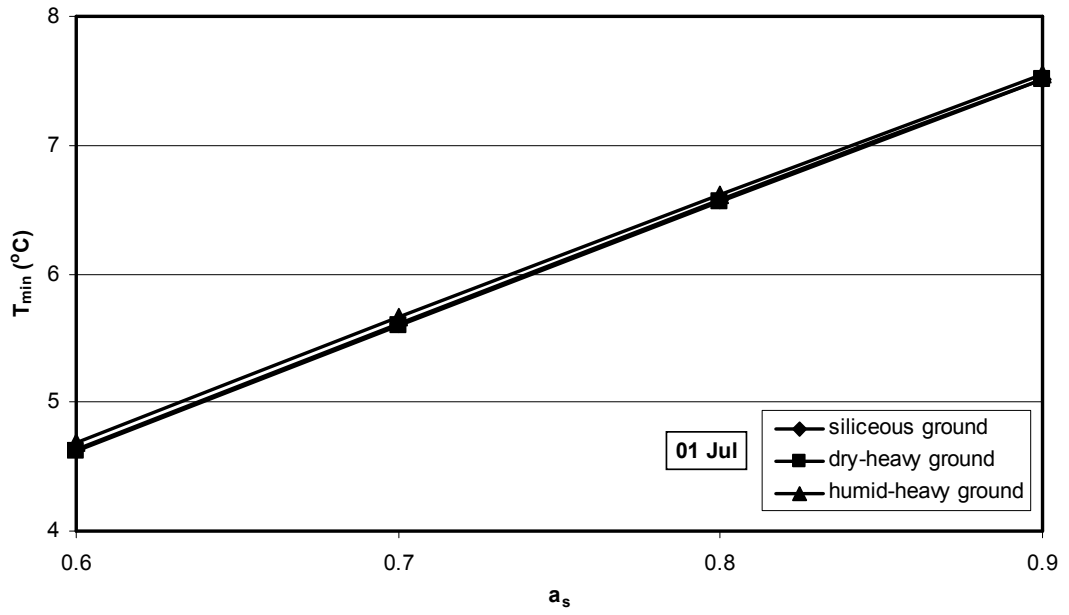


Figure 4.137. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

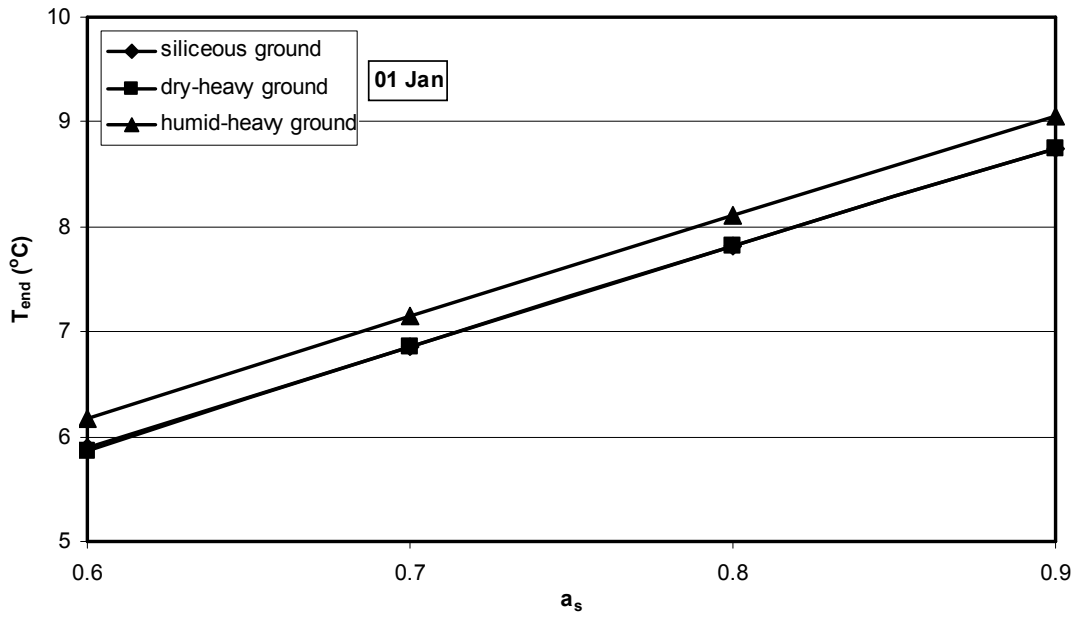


Figure 4.138. Variation of end temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

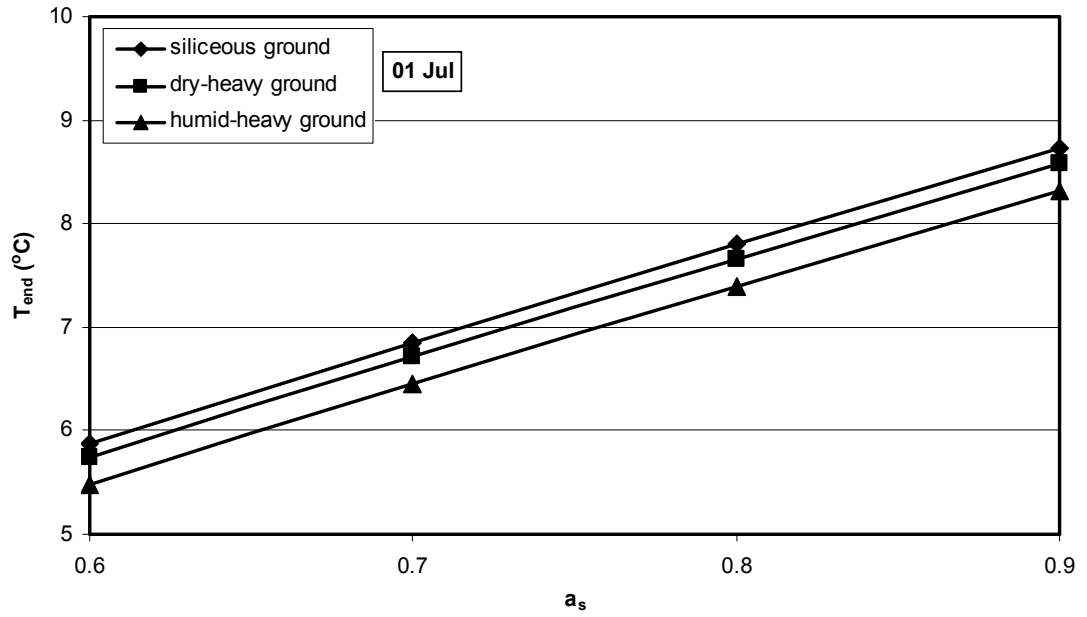


Figure 4.139. Variation of end temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

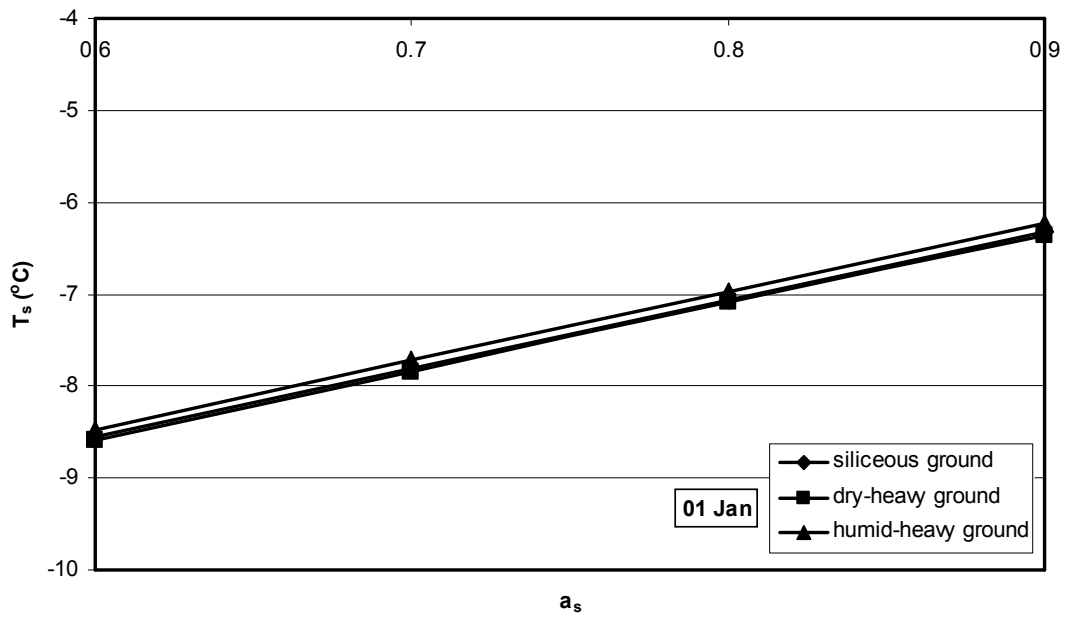


Figure 4.140. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

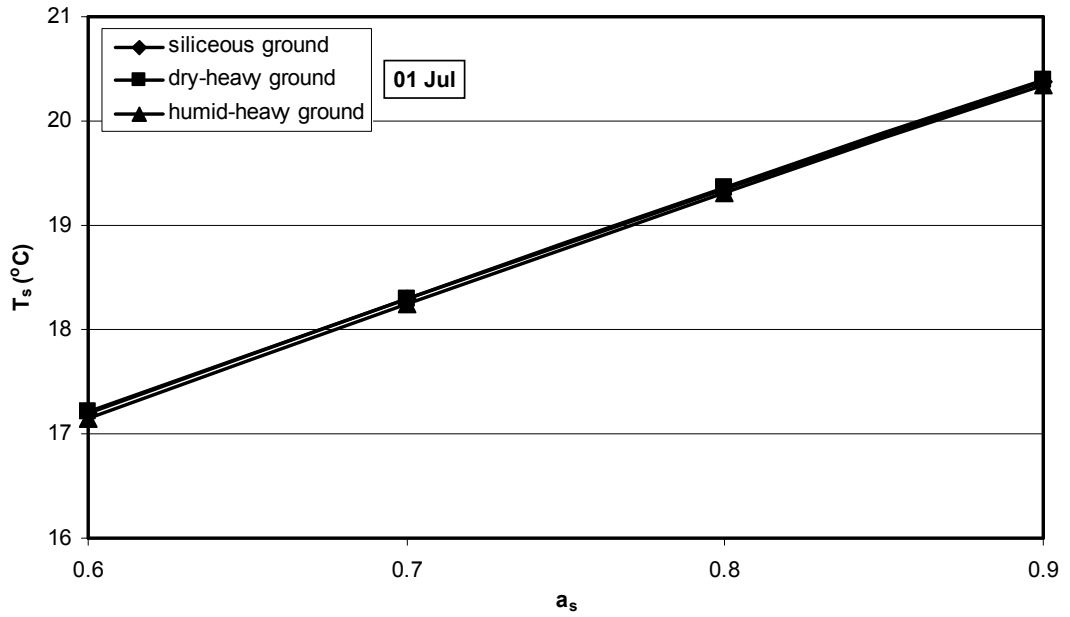


Figure 4.141. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Figures 4.142 and 4.143 show the variations of the depth of maximum and minimum temperatures with ground surface absorption coefficient for January 01 and July 01 for Kars.

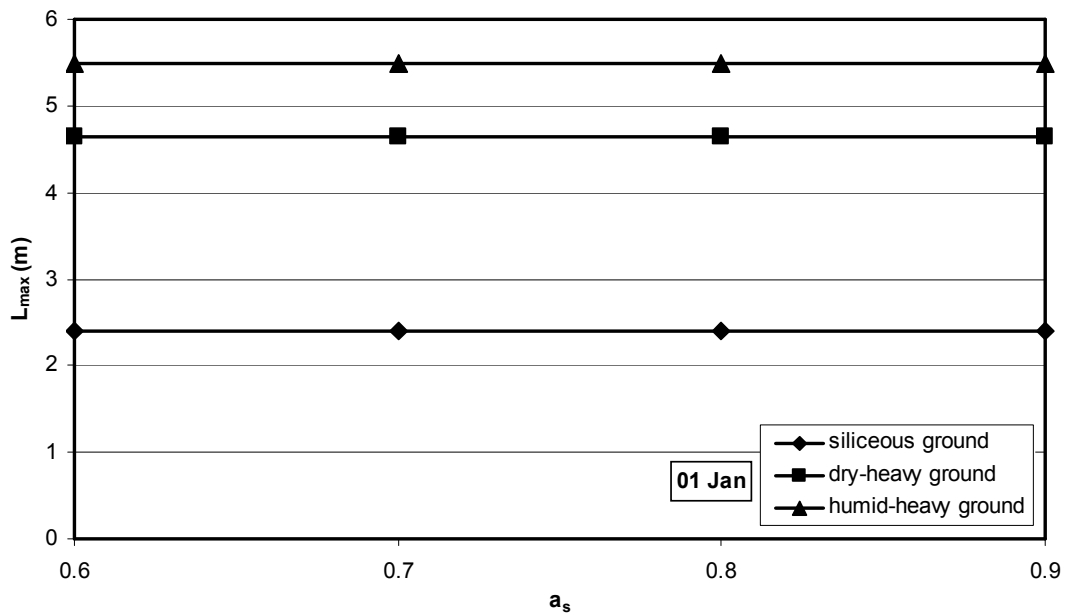


Figure 4.142. Variation of the depth of maximum temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

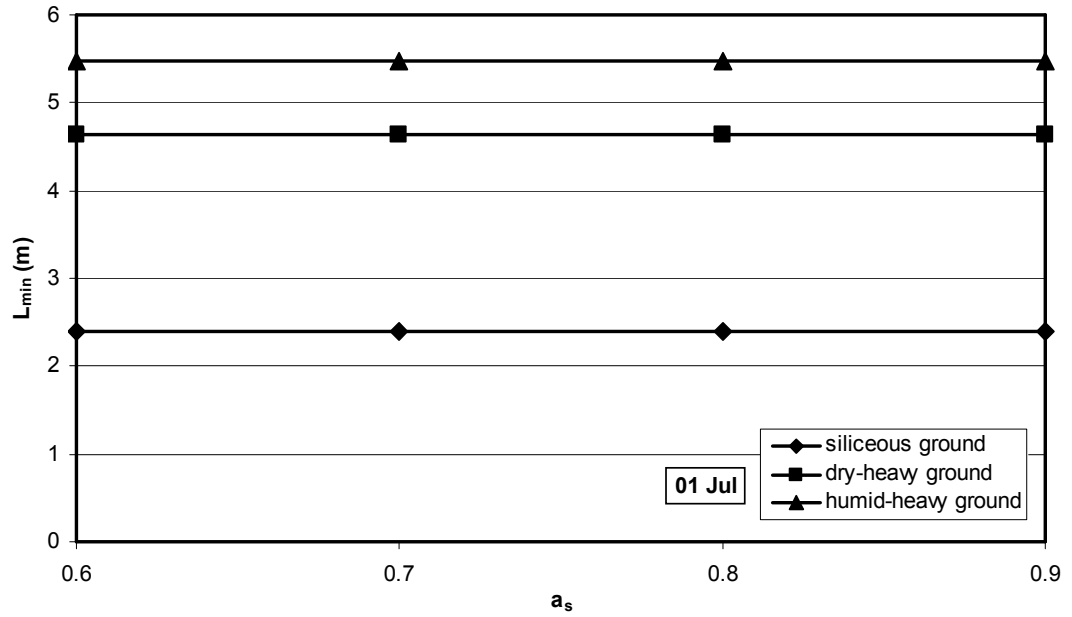


Figure 4.143. Variation of the depth of minimum temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for various ground layer types and ground surface absorption coefficients for Kars are illustrated in figures 4.144, 4.145, 4.146 and 4.147.

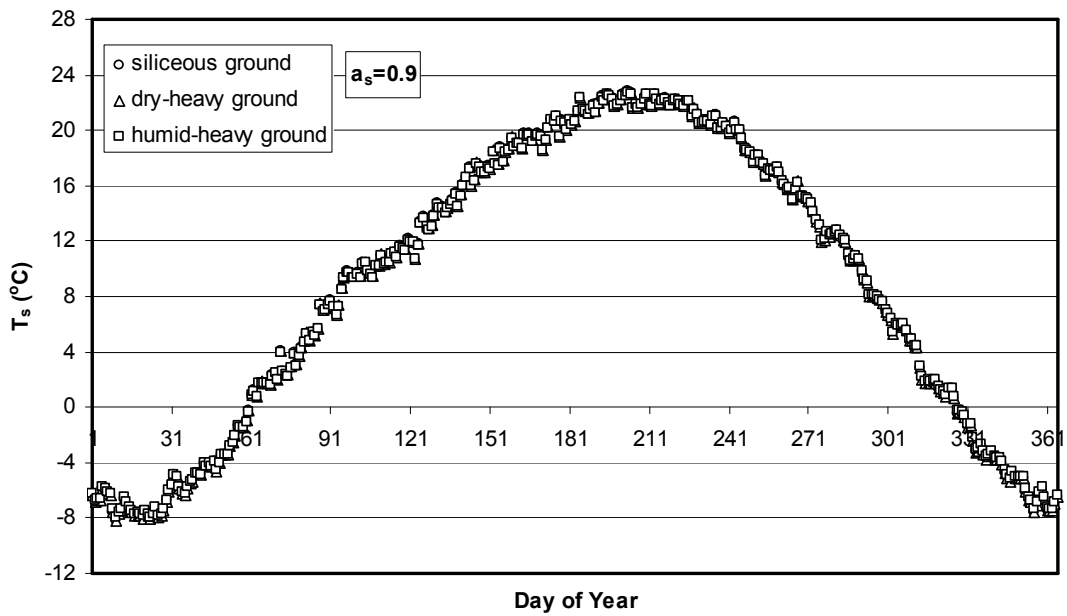


Figure 4.144. Yearly variation of ground surface temperatures for various ground types for Kars, ($f=0.45$, $a_s=0.9$, $L1=0.005$ m, $L2=10$ m)

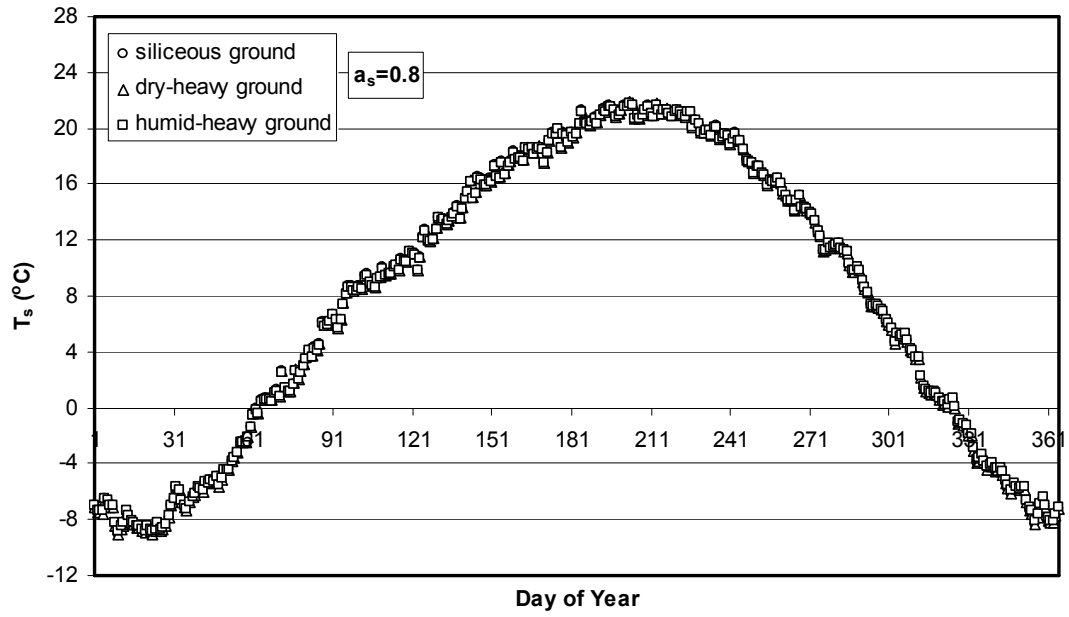


Figure 4.145. Yearly variation of ground surface temperatures for various ground types for Kars, ($f=0.45$, $a_s=0.8$, $L1=0.005$ m, $L2=10$ m)

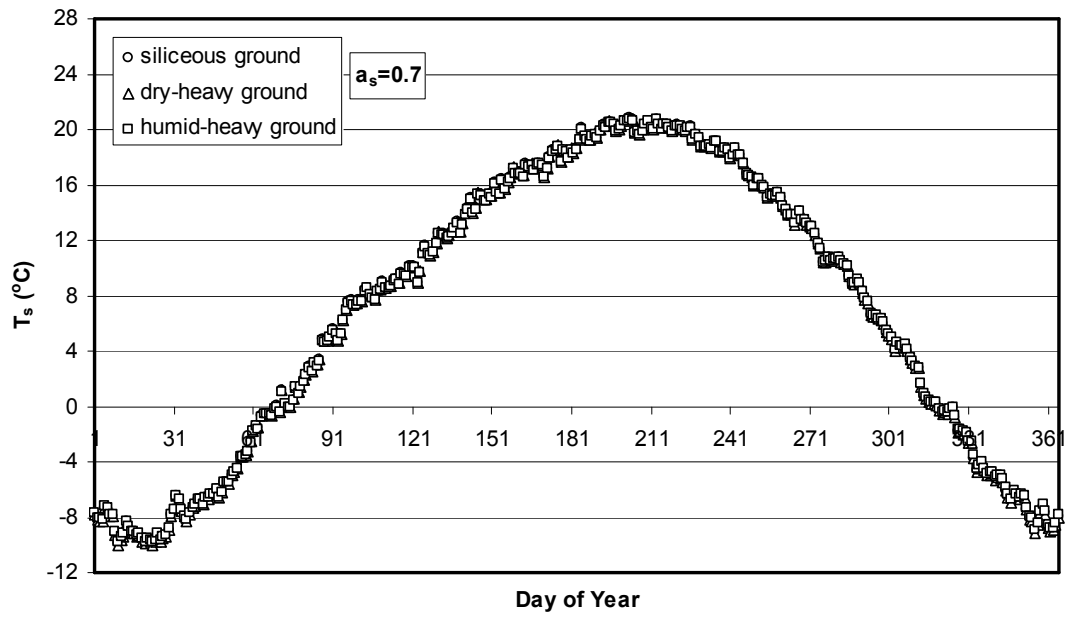


Figure 4.146. Yearly variation of ground surface temperatures for various ground types for Kars, ($f=0.45$, $a_s=0.7$, $L1=0.005$ m, $L2=10$ m)

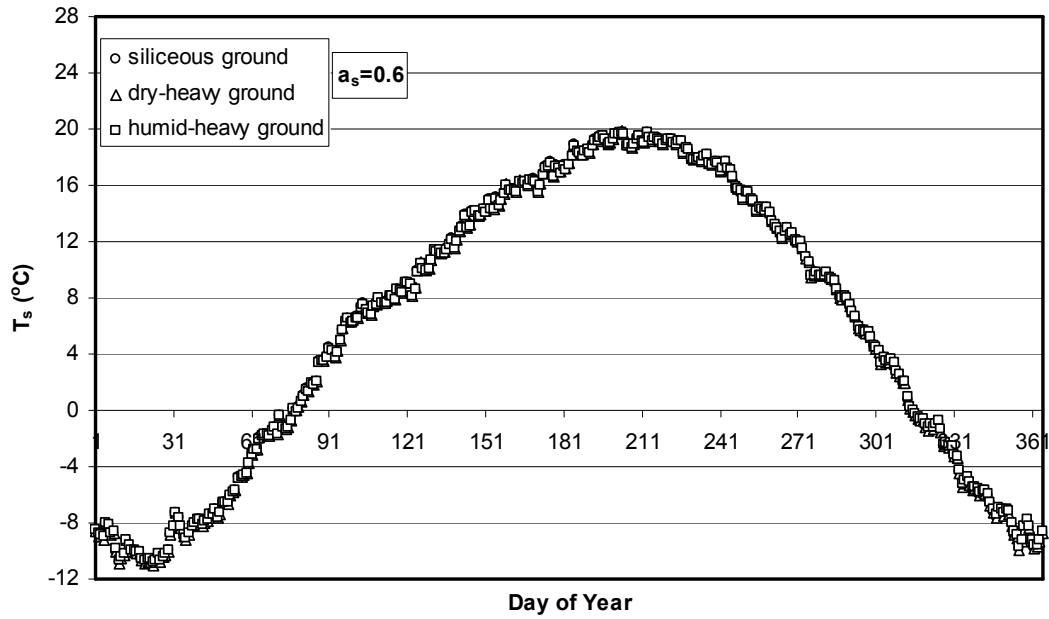


Figure 4.147. Yearly variation of ground surface temperatures for various ground types for Kars, ($f=0.45$, $a_s=0.6$, $L1=0.005$ m, $L2=10$ m)

Figure 4.148 demonstrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous ground layer for Kars.

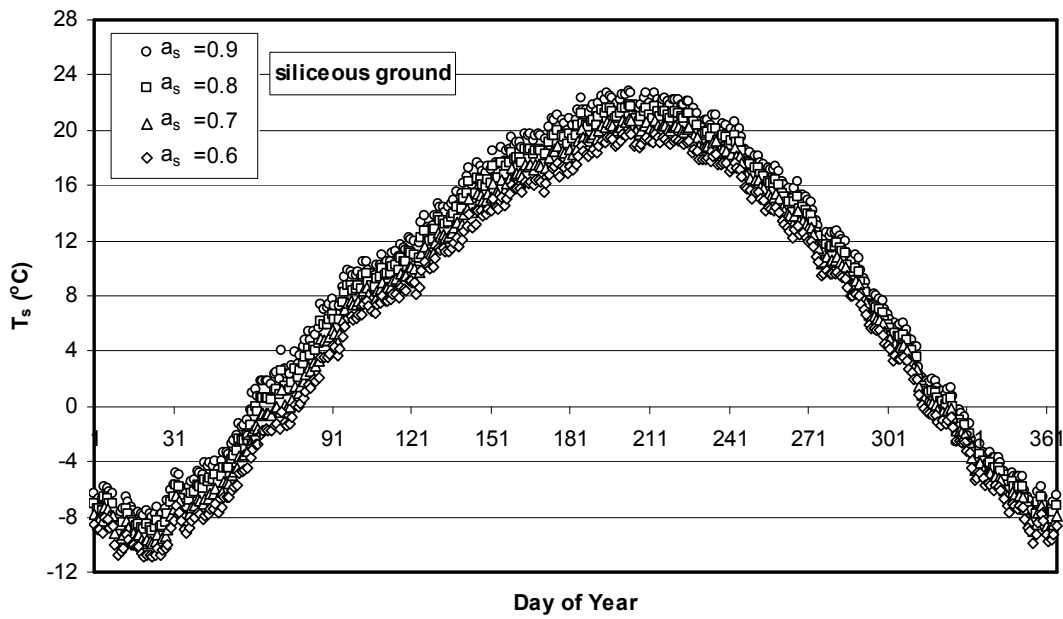


Figure 4.148. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous ground layer for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

Yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy ground layer for Kars is shown in figure 4.149.

Figure 4.150 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy ground layer for Kars.

It is clearly seen from these figures that the value of ground surface absorption coefficient affects the ground surface temperatures.

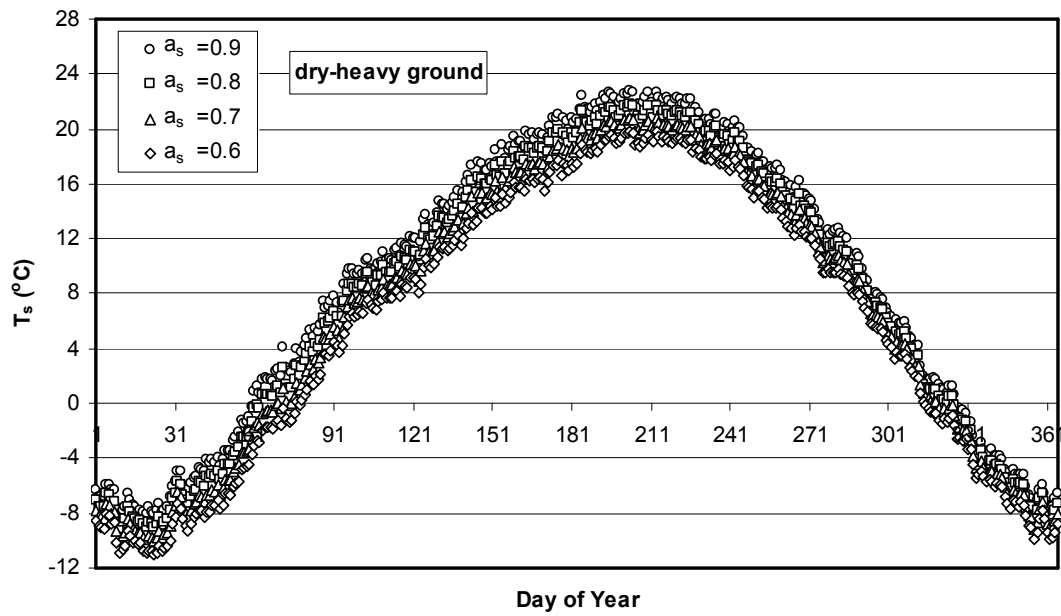


Figure 4.149. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy ground layer for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

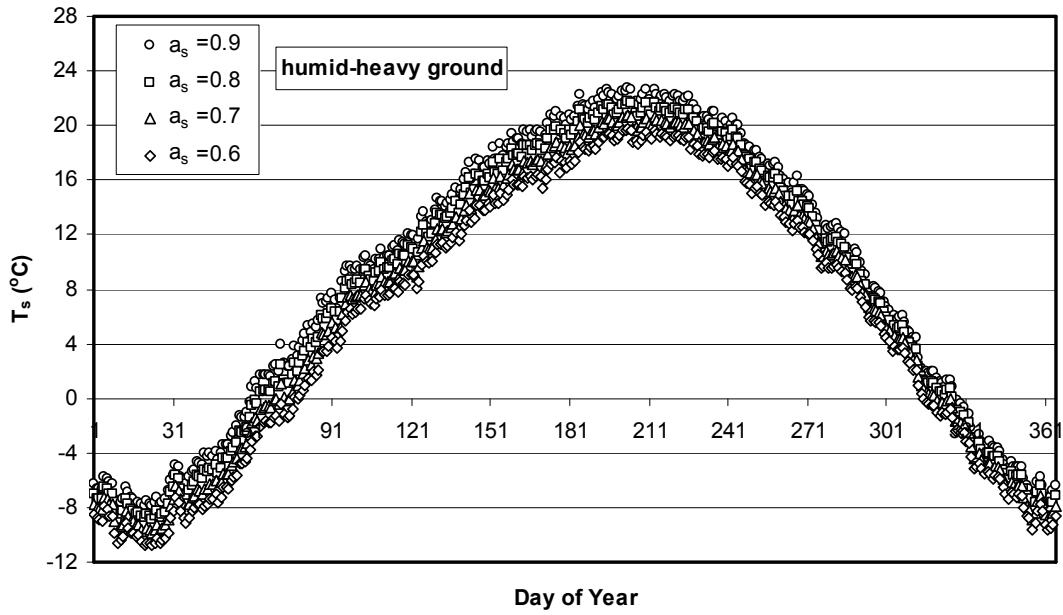


Figure 4.150. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy ground layer for Kars, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

4.4.4.2. Thickness of Upper Layer is 50 cm

Ground surface, maximum, minimum and end temperatures are shown in tables 4.29, 4.30 and 4.31 for January 01 and July 01 for Kars when 50 cm thick humid-light upper layer and different physical properties of lower layers are used.

Table 4.29. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid-Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., (°C)	9.97	9.05	8.10	7.13	7.53	6.58	5.62	4.64
	(Max.)	(Max.)	(Max.)	(Max.)	(Min.)	(Min.)	(Min.)	(Min.)
The depth, (m)	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
End temp., T_{end} (°C)	8.74	7.80	6.86	5.88	8.73	7.79	6.84	5.87
Surface temp., T_s (°C)	-6.32	-7.06	-7.81	-8.56	20.38	19.35	18.29	17.20

Table 4.30. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	9.95 (Max.)	9.02 (Max.)	8.07 (Max.)	7.10 (Max.)	7.52 (Min.)	6.57 (Min.)	5.61 (Min.)	4.63 (Min.)
The depth, (m)	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
End temp., T_{end} ($^{\circ}\text{C}$)	8.72	7.78	6.83	5.84	8.62	7.69	6.74	5.76
Surface temp., T_s ($^{\circ}\text{C}$)	-6.35	-7.09	-7.84	-8.59	20.39	19.36	18.30	17.21

Table 4.31. Surface, maximum, minimum and end temperatures for January 01 and July 01 for Kars (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
Ground temp., ($^{\circ}\text{C}$)	9.90 (Max.)	8.98 (Max.)	8.03 (Max.)	7.07 (Max.)	7.58 (Min.)	6.63 (Min.)	5.67 (Min.)	4.69 (Min.)
The depth, (m)	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
End temp., T_{end} ($^{\circ}\text{C}$)	8.94	8.00	7.05	6.07	8.41	7.48	6.54	5.57
Surface temp., T_s ($^{\circ}\text{C}$)	-6.24	-6.98	-7.73	-8.48	20.35	19.32	18.26	17.17

The variation of maximum and minimum ground temperatures with ground surface absorption coefficient for January 01 and July 01 are demonstrated in figures 4.151 and 4.152 for Kars. The effect of 50 cm thick upper layer ground on maximum and minimum temperatures compared with Adana, Ankara and İstanbul values can be neglected.

Variation of ground end temperatures at $L=10$ m with ground surface absorption coefficient are illustrated in figures 4.153 and 4.154 for January 01 and July 01 for Kars. The effect of physical properties of upper layer ground on end temperatures compared with Adana, Ankara and İstanbul values can be neglected.

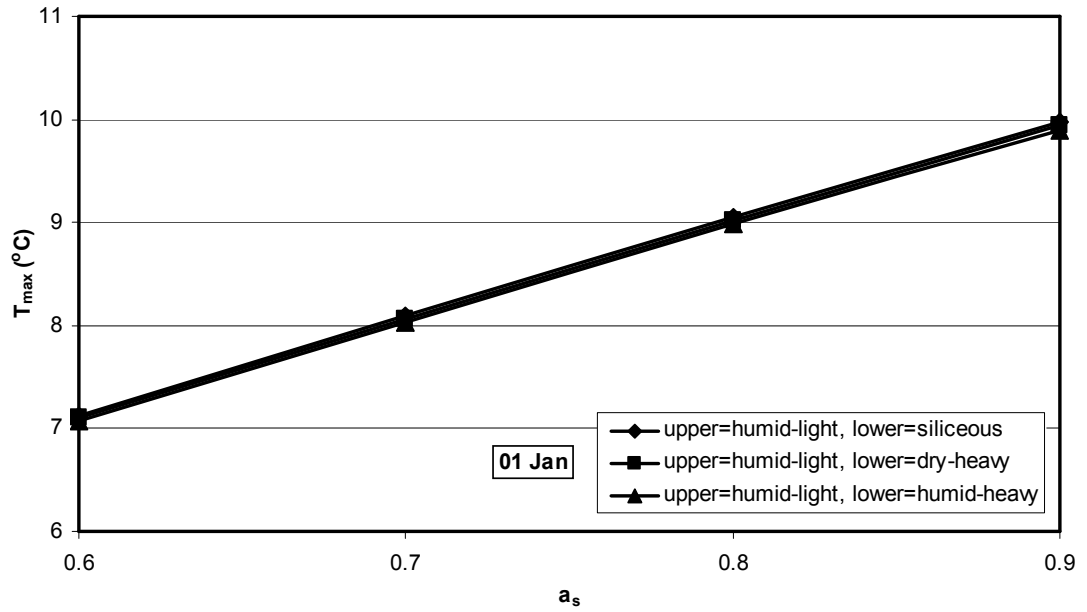


Figure 4.151. Variation of maximum ground temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

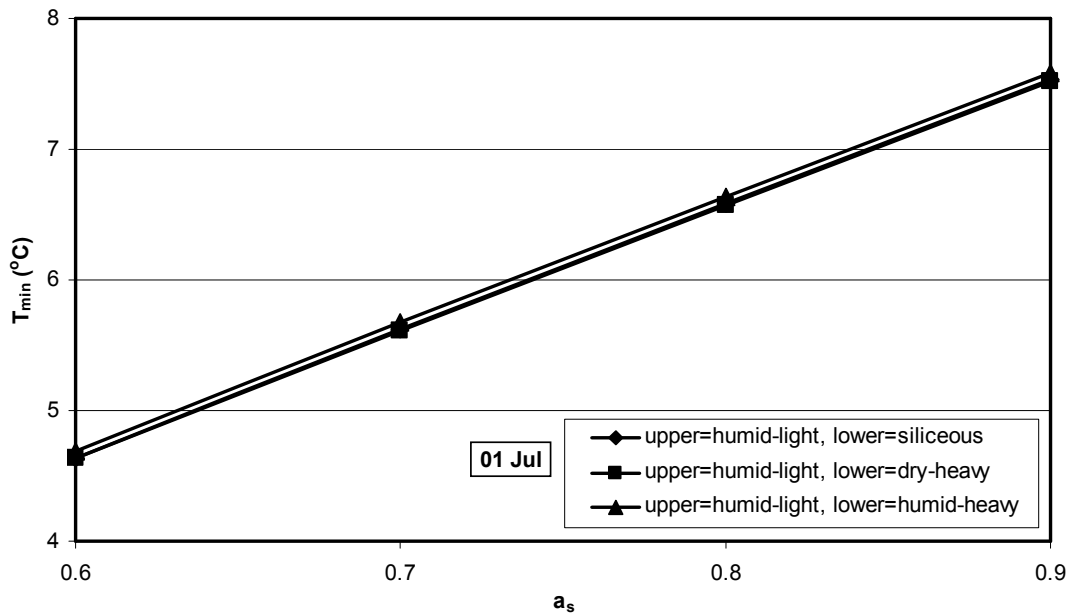


Figure 4.152. Variation of minimum ground temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

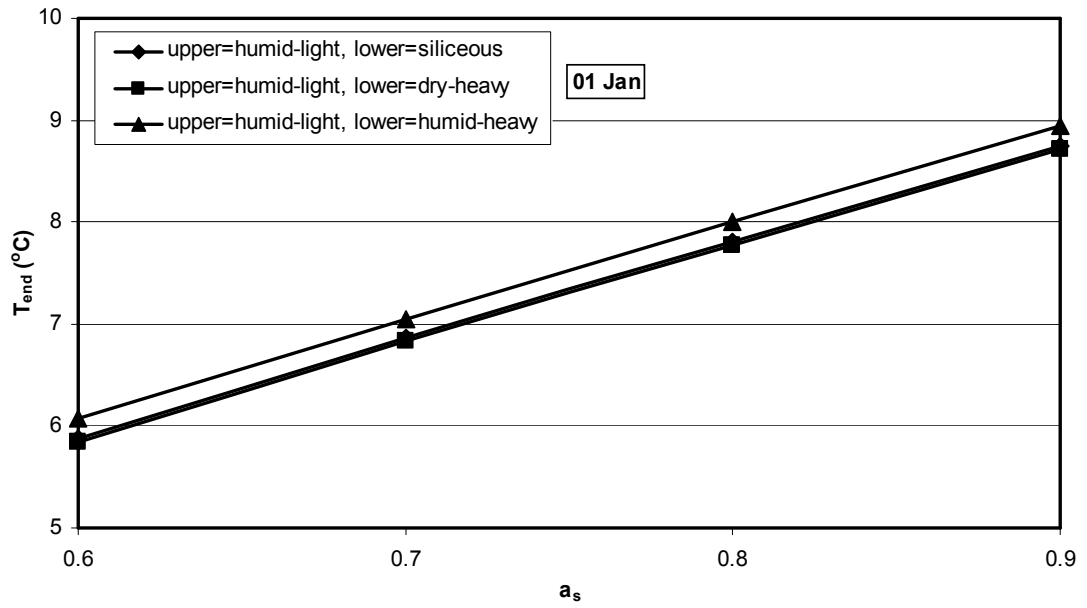


Figure 4.153. Variation of end temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

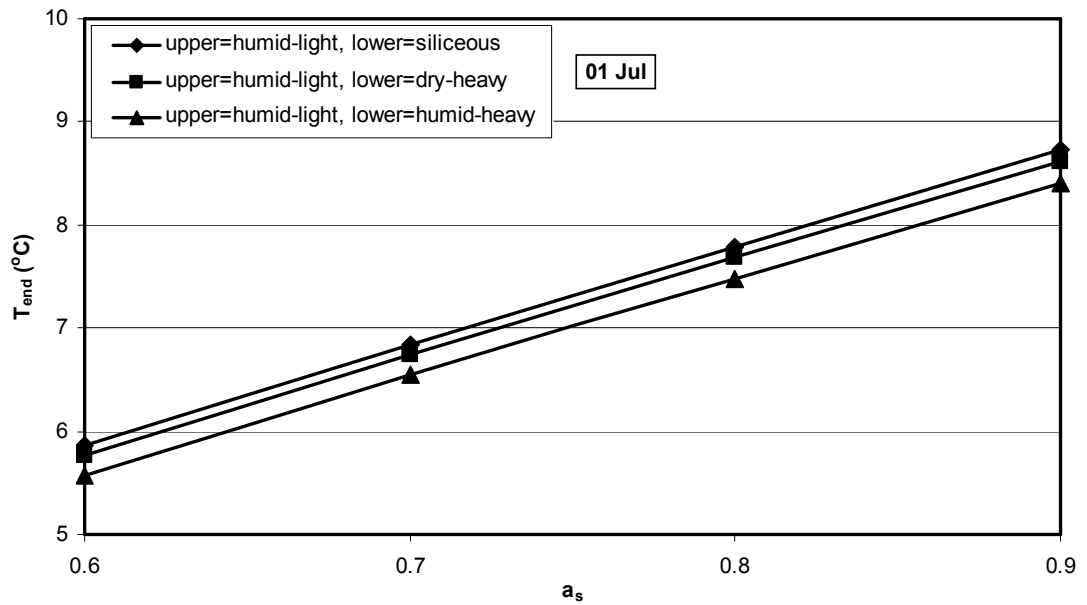


Figure 4.154. Variation of end temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figures 4.155 and 4.156 show the variation of ground surface temperature with ground surface absorption coefficient for various ground types for January 01 and July 01 for Kars. It is shown from these figures that upper layer does not affect the ground surface temperatures.

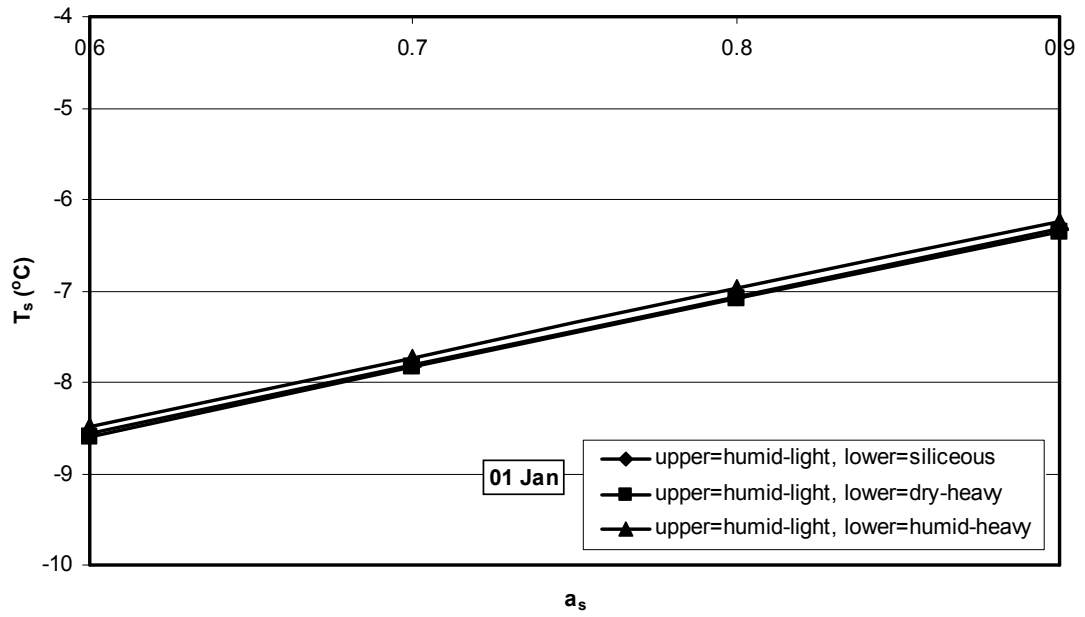


Figure 4.155. Variation of ground surface temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

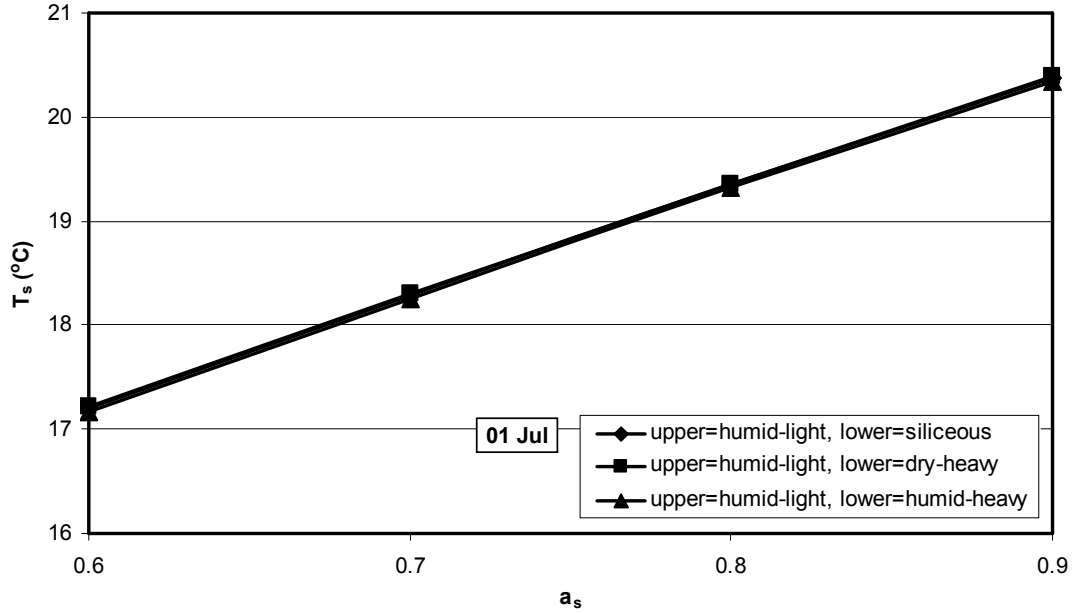


Figure 4.156. Variation of ground surface temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

Figures 4.157 and 4.158 demonstrate the variation of depth of maximum and minimum temperatures with ground surface absorption coefficient for January 01 and July 01 for Kars. When 50 cm thick of humid-light upper layer ground is located on the siliceous lower layer ground; the depths of maximum and minimum temperatures increase but remain constant when humid-heavy and dry-heavy lower layers used compared to 10 m thick ground layer.

In figures 4.159, 4.160, 4.161 and 4.162, yearly variation of ground surface temperatures for various ground types and ground surface absorption coefficients are shown for Kars.

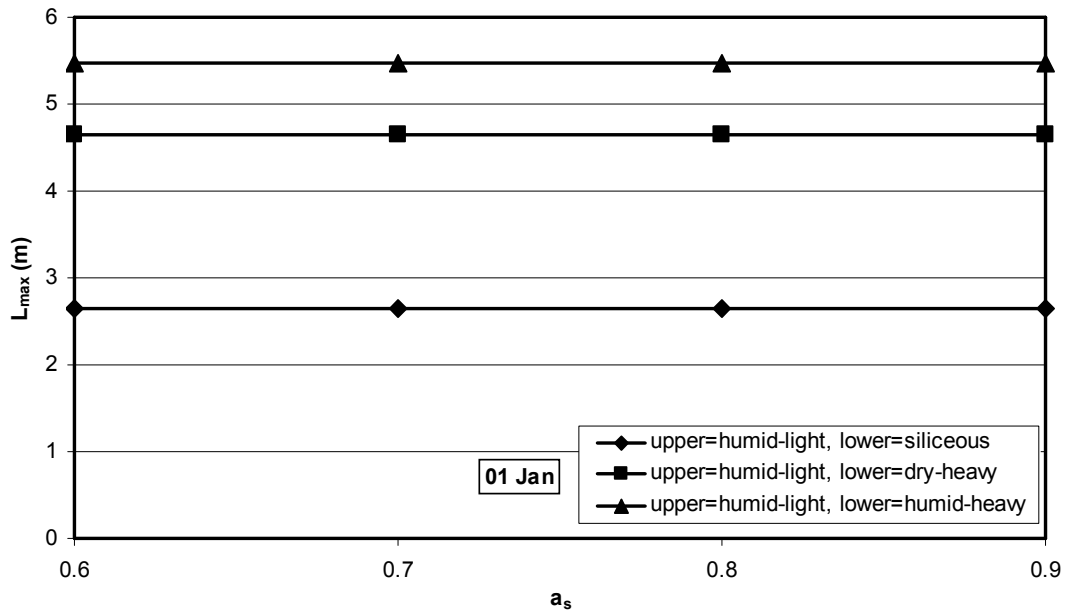


Figure 4.157. Variation of depth of maximum temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

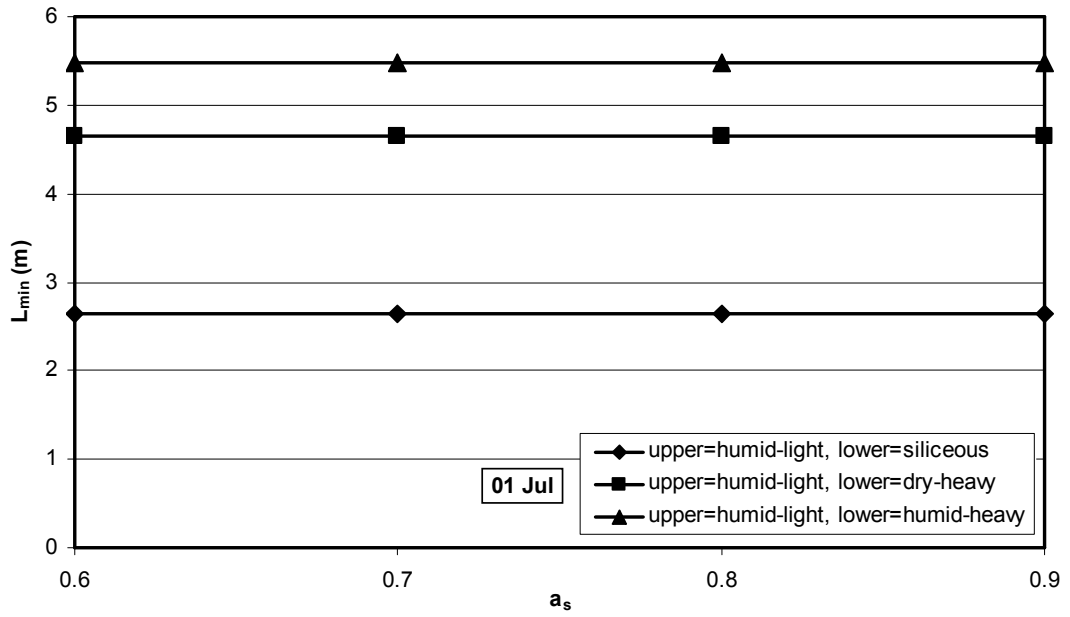


Figure 4.158. Variation of depth of minimum temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

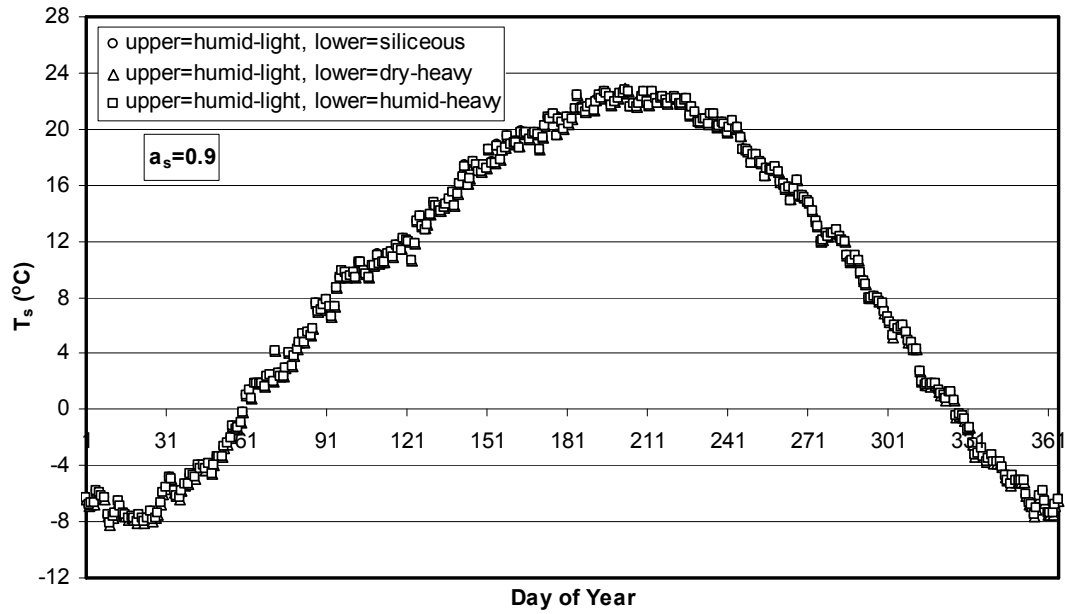


Figure 4.159. Yearly variation of ground surface temperatures for various lower layer ground types for Kars, ($f=0.45$, $a_s=0.9$, $L1=0.5$ m, $L2=10$ m)

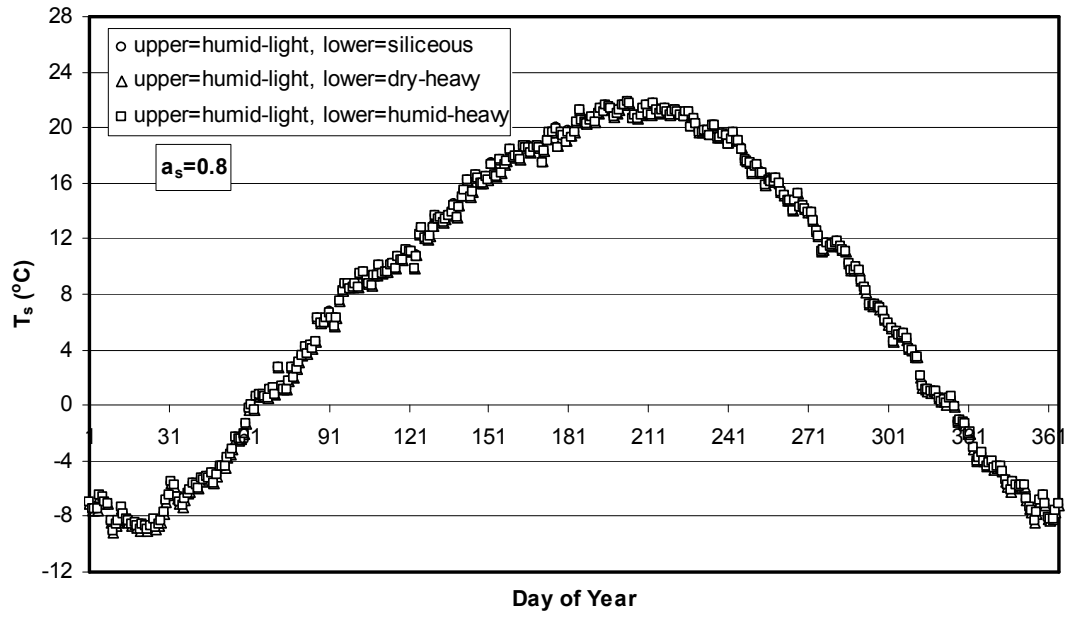


Figure 4.160. Yearly variation of ground surface temperatures for various lower layer ground types for Kars, ($f=0.45$, $a_s=0.8$, $L1=0.5$ m, $L2=10$ m)

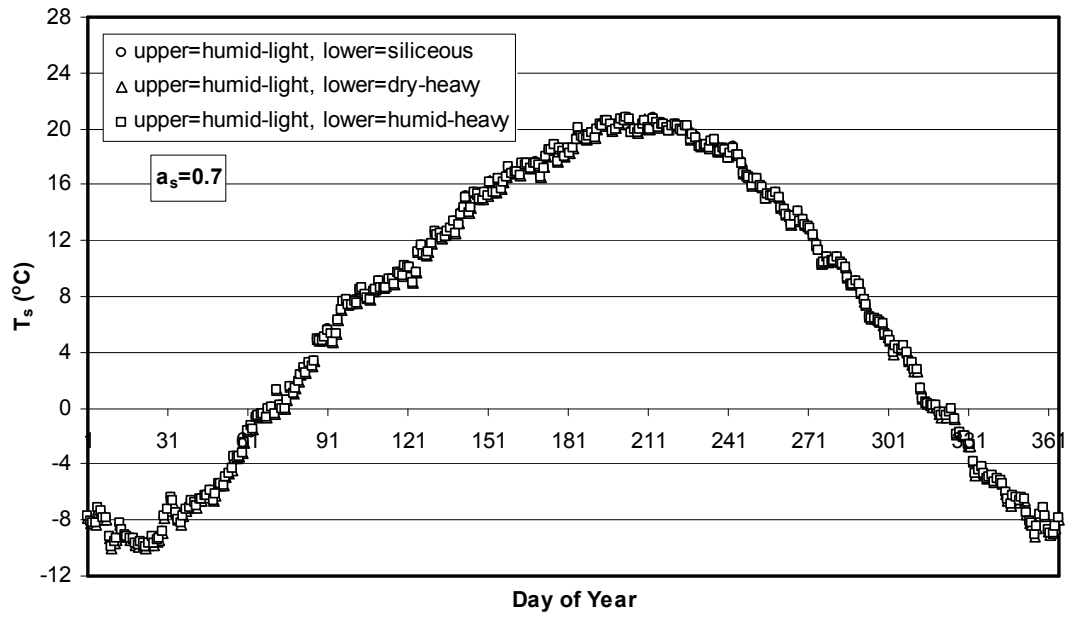


Figure 4.161. Yearly variation of ground surface temperatures for various lower layer ground types for Kars, ($f=0.45$, $a_s=0.7$, $L1=0.5$ m, $L2=10$ m)

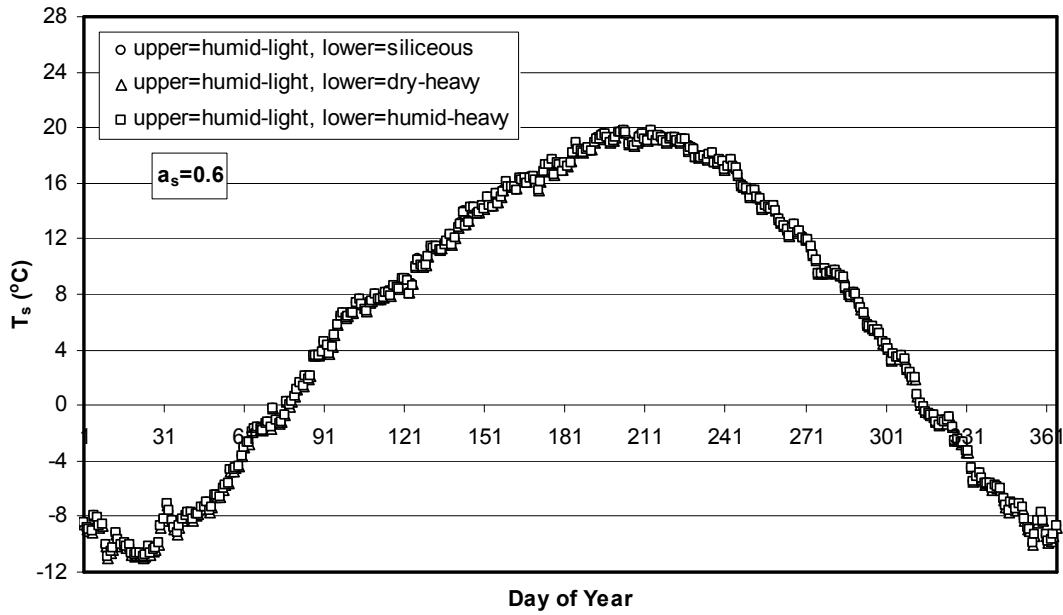


Figure 4.162. Yearly variation of ground surface temperatures for various lower layer ground types for Kars, ($f=0.45$, $a_s=0.6$, $L1=0.5$ m, $L2=10$ m)

Figure 4.163 illustrates yearly variation of ground surface temperatures for different ground surface absorption coefficients and siliceous lower layer ground for Kars.

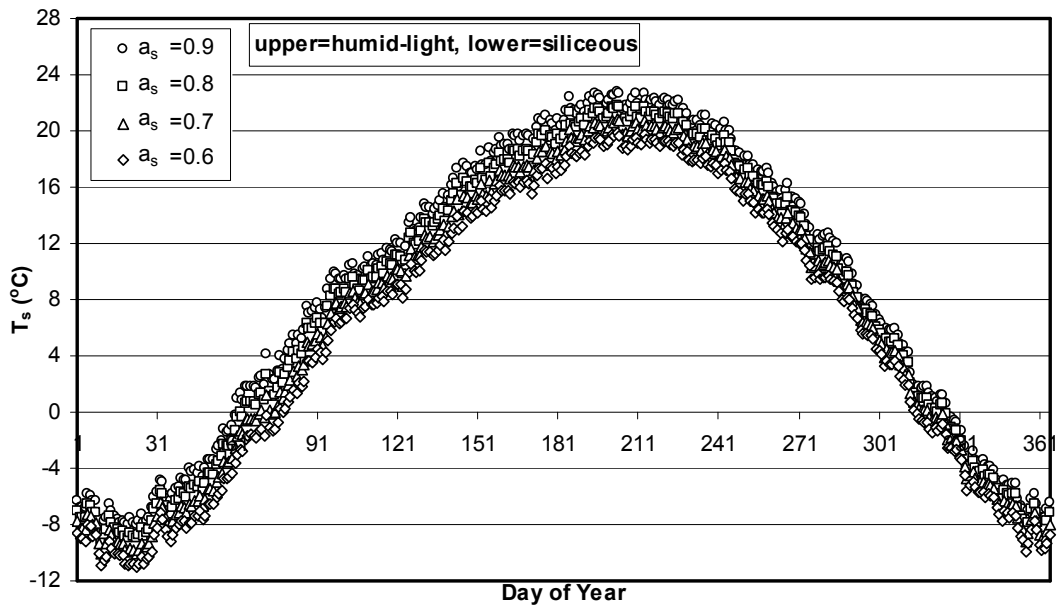


Figure 4.163. Yearly variation of ground surface temperatures for different surface absorption coefficients and siliceous lower layer ground for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

In figure 4.164, yearly variation of ground surface temperatures for different ground surface absorption coefficients and dry-heavy lower layer ground is demonstrated for Kars.

Figure 4.165 shows yearly variation of ground surface temperatures for different ground surface absorption coefficients and humid-heavy lower layer ground for Kars.

It is seen from these figures that the value of ground surface absorption coefficient affects the ground surface temperatures.

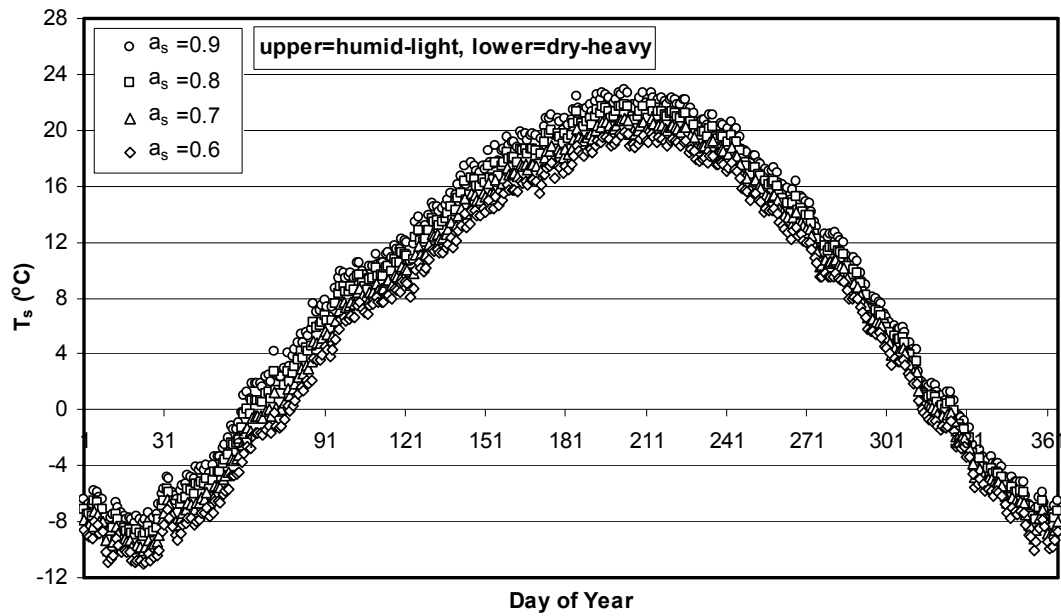


Figure 4.164. Yearly variation of ground surface temperatures for different surface absorption coefficients and dry-heavy lower layer ground for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

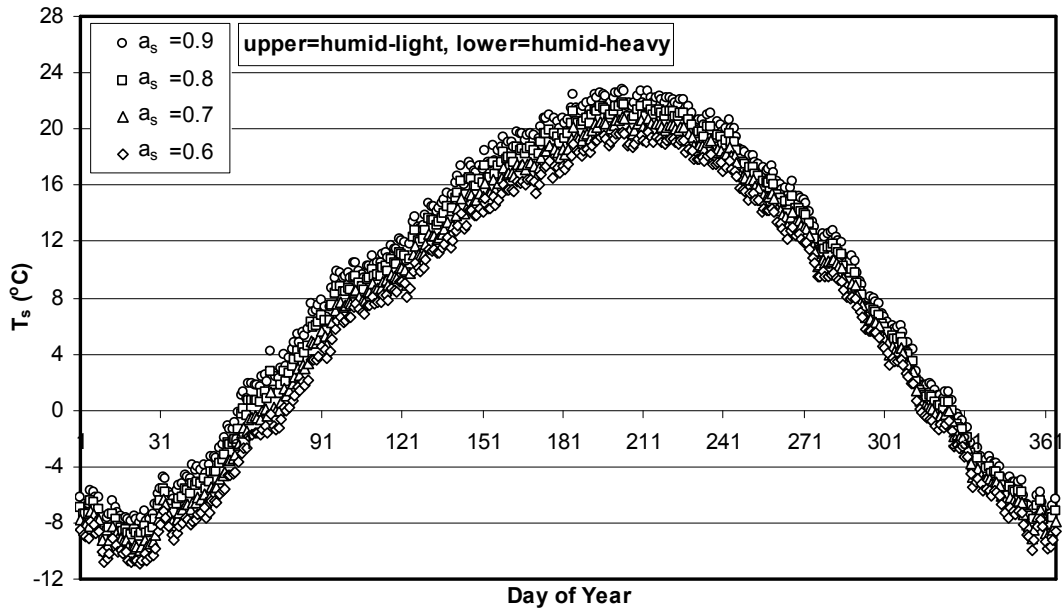


Figure 4.165. Yearly variation of ground surface temperatures for different surface absorption coefficients and humid-heavy lower layer ground for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.5. Difference between End and Mean Ambient Temperatures for Adana, Ankara, İstanbul and Kars Provinces

The mean values of 20 years daily mean ambient temperatures for Adana, 23 years daily mean ambient temperatures for İstanbul, 24 years daily mean ambient temperatures for Ankara and 23 years daily mean ambient temperatures for Kars (T_{mean}) were determined. The differences between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and T_{mean} are given in tables and compared with diagrams.

4.5.1. Results for Adana

4.5.1.1. Thickness of Upper Layer is 5 mm

The mean value of 20 years daily mean ambient temperatures for Adana were calculated as 19.17 °C.

Tables 4.32, 4.33 and 4.34 show the differences between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 20 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Adana for different physical properties of ground layers.

Table 4.32. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	22.38	21.45	20.31	19.13	22.38	21.44	20.30	19.12
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.21	2.28	1.14	-0.04	3.21	2.27	1.13	-0.05

Table 4.33. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	22.50	21.44	20.29	19.11	22.37	21.32	20.18	19.00
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.33	2.27	1.12	-0.06	3.20	2.15	1.01	-0.17

Table 4.34. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	22.76	21.68	20.54	19.34	22.16	21.09	19.97	18.80
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.59	2.51	1.37	0.17	2.99	1.92	0.80	-0.37

Variation of the difference between ground end temperatures (T_{end}) calculated at $L=10$ m ground depth and the mean value of 20 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Adana are demonstrated in figures 4.166 and 4.167. It is understood from these figures that the difference between ground end temperature and mean ambient temperature can be accepted as zero for 0.6 value of ground surface absorption coefficient but this temperature difference can be accepted about 3.4 °C for $a_s=0.9$.

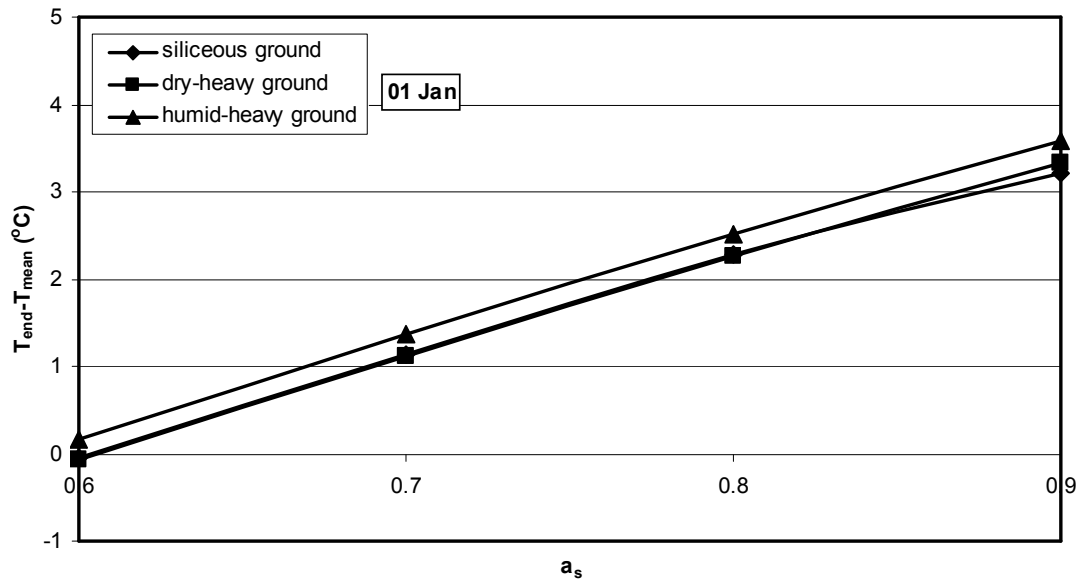


Figure 4.166. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

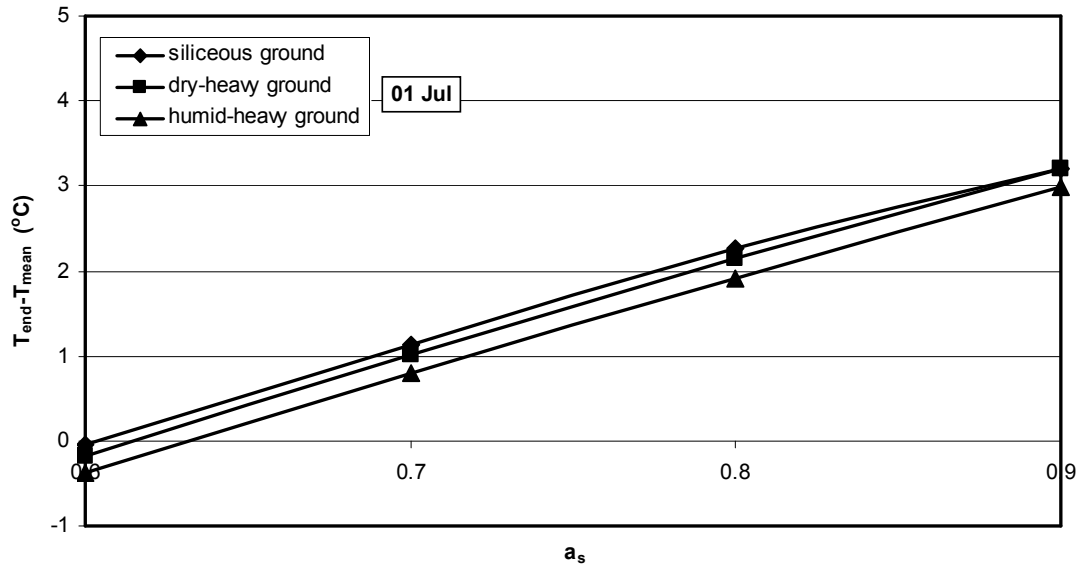


Figure 4.167. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

4.5.1.2. Thickness of Upper Layer is 50 cm

In tables 4.35, 4.36 and 4.37, the temperature difference between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 20 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Adana are illustrated by using 50 cm thick upper layer and different lower layers.

Table 4.35. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid- Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
T_{end} ,(°C)	22.37	21.45	20.31	19.12	22.37	21.44	20.30	19.11
$T_{end}-T_{mean}$,(°C)	3.20	2.28	1.14	-0.05	3.20	2.27	1.13	-0.06

Table 4.36. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}C)$	22.47	21.41	20.27	19.09	22.39	21.34	20.20	19.03
$T_{end}-T_{mean},(^{\circ}C)$	3.30	2.24	1.10	-0.08	3.22	2.17	1.03	-0.14

Table 4.37. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Adana (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}C)$	22.66	21.60	20.45	19.26	22.23	21.17	20.03	18.86
$T_{end}-T_{mean},(^{\circ}C)$	3.49	2.43	1.28	0.09	3.06	2.00	0.86	-0.31

Figures 4.168 and 4.169 demonstrate the variations of the difference between ground end temperatures (T_{end}) and the mean value of 20 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Adana. There is no more effect of 50 cm thick of humid-light upper layer on the temperature difference compared to 10 m ground layers.

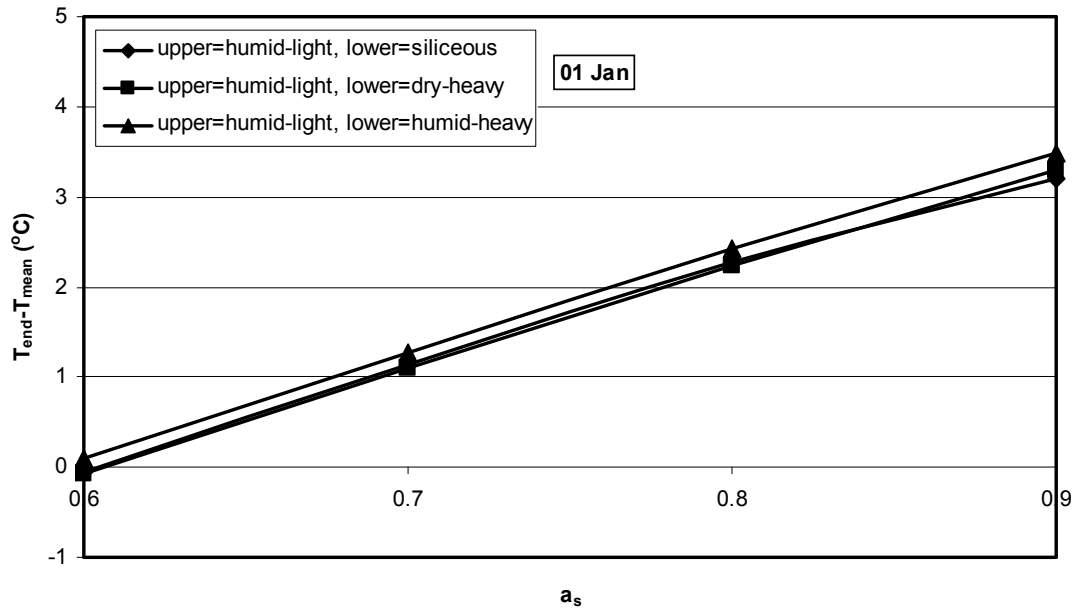


Figure 4.168. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

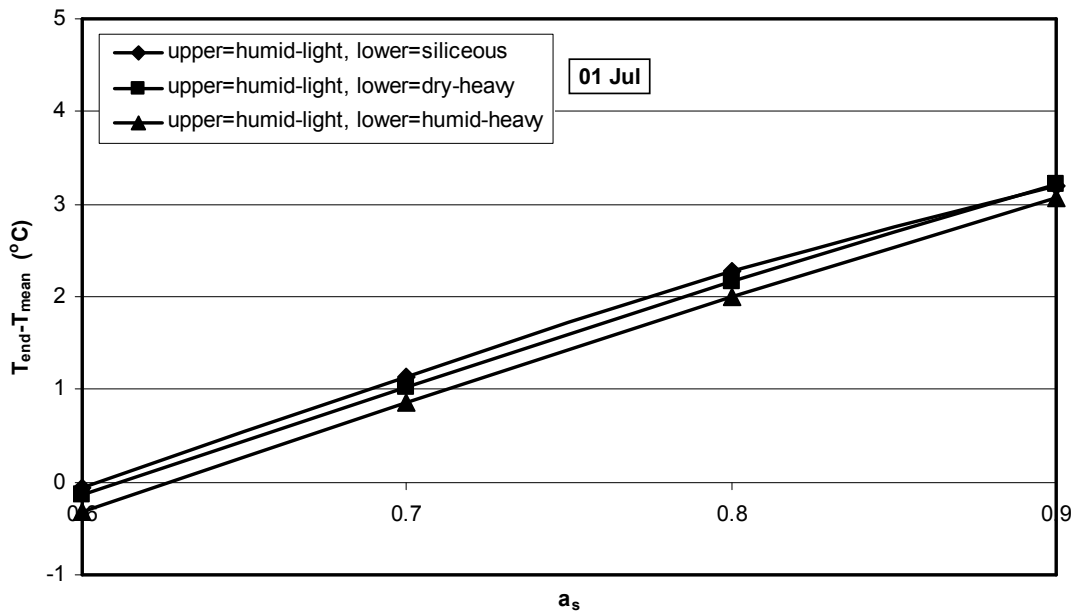


Figure 4.169. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Adana, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.5.2. Results for İstanbul

4.5.2.1. Thickness of Upper Layer is 5 mm

The mean value of 23 years daily mean ambient temperatures for İstanbul were calculated as 14.48 °C.

Tables 4.38, 4.39 and 4.40 illustrate the differences between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 23 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in İstanbul for different physical properties of ground layers.

Table 4.38. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	16.30	15.57	14.82	14.05	16.29	15.56	14.81	14.04
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	1.82	1.09	0.34	-0.43	1.81	1.08	0.33	-0.44

Table 4.39. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	16.28	15.55	14.80	14.03	16.16	15.44	14.71	13.95
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	1.80	1.07	0.32	-0.45	1.68	0.96	0.23	-0.53

Table 4.40. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	16.53	15.78	15.02	14.24	15.94	15.22	14.49	13.74
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.05	1.30	0.54	-0.24	1.46	0.74	0.01	-0.74

In figures 4.170 and 4.171, the variation of the difference between ground end temperatures (T_{end}) calculated at $L=10$ m ground depth and the mean value of 23 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for İstanbul are shown. It is understood from these figures that the difference between the ground end temperature and the mean ambient temperature can be accepted as zero for $a_s=0.65$ but this temperature difference can be accepted about 1.8°C for $a_s=0.9$.

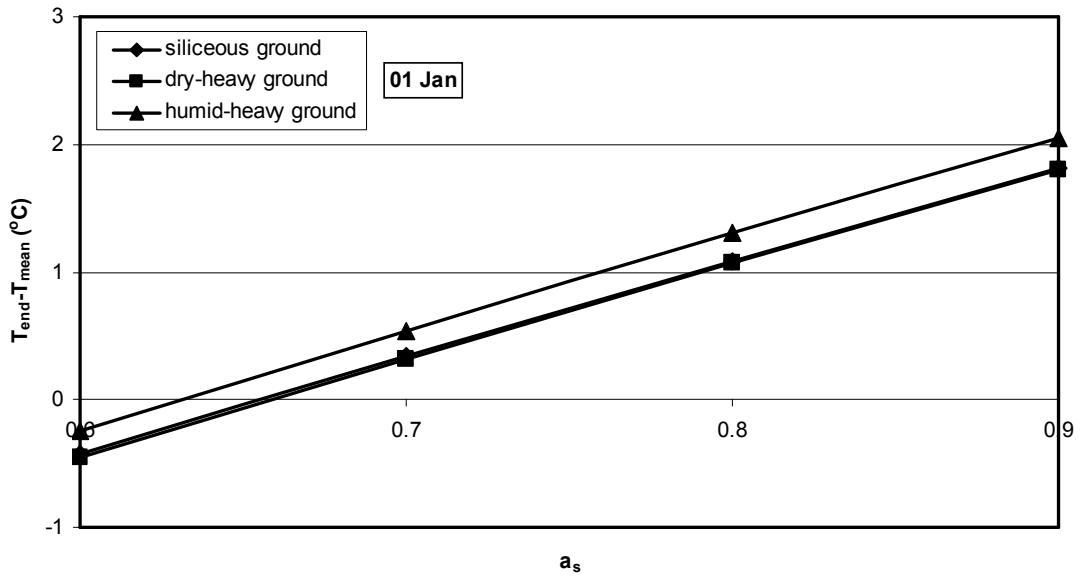


Figure 4.170. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

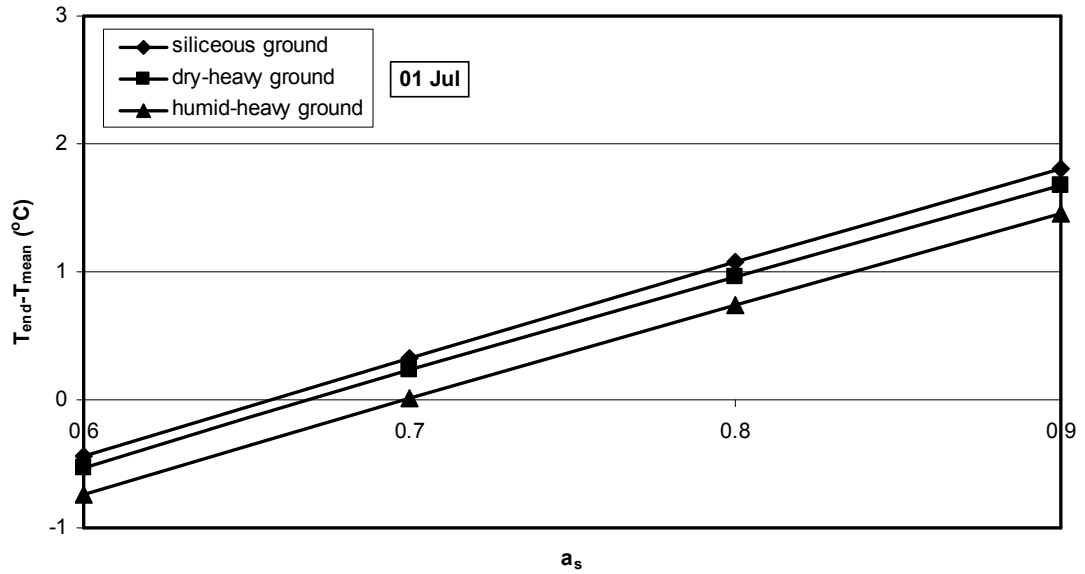


Figure 4.171. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

4.5.2.2. Thickness of Upper Layer is 50 cm

The temperature difference between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 23 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in İstanbul are demonstrated in tables 4.41, 4.42 and 4.43 by using 50 cm thickness of a constant upper layer and different lower layers.

Table 4.41. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid- Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}\text{C})$	16.29	15.56	14.81	14.05	16.28	15.55	14.80	14.04
$T_{end}-T_{mean},(^{\circ}\text{C})$	1.81	1.08	0.33	-0.43	1.80	1.07	0.32	-0.44

Table 4.42. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	16.26	15.53	14.77	14.00	16.19	15.47	14.72	13.97
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	1.78	1.05	0.29	-0.48	1.71	0.99	0.24	-0.51

Table 4.43. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for İstanbul (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	16.44	15.70	14.94	14.16	16.02	15.30	14.56	13.81
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	1.96	1.22	0.46	-0.32	1.54	0.82	0.08	-0.67

In figures 4.172 and 4.173, variation of the difference between ground end temperatures (T_{end}) and the mean value of 23 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for İstanbul are shown. There is no more effect of 50 cm thickness of humid-light upper layer on the temperature difference compared to 10 m thick ground layers.

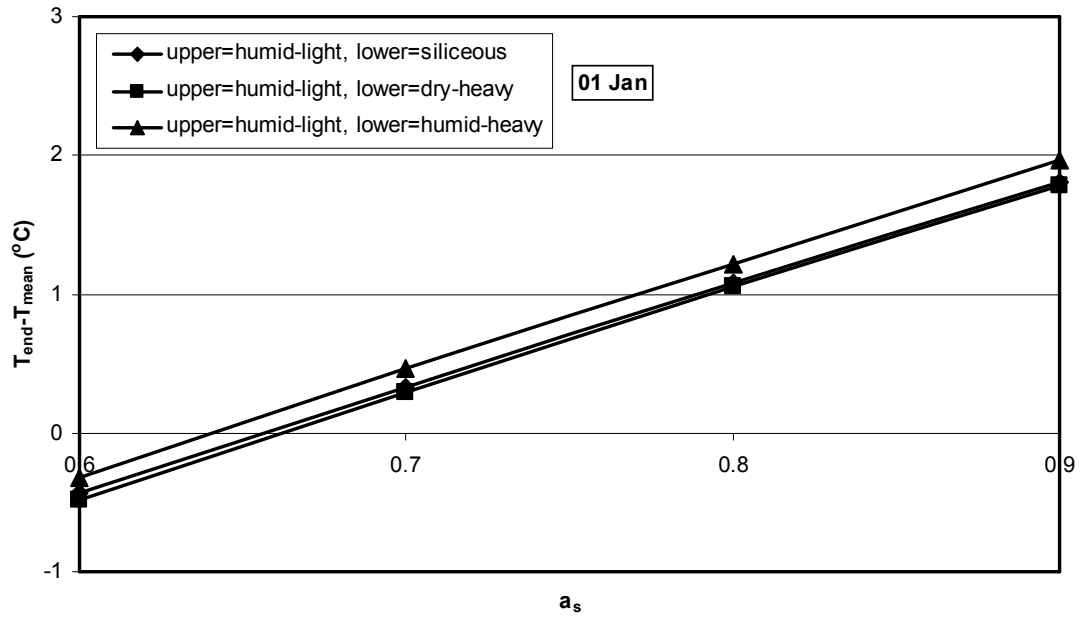


Figure 4.172. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

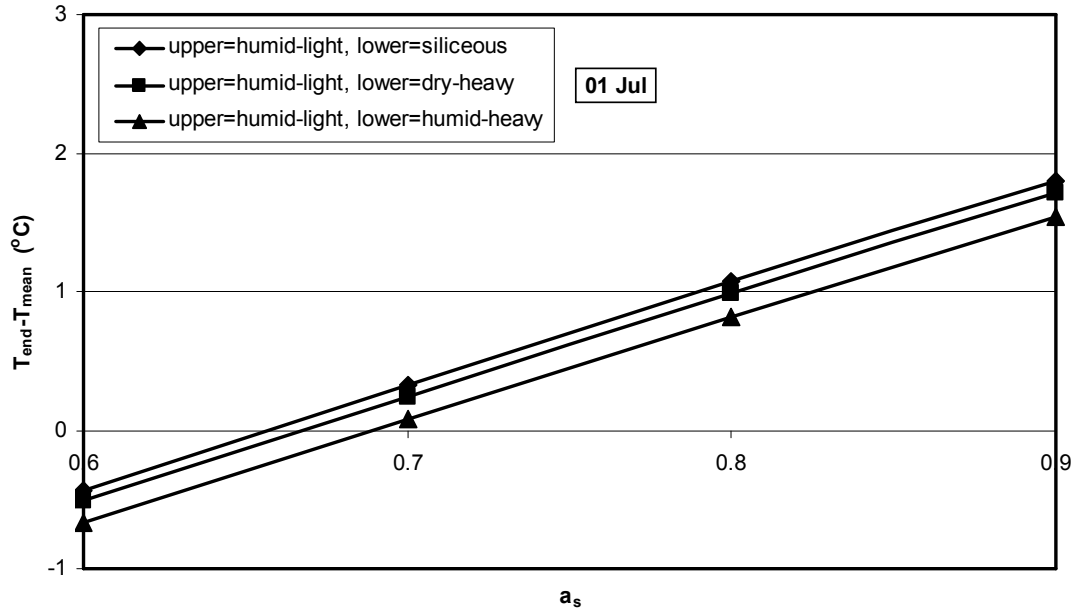


Figure 4.173. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for İstanbul, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.5.3. Results for Ankara

4.5.3.1. Thickness of Upper Layer is 5 mm

The mean value of 24 years daily mean ambient temperatures of Ankara were calculated as 11.99 °C.

Tables 4.44, 4.45 and 4.46 show the differences between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 24 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Ankara for different physical properties of ground layers.

Table 4.44. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	14.46	13.47	12.44	11.39	14.45	13.46	12.43	11.38
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.47	1.48	0.45	-0.60	2.46	1.47	0.44	-0.61

Table 4.45. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	14.48	13.48	12.45	11.40	14.30	13.30	12.29	11.25
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.49	1.49	0.46	-0.59	2.31	1.31	0.30	-0.74

Table 4.46. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	14.76	13.76	12.73	11.65	14.04	13.06	12.05	11.01
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.77	1.77	0.74	-0.34	2.05	1.07	0.06	-0.98

Figures 4.174 and 4.175 demonstrate the variation of the difference between ground end temperatures (T_{end}) calculated at $L=10$ m ground depth and the mean value of 24 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Ankara. It is understood from these figures that the difference between the ground end temperature and the mean ambient temperature can be accepted as zero for $a_s=0.65$ but this temperature difference can be accepted about 2.4 °C for $a_s=0.9$.

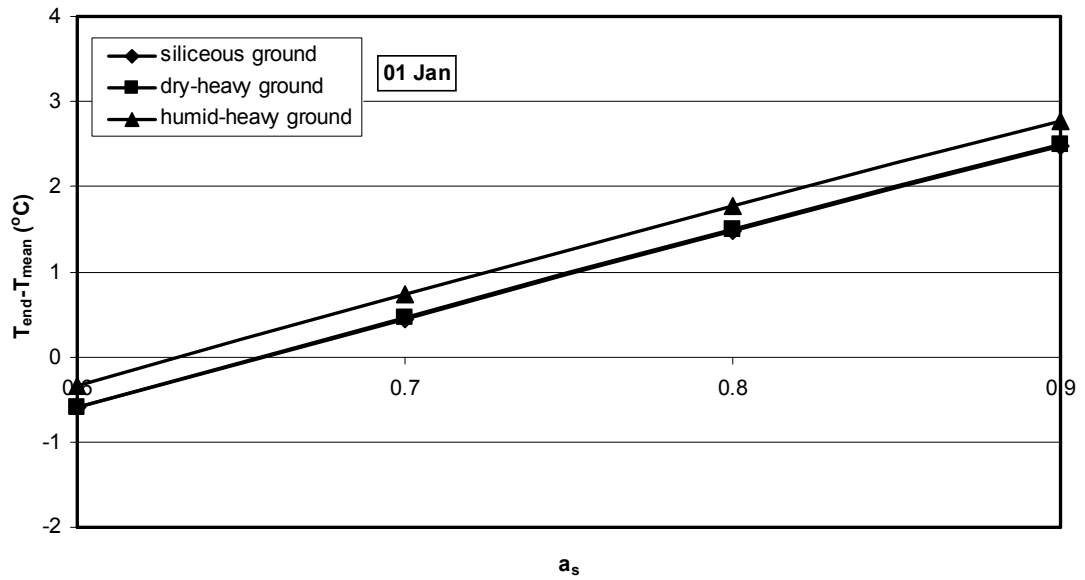


Figure 4.174. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

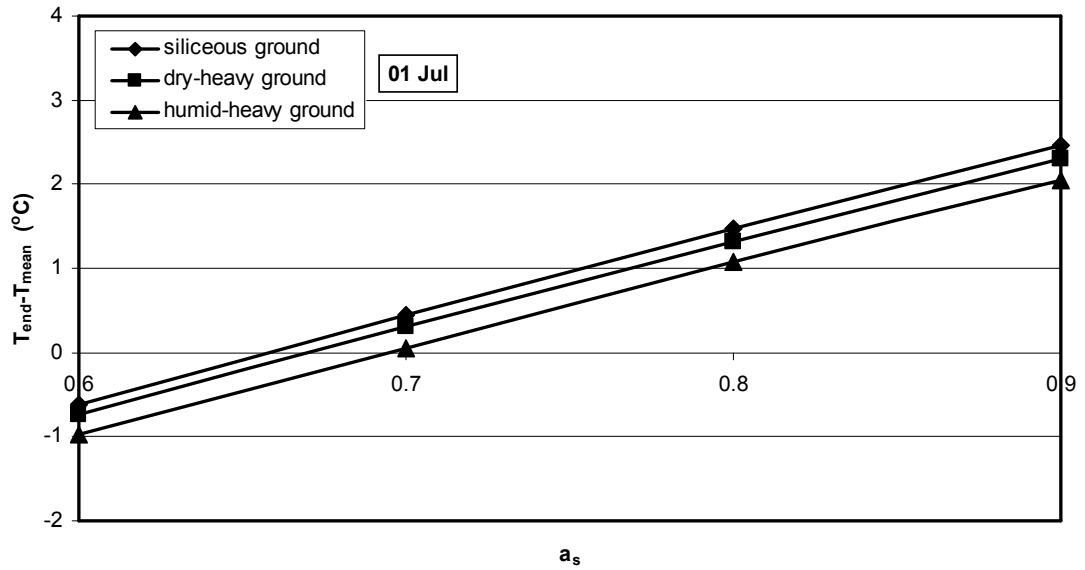


Figure 4.175. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

4.5.3.2. Thickness of Upper Layer is 50 cm

The temperature difference between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 24 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Ankara are illustrated in tables 4.47, 4.48 and 4.49 by using 50 cm thickness of a constant upper layer and various lower layers.

Table 4.47. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid- Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end}, (°C)$	14.46	13.47	12.45	11.39	14.45	13.46	12.43	11.38
$T_{end}-T_{mean}, (°C)$	2.47	1.48	0.46	-0.60	2.46	1.47	0.44	-0.61

Table 4.48. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	14.45	13.45	12.43	11.36	14.32	13.33	12.32	11.27
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.46	1.46	0.44	-0.63	2.33	1.34	0.33	-0.72

Table 4.49. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Ankara (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	14.66	13.66	12.63	11.57	14.13	13.14	12.13	11.09
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	2.67	1.67	0.64	-0.42	2.14	1.15	0.14	-0.90

In figures 4.176 and 4.177, variation of the difference between ground end temperatures (T_{end}) and the mean value of 24 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Ankara were shown. There is no more effect of 50 cm thick of humid-light upper layer on the temperature difference compared to 10 m thick ground layers.

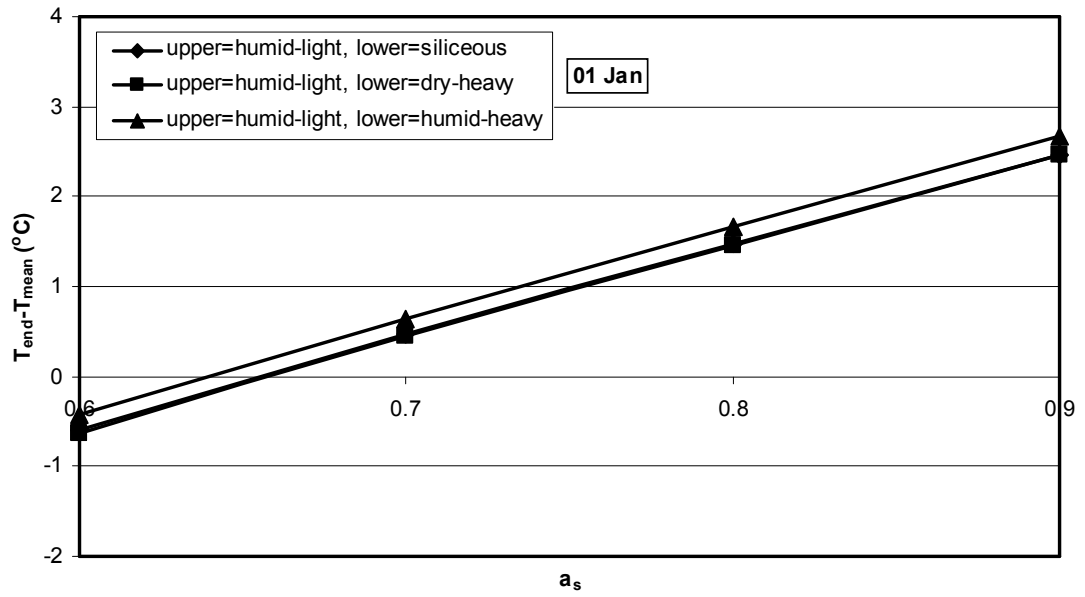


Figure 4.176. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

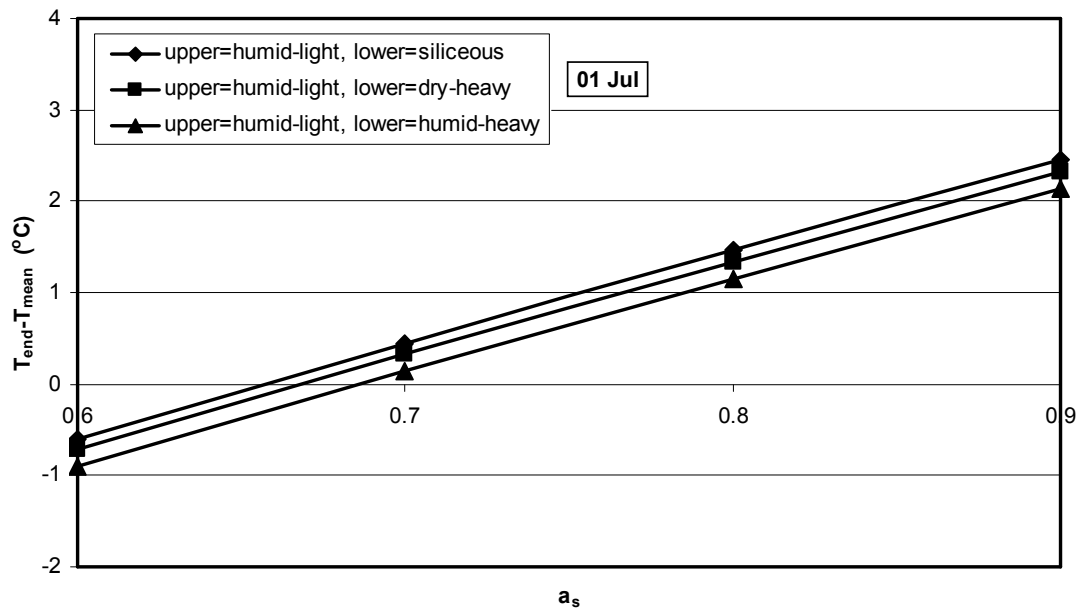


Figure 4.177. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Ankara, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.5.4. Results for Kars

4.5.4.1. Thickness of Upper Layer is 5 mm

The mean value of 23 years daily mean ambient temperatures were calculated as 5.12 °C.

The differences between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 23 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Kars are shown in tables 4.50, 4.51 and 4.52 for different physical properties of ground layers.

Table 4.50. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (siliceous ground layer)

	Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	8.74	7.81	6.86	5.89	8.73	7.80	6.84	5.88
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.62	2.69	1.74	0.77	3.61	2.68	1.72	0.76

Table 4.51. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (dry-heavy ground layer)

	Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	8.74	7.81	6.85	5.87	8.58	7.66	6.71	5.74
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.62	2.69	1.73	0.75	3.46	2.54	1.59	0.62

Table 4.52. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (humid-heavy ground layer)

	Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{\text{end}},(^{\circ}\text{C})$	9.05	8.11	7.15	6.17	8.32	7.39	6.45	5.48
$T_{\text{end}}-T_{\text{mean}},(^{\circ}\text{C})$	3.93	2.99	2.03	1.05	3.20	2.27	1.33	0.36

Variation of the difference between ground end temperatures (T_{end}) calculated at $L=10$ m ground depth and the mean value of 23 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Kars are demonstrated in figures 4.178 and 4.179. It is understood from these figures that the difference between the ground end temperature and the mean ambient temperature can be accepted as 0.8 °C for $a_s=0.6$ but this temperature difference can be accepted about 3.5 °C for $a_s=0.9$.

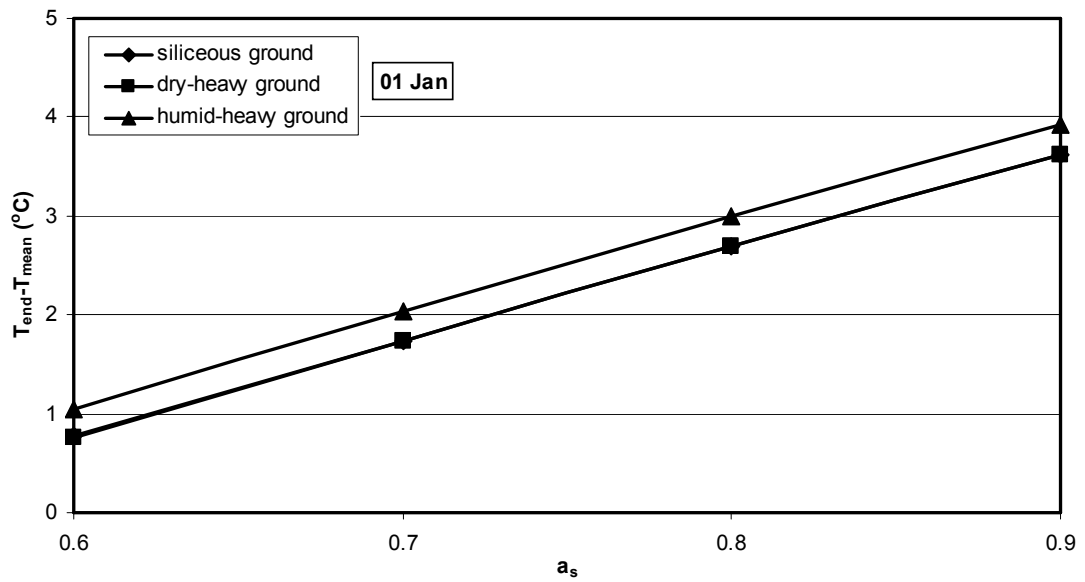


Figure 4.178. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

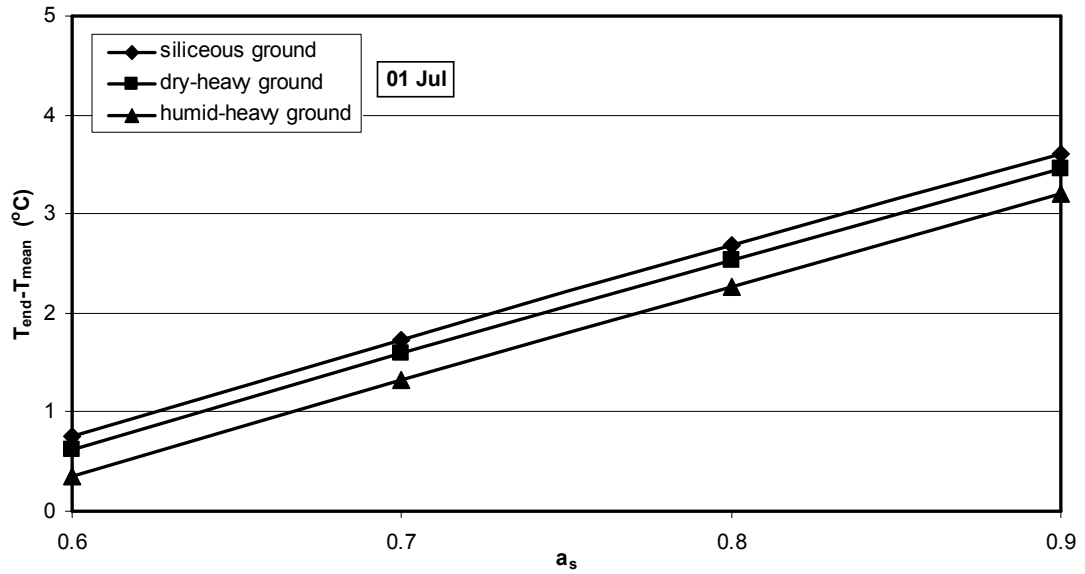


Figure 4.179. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L_1=0.005$ m, $L_2=10$ m)

4.5.4.2. Thickness of Upper Layer is 50 cm

Tables 4.53, 4.54 and 4.55 show the temperature difference between ground end temperatures (T_{end}) calculated at $L=10$ m for various ground surface absorption coefficients and the mean value of 23 years daily mean ambient temperatures (T_{mean}) for January 01 and July 01 in Kars by using 50 cm thick upper layer and various lower layers.

Table 4.53. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (50 cm humid-light upper layer and siliceous lower layer)

	Upper=Humid- Light Ground, Lower= Siliceous Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}\text{C})$	8.74	7.80	6.86	5.88	8.73	7.79	6.84	5.87
$T_{end}-T_{mean},(^{\circ}\text{C})$	3.62	2.68	1.74	0.76	3.61	2.67	1.72	0.75

Table 4.54. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (50 cm humid-light upper layer and dry-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Dry-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}C)$	8.72	7.78	6.83	5.84	8.62	7.69	6.74	5.76
$T_{end}-T_{mean},(^{\circ}C)$	3.60	2.66	1.71	0.72	3.50	2.57	1.62	0.64

Table 4.55. Temperature difference between T_{end} and T_{mean} for January 01 and July 01 for Kars (50 cm humid-light upper layer and humid-heavy lower layer)

	Upper=Humid- Light Ground, Lower= Humid-Heavy Ground							
	January 01				July 01			
	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$	$a_s=0.9$	$a_s=0.8$	$a_s=0.7$	$a_s=0.6$
$T_{end},(^{\circ}C)$	8.94	8.00	7.05	6.07	8.41	7.48	6.54	5.57
$T_{end}-T_{mean},(^{\circ}C)$	3.82	2.88	1.93	0.95	3.29	2.36	1.42	0.45

Figures 4.180 and 4.181 demonstrate the variation of the difference between ground end temperatures (T_{end}) and the mean value of 23 years daily mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for Kars. There is no more effect of 50 cm thick of humid-light upper layer on the temperature difference compared to 10 m ground layers.

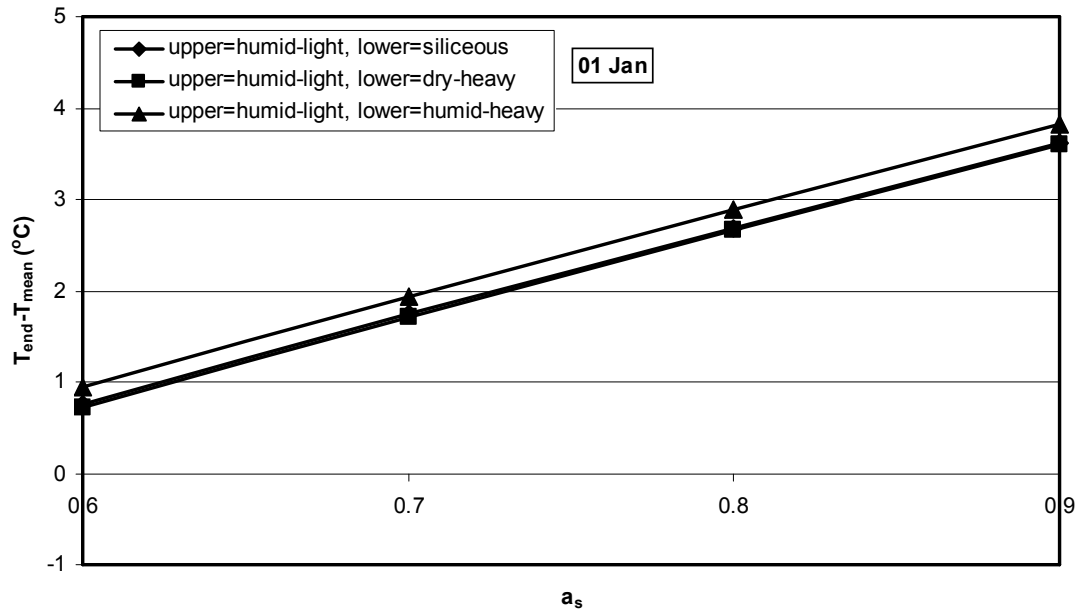


Figure 4.180. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

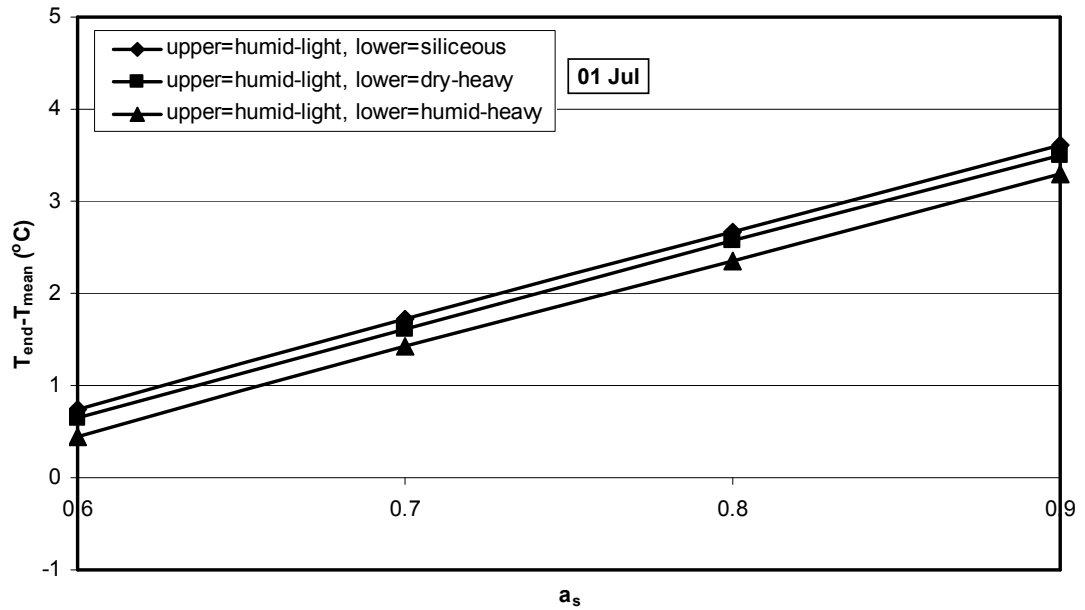


Figure 4.181. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01 for Kars, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

4.6. Comparison of the Difference between Ground End and Mean Ambient Temperatures for 4 Provinces

4.6.1. Thickness of Upper Layer is 5 mm

In figures 4.182 and 4.183, variation of the difference between ground end temperatures (T_{end}) and the mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for the provinces Adana, İstanbul, Ankara and Kars are illustrated. Higher temperature difference in Adana and Kars can be explained with higher solar energy.

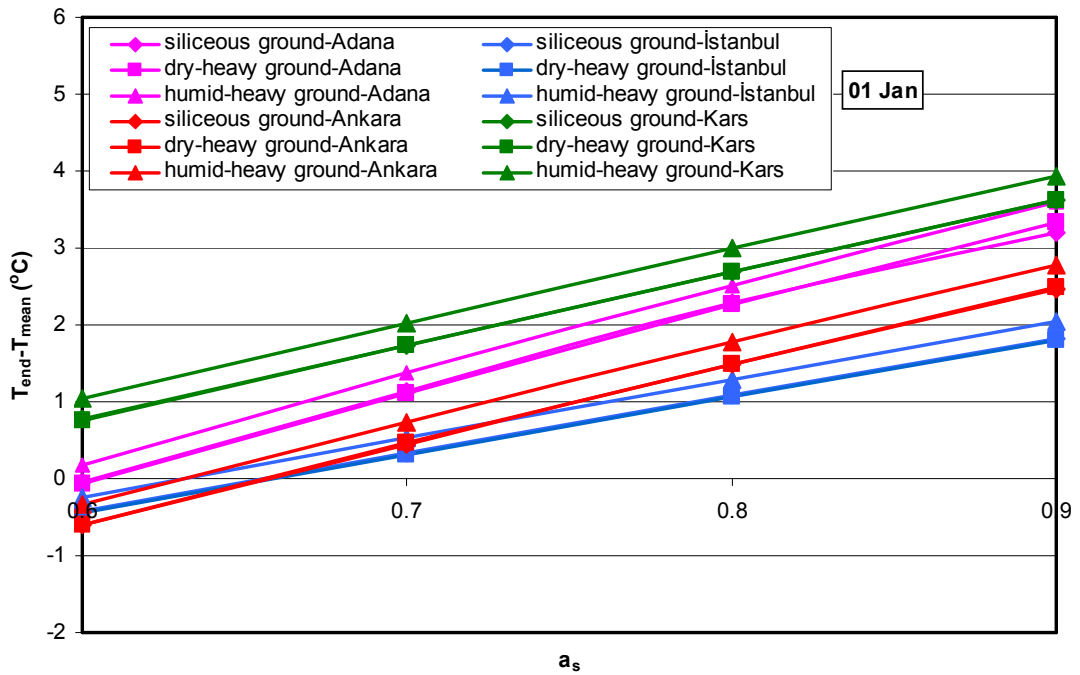


Figure 4.182. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

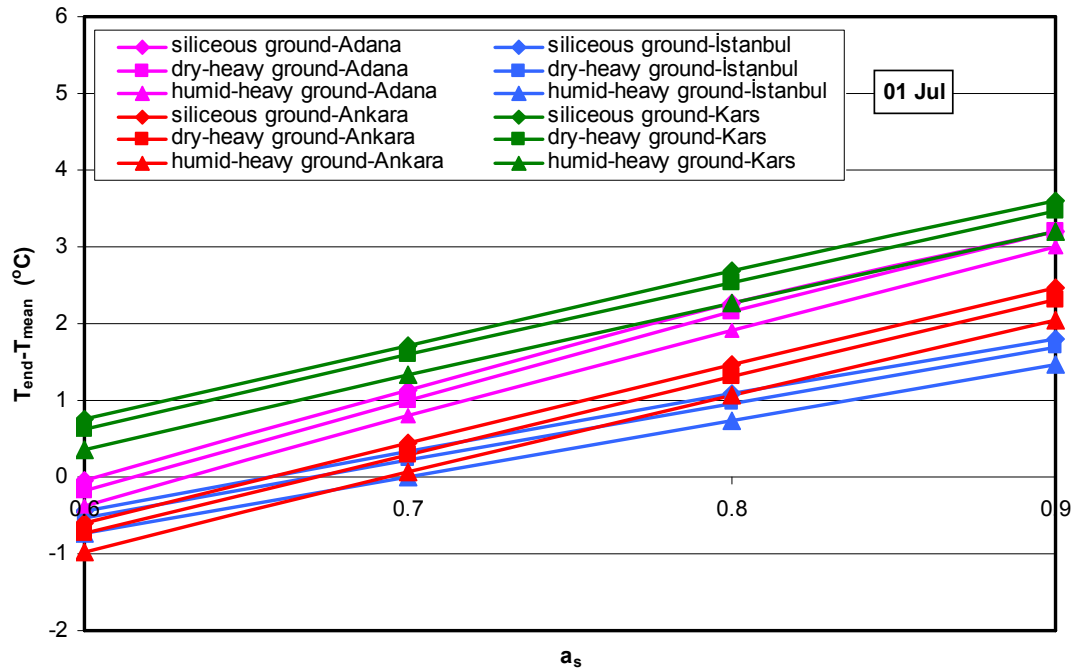


Figure 4.183. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01, ($f=0.45$, $L1=0.005$ m, $L2=10$ m)

4.6.2. Thickness of Upper Layer is 50 cm

The variation of the difference between ground end temperatures (T_{end}) and the mean ambient temperatures (T_{mean}) with ground surface absorption coefficient for January 01 and July 01 for the provinces Adana, İstanbul, Ankara and Kars are demonstrated in figures 4.184 and 4.185 when the thickness of upper layer is 50 cm. Temperature differences in Adana and Kars are greater than the others.

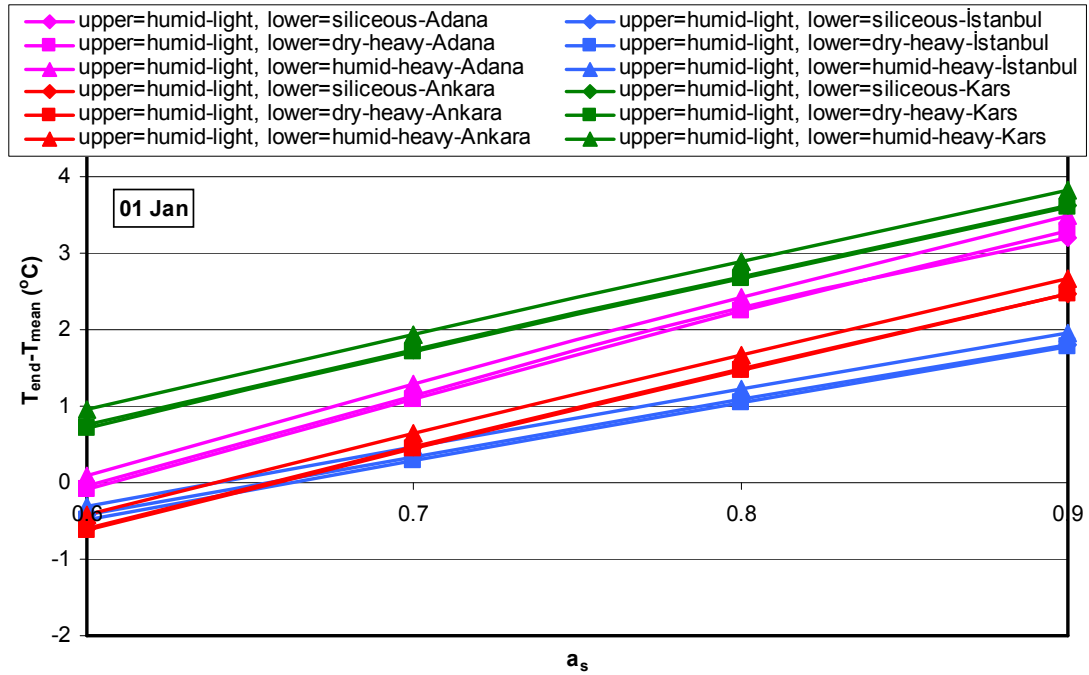


Figure 4.184. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for January 01, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

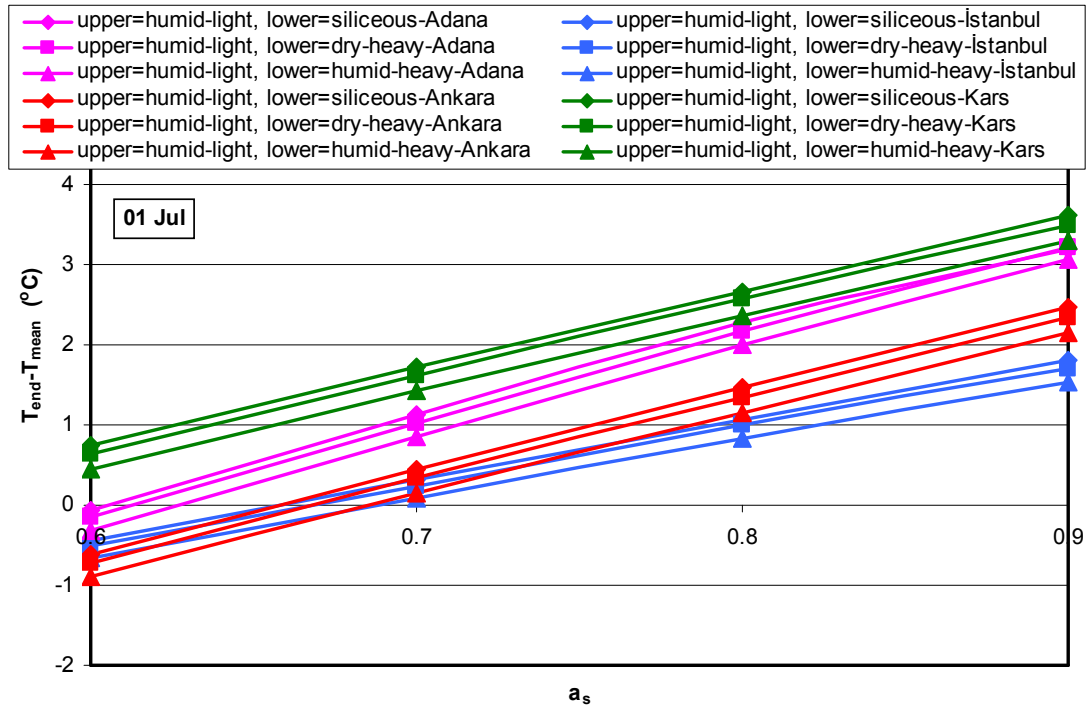


Figure 4.185. Variation of the difference between ground end temperature and mean ambient temperature with ground surface absorption coefficient for July 01, ($f=0.45$, $L1=0.5$ m, $L2=10$ m)

It is observed from figures between 4.182 and 4.185 that, the temperature difference between ground end temperatures (T_{end}) and the mean ambient temperatures (T_{mean}) does not depend on physical properties of the ground but increases with increasing of ground surface absorption coefficient for January 01 and July 01 for Adana, İstanbul, Ankara and Kars provinces.

4.7. Results for Two Vertical Layer Ground Model

Figures 4.186 and 4.187 demonstrate the variation of ground surface and end temperatures with horizontal y-direction for January 01 and July 01 in Adana when granite in the 1st vertical layer and humid-light ground in 2nd vertical layer are used. It is seen that there is an obvious temperature difference in which A and B layers contact. The variation of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction are illustrated in figures 4.188 and 4.189.

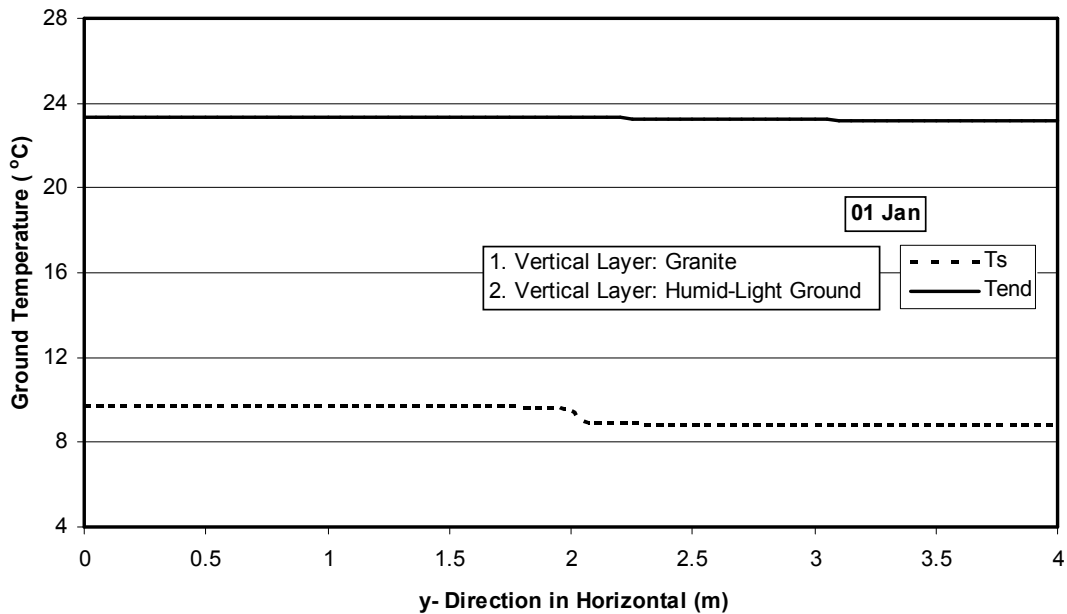


Figure 4.186. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=2.0$ m)

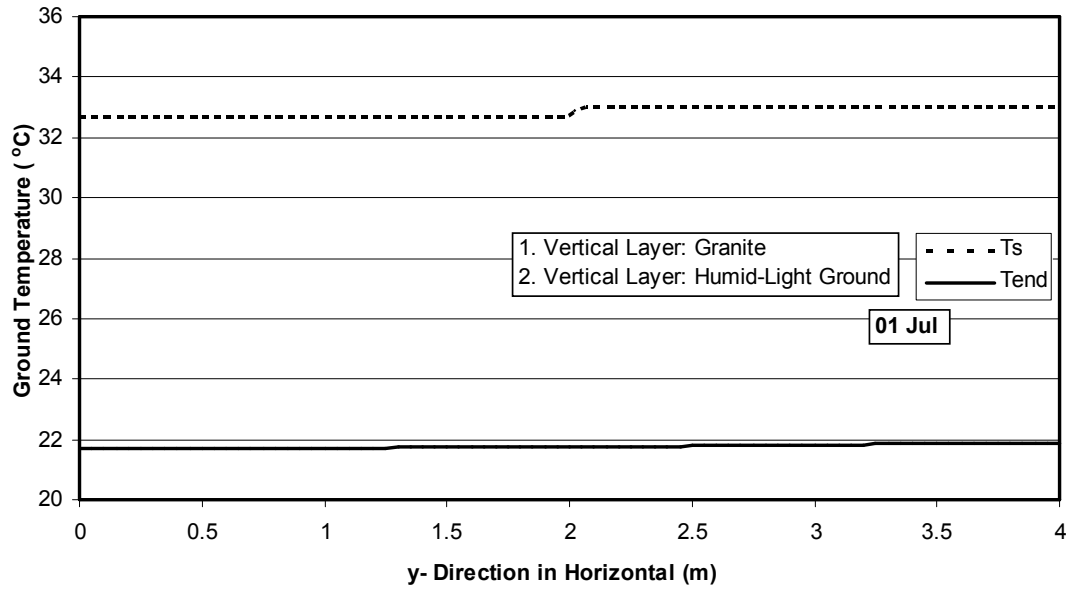


Figure 4.187. Variation of ground surface and end temperatures with horizontal y-direction in the 1st and 2nd vertical layers for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=2.0$ m)

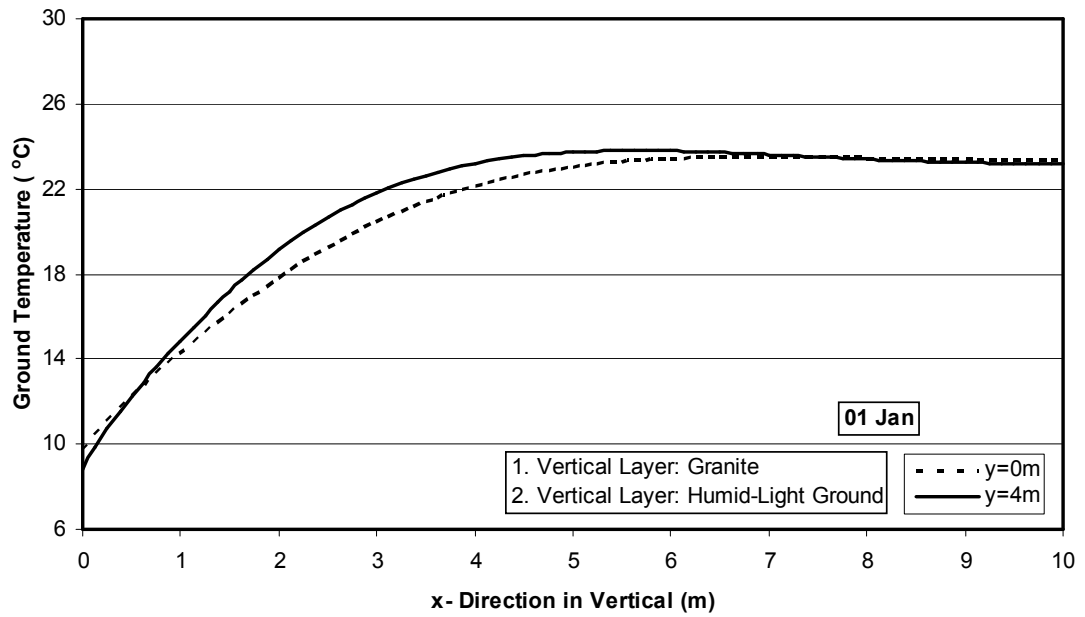


Figure 4.188. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=2.0$ m)

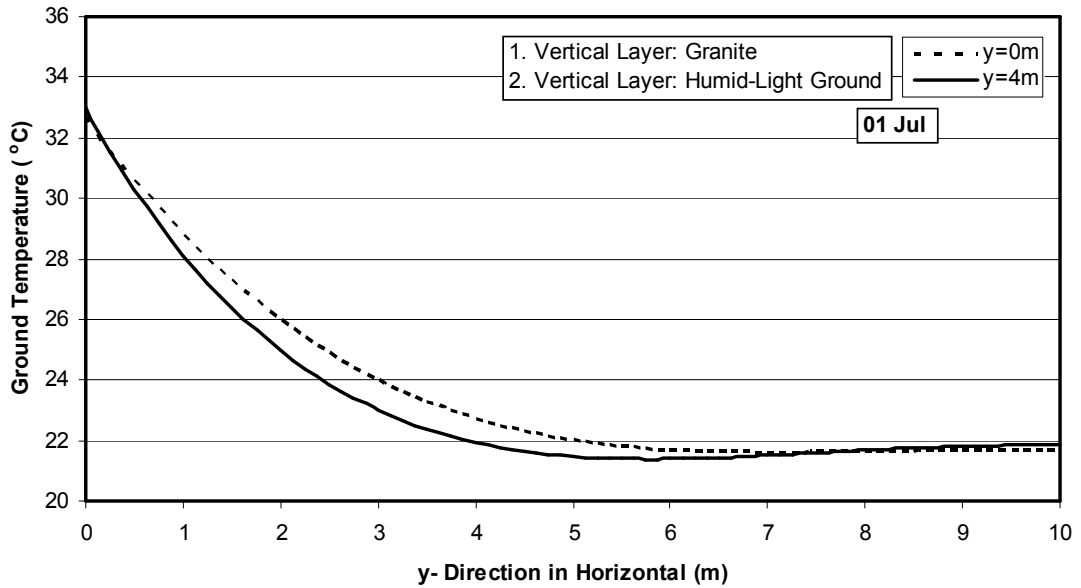


Figure 4.189. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=2.0$ m)

4.8. Results for Trench Filled Two Vertical Layer Ground Model

Figures 4.190 and 4.191 show the variation of ground surface and end temperatures with horizontal y -direction when granite in trench layer and siliceous ground in vertical layer are used for January 01 and July 01 in Adana. It is seen from these figures that there is a clear temperature difference in which A and B layers contact (in horizontal direction, $y=S_A=1.0$ m). The ground temperatures at certain depths between the ground surface and end point in the horizontal direction are illustrated in figures 4.192 and 4.193. The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction are demonstrated in figures 4.194 and 4.195.

Because more heat energy due to solar energy is transferred from atmosphere to the ground surface in the trench layer compared to 2nd vertical layer in January 01, the ground surface temperature is higher in the trench layer (figure 4.190).

Heat energy flows from ground depth to ground surface in winter months and k and α coefficients of the granite layer are higher than the siliceous layer's one. Because heat energy flows faster in the trench layer compared to 2nd vertical layer in

the ground, temperatures of the trench layer at $x=0.5$ m, 1.0 m and 2.0 m depths are lower than the temperatures of 2nd vertical layer (siliceous ground) for January 01 in Adana. Trench layer acts as a fin. Because of fin effect of the trench layer, heat energy flows from the 2nd vertical layer to the trench layer in figure 4.192. Since the depth of maximum temperature for siliceous ground occurs about 2m depth as seen in figure 4.194, the temperature at $x=2$ m in figure 4.192 is higher than the deep temperature at $x=10$ m between $y=1.5$ m and $y=4$ m. In figure 4.194, the transition from trench layer to vertical layer in the x -direction (at $y=0$ m and $x=2$ m) can be seen clearly.

Because heat energy which is transferred from atmosphere to the ground surface moves faster in the trench layer compared to 2nd vertical layer in July 01, the ground surface temperature is lower in the trench layer (figure 4.191).

Heat energy flows from ground surface to ground depth in summer months. Because more heat energy flows faster in the trench layer compared to 2nd vertical layer in the ground, temperatures of the trench layer at $x=0.5$ m, 1.0 m and 2.0 m depths are higher than the temperatures of 2nd vertical layer (siliceous ground) for July 01 in Adana (figures 4.193 and 4.195). Thus heat energy flows from the trench layer to the 2nd vertical layer in figure 4.193. Since the depth of minimum temperature for siliceous ground occurs about 2m depth in figure 4.195, the temperature at $x=2$ m in figure 4.193 is lower than the deep temperature at $x=10$ m between $y=1.5$ m and $y=4$ m. The transition from trench layer to vertical layer in the x -direction (at $y=0$ m and $x=2$ m) can observe clearly in figure 4.195.

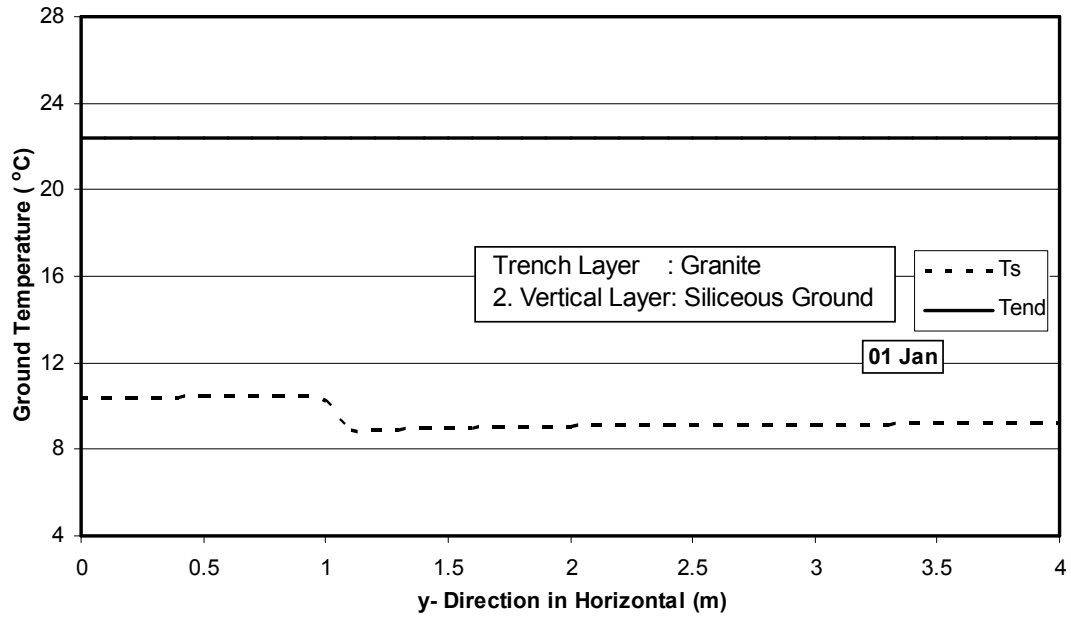


Figure 4.190. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

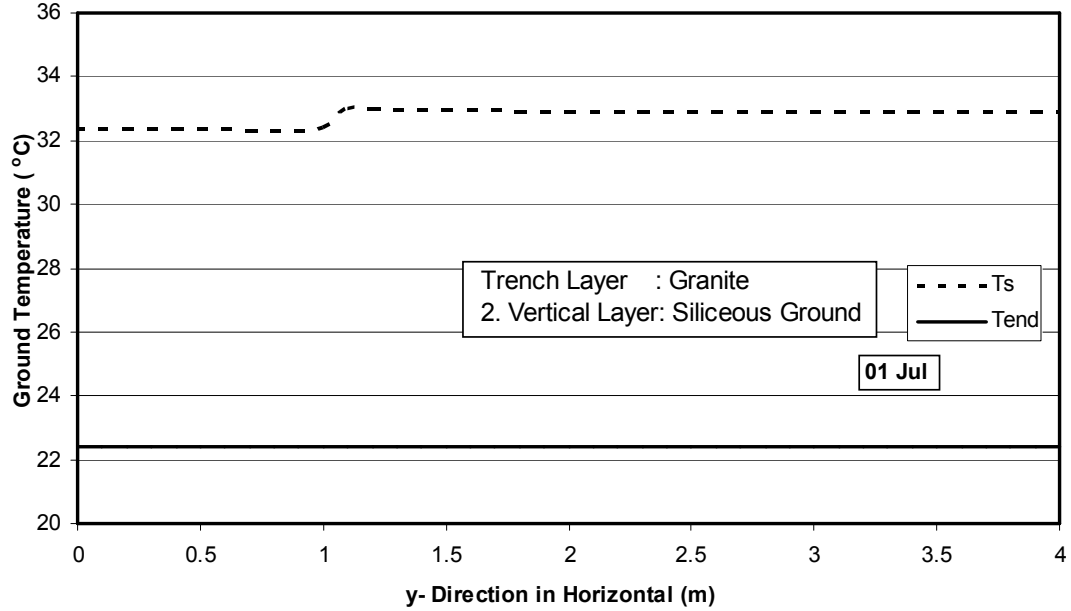


Figure 4.191. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

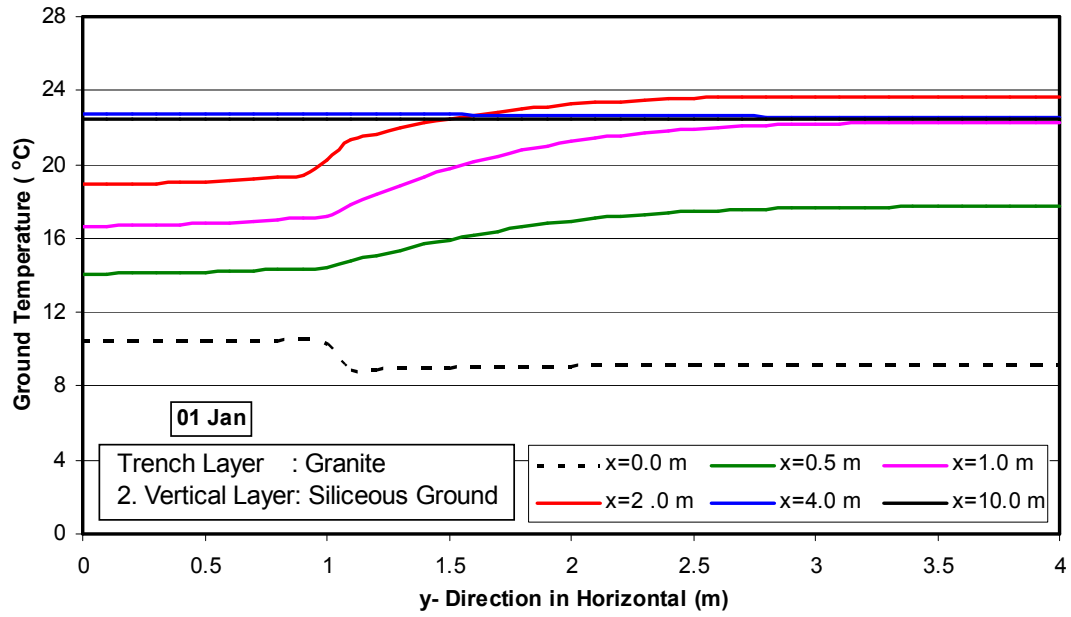


Figure 4.192. Variation of ground temperatures at different ground depths with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

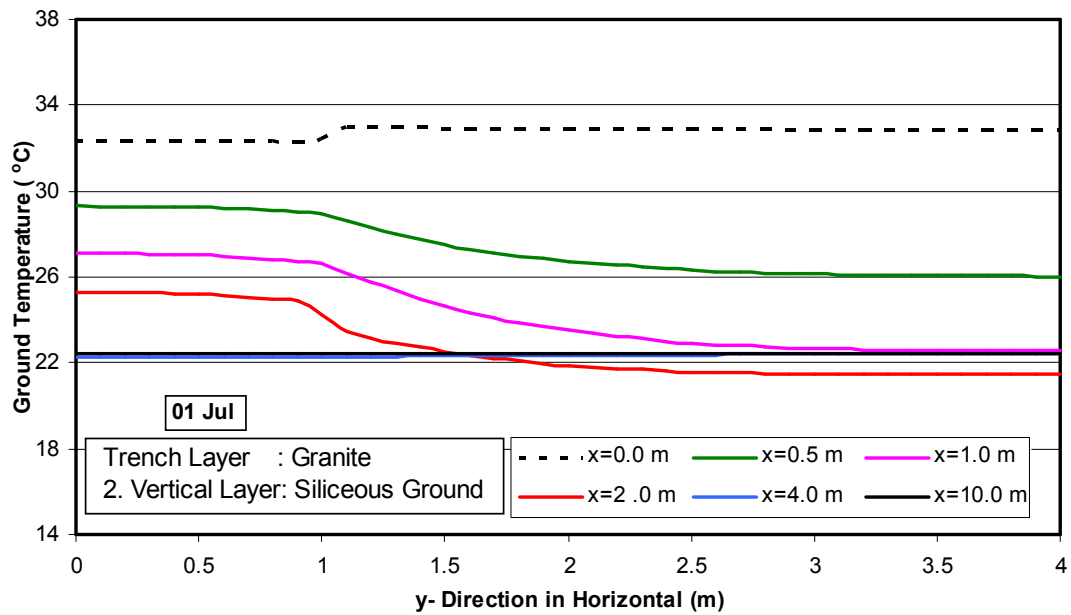


Figure 4.193. Variation of ground temperatures at different ground depths with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

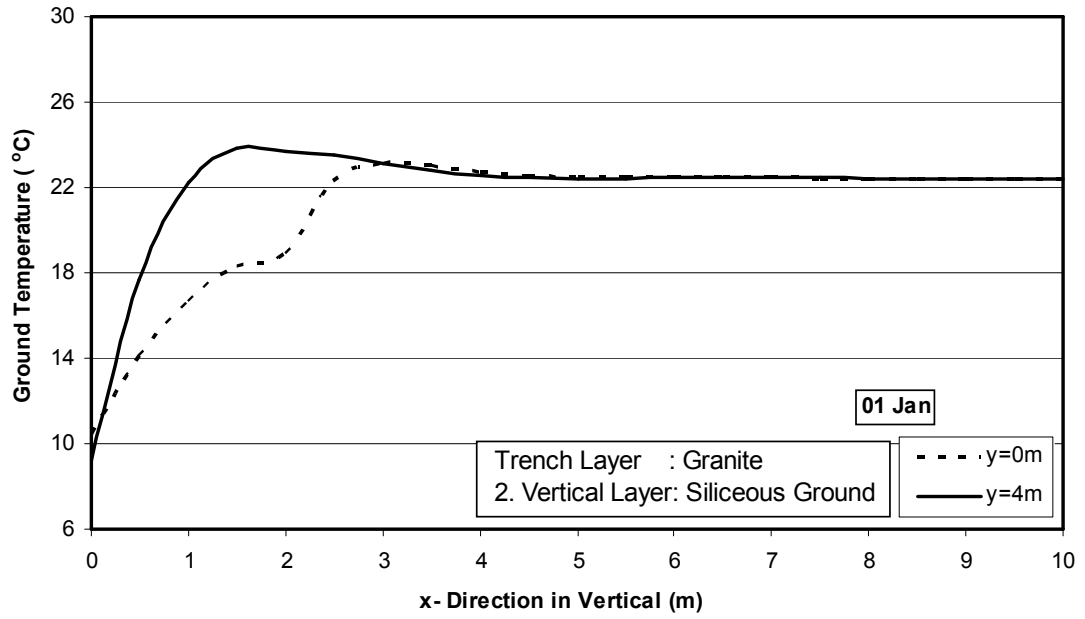


Figure 4.194. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

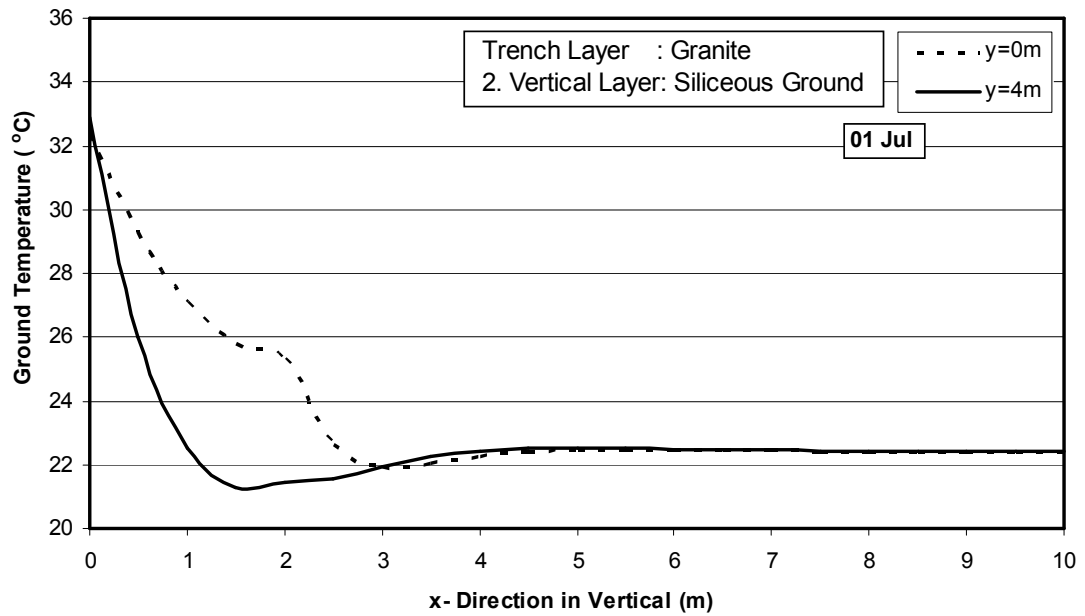


Figure 4.195. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

Figures 4.196 and 4.197 illustrate the variation of ground surface and end temperatures with horizontal y-direction when granite in trench layer and humid-light ground in vertical layer are used for January 01 and July 01 in Adana. It is observed that there is a clear temperature difference in which A and B layers contact (in horizontal direction, $y=S_A=1.0$ m). The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction are shown in figures 4.198 and 4.199. Temperature change between granite layer and humid-light ground layer at $y=0$ m (in vertical direction, $x=L_A=2.0$ m) can be seen from these figures. This temperature difference occurs due to the fact that k and α coefficients of granite layer are higher than the humid-light ground layer coefficients. Because of the fin effect of trench layer, heat energy flows from 2nd vertical layer to trench layer.

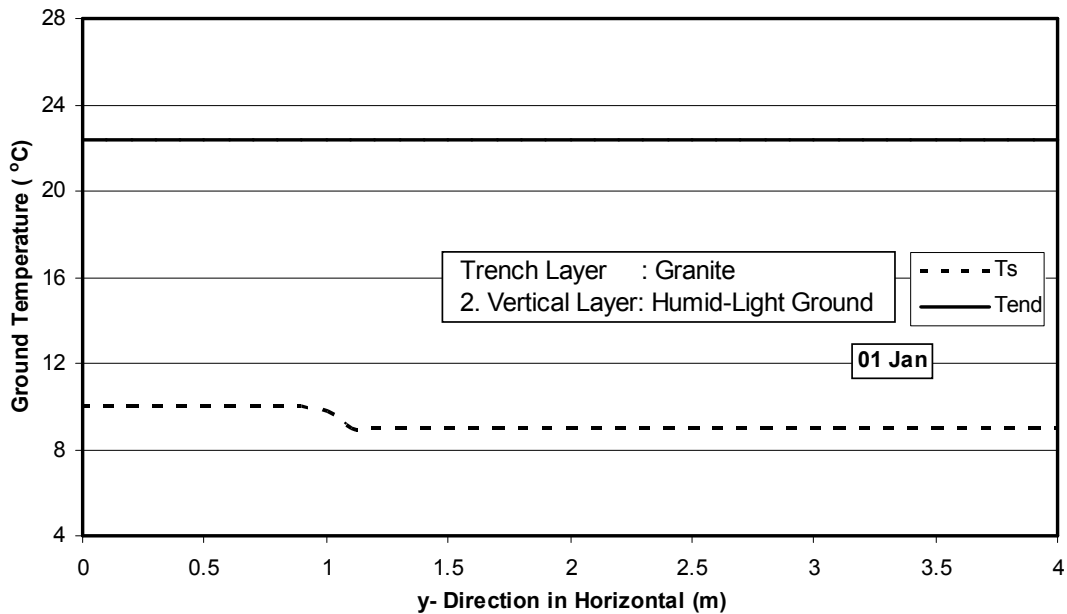


Figure 4.196. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

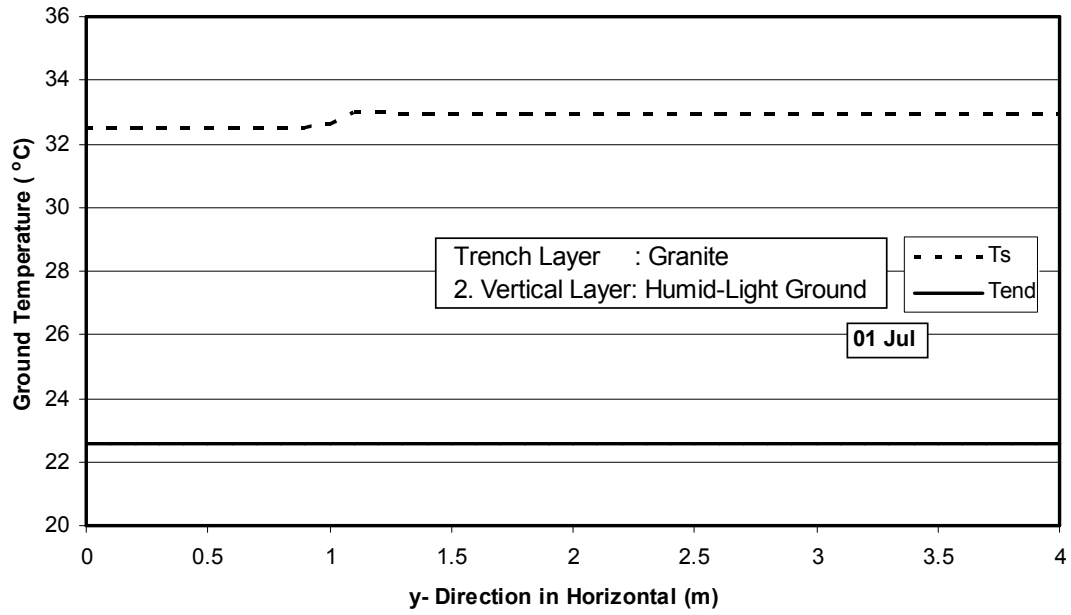


Figure 4.197. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

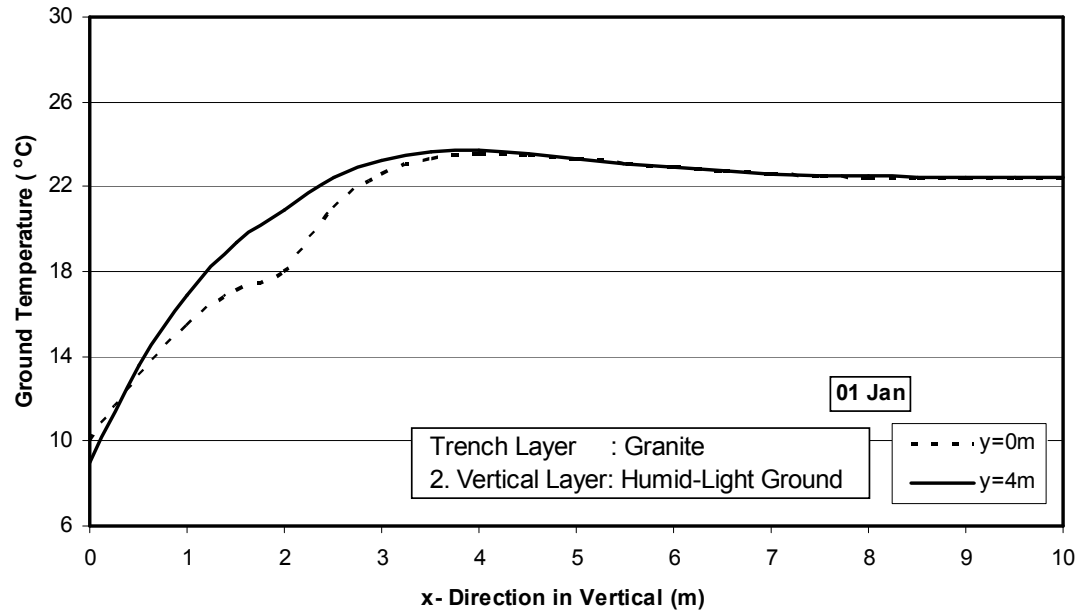


Figure 4.198. Variation of ground temperatures at y=0 m and y=4 m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

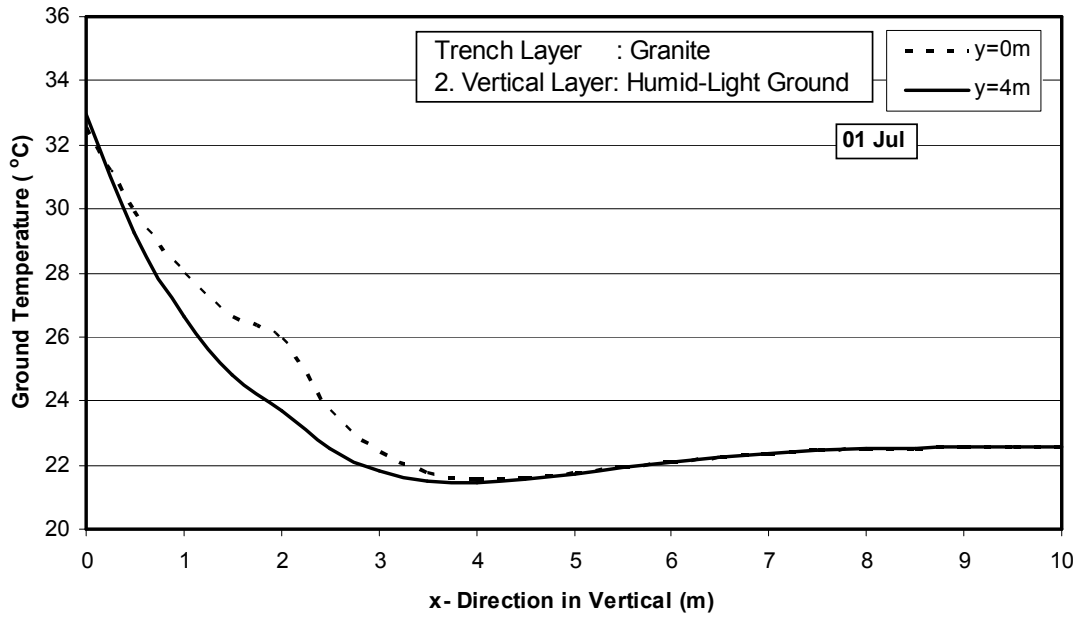


Figure 4.199. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

Figures 4.200 and 4.201 demonstrate the variation of ground surface and end temperatures with horizontal y -direction when granite in trench layer and humid-heavy ground in vertical layer are used for January 01 and July 01 in Adana. The temperature difference in which A and B layers contact (in horizontal direction, $y=S_A=1.0$ m) can be seen in these figures. The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction were illustrated in figures 4.202 and 4.203. The temperature change can be observed between the granite layer and the humid-heavy ground layer at $y=0$ m (in vertical direction, $x=L_A=2.0$ m). This small temperature difference occurs due to the fact that k and a coefficients of the granite layer are higher than the humid-heavy ground layer coefficients. But temperature difference between the layers is much smaller when compared with siliceous and humid-light ground layers.

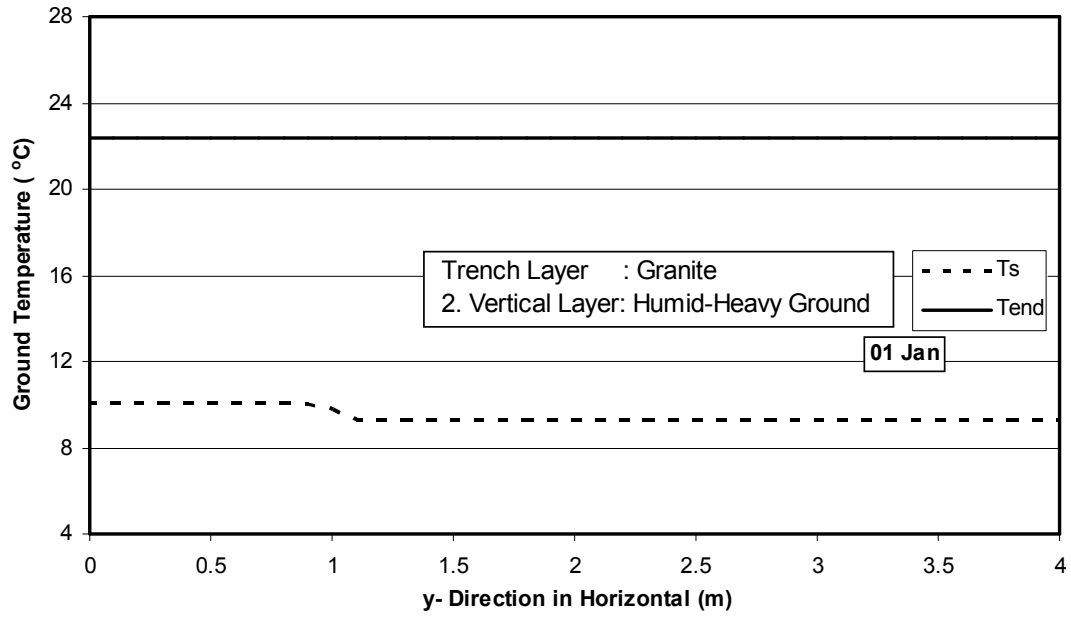


Figure 4.200. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

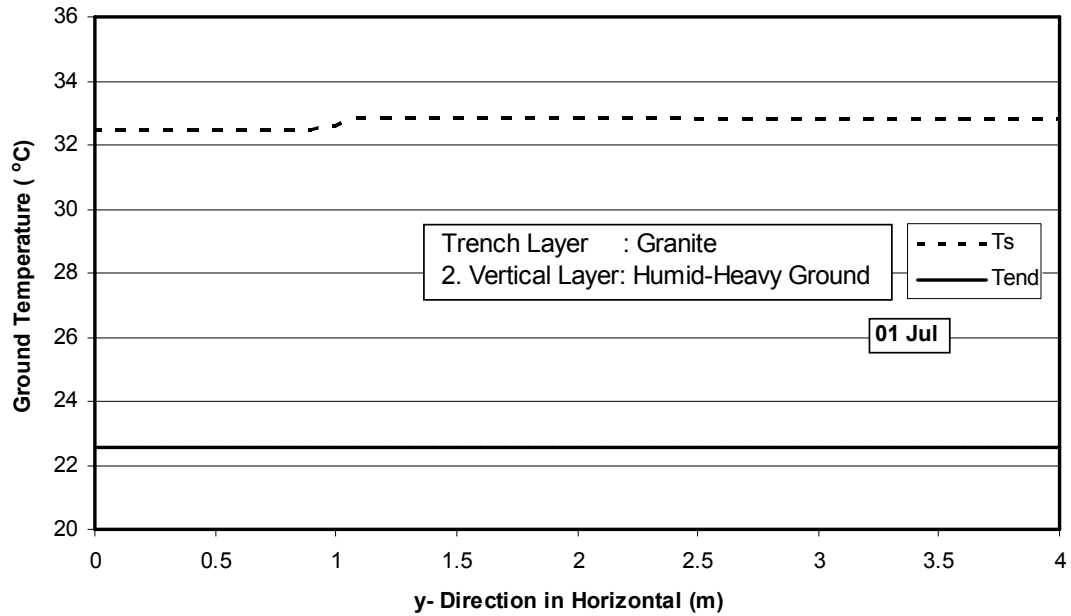


Figure 4.201. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

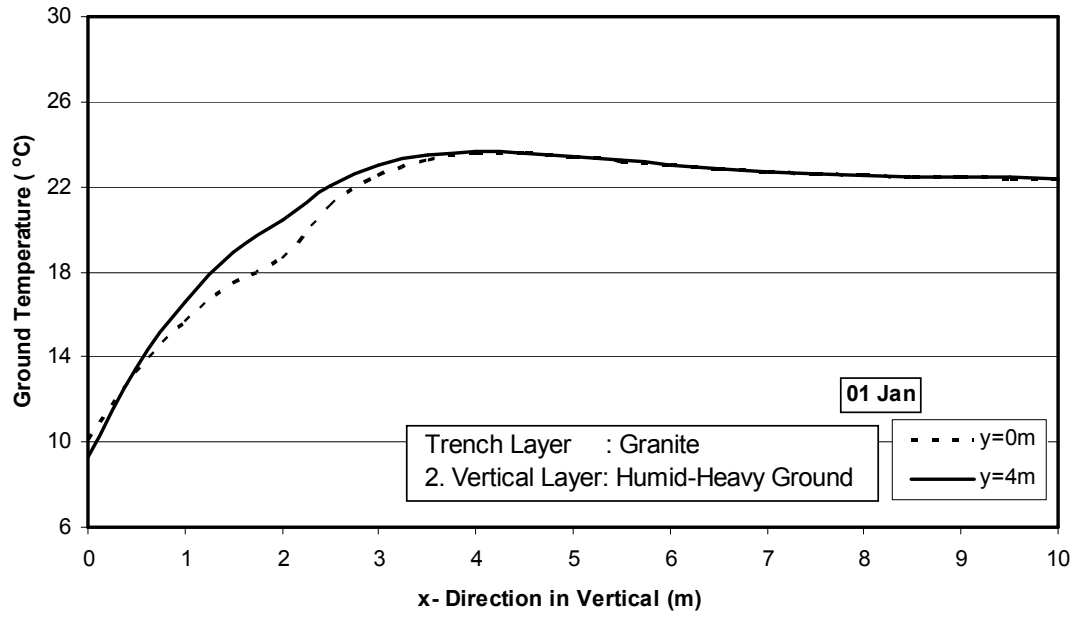


Figure 4.202. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

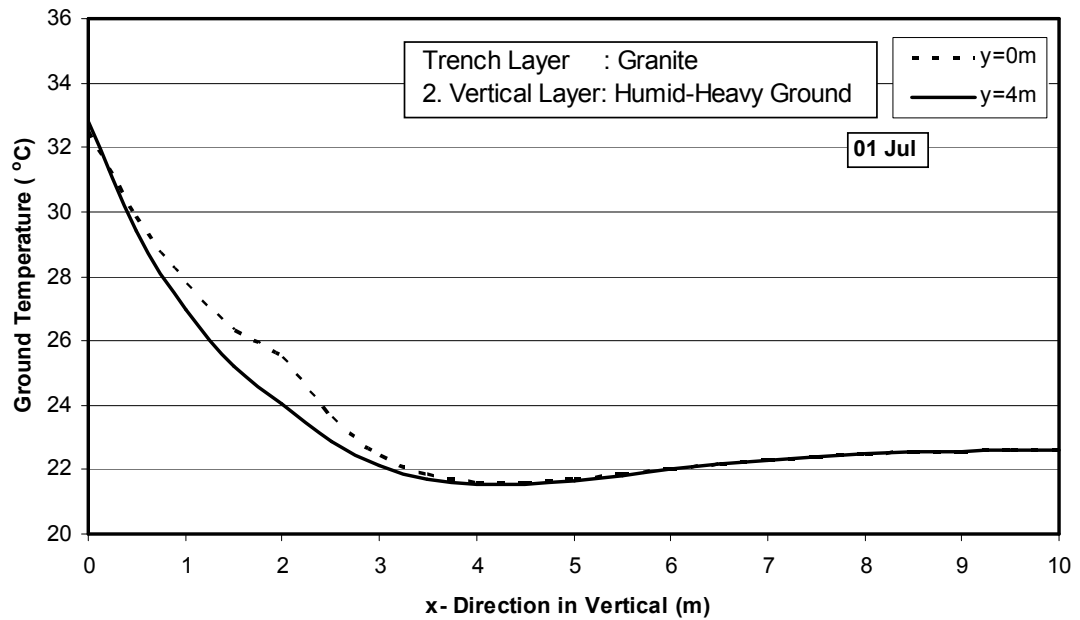


Figure 4.203. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

In this part of the study, the same numerical parameters which are used for the figures above were used in the calculations but the physical properties of the layers were only changed.

Figures 4.204 and 4.205 demonstrate the variation of ground surface and end temperatures with horizontal y-direction when siliceous ground in trench layer and granite in vertical layer are used for January 01 and July 01 in Adana. A clear temperature difference in which A and B layers contact (in the horizontal direction, $S_A=1.0$ m) can be seen in these figures. The ground temperatures at certain depths between the ground surface and end point in the horizontal direction were shown in figures 4.206 and 4.207. The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction were illustrated in figures 4.208 and 4.209.

Because more heat energy is transferred from the atmosphere to the ground surface in the 2nd vertical layer compared to the trench layer in January 01, the ground surface temperature is higher in the 2nd vertical layer (figure 4.204).

As can be seen from figures 4.206 and 4.208 that ground temperatures of the trench layer (siliceous ground) at $x=0.5$ m, 1.0 m and 2.0 m depths are higher than the temperatures of 2nd vertical layer (Granite) for January 01 in Adana. This clear temperature difference occurs due to the fact that k and α coefficients of the granite layer are higher than the siliceous ground layer coefficients. Thus heat energy flows from the trench layer to the 2nd vertical layer. Since the depth of maximum temperature of granite layer occurs about 4 m depth in figure 4.208, the temperature at $x=4$ m in figure 4.206 is higher than the deep temperature (at $x=10$ m). In figure 4.208, the transition from trench layer to vertical layer in the x-direction (at $y=0$ m and $x=2$ m) occurs before reaching the maximum temperature of the trench layer ground.

Because heat energy which is transferred from the atmosphere to the ground surface moves faster in the 2nd vertical layer compared to trench layer in July 01, the ground surface temperature is lower in the 2nd vertical layer (figure 4.205).

The ground temperatures of trench layer (Siliceous ground) at $x=0.5$ m, 1.0 m and 2.0 m depths are illustrated in figures 4.207 and 4.209 and they are lower than the temperatures of 2nd vertical layer (Granite) for July 01 in Adana. This

temperature difference occurs due to the fact that k and a coefficients of granite layer are higher than the siliceous ground layer coefficients. Thus heat energy flows from the 2nd vertical layer to the trench layer. Since the depth of minimum temperature occurs about 4 m depth in figure 4.209, the temperature at $x=4$ m in figure 4.207 is lower than the deep temperature ($x=10$ m). In figure 4.209, the transition from trench layer to vertical layer in the x -direction (at $y=0$ m and $x=2$ m) occurs before reaching the minimum temperature of the trench layer ground.

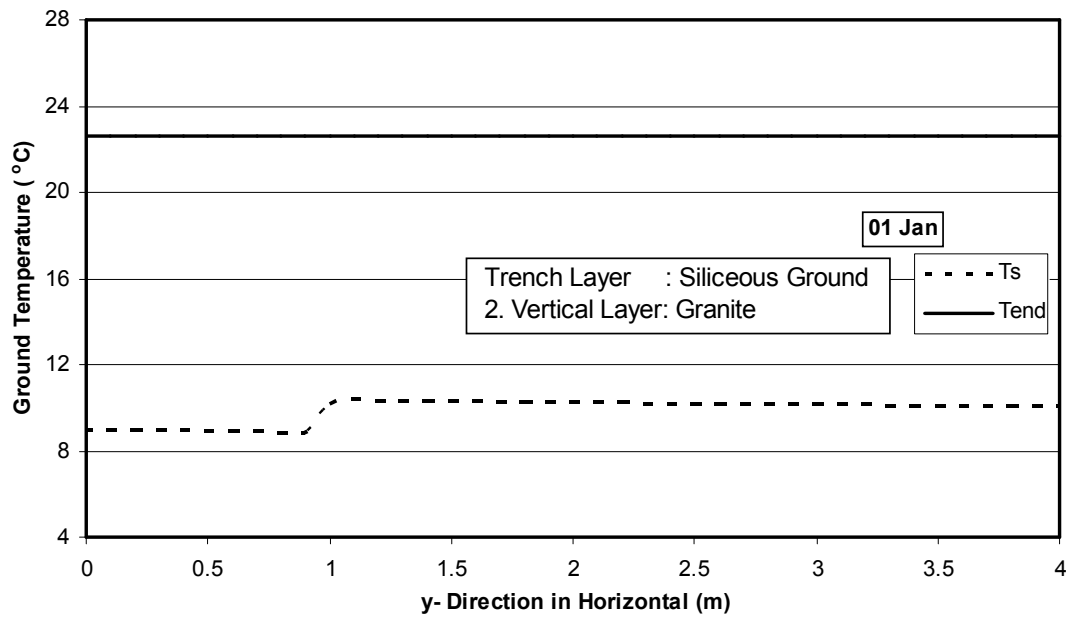


Figure 4.204. Variation of ground surface and end temperatures with horizontal y -direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

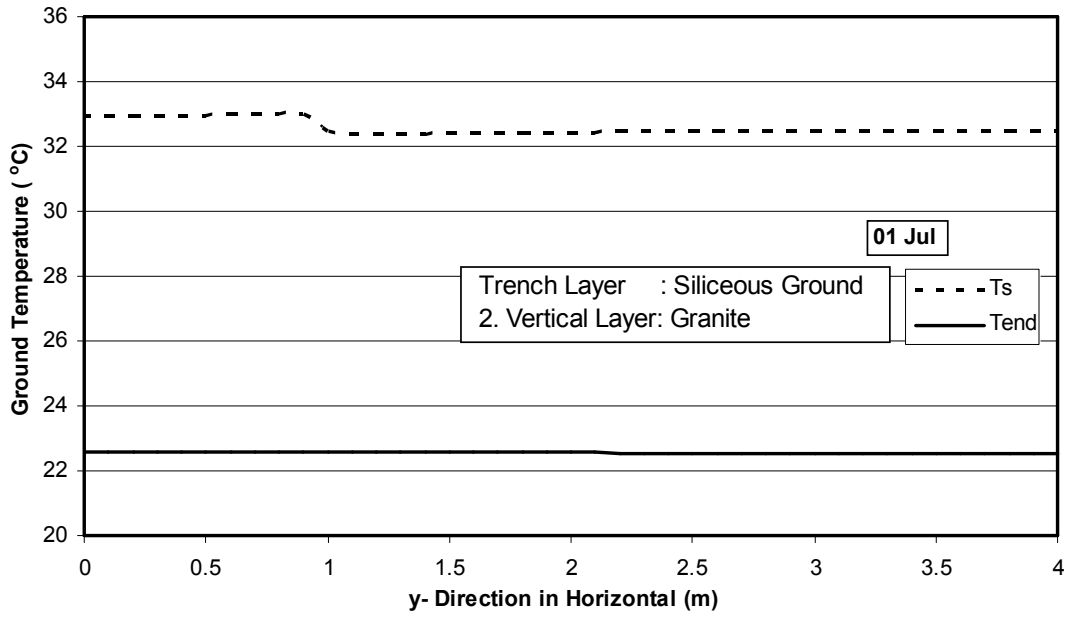


Figure 4.205. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

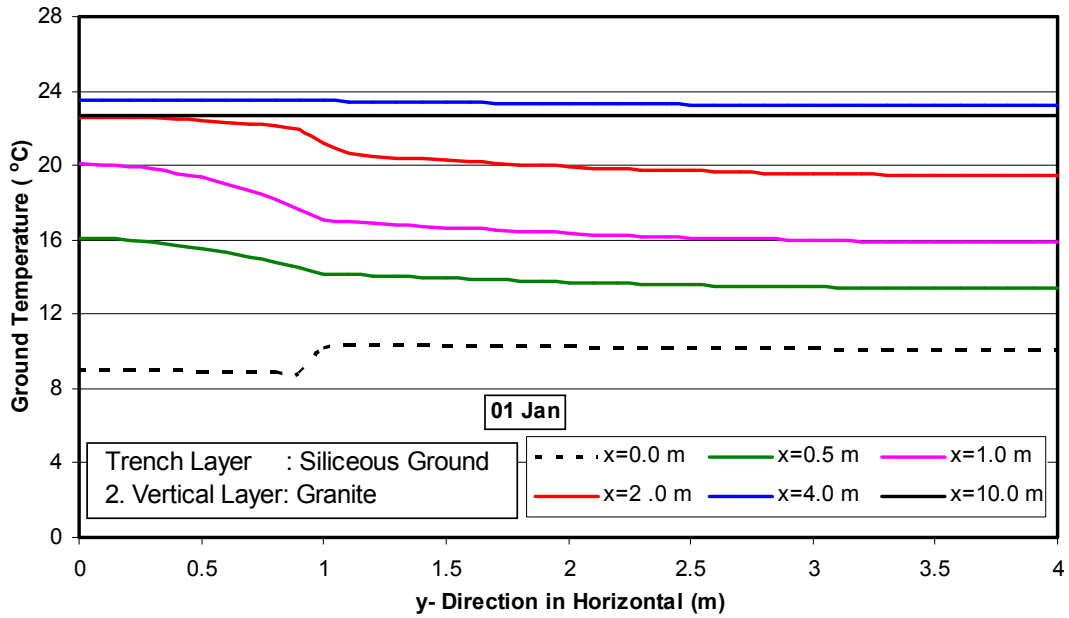


Figure 4.206. Variation of ground temperatures at different ground depths with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

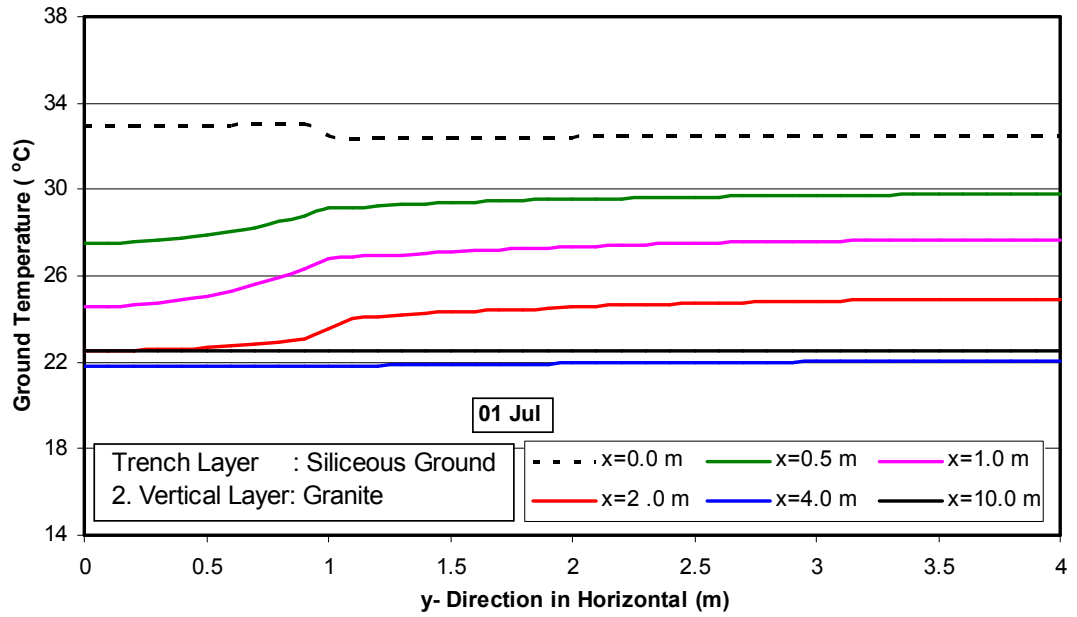


Figure 4.207. Variation of ground temperatures at different ground depths with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

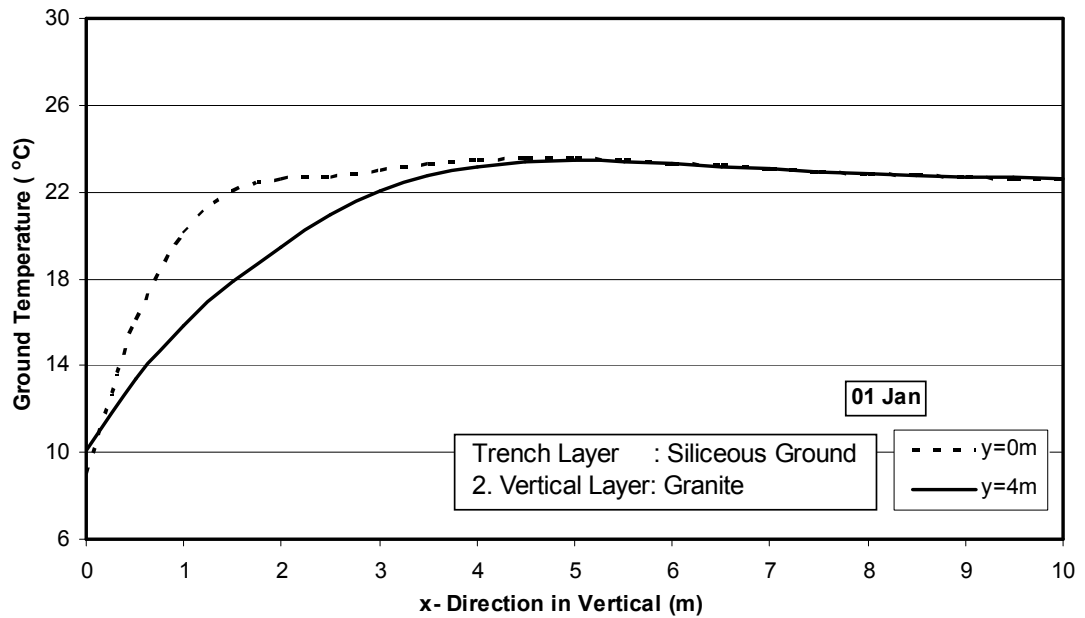


Figure 4.208. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

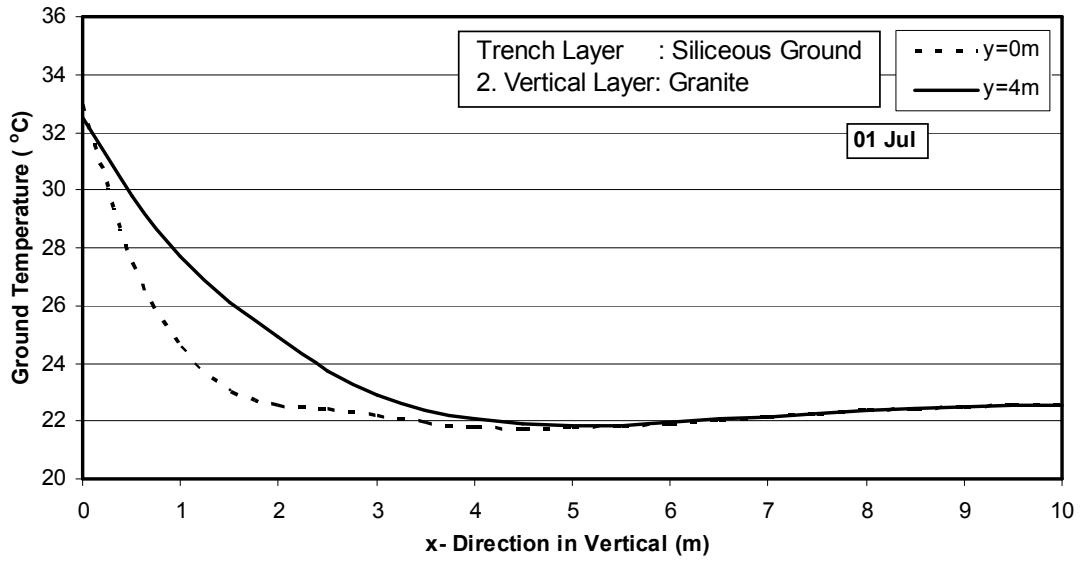


Figure 4.209. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

Figures 4.210 and 4.211 illustrate the variation of ground surface and end temperatures with horizontal y-direction when humid-light ground in trench layer and granite in vertical layer are used for January 01 and July 01 in Adana. It is observed from these figures that there is a clear temperature difference in which A and B layers contact (in horizontal direction, $y=S_A=1.0$ m). The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction were demonstrated in figures 4.212 and 4.213. The temperature change between humid-light ground layer and granite layer at $y=0$ m (in vertical direction, $x=L_A=2.0$ m) can observe.

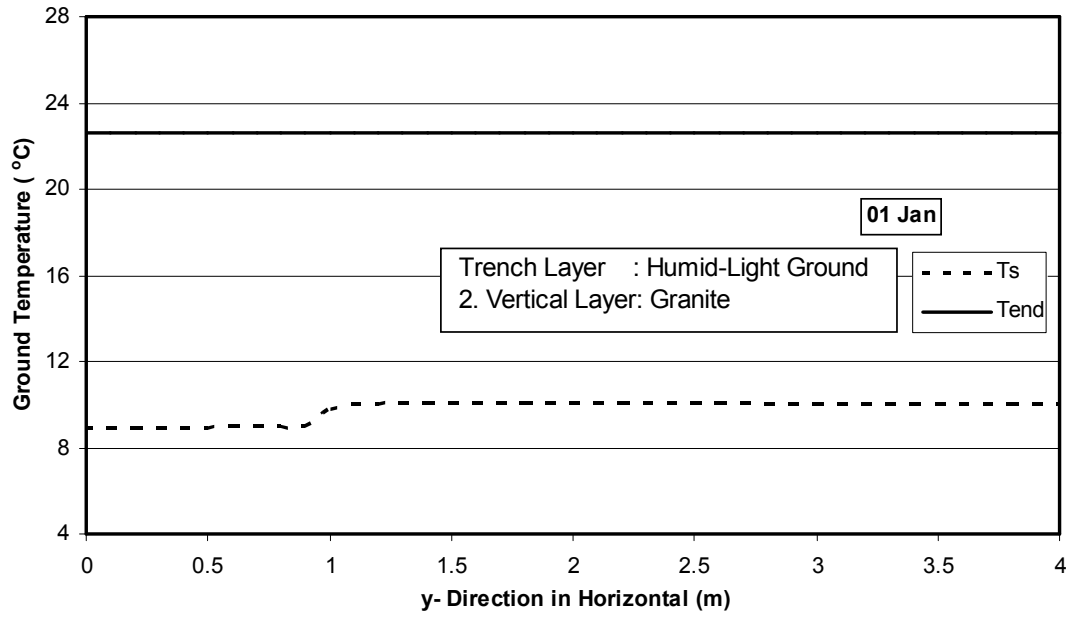


Figure 4.210. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

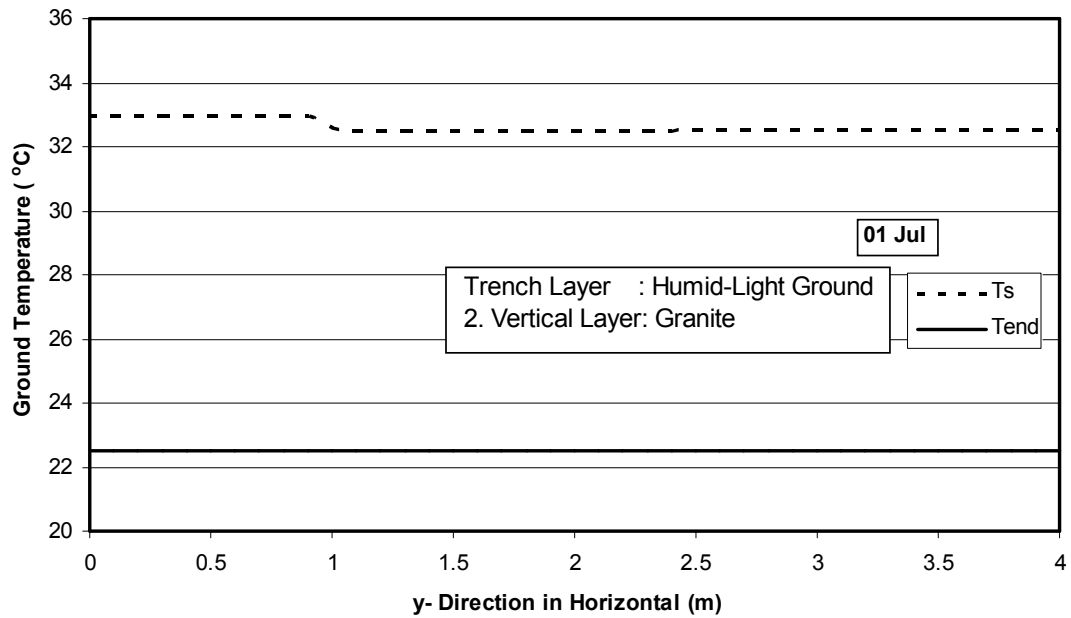


Figure 4.211. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

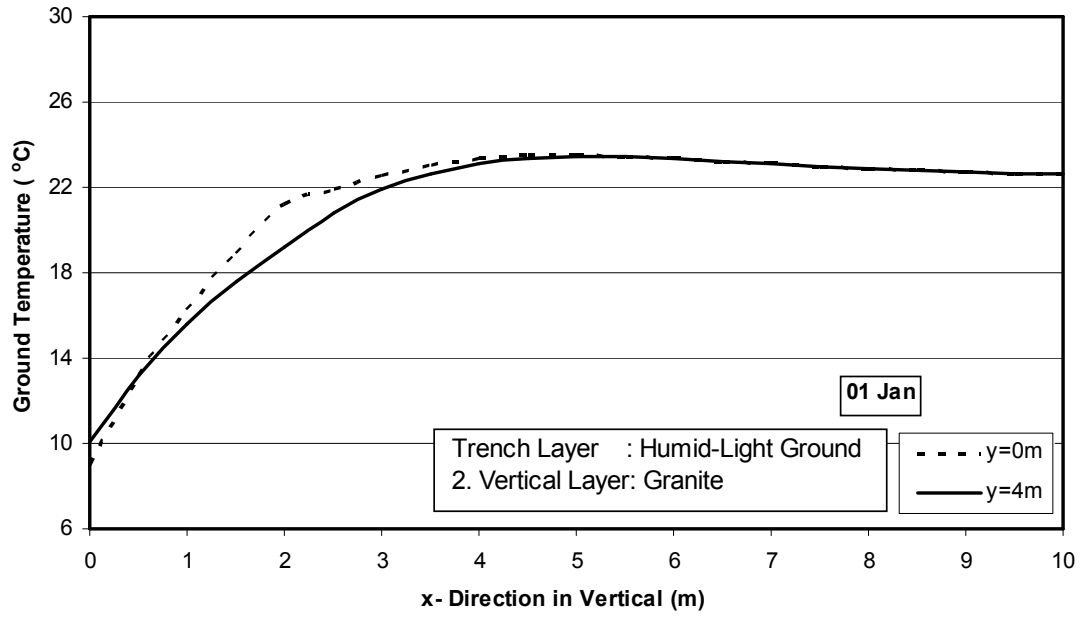


Figure 4.212. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

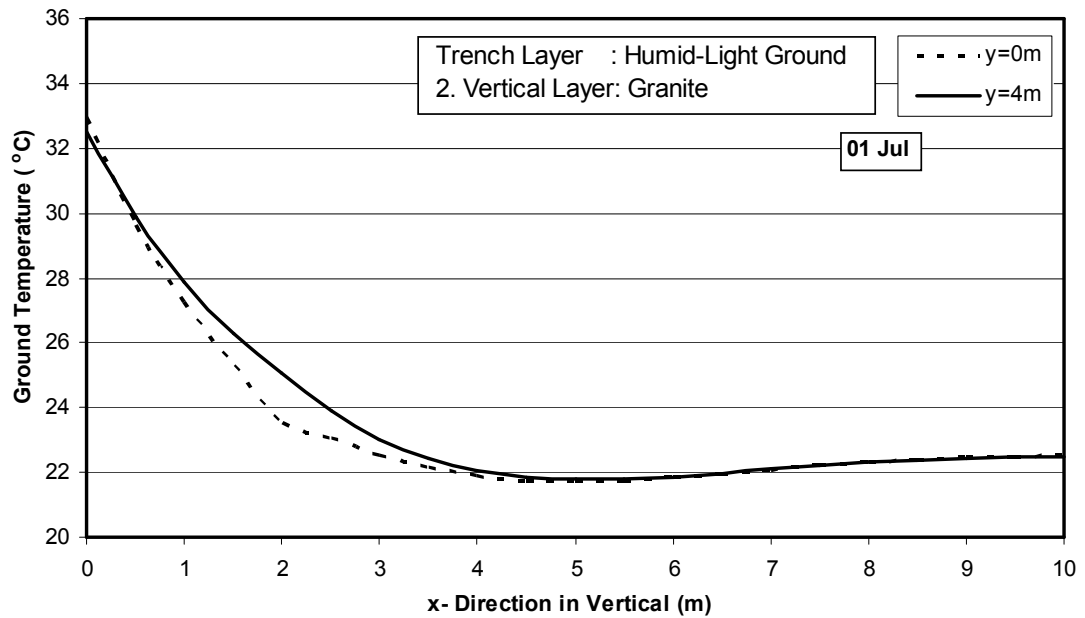


Figure 4.213. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

Figures 4.214 and 4.215 show the variation of ground surface and end temperatures with horizontal y-direction when humid-heavy ground in trench layer and granite in vertical layer are used for January 01 and July 01 in Adana. The temperature difference in which A and B layers contact (in the horizontal direction, $y=S_A=1.0$ m) can be observed. The variations of the ground temperatures at $y=0$ m and $y=4$ m with ground depth in the vertical direction were demonstrated in figures 4.216 and 4.217. The temperature change between the layers in $y=0$ m (in the vertical direction, $x=L_A=2.0$ m) can be seen. Because k and a coefficients of trench layer and vertical layer are close to each other, there is a small temperature difference between these layers.

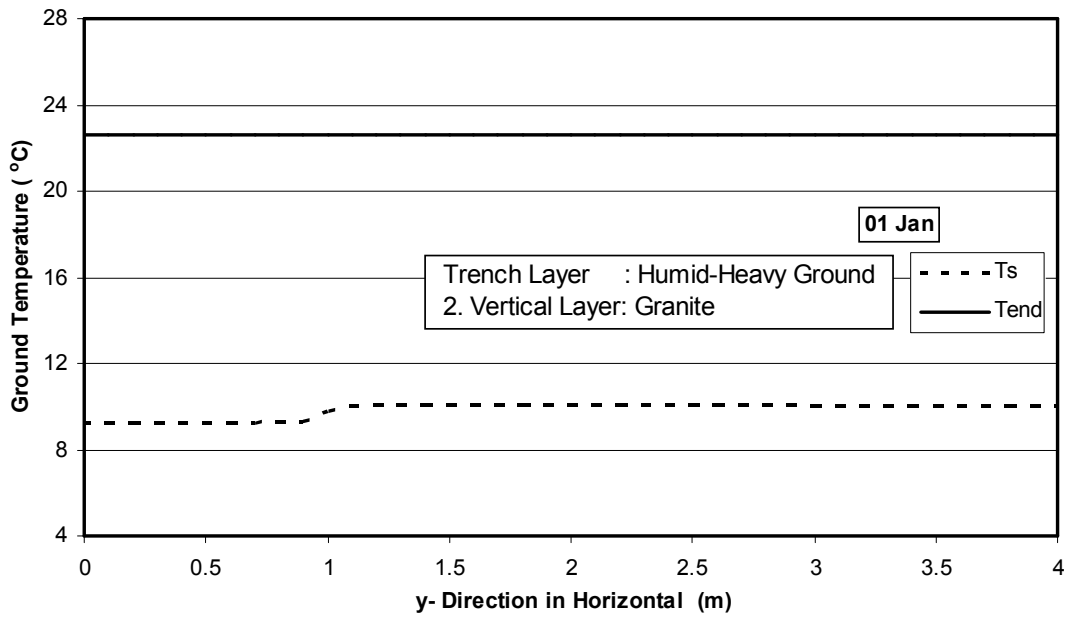


Figure 4.214. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

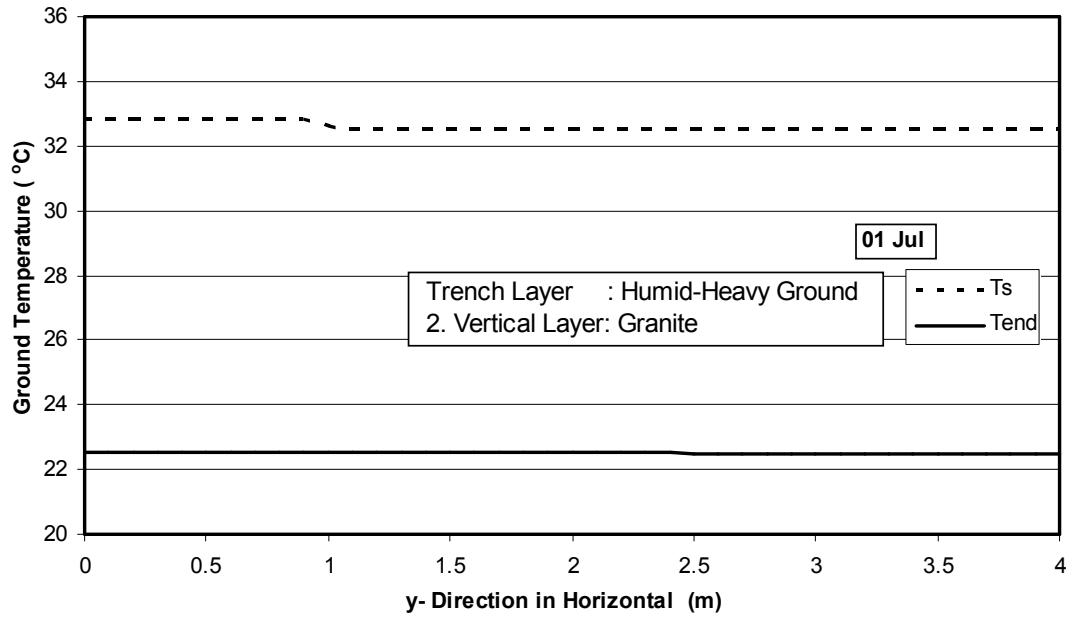


Figure 4.215. Variation of ground surface and end temperatures with horizontal y-direction in trench and vertical ground layer for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

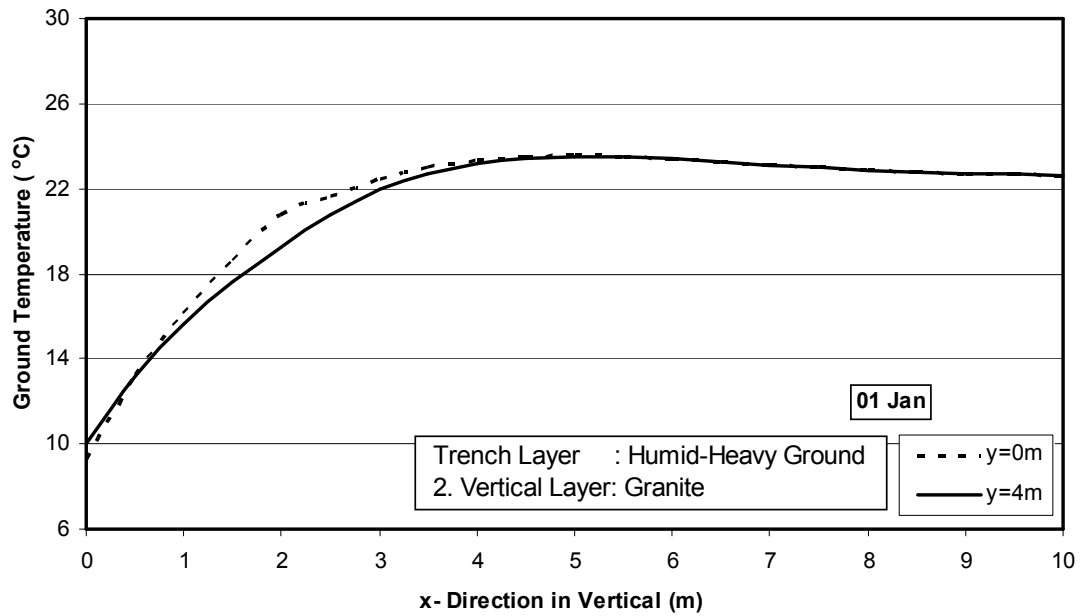


Figure 4.216. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for January 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

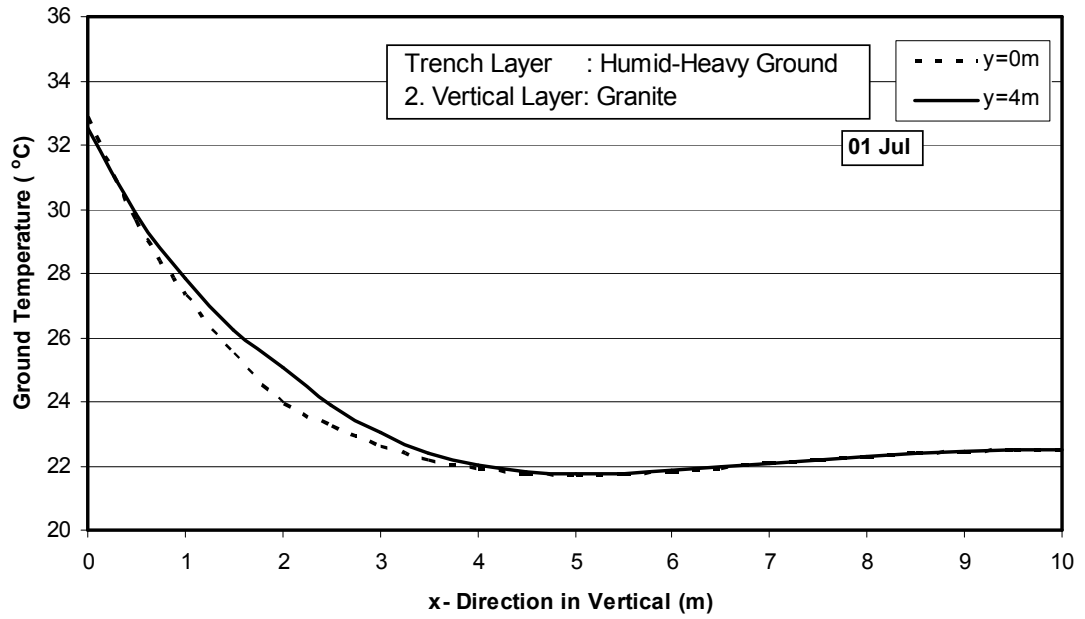


Figure 4.217. Variation of ground temperatures at $y=0$ m and $y=4$ m with ground depth in vertical direction for July 01 in Adana, ($a_s=0.9$, $f=0.45$, $L=10.0$ m, $S=4.0$ m, $S_A=1.0$ m, $L_A=2.0$ m)

It is seen from these figures that when the siliceous ground is used in the trench or 2nd vertical layers, the temperature difference between the layers is more noticeable.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study, ground surface temperatures and ground temperatures at certain depths are calculated numerically for multi layered and different types of ground structures and properties by utilizing the climatic parameters that are measured by DMİ. In the numerical calculations, daily values of solar energy, relative humidity, wind velocity and ambient temperature are used for yearly calculations of ground temperature distribution.

One and multi-layer ground temperatures were calculated numerically considering the climatic conditions of 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.

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. These effects can be used to control ground temperature distributions in winter and summer.

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. Ground temperature distribution can be altered by the upper or lower layers such as siliceous ground.

5.2. Recommendations for Future Works

This work show that temperature distribution in the ground can only be calculated accurately using numerical methods. Therefore, one and multi-layer ground temperatures are calculated numerically by using the climatic parameters for Turkey.

With the ground surface and ground temperatures which are determined as the scopes of this work, the design of GSHP systems that can be done much more realistic and this will contribute to our country's economy.

In future works, heat exchanger of GSHP systems should be calculated using temperature distribution in the ground with the model described in this work.

Mulching in agricultural application causes temperature changes in the ground. Optimal mulching programs should be determined using the numerical model in this work.

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CURRICULUM VITAE

Arif ÖZBEK was born on August 09, 1977 in Osmaniye. After completing his education in primary and high school, he enrolled in Çukurova University Mechanical Engineering Department in 1995. He had graduated from the Mechanical Engineer Department of Çukurova University in 2000. He earned Master of Science degree from the Mechanical Engineer Department of Çukurova University in 2003. He had commenced the studies leading to the degree of Doctor of Philosophy in 2003 at the Department of Mechanical Engineering, Çukurova University. He has been working as a Research Assistant at the Mechanical Engineering Department of Çukurova University since 2001.

APPENDIX

APPENDIX-1. PREPARED COMPUTER PROGRAM FOR ONE LAYER GROUND MODEL

```
DIMENSION TN(202),TA(202),TNA(202),DX(202),TI(202),TIN(202)
DIMENSION TE0(365),TE1(365),TE2(365),TE3(365),TX10(367)
DIMENSION TE4(365),TE5(365),TE6(365),TE7(365)
DIMENSION TAD(365),QSD(365),UAD(365),FAD(365)
DIMENSION A(202),B(202),D(202),DN(202)
DIMENSION CN1(202),CN2(202),CN3(202)
DIMENSION CA1(202),CA2(202),CA3(202)

OPEN(1,FILE='TAD.TXT')
OPEN(2,FILE='QSD.TXT')
OPEN(3,FILE='UAD.TXT')
OPEN(4,FILE='FAD.TXT')
OPEN(5,FILE='TS.TXT')
OPEN(6,FILE='TYS.TXT')
C----- M=200, ALX=10.0, AK=1.00 -----
C   READ(*,*) M,AK,LX
      M=100
      ALX=10.0
      AK=1.0
C-----DATA ARE READING FROM THE FILES-----
      DO 5 I=1,365
        READ(1,*)TAD(I)
        READ(2,*)QSD(I)
        READ(3,*)UAD(I)
        READ(4,*)FAD(I)
5    CONTINUE
      C1=0.0

      AE=0.02186
      AKE=1.142
      AS=0.9
      EPSE=1.0
      DR=63.0
C    UW=7.0
      AW=2.8
      BW=3.0
      EN=1.0
      F=0.45
      CV=0.0168*F
C    AP=103.0
C    BP=609.0
      DT=1.0
      BET=0.75
      BET1=1.0-BET
      ITE=365
      M1=M-1
      MP1=M+1
      MP2=M+2
```

```

ITL=100
RS=1.0
DO 20 J=1,M1
  RS=RS+AK**J
20  CONTINUE
  DX(1)=ALX/RS
  ALXX=DX(1)
  DO 21 J=2,M
    DX(J)=DX(J-1)*AK
    ALXX=ALXX+DX(J)
21  CONTINUE
  WRITE(5,*)' DX(1)  DX(200)  ALXX  ALX'
  WRITE(5,*)'-----'
  WRITE(5,12)DX(1),DX(M),ALXX,ALX
12  FORMAT(F8.5,2X,F8.5,2X,F8.5,2X,F8.5)
  WRITE(5,*)'-----'
  DO 19 K=1,MP2
    TI(K)=22.0
19  CONTINUE
  DX(MP1)=DX(M)
  CC=AE*DT
  DO 22 J=2,MP1
    J1=J-1
    CN1(J)=-2.0/(DX(J1)*(DX(J1)+DX(J)))*CC*BET
    CN2(J)=1.0+2.0/DX(J1)/DX(J)*CC*BET
    CN3(J)=-2.0/(DX(J1)+DX(J))/DX(J)*CC*BET
    CA1(J)=CC*BET1*2.0/DX(J1)/(DX(J1)+DX(J))
    CA2(J)=1.0-CC*BET1*2.0/DX(J1)/DX(J)
    CA3(J)=CC*BET1*2.0/DX(J)/(DX(J1)+DX(J))
22  CONTINUE
  ES1=-(2.0+AK)/(1.0+AK)/DX(1)
  ES2=(1.0+AK)/AK/DX(1)
  ES3=-1.0/(1.0+AK)/AK/DX(1)
  DO 23 J=1,MP1
    TN(J)=TI(J)
    TIN(J)=TI(J)
23  CONTINUE
  TN(MP2)=TN(M)
  I=0
  NY=1
100 CONTINUE
  I=I+1
  DO 101 J=1,MP1
    TA(J)=TN(J)
101 CONTINUE
  TA(MP2)=TA(M)
  QS=QSD(I)
  TAT=TAD(I)
  UA=UAD(I)
  FI=FAD(I)
  HA=AW+BW*UA**EN
  ALEC=CV*HA
  IT=0
103 CONTINUE
  IT=IT+1

```

```

IF(IT.GT.ITL) GO TO 500
DO 104 J=1,MP1
TNA(J)=TN(J)
104 CONTINUE
TNA(MP2)=TNA(M)
TS=TN(1)
TSS=C1*TA(1)+(1-C1)*TN(1)
IF (TAT.GT.30.0) GO TO 110
PA=288.68*(1.098+TAT/100.0)**8.024
GO TO 111
110 CONTINUE
PA=975.29*(0.9303+TAT/100.0)**7.094
111 CONTINUE
IF (TSS.GT.30.0) GO TO 112
PS=288.68*(1.098+TSS/100.0)**8.024
GO TO 113
112 CONTINUE
PS=975.29*(0.9303+TSS/100.0)**7.094
113 CONTINUE
AP=(PS-PA)/(TSS-TAT)
BP=PA-AP*TAT
ALE=ALEC*(BP-FI*(AP*TAT+BP))
ELD=HA*TAT+AS*QS-EPSE*DR-ALE
ESN1=-ES1*AKE+HA+ALEC*AP
ESN2=-ES2*AKE
ESN3=-ES3*AKE
DO 105 J=2,MP1
DN(J)=CA1(J)*TA(J-1)+CA2(J)*TA(J)+CA3(J)*TA(J+1)
105 CONTINUE
C-----MATRIX SOLUTION-----
W=CN1(2)/ESN1
B(2)=CN2(2)-W*ESN2
A(2)=CN3(2)-W*ESN3
D(2)=DN(2)-W*ELD
DO 106 J=3,M
J1=J-1
W=CN1(J)/B(J1)
B(J)=CN2(J)-W*A(J1)
A(J)=CN3(J)
D(J)=DN(J)-W*D(J1)
106 CONTINUE
BB=CN1(MP1)+CN3(MP1)
W=BB/B(M)
TN(MP1)=(W*D(M)-DN(MP1))/(W*A(M)-CN2(MP1))
DO 107 J=1,M1
JJ=MP1-J
TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
107 CONTINUE
TN(1)=(DN(2)-CN2(2)*TN(2)-CN3(2)*TN(3))/CN1(2)
TN(MP2)=TN(M)
C-----
DO 200 J=1,MP1
IF(ABS(TN(J)-TNA(J)).GT.0.01) GO TO 103
200 CONTINUE
TIME=I*DT

```



```

WRITE(5,*)NY,' TIME=',TIME
WRITE(5,*)'-----'
WRITE(5,13)(TN(J),J=1,MP2)
13  FORMAT(F8.2)
C13  FORMAT(F8.2,2X,F8.2,2X,F8.2,2X,F8.2,2X,F8.2)
WRITE(5,*)'-----'
WRITE(5,*)TIME,ITE
WRITE(5,*)'*****'
TE0(I)=TN(1)
TX10(I)=TN(MP1)
IF (I.EQ.ITE) GO TO 201
GO TO 100
201  CONTINUE
DO 205 J=1,MP1
IF(ABS(TN(J)-TIN(J)).GT.0.01) GO TO 202
205  CONTINUE
GO TO 203
202  CONTINUE
WRITE(5,*)'NY ENDS'
DO 204 J=1,MP1
TIN(J)=TN(J)
204  CONTINUE
I=0
NY=NY+1
GO TO 100
203  CONTINUE
WRITE(6,8)(TE0(I),I=1,365)
8  FORMAT(F8.2)
WRITE(5,14)NY,TIME
14  FORMAT('IY=',I2,7X,'TIME=',F7.1)
WRITE(5,*)'-----'
WRITE(5,*)'!!!!!!! CALCULATION ENDS !!!!!!!!'
WRITE(5,*)'-----'
500  CONTINUE
WRITE(5,15)IT,ITL
15  FORMAT('IT=',I4,4X,'ITL='I4)
C-----MEAN GROUND TEMPERATURE AT 10M DEPTH-----
MM=365
MMP1=MM+1
TX10(MMP1)=TX10(MM)
TXM2=(TX10(1)+3.0*TX10(2)+3.0*TX10(3)+TX10(4))/8.0
TTT1=TX10(4)+TX10(MMP1)
TTT2=0.0
DO 600 I=5,MM,2
TTT2=TTT2+TX10(I)
600  CONTINUE
TTT2=4.0*TTT2
TTT3=0.0
DO 601 I=6,MM,2
TTT3=TTT3+TX10(I)
601  CONTINUE
TTT3=2.0*TTT3
TXMM2=(TTT1+TTT2+TTT3)/(3.0*(MM-2.0))
TXM=(2.0*TXM2+TXMM2*(MM-2.0))/MM
TXT=0.0

```

```

DO 602 I=1,MM
  TXT=TX10(I)
602 CONTINUE
  TXMT=TX10/MM
  WRITE(5,*)'-----'
  WRITE(5,52)TXM,TXMT
52  FORMAT(2X,'TXM=',F6.2,4X,'TXMT=',F6.2)
C-----
c   WRITE (5,*)(TN(J),J=1,MP1)
c   WRITE (5,*)(TNA(J),J=1,MP1)
  STOP
  END

```

INPUT VALUES USED IN THE NUMERICAL PROGRAM PREPARED FOR ONE LAYER GROUND MODEL

TAD : The file of 20 years daily mean ambient temperatures

QSD : The file of 20 years daily mean solar radiation

UAD : The file of 20 years daily mean wind speed

FAD : The file of 20 years daily mean relative humidity

M : Step number in vertical direction

AK : Step increment coefficient

AE : Thermal diffusivity of ground

AKE : Thermal conductivity of ground

AS : Ground surface absorption coefficient

F : Evaporation fraction

DR : Long wave radiation

EPSE : Emission coefficient

SOME OF THE OUTPUT VALUES OBTAINED FROM THE NUMERICAL PROGRAM PREPARED FOR ONE LAYER GROUND MODEL

[illegible]

15 TIME= 364.0000

10.28 11.07 11.91 12.77 13.64 14.49 15.31 16.10
16.85 17.56 18.22 18.83 19.41 19.93 20.41 20.85
21.25 21.61 21.93 22.22 22.47 22.69 22.89 23.05
23.19 23.31 23.41 23.49 23.55 23.60 23.63 23.64
23.65 23.65 23.64 23.62 23.60 23.57 23.53 23.49
23.45 23.41 23.36 23.32 23.27 23.22 23.18 23.13
23.09 23.04 23.00 22.96 22.92 22.88 22.84 22.81
22.78 22.75 22.72 22.69 22.66 22.64 22.62 22.60
22.58 22.56 22.55 22.54 22.52 22.51 22.50 22.49
22.48 22.48 22.47 22.47 22.46 22.46 22.46 22.45
22.45 22.45 22.45 22.45 22.45 22.45 22.45 22.45
22.45 22.45 22.45 22.45 22.45 22.45 22.45 22.45
22.45 22.45 22.45 22.45 22.45

364.0000 365

15 TIME= 365.0000

10.53 11.22 11.99 12.80 13.63 14.45 15.25 16.02
16.76 17.46 18.12 18.74 19.31 19.84 20.32 20.76
21.16 21.53 21.85 22.14 22.40 22.63 22.83 23.00
23.14 23.27 23.37 23.45 23.52 23.56 23.60 23.62
23.63 23.63 23.62 23.61 23.58 23.56 23.52 23.49
23.45 23.40 23.36 23.32 23.27 23.22 23.18 23.13
23.09 23.04 23.00 22.96 22.92 22.88 22.85 22.81
22.78 22.75 22.72 22.69 22.67 22.64 22.62 22.60
22.58 22.57 22.55 22.54 22.53 22.51 22.50 22.49
22.49 22.48 22.47 22.47 22.46 22.46 22.46 22.45
22.45 22.45 22.45 22.45 22.45 22.45 22.45 22.45
22.45 22.45 22.45 22.45 22.45 22.45 22.45 22.45
22.45 22.45 22.45 22.45 22.45

365.0000 365

IY=15 TIME= 365.0

!!!!!!! CALCULATION ENDS !!!!!!!!

IT= 2 ITL= 100

TXM= 22.43 TXMT= 22.49

APPENDIX-2. PREPARED COMPUTER PROGRAM FOR TWO HORIZONTAL LAYER GROUND MODEL

```

PROGRAM NONLINEAR_SATURATION
DIMENSION TN(202),TA(202),TNA(202),DX(202),TI(202),TIN(202)
DIMENSION TE0(365),TE1(365),TE2(365),TE3(365),TX10(367)
DIMENSION TE4(365),TE5(365),TE6(365),TE7(365)
DIMENSION TAD(365),QSD(365),UAD(365),FAD(365),BAS(365)
DIMENSION A(202),B(202),D(202),DN(202),X(202)
DIMENSION CN1(202),CN2(202),CN3(202)
DIMENSION CA1(202),CA2(202),CA3(202)

OPEN(1,FILE='TAD.TXT')
OPEN(2,FILE='QSD.TXT')
OPEN(3,FILE='UAD.TXT')
OPEN(4,FILE='FAD.TXT')
OPEN(8,FILE='BAS09.TXT')
OPEN(5,FILE='TS.TXT')
OPEN(7,FILE='DX.TXT')
OPEN(6,FILE='TYS.TXT')

C----- M=200, ALX=10.0, AK=1.00 -----
C    READ(*,*) M,AK,LX
      M=50
      N=50
      ALX=0.5
      ALXB=10.0
      AK=1.0
C-----DATA ARE READING FROM THE FILES-----
      DO 5 I=1,365
        READ(1,*)TAD(I)
        READ(2,*)QSD(I)
        READ(3,*)UAD(I)
        READ(4,*)FAD(I)
        READ(8,*)BAS(I)
5      CONTINUE
      C1=0.0

C    AS=0.9
      AE=0.056
      AKE=1.3
      AEB=0.048
      AKB=0.87
      AKT=AKE
      AKBY=AKB/AKT
      AKTY=AKT/AKB
      EPSE=1.0
      DR=63.0
C    UW=7.0
      AW=2.8
      BW=3.0
      EN=1.0
      F=0.45
      CV=0.0168*F

```

```

C   AP=103.0
C   BP=609.0
      DT=1.0
      BET=0.75
      BET1=1.0-BET
      ITE=365
      M1=M-1
      MP1=M+1
      MP2=M+2
      MN=M+N
      MNP1=MN+1
      MNP2=MN+2
      MN1=MN-1
      N1=N-1
      NP1=N+1
      ITL=100
      RS=1.0
      DO 20 J=1,M1
        RS=RS+AK**J
20   CONTINUE
      DX(1)=ALX/RS
      ALXX=DX(1)
      DO 21 J=2,M
        DX(J)=DX(J-1)*AK
        ALXX=ALXX+DX(J)
21   CONTINUE
      WRITE(5,*)DX(1),DX(M),ALXX
      WRITE(5,*)'-----'
      DO 19 K=1,MNP2
        TI(K)=22.0
19   CONTINUE
      DAK1=0.001
      AK1=1.0-DAK1
25   CONTINUE
      JJ=JJ+1
      IF (ALXXB.GT.ALXB) GO TO 26
      AK1=AK1+DAK1
      RSB=1.0
      DO 18 J=1,N1
        RSB=RSB+AK1**J
18   CONTINUE
      DX(MP1)=DX(M)
      ALXXB=DX(M)
      DO 33 J=MP2,MN
        DX(J)=DX(J-1)*AK1
        ALXXB=ALXXB+DX(J)
33   CONTINUE
      IF (ALXXB.GE.(ALXB-DX(MN)).AND.ALXXB.LE.(ALXB+DX(MN))) GO TO 26
C   WRITE(5,*)ALXB,ALXXB,AK1
C   WRITE(5,*)'-----'
      GO TO 25
26   CONTINUE
      DXS=DX(M)/DX(MP1)
      WRITE(5,*)'AK1   ALXX   ALXXB   DX(1)  DX(M)
      *DX(MP1) DX(MN)'

```

```

WRITE(5,*)'-----'
WRITE(5,12)AK1,ALXX,ALXXB,DX(1),DX(M),DX(MP1),DX(MN)
WRITE(5,*)'*****'
DX(MNP1)=DX(MN)
C   WRITE(5,*) DX(1) DX(100) ALXX ALX'
C   WRITE(5,*)'-----'
C   WRITE(5,12)DX(1),DX(M),ALXX,ALX
C   WRITE(5,*)'-----'
C   WRITE(5,12)(DX(J),J=1,MNP1)
C   WRITE(5,*)'-----'
12  FORMAT(F8.5,X,F8.5,2X,F8.5,2X,F8.5,X,F8.5,X,F8.5,X,F8.5)
C   WRITE(5,*)'-----'
C-----DX LER YAZDIRILİYOR-----
C   X(1)=0.0
      DO 400 J=2,M
      X(J)=X(J-1)+DX(J-1)
400  CONTINUE
      DO 401 J=MP1,MNP1
      X(J)=X(J-1)+DX(J-1)
401  CONTINUE
      WRITE(7,16)(X(I),I=1,M)
      WRITE(7,16)(X(I),I=MP1,MNP1)
16  FORMAT(F9.5)
C-----
      CC=AE*DT
      CCB=AEB*DT
      DO 22 J=2,M
      J1=J-1
      CN1(J)=-2.0/(DX(J1)*(DX(J1)+DX(J)))*CC*BET
      CN2(J)=1.0+2.0/DX(J1)/DX(J)*CC*BET
      CN3(J)=-2.0/(DX(J1)+DX(J))/DX(J)*CC*BET
      CA1(J)=CC*BET1*2.0/DX(J1)/(DX(J1)+DX(J))
      CA2(J)=1.0-CC*BET1*2.0/DX(J1)/DX(J)
      CA3(J)=CC*BET1*2.0/DX(J)/(DX(J1)+DX(J))
22  CONTINUE
      DO 32 J=MP2,MNP1
      J1=J-1
      CN1(J)=-2.0/(DX(J1)*(DX(J1)+DX(J)))*CCB*BET
      CN2(J)=1.0+2.0/DX(J1)/DX(J)*CCB*BET
      CN3(J)=-2.0/(DX(J1)+DX(J))/DX(J)*CCB*BET
      CA1(J)=CCB*BET1*2.0/DX(J1)/(DX(J1)+DX(J))
      CA2(J)=1.0-CCB*BET1*2.0/DX(J1)/DX(J)
      CA3(J)=CCB*BET1*2.0/DX(J)/(DX(J1)+DX(J))
32  CONTINUE
      ES1=-(2.0+AK)/(1.0+AK)/DX(1)
      ES2=(1.0+AK)/AK/DX(1)
      ES3=-1.0/(1.0+AK)/AK/DX(1)
      CN1(MP1)=1.0
      CN2(MP1)=-1.0+AKBY*DXS
      CN3(MP1)=AKBY*DXS
      CA1(MP1)=0.0
      CA2(MP1)=0.0
      CA3(MP1)=0.0
      DO 23 J=1,MNP1
      TN(J)=TI(J)

```

```

23      TIN(J)=TI(J)
      CONTINUE
      TN(MNP2)=TN(MN)
      I=0
      NY=1
100     CONTINUE
      I=I+1
      DO 101 J=1,MNP1
      TA(J)=TN(J)
101     CONTINUE
      TA(MNP2)=TA(MN)
      QS=QSD(I)
      TAT=TAD(I)
      UA=UAD(I)
      FI=FAD(I)
      AS=BAS(I)
      HA=AW+BW*UA**EN
      ALEC=CV*HA
      IT=0
103     CONTINUE
      IT=IT+1
      IF(IT.GT.ITL) GO TO 500
      DO 104 J=1,MNP1
      TNA(J)=TN(J)
104     CONTINUE
      TNA(MNP2)=TNA(MN)
      TS=TN(1)
      TSS=C1*TA(1)+(1-C1)*TN(1)
      IF (TAT.GT.30.0) GO TO 110
      PA=288.68*(1.098+TAT/100.0)**8.024
      GO TO 111
110     CONTINUE
      PA=975.29*(0.9303+TAT/100.0)**7.094
111     CONTINUE
      IF (TSS.GT.30.0) GO TO 112
      PS=288.68*(1.098+TSS/100.0)**8.024
      GO TO 113
112     CONTINUE
      PS=975.29*(0.9303+TSS/100.0)**7.094
113     CONTINUE
      AP=(PS-PA)/(TSS-TAT)
      BP=PA-AP*TAT
      ALE=ALEC*(BP-FI*(AP*TAT+BP))
      ELD=HA*TAT+AS*QS-EPSE*DR-ALE
      ESN1=-ES1*AKE+HA+ALEC*AP
      ESN2=-ES2*AKE
      ESN3=-ES3*AKE
      DO 105 J=2,M
      DN(J)=CA1(J)*TA(J-1)+CA2(J)*TA(J)+CA3(J)*TA(J+1)
105     CONTINUE
      DN(MP1)=0.0
      DO 305 J=MP2,MNP1
      DN(J)=CA1(J)*TA(J-1)+CA2(J)*TA(J)+CA3(J)*TA(J+1)
305     CONTINUE
C-----MATRIX SOLUTION-----

```



```

W=CN1(2)/ESN1
B(2)=CN2(2)-W*ESN2
A(2)=CN3(2)-W*ESN3
D(2)=DN(2)-W*ELD
DO 106 J=3,MN
  J1=J-1
  W=CN1(J)/B(J1)
  B(J)=CN2(J)-W*A(J1)
  A(J)=CN3(J)
  D(J)=DN(J)-W*D(J1)
106 CONTINUE
BB=CN1(MNP1)+CN3(MNP1)
W=BB/B(MN)
TN(MNP1)=(W*D(MN)-DN(MNP1))/(W*A(MN)-CN2(MNP1))
DO 107 J=1,MN1
  JJ=MNP1-J
  TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
107 CONTINUE
TN(1)=(DN(2)-CN2(2)*TN(2)-CN3(2)*TN(3))/CN1(2)
TN(MNP2)=TN(MN)
C WRITE(7,13)(TN(J),J=1,MNP1)
C-----
DO 200 J=1,MNP1
IF(ABS(TN(J)-TNA(J)).GT.0.01) GO TO 103
200 CONTINUE
TIME=I*DT
WRITE(5,*)NY,' TIME=',TIME
WRITE(5,*)'-----'
WRITE(5,13)(TN(J),J=1,MNP1)
13 FORMAT(F8.2)
C13 FORMAT(F8.2,2X,F8.2,2X,F8.2,2X,F8.2,2X,F8.2)
WRITE(5,*)'-----'
WRITE(5,*)TIME,ITE
WRITE(5,*)'*****'
TE0(I)=TN(1)
TX10(I)=TN(MP1)
IF (I.EQ.ITE) GO TO 201
GO TO 100
201 CONTINUE
DO 205 J=1,MNP1
IF(ABS(TN(J)-TIN(J)).GT.0.01) GO TO 202
205 CONTINUE
GO TO 203
202 CONTINUE
WRITE(5,*)'NY ENDS'
DO 204 J=1,MNP1
  TIN(J)=TN(J)
204 CONTINUE
I=0
NY=NY+1
GO TO 100
203 CONTINUE
WRITE(6,8)(TE0(I),I=1,365)
8 FORMAT(F8.2)
WRITE(5,14)NY,TIME

```

```

14    FORMAT('IY=',I2,7X,'TIME=',F7.1)
      WRITE(5,*)'-----'
      WRITE(5,*)'!!!!!!! CALCULATION ENDS !!!!!!!!'
      WRITE(5,*)'-----'
500   CONTINUE
      WRITE(5,15)IT,ITL
15    FORMAT('IT=',I4,4X,'ITL='I4)
C-----MEAN GROUND TEMPERATURE AT 10M DEPTH-----
      MM=365
      MMP1=MM+1
      TX10(MMP1)=TX10(MM)
      TXM2=(TX10(1)+3.0*TX10(2)+3.0*TX10(3)+TX10(4))/8.0
      TTT1=TX10(4)+TX10(MMP1)
      TTT2=0.0
      DO 600 I=5,MM,2
        TTT2=TTT2+TX10(I)
600   CONTINUE
      TTT2=4.0*TTT2
      TTT3=0.0
      DO 601 I=6,MM,2
        TTT3=TTT3+TX10(I)
601   CONTINUE
      TTT3=2.0*TTT3
      TXMM2=(TTT1+TTT2+TTT3)/(3.0*(MM-2.0))
      TXM=(2.0*TXM2+TXMM2*(MM-2.0))/MM
      TXT=0.0
      DO 602 I=1,MM
        TXT=TXT+TX10(I)
602   CONTINUE
      TXMT=TXT/MM
      WRITE(5,*)'-----'
      WRITE(5,52)TXM,TXMT
52    FORMAT(2X,'TXM=',F6.2,4X,'TXMT=',F6.2)
C-----
      STOP
      END

```

INPUT VALUES USED IN THE NUMERICAL PROGRAM PREPARED FOR TWO HORIZONTAL LAYER GROUND MODEL

TAD : The file of 20 years daily mean ambient temperatures

QSD : The file of 20 years daily mean solar radiation

UAD : The file of 20 years daily mean wind speed

FAD : The file of 20 years daily mean relative humidity

BAS : The file of ground surface absorption coefficient

M : Upper layer step number

N : Lower layer step number

ALX : Thick of upper layer

ALXB : Thick of lower layer

AK : Step increment coefficient of upper layer

AE : Thermal diffusivity of upper layer

AKE : Thermal conductivity of upper layer

AEB : Thermal diffusivity of lower layer

AKB : Thermal conductivity of lower layer

AS : Ground surface absorption coefficient

F : Evaporation fraction

DR : Long wave radiation

EPSE : Emission coefficient

**SOME OF THE OUTPUT VALUES OBTAINED FROM THE NUMERICAL
PROGRAM PREPARED FOR TWO HORIZONTAL LAYER GROUND
MODEL**

AK1	ALXX	ALXXB	DX(1)	DX(M)	DX(MP1)	DX(MN)
1.09400	0.50000	9.39541	0.01000	0.01000	0.01000	0.81646

1 TIME= 1.000000						

13.13	14.02	14.82	15.54	16.18	16.76	17.29
17.76	18.18	18.56	18.91	19.22	19.50	19.75
19.97	20.36	20.52	20.67	20.80	20.92	21.03
21.13	21.29	21.36	21.43	21.48	21.53	21.58
21.62	21.69	21.72	21.75	21.77	21.80	21.82
21.83	21.86	21.87	21.89	21.90	21.90	21.91
21.92	21.93	21.93	21.93	21.94	21.94	21.94
21.95	21.95	21.96	21.96	21.97	21.97	21.97
21.98	21.98	21.99	21.99	21.99	21.99	22.00
22.00	22.00	22.00	22.00	22.00	22.00	22.00
22.00	22.00	22.00	22.00	22.00	22.00	22.00
22.00	22.00	22.00	22.00	22.00	22.00	22.00
22.00	22.00	22.00	22.00	22.00	22.00	22.00

1.000000		365				
.						
.						
.						
8 TIME= 364.0000						

9.50	9.54	9.58	9.63	9.69	9.75	9.81
9.87	9.94	10.00	10.07	10.14	10.21	10.28
10.35	10.50	10.57	10.64	10.72	10.79	10.87
10.94	11.09	11.16	11.23	11.31	11.38	11.45
11.52	11.67	11.74	11.81	11.88	11.95	12.02
12.09	12.23	12.29	12.36	12.43	12.49	12.56
12.62	12.75	12.81	12.87	12.94	13.00	13.08
13.16	13.34	13.45	13.56	13.68	13.82	13.96
14.12	14.48	14.68	14.90	15.13	15.39	15.66
15.95	16.60	16.95	17.33	17.73	18.14	18.58
19.03	19.96	20.43	20.90	21.36	21.81	22.22
22.60	23.22	23.44	23.59	23.67	23.68	23.62
23.50	23.15	22.96	22.79	22.67	22.62	

364.0000		365				

8 TIME= 365.0000

9.83	9.87	9.90	9.94	9.98	10.02	10.07	10.11
10.16	10.21	10.26	10.31	10.37	10.43	10.48	10.54
10.60	10.66	10.73	10.79	10.85	10.92	10.98	11.05
11.11	11.18	11.25	11.31	11.38	11.45	11.51	11.58
11.65	11.72	11.78	11.85	11.92	11.98	12.05	12.11
12.18	12.24	12.31	12.37	12.43	12.50	12.56	12.62
12.68	12.75	12.81	12.87	12.93	13.01	13.08	13.17
13.26	13.37	13.48	13.60	13.73	13.88	14.03	14.20
14.39	14.58	14.80	15.03	15.28	15.55	15.84	16.16
16.49	16.84	17.22	17.61	18.03	18.46	18.91	19.38
19.85	20.33	20.80	21.27	21.72	22.14	22.53	22.88
23.17	23.39	23.56	23.64	23.66	23.61	23.50	23.34
23.15	22.97	22.80	22.68	22.63			

365.0000 365

IY= 8 TIME= 365.0

!!!!!!! CALCULATION ENDS !!!!!!!!

IT= 2 ITL= 100

TXM= 22.40 TXMT= 22.44

APPENDIX-3. PREPARED COMPUTER PROGRAM FOR TWO VERTICAL LAYER GROUND MODEL

```

PROGRAM VERTICAL GROUND LAYER TEMPERATURES
DIMENSION TAD(365),QSD(365),UAD(365),FAD(365)
DIMENSION TN(103),TA(103),TNA(103),TI(103)
DIMENSION TDX(103,103),TDY(103,103),TIN(103,103),TTNA1(103,103)
DIMENSION TTN(103,103),TTNA(103,103),TTNAXX(103,103)
DIMENSION TTNAYY(103,103),TTA(103,103),TAXY2(103,103)
DIMENSION TTNK(103,103),TTNY(103,103)
DIMENSION CNY1(103),CNY2(103),CNY3(103),DY(103)
DIMENSION A(103),B(103),D(103),DN(103),DX(103)
DIMENSION AXA1(103),AXA2(103),AXA3(103),AY1(103),AY2(103),AY3(103)
DIMENSION AXB1(103),AXB2(103),AXB3(103)
DIMENSION CNXA1(103),CNXA3(103),CNXA2(103)
DIMENSION CA1(103),CA2(103),CA3(103)
DIMENSION CNXB1(103),CNXB3(103),CNXB2(103)

OPEN(1,FILE='TAD.TXT')
OPEN(2,FILE='QSD.TXT')
OPEN(3,FILE='UAD.TXT')
OPEN(4,FILE='FAD.TXT')

OPEN(5,FILE='TS.TXT')
C----- M=200, ALX=10.0, AK=1.00 -----
C----- READ(*,*) M,AK,LX -----
TIMEE=364.0
M=40
NA=20
NB=20
EPTE=0.01
ALX=10.0
ALY=4.0
ALYA=2.0
ALYB=ALY-ALYA
N=NA+NB
NAD=N/N
MAD=M/M
NAP1=NA+1
NAP2=NA+2
NAP3=NA+3
NAP4=NA+4
NBP1=NB+1
NA1=NA-1
NB1=NB-1
NP1=N+1
NP2=N+2
NP3=N+3
AKYA=1.05
AKYB=1.05
AKX=1.05
EPRS=0.0001
ADA=0.098
AKA=2.93

```

```

      ADB=0.056
      AKB=1.3
      AKAB=AKB/AKA
C-----DATA ARE READING FROM THE FILES-----
      DO 5 I=1,365
      READ(1,*)TAD(I)
      READ(2,*)QSD(I)
      READ(3,*)UAD(I)
      READ(4,*)FAD(I)
5      CONTINUE
      C1=1.0
      AS=0.9
      F=0.45
      EPSE=1.0
      DR=63.0
      UW=7.0
      AW=2.8
      BW=3.0
      EN=1.0
      CV=0.0168*F
      DT=1.0
      BET=0.5
      BET1=1.0-BET
      BETF=BET1/BET
      BBA=1.0/(DT*ADA*BET)
      BBB=1.0/(DT*ADB*BET)
      ITE=365
      M1=M-1
      MP1=M+1
      MP2=M+2
      ITL=100
      RS=1.0
      DO 30 J=1,M1
      RS=RS+AKX**J
30      CONTINUE
      DX(1)=ALX/RS
      ALXX=DX(1)
      DO 31 J=2,M
      DX(J)=DX(J-1)*AKX
      ALXX=ALXX+DX(J)
31      CONTINUE
      WRITE(5,*)ALX,ALXX,DX(1),DX(M)
      DX(MP1)=DX(M)
C      WRITE(5,*)(DX(J),J=1,MP1)
      RS=1.0
      DO 24 K=1,NA1
      RS=RS+AKYA**K
24      CONTINUE
      DY(NAP1)=ALYA/RS
      ALYAY=DY(NAP1)
      DO 25 K=1,NA1
      J=NAP1-K
      DY(J)=DY(J+1)*AKYA
      ALYAY=ALYAY+DY(J)
25      CONTINUE

```

```

DY(1)=DY(2)
  WRITE(5,*)ALYA,ALYAY,DY(2),DY(NAP1)
  DY(NAP2)=DY(NAP1)
RSR=ALYB/DY(NAP2)
  EMB=RSR
  ANB=1.0*NB
  IF(ANB.LT.EMB) GO TO 60
C  WRITE(5,*) EMB,ANB
60  CONTINUE
  RS=1.0
  AKYB=1.01
  ITRS=0
28  CONTINUE
  ITRS=ITRS+1
  IF(ITRS.GT.100) GO TO 502
  DO 26 K=1,NB1
    RS=RS+AKYB**K
26  CONTINUE
  WRITE(5,*)ITRS,AKYB,RS,RSR
  IF (ABS(1.0-RS/RSR).LT.EPRS) GO TO 27
    AKYB=1.0+(RSR-1.0*NB)*(AKYB-1.0)/(RS-1.0*NB)
  RS=1
  GO TO 28
27  CONTINUE
  ALYBY=DY(NAP2)
  DO 29 K=NAP3,NP1
    DY(K)=DY(K-1)*AKYB
    ALYBY=ALYBY+DY(K)
29  CONTINUE
  DY(NP2)=DY(NP1)
C  WRITE(5,*)(DY(K),K=1,NP2)
  WRITE(5,*)DY(1),DY(NAP1),DY(NAP2),DY(NP1),ALYB,ALYBY
C  WRITE(5,*)(DY(K),K=1,NP2)
  DO 39 J=2,MP1
    AXA1(J)=2.0/DX(J-1)/(DX(J-1)+DX(J))/BBA
    AXA2(J)=-2.0/DX(J-1)/DX(J)/BBA
    AXA3(J)=2.0/DX(J)/(DX(J-1)+DX(J))/BBA
39  CONTINUE
  DO 40 J=2,MP1
    AXB1(J)=2.0/DX(J-1)/(DX(J-1)+DX(J))/BBB
    AXB2(J)=-2.0/DX(J-1)/DX(J)/BBB
    AXB3(J)=2.0/DX(J)/(DX(J-1)+DX(J))/BBB
40  CONTINUE
  DO 38 K=2,NAP1
    AY1(K)=2.0/DY(K-1)/(DY(K-1)+DY(K))/BBA
    AY2(K)=-2.0/DY(K-1)/DY(K)/BBA
    AY3(K)=2.0/DY(K)/(DY(K-1)+DY(K))/BBA
38  CONTINUE
  DO 32 K=NAP3,NP2
    AY1(K)=2.0/DY(K-1)/(DY(K-1)+DY(K))/BBB
    AY2(K)=-2.0/DY(K-1)/DY(K)/BBB
    AY3(K)=2.0/DY(K)/(DY(K-1)+DY(K))/BBB
32  CONTINUE
  DO 11 J=1,MP2
    TI(J)=20.0

```



```

11    CONTINUE
      DO 22 J=2,MP1
      CNXA1(J)=-AXA1(J)
      CNXA2(J)=1.0-AXA2(J)
      CNXA3(J)=-AXA3(J)
      CNXB1(J)=-AXB1(J)
      CNXB2(J)=1.0-AXB2(J)
      CNXB3(J)=-AXB3(J)
22    CONTINUE
      ES1=-(2.0+AKX)/(1.0+AKX)/DX(1)
      ES2=(1.0+AKX)/AKX/DX(1)
      ES3=-1.0/(1.0+AKX)/AKX/DX(1)
      DO 23 K=1,NP3
      DO 23 J=1,MP2
        TTN(K,J)=TI(J)
23    CONTINUE
      DO 37 K=2,NAP1
      CNY1(K)=-AY1(K)
      CNY2(K)=1.0-AY2(K)
      CNY3(K)=-AY3(K)
37    CONTINUE
      DO 21 K=NAP3,NP2
      CNY1(K)=-AY1(K)
      CNY2(K)=1.0-AY2(K)
      CNY3(K)=-AY3(K)
21    CONTINUE
      CNY1(NAP2)=-1.0
      CNY2(NAP2)=1.0+AKAB
      CNY3(NAP2)=-AKAB

      NY=1
      I=0
100   CONTINUE
      IF(I.NE.2) GO TO 74
      DO 71 K=2,NP2
      DO 71 J=1,MP1
        TTNK(K,J)=TTN(K,J)
71    CONTINUE
74    CONTINUE
      IF(I.NE.183) GO TO 73
      DO 72 K=2,NP2
      DO 72 J=1,MP1
        TTNK(K,J)=TTN(K,J)
72    CONTINUE
73    CONTINUE
      I=I+1
      TIME=I*DT
      QS=QSD(I)
      TAT=TAD(I)
      UA=UAD(I)
      FI=FAD(I)
      HA=AW+BW*UA**EN
      ALEC=CV*HA
      IF (TAT.GT.30.0) GO TO 110
      PA=288.68*(1.098+TAT/100.0)**8.024

```

```

GO TO 111
110 CONTINUE
    PA=975.29*(0.9303+TAT/100.0)**7.094
111 CONTINUE

    DO 101 K=1,NP3
    DO 101 J=1,MP2
        TTA(K,J)=TTN(K,J)
101 CONTINUE

    DO 105 K=2,NAP1
    DO 105 J=2,MP1
        TAXY2(K,J)=(AXA3(J)*TTA(K,J+1)+AXA2(J)*TTA(K,J)+AXA1(J)*TTA(K,J-1)+
* AY3(K)*TTA(K+1,J)+AY2(K)*TTA(K,J)+AY1(K)*TTA(K-1,J))
105 CONTINUE
    DO 106 K=NAP3,NP2
    DO 106 J=2,MP1
        TAXY2(K,J)=(AXB3(J)*TTA(K,J+1)+AXB2(J)*TTA(K,J)+AXB1(J)*TTA(K,J-1)+
* AY3(K)*TTA(K+1,J)+AY2(K)*TTA(K,J)+AY1(K)*TTA(K-1,J))
106 CONTINUE

    IT=0
401 CONTINUE
    IT=IT+1
    WRITE(5,*)'IT=',IT
C    DO 703 K=1,NP3
C    WRITE(5,*)(TTN(K,J),J=1,MP2)
C703 CONTINUE
    IF (IT.GT.ITL) GO TO 501

    DO 402 K=1,NP3
    DO 402 J=1,MP2
        TTNA(K,J)=TTN(K,J)
        TTNA1(K,J)=TTN(K,J)
402 CONTINUE

    DO 107 K=2,NAP1
    DO 107 J=1,MP1
        TTNAYY(K,J)=(AY3(K)*TTNA(K+1,J)+
* AY1(K)*TTNA(K-1,J)+AY2(K)*TTNA(K,J))
107 CONTINUE
    DO 108 K=NAP3,NP2
    DO 108 J=1,MP1
        TTNAYY(K,J)=AY3(K)*TTNA(K+1,J)+
* AY1(K)*TTNA(K-1,J)+AY2(K)*TTNA(K,J)
108 CONTINUE

    DO 109 K=2,NAP1
    DO 109 J=2,MP1
        TDX(K,J)=(TTA(K,J)+TTNAYY(K,J)+BETF*TAXY2(K,J))
109 CONTINUE
    DO 114 K=NAP3,NP2
    DO 114 J=2,MP1
        TDX(K,J)=(TTA(K,J)+TTNAYY(K,J)+BETF*TAXY2(K,J))
114 CONTINUE

```

```

C403  CONTINUE
      DO 120 K=2,NAP1
      DO 104 J=1,MP2
        TN(J)=TTN(K,J)
104   CONTINUE
      ITJ=0
103   CONTINUE
      ITJ=ITJ+1
      IF (ITJ.GT.ITL) GO TO 501
      DO 102 J=1,MP2
        TNA(J)=TN(J)
102   CONTINUE
      TSS=C1*TTA(K,1)+(1-C1)*TTNA(K,1)
      IF (TSS.GT.30.0) GO TO 112
      PS=288.68*(1.098+TSS/100.0)**8.024
      GO TO 113
112   CONTINUE
      PS=975.29*(0.9303+TSS/100.0)**7.094
113   CONTINUE
      AP=(PS-PA)/(TSS-TAT)
      BP=PA-AP*TAT
      ALE=ALEC*(BP-FI*(AP*TAT+BP))
      ELD=HA*TAT+AS*QS-EPSE*DR-ALE
      ESN1=-ES1*AKA+HA+ALEC*AP
      ESN2=-ES2*AKA
      ESN3=-ES3*AKA
C-----MATRIX SOLUTION-----
      DO 116 J=2,MP1
        DN(J)=TDX(K,J)
116   CONTINUE
      W=CNXA1(2)/ESN1
      B(2)=CNXA2(2)-W*ESN2
      A(2)=CNXA3(2)-W*ESN3
      D(2)=DN(2)-W*ELD
      DO 118 J=3,M
        J1=J-1
        W=CNXA1(J)/B(J1)
        B(J)=CNXA2(J)-W*A(J1)
        A(J)=CNXA3(J)
        D(J)=DN(J)-W*D(J1)
118   CONTINUE
      BB=CNXA1(MP1)+CNXA3(MP1)
      W=BB/B(M)
      TN(MP1)=(W*D(M)-DN(MP1))/(W*A(M)-CNXA2(MP1))
      DO 117 J=1,M1
        JJ=MP1-J
        TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
117   CONTINUE
      TN(1)=(DN(2)-CNXA2(2)*TN(2)-CNXA3(2)*TN(3))/CNXA1(2)
      TN(MP2)=TN(M)
C-----
      DO 200 J=1,MP1
        IF(ABS(TN(J)-TNA(J)).GT.EPTE) GO TO 103
200   CONTINUE

```

```

C405  CONTINUE
      DO 115 J=1,MP2
        TTN(K,J)=TN(J)
115   CONTINUE
120   CONTINUE
      DO 620 K=NAP3,NP2
        DO 606 J=1,MP2
          TN(J)=TTN(K,J)
606   CONTINUE
        ITJ=0
603   CONTINUE
        ITJ=ITJ+1
        IF (ITJ.GT.ITL) GO TO 501
        DO 602 J=1,MP2
          TNA(J)=TN(J)
602   CONTINUE
        TSS=C1*TTA(K,1)+(1-C1)*TTNA(K,1)
        IF (TSS.GT.30.0) GO TO 612
        PS=288.68*(1.098+TSS/100.0)**8.024
        GO TO 613
612   CONTINUE
        PS=975.29*(0.9303+TSS/100.0)**7.094
613   CONTINUE
        AP=(PS-PA)/(TSS-TAT)
        BP=PA-AP*TAT
        ALE=ALEC*(BP-FI*(AP*TAT+BP))
        ELD=HA*TAT+AS*QS-EPSE*DR-ALE
        ESN1=-ES1*AKB+HA+ALEC*AP
        ESN2=-ES2*AKB
        ESN3=-ES3*AKB
C-----MATRIX SOLUTION-----
      DO 616 J=2,MP1
        DN(J)=TDX(K,J)
616   CONTINUE
        W=CNXB1(2)/ESN1
        B(2)=CNXB2(2)-W*ESN2
        A(2)=CNXB3(2)-W*ESN3
        D(2)=DN(2)-W*ELD
        DO 618 J=3,M
          J1=J-1
          W=CNXB1(J)/B(J1)
          B(J)=CNXB2(J)-W*A(J1)
          A(J)=CNXB3(J)
          D(J)=DN(J)-W*D(J1)
618   CONTINUE
        BB=CNXB1(MP1)+CNXB3(MP1)
        W=BB/B(M)
        TN(MP1)=(W*D(M)-DN(MP1))/(W*A(M)-CNXB2(MP1))
        DO 617 J=1,M1
          JJ=MP1-J
          TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
617   CONTINUE
        TN(1)=(DN(2)-CNXB2(2)*TN(2)-CNXB3(2)*TN(3))/CNXB1(2)
        TN(MP2)=TN(M)
C-----

```

```

DO 600 J=1,MP1
  IF(ABS(TN(J)-TNA(J)).GT.EPTE) GO TO 603
600  CONTINUE
C405  CONTINUE
      DO 615 J=1,MP2
        TTN(K,J)=TN(J)
615  CONTINUE
620  CONTINUE
406  CONTINUE
      DO 130 J=1,MP2
        TTN(NAP2,J)=(TTN(NAP1,J)+AKAB*TTN(NAP3,J))/(1.0+AKAB)
130  CONTINUE
      DO 700 J=1,MP2
        TTN(1,J)=TTN(3,J)
        TTN(NP3,J)=TTN(NP1,J)
700  CONTINUE

      DO 701 K=1,NP3
        DO 701 J=1,NP2
          TTNA(K,J)=TTN(K,J)
701  CONTINUE
        DO 207 K=2,NAP1
          DO 207 J=2,MP1
            TTNAXX(K,J)=AXA3(J)*TTNA(K,J+1)+
* AXA1(J)*TTNA(K,J-1)+AXA2(J)*TTNA(K,J)
207  CONTINUE
          DO 208 K=NAP3,NP2
            DO 208 J=2,MP1
              TTNAXX(K,J)=AXB3(J)*TTNA(K,J+1)+
* AXB1(J)*TTNA(K,J-1)+AXB2(J)*TTNA(K,J)
208  CONTINUE

          DO 209 K=2,NAP1
            DO 209 J=2,MP1
              TDY(K,J)=TTA(K,J)+TTNAXX(K,J)+BETF*TAXY2(K,J)
209  CONTINUE
            DO 210 K=NAP3,NP2
              DO 210 J=2,MP1
                TDY(K,J)=TTA(K,J)+TTNAXX(K,J)+BETF*TAXY2(K,J)
210  CONTINUE
            DO 212 J=2,MP1
              TDY(NAP2,J)=0.0
212  CONTINUE
            B(2)=CNY2(2)
            A(2)=CNY3(2)+CNY1(2)
            DO 220 J=2,MP1
              DO 304 K=2,NP2
                TN(K)=TTN(K,J)
304  CONTINUE
                ITK=0
303  CONTINUE
                ITK=ITK+1
                IF (ITK.GT.ITL) GO TO 501
                DO 302 K=2,NP2
                  TNA(K)=TN(K)

```

```

302 CONTINUE
      DO 213 K=2,NP2
        DN(K)=TDY(K,J)
213  CONTINUE
      D(2)=TDY(2,J)
      D(NAP2)=0.0
      A(2)=CNY1(2)+CNY3(2)
      B(2)=CNY2(2)
      DO 206 K=3,NP1
        DN(K)=TDY(K,J)
        K1=K-1
        W=CNY1(K)/B(K1)
        B(K)=CNY2(K)-W*A(K1)
        A(K)=CNY3(K)
        D(K)=DN(K)-W*D(K1)
206  CONTINUE
      BB=CNY1(NP2)+CNY3(NP2)
      W=BB/B(NP1)
      TN(NP2)=(W*D(NP1)-DN(NP2))/(W*A(NP1)-CNY2(NP2))
      DO 211 K=1,N
        KK=NP2-K
        TN(KK)=(-A(KK)*TN(KK+1)+D(KK))/B(KK)
211  CONTINUE
      TN(1)=TN(3)
      TN(NP3)=TN(NP1)
      DO 300 K=2,NP2
        IF (ABS(TN(K)-TNA(K)).GT.EPTE) GO TO 303
300  CONTINUE
      DO 315 K=1,NP3
        TTN(K,J)=TN(K)
315  CONTINUE
220  CONTINUE
      DO 321 K=1,NP3
        TTN(K,MP2)=TTN(K,M)
321  CONTINUE
C      GO TO 411
      DO 322 K=1,NP3
        IF (K.EQ.NAP2) GO TO 322
        TSS=C1*TTA(K,1)+(1-C1)*TTN(K,1)
        IF (TSS.GT.30.0) GO TO 119
        PS=288.68*(1.098+TSS/100.0)**8.024
        GO TO 121
119  CONTINUE
        PS=975.29*(0.9303+TSS/100.0)**7.094
121  CONTINUE
      AP=(PS-PA)/(TSS-TAT)
      BP=PA-AP*TAT
      ALE=ALEC*(BP-FI*(AP*TAT+BP))
      ELD=HA*TAT+AS*QS-EPSE*DR-ALE
      IF (K.GT.NAP1) GO TO 409
      ESN1=-ES1*AKA+HA+ALEC*AP
      ESN2=-ES2*AKA
      ESN3=-ES3*AKA
      GO TO 410
409  CONTINUE

```

```

        ESN1=-ES1*AKB+HA+ALEC*AP
        ESN2=-ES2*AKB
        ESN3=-ES3*AKB
410    CONTINUE
        TTN(K,1)=(-ESN2*TTN(K,2)-ESN3*TTN(K,3)+ELD)/ESN1
322    CONTINUE

        TTN(NAP2,1)=(4.0*TTN(NAP1,1)+4.0*AKAB*TTN(NAP3,1)-TTN(NA,1)-
* AKAB*TTN(NAP4,1))/(3.0*(1.0+AKAB))
411    CONTINUE
        DO 400 K=2,NP2
        DO 400 J=1,MP1
            IF (ABS(TTN(K,J)-TTNA1(K,J)).LT.EPTE) GO TO 399
C      WRITE(5,*)K,J
        GO TO 401
399    CONTINUE
400    CONTINUE
C800   CONTINUE
        IF (I.EQ.365) GO TO 803
        GO TO 100
803    CONTINUE
        IF (NY.EQ.1) GO TO 805
        DO 806 K=2,NP2
        DO 806 J=1,MP1
            IF (ABS(TTN(K,J)-TIN(K,J)).GT.EPTE) GO TO 805
806    CONTINUE
        GO TO 807
805    CONTINUE
        WRITE(5,335)NY,I
335    FORMAT(2X,'NY=',I2,4X,'I=',I3)
        DO 809 K=2,NP2,NAD
        WRITE(5,333)(TTN(K,J),J=1,MP1,MAD)
809    CONTINUE
        NY=NY+1
        DO 804 K=2,NP2
        DO 804 J=1,MP1
            TIN(K,J)=TTN(K,J)
804    CONTINUE
        I=0
        GO TO 100
807    CONTINUE
        WRITE(5,*)'-----CALCULATION ENDS-----'
        WRITE(5,334)NY,I
334    FORMAT(2X,'NY=',I2,4X,'I=',I3)
        DO 808 K=2,NP2,NAD
        WRITE(5,333)(TTN(K,J),J=1,MP1,MAD)
808    CONTINUE
        DO 811 K=2,NP2,NAD
        WRITE(5,333)(TTNK(K,J),J=1,MP1,MAD)
811    CONTINUE
        DO 810 K=2,NP2,NAD
        WRITE(5,333)(TTNY(K,J),J=1,MP1,MAD)
810    CONTINUE
        WRITE(5,*)'-----CALCULATION ENDS-----'
        WRITE(5,334)NY,I

```

```

501 CONTINUE
      WRITE(5,340)IT,ITJ,ITK
340   FORMAT('IT=',I3,3X,'ITJ=',I2,3X,'ITK=',I2)
502   CONTINUE
      WRITE(5,341)I,TIME
341   FORMAT('I=',I3,3X,'TIME=',F5.1)
      WRITE(5,*)'*****'
333   FORMAT(15(F5.2,3X))
      STOP
      END

```


INPUT VALUES USED IN THE NUMERICAL PROGRAM PREPARED FOR TWO VERTICAL LAYER GROUND MODEL

TAD : The file of 20 years daily mean ambient temperatures
QSD : The file of 20 years daily mean solar radiation
UAD : The file of 20 years daily mean wind speed
FAD : The file of 20 years daily mean relative humidity
M : Step number in vertical
NA : Step numbers in horizontal for 1st layer in vertical
NB : Step numbers in horizontal for 2nd layer in vertical
ALX : Ground depth in vertical direction
ALY : Ground depth in horizontal direction
ALYA: Thick of 1st layer in horizontal direction
ALYB: Thick of 2nd layer in horizontal direction
AKYA: Step increment coefficient for 1st layer in horizontal direction
AKYB: Step increment coefficient for 2nd layer in horizontal direction
AKX : Step increment coefficient for the layer in vertical direction
ADA : Thermal diffusivity of 1st layer in vertical direction
AKA : Thermal conductivity of 2nd layer in vertical direction
ADB : Thermal diffusivity of 1st layer in vertical direction
AKB : Thermal conductivity of 2nd layer in vertical direction
AS : Ground surface absorption coefficient
F : Evaporation fraction
DR : Long wave radiation
EPSE : Emission coefficient

SOME OF THE OUTPUT VALUES OBTAINED FROM THE NUMERICAL PROGRAM PREPARED FOR TWO VERTICAL LAYER GROUND MODEL

-----CALCULATION ENDS-----

NY= 9 I=365

JANUARY 01

9.73	10.19	10.66	11.13	11.60	12.06	12.53	12.99	13.46	13.95	14.44	14.96	15.48	16.03	16.58
17.13	17.69	18.25	18.81	19.35	19.87	20.38	20.86	21.30	21.72	22.09	22.42	22.71	22.95	23.15
23.30	23.41	23.48	23.51	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.19	10.66	11.13	11.60	12.06	12.53	12.99	13.47	13.95	14.45	14.96	15.49	16.03	16.58
17.14	17.70	18.26	18.81	19.35	19.87	20.38	20.86	21.30	21.72	22.09	22.42	22.71	22.95	23.15
23.30	23.41	23.48	23.51	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.19	10.66	11.13	11.60	12.06	12.53	12.99	13.47	13.95	14.45	14.96	15.49	16.03	16.58
17.14	17.70	18.26	18.81	19.35	19.88	20.38	20.86	21.31	21.72	22.10	22.43	22.71	22.96	23.15
23.30	23.41	23.48	23.52	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.19	10.66	11.13	11.60	12.07	12.53	13.00	13.47	13.95	14.45	14.96	15.49	16.03	16.59
17.15	17.71	18.27	18.82	19.36	19.89	20.39	20.87	21.32	21.73	22.10	22.43	22.72	22.96	23.16
23.31	23.42	23.48	23.52	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.19	10.66	11.13	11.60	12.07	12.53	13.00	13.47	13.96	14.46	14.97	15.50	16.04	16.59
17.15	17.72	18.28	18.83	19.37	19.90	20.40	20.88	21.33	21.74	22.11	22.44	22.73	22.97	23.16
23.31	23.42	23.49	23.52	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.20	10.66	11.13	11.60	12.07	12.53	13.00	13.48	13.96	14.46	14.98	15.51	16.05	16.60
17.16	17.73	18.29	18.84	19.38	19.91	20.41	20.89	21.34	21.75	22.12	22.45	22.73	22.97	23.17
23.32	23.42	23.49	23.52	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.20	10.66	11.13	11.60	12.07	12.54	13.00	13.48	13.97	14.47	14.98	15.51	16.06	16.61
17.17	17.74	18.30	18.85	19.40	19.92	20.43	20.90	21.35	21.76	22.13	22.46	22.74	22.98	23.17
23.32	23.43	23.49	23.52	23.52	23.50	23.47	23.43	23.39	23.36	23.35				
9.73	10.20	10.66	11.13	11.60	12.07	12.54	13.01	13.48	13.97	14.47	14.99	15.52	16.07	16.62
17.19	17.75	18.31	18.87	19.41	19.94	20.44	20.92	21.36	21.77	22.14	22.47	22.75	22.99	23.18
23.33	23.43	23.50	23.53	23.53	23.50	23.47	23.42	23.39	23.36	23.35				
9.73	10.19	10.66	11.13	11.60	12.07	12.54	13.01	13.49	13.98	14.48	15.00	15.53	16.08	16.64
17.20	17.76	18.33	18.88	19.43	19.95	20.46	20.93	21.38	21.79	22.16	22.48	22.76	23.00	23.19
23.34	23.44	23.50	23.53	23.53	23.50	23.47	23.42	23.38	23.35	23.34				
9.73	10.19	10.66	11.13	11.60	12.07	12.54	13.01	13.49	13.98	14.49	15.01	15.54	16.09	16.65
17.21	17.78	18.34	18.90	19.44	19.97	20.47	20.95	21.39	21.80	22.17	22.50	22.78	23.01	23.20
23.34	23.44	23.50	23.53	23.53	23.50	23.47	23.42	23.38	23.35	23.34				
9.72	10.19	10.66	11.13	11.60	12.07	12.54	13.01	13.49	13.99	14.49	15.02	15.55	16.10	16.66
17.23	17.80	18.36	18.92	19.46	19.99	20.49	20.97	21.41	21.82	22.18	22.51	22.79	23.02	23.21
23.35	23.45	23.51	23.53	23.53	23.51	23.47	23.42	23.38	23.35	23.34				
9.72	10.19	10.65	11.13	11.60	12.07	12.54	13.02	13.50	13.99	14.50	15.02	15.56	16.12	16.68
17.24	17.81	18.38	18.94	19.48	20.01	20.51	20.98	21.43	21.83	22.20	22.52	22.80	23.03	23.22
23.36	23.46	23.51	23.54	23.53	23.51	23.47	23.42	23.38	23.35	23.34				
9.72	10.19	10.65	11.12	11.60	12.07	12.54	13.02	13.50	14.00	14.51	15.03	15.57	16.13	16.69
17.26	17.83	18.40	18.95	19.50	20.03	20.53	21.00	21.44	21.85	22.21	22.54	22.81	23.04	23.23
23.37	23.46	23.52	23.54	23.53	23.51	23.47	23.42	23.38	23.35	23.34				
9.72	10.18	10.64	11.12	11.59	12.07	12.54	13.02	13.50	14.00	14.51	15.04	15.59	16.14	16.71
17.28	17.85	18.41	18.97	19.52	20.04	20.55	21.02	21.46	21.87	22.23	22.55	22.83	23.05	23.24
23.37	23.47	23.52	23.54	23.54	23.51	23.47	23.42	23.38	23.35	23.33				
9.71	10.17	10.64	11.11	11.59	12.06	12.54	13.02	13.51	14.01	14.52	15.05	15.60	16.15	16.72
17.29	17.87	18.43	18.99	19.54	20.06	20.57	21.04	21.48	21.88	22.25	22.56	22.84	23.07	23.25
23.38	23.47	23.53	23.55	23.54	23.51	23.47	23.42	23.37	23.34	23.33				
9.70	10.16	10.63	11.10	11.58	12.06	12.54	13.02	13.51	14.01	14.53	15.06	15.61	16.17	16.74
17.31	17.88	18.45	19.01	19.56	20.08	20.59	21.06	21.50	21.90	22.26	22.58	22.85	23.08	23.26
23.39	23.48	23.53	23.55	23.54	23.51	23.47	23.42	23.37	23.34	23.33				
9.69	10.15	10.61	11.09	11.57	12.06	12.54	13.02	13.51	14.02	14.54	15.07	15.62	16.18	16.75
17.33	17.90	18.47	19.03	19.58	20.11	20.61	21.08	21.52	21.92	22.28	22.59	22.86	23.09	23.26
23.40	23.49	23.54	23.55	23.54	23.51	23.47	23.42	23.37	23.34	23.33				
9.67	10.13	10.60	11.08	11.57	12.05	12.53	13.02	13.52	14.02	14.54	15.08	15.63	16.20	16.77
17.34	17.92	18.49	19.05	19.60	20.13	20.63	21.10	21.54	21.94	22.29	22.61	22.88	23.10	23.27
23.40	23.49	23.54	23.56	23.54	23.51	23.47	23.42	23.37	23.34	23.33				
9.65	10.11	10.58	11.07	11.56	12.05	12.53	13.02	13.52	14.03	14.55	15.09	15.65	16.21	16.78
17.36	17.94	18.51	19.07	19.62	20.15	20.65	21.12	21.55	21.95	22.31	22.62	22.89	23.11	23.28
23.41	23.50	23.55	23.56	23.55	23.51	23.46	23.41	23.37	23.34	23.32				
9.62	10.07	10.56	11.05	11.55	12.04	12.53	13.02	13.52	14.03	14.56	15.10	15.66	16.23	16.80
17.38	17.96	18.53	19.09	19.64	20.17	20.67	21.14	21.57	21.97	22.33	22.64	22.90	23.12	23.29
23.42	23.50	23.55	23.56	23.55	23.51	23.46	23.41	23.37	23.33	23.32				

9.50	10.02	10.53	11.04	11.55	12.04	12.53	13.02	13.52	14.04	14.57	15.11	15.67	16.24	16.82
17.40	17.98	18.55	19.11	19.66	20.19	20.69	21.16	21.59	21.99	22.34	22.65	22.92	23.13	23.30
23.43	23.51	23.56	23.57	23.55	23.51	23.46	23.41	23.37	23.33	23.32				
9.23	9.90	10.47	11.01	11.53	12.04	12.53	13.03	13.53	14.05	14.58	15.13	15.70	16.27	16.85
17.44	18.02	18.59	19.16	19.70	20.23	20.73	21.20	21.63	22.02	22.38	22.68	22.94	23.16	23.32
23.45	23.52	23.57	23.57	23.55	23.51	23.46	23.41	23.36	23.33	23.31				
9.18	9.83	10.42	10.98	11.51	12.03	12.53	13.03	13.54	14.06	14.60	15.16	15.73	16.30	16.89
17.48	18.06	18.64	19.20	19.75	20.28	20.77	21.24	21.67	22.06	22.41	22.72	22.97	23.18	23.34
23.46	23.54	23.58	23.58	23.56	23.52	23.46	23.41	23.36	23.32	23.31				
9.14	9.78	10.38	10.95	11.50	12.02	12.53	13.03	13.55	14.08	14.62	15.18	15.75	16.34	16.92
17.52	18.10	18.68	19.25	19.80	20.32	20.82	21.28	21.71	22.10	22.45	22.75	23.00	23.21	23.37
23.48	23.55	23.59	23.59	23.56	23.52	23.46	23.41	23.35	23.32	23.30				
9.12	9.75	10.35	10.93	11.48	12.01	12.52	13.03	13.55	14.09	14.64	15.20	15.78	16.37	16.96
17.56	18.14	18.73	19.29	19.84	20.37	20.86	21.33	21.75	22.14	22.48	22.78	23.03	23.23	23.39
23.50	23.57	23.60	23.59	23.57	23.52	23.46	23.40	23.35	23.31	23.30				
9.11	9.73	10.33	10.91	11.47	12.00	12.52	13.03	13.56	14.10	14.66	15.23	15.81	16.40	17.00
17.59	18.19	18.77	19.34	19.89	20.41	20.91	21.37	21.80	22.18	22.52	22.81	23.06	23.26	23.41
23.52	23.58	23.61	23.60	23.57	23.52	23.46	23.40	23.35	23.31	23.30				
9.10	9.71	10.31	10.89	11.45	11.99	12.51	13.04	13.57	14.11	14.67	15.25	15.84	16.43	17.03
17.63	18.23	18.81	19.38	19.93	20.46	20.95	21.41	21.84	22.22	22.56	22.85	23.09	23.28	23.43
23.53	23.59	23.62	23.61	23.57	23.52	23.46	23.40	23.34	23.30	23.29				
9.09	9.70	10.30	10.88	11.45	11.99	12.51	13.04	13.58	14.13	14.69	15.27	15.86	16.47	17.07
17.67	18.27	18.86	19.43	19.98	20.50	21.00	21.46	21.88	22.26	22.59	22.88	23.12	23.31	23.45
23.55	23.61	23.63	23.61	23.58	23.52	23.46	23.39	23.34	23.30	23.28				
9.08	9.70	10.29	10.88	11.44	11.98	12.51	13.04	13.58	14.14	14.71	15.30	15.89	16.50	17.11
17.71	18.31	18.90	19.47	20.02	20.55	21.04	21.50	21.92	22.30	22.63	22.91	23.14	23.33	23.47
23.57	23.62	23.64	23.62	23.58	23.52	23.46	23.39	23.33	23.29	23.28				
9.08	9.69	10.28	10.87	11.44	11.98	12.52	13.05	13.59	14.15	14.73	15.32	15.92	16.53	17.14
17.75	18.35	18.94	19.52	20.07	20.59	21.09	21.54	21.96	22.33	22.66	22.94	23.17	23.36	23.49
23.58	23.63	23.65	23.63	23.59	23.53	23.46	23.39	23.33	23.29	23.27				
9.08	9.69	10.28	10.87	11.43	11.98	12.52	13.06	13.60	14.17	14.75	15.34	15.95	16.56	17.17
17.79	18.39	18.98	19.56	20.11	20.64	21.13	21.58	22.00	22.37	22.69	22.97	23.20	23.38	23.51
23.60	23.65	23.66	23.63	23.59	23.53	23.46	23.39	23.33	23.29	23.27				
9.08	9.69	10.28	10.87	11.44	11.98	12.52	13.06	13.61	14.18	14.77	15.36	15.97	16.59	17.21
17.82	18.43	19.02	19.60	20.15	20.68	21.17	21.62	22.03	22.40	22.73	23.00	23.23	23.40	23.53
23.62	23.66	23.67	23.64	23.59	23.53	23.46	23.38	23.32	23.28	23.26				
9.08	9.69	10.28	10.87	11.44	11.99	12.53	13.07	13.63	14.20	14.78	15.38	16.00	16.62	17.24
17.86	18.46	19.06	19.64	20.19	20.71	21.21	21.66	22.07	22.44	22.76	23.03	23.25	23.42	23.55
23.63	23.67	23.67	23.65	23.60	23.53	23.45	23.38	23.32	23.28	23.26				
9.08	9.69	10.28	10.87	11.44	11.99	12.53	13.08	13.64	14.21	14.80	15.40	16.02	16.64	17.27
17.89	18.50	19.10	19.67	20.23	20.75	21.24	21.69	22.10	22.47	22.79	23.05	23.27	23.44	23.57
23.64	23.68	23.68	23.65	23.60	23.53	23.45	23.38	23.32	23.27	23.26				
9.08	9.69	10.28	10.87	11.44	12.00	12.54	13.09	13.65	14.22	14.82	15.42	16.04	16.67	17.29
17.92	18.53	19.13	19.71	20.26	20.79	21.27	21.73	22.13	22.50	22.81	23.08	23.30	23.46	23.58
23.66	23.69	23.69	23.66	23.60	23.53	23.45	23.38	23.31	23.27	23.25				
9.08	9.69	10.28	10.87	11.45	12.00	12.55	13.10	13.66	14.24	14.83	15.44	16.06	16.69	17.32
17.94	18.56	19.16	19.74	20.29	20.82	21.30	21.75	22.16	22.52	22.84	23.10	23.32	23.48	23.60
23.67	23.70	23.70	23.66	23.60	23.53	23.45	23.37	23.31	23.26	23.25				
9.08	9.69	10.29	10.88	11.45	12.01	12.55	13.10	13.67	14.25	14.84	15.46	16.08	16.71	17.34
17.96	18.58	19.18	19.76	20.32	20.84	21.33	21.78	22.19	22.55	22.86	23.12	23.33	23.50	23.61
23.68	23.71	23.70	23.67	23.61	23.53	23.45	23.37	23.31	23.26	23.24				
9.08	9.69	10.29	10.88	11.45	12.01	12.56	13.11	13.68	14.26	14.86	15.47	16.09	16.72	17.36
17.98	18.60	19.20	19.78	20.34	20.86	21.35	21.80	22.21	22.57	22.88	23.14	23.35	23.51	23.62
23.69	23.72	23.71	23.67	23.61	23.53	23.45	23.37	23.30	23.26	23.24				
9.08	9.69	10.29	10.88	11.46	12.01	12.56	13.12	13.68	14.26	14.86	15.48	16.10	16.74	17.37
18.00	18.62	19.22	19.80	20.36	20.88	21.37	21.82	22.22	22.58	22.89	23.15	23.36	23.52	23.63
23.70	23.72	23.71	23.67	23.61	23.53	23.45	23.37	23.30	23.26	23.24				
9.08	9.69	10.29	10.88	11.46	12.02	12.57	13.12	13.69	14.27	14.87	15.48	16.11	16.74	17.38
18.01	18.63	19.23	19.81	20.37	20.89	21.38	21.83	22.23	22.59	22.90	23.16	23.36	23.52	23.63
23.70	23.72	23.71	23.67	23.61	23.53	23.45	23.37	23.30	23.25	23.24				
9.08	9.69	10.29	10.88	11.46	12.02	12.57	13.12	13.69	14.27	14.87	15.49	16.11	16.75	17.38
18.01	18.63	19.23	19.82	20.37	20.90	21.38	21.83	22.24	22.59	22.90	23.16	23.37	23.53	23.64
23.70	23.73	23.71	23.67	23.61	23.53	23.45	23.37	23.30	23.25	23.24				

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32.65	32.26	31.88	31.51	31.13	30.74	30.34	29.93	29.50	29.08	28.65	28.22	27.79	27.36	26.93
26.50	26.07	25.65	25.24	24.83	24.44	24.07	23.71	23.37	23.06	22.77	22.52	22.29	22.10	21.94
21.81	21.71	21.65	21.61	21.60	21.60	21.62	21.65	21.68	21.70	21.70				
32.64	32.26	31.88	31.51	31.13	30.74	30.34	29.92	29.50	29.08	28.65	28.22	27.79	27.36	26.93
26.50	26.07	25.65	25.24	24.83	24.44	24.06	23.71	23.37	23.06	22.77	22.52	22.29	22.10	21.93
21.81	21.71	21.65	21.61	21.60	21.60	21.62	21.65	21.68	21.70	21.70				
32.64	32.26	31.88	31.51	31.13	30.74	30.34	29.92	29.50	29.07	28.65	28.21	27.78	27.35	26.92
26.50	26.07	25.65	25.23	24.83	24.44	24.06	23.70	23.37	23.06	22.77	22.51	22.29	22.09	21.93
21.81	21.71	21.65	21.61	21.60	21.60	21.62	21.65	21.68	21.70	21.70				
32.64	32.26	31.88	31.51	31.13	30.74	30.34	29.92	29.50	29.07	28.64	28.21	27.78	27.35	26.92
26.49	26.06	25.64	25.23	24.82	24.43	24.06	23.70	23.36	23.05	22.77	22.51	22.28	22.09	21.93
21.80	21.71	21.64	21.61	21.60	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.88	31.51	31.13	30.74	30.33	29.92	29.50	29.07	28.64	28.21	27.77	27.34	26.91
26.48	26.06	25.64	25.22	24.82	24.43	24.05	23.69	23.36	23.04	22.76	22.50	22.28	22.09	21.93
21.80	21.70	21.64	21.61	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.88	31.50	31.12	30.73	30.33	29.91	29.49	29.06	28.63	28.20	27.77	27.34	26.91
26.48	26.05	25.63	25.21	24.81	24.42	24.04	23.68	23.35	23.04	22.75	22.50	22.27	22.08	21.92
21.80	21.70	21.64	21.60	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.88	31.50	31.12	30.73	30.33	29.91	29.49	29.06	28.63	28.19	27.76	27.33	26.90
26.47	26.04	25.62	25.20	24.80	24.41	24.03	23.67	23.34	23.03	22.74	22.49	22.27	22.07	21.92
21.79	21.70	21.64	21.60	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.88	31.50	31.12	30.73	30.32	29.91	29.48	29.05	28.62	28.19	27.75	27.32	26.89
26.46	26.03	25.61	25.19	24.79	24.40	24.02	23.66	23.33	23.02	22.73	22.48	22.26	22.07	21.91
21.79	21.69	21.63	21.60	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.87	31.50	31.12	30.72	30.32	29.90	29.48	29.05	28.61	28.18	27.74	27.31	26.88
26.45	26.02	25.60	25.18	24.78	24.38	24.01	23.65	23.32	23.01	22.72	22.47	22.25	22.06	21.90
21.78	21.69	21.63	21.60	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.87	31.50	31.12	30.72	30.31	29.90	29.47	29.04	28.61	28.17	27.74	27.30	26.87
26.44	26.01	25.58	25.17	24.76	24.37	24.00	23.64	23.31	23.00	22.71	22.46	22.24	22.05	21.90
21.77	21.68	21.63	21.59	21.59	21.60	21.62	21.65	21.68	21.70	21.71				
32.64	32.26	31.87	31.50	31.11	30.72	30.31	29.89	29.46	29.03	28.60	28.16	27.73	27.29	26.86
26.42	25.99	25.57	25.16	24.75	24.36	23.98	23.63	23.29	22.98	22.70	22.45	22.23	22.04	21.89
21.77	21.68	21.62	21.59	21.59	21.60	21.62	21.65	21.68	21.71	21.71				
32.64	32.26	31.87	31.49	31.11	30.71	30.31	29.89	29.46	29.02	28.59	28.15	27.71	27.28	26.84
26.41	25.98	25.56	25.14	24.74	24.34	23.97	23.61	23.28	22.97	22.69	22.44	22.22	22.04	21.88
21.76	21.67	21.62	21.59	21.58	21.60	21.62	21.65	21.68	21.71	21.72				
32.64	32.26	31.87	31.49	31.11	30.71	30.30	29.88	29.45	29.02	28.58	28.14	27.70	27.27	26.83
26.40	25.97	25.54	25.13	24.72	24.33	23.96	23.60	23.27	22.96	22.68	22.43	22.21	22.03	21.87
21.76	21.67	21.61	21.59	21.58	21.60	21.62	21.65	21.69	21.71	21.72				
32.64	32.26	31.87	31.49	31.11	30.71	30.30	29.87	29.44	29.01	28.57	28.13	27.69	27.25	26.82
26.38	25.95	25.53	25.11	24.71	24.32	23.94	23.59	23.25	22.95	22.67	22.42	22.20	22.02	21.87
21.75	21.66	21.61	21.58	21.58	21.59	21.62	21.66	21.69	21.71	21.72				
32.64	32.26	31.87	31.49	31.10	30.71	30.29	29.87	29.44	29.00	28.56	28.12	27.68	27.24	26.81
26.37	25.94	25.51	25.10	24.69	24.30	23.93	23.57	23.24	22.94	22.66	22.41	22.19	22.01	21.86
21.74	21.66	21.61	21.58	21.58	21.59	21.62	21.66	21.69	21.71	21.72				
32.64	32.26	31.87	31.49	31.10	30.70	30.29	29.86	29.43	28.99	28.55	28.11	27.67	27.23	26.79
26.36	25.93	25.50	25.08	24.68	24.29	23.91	23.56	23.23	22.92	22.65	22.40	22.18	22.00	21.85
21.74	21.65	21.60	21.58	21.58	21.59	21.62	21.66	21.69	21.71	21.72				
32.65	32.26	31.87	31.49	31.10	30.70	30.28	29.86	29.42	28.98	28.54	28.10	27.66	27.22	26.78
26.34	25.91	25.49	25.07	24.66	24.27	23.90	23.54	23.21	22.91	22.63	22.39	22.17	21.99	21.84
21.73	21.65	21.60	21.57	21.57	21.59	21.62	21.66	21.69	21.71	21.72				
32.65	32.27	31.88	31.50	31.10	30.70	30.28	29.85	29.41	28.97	28.53	28.09	27.64	27.20	26.76
26.33	25.90	25.47	25.05	24.65	24.26	23.88	23.53	23.20	22.90	22.62	22.38	22.16	21.98	21.84
21.72	21.64	21.59	21.57	21.57	21.59	21.62	21.66	21.69	21.72	21.73				
32.66	32.28	31.88	31.50	31.10	30.70	30.27	29.84	29.40	28.96	28.52	28.07	27.63	27.19	26.75
26.31	25.88	25.46	25.04	24.63	24.24	23.87	23.52	23.19	22.88	22.61	22.37	22.15	21.97	21.83
21.72	21.64	21.59	21.57	21.57	21.59	21.62	21.66	21.69	21.72	21.73				
32.67	32.29	31.89	31.50	31.10	30.69	30.27	29.83	29.39	28.95	28.51	28.06	27.62	27.18	26.74
26.30	25.87	25.44	25.02	24.62	24.23	23.85	23.50	23.17	22.87	22.60	22.35	22.14	21.97	21.82
21.71	21.63	21.59	21.57	21.57	21.59	21.62	21.66	21.69	21.72	21.73				
32.73	32.31	31.90	31.51	31.10	30.69	30.26	29.83	29.38	28.94	28.49	28.05	27.61	27.16	26.72
26.29	25.85	25.43	25.01	24.60	24.21	23.84	23.49	23.16	22.86	22.59	22.34	22.13	21.96	21.81
21.70	21.63	21.58	21.56	21.57	21.59	21.62	21.66	21.70	21.72	21.73				
32.87	32.37	31.93	31.52	31.11	30.68	30.25	29.81	29.36	28.91	28.47	28.02	27.58	27.13	26.69
26.25	25.82	25.39	24.97	24.57	24.18	23.81	23.46	23.13	22.83	22.56	22.32	22.11	21.94	21.80
21.69	21.62	21.57	21.56	21.56	21.59	21.62	21.66	21.70	21.72	21.73				
32.89	32.40	31.95	31.53	31.11	30.68	30.24	29.79	29.34	28.89	28.44	28.00	27.55	27.10	26.66
26.22	25.79	25.36	24.94	24.54	24.15	23.78	23.43	23.10	22.80	22.54	22.30	22.09	21.92	21.78

21.68	21.60	21.56	21.55	21.56	21.58	21.62	21.66	21.70	21.73	21.74				
32.90	32.41	31.96	31.53	31.11	30.67	30.22	29.77	29.32	28.87	28.42	27.97	27.52	27.07	26.63
26.19	25.75	25.33	24.91	24.50	24.11	23.74	23.40	23.07	22.78	22.51	22.27	22.07	21.90	21.76
21.66	21.59	21.55	21.54	21.55	21.58	21.62	21.66	21.70	21.73	21.74				
32.90	32.42	31.97	31.54	31.11	30.66	30.21	29.76	29.30	28.85	28.39	27.94	27.49	27.05	26.60
26.16	25.72	25.29	24.87	24.47	24.08	23.71	23.36	23.04	22.75	22.48	22.25	22.05	21.88	21.75
21.65	21.58	21.55	21.54	21.55	21.58	21.62	21.67	21.71	21.73	21.75				
32.90	32.43	31.97	31.54	31.10	30.66	30.20	29.74	29.28	28.82	28.37	27.92	27.47	27.02	26.57
26.13	25.69	25.26	24.84	24.43	24.05	23.68	23.33	23.01	22.72	22.46	22.22	22.02	21.86	21.73
21.63	21.57	21.54	21.53	21.55	21.58	21.62	21.67	21.71	21.74	21.75				
32.90	32.43	31.98	31.54	31.10	30.65	30.19	29.73	29.27	28.80	28.35	27.89	27.44	26.99	26.54
26.09	25.65	25.22	24.81	24.40	24.01	23.65	23.30	22.98	22.69	22.43	22.20	22.00	21.84	21.71
21.62	21.56	21.53	21.52	21.54	21.58	21.62	21.67	21.71	21.74	21.75				
32.90	32.43	31.98	31.54	31.10	30.64	30.18	29.71	29.25	28.79	28.33	27.87	27.41	26.96	26.51
26.06	25.62	25.19	24.77	24.37	23.98	23.61	23.27	22.95	22.66	22.40	22.17	21.98	21.82	21.69
21.60	21.55	21.52	21.52	21.54	21.58	21.62	21.67	21.71	21.75	21.76				
32.90	32.43	31.97	31.54	31.09	30.64	30.17	29.70	29.23	28.77	28.30	27.84	27.39	26.93	26.48
26.03	25.59	25.16	24.74	24.33	23.95	23.58	23.24	22.92	22.63	22.38	22.15	21.96	21.80	21.68
21.59	21.53	21.51	21.51	21.53	21.57	21.62	21.67	21.72	21.75	21.76				
32.90	32.43	31.97	31.53	31.09	30.63	30.16	29.69	29.22	28.75	28.28	27.82	27.36	26.91	26.45
26.00	25.56	25.13	24.71	24.30	23.92	23.55	23.21	22.89	22.61	22.35	22.13	21.94	21.78	21.66
21.58	21.52	21.50	21.51	21.53	21.57	21.62	21.67	21.72	21.75	21.77				
32.90	32.43	31.97	31.53	31.08	30.62	30.15	29.68	29.20	28.73	28.26	27.80	27.34	26.88	26.42
25.97	25.53	25.10	24.68	24.27	23.89	23.52	23.18	22.87	22.58	22.33	22.10	21.92	21.76	21.65
21.56	21.51	21.49	21.50	21.53	21.57	21.62	21.68	21.72	21.76	21.77				
32.90	32.43	31.97	31.53	31.08	30.61	30.14	29.66	29.19	28.72	28.25	27.78	27.32	26.86	26.40
25.95	25.50	25.07	24.65	24.24	23.86	23.49	23.15	22.84	22.55	22.30	22.08	21.89	21.74	21.63
21.55	21.50	21.48	21.49	21.52	21.57	21.62	21.68	21.73	21.76	21.77				
32.90	32.42	31.97	31.52	31.07	30.61	30.13	29.65	29.18	28.70	28.23	27.76	27.30	26.83	26.37
25.92	25.47	25.04	24.62	24.21	23.83	23.46	23.12	22.81	22.53	22.28	22.06	21.88	21.73	21.61
21.54	21.49	21.48	21.49	21.52	21.57	21.62	21.68	21.73	21.76	21.78				
32.90	32.42	31.96	31.52	31.06	30.60	30.12	29.64	29.16	28.69	28.21	27.74	27.28	26.81	26.35
25.89	25.45	25.01	24.59	24.19	23.80	23.44	23.10	22.79	22.51	22.26	22.04	21.86	21.71	21.60
21.52	21.48	21.47	21.48	21.52	21.57	21.62	21.68	21.73	21.77	21.78				
32.90	32.42	31.96	31.51	31.06	30.59	30.12	29.63	29.15	28.67	28.20	27.73	27.26	26.79	26.33
25.87	25.42	24.99	24.57	24.16	23.78	23.41	23.08	22.76	22.48	22.24	22.02	21.84	21.70	21.59
21.51	21.47	21.46	21.48	21.51	21.57	21.62	21.68	21.73	21.77	21.78				
32.90	32.42	31.96	31.51	31.05	30.59	30.11	29.62	29.14	28.66	28.18	27.71	27.24	26.77	26.31
25.85	25.40	24.97	24.54	24.14	23.75	23.39	23.05	22.74	22.46	22.22	22.00	21.82	21.68	21.58
21.50	21.47	21.46	21.47	21.51	21.56	21.62	21.68	21.74	21.77	21.79				
32.90	32.42	31.95	31.51	31.05	30.58	30.10	29.62	29.13	28.65	28.17	27.70	27.23	26.76	26.29
25.83	25.39	24.95	24.52	24.12	23.73	23.37	23.04	22.73	22.45	22.20	21.99	21.81	21.67	21.57
21.50	21.46	21.45	21.47	21.51	21.56	21.62	21.69	21.74	21.78	21.79				
32.90	32.42	31.95	31.50	31.05	30.58	30.10	29.61	29.12	28.64	28.16	27.69	27.21	26.74	26.28
25.82	25.37	24.93	24.51	24.10	23.72	23.36	23.02	22.71	22.43	22.19	21.98	21.80	21.66	21.56
21.49	21.45	21.45	21.47	21.51	21.56	21.63	21.69	21.74	21.78	21.79				
32.90	32.42	31.95	31.50	31.04	30.57	30.09	29.60	29.12	28.63	28.15	27.68	27.20	26.73	26.27
25.81	25.36	24.92	24.50	24.09	23.71	23.34	23.01	22.70	22.42	22.18	21.97	21.79	21.65	21.55
21.48	21.45	21.44	21.46	21.51	21.56	21.63	21.69	21.74	21.78	21.79				
32.90	32.41	31.95	31.50	31.04	30.57	30.09	29.60	29.11	28.63	28.15	27.67	27.20	26.73	26.26
25.80	25.35	24.91	24.49	24.08	23.70	23.34	23.00	22.69	22.41	22.17	21.96	21.79	21.65	21.55
21.48	21.44	21.44	21.46	21.51	21.56	21.63	21.69	21.74	21.78	21.80				
32.90	32.41	31.95	31.50	31.04	30.57	30.09	29.60	29.11	28.63	28.15	27.67	27.20	26.73	26.26
25.80	25.35	24.91	24.49	24.08	23.69	23.33	23.00	22.69	22.41	22.17	21.96	21.78	21.65	21.54
21.48	21.44	21.44	21.46	21.50	21.56	21.63	21.69	21.74	21.78	21.80				

-----CALCULATION ENDS-----

NY=9 I=365

IT= 2 ITJ= 1 ITK= 1

I=365 TIME=365.0

APPENDIX-4. PREPARED COMPUTER PROGRAM FOR TRENCH-FILLED TWO VERTICAL LAYER GROUND MODEL

```

DIMENSION TAD(365),QSD(365),UAD(365),FAD(365)
DIMENSION TN(103),TA(103),TNA(103),TI(103)
DIMENSION TDX(103,103),TDY(103,103),TIN(103,103),TTNA1(103,103)
DIMENSION TTN(103,103),TTNA(103,103),TTNAXX(103,103)
DIMENSION TTNAYY(103,103),TTA(103,103),TAXY2(103,103)
DIMENSION CNY1(103),CNY2(103),CNY3(103),X(105),Y(105)
DIMENSION CNYB1(103),CNYB2(103),CNYB3(103)
DIMENSION A(103),B(103),D(103),DN(103)
DIMENSION TTNK(103,103),TTNY(103,103)
DIMENSION CN1(103),CN3(103),CNA2(103),CNB2(103)
DIMENSION CA1(103),CA2(103),CA3(103)

OPEN(1,FILE='TAD.TXT')
OPEN(2,FILE='QSD.TXT')
OPEN(3,FILE='UAD.TXT')
OPEN(4,FILE='FAD.TXT')
OPEN(5,FILE='TS_.TXT')
OPEN(6,FILE='DXX_.TXT')
OPEN(7,FILE='DXY_.TXT')
C----- M=200, ALX=10.0, AK=1.00 -----
C----- READ(*,*) M,AK,LX -----
TIMEE=364.0
M=60
MA=40
MB=M-MA
N=40
NA=20
NB=N-NA
EPTE=0.01
ALX=10.0
ALY=4.0
ALA=2.0
ALB=ALY-ALA
NAD=N/40
MAD=M/60
NAP1=NA+1
NAP2=NA+2
NAP3=NA+3
NAP4=NA+4
NBP1=NB+1
NP1=N+1
NP2=N+2
NP3=N+3
MA1=MA-1
MAP1=MA+1
MAP2=MA+2
MAP3=MA+3
DYA=ALA/NA
DYB=ALB/NB
DX=ALX/M
DX2=DX**2.0
DYA2=DYA**2.0

```

```

DYB2=DYB**2.0
DYAB=DYA/DYB

ADA=0.098
AKA=2.93
ADB=0.048
AKB=0.87
AKAB=AKB*DYA/AKA/DYB
ABK=AKA/AKB
C   CNC1=-ABK
C   CNC2=1.0+ABK
C   CNC3=-1.0
    CNC1=1.0*ABK
    CNC2=-0.75*(1.0+ABK)
    CNC3=1.0
C-----DATA ARE READING FROM THE FILES-----
    DO 5 I=1,365
      READ(1,*)TAD(I)
      READ(2,*)QSD(I)
      READ(3,*)UAD(I)
      READ(4,*)FAD(I)
5    CONTINUE
C    C1=0.0
    C1=1.0
    CXY=1.0

    AS=0.9
    F=0.45
    EPSE=1.0
    DR=63.0
    UW=7.0
    AW=2.8
    BW=3.0
    EN=1.0
    CV=0.0168*F
    DT=1.0
    DXYA2=DX2/DYA2
    DXYB2=DX2/DYB2
    BBXA=2.0*DX2/(DT*ADA)
    BBXB=2.0*DX2/(DT*ADB)
    BBYA=2.0*DYA2/(DT*ADA)
    BBYB=2.0*DYB2/(DT*ADB)
    BBYAB=2.0*DYA2/(DT*ADB)
    ITE=365
    M1=M-1
    MP1=M+1
    MP2=M+2
    ITL=100
    RS=1.0
C    CC=AE*DT
    DO 11 J=1,MP2
      TI(J)=20.0
11   CONTINUE
    DO 22 J=2,MP1
      CN1(J)=-1.0

```

```

        CNA2(J)=BBXA+2.0
        CNB2(J)=BBXB+2.0
        CN3(J)=-1.0
22      CONTINUE
        ES1=-1.5/DX
        ES2=2.0/DX
        ES3=-0.5/DX
        DO 23 K=1,NP3
        DO 23 J=1,MP2
            TTN(K,J)=TI(J)
23      CONTINUE
        DO 24 K=2,NAP1
            CNY1(K)=-1.0
            CNY2(K)=BBYA+2.0
            CNY3(K)=-1.0
24      CONTINUE
        CNCB3=-AKAB
        DO 21 K=NAP3,NP2
            CNY1(K)=-1.0
            CNY2(K)=BBYB+2.0
            CNY3(K)=-1.0
21      CONTINUE
        CNCB2=1.+AKAB
        CNY1(NAP2)=-1.0
        CNY2(NAP2)=1.0+AKAB
        CNY3(NAP2)=-AKAB
        CNCB1=-1.0
        DO 25 K=2,NP2
            CNYB1(K)=-1.0
            CNYB2(K)=2.0+BBYB
            CNYB3(K)=-1.0
25      CONTINUE
        X(1)=0.0
        DO 480 J=2,MP1
            X(J)=X(J-1)+DX
480     CONTINUE
        WRITE(6,16)(X(J),J=1,MP1)C
        Y(1)=0.0
        DO 482 K=2,NAP1
            Y(K)=Y(K-1)+DYA
482     CONTINUE
        C      Y(NAP1)=Y(NA)
        DO 483 K=NAP2,NP1
            Y(K)=Y(K-1)+DYB
483     CONTINUE
        WRITE(7,16)(Y(K),K=1,NA)
        WRITE(7,16)(Y(K),K=NAP1,NP1)
16      FORMAT(F9.4)
c-----
        NY=1
        I=0
100     CONTINUE
        IF(I.NE.2) GO TO 74
        DO 71 K=2,NP2
        DO 71 J=1,MP1

```



```

        TTNK(K,J)=TTN(K,J)
71  CONTINUE
74  CONTINUE
    IF(I.NE.183) GO TO 73
        DO 72 K=2,NP2
        DO 72 J=1,MP1
        TTNJ(K,J)=TTN(K,J)
72  CONTINUE
73  CONTINUE
    I=I+1
    TIME=I*DT
    QS=QSD(I)
    TAT=TAD(I)
    UA=UAD(I)
    FI=FAD(I)
    HA=AW+BW*UA**EN
    ALEC=CV*HA
    IF (TAT.GT.30.0) GO TO 110
        PA=288.68*(1.098+TAT/100.0)**8.024
    GO TO 111
110  CONTINUE
        PA=975.29*(0.9303+TAT/100.0)**7.094
111  CONTINUE

        DO 101 K=1,NP3
        DO 101 J=1,MP2
        TTA(K,J)=TTN(K,J)
101  CONTINUE

        DO 105 K=2,NAP1
        DO 105 J=2,MP1
        TAXY2(K,J)=( TTA(K,J+1)+TTA(K,J-1)-2.0*TTA(K,J) )/DX2
        *+(TTA(K+1,J)+TTA(K-1,J)-2.0*TTA(K,J))/DYA2
105  CONTINUE
        DO 106 K=NAP3,NP2
        DO 106 J=2,MP1
        TAXY2(K,J)=(TTA(K,J+1)+TTA(K,J-1)-2.0*TTA(K,J))/DX2
        *+(TTA(K+1,J)+TTA(K-1,J)-2.0*TTA(K,J))/DYB2
106  CONTINUE

        DO 705 K=1,NP3
        DO 705 J=1,MP2
        TTNA(K,J)=TTN(K,J)
705  CONTINUE
    IT=0
401  CONTINUE
    IT=IT+1
    WRITE(5,*)'IT=',IT
C    DO 703 K=1,NP3,NAD
C    WRITE(5,*)(TTNA(K,J),J=1,MP2,MAD)
C703  CONTINUE
    WRITE(5,*)'IT=',IT
C    DO 704 K=1,NP3,NAD
C    WRITE(5,*)(TTN(K,J),J=1,MP2,MAD)
C704  CONTINUE

```

```

IF (IT.GT.ITL) GO TO 501

DO 402 K=1,NP3
DO 402 J=1,MP2
  TTNA(K,J)=CXY*TTN(K,J)+(1.0-CXY)*TTNA(K,J)
  TTNA1(K,J)=TTN(K,J)
402 CONTINUE

DO 107 K=2,NAP1
DO 107 J=1,MP1
  TTNAYY(K,J)=(TTNA(K+1,J)+TTNA(K-1,J)-2.0*TTNA(K,J))/DYA2
107 CONTINUE
DO 108 K=NAP3,NP2
DO 108 J=1,MP1
  TTNAYY(K,J)=(TTNA(K+1,J)+TTNA(K-1,J)-2.0*TTNA(K,J))/DYB2
108 CONTINUE

DO 109 K=2,NAP1
DO 109 J=2,MA
  TDY(K,J)=BBXA*TTA(K,J)+DX2*TTNAYY(K,J)+DX2*TAXY2(K,J)
109 CONTINUE
DO 310 K=2,NAP1
DO 310 J=MAP2,MP1
  TDY(K,J)=BBXB*TTA(K,J)+DX2*TTNAYY(K,J)+DX2*TAXY2(K,J)
310 CONTINUE
DO 114 K=NAP3,NP2
DO 114 J=2,MP1
  TDY(K,J)=BBXB*TTA(K,J)+DX2*TTNAYY(K,J)+DX2*TAXY2(K,J)
114 CONTINUE

C403 CONTINUE
DO 120 K=2,NAP1
DO 104 J=1,MP2
  TN(J)=TTN(K,J)
104 CONTINUE
ITJ=0
103 CONTINUE
ITJ=ITJ+1
IF (ITJ.GT.ITL) GO TO 501
DO 102 J=1,MP2
  TNA(J)=TN(J)
102 CONTINUE
TSS=C1*TTA(K,1)+(1-C1)*TTNA(K,1)
IF (TSS.GT.30.0) GO TO 112
PS=288.68*(1.098+TSS/100.0)**8.024
GO TO 113
112 CONTINUE
PS=975.29*(0.9303+TSS/100.0)**7.094
113 CONTINUE
AP=(PS-PA)/(TSS-TAT)
BP=PA-AP*TAT
ALE=ALEC*(BP-FI*(AP*TAT+BP))
ELD=HA*TAT+AS*QS-EPSE*DR-ALE
IF (K.GT.NAP1) GO TO 404
ESN1=-ES1*AKA+HA+ALEC*AP

```

```

        ESN2=-ES2*AKA
        ESN3=-ES3*AKA
        GO TO 405
404    CONTINUE
        ESN1=-ES1*AKB+HA+ALEC*AP
        ESN2=-ES2*AKB
        ESN3=-ES3*AKB
405    CONTINUE

C-----MATRIX SOLUTION-----
        DO 116 J=2,MP1
            DN(J)=TDY(K,J)
116    CONTINUE
        DN(MAP1)=(ABK*TN(MA1)+TN(MAP3))/4.0
        W=CN1(2)/ESN1
        B(2)=CNA2(2)-W*ESN2
        A(2)=CN3(2)-W*ESN3
        D(2)=DN(2)-W*ELD
        DO 118 J=3,MA
            J1=J-1
            W=CN1(J)/B(J1)
            B(J)=CNA2(J)-W*A(J1)
            A(J)=CN3(J)
            D(J)=DN(J)-W*D(J1)
118    CONTINUE
        W=CNC1/B(MA)
        B(MAP1)=CNC2-W*A(MA)
        A(MAP1)=CNC3
        D(MAP1)=DN(MAP1)-W*D(MA)
        DO 119 J=MAP2,M
            J1=J-1
            W=CN1(J)/B(J1)
            B(J)=CNB2(J)-W*A(J1)
            A(J)=CN3(J)
            D(J)=DN(J)-W*D(J1)
119    CONTINUE
        BB=CN1(MP1)+CN3(MP1)
        W=BB/B(M)
        TN(MP1)=(W*D(M)-DN(MP1))/(W*A(M)-CNB2(MP1))
        DO 117 J=1,M1
            JJ=MP1-J
            TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
117    CONTINUE
        TN(1)=(DN(2)-CNA2(2)*TN(2)-CN3(2)*TN(3))/CN1(2)
        TN(MP2)=TN(M)

C-----
        DO 200 J=1,MP1
            IF(ABS(TN(J)-TNA(J)).GT.EPTE) GO TO 103
200    CONTINUE
C405    CONTINUE
        DO 115 J=1,MP2
            TTN(K,J)=TN(J)
115    CONTINUE
120    CONTINUE
        DO 620 K=NAP3,NP2

```

```

DO 606 J=1,MP2
  TN(J)=TTN(K,J)
606 CONTINUE
  ITJ=0
603 CONTINUE
  ITJ=ITJ+1
  IF (ITJ.GT.ITL) GO TO 501
  DO 602 J=1,MP2
    TNA(J)=TN(J)
602 CONTINUE
    TSS=C1*TTA(K,1)+(1-C1)*TTNA(K,1)
    IF (TSS.GT.30.0) GO TO 612
    PS=288.68*(1.098+TSS/100.0)**8.024
    GO TO 613
612 CONTINUE
    PS=975.29*(0.9303+TSS/100.0)**7.094
613 CONTINUE
    AP=(PS-PA)/(TSS-TAT)
    BP=PA-AP*TAT
    ALE=ALEC*(BP-FI*(AP*TAT+BP))
    ELD=HA*TAT+AS*QS-EPSE*DR-ALE
    IF (K.GT.NAP1) GO TO 604
    ESN1=-ES1*AKA+HA+ALEC*AP
    ESN2=-ES2*AKA
    ESN3=-ES3*AKA
    GO TO 605
604 CONTINUE
    ESN1=-ES1*AKB+HA+ALEC*AP
    ESN2=-ES2*AKB
    ESN3=-ES3*AKB
605 CONTINUE
C-----MATRIX SOLUTION-----
DO 616 J=2,MP1
  DN(J)=TDY(K,J)
616 CONTINUE
  W=CN1(2)/ESN1
  B(2)=CNB2(2)-W*ESN2
  A(2)=CN3(2)-W*ESN3
  D(2)=DN(2)-W*ELD
  DO 618 J=3,M
    J1=J-1
    W=CN1(J)/B(J1)
    B(J)=CNB2(J)-W*A(J1)
    A(J)=CN3(J)
    D(J)=DN(J)-W*D(J1)
618 CONTINUE
    BB=CN1(MP1)+CN3(MP1)
    W=BB/B(M)
    TN(MP1)=(W*D(M)-DN(MP1))/(W*A(M)-CNB2(MP1))
    DO 617 J=1,M1
      JJ=MP1-J
      TN(JJ)=(-A(JJ)*TN(JJ+1)+D(JJ))/B(JJ)
617 CONTINUE
    TN(1)=(DN(2)-CNB2(2)*TN(2)-CN3(2)*TN(3))/CN1(2)
    TN(MP2)=TN(M)

```

```

C-----
      DO 600 J=1,MP1
      IF(ABS(TN(J)-TNA(J)).GT.EPTE) GO TO 603
600  CONTINUE
C405  CONTINUE
      DO 615 J=1,MP2
      TTN(K,J)=TN(J)
615  CONTINUE
620  CONTINUE
406  CONTINUE
      DO 130 J=1,MA
      TTN(NAP2,J)=(TTN(NAP1,J)+AKAB*TTN(NAP3,J))/(1.0+AKAB)
130  CONTINUE
      DO 131 J=MAP2,MP2
      TTN(NAP2,J)=(TTN(NAP1,J)+DYAB*TTN(NAP3,J))/(1.0+DYAB)
131  CONTINUE
      TTCX=(TTN(NAP2,MAP1)+ABK*TTN(NAP2,MAP2))/(1.0+ABK)
      TTCY=(TTN(NAP1,MAP1)+AKAB*TTN(NAP3,MAP1))/(1.0+AKAB)
      TTN(NAP2,MAP1)=(TTCX+TTCY)/2.0
      DO 700 J=1,MP2
      TTN(1,J)=TTN(3,J)
      TTN(NP3,J)=TTN(NP1,J)
700  CONTINUE

      WRITE(5,*)'ITJ=',ITJ
C      DO 753 K=1,NP3,NAD
C      WRITE(5,*)(TTN(K,J),J=1,MP2,MAD)
C753  CONTINUE
      DO 701 K=1,NP3
      DO 701 J=1,MP2
      TTNA(K,J)=TTN(K,J)
701  CONTINUE
      DO 211 K=2,NAP2
      DO 211 J=MAP2,MP1
      TDX(K,J)=BBYAB*TTA(K,J)+DYA2*TTNAXX(K,J)+DYA2*TAXY2(K,J)
211  CONTINUE
      DO 261 K=NAP3,NP2
      DO 261 J=2,MP1
      TDX(K,J)=BBYB*TTA(K,J)+DYB2*TTNAXX(K,J)+DYB2*TAXY2(K,J)
261  CONTINUE
      DO 251 K=2,NAP1
      DO 251 J=2,MA
      TDX(K,J)=BBYA*TTA(K,J)+DYA2*TTNAXX(K,J)+DYA2*TAXY2(K,J)
251  CONTINUE
      DO 212 J=2,MAP1
      TDX(NAP2,J)=0.0
212  CONTINUE
      B(2)=CNY2(2)
      A(2)=CNY3(2)+CNY1(2)
      DO 220 J=2,MA
      DO 304 K=2,NP2
      TN(K)=TTN(K,J)
304  CONTINUE
      ITK=0
303  CONTINUE

```

```

      ITK=ITK+1
      IF (ITK.GT.ITL) GO TO 501
      DO 302 K=2,NP2
        TNA(K)=TN(K)
302  CONTINUE
      DO 213 K=2,NP2
        DN(K)=TDX(K,J)
213  CONTINUE
      D(2)=TDX(2,J)
      DN(NAP2)=0.0
      A(2)=CNY1(2)+CNY3(2)
      B(2)=CNY2(2)
      DO 206 K=3,NAP1
        DN(K)=TDX(K,J)
        K1=K-1
        W=CNY1(K)/B(K1)
        B(K)=CNY2(K)-W*A(K1)
        A(K)=CNY3(K)
        D(K)=DN(K)-W*D(K1)
206  CONTINUE
      W=CNCB1/B(NAP1)
      B(NAP2)=CNCB2-W*A(NAP1)
      A(NAP2)=CNCB3
      D(NAP2)=DN(NAP2)-W*D(NAP1)
      DO 266 K=NAP3,NP1
        DN(K)=TDX(K,J)
        K1=K-1
        W=CNYB1(K)/B(K1)
        B(K)=CNYB2(K)-W*A(K1)
        A(K)=CNYB3(K)
        D(K)=DN(K)-W*D(K1)
266  CONTINUE
      BB=CNY1(NP2)+CNY3(NP2)
      W=BB/B(NP1)
      TN(NP2)=(W*D(NP1)-DN(NP2))/(W*A(NP1)-CNY2(NP2))
      DO 218 K=1,N
        KK=NP2-K
        TN(KK)=(-A(KK)*TN(KK+1)+D(KK))/B(KK)
218  CONTINUE
      TN(1)=TN(3)
      TN(NP3)=TN(NP1)
      DO 300 K=2,NP2
        IF (ABS(TN(K)-TNA(K)).GT.EPTE) GO TO 303
300  CONTINUE
      DO 315 K=1,NP3
        TTN(K,J)=TN(K)
315  CONTINUE
220  CONTINUE
      DO 240 J=MAP2,MP1
        DO 344 K=2,NP2
          TN(K)=TTN(K,J)
344  CONTINUE
      ITK=0
305  CONTINUE
      ITK=ITK+1

```

```

        IF (ITK.GT.ITL) GO TO 501
        DO 342 K=2,NP2
            TNA(K)=TN(K)
342  CONTINUE
        DO 243 K=2,NP2
            DN(K)=TDX(K,J)
243  CONTINUE
        D(2)=TDX(2,J)
        A(2)=CNYB1(2)+CNYB3(2)
        B(2)=CNYB2(2)
        DO 246 K=3,NP1
            DN(K)=TDX(K,J)
            K1=K-1
            W=CNYB1(K)/B(K1)
            B(K)=CNYB2(K)-W*A(K1)
            A(K)=CNYB3(K)
            D(K)=DN(K)-W*D(K1)
246  CONTINUE
        BB=CNYB1(NP2)+CNYB3(NP2)
        W=BB/B(NP1)
        TN(NP2)=(W*D(NP1)-DN(NP2))/(W*A(NP1)-CNYB2(NP2))

        DO 241 K=1,N
            KK=NP2-K
            TN(KK)=(-A(KK)*TN(KK+1)+D(KK))/B(KK)
241  CONTINUE
        TN(1)=TN(3)
        TN(NP3)=TN(NP1)
        DO 339 K=2,NP2
            IF (ABS(TN(K)-TNA(K)).GT.EPTE) GO TO 305
339  CONTINUE
        DO 345 K=1,NP3
            TTN(K,J)=TN(K)
345  CONTINUE
240  CONTINUE

        DO 321 K=1,NP3
            TTN(K,MP2)=TTN(K,M)
321  CONTINUE

C      GO TO 411
        DO 322 K=1,NP3
            IF(K.EQ.NAP2) GO TO 322
            TSS=C1*TTA(K,1)+(1-C1)*TTN(K,1)
            IF (TSS.GT.30.0) GO TO 219
            PS=288.68*(1.098+TSS/100.0)**8.024
            GO TO 121
219  CONTINUE
            PS=975.29*(0.9303+TSS/100.0)**7.094
121  CONTINUE
            AP=(PS-PA)/(TSS-TAT)
            BP=PA-AP*TAT
            ALE=ALEC*(BP-FI*(AP*TAT+BP))
            ELD=HA*TAT+AS*QS-EPSE*DR-ALE
            IF (K.GT.NAP1) GO TO 409

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```

        ESN1=-ES1*AKA+HA+ALEC*AP
        ESN2=-ES2*AKA
        ESN3=-ES3*AKA
        GO TO 410
409    CONTINUE
        ESN1=-ES1*AKB+HA+ALEC*AP
        ESN2=-ES2*AKB
        ESN3=-ES3*AKB
410    CONTINUE
        TTN(K,1)=(-ESN2*TTN(K,2)-ESN3*TTN(K,3)+ELD)/ESN1
322    CONTINUE
        TTN(NAP2,1)=(4.0*TTN(NAP1,1)+4.0*AKAB*TTN(NAP3,1)-TTN(NAP4,1)
        *-AKAB*TTN(NAP4,1))/(3.0*(1.0+AKAB))
411    CONTINUE

        DO 351 K=2,NAP1
        TTN(K,MAP1)=(TTN(K,MAP2)+ABK*TTN(K,MA))/(1.0+ABK)
351    CONTINUE
        DO 352 K=NAP3,NP2
        TTN(K,MAP1)=(TTN(K,MAP2)+TTN(K,MA))/2.0
352    CONTINUE
        TC1=(TTN(NAP2,MAP2)+ABK*TTN(NAP2,MA))/(1.0+ABK)
        TC2=(TTN(NAP2,MAP2)+TTN(NAP2,MA))/2.0
        TTN(NAP2,MAP1)=(TC1+TC2)/2.0
        WRITE(5,*)'ITK=',ITK
C      DO 763 K=1,NP3,NAD
C      WRITE(5,*)(TTN(K,J),J=1,MP2,MAD)
C763    CONTINUE
        DO 400 K=2,NP2
        DO 400 J=1,MP1
            IF (ABS(TTN(K,J)-TTNA1(K,J)).LT.EPTE) GO TO 399
C      WRITE(5,*)K,J
        GO TO 401
399    CONTINUE
400    CONTINUE
        IF (I.EQ.365) GO TO 803
        GO TO 100
803    CONTINUE
        IF (NY.EQ.1) GO TO 805
        DO 806 K=2,NP2
        DO 806 J=1,MP1
            IF (ABS(TTN(K,J)-TIN(K,J)).GT.EPTE) GO TO 805
806    CONTINUE
        GO TO 807
805    CONTINUE
        WRITE(5,335)NY,I
335    FORMAT(2X,'NY=',I2,4X,'I=',I3)
        DO 809 K=2,NP2,NAD
        WRITE(5,333)(TTN(K,J),J=1,MP1,MAD)
809    CONTINUE
        NY=NY+1
        DO 804 K=2,NP2
        DO 804 J=1,MP1
            TIN(K,J)=TTN(K,J)
804    CONTINUE

```



```

      I=0
      GO TO 100
807   CONTINUE
      WRITE(5,*)'-----CALCULATION ENDS-----'
      WRITE(5,334)NY,I
334   FORMAT(2X,'NY=',I2,4X,'I=',I3)
C     DO 808 K=2,NP2,NAD
C     WRITE(5,333)(TTN(K,J),J=1,MP1,MAD)
C808  CONTINUE
      DO 811 K=2,NP2,NAD
      WRITE(5,333)(TTNK(K,J),J=1,MP1,MAD)
811   CONTINUE
      DO 810 K=2,NP2,NAD
      WRITE(5,333)(TTNY(K,J),J=1,MP1,MAD)
810   CONTINUE
      WRITE(5,*)'-----CALCULATION ENDS-----'
      WRITE(5,334)NY,I
501   CONTINUE
      WRITE(5,340)IT,ITJ,ITK
340   FORMAT('IT=',I3,3X,'ITJ=',I2,3X,'ITK=',I2)
502   CONTINUE
      WRITE(5,341)I,TIME
341   FORMAT('I=',I3,3X,'TIME=',F5.1)
      WRITE(5,*)'*****'
333   FORMAT(61(F5.2,3X))
      STOP
      END

```

INPUT VALUES USED IN THE NUMERICAL PROGRAM PREPARED FOR TRENCH-FILLED TWO VERTICAL LAYER GROUND MODEL

TAD : The file of 20 years daily mean ambient temperatures
QSD : The file of 20 years daily mean solar radiation
UAD : The file of 20 years daily mean wind speed
FAD : The file of 20 years daily mean relative humidity
M : Step number in vertical
NA : Step numbers in horizontal for trench layer in horizontal
NB : Step numbers in horizontal for ground layer in horizontal
ALX : Ground depth in vertical direction
ALY : Ground depth in horizontal direction
ALA : Trench layer depth
ALB : Ground layer depth
ADA : Thermal diffusivity of trench layer
AKA : Thermal conductivity of trench layer
ADB : Thermal diffusivity of ground layer
AKB : Thermal conductivity of ground layer
AS : Ground surface absorption coefficient
F : Evaporation fraction
DR : Long wave radiation
EPSE : Emission coefficient

SOME OF THE OUTPUT VALUES OBTAINED FROM THE NUMERICAL PROGRAM PREPARED FOR TRENCH-FILLED TWO VERTICAL LAYER GROUND MODEL

-----CALCULATION ENDS-----

NY=14 I=365

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10.22	12.58	14.50	16.20	17.77	19.16	20.33	21.28	22.03	22.59	23.01	23.29	23.47	23.57	23.61
23.60	23.57	23.52	23.46	23.40	23.35	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.20	17.77	19.16	20.33	21.28	22.03	22.59	23.01	23.29	23.47	23.57	23.61
23.60	23.57	23.52	23.46	23.40	23.35	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.20	17.77	19.17	20.33	21.28	22.03	22.60	23.01	23.29	23.47	23.57	23.61
23.61	23.57	23.52	23.46	23.40	23.35	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.20	17.77	19.17	20.33	21.28	22.03	22.60	23.01	23.29	23.47	23.57	23.61
23.61	23.57	23.52	23.46	23.40	23.35	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.20	17.78	19.17	20.34	21.29	22.04	22.60	23.01	23.30	23.48	23.57	23.61
23.61	23.57	23.52	23.46	23.40	23.34	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.21	17.78	19.18	20.34	21.30	22.04	22.61	23.02	23.30	23.48	23.58	23.61
23.61	23.57	23.52	23.46	23.40	23.34	23.16	22.99	22.85	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.50	16.21	17.79	19.19	20.35	21.30	22.05	22.61	23.02	23.30	23.48	23.58	23.61
23.61	23.57	23.52	23.46	23.40	23.34	23.15	22.98	22.84	22.73	22.64	22.57	22.52	22.48	22.46
10.22	12.58	14.51	16.22	17.79	19.20	20.36	21.31	22.06	22.62	23.03	23.31	23.48	23.58	23.62
23.61	23.57	23.52	23.46	23.40	23.34	23.15	22.98	22.84	22.73	22.63	22.57	22.51	22.48	22.46
10.22	12.58	14.51	16.22	17.80	19.21	20.37	21.32	22.07	22.63	23.03	23.31	23.49	23.58	23.62
23.61	23.57	23.52	23.46	23.39	23.34	23.15	22.98	22.84	22.72	22.63	22.56	22.51	22.48	22.45
10.22	12.58	14.51	16.23	17.81	19.22	20.38	21.33	22.08	22.64	23.04	23.32	23.49	23.59	23.62
23.61	23.57	23.52	23.45	23.39	23.33	23.14	22.98	22.84	22.72	22.63	22.56	22.51	22.48	22.45
10.22	12.58	14.52	16.24	17.82	19.23	20.40	21.35	22.09	22.65	23.05	23.33	23.50	23.59	23.62
23.61	23.57	23.51	23.45	23.39	23.33	23.14	22.97	22.83	22.72	22.63	22.56	22.51	22.48	22.45
10.22	12.58	14.52	16.25	17.84	19.25	20.41	21.36	22.10	22.66	23.06	23.33	23.50	23.59	23.62
23.61	23.57	23.51	23.45	23.39	23.33	23.14	22.97	22.83	22.72	22.63	22.56	22.51	22.48	22.45
10.22	12.58	14.53	16.26	17.85	19.26	20.43	21.38	22.11	22.67	23.07	23.34	23.51	23.60	23.63
23.61	23.57	23.51	23.45	23.38	23.33	23.13	22.96	22.82	22.71	22.62	22.56	22.51	22.48	22.45
10.22	12.58	14.53	16.27	17.87	19.28	20.45	21.39	22.13	22.68	23.08	23.35	23.52	23.60	23.63
23.61	23.57	23.51	23.44	23.38	23.32	23.13	22.96	22.82	22.71	22.62	22.56	22.51	22.48	22.45
10.21	12.57	14.53	16.28	17.89	19.30	20.47	21.41	22.15	22.70	23.09	23.36	23.52	23.61	23.63
23.61	23.57	23.51	23.44	23.38	23.32	23.12	22.95	22.82	22.71	22.62	22.55	22.51	22.47	22.45
10.21	12.57	14.54	16.30	17.90	19.32	20.49	21.43	22.17	22.71	23.11	23.37	23.53	23.61	23.63
23.62	23.57	23.51	23.44	23.37	23.31	23.11	22.95	22.81	22.70	22.62	22.55	22.50	22.47	22.45
10.21	12.56	14.54	16.31	17.92	19.34	20.51	21.46	22.19	22.73	23.12	23.38	23.54	23.62	23.64
23.62	23.57	23.51	23.44	23.37	23.31	23.10	22.94	22.81	22.70	22.61	22.55	22.50	22.47	22.45
10.20	12.55	14.55	16.33	17.95	19.37	20.54	21.48	22.21	22.75	23.13	23.39	23.55	23.62	23.64
23.62	23.57	23.51	23.43	23.36	23.30	23.09	22.93	22.80	22.69	22.61	22.55	22.50	22.47	22.45
10.19	12.54	14.55	16.34	17.97	19.40	20.57	21.50	22.23	22.77	23.15	23.40	23.56	23.63	23.65
23.62	23.57	23.50	23.43	23.36	23.29	23.08	22.92	22.79	22.69	22.61	22.55	22.50	22.47	22.45
10.18	12.53	14.55	16.36	18.00	19.43	20.60	21.53	22.25	22.79	23.17	23.42	23.57	23.64	23.65
23.62	23.57	23.50	23.43	23.35	23.29	23.07	22.92	22.79	22.69	22.60	22.54	22.50	22.47	22.44
9.93	12.51	14.56	16.38	18.03	19.46	20.63	21.56	22.28	22.81	23.18	23.43	23.58	23.64	23.65
23.63	23.57	23.50	23.42	23.34	23.24	23.06	22.91	22.78	22.68	22.60	22.54	22.50	22.47	22.44
9.11	12.44	14.58	16.44	18.13	19.56	20.73	21.66	22.37	22.88	23.24	23.48	23.61	23.67	23.67
23.63	23.57	23.50	23.41	23.32	23.18	23.04	22.90	22.78	22.68	22.60	22.54	22.50	22.47	22.44
9.10	12.40	14.59	16.51	18.22	19.66	20.83	21.75	22.45	22.95	23.30	23.52	23.64	23.69	23.68
23.64	23.57	23.49	23.40	23.30	23.17	23.03	22.89	22.77	22.68	22.60	22.54	22.49	22.47	22.44
9.08	12.36	14.61	16.57	18.30	19.75	20.92	21.84	22.52	23.02	23.35	23.56	23.67	23.71	23.70
23.65	23.57	23.48	23.39	23.29	23.15	23.02	22.89	22.77	22.67	22.60	22.54	22.49	22.47	22.44
9.07	12.33	14.62	16.62	18.38	19.84	21.01	21.92	22.59	23.08	23.40	23.60	23.70	23.73	23.71
23.65	23.57	23.48	23.38	23.27	23.14	23.01	22.88	22.76	22.67	22.59	22.54	22.49	22.46	22.44
9.06	12.31	14.64	16.68	18.45	19.92	21.09	21.99	22.66	23.13	23.45	23.64	23.73	23.75	23.72
23.65	23.57	23.47	23.37	23.26	23.13	23.00	22.87	22.76	22.67	22.59	22.53	22.49	22.46	22.44
9.06	12.30	14.66	16.72	18.52	19.99	21.16	22.06	22.72	23.18	23.49	23.67	23.75	23.77	23.73
23.66	23.57	23.47	23.36	23.25	23.12	22.99	22.87	22.76	22.66	22.59	22.53	22.49	22.46	22.44
9.05	12.30	14.68	16.77	18.58	20.06	21.23	22.12	22.78	23.23	23.53	23.70	23.77	23.78	23.74
23.66	23.57	23.46	23.35	23.24	23.11	22.98	22.86	22.75	22.66	22.59	22.53	22.49	22.46	22.44
9.05	12.29	14.70	16.81	18.63	20.12	21.29	22.18	22.83	23.28	23.56	23.73	23.79	23.79	23.74
23.67	23.57	23.46	23.34	23.23	23.10	22.97	22.85	22.75	22.66	22.59	22.53	22.49	22.46	22.44
9.05	12.29	14.71	16.85	18.68	20.18	21.35	22.23	22.88	23.32	23.60	23.75	23.81	23.81	23.75

23.67	23.57	23.45	23.34	23.22	23.09	22.97	22.85	22.74	22.66	22.59	22.53	22.49	22.46	22.45	22.44
9.05	12.30	14.73	16.88	18.73	20.23	21.40	22.28	22.92	23.35	23.62	23.77	23.83	23.82	23.76	
23.67	23.56	23.45	23.33	23.21	23.09	22.96	22.84	22.74	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.30	14.75	16.91	18.77	20.28	21.45	22.33	22.96	23.38	23.65	23.79	23.84	23.83	23.76	
23.67	23.56	23.45	23.32	23.20	23.08	22.96	22.84	22.74	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.30	14.76	16.94	18.81	20.32	21.49	22.36	22.99	23.41	23.67	23.81	23.86	23.84	23.77	
23.67	23.56	23.44	23.32	23.20	23.07	22.95	22.84	22.74	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.31	14.78	16.96	18.84	20.35	21.52	22.40	23.02	23.44	23.69	23.83	23.87	23.84	23.77	
23.67	23.56	23.44	23.32	23.19	23.07	22.95	22.83	22.73	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.31	14.79	16.98	18.86	20.38	21.55	22.43	23.04	23.46	23.71	23.84	23.88	23.85	23.78	
23.68	23.56	23.44	23.31	23.19	23.06	22.94	22.83	22.73	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.31	14.80	17.00	18.89	20.41	21.58	22.45	23.07	23.48	23.73	23.85	23.89	23.85	23.78	
23.68	23.56	23.43	23.31	23.18	23.06	22.94	22.83	22.73	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.32	14.81	17.01	18.90	20.43	21.60	22.47	23.08	23.49	23.74	23.86	23.89	23.86	23.78	
23.68	23.56	23.43	23.30	23.18	23.06	22.94	22.83	22.73	22.65	22.58	22.53	22.49	22.46	22.45	22.44
9.05	12.32	14.81	17.02	18.92	20.44	21.62	22.48	23.10	23.50	23.75	23.87	23.90	23.86	23.78	
23.68	23.56	23.43	23.30	23.18	23.06	22.93	22.82	22.73	22.64	22.58	22.53	22.49	22.46	22.44	22.44
9.05	12.32	14.82	17.03	18.93	20.45	21.63	22.50	23.11	23.51	23.75	23.87	23.90	23.86	23.78	
23.68	23.56	23.43	23.30	23.18	23.05	22.93	22.82	22.73	22.64	22.58	22.52	22.49	22.46	22.44	22.44
9.05	12.32	14.82	17.04	18.93	20.46	21.63	22.50	23.11	23.52	23.76	23.88	23.90	23.87	23.79	
23.68	23.56	23.43	23.30	23.17	23.05	22.93	22.82	22.73	22.64	22.58	22.52	22.49	22.46	22.44	22.44
9.05	12.32	14.82	17.04	18.94	20.46	21.64	22.50	23.11	23.52	23.76	23.88	23.90	23.87	23.79	
23.68	23.56	23.43	23.30	23.17	23.05	22.93	22.82	22.73	22.64	22.58	22.52	22.49	22.46	22.44	22.44

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32.44	30.47	28.82	27.36	26.12	25.08	24.20	23.48	22.91	22.47	22.14	21.90	21.75	21.66	21.62	
21.61	21.63	21.67	21.72	21.77	21.82	21.98	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.82	27.36	26.12	25.08	24.20	23.48	22.91	22.47	22.14	21.90	21.75	21.66	21.62	
21.61	21.63	21.67	21.72	21.77	21.82	21.98	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.82	27.36	26.12	25.08	24.20	23.48	22.91	22.47	22.14	21.90	21.75	21.66	21.62	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.82	27.35	26.12	25.08	24.20	23.48	22.90	22.46	22.13	21.90	21.75	21.66	21.61	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.82	27.35	26.12	25.08	24.19	23.47	22.90	22.46	22.13	21.90	21.74	21.65	21.61	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.82	27.35	26.11	25.07	24.19	23.47	22.90	22.46	22.13	21.90	21.74	21.65	21.61	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.47	28.81	27.34	26.11	25.07	24.18	23.46	22.89	22.45	22.13	21.89	21.74	21.65	21.61	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.14	22.27	22.38	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.46	28.81	27.34	26.10	25.06	24.18	23.46	22.89	22.45	22.12	21.89	21.74	21.65	21.61	
21.61	21.63	21.67	21.72	21.77	21.82	21.99	22.15	22.28	22.39	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.46	28.81	27.33	26.09	25.05	24.17	23.45	22.88	22.44	22.12	21.89	21.73	21.65	21.61	
21.61	21.63	21.67	21.72	21.78	21.83	22.00	22.15	22.28	22.39	22.47	22.54	22.59	22.62	22.64	22.65
32.44	30.46	28.80	27.33	26.09	25.04	24.16	23.44	22.87	22.43	22.11	21.88	21.73	21.64	21.61	
21.61	21.63	21.67	21.73	21.78	21.83	22.00	22.15	22.28	22.39	22.48	22.54	22.59	22.62	22.64	22.65
32.44	30.46	28.80	27.32	26.08	25.03	24.15	23.43	22.86	22.43	22.10	21.87	21.73	21.64	21.61	
21.61	21.63	21.68	21.73	21.78	21.83	22.00	22.15	22.28	22.39	22.48	22.54	22.59	22.62	22.64	22.65
32.44	30.45	28.79	27.31	26.07	25.02	24.14	23.42	22.85	22.42	22.10	21.87	21.72	21.64	21.60	
21.60	21.63	21.68	21.73	21.78	21.83	22.01	22.16	22.29	22.39	22.48	22.54	22.59	22.62	22.64	22.65
32.43	30.45	28.78	27.30	26.05	25.01	24.12	23.41	22.84	22.41	22.09	21.86	21.72	21.63	21.60	
21.60	21.63	21.68	21.73	21.79	21.84	22.01	22.16	22.29	22.40	22.48	22.55	22.59	22.63	22.64	22.65
32.43	30.45	28.78	27.29	26.04	24.99	24.11	23.39	22.83	22.40	22.08	21.86	21.71	21.63	21.60	
21.60	21.63	21.68	21.73	21.79	21.84	22.02	22.17	22.30	22.40	22.48	22.55	22.60	22.63	22.65	22.65
32.43	30.44	28.77	27.28	26.03	24.98	24.09	23.38	22.82	22.39	22.07	21.85	21.70	21.63	21.59	
21.60	21.63	21.68	21.73	21.79	21.84	22.02	22.17	22.30	22.40	22.49	22.55	22.60	22.63	22.65	22.65
32.43	30.44	28.76	27.26	26.01	24.96	24.08	23.37	22.80	22.37	22.06	21.84	21.70	21.62	21.59	
21.60	21.63	21.68	21.74	21.80	21.85	22.03	22.18	22.30	22.41	22.49	22.55	22.60	22.63	22.65	22.65
32.43	30.44	28.75	27.25	25.99	24.94	24.06	23.35	22.79	22.36	22.05	21.83	21.69	21.62	21.59	
21.60	21.63	21.68	21.74	21.80	21.85	22.03	22.18	22.31	22.41	22.49	22.55	22.60	22.63	22.65	22.65
32.43	30.44	28.74	27.24	25.98	24.92	24.04	23.33	22.77	22.35	22.04	21.82	21.68	21.61	21.58	
21.60	21.63	21.68	21.74	21.80	21.86	22.04	22.19	22.31	22.41	22.49	22.56	22.60	22.63	22.65	22.66
32.43	30.43	28.72	27.22	25.96	24.90	24.02	23.31	22.75	22.33	22.02	21.81	21.68	21.60	21.58	
21.59	21.63	21.68	21.74	21.81	21.86	22.05	22.20	22.32	22.42	22.50	22.56	22.60	22.63	22.65	22.66
32.44	30.44	28.71	27.20	25.94	24.88	24.00	23.29	22.74	22.32	22.01	21.80	21.67	21.60	21.58	
21.59	21.63	21.68	21.75	21.81	21.87	22.06	22.21	22.32	22.42	22.50	22.56	22.60	22.63	22.65	22.66
32.55	30.44	28.69	27.18	25.91	24.86	23.98	23.27	22.72	22.30	22.00	21.79	21.66	21.59	21.57	
21.59	21.63	21.68	21.75	21.82	21.91	22.08	22.21	22.33	22.43	22.50	22.56	22.61	22.64	22.65	22.66

32.93	30.44	28.64	27.11	25.84	24.77	23.90	23.20	22.65	22.24	21.95	21.75	21.63	21.57	21.56
21.58	21.63	21.69	21.76	21.84	21.96	22.09	22.22	22.33	22.43	22.51	22.56	22.61	22.64	22.65
32.93	30.44	28.59	27.04	25.77	24.70	23.82	23.13	22.59	22.19	21.90	21.71	21.60	21.55	21.54
21.57	21.62	21.69	21.77	21.85	21.98	22.10	22.23	22.34	22.43	22.51	22.57	22.61	22.64	22.65
32.93	30.44	28.54	26.99	25.70	24.63	23.75	23.06	22.53	22.14	21.86	21.68	21.57	21.53	21.53
21.57	21.62	21.69	21.78	21.87	21.99	22.11	22.23	22.34	22.43	22.51	22.57	22.61	22.64	22.65
32.93	30.43	28.51	26.94	25.64	24.56	23.69	23.00	22.48	22.09	21.82	21.65	21.55	21.51	21.52
21.56	21.62	21.70	21.78	21.88	22.00	22.12	22.24	22.35	22.44	22.51	22.57	22.61	22.64	22.65
32.93	30.42	28.47	26.89	25.58	24.50	23.63	22.95	22.43	22.05	21.78	21.62	21.53	21.50	21.51
21.55	21.62	21.70	21.79	21.89	22.01	22.13	22.24	22.35	22.44	22.51	22.57	22.61	22.64	22.65
32.93	30.41	28.44	26.84	25.53	24.44	23.57	22.90	22.38	22.01	21.75	21.59	21.51	21.48	21.50
21.55	21.62	21.71	21.80	21.90	22.02	22.13	22.25	22.35	22.44	22.51	22.57	22.61	22.64	22.65
32.93	30.40	28.42	26.80	25.48	24.39	23.52	22.85	22.34	21.97	21.72	21.56	21.49	21.47	21.49
21.55	21.62	21.71	21.80	21.91	22.03	22.14	22.26	22.36	22.44	22.52	22.57	22.61	22.64	22.65
32.93	30.39	28.39	26.77	25.43	24.34	23.48	22.81	22.30	21.94	21.69	21.54	21.47	21.45	21.48
21.54	21.62	21.71	21.81	21.92	22.03	22.15	22.26	22.36	22.45	22.52	22.57	22.61	22.64	22.66
32.93	30.38	28.37	26.73	25.39	24.30	23.44	22.77	22.26	21.90	21.66	21.52	21.45	21.44	21.48
21.54	21.62	21.71	21.82	21.92	22.04	22.15	22.26	22.36	22.45	22.52	22.57	22.61	22.64	22.66
32.93	30.37	28.35	26.70	25.36	24.26	23.40	22.73	22.23	21.88	21.64	21.50	21.44	21.43	21.47
21.54	21.62	21.72	21.82	21.93	22.05	22.16	22.27	22.37	22.45	22.52	22.57	22.61	22.64	22.66
32.93	30.36	28.33	26.68	25.33	24.23	23.36	22.70	22.20	21.85	21.62	21.48	21.42	21.42	21.46
21.53	21.62	21.72	21.83	21.94	22.05	22.16	22.27	22.37	22.45	22.52	22.57	22.61	22.64	22.66
32.93	30.35	28.32	26.65	25.30	24.20	23.33	22.67	22.17	21.83	21.60	21.47	21.41	21.41	21.46
21.53	21.62	21.72	21.83	21.94	22.06	22.17	22.28	22.37	22.45	22.52	22.57	22.61	22.64	22.66
32.93	30.35	28.30	26.63	25.27	24.17	23.30	22.64	22.15	21.81	21.58	21.45	21.40	21.41	21.45
21.53	21.62	21.72	21.83	21.95	22.06	22.17	22.28	22.37	22.46	22.52	22.58	22.61	22.64	22.66
32.93	30.34	28.29	26.62	25.25	24.15	23.28	22.62	22.13	21.79	21.57	21.44	21.39	21.40	21.45
21.53	21.62	21.73	21.84	21.95	22.06	22.18	22.28	22.38	22.46	22.52	22.58	22.61	22.64	22.66
32.93	30.34	28.28	26.60	25.23	24.13	23.26	22.60	22.11	21.77	21.55	21.43	21.39	21.40	21.45
21.53	21.62	21.73	21.84	21.95	22.07	22.18	22.28	22.38	22.46	22.52	22.58	22.62	22.64	22.66
32.92	30.33	28.27	26.59	25.22	24.11	23.25	22.59	22.10	21.76	21.54	21.42	21.38	21.39	21.44
21.52	21.62	21.73	21.84	21.96	22.07	22.18	22.29	22.38	22.46	22.53	22.58	22.62	22.64	22.66
32.92	30.33	28.26	26.58	25.21	24.10	23.23	22.57	22.09	21.75	21.54	21.42	21.37	21.39	21.44
21.52	21.62	21.73	21.84	21.96	22.07	22.18	22.29	22.38	22.46	22.53	22.58	22.62	22.64	22.66
32.92	30.33	28.26	26.57	25.20	24.09	23.23	22.57	22.08	21.75	21.53	21.41	21.37	21.39	21.44
21.52	21.62	21.73	21.84	21.96	22.07	22.18	22.29	22.38	22.46	22.53	22.58	22.62	22.64	22.66
32.92	30.33	28.26	26.57	25.19	24.09	23.22	22.56	22.08	21.74	21.53	21.41	21.37	21.38	21.44
21.52	21.62	21.73	21.85	21.96	22.07	22.19	22.29	22.38	22.46	22.53	22.58	22.62	22.64	22.66
32.92	30.32	28.26	26.57	25.19	24.08	23.22	22.56	22.08	21.74	21.53	21.41	21.37	21.38	21.44
21.52	21.62	21.73	21.85	21.96	22.07	22.19	22.29	22.38	22.46	22.53	22.58	22.62	22.64	22.66

-----CALCULATION ENDS-----

NY=14 I=365

IT= 2 ITJ= 2 ITK= 1

I=365 TIME=365.0
