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A Technical Feasibility Study on the Use of Çavundur Geothermal Field for Greenhouse Heating

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ABSTRACT

Heating of a greenhouse can be done using different systems and design procedures. The applicability of different types of greenhouses is studied at the field local conditions, Çavundur-Çankiri, Turkey. Required heating load was calculated that is due to infiltration and conduction through the greenhouse cover at a single design point, which is the minimum outside temperature. Two types of heating systems, soil heating system and bare tube system, were considered.

Analysis of results showed that, Çavundur geothermal field with 54 °C fluid temperature is suitable for greenhouse heating. Although the existing well Ç-1 is capable of producing 47 l/s, the flow rate of geothermal fluid for greenhouse heating was limited by 35 l/s due to existing thermal facilities in the area.

Among different glazing materials, plastic film covered greenhouses with double poly was found to be the most suitable in terms of heat load calculations.

The maximum number of greenhouses (the area of each green house is 216 m^2) that can be heated by Çavundur Geothermal field was found to be 138 by considering soil heating with double poly glazing material. Annual heat load factor of geothermal energy for greenhouse heating in Çavundur area was found to be as high as 96% depending on indoor design temperature and base load.

1. INTRODUCTION

Direct utilization of geothermal energy consists of various forms for heating and cooling instead of converting the energy for electric power generation. The major areas of direct utilization are; Swimming, bathing and balneology; Space heating and cooling including district heating; Agriculture applications ; Aquaculture applications ; Industrial processes and Heat pumps.

Agribusiness applications (agriculture and aquaculture) are particularly attractive because they require heating at the lower end of the temperature range where there is an abundance of geothermal resources. Use of waste heat or the cascading of geothermal energy also has excellent possibilities. A number of agribusiness applications can be considered: greenhouse heating, aquaculture and animal husbandry, soil warming and irrigation, mushroom culture, and bio-gas generation.

Numerous commercially marketable crops have been raised in geothermally heated greenhouses in Hungary, Russia, New Zealand, Japan, Iceland, China, Turkey and the U.S. These include vegetables, such as cucumbers and tomatoes, flowers (both potted and bedded), houseplants, tree seedlings, and cacti. Using geothermal energy for heating reduces operating costs (which can account for 35% of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical.

Direct use applications of geothermal energy in Turkey are mainly focused on space heating and bathing. Today space-heating covers 53.83% of the total use with an installed capacity of 534 MW_t. Moreover, 195 spas utilize geothermal energy for bathing, swimming and balneology. Their total installed capacity is 327 MW_t. The total area of greenhouses heated by geothermal is 565000 m^2 with an installed capacity of 131 MW_t. In Şanlıurfa, a 106000 m^2 geothermal greenhouse exports its entire yield to Europe. (Mertoğlu, et al. 2003).

A greenhouse is a construction aimed at creating a protected space for plant cultivation in a controlled environment, even during climatically unfavorable periods. The importance of light in the life processes of the plants entails the use of transparent materials such as glass, plastic films, and plates, fiberglass, which also exploit solar energy to raise the inside temperature conditions. However, this is not enough to maintain optimal growing conditions during periods when solar radiation is not strong enough and during night. This means that, an additional source of heat is required that can be regulated. The amount of extra heat required depends on the local climate, plant requirements and the type of greenhouse construction. Over a year, it mainly depends on changes in the outside air temperature and in the intensity of solar radiation (Figure 1).

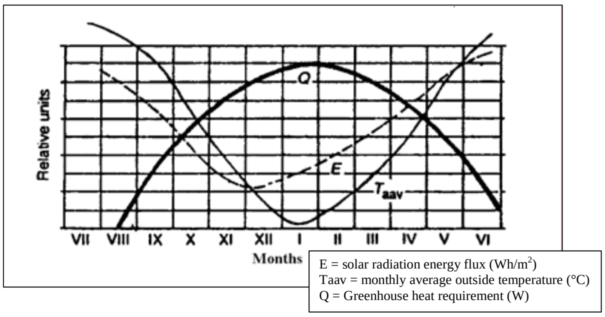

Figure 1: Heat requirement in a greenhouse over a typical year in Gevgelia, Rep. Of Macedonia (Popovski, 1984)

Heating of a greenhouse can be done using different systems and design procedures, but in all these attempts the first step is the determination of peak-heating requirement for the structure. Peak heat load of a greenhouse can be estimated by two methods. The first method, *static method*, includes calculations of heat losses due to infiltration and conduction through the greenhouse at a single design point, which is the minimum outside temperature. It also assumes the greenhouse to be empty with no plants in it. This method also disregards moisture transfer and assumes air to be dry. The second method is rather complicated and requires computer simulation but it incorporates all energy and mass transfer to the greenhouse and gives results based on the true outside conditions. Emeish (1999) made a comparison of the two methods and concluded that the greenhouse heating design by static method with a 10% safety factor can be used with sufficient accuracy and, thus, the use of complex relations are not needed. The following sections will include the details of static method in greenhouse heating.

2. HEAT LOAD CALCULATIONS

In static method, heat loss for a greenhouse is composed of two components:

- Transmission losses through the walls and roof,
- Infiltration and ventilation losses caused by cold outside air.

2.1 Transmission Heat Losses

The calculation of the surface area of the greenhouse structure is the first step while evaluating transmission heat losses. The surface area of the greenhouse can be subdivided into the various glazing materials employed, i.e. square meters of polyethylene, square meters of fiberglass, etc. Then, the transmission losses can be estimated using the following equation:

$$Q_t = UA(T_i - T_o) \qquad (1)$$

where

Q_t = Heat transmission losses through walls and roof [W]

U = Heat transfer coefficient [W/m^2 °C]

A = Surface area [m^2]

T_i = Indoor design temperature [°C]

T_o = Outdoor design temperature [°C]

Heat transfer coefficient values (U) vary with the type of glazing material and depend on wind speed. Table 1 gives the correlation between the heat transfer coefficient and wind speed for the common glazing materials.

Table 1: Heat transfer coefficient values as function of wind speed for the common glazing materials (W/m^2 °C) (Rafferty, 1998)

	Wind speed (m/s)					
Material	**0.00**	**2.24**	**4.47**	**8.94**	**11.18**	**13.41**
Glass	4.34	5.40	5.91	6.47	6.59	6.70
Fiberglass	3.95	4.91	5.39	5.87	6.01	6.12
Single poly	4.60	5.68	6.19	6.76	6.87	6.98
Double poly	3.04	3.58	3.83	4.07	4.13	4.18

2.2 Infiltration Heat Losses

The air change method is the general method for the calculation of infiltration heat losses. The method is based upon the number of times per hour (ACH) that the air in the greenhouse is replaced by cold air leaking from outside. The number of air changes, which occur, is a function of wind speed, greenhouse construction, and inside and outside temperatures. Table 2 outlines general values for different types of greenhouse constructions, which can be used by the designers.

Table 2: Air change data for different glazing materials (Rafferty, 1998)

Greenhouse Cover Material	ACH
Single Glass	2.5 – 3.5
Double Glass	1.0 - 1.5
Fiberglass	2.1 - 3.1
Single Polyethylene	0.5 – 1.0
Double Polyethylene	0.0 – 1.0

After selecting the appropriate number from Table 2, it is necessary to calculate the volume of greenhouse. Then, Equation 2 is used to calculate the infiltration heat losses:

$$Q_i = V \times ACH \times C_p \times \rho \times (T_i - T_o)/3600 \qquad (2)$$

where

Q_i = Infiltration heat loss [W]

V = Volume of greenhouse [m^3]

ACH = Air change per hour (from Table 2)

C_p = Specific heat capacity of air [J/kg °C]

ρ = Density of air [kg/m^3]

Total heat loss can be calculated by addition of transmission heat loss and infiltration heat loss.

By calculating maximum heating load for the greenhouse, the adequate system to heat the greenhouse can be chosen. If the soil heating or bare tube heating systems are chosen, further calculations are required to complete the design of these heating systems. These calculations are presented in the following sections.

2.3 Soil Heating System Design

The procedure for designing a floor system consists of:

- Determining the heat load for the greenhouse;
- Calculating the required floor temperature to meet the load;
- Calculating the required size, depth and spacing of the tubes.

Determination of the heat load was covered in Sections 2.1 and 2.2. Therefore, the next step is to determine the required floor surface temperature in the greenhouse. The heat output of the floor is a function of a floor surface temperature, greenhouse air temperature and average temperature of unheated surfaces in the room. Heat output from the floor occurs by two mechanism, convection and radiation. The calculated heat loss of the greenhouse is divided by the area of the greenhouse floor, which will be used for heating purposes. This gives the required energy per area (W/m^2) to be supplied by the floor surface to cover for the heat loss. Equation 3 (Lund, 1996) is used to calculate the required floor surface temperature.

$$\frac{q}{A}=0.472\left[\left(\frac{1.8T_p+492}{100}\right)^4-\left(\frac{1.8AUST+492}{100}\right)^4\right]+2.186\left(T_p-T_a\right)^{1.32} \quad (3)$$

where

q/A = Heat/Area [W/m^2];

T_p= Floor surface temperature [°C]

T_a= Indoor air temperature [°C]

AUST = Average temperature of unheated surfaces in the greenhouse (walls and roof) [°C]

Furthermore;

$$IST=IDT-(0.0291\times3.6\times U\times DT) \quad (4)$$

where

IST = Inside surface temperature [°C]

IDT = Inside design temperature [°C]

U = Glazing material heat loss factor [W/m^2 °C];

DT= Design temperature difference (inside-outside) [°C]

and

$$AUST=\frac{A_1\times IST_1+A_2\times IST_2+\cdots\cdots+A_n\times IST_n}{A_1+A_2+\cdots\cdots+A_n} \quad (5)$$

where

A = Surface area of glazing material [m^2]

The floor temperature (T_p) can be determined by solving Equation 3.

At this point the designer should check whether this temperature is too hot for the plants or for the workers in the greenhouse, and if the soil heating system should be used to cover only a fraction of the total load or if it can cover the total load. After determining the required soil surface temperature, the next step is to determine the depth and spacing of the tubes needed to meet this requirement. Generally, the depth is more a function of protecting the tubes from surface activity than system design. It is commonly 5-15 cm. below the surface. Since it is the purpose of the floor panel system to use the floor as a large radiator, it follows that the installation of the tubing should result in as uniform a floor surface temperature as possible. This can be accomplished in two ways: (a) placing smaller diameter tubes at close spacing near the surface of the floor, or (b) placing larger tubes spaced further apart at deeper levels (Lund, 1996).

At this point the designer should know the heating load required, the floor surface temperature, heating water temperature and burial depth, which provides protection the tubes from surface activity. After that, and using Equation 6 (Björnson, 1980), the designer has to decide the size and length of pipes needed to supply the necessary heating load.

$$L=\frac{Q\times\ln\left[\left(8\left(\frac{H}{d}\right)^2-1\right)+4\left(\frac{H}{d}\right)\times\sqrt{4\times\left(\frac{H}{d}\right)^2-1}\right]}{4\times\pi\times\lambda_j\times t_m} \quad (6)$$

where

Q = Heating Load [W]

L= Pipe Length [m]

H = Pipe burial depth (floor surface to pipe) [mm]

d = Pipe outside diameter [mm]

λ_j = Earth heat conductivity [W/m °C]

t_m = Log mean temperature difference [°C]

and

$$t_m=\frac{\left(T_{wi}-T_{w0}\right)}{\ln\left(\frac{T_{wi}-T_P}{T_{w0}-T_P}\right)} \quad (7)$$

where

T_{wi} = Water inlet temperature [°C]

T_{wo} = Water outlet temperature [°C]

T_P = Floor surface temperature [°C]

From Equation 6, it is seen that the length of the heating pipe depends on many variables, most of which cannot be controlled by the designer, but are function of location and construction of the greenhouse. Where the pipe burial depth is a function of surface activity and plants location within the greenhouse, heating load is a function of the construction of the greenhouse. Water inlet temperature is a function of the geothermal field from which the water is being taken. The designer can only decide the pipe diameter and water temperature drop across the loop, and then get the length of the pipe needed to cover the load required.

In order to have homogeneous temperature distribution the pipes are arranged parallel to the greenhouse length. After determining the length of the pipe, the number of pipes (n), is determined by

$$n=\frac{L_{pipe}}{L_{greenhouse}} \quad (8)$$

where

n = Number of pipes

L_{pipe} = Pipe length [m]

$L_{greenhouse}$ = Greenhouse length [m]

2.4 Bare Tube System Design

This system involves installing bare polybutylene tubes, or similar material, on the floor of the greenhouse. The tubes are arranged in such a way that each tube is separated from the others. Otherwise if the tubes were bunched together, the effective surface area of each is reduced, thus lowering heating capacity.

The first step in designing this heating system is of course to determine the heating load. Next, the designer has to determine the temperature drop across the loop, which is usually between 10 °C and 20 °C. Knowing the heating water inlet temperature, which is determined by the geothermal field, the temperature drop and the heating pipe diameter, determined by the designer, the heating pipe can be calculated according to Equation 9 (Lund, 1996).

$$L = \frac{3.6Q}{\left[4.422\times\left(\frac{1}{D}\right)^{0.2}\times\left(\frac{1}{1.8T_{ave}+32}\right)^{0.181}\times(\Delta T)^{1.266}+15.7\times10^{-10}\left[(1.8T_1+32)^4-(1.8T_2+32)^4\right]\right]11.345A} \quad (9)$$

L = Pipe Length [m]

Q = Heating Load [W]

D = Outside diameter of tubing [mm]

T_{ave} = 255.6+ (AWT + T_{air})/2 [°C]

AWT = T_{wi} - DT/2 [°C];

T_{wi} = Heating water supply temperature [°C]

T_{air} = Greenhouse design air temperature [°C]

T_1= 255.6 + AWT [°C]

T_3 = (AUST + T_{air}) / 2 [°C]

T_2 = 255.6 + T_3 [°C]

A = Outside surface area of pipe / unit length [m^2/m]

As in the soil heating system, the two variables that the designer has real control over are the temperature drop across the loop, and the pipe diameter.

3. ÇAVUNDUR GEOTHERMAL FIELD

Çavundur geothermal field, located in Çavundur village, is 8 km far from Kurşunlu town of Çankırı (Figure 2).

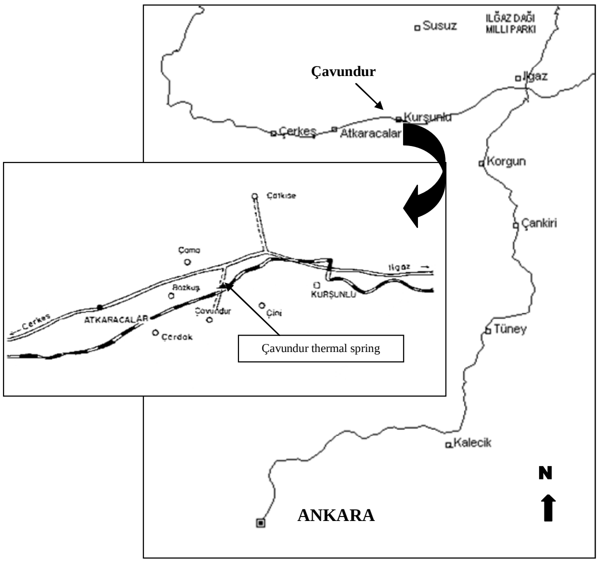

Figure 2: Location map of Çavundur geothermal field (not to scale).

There were two hot water springs in Çavundur area issuing through the Pliocene age sediments. Those hot springs had temperatures of 38 °C and 19 °C with flow rates of 0.2 l/s and 0.1 l/s, respectively. Governorship of Çankırı requested the drilling of the Well Çavundur-1 (Ç-1) from Mineral Research and Exploration General Directorate (MTA) to increase the flow rate. Ç-1 was drilled by MTA in 1987 to a total depth of 270 m. The composite log of Ç-1 is presented in Figure 3 (Günay and Şimşek, 2001). Initial measurements showed a maximum flow rate of 47 l/s geothermal fluid at 54 °C (Uzel and Didik, 1988). Geothermal fluid from Ç-1 has a TDS of 11652 mg/l and can be classified as sodium-bicarbonate water (Table 3, Uzel and Didik, 1988). There is a continuous inhibitor injection into the wellbore due to tendency of water for calcite scaling.

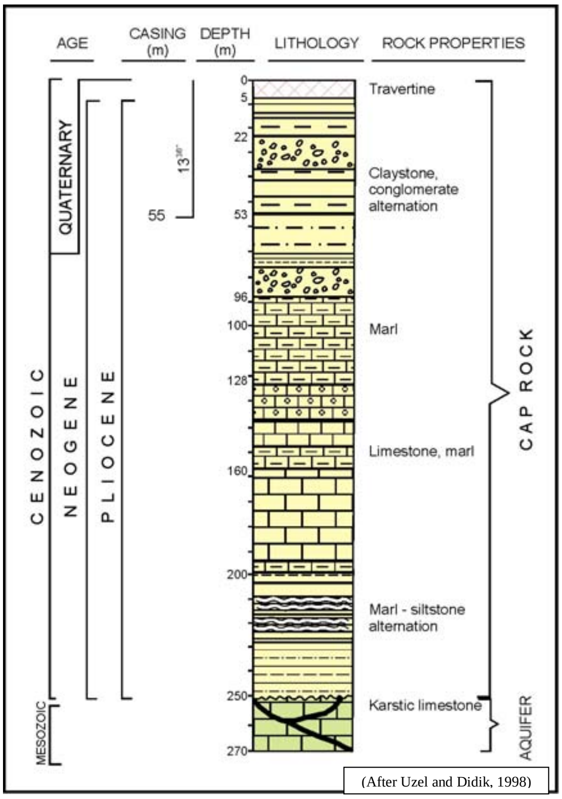

Figure 3: Composite log of Ç-1 (Günay and Şimşek, 2001).

Table 3: Chemical composition of geothermal fluid from Ç-1 (Uzel and Didik, 1988).

CATIONS		ANIONS		OTHER MEASUREMENTS
Element	**mg/l**	**Element**	**mg/l**	
K^+	170	HCO^-_3	7210	SiO_2 = 44 mg/l
Na^+	2950	CO^{--}_3	234	CO_2 (dissolved in water) = 100.47
NH^+_4	6.9	SO^{--}_4	120	pH (25° C) = 8.06
Ca^{++}	7.6	Cl^-	726	Specific conductivity = 8800 mho cm^{-1}
Mg^{++}	18	F^-	7	Specific Gravity (25°C) = 1.005 gr/cm^3
$Fe_{(total)}$	<0.1	NO_2^-	<0.01	Total Hardness = 9.32 Fr
$As_{(total)}$	6.6	NO^-_3	<0.1	
$B_{(total)}$	51	I^-	<0.5	
		PO^{--}_4(total)	<0.1	
Total	**3210**		**8297**	

Governorship of Çankırı established a firm (ÇANTUR A.Ş.) for the utilization of Çavundur geothermal field for bathing, balneology and thermal tourism. Geothermal water of Çavundur field is known to be suitable for the curing of rheumatic ilnesses, blood circulation and heart diseases, digestive system diseases as well as metabolism disorders and exhaustions (İncekara, 1996). The thermal facilities are generally full during the summer months (June-September) by the maximum capacity of 500 visitors but there is only 10% occupancy in the rest of the year.

3.1 Meteorological Conditions in the Study Area

The area where the geothermal field is located has an altitude of 1230 m and it has long and cold winters. In order to include the changes in outside temperature for greenhouse design, the meteorological data of Kurşunlu town (8 kilometers far from Çavundur) for the year 2002 was taken from the Directorate of Meteorology of Çankırı. This data include daily measurements of temperature, wind speeds, relative humidity taken at 7 AM, 2 PM and 9 PM.

Figure 4 shows the daily temperature changes along the year recorded at 7 AM and 2 PM, as well as the arithmetic average of these two values. As observed from the figure three-temperature values for a given day do not show great differences. As a consequence, it was decided to use daily mean temperatures throughout this study.

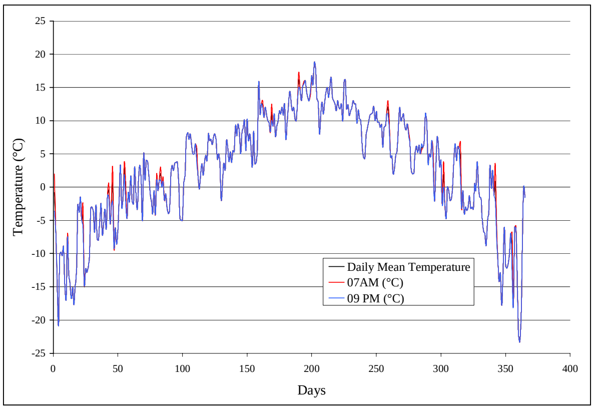

Figure 4: Daily temperature measurements at Kurşunlu for the year 2002.

On the other hand, monthly mean temperature values were estimated from daily mean temperatures to use them for calculating monthly peak-heat loads for greenhouse heating. For this purpose, changes in daily mean temperature for a given month were plotted and a linear trend line was obtained. This trend line was utilized to identify the monthly mean temperature of a given month. An example of these plots is given in Figure 5 for January 2002, and the data for other months of the year are listed in Table 4, which were assigned to the middle of each month. The plot of daily and monthly mean temperatures shows a good agreement indicating that the use of monthly mean temperatures is an acceptable approach (Figure 6).

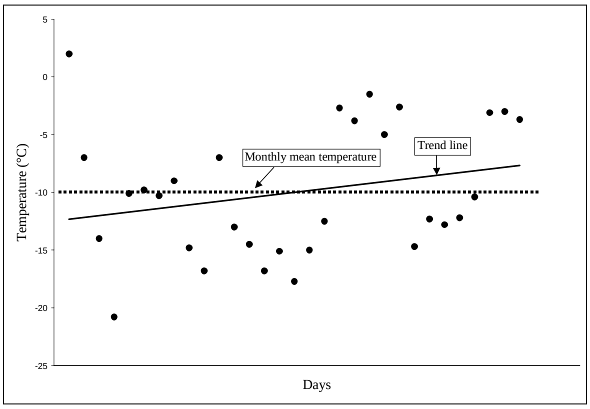

Figure 5: Daily mean temperature changes at Kurşunlu in January 2002.

Another meteorological data for the calculation of heat load is the wind speed of a given locality. Figure 7 gives the daily maximum wind speeds of Kurşunlu. Since the heat loads for greenhouse heating will be estimated monthly, it is also necessary to assign a representative wind speed for a given month. Although the wind speed at Kurşunlu fluctuates between 0.5 m/s and 8.0 m/s with an approximate average value of 2.0 m/s (Figure 7), the maximum wind speed of a given month was assigned as a constant value of this specific month (Table 5). This is a conservative approach where the wind speed affects heat transfer coefficient of glazing material hence the transmission heat losses.

Table 4: Monthly mean temperatures at Kurşunlu for the year 2002.

Month	Monthly Mean Temperature (°C)
January	-10.0
February	-3.0
March	0.0
April	3.0
May	6.0
June	9.0
July	13.5
August	11.0
September	9.0
October	4.0
November	-1.0
December	-8.0

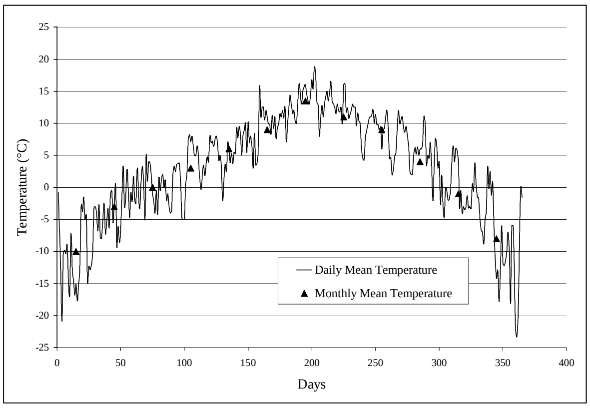

Figure 6: Comparison of daily and monthly mean temperature values.

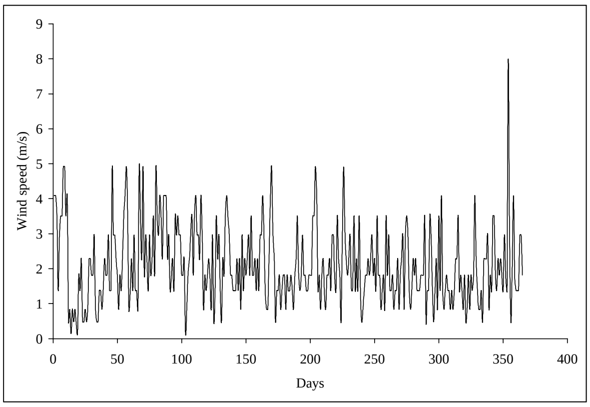

Figure 7: Changes in wind speed at Kurşunlu.

Table 5: Maximum wind speeds of each month at Kurşunlu for the year 2002.

Month	Wind $Speeds_{max}$ (m/s)
January	4.91
February	4.91
March	4.91
April	4.09
May	4.09
June	4.91
July	4.91
August	3.51
September	3.51
October	4.09
November	4.09
December	7.99

4. RESULTS AND DISCUSSIONS

Heat load of a greenhouse can simply be calculated by taking into account transmission heat losses (Equation 1) and infiltration heat losses (Equation 2) (static method). Both heat loss equations require physical dimensions of greenhouse (surface area of glazing material and volume of greenhouse). The shape of a greenhouse determines the surface area of the glazing material and volume of greenhouse. The common size of a greenhouse in Çankırı was obtained from the Directorate of Agriculture of Çankırı as 6 m in width, 36 m in length and 3 m in height (Figure 8). The shape of the greenhouse was selected as arched roof after the discussion by the authorities of Directorate of Agriculture of Çankırı (Figure 8), since it is the most common type used in the area. This shape is actually suitable for the greenhouses with plastic films (single-poly and double-poly), but the same area and volume values will also be used for glass and fiberglass greenhouses. Table 6 gives the dimensions of a greenhouse that will be used throughout this study.

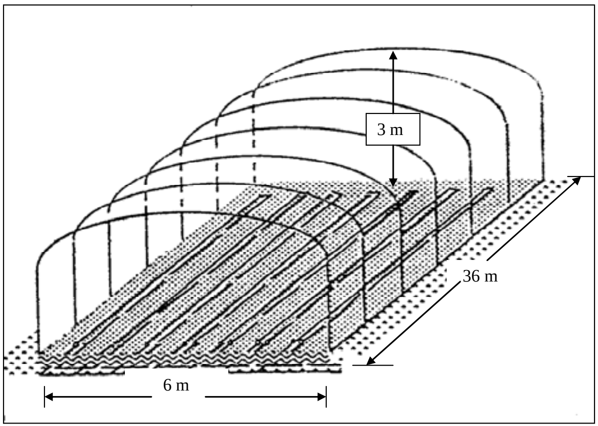

Figure 8: Shape and size of a greenhouse.

Table 6: Dimensions of a greenhouse.

Width (m)	6
Length (m)	36
Height (m)	3
Surface area of the glazing material (m^2)	367.4
Floor surface area (m^2)	216
Volume of the greenhouse (m^3)	1017.4

Another factor for the design of a greenhouse is the indoor design temperature, which is a function of the crop to be cultivated. Each crop has an optimum temperature range to maximize the yield from the system. Table 7 and Figure 9 give the optimum temperatures for different crops. As seen from Figure 9, cucumbers grow best in the temperature range 25 – 30 °C, tomatoes near 20 °C, and lettuce at 15 °C, and below.

Table 7: Temperature requirements of different vegetables (Sevgican, 1989).

Vegetable	Day time requirement (°C)	Night requirement (°C)
Tomato	19 – 24	14 – 18
Egg plant	25 –30	18 – 19
Paprika	21 – 27	15 – 19
Cucumber	22 – 24	16 –18
Beans	15 – 21	-

In order cover the temperature requirement of the most of the agricultural products a temperature range of 12 to 22 °C was selected and the heating load calculations were carried out at 12 °C, 17 °C and 22 °C indoor temperatures.

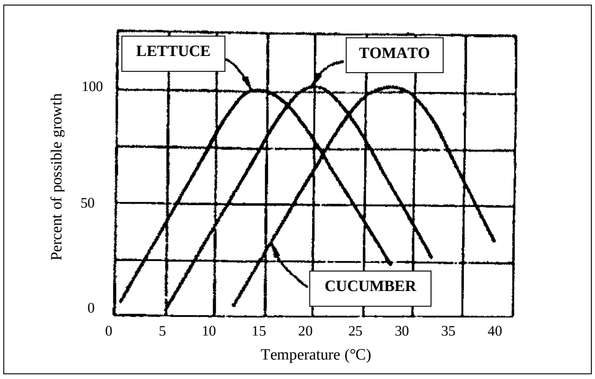

Figure 9: Optimum growing temperatures for selected agricultural products (Barbier and Fanelli, 1977).

Monthly peak-heat requirements for glass as glazing material when the indoor design temperature is 12 °C are presented in Table 8 and Figure 10. Heat transfer coefficients (U) in 8 are the function of wind speed. Transmission heat losses (Q_t) and infiltration heat losses (Q_i) were calculated by using Equations 1 and 2, respectively.

While applying Equation 2 for infiltration heat losses, the mean values of air change data (ACH) for different glazing materials were used (Table 2). Other parameters in Equation 2 are specific heat capacity of air (C_p) and density of air (ρ), and they were taken as 1006 J/kg °C, 1.29 kg/m^3, respectively.

Table 8: Monthly peak-heat requirements for greenhouse heating for glass and 12 °C as indoor design temperature.

Month	U(W/m^2 °C)	Q_i [W]	Q_t [W]	Q_{TOTAL}
January	5.96	24205	48138	**72343**
February	5.96	16503	32822	**49325**
March	5.96	13203	26257	**39460**
April	5.76	9902	19054	**28956**
May	5.76	6601	12702	**19304**
June	5.96	3301	6564	**9865**
July	5.96	-1650	-3282	**0**
August	5.61	1100	2062	**3162**
September	5.61	3301	6186	**9487**
October	5.76	8802	16937	**25738**
November	5.76	14303	27522	**41825**
December	6.47	22004	47572	**69577**
ANNUAL TOTAL HEAT REQUIREMENT (W)				**369042**

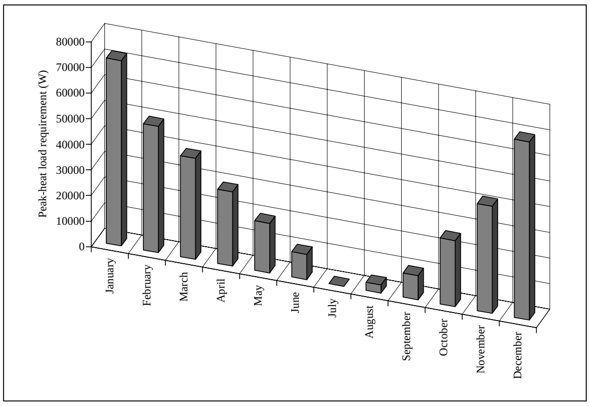

Figure 10: Monthly peak-heat requirements for glass at 12 °C indoor temperature.

As observed in Table 8 that the peak-heat requirement for July was calculated as a negative value because of the higher monthly mean temperature (13.5 °C) compared to that of indoor design temperature (12 °C). This negative value was treated as zero while calculating annual total heat requirement and plotting Figure 10. One of the characteristics of greenhouse heating is clearly seen in Figure 10, which is the variable nature of heating requirement throughout the year.

Figure 11 shows the annual total heat requirements for different glazing materials and design indoor temperatures. It should be remembered here that these heat requirements are for a single greenhouse having dimensions of 6×36×3 m and there is no plant in the greenhouse, as well as solar radiation and condensation of water vapor in the greenhouse were not considered. Analysis of Figure 11 indicates that glass has the poorest performance among the four glazing materials. On the other hand, use of plastic film material in the form of double layer (double poly) as glazing material is the best in terms of heat requirement. The double poly design is a very efficient approach to greenhouse design. The double layer of plastic film forms an air space, which is maintained by a small blower pressurizing the volume between the layers. Double poly design does not only reduce transmission losses (losses through the walls and roof) by 30-40%, but also substantially reduces infiltration (in leakage of cold air). Infiltration is reduced because the cracks present in glass and fiberglass types of construction are eliminated through the use of continuous plastic film (Rafferty and Lund, 1998)

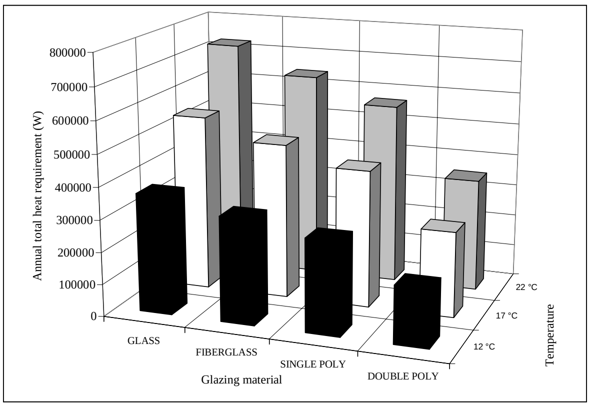

Figure 11: Annual total heat requirements (W).

4.1 Number of Greenhouses

It is possible to calculate the number of greenhouses that can be supplied by the available geothermal resource after getting the monthly peak-heat requirements for given conditions (glazing material, indoor design temperature). In most of the cases it is not feasible to design the geothermal heating system to cover 100% of the heating load; instead peaking equipment using fossil fuels are used to cover the peak load, while the geothermal system is used to cover a base load. Figure 12 shows the sorted monthly peak heat loads calculated for glass as glazing material at 12 °C indoor temperature. The maximum monthly heat load is about 72500 W for the coldest month (January with a average monthly temperature of -10 °C), and except January and December all the other months require heat less than 50000 W. It is a common approach in greenhouse design to carry out study to maximize the annual heat load factor as function of base load. Base load is generally taken as the fraction of maximum heat load required, and in this study the analysis was made with the base loads of 60, 70, 80, 90 and 100% of the maximum.

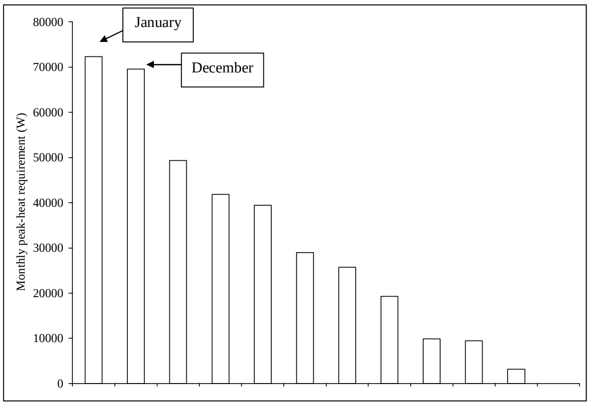

Figure 12: Sorted monthly peak heat loads calculated for glass as glazing material at 12 °C indoor temperature.

Equation 10 is used calculate the number of greenhouses;

$$NG=\frac{H_{available}}{H_{base}} \qquad (10)$$

where;

NG = number of greenhouses that can be supplied by available energy,

$H_{available}$ = available heat energy from geothermal fluid, W

H_{base} = base heat at which the greenhouse will be designed, W.

Available heat energy from geothermal fluid is calculated from Equation 11.

$$H_{available}=m\times C_p\times\Delta T \qquad (11)$$

where;

m = mass flow rate of geothermal fluid, kg/s

C_p = specific heat capacity of geothermal fluid, J/kg°C

ΔT = temperature drop along the heating loop, °C

The application of Equations 10 and 11 requires the knowledge of flow rate and heat capacity of geothermal fluid as well as design temperature drop value along the heating loop.

Several measurements showed that the flow rate of Ç-1 is 47 l/s. On the other hand there is already some use of the geothermal fluid of Çavundur field. If the maximum bed capacity of thermal facilities (500 beds) is considered with the use of geothermal fluid as 500 l/day/person, the daily use for bathing amounts 250000 l/day or 3 l/s. (The Turkish standards for spa and bathing is actually 350 l/day/person (İncekara, 1996), but the value of 500 l/day/person was used as a conservative approach). Another use of Çavundur geothermal fluid is the space heating of thermal facilities through a floor heating system. The system has a heat exchanger with a capacity of 400000 kCal and the maximum geothermal fluid consumption is about 8 – 10 l/s

(Kaya, 2003). The total use of geothermal fluid is about 12 l/s and 35 l/s is available for greenhouse heating. Having the specific heat of pure water as 4.180 kJ/kg °C, density of geothermal fluid as 990 kg/m^3 and a temperature drop along the heat loop of 20 °C, the available heat energy of the geothermal fluid is found as **2896740 W**. It should be mentioned that the density of geothermal fluid with total dissolved solids of 11500 mg/l (Table 4.1) is higher than pure water density resulting with higher mass flow rate. But the change in density is not very significant to cause a drastic change in the calculation of available geothermal energy. Consequently the density of pure water was used which actually gives a conservative approach for the calculation of number of greenhouses.

The number of greenhouses for different glazing materials as function of indoor design temperatures and base loads are given in Figure 13. The number of greenhouses is in the range of 28 - 138. The minimum corresponds to a glass greenhouse at 22 °C indoor temperature with 100% base load. On the other hand, maximum is obtained for a plastic film (double poly) greenhouse with 12 °C indoor design temperature and 60% base load. Decrease in base load and indoor design temperature cause an increase in the number of greenhouse that can be supplied by Çavundur geothermal fluid. It should be stressed here that, except the theoretical heat load calculations no other heat transfer efficiency factor was considered.

4.2 Annual Heat Load Factor

Another way of expressing the efficiency of a geothermal greenhouse project is the Annual Heat Load Factor (AHLF), which is calculated by Equation 12.

$$AHFL = \frac{E_{Annual}}{E_{Available}} \qquad (12)$$

where

AHLF = annual heat load factor

$E_{available}$ = Yearly available geothermal heat energy, MJ

E_{Annual} = Annual heat requirement of the greenhouse system, MJ

The factors in Equation 12 are obtained as:

$E_{available}$: This is actually the amount of energy that can be obtained from geothermal fluid in a year. As it was calculated previously, the geothermal fluid of Çavundur field has the energy of 2896740 W by considering the flow rate as 35 l/s and temperature drop as 20 °C. This heat energy corresponds to a total energy of **90100201 MJ.**

E_{Annual}: Annual heat requirement of the greenhouse system is obtained from monthly heat requirement data (W). Each heat requirement data is converted to MJ and their sum gives the annual heat requirement for a single greenhouse. If the number of greenhouses for specified conditions is multiplied by the obtained annual heat requirement, the system requirement is obtained. An example is given in Table 9 for a glass greenhouse at 12 °C indoor design temperature and 100% base load. As indicated in Table 9, the total annual heat requirement is 956556 MJ and the number of greenhouses for this specified conditions is 40, therefore the system requirement is 956556×40 = 38262240 MJ. The annual heat load factor for the example given above is obtained as 43%.

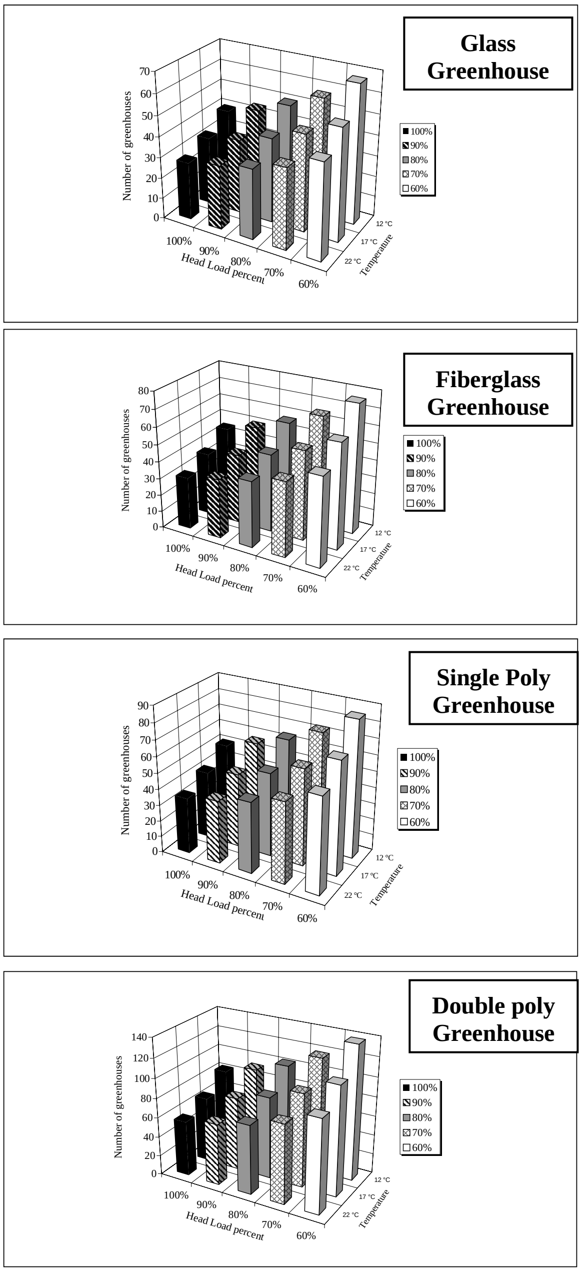

Figure 13: Number of greenhouses.

Table 9: Annual heat requirement for glass greenhouse at 12 °C indoor design temperature and 100% base load.

Month	Q_{TOTAL} (W)	Q_{TOTAL} (MJ)
January	72343	187514
February	49325	127850
March	39460	102280
April	28956	75053
May	19304	50035
June	9865	25570
July	0	0
August	3162	8196
September	9487	24589
October	25738	66714
November	41825	108410
December	69577	180343
TOTAL	**369042**	**956556**

Figure 14 gives the annual heat load factors of greenhouse systems as function of indoor design temperatures and base loads. The annual heat loads do not change with glazing material for a given indoor design temperature and base load. On the other hand, annual heat load factor increases with the increase in indoor design temperature. This is due to the higher heat requirement of greenhouses with higher indoor temperatures and higher proportion of this energy is actually fed by geothermal energy.

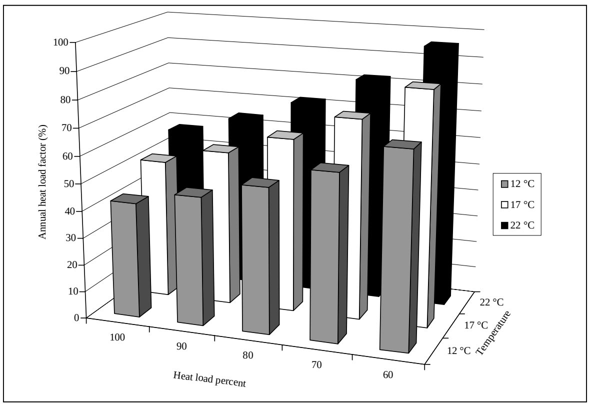

Figure 14: Annual heat load factors for all studied greenhouse systems.

4. 3 Pipe Lengths

The length of pipe that is required for a given greenhouse design is dependent on the type of heating system used. In this study, two types of heating systems are considered, soil heating and bare tube heating. The equations for these heating systems are discussed in Sections 2.3 and 2.4. The following sections will discuss the details of these heating systems for Çavundur field greenhouse study.

4.4.1 Soil Heating

The required pipe length for a single greenhouse is calculated by using Equations 6 and 7.

Table 10 gives the values of the parameters of Equations 6 and 7 that are used for Çavundur field greenhouse design study.

Table 10: Values of parameters of Equations 6 and 7.

Parameter	Value
H (mm)	150
d (mm)	32
λ_j (W/m °C)	1.25
T_{wi} (°C)	54
T_{wo} (°C)	34
T_P (°C)	26

The depth at which the tubes are to be buried is often a function of protecting them from surface activity. For burial in the soil floor of a greenhouse, a depth of at least 5-8 cm should be employed. The depth of burial is also affected by the tubing size. For common sizes of such as 12 and 19 mm diameters, the burial depth is in the range of 5-10 cm and the larger lines are buried deeper than 13 cm. Since it was decided to use a tubing size of 32 mm outside diameter, the burial depth for this study was chosen as 150 mm.

Soil heat conductivity with organic matter is in the range of 0.15 – 2.00 W/m°C and an average value of 1.25 W/m °C was used (http://www.hukseflux.com / thermal%20conductivity / thermal.htm).

Inlet and outlet temperatures of the heating loop (T_{wi} and T_{wo}) are taken as 54 °C and 34 °C, respectively. The inlet temperature is the production temperature of the Çavundur geothermal fluid and an assumed temperature drop of 20 °C along the loop makes the outlet temperature as 34 °C.

The floor surface temperature in the greenhouse should be selected such that it should not be too hot for the plants or for the workers in the greenhouse. As mentioned in Figure 9 and Table 7 that the maximum temperature for several crops is in the range of 25 – 30 °C. This parameter was set to a value of 26 °C as an inspiration from Emeish (1999).

Floor surface temperature that can be achieved from the installed system is calculated from Equation 3. In this equation, all the parameters except floor surface temperature are known, but since the equation is a 4^{th} order quadratic equation in terms of T_P, the value of surface floor temperature was found numerically from the GOAL SEEK option of Microsoft EXCEL. Table 11 lists the floor surface temperatures calculated from Equation 3 for different type greenhouses at different indoor temperatures and 100% heating load.

Table 11: Floor Surface Temperatures (T_p) at Different Glazing Materials.

	DOUBLEPOLY			SINGLEPOLY			FIBERGLASS			GLASS		
Month	12 °C	17°C	22°C	12 °C	17°C	22°C	12 °C	17°C	22°C	12 °C	17°C	22°C
January	18	21	23	22	25	28	24	28	31	26	29	33
February	17	19	21	19	22	25	27	24	28	22	26	29
March	16	18	20	18	21	24	19	23	26	20	24	28
April	15	17	19	16	20	22	18	21	25	18	22	26
May	14	16	19	15	19	21	16	20	23	16	21	25
June	13	16	18	14	18	21	14	18	22	14	19	23
July	12	12	12	12	12	12	12	12	12	12	12	12
August	12	15	17	13	17	20	13	17	21	13	18	22
September	13	13	18	14	17	21	14	18	22	14	19	21
October	15	17	19	16	19	22	17	21	24	18	22	26
November	16	18	20	18	21	24	20	23	26	21	25	28
December	18	17	23	22	25	28	24	27	31	25	29	33

Application of Equation 6 requires heat loads (Q) and those values were already calculated. Calculated heat loads of the coldest month for different glazing materials at 12 °C indoor design temperatures are presented in Table 12 as function of peak load. The reason of choosing the coldest month is to design a system that can support the worst case.

Table 12: Heat Loads for different glazing materials (indoor design temperature=12 °C) (W).

Peak Load%	100	90	80	70	60
GLASS	72343	65109	57875	50640	43406
FIBERGLASS	63941	57547	51152	44758	38364
SINGLE POLY	56481	50833	45185	39537	33889
DOUBLEPOLY	35097	31588	28078	24568	21058

Table 13 gives the length of 32 mm diameter pipe to be used in a single greenhouse, calculated from Equation 6. If the total pipe length is divided to the length of greenhouse (36 m), the number of pipes can be obtained (Table 14). As observed from Table 13 and 14, the shortest pipe length is obtained for double poly greenhouses for all peak loads resulting with a decrease in investment cost.

Table 13: Pipe lengths of soil heated greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=12 °C).

Peak Load%	100	90	80	70	60
GLASS	1690	1521	1352	1183	1014
FIBERGLASS	1494	1345	1195	1046	896
SINGLE POLY	1320	1188	1056	924	792
DOUBLEPOLY	820	738	656	574	492

Table 14: Number of pipes of soil heated greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=12 °C).

Peak Load%	100	90	80	70	60
GLASS	47	42	38	33	28
FIBERGLASS	42	37	33	29	25
SINGLE POLY	37	33	29	26	22
DOUBLEPOLY	23	21	18	16	14

4.4.2 Bare Tube System

The required pipe length for a single greenhouse heated by bare tube system is calculated by using Equations 9.

As demonstrated at Tables 15 and 16 the required minimum pipe length for a greenhouse at bare tube system is obtained at double poly greenhouse similar to soil heated greenhouse.

Table 15: Pipe lengths of bare tube system greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=12 °C).

Peak Load%	100	90	80	70	60
GLASS	1897	1707	1517	1328	1138
FIBERGLASS	1677	1509	1341	1174	1006
SINGLE POLY	1481	1333	1185	1037	889
DOUBLEPOLY	920	828	736	644	552

Table 16: Number of pipes used at bare tube system greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=12 °C).

Peak Load%	100	90	80	70	60
GLASS	53	47	42	37	32
FIBERGLASS	47	42	37	33	28
SINGLE POLY	41	37	33	29	25
DOUBLEPOLY	26	23	20	18	15

CONCLUSIONS

The following conclusions can be drawn from the results of the current study,

- Heat load calculations demonstrated that Çavundur geothermal field is suitable for greenhouse applications.
- Among the four different glazing materials considered, double poly plastic film construction was found to be the most suitable in terms of heat load calculations.
- Annual heat load factor for greenhouse heating by geothermal energy in Çavundur area varies between 43 and 96 %, depending on indoor design temperature and base load. The higher the indoor design temperature and the lower base load (percent of peak load) is the higher annual heat load factor.
- The number of greenhouses that can be heated by Çavundur Geothermal fluid is between 40 and 138. The area of each greenhouse was taken as 216 m^2 and the soil heating system was considered for this calculation.

REFERENCES

Barbier, E., Fanelli, M., (1977), “Non-Electrical Uses of Geothermal Energy”, prog. Energy Combust. Sci., Vol. 3, No:2.

Björnsson, O., (1980) “Cooling of Water in District Heating Pipes”, Orkustofnun, Reykjavik, Report OS80008/JHD04, (in Icelandic).

Emeish, M.S., (1999), “Geothermal Heating System for Jordanian Greenhouses”, UNU Geothermal Training Programme, Report No:2.

Günay, G., Şimşek, Ş., (2001) “Karst Hydrogeology in Hydrothermal Systems” paper presented in Present State and Future Studies of Karst Studies, Ed: Günay, Ford, Johnson&Johnson, Marmaris-Turkey, 17-26 September 2000, 501-513.

İncekara, A., (1996), “Sağlık Turizminde Jeotermal Kaynaklar”, Published by İstanbul Ticaret Odası (in Turkish).

Kaya, T., (2003), Personal communication.

Lund, J.W., (1996) “Lectures on Direct Utilization fo Geothermal Energy”, UNU Goethermal Training Programme, Report-1, Iceland, 123 pp.

Mertoğlu, O., Bakır, N., Kaya, T., (2003) “Geothermal Applications Experiences in Turkey”, European Geothermal Conferences, Szeged, Hungary, 25-30 May, paper No: I-4-02.

Popovski, K., (1984) “Use of Solar Energy and Heat Accumulator in the Soil for Greenhouse Heating”, Ph.D. Dissertation, Faculty of Mechanical Sciences, Edward Kardelj University, Ljubljana, Yugoslavia.

Rafferty, K.D., (1998), “Greenhouses”, Geothermal Direct Use Engineering and Design Guidebook, Lund, J.W., Lienau, P.J., Lunis, B.C., (editors), Geo-Heat Center, Klamath Falls, OR, 307-332.

Rafferty, K.D., Lund, J.W., (1998) “Geothermal Greenhouse Design”, Proc. International Summer School on Direct Application of Geothermal Energy, Ed. Popovski, K. Rodrigues, A.C., Azores, Portugal, September 14, 147-167.

Sevgican, A., (1989), “Örtüaltı Sebzeciliği”, TAV Tarımsal Araştırmalar Destekleme ve Geliştirme Vakfı, Yayın No: 19, Yalova (in Turkish).

Uzel, Ö.F., Didik, S., (1988), “Çankırı-Kurşunlu-Çavundur Kaplıcası (Ç-1) Sıcaksu Sondajı Kuyu Bitirme Raporu”, Mineral Research and Exploration General Directorate – Report No 8398, March 1988 (in Turkish).