A TECHNICAL FEASIBILITY STUDY ON THE USE OF ÇAVUNDUR GEOTHERMAL FIELD FOR GREENHOUSE HEATING

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HÜSEYIN KASAPOGLU

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Approval of Graduate School of Natural and Applied Sciences

Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master Science

Prof. Dr. Birol Demiral
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science

Prof. Dr. Mahmut Parlaktuna
Supervisor

Examining Committee Members

Prof. Dr. Birol Demiral

Prof. Dr. Sakir Simsek

Prof. Dr. Nilgün Güleç

Prof. Dr. Fevzi Gümrah

Prof. Dr. Mahmut Parlaktuna

ABSTRACT

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Kasapoglu, Hüseyin

M.Sc. Department of Petroleum and Natural Gas Engineering

Supervisor: Prof. Dr. Mahmut Parlaktuna

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Protective cultivation is widely used nowadays in order to increase crop yield by creating the optimum conditions such as temperature, humidity and CO_2 content, irrespective of outside conditions. Since plant production doubles for every 10 degrees increase in temperature to a certain limit, this makes temperature a very important factor for optimum plant growth. In order to keep the greenhouse temperature constant during changes in outside conditions, heating and often cooling are required.

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.

Key words: Geothermal Energy, Greenhouse Heating, Çankiri, Çavundur Geothermal Field

ÖZ

ÇAVUNDUR JEOTERMAL SAHASININ SERA ISITMASI KULLANIMI ÜZERINE BIR TEKNIK FIZIBILITE ÇALISMASI

Kasapoglu, Hüseyin

Yüksek Lisans, Petrol ve Dogal Gaz Mühendisligi Bölümü

Tez Yöneticisi: Prof. Dr. Mahmut Parlaktuna

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Günümüzde ürün veriminin arttirilmasi amaciyla, uygun CO_2, sicaklik ve nem kosullarinin dis ortam sartlarina bagli kalmaksizin saglandigi korumali tarim yöntemleri siklikla uygulanmaktadir. Belli sicaklik sinirlarina kadar, sicakligin her 10 °C arttirilmasiyla ürün veriminin ikiye katlandiginin bilinmesi, sicakligi önemli bir parametre haline getirmektedir. Dis sicaklik degisimlerine ragmen sera içi sicakligini sabit tutabilmek için isitma ve sogutma yapilmasi gereksinimi vardir.

Sera isitmaciligi degisik sistemler ve yöntemler kullanilarak yapilabilmektedir. Farkli türlerdeki seralarin Çankiri-Çavundur yerel sartlarinda uygulanabilirligi çalisildi. Belirlenen bir en düsük sicaklik degerinde iletim ve sizdirma ile olusan enerji gereksinimi hesaplandi. Toprak ve toprak üstü olmak üzere iki tür isitma yöntemi göz önüne alindi.

Sonuçlarin incelenmesiyle, 54 °C sicaklikta jeotermal akiskana sahip olan Çavundur jeotermal sahasinin sera isitmaciligina uygun oldugu saptanmistir. Açilmis olan Ç-1 kuyusunun üretim potansiyeli 47 l/s olmasina ragmen, alanda varolan termal

tesislerin jeotermal akiskani kullanmasi sebebiyle, sera için kullanilan debi 35 l/s ile sinirlandirilmistir.

Çalisilan farkli sera kaplama malzemeleri içinde çift katli plastik film seranin, isi yükü yönünden, en uygun tür oldugu bulundu.

Çavundur Jeotermal Sahasi ile isitilabilecek maksimum sera sayisi (her bir sera 216 m^2 dir), çift katli plastik film ve toprak isitmasi kosullarinda, 138 olarak bulunmustur.

Çavundur sahasindaki sera isitmaciligi için jeotermal enerji yillik isi yükü faktörü, sera içi tasarim sicaklik degeri ve baz yüke bagli olarak, % 96 kadar olmaktadir.

Anahtar kelimeler: Jeotermal Enerji, Sera Isitmaciligi, Çankiri, Çavundur Jeotermal Alani

ACKNOWLEDGEMENTS

I would like to express my gratitude to Prof. Dr. Mahmut Parlaktuna for his guidance, patient, advice, assistance, all the support I needed and provided all help possible throughout the M.Sc. study.

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NOMENCLATURE

Normal Symbol	Definition	Units
A	Surface area	m^2
AUST	Average temperature of unheated surfaces in the greenhouses	°C
C_p	Specific heat capacity of air,specific heat capacity of geothermal fluid	J/kg °C
d	Pipe outside diameter	mm
DT	Design temperature difference (inside-outside)	°C
E	Solar radiation energy flux	Wh/m^2
E_{annual}	Annual heat requirement of the greenhouse system	MJ
$E_{available}$	Yearly available geothermal heat energy	MJ
H	Pipe burial depth (floor surface to pipe)	mm
$H_{available}$	Available heat energy from geothermal fluid	W
H_{base}	Base heat at which the greenhouse will be design	W
IDT	Inside design temperature	°C
IST	Inside surface temperature	°C
L	Length of pipe	m
$L_{greenhouse}$	Greenhouse length	m
L_{pipe}	Pipe length	m
m	Mass flow rate of geothermal fluid	kg/s
n	Number of pipes	
Q	Greenhouse heat requirement	W
q	Heat	W
Q_i	Infiltration heat loss	W
Q_t	Heat tranmission losses through wall and roof	W
T_a	Indoor air temperature	°C
T_{aav}	Monthly average outside temperature	°C
T_{air}	Greenhouse design air temperature	°C
T_i	Indoor design temperature	°C
T_{wi}	Water inlet temperature	°C
t_m	Log mean temperature difference	°C
T_o	Outdoor design temperature	°C
T_{wo}	Water outlet temperature	°C

T_p	Floor surface temperature	°C
U	Heat transfer coefficient	W/m^2 °C
V	Volume of greenhouse	m^3
ACH	Air change per hour	
AHLF	Annual heat load factor	
n	Number of pipes	
NG	Number of greenhouses that can be supplied by available energy	
TDS	Total dissolved solids	ppm
ÇANTUR A.S.	Çankiri Turizm Sirketi	
Ç-1	Çavundur 1 Well	
MTA	Mineral Research and Exploration General Directorate	
ORME Inc.	Orhan Mertoglu Incorporated	

Greek Symbol

r	Density of air	kg/m^3
l **j**	Earth heat conductivity	W/m^2 °C

CHAPTER 1

INTRODUCTION

Geothermal energy is the energy contained as heat in the earth's interior. The origin of this heat is linked with the interior nature of our planet and the physical processes occurring there. Despite the fact that this heat is in huge quantity and practically inexhaustible, even taking into account the Earth's crust alone and not to deeper areas of the planet, it is highly dispersed, seldom concentrated, and often at depths too great to be exploited industrially.

Geothermal energy can be defined as the energy coming from the hot water or steam, which is formed by the different layers of the earth crust, and has temperature higher than 20 °C. It consists more dissolved minerals; a number of salts and gases, normally at a higher rate than the other surface or under ground waters and the other environment. Geothermal fluids can be categorized in the following three groups:

1. Low-temperature fluids (20-70 °C)
2. Medium temperature fluids (70-150 °C)
3. High temperature fluids (>150 °C)

In many cases a reservoir is covered with impermeable rocks, which prevent the hot fluids from reaching the surface and keep them under pressure. Industrial production of superheated steam or steam mixed with water, or hot water only, can be obtained depending on the hydrogeological situation and the temperature of rocks present. If wells are drilled into the reservoir hot fluids can be extracted and exploited, either for generation of electricity or for space heating, greenhouse heating, and industrial processes, depending on the temperature and pressure of the fields.

By definition, a greenhouse is a structure covering ground for growing a crop that return a profit to the owner. The main function of a greenhouse is to provide and maintain an environment, which results in optimum crop production. From this definition it is understood that a greenhouse is used for overcoming climatic adversity, where favorable conditions for optimum crop growth are created inside the greenhouse environment without any concern for changes in outside climate conditions. The design of a geothermal greenhouse is analogous to a greenhouse, which is heated by using conventional fuels or electricity. The differences include the energy source for space heating, the selection of the site and the cost. A geothermal greenhouse is almost always located close to the geothermal source for economic reasons. The cost is a great advantage of the geothermal greenhouse. The initial construction costs are almost independent of the heating energy but the operating cost is usually incomparably cheaper in geothermal greenhouse. Heating a greenhouse can be performed using different systems and energy sources have their advantages and disadvantages in the greenhouse heating system. Heating systems utilizing fossil fuels might have low initial cost but their running costs are high, as well as causing pollution to the environment. On the other hand geothermal energy heating systems might have high initial costs but low running costs which makes these systems highly attractive to farmers.

The price of geothermal energy depends on the policy of the country. Sometimes the user has to pay the owner of the source, possibly the government, an individual, a private enterprise, etc. The costs of geothermal energy cover drilling, the pumps, the transmission and the distribution system, expenses that is not present when other forms of energy are used. Thus, the cost is high when the source is used for the first time but the total cost, including operation, is lower in a geothermal greenhouse.

Although greenhouse provide a protected environment for crops, they are in contact with the outside environment which leads to energy transfer between the inside and the outside of the greenhouses. Hence, in order to keep the inside conditions approximately constant against varying outside conditions, the greenhouse have to be heated, cooled and ventilated depending on outside climatic conditions. Since the primary aim of protected cultivation is to increase profits by improving product quality and increasing crop yield, the climate control system must be as cheap and as reliable as possible.

The aim of this study is to assess the suitability of Çavundur geothermal field for greenhouse heating with a temperature of 54 °C at 47 l/s flow rate. The heat losses from the greenhouse were estimated at local climatic conditions for this purpose. To ensure the appropriate conditions for different crops to be cultivated, several scenarios were applied by using different glazing materials, with different heating systems.

CHAPTER 2

GREENHOUSE HEATING BY GEOTHERMAL ENERGY

2.1 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.

Worldwide (Lund and Freeston, 2000), the installed capacity of direct utilization is 16200 MW_t and the energy use is about 162000 TJ/yr (45000 GWh/yr) distributed among 60 countries. The distribution of the energy use among the various types of use is shown in Figure 2.1 for the entire world (Lund and Freeston, 2000). Greenhouse heating occupies the third position (excluding heat pumps) among the other direct use applications with 11.75 % of total installed capacity.

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.

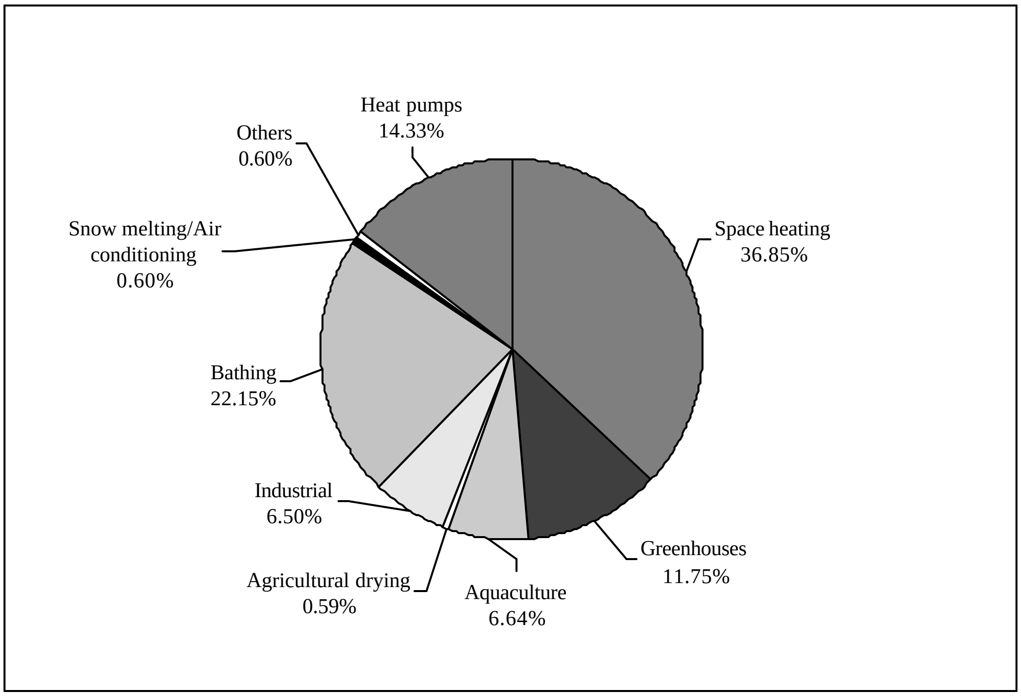

Figure 2.1 Distribution of direct use of geothermal energy in the world (Lund and Freeston, 2000).

Direct use applications of geothermal energy in Turkey are mainly focused on space heating and bathing (Figure 2.2). 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 Sanliurfa, a 106000 m^2 geothermal greenhouse exports its entire yield to Europe. Table 2.1 gives the locations and capacities of greenhouses in Turkey heated by geothermal energy (Mertoglu, et al. 2003).

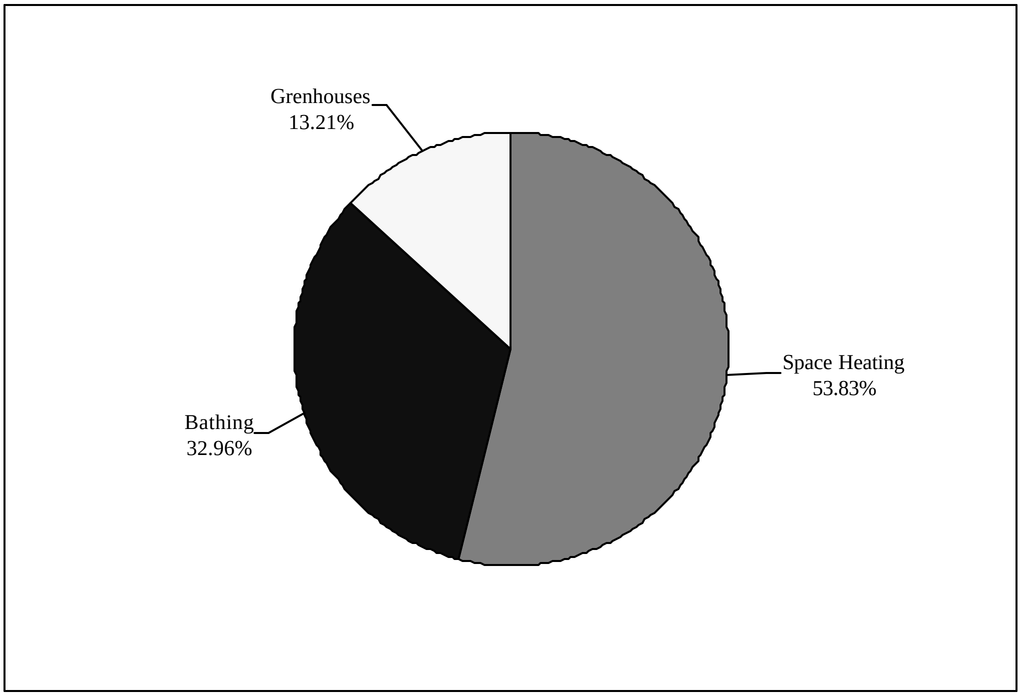

Figure 2.2 Distribution of direct use of geothermal energy in Turkey (Mertoglu et al., 2003).

Table 2.1 Locations and capacities of greenhouses in Turkey heated by geothermal energy (Mertoglu, et al., 2003)

LOCATION	AREA (m^2)	CAPACITY (MWt*)	LOCATION	AREA m^2)	CAPACITY (MWt*)
Sanliurfa	106000	24.5	Dikili	120000	24
Simav	120000	33	**Gölemezli**	1000	0.2
Sindirgi	2000	0.4	**Seferihisar**	6000	1.06
Afyon	5500	1.5	**Bergama**	2000	0.4
Kizildere	10750	2.4	**Germencik**	500	0.1
Balçova	100000	17.4	**Edremit**	49620	8.7
Kestanbol	2000	0.4	**Ezine**	1500	0.3
Saraykent	2000	0.6	**Niksar**	500	0.14
Tekkehamam	8000	1.8	**Kizilcahamam**	5000	1.45
Yalova	600	0.12	**Gediz**	8500	2.1
Kozakli	4000	1.2	**Çanakkale**	50000	9

* Load factor = 0.6

2.2 GREENHOUSE CONSTRUCTION

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 2.3)

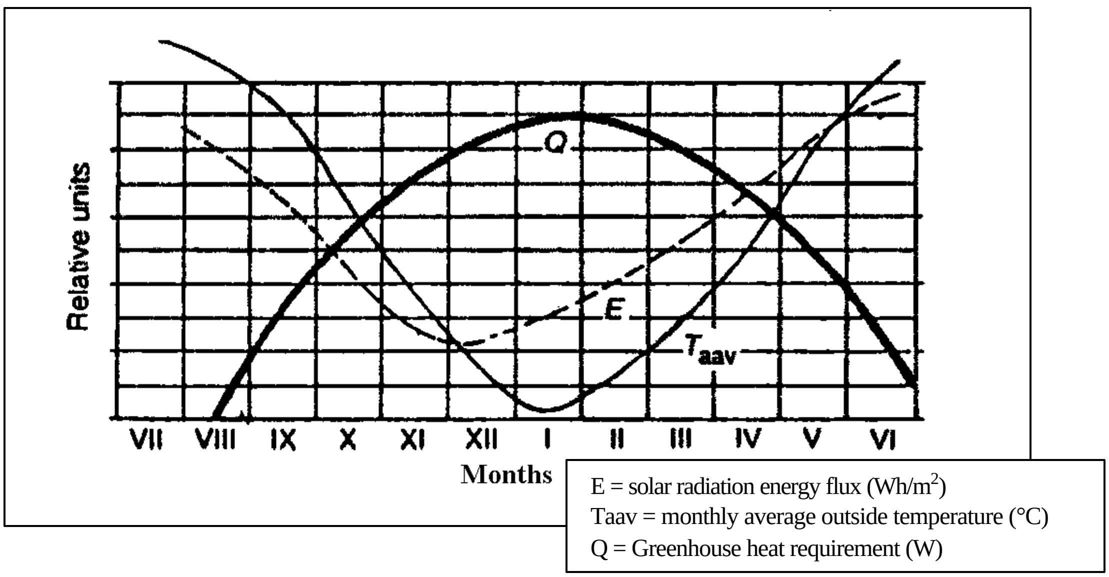

Figure 2.3 Heat requirement in a greenhouse over a typical year in Gevgelia, Rep. Of Macedonia (Popovski, 1984)

Greenhouses are among the most interesting and widespread applications of geothermal energy as a heat source. That is somewhat surprising, because it is rather bad heat consumer when considering the annual heat load factor. The beauty of greenhouse heating by geothermal energy lies probably in the possibility to install the projects near the geothermal sources, without disturbing the whole organization of the production and marketing of the products. The large introduction of cheap plastic material for the distribution of geothermal brines and heat exchangers is the most significant characteristic for this particular energy use. Thus, direct use is possible, i.e. the corrosion problem is eliminated, which is very convenient for small artesian wells; where it is difficult to justify the installation of expensive equipment, the use of expensive material for heat exchangers, etc.

2.2.1 Heating Systems

The heating systems can be classified according to the position of the heating installation. The categories are the following:

1. Heating systems in the soil
2. Heating systems laid on the soil surface or on the benches;
3. Aerial heating systems;
4. Cascading
5. Combination of the above.

2.2.1.1 Soil Heating

In this system the soil is used as a large radiator. The tubes are buried in the soil and the determination of their size and spacing is a function of heat output required, mean-water temperature, soil conductivity and burial depth. The warm water is circulated through the tubes and the produced heat is transferred to the soil and eventually to the air of the greenhouse (Figure 2.4). In recent years, material used for pipes is polypropylene, polyethylene or polybutylene because of the corrosion and expansion problems of steel. The polybutylene is the most resistant of these in the high temperature range and the most expensive.

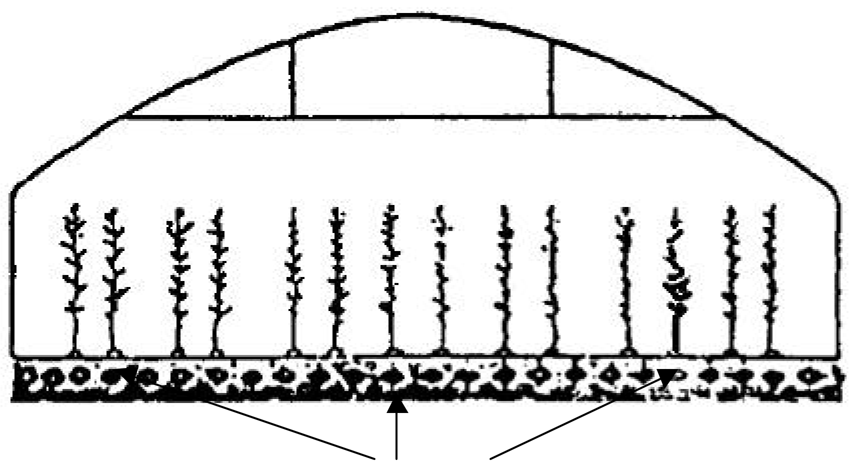

Figure 2.4 Soil heating (Dickson and Fanelli, 1995).

This system results in an even air temperature distribution from the floor to the ceiling (Figure 2.5); it does not obstruct floor space and does not cause shadows. Furthermore, it is proven that the use of soil heating is very positive for a list of vegetables and bulbous flower cultivations providing earlier harvesting, improved yield and quality of products. Also, it is convenient for root temperature control and for covering minimal heat requirements (Figure 2.6). Consequently, if it will be used as the only heating system it should be applied in mild climate areas and low inside design temperature. This is caused by the nature of the heat transfer in the system. When the heating requirements increase, the floor temperature must be increased to meet these requirements. As a result, such a radiant and hot floor cannot be used for extended periods because excessive heat transfer to the plants is created. The solution is the combination of this system with other types of heating installations as, for example, unit heaters.

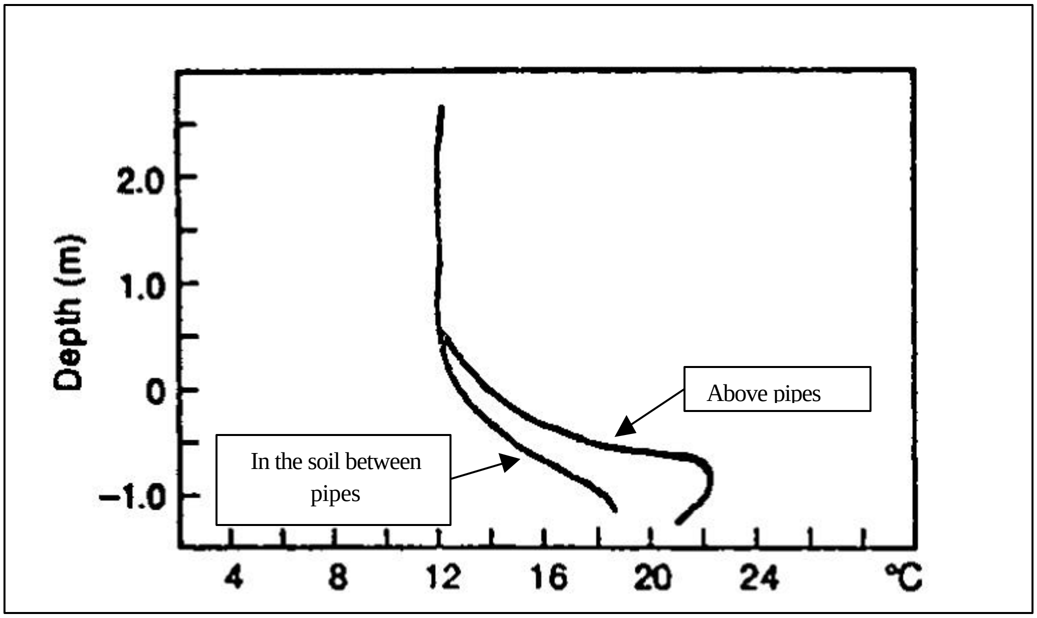

Figure 2.5 Vertical temperature profiles in a greenhouse with soil heating (Dickson and Fanelli, 1995).

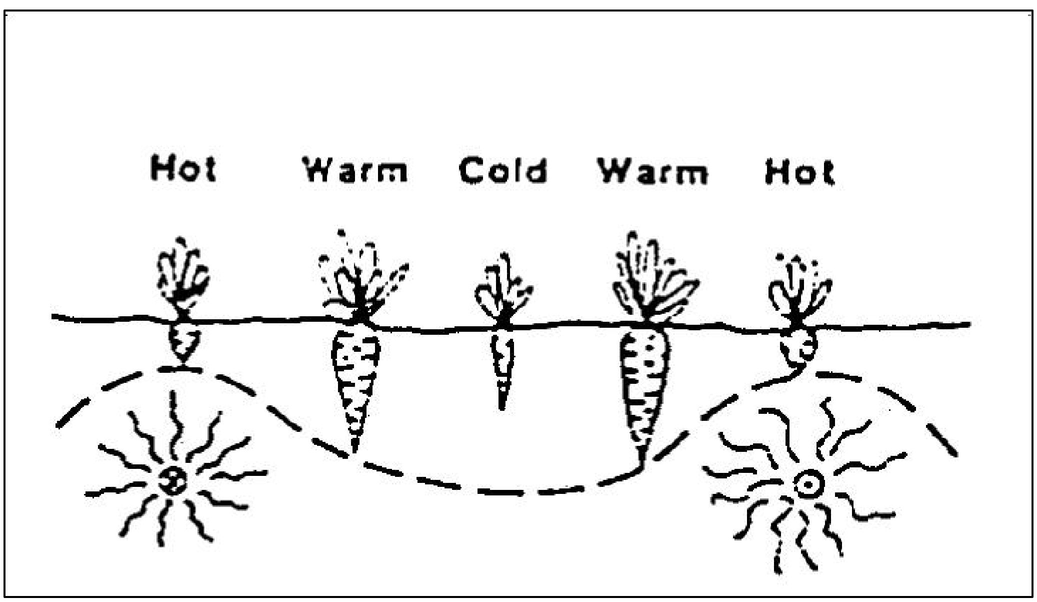

Figure 2.6 Idealized effect of temperature on carrots (Rafferty and Lund, 1998).

2.2.1.2 Heating Systems Laid on Soil Surface or on the Benches

These installations consist of a system of heating elements positioned on the ground surface (Figure 2.7). With this layout the upper layer of the soil and the air are heated, which is very convenient for many cultures. This category includes thin pipes, polyethylene sleeves or plastic pipes located on the ground. The thin pipe system is widely used and the others are installed only in small or inexpensive greenhouses. The pipes are made of steel or poly material. The location of the pipes can be between the plant rows or directly in the plant rows. The system can be arranged in unit loops or in a loop with a parallel system of two or three pipes.

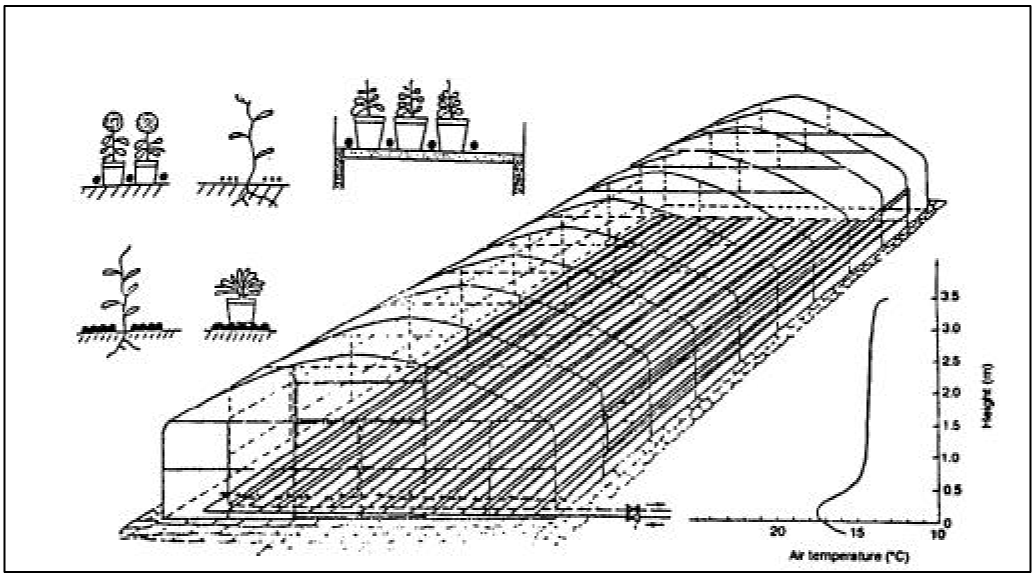

Figure 2.7 Heating systems on soil surface or on the benches (Dickson and Fanelli, 1995).

Proper positioning of heating elements permits an optimum transfer of heat to the plants and minimum heat loss to the environment. It is an excellent solution for covering total heat demand in milder climates or the base demand in moderate and rigid climates.

A disadvantage of this system is that after the end of the production season the plastic pipes must be collected and the steel ones lifted for soil cultivation. Moreover, when the pipes are made by polyethylene they periodically need rearrangement because of the uncontrolled temperature dilations and they do not allow temperatures above 60 °C. When the temperature is below 60 °C, the heating system will consist of a great number of pipelines. Such a system might not be feasible because of high investments cost and the shading of pipelines. Another disadvantage is the unprotected top leaves of the plants against the cold sky radiation and condition. For this reason in cold climates it is used in combination with another heating system. The system has a small but significant influence on the soil temperature and as in the soil heating system, provides earlier harvesting, improved yield and good quality of the products in most of the known cultivation.

2.2.1.3 Aerial Heating System

This group of heating installations consists of metallic pipes, finned metallic pipes or convectors, positioned above the ground surface (Figure 2.8). The advantage with these installations is that they permit a rapid and precise regulation of temperature, and can be used on their own even in moderate and rigid climates. The draw-back is that the heat transfer coefficient for low-temperature heating fluids is very low, which means that the heating surfaces must be very large and may thus reduce light diffusion in the greenhouse and jeopardize working conditions. The vertical temperature profiles are rather uneven for the pipe heating elements, but not for the convectors. However, convectors are unsuitable for low temperature thermal waters.

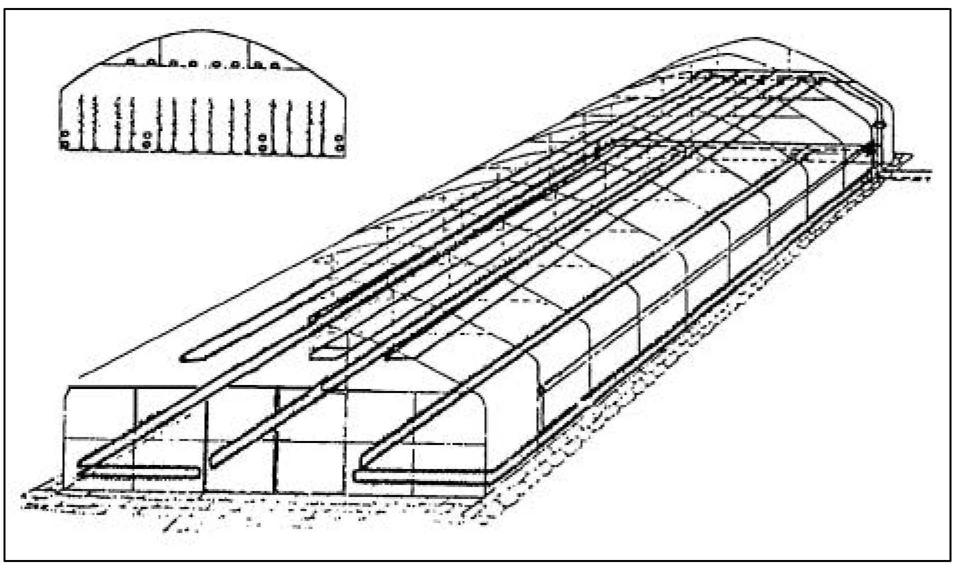

Figure 2.8 Aerial pipe heating installations (Dickson and Fanelli, 1995).

The dominant aerial systems are pipe heater units and fan coil units (Figure 2.9). The pipes can be smooth or finned steel pipes or smooth plastic pipes, which are placed along the length of plant rows, along the sidewalls, under the roof or below the cultivation benches. The position of the system depends on cultivates, the plants requirements, the greenhouse construction, farmer preference, the climate and the cultivation technology. This heating system is the oldest known system. It is convenient in any climate, usable in big greenhouses. It is not economically feasible in small and inexpensive greenhouses. The system is also convenient for combination with other heating systems. The aerial pipes benefit several cultivations but there are differences in the yield and quality of products depending on the location of the pipes. The temperature of geothermal water should be above 60 °C for the same reason as the above systems. The limitation of the water temperature can be solved with the spaghetti aerial heating system. It consists of plastic pipes with very small diameters, placed below the heated benches and results in even temperature distribution in the greenhouse. The temperature of the geothermal water should be low and quality of the water very high because of the small diameter. This system is costly and is used only for pot plants and small extravagant cultivation.

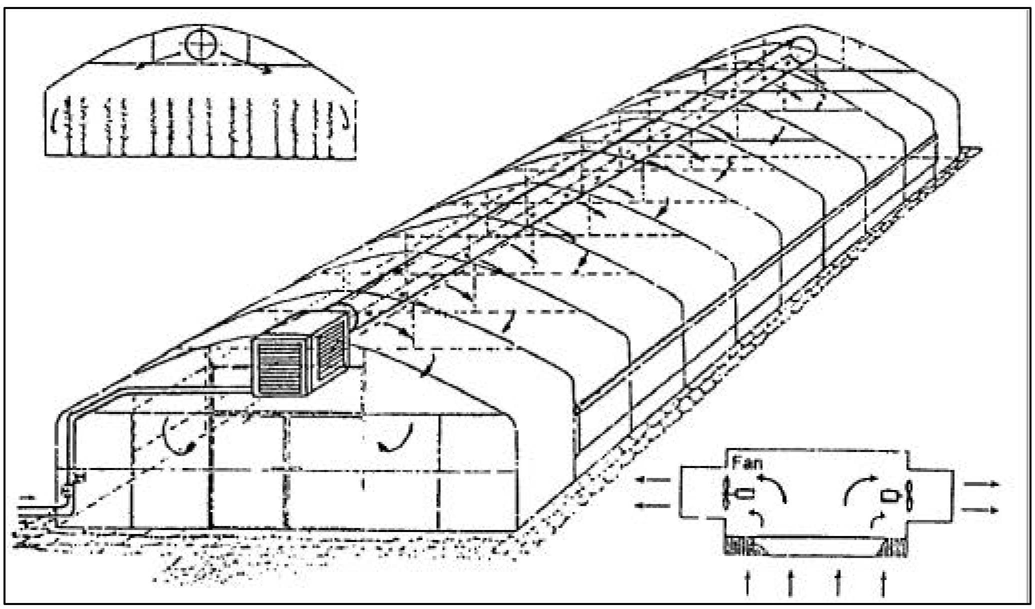

Figure 2.9 Fan-coil air heating system (Dickson and Fanelli, 1995).

The forced air heated units are usually aerial systems, placed along the greenhouse sidewalls, between the plant rows or hung from the roof. The two main categories are the unit heaters and the fan coil units. The difference is primarily in the coil itself. The unit heaters usually have one or two row coils. The coil in the fan systems is much thicker and has closer fin spacing than in unit heaters. It has six or eight rows creating more surface area. The additional area gives more effective heat transfer, resulting in the ability to extract more heat from the water. The fan and unit systems usually need high geothermal fluid temperature because with low temperatures the efficiency of the system is lower and some adjustments of unit capacity is necessary. The geothermal fluid must be clean enough because the most common construction material of the units is copper and it is very sensitive to corrosion. In addition, the long path through which the water flows can result in scaling thus makes a heat exchanger necessary.

2.2.1.4 Cascading

This heating system is applied only in double-layered construction and is common in cheap plastic greenhouses. A water pipeline is installed into the space between the two layers and warm water is sprayed in this space (Figure 2.10). As a heating method, it is effective but it has lot of disadvantages and is not widely applicable. The water must be extremely clean and without inclination of deposition. Although many trials with chemical additives have been performed the problems of the depositions are not resolved. The installation of roof windows is not possible. Additionally, infiltration of geothermal water can harm the plants.

2.2.1.5 Combination

A combination of the different heating system is necessary in cold climates. The forced aerial are usually applied together with soil heating system (in or on the soil) providing even temperature distribution in the greenhouse. Common combination of aerial heating systems are for example system with pipes placed along the walls and under the roof or hung from the roof and beside the plants. When the pipes are placed only on the roof and the walls, the plants have pathogenic problems. This happens because the moisture remains on the plant leaf surface but when the thermal pipes are placed beside the rows of cultivation, a significant amount of moisture disappears.

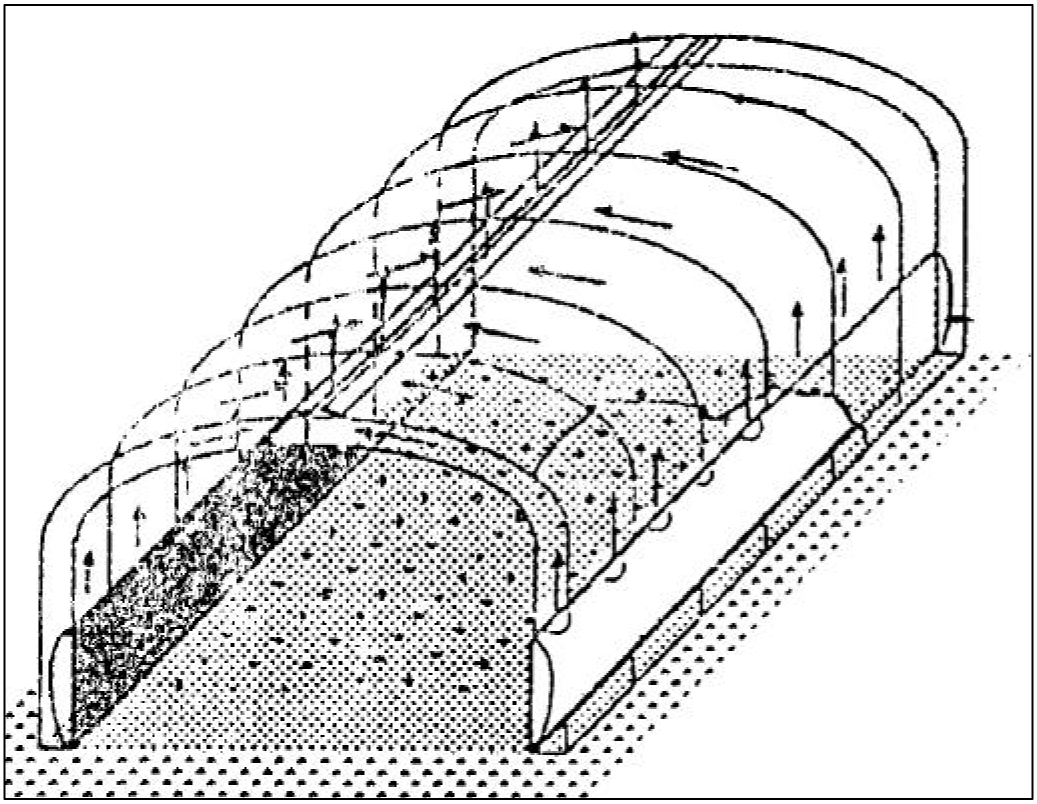

Figure 2.10 Low-temperature roof heating system (Popovski and Popovska-Vasilevska, 1997).

2.3 HEAT LOAD CALCULATIONS

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 which will be used throughout this study.

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

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

The following sections will discuss the heat loss calculations in detail.

2.3.1 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:

$$Q_t = UA(T_i - T_o) \tag{2.1}$$

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 glazing material and depend on wind speed. Table 2.2 gives the correlation between the heat transfer coefficient and wind speed for the common glazing materials.

Table 2.2 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

Heat transfer coefficient values given in Table 2.2 were fitted to second order quadratic equations as function of wind speed for each glazing material using EXCEL. The resultant fit for glass as glazing material with correlation coefficient is presented in Figure 2.11 with the equation of trend line. Fits for fiberglass, single poly and double poly can be found in Appendix A.

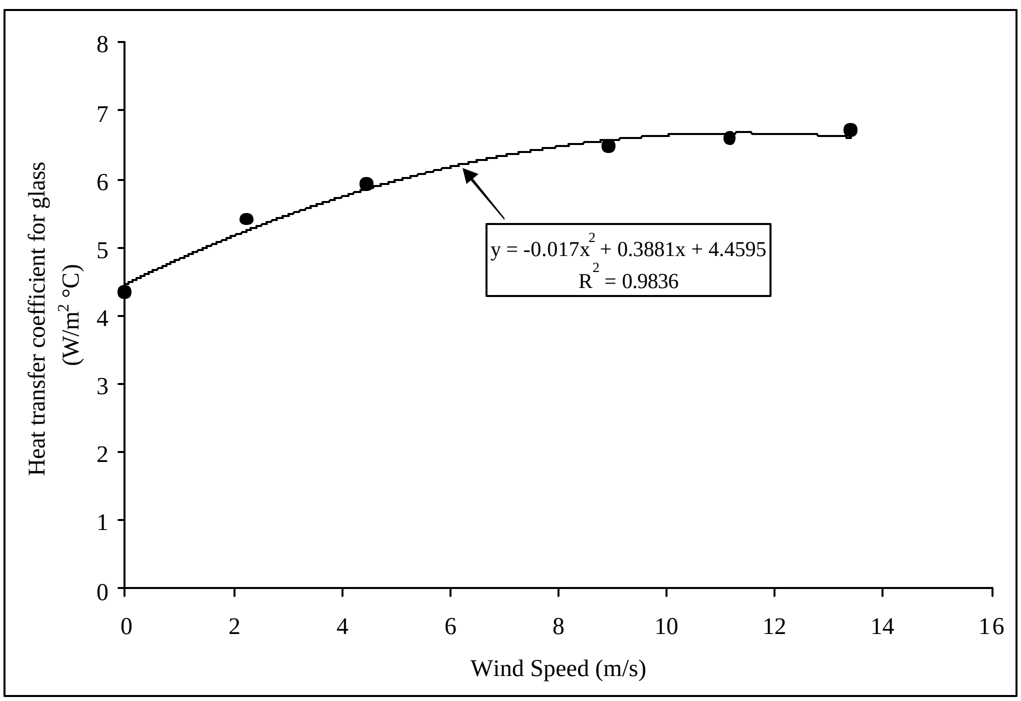

Figure 2.11 Heat transfer coefficient for glass as function of wind speed.

2.3.2 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 2.3 outlines general values for different types of greenhouse constructions, which can be used by the designers.

Table 2.3 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 2.3, it is necessary to calculate the volume of greenhouse. Then, Equation 2.2 is used to calculate the infiltration heat losses:

$$Q_i = V \times ACH \times C_p \times ? \times \left(T_i - T_o\right)/3600 \qquad (2.2)$$

where

Q_i = Infiltration heat loss [W]

V = Volume of greenhouse [m^3]

ACH = Air change per hour (from Table 2.2)

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

ρ = Density of air [kg/m^3]

T_i = Indoor design temperature [°C]

T_o = Outdoor design temperature [°C]

Total heat loss can be calculated by addition of transmission heat loss and infiltration heat loss as shown in Equation 2.3.

$$Q_{TOTAL} = Q_t + Q_i \tag{2.3}$$

By calculating maximum heating load for the greenhouse, the adequate system to heat the greenhouse can be chosen. If unit heaters or fan coil units are chosen, the only thing is to select the devices from the manufacturer's catalogue with the required capacities and to be installed in the greenhouse. On the other hand, 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.

2.4 SOIL HEATING SYSTEM DESIGN

The procedure for designing a floor system consists of:

a) Determining the heat load for the greenhouse;

b) Calculating the required floor temperature to meet the load;

c) Calculating the required size, depth and spacing of the tubes.

Determination of the heat load was covered in Section 2.3. 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 2.4 (Lund, 1996) is used to calculate the required floor surface temperature.

$$\frac{q}{A} = 0.472\left[\left(\frac{1.8T_p+492}{100}\right)^4 - \left(\frac{1.8AUST+492}{100}\right)^4\right] + 2.186\left(T_p - T_a\right)^{1.32} \tag{2.4}$$

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;

$$IST = IDT - (0.0291 \times 3.6 \times U \times DT) \tag{2.5}$$

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

$$AUST = \frac{A_1 \times IST_1 + A_2 \times IST_2 + \cdots\cdots + A_n \times IST_n}{A_1 + A_2 + \cdots\cdots + A_n} \tag{2.6}$$

where

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

The floor temperature (T_p) can be determined by solving Equation 2.4.

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 2.7 (Björnson, 1980), the designer has to decide the size and length of pipes needed to supply the necessary heating load.

$$L = \frac{Q \times \ln\left[\left(8\left(\frac{H}{d}\right)^2 - 1\right) + 4\left(\frac{H}{d}\right) \times \sqrt{4 \times \left(\frac{H}{d}\right)^2 - 1}\right]}{4 \times p \times l_j \times t_m} \qquad (2.7)$$

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

$$t_m = \frac{\left(T_{wi} - T_{w0}\right)}{\ln\left(\frac{T_{wi} - T_P}{T_{w0} - T_P}\right)} \qquad (2.8)$$

where

T_{wi} = Water inlet temperature [°C]

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

T_P = Floor surface temperature [°C]

From Equation 2.7, 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

$$n = \frac{L_{pipe}}{L_{greenhouse}} \tag{2.9}$$

where

n = Number of pipes

L_{pipe} = Pipe length [m]

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

2.5 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 2.10 (Lund, 1996).

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

(2.10)

where

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.

2.6 PEAKING WITH FOSSIL FUELS

There are certain cases in which it is not feasible to design the geothermal heating system to cover 100 % of the 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. The rationale behind different base load and peak load heating system lies in the annual temperature profile, where the base load, using geothermal energy, might be designed to cover 50-70 % of the peak load, and it will still meet up to 90% of the annual heating energy requirements.

2.6.1 Peaking With Air Heating Equipment

Sizing an air heating peaking equipment procedure is rather simple; the capacity of this equipment (W) is the peak (W) load minus the base load (W) covered by a bare tube or soil heating system.

Heating Equipment Capacity = Peak Load - Base Load

2.6.2 Peaking With A Boiler

Calculating the capacity of the heating boiler needed to cover the peak load is not as simple as the air heating equipment calculations. The boiler increases the supply water temperature, which not only influences the output of the terminal equipment, but also the capacity of the geothermal heat exchanger. As the supply water temperature rises, the output of the terminal rises. At the same time, the return water temperature rises as well; the geothermal heat source capacity to increase the return water temperature is greatly reduced. In some extreme cases, the return water temperature from the heating loop might be higher than the temperature of the geothermal water temperature, which implies that the boiler has to cover the total load.

CHAPTER 3

STATEMENT OF THE PROBLEM

The availability of geothermal water in Çavundur area was verified after the drilling of Ç-1 well by MTA in 1987. The Municipality of Çavundur is utilizing the geothermal fluid having the temperature of 54 °C with a flow rate of 47 l/s for thermal tourism and balneology since its discovery. Governorship of Çankiri established a firm for further utilization of the geothermal fluid for bathing, balneology and thermal tourism. This new establishment has a bed capacity of 500 and started in operation in July 2001. Utilization of Çavundur geothermal fluid for these applications is limited to summer months. These thermal facilities are 10% full only for the remaining nine months of the year leaving a considerable potential for other direct applications of geothermal energy. One of the possible applications of geothermal energy in this area is greenhouse heating.

It is aimed in this study to carry out a technical feasibility study for the utilization of Çavundur geothermal fluid for greenhouse heating. The study will be based on the daily meteorological data of the area and suitable crops for the climate. Different scenarios will be studied by different kinds of greenhouse glazing materials to find the optimum utilization of geothermal fluid for greenhouse heating. Peak loading with fossil fuel firing will also be considered.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ÇAVUNDUR GEOTHERMAL FIELD

Çavundur geothermal field, located in Çavundur village, is 8 km far from Kursunlu town of Çankiri (Figure 4.1).

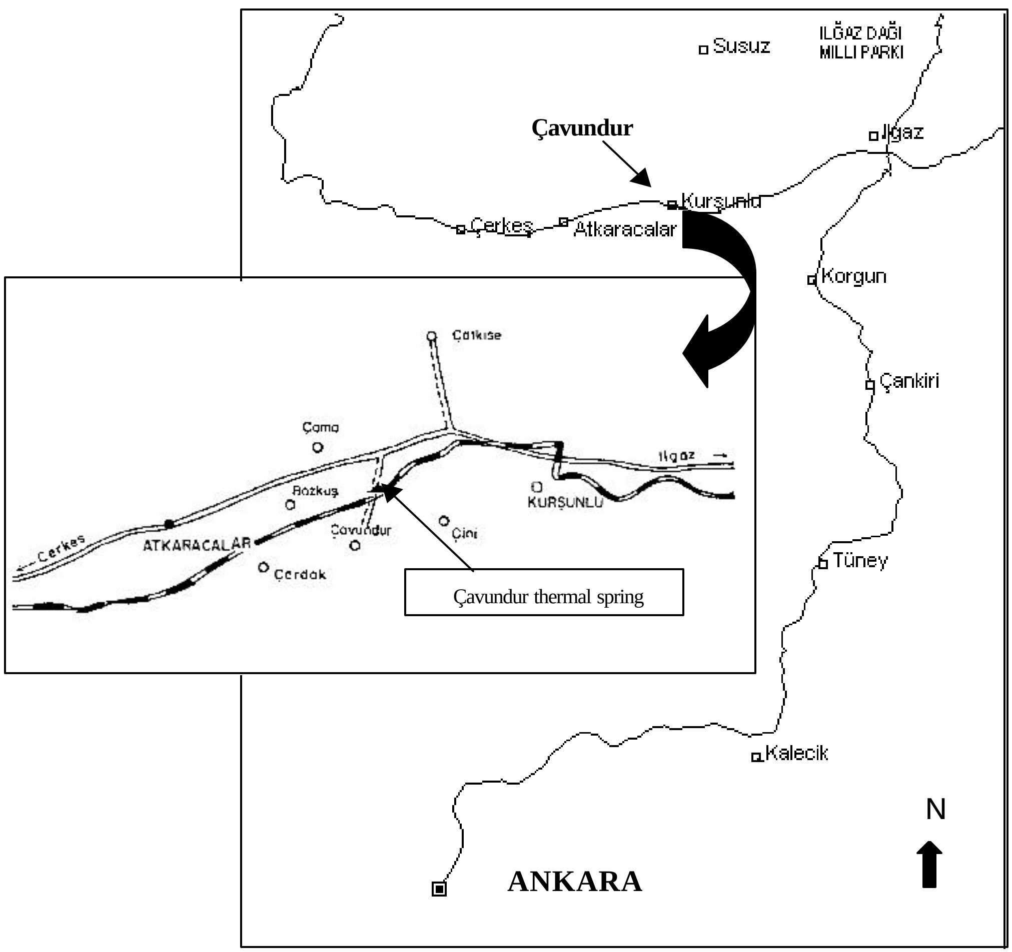

Figure 4.1 Location map of Çavundur geothermal field (not to scale).

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 Çankiri 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 4.2 (Günay and Simsek, 2001). Initial measurements showed a maximum flow rate of 47 l/s geothermal fluid at 54 °C (Uzel and Didik, 1988). Measurements by ORME Inc. (1997) also resulted with a flow rate of 47 l/s at 1.8 bar-g wellhead pressure (Figure 4.3). Geothermal fluid from Ç-1 has a TDS of 11652 mg/l and can be classified as sodium-bicarbonate water (Table 4.1, Uzel and Didik, 1988). There is a continuous inhibitor injection into the wellbore due to tendency of water for calcite scaling.

Table 4.1 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 Çankiri established a firm (ÇANTUR A.S.) 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 (Incekara, 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 (Figure 4.4)

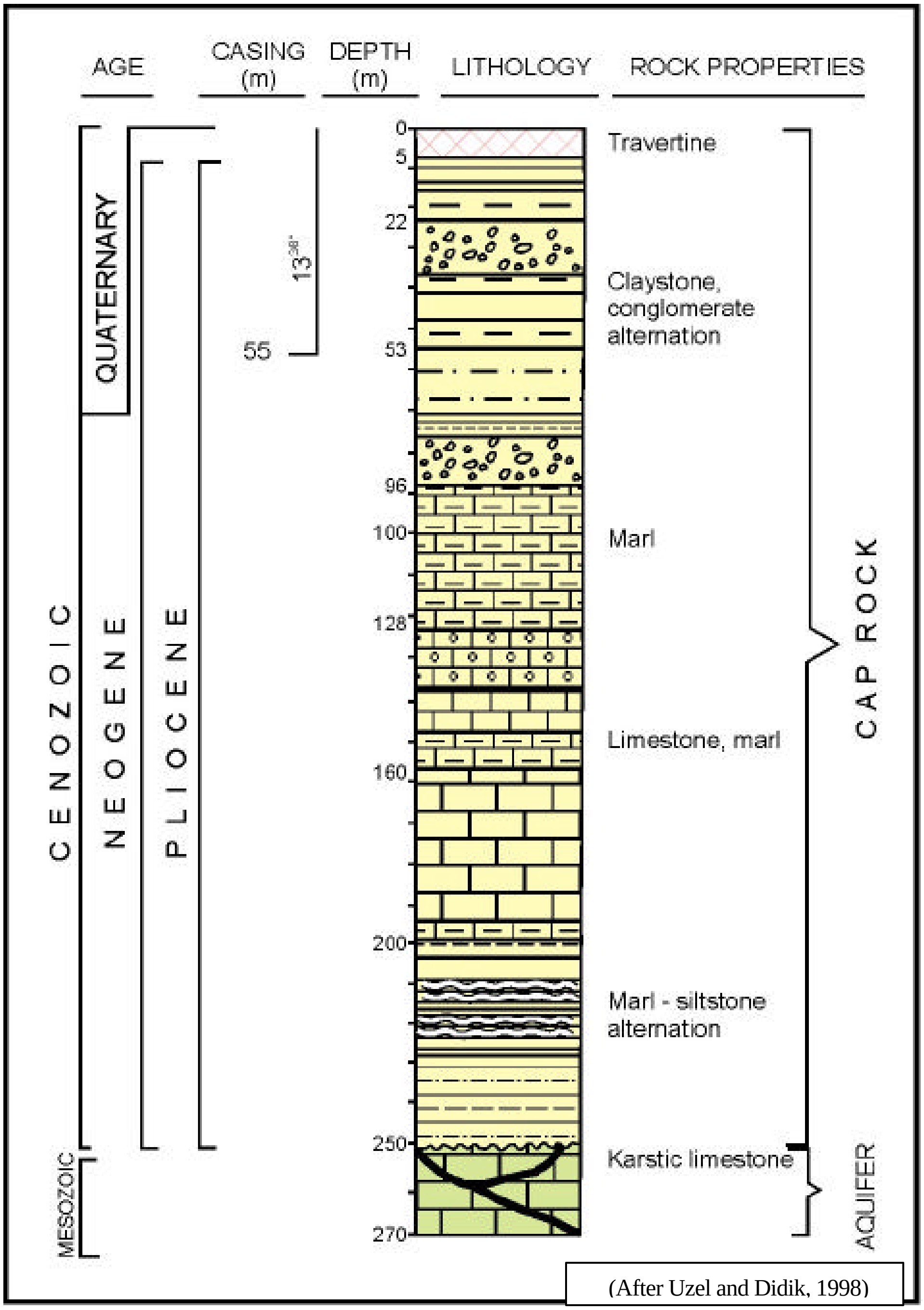

Figure 4.2 Composite log of Ç-1 (Günay and Simsek, 2001).

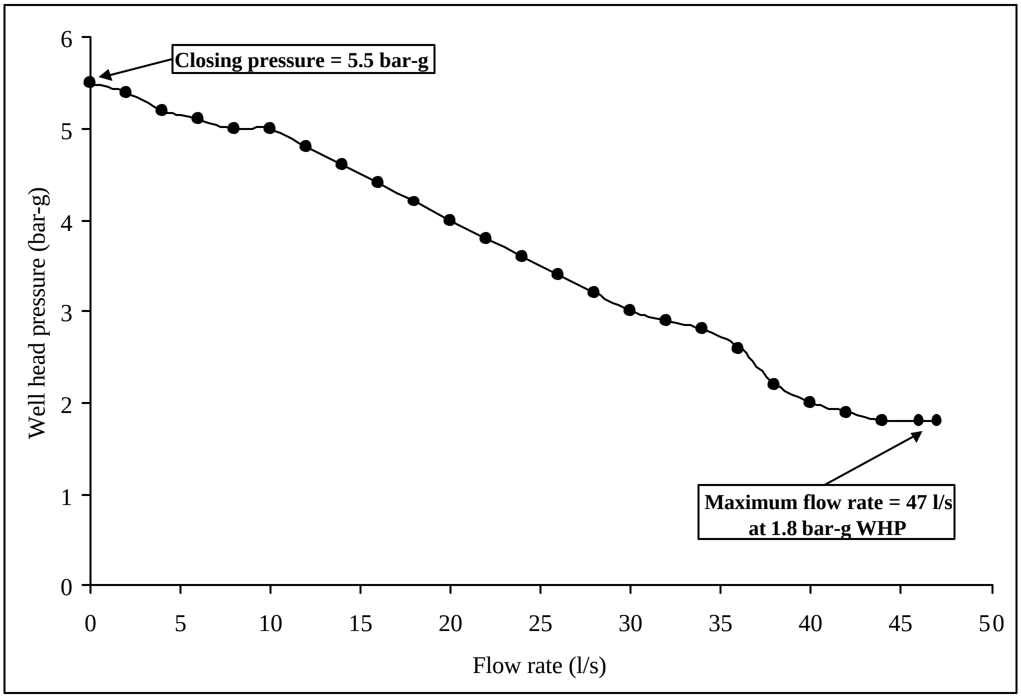

Figure 4.3 Deliverability curve of Ç-1 (ORME Inc., 1997).

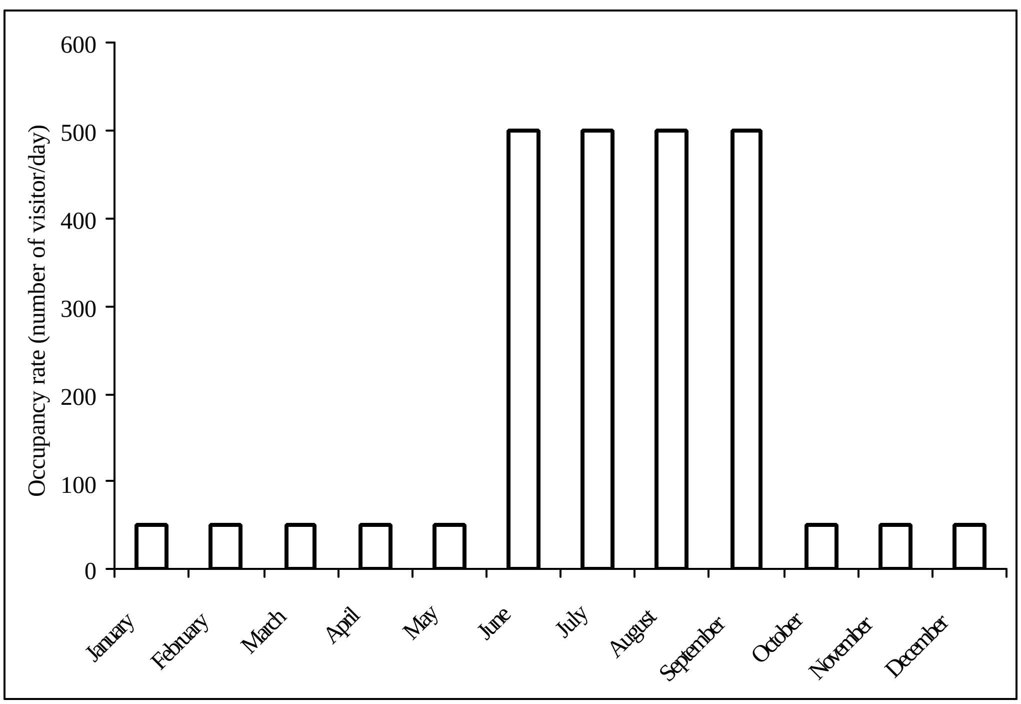

Figure 4.4 Occupancy rate of Çavundur thermal facilities

Two pictures taken from Çavundur geothermal field are presented in Figures 4.5 and 4.6. Figure 4.6 was taken from the thermal facilities of ÇANTUR A.S. and shows a general view that the geothermal field is located in the countryside, which is very suitable for agriculture.

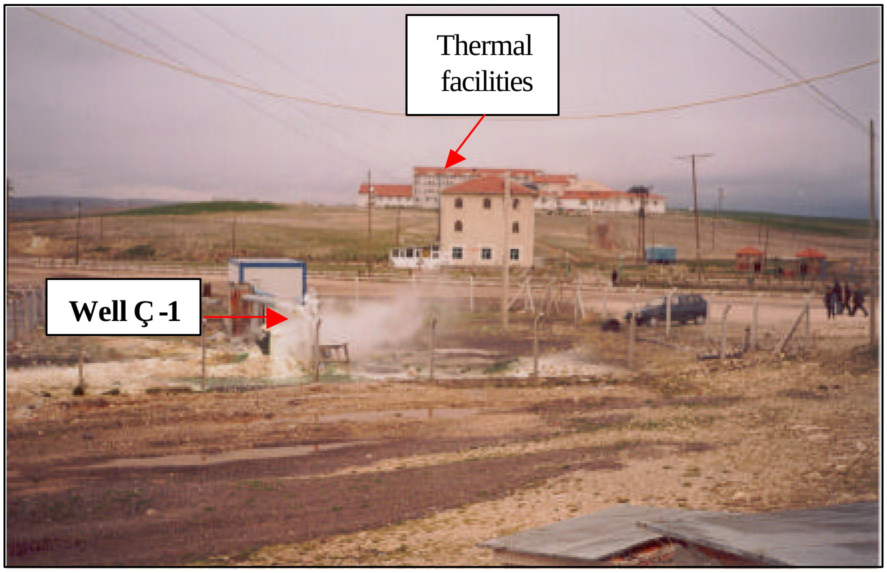

Figure 4.5 View of Well Ç-1 and Çavundur thermal facilities.

Figure 4.6 A general view of Çavundur geothermal field.

4.2 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 Kursunlu town (8 kilometers far from Çavundur) for the year 2002 was taken from the Directorate of Meteorology of Çankiri. This data include daily measurements of temperature, wind speeds, relative humidity taken at 7 AM, 2 PM and 9 PM. Figure 4.7 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.

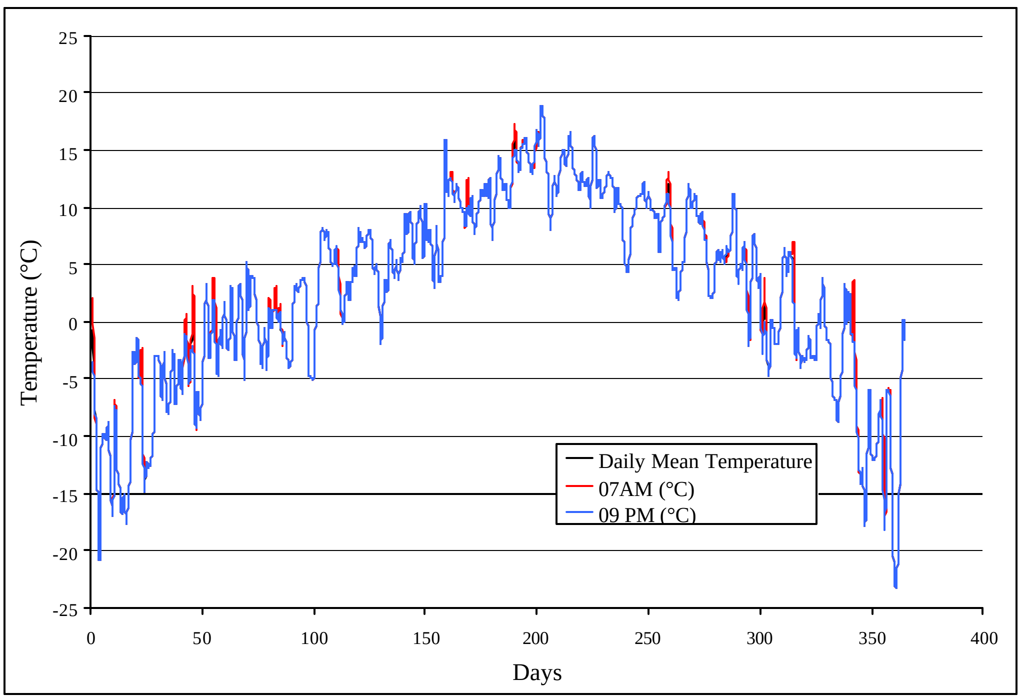

Figure 4.7 Daily temperature measurements at Kursunlu for the year 2002.

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 4.8 for January 2002, and the data for other months of the year are presented in Appendix B. Monthly mean temperatures from these plots are listed in Table 4.2, 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 4.9).

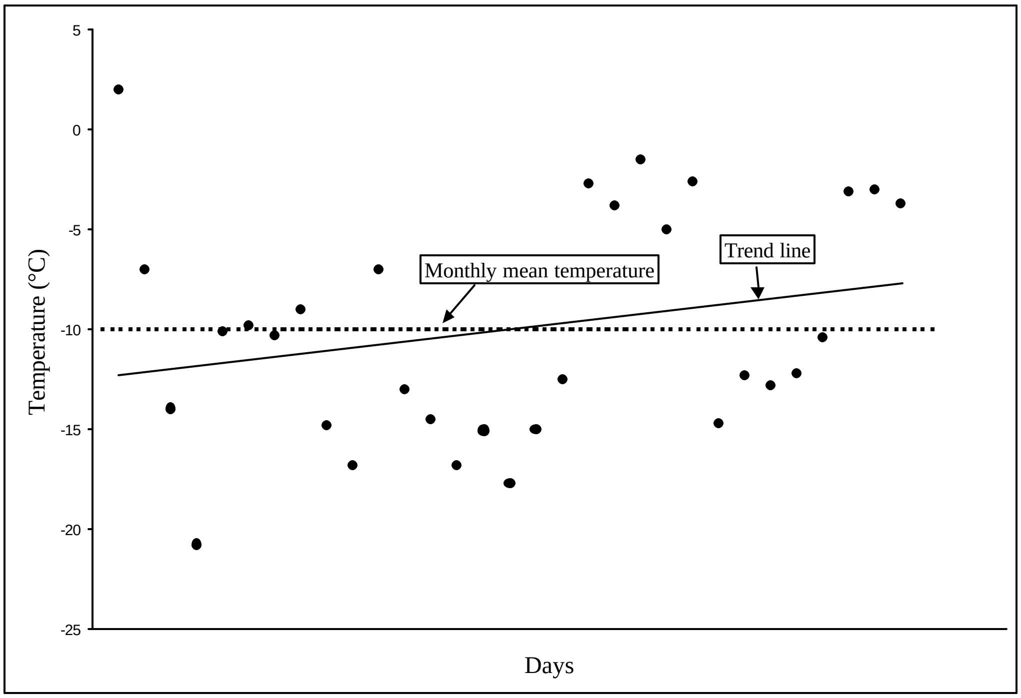

Figure 4.8 Daily mean temperature changes at Kursunlu in January 2002.

Table 4.2 Monthly mean temperatures at Kursunlu 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

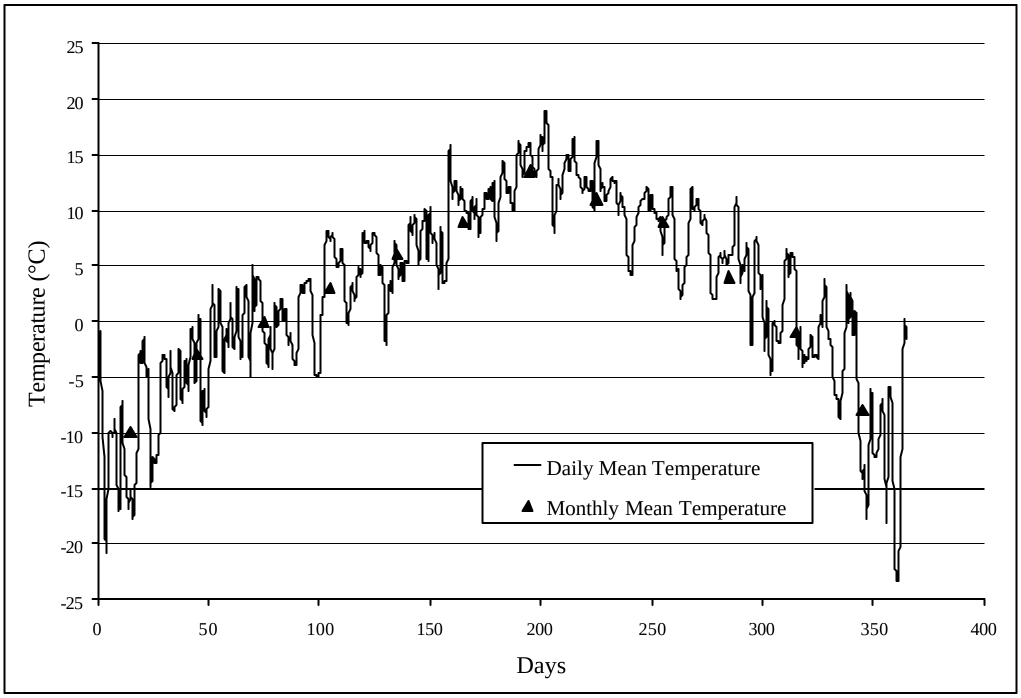

Figure 4.9 Comparison of daily and monthly mean temperature values.

Another meteorological data for the calculation of heat load is the wind speed of a given locality. Figure 4.10 gives the daily maximum wind speeds of Kursunlu. 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 Kursunlu fluctuates between 0.5 m/s and 8.0 m/s with an approximate average value of 2.0 m/s (Figure 4.10), the maximum wind speed of a given month was assigned as a constant value of this specific month (Table 4.3). This is a conservative approach where the wind speed affects heat transfer coefficient of glazing material hence the transmission heat losses.

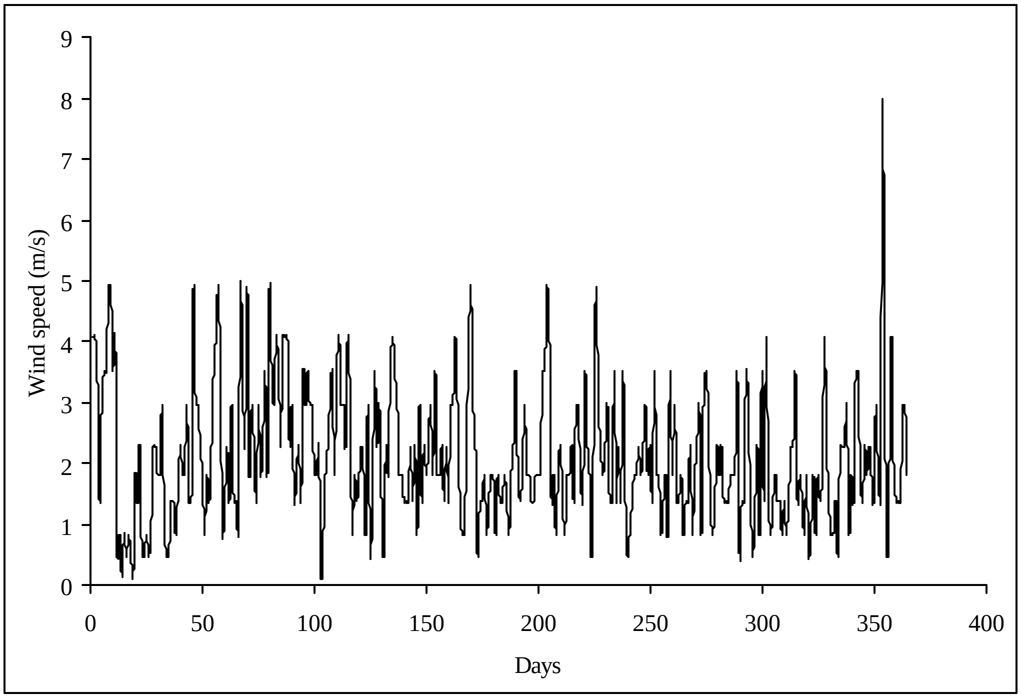

Figure 4.10 Changes in wind speed at Kursunlu.

Table 4.3 Maximum wind speeds of each month at Kursunlu 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

4.3 HEAT LOAD CALCULATIONS

Heat load of a greenhouse can simply be calculated by taking into account transmission heat losses (Equation 2.1) and infiltration heat losses (Equation 2.2) (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 Çankiri was obtained from the Directorate of Agriculture of Çankiri as 6 m in width, 36 m in length and 3 m in height (Figure 4.11). The shape of the greenhouse was selected as arched roof after the discussion by the authorities of Directorate of Agriculture of Çankiri (Figure 4.11), 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 4.4 gives the dimensions of a greenhouse that will be used throughout this study.

Table 4.4 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

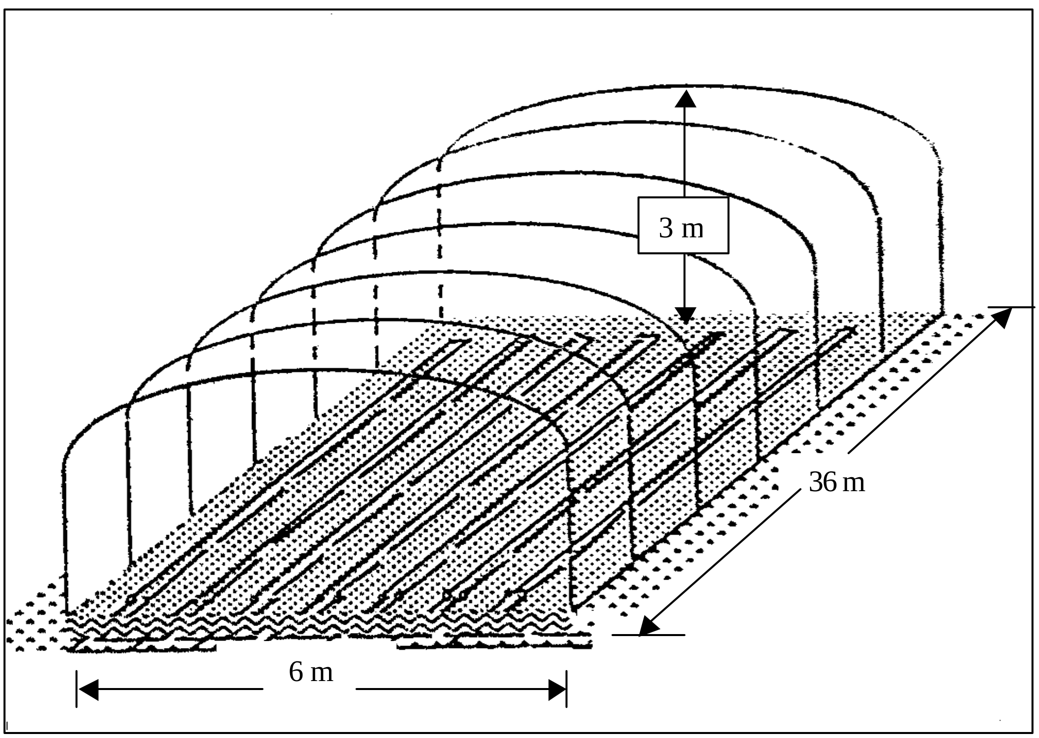

Figure 4.11 Shape and size of a greenhouse.

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 4.5 and Figure 4.12 give the optimum temperatures for different crops. As seen from Figure 4.12, cucumbers grow best in the temperature range 25 – 30 °C, tomatoes near 20 °C, and lettuce at 15 °C, and below.

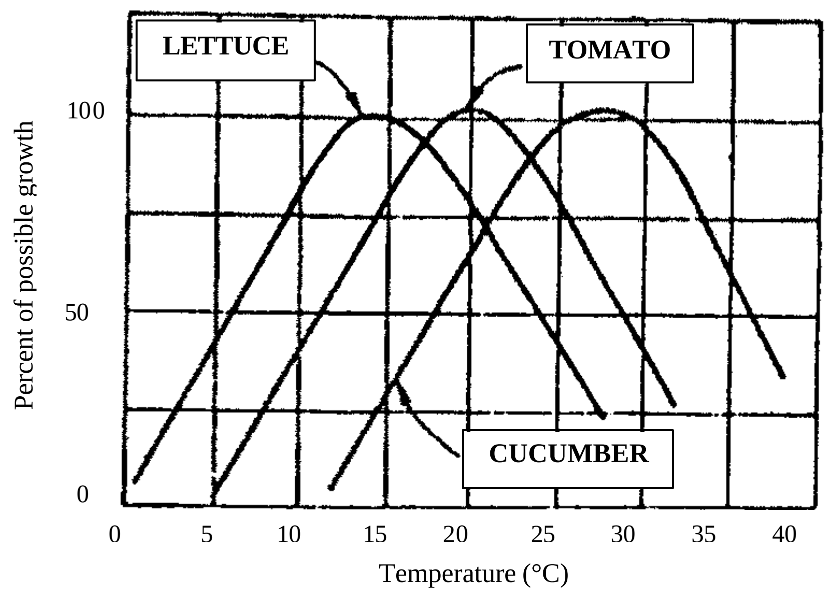

Figure 4.12 Optimum growing temperatures for selected agricultural products (Barbier and Fanelli, 1977).

Table 4.5 Temperature requirements of different vegetables (Sevgican, 1989)

Vegetable	**Day time requirement (°C)**	**Night requirement (°C)**
Tomato Egg plant	19 – 24 25 – 30	14 – 18 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.

Monthly peak-heat requirements for glass as glazing material when the indoor design temperature is 12 °C are presented in Table 4.6 and Figure 4.13. Heat transfer coefficients (U) in Table 4.6 are the function of wind speed and were estimated from Figure 2.11. Transmission heat losses (Q_t) and infiltration heat losses (Q_i) were calculated by using Equations 2.1 and 2.2, respectively.

$$Q_t = UA(T_i - T_o) \qquad (2.1)$$

where

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

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

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

T_i = Indoor design temperature [°C]

T_o = Outdoor design temperature [°C] (from Table 4.2)

and

$$Q_i = V \times ACH \times C_p \times ? \times (T_i - T_o)/3600 \qquad (2.2)$$

where

Q_i = Infiltration heat loss [W]

V = Volume of greenhouse [m^3]

ACH = Air change per hour (from Table 2.2)

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

ρ = Density of air [kg/m^3]

While applying Equation 2.2 for infiltration heat losses, the mean values of air change data (ACH) for different glazing materials were used (Table 2.3). Other parameters in Equation 2.2 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 (http://hypertextbook.com/facts/2000/RachelChu.shtml). Monthly peak-heat requirements for other glazing materials as well as other indoor design temperatures are presented in Appendix C.

Table 4.6 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**

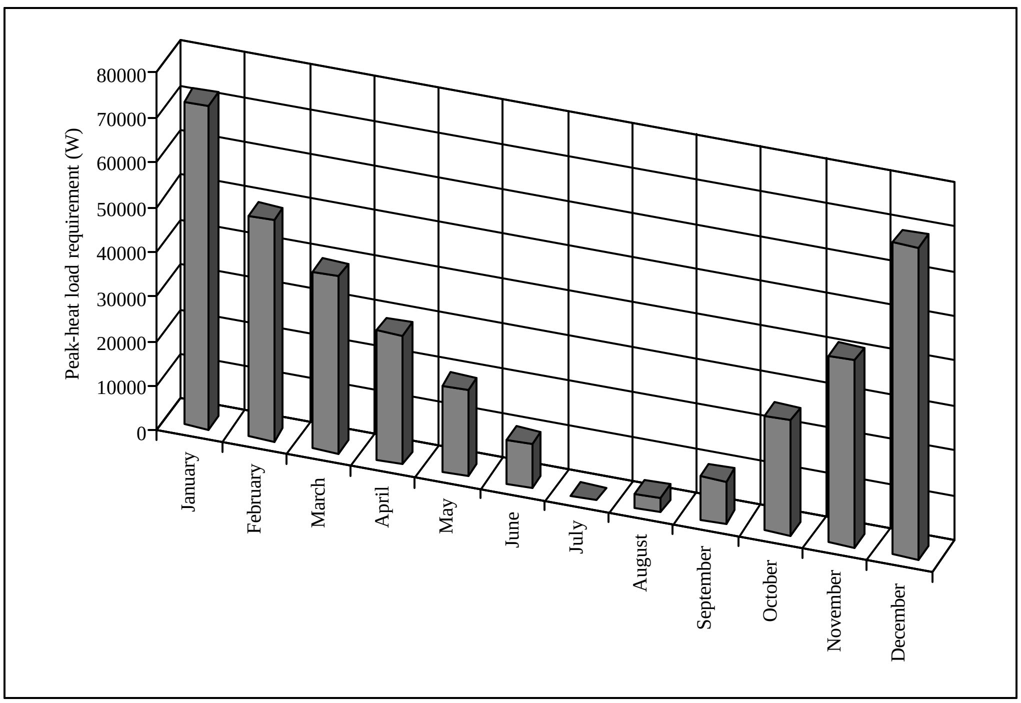

Figure 4.13 Monthly peak-heat requirements for glass at 12 °C indoor temperature.

As observed in Table 4.6 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 4.13. One of the characteristics of greenhouse heating is clearly seen in Figure 4.13, which is the variable nature of heating requirement throughout the year.

Table 4.7 and Figure 4.14 show 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 4.14 indicates that glass has the poorest performance among the four glazing materials. On the other hand, use of pla stic 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).

Table 4.7 Annual total heat requirements for different glazing materials and indoor design temperatures (W).

	INDOOR DESIGN TEMPERATURE (°C)		
GLAZING MATERIAL	**12**	**17**	**22**
GLASS	369042	548170	727300
FIBERGLASS	326227	484516	642806
SINGLE POLY	288277	427726	567175
DOUBLE POLY	179015	265908	352801

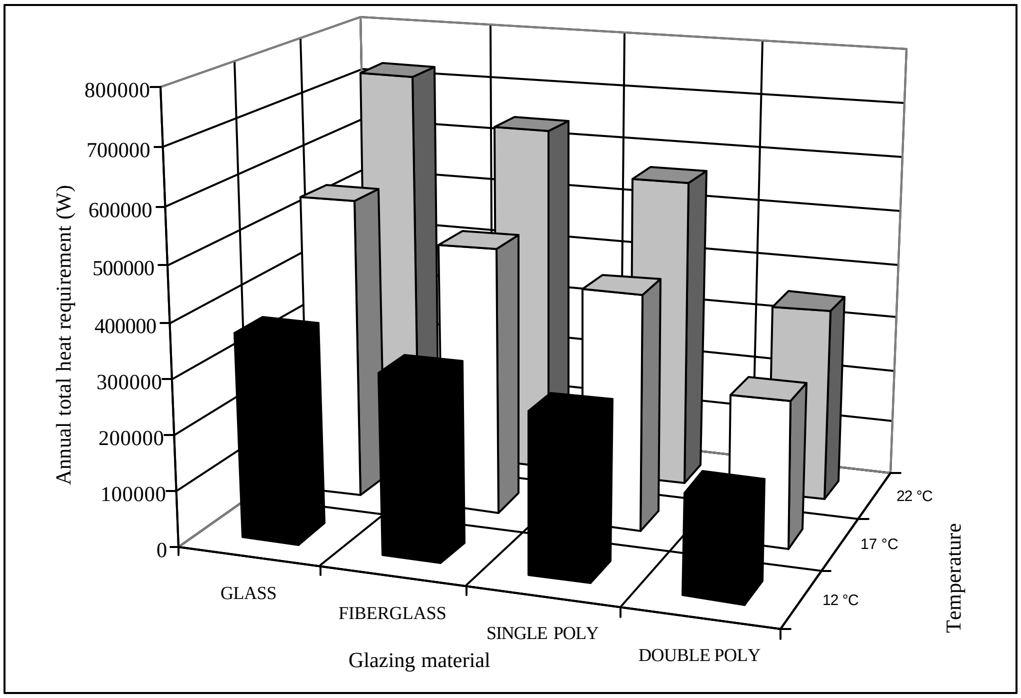

Figure 4.14 Annual total heat requirements (W).

4.3.1 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 4.15 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.

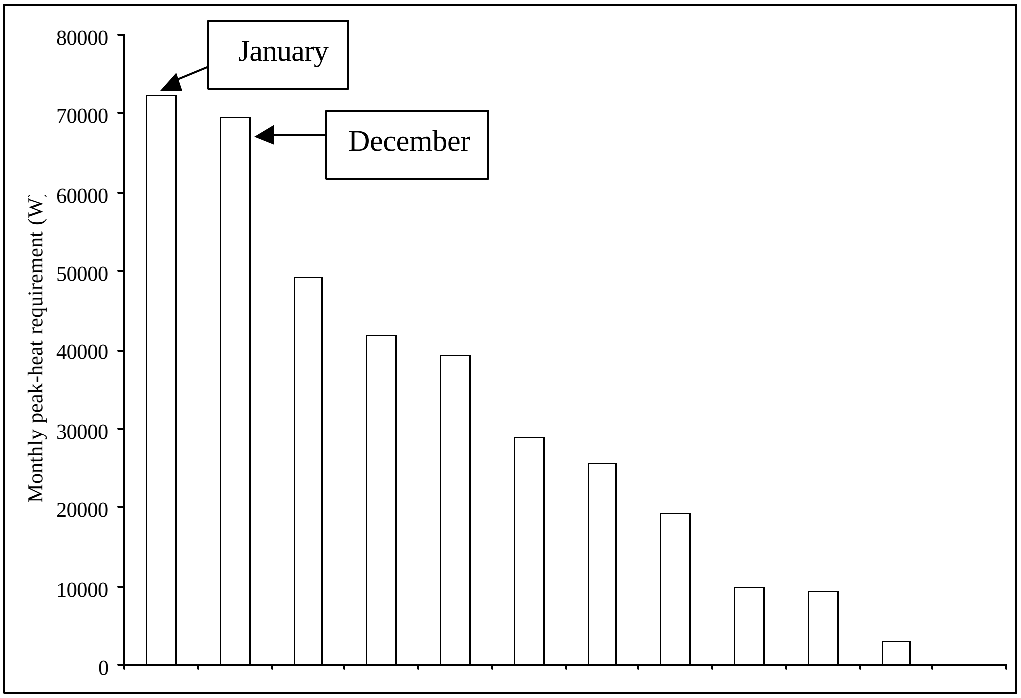

Figure 4.15 Sorted monthly peak heat loads calculated for glass as glazing material at 12 °C indoor temperature.

Equation 4.1 can calculate the number of greenhouses;

$$NG = \frac{H_{available}}{H_{base}} \qquad (4.1)$$

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 4.2.

$$H_{available} = m \times C_p \times ?\,T \qquad (4.2)$$

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 4.1 and 4.2 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 (Incekara, 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 indoor design temperatures and base loads are given in Tables 4.8 – 4.10. 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. The number of greenhouse data is also presented in Figures 4.16 – 4.19 for each glazing material. 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.

Table 4.8 Number of greenhouses for different type of glazing materials (indoor design temperature = 12 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	40	44	50	57	67
FIBERGLASS	45	50	57	65	76
DOUBLEPOLY	83	92	103	118	138
SINGLEPOLY	51	57	64	73	85

Table 4.9 Number of greenhouses for different type of glazing materials (indoor design temperature = 17 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	33	36	41	47	54
FIBERGLASS	37	41	46	53	62
DOUBLEPOLY	67	75	84	96	112
SINGLEPOLY	42	46	52	60	70

Table 4.10 Number of greenhouses for different type of glazing materials (indoor design temperature = 22 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	28	31	34	39	46
FIBERGLASS	31	35	39	44	52
DOUBLEPOLY	57	63	71	81	95
SINGLEPOLY	35	39	44	50	59

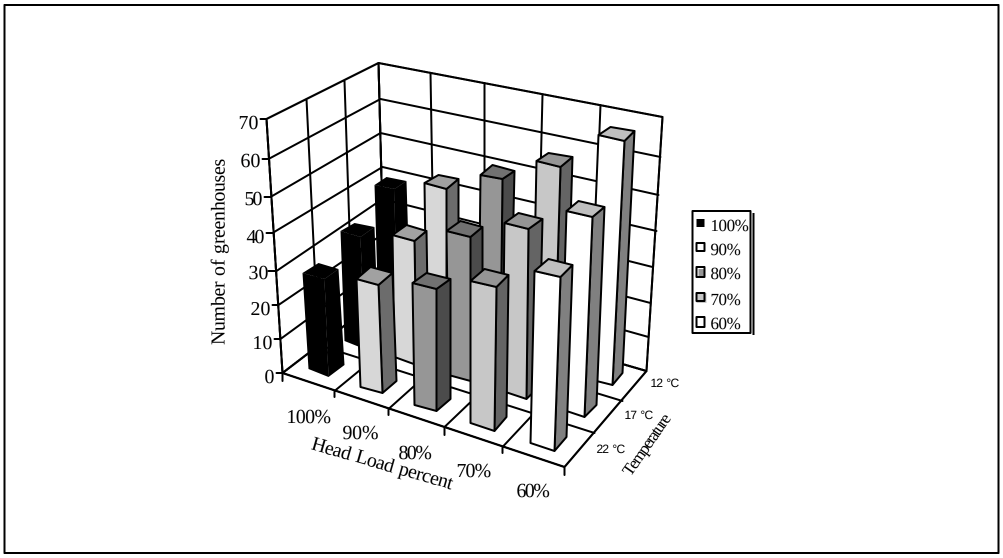

Figure 4.16 Number of glass greenhouses

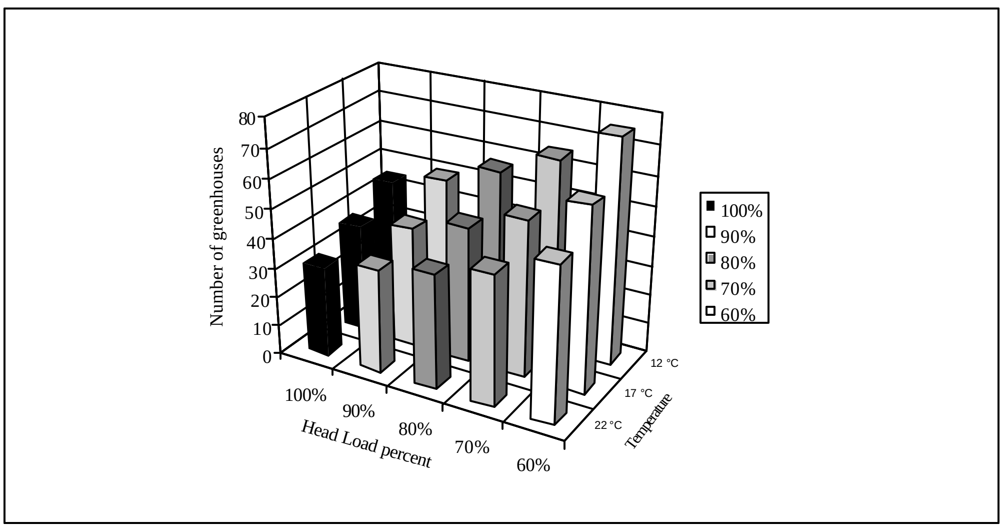

Figure 4.17 Number of fiberglass greenhouses

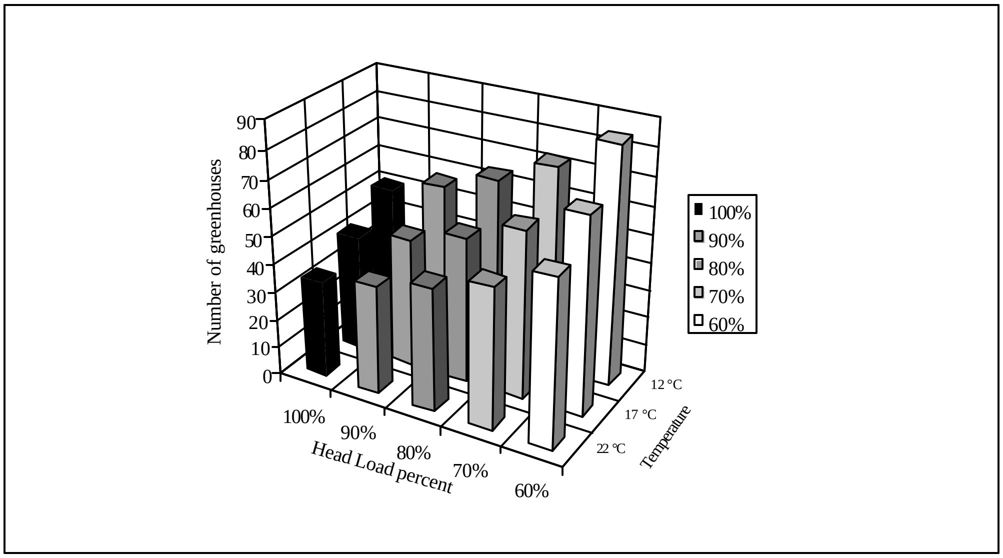

Figure 4.18 Number of plastic film (single poly) greenhouses

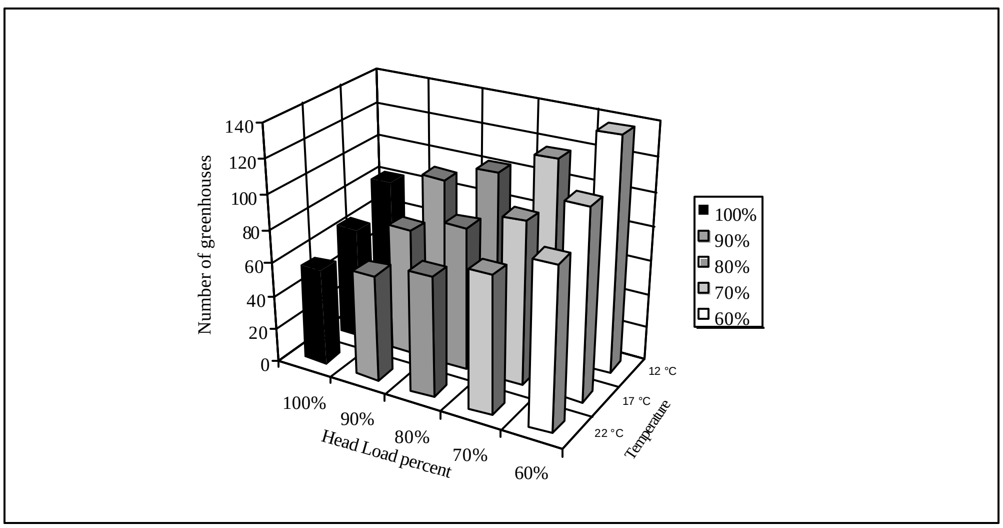

Figure 4.19 Number of plastic film (double poly) greenhouses

4.3.2 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 4.3.

$$\text{AHFL} = \frac{E_{Annual}}{E_{Available}} \qquad (4.3)$$

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 4.3 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 4.11 for a glass greenhouse at 12 °C indoor design temperature and 100% base load. As indicated in Table 4.11, 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%.**

Tables 4.12 – 4.14 give 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 (Figure 4.20). 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.

Table 4.11 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**

Table 4.12 Annual heat load factors of greenhouses for different type of glazing materials (indoor design temperature = 12 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	43	47	53	61	71
FIBERGLASS	43	47	53	61	71
DOUBLEPOLY	43	47	53	61	71
SINGLEPOLY	43	47	53	61	71

Table 4.13 Annual heat load factors of greenhouses for different type of glazing materials (indoor design temperature = 17 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	51	57	64	73	86
FIBERGLASS	51	57	64	73	86
DOUBLEPOLY	51	57	64	73	86
SINGLEPOLY	51	57	64	73	86

Table 4.14 Annual heat load factors of greenhouses for different type of glazing materials (indoor design temperature = 22 °C)

	BASE LOAD (percent of maximum heat requirement)				
GLAZING MATERIAL	**100**	**90**	**80**	**70**	**60**
GLASS	58	64	72	82	96
FIBERGLASS	58	64	72	82	96
DOUBLEPOLY	58	64	72	82	96
SINGLEPOLY	58	64	72	82	96

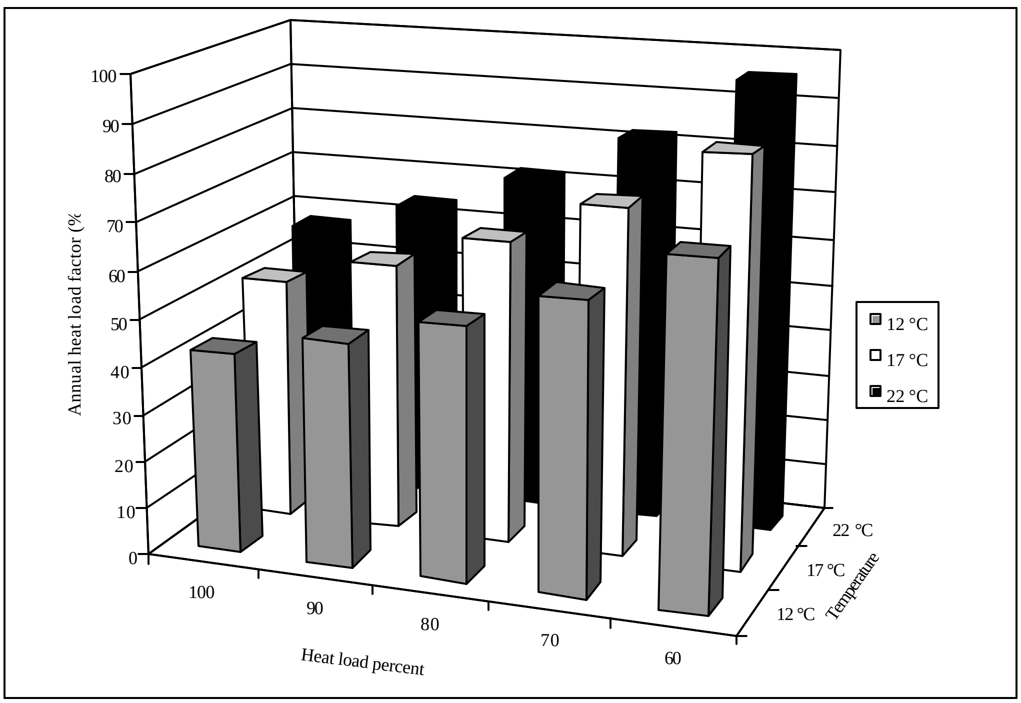

Figure 4.20 Annual heat load factors for all studied greenhouse systems.

4. 4 PIPE LENGHTS

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 Chapters 2.4 and 2.5. 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 2.7 and 2.8.

$$L = \frac{Q \times \ln\left[\left(8\left(\frac{H}{d}\right)^2 - 1\right) + 4\left(\frac{H}{d}\right) \times \sqrt{4 \times \left(\frac{H}{d}\right)^2 - 1}\right]}{4 \times p \times l_j \times t_m} \tag{2.7}$$

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

$$t_m = \frac{(T_{wi} - T_0)}{\ln\left(\frac{T_{wi} - T_P}{T_{w0} - T_P}\right)} \tag{2.8}$$

where

T_{wi} = Water inlet temperature [°C]

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

T_P = Floor surface temperature [°C]

Table 4.15 gives the values of the parameters of Equations 2.7 and 2.8 that are used for Çavundur field greenhouse design study.

Table 4.15 Values of parameters of Equations 2.7 and 2.8

Parameter	**Value**
Q (W)	Calculated in Section 4.3 for different greenhouse systems
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 (http://www.hukseflux.com/thermal%20conductivity/thermal.htm) and an average value of 1.25 W/m °C was used.

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 4.12 and Table 4.5 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 2.4. In this equation, all the parameters except floor surface temperature are known, but since the equation is a 4th 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 4.16 lists the floor surface temperatures calculated from Equation 2.4 for different type greenhouses at different indoor temperatures and 100% heating load.

Calculated floor surface temperatures for different types of glazing materials indicated that construction of greenhouse with double poly plastic film with the burial of 32 mm diameter pipe to a depth of 150 mm will not exceed the maximum allowable floor surface temperature, but all the other construction materials will have some deviation from the maximum allowable floor surface temperature in the colder months.

Table 4.16 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 2.7 requires heat loads (Q) and those values were already calculated in Section 4.3. Calculated heat loads of the coldest month for different glazing materials at 12 °C indoor design temperatures are presented in Table 4.17 as function of peak load. The reason of choosing the coldest month is to design a system that can support the worst case.

Table 4.17 Heat Loads for different glazing materials (W)
(indoor design temperature=12 °C)

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 4.18 gives the length of 32 mm diameter pipe to be used in a single greenhouse, calculated from Equation 2.7. If the total pipe length is divided to the length of greenhouse (36 m), the number of pipes can be obtained (Table 4.19). As observed from Table 4.18 and 4.19, the shortest pipe length is obtained for double poly greenhouses for all peak loads resulting with a decrease in investment cost. Heat loads, pipe lengths and pipe numbers for other indoor design temperatures (17 °C and 22 °C) are given in Appendix D.

Table 4.18 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 4.19 Number of pipes of soil heated greenhouses for different glazing materials at different heat loads (indoor design temperature=12 °C) (m)

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 2.10.

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

(2.10)

where

L = Pipe Lenght [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 demonstrated at Table 4.20 the required minimum pipe length for a greenhouse at bare tube system is obtained at double poly greenhouse similar to soil heated greenhouse. Heat loads, pipe lengths and pipe numbers for other indoor design temperatures (17 °C and 22 °C) are given in Appendix D.

Table 4.20 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 4.21 Number of pipes used at bare tube system greenhouses for different glazing materials at different heat loads (indoor design temperature=12 °C) (m)

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

CHAPTER 5

CONCLUSIONS

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

1. Heat load calculations demonstrated that Çavundur geothermal field is suitable for greenhouse applications.
2. 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.
3. 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.
4. 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.

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APPENDIX A

HEAT TRANSFER COEFFICIENTS FOR GLAZING MATERIALS

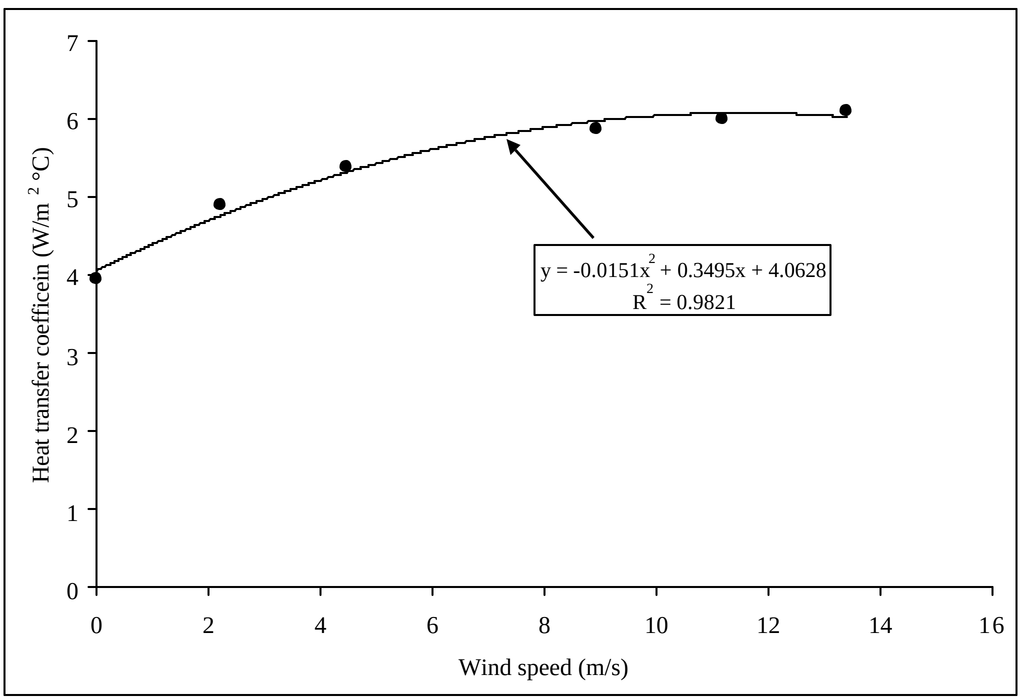

Figure A.1 Heat transfer coefficient for fiberglass as function of wind speed.

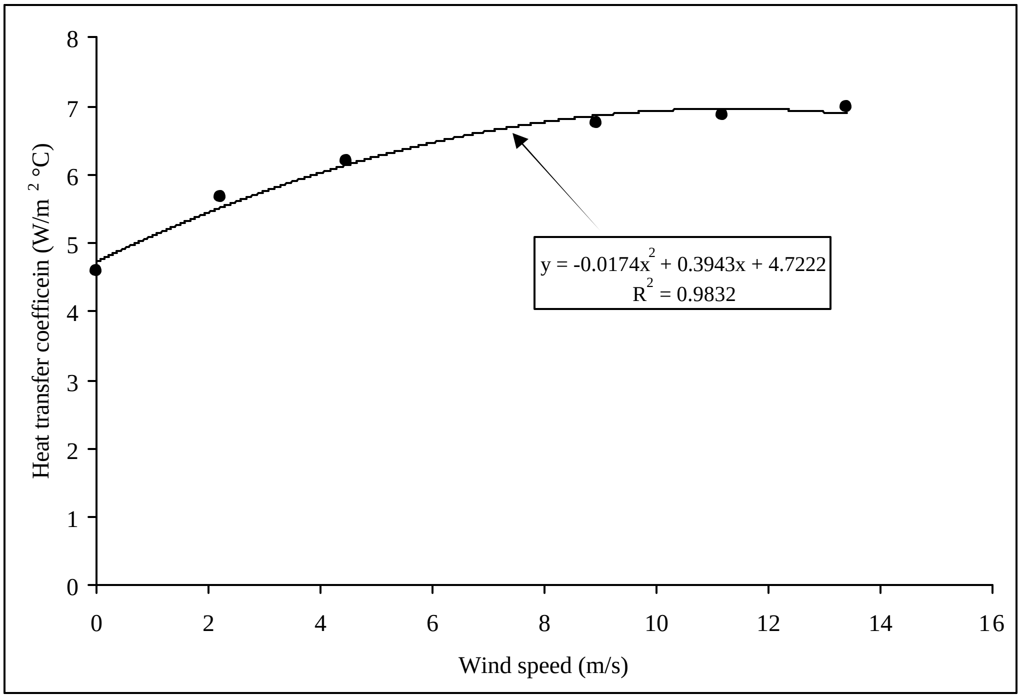

Figure A.2 Heat transfer coefficient for singlepoly as function of wind speed.

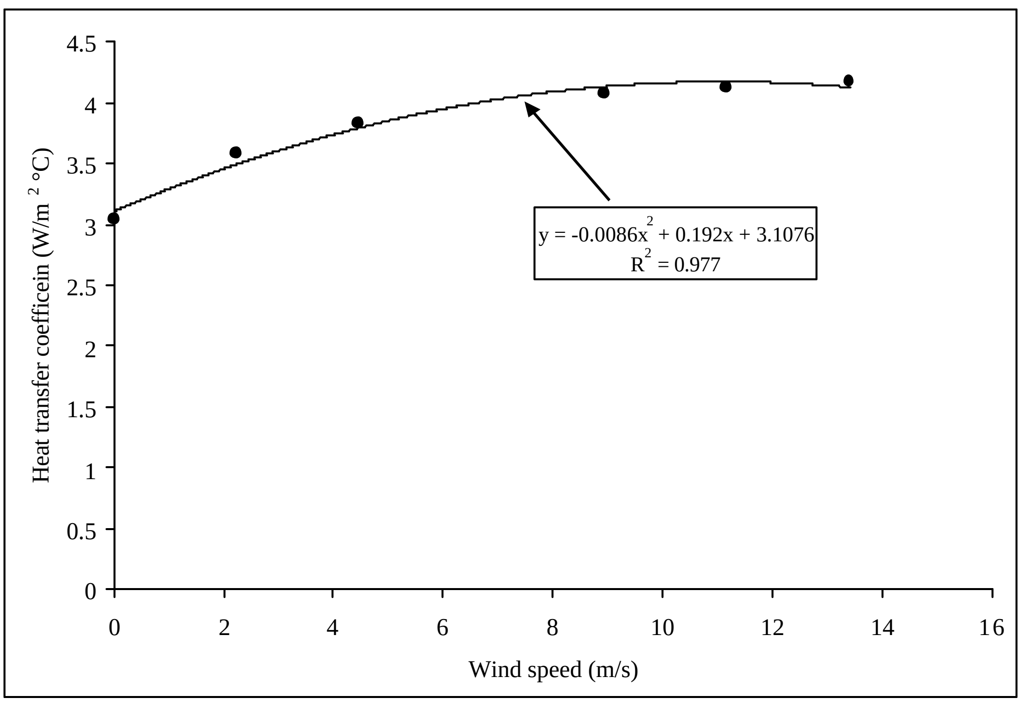

Figure A.3 Heat transfer coefficient for doublepoly as function of wind speed.

APPENDIX B

DAILY MEAN TEMPERATURE CHANGES AT KURSUNLU IN 2002

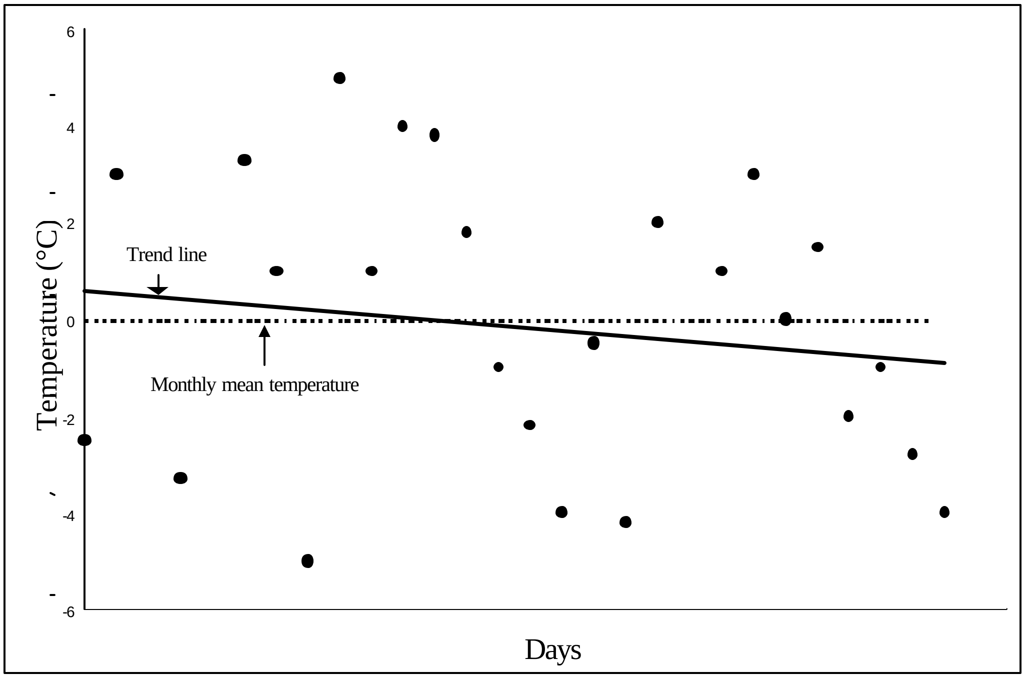

Figure B.1 Daily mean temperature changes at Kursunlu in February 2002.

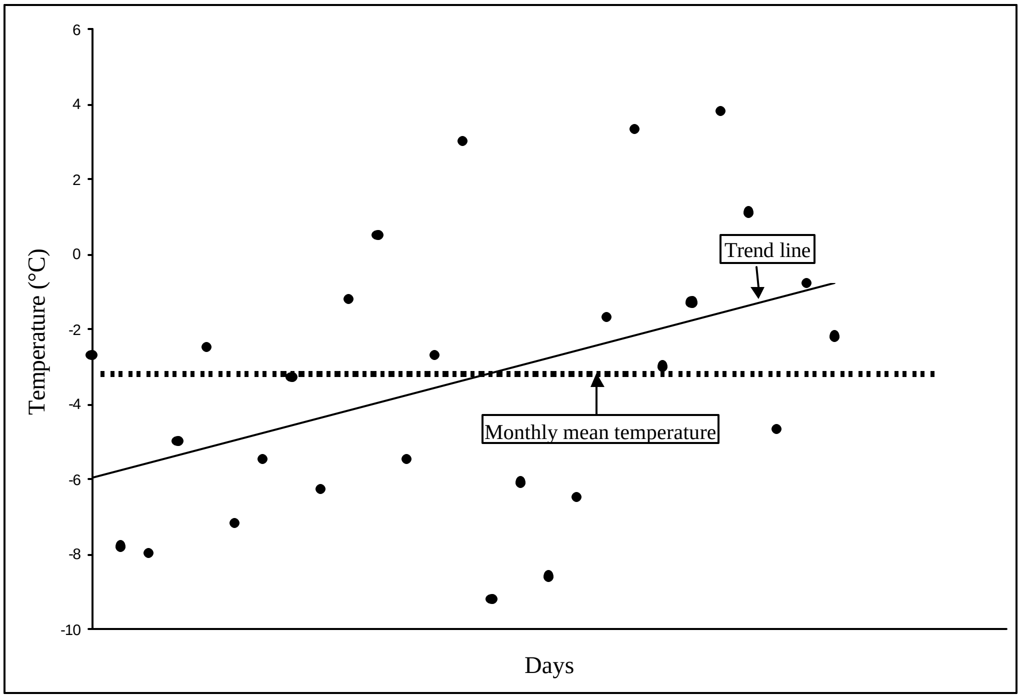

Figure B.2 Daily mean temperature changes at Kursunlu in March 2002.

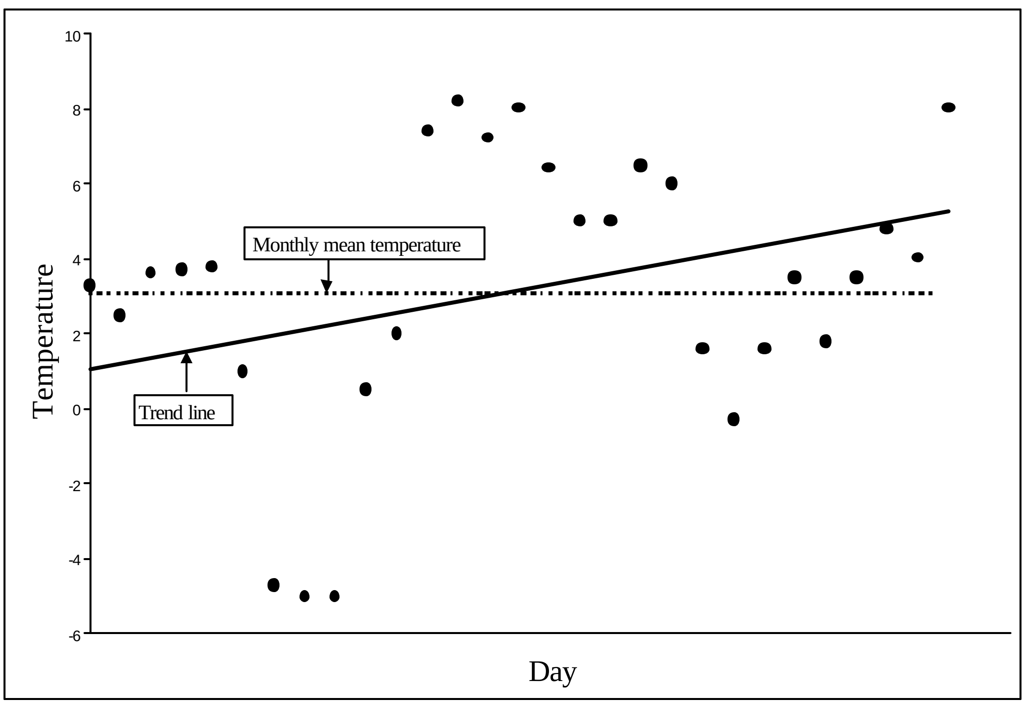

Figure B.3 Daily mean temperature changes at Kursunlu in April 2002.

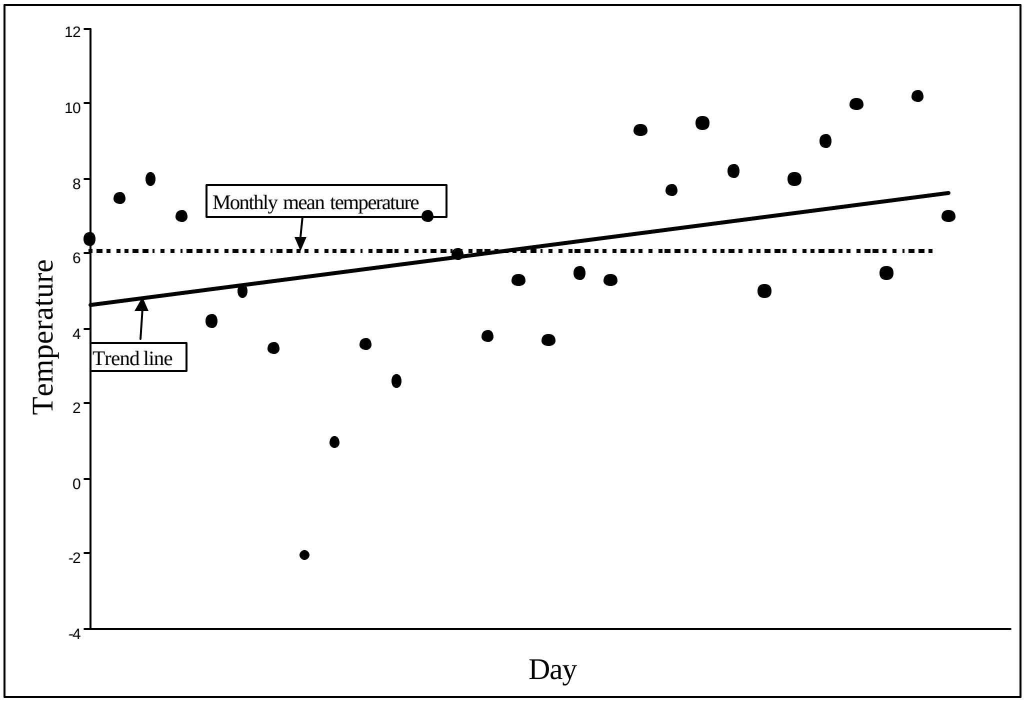

Figure B.4 Daily mean temperature changes at Kursunlu in May 2002.

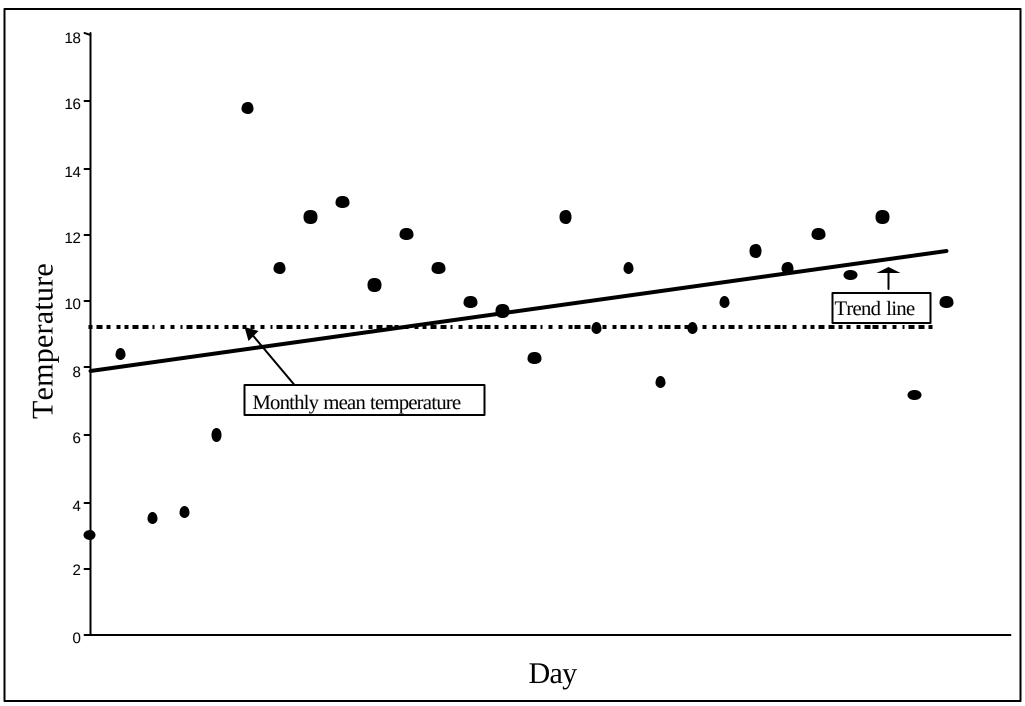

Figure B.5 Daily mean temperature changes at Kursunlu in June 2002.

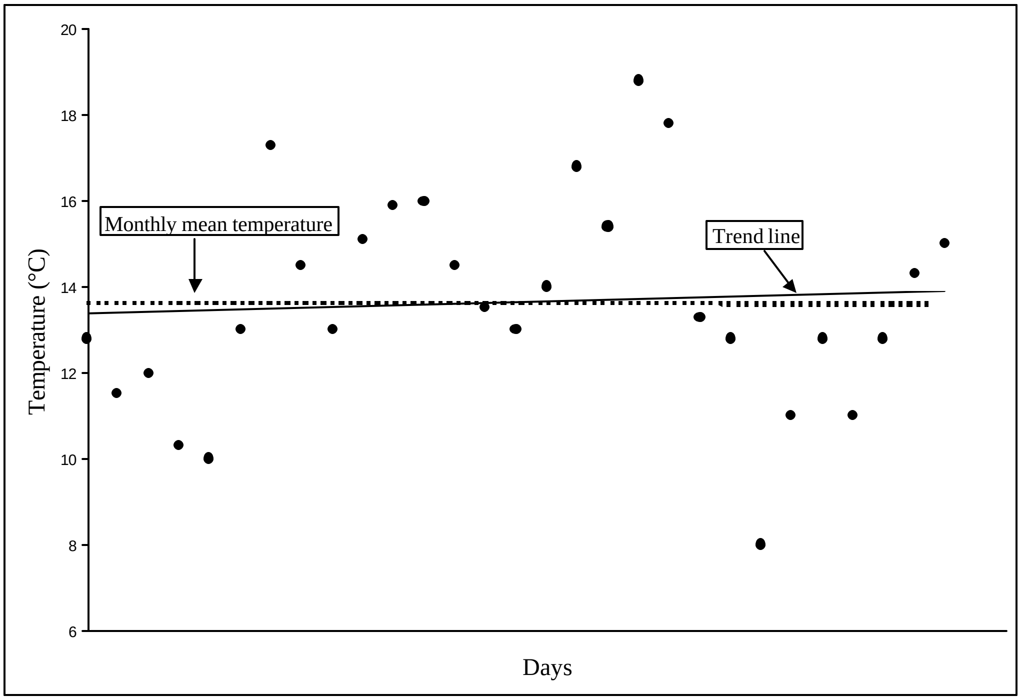

Figure B.6 Daily mean temperature changes at Kursunlu in July 2002.

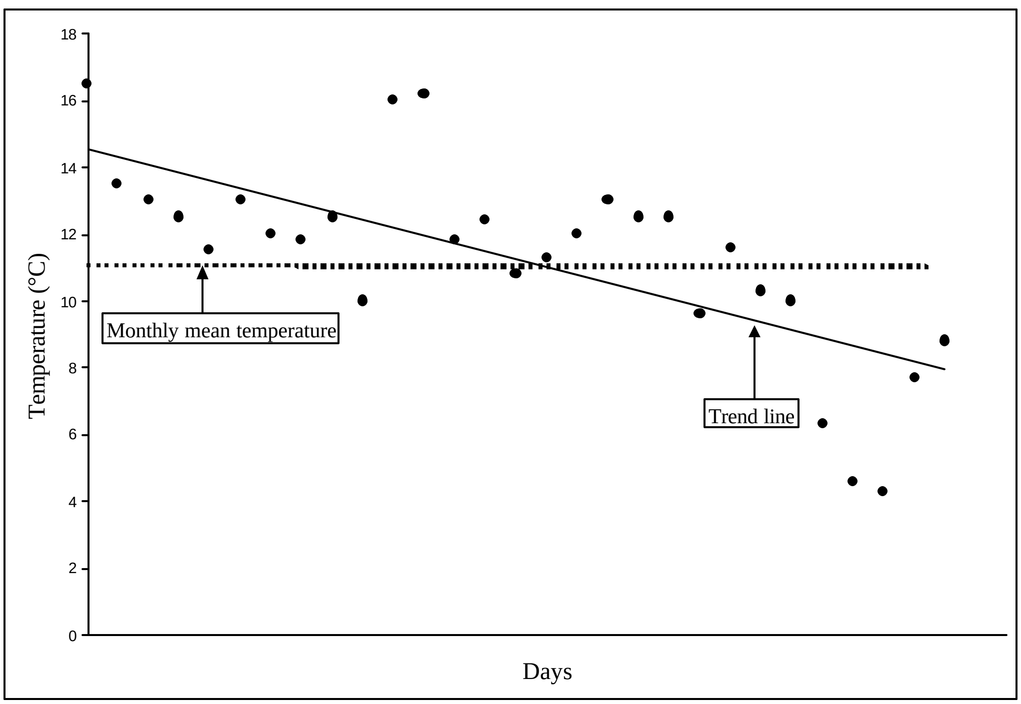

Figure B.7 Daily mean temperature changes at Kursunlu in August 2002.

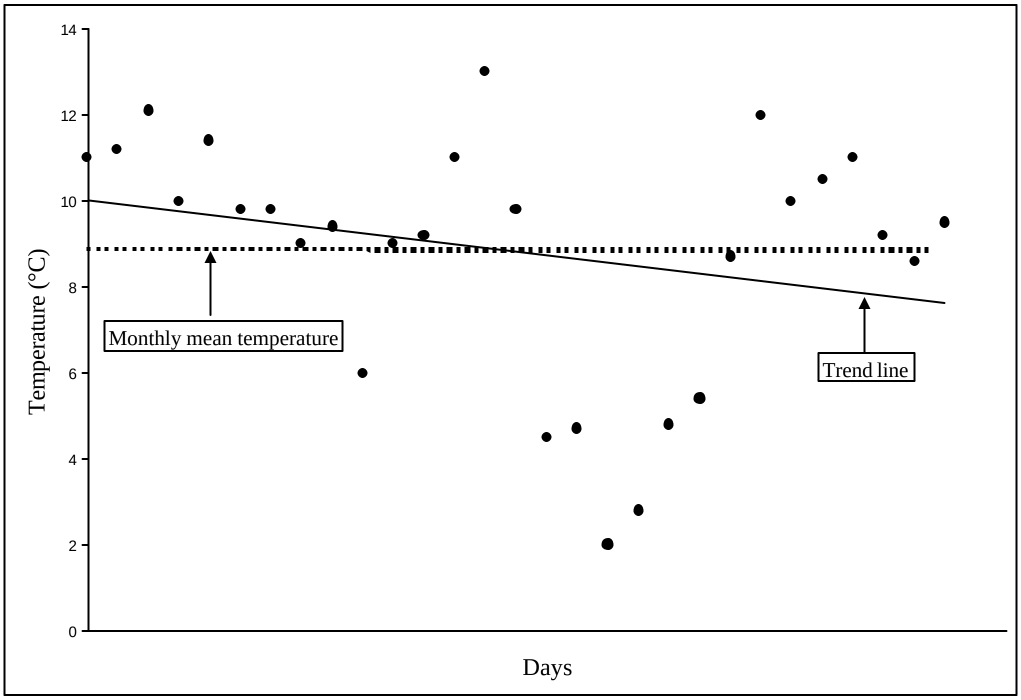

Figure B.8 Daily mean temperature changes at Kursunlu in September 2002.

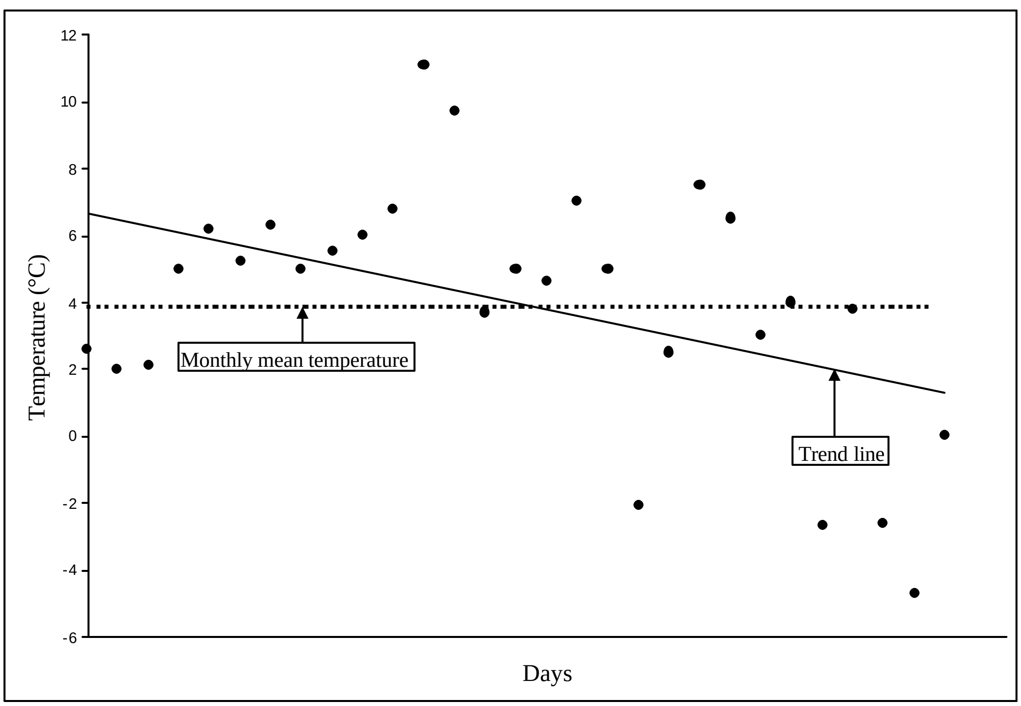

Figure B.9 Daily mean temperature changes at Kursunlu in October 2002.

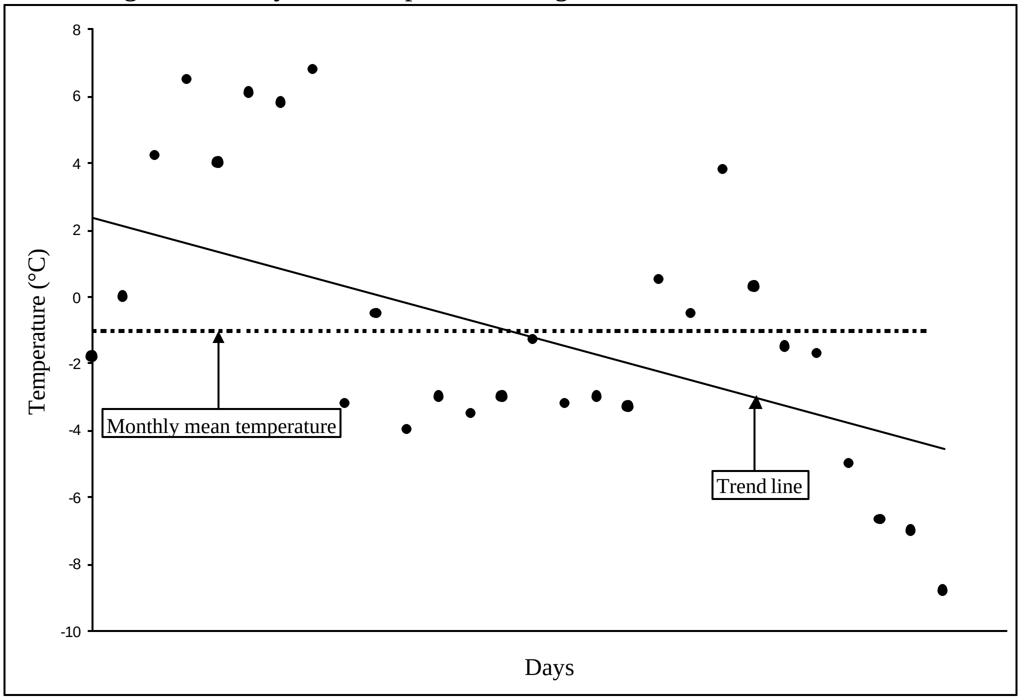

Figure B.10 Daily mean temperature changes at Kursunlu in November 2002.

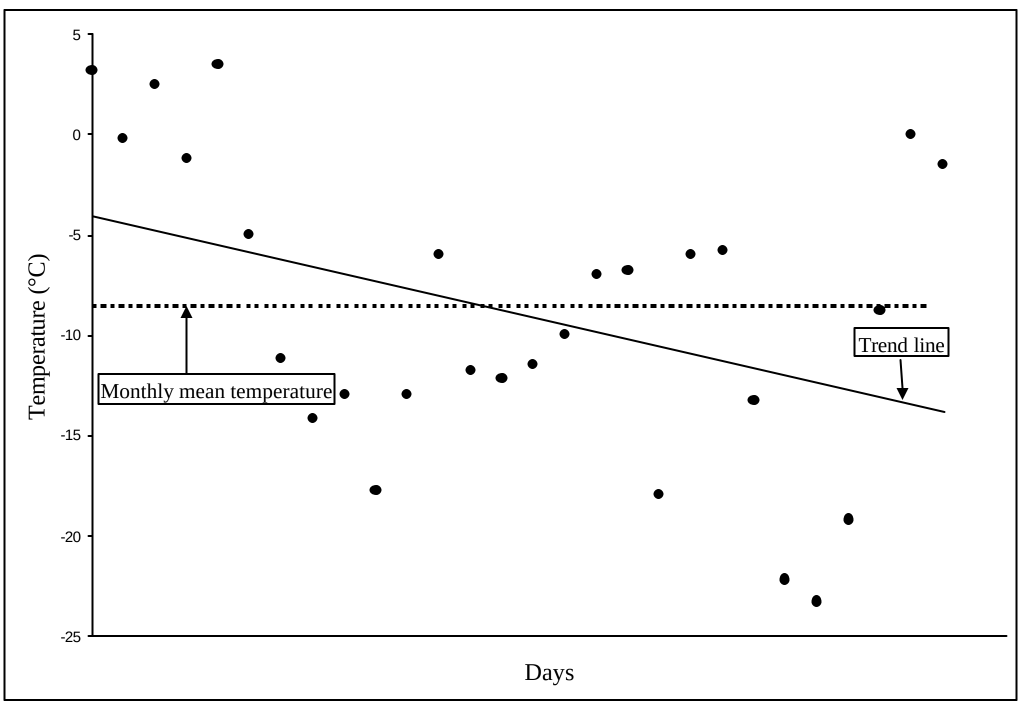

Figure B.11 Daily mean temperature changes at Kursunlu in December 2002.

APPENDIX C

MONTHLY PEAK-HEAT REQUIREMENTS

Table C.1 Monthly peak-heat requirements for glass greenhouses as function of indoor design temperature.

Month	U(W/m^2 °C)	12 °C	17 °C	22 °C
January	5.96	72343	88785	105226
February	5.96	49325	65767	82208
March	5.96	39460	55902	72343
April	5.76	28956	45042	61129
May	5.76	19304	35390	51477
June	5.96	9865	26307	42748
July	5.96	0	0	0
August	5.61	3162	18973	34784
September	5.61	9487	25298	41109
October	5.76	25738	41825	57911
November	5.76	41825	57911	73998
December	6.47	69577	86971	104365
ANNUAL TOTAL HEAT REQUIREMENT (W)		369042	**548170**	**727299**

Table C.2 Monthly peak-heat requirements for fiberglass greenhouses as function of indoor design temperature.

Month	U(W/m^2 °C)	12 °C	17 °C	22 °C
January	5.42	63941	78473	93005
February	5.42	43596	58128	72660
March	5.42	34877	49409	63941
April	5.24	25577	39786	53995
May	5.24	17051	31260	45470
June	5.42	8719	23251	37783
July	5.42	0	0	0
August	5.10	2792	16752	30711
September	5.10	8376	22335	36295
October	5.24	22735	36944	51153
November	5.24	36944	51153	65363
December	5.89	61620	77025	92430
ANNUAL TOTAL HEAT REQUIREMENT (W)		**326227**	**484516**	**642806**

Table C.3 Monthly peak-heat requirements for singlepoly greenhouses as function of indoor design temperature.

Month	U (W/m^2 °C)	12 °C	17 °C	22 °C
January	6.24	56481	69317	82154
February	6.24	38510	51346	64183
March	6.24	30808	43644	56481
April	6.04	22459	34937	47414
May	6.04	14973	27450	39928
June	6.24	7702	20539	33375
July	6.24	0	0	0
August	5.89	2440	14639	26837
September	5.89	7319	19518	31717
October	6.04	19964	32441	44919
November	6.04	32441	44919	57396
December	6.76	55180	68975	82770
ANNUAL TOTAL HEAT REQUIREMENT (W)		**288227**	**427726**	**567175**

Table C.4 Monthly peak-heat requirements for doublepoly greenhouses as function of indoor design temperature.

Month	U(W/m^2 °C)	12 °C	17 °C	22 °C
January	3.84	35097	43074	51051
February	3.84	23930	31907	39883
March	3.84	19144	27121	35097
April	3.75	14046	21850	29654
May	3.75	9364	17168	24971
June	3.84	4786	12763	20739
July	3.84	0	0	0
August	3.68	1534	9203	16872
September	3.68	4601	12270	19939
October	3.75	12486	20289	28093
November	3.75	20289	28093	35896
December	4.09	33737	42171	50605
ANNUAL TOTAL HEAT REQUIREMENT (W)		**179015**	**265908**	**352801**

APPENDIX D

PIPE LENGTHS AND NUMBER OF PIPES AT SOIL HEATING SYSTEM AND BARE TUBE SYSTEM

Table D.1 Heat Loads for different glazing materials (W)
(indoor design temperature=17 °C)

Peak Load%	100	90	80	70	60
GLASS	88785	79906	71028	62149	53271
FIBERGLASS	78473	70625	62778	54931	47084
SINGLE POLY	69317	62386	55454	48522	41590
DOUBLEPOLY	43074	38767	34459	30152	25844

Table D.2 Pipe lengths of soil-heated greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=17 °C)

Peak Load%	100	90	80	70	60
GLASS	2075	1867	1660	1452	1245
FIBERGLASS	1834	1650	1467	1284	1100
SINGLE POLY	1620	1458	1296	1134	972
DOUBLEPOLY	1006	906	805	705	604

Table D.3 Number of pipes of soil heated greenhouses for different glazing materials at different heat loads (indoor design temperature=17 °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

Table D.4 Pipe lengths of bare tube system greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=17 °C)

Peak Load%	100	90	80	70	60
GLASS	2328	2095	1862	1630	1397
FIBERGLASS	2058	1852	1646	1440	1235
SINGLE POLY	1817	1636	1454	1272	1090
DOUBLEPOLY	1129	1016	904	791	678

Table D.5 Number of pipes used at bare tube system greenhouses for different glazing materials at different heat loads (indoor design temperature=17 °C)

Peak Load%	100	90	80	70	60
GLASS	65	58	52	45	39
FIBERGLASS	57	51	46	40	34
SINGLE POLY	50	45	40	35	30
DOUBLEPOLY	31	28	25	22	19

Table D.6 Heat loads for different glazing materials (W) (indoor design temperature=22 °C)

Peak Load%	100	90	80	70	60
GLASS	105226	94704	84181	73659	63136
FIBERGLASS	93005	83704	74404	65103	55803
SINGLE POLY	82154	73939	65723	57508	49292
DOUBLEPOLY	51051	45946	40841	35736	30631

Table D.7 Pipe lengths of soil-heated greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=22 °C)

Peak Load%	100	90	80	70	60
GLASS	2459	2213	1967	1721	1475
FIBERGLASS	2173	1956	1739	1521	1304
SINGLE POLY	1920	1728	1536	1344	1152
DOUBLEPOLY	1193	1074	954	835	716

Table D.8 Number of pipes of soil heated greenhouses for different glazing materials at different heat loads (indoor design temperature=22 °C)

Peak Load%	100	90	80	70	60
GLASS	68	61	55	48	41
FIBERGLASS	60	54	48	42	36
SINGLE POLY	53	48	43	37	32
DOUBLEPOLY	33	30	27	23	20

Table D.9 Pipe lengths of bare tube system greenhouses for different glazing materials at different heat loads (m) (indoor design temperature=22 °C)

Peak Load%	100	90	80	70	60
GLASS	2759	2483	2207	1931	1655
FIBERGLASS	2439	2195	1951	1707	1463
SINGLE POLY	2154	1939	1723	1508	1292
DOUBLEPOLY	1339	1205	1071	937	803

Table D.10 Number of pipes used at bare tube system greenhouses for different glazing materials at different heat loads (indoor design temperature=22 °C)

Peak Load%	**100**	**90**	**80**	**70**	**60**
GLASS	77	69	61	54	46
FIBERGLASS	68	61	54	47	41
SINGLE POLY	60	54	48	42	36
DOUBLEPOLY	37	33	30	26	22