The Effect of Fossil Fuel and Renewable Energy on Heat Requirement of Plastic and Polycarbonate Greenhouses

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Abstract: Greenhouse have to provide optimal climate conditions for healthy plant growth and high production. Heating of greenhouses is required for an efficient and reliable production specially during winter time in Turkey. However, even in the temperate zones, heating costs has a great portion in the total production costs. Coal is preferred as a fuel in the greenhouse heating in provinces of Turkey where there is no geothermal energy. In this study, the heating requirements and fuel cost (fossil and geothermal energy) for Antalya, Afyon, Kütahya, Denizli, and Aydın provinces in the Aegean and Mediterranean region have been identified based on long term meteorological data. The calculations were made for two model greenhouses located in an area with 1 ha representing modern greenhouses of the regions. The first is a gothic roofed plastic model greenhouse and the second is a gable roofed polycarbonate model greenhouse. According to the results of calculations, total annual heatingrequirement values ranged from 6,096,283 (for Antalya) to 20,359,946 MJ/ha (for Afyon) for the plastic greenhouse wheras these values ranged from 3,187,074 (for Antalya) to 10,643,972 MJ/ha (for Afyon) for the polycarbonate greenhouse.

Keywords: Polycarbonate; plastic; greenhouse; heating requirement; geothermal energy; Turkey

1. Introduction

Greenhouses are used in order to create a more favorable environment that is essential for plant growth and productivity. The growth factors (light, temperature, humidity and air composition) should be delivered and maintained at optimal levels [1]. Greenhouses must be heated in order to achieve these optimum conditions especially in cold seasons. Heating of a greenhouse is an essential requirement for proper growth and development of winter growing crops. However, heating costs have a large share (40%-60%) in total production expenditure, even in temperate climate regions [2,3]. Reducing this share will increase the operating profit in the greenhouse sector, which constitutes an important potential in agriculture, and will contribute greatly to the economy of the countries. Therefore, it is important to use renewable energy sources in greenhouses in order to minimize both greenhouse heating expenditures and the use of increasingly depleted fossil energy resources.

The world primary energy consumption is about 400 EJ/year, mostly provided by fossil fuels (80%). The renewables collectively provide 14% of the primary energy, in the form of traditional biomass (10%), large (>10 MW) hydropower stations (2%), and the "new renewables" (2%). Nuclear energy provides 6% [4]. Turkey's primary-energy sources are hard coal, lignite, asphalt, bituminous schist, hydropower, oil, natural gas, geothermal and solar energy, wood, as well as animal and plant wastes. Although Turkey has energy resources, these are limited. More than half (52%) of the net energy consumption in the country is met by imports, and the share of imports continues to increase each year. However, the level of energy production in Turkey is very low [5]. Coal is a major fuel source for Turkey, used primarily for power generation, steel manufacturing, cement production, and greenhouse heating. Turkish coal consumption has remained roughly stable over the past decade and currently accounts for about 24% of the country's total energy consumption [6,7]. On the other hand, Turkey has very limited oil and natural gas resources. Because the

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consumption of oil and natural gas is significantly higher than the reserves, the import of these two energy inputs is increasing year by year. Turkey has substantial reserves of renewable energy resources. These resources represented about 12.7% of total primary energy consumption. Renewable resources are the second-largest domestic energy source after coal. In Turkey, main renewable energy resources are hydro, biomass, wind, geothermal, and solar [8]. Turkey is the seventh richest country in the world in geothermal energy potential [9]. The overall geothermal potential of Turkey is about 38,000 MW. Around 88% of this potential is appropriate for thermal use (low enthalpy fields with temperature less than 200 ºC) and the remainder for electricity production (high enthalpy fields with temperature more than 200 ºC). Only 7.2% of the low enthalpy fields and 4.4% of the high enthalpy fields are proven, and the remainder is probable and possible reserve [10]. The main uses of geothermal energy are space heating and domestic hot water supply, greenhouse heating, industrial processes, heat pumps and electricity generation [9]. Most of the development has been in district heating, which now serves 103,000 residences (827 MWt and 7712.7 TJ/year), and in individual space heating (74 MWt and 816.8 TJ/year). A total of 800,000 m^2 of greenhouses are heated by geothermal fluids (192 MWt and 3633 TJ/year). Geothermally heated pools used for bathing and swimming account for a capacity of 402 MWt and utilize 12,677.4 TJ/year. Geothermal heat is used in 54 combined space heating and spa installations, and at 215 balneological facilities. About 120,000 tonnes of liquid carbon dioxide and dry ice are produced annually at the Kizildere power plant [11].

Sustainability of greenhouses can be achieved by increasing energy efficiency. However, the improvement of energy efficiency is possible by using renewable energy sources that don't produce waste instead of using fossil energy resources that contribute to global warming by increasing the greenhouse effect [12]. Clean, domestic, and renewable energy is commonly accepted as the key for future life, not only for Turkey but also for the world [10]. When heating is done in modern greenhouses to be established in the regions where geothermal resources are available, high quality high efficiency can be achieved all year [12].

Gourdo et al. [13] have studied a solar energy storing rock-bed system to heat the ambient air inside a canarian type greenhouse. The results showed that the rock-bed system increased the greenhouse air temperature during the night by 3 ºC compared to the conventional greenhouse, and 4.7 ºC compared to the outside. Hassanien et al. [14] analyzed the integration of an evacuated tube solar collector (ETC) with an electric heat pump for greenhouse heating in Kunming, China. It was concluded that the ETC could increase the internal air temperature in the heated greenhouse by 2 ºC-3 ºC and decrease the relative humidity by 10% compared to the unheated and provide more than 35% of the annual required heat for heating the greenhouse and maintain the nocturnal temperature at 14°C inside the greenhouse. Bazgaou et al. [15] investigated the thermal performance of a rock-bed heating active systems to heat a canarian greenhouse during winter period in order to improve the climatic conditions and to increase the production. This heating system improved the greenhouse microclimate during the nocturnal and winter periods with an increase of the inside air temperature of the greenhouse by 2.6 ºC and reduction of its relative humidity by 10%. This improvement had a very positive impact on plants development and tomato yield which is improved by 29%. Canakci et al. [7] reported the heating requirements of the greenhouses in a Mediterranean basin by using monthly average meteorological data. The calculation of the annual heating requirement for plastic model greenhouse (approximately 1 ha) and coal heated in Turkey was between 3,592,848 and 10,459,688 MJ/ha and coal costs were between 37,412 and 108,916 $/ha. Kasap and Erdem [16] realized a study to compare different heating systems with a geothermal one in Tokat Province, Turkey. It was concluded that the heating system powered by geothermal energy was more economical in both glass and plastic houses.

Located in the Mediterranean countries zone, Turkey is a prominent center of greenhouse cultivation. The Mediterranean, Aegean and Marmara regions are the areas where greenhouse cultivation is common in Turkey. About 87% of the greenhouse production area in Turkey is concentrated in the Mediterranean region [17]. The majority of the greenhouses in the Mediterranean region are located in city of Antalya. In recent years, greenhouse cultivation has started to develop in the internal regions (such as Denizli, Aydın, Manisa, İzmir, Kütahya, Afyon, Balıkesir and Urfa) with the use of geothermal energy from alternative energy sources. According to statistics of 2018, the total greenhouse area in Turkey is 44,700 ha of which 7800 ha is covered glass and 36,900 ha covered plastic. Today, the annual export value of greenhouse vegetables has reached 453 million $ [18,19,20,21,22].

Greenhouse vegetable production in the Turkey is performed widely in the farmer greenhouses by traditional methods. Due to the high costs of fossil fuels used in greenhouse heating, the heating operation is done only to protect plants from frost hazards and the traditional wood stoves are used fuel for this purpose [23,24]. However, adequate levels of the heating process affect the production quality and can increase yield by 50-60%. The geothermal energy is more economical to provide the necessary temperature values for plant development in greenhouses. In addition, the humidity inside the greenhouse is kept under control and thus the spread of disease can be prevented [25]. In Turkey, the production in farmer greenhouses can be done as single crop cultivation per year as well as double crop cultivation in autumn and spring periods. Depending on the production period, an average yield of 150,000 kg/ha (tomato) can be taken from these greenhouses. On the other hand, changes consumer demand and enviromentally conscious manufacturing have brought up food production tecniques highlighting the food security and related certification processes (Good Agricultural Practice-GAP). Therefore, after 2000s, climate-controlled modern greenhouse aplications obtaining higher quality products and food security has been widespread applications [23,26]. Modern greenhouse is an industrial application that combines technologies from different disciplines such as agriculture, biosystem, construction, machinery, electrical-electronics and computer engineering [27]. According to the data of the year 2010, a total area of modern greenhouses is 391.2 ha of which 227.0 ha is located in Antalya province. In recent years, greenhouses have been developing rapidly in our internal regions thanks to the cheap heating provided by geothermal energy. Production in modern greenhouses is applied usually as single crop cultivation per year (commonly tomato). The yield in these greenhouses varies between 350,000-450,000 kg/ha. When greenhouse indoor conditions are better achieved, this yield increases to even higher values. For example, suitable temperature values can not be provided for plant requests due to the heating costs in modern greenhouses on the Antalya coastline at cold nights. Accordingly, the yield is observed decline in greenhouses. Thus, it can be said that the heating of modern greenhouses with geothermal energy is cost-effective compared to fossil fuels and this situation affects the efficiency of production.

Heating costs are one of the most important factors affecting the profitability of the greenhouse in the temperate climate zone (Mediterranean coastline, Italy, Spain, Turkey etc.). In these countries, greenhouse cultivation is carried out depending on ecological conditions. As the heating costs by conventional energy sources (coal, oil, and natural gas) is too high, the use of renewable energy technologies and systems to heat the greenhouses have gained much attention in recent years. In this research, the heating requirements and costs (coal and geothermal energy heated) for a model modern plastic and polycarbonate greenhouse were determined by considering the meteorological data for five provinces located in the Mediterranean and Aegean region in Turkey.

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2. Materials and Methods

2.1. Research region

Turkey is situated on the Alpine-Himalayan orogenic belt and the Miocene or younger grabens are developed as the result of this orogeny. Wide spread volcanism, fumarole hydrothermal alterations and the existence of more than 600 hot springs, some of which have 100°C and greater temperatures, indicate that Turkey has an important geothermal energy potential [10]. Geothermal fields in Turkey are concentrated mostly in the Marmara, Aegean and inner western parts of Anatolia [28]. The most important region within these regions for geothermal potential is Aegean region, covering almost 78% of total geothermal fields [29]. Aegean region has a rich potential in terms of geothermal energy and takes first place in geothermal greenhouse [24].

Geothermal systems in Western Anatolia have generally high temperatures and take place in grabens due to opening tectonics. Geothermal fields in this region are among the high temperature fields, such as Denizli-Kızıldere geothermal field (242 ºC), Aydın-Germencik geothermal field (232 ºC), Aydın-Salavatlı geothermal field (171 ºC), Aydın-Yılmazköy-İmamköy geothermal field (142 ºC), Manisa-Salihli Caferbeyli field (155 ºC), Manisa-Salihli-Kurşunlu field (96 ºC), Manisa-Alaşehir-Kavaklıdere field (116 ºC), Manisa-Turgutlu-Urganlı field (86ºC), Kütahya-Simav geothermal field (162 ºC), Kütahya-Gediz-Abide geothermal field (97 ºC), İzmir-Seferihisar field (153 ºC), İzmir-Balcova field (130 ºC), İzmir-Dikili field (130 ºC), and İzmir-Aliağa field (96 ºC). There are also low and middle enthalpy geothermal fields in Afyonkarahisar, Manisa, Pamukkale and İzmir provinces. Afyonkarahisar, Manisa, Pamukkale and İzmir provinces have also low and medium enthalpy geothermal fields.

Heating of greenhouses using geothermal fluids has become very popular in Turkey in recent years. Most of these greenhouses are in Western Anatolia. The ones in operation cover more than 13 ha and some 6 ha of new greenhouses are in the planning stage and may be built in the near future. The greenhouses are geothermally heated between 1500 and 2000 h per year; tomatoes and peppers (California Wonders) are the main crops [30]. According to statistics of 2015, total greenhouse area by using geothermal resources in Turkey is 3858.9 acres in 15 provinces. The majority of the greenhouses in these provinces are located in İzmir (21.2%), Manisa (16.2%), Afyonkarahisar (15.8%) and Denizli (13.3%) [31].

Geographic location of research area is shown in Figure 1. Except for the province of Antalya, other selected provinces are geothermal resources.

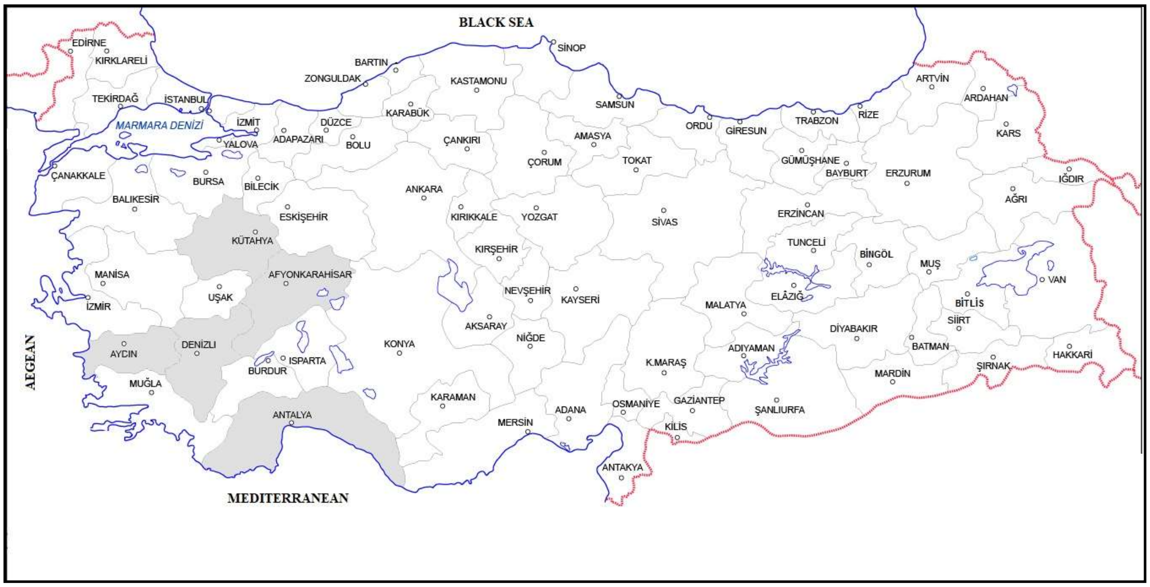


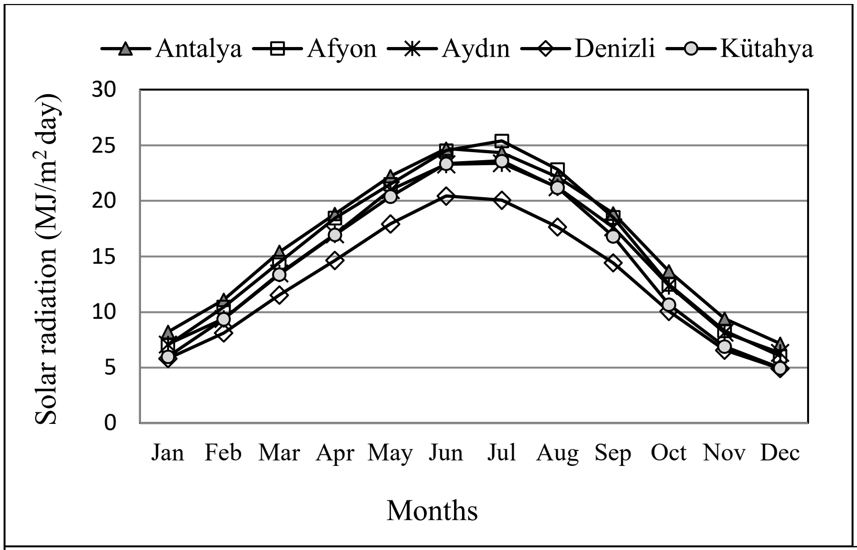
Figure 1. Locations of study areas.

Protected cultivation areas of the selected provinces and also of Turkey's total are given in Table 1. As seen in this table, the majority of the greenhouses in the Turkey are located in city of Antalya [20,22]. In the selected regions, greenhouse farming generally starts in the months of August or September depends on the crop and the method of growing continues until the end of June [7].

Table 1. Protected cultivation area in Aegean and Mediterranean Region in Turkey.

Province	Glasshouse		Plastichouse		Total area	
	ha	%	ha	%	ha	%
Antalya	6358.4	81.4	19,344.3	52.5	25,702.8	57.5
Afyon	9,5	0.1	101.4	0.3	110.9	0.2
Aydın	14.2	0,2	90.3	0.2	104.5	0.2
Denizli	0.6	-	138.6	0.4	139.2	0.4
Kütahya	0.5	-	46.6	0.1	47.1	0,1
Total	6383.2	81.7	19,721.1	53.5	26,104.5	58.4
Others	1427.8	18.3	17,131.6	46.5	18,559.4	41.6
Turkey	7811.0	100.0	36,852.7	100.0	44,663.9	100.0

Climate data on average, maximum and minimum temperatures, solar radiation intensity and and sun exposure duration were gathered from long-term averages of the selected regions recorded by General Directorate of Meteorology [32]. Climate data for study area were given in Table 2 and Figure 2.



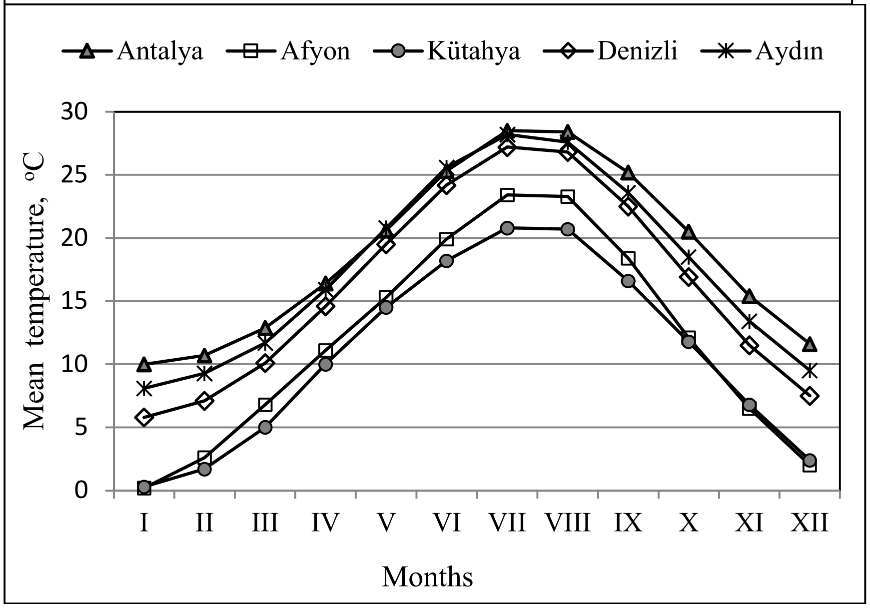


Figure 2. Mean temperature values and solar radiation values for the selected provinces (1929-2018).

Table 2. Some climate data for long-term averages of selected provinces (1929-2018).

Province	Mean temperature (°C)	Mean high temperature (°C)	Mean Low temperature (°C)	Daily shiny (h)
Antalya	18.8	35.7	4.2	8.4
Afyon	11.8	29.3	-8.1	6.8
Aydın	17.7	35.8	1.3	7.0
Denizli	16.1	34.8	-0.4	7.4
Kütahya	10.7	30.1	-10.7	6.0

2.2. Model greenhouses

In this study, considering the conditions of the region and farm properties a typical plastic greenhouse and polycarbonate greenhouse has been identified and used as material.
Plastic greenhouse: The geometrical characteristics of this greenhouse are as follows: side height of 4.5 m; ridge height of 6.5 m, width of 9.6 m, length of 104.2 m, 10 tunnels. The frame of the greenhouse was made of steel. The model greenhouse has gothic roof, total area of 10,003 m^2, cover surface area of 13,055 m^2. Its covering material is single-layer polyethylene film [7].
Polycarbonate (PC) greenhouse: The geometrical characteristics of PC greenhouse are as follows: side height of 4.5 m; ridge height of 7.5 m, width of 12.0 m, length of 104.2 m, 8 tunnels. The frame of the greenhouse was made of steel. The model greenhouse has saddle roof, total area of 10,003 m^2, cover surface area of 13,260 m^2. Its covering material is double-layer PC film.

2.3. Calculations

Heat and fuel requirements of the model greenhouse were calculated in this study. The desired amount of heat requirements to ensure the ambient inside temperature of the greenhouse was calculated with the help of following equation:

$$Q = Q_K - Q_G \tag{1}$$

where, Q is the total heat requirement (W), Q_K is the amount of heat loss from the greenhouse (W), Q_G is the amount of incoming solar radiation inside the greenhouse (W).

The amount of incoming solar radiation can be determined with the following equation:

$$Q_G = I_o \times A_r \times \eta_s \tag{2}$$

where, I_o is the average daily solar radiation intensity (W/m^2), A_r is the roof area (m^2), η_s is the conversion ratio of solar energy to beneficial energy for greenhouse heating during the day (decimal) and this value is accepted as 0.5 [33,34].

The values related to temperature, solar radiation intensity and sun exposure duration obtained from the records of the State Meteorology Affairs General Directorate were taken as the average of years in the study. Calculations were made by taking into account the average temperature values at night time and daytime depending on the sun exposure.

The amount of heat energy lost from the greenhouse was calculated with the help of following equation [21,33,35]:

$$Q_K = \Sigma A_o U (T_i - T_d) \tag{3}$$

where, ΣA_o is total cover surface area (m^2), U is overall heat transfer coefficient ($W/m^{2\,o}K$), T_i is greenhouse internal ambient temperature (ºC), T_d is greenhouse outdoor temperature (ºC). The night and day ambient temperatures for the model greenhouse in the calculations was taken 16 °C and 21 °C which are accepted as the favorable inside temperature (ti) in greenhouse vegetable growing [2]. The total value related to coefficient (*U*) of heat transmission in the greenhouse depends on various factors such as the size of the greenhouse, the type of the cover material and heaters, and wind speed. Therefore, it is reported that it is not possible to determine the heat transfer coefficient completely and accurately under the application conditions, so, the coefficient values determined and proposed based on experience rather than detailed calculations were used for the application processes. In the calculations, the total heat transfer coefficient for the plastic and PC greenhouse was taken as a value of 6.8 W/m^2 K and 3.5 W/m^2 K, respectively [33,36,37].

Monthly heating requirement value (W/ha) was determined by take into consideration the values of heat loss (Q_k). The value was calculated with the help of following equation [35]. Also, annual heating requirement of the greenhouses can be found by collecting of the monthly values. Considering the calculations, it has beenidentified that heating is not necessary during the daytime since the average solar radiation meets the heat loss of the greenhouse. Therefore, heating calculations were done for the night time inwhich there is no solar radiation [7,19].

$$\Sigma Q_m = \Sigma A_o \times U \times (t_i - t_d) \times 3.6 \times HH_d \times DN_m \tag{4}$$

where, ΣQ_m is monthly heating requirement (kj), HH_d is daily heating hour (h/day) and DN_m is number of day per month (day/month).

Fuel (coal) requirement per month was determined with the help of the following equation [37]:

$$CR_m = \frac{\Sigma Q_m}{LHV \times \eta} \tag{5}$$

where, CR_m is the monthly coal requirement (kg), LHV is the low heat energy value of coal (kJ/kg), η is the efficiency of the heating system. The low heat energy value of coal and the efficiency of the heating system were considered as 28,010 kj/kg and 80%, respectively [38]. In addition, the price of fuel per unit was regarded \$310/ton and fuel costs were calculated with the help of the following equation:

$$CC_m = CR_m \times CP \tag{6}$$

where, CC_m is the coal cost per month (\$/month), CP is coal price per unit (\$/kg).

The required water flow for heating systems in the greenhouses that use geothermal energy can be determined by the following equation:

$$FFR_m = \frac{\Sigma Q_m}{\rho \times C_p \times \Delta T \times \eta} \times 3600 \tag{7}$$

where, FFR_m is the fluid flow rate for greenhouse heating system (m^3/h), ρ is the density of water (kg/m^3) (977.52 kg/m^3), C_p is the specific heat of water (kj/kg °C) (4.191 kj/kg °C), ΔT is is the average of the temperatures of the water exiting from and returning the furnace (°C) and η is the efficiency of the exchanger. In this study, the efficiency of the exchanger was considered as 85% [34]. It was also considered that temperature of the water coming out of the furnace was 80 °C and that of returning water was 60 °C in the calculations. In addition, the price of fluid flow per unit was regarded \$0.18/m^3 and fluid flow costs were calculated with the help of the following equation:

$$FFC_m = FFR_m \times FFP \tag{8}$$

where, FFC_m is the fluid flow cost per month (\$/month), FFP is fluid flow price per unit (\$/m^3).

3. Results

3.1. Heat operation

Average night temperature values in the research area during a year were given in Figure 3. Also, the value of 16 °C is accepted as the favorable inside temperature (t_i) in greenhouse vegetable growing was shown in the Figure 3.

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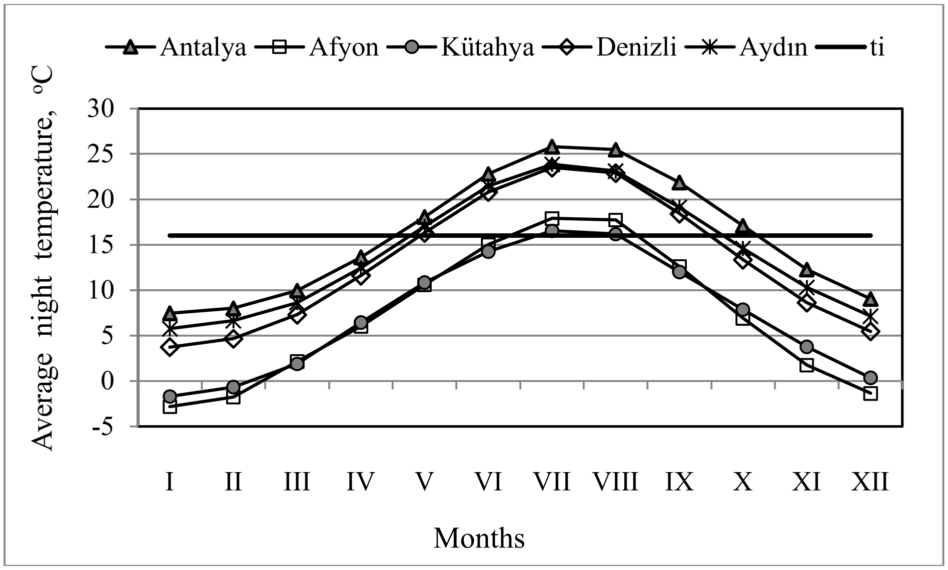

Figure 3. Average night temperature values for the selected provinces.

As seen in this figure, heating operations should be realized for the section below the straight line of 16ºC. For this reason, heating operation needs to be done in the period between November and April in the province of Antalya, October and April in the province of Denizli and Aydın when this operation needs to be done in the period between September and June in Afyon and Kütahya provinces. The highest night temperature values occur in the province of Antalya. The period required for the heating operation depends on both the temperature and the length of the solar radiation time. Total monthly heating time (hour) calculated for the operations in the specified period are given in Table 3.

Table 3. The average monthly heating time (h/month) for the selected provinces.

Months	Antalya	Afyon	Aydın	Denizli	Kütahya
Sep	-	532.2	-	-	578.7
Oct	-	560.0	516.7	516.7	600.0
Nov	510.0	640.7	565.0	570.0	671.7
Dec	589.0	651.0	609.7	625.2	661.3
Jan	578.7	555.3	614.8	614.8	569.3
Feb	490.0	578.7	536.7	536.7	589.0
Mar	511.5	515.0	552.8	558.0	530.0
Apr	475.0	485.7	510.0	510.0	496.0
May	-	420.0	-	-	430.0
Jun	-	440.0	-	-	475.0
Total (h/year)	3154.2	5378.5	3905.7	3931.3	5601.0

According to Table 3, the shortest heating period is required for the province of Antalya (3154,2 h/year) and the longest for Kütahya province (5601,0 h/year). It can be said that Afyon and Kütahya provinces have low night temperature values (Figure 3) and so needs heating operations three or four months more than the others (Denizli, Aydın, Antalya). High average night temperature values and long solar radiation time caused lower values in Antalya than the other provinces.

3.2. Heat requirement

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Total monthly heat requirements (MJ/ha) calculated for plastic and polycarbonate greenhouses are given in Table 4 and in Table 5.

Table 4. The values of the heat requirement (MJ/ha per month) for plastic greenhouse.

Months	Antalya	Afyon	Aydın	Denizli	Kütahya
Sep	-	478,101	-	-	607,214
Oct	-	1,547,666	231,167	434,815	1,504,130
Nov	608,493	2,547,317	1,023,209	1,341,943	2,345,764
Dec	1,311,380	3,555,796	1,727,592	2,104,505	3,355,781
Jan	1,578,103	3,911,354	2,010,772	2,410,306	3,740,951
Feb	1,252,779	3,153,174	1,600,773	1,943,796	3,032,520
Mar	986,260	2,558,254	1,301,528	1,551,464	2,654,133
Apr	359,268	1,640,384	581,328	717,152	1,614,764
May	-	838,147	-	-	813,710
June	-	129,752	-	-	238,198
Total	6,096,283	20,359,946	8,476,369	10,503,981	19,907,165

Table 5. The values of the heat requirement (MJ/ha per month) for polycarbonate greenhouse.

Months	Antalya	Afyon	Aydın	Denizli	Kütahya
Sep	-	249,946	-	-	317,445
Oct	-	809,104	120,852	227,317	786,344
Nov	318,114	1,331,711	534,923	701,554	1,226,342
Dec	685,576	1,858,934	903,167	1,100,214	1,754,368
Jan	825,016	2,044,816	1,051,211	1,260,084	1,955,731
Feb	654,940	1,648,447	836,868	1,016,196	1,585,370
Mar	515,606	1,337,429	680,426	811,090	1,387,554
Apr	187,822	857,576	303,912	374,920	844,182
May	-	438,175	-	-	425,399
June	-	67,833	-	-	124,528
Total	3,187,074	10,643,972	4,431,359	5,491,374	10,407,262

As seen in these tables, plastic greenhouse has the highest annual heating requirements, whereas polycarbonate greenhouse has the lowest annual heating requirements in all provinces in specified periods. The annual heating requirement ranged from 6,096,283 (for Antalya) to 20,359,946 MJ/ha (for Afyon) for the plastic greenhouse (Table 4). Similar results were also reported by other researchers [7,39].

The annual heating requirement ranged from 3,187,074 (for Antalya) to 10,643,972 MJ/ha (for Afyon) for the polycarbonate greenhouse (Table 5). It can be said that the polycarbonate greenhouse reduces heat requirement by 47.7%. January was determined as the month in which the heating requirements for two model greenhouses was the highest. This value ranged from 1,578,103 (for Antalya) to 3,911,354 (for Afyon) MJ/ha and from 825,016 (for Antalya) to 2,044,816 (for Afyon) MJ/ha for plastic and polycarbonate greenhouses, respectively.

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3.3. Fuel requirement and costs

Coal is widely used as a fuel in heating systems due to low price in Antalya province in the study area and this province has not geothermal energy [7,19]. The heating of modern greenhouses in Kütahya, Afyon, Aydın and Denizli provinces is provided by geothermal resources. The calculated findings related to fuel (coal and geothermal water) requirements and costs for plastic and polycarbonate greenhouses are presented in Table 6, 7, 8 and 9.

Table 6. The average coal requirement and costs per month for plastic greenhouse.

Months	Antalya		Afyon		Aydın		Denizli		Kütahya	
	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha
Sep	-	-	21.3	6625	-	-	-	-	27.1	8415
Oct	-	-	69.1	21,447	10.3	3203	19.4	6026	67.1	20,844
Nov	27.2	8432	113.7	35,300	45.7	14,179	59.9	18,596	104.7	32,507
Dec	58.5	18,173	158.7	49,276	77.1	23,941	93.9	29,164	149.8	46,504
Jan	70.4	21,869	174.6	54,203	89.7	27,865	107.6	33,402	166.9	51,841
Feb	55.9	17,361	140.7	43,696	71.4	22,183	86.7	26,937	135.3	42,024
Mar	44.0	13,667	114.2	35,452	58.1	18,036	69.2	21,500	118.4	36,781
Apr	16.0	4979	73.2	22,732	25.9	8056	32.0	9938	72.1	22,377
May	-	-	37.4	11,615	-	-	-	-	36.3	11,276
June	-	-	5.8	1798	-	-	-	-	10.6	3301
Annual	272.1	84,481	908.6	282,145	378.3	117,464	468.8	145,562	888.4	275,870

According to Table 6, the annual coal requirement values for plastic greenhouse ranged between 272.1 and 908.6 t/ha depending on the heat requirements and heatingh time. Afyon province has the highest coal costs in respect to coal prices per unit (282,145 $/ha) whereas Antalya (84,481 $/ha) has the lowest coal costs.

Table 7. The average coal requirement and costs per month for polycarbonate greenhouse.

Months	Antalya		Afyon		Aydın		Denizli		Kütahya	
	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha
Sep	-	-	11.2	3464	-	-	-	-	14.2	4399
Oct	-	-	36.1	11,212	5.4	1675	10.1	3150	35.1	10,897
Nov	14.2	4408	59.4	18,455	23.9	7413	31.3	9722	54.7	16,994
Dec	30.6	9501	83.0	25,761	40.3	12,516	49.1	15,247	78.3	24,312
Jan	36.8	11,433	91.3	28,337	46.9	14,568	56.2	17,462	87.3	27,102
Feb	29.2	9076	73.6	22,844	37.3	11,597	45.3	14,082	70.8	21,970
Mar	23.0	7145	59.7	18,534	30.4	9429	36.2	11,240	61.9	19,228
Apr	8.4	2603	38.3	11,884	13.6	4212	16.7	5196	37.7	11,699
May	-	-	19.6	6072	-	-	-	-	19.0	5895
June	-	-	3.0	940	-	-	-	-	5.6	1726
Annual	142.2	44,166	475.0	147,502	197.8	61,409	245.1	76,099	464.4	144,222

According to Table 7, the annual coal requirement values for polycarbonate greenhouse ranged between 142.2 and 475.0 t/ha depending on the heat requirements and heating time. Afyon province has the highest coal costs in respect to coal prices (147,502 $/ha). Kütahya (144,222 $/ha), Denizli (76,099 $/ha), Aydın (61,409 $/ha), Antalya (44,166 $/ha) provinces are followed by Afyon Province.

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Table 8. The average geothermal water requirement and costs per month for plastis greenhouse.

Months	Afyon		Aydın		Denizli		Kütahya	
	m^3/ha	$/ha	m^3/ha	$/ha	m^3/ha	$/ha	m^3/ha	$/ha
Sep	6865	1204	-	-	-	-	8719	1530
Oct	22.222	3899	3319	582	6243	1095	21.597	3789
Nov	36.576	6417	14.692	2577	19.268	3380	33.682	5909
Dec	51.056	8957	24.806	4352	30.217	5301	48.184	8453
Jan	56.161	9853	28.872	5065	34.608	6072	53.714	9424
Feb	45.275	7943	22.985	4032	27.910	4896	43.542	7639
Mar	36.733	6444	18.688	3279	22.277	3908	38.109	6686
Apr	23.553	4132	8347	1464	10.297	1807	23.186	4068
May	12.035	2111	-	-	-	-	11.684	2050
June	1863	327	-	-	-	-	3420	600
Annual	292.337	51,287	121.708	21,352	150.821	26,460	285.836	50,147

According to Table 8, the annual geothermal water requirement values for plastic greenhouse in Afyon, Kütahya, Denizli, and Aydın provinces ranged between 121.708 and 292.337 m^3/ha depending on the heat requirements and heating time. Antalya province have not geothermal energy so geothermal water requirement of the greenhouses in this region was not calculated. Afyon province has the highest geothermal water costs (51,287 $/ha) whereas Aydın (21,352 $/ha) has the lowest costs. It can be said that the geothermal energy reduces fuel costs of plastic greenhouse by 81.8% compared to coal costs (Table 6).

Table 9. The average geothermal water requirement and costs per month for polycarbonate greenhouse.

Months	Afyon		Aydın		Denizli		Kütahya	
	m^3/ha	$/ha	m^3/ha	$/ha	m^3/ha	$/ha	m^3/ha	$/ha
Sep	3589	630	-	-	-	-	4558	800
Oct	11.617	2038	1735	304	3264	573	11.291	1981
Nov	19.121	3355	7681	1347	10.073	1767	17.608	3089
Dec	26.691	4683	12.968	2275	15.797	2771	25.190	4419
Jan	29.360	5151	15.094	2648	18.093	3174	28.081	4927
Feb	23.669	4152	12.016	2108	14.591	2560	22.763	3994
Mar	19.203	3369	9770	1714	11.646	2043	19.923	3495
Apr	12.313	2160	4364	766	5383	944	12.121	2127
May	6292	1104	-	-	-	-	6108	1072
June	974	171	-	-	-	-	1788	314
Annual	152.831	26,812	63.627	11,163	78.848	13,833	149.432	26,216

According to Table 9, the annual geothermal water requirement values for polycarbonate greenhouse ranged between 63.627 and 152.831 m^3/ha depending on the heat requirements and heating time. It was observed that the annual geothermal water costs of polycarbonate greenhouse are between 11,163 and 26,812 $/ha. It can be said that the geothermal water costs were reduced by 47.7% compared to plastic greenhouse with geothermal energy (Table 8).

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In order to compare fuel requirement and cost in greenhouses, it is necessary to consider the amount of product obtained in the evaluations for healthier results. Tomato yields of 50 kg/m^2 in Kütahya, 34 kg/m^2 in Aydın, and 32 kg/m^2 in Antalya can be obtained from regularly heated greenhouses depending on the length of the production period [39].

According to the data of Table 6, when coal is used, the fuel cost for one kg of tomato production in Afyon, Kütahya, Aydın and Antalya provinces is 0.56 $/kg, 0.55 $/kg, 0.35 $/kg, and 0.26 $/kg, respectively. These values for polycarbonate greenhouse in Afyon, Kütahya, Aydın and Antalya provinces were 0.29 $/kg, 0.28 $/kg, 0.18 $/kg, and 0.14 $/kg, respectively (Table 7). When fossil energy sources are used in greenhouses, Afyon and Kütahya provinces can not compete with Antalya. However, it was determined that the polycarbonate greenhouses reduced fuel cost between 48.2 and 46.2%.

According to the data of Table 8, when geothermal energy is used, the fuel cost for one kg of tomato production in Afyon and Kütahya, and Aydın provinces is 0.10 $/kg, and 0.06 $/kg, respectively. These values for polycarbonate greenhouses in Afyon, Kütahya, and Aydın provinces were 0.054 $/kg, 0.052 $/kg, and 0.033 $/kg, respectively (Table 9). The cost of production in the provinces where geothermal energy is available is more economical than fossil energy resources. It is also seen that polycarbonate greenhouses had a positive effect on this situation.

4. Discussion

Modern greenhouse production areas have continued to rise in Turkey in recent years and these greenhouse areas are especially increasing in the inner regions of the country. The main reason for this increase is the cheap heating provided by geothermal energy. For this reason, studies have started for the establishment of organized greenhouse zones in the provinces where geothermal energy is located.

Unlike the traditional greenhouses, these types of greenhouses are used for soilless growing and have automation systems. Heating process is carried out in accordance with the plant needs [7].

In this study, the heating requirements and costs were calculated for two model greenhouses having an area of approximately 1 ha at five different provinces. The maximum heating requirement was calculated for January at all provinces. When the annual heating requirement ranged between 6,096,283 MJ/ha (for Antalya) and 20,359,946 MJ/ha (for Ayfon) for plastic greenhouses, this heating requirement ranged from 3,187,074 (for Antalya) to 10,643,972 MJ/ha (for Afyon) for the polycarbonate greenhouse. Polycarbonate greenhouse significantly reduced the heating requirement. This situation reflected the fuel costs. The coal costs for plastic greenhouse ranged between 84,481 $/ha (for Antalya) and 282,145 $/ha (for Ayfon) whereas these costs ranged from 44,166 $/ha (for Antalya) to 147,502 $/ha (for Afyon) for the polycarbonate greenhouse. The use of geothermal energy in greenhouse heating has reduced fuel costs by 81.8%. The geothermal water costs for plastic greenhouse in Afyon, Kütahya, Denizli, and Aydın ranged between 21,352 $/ha (for Aydın) and 51,287 $/ha (for Ayfon) whereas these costs ranged from 11,163 $/ha (for Aydın) to 26,812 $/ha (for Afyon) for the polycarbonate greenhouse. The geothermal energy were reduced the fuel cost for one kg of tomato production in provinces where geothermal energy is available. For the province of Antalya, which has a significant potential in terms of greenhouse area, it can be said that the use of natural gas in greenhouse heating will reduce fuel costs. This will even increase the quantity and quality of the product received from the unit area.

5. Conclusion

The limiting factors for crop production in greenhouses are in particular the outdoor temperature and the financial value of heating costs. Heating costs are one of the most important criteria that determine whether greenhouse cultivation can be made economically. These costs can be up to 60% of the total operating costs. Covering material is also important in reducing these costs. As a matter of fact, the cover material is effective on the internal microclimate of the greenhouse. In this study, it was determined that covering material had a significant effect on reducing these expenses. PC greenhouse cover material reduced heating requirement and fuel costs. Also, the use of geothermal energy in PC modern greenhouse heating has significantly affected reduced fuel costs.

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