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Heating requirement and its costs in greenhouse structures: A case study for Mediterranean region of Turkey

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A B S T R A C T

Greenhouse cultivation has a special place in agricultural production. The most distinctive characteristic of the greenhouse cultivation compared to other agricultural production method is that it is carried out under a structure called greenhouse. The air conditioning systems in greenhouse provide a suitable environmental condition for agricultural production. This cultivation method has been widely utilized in many different regions of the world. Southern coast of Turkey is an important greenhouse-growing center in Mediterranean basin. In addition to the traditional greenhouse production, there has been an increase in the number of the modern greenhouse structures that allows climate control in Turkey in recent years. Heating is an important factor in providing favorable climate conditions for greenhouse production that affects directly both quality and cost of the production. Heating of greenhouses is required for an efficient and reliable production especially during winter time in Turkey. Currently, coal is preferred as a fuel in the greenhouse heating because it is more economical in comparison to the other fuels such as diesel, LPG, LNG and natural gas and can be easily supplied. In this study, the heating requirements and their costs for the provinces in the Mediterranean region have been identified by using the meteorological data. The calculations were made for a gothic roofed and coal heated, plastic model greenhouse located in an area with 1 ha representing modern greenhouses of the region. According to the results of calculations, total annual heating requirement was between 3,592,848 and 10,459,688 MJ/ha. The calculated total annual and hourly costs per ha were 65,891.5–151,220.6 $/year and 23.8–34.2 $/h, respectively.

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1. Introduction

As a result of misused agricultural land, rapid population growth and inadequate product quality, precautions that will help to increase the productivity must be taken as soon as possible. These precautions include providing and distributing the inputs

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Nomenclature

Q	Total heat power (Heating requirements)
Q_K	Amount of heat loss from the greenhouse
Q_G	Amount of incoming solar radiation inside the greenhouse
I_o	Average daily solar radiation intensity
A_r	Roof area
η_s	Conversion ratio of solar energy to beneficial energy for greenhouse heating during the day.
ΣA_o	Total area of the cover
U	Overall heat transfer coefficient
t_i	Greenhouse inside temperature
t_o	Greenhouse outside temperature
ΣQ_m	Monthly heating requirement
HH_d	Daily heating hour
DN_m	Number of day per month
L	Total length of pipe
Q_h	Maximum heating requirement in greenhouse
d	Pipe diameter
U_p	Heat transfer coefficient of the pipe
t_p	Average of the temperatures of the water exiting from and returning the furnace
C_A	Annual fixed cost
C_o	Construction cost of heating system
i	Real interest rate
n	Heating system's life
CR_m	Monthly coal requirement
LHV	Low heat energy value of coal
η	Efficiency of the heating system
CC_m	Coal cost per month
CP	Coal price

required for use of modern technology in agricultural production, advancing vegetable, fruit production and especially extending greenhouse areas [1]. Over the last two decades, use of solar agricultural greenhouses in agricultural production has increased. The primary objective of a greenhouse is to produce higher yield during the non-cultivation season, which is possible by maintaining the optimum temperature at every stage of the crop [2,3]. An appropriate air conditioning including heating or cooling can be coupled with the greenhouse for this purpose. These, as a result, will have significant impacts on the cultivation time, quality and quantity of the products [2].

A greenhouse can be defined as a sophisticated structure, providing ideal conditions for satisfactory plant growth and production throughout the year. The inside environment of the greenhouse is controlled by growth factors including light, temperature, humidity and air composition. These are scientifically controlled to provide the optimum level throughout the cultivation period, thus increasing the productivity several folds [4].

The greenhouse climate with the optimum value in terms of light, temperature, ventilation and moisture directly affects the success of the production. Among these factors, the temperature is one of the most important climatologic factor should be created inside the greenhouse [5]. The vital (physiological and biological) activities of the plants usually slows down at +7 °C, and ceases at 0 °C [6]. Providing appropriate temperature and humidity in the greenhouse help to decrease diseases and usage of pesticides. Thus, problem of pesticide residue on crops is alleviated and high quality of products is obtained. It is reported that 10 °C increase in greenhouse temperature provides two-fold increase in yield. In addition, heating operations shortens the growth period and reduces labor requirements. Therefore, heating of the greenhouses is necessary at night or even daytime hours in case of insufficient solar radiation [5,7]. In contrast, heating is one of the most important cost factors in greenhouse cultivation and its profitability. Therefore, heating operations carried out for the needs of plants in some regions might not be economical. In these regions, the operation should be applied only to protect plants from frost hazard.

Greenhouse cultivation has a widespread area in the world. For greenhouse cultivation, countries can be classified as the cool climate zone (Holland, England, Germany, etc.), the temperate climate zone (Mediterranean coastline, Spain, Italy, Turkey, Greece, Israel, Egypt etc.) and the zone where the countries are dominated by two climate zones (USA, Japan etc.) by considering their latitude and greenhouse technologies. It is stated that greenhouse cultivation is more favorable in the countries located between 30 and 40 degrees of latitude. The cooling costs increase below 30th, while heating costs above the 40th degree of latitude [8].

A greenhouse air conditioning system is used to increase the thermal energy storage inside during the day or to transfer excess heat from inside the greenhouse to the heat storage area [9]. Heating is required for the greenhouses in the Northern European countries in the cool climate zone. In many Mediterranean countries, even in cold nights heating is not realized. This situation leads to low quality and efficiency in products. To heat the greenhouses, instead of fossil fuels alternative energy sources and energy conservation should be taken into consideration. Solar energy is an important alternative energy source and is a significant opportunity for the Mediterranean basin and the Arab countries zone. In spite of being a cheap and favorable source, solar energy has some economic and technical drawbacks [10]. Therefore, many researches have been conducted related to heating of greenhouse with alternative energy resources.

A study was carried out to store solar energy in an underground rock-bed for greenhouse heating. The results showed that the rock-bed system created an air temperature difference of about 10 °C at night. Furthermore, it kept the inside air temperature higher than that of outside air at night, even in an overcast day following a clear day [11]. Kasap and Erdem (1994) 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 [12]. Bascetincelik and Ozturk (2003) investigated energy and exergy efficiency of a packed-bed heat storage unit for greenhouse heating. In the study, solar energy was stored daily using the volcanic material with the sensible heat technique for heating the tunnel greenhouse of 120 m^2. The results showed that 18.9% of the total heating requirement of the tunnel greenhouse was obtained from the heat storage unit [13]. Lazâar et al., [14] compared economy of a solar system for greenhouse conditioning in order to maintain the greenhouse air temperature at 12 °C at night during the coldest months with a conventional heating system, concluded that greenhouse heating by a solar system was environmentally-friendly and more profitable but less powerful than a conventional system [14].

Bargach et al. [15] realized an experimental investigation by using two different types of solar systems to reduce heating costs in traditional greenhouses in Morocco [15]. Karacabey [16] profounded necessary information for the growers about the cost of heating that significantly affects the production costs of greenhouses. For this purpose, fixed and variable costs for heating by either brown coal or geothermal hot water for a typical

Table 1
Protected cultivation area in the Mediterranean Coastline of Turkey [18].

Province	Glasshouse		Plastichouse		High tunnel		Low tunnel		Total area	
	ha	%	ha	%	ha	%	ha	%	ha	%
Antalya	6426.2	82.1	12,752.5	53.4	2138.1	19.9	730.3	4.2	22,047.1	36.8
Mersin	645.6	8.3	6807.0	28.6	5413.7	50.5	2441.3	13.9	15,307.6	25.5
Muğla	670.9	8.6	2106.2	8.8	46.8	0.4	371.4	2.1	3195.3	5.3
Hatay	0.3	0.0	78.7	0.3	176.7	1.6	860.1	4.9	1115.8	1.9
Adana	1.6	0.0	65.5	0.3	316.8	3.0	11,438.0	65.1	11,821.9	19.7
Total	7744.6	99.0	21,809.9	91.4	8092.1	75.4	15,841.1	90.2	53,487.7	89.2
Others	74.4	1.0	2044.3	8.6	2631.1	24.6	1723.7	9.8	6473.5	10.8
Turkey	7819.0	100.0	23,854.2	100.0	10,723.2	100.0	17,564.8	100.0	59,961.2	100.0

greenhouse operation located in Balçova district of Turkey were calculated. It has been found that fixed costs of brown coal were 27% bigger than geothermal hot watery heating systems. In point of variable operation costs, brown coal had nearly ten-fold cost less than geothermal hot watery heating systems [16].

Located in the Mediterranean countries zone, Turkey is a prominent center of greenhouse cultivation. Today, the annual export value of greenhouse vegetables has reached 453 million $ [17]. Greenhouse cultivation began in the 1940s and the amount of greenhouse areas increased with the start of plastic use as the covering material after the 1970s. Total protected cultivation area of Turkey is 59,961 ha of which 31,673 ha (52.8%) is greenhouse [18]. Vegetables (95%) are the primary production type in the greenhouse areas where ornamental plants and seedlings are also grown. Greenhouse vegetable growing in the region is performed widely in the farmer greenhouses by traditional methods. The heating operation is done only to protect plants from frost hazards and the traditional wood stoves are used fuel for this purpose [19]. However, inadequate levels of the heating process affect the production quality and the yield negatively, and cause the diseases to multiply. On the other hand, changes in consumer demand and environmentally conscious manufacturing have brought up food production techniques highlighting the food security and related certification processes (Good Agricultural Practice—GAP). Therefore, after the 2000s, climate-controlled modern greenhouse applications obtaining higher quality products and food security has been widespread applications [20,21]. Modernization for the greenhouses can be defined as the usage of relatively high technologies on the subjects of structure–cover material, air conditioning systems and cultivation techniques. These greenhouses are located mostly in the Mediterranean region. The modern greenhouses with high initial investment costs have automation systems to maintain climate control soilless culture. Total investment cost (except land price) of a modern plastic greenhouse with 30 ha was indicated as 604,500 $/ha [20].

The modern greenhouses in the research area have hot water piped heating systems. Currently, coal is preferred as a fuel in the greenhouse heating because it is more economical in comparison to the other fuels such as diesel, LPG, LNG and natural gas and can be easily supplied. Today, the total area of modern greenhouses in Turkey is 300 ha and 92% of which used for tomato and pepper cultivation [18]. Thanks to favorable regional climate and an economical type of production opportunity, the number has increased in recent years. Heating costs are one of the important expenses in this type greenhouse cultivation. Therefore, heating-related calculations should be done carefully in management studies carried out for economical production.

In this research, the heating requirements and costs for a model modern plastic greenhouse were determined by considering the meteorological data for five provinces located in the Mediterranean region in Turkey.

2. Materials and methods

2.1. Research region

Turkey's southern coast covering Muğla, Antalya, Mersin, Adana and Hatay provinces are located on the east of Mediterranean Sea. Agricultural production is carried out in very different production branches thanks to favorable geographical and climatic features in the region. Geographic location of the research area is shown in Fig. 1.

Protected cultivation areas of the selected provinces and also of Turkey's total are given in Table 1. The glasshouses and plastic greenhouses in the region constitute about 99.0% and 91.4% of the of Turkey's total glasshouses and plastichouse areas (Table 1). In the selected regions, greenhouse farming generally starts in the months of August or September depends on the crop and the method of growing and continues until the end of June. Some long-term meteorological data of each province are presented in Table 2, Figs. 2 and 3 [22].

2.2. A model greenhouse

In this study, considering the conditions of the region and farm properties a typical plastic greenhouse has been identified as a model (Fig. 4) and used as material. The model greenhouse has gothic roof and 10 tunnels with a total width of 96.0 m, length of 104.2 m floor area of 10,003 m^2, cover surface area of 13,055 m^2, side wall height of 4.5 m and ridge height of 6.5 m. Its covering material is single-layer plastic.

2.3. Calculations

Appropriate heater capacity, monthly heating requirements and the operating costs for heating operations of the model greenhouse were calculated in this study. The desired amount of heat power (heating requirement) to ensure the ambient inside temperature of the greenhouse was calculated by using Eq. (1):

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

where, Q is the total heat power (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 from Eq. (2):

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

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 [5,16].

Fig. 1. Locations of the study areas.

Table 2
Some meteorological data of the selected provinces [22].

Province	Mean temperature (°C)	Mean high temperature (°C)	Mean low temperature (°C)	Daily sunshine period (h:min)
Antalya	18.1	24.2	13.0	8:24
Muğla	15.0	21.2	9.5	7:18
Mersin	19.5	23.1	15.3	7:42
Adana	19.1	25.2	14.2	7:19
Hatay	18.3	23.2	13.9	7:34

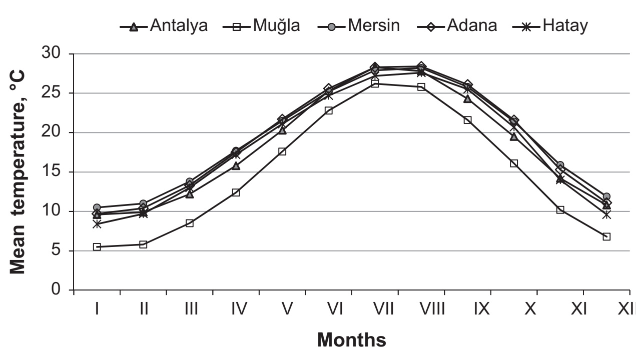

Fig. 2. Mean temperature values for the selected provinces.

The amount of heat loss from the greenhouse can be determined by using Eq. (3) [5,7,8].

$$Q_K = \Sigma A_o \times U \times (t_i - t_o) \quad (3)$$

where, ΣA_o is the total area of the cover (m^2), U is overall heat transfer coefficient (W/m^2 K), t_i and t_o are greenhouse inside and outside temperatures (°C), respectively.

In this study, monthly heating requirement value (MJ/ha) was determined by take into consideration the values of heat loss (Q_K). The value was calculated by using Eq. (4) [7]. Also, the annual heating requirement of the greenhouses can be found by collecting

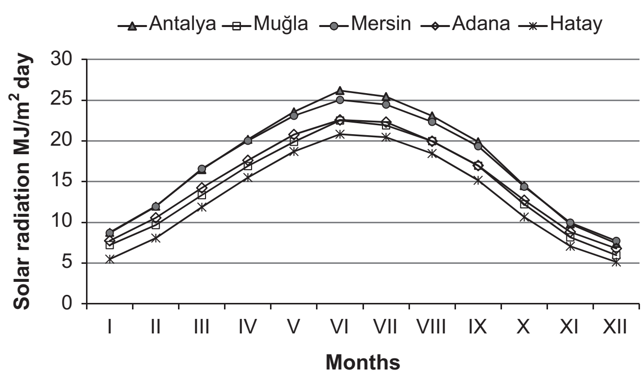

Fig. 3. Solar radiation values for the selected provinces.

of the monthly values.

$$\Sigma Q_m = \Sigma A_o \times U \times (t_i - t_o) \times 3.6 \times HH_d \times DN_m \quad (4)$$

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).

For the selected provisions, the average values of temperature, solar radiation intensity and sun exposure duration were obtained from the long-term records of the State Meteorology Affairs General Directorate and used in the calculations [22].

The total value related to coefficient of heat transfer in the greenhouse (U) depends on various factors such as the size of the greenhouse, type of the cover material and heaters, wind speed etc. Therefore, it is reported that complete and accurate determination of heat transfer coefficient is not possible, so, the coefficient values determined and proposed based on experience rather than detailed calculations were used for the application processes. In the calculations, a value of 6.8 W/m^2 K can be used as total heat transfer coefficient [5,23–25]. Since mostly vegetables are grown in the region greenhouses, the required inside temperatures at night and daytime were considered as 16 and 21 °C, respectively [5,23,24,26]. Considering the calculations, it has been identified that heating is not necessary during the daytime since

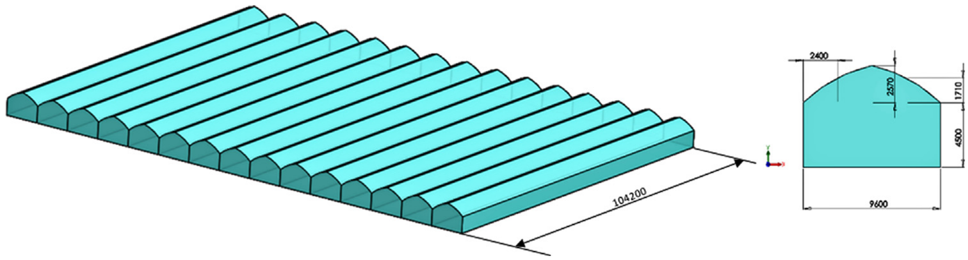

Fig. 4. View and dimensions of the model greenhouse.

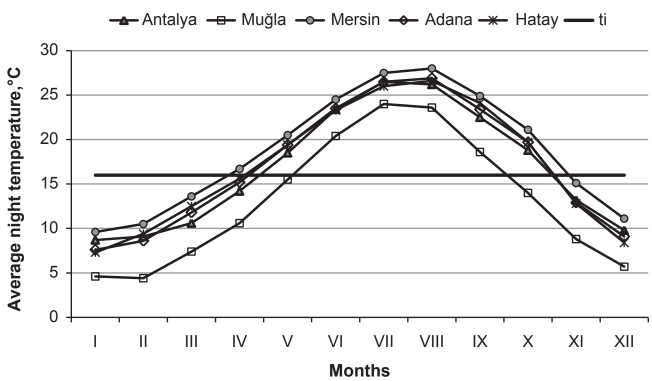

Fig. 5. Average night temperature values for the selected provinces.

the average solar radiation meets the heat loss of the greenhouse. Therefore, heating calculations were done for the night time in which there is no solar radiation. It was stated that lower temperatures of the region must be considered instead of average minimum temperatures to determine the heater capacity. Therefore, as a minimum outside temperature value, 3 °C for Antalya and Mersin, 0 °C for Adana and Hatay provinces and −3 °C for Muğla province was used in the heater capacity calculations [7,8]. Eq. (5) was used to calculate the total pipe length for the heating system [5,16]:

$$L = \frac{Q_h}{[\pi \times d \times U_p \times (t_p - t_i)]} \tag{5}$$

where, L is the total length of pipe (m), Q_h is the maximum heating requirement in greenhouse (W), d is the pipe diameter (m), U_p is heat transfer coefficient of the pipe (W/m^2 K), t_p is the average of the temperatures of the water exiting from and returning the furnace (°C). The heating pipe diameter and pipe heat transfer coefficient were regarded 51 mm and 13 W/m^2 K, respectively [5,8]. It was also considered that temperature of the water coming out of the furnace was 80 and that of returning water was 60 °C in the calculations.

Fixed and variable costs were taken into account in determining the costs of the heating system. Fixed costs can be calculated by using Eq. (6) [16,27]. The equation includes expenses of depreciation and interest:

$$C_A = C_o \times \left[\frac{(i \times (1+i)^n)}{((1+i)^n - 1)}\right] \tag{6}$$

where, C_A is the annual fixed cost ($/year), C_o is the construction cost of heating system ($), i is the real interest rate (decimal), n is the heating system's life, year. Real interest rate was taken as 0.08 in terms of 2009 in Turkey [28]. The life of heating systems was assumed as 20 years [16].

Basic variable costs of heating system consist of fuel, labor, and electricity and maintenance inputs. The labor and electricity costs were determined by consulting heater manufacturers and greenhouse farmers. A general approach, the system maintenance costs were regarded as 5% of the investment cost [16].

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

Months	Antalya	Muğla	Mersin	Adana	Hatay
October	–	515.6	–	–	–
November	530.5	567.0	539.5	552.0	574.0
December	594.7	648.9	592.1	608.6	644.3
January	578.7	613.8	585.9	596.8	637.1
February	501.2	532.0	513.8	526.4	544.6
March	528.6	556.5	533.2	562.7	556.5
April	479.5	506.5	–	513.0	494.0
May	–	484.1	–	–	–
Total (h/year)	3213.1	4424.4	2764.5	3359.4	3450.4

Fuel requirement per month was calculated by using the following Equation [23]:

$$CR_m = \frac{\Sigma Q_m}{(LHV \times \eta)} \tag{7}$$

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. In the calculations, the low heat energy value of coal and efficiency value for the heating system were considered as 28010 kj/kg and 80%, respectively [29]. In addition, $250/ton as the coal price was considered in fuel costs calculations given below:

$$CC_m = CP \times CR_m \tag{8}$$

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

3. Results and discussion

3.1. Heating requirement

Average annual night temperature values of the selected provinces were given in Fig. 5. As seen in this figure, heating operations should be realized for section below the straight line of 16 °C which is accepted as the favorable inside temperature (t_i) in greenhouse vegetable growing. For this reason, heating operation needs to be realized in the period between November and April in the provinces of Antalya, Adana and Hatay, October and May in Muğla and October and March in Mersin province. 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) and heating requirements (MJ/ha) calculated for the specified period of each province are presented in Tables 3 and 4. According to Table 3, the shortest heating period is required for Mersin (2764.5 h/year) and the longest for Muğla province (4424.4 h/year). Muğla province has the lowest night temperature values and needs heating operations two or three months more than the others. January was determined as the

month in which the heating requirement is the highest (Table 4). This value ranged from 1,198,372–2,236,248 MJ/ha for the provinces. Muğla province has the highest annual heating requirement (10,459,688 MJ/ha) whereas Mersin has the lowest (3,592,848 MJ/ha). High average temperature values and long solar radiation time caused lower values in Mersin province.

3.2. Heating costs

Fuel consumption is one of the most important factors among all cost inputs in greenhouse operations. In the research area, coal is used widely as fuel due to low price. It can be said that greenhouse farmers prefer imported coal because of its high calorific value, but some farmers prefer local lignite coal. The calculated findings related to coal requirements and costs for the provinces are given in Table 5. As shown in Table 5, annual coal requirement ranged between 160.34 and 466.78 t/ha depending on the heating requirements and heating time. Muğla has the highest coal costs in respect to coal prices (108,916 $/ha). Hatay (59,952 $/ha), Adana (58,544 $/ha), Antalya (55,150 $/ha) and Mersin (37412 $/ha) provinces are followed by Muğla Province.

Heating systems with solid fuel produced in Turkey are widely used in greenhouses. After the 2000s, with the increases in modern greenhouse areas, some local firms producing heaters for different purposes have begun to produce heating systems for greenhouses. The heater capacity values, total pipe lengths and the system's fixed costs for each selected provinces were calculated in the scope of the study and are presented in Table 6. Total heating requirement values of the model greenhouse changed from 4155–6072 MJ/h per ha, and total length of steel pipe values ranged between 10266 and 15004 m. Also, the heater capacities required for the model greenhouses were between 5193 and 7590 MJ/h.

Prices of the other system components include circulation pumps, fittings, valves, stopcocks, control systems, labor, etc. It was found that heater, hot water pipes and other costs of the system together with the construction costs ranged from 101,375–140,677 $ and it was observed that the annual fixed costs of the system are between 10,325 and 14,328 $/ha-year.

Variable costs depending on the use of the system consist of coal, labor, electricity and maintenance costs (Table 7). Circulation pumps are used to supply water circulation within the system and electric motors are used to activate the coal feeding mechanisms and fans in the heaters. The hourly variable cost was ranged from 20.1–30.9 $/h per ha. The lowest variable cost value was determined in Mersin and the highest value in Muğla province. Hourly coal costs have the highest percentage (67–80%) among the variable cost items. Considering annual usage time of heating systems, total annual variable cost values were between 55,566 and 136,892 $/year per ha. The annual fixed and the variable costs were considered together and the total annual cost per ha was given in Table 8. The lowest and the highest total cost values per ha ranged between 65,891.5 $/year, 23.8 $/h and 151,220.6 $/year, 34.2 $/h, respectively.

During the cultivation season, it is important to keep inside temperature of the greenhouse at favorable value. Sometimes, the grower can keep inside temperature higher than 16 °C. For all that, it may be required to keep this temperature at lower values than 16 °C for some period due to economic reasons. Because, the harvested crop price may fall or fuel price may increase during the growing season. The values showing the change in the total variable costs were given Fig. 6. There is a linear relationship between inside temperature in the greenhouse and the total variable costs and R^2 values in the regression equations are over 0.99. If Fig. 6 is investigated, it can be seen that 1 °C variation on heating operations causes important changes in variable costs. These variations are so important in terms of economic production and profitability. Some different precautions can be considered to decrease variable costs like usage of double plastic cover and thermal screen in the greenhouses. The protection methods decrease heat transfer coefficient and heating requirement especially at nights. Thus, it can be seen that some greenhouse farmers begun to use thermal screen.

Alternative energy sources can be used in terms of both economy and the environment. It is a well-known fact today that due to decline of the world's fossil energy resources and the environmental impacts of the resources, utilization and storage of renewable energies are by no means, issues which should be neglected [11]. It can be seen that solar and geothermal energy resources are applied in some regions in Turkey. It can be said that, the selected regions have not sufficient geothermal energy resources but an important potential concerning solar energy. Solar energy as an abundant but not used yet, clean and safe source, is an attractive substitute for conventional fuels for passive and active heating of greenhouses. It was shown that, solar energy can be stored in an underground rock-bed and used on greenhouse heating operations economically [11]. In the region, the greenhouse farmer should be encouraged and supported for using

Table 4
The values of the heating requirement (MJ/ha per month) for selected the provinces.

Months	Antalya	Muğla	Mersin	Adana	Hatay
October	–	329,579	–	–	–
November	474,714	1,304,680	155,175	546,876	587,016
December	1,178,327	2,136,120	927,213	1,342,125	1,564,872
January	1,350,018	2,236,248	1,198,372	1,601,991	1,771,255
February	1,105,219	1,972,232	903,119	1,244,904	1,148,709
March	912,154	1,529,371	408,968	755,224	622,418
April	275,835	874,101	–	131,158	63,150
May	–	77,359	–	–	–
Total	5,296,267	10,459,688	3,592,848	5,622,279	5,757,420

Table 5
The average coal requirement and costs per month for the selected provinces.

Months	Antalya		Muğla		Mersin		Adana		Hatay	
	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha	t/ha	$/ha
October	–	–	14.71	3432	–	–	–	–	–	–
November	21.19	4943	58.22	13,586	6.92	1616	24.41	5695	26.20	6113
December	52.59	12,270	95.33	22,243	41.38	9655	59.89	13,975	69.84	16,295
January	60.25	14,058	99.80	23,286	53.48	12479	71.49	16,681	79.05	18,444
February	49.32	11,509	88.01	20,537	40.30	9404	55.56	12,963	51.26	11,961
March	40.71	9498	68.25	15,925	18.25	4259	33.70	7864	27.78	6481
April	12.31	2872	39.01	9102	–	–	5.85	1366	2.82	658
May	–	–	3.45	806	–	–	–	–	–	–
Annual	236.36	55,150	466.78	108,916	160.34	37412	250.90	58,544	256.94	59,952

Table 6
Fixed costs of greenhouse heating system per ha for the selected provinces.

Province	Min Temp.	Heating requirement MJ/h	Heater capacity MJ/h	Heater price $	Total pipe length m	Total pipe price $	Price of the other components $	Total system cost $	Fixed cost $/year
Antalya	3	4155	5193	43,333	10,266	27,375	30,667	101,375	10,325
Muğla	−3	6072	7590	56,667	15,004	40,010	44,000	140,677	14,328
Mersin	3	4155	5193	43,333	10,266	27,375	30,667	101,375	10,325
Adana	0	5113	6392	50,000	12,635	33,693	37,333	121,026	12,327
Hatay	0	5113	6392	50,000	12,635	33,693	37,333	121,026	12,327

Table 7
Variable cost of greenhouse heating system per ha for the selected provinces.

Province	Coal		Labor		Electricity		Repair and Maintenance		Total hourly variable cost		Total yearly variable cost
	$/h	%	$/h	%	$/h	%	$/h	%	$/h	%	$/year
Antalya	17.2	73	3.3	14	1.4	6	1.6	7	23.5	100	75,427
Muğla	24.6	80	3.3	11	1.4	5	1.6	5	30.9	100	136,892
Mersin	13.5	67	3.3	17	1.4	7	1.8	9	20.1	100	55,566
Adana	17.4	73	3.3	14	1.4	6	1.8	8	24.0	100	80,497
Hatay	17.4	73	3.3	14	1.4	6	1.8	7	23.9	100	82,335

Table 8
Greenhouse total heating costs per ha for the selected provinces.

Province	Total cost	
	($/year)	($/h)
Antalya	85,752.5	26.7
Muğla	151,220.6	34.2
Mersin	65,891.5	23.8
Adana	92,823.9	27.6
Hatay	94,661.6	27.4

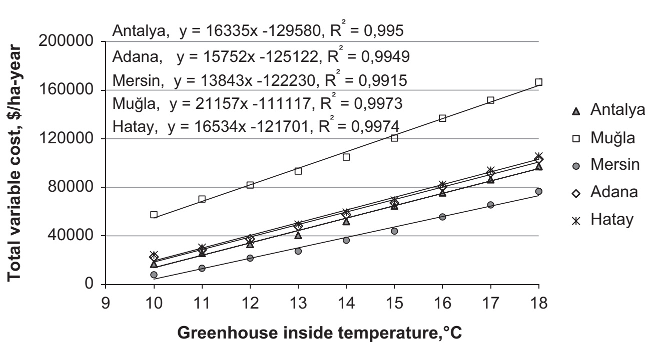

Fig. 6. Changes in total variable costs related to greenhouse inside temperature.

of solar energy systems in heating operation for less fossil fuel consumption and environmentally-friendly cultivation.

4. Conclusion

Modern greenhouse production areas have continued to rise in Turkey in recent years. 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. The heating requirements and costs were calculated for a model greenhouse having an area of approximately 1 ha at five different provinces. The greenhouses have central heating systems with hot water and coal is preferred as fuel.

Generally heating is not carried out in the daytime hours due to sufficient intensity of solar radiation. The maximum heating requirement was calculated for January at all provinces. The annual heating requirement ranged between 35,928,487 and 10,459,688 MJ/ha. The annual total coal requirement was ranged from 160.34–466.78 t/ha, while coal costs were between 37,412 and 108,916 $/ha. Total annual fixed cost per ha was ranged between 10,325 and 14,328 $/year while the total variable cost was varied from 20.1–30.9 $/h. The calculated total annual and hourly costs per ha were 65,891.5–151,220.6 $/year and 23.8–34.2 $/h, respectively.

Considering the climate data, high cost of heating is observed when the heating is applied. However, an economical production is provided thanks to the fact that the purchase prices of the products are sufficient and the products can have a place in foreign markets in winter season. Moreover, measures including heat conservation in the greenhouses can be taken to reduce heating requirements and lower costs. Using thermal screens, double-storied or different types of cover materials and passive solar heating systems will decrease heating requirements in the greenhouses. In addition, structural and economic conditions of the business should be assessed and the most suitable method of heating should be identified.

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