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Comparison of Different Cover Materials and Energy Resources in Determining Greenhouse Heat Requirements in Kırşehir Province of Turkey

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Abstract

Creating suitable temperatures for the plants in a greenhouse is possible by heating the greenhouse when temperature is not suitable for plant breeding. In this study, it is aimed to determine different amounts of fuel (natural gas, imported coal, fuel oil and geothermal) to meet the calculated heat requirements of a greenhouse with different cover materials (single-layer polyethylene, double-layer polyethylene, single-layer glass and polycarbonate), their costs and and the amounts of carbon dioxide emissions to be given to the atmosfere by calculating the heat requirements for Kirsehir province when the indoor temperature of the greenhouse is kept at 16 °C and 18 °C.

In the study, it has been determined that the need for heat in the greenhouses in Kirsehir province is minimum when double-layer (PE) plastic cover material is used (321.62 kWh/m² year at ti=16 ºC). A change of 2 °C (16/18 °C) in indoor temperature of the greenhouse caused an increase of heat consumption of approximately 15% in the greenhouse. In addition, it has been determined that an economical saving by 81% could be achieved compared to natural gas, by 91% compared to imported coal, by 92.3% compared to fuel oil when available geothermal resources are used for heating purposes instead of fossil fuels in greenhouse cultivationin Kirsehir province. As a result of the study carried out, it has been determined that a more economical and sustainable breeding can be achieved when geothermal energy is preferred for the purpose of heating the greenhouses in Kırşehir province.

Keywords: Greenhouse heating, Heat requirements, Fossil fuel, Geothermal energy

INTRODUCTION

The most common and effective use of environmentally stabilized production in plant breeding is made in greenhouses [1]. One of the advantages of breeding in a greenhouse is the possibility to stabilize the main factors which have an impact on environmental monitoring such as light, humidity, temperature, amount of carbon dioxide (CO_2) and amount of ventilation required for plant breeding. Among these factors, one of the most significant factors is temperature that influences the growth of a plant in a greenhouse. Types of plants grown in a greenhouse require different optimum growth temperatures in their growth stage. The increase or decrease of temperature has a direct effect on the crop and quality parameters of the plant.

Not only does the high humidity lead to illnesses, but also to a decrease of transpiration in plants, and therefore a negative effect in the plant development in unwarmed greenhouses. Additionally, plant breeding is more profitable in greenhouses with well-planned and efficient heating systems.

Heating systems are of high importance in the planning of greenhouses because the foremost important input in greenhouse cultivation is the heating cost. The heating costs in greenhouse enterprises substantially influence the cost of production changing within the range of 20-60% of the total production cost depending on the season of breeding and location [1, 2, 3]. Therefore, it is most important that the heating system is appropriately designed before given decision of greenhouse heating to save energy and reduce initial investment cost. During the selection and design of the heating systems in greenhouses, above all it is compulsory to determine the maximum heat requirement based on the climatic conditions of the location the greenhouse is built, the type of greenhouse selected and the greenhouse equipment.

The required energy amount in a unit area in the sector of agriculture is the most in greenhouse enterprises. Fossil energy resources are used for greenhouse heating in Turkey. The greatest drawback of fossil energy resources is the CO_2 emission released in the atmosphere. The CO_2 emission value changes depending on the type and amount of fuel used. It is possible to reduce the value of emission in greenhouses with the use of renewable energy sources [1, 4].

In a study on the use of geothermal resources in greenhouse heating in the province of Aydın, it was reported that the use of new and renewable energy resources in the heating of greenhouses gained importance due to the high energy costs obtained from the usual energy resources. It was found that the big share of heating costs within the total production costs of greenhouse cultivation would drop through the use of geothermal energy, a new and renewable energy source, in greenhouse heating. Furthermore, it was highlighted that it is an immediate necessity to make use of natural energy sources instead of fossil energy resources in order to preserve the existence of today's energy and prevent pollution, and that research and development studies on the design of heating systems with geothermal energy in greenhouses have recently gained importance [5].

The present study aims to determine the required amount of fuel, cost and amount of carbon dioxide emissions by calculating the all year heat requirement of greenhouses for four different cover materials and two different indoor temperatures in the Kırşehir province which has a rich potential in geothermal resources.

MATERIALS and METHODS

The location of the province Kırşehir, which is situated in Central Kızılırmak in the Central Anatolian Region, is between the 38°50'-39°50' northern latitude and 33°30'-34°50' eastern meridian. Its elevation from sea level is 985 m. The continental climate is seen in Kırşehir where the winters are cold and snowy and the summers are hot and dry. According to the data stored in the meteorological station in

Kırşehir, the average yearly temperature is 11.4°C, while the lowest temperature is observed ad -28 °C in January and the highest temperature is 40.2 °C in July. Based on the data of the meteorological station in Kırşehir, the data on the long term yearly climate conditions of Kırşehir (57 years) are presented in Table 1.

The average annual sunshine period is 7.1 hours with the highest of 11.6 hours in July and the lowest of 3.0 hours in January. The monthly average solar radiation is the highest with 563 cal/cm² in July, the lowest with 155.5 cal/cm² in January, and the average annual is 367.9 cal/cm². The greenhouse dimensions which were based on in the calculation to determine the need for heat in greenhouses in the center of Kırşehir are presented in Table 2.

The effective heat consumption (qH) is determined with the help of the equation by [6].

$$qh = \left(\frac{A_c}{A_g}\right) \times u \times (ti - to) - q_o \times \tau \times \eta \qquad (1)$$

In the Equation; qh effective heat consumption (W/m²), Ac/Ag relationship of greenhouse cover to floor area, overall heat transfer coefficent (W/m²°C), ti inside temperature (°C), td actual outside temperature (°C), qo outside global radiation (W/m²), τ transmittance of greenhouse (0.6-0.7), η conversion factor of global radiation energy to thermal energy inside the greenhouse (0.5-0.7)

Two different values of indoor temperature of the greenhouse (16-18°C) were used for the heat requirements calculation of the tomato plant which is commonly grown in greenhouses in the province Kırşehir.

The heat transmission loss was considered to be 5 % which occurs due to transportation pipes [7].

Table 1. Data of long term yearly climate conditions in Kırşehir

Parameters	Months												Annual
	1	2	3	4	5	6	7	8	9	10	11	12	
Mean T(°C)	1	2	3	4	5	6	7	8	9	10	11	12	
Average	-0.2	1.3	5.2	10.7	15.5	19.7	23.1	22.9	18.2	12.3	6.3	2.0	11.4
Max. T (°C)	4.5	6.5	11.2	17.1	21.9	26.2	29.7	29.9	25.9	19.9	12.9	6.8	17.7
Average Min. T(°C)	-4.3	-3.2	-0.3	4.3	8.6	12.3	15.5	15.5	10.9	6.0	1.1	-2.0	5.4
Max. T(°C)	19.0	20.6	28.0	30.9	34.5	36.2	40.2	39.4	36.2	33.6	26.2	19.9	40.2
Min. T(°C)	-28.0	-25.3	-21.8	-8.2	-1.4	2.6	5.1	5.0	-1.2	-6.6	-21.5	-24.3	-28.0
Average Sunshine period (h)	3.0	4.1	5.2	6.5	8.5	10.5	11.6	11.0	9.3	6.9	5.1	3.1	7.1
Solar radiation (kWh/m²d)	2.06	2.96	4.07	4.90	5.85	6.46	6.58	5.94	4.96	3.52	2.40	1.82	4.29

Table 2. The greenhouse dimensions based on in calculations and heat transmission coefficients

Dimension	Unit	Value	Dimension	Unit	Value
Width	m	9.60	Ridge height	m	7.00
Length	m	50.00	Surface area of the greenhouse cover (Ac)	m²	1747.00
Span number	number	2.00	Ground area of the greenhouse (Ag)	m²	960.00
Gutter height	m	4.25	Ac/Ag	-	1.82
Single layer polythene (SLPE)	W/m2ºC	6.80	Single glass (SG)	W/m²ºC	6.3
Double layer polythene (DLPE)	W/m2ºC	4.00	Polycarbonate4 mm (PC)	W/m²ºC	4.1

The required fuel consumption based on the annual thermal energy in greenhouses was calculated through the Equation 2, and the carbon dioxide emissions to the atmosphere of the fuel used for heating the greenhouses were calculated with the help of Equation 3 [1].

$$By = \frac{qH}{Hu \times \eta ges} \qquad (2)$$

$$SEGMy = By \times Hu \times FSEG \qquad (3)$$

In the Equations; By = Fuel amount corresponding a unit area (kg/m² or m3/m²), Hu = Low heating value of fuel (kWh/kg), qH = Heat requirement for certain greenhouse temperatures (kWh/m²), ηges = Average enterprise profit, SEGMy = Yearly carbon dioxide emission amount (kg eqv. CO_2), FSEG = CO_2 emission conversion factor as to the type of fuel (kg eqv.CO_2/kWh).

The heating value of the different fuels used for greenhouse heating, enterprise profit, unit cost and the CO_2 emission conversion factors are presented in Table 3.

Table 3. Values for different fuels used in calculations

Fuel type	Hu (kWh)	ηges (%)	Cost ($/kWh)	FSEG (CO_2/kWh)
Natural gas (m3)	9.59	93	0.027	0.239
Impoted coal (kg)	8.14	65	0.055	0.448
Fuel Oil No 6 (kg)	11.12	80	0.067	0.313
In calculations 1 USD $ =3.5968 Turkish Lira				

RESULTS and DISCUSSION

The long term yearly meteorological data is shown in Table 1 and the long term yearly average temperature and radiation values are given in Figure 1. Considering these, the daily average temperature between November and April is below 12 °C, and the minimum average temperature is below 0 °C. Heating is required during this period to ensure abundant crop with high quality. However, the temporary low temperatures in April may be ignored because the average temperature of this month is above 7 °C. The fact that the average temperature in May, June and October is between 12-22 °C shows that natural ventilation can be sufficient during this period. Because the average temperature during the period between July and August is above 22°C, it is required to perform cooling to satisfy the optimum conditions. The need for cooling during July and August may be ignored because the average temperature is slightly above average in these months and does not increase above 30 °C. Even though the average maximum temperature in July and August is around 35°C, the high wind speed during these months is a factor aiding natural ventilation. Through well-planned ventilating openings the indoor temperature values can be dropped down to the outdoor temperature value.

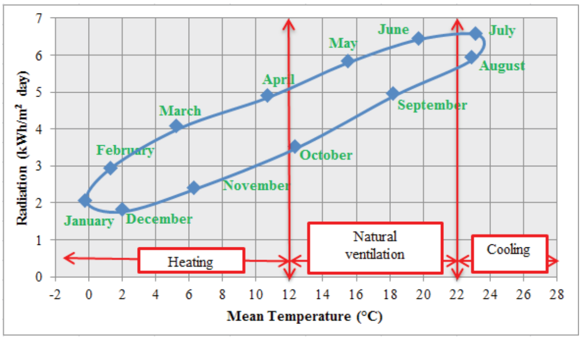

Figure 1. Long-term average temperature and radiation values in Kırşehir province

Data on the monthly climate of the region can be referred to in the case of greenhouses used only during certain periods of a year. Nevertheless, a greenhouse ought to be designed to have the potential to produce year-round. Data on the climate can be obtained in the nearest metrological station to the region of the established greenhouses. The average of the lowest temperatures of the coldest periods of the year, based on the climate conditions of the region the greenhouse is established, are taken into consideration for the determination of the outdoor temperature [7, 8, 9].

The monthly changes of the greenhouse need for heat based on the average lowest temperatures during the production period are presented in Table 4. According to the table, the average heat requirement of a greenhouse with single-layer polyethylene is 733.41-843.62 kWh/m² year, with a double-layer polyethylene is 337.71-388.07 kWh/m² year, with a single-layer glass is 667.50-769.60 kWh/m² year, and with polycarbonate 348.94-400.56 kWh/m² year when the indoor temperature is kept at 16/18 °C.

Table 4. The amount of heat energy required during the production period in Kırşehir province

Month	SLPE		DLPE		SLG		PC	
	16 °C	18 °C	16 °C	18 °C	16 °C	18 °C	16 °C	18 °C
January	167.79	186.21	90.84	101.67	154.05	171.11	93.59	104.69
February	118.09	132.64	60.56	69.12	107.81	121.30	62.62	71.39
March	88.97	103.55	40.05	48.63	80.24	93.74	41.80	50.59
April	37.72	48.86	-	-	32.93	43.25	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-
October	39.67	51.95	-	-	35.16	46.53	-	-
December	97.34	112.93	49.51	58.68	88.80	103.24	51.22	60.62
November	148.90	167.32	80.66	91.50	136.72	153.78	83.10	94.20
Heat requirement	698.49	803.45	321.62	369.59	635.71	732.95	332.32	381.49
Loss of heat transmission 5%	34.92	40.17	16.08	18.48	31.79	36.65	16.62	19.07
Total (kWh/m² year)	733.41	843.62	337.71	388.07	667.50	769.60	348.94	400.56

A change of greenhouse indoor temperature by 2 ºC caused an increase of heat consumption by approximately 15%. Furthermore, it was found that a greenhouse covered with the single-layer PE, which has the highest heat requirement needs 2.17 times more heat energy than a greenhouse with double-layer, which has the lowest heat requirement. The present study showed that the heat consumption values vary depending on the cover material. Considering the differences, it was found that while single-layer PE greenhouses require the highest amount of heat due to the heat transmission of the cover material, the double-layer PE cover material requires the lowest amount of heat (Figure 2).

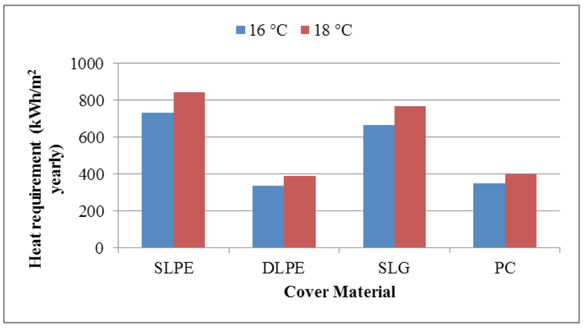

Figure 2. Heat requirement quantities for different cover materials

The fuel quantities spent based on the heat requirements of different cover materials, the fuel cost and the amount of CO_2 released depending on the type of fuel are presented in Table 5. Based on the cover materials in greenhouses, the fuel quantities in a single-layer PE greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was 82.23-138.62-82.44 kg/m²; whereas at 18ºC it was 94.59-159.45-94.83 kg/m², respectively. While the fuel quantities in a double-layer PE greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was found to be 37.86-63.83-37.96 kg/m², at 18 ºC it was 43.51-73.35-43.62 kg/m², respectively. The results revealed that the amount of fuel in a single-layer glass greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was 74.84-126.16-75.03 kg/m², and at 18 ºC it was revealed to be 86.29-145.45-86.51 kg/m², respectively. Finally, the fuel quantity of a polycarbonate greenhouse heated at 16 ºC with natural gas, imported coal and fuel oil was calculated as 39.12-65.95-39.22 kg/m², and at 18 ºC it was found to be 44.91-75.71-45.03 kg/m², respectively (Figure 3). Considering all three types of fuel, natural gas and fuel oil were revealed to possess similar fuel quantities; however, imported coal was detected to have a 1.7 times greater amount of fuel compared to the other two types of fuel.

Table 5. Depending on different cover materials, heat requirement, fuel quantities, fuel cost and amount of CO_2 given to the environment

Features		SLPE		DLPE		SLG		PC	
		16 °C	18 °C	16 °C	18 °C	16 °C	18 °C	16 °C	18 °C
Heating system	Heat energy (kWh/m² yıl)	733.41	843.62	337.71	388.07	667.50	769.60	348.94	400.56
Amount of fuel	Natural gas (m³/m²)	82.23	94.59	37.86	43.51	74.84	86.29	39.12	44.91
	Imported coal (kg/m²)	138.62	159.45	63.83	73.35	126.16	145.45	65.95	75.71
	Fuel oil (kg/m²)	82.44	94.83	37.96	43.62	75.03	86.51	39.22	45.03
Fuel cost ($/m² year)	Natural gas	19.62	22.56	9.03	10.38	17.85	20.58	9.33	10.71
	Imported coal	40.08	46.10	18.46	21.21	36.48	42.06	19.07	21.89
	Fuel oil	48.82	56.16	22.48	25.83	44.43	51.23	23.23	26.66
CO_2 Emission (kg/m² year)	Natural gas	188.48	216.80	86.79	99.73	171.54	197.78	89.67	102.94
	Imported coal	505.49	581.45	232.76	267.47	460.06	530.43	240.50	276.08
	Fuel oil	286.95	330.07	132.13	151.83	261.16	301.11	136.52	156.72

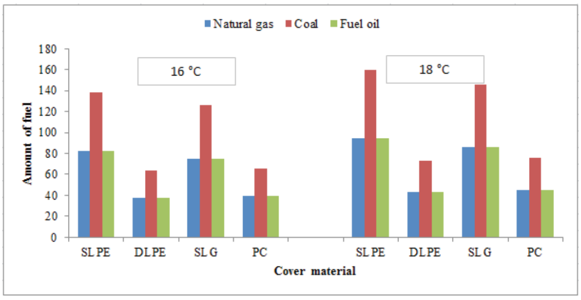

Figure 3. Fuel quantities for different cover materials

Based on the cover materials in greenhouses, the fuel cost in a single-layer PE greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was 19.62-40.08-48.82($/m² year); whereas at 18ºC it was 22.56-46.10-56.16($/m² year), respectively. While the fuel cost in a double-layer PE greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was found to be 9.03-18.46-22.48($/m² year), at 18 ºC it was 10.38-21.21-25.83 ($/m² year), respectively. The results revealed that the amount of fuel in a single-layer glass greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was 17.85-36.48-44.43($/m² year), and at 18 ºC it was revealed to be 20.58-42.06-51.23($/m² year), respectively. Finally, the fuel cost of a polycarbonate greenhouse heated at 16 ºC with natural gas, imported coal and fuel oil was calculated as 9.33-19.07-23.23 ($/m² year), and at 18 ºC it was found to be 10.71-21.89-26.66($/m² year), respectively (Figure 4). Considering the fuel cost, natural gas was found to have a 2.04 times lower cost than the fuel cost of imported coal and a 2.49 times lower cost than the fuel cost of fuel oil.

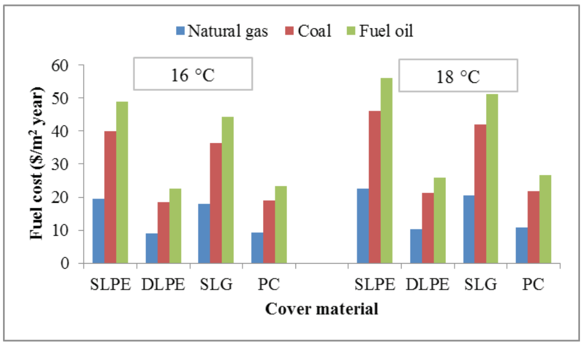

Figure 4. Fuel cost for different cover material

The fuel cost and CO_2 emission released in the atmosphere of different fossil energy sources used in greenhouses are different from each other. When the indoor greenhouse temperature is kept at 16 ºC the CO_2 emission released in the atmosphere of a single-layer PE greenhouse heated with natural gas, imported coal and fuel oil was 188.48-505.49-286.95 kg/m²; whereas at 18ºC it was 216.80-581.45-330.07 kg/m², respectively. While the CO_2 emission in a double-layer PE greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was found to be 86.79-232.76-132.13 kg/m², at 18 ºC it was 99.73-267.47-151.83 kg/m², respectively. The results revealed that the CO_2 emission in a single-layer glass greenhouse at 16 ºC heated with natural gas, imported coal and fuel oil was 171.54-460.06-261.16 kg/m², and at 18 ºC it was revealed to be 197.78-530.43-301.11 kg/m², respectively. Finally, the CO_2 emission of a polycarbonate greenhouse heated at 16 ºC with natural gas, imported coal and fuel oil was calculated as 89.67-240.50-136.52 kg/m², and at 18 ºC it was found to be 102.94-276.08-156.72 kg/m², respectively (Figure 5). Considering the amount of the CO_2 emissions, natural gas was found to release 2.68 times less CO_2 emission than imported coal and 1.52 times less CO_2 emission than fuel oil into the atmosphere.

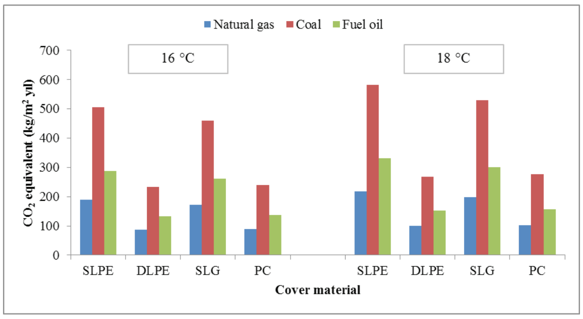

Figure 5. CO_2 emission amount for different cover material

Natural gas was identified as the most favorable fuel in terms of cost and CO_2 emission for the heating of greenhouses as illustrated in Figure 5. An economical saving by 51% could be achieved compared to imported coal and by 60% compared to fuel oil when natural gas resources are used for heating purposes. However, the use of natural gas for greenhouse cultivation is still uncommon in Turkey due to the current lack of infrastructure of natural gas in the rural areas where greenhouse cultivation is implemented and import of natural gas from abroad. It is crucially important to establish the infrastructure in provinces which do not possess alternative energy resources in Turkey in terms of costs and to maintain year-long greenhouse cultivation.

Kırşehir is one of the important provinces which possess geothermal energy resources in Turkey. Thus, production with less heating costs and more environmental concerns can be implemented with the use of the province's possessed geothermal energy resources instead of the fossil sources which are high-cost and release an extensive amount of CO_2 emission. Thereby, a more profitable production could be achieved as the cost share of heating would considerably drop.

The price of geothermal energy is determined by m² instead of kWh in the province of Kırşehir. Consequently, the heating cost of geothermal energy in Kırşehir for a 7-month period between October and April is determined as 3.75$/m². No need of heating is considered outside of the period between October and April because heating is done between these months, looking at the heat requirements of greenhouses in Kırşehir (Figure 4). In this way, economical saving of the m² cost by 81% could be achieved compared to natural gas, by 91% compared to imported coal and by 92.3% compared to fuel oil when available geothermal resources are used for heating purposes for greenhouses. In addition, the amount of released CO_2 emission into the atmosphere would be considerably lower when geothermal energy is used in greenhouse heating.

Environmental pollution nowadays being a serious threat to human health, it is crucially important that the technological tools provide cheap energy and restrain environmental pollution [10]. Not only does the share of heating cost in the total production cost increase, but also a considerable rise in the amount of CO_2 of fossil fuel released into the atmosphere is seen when fossil energy sources are used for year-long production in Kırşehir. Nonetheless, the use of geothermal energy resources in greenhouse cultivation gains importance day by day due to the fact that it has a lower cost compared to the other energy sources and is environmentally friendly. The use of available geothermal sources in greenhouse cultivation will lead to profitable production and an increase in crop per unit; furthermore, it will cause an improvement of welfare of the producer due to the income provided by the products' high value during the cold winter days. Therefore, the organized greenhouse zones established in Kırşehir will make a great contribution to the greenhouse sector and producers in Turkey providing that the modern greenhouse structures are designed in accordance with today's technologies.

CONCLUSION

The heating of greenhouses leads to an increase in crop and positively influences the quality of the grown product during the time periods when the indoor greenhouse temperature is not suitable for plant growing. However, the heating expence, which takes up a big share in the total production expenses based on the location and cultivation season of the greenhouse enterprises, causes a considerable increase of production cost and negative environmental impacts due to the CO_2 emission of fossil sources released into the atmosphere. Thus, one of the primary issues in greenhouse cultivation is to take precautions in order to increase energy productivity and to use renewable energy sources with the aim of decreasing the negative impacts of fossil sources and the heating expenses in heated greenhouses. Kırşehir is one of the provinces with high heating costs in greenhouse cultivation in Turkey due to the dominance of the continental climate. The minimization of the surface of the cover material which causes heat loss, the use cover materials with high heat transmission strength, the accurate montage and use of thermal curtains, the selection and design of suitable heating systems are required to be assured for the greenhouse which are planned to be establish in order to decrease heating costs during cultivation. Thereby, enterprises can significantly save money. Furthermore, the use of available geothermal energy sources in greenhouse heating instead of the fossil energy sources which have a high cost and is harmful to the environment is remarkably important in terms of the effective use of the country's sources. The use of a renewable energy source, such as geothermal energy for greenhouse heating would decrease the heating expenses, which take up a great share in the total production expenses of greenhouse cultivation, and the CO_2 emission of fossil sources released to the atmosphere. Additionally, export oriented products of high quality obtained from the greenhouse enterprises of the province will provide substantial contributions to the country's economy.

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