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AN INVESTIGATION OF TEMPORAL VARIABILITY OF HEAT REQUIREMENTS FOR GREENHOUSE TOMATO PRODUCTION IN TURKEY'S MEDITERRANEAN REGION

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ABSTRACT

Turkey's Mediterranean region is part of an important industry for the greenhouse production of tomatoes. Due to climatic conditions, greenhouses in this region require heating on cold winter nights for sufficient, high-quality yields. In terms of production costs, heating costs make up 20% of total expenses, and can be seen as an important input item. Therefore, in order to assess the construction and production costs in the planning and production stages, it is beneficial to know the heating expenses. By knowing the required heat energy, it is possible to choose the appropriate power and heating systems, and to evaluate the competition and market conditions on a broader scale. In addition, various studies have shown that global climate change affects agricultural production in many ways, particularly because production areas and types of cultivated product may vary regionally

For this study, we focused on the impact of global climate change on greenhouse heat requirements in Turkey's Mediterranean region, in which greenhouse tomato cultivation is common. Using the official station data from 1985-2018, and a model that is presented in this study, we calculated the hourly heat requirements from two periods—1985-2004 and 2005-2018—and compared the data. The results showed that there was a 12–25% reduction in greenhouse heat requirements between the two selected periods.

KEYWORDS:
Greenhouses, Greenhouse heat requirement, Global warming, Climate change, Energy balance

INTRODUCTION

In recent years, environmental conditions have changed rapidly due to global climate change, which poses risks to crop production, especially in open field conditions. Decreases in agricultural production are foreseen in the near future, especially with the rise in temperature [1, 2]. In order to minimize environmental risks, plant production is increasing all over the world in modern greenhouse structures where climate can be kept under control. Global warming and its effects make controlled environments an attractive alternative for growing systems. At the same time, existing controlled systems can cause excessive consumption of environmental resources, contribute to climate change, and cause pollution of the environment and groundwater. One of these environmental problems is the contribution of greenhouse gases to agricultural production. Agriculture contributes to 10–12% of total global anthropogenic greenhouse gases through the release of nitrogen oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) [3, 4].

When deciding how to adapt to the impacts of climate change, it is important to understand how different climatic factors interact and affect food production [2]. The impact of climate variables on agricultural production should be measured when determining a strategy for this issue.

Altering climatic conditions adversely affects production in open field conditions, and may also bring about new needs in controlled production structures. In particular, the calculations made in the design phase of heating systems that take the conditions of previous years into account may have been different in this new period. This difference may be considered negative for the environment, but it may have a positive effect on production costs, especially in the cold season, due to reduced heating requirements in the greenhouse.

In parts of the world where consumer demand is rapidly changing, greenhouse cultivation and technology are also rapidly developing. Most of the greenhouse cultivation is in the Mediterranean basin where the climate is suitable for greenhouse cultivation. Turkey is fourth in the world for greenhouse production, and second in the Mediterranean countries, after Spain [5]. The most produced plant in greenhouses is the tomato.

The exact time and place of the first tomato cultivation is unknown, but Mexico is considered the likeliest location. After the discovery of the New World, the tomato spread all over the globe [6]. Tomatoes are prominent in greenhouse production because of their high yield and economic income. One hundred and eighty million tons of production is carried out on an area of 4.8 million hectares across the world. Turkey's annual tomato production is about 10 million tons [7].

Greenhouse plants develop optimally within a certain temperature range. Low temperatures cause excessive growth of plants and reduce pollen germination, resulting in high flower loss as flower fertilization fails [8-10].

In agricultural production, the highest yield can be obtained only by meeting the plant's climate demands. It is important to keep the environmental conditions, such as temperature, humidity, light, and CO_2 at an optimum level in order to obtain high-quality and high-efficiency greenhouses. Tomatoes are grown in warm climates, similar to other plants grown in a greenhouse environment. Therefore, the following generalization can be made for the climate requirements of the plants grown in the greenhouse: (1) Plants grown in the greenhouse were adapted to an average of 17–27 °C; (2) For good plant growth, the temperature difference between day and night must be between 5 °C and 7 °C; (3) The absolute maximum temperature for plants must not exceed 35–40 °C; (6) Total day length should be a total of 500–550 hours during the three winter months (November, December, and January); (7) The total daily solar radiation should be 2.3 kWh m^{-2}; (8) The minimum soil temperature should be 15 °C; and (9) The relative humidity of the air should be between 70% and 90% [8, 11-14].

Crop production in controlled environments is a source of income, regardless of external climatic conditions and seasons. By heating greenhouses during cold periods, a significant increase in yield can be achieved. In unheated greenhouses, an average tomato cultivation yield of 15–18 kg m^{-2} can be obtained, of which 12 kg m^{-2} takes place in spring, and 9 kg m^{-2} in autumn [15, 16]. In modern greenhouses with high technology, the yield increases up to 30–32 kg m^{-2} [17].

The greenhouse climate is a system that is balanced with the solar energy generated in the indoor environment by the heat energy and the heat flux from the covering material. It is also effective in some other ways, such as evapotranspiration and moisture condensation. There are many different approaches that take these factors into consideration when calculating the heat requirement. Researchers have reported that, among these approaches, calculating heat requirement by hourly data renders the most accurate results [14, 17-21].

In greenhouses that are not structurally well designed, it is difficult to reach the expected quality and yield, and operating and maintenance costs are high [5, 22]. At the same time, the heat energy consumed in the greenhouse is the biggest input on production costs. Therefore, the generated heat energy must be used effectively and efficiently. Researchers have reported that between 20% and 50% of energy can be saved by the use of heat-saving measures, such as thermal screens and double-layered covering materials [14, 19, 23-26].

Global climate change can reduce heat requirements in greenhouses, and lead to changes in greenhouse locations and cultivated plants. The aim of this research was to investigate the temporal variability of the greenhouse heat requirement for provinces in Turkey's Mediterranean region, where greenhouse tomato cultivation is common. For this purpose, the heat requirements of the greenhouse were calculated using hourly meteorological data of the provinces, and a comparison was made between the two chosen periods.

MATERIALS AND METHODS

Turkey's Mediterranean region was the area of choice for this research. This region has very suitable climate for greenhouse cultivation. There are also many greenhouses in this region in which tomatoes are cultivated.

A modern type of greenhouse has been selected as the preferred type for tomato production in the provinces in the research region. In this greenhouse, the roof is covered with single layer of PE, and the side walls are made of 16 mm of PC material. The boiler heating system is used and the heating pipes are located along the side walls. All calculations in this study were made according to this greenhouse, whose detailed properties are given in Table 1.

TABLE 1
Characteristics of the study's selected greenhouse

Greenhouse Property	Value	Unit
Surface area	3091.2	m^2
Floor area	1920	m^2
Number of spans	4	-
Span length	50	m
Span width	9.6	m
Ridge height	6.5	m
Eaves height	4.0	m
Greenhouse volume	10880	m^3
Coefficient of air exchange	1	-
Thickness of side wall	16	mm
Thickness of roofing material	0.180	mm
Ventilation opening area	480	m^2

Tomatoes are produced all year round in Turkey's Mediterranean coastal region. Therefore, for this study, the heat requirement for the whole year was calculated. Researchers have reported that optimum yield can be obtained for tomatoes if the temperature in the greenhouse is above 16 °C [9, 10, 18, 27]. Therefore, the daytime temperature in the greenhouse should be 18 °C, the night temperature 16 °C, and the ventilation temperature 25 °C.

In the greenhouse energy balance model, the cover material light transmittance is the main parameter. The main feature of these materials is that they transmit visible radiation (VIR) at a maximum level (up to 70% in summer), while transmitting less far infrared (FIR) long wave radiation (>3000 nm). FIR transmittance also varies according to the type of covering material. Although FIR transmittance is 0–3% for glass, it increases to 60% for PE cover material [14, 28].

In this study, an ISIGER-SERA expert system model was used to calculate the heat requirements [29]. The heat energy stored in the greenhouse during the day causes the temperature rise. More accurate results can be obtained by taking the temperature rise in the greenhouse into account for the calculations to be made for the heat requirement, according to the heat storage property of the greenhouse [18, 20, 30].

The greenhouse heat requirement is calculated according to energy balance management. First, the energy gains and losses of the greenhouse are determined, and then the amount of heat energy required for the desired internal temperature value is determined.

The heat requirement was calculated by using Equation 1 below, which is also used in ISIGER-SERA model from hourly temperature, solar radiation, and wind speed values considering the temperature rise [20, 27, 31].

$$\Phi_{cs} = \sum_{n=1}^{8760} \left(U_{cs} * A_c * \left(\theta_{i_n} - \theta_{i,oH_n} - \Delta\theta_{sp_n}\right) * t_{si}\right) \quad (1)$$

Where Φ_{cs} is heat energy requirement during the cultivation period (kWh), U_{cs} is heat consumption coefficient (W m^{-2} K^{-1}), A_c is surface area (m^2), θ_{i_n} is desired temperature in the greenhouse (°C), θ_{i,oH_n} is temperature in the greenhouse not heated and not ventilated to a certain temperature (°C), $\Delta\theta_{sp_n}$ is temperature rise due to greenhouse property (°C), and t_{si} is simulation time interval (1h).

The heat consumption coefficient (U_{cs}) related to wind speed shows an increasing linear change [9], and as the greenhouse insulation increases, the effect of the wind speed decreases [32]. In the model, the heat consumption coefficient is calculated according to Equation 2, developed by Rath [20].

$$U_{cs} = U + \frac{U}{x_1}(x_2 + v_w + x_3) \quad (2)$$

Where U is the heat transmission coefficient for the cover material at wind speed of 4 m s^{-1}, v_w is wind speed, and x_1, x_2, and x_3 are constants 7.56, 0.35, and 1.4, respectively.

The temperature rise in the greenhouse ($\vartheta_{i,th}$), which is neither heated nor ventilated to a certain temperature, is calculated according to Equation 3 [9, 33].

$$\vartheta_{i,th} = \frac{q_{GS} * D_G * \eta * A_G}{U_{cs} * (1 - EE_{ES}) * A_H} + \vartheta_a \quad (3)$$

Where $\vartheta_{i,th}$ is the theoretical temperature in a non-ventilated, unheated greenhouse (°C), q_{GS} is solar radiation (W m^{-2}), D_G is light transmittance of cover material, η is the conversion factor of solar energy to heat energy (standard = 0.7), A_G is the greenhouse floor area (m^2), and ϑ_a is the outdoor temperature (°C).

In the model, the temperature in the unheated and non-ventilated greenhouse (θ_{i,oH_n}) is determined according to logical relations, and taking the calculated theoretical temperature ($\vartheta_{i,th}$), ventilation temperature, and outdoor temperature into consideration. These logical relationships and equations are explained in detail in Baytorun, et al. [29].

Baytorun, et al. [17] tested the model in a commercial production greenhouse using lignite coal as fuel for heating. In their findings, they reported that the actual consumed heat energy during production season was measured at 77.80 kWh m^{-2}, and calculated as 75.44 kWh m^{-2} using the model. They also reported that the actual amount of consumed heat energy and the calculated amount of heat energy did not differ statistically, and that the model could be used safely in the calculation of heat power and heat requirement for greenhouses.

In the calculations, hourly average data on temperature, wind speed, and solar radiation were used for a total of 34 years between 1985 and 2018. There were approximately 289,000 records in each data set used for each province. The data provided from the Turkish State Meteorological Service were used in this data set. However, for some provinces, partially missing data were restored using the NOAA GSOD data set (http://www7.ncdc.noaa.gov/pub/data/gsod/).

Hourly values were calculated from the maximum and minimum temperature values for the restoration of the data set. The calculation method was performed according to the interpolation method [34], as described by Chow and Levermore [35].

The missing data for solar radiation were obtained from the nearest meteorological station. After the data set was prepared, the data were entered into a SQL-based database software. Then, using the ISIGER-SERA expert system software, we calculated hourly heat requirements for each year and province. The results were transferred to the database, and daily, monthly, and annual heat requirements were calculated from the sum of hourly heat requirements. The variability in heat requirement for years was determined by database queries. In addition, the seasonal variability was determined, and the proportional variation and standard deviations between the two periods were calculated. The overall statistical differences between the two periods were then investigated.

RESULTS

The heat requirements were calculated based on a standard greenhouse of the size and structure described in the previous section. This type of greenhouse is preferred because it has the same structural characteristics as the greenhouses commonly used in the area of investigation. For this study, we assumed that the greenhouse structure is constant in the region, and would therefore render more accurate results and allow for a more precise comparison.

Both the proportional changes between the average heat requirements that were calculated using the model for tomato production in the provinces of the Mediterranean region and the average heat requirements calculated for the periods 1985–2004 and 2005–2018 were calculated in groups of three months: September-November, December-February and March-May (Table 2). As there is no need for heating in the region during the June-July period, it is not shown in the table.

Table 1 shows that the highest annual greenhouse heat energy requirement was in Kahramanmaraş, at a maximum of 179.7 kWh m^{-2}, and the lowest in Mersin, with a minimum of 65.9 kWh m^{-2}. The highest variability in average annual energy requirements was in Antakya, with -24.5%,

TABLE 2
Annual and seasonal average heat requirements (kWh m^{-2} a^{-1}) and variability between the 2004-2018 and 1985-2004 cultivation periods

	*Mean Heat Req.	(Std)	Var. (%)	*Mean Heat Req.	(Std)	Var. (%)	*Mean Heat Req.	(Std)	Var. (%)	*Mean Heat Req.	(Std)	Var. (%)
Provinces		Annual			Dec-Feb			Mar-May			Sep-Nov	
Adana	97.5	16.9	-12.8	72.6	7.1	-7.8	15.9	6.0	-32.2	9.1	4.3	-15.0
Mersin	65.9	17.8	-17.7	51.8	6.7	-19.1	9.1	4.3	-52.2	5.0	3.0	-48.3
Antalya	100.1	20.2	-22.7	71.6	7.6	-10.8	18.9	6.9	-43.9	9.5	4.9	-56.0
Antakya	118.2	26.5	-24.5	90.4	10.1	-19.8	15.1	6.4	-46.8	12.7	6.1	-27.8
Kahramanmaraş	179.7	29.6	-15.3	126.7	11.5	-10.6	29.1	10.1	-35.5	23.8	9.8	-12.4
Osmaniye	111.3	18.7	-12.2	80.7	7.9	-12.5	18.6	6.4	-17.8	12.0	5.6	-0.4
Mean Var. (%)		-17.5			-13.4			-38.1			-26.7	

*Average for the years 1985-2018

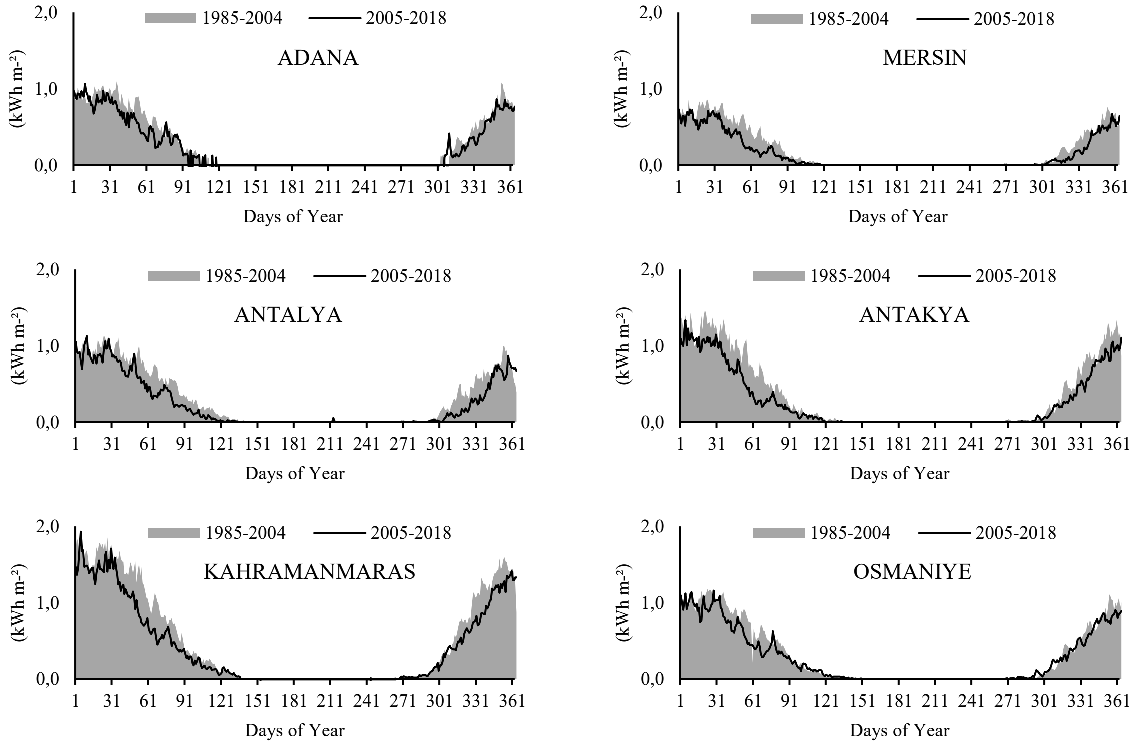

FIGURE 1
Daily average heat requirements for periods 1985-2004 and 2005-2018

and the lowest variability in Osmaniye, with -12.2%. The average heat requirement variability for all provinces between 1985-2004 and 2005-2018 was -17.5%. Seasonal evaluation reveals that there was maximum variability in heat requirement during the March-May period (-38.1%), and the least variability in December-February period (-13.4%). High variability during the transitional seasons is interesting.

Heating requirements may vary over the years depending on climatic conditions due to climate change. In order to investigate this variability on a daily basis, the average daily heat requirements of both periods are given in Figure 1.

Figure 1 shows that there is significant variability between 30-90 days of the year matching February and March. At the same time, there was a significant decrease in the daily heat requirements of the selected two periods, as well as a significant correlation between the periods for all provinces ($P<0.01$).

The average daily heat requirements for the whole period (1985-2018) are given in Figure 2.

According to the data, the oscillation was higher in the Kahramanmaras and Antakya provinces, where the heat requirement is relatively high, and the need for heating continues in the spring months (Figure 2). Mariani, et al. [36] reported that lower oscillations were observed in regions with low heat requirements. In Mersin, Adana, and Antalya, where heat requirements are low, a lower oscillation was observed.

The heat requirement decreased significantly in all provinces in February and March. Although there was only a slight decrease in the heat requirement in January in Kahramanmaraş and Adana, there was a decrease of approximately 16% in Antakya and Mersin.

The average annual heat requirement difference between the two periods was also investigated, and the difference between the periods was found to be statistically significant for all provinces ($P<0.05$). Independent-sample T test results are given in Table 3.

In order to investigate the relationships between heat requirements among the provinces, the heat requirements calculated on a provincial basis for all years were compared. The results of Spearman correlation analysis are given in Table 4.

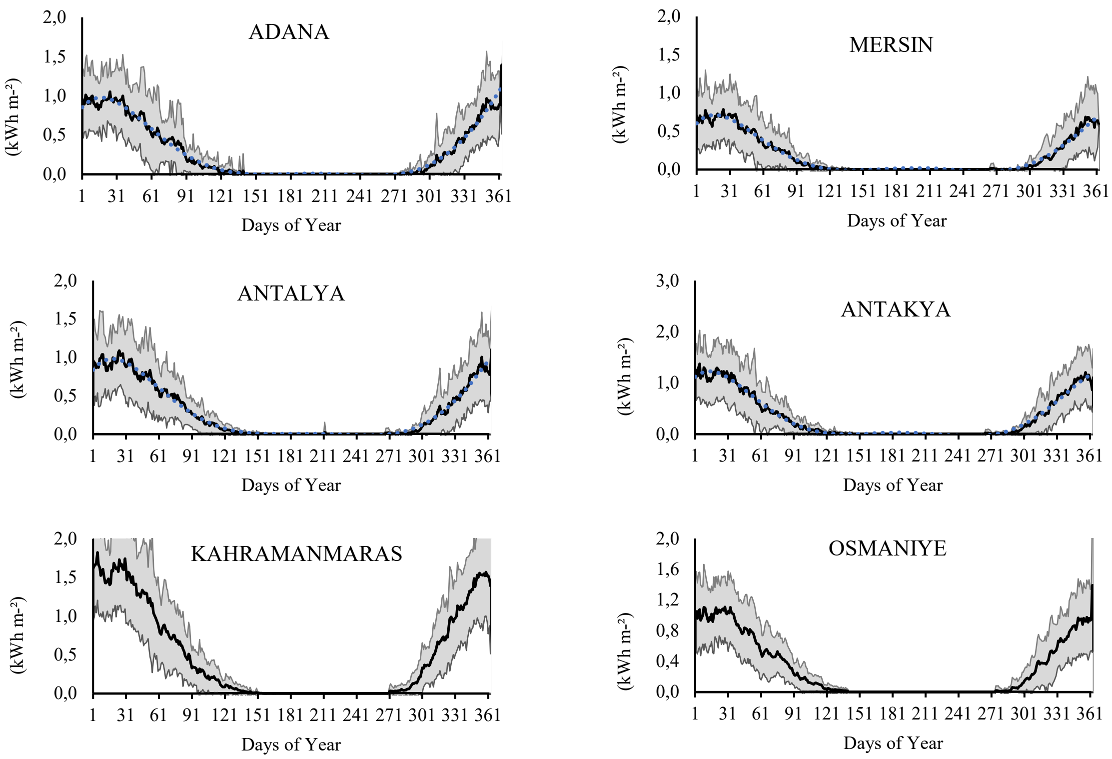

FIGURE 2
Heat requirement daily averages (gray area ± standard deviation; black line average)

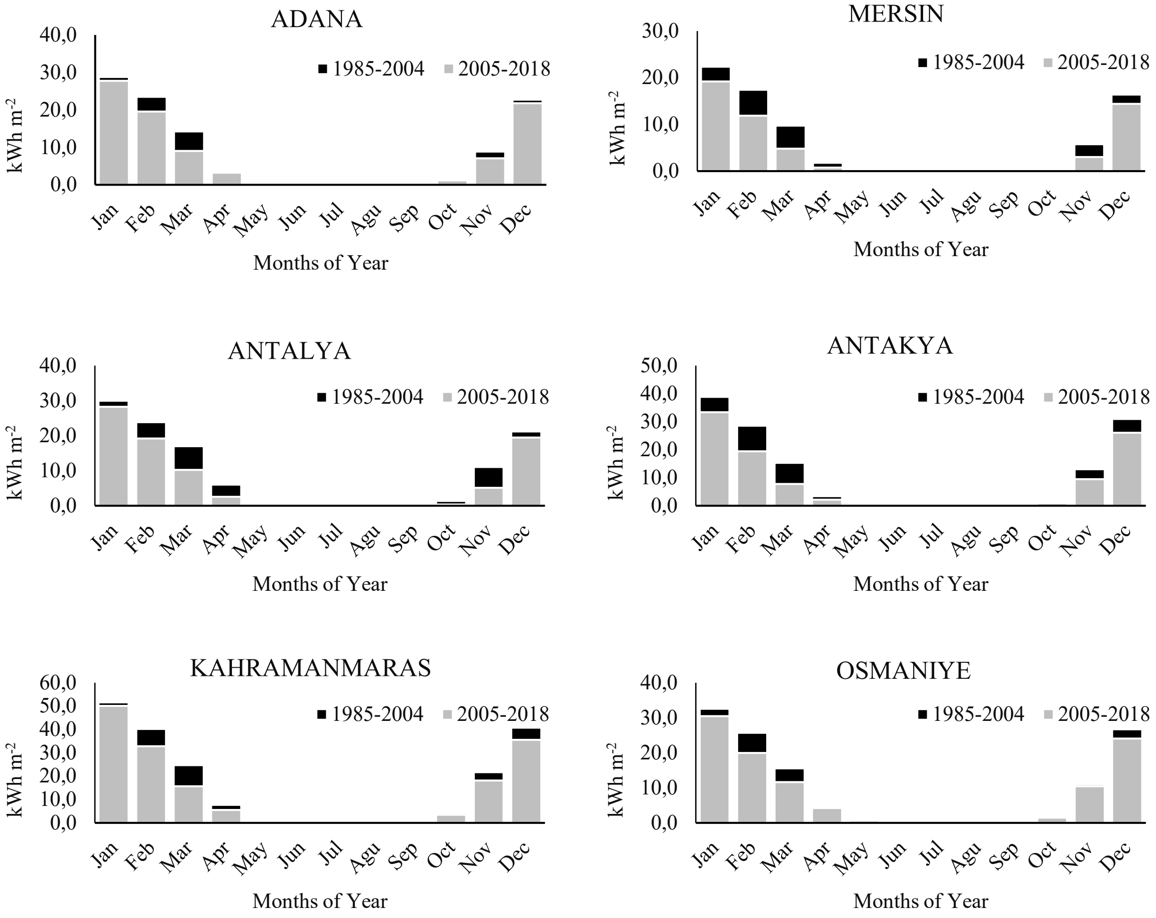

FIGURE 3
Average monthly heat requirements for the two periods (1985-2004 and 2005-2018)

TABLE 3
Independent-samples test results

Provinces	F	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Adana	0.070	2.353	32	0.025	13.174	5.598	1.771	24.578
Mersin	0.285	3.714	32	0.001	19.800	5.332	8.940	30.660
Antalya	0.089	4.385	32	0.000	25.110	5.727	13.445	36.775
Antakya	0.048	4.231	32	0.000	32.252	7.623	16.725	47.779
Kahramanmaras	2.272	3.162	32	0.003	29.326	9.276	10.433	48.220
Osmaniye	0.432	2.291	32	0.029	14.273	6.230	1.584	26.962

TABLE 4
Annual average heat requirements correlation analysis results

	Adana	Mersin	Antalya	Antakya	Kahramanmaraş	Osmaniye
Adana	1	0.556**	0.331	0.616**	0.712**	0.660**
Mersin	0.556**	1	0.861**	0.894**	0.688**	0.778**
Antalya	0.331	0.861**	1	0.755**	0.547**	0.649**
Antakya	0.616**	0.894**	0.755**	1	0.731**	0.793**
Kahramanmaraş	0.712**	0.688**	0.547**	0.731**	1	0.706**
Osmaniye	0.660**	0.778**	0.649**	0.793**	0.706**	1

**Correlation is significant at the 0.01 level (2-tailed)

The correlation between the provinces was found to be significant (*P<0.01*), apart from between Antalya and Adana (*P>0.05*). The highest correlation was found between Antakya–Mersin and Antalya–Mersin.

DISCUSSION

In many studies, researchers have reported that high yields can be achieved by ensuring optimum production conditions. The tomato prefers warm climates, like many plants grown in greenhouses, and has been adapted for an average temperature of 17–27 °C. When daily average temperatures exceed 12 °C, heating is not necessary in the greenhouse. If the daily average temperature rises above 27 °C, cooling systems must be installed in greenhouses. For good plant growth, the temperature difference between day and night should be 5–7 °C, and the absolute maximum temperature range is 35–40 °C [8, 11-14, 37].

Although there was a significant decrease in the heat requirement compared to the previous period, the findings suggest that the minimum conditions for tomato growth in greenhouses cannot be met without heating, particularly in December, January, and February

Many researchers have sought to determine the greenhouse heat requirement by using different methods that factor in all aspects affecting greenhouse heat balance [14, 38-43]. However, these methods may not produce accurate results if the calculations are made using average temperatures [33]. In addition, there is an average difference of 11% between calculations using long-term climate data average minimums, and calculations based on hourly temperature values [18]. The ISIGER-SERA expert system model used in this study makes hourly calculations by using real climate data that accounts for many factors affecting greenhouse heat balance. Therefore, the findings are more likely to be accurate.

In this study, the results revealed that there is a significant difference in greenhouse heat requirements between the two periods. In other words, the greenhouse heat requirement in the Mediterranean region has decreased compared to past years' requirements. We emphasize that the main reason for the reduction in greenhouse heat requirements is global warming and climate change. These effects of climate change disrupt the food market and pose risks to food supply worldwide [44]. Due to climate change, a yield decline of 18–45% is predicted for various agricultural productions toward the end of the century [45, 46]. National governments are taking measures to mitigate the impact of climate change on agricultural production, but these measures will not fully compensate for the negative effects of climate change [47].

From a greenhouse perspective, this may reduce production costs and strengthen the chances of competing in the global tomato market. However, there are some negative consequences. For example, there may be regional changes in crop production areas. Due to the increase in the effects of high temperatures in the summer, periods of non-production may be extended. Even in the spring, additional measures, such as cooling, may be required to produce tomatoes in the greenhouse.

The variability of greenhouse heat requirements should be taken into account, especially in long-term greenhouse investments in the planning of greenhouses in the region of investigation for this study. The model described in this study can be applied to different provinces and regions, and may be useful in determining the effect of global warming on greenhouse heat requirements on a broader scale. The findings may also be useful in determining the production period and appropriate plant species.

CONCLUSION

The greenhouse heat requirement varies depending on the climate conditions in the region, as well as the characteristics of the greenhouse structure, heating system, and heat-saving measures. In this research, we evaluated the conditions of the modern greenhouse system in which heat saving measures are applied. We divided the climate data for the last 34 years into two groups, and calculated the hourly greenhouse heat requirement. In order to compare the results, we assumed that all provinces had the same greenhouse structure. This made it possible to observe only climate-related changes. The results show that there is a significant variability in heat requirement between the two periods. We argue that this variability is caused by global warming. The variability in heat requirement may affect production locations and crop selection. This research may be useful in determining the energy required for heating, greenhouse location, and crop selection in greenhouse planning in the region.

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