Chapter 9

Climate Control in Mediterranean Greenhouses

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Additional information is available at the end of the chapter

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Abstract

As climate control in greenhouses directly affects crop yields, there is an increasing trend for advancements in environmentally controlled agricultural-production techniques. In the Mediterranean region, the temperatures during the period from December to February are below 12°C when the daily total radiation 8.4 MJ/m^2day. Based on the region's climate data, greenhouses require heating during the period from November to March, ventilation and shading from February to May and cooling from June to September. In order to maintain day and night temperatures of 18/16°C, annual heat energy requirement of PE greenhouses is 95-256 kWh/m^2. In view of environment and production costs, conservation of heating energy is as important as heating itself. Heat energy saving is about 37% when energy curtains are used. Greenhouse temperature can be increased by 8°C in palliative non-heated greenhouses where energy curtains and water mattresses are used in addition to passively used solar energy. Ventilation openings at the roofs of these greenhouses should adequately be 20-25%. When outside noon-time temperature is above 30°C in June, evaporative cooling of greenhouse is essential. Depending on outside humidity and volume of exchanged air for cooling, a temperature difference of 6°C can be achieved with evaporative cooling of greenhouses in August.

Keywords: greenhouse heating, energy saving, ventilation, cooling

1. Introduction

Countries need to increase the efficiency and quality of their agricultural production in order to meet their future requirements in line with population increase. In our country, it has become necessary to take particular measures due to rapid population increase and globalization of trade. Growing fruits and vegetables in controlled environments with low production costs is among these measures to be taken.

Controlling environmental conditions in agricultural production has direct influence on efficiency. For this reason, environmentally controlled agricultural techniques have developed at an increasing rate. In environmentally controlled plant production systems, it is aimed to change natural environmental factors according to the optimum requirements of plants. The most common and effective implementation of environmentally controlled plant production takes place in greenhouses.

The objective of innovative technologies in greenhouses is to improve "Quality of Life Cycles." Therefore, in order to achieve sustainability, it is highly important to correctly analyze the inputs and outputs required for the efficiency to be obtained from a unit area in greenhouses [1].

Sustainable greenhouse systems should be equipped with resource conserving, socially supported, commercial, competitive, environmentally friendly, reliable production technologies, and they should aim to reduce energy, water and chemical pesticide requirements besides avoiding waste production [2].

Greenhouse practices in Turkey started first in the 1940s in the Mediterranean region, particularly in Antalya, and then spread to the Aegean and Marmara regions depending on ecological conditions. The Mediterranean region has 84% of the country's total greenhouse area, followed by the Aegean, Black Sea and Marmara regions with 9.4, 4.8 and 1.7%, respectively.

With 22,000 ha, Antalya has 37% of the country's total greenhouse area. A total of 32,000 ha of the 61,500 ha greenhouse area in the country consists of greenhouses, which are defined as high greenhouse systems [3, 4]. As big investment groups entered the sector, modern greenhousing has rapidly developed and reached a level of 1000 ha. This figure increases by 150–200 ha every year. Nowadays, modern greenhousing is practiced in 3% of our total greenhouse area, and in the following decade, this share is expected to reach 15% [5].

In terms of equipment and technology, greenhouses in the Mediterranean region can be divided into two groups:

1. *Greenhouses with low technology:* These greenhouses have simple iron structures. They are covered with PE plastic or mixed PE plastic. Starting from 1987, galvanized pipes have been used in greenhouses built with government support provided within the framework of Resource Utilization Support Fund (RUSF). These greenhouses with ventilation openings only on the sidewalls have been built as blocks consisting of four sections. In all greenhouses installed with RUSF support, drop irrigation systems are used, and these greenhouses are heated on a regular basis.

2. *Modern greenhouses with high technology:* These greenhouses require quite high initial investment costs, which are considered as big businesses. They are generally built with galvanized steel and aluminum materials. As cover material glass, mixed PE plastic or double pane PC is used. They are projected as high volume structures. In these types of greenhouses, modern production techniques like soilless agriculture are used. Their irrigation systems are projected as computer-aided closed systems, and they have central heating systems. In addition to natural ventilation, these greenhouses have fans that provide air circulation. Greenhouses, in which ornamental plants are grown, have evaporative cooling systems. During hot periods, besides cooling, moving shading systems are activated.

2. Climatic values in the Mediterranean region

The most important climatic parameters in greenhouse cultivation are solar radiation, day length and temperature values. Solar radiation is one of the most important climatic parameters to be taken into consideration in a location where a greenhouse is going to be built. Total daily solar radiation in a greenhouse location should be minimum 8.5 MJ/m^2 day (2.34 kWh/m^2day) [6]. However, insolation time is as important as solar radiation. Products grown in greenhouses require an average of 6 h of day length. In other words, during months with short day length (e.g., November, December and January), total day length should be minimum of 500–550 h [6].

Total annual insolation time and intensity of radiation in Turkey are 2.640 h (7.2 h/day) and 1.311 kWh/m^2year (3.6 kWh/m^2day), respectively. In **Tables 1** and **2**, long-year average total daily radiation values and insolation time for some cities on the Mediterranean coastline are given. As can be seen from the tables, insolation time and total daily solar radiation values in the Mediterranean region are above average values in whole Turkey.

Vegetables grown in greenhouses have adapted to an average temperature of 17–28°C. Products grown in greenhouses undergo stress at temperatures below 12°C and above 32°C. At low temperature values like frost, irreversible harms occur. Greenhouses should be heated when the outside temperature falls below 12°C. When outside temperature is between 7 and 12°C, heating is necessary only during night hours. For desirable plant growth, the difference between night and day temperatures should be 5–7°C [6].

City	January	February	March	April	May	June	July	August	September	October	November	December
Adana	1.98	2.42	4.12	4.98	6.07	6.68	6.46	5.91	4.90	3.78	2.33	1.81
Antalya	2.12	2.57	4.37	5.47	6.36	6.93	6.65	6.14	5.16	3.93	2.51	1.92
Hatay	1.99	2.42	4.01	4.87	5.96	6.63	6.31	5.82	4.75	3.63	2.35	1.79
İçel	2.11	2.65	4.27	5.24	6.28	6.86	6.66	6.08	5.04	3.84	2.47	1.91
Muğla	2.11	2.42	4.24	5.40	6.22	6.81	6.47	6.05	5.05	3.96	2.56	1.88
Turkey	1.79	2.50	3.87	4.93	6.14	6.57	6.50	5.81	4.81	3.46	2.14	1.59

Table 1. Total daily radiation values in different cities in the Mediterranean region (kWh/m^2day).

City	January	February	March	April	May	June	July	August	September	October	November	December
Adana	4.67	5.65	6.97	7.84	9.72	11.29	11.17	11.22	10.15	7.78	5.86	4.21
Antalya	4.95	6.10	7.24	8.29	9.70	11.55	11.84	11.29	9.80	7.68	5.97	4.55
Hatay	5.09	6.22	7.17	8.28	10.23	11.14	10.89	10.47	9.80	7.86	6.37	4.99
İçel	4.99	6.04	7.35	8.38	9.94	11.18	11.45	11.03	10.02	7.91	6.15	4.64
Muğla	5.13	6.20	7.12	8.18	9.91	11.73	11.90	11.31	9.92	7.85	6.01	4.67
Turkey	4.11	5.22	6.27	7.46	9.10	10.81	11.31	10.70	9.23	6.87	5.15	3.75

Table 2. Insolation time in different cities in the Mediterranean region (h).

At temperatures between 12 and 22°C, by using passive acclimatization (natural ventilation), it is possible to arrange the greenhouse environment according to the values required by plants. When outside temperature exceeds 27°C, it is necessary to install highly expensive cooling systems in greenhouses. The greenhouses on the Mediterranean region should be left idle during the specified periods.

The graphical representation of long year average temperatures and total daily radiation values of Mediterranean cities Antalya (36°:53′ N), Mersin (36°:48′ N) and Hatay (36°:14′ N) is given in **Figure 1**. As seen in the figure, total daily radiation in all these three cities on the Mediterranean coastline is below 2.3 kWh/m^{2}day (8.4 MJ/m^2 day) during December and January. This indicates that solar radiation is insufficient for plant growth during these 2 months. In order to allow more solar radiation into the greenhouse in December and January, greenhouse roofs should be covered using a material with high impermeability. The 1% decrease in intensity of light reaching the greenhouse results in the same decrease in efficiency.

Another factor that affects plant growth is day length. Total day length in Antalya during November–January in Antalya is 474 h. This value is close to the limit value, which is accepted as 500–550 h.

An overview of the temperature values of cities in the Mediterranean region (**Table 3**) shows that average daily temperature during the period between December and February is below 12°C. However, as average temperature during these months does not fall below 7°C, producers in this region prefer cold greenhousing and take simple heating measures in order to continue production during very cold days.

One of the main problems in unheated PE plastic greenhouses in the Mediterranean region is that greenhouse temperature falls below outside temperature on nights when the sky is clear. This results from the fact that PE plastic transmits long-wave heat rays on a specific band. In their measurements taken in glass and PE plastic greenhouses in the Mediterranean region

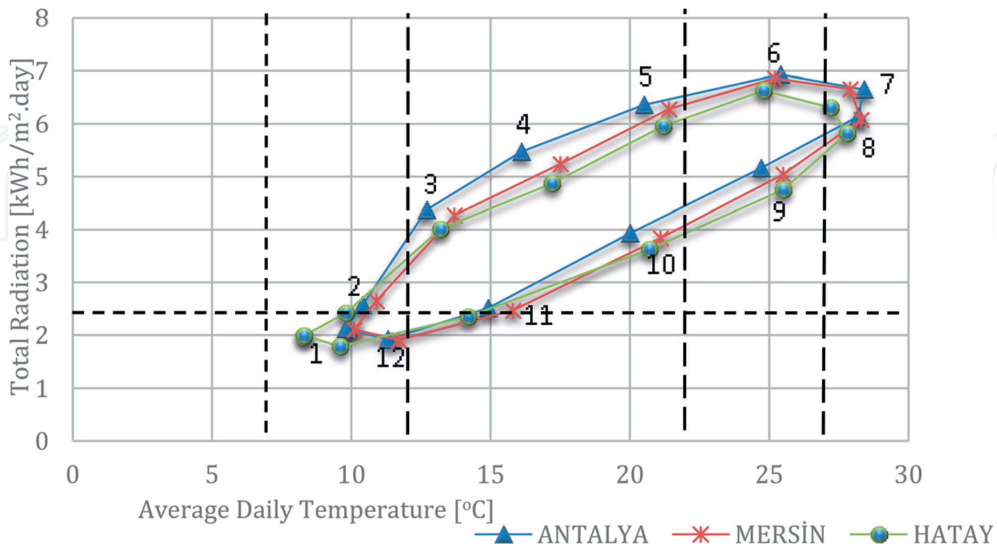

Figure 1. Average daily temperatures and total radiation values in three cities in the Mediterranean region: Antalya (36°:53′ N), Mersin (36°:48′ N) and Hatay (36°:14′ N).

City	January	February	March	April	May	June	July	August	September	October	November	December
Adana	9.6	10.6	13.6	17.6	21.7	25.6	28.2	28.6	26.1	21.8	15.7	*11.1*
Hatay	8.1	9.8	13.2	17.1	21.1	24.8	27.2	27.8	25.7	20.8	14.2	*9.5*
Antalya	9.9	10.4	12.8	16.1	20.3	25.1	28.2	28.0	24.9	20.3	15.1	*11.4*
Mersin	10.3	11.1	13.9	17.4	21.1	24.8	27.7	28.2	25.7	21.5	16.1	*11.9*
Muğla	5.3	5.9	*8.6*	12.5	17.7	22.9	26.3	26.1	21.8	16.1	*10.5*	*6.8*

Table 3. Average daily temperature values of different cities in the Mediterranean region (°C).

Cover material	Outside temperature (°C)	Inside temperature (°C)	($t_i - t_o$) (°C)
Plastic	9.3	9.0	−0.3
	10.3	9.0	−1.3
	8.1	8.1	0.0
Glass	7.3	9.1	1.8
	6.8	7.7	0.9
	8.3	10.1	1.8

Table 4. Inside and outside temperature values recorded on different days in an unheated PE plastic greenhouse (time 17:00–07:00 Average values).

(Adana), it is observed that the temperature falls below outside temperature in PE greenhouses without thermal curtains [7]. This situation was not seen in unheated glass greenhouses (**Table 4**).

In order to achieve year-long production in greenhouses in the Mediterranean region, greenhouses should be heated during night hours in the winter, ventilated and shaded in transition periods and cooled during hot periods. As cooling is a very costly acclimatization measure, it is not a preferable method for greenhouses, which are usually left idle during such periods.

2.1. Heating

Total daily solar energy values for Antalya (36°:53′ N) in different months and required daily heat energy values for PE plastic and glass greenhouses for specific temperatures are given in **Table 5**. As can be seen from **Table 6**, total daily solar energy reaching the greenhouse in Mediterranean climatic condition exceedingly meets the heat energy requirement in all months of the year. However, only some of the solar energy reaching the greenhouse during day hours can be stored. Heat losses that occur through the cover material immediately after sunset lead to rapid decreases in greenhouse temperature.

Heating in greenhouses has a significant effect on production costs. Heat energy requirements of plastic greenhouses installed in the Mediterranean region vary depending on climate of the location, greenhouse type and greenhouse equipment.

Months	January	February	March	April	May	June	July	August	September	October	November	December
Q_{sun}	2.12	2.57	4.37	5.47	3.37	6.93	6.65	6.0	5.17	3.93	2.52	1.92
							PE plastic greenhouse					
$Q_{(16)}$	1.06	0.94	0.57	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.79
$Q_{(17/18)}$	1.27	1.13	0.73	0.31	0.00	0.00	0.00	0.00	0.00	0.04	0.49	0.98
							Glass greenhouse					
$Q_{(16)}$	1.04	0.92	0.53	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.75
$Q_{(17/18)}$	1.27	1.13	0.69	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.96

Table 5. Daily solar energy reaching the greenhouse in Antalya climatic conditions required daily heat energy values for PE plastic and glass greenhouses for different temperatures (kWh/m^{2}day).

Greenhouse requirement	Heat energy requirement kWh/m^2 a				
	Antalya	Adana	Mersin	Hatay	Muğla
Single pane plastic	126.6	113.6	95.5	140.2	256.3
Roof single, side wall double pane PE plastic	118.3	106.3	89.3	130.6	239.2
Roof single, side wall double pane PE plastic + Thermal curtain moderately insulated	95.1	87.4	72.7	107.7	198.3

Table 6. Heat energy requirements during the production year for different PE plastic greenhouses in some cities in the Mediterranean region when night/day temperature is kept at 16/18°C [8].

Daily heat energy values based on climatic conditions of Antalya for weeks of the year when greenhouse temperature is kept at 18/16°C, 18/14°C and 16/12°C are given in **Figure 2**. As can be seen from the figure, daily heat energy requirement varies between 0 and 1.3 kWh/m^{2}day depending on the desired greenhouse temperature. A similar change is observed during hours of the day. Heat power requirement in plastic greenhouses installed in the Mediterranean region from 04:00 to 07:00 in January is 85 W/m^2, while after 08:00 this value drops to 0 W/m^2 [8].

Heat power iterations required for a single pane PE plastic greenhouse in Antalya climatic conditions with temperature kept at 14, 16 and 18°C are given in **Figure 3**. As can be seen from the figure, there is need for high heat power only during a very short period of the year. In Mediterranean climatic conditions, 3012 h of heating is required when day/night temperature is kept at 18°C. When temperature is dropped to 16°C, 2567 h of heating is required.

Heat energy values required throughout the production period for greenhouses in different cities in the Mediterranean region are given in **Table 7**. These values are for greenhouses with different equipment and when day/night temperature is kept at 16/18°C and ventilation temperature is kept at 25°C [8]. As can be seen from the table, for each type of greenhouse equipment, the lowest heat energy requirement is observed in Mersin (36°:48′ N) with 72.7 kWh/m^{2}a, while the highest heat energy requirement is observed in Muğla with 198.3 kWh/m^{2}a.

In the Mediterranean region, greenhouses with low technology are not heated. On days when the temperature is low, plants are protected from frost with the help of simple heating stoves.

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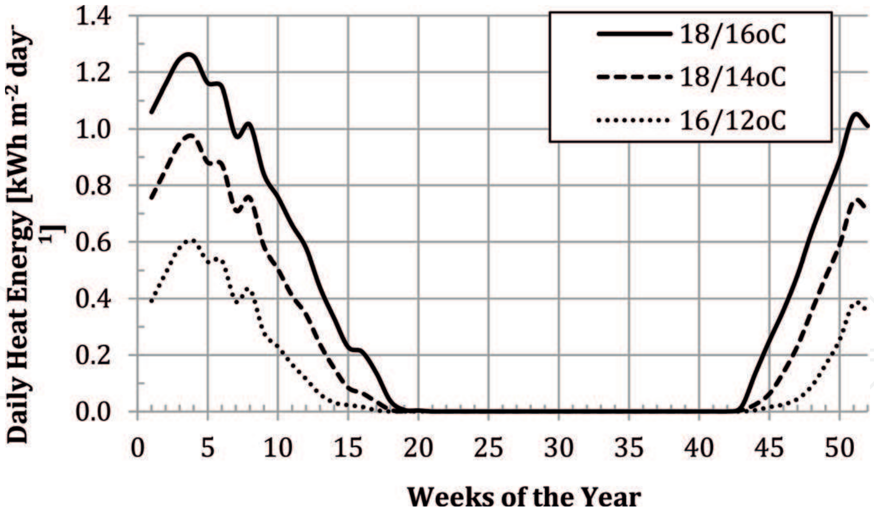

Figure 2. Daily heat energy requirements depending on different day/night temperature values for a single pane PE plastic-covered greenhouse in Antalya climatic conditions (kWh/m^{2}day).

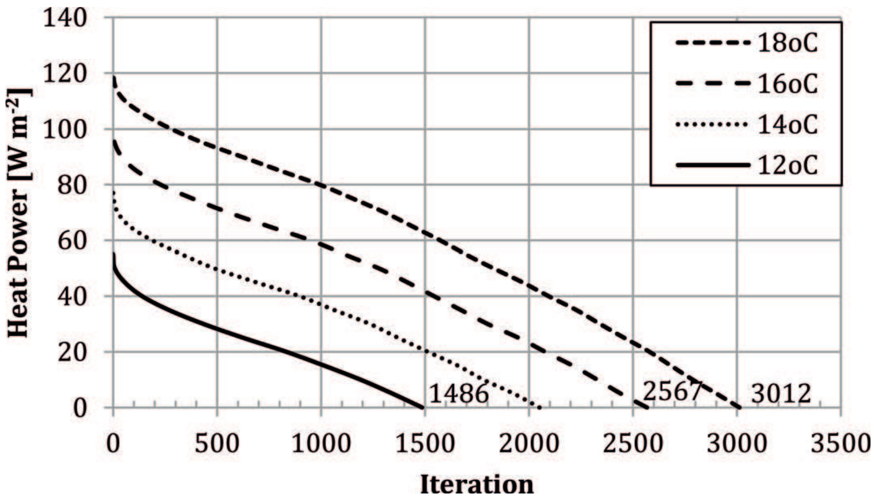

Figure 3. Heat power iterations for different greenhouse temperatures in Antalya climatic conditions.

Cover material	Outside temperature (°C)	Under curtain temperature (°C)	Over curtain temperature (°C)	$(t_{i\text{-palt}}-t_o)$ (°C)	$(t_{i\text{-püst}}-t_o)$ (°C)
Plastic	9.1	10.7	8.8	1.6	−0.3
	5.0	5.6	3.3	0.6	−1.7
	8.5	10.0	7.8	1.5	−0.7
Glass	9.0	12.7	9.5	3.6	0.5
	8.2	12.0	8.6	3.7	0.4
	10.1	13.6	10.7	3.4	0.6

Table 7. Under curtain, over curtain and outside temperature values in unheated plastic and glass greenhouses with thermal curtains opened and closed (time 17:00–07:00 Average values).

However, with this kind of heating, heat energy is not distributed properly in the greenhouse, and plants close to the heating stove are harmed. In small family businesses, pipe heating systems are not economical due to greenhouse sizes and initial investment costs. In these businesses, instead of pipe heating, low-cost direct-fire air blast heating systems are preferred.

2.2. Heat energy conservation

As much as greenhouse heating, conservation of heat energy has great importance due to increasing energy prices and CO_2 releases of energy sources. In order to conserve heat energy in greenhouses, multipane cover materials may be used. However, besides temperature and humidity values, light (PAR) in the greenhouse should be kept at the highest levels as it is one of the most significant factors for plant growth. For these reasons, it is suggested to cover the side walls of greenhouse in the Mediterranean region with multipane cover material for heat conservation, while the roof area should be covered with single pane material in order to allow sufficient light into the greenhouse.

Thermal curtains are used for heat conservation in greenhouses. Average under curtain, over curtain and outside temperatures measured in unheated glass and PE plastic Mediterranean greenhouses with open and closed thermal curtains between 17:00 and 7:00 are given in **Table 7**. As can be seen from the table, under curtain temperature in the PE plastic greenhouse with thermal curtains closed is above outside temperature, while over curtain temperature values are below outside temperature. In the glass greenhouse, both under curtain and over curtain temperature values recorded are above outside [7, 9].

Depending on the properties of thermal curtains, heat conservation in heated greenhouses can be achieved at different ratios. In **Figure 4**, fuel quantities based on temperature differences (ΔT) in a PE plastic greenhouse with and without thermal curtains are given [7]. When the thermal curtain is open, the amount of fuel (diesel) required for a 7 K temperature difference is

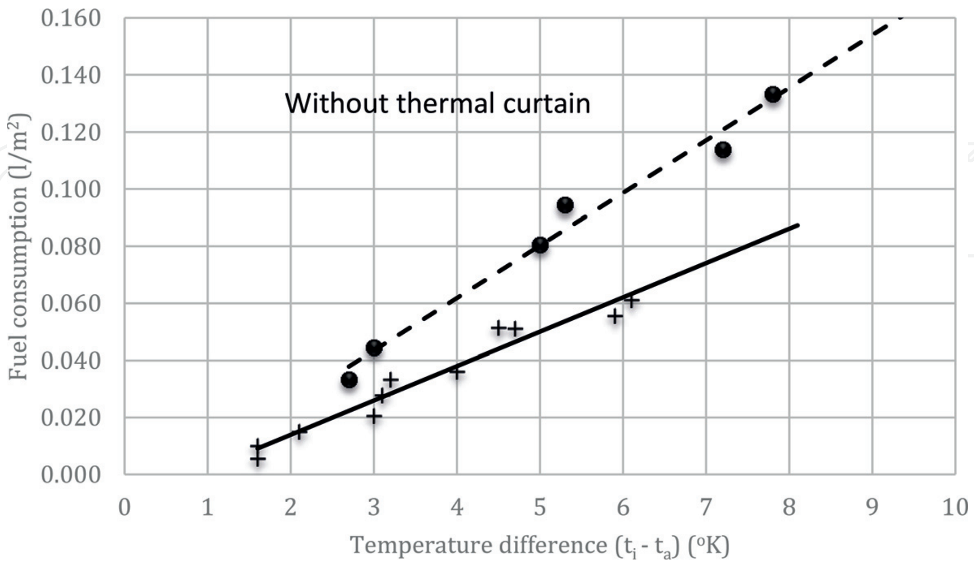

Figure 4. Fuel consumption based on temperature differences (ΔT) in a PE plastic greenhouse heated with direct-fired air blast heating system, with thermal curtains opened and closed.

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0.118 l/m^2. The fuel requirement for the same temperature difference with the thermal curtain closed is 0.074 l/m^2. This is equivalent to a 37% energy saving in a greenhouse with a direct-fired air blast heating system.

Impermeability of thermal curtains used in greenhouses is very important in terms of energy savings. Edges where thermal curtains meet the side walls and facades should be leakproof. Otherwise, transfer of heated and rising air through the roof cover material will be unavoidable. Annual heat energy and saving ratios calculated based on the impermeability of thermal curtains in PE plastic greenhouses under Mediterranean climatic conditions with night/day temperature 16/18°C and ventilation temperature 25°C are given in **Table 8** [9]. As can be seen from the table, there will be a 27% difference in energy savings between thermal curtains with perfect insulation and those with poor insulation.

2.3. Passively benefiting from solar energy in unheated greenhouses

In Mediterranean climatic conditions, there is no need for heating during day hours as solar energy reaching the greenhouse exceedingly meets the daily energy requirement of the greenhouse. However, after sunset, greenhouse temperature drops rapidly depending on the thermal properties of the cover material. In a study aiming to passively benefit from solar energy in greenhouses with low technology, water mattresses consisting of transparent PE tubes (with a diameter of 31.8 cm, width of 150 μm and water capacity of 80 l/m) were placed between plant rows. Measurements showed that in the case of using water mattresses in a glass greenhouse, the temperature difference is 2.8–3.4°C, while in a greenhouse without water mattresses, this value is 1.2–2.7°C (**Table 9**) [7].

While the temperature difference in a glass greenhouse with thermal curtains and water mattresses ranges from 6.3 to 8.1°K, the temperature difference in a greenhouse with thermal curtains but without water mattresses were recorded as 1.6 to 2.2°K (**Table 10**) [7].

2.4. Ventilation

In the Mediterranean region, it is necessary to ventilate greenhouses during day hours of the winter months. Ventilation in winter months is done more to regulate CO_2 concentration than

Greenhouse equipment	Heat energy requirement [kWh/m^{2}a]			Savings ratio [%]	
	Impermeability				
	Good	Average	Poor	Good-Average	Good-Poor
Without thermal curtain	118.3				
With thermal curtain	80.5	95.1	109.6	15.4	26.6
Savings ratio	32.0	19.6	7.4		

Table 8. Heat energy requirements based on the impermeability of thermal curtains in PE plastic greenhouses with single pane roof and double pane side walls under Antalya climatic conditions with night/day temperature 16/18°C [7].

$t_{o,min}$(°C)	$t_{i,min\text{-}tube}$ With water mattresses (°C)	$t_{i,min\text{-}tubeless}$ Without water mattresses (°C)	ΔT With water mattresses (°C)	ΔT Without water mattresses(°C)	$t_{tube}-t_{tubeless}$ (°C)
2.9	6.1	4.1	3.2	1.2	2.0
3.0	5.8	4.7	2.8	1.7	1.1
4.1	7.5	6.8	3.4	2.7	1.7

Table 9. Minimum temperature differences obtained in an unheated Mediterranean greenhouse with water mattresses (°C).

$t_{o,min}$(°C)	$t_{i,min\text{-}tube}$ With water mattresses (°C)	$t_{i,min\text{-}tubeless}$ With water mattresses (°C)	ΔT With water mattresses (°C)	ΔT Without water mattresses (°C)	$t_{tube}-t_{tubeless}$ (°C)
0.0	6.8	2.2	6.8	2.2	4.6
1.8	8.1	3.5	6.3	1.7	4.6
5.2	11.6	6.8	6.4	1.6	4.8
−0.1	8.0	2.0	8.1	2.1	6.0

Table 10. Minimum temperature differences obtained in an unheated Mediterranean greenhouse with thermal curtains and water mattresses (°C).

to send away high temperatures. It is only possible to obtain the temperatures that plants have adapted to (17–27°C) by regular ventilation from mid-February until the first week of May [5]. In the evaluations based on long year hourly temperature data for Antalya (36°:53′ N), where greenhousing is a common agricultural practice, it is seen that the temperature is above 26°C in 1628 h of the year (**Table 11**).

Temperature iterations for temperatures above 26°C based on the ratio of ventilation openings to greenhouse floor area are given in **Table 10**. As can be seen from the table, as the ratio of ventilation openings to greenhouse floor area increases, iterations for temperatures above 26°C decrease. In Antalya climatic conditions, when the ratio of ventilation openings to greenhouse floor area is 20%, during 206 h of the total 744 h of May, the greenhouse temperature is above 26°C.

Taking into consideration the long year hourly climatic values of Antalya, hourly temperature values calculated for greenhouses with different ventilation openings are given in **Table 12**. As can be seen from the table, average outside temperature values obtained from long year climatic values in May vary between 16 and 26°C. The simulation calculations show that when the outside temperature is 25.7°C at 12:00 in May, temperature in a greenhouse with 5% ventilation opening is 30.4°C and temperature in a greenhouse with 10% ventilation opening is 28.5°C.

2.5. Ventilation and shading

Starting from the first week of May, greenhouses in the Mediterranean region are shaded with clay or whitewash. With shading, greenhouse temperature rises are prevented by reducing solar radiation that reaches the greenhouse. In greenhouses installed in recent years, solar

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radiation is reduced by partially opening thermal curtains. In June, under Antalya climatic conditions, when radiation reaching the greenhouse is reduced by 50% with shading and when the ratio of ventilation openings is 20%, greenhouse temperature is above 26°C for 96 h.

A_V/A_G	January	February	Mach	April	May	June	July	Augusts	September	October	November	December	Total
	Number of hours when outside temperature is above 26°C												
	0	0	0	0	0	311	487	466	298	66	0	0	1628
	Number of hours when greenhouse temperature is above 26°												
0.01	102	145	237	290	366	405	518	488	357	288	200	105	3501
0.05	0	0	78	205	335	389	504	480	336	254	98	0	2679
0.10	0	0	0	82	278	382	496	479	329	222	40	0	2308
0.15	0	0	0	18	246	375	489	477	323	201	10	0	2139
0.20	0	0	0	5	206	373	488	476	321	177	2	0	2048
0.25	0	0	0	0	160	370	488	474	320	163	0	0	1975
0.30	0	0	0	0	130	367	488	474	319	148	0	0	1926
0.35	0	0	0	0	113	362	487	474	318	142	0	0	1896
0.40	0	0	0	0	99	357	487	474	317	134	0	0	1868

Table 11. Temperature iterations for temperatures above 26°C outside the greenhouse and in a plastic greenhouse with different ventilation opening ratios under Antalya climatic conditions in May (h).

Time	Ratio of ventilation opening ratio to greenhouse floor area ($\frac{A_V}{A_G}$) (%)					Outside temperature t_a (°C)
	1	5	10	15	25	
	Temperature in the greenhouse t_i (°C)					
7	23.1	21.7	21.1	20.8	20.6	20.0
8	28.0	25.5	24.4	23.9	23.4	22.4
9	32.0	28.4	26.9	26.2	25.6	24.2
10	34.6	30.0	28.2	27.4	26.6	25.3
11	35.7	30.4	28.5	27.7	27.0	25.6
12	36.1	30.4	28.5	27.7	27.0	25.7
13	35.7	30.1	28.3	27.5	26.8	25.6
14	34.8	29.6	27.9	27.2	26.6	25.5
15	33.1	28.7	27.2	26.6	26.1	25.1
16	30.5	27.3	26.2	25.7	25.3	24.5
17	28.0	25.9	25.1	24.8	24.5	23.9
18	25.0	24.0	23.6	23.4	23.2	22.9
19	22.0	21.8	21.8	21.7	21.7	21.6

Table 12. Inside temperature values calculated for a plastic greenhouse with different ventilation opening ratios (A_V/A_G) under Antalya climatic conditions in May.

Time	Ratio of ventilation opening ratio to greenhouse floor area ($\frac{A_V}{A_G}$) (%)					Outside temperature t_a (°C)
	1	10	15	20	25	
	Temperature in the greenhouse t_i (°C)					
7	27.0	25.8	25.6	25.5	25.5	25.1
8	30.3	28.3	28.0	27.9	27.8	27.3
9	32.8	30.1	29.7	29.5	29.4	28.8
10	34.5	31.1	30.7	30.5	30.3	29.6
11	35.4	31.5	31.1	30.8	30.6	29.9
12	35.6	31.6	31.2	31.0	30.8	30.1
13	35.1	31.2	30.8	30.6	30.4	29.8
14	34.5	30.8	30.5	30.3	30.1	29.6
15	*33.6*	*30.5*	*30.2*	*30.0*	*29.9*	*29.4*
16	*32.3*	*29.9*	*29.6*	*29.5*	*29.4*	*29*
17	*30.7*	*29.0*	*28.8*	*28.7*	*28.7*	*28.3*
18	*28.9*	27.9	27.8	27.7	27.7	27.5
19	26.5	26.3	26.2	26.2	26.2	26.1

Table 13. Temperature values calculated for different ratios of ventilation openings in a plastic greenhouse where 50% shading is done in June, under Antalya climatic conditions.

Although solar radiation causing increases in greenhouse temperatures under Mediterranean climatic conditions can be reduced to a certain degree with shading, it is not possible to obtain the environment temperature that can be tolerated by plants using shading in certain months of the year. Temperature values based on hours of the day and ratios of ventilation openings for a plastic greenhouse where 50% shading is done during June are given in **Table 13**. As can be seen from the table, even when the ratio of ventilation openings to greenhouse floor area is 25%, temperature values in a shaded greenhouse are above 30°C at 10.00–14.00. Under these conditions, evaporative cooling becomes necessary for continuation of plant growth.

2.6. Cooling

When average daily temperature is above 22°C and the maximum temperature is 27°C, active cooling in the greenhouse is necessary [10]. When average daily temperature values of the Mediterranean climate zone are reviewed, it is seen that starting from June average temperature values are above 22°C (**Table 3**).

Temperature and humidity values calculated in August for a glass greenhouse in Adana (37°:01′ N) with shading and evaporative (Fan&Pad) system is given in **Figure 5**. As can be seen from the figure, in the Mediterranean region, outside temperature values during the day can be as high as 35.2°C in August. Despite shading and evaporative cooling, temperature in the greenhouse reached 29.1°C at 15:00. As can be seen from the figure, humidity values throughout the day varied between 90 and 98%. In Adana climatic conditions, using shading and active cooling in August resulted in a temperature difference (ΔT) of 6.1 K [11].

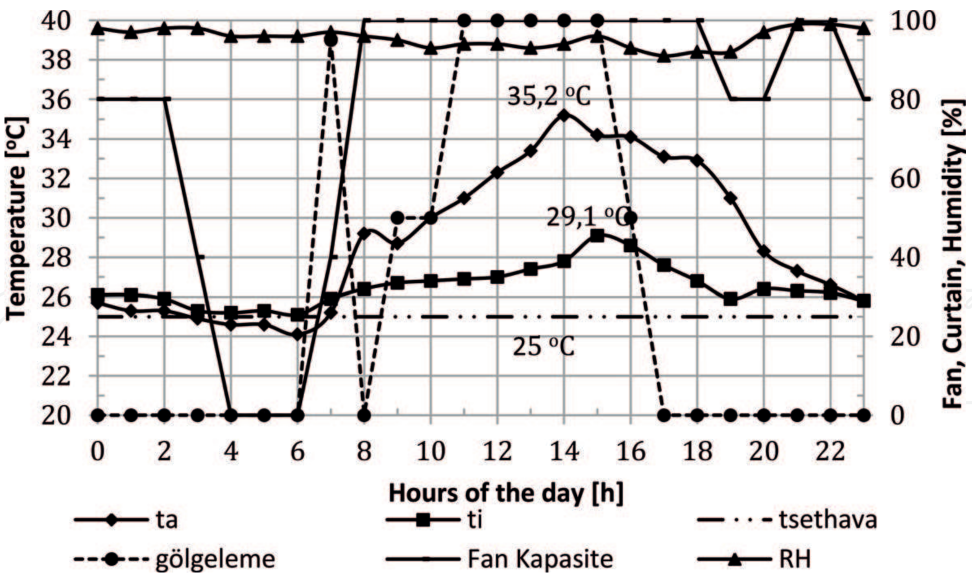

Figure 5. Temperature values calculated in August for a glass greenhouse obtained with shading and evaporative cooling.

3. Result and evaluation

In order to be able to achieve high-quality production and efficiency in the Mediterranean climate zone, greenhouses should be heated during November–March, ventilated and shaded during February–May and cooled during June–September. On the Mediterranean coastline, simple greenhouses are not heated regularly as average daily temperature does not fall below 7°C. In such businesses, when the temperature is very low, plants in the greenhouse are protected against frost using simple methods. Depending on the production (single production, spring or fall production), a 9–12 kg/m^2 efficiency can be obtained in tomato production. In simple plastic greenhouses, it is not economical to install pipe heating systems due to greenhouse dimensions and cost of heating systems. In these greenhouses, instead of pipe heating systems, direct-fire air blast heating systems could be used. However, in this case, it is necessary to choose cheap fuel as well.

In greenhouses built on the Mediterranean coastline in recent years, central heating systems are installed, and coal is used as fuel. Heat requirement of a single pane PE plastic greenhouse on the Mediterranean coastline, in which there is no heat conservation and day/night temperature is kept at 18/16°C day/night, varies between 95 and 256 kWh/m^2 depending on the climatic properties of the greenhouse site. This is equivalent to approximately 18–47 kg/m^2 year imported coal.

As much as greenhouse heating, heat conservation in heated greenhouses has great importance. Since total solar radiation in the Mediterranean region is lower than 2.34 kWh/m^{2}day during December and January, greenhouse roofs are covered with single pane and side walls are covered with double pane cover material. In the Mediterranean region, thermal curtains are used in greenhouses for heat conservation. In Antalya climatic conditions, heat requirement for a PE plastic greenhouse with side walls covered with double pane thermal curtains is 80.5 kWh/m^2 area when night/day temperature is kept at 16/18°C. In a greenhouse without thermal curtains, this value is 118.3 kHz/m^2 areas. In other words, 32% heat energy is saved in a greenhouse with thermal curtains. This is equivalent to 7.1 kg/m^2 year imported coals.

In Mediterranean climatic conditions, 30 kg/m^2 truss tomatoes can be produced in heated modern greenhouses which in heated greenhouses where CO_2 fertilization is done, the efficiency is 40 kg/m^2. Approximately 18–28 kg/m^2 efficiency increase in heated greenhouses should cover heating expenses. Depending on the climate of the region, the cost of truss tomato production in heated modern greenhouses varies between 1.29 and 1.69 TL/kg. In the feasibility calculations made for modern greenhouses in the Mediterranean region, return on investment is 14–25%, depending on the production methods of the business [12]. The quality of products obtained from heated greenhouses is higher than the quality of plants grown in unheated greenhouse. Also, due to humidity control, agricultural pesticide use is less.

In order to benefit more from solar energy on the Mediterranean climate zone, it is appropriate to use water mattresses. With the help of water mattresses, a 2–3°K temperature difference can be obtained, but when water mattresses are used together with thermal curtains, the temperature difference obtained becomes 6°K. However, using water mattresses, it is not possible to obtain the optimum greenhouse temperature during night hours.

In Mediterranean climatic conditions, a 20–25% ratio for ventilation openings in the roof area is sufficient. Increasing the sizes of the ventilation openings on the roof in May has very little impact on temperature difference. However, it should be kept in mind that insect screens placed on ventilation openings in modern greenhouses decrease the effectiveness of ventilation.

Greenhouse shading implemented in a way that it does not affect air circulation can help reduce temperature difference in the greenhouse when used together with ventilation. In a greenhouse with 20% ventilation area on the roof, reducing solar radiation by 50% with shading can reduce the temperature difference (ΔT) in June up to 1°C. However, in June, evaporative cooling is needed as outside temperature around noon is above 30°C. In Mediterranean climatic conditions, temperature difference obtained with evaporative cooling in August (depending on outside humidity and exchanged air volume) is nearly 6°C. However, evaporative cooling is not preferred in production greenhouses because it requires electrical energy and a high quantity of clean water. For this reason, greenhouses on the Mediterranean coastline should be left idle starting from the second week of June.

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