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Research Article

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A Research on Determining the Heating Load and Projecting Criteria of Greenhouses to be Established in the Thrace Region

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Abstract This study was conducted to determine the project criteria and calculate the heating load of greenhouses to be established in Edirne, Kirklareli and Tekirdag provinces in the Thrace part of Turkey. As a result of the research, it was recommended that single greenhouses be positioned in the east-west direction and block greenhouses in the south-north direction in order to benefit from solar energy to the maximum extent in the greenhouses to be established in the region. When selecting the greenhouse construction and cross-sectional checks on the elements, it is appropriate to take the dynamic wind load value as 52.2 kg/m^2 for Edirne, 73.9 kg/m^2 for Kirklareli and 108.6 kg/m^2 for Tekirdag. Snow load of 50-75 kg/m^2 should be taken into account, depending on the greenhouse roof slope and shape. In the region, double-layered glass or double-layered hard plastic with the highest thermal conductivity resistance should be used as greenhouse cover material. In heating greenhouses, air blower systems through heating pipes or perforated channels laid on the greenhouse floor may be preferred. The husks released by the processing of rice in the region can be recommended for use as fuel for heating greenhouses.

Keywords Greenhouses, structural features, heating load, number of degree-days

1. Introduction

The transition from agricultural ecosystem to industrial ecosystem has brought about a number of environmental problems. Water and soil pollution are among the main environmental problems. Excessive pollution, especially on soil and water resources, brought about by rapid urbanization and industrialization, negatively affects field agriculture in the Thrace region. In order to eliminate these negativities and ensure the sustainability of agricultural production, it is important for the region to develop greenhouse farming as an alternative production in addition to field agriculture in the Thrace region and to support the studies to be carried out on this subject.

Greenhouses are briefly defined as "facilities where vegetables, fruits and ornamental plants are grown economically all year round, regardless of the climate." Greenhouse farming in Turkey first started in the Mediterranean region and increased rapidly after the 1970s and concentrated in the Mediterranean, Aegean and Marmara regions. As of today, greenhouse cultivation has exceeded 854 000 decares across Turkey. In the Thrace region, greenhouse cultivation has started to increase in recent years and today it has reached over 583 decares [1]. In the Thrace Region, wheat, sunflower and paddy products are grown in approximately 95% of the total agricultural land in the region. However, in recent years, since the net income per decare from these products is quite low, greenhouse cultivation has begun to be seen as an alternative source of income in the region. The climate and soil structure of the Thrace region and the sufficient underground and surface water resources create suitable conditions for greenhouse cultivation in the region. The region's proximity to a large consumption center such as Istanbul also facilitates the marketing of products that can be grown in the region. However, preliminary studies have revealed that structural features and technical principles are not taken into consideration sufficiently in the planning, projecting and implementation of greenhouses in the region, and the heating load is not determined according to the type of product to be grown in the greenhouses. One of the main indicators of whether greenhouse cultivation will be economical in a region is the determination of greenhouse heating load. It should be decided to establish greenhouse enterprises by taking into account the investment and operating costs as well as the heating load expenses.

This study was conducted to determine some project criteria and structural features of greenhouses to be established in Edirne, Kirklareli and Tekirdag provinces in the Thrace part of Turkey and to calculate the heating load.

2. Materials and Equipment Used

The Thrace region, with a surface area of 23,764 km^2, is located on the European continent of Turkey, between 26°-29° east longitudes and 40°-42° north latitudes. The region has borders with the Marmara Sea, the Aegean Sea and the Black Sea. It is under the influence of Mediterranean climates along the sea coasts and continental climates in the inner parts. Its average altitude above sea level is between 50-150 m. The average annual precipitation is 647 mm. Almost all of the precipitation is in the form of rain, and according to multi-year averages, the number of snowy days is 4-10 and the number of snow-covered days is 6-17. Again, according to the multi-year averages of the region; The annual average temperature is 13.0-14.6 °C, the annual average relative humidity is 70-76%, the annual total evaporation amount is 600-1100 mm and the annual average wind speed is between 1.6-4.1 m/s. Winds mostly blow from the north. The first frost occurs in the first week of November and the last frost occurs in the last week of March [2].

The technical information and principles given in Filiz [3], Ozturk [4], and Yuksel [5] were used in determining the location, positioning and structural features of the greenhouses to be established in the region and in obtaining basic data about heating systems.

The dynamic wind load and snow load that should be taken in the cross-section calculations of greenhouse structural elements were calculated with the help of the following equations given in Ekmekyapar [6], Yuksel and Kocaman [7].

Dynamic wind load;

$$q = \frac{1}{16} \times V^2 \quad (1)$$

Snow load;

$$W_K = 75 \times \text{Cos}\alpha \quad (2)$$

where V is the highest wind speed (m/s) recorded in the region where the building was built; α is the roof slope angle (degrees).

In determining the heating load of the greenhouses to be installed, it was calculated using the following equation given in Yuksel [5], based on the number of degree-days.

$$Q = 24 \times U \times G \times A/\eta \quad (3)$$

where Q is the annual heat requirement of the greenhouse (W/year); U is the heat transfer coefficient (W/m^2 °C); G is the number of degrees-days; A is the outer surface area of the greenhouse (m^2); η is the efficiency of the heating system (70%).

The heat transfer coefficient (U) was calculated with the help of the following equations, based on the wind resistance of the greenhouse and the recommended heating methods for heating the greenhouses.

$$U = \frac{1}{R} \quad (4)$$

$$R = R_i + R_\lambda + R_d \quad (5)$$

where R is the total heat transfer resistance (m^2 °C/W); R_i is the inner surface thermal resistance of the greenhouse cover (m^2 °C/W); R_λ is the thermal resistance of greenhouse cover materials (m^2 °CW); R_d is the outer surface thermal resistance of the greenhouse cover (m^2 °C/W).

Using the research results and literature information, the annual heating load for the greenhouse with a 1000 m^2 cover surface for the provinces in the research area was calculated separately for the use of different cover materials.

3. Results and Discussion

Structural features of greenhouses to be established in the Thrace region

In choosing a greenhouse location, factors such as climate, irrigation water availability and quality, electrification, topographic structure and soil characteristics, transportation facilities, labor supply and the presence of natural hot water resources are generally taken into consideration [3, 8]. The Thrace region topographically consists of flat and almost flat, slightly undulated lands. Paddy rice production is carried out intensively in the irrigable flat agricultural lands in the region, in the Meric and Ergene river basins. Therefore, lands in the region where rice production cannot be done or are not suitable for field agriculture can be considered as greenhouse areas. When meteorological data is examined, it is seen that the dominant winds mostly blow from the north. For this reason, in order to reduce the heating load in greenhouses and to benefit from solar radiation to the maximum extent, sloping lands facing south, closed to northern winds, should be preferred. In addition, it is appropriate that the slope of the land where the greenhouse will be established is between 0.5-1.5% [5]. When greenhouse cultivation becomes widespread in the region, especially infertile lands where normal field agriculture cannot be done will be brought into the economy.

The placement direction of the greenhouse long axis is effective on the utilization rate of sunlight. As the latitude in the northern hemisphere increases, the angle of incidence of the sun's rays decreases. Average sunshine duration and average global sunshine intensity values calculated using multi-year meteorological data for the Thrace region are given in Table 1.

Table 1: Sunshine duration and intensity for the Thrace region [2]

Seasons	Meteorological data	
	Average sunshine duration (h)	**Average insolation intensity (W h /m^2)**
Autumn	6.08	118.3
Winter	3.98	67.6
Spring	7.3	182.7

Apart from the general average values, when the sun exposure duration and intensity values are taken into consideration for the provinces in the region, it can be seen that there are not big differences between the provinces. In order to reduce heating costs in greenhouses to be established in the research area and to improve the vegetative and generative development of plants, individual greenhouses should be oriented in the east-west direction, and block greenhouses should be oriented in the north-south direction. Additionally, a shading distance of 30% of the floor area should be left between neigh boring greenhouses. Considering the direction and number of prevailing winds, which are effective in heat loss through infiltration in winter and transition seasons, and the topographic structure of the region, it may be recommended to install wind curtains at a distance that will not cause shading in greenhouse areas.

Greenhouse width is planned as multiples of 3 (3-6-9-12-15 m) for individual greenhouses, depending on the greenhouse type. In block greenhouses, the greenhouse width can be increased to 100-200 m, provided that a wide path is left in the middle. In a naturally ventilated individual greenhouse, the length of the greenhouse should not exceed 50 m for the ventilation to work effectively. In block greenhouses, the greenhouse length can be increased up to 100-110 m, provided that ventilation is sufficient. Greenhouse side wall height varies between 1.8–4.0 m [4, 5]. Since the continental climate characteristics are effective especially in the inner parts of the Thrace region, the greenhouse side wall height should be kept between 2.0-3.0 m in order to keep the climate conditions inside the greenhouse at an optimum level during winter and transition seasons. In our country, the roof slope angle should be taken between 26-30° depending on the angle of incidence of the sun rays [5]. Considering the climatic conditions of the region, the amount of openings required for natural ventilation in greenhouses should be 15-20% of the greenhouse floor area. For effective ventilation, a ventilation window must be made on the ridge. . The opening angles of the windows to be built on the ridge should be at least 15° from the horizontal. The opening angle of the windows to be placed on the side surfaces must be at least 65° from the vertical.

The wind speed value that should be taken according to meteorological observations when cross-sectional checks on greenhouse bearing elements is 28.9 m/s for Edirne, 34.4 m/s for Kirklareli and 41.7 m/s for Tekirdag [2]. The dynamic wind load calculated according to the mentioned values is 52.2 kg/m^2 for Edirne province, 73.9 kg/m^2

for Kirklareli province and 108.6 kg/m^2 for Tekirdag province, respectively. When meteorological records are examined, it can be seen that the snow thickness in the region is up to 50 cm in places. The snow load that causes structural failure in greenhouses should be taken into account in the cross-section calculation of the roof elements. Accordingly, a load of 50-75 kg/m^2 should be taken into account depending on the snow load greenhouse roof shape and roof slope angle.

Determination of heating load in greenhouses to be established in the Thrace region

There are different approaches to determining the annual heating load in greenhouses. Among these approaches, the degree-day numbers method stands out. The number of degree-days, which forms the basis of the method, is calculated by using meteorological observations for many years, based on the days when the outside temperature drops below 12 °C and the temperature inside the greenhouse is 19 °C [5]. Accordingly, the degree day numbers of Edirne, Kirklareli and Tekirdag provinces located in the research region are 2142.5, 2201.4 and 1941.2, respectively [9]. Based on these degree-day numbers, the annual heating load for a greenhouse with a 1000 m^2 cover surface that can be built in the mentioned provinces has been calculated for the use of different cover materials. The technical data that forms the basis of the calculations are given in Table 2, Table 3 and Table 4.

Table 2: Thermal resistances of greenhouse cover materials [10]

Cover material	R□□ (m^2 °C/W)
Greenhouse glass	0.01
Hard plastic (1 mm thick)	0.01
Double glazing in steel frames (15 mm spacing)	0.14
Frameless double-layered rigid plastic (12 mm spacing)	0.15
Double-layer plastic (10 mm spacing)	0.10
Single ply plastic (0.2 mm) (PVC, PE)	0.01

Table 3: Outer surface thermal resistance of greenhouse cover [11]

Situation of the greenhouse against the wind	R_d (m^2 °C/W)
Protected	0.070
Normal	0.045
Open	0.020

Table 4: Inner surface thermal resistance of greenhouse cover [11]

Heating system	R_i (m^2 °C/W)
Heating pipes in the greenhouse floor	0.12
Air blowers from perforated ducts	0.10

Hot water heating pipes laid on the greenhouse floor are widely used, especially in greenhouses where soilless agriculture is practiced. It is the most efficient and most effective method among the known heating methods. The hot water supplied to the heating pipes varies between 80-100 °C [5]. The heat transfer coefficient (U) values required for this heating method are calculated for different cover materials and given in Table 5.

Table 5: U values in case the greenhouse is heated with heating pipes laid on the floor

Cover material	U value (W/m^2°C)		
	Situation of the greenhouse against the wind		
	Protected	Normal	Open
Greenhouse glass	5.0	5.7	6.7
Hard plastic (1 mm thick)	5.0	5.7	6.7
Double glazing in steel frames (15 mm spacing)	3.0	3.3	3.6

Frameless double-layered rigid plastic (12 mm sp.)	2.9	3.2	3.4
Double-layer plastic (10 mm spacing)	3.4	3.8	4.2
Single ply plastic (0.2 mm) (PVC, PE)	5.0	5.7	6.7

Using the U values given in Table 5, if a greenhouse with a 1000 m^2 cover surface is heated with pipes laid on the floor for Edirne, Kirklareli and Tekirdag provinces, the annual heat requirements are calculated and given in Table 6.

Table 6: Annual heating load amounts

Province	**Cover material**	**Heating load (W/year)**		
		Situation of the greenhouse against the wind		
		Protected	Normal	Open
Edirne	Greenhouse glass	367285710	418705714	492162851
	Hard plastic (1 mm thick)	367285710	418705714	492162851
	Double glazing in steel frames (15 mm sp)	220371426	242408568	264445711
	Frameless double-layered rigid plastic (12mm sp.)	213025711	235062854	249754282
	Double-layer plastic (10 mm spacing)	249754282	279137139	308519996
	Single ply plastic (0.2 mm) (PVC, PE)	367285710	418705709	492162851
Kirklareli	Greenhouse glass	377382857	430216457	505693028
	Hard plastic (1 mm thick)	377382857	430216457	505693028
	Double glazing in steel frames (15 mm sp)	226429714	249072685	271715657
	Frameless double-layered rigid plastic (12mm sp.)	218882057	241525028	256620342
	Double-layer plastic (10 mm spacing)	256620342	286810971	317001600
	Single ply plastic (0.2 mm) (PVC, PE)	377382857	430216457	505693028
Tekirdag	Greenhouse glass	332777142	379365942	445921371
	Hard plastic (1 mm thick)	332777142	379365942	445921371
	Double glazing in steel frames (15 mm sp)	199666285	219632914	239599542
	Frameless double-layered rigid plastic (12mm sp.)	193010742	212977371	226288457
	Double-layer plastic (10 mm spacing)	226288457	252910628	279532800
	Single ply plastic (0.2 mm) (PVC, PE)	332777142	379365942	445921371

Another widely used method for heating greenhouses is the use of hot air blowers through perforated ducts. The heat transfer coefficient (U) values required for this heating method are calculated for different cover materials and given in Table 7.

Table 7: U values in case of heating the greenhouse with hot air from perforated ducts

Cover material	**U value ($W/m^2 °C$)**		
	Situation of the greenhouse against the wind		
	Protected	Normal	Open
Greenhouse glass	5.6	6.5	7.7
Hard plastic (1 mm thick)	5.6	6.5	7.7
Double glazing in steel frames (15 mm sp)	3.2	3.5	3.8
Frameless double-layered rigid plastic (12mm sp.)	3.1	3.4	3.7
Double-layer plastic (10 mm spacing)	3.7	4.1	4.5
Single ply plastic (0.2 mm) (PVC, PE)	5.6	6.5	7.7

In case the greenhouses in the research area were heated with hot air, annual heat requirements were calculated using the U values given in Table 7 according to the degree-day number method. The data obtained are given in Table 8.

Table 8: Annual heating load amounts

Province	Cover material	Heating load (W/year) Situation of the greenhouse against the wind		
		Protected	Normal	Open
Edirne	Greenhouse glass	411360000	477471428	565620000
	Hard plastic (1 mm thick)	411360000	477471428	565620000
	Double glazing in steel frames (15 mm sp)	235062857	257100000	279137142
	Frameless double-layered rigid plastic (12mm sp.)	227717142	249754285	271791428
	Double-layer plastic (10 mm spacing)	271791428	301174285	330557142
	Single ply plastic (0.2 mm) (PVC, PE)	411360000	477471428	565620000
Kirklareli	Greenhouse glass	422668800	490597714	581169600
	Hard plastic (1 mm thick)	422668800	490597714	581169600
	Double glazing in steel frames (15 mm sp)	241525028	264168000	286810971
	Frameless double-layered rigid plastic (12mm sp.)	233977371	256620342	279263314
	Double-layer plastic (10 mm spacing)	279263314	309453942	339644571
	Single ply plastic (0.2 mm) (PVC, PE)	422668800	490597714	581169600
Tekirdag	Greenhouse glass	372710400	432610285	512476800
	Hard plastic (1 mm thick)	372710400	432610285	512476800
	Double glazing in steel frames (15 mm sp)	212977371	226288457	252910628
	Frameless double-layered rigid plastic (12mm sp.)	206321828	226288457	246255085
	Double-layer plastic (10 mm spacing)	246255085	272877257	299499428
	Single ply plastic (0.2 mm) (PVC, PE)	372710400	432610285	512476800

When the data obtained as a result of the research and the long-term meteorological observation results of the region are evaluated together, it is necessary to heat the greenhouses in order to carry out greenhouse cultivation in winter and transition seasons. When the values calculated according to the number of degree-days are examined, it is clear that the heating load will bring a significant cost to greenhouse enterprises. However, the widespread use of rice cultivation in the region and the use of husks resulting from rice processing as fuel can significantly reduce the cost of greenhouse heating. The lower calorific value of paddy husk is given as 3666.12 W/kg, and the upper calorific value is 3991.86 W/kg [12, 13]. An average of 437740 tons of paddy is produced annually in the Thrace region. Approximately 15-20% of the processed paddy consists of husk. Accordingly, approximately 76600 tons of rice husks are released in the region annually. Based on this amount of husk and its average calorific value, 518 decares of greenhouse can be heated according to the highest heating load and 1520 decares of greenhouse according to the lowest heating load.

In addition, it can be suggested that the waste hot water and water vapor released during the production stages of many textile factories in the region be used alternatively for heating greenhouses. Again, the region is rich in lignite deposits and the lignite coal extracted from these deposits can be considered to be used in heating greenhouses.

4. Conclusion

In order to reduce the heating load in greenhouses to be built in the region, when choosing a greenhouse location, areas facing south, closed to cold winter winds, should be preferred. In order to benefit from solar energy to the maximum extent, individual greenhouses should be positioned in the east-west direction, and block greenhouses should be positioned in the south-north direction. In greenhouses to be installed, it is appropriate to take the side wall height between 2.0-3.0 m and the roof slope angle between 26-30°. It should be preferred to use double-layered glass or frameless double-layered hard plastic on a steel frame, which has the highest thermal conductivity resistance, as a covering material in greenhouses. Air blower systems through heating pipes or perforated channels laid on the greenhouse floor should be used to heat greenhouses. Paddy husks can be used as fuel in heating systems. Again, waste hot water and steam resulting from various industrial productions can be used to heat greenhouses with good planning.

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