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ESTIMATING ENERGY NEEDS FOR CLIMATE-CONTROLLED GREENHOUSES IN SYRIA WITH A SOFTWARE TOOL

Laith GHANEM[1], Gürkan Alp Kağan GÜRDİL[1*], Bahadır DEMİREL[2], Mohamedeltayib Omer Salih EISSA[1,3]

[1]*Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, 55105, Samsun, Türkiye*
[2]*Erciyes University, Faculty of Agriculture, Department of Biosystems Engineering, 38030, Kayseri, Türkiye*
[3]*Bahri University, Faculty of Engineering, Department of Agricultural Engineering, Khartoum Bahri, Sudan*

Abstract: Amid the current conditions in Syria, the study of energy consumption within plastic greenhouses emerges as a fundamental element in the agricultural economy, especially in areas subject to extreme climate variations. With many thermal power stations ceasing operation due to conflicts and the diminishing sources of energy, understanding energy consumption becomes more urgent to enhance productivity and reduce costs. Successful management of protected agriculture requires in-depth knowledge of weather dynamics and the optimal environmental conditions for crops. To implement effective management of plastic greenhouses, it is essential to recognize how climatic fluctuations affect plant growth and production throughout the various seasons. Heating systems form a significant part of the costs in constructing plastic greenhouses, and deficiencies in these systems can lead to negative impacts on quality, quantity, duration of cultivation, and production volume. Therefore, accurately calculating heating costs is crucial for reducing operational expenses. This study included the development of a computer program to determine the heating needs of plastic greenhouses, considering various factors such as the geographical location of the greenhouse, crop type, covering materials, heating system used, and land area. The results showed that Syria needs 4.56 megawatts of energy for the greenhouses, with the Tartus Governorate consuming the largest share, with energy consumption rates in Tartus, Latakia, Homs, and Damascus countryside amounting to 3.6, 0.3, 0.51, and 0.19 megawatts, respectively. The crops of tomatoes, vegetables, strawberries, and tropical plants consumed 2.2, 1.66, 2.21, and 0.244 megawatts of energy, respectively. This study is an important step towards achieving sustainable and efficient agriculture that contributes to supporting the economy and protecting the environment in Syria.

Keywords: Greenhouse, Heating, Energy, Syria

***Corresponding author:** Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, 55105, Samsun, Türkiye
E mail: ggurdil@omu.edu.tr (G. A. K. GÜRDİL)
Laith GHANEM https://orcid.org/0009-0005-5195-2647
Gürkan Alp Kağan GÜRDİL https://orcid.org/0000-0001-7764-3977
Bahadır DEMİREL https://orcid.org/0000-0002-2650-1167
Mohamedeltayib Omer Salih EISSA https://orcid.org/0000-0003-0186-1112

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1. Introduction

Calculating the capacity of energy in greenhouses in Syria is of paramount importance due to its significant implications for energy management, cost efficiency, and environmental sustainability. As the country faces energy challenges and strives to optimize resource utilization, accurately determining the energy requirements and capacity of greenhouses becomes crucial for effective planning, decision-making, and overall greenhouse performance (Hesenow et al., 2015; Kelley et al., 2015).

Heating is a critical aspect of greenhouse energy management, particularly during the colder months. In Syria's harsh climate, where low temperatures and frost can pose risks to crop growth, providing adequate heating is essential. Calculating the heating capacity involves considering factors such as the greenhouse structure, insulation, outside temperature, desired inside temperature, heat loss, and specific crop requirements (Hainoun et al., 2010). Accurate calculations enable farmers to select appropriate heating systems, optimize energy usage, and minimize costs. Accurate capacity calculations not only aid in optimizing energy use but also have economic and environmental implications. Understanding the energy requirements enables farmers to estimate energy costs, budget effectively, and explore renewable energy options to reduce reliance on fossil fuels. Moreover, efficient energy management in greenhouses contributes to reducing greenhouse gas emissions, promoting environmental sustainability, and aligning with Syria's commitments towards mitigating climate change (Chou et al., 2004).

Ghaly et al. (2024) developed a computer program to calculate the heating requirements for greenhouses in Egypt, based on geographic location, type of product, covering material, type of heating system, and the size of the greenhouse land area. The results showed that the provinces of Dakahlia and Al-Buhayrah had the highest heating requirements, with values of 37.31 kilowatts for strawberries, 27.8 kilowatts for peppers, 50.89 kilowatts for strawberries, and 40.62 kilowatts for peppers, respectively. (Dimitropoulou et al., 2023) proposed a simple model for predicting the thermal energy requirements of greenhouses in Europe. The model estimates the annual heating requirements and the maximum required heating power, along with the corresponding heating and zero-energy operating periods. It is based on the greenhouse technical data (the overall heat loss coefficient, cover transmission, sensible absorbance), the cultivation conditions (temperature range), and the meteorological data (solar radiation and ambient temperature) according to the site characteristics (longitude and latitude). The results proved that the most significant factor affecting heating requirements, the maximum heating power, and heating periods is the latitude of the greenhouse site, . According to our findings, in lower latitudes (40 to 50 degrees), heating requirements range from 250 to 430 kWh/m^2/y, whereas, in higher latitudes (50 to 60 degrees), heating needs range from 430 to 650 kWh/m^2/y.

(van der Salm et al., 2023) designed a greenhouse for optimal production in the coastal area near Algiers. They evaluated two main options for growing tomatoes and cucumbers: winter production with heating and summer production with air-conditioning and CO_2 injection. The study found that while the production output is similar for both seasons, summer production is more costly by 30%. It also noted that summer production has higher initial investment costs but lower operational costs due to decreased water and energy requirements.

(Morshed et al., 2022) utilized a tubular heat exchanger to heat a greenhouse in the Baniyas region of Syria in a simple, more economical, and environmentally friendly manner. The exchanger pipes, measuring 20 meters in length, were buried at a depth of 1 meter. Two exchangers were established along the length of the plastic greenhouse. The results showed a significant effect of the variables on the heating performance of both exchangers. During the heating period, the soil temperature was between 18 and 19 degrees Celsius, and the average indoor air temperature was between 11 and 12 degrees Celsius. Increasing the pipe length to 20 meters led to an improvement in heating performance by 56%.

(Hainoun et al., 2010) conducted a two-year project to develop an optimal energy supply strategy for Syria, focusing on reducing greenhouse gas emissions and protecting the climate at the lowest cost. The first one deals with the construction of 100 MW wind farm, whereas the second explores the potential of installing about 1.2 million active solar systems for water heating to the year 2030. The result of the first project has shown that the expected annual electricity generation of about 275 GWh leads to a net annual greenhouse gas emission reduction of about 190 kt CO_2 eq corresponding to a cumulative reduction of 3.8 Mt CO_2 during the whole life time of the project. The second project leads to an electricity saving of about 19.33 TWh and depicts a GHG reduction of about 11 M ton of CO_2. (Al Miaari et al., 2023) presents the design and thermal performance evaluation of a novel solar greenhouse with humidification-dehumidification unit, water-cooled heat exchanger and variable mixing ratio in the Mediterranean climate. The greenhouse is designed to provide proper microclimatic conditions for crops, produce fresh water through condensing water vapor released from the plants, and save energy using the semitransparent PV panels. Results showed that on a typical summer day, the solar greenhouse ensures proper microclimatic conditions all day long by reducing the temperature by 11.14 °C compared to conventional greenhouses, while maintaining acceptable values of relative humidity and producing 70 L of fresh water per day.

Attar et al. (2013) stated that the implementation of a flat plate solar collector (FPC) combined with a capillary polypropylene heat exchanger for greenhouse heating in Tunisia resulted in a substantial 51.8% reduction in heating costs for a 1000 m^3 greenhouse during April. Furthermore, this system was found to elevate the internal air temperature of the greenhouse by 5°C. Nonetheless, the accumulated solar energy alone proved insufficient to fully satisfy the heating demands (Attar and Farhat, 2015). It was observed that the influence of reduced temperatures has a significant impact on plant growth, and adjusting the heating temperature set point downward could potentially postpone the initial harvest (Kläring et al., 2015).

In Syria, there are approximately 6,809 hectares of plastic greenhouses. The use of these greenhouse systems serves the purpose of meeting the local market requirements for both vegetables and ornamental plants. In addition to fulfilling local needs, there is an increasing use of polyethylene-made greenhouses for the early cultivation of vegetables, fruits, and flowers in the warm season. Moreover, the production of greenhouses usually surpasses field production in terms of productivity per unit area, consistently delivering higher product quality. Overall, maintaining climate control is of utmost importance in greenhouse agriculture to achieve high crop productivity and high-quality production that meets consumer requirements while ensuring cost-effective production (Khatib and Sizov, 2022).

In this research, the heat balance within a greenhouse can be determined through a comprehensive analysis, which considers various parameters including the greenhouse's geographical location, the type of crops cultivated, the material used for the greenhouse cover, the heating technique employed, and the dimensions of the greenhouse. A computer program has been created, with the expectation that it will offer utility to farmers, agricultural engineers, and individuals interested in these matters.

2. Material and Method

The materials used in greenhouses in the research were regulated according to the thickness of some material's conduction resistances in Table 1. The geographical distribution of greenhouses of Syria in 2022 is given in Table 2. Some meteorological data that can be used in calculating the heating loads of greenhouses that can be established are given in Table 3.

Temperature distribution in degrees Celsius in the regions of Syria is given in Figure 1. Distribution of solar radiation (MJ/m2.day) in Syria shown in Figure 2. The calculation of heating capacities in greenhouses and the flowchart of the program have been developed as shown in Figure 3.

Table. 1 Thermal conduction resistances of some materials used in greenhouses, arranged according to their thickness.

Type of cover material	Thickness (mm)	Thermal conductivity (W/m^2 c)
Glass	3.18	6.3
A layer of fiberglass	1.02	5.7
Ultraviolet stabilized polyethylene film, PE	0.0003	6.3
Polyethylene film IR absorbing	0.0003	5.7
Polyvinyl fluoride film PVF	0.0008	5.7
Glass-double pane	25.4	3.0
Polycarbonate structured sheets	6.8	3.5

Table 2. The geographical distribution of greenhouses in Syria (2022)*

Location	Varity	Cultivated area (km^2)	Production (ton)	Number of Greenhouses
Tartous	Tomato	35.16	300000	82749
	Vegetables	21.03	104000	49476
	Strawberry	2.31	6000	5426
	Tropical Fruit	0.36	0	850
Lattakia	Tomato	2.64	33000	6600
	Vegetables	3.14	19354	7826
	Strawberry	0.03	6	5
	Tropical Fruit	0.32	0	813
Damascus countryside	Tomato	0.004	34	10
	Vegetables	0.35	2612	753
	Strawberry	0	0	0
	Tropical Fruit	0.18	0	438
Homs	Tomato	0.51	4952	1632
	Vegetables	0.14	917	430
	Strawberry	1.7	4728	9493
	Tropical Fruit	0	0	0
Total		67.874	475603	166501

*Ministry of Agriculture and Land Reclamation.

Table 3 Average temperature, wind speed, and solar energy for some Syrian locations:

Location	AT (°C)	AWS (m/s)	SE (MJ/m^2.day)	SE (kW/m^2.day)
Tartous	19.36	3.6 m/s	4.826	56.7055
Lattakia	19.4	2.9 m/s	4.481	52.6518
Damascus countryside	18.8	4.3m/s	5.819	68.3733
Homs	17.0	4 m/s	5.462	64.1785

SE= solar energy, AWS= average wind speed, AT= average temperature. Average Temperature and average wind speed data are available: https://unfccc.int/sites/default/files/resource/Syria_Initial%20National%20Communication.pdf. Solar Energy data is available (Global horizontal irradiation is choosed): https://globalsolaratlas.info/map?c=34.375179,37.133789,7&s=34.85889,35.991211&m=site.

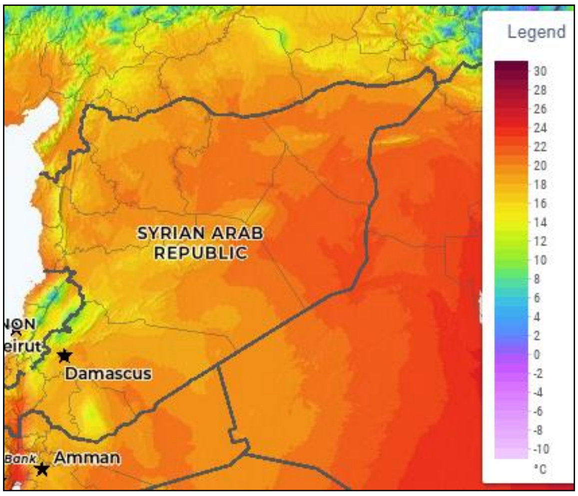

Figure 1. Temperature distribution in degrees Celsius in the regions of Syria

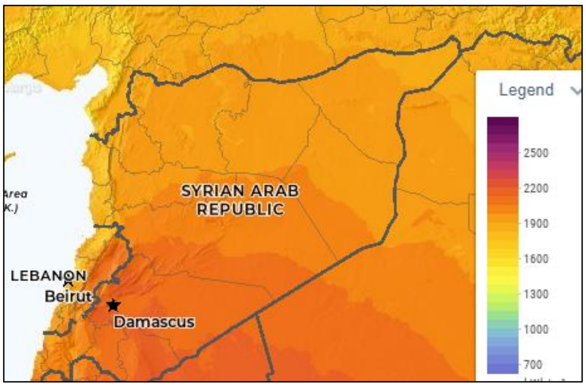

Figure (2) Distribution of solar radiation (MJ/m2.day) in Syria

The program adjusts the greenhouse heating capacity as follows: calculations according to equations (Yavuzcan, 1995).

The current requirements for greenhouse heating are determined by assessing the heat losses and gains within the greenhouse, and this calculation is based on the disparity between these factors (equation 1).

$$Q = Q_1 - Q_2 \tag{1}$$

Where:
Q = Greenhouse heat current requirement (W).
Q_1 = Total heat flow lost from the greenhouse (W).
Q_2 = Heat gained from solar energy in the greenhouse (W).

The heat loss from the greenhouse can be quantified using the following equation 2:

$$Q_1 = A * K * (T_i - T_d) \tag{2}$$

Where:
A = Total area of glass or plastic (m2).
K = The coefficient of the total heat transfer (W/m2.k).
T_i = Temperature inside the greenhouse (k).
T_d = External temperature (k).

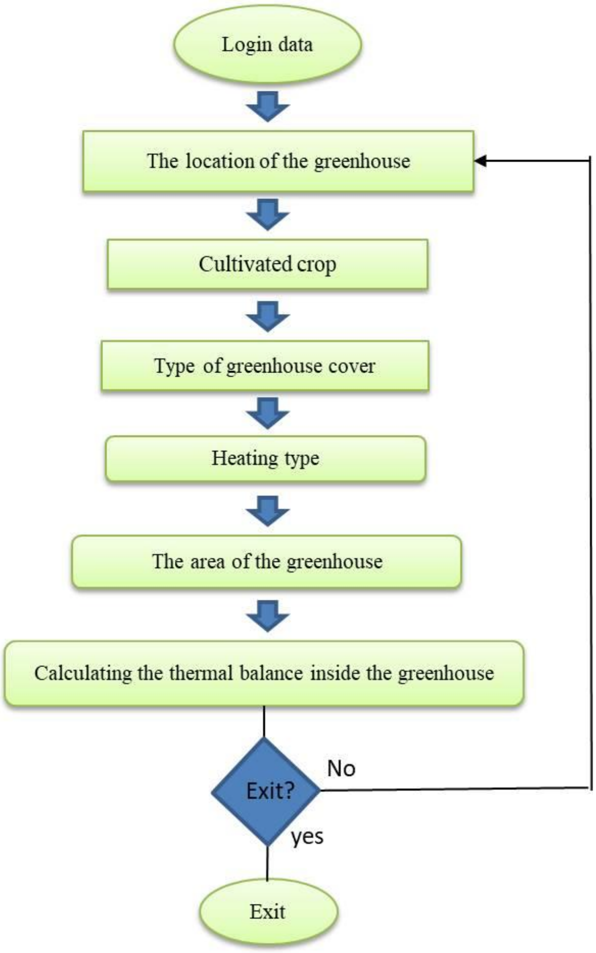

Figure 3. Diagram of the calculation program.

The cumulative heat transfer coefficient from the greenhouse to the atmosphere, encompassing both the total heat transfer and ventilation heat, is the summation of convection coefficients (equations 3, 4 and 5).

$$K = K_1 - K_2 \tag{3}$$

$$K_1 = \frac{1}{\frac{1}{\alpha_1} + \frac{d}{\lambda} + \frac{1}{\alpha_d}} \tag{4}$$

$$K_2 = 0.19 * v \tag{5}$$

where:
K_1 = Total heat transfer coefficient from the greenhouse to the atmosphere (W/m2.K).
K_2 = Heat convection that meets the ventilation temperature coefficient (W/m2.K).
α_i = Heat transfer coefficient inside the greenhouse (W/m2.K).
d = Thickness of the used cover material (m).
λ= Thermal conduction coefficient of the used cover material (W/m.K).
α_d= External heat transfer coefficient from the cover surface to the atmosphere (W/m2.K).
In Syria, greenhouses commonly employ pneumatic and tubular heaters. Nonetheless, when considering the initial investment and operational expenses, particularly in the context of higher energy costs and central heating

systems, air-type heaters are typically the preferred choice for greenhouse heating (equations 6, 7 and 8).

$$\propto_i = \propto_h + \propto_{tö} \quad (6)$$

$$\propto_{tö} = \frac{Q_{tö}}{A_{tö}(T_i - T_{öi})} \quad (7)$$

$$Q_{tö} = C_t * Q_t * \left[\left(\frac{T_t}{100}\right)^4 - \left(\frac{T_{öi}}{100}\right)^4\right] \quad (8)$$

where:
$\propto_h$= Heat transfer coefficient between hot air and greenhouse air (W/m²K).
$\propto_{tö}$= Heat transfer coefficient of the heat carried from the soil to the inner surface of the cover (W/m²K).
$Q_{tö}$= Heat flow radiating from the soil to the inner surface of the cover (W).
$A_{tö}$= Greenhouse cover surface area hitting the soil surface (m²).
$T_{öi}$= Inner surface temperature of the greenhouse cover (K).
C_t= Thermal radiation coefficient of the upper surface of the soil (W/m²K⁴).
A_t= Top surface area of soil (m²).
T_t= Temperature of the upper soil surface (K).

The inner surface temperature of the greenhouse cover can be determined using the following equation 9:

$$T_{öi} = 0.43 * (T_i - T_d) + T_d \quad (9)$$

When calculating the total heat transfer coefficient from the greenhouse to the atmosphere, the convection coefficient for external heat transfer from the cover surface to the atmosphere is determined as follows (equation 10).

$$\propto_d = \propto_{rü} + \propto_{öt} \quad (10)$$

where:
$\propto_{rü}$= External heat transfer coefficient caused by wind (W/m²K).
$\propto_{öt}$= Heat transfer coefficient from the cover surface to the atmosphere (W/m²K).

The amount of heat gained in the greenhouse environment can be calculated from the equation 11:

$$Q_2 = I_0 * A_{ça} * \eta \quad (11)$$

where:
I_0= Average daily solar radiation intensity (W/m²day).
$A_{ça}$= The surface area of the greenhouse (m²).
η= The percentage (%) of solar energy coming to the greenhouse that is converted into useful form in the greenhouse.
The calculation of heating capacities in greenhouses is performed through a computer program developed using MS Visual Basic 6.0 programming language.

3. Results and Discussion

From Table 7, we observe that the Tartus Governorate consumes 86.7% of the thermal capacity for agricultural greenhouses in Syria (Hainoun et al., 2010), due to its extensive cultivation of tomatoes as shown in Table 2, and because tomatoes require higher heat compared to other crops as indicated in Table 4. Following the Tartus Governorate, the Latakia Governorate has consumed 7.45% of the thermal capacity for agricultural greenhouses, then the Rural Damascus Governorate consumes 1.3% of the necessary thermal energy, and the remaining 4.5% is for the Homs Governorate.
From Table 8, we find that tomatoes are the most energy-consuming in Syria, having consumed 53.8% of the thermal energy. This is due to two reasons: the first is the extensive cultivation of tomatoes as shown in Table (2), and the second is the plant's need for high heat compared to other vegetables (Table 4). Vegetables require 40.1% of the thermal energy, strawberries 5.3%, and the rest is for tropical fruits.
From Table 5, in the coastal governorates (Tartus and Latakia), the wind speed is lower than in the inland governorates, and we can also notice a decrease in solar radiation for them (Dimitropoulou et al., 2023).
From Table 1, the use of glass is considered effective in saving energy consumption due to its high thermal insulation, but its high price is one of the main reasons for its limited (Al Miaari et al., 2023).

Table 4. Climate requirements for selected greenhouse crops in hot and arid regions

Crops	Optimal T (c°)		Optimal RH (%)	Reference
	Day	Night		
Tomato	23-27	13-16	50-80	(Ponce et al., 2014)
Vıgıtabels	>24	>14	70-90	(Gruda, 2005) (Kawasaki and Yoneda, 2019)
Strawberry	20-26	13-16	50-65	(Khammayom et al., 2022)
Tropical Fruit	18-24	4-8	70-80	(Max et al., 2009)

Table 5. The total amount of required heat for greenhouses in some regions in Syria

Location	Tartous				Lattakia				Damascus countryside				Homs				Total
Varity	Tomato	Vegetables	Strawberry	Tropical Fruit	Tomato	Vegetables	Strawberry	Tropical Fruit	Tomato	Vegetables	Strawberry	Tropical Fruit	Tomato	Vegetables	Strawberry	Tropical Fruit	--
Q1 (Kw)	3225.003	2125.320	168.952	19.683	207.436	274.582	1.827	13.878	0.592	55.233	0	19.635	67.019	19.743	190.855	0	--
Q2 (Kw)	1156.383	691.659	75.974	11.840	80.620	95.889	0.916	9.772	158	13.879	0	7.138	18.984	5.211	63.280	0	--
Q (Kw)	2068.619	1433.660	92.978	7.843	126.816	178.692	0.911	4.106	0.433	41.353	0	12.497	48.035	14.532	127.575	0	4158.055

Table 7. The required amount of heat for greenhouses by region

Location	Tartous	Lattakia	Damascus countryside	Homs	Total
The required amount of heat (w)	3603100.935	310527.295	54284.4177	190143.096	4158056

Table 8. The required amount of heat for greenhouses by product

Product	Tomato	Vegetables	Strawberry	Tropical Fruit	Total
The required amount of heat (W)	2243904.2	1668239.1	221464.84	24447.64	4158056

4. Conclusion

In Syria, energy consumption in plastic greenhouses is crucial for the agricultural economy, particularly due to climate changes and energy shortages. The study developed a computer program to calculate the heating needs for greenhouses, factoring in location, crop type, and other variables. Syria requires 4.56 megawatts of energy for greenhouses, with Tartus Governorate being the largest consumer at 3.6 megawatts. Tomatoes, vegetables, strawberries, and tropical plants consume 2.2, 1.66, 2.21, and 0.244 megawatts respectively. This research aids in advancing sustainable agriculture in Syria.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	L.G.	G.A.K.G.	B.D.	M. E.
C	40	40	10	10
D	60	20	10	10
S		80	20	
DCP	60	20	10	10
DAI	60	20	10	10
L	40	20	20	20
W	40	20	20	20
CR	50	30	20	
SR	60	20	20	
PM	50	20	20	10
PM	50	20	20	10

C=Concept, D= design, S= supervision, DCP= data collection, and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, PM = funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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