DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DYNAMIC THERMAL MODELLING OF A GREENHOUSE

by
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October, 2023
İZMİR

DYNAMIC THERMAL MODELLING OF A GREENHOUSE

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DYNAMIC THERMAL MODELLING OF A GREENHOUSE"** completed by **GÜNEŞ ÇALIŞKANBAŞ** under supervision of **ASSOC. PROF.DR. MEHMET AKİF EZAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Güneş ÇALIŞKANBAŞ

DYNAMIC THERMAL MODELLING OF A GREENHOUSE

ABSTRACT

Climate change, which has become more and more threatening in recent years, negatively affects food production in many parts of the world. Climate change also causes a decrease in the quality and yield of the crops planted by farmers. This affects farmers' livelihoods and puts consumers in a difficult situation. Considering all these negative effects, it is necessary to use the limited natural resources effectively in order to meet the food needs of the ever-increasing world population. Sustainable and manageable farming methods can be the main solution to the food crisis. Covered agriculture is a more sheltered and efficient agricultural management system than traditional open field farming. However, of course, the effect of greenhouses on agricultural production for different climatic regions and which crops they are suitable for should be investigated.

In this study, thermal modeling of a greenhouse for tomato production in selected provinces from Turkey and Qatar was made and the effects of different climatic regions were examined throughout the year. The effects of variable climatic conditions on the indoor temperature of the greenhouse and the temperature of the agricultural plant were investigated. In addition, the effect of vegetation and indoor temperatures on greenhouse tomato production is also questioned. A dynamic energy balance model was used to make the necessary temperature analyzes and predict these temperatures such as indoor temperature, vegetation temperature, mulch temperature and soil temperature. In a naturally ventilated greenhouse, the effect of ventilation rates on the thermal comfort of the greenhouse was initially examined for different natural ventilation rates ranging from 0 m^3/s to 10 m^3/s, and then the actual ventilation was added to the account with meteorological data. Numerical studies were carried out using a MATLAB program.

Keywords: greenhouse, tomatoes, vegetation, crop, ventilation, temperature, heat transfer.

BİR SERANIN DİNAMİK ISIL MODELLEMESİ

ÖZ

Son yıllarda giderek daha fazla tehdit edici bir hal alan iklim değişikliği, dünyanın birçok yerinde gıda üretimini olumsuz etkiliyor. İklim değişikliği, çiftçilerin ektikleri mahsulün kalitesinde ve veriminde de düşüşe neden oluyor. Bu durum çiftçilerin geçim kaynaklarını etkilemekte ve tüketicileri zor durumda bırakmaktadır. Tüm bu olumsuz etkiler göz önüne alındığında, sürekli artan dünya nüfusunun gıda ihtiyacını karşılayabilmek için sınırlı olan doğal kaynakların etkin bir şekilde kullanılması gerekmektedir. Sürdürülebilir ve yönetilebilir tarım yöntemleri, gıda krizinin ana çözümü olabilir. Örtülü tarım, geleneksel açık alan çiftçiliğine göre daha korunaklı ve verimli bir tarımsal yönetim sistemidir. Ancak elbette farklı iklim bölgeleri için seraların tarımsal üretime etkisi ve hangi ürünlere uygun olduğu araştırılmalıdır.

Bu çalışmada, Türkiye ve Katar'dan seçilen illerde domates üretimine yönelik bir seranın termal modellemesi yapılmış ve yıl boyunca farklı iklim bölgelerinin etkileri incelenmiştir. Değişken iklim koşullarının sera iç ortam sıcaklığına ve tarım bitkisinin sıcaklığına etkileri araştırılmıştır. Ayrıca bitki örtüsü ve iç ortam sıcaklıklarının sera domatesi üretimine etkisi de sorgulanmaktadır. İç ortam sıcaklığı, bitki örtüsü sıcaklığı, malç sıcaklığı ve toprak sıcaklığı gibi gerekli sıcaklık analizlerini yapmak ve bu sıcaklıkları tahmin etmek için dinamik enerji dengesi modeli kullanılmıştır. Doğal olarak havalandırılan serada, havalandırma oranlarının seranın ısıl konforu üzerindeki etkisi başlangıçta 0 m^3/s ile 10 m^3/s arasında değişen farklı doğal havalandırma oranları için incelenmiştir, ardından meteorolojik veriler ile gerçek havalandırma hesaba eklenmiştir. MATLAB programı kullanılarak sayısal çalışmalar yapılmıştır.

Anahtar kelimeler: sera, domates, bitki örtüsü, mahsul, havalandırma, sıcaklık, ısı transfereri.

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CHAPTER ONE

INTRODUCTION

Sustainable agriculture is an essential topic for food security and sustainable food production. The purpose of climate management is to achieve optimal growth and development all season long of a crop in the greenhouse. The physical interaction between plants and their environment is a complex process but contributes greatly to heat, water and CO_2 exchanges with the air so that the temperature of the vegetation should be known as well. The vegetation temperature refers usually to the leaf temperature (Wang & Deltour, 1999).

Predicting and controlling of the inside environmental conditions in greenhouse is important for managing crop production and for improving operation and production efficiencies. Simulation models are often used to predict the greenhouse environment because they provide a faster, cheaper, more flexible, and repeatable way than predictions based on experiments. (Abdel-Ghany & Al-Helal, 2011).

During the process of simulation, the relevant parameters such as the inside air temperature, the incoming global solar radiation, cover temperature, soil surface temperature and relative humidity are classified by the sensitive study (Wang & Deltour, 1999).

Several studies were completed to develop greenhouse thermal models to define heat and mass transport processes in a greenhouse microclimate (Soribe & Curry, 1973; Yang et al., 1990). Elaborative time dependent greenhouse dynamic thermal models are presented. Indoor environment was controlled by attaching the greenhouse with either active/passive heating or cooling system like mass storage, buried pipes, natural ventilation, shading devices, evaporative cooling, geothermal energy, etc. (Santamouris & Vallindras, 1994; Sethi & Sharma, 2007) or with the use of mechanical and electrical support such as heat pumps (Chou et al., 2004).

In Tiwari et al., study, a mathematical model was developed to describe the processes of heat and mass transport in a greenhouse microclimate. The energy balance equations were used to create a model that allows predicting the climatic conditions in a greenhouse based on external weather conditions. In this model, the effect of evaporative and conductive losses from plant components and the ground, which are important for estimating the thermal performance of a greenhouse, was not considered. And to facilitate the modelling procedure, a greenhouse is considered to be composed of a number of separate but interactive components (Tiwari et al., 1988).

In this study a dynamic energy balance model was used to make the necessary temperature analyzes and predict these temperatures. In the greenhouse model, six nonlinear energy equations were used, mainly for indoor air temperature, leaf temperature, greenhouse cover temperature, polypropylene mulch temperature and soil temperatures divided into 3 layers. We used multiple linear regressions to estimate the crop temperature in a simple way that allows a reduction in the number of parameters required as input (Reyes Rosas et al., 2017). Mulch is a layer of material applied to the soil surface. The reason for mulch application is to maintain soil moisture. In this study, the MATLAB program was used, and internal temperatures were obtained as a function of external climate parameters and greenhouse properties.

For the modelling, the data for the province of İzmir was taken as the basis and the analyzes were made according to these values. Outdoor temperature, wind speed and solar radiation values were taken for İzmir province. The model was validated using experimental data of the province Almería (Spain).

1.1. Greenhouse sector in the world

World greenhouse areas have reached approximately 420,000 ha. The ranking of countries with intensive greenhouse cultivation are China, Spain, South Korea, Japan and Turkey. Turkey ranks second in Europe after Spain, with a greenhouse area of approximately 35,000 ha (Silleli et al., 2020).

With the widespread use of glass and plastic greenhouses around the world, both are used commercially in at least 89 countries. The total global area covered by greenhouses has increased from 0.7 million to 3.7 million hectares (ha) over the past two decades alone. Countries with extensive greenhouse usage include Spain, China, South Korea, Japan, and Turkey, which cumulatively accounted for 92% and 96% of the world's total greenhouse coverage in the 1990s and late 2010, respectively. In these countries, plastic greenhouses occupied ~95% of the area covered by vegetable greenhouses, whereas glass greenhouses accounted for <5% (Jie Chang1 et al., 2013).

While greenhouse cultivation was carried out in countries with temperate climate in the past, countries with a desert climate such as Qatar, United Arab Emirates and Saudi Arabia, as well as countries with cold climates such as Russia and Canada, have started to invest in this sector in recent years. The need for technological greenhouses has increased at the same rate as being able to produce in difficult climatic conditions. Today, in greenhouses controlled by automation systems, data obtained from both the plant and the greenhouse microclimate are evaluated to provide the most suitable conditions for the plant, and irrigation, feeding and care are arranged accordingly (Silleli et al., 2020).

Agricultural production statistics from the Food and Agriculture Organization (FAO) for the years 2000 to 2020 Global production of primary crops increased by 52 percent between 2000 and 2020 to 9.3 billion tons in 2020, according to its analytical brief. Sugarcane, corn, rice and wheat accounted for half of primary production in 2020. Between 2000 and 2020, global fruit production increased 55 percent and vegetable production increased 65 percent in the same period.

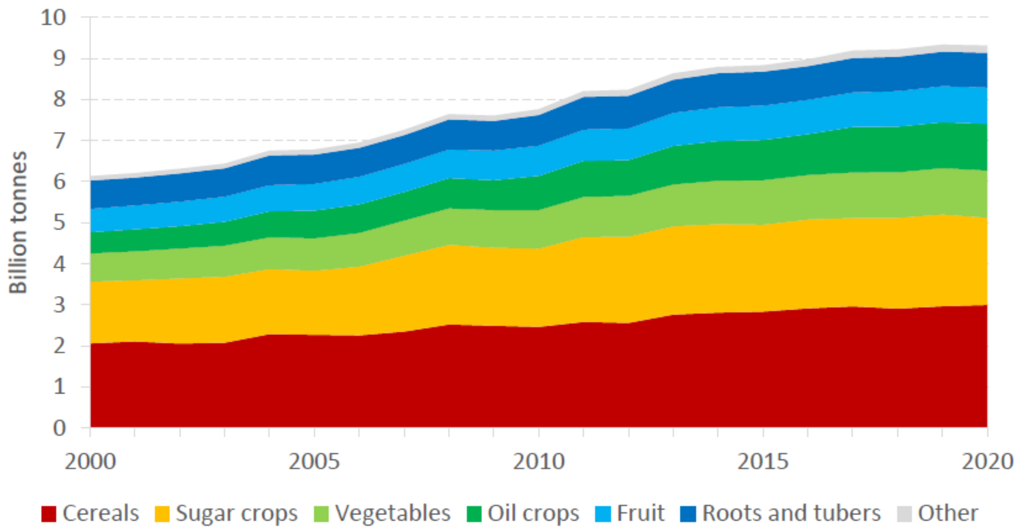


Figure 1.1 Global production of crops by commidty group (Crops and livestock products.)

When Figure 1.1 is examined, an increase is seen in the cultivation of all crops planted worldwide. It can be seen from the figure that more than half of the main crops produced are cereal and sugar crops. After cereals and sugar crops, vegetables are the most produced crops.

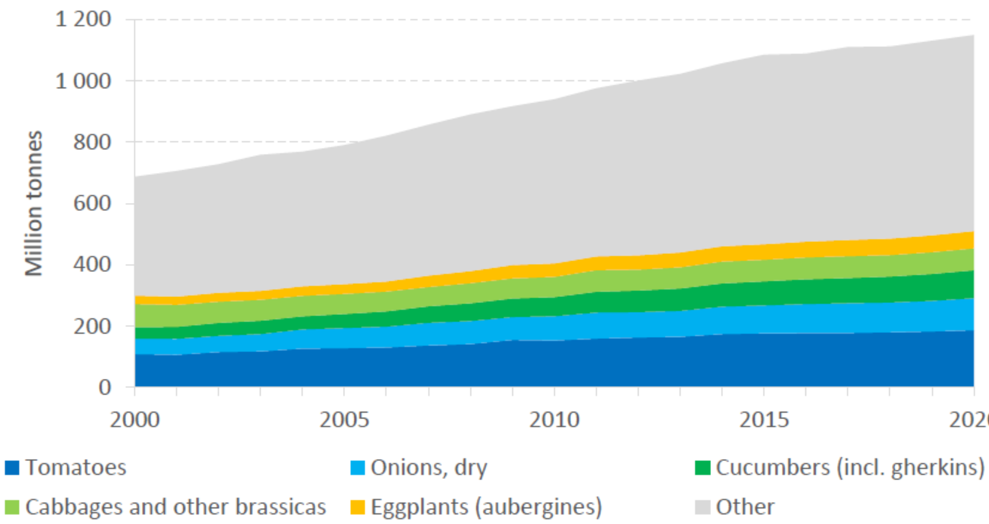


Figure 1.2 Global production of vegetables by main commodities (Crops and livestock products.)

Looking at Figure 1.2, it is seen that vegetable production has experienced a much larger increase. It can also be deduced that tomatoes have the largest share in vegetable production.

According to the data of the TUIK (Turkish Statistical Institution) between 2013 and 2018, the amount and proportions of the products produced in greenhouses in Turkey are given in the table below. The unit of quantities given is given as tons.

Table 1.1 Crop amount and proportions produced greenhouses in Turkey.

Products	2013	2014	2015	2016	2017	2018
Vegetable total	**5928543**	**6111737**	**6312622**	**6699222**	**7238316**	**7377856**
Pea	35	35	35	36	56	58
Green pepper	94173	90414	94598	103413	100514	100253
Black pepper	384171	387006	385548	414058	394756	382029
Charleston pepper	0	32563	47909	52883	80049	70645
Tomato	3200930	3285570	3394447	3614472	3829831	3888555
Green beans	42646	46008	39049	45879	47936	57421
Cucumber	1001940	1030349	1080213	1077783	1121625	1134182
Spinach	3186	3179	3872	4068	3733	3213
Courgetti	104149	108086	121250	143150	219304	242218
Watermelon	640513	653343	679375	701532	791277	871845
Melon	136396	143889	145347	165386	185762	178008
Cabbage	463	476	463	492	493	467
Core lettuce	17021	16325	16039	18864	28888	24510
Curly lettuce	42478	45097	45664	56232	67414	66025
Iceberg lettuce	7494	7002	7244	7864	19001	21591
Parsley	552	521	1258	1796	3057	4094
Aubergine	252396	261874	250311	291314	344620	332742

When Table 1.1 is examined, it is seen that the amount of production increases every year, and the biggest share is in tomato planting. These numbers are expected to increase further in the coming years.

1.2. Greenhouse types

Worldwide there is more than 420,000 ha of land currently occupied by different types of greenhouses. These greenhouses vary due to factors such as the regions where they are used, their types, costs, and usage purposes. Figure 1.3 shows the 10 basic greenhouse types classified by their structural shapes and materials.

Figure 1.3 Greenhouse types of categorizations based on structural shapes and materials (10 Different Types of Greenhouses)

1.2.1. Lean to greenhouses

It is a type of greenhouse attached to one side of a building or one side of a structure. It can be placed on the edge of a building or between two structures. As an advantage, it is easy to access resources such as electricity and water from the adjacent building, its cost is lower due to the use of less material, and it does not require large areas for its installation; but the last item can be a disadvantage as well as an advantage. In addition to the disadvantage, there may be insufficient radiation due to the structures. This problem will increase even more when it is built between two buildings, and it may be more difficult to control the temperature because of the limited ventilation. Air conditioning system installation may not be possible due to space constraints.

1.2.2. *Ridge and furrow greenhouses*

It is a design reminiscent of an A-frame structure. The installation cost is low and can be built with only basic materials, this greenhouse can be built using very little wood or plastic film covering. It has a wide floor and low ceiling. It does not have ideal airflow due to narrow angles. It is generally preferred and very popular to prevent crops from being damaged by rain and snow. It is also used to connect multiple greenhouses, this will increase both the space and the use of sunlight. As a disadvantage, it can be said that it requires more space than the previous greenhouse type.

1.2.3. *Even span greenhouses*

Two different pitched roofs are used in this type of greenhouse. It can be made in the desired size depending on the type and amount of product desired to be grown. Transparent glass is used throughout the greenhouse so that the plants receive sufficient sunlight. As the area grows, investment costs may be required to heat the environment during night or seasonal temperature drops, or vice versa, to cool it. Also, as a disadvantage, higher investment cost is required compared to the previous two greenhouse types.

1.2.4. *Gothic arch greenhouses*

This type of greenhouse has a distinctively pointed roof, which eliminates the need to structurally include trusses. The size of the building can change according to demand. Snow and rainwater are easy to drain. As a disadvantage, it occupies more material than other greenhouse types and sufficient air circulation cannot be provided in the corners.

1.2.5. Uneven span greenhouses

In this structure, one roof is much longer than the other roof. The main reason for this design is that the design of the building can benefit more from sunlight on uneven, rough terrain. To benefit from the sunlight at the maximum level, mostly the long side of the roof faces south and transparent glass or other transparent material is used.

1.2.6. Pipe metal frame greenhouses

This type shows a greenhouse structure framed by metal pipes, and steel or aluminum pipes are generally preferred because of their longevity. It is a solid structure, but expensive due to the materials used. Quality PVC materials are used to get maximum efficiency from the grown crops. It can be installed in large areas and can be moved from one place to another.

1.2.7. Wooden frame greenhouses

It is a type of greenhouse that is generally preferred in cold climates, they contain wooden frame structures to preserve the heat inside. The material is easy to find and build. On the other hand, it can be said that the material is expensive.

1.2.8. Plastic greenhouses

With hard plastic, highly durable structures can be obtained, and crops can be easily protected from harsh environmental conditions. There are various alternatives in plastic selection according to the thickness of the material and its thermophysical properties. Plastic greenhouse was also studied in the work of Reyes Rosas, who was accepted as a reference in this study.

1.2.9. PVC or polyester greenhouses

PVC material is a type of plastic, it is one of the popular greenhouse materials. It is transparent so that every area of the greenhouse can benefit from the sun's rays. Thanks to the openings on the sides, it can be easily ventilated, and temperature control is relatively easy.

1.2.10. Glass material greenhouses

Glass is also an expensive but high-quality material used in greenhouse covering. The light transmittance is quite good. It can be used from very small greenhouses to very large greenhouses.

CHAPTER TWO
MATHEMATICAL MODELLING

In this study, a dynamic thermal model is developed using MATLAB to predict the temperature of the indoor environment and other components of a greenhouse as a function of external climate parameters and greenhouse properties. As a result of an extensive literature review, a mathematical model was created, and the study of Reyes Rosas was used to validate the method. In this section, the mathematical model details and the result of the validation analyzes are explained in the relevant subsections.

2.1. Problem Description

For the designed model it is necessary to estimate the temperatures for the primary seven components of the greenhouse and to determine in which periods the tomato plant can be planted in the greenhouse in line with these estimates. For the months that are not suitable for planting, determining whether heating or cooling should be done is also important. These seven components are crop, cover, mulch, soil (which has three layers and separate equation was used for each layer) and inside air.

To make sure that the problem is solved correctly, first, validation analyzes should be performed. After the validation analysis, as a second step, it should be known how and to what extent the plant, coating, mulch, indoor and soil temperatures are affected by which specific parameters. Thus, as a result of sensitivity analysis, it is possible to have an idea about how the harvest period will be affected and how the planting period will be more productive. The geometric properties of the greenhouse are given in the method section.

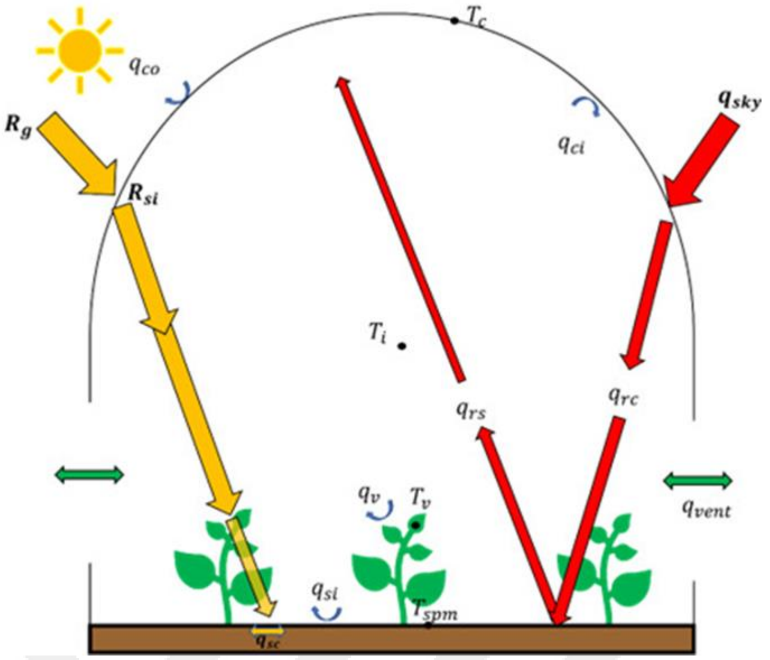


Figure 2.1 Reduced mathematical model for heat transfer between the greenhouse components

Figure 2.1 shows the heat transfer between the different components in the greenhouse model. The yellow and red color arrows represent solar and thermal radiation transmitted, absorbed, or reflected, blue color arrows represent convection and the green color arrows represent ventilation. In this model, it is considered that heat transfer takes place between greenhouse components by conduction, convection, and radiation (both solar and thermal). It is assumed that the greenhouse is built for tomato production.

Table 2.1 Geometrical parameters of the greenhouse

Dimensions of Greenhouse	
Length	24 m
Width	45 m
Height	4.2 m
Roof Height	2 m
Side Opening Width	40 m
Side Opening Height	1.05 m
Roof Window Width	40 m
Roof Window Height	0.97 m
Greenhouse Ceiling	1198 m^2

The geometric dimensions of the greenhouse were chosen the same as the work of Reyes Rosas et al., (2017) to carry out the verification analysis. The geometric parameters of the greenhouse are given in Table 2.1.

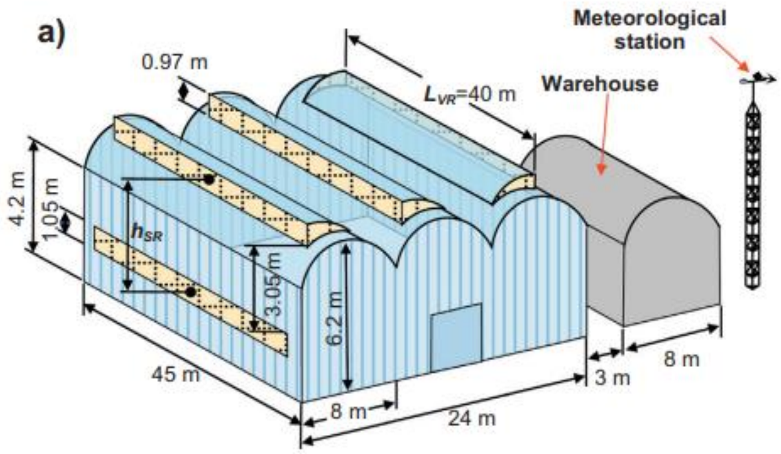


Figure 2.2 (a) Dimensions for the experimental greenhouse and (b) neighbouring obstacles in the reference study (Reyes Rosas et al., 2017)

In Figure 2.2 taken from the reference study, the geometric dimensions, orientation, and other auxiliary equipment of the experimental greenhouse are given. In Figure 2.2b, there is also a meteorology station established for keeping climate records outside the greenhouse.

2.2. Solution Methodology of The Problem

The dynamic transition model developed for greenhouse is based on the energy balance of the seven components of the greenhouse system. In this model, it is considered that heat transfer takes place between greenhouse components by conduction, convection, and radiation (both solar and thermal).

The approximate crop temperature was defined as a function of dependent on two parameters. These parameters are inside global solar radiation and indoor air temperature by Wang & Deltour (1999). Where T_v is temperature of vegetation, T_i is indoor air temperature and R_{Si} is inside global solar radiation. In Figure 2.3, the heat transfers between the plant and its environment are given with a mathematical model, and the formulation is given in Eq. (2.1).

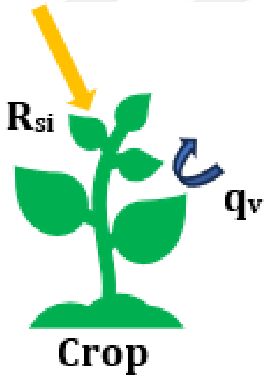


Figure 2.3 Mathematical modelling of heat transfer for crop

$$T_v = -2.05 + 1.01T_i + 0.00425R_{Si} \qquad (2.1)$$

The inside global solar radiation value required for the plant temperature is calculated by the following Eq. (2.2), which depends on two parameters. Inside global radiation (R_{Si}) was determined as a function of global solar radiation flux (R_g) for outside and the greenhouse cover's transmissivity (τ_{cw}). The solar radiation values of the external environment are already known because they are taken from meteorological data.

$$R_{Si} = \tau_{cw} R_g \quad (2.2)$$

Cover temperature of the greenhouse (T_c), was calculated with a first-order differential equation and it is defined as in Eq. (2.3). The mathematical model is given in Figure 2.4.

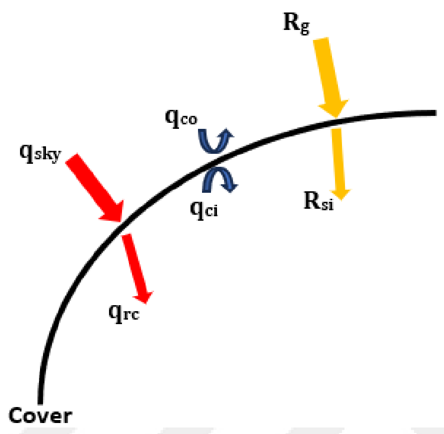


Figure 2.4 Mathematical modelling of heat transfer for cover material

$$\delta_c c_{pc} e_c \frac{dT_c}{dt} = q_{ac} + q_{rcNET} - h_{ci}(T_c - T_i) - h_{co}(T_c - T_e) \quad (2.3)$$

Where δ_c is the density of the cover material of the greenhouse ($kg\ m^{-3}$), c_{pc} the cover material specific heat ($J\ kg^{-1}K^{-1}$) of the greenhouse, e_c the cover thickness (m), q_{ac} is the absorbed solar radiation by the greenhouse cover ($W\ m^{-2}$) and q_{rcNET} is the net thermal radiation rate at cover of the greenhouse ($W\ m^{-2}$). The energy transfers at the greenhouse cover to the outside and inside air by convection were defined with last two terms in the Eq. (2.3).

According to the formulation taken from the study of Joudi and Farhan (2015), solar radiation the absorbed by the greenhouse cover (q_{ac}) is calculated as following equation as Eq. (2.4).

$$q_{ac} = \alpha_{cw} R_g \left(1 + \left(1 - \alpha_{spm}\right)\right) \quad (2.4)$$

In the formulation given above, α_{cw} is absorptivity of the greenhouse cover to solar radiation and α_{spm} is absorbed fraction of solar radiation in the polypropylene mulch covering. Value of α_{cw} was taken 0.03.

$$\alpha_{spm} = \frac{(1-\rho_{spm})\tau_{cs}}{(1-\rho_{spm}\rho_{cs})} \quad (2.5)$$

Reflectance of the polypropylene mulch is calculated by $\rho_{spm} = 1 - \alpha_{pp}$ and since polypropylene absorption to solar radiation (α_{pp}) is 0.95 (Kurzböck et al., 2012), the reflectance of the polypropylene mulch is taken as 0.05.

τ_{cs} is the downward effective transmittance between the cover and the soil and it was calculated as in the Eq. (2.6) (Abdel-Ghany and Al-Helal,2011):

$$\tau_{cs} = \frac{\tau_{cw}\tau_{ha}\tau_{pl}}{(1 - \rho_{pl}\rho_{cw}\tau_{ha}{}^{2})} \quad (2.6)$$

τ_{cw} is transmittance of the greenhouse cover to solar radiation, values for τ_{cw} in Reyes Rosas et al., (2017) work are given in the Table 2.2 below. In this study, sensitivity analyzes will be made for different values in order to observe the effect of τ_{cw} coefficient after confirmation analysis. In the study of Reyes Rosas et al., (2017) the cover was whitened of the experimental greenhouse at different dates when measurements were made, so the τ_{cw} value varied during the harvest season.

Table 2.2 Periodic measurement results of transmittance of the whitened cover to solar radiation

Period	$\boldsymbol{\tau_{cw}}$
21-25 December 2014	0.82
5-9 January 2015	0.82
15-19 April 2015	0.42
29 April-3 May 2015	0.47
1-5 June 2015	0.47

τ_{ha} is humid air transmissivity and it's defined as following equation. R_{Hi} is the indoor air relative humidity and was accepted as 60, L_b is the mean path length of solar beam radiation and taken 15.1 as the work of Reyes Rosas et al., (2017).

$$\tau_{ha} = 0.79\left(\frac{3280}{R_{Hi}L_b}\right)^{\frac{1}{16}} \tag{2.7}$$

τ_{pl} is the transmittance of the plant layer to solar radiation and calculated by the Eq. (2.8) given below and the related equations are also given in the Eq. (2.9) and Eq. (2.10) respectively. C_1 and C_2 are coefficients that depends on plant. L_{Al} is leaf area index and measurements taken from the experimental greenhouse for different time periods were used for the validation study. Later, this value will be examined in detail throughout the cycle until the harvest time of the plant.

$$\tau_{pl} = \exp\left(-(C_2 L_{Al})\right) \tag{2.8}$$

$$C_2 = C_1[(1-\tau_L)^2 - {\rho_L}^2]^{0.5} \tag{2.9}$$

$$C_1 = 0.87 \tag{2.10}$$

ρ_L is reflectance of the tomato leaf tissue and it was taken 0.28 according to work of Monteith et al., 2008. τ_L is transmittance of the leaf tissue and it was taken as 0.20 according to study of Stanghellini, C., 1987.

ρ_{pl} is effective reflectance of the plant layer to solar radiation and calculated with the following formulation. ρ_∞ is reflectance of a dense tomato stand and it was taken 0.12 according to Stanghellini, C., 1987. Other formulas in the correlation are given below.

$$\rho_{pl} = \rho_\infty\left(1-\tau_{Lpl}\right) + {\tau_{Spl}}^2\rho_{spm} \tag{2.11}$$

τ_{Lpl} is transmittance for radiation for the diffuse longwave of the tomato crop, τ_{Lpl} is canopy transmittance for diffuse shortwave radiation and these terms are defined as in Eq. (2.12) and Eq. (2.13) respectively. k_L is the extinction coefficient of conical leaf distribution and it was taken 0.87 according to study of Monteith et al., 2008. τ_{Spl} is diffuse shortwave radiation for canopy transmittance and k_s is plant extinction coefficient of for shortwave radiation.

$$\tau_{Lpl} = \exp(-k_L L_{Al}) \tag{2.12}$$

$$\tau_{Spl} = \exp(-k_s L_{Al}) \tag{2.13}$$

$$k_s = k_L[(1-\tau_L)^2 - {\rho_L}^2]^{0.5} \tag{2.14}$$

Reflectance of the whitened cover to solar radiation was calculated by the given formula below. α_{cw} is the absorptivity of the cover to solar radiation and it was taken 0.03 according to work of Nijskens, J., Deltour, J., Coutisse, S., Nisen, A., 1984.

$$\rho_{cw} = 1 - \alpha_{cw} - \tau_{cw} \tag{2.15}$$

Downward effective reflectance of the greenhouse cover is indicated by ρ_{cs} and can be calculated by in the Eq. (2.16) Abdel-Ghany, A.M., Al-Helal, I.M., 2011.

$$\rho_{cs} = \rho_{pl} + \frac{\rho_{cw}{\tau_{spl}}^2{\tau_{ha}}^2}{(1-\rho_{pl}\rho_{cw}{\tau_{ha}}^2)} \tag{2.16}$$

The longwave net radiative energy flux on the cover is indicated by q_{rcNET} and it's defined as in Eq. (2.17) (Kittas, 1986; Singh et al., 2006; Joudi and Farhan, 2015). In the equation first part expresses the thermal radiation emitted by cover, the second therm is the atmospheric thermal irradiance absorbed by the greenhouse cover material and the last part is the thermal radiation emitted by the polypropylene mulch and absorbed by cover.

$$q_{rcNET} = \frac{-\varepsilon_c \sigma T_c{}^4 S_c + \alpha_{ct} q_{sky} S_c + \alpha_{ct} \varepsilon_{spm} \sigma T_{spm}{}^4 S_s}{S_s} \tag{2.17}$$

In the equation ε_c is emissivity of the greenhouse cover to thermal radiation, σ is the Stefan-Boltzmann constant it's equal to $5.67x10^{-8}\,\frac{W}{m^2K^4}$. S_c is the surface area of greenhouse cover (m^2) and S_s is the surface area of the soil (m^2). α_{ct} is the coefficient of greenhouse cover absorptivity of thermal radiation, both emissivity and absorptivity coefficients of greenhouse cover to solar radiation were taken 0.59 according to Feuilloley, P., Guillaume, S., Issanchou, G., Davenel, A., 1990.

q_{sky} is the downward longwave atmospheric irradiance incident on the cover surface which it was calculated according to the Eq. (2.18) which was given below (Swinbank, 1963; Pieters et al., 1997; Iziomon et al., 2003; Abdel-Ghany and Kozai, 2006):

$$q_{sky} = A_1 T_e{}^6 \tag{2.18}$$

In the present model, surface of the soil was covered with polypropylene mulch to avoid evapotranspiration. In addition, black plastic mulch increases the absorption of solar radiation and emission of infrared radiation of a bare sandy soil. The mulch temperature was determined from the differential equation by first ordered written from the energy balance in the plastic mulch covering the soil. The mathematical model is given in Figure 2.5.

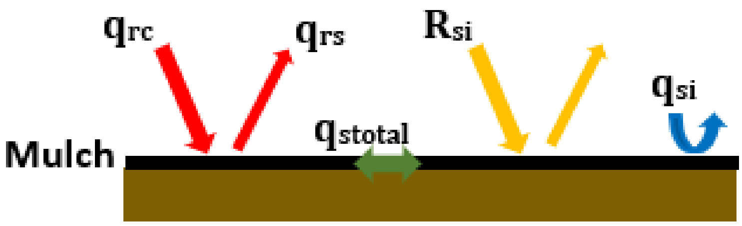


Figure 2.5 Mathematical modelling of heat transfer for plastic mulch

$$\delta_{spm}c_{spm}e_{spm}\frac{dT_{spm}}{dt} = q_{aspm} - h_{si}(T_{spm} - T_i) - q_{sc} - q_{rsNET} \qquad (2.19)$$

The density of the mulch is δ_{spm}, the plastic mulch specific heat is c_{spm}, thickness of the plastic mulch represented with e_{spm}. The solar radiation of the outside absorbed by the plastic mulch (q_{aspm}) is function of mulch absorption to solar radiation and outside global radiation. Terms of q_{sc} represents the heat transfer between soil and plastic mulch while q_{rsNET} representing the net radiative heat exchange on the soil surface.

The density of the mulch was taken 890 $\frac{kg}{m^3}$ according to studies of Wypych, 2016; Puszkarz et al., 2016. The plastic mulch specific heat was taken 1881 $\frac{J}{Kg.K}$ according to study of Puszkarz et al., 2016. Thickness of the plastic mulch was taken 0.0025 according to measurement of the study Reyes Rosas et al., (2017).

The outside solar radiation absorbed by the plastic mulch was calculated as in the Eq. (2.20).

$$q_{aspm} = \alpha_{spm}R_g \qquad (2.20)$$

The h_{si} heat transfer coefficient number used to calculate the heat transferred between the indoor air and soil surface was estimated with the equation taken from work of Fatnassi et al., 2013.

$$h_{si} = 1.75|T_{spm} - T_i|^{1/3} \qquad (2.21)$$

Heat conduction between the soil surface and plastic mulch calculated by the formula given below. R_{sz0} ($\frac{m^2K}{W}$) is the thermal resistance of the polypropylene mulch and it's calculated as in the Eq. (2.22).

$$q_{sc} = \frac{(T_{spm} - T_{s0})}{R_{sz0}} \qquad (2.22)$$

The temperatures for soil layers at different depths were calculated by the heat conduction equations as in the Eq. (2.23), Eq. (2.24) and Eq. (2.25). It is assumed that the soil temperature will not change after 0.5m depth.

$$\delta_{s01} c_{s01} e_{s01} \frac{dT_{s0}}{dt} = \frac{(T_{spm} - T_{s0})}{R_{sc,z0}} - \frac{k_{s01}(T_{s0} - T_{s1})}{e_{s01}} \qquad 0.01 < z \leq 0.05\ m \quad (2.23)$$

$$\delta_{s12} c_{s12} e_{s12} \frac{dT_{s1}}{dt} = \frac{k_{s01}(T_{s0} - T_{s1})}{e_{s01}} - \frac{k_{s12}(T_{s1} - T_{s2})}{e_{s12}} \qquad 0.05 < z \leq 0.1\ m \ (2.24)$$

$$\delta_{s23} c_{s23} e_{s23} \frac{dT_{s2}}{dt} = \frac{k_{s12}(T_{s1} - T_{s2})}{e_{s12}} - \frac{k_{s23}(T_{s2} - T_{s3})}{e_{s23}} \qquad 0.1 < z \leq 0.5\ m \quad (2.25)$$

The constants required for the solution of the Eq. (2.23), Eq. (2.24) and Eq. (2.25) are given in the Table 2.3 with their values and sources.

Table 2.3 Coefficients for soil layers

Coefficient	Symbol/Unıt	Value	Source
Temperature of soil at depth 0.5m	T_{s3} (°C)	24	Reyes Rosas et al., 2017
Density of the first layer sand-soil	δ_{s01} (kg/m^3)	1700	Reyes Rosas et al., 2017
Density of the second layer clay loam-soil	δ_{s12} (kg/m3)	1450	Reyes Rosas et al., 2017
Density of the third layer sandy clay-soil	δ_{s23} (kg/m3)	1500	Reyes Rosas et al., 2017
Specific heat of the first soil layer	c_{p01} (J/kg.K)	800	Reyes Rosas et al., 2017
Specific heat of the second soil layer	c_{p12} (J/kg.K)	1900	Reyes Rosas et al., 2017
Specific heat of the third soil layer	c_{p23} (J/kg.K)	1696	Reyes Rosas et al., 2017
Thermal conductivity of the first soil layer	k_{s01} (W/m.K)	0.27	Reyes Rosas et al., 2017

Table 2.3 Continue

Thermal conductivity of the second soil layer	k_{s12} (W/m.K)	0.48	Reyes Rosas et al., 2017
Thermal conductivity of the third soil layer	k_{s23} (W/m.K)	1.61	Reyes Rosas et al., 2017

Net radiative heat exchange on the soil surface was calculated by the Eq. (2.26) (Joudi, K.A., Farhan, A.A., 2015.). It is assumed that the polypropylene mulch absorption coefficient equal to emissivity of the polypropylene.

$$q_{rsNET} = \frac{-\varepsilon_{spm}\sigma T_{spm}{}^4 S_s + \alpha_{Ls}\varepsilon_c \sigma T_c{}^4 S_c}{S_s} \tag{2.28}$$

$$\alpha_{Ls} = \alpha_{Lpm}\tau_{Lpl} \tag{2.29}$$

The inside air temperature of the greenhouse (T_i) is based on energy balance calculating the sensible heat fluxes transferred between the air and other elements of the greenhouse (Fatnassi et al., 2013).

$$\delta_a c_{pa}\frac{V_g}{S_s}\frac{dT_i}{dt} = P_v L_{al} h_{vi}(T_v - T_i) - h_{si}(T_i - T_{spm}) - \frac{S_c}{S_s}h_{ci}(T_i - T_c) - \delta_a c_{pa}\frac{G}{S_s} f_G(T_i - T_e) \tag{2.30}$$

Where δ_a is the density of air ($kg\ m^{-3}$), cp_a inside air specific heat ($J\ kg^{-1}K^{-1}$), V_g is the volume of greenhouse (m^3) and $P_v = 0.725$ the proportion of area covered by plants ($m^2\ m^{-2}$), L_{AI} is the leaf area index, G the natural ventilation rate ($m^3\ s^{-1}$).

Convective heat transfer coefficient between the air inside and plants calculated by the Eq. (2.31) taken from work of Fatnassi et al., 2013. L_{cl} is the characteristic leaf lenght of the tomato crop and it was accepted 0.14 according to Reyes Rosas et al., (2017).

$$h_{vi} = 1.4(\frac{|T_v - T_i|}{L_{cl}})^{0.25} \quad (2.31)$$

The convective heat transfer coefficient of the h_{si}, for the calculation of heat transferred between the inside air and soil surface was calculated by the following equation. (Fatnassi et al., 2013)

$$h_{si} = 1.75|T_{spm} - T_i|^{1/3} \quad (2.32)$$

Just like the h_{si}, the h_{ci} heat transfer coefficient is also calculated with a similar formula. For estimated the heat transfer between the indoor air and the greenhouse cover, heat transfer coefficient h_{ci} was calculated by the Eq. (2.33) (Fatnassi et al., 2013).

$$h_{ci} = 1.75|T_c - T_i|^{1/3} \quad (2.33)$$

For the calculation of convective heat transfer coefficient between greenhouse cover and air of the outside weather, given equation was used. It’s a function of the wind speed (Garzoli and Blackwell, 1981).

$$h_{co} = 7.2 + 3.8U_o \quad (2.34)$$

Due to the openings on the roof and on the side, natural ventilation occurs between the indoor andoutdoor environment. Volumetric ventilation flow (G) and ventilation flux correction coefficient (f_G) calculated by the given equations. (Pearson & Owen, 1994; Kittas et al., 1997)

$$G = \left[\left(\frac{1}{\frac{1}{{C_{dVR}}^2 {S_{VR}}^2} + \frac{1}{{C_{dVS}}^2 {S_{VS}}^2}} \right) \left(2g \frac{|T_i - T_e|}{T_e} H_{SR} \right) + \left(\frac{C_{dVR} S_{VR} + C_{dVS} S_{VS}}{2} \right)^2 C_w {U_o}^2 \right]^{0.5} \quad (2.35)$$

$$f_G = 4.62 * 10^{-8} {\theta_G}^4 - 9.87 * 10^{-6} {\theta_G}^3 + 0.00058 * {\theta_G}^2 + 0.0024\theta_G + 0.247 \quad (2.36)$$

$$\theta_G = \theta_W - 28^{\circ} \quad if\ \theta_w > 28^{\circ} \quad (2.37)$$

$$\theta_G = \theta_W + 332^{\circ} \quad if\ \theta_w < 28^{\circ} \quad (2.38)$$

In the formula g is the gravitational constant, H_{SR} is the vertical distance between midpoint of side and roof openings, C_w is the wind effect coefficient. C_{dVR} and C_{dVS} are roof vent discharge and side vent discharge coefficients respectively. S_{VR} and S_{VS} roof and the side openings' surface areas.

In de Eq. (2.36) f_G depends on θ_G which represents angle of incidence of wind. And θ_G also changes depending on the wind direction as seen in Eq. (2.37) and Eq. (2.38), respectively.

2.3. Validation of the Model

Validation analyzes for the work of Reyes Rosas, taken as the base study, will be shown in this section. Meteorological datas taken from the article for analysis are given below. In the figure below, solar radiation values in the city of Almeria, Spain for the month of December are given in the graph. The red curve represent outside solar radiation and the black curve represent inside solar radiation. The data are given for 5 days selected from December.

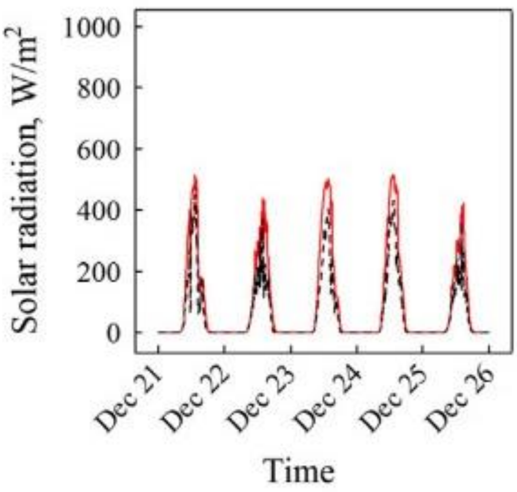


Figure 2.6 Solar radiation for December in Almeria (Reyes Rosas et al., 2017)

In Figure 2.7, the red line represents the outdoor temperature, the black dashed lines represent the measured indoor temperature, and the blue dashed lines represent the calculated indoor temperature. Values are for 5 days selected from December.

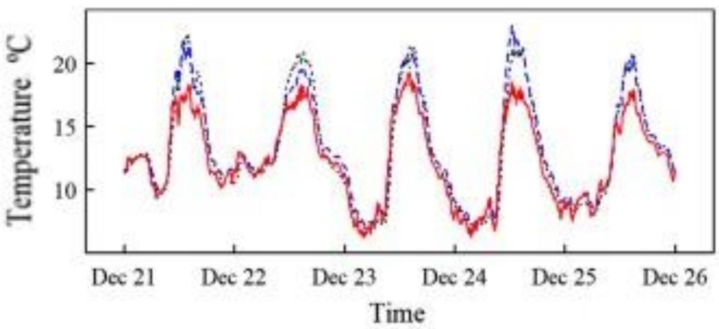


Figure 2.7 Temperature values for Almeria (Reyes Rosas et al., 2017)

In Figure 2.8 and Figure 2.9, verification analyses for plant and soil temperatures for December are given.

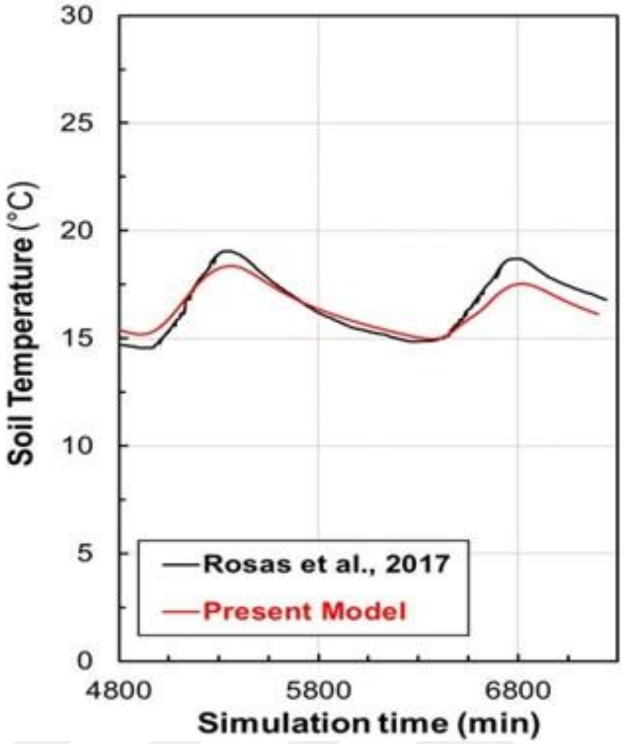


Figure 2.8 Soil temperature for Almeria greenhouse

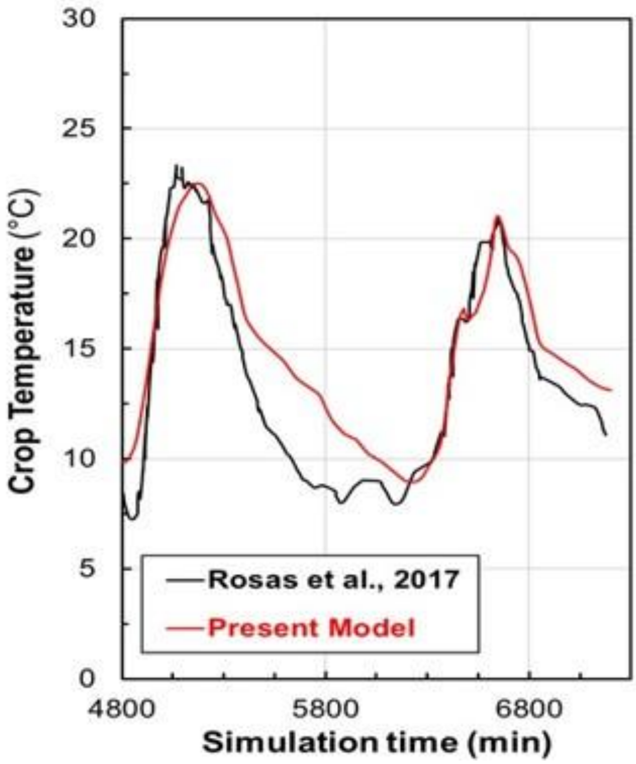
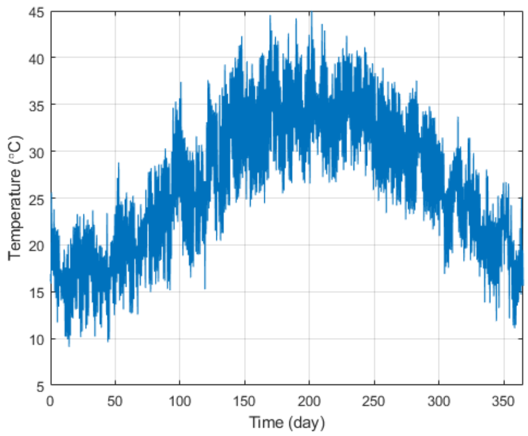


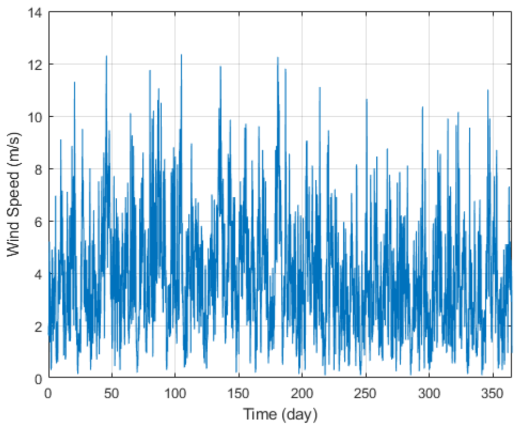
Figure 2.9 Crop temperature for Almeria greenhouse

2.4. Analysis for Izmir and Doha

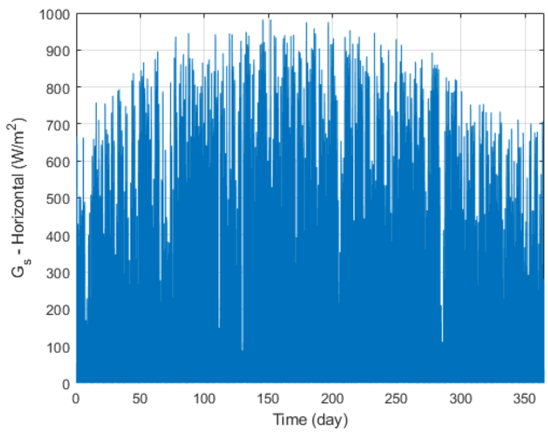
In the present model, the differential equations were discretized via using explicit finite difference method. The simulation duration was determined as 1 year (31,536,000 s), and time step dt=1 s. However, the hourly mean values of input parameters such as ambient temperature, solar irradiation, wind velocity and direction were defined hourly into simulation to reduce computing time of the MATLAB code. Input parameters for Izmir and Doha were taken from Meteonorm database. The crop temperature, indoor air temperature, greenhouse cover temperature, plastic mulch temperature and soil temperature were visualized at the end of the MATLAB code.



(a) Ambient Temperature of Doha



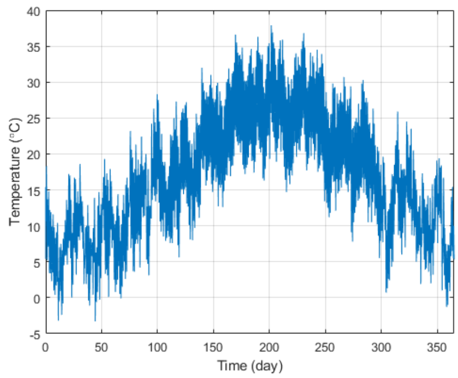
(b) Wind Velocity of Doha



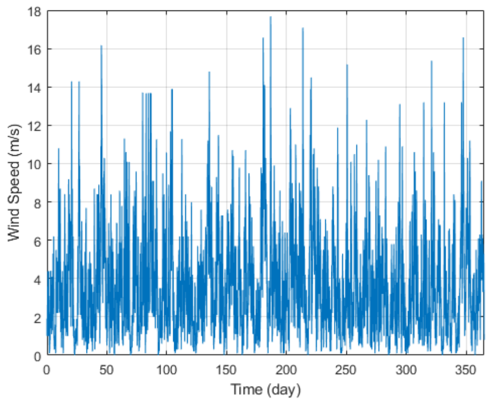
(c) Solar Radiation of Doha

Figure 2.10 Climate datas for Doha

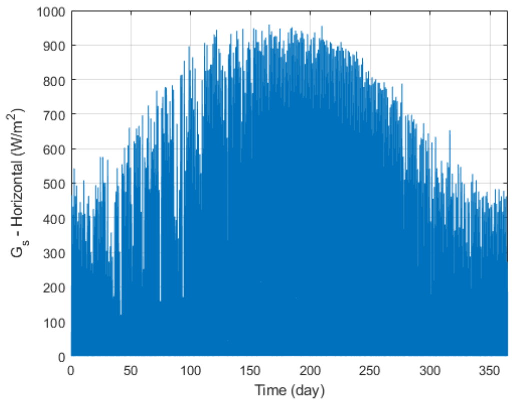
Figure 2.10 shows the input parameters (a) ambient temperature of Doha, (b) wind velocity of Doha and (c) solar radiation of Doha.



(a) Ambient Temperature of Izmir



(b) Wind Velocity of Izmir

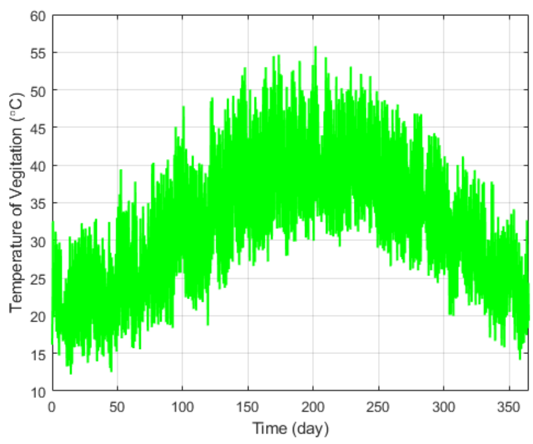


(c) Global Solar Radiation of Izmir

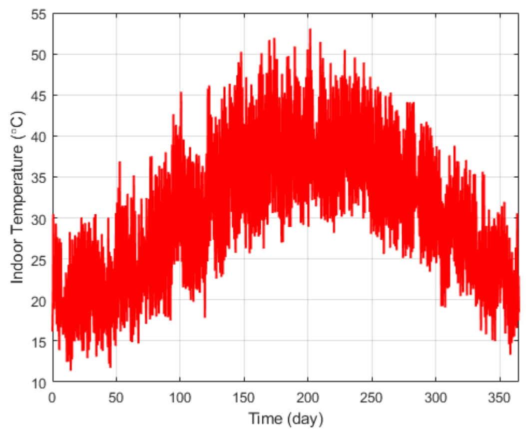
Figure 2.11 Climate datas for Izmir

Figure 2.11 shows input parameters for the thermal model of the greenhouse in Izmir.

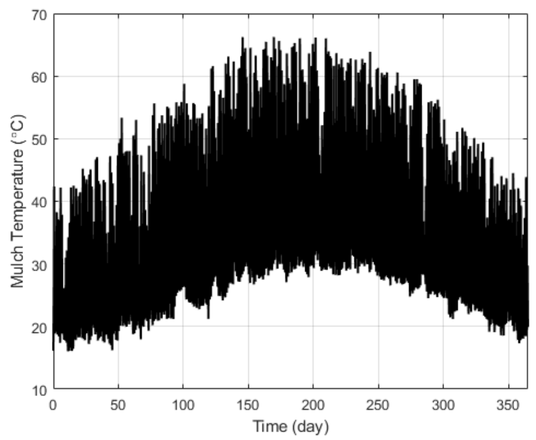
The crop temperature, greenhouse inside temperature, plastic mulch temperature was determined with the current thermal model of the greenhouse in Izmir and Doha. In the Shamshiri et al., the optimal temperature for tomatoes crop was determined as 24 °C. Figure 2.12 shows (a) the crop temperature, (b) the indoor temperature, (c) the plastic mulch temperature at the greenhouse in Doha with 10 m^3/s ventilation.



(a) Vegetation Temperature in Doha



(b) Indoor Temperature in Doha

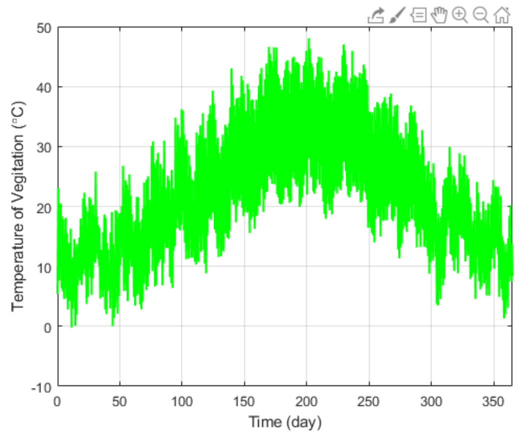


(c) Mulch Temperature in Doha

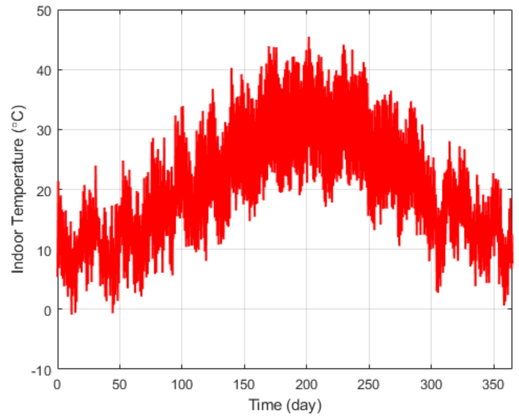
Figure 2.12 Crop, indoor and mulch temperatures for Doha

The temperature of vegetation goes up to 55 °C, while inside air temperature increasing to 52 °C in year and the lowest temperature in the year is determined as 13 °C and 12 °C for vegetation and inside air respectively. Due to thermophysical properties the mulch temperature increases to 68 °C and the minimum temperature is 18 °C in the year.

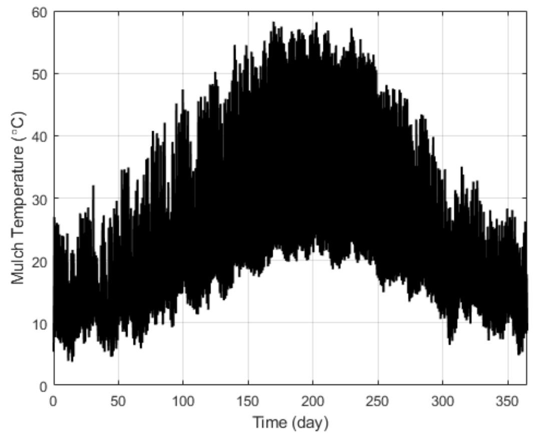
Figure 2.13 shows the temperature of the (a) vegetation, (b) inside air, (c) mulch at the greenhouse in Izmir.



(a) Temperature of vegetation



(b) Temperature of inside air



(c) Temperature of the mulch

Figure 2.13 Crop, indoor and mulch temperatures for Izmir

The temperature of the vegetation varies between 50 °C and 0 °C while the inside air temperature alters between 45 °C and 0 °C in a year. The temperatures of the mulch changes between 55 °C and 5 °C.

Monthly mean vegetation and inside air temperature in °C for Doha and Izmir is visualized in the Figure 2.14.

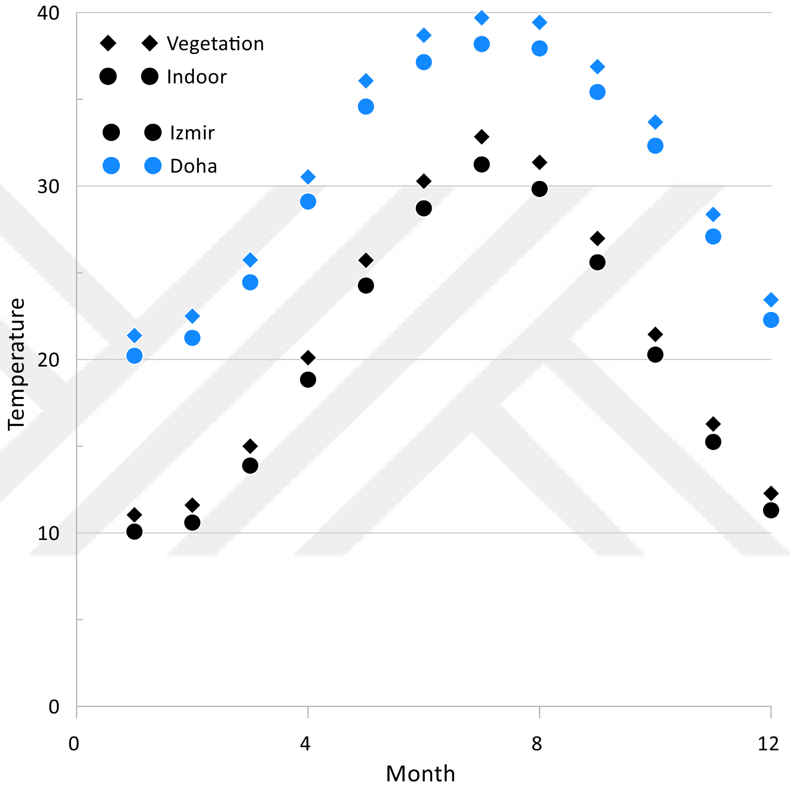


Figure 2.14 Crop and inside air temperatures for Doha and Izmir

The vegetation temperature is higher on every month in Doha and Izmir. The monthly mean temperature of vegetation increases to 40 °C in Doha, when it increases to 32 °C in Izmir. Due to the global solar radiation difference between Doha and Izmir, the vegetation and indoor temperature differences increase in the winter season, decrease in the summer season.

Figure 2.15 shows the influence of ventilation rate (G) on vegetation temperature in Doha.

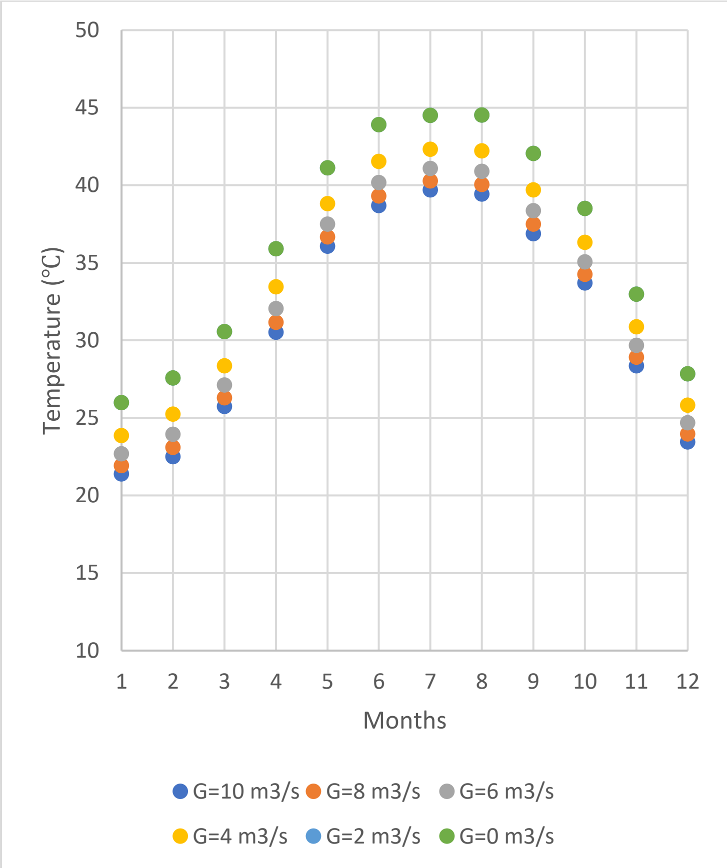


Figure 2.15 Influence of ventilation rate on crop temperature in Doha

When the natural ventilation rate is 0 m^3/s the monthly mean vegetation temperature at the maximum level and above the optimal vegetation temperature on all months in Doha. The natural ventilation causes some reduction on temperature of vegetation in the greenhouse. When the natural ventilation rate G=10 m^3/s, the mean vegetation temperature decreases to 21 °C in January, and in July and August the mean vegetation temperature decreases to 38 °C from 45 °C.

The influence of the natural ventilation rate on the temperature of the vegetation in Izmir is shown in the Figure 2.16.

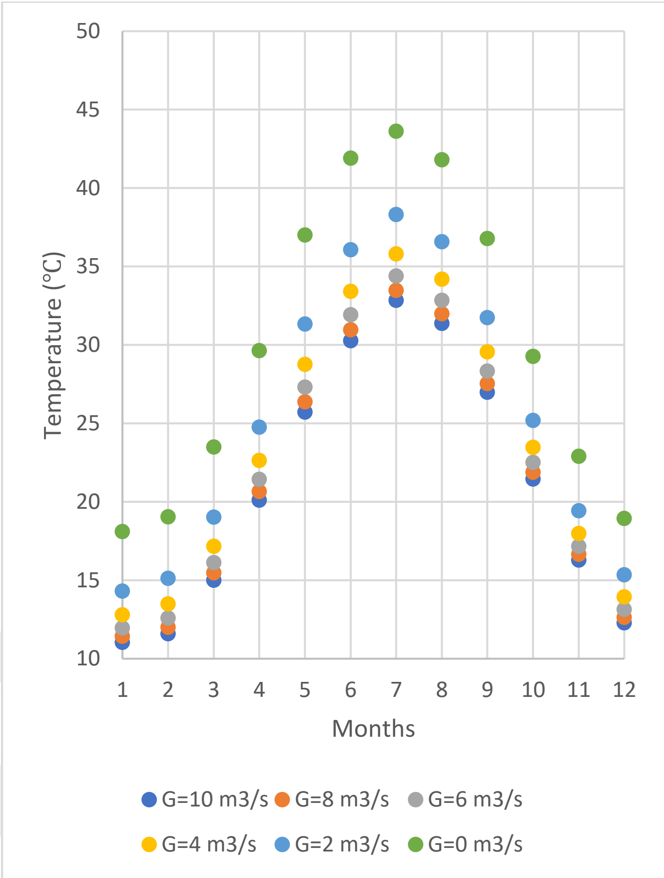


Figure 2.16 Influence of ventilation rate on crop temperature in Izmir

The vegetation temperature alters with the natural ventilation inversely. In January, the monthly vegetation temperature without natural ventilation increases to 16 ℃, while G=10 m^3/s the monthly mean vegetation temperature is 11 ℃. Considering that the optimal temperature for tomatoes is 24 ℃, using natural ventilation for İzmir in January will increase the difference between the temperature in the greenhouse and the optimum temperature value. In this case, it will cause an extra heating need in winter months for Izmir.

CHAPTER THREE
NUMERICAL ANALYZES AND RESULTS

In this part of the study, parametric analyzes were carried out in Izmir climate for the geometry of the reference model, which was verified in the previous section. The climate data received for the province of Izmir are given in the validation of the model in chapter two. The analyzes for each changed parameter will be examined under sub-headings in this section.

The optimum temperature for growing tomatoes is expected to be tomato temperature is around 24℃, the soil temperature to be 20-29℃ and the indoor temperature to be 22-26℃.

3.1. Effect of Changing Cover Thickness (e_c)

In the base study, the thickness of the coating was taken as 0.002mm from the reference study in the verification analyses. The effect of the change of this parameter on indoor temperature, plant temperature, coating temperature, mulch temperature and soil temperatures are given in the graphics and table below. The effect of the change of this parameter on indoor temperature, plant temperature, cover temperature, mulch temperature and soil temperatures are given in the graphics and table below.

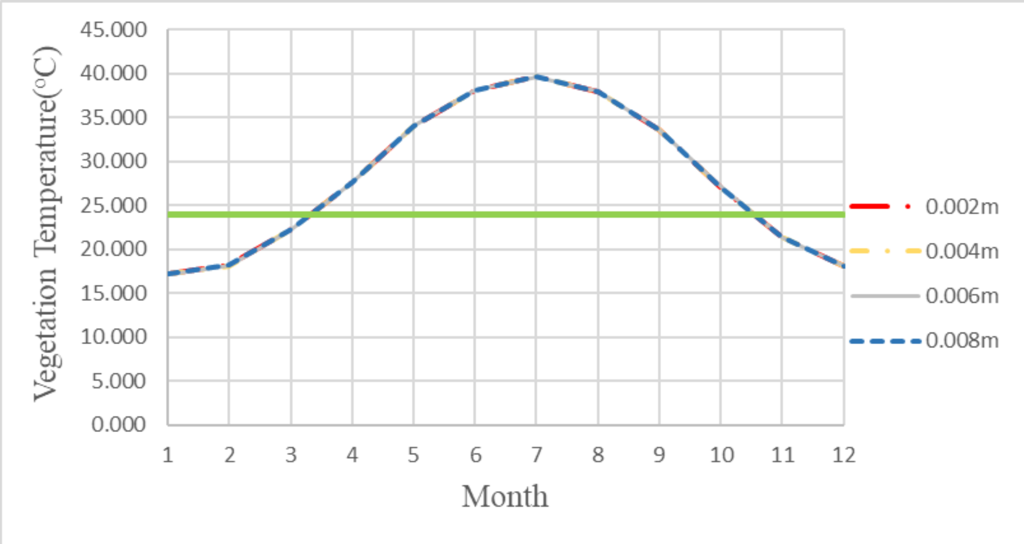


Figure 3.1 Average monthly plant temperature for different cover thickness values

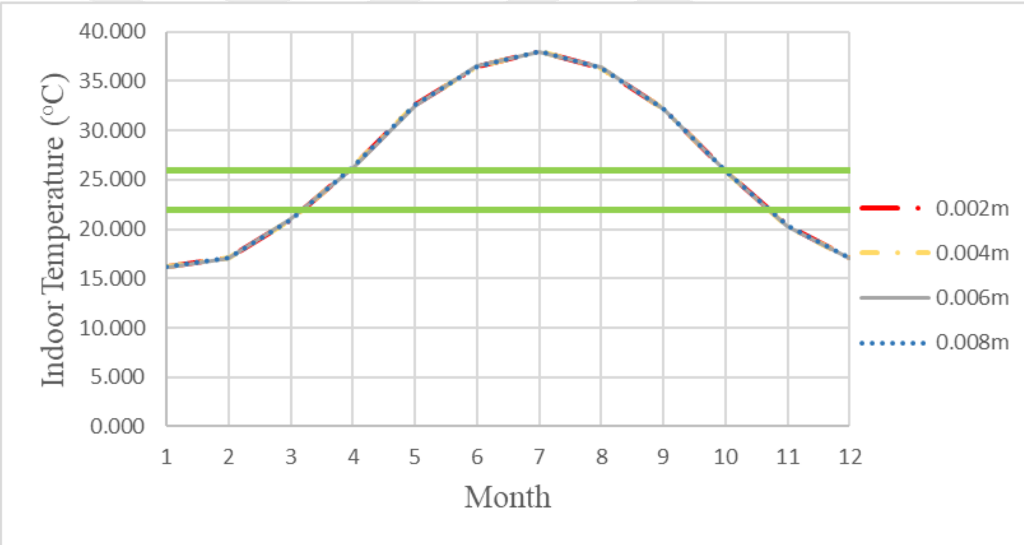


Figure 3.2 Average monthly indoor temperature for different cover thickness values

In the second chapter Figure 2.13 show the analyses for 0.002mm cover thickness. In Figure 3.1 monthly average plant temperatures for different cover thickness values are shown. The green line in the graph represents the optimum temperature. In Figure 3.2, monthly average indoor temperatures are shown for different cover thickness values. The green lines in the graph represent the optimum temperature range.

Table 3.1 Average monthly temperatures for different cover thickness values

e_c=0.002								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.20	15.82	16.57	16.17	13.94	11.19	9.30	5.30
February	18.15	15.99	18.15	17.08	15.31	12.30	10.19	5.30
March	22.22	19.30	22.72	21.03	18.92	14.90	12.07	5.30
April	27.59	24.28	28.20	26.25	23.07	17.67	13.90	5.30
May	34.10	29.61	35.54	32.56	28.86	21.80	16.86	5.30
June	38.17	33.55	39.63	36.52	32.12	24.18	18.59	5.30
July	39.64	35.40	40.67	37.97	32.92	24.72	18.97	5.30
August	37.96	34.20	38.63	36.36	31.38	23.70	18.30	5.30
September	33.66	30.93	33.38	32.22	27.31	20.89	16.35	5.30
October	27.14	25.78	25.78	25.91	21.43	16.80	13.51	5.30
November	21.35	20.45	19.84	20.27	16.71	13.39	11.05	5.30
December	18.13	16.64	17.38	17.10	14.75	11.98	10.02	5.30
e_c=0.004								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.19	15.80	16.55	16.16	13.93	11.18	9.29	5.30
February	18.14	15.97	18.13	17.07	15.29	12.29	10.18	5.30
March	22.21	19.28	22.71	21.02	18.91	14.88	12.06	5.30
April	27.58	24.26	28.18	26.24	23.06	17.66	13.89	5.30
May	34.09	29.59	35.52	32.55	28.85	21.79	16.84	5.30
June	38.15	33.53	39.62	36.51	32.11	24.16	18.58	5.30
July	39.62	35.38	40.66	37.96	32.91	24.71	18.96	5.30
August	37.95	34.19	38.62	36.35	31.37	23.69	18.29	5.30
September	33.64	30.91	33.36	32.20	27.30	20.87	16.34	5.30
October	27.13	25.77	25.77	25.90	21.42	16.79	13.50	5.30
November	21.34	20.44	19.83	20.26	16.70	13.38	11.04	5.30
December	18.12	16.63	17.37	17.09	14.74	11.97	10.01	5.30
	e_c=0.006							
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.19	15.81	16.56	16.16	13.93	11.19	9.30	5.30
February	18.15	15.98	18.14	17.08	15.30	12.30	10.19	5.30
March	22.21	19.29	22.71	21.02	18.91	14.89	12.06	5.30
April	27.59	24.27	28.19	26.24	23.07	17.66	13.89	5.30
May	34.09	29.59	35.53	32.55	28.85	21.80	16.85	5.30
June	38.16	33.54	39.62	36.52	32.11	24.17	18.59	5.30
July	39.63	35.39	40.66	37.97	32.91	24.72	18.96	5.30
August	37.95	34.19	38.62	36.36	31.37	23.70	18.30	5.30
September	33.65	30.91	33.37	32.20	27.31	20.88	16.35	5.30
October	27.13	25.78	25.77	25.91	21.42	16.80	13.51	5.30
November	21.35	20.44	19.84	20.27	16.71	13.39	11.05	5.30
December	18.13	16.64	17.37	17.09	14.75	11.98	10.02	5.30
	e_c=0.008							

Table 3.1 Continue

Months	Vegetation	Cover	Mulch	Indoor	S0	S1	S2	S3
January	17.19	15.80	16.56	16.16	13.93	11.18	9.30	5.30
February	18.15	15.98	18.14	17.08	15.30	12.29	10.19	5.30
March	22.21	19.28	22.71	21.02	18.91	14.89	12.06	5.30
April	27.58	24.26	28.19	26.24	23.06	17.66	13.89	5.30
May	34.09	29.59	35.52	32.55	28.85	21.79	16.85	5.30
June	38.16	33.53	39.62	36.52	32.11	24.17	18.59	5.30
July	39.63	35.38	40.66	37.96	32.91	24.72	18.96	5.30
August	37.95	34.19	38.62	36.35	31.37	23.70	18.29	5.30
September	33.64	30.90	33.36	32.20	27.30	20.88	16.34	5.30
October	27.13	25.78	25.77	25.90	21.42	16.80	13.51	5.30
November	21.35	20.44	19.84	20.26	16.71	13.39	11.05	5.30
December	18.13	16.63	17.37	17.09	14.75	11.98	10.02	5.30

In Table 3.1, monthly average plant, cover, mulch, indoor and soil temperatures are given for different cover thickness values. When the graphs and the table are examined, it is clearly seen that cover thickness has little or no effect on indoor and plant temperatures. Considering the raw material costs, 0.002mm thickness will be the most ideal thickness. It seems that the optimum temperatures for planting are in the spring months. Cooling is required for the summer months and heating is required for the winter months.

3.2. Effect of Changing Polypropylene Mulch Sheet Thickness (e_{spm})

In the base study, the polypropylene mulch sheet thickness was taken as 0.0025mm from the reference study in the verification analyses. The effect of the change of this parameter on indoor temperature, plant temperature, coating temperature, mulch temperature and soil temperatures are given in the graphics and table below. The effect of the change of this parameter on indoor temperature, plant temperature, cover temperature, mulch temperature and soil temperatures are given in the Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6 and Table 3.2 below.

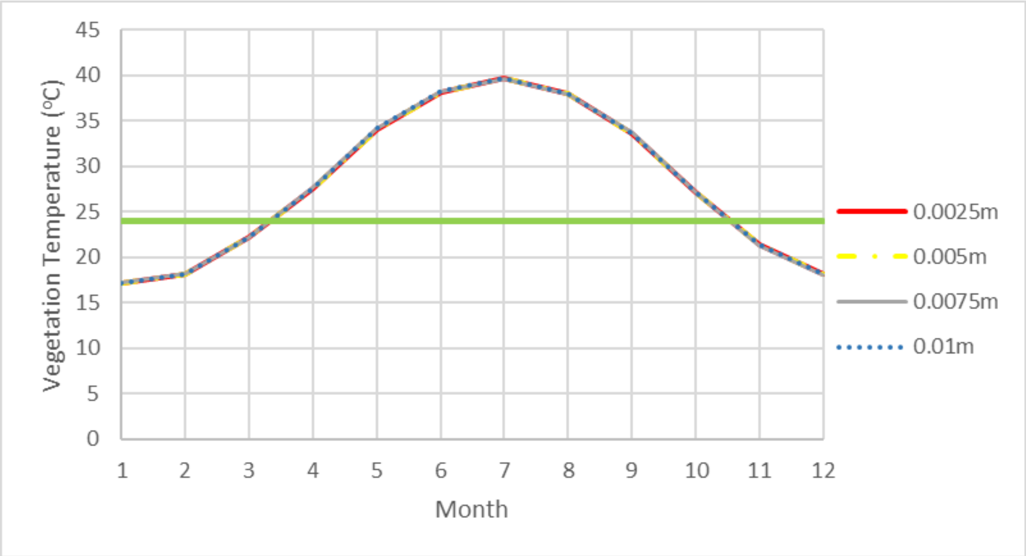


Figure 3.3 Average monthly plant temperature for different mulch thickness values

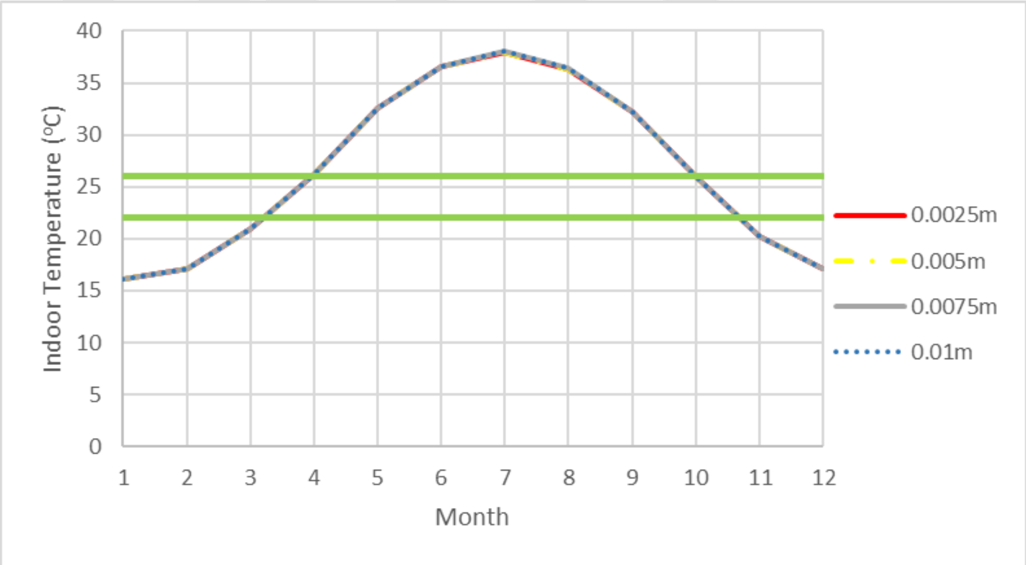


Figure 3.4 Average monthly indoor temperature for different mulch thickness values

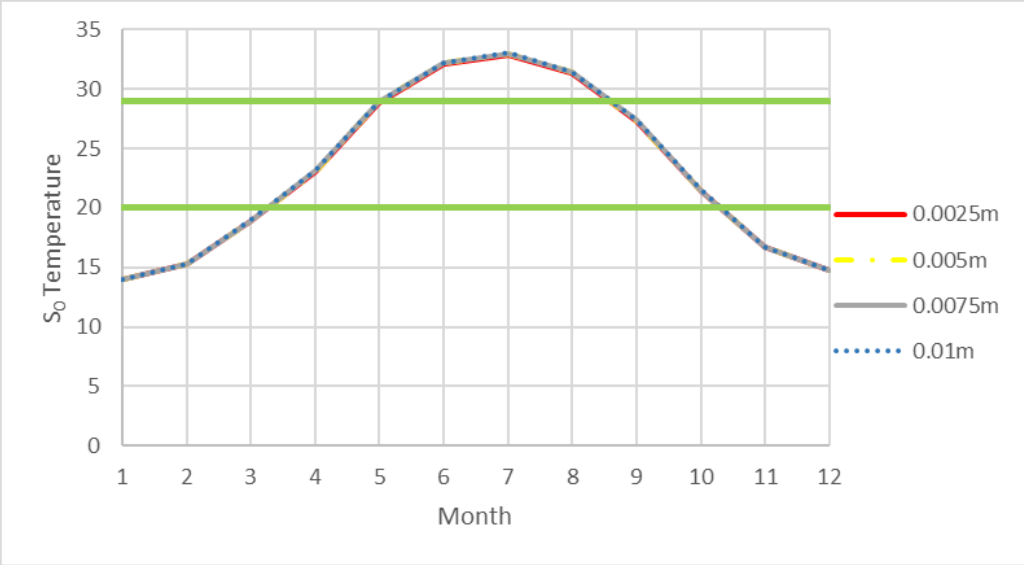


Figure 3.5 Average monthly soil temperature for different mulch thickness values

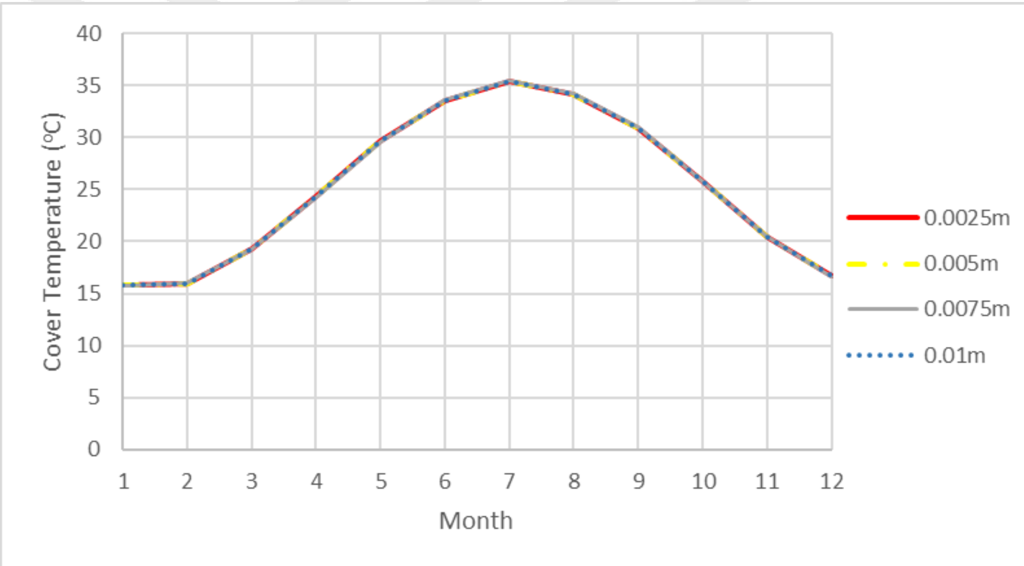


Figure 3.6 Average monthly cover temperature for different mulch thickness values

In the second chapter Figure 2.13 show the crop temperature, inside air temperature, and mulch temperature analyses for 0.0025mm polypropylene mulch sheet thickness. In Figure 3.3, monthly average plant temperatures for different mulch thickness values are shown. The green line in the graph represents the optimum temperature. In Figure 3.4, monthly average indoor temperatures are shown for different mulch thickness values. The green lines in the graph represent the optimum temperature range. In Figure 3.5, monthly average first layer of soil temperatures is shown for different mulch thickness values. The green lines in the graph represent the optimum temperature range and Figure 3.6 shows the average monthly cover temperature values for different mulch thickness values.

Table 3.2 Average monthly temperatures for different mulch thickness values

e_spm=0.0025								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.20	15.82	16.57	16.17	13.94	11.19	9.30	5.30
February	18.15	15.99	18.15	17.08	15.31	12.30	10.19	5.30
March	22.22	19.30	22.72	21.03	18.92	14.90	12.07	5.30
April	27.59	24.28	28.20	26.25	23.07	17.67	13.90	5.30
May	34.10	29.61	35.54	32.56	28.86	21.80	16.86	5.30
June	38.17	33.55	39.63	36.52	32.12	24.18	18.59	5.30
July	39.64	35.40	40.67	37.97	32.92	24.72	18.97	5.30
August	37.96	34.20	38.63	36.36	31.38	23.70	18.30	5.30
September	33.66	30.93	33.38	32.22	27.31	20.89	16.35	5.30
October	27.14	25.78	25.78	25.91	21.43	16.80	13.51	5.30
November	21.35	20.45	19.84	20.27	16.71	13.39	11.05	5.30
December	18.13	16.64	17.38	17.10	14.75	11.98	10.02	5.30
e_spm=0.005								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.19	15.81	16.57	16.16	13.94	11.19	9.30	5.30
February	18.16	15.99	18.17	17.08	15.32	12.31	10.20	5.30
March	22.22	19.29	22.74	21.03	18.94	14.91	12.08	5.30
April	27.60	24.28	28.23	26.26	23.09	17.68	13.91	5.30
May	34.12	29.61	35.58	32.58	28.89	21.83	16.87	5.30
June	38.19	33.55	39.68	36.54	32.16	24.20	18.61	5.30
July	39.66	35.40	40.72	38.00	32.96	24.75	18.99	5.30
August	37.97	34.20	38.67	36.38	31.41	23.73	18.32	5.30
September	33.66	30.92	33.40	32.22	27.34	20.90	16.36	5.30
October	27.15	25.79	25.80	25.92	21.44	16.81	13.52	5.30
November	21.35	20.45	19.85	20.27	16.72	13.40	11.05	5.30
December	18.13	16.64	17.39	17.10	14.77	11.99	10.03	5.30
e_spm=0.0075								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.18	15.81	16.57	16.16	13.94	11.19	9.30	5.30
February	18.16	15.99	18.18	17.09	15.33	12.32	10.20	5.30
March	22.22	19.29	22.77	21.03	18.96	14.92	12.08	5.30
April	27.61	24.28	28.26	26.27	23.12	17.70	13.92	5.30
May	34.14	29.61	35.63	32.60	28.93	21.85	16.89	5.30
June	38.21	33.55	39.74	36.57	32.20	24.23	18.63	5.30
July	39.69	35.40	40.77	38.03	33.00	24.78	19.01	5.30
August	37.99	34.20	38.72	36.39	31.45	23.75	18.33	5.30
September	33.68	30.91	33.44	32.23	27.36	20.92	16.38	5.30

Table 3.2 Continue

October	27.16	25.79	25.82	25.94	21.46	16.82	13.53	5.30
November	21.36	20.45	19.86	20.28	16.72	13.40	11.06	5.30
December	18.14	16.64	17.41	17.10	14.78	11.99	10.03	5.30
e_spm=0.01								
Months	**Vegetation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.18	15.80	16.57	16.15	13.94	11.19	9.30	5.30
February	18.16	15.99	18.20	17.09	15.35	12.33	10.21	5.30
March	22.22	19.28	22.79	21.03	18.97	14.93	12.09	5.30
April	27.62	24.28	28.29	26.28	23.14	17.71	13.93	5.30
May	34.16	29.61	35.67	32.62	28.97	21.88	16.91	5.30
June	38.23	33.55	39.79	36.59	32.25	24.26	18.65	5.30
July	39.72	35.40	40.83	38.06	33.04	24.81	19.03	5.30
August	38.01	34.20	38.77	36.41	31.49	23.78	18.35	5.30
September	33.69	30.91	33.47	32.25	27.39	20.94	16.39	5.30
October	27.18	25.79	25.85	25.95	21.48	16.84	13.54	5.30
November	21.36	20.45	19.87	20.28	16.73	13.41	11.06	5.30
December	18.14	16.64	17.42	17.11	14.79	12.00	10.04	5.30

In Table 3.2, monthly average plant, cover, mulch, indoor and soil temperatures are given for different mulch thickness values. When the graphs and the table are examined, it is clearly seen that mulch thickness has almost no effect on indoor and plant temperatures. Considering the raw material costs, 0.0025mm thickness will be the most ideal thickness. It seems that the optimum temperatures for planting are in the spring months. Cooling is required for the summer months and heating is required for the winter months.

3.3. Effect of Changing Transmittance of the Whitened Cover to Solar Radiation (τ_{cw})

In the base study, the results of periodic measurements for transmittance of the whitened cover to solar radiation are given in Table 2.2. In the validation analyses, this coefficient was accepted as 0.47. In this section, the effect of the change in the parameter on indoor temperature, plant temperature, cover temperature, mulch temperature and soil temperature is given in the graphs and table below.

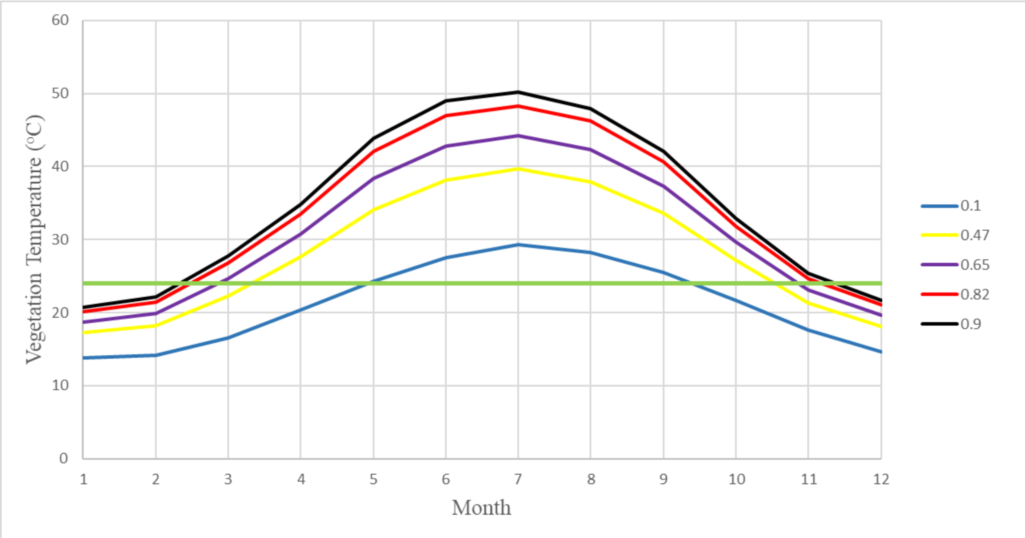


Figure 3.7 Average monthly plant temperature for different τ_{cw} values

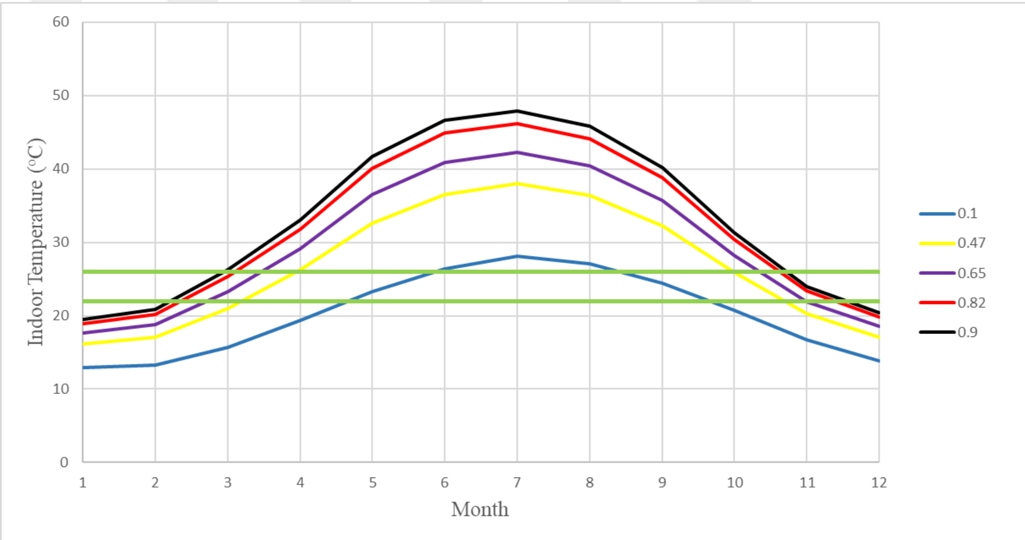


Figure 3.8 Average monthly indoor temperature for different τ_{cw} values

In Figure 3.7, monthly average plant temperatures for different transmittance of the whitened cover to solar radiation values are shown. The green line in the graph represents the optimum temperature. In Figure 3.8, monthly average indoor temperatures are shown. The green lines in the graph represent the optimum temperature range.

Table 3.3 Average monthly temperatures for different τ_{cw} values

tau_cw=0.1								
Months	**Vigitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	13.80	14.74	10.92	12.95	9.60	8.23	7.29	5.30
February	14.11	14.79	11.43	13.25	10.08	8.65	7.65	5.30
March	16.59	17.54	13.43	15.69	11.64	9.76	8.43	5.30
April	20.39	21.98	16.39	19.42	13.93	11.34	9.52	5.30
May	24.34	26.36	19.67	23.31	16.48	13.12	10.76	5.30
June	27.51	30.00	22.19	26.44	18.49	14.57	11.82	5.30
July	29.25	32.12	23.42	28.16	19.44	15.23	12.28	5.30
August	28.20	31.00	22.51	27.13	18.77	14.81	12.01	5.30
September	25.51	28.11	20.16	24.49	16.95	13.54	11.14	5.30
October	21.67	23.98	16.86	20.72	14.40	11.77	9.91	5.30
November	17.59	19.27	13.66	16.70	11.86	9.95	8.60	5.30
December	14.68	15.60	11.64	13.82	10.28	8.84	7.82	5.30
tau_cw=0.47								
Months	**Vegitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	17.20	15.82	16.57	16.17	13.94	11.19	9.30	5.30
February	18.15	15.99	18.15	17.08	15.31	12.30	10.19	5.30
March	22.22	19.30	22.72	21.03	18.92	14.90	12.07	5.30
April	27.59	24.28	28.20	26.25	23.07	17.67	13.90	5.30
May	34.10	29.61	35.54	32.56	28.86	21.80	16.86	5.30
June	38.17	33.55	39.63	36.52	32.12	24.18	18.59	5.30
July	39.64	35.40	40.67	37.97	32.92	24.72	18.97	5.30
August	37.96	34.20	38.63	36.36	31.38	23.70	18.30	5.30
September	33.66	30.93	33.38	32.22	27.31	20.89	16.35	5.30
October	27.14	25.78	25.78	25.91	21.43	16.80	13.51	5.30
November	21.35	20.45	19.84	20.27	16.71	13.39	11.05	5.30
December	18.13	16.64	17.38	17.10	14.75	11.98	10.02	5.30
tau_cw=0.65								
Months	**Vegitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	18.72	16.34	19.03	17.61	15.83	12.48	10.18	5.30
February	19.91	16.56	21.02	18.74	17.54	13.86	11.28	5.30
March	24.64	20.15	26.63	23.32	21.98	17.06	13.59	5.30
April	30.72	25.40	33.18	29.19	26.93	20.35	15.75	5.30
May	38.33	31.21	42.17	36.55	34.03	25.43	19.40	5.30
June	42.84	35.33	47.01	40.93	37.88	28.24	21.45	5.30
July	44.23	37.03	48.00	42.30	38.65	28.75	21.81	5.30
August	42.31	35.80	45.51	40.46	36.77	27.50	20.98	5.30
September	37.33	32.33	39.13	35.69	31.83	24.08	18.62	5.30
October	29.63	26.66	29.72	28.27	24.53	19.02	15.10	5.30
November	23.08	21.02	22.64	21.91	18.90	14.95	12.16	5.30
December	19.67	17.13	19.89	18.55	16.72	13.36	10.99	5.30
tau_cw=0.82								

Table 3.3 Continue

Months	Vegitation	Cover	Mulch	Indoor	S0	S1	S2	S3
January	20.08	16.82	21.21	18.89	17.51	13.63	10.95	5.30
February	21.49	17.10	23.54	20.22	19.50	15.23	12.24	5.30
March	26.81	20.95	30.06	25.35	24.66	18.95	14.93	5.30
April	33.52	26.46	37.56	31.82	30.33	22.70	17.38	5.30
May	42.12	32.74	48.01	40.10	38.58	28.62	21.64	5.30
June	47.02	37.03	53.47	44.86	42.94	31.80	23.97	5.30
July	48.33	38.61	54.46	46.14	43.69	32.30	24.30	5.30
August	46.20	37.33	51.59	44.12	41.52	30.85	23.35	5.30
September	40.61	33.66	44.21	38.78	35.81	26.91	20.62	5.30
October	31.86	27.49	33.21	30.37	27.29	20.98	16.51	5.30
November	24.63	21.55	25.10	23.36	20.84	16.32	13.14	5.30
December	21.04	17.60	22.11	19.84	18.45	14.57	11.85	5.30
tau_cw=0.9								
Months	**Vegitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**S1**	**S2**	**S3**
January	20.70	17.04	22.20	19.47	18.26	14.14	11.30	5.30
February	22.20	17.35	24.68	20.90	20.39	15.85	12.67	5.30
March	27.79	21.32	31.60	26.27	25.87	19.80	15.54	5.30
April	34.80	26.96	39.53	33.02	31.86	23.76	18.12	5.30
May	43.85	33.47	50.64	41.73	40.64	30.06	22.65	5.30
June	48.95	37.85	56.40	46.66	45.23	33.41	25.10	5.30
July	50.21	39.36	57.37	47.90	45.96	33.90	25.43	5.30
August	47.98	38.06	54.33	45.79	43.66	32.37	24.42	5.30
September	42.11	34.30	46.51	40.18	37.61	28.18	21.52	5.30
October	32.87	27.88	34.79	31.33	28.53	21.87	17.14	5.30
November	25.32	21.80	26.21	24.02	21.71	16.94	13.58	5.30
December	21.66	17.81	23.11	20.43	19.23	15.12	12.24	5.30

In Table 3.3, monthly average plant, cover, mulch, indoor and soil temperatures are given for different mulch thickness values. When the graphs and the table are examined, it is seen that the increase in the transmittance value negatively affects the growing conditions for tomatoes. For cold climatic conditions, it may be a good option to use use of materials with high solar radiation transmittance may give better results, but it would be more appropriate to use the 0.47 coefficient, which is the measurement value in the reference article for the province of Izmir.

3.4. Effect of Variable Leaf Area Index and Characteristic Leaf Lenght

For leaf area index L_{Al} and characteristic leaf length of the tomato crop (m) L_{cl}, measurements taken from 5 different time periods during the year were given in Reyes Rosas et al., 2017. The values taken from these measurements were used in the analyses. In this part of the study, sigmoid growth models were used to simulate the growth and development of the greenhouse tomato. Logistic model was used to calculate leaf area index and characteristic leaf length. Related graphics for the model used are also given in Figure 3.9.

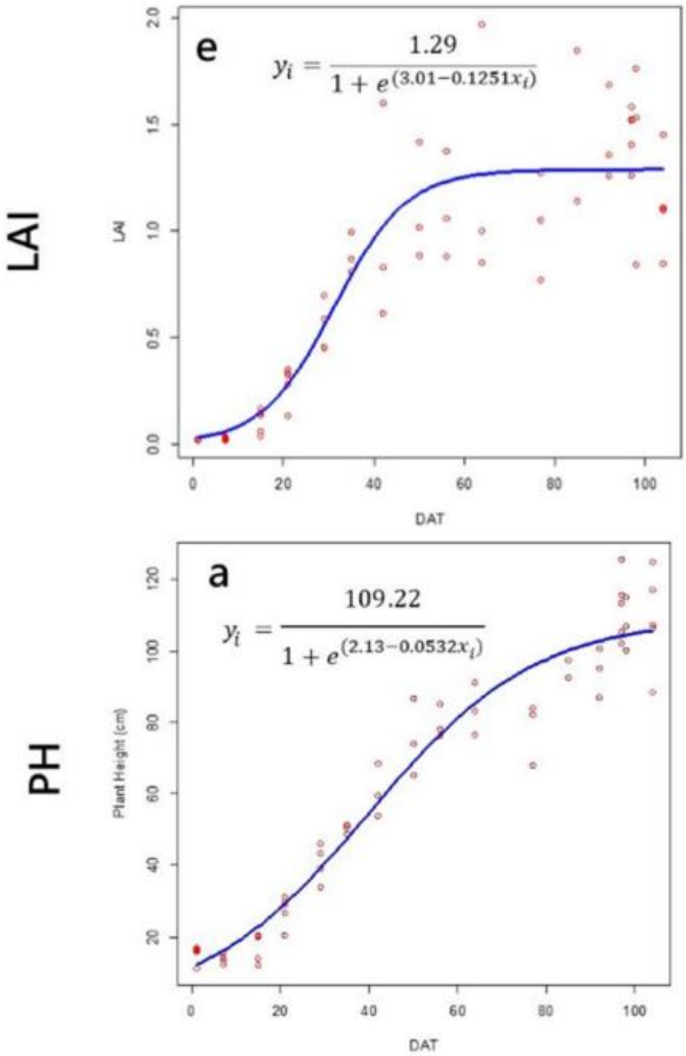


Figure 3.9 Scatter plots of the fitted Logistic growth curves with days after transplanting (Fang et al., 2022)

The effect of the change of this parameters on indoor temperature and plant temperature are given in the graphics and table below. The effect of the change of this parameter on these temperatures are given in the Figure 3.10, Figure 3.11, and Table 3.4 below.

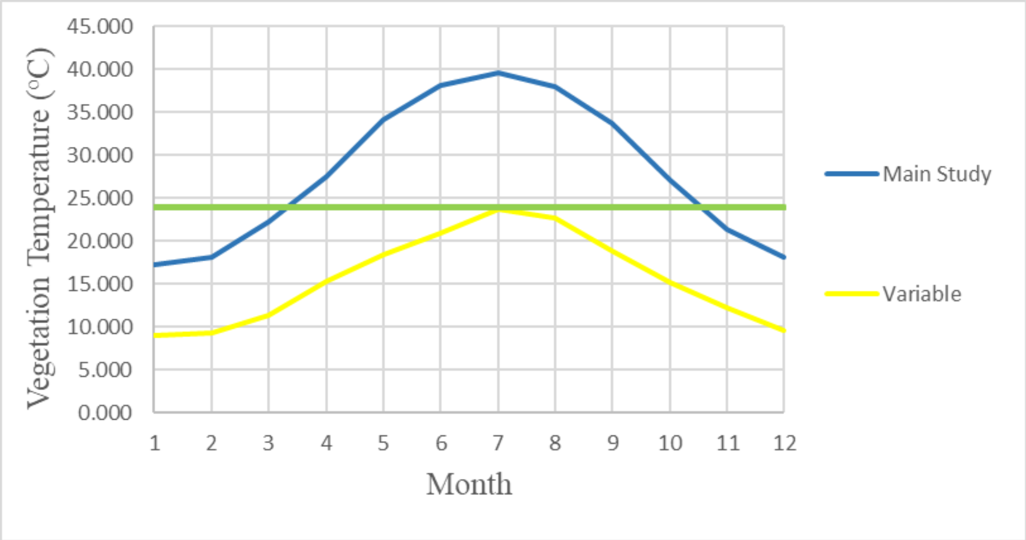


Figure 3.10 Average monthly indoor temperature for variable L_{Al} and L_{cl}

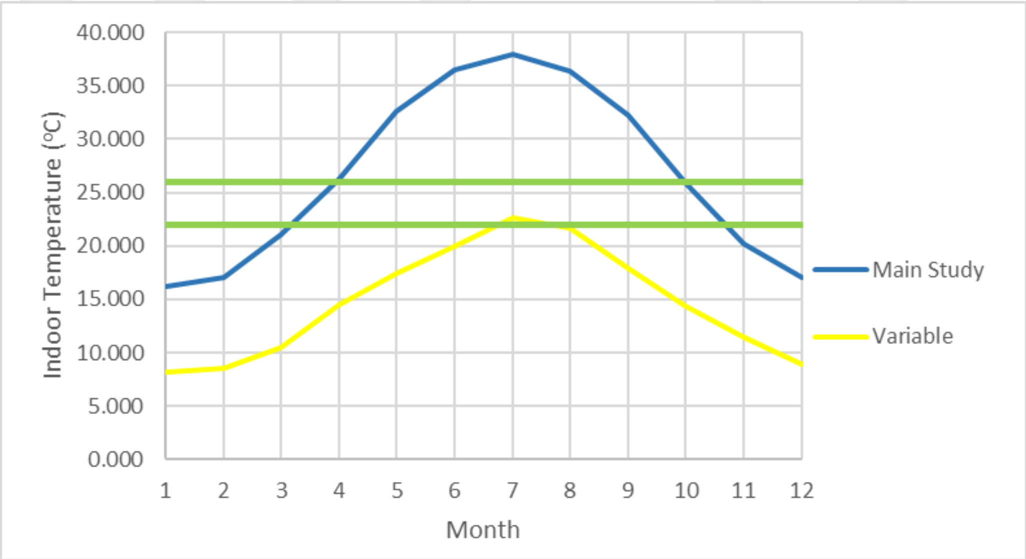


Figure 3.11 Average monthly indoor temperature for variable L_{Al} and L_{cl}

Table 3.4 Average monthly temperatures for variable L_{Al} and L_{cl}

Main Study							
Months	**Vegitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**L_Al**	**L_cl**
January	17.199	15.821	16.567	16.171	13.940	0.920	0.140
February	18.152	15.987	18.147	17.081	15.306	0.920	0.140
March	22.219	19.299	22.722	21.028	18.921	0.920	0.140
April	27.591	24.278	28.197	26.248	23.072	0.920	0.140
May	34.100	29.607	35.536	32.558	28.858	0.920	0.140
June	38.167	33.550	39.632	36.525	32.121	0.920	0.140
July	39.637	35.397	40.670	37.975	32.918	0.920	0.140
August	37.958	34.201	38.629	36.361	31.379	0.920	0.140
September	33.658	30.926	33.377	32.216	27.314	0.920	0.140
October	27.137	25.785	25.778	25.909	21.426	0.920	0.140
November	21.352	20.449	19.844	20.269	16.712	0.920	0.140
December	18.129	16.635	17.376	17.095	14.755	0.920	0.140
L_Al and L_cl Adapted							
Months	**Vegitation**	**Cover**	**Mulch**	**Indoor**	**S0**	**L_Al**	**L_cl**
January	9.028	7.704	8.573	8.225	7.808	0.401	0.246
February	9.305	8.195	8.325	8.493	7.661	1.143	0.600
March	11.320	10.547	9.790	10.470	8.791	1.286	0.935
April	15.373	14.518	14.043	14.462	12.079	0.539	0.439
May	18.373	18.396	15.699	17.404	13.417	0.988	0.491
June	20.998	21.878	17.122	19.990	14.517	1.279	0.867
July	23.673	24.462	20.019	22.638	16.748	0.802	0.654
August	22.650	23.242	19.201	21.634	16.224	0.753	0.378
September	18.821	19.627	15.189	17.868	13.065	1.259	0.778
October	15.258	15.644	12.401	14.371	10.892	1.125	0.881
November	12.269	11.819	10.663	11.430	9.518	0.490	0.280
December	9.673	8.764	8.367	8.864	7.708	1.210	0.674

In Table 3.4, monthly average plant, cover, mulch, indoor and soil temperatures are given for main parameters and sigmoid growth model. When the model used for plant growth is simulated, it is seen that there is a decrease in temperature with the change in the characteristic leaf length and leaf area index values.

CHAPTER FOUR
CONCLUSIONS

In this study, the thermal model was developed to investigate effects of weather data for two different cities, Izmir, and Doha, on a Mediterranean greenhouse for sustainable agriculture. Furthermore, the natural ventilation effect on the greenhouse is investigated and discussed. Conclusions of this study are listed below:

For analyzes of Izmir and Doha:

- The vegetation temperature and the greenhouse indoor temperature were determined above the optimal temperature for vegetation in Doha except January, February, and December. In these three months, if the natural ventilation rate is set greater than 6 m^3/s, the heating need may occur. However, with the natural ventilation control strategy, the cooling requirement of the greenhouse may be reduced in Doha.
- In Izmir, the monthly mean indoor temperature of the greenhouse and the vegetation temperature were determined less than the optimal vegetation temperature except May, June, July, August, and September. In these five months, the increase in the natural ventilation rate decreases the monthly mean temperature and cooling need of the greenhouse. Furthermore, the monthly mean indoor and vegetation temperature was determined below the optimal crop temperature and heating requirement in the greenhouse occurred in other seven months.

For the third chapter analyzes:

- The indoor temperature, the vegetation temperature, heating and cooling needs of the greenhouse may be stabilized with the natural ventilation rate-based controller units.
- Changing the cover thickness and polypropylene mulch sheet thickness has almost no effect on indoor and plant temperatures.

- Considering the model used for the growth of the plant, it is seen that there is a heating need for the winter months. To reduce this need, cover material with a transmittance value (τ_{cw}) of 0.87 can be used in winter and spring.

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