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RESEARCH ARTICLE

USE OF SOLAR PANELS IN GREENHOUSE VENTILATION AND COOLING

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ABSTRACT

One of the major problems encountered in greenhouse establishments is the ventilation and cooling processes of greenhouses. Natural ventilation employed in greenhouses is generally not sufficient. Compulsory ventilation applications should be provided to enhance the volume of ventilation. However, compulsory ventilation cannot be applied in greenhouses due to their location at countryside and lack of electric energy. This energy problem can be solved with the use of solar panels in greenhouses. 12 m^2 fan pad area and 0,1 kW circulation pump intended for water circulation system are required for the installation of the cooling system to be founded in a high tunnel in Tekirdağ with the surface area of 298 m^2. For operation of the required ventilation system, 4 aspirators with 0,55 kW power and 9500 m^3h^{-1} flow rate will be sufficient. A 4 kW solar panel system will supply required energy for the cooling system.

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INTRODUCTION

Sources of energy across the world can be divided into two categories which are namely fossil and renewable energy sources. The effect of greenhouse gases in the atmosphere due to intensive use of fossil fuels is increasing day by day. Greenhouse gases lead to global warming (Öztürk, 2012). Sources of fossil fuel are limited and their prices are gradually increasing. The increase of energy prices increases the heating costs of greenhouses which, in turn, increases the prices of the grown products. Some studies have recently been launched for the use of renewable sources of energy (sun, wind, biomass etc.) in order to reduce the heating cost in greenhouses (Kendirli and Çakmak, 2010). The most important renewable source of energy of the world is the sun. The flow of material and energy on earth can only be possible by means of solar energy. Wind, sea wave, temperature difference in the ocean and biomass energies are different forms of the solar energy. Solar energy ensures water cycle in nature and constitutes the power of stream. Solar energy is directly used in the generation of hot water and electric energy (Varınca *et al.,* 2006; Anonymous, 2016a).

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The purpose of greenhouse cultivation is to obtain high quality and high yield from plants. Optimum air temperature should be ensured for this purpose. Greenhouses should be heated when the exterior temperature drops below 12 ºC in winter. Greenhouses should be subjected to ventilation in autumn and spring. A compulsory ventilation system equipped with fans can be employed in cases where natural ventilation is insufficient. Greenhouses can be cooled with the help of fan pads if exterior temperature exceeds 22 ºC due to the greenhouse effect (Baytorun *et al.,* 1996; Boyacı *et al.,* 2012). Cooling should be ensured by means of placing fan pads on the frontal surface of greenhouses and ventilation fans on the opposite surfaces. Electric energy is required to install this system in greenhouses. If greenhouses are located at countryside and electric energy is not available, the electric energy can be generated with the use of solar panels.

Potential of Renewable Sources of Energy

Environmental problems encountered during the generation and utilization of energy across the world have revealed the obligation to abandon old technologies. The world population increased 4 times whereas the energy demand increased 16 times in the twentieth century. In today's world, the amount of energy required for 6,5 billion people to sustain the same lifestyle is 16 terawatt (TW).

According to the projections made, energy demands of people will increase 10 terawatt (TW) in 2050 in comparison with the present demand (Kamat, 2007). The potentials of the worldwide renewable sources of energy are shown in Table 1.

Table 1. Worldwide renewable sources of energy and their potentials (Kamat, 2007)

Source of Energy	Energy Potential (TW)
Wind energy	2-4
Hydroelectricity energy	0,5
Geothermal energy	12
Tide and ocean current energy	2
Solar energy	120.000

(TW=terawatt=$1x10^{12}$ watt)

These data clearly reveal the importance of using solar energy. The sources of energy shown in Table 1 have a regional distribution across the world. However, solar energy is available almost all over the world. Our country has great opportunities in terms of solar energy. Daily sunshine time in Turkey is 5 hours in winter, 7 hours in autumn and spring and about 11 hours in summer (Anonymous, 2016b). Solar panels are required to benefit from solar energy and generate electric power.

Use of Solar Panels in Greenhouses

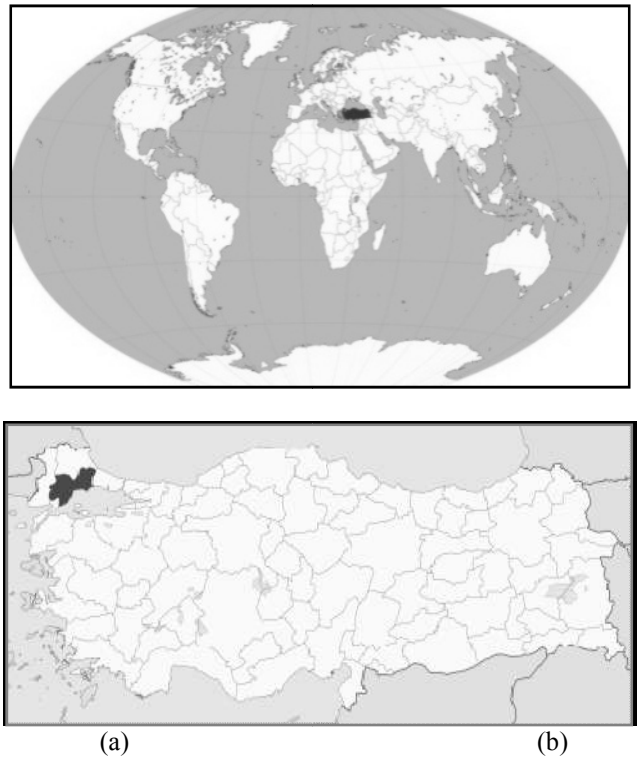
Greenhouses are far from electric networks as they generally located at countryside. For this reason, the use of electric energy in greenhouses is quite limited. The use of electric energy in greenhouse cultivation can be generalized with the help of solar panels. The electric energy which is generated by solar panels or obtained from the network is used in greenhouses in various ways including greenhouse lighting, mechanical ventilation, operation of pumps in watering and cooling systems and of computers and other devices in automated greenhouses, supply of energy requirements of circulation pumps in centrally heated greenhouses etc. The purpose of the study is to ensure the generation of electric energy required for greenhouses at countryside with the use of solar panels. A quality and effective production generally cannot be performed with natural ventilation in greenhouses located at countryside where electric energy is not available. It will be possible to ensure sufficient ventilation and cooling in greenhouses thanks to the electric energy generated with the use of solar panels. Greenhouses can be ventilated and cooled through the system of a solar panel to be installed in greenhouses, fan and fan pad system. Furthermore, energy requirements of other measurement devices to be used in greenhouses as well as computers and lighting systems will also be met with solar panel systems.

MATERIALS AND METHODS

Material

Being the study area, Tekirdağ province is located in Thrace Region. Thrace Region is situated between 26º-29º east longitudes and 40º-42º north latitudes on the European side of Turkey. Tekirdağ is on the northwest of Turkey and north of Marmara Sea with a surface area of 6313 km^2. There are not any high mountains, steep slopes or valleys in Tekirdağ province. Tekirdağ falls into semi-humid climate type among hydrographical regions identified on the basis of general humidity indexes.

Tekirdağ has a windy climate in summer and winter. Prevailing and continuous wind is northeaster and the secondary significant wind is southwester (Anonymous, 2017c). Tekirdağ province is eligible for greenhouse cultivation in terms of climate, soil and sources of water. It is also advantages in terms of marketing opportunities as it is 135 km away from İstanbul, being a large consumption centre for the products obtained as a result of greenhouse cultivation. The position of Turkey in the world (a) and the position of Tekirdağ in Turkey (b) are shown in Figure 1.



(a) (b)

Figure 1. The position of Turkey in the world (a) (Anonymous, 2017a) and the position of the study area in Turkey (b) (Anonymous, 2017b)

Solar Panel

Consisting of solar cells, solar panel is a device which directly converts sunlight into electricity current (photovoltaic). Solar cells can be constructed with organic and inorganic bases. Organic cells are cheap but they offer some disadvantages as they can easily be oxidized and convert sunlight into energy only at the rate of 11%. The use of solar cells with inorganic base is more common because of the fact that their efficiency varies between 15-20% (Grätzel, 2009).

Method

System Design

The structure of solar cells consists of photovoltaic solar batteries, accumulator and accumulator charge control unit and inverter depending on the application (Anonymous, 2016c). This system uses certain number of solar cells as a source of energy. The system is supplied energy by the accumulators in case of unavailability or insufficiency of the sun. A charge regulator is used to prevent excessive charge or discharge of the accumulator. It switches off the current which is supplied by solar cells or from which the load is drawn depending on the status of the accumulator.

An inverter should be used in the system if 220 V 50 Hz alternate current is to be used in the system or a current will be supplied to the mains (Köroğlu *et al.,* 2010). Solar panel system and the fan and fan pad system intended for greenhouse ventilation and cooling are shown in Figure 2.

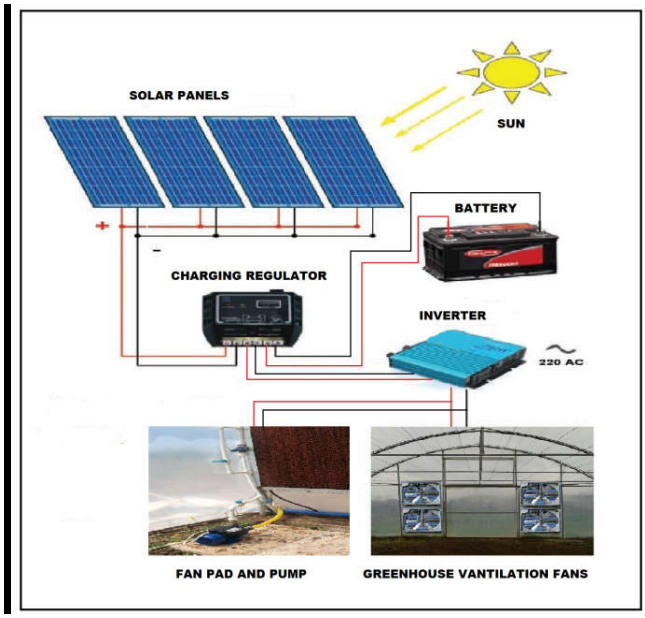


Figure 2. Components of the solar panels and greenhouse ventilation and cooling system

Cooling is ensured by means of ventilation, shadowing and different water usages in greenhouses (Yağcıoğlu, 2005; Yüksel and Yüksel, 2012). Cooling system intended for greenhouses consists of fans, fan pads, circulation pump, water tank and water transmission pipes (Baytorun, 1995). These methods are mainly employed together. In the use of water for cooling in the greenhouses, water vaporization is generally benefited from. Water is sprayed to plants and it vaporizes on them according to the cooling in the form of fogging. Another water vaporization method is the use of fan pads in greenhouses. The effect of water in cooling is that is obtains 598 calorie (2500 j) perceptible heat from air during the vaporization of 1 gram water. The air is loaded with the vaporized water steam while it is passing through the pads. Almost all of the hidden energy required for the evaporization of the water is taken from the incoming air.

In this way, the temperature of the air entering into the greenhouse drops. Air temperature in the greenhouse drops down to 6 ºC with the help of the fan pads. In his study, Davies (2005) notes that during hot weather the temperature of the greenhouse indoor air will be reduced to 15 ° C with fan pads. Kittas et. al. (2003), on the other hand, confirms that fan pads ensure 10 ºC temperature decrease in greenhouses. Fan pads placed along the air inlet gap are continuously moistened with the flow of water through a perforated pipe. Water movement on fan pads is ensured with the help of a circulation pump. The water in the perforated pipe located on fan pad moves downward in the fan pad. Excessive water in fan pad is collected in the tank located at the bottom and supplied to the system again through the pump (Öztürk and Başçetinçelik, 2002; Yüksel and Yüksel, 2012). Mechanical ventilation is required for the use of fan pads in greenhouses. Aspirators are placed to the greenhouse side opposite the greenhouse surface where fan pads are located.

In this way, moist and cool air passing through fan pads is supplied in the greenhouse instead of the air which is absorbed through aspirators and taken outside the greenhouse (Yüksel, 1986; Yüksel and Yüksel, 2012; Boyacı *et al.,* 2012).

Cooling Systems in Greenhouses

One of the most important factors affecting growth in greenhouses is temperature. It is known that tomato, pepper, cucumber etc. which is generally grown in greenhouses gives optimum yield at 17-27 ºC. (Castilla and Hernandez, 2007). Greenhouses should be heated if daily average exterior temperature drops below 12 ºC in consideration of the greenhouse effect (Nisen *et al.,* 1998). On the contrary, greenhouses should be cooled if exterior temperature exceeds 22 ºC (Figure 3).

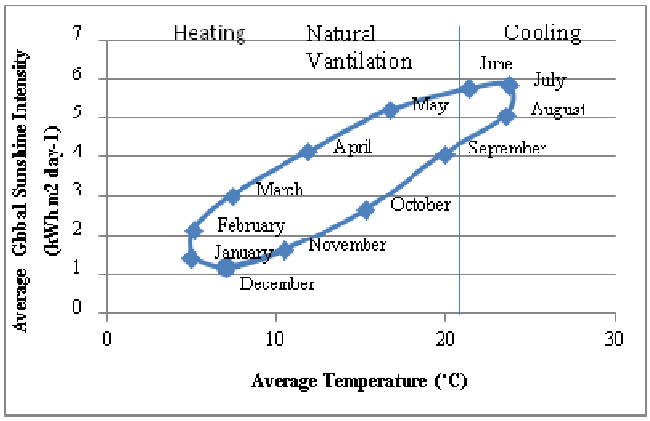


Figure 3. Air-conditioning in greenhouses depending on exterior temperature under climatic conditions of Tekirdağ

In winter, the temperature in greenhouse should not drop below 0 ºC in order not to allow the plants to be damaged due to frost. Maximum temperature, on the other hand, should be between 35-40 ºC in greenhouses (Baytorun *et al.,* 1996; Boyacı *et al.,* 2012). The control of moisture which is the primary cause of diseases in greenhouses can easily be ensured in ventilated and heated greenhouses. High moisture leading to diseases and pests can be controlled through greenhouse ventilation and heating. In this way, the use of chemicals and drugs which have a negative effect on the environment and human health is significantly reduced in ventilated greenhouses (Zabeltitz, 1992). For this reason, ventilation is required to be performed when daily average temperature varies between 12-22 ºC in greenhouse (Baytorun *et al.,* 1996; Boyacı *et al.,* 2012). Greenhouses should be cooled when the temperature exceeds 22 ºC.

When Figure 4 is reviewed in terms of exterior temperature under the climatic conditions of Tekirdağ, it can be understood that the greenhouse intended for cultivation should be subjected to heating, ventilation and cooling in certain months. Heating is compulsory in greenhouses in some period of March and November and in January and February when exterior temperature drops below 12 ºC. On the contrary, ventilation is necessary in some period of September and March and in April, May and October when exterior temperature varies between 12-22 ºC. Greenhouses should be cooled in some period of September and May and in June. Greenhouse cultivation is not performed in Tekirdağ in July and August when exterior temperature is high.

Project Design of Fan Pads To Be Used in Greenhouses

The dimensions on the high tunnel where the fan pads are subjected to project design should be known. Some technical specifications of the high tunnel intended for the project are given in Table 2 and its image is shown in Figure 4.

Figure 4. High tunnel for the establishment of the project

Table 2. Dimensions of the high tunnel planned to be cooled

Length (m)	Width (m)	Ridge Height (m)	Area (m^2)
38,2	7,8	3,6	298,0

The studies of Baytorun (1995), Yağcıoğlu (2005) and Yüksel and Yüksel (2012) were made use of for the project design of fan pads. 1 m^2 fan pad area is required for each 25 m^2 surface area of the greenhouse. Required fan pad area for the high tunnel can be calculated with the equation 1 below.

$$A_y = A/a_y \quad (1)$$

In equation 1:
A_y: Fan pad area (m^2)
A: Surface area of the greenhouse (m^2)
a_y: Surface area of the greenhouse cooled by the unit area of the fan pad ($m^2\ m^{-2}$)

Daily water need of this fan pad is about 30-40 L for 1 m^2 fan pad area at high temperatures (Bucklin *et al.,* 1993). A small circulation pump is required to take daily water need of the fan pad from water thank and supply the same to the upper section of the fan pad. The calculation of the ventilation quantity is made on the basis of the surface area of the greenhouse. Accordingly, 0,033-0,042 m^3s^{-1} or 120-150 m^3h^{-1} ventilation is required for 1 m^2 surface area of the greenhouse (Anonymous, 1993; Yüksel and Yüksel, 2012). Ventilation quantity in the high tunnel on the basis of the surface area is calculated as shown in equation 2 below.

$$Q = A * q \quad (2)$$

In equation 2:
Q: Ventilation quantity ($m^3\ h^{-1}$)
A: Surface area of the greenhouse (m^2)
q: Ventilation quantity per unit surface area of the greenhouse ($m^3h^{-1}m^{-2}$)

The number of aspirators with 60 cm diameter, at 1300 rpm (dd^{-1}), with 0,55 kW capacity and with the ability of providing 9500 m^3h^{-1} air circulation for the supply of the abovementioned ventilation quantity in the tunnel can be calculated with the help of equation 3 (Anonymous, 2016d).

$$S_a = Q * q_a \quad (3)$$

In equation 3:
Sa: Number of aspirators (piece)
Q: Ventilation quantity (m^3h^{-1})
q_a: Aspirator efficiency (m^3h^{-1})

Total energy requirement of the system can be calculated through equation 4.

$$e = S_a * q_e + P_e \quad (4)$$

In equation 4:
e: Total energy requirement of the system (kWh^{-1})
S_a: Number of aspirators (piece)
q_e: Power of the aspirator (kWh^{-1})
P_e: Power of the circulation pump (kWh^{-1})

RESULTS AND DISCUSSION

Efficiency of the Fan Pads

Vaporization based cooling systems are effective, practical and economically applicable under the conditions when the temperature in greenhouses is high. Therefore, it can be expected that such systems will commonly be used for cooling greenhouses in the near future. The efficiency of evaporative cooling system depends on the saturation level of the air which passes through the fan pad and is loaded with moisture. When unsaturated air contacts with water surface, a heat-mass change takes place between them. As the vapour pressure of water is greater than partial vapour pressure of air, vapour is transmitted to air from water surface. Meanwhile, all hidden heat required for vaporization is supplied by the air. This perceptible heat supplied by the air cools the air (Atılgan and Öz, 2007). For this reason, fan pads are required to be dampened sufficiently.

Fan pads should not be dampened insufficiently or excessively. In case of insufficient dampening, their cooling effectiveness reduces. Moreover, any salt, lime and such other substances contained by the water deposit on the fan pad as the dampening water fully vaporizes. These substances lead to blockage on the pores of the fan pad. As excessive water to be used in the fan pads will cover the whole surface of the pad and remove any roughness, it ensures the reduction of effective heat mass change (Yağcıoğlu *et al.,* 2006). Furthermore, it makes air shift difficult as it will also fill the pores between the fibres of the fan pad material. This sometimes causes the suspension of the effectiveness of the fan pad.

Energy Requirement of the System

The results of the study concerning the solar panels and greenhouse cooling system to be installed on the basis of equations 1, 2, 3 and 4 are given in Table 3.

Table 3. Research results

Fan pad area (m^2)	Ventilation quantity (m^3h^{-1})	Average number of aspirators (piece)	Total energy requirement of the system (kWh^{-1})
11,92	35760 - 44700	4	2,21

4 pieces of 0,55 kWh^{-1} aspirator and 0,1 kW circulation pump will be used for the fan pad system to be installed to cool and moisturize the air of the high tunnel as a result of the calculations made and as shown in Table 3. Total energy requirement of the system for the ventilation need of the high tunnel for which the calculation has been made will be 2,21 kWh^{-1}.

2,21 kWh^{-1} larger solar panel system than the calculated value is required (*i.e.* 4 kWh^{-1}) effective operation of the system in question. The panels can supply their optimum power under optimum conditions. Sufficient energy cannot be generated in the system due to dirty panel glasses, negative exterior temperature conditions, non-vertical position of the sunlight in the morning and in the evening and certain losses (Anonymous, 2016e). For these reasons, a larger system than the required dimensions should be preferred. Surplus energy of the system can be stored in accumulators for subsequent use. Surplus energy can also be used for the computer to be employed in the greenhouse, other measurement devices and for lighting.

Conclusion and Suggestions

Primary objective of plant cultivation in greenhouses is to meet temperature needs of plants at an optimum level. Greenhouses require heating, ventilation and cooling according to the air temperature in the greenhouse to obtain a quality and high efficiency. Fans and fan pads can be used in greenhouses to perform ventilation and cooling at high temperature. Electric energy is necessary for the use of such systems and fans and fan pads. However, the use of electric energy is limited as greenhouses are mainly located at countryside. This problem can be solved with the help of electric energy generated by using solar panel systems in greenhouses. Solar panels can be used in each region under the climatic conditions of Turkey and generate sufficient electric energy. The investments in Turkey on this regard are gradually increasing.

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