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INVESTIGATION AND UTILISATION OF A HYBRID HEATING SYSTEM OF BIOMASS BURNING ASSISTED SOLAR ENERGY FOR SWEET COLOURED PEPPERS GREENHOUSE

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ABSTRACT

In this study, a complete solar water heating system has been located beside two experimental greenhouses cultivated by sweet coloured peppers crop from 27th of August 2010 until 26th of July 2011. The total heat energy required for heating the greenhouse was computed based on the requirements for heating a greenhouse reside in the task of adding heat at the rate at which it is lost. One greenhouse equipped with a complete solar heating system (two solar collectors, heat distributing system, and storage tank) connected to biomass burning unit as an auxiliary heater. Another greenhouse was connected to a complete solar heating system equipped with electric heater as an auxiliary heater to compare and investigate how much heat energy can be provided when using the renewable energy for greenhouse heating in winter and cold days. The thermal performance analysis of the solar heating system was experimentally determined, by measuring the temperature increase at various water inlet temperatures and intensity of solar radiation, under clear sky conditions. The daily average overall thermal efficiencies of the solar collector and the storage system during the experimental period were 76.39% and 93.17%, respectively. During the 181 days heating season, the solar panels collected 3922 kWh of energy which provided 47.74% of the total heat energy required to heat the greenhouse (8215 kWh). The hybrid system (biomass burning and solar energy systems) provided 46.585 kWh (85.90%) of the daily total heat energy required (54.230 kWh). While, the solar heating (solar and electric energy) system with greenhouse 2 only provided 20.223 kWh (38.32%) of the total heat energy required (52.778 kWh). Due to the microclimatic conditions of the greenhouse were at or around the desired level, the sweet coloured pepper had have optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield. The total costs per square meter of greenhouse were L.E. 57.01.The fresh yield of sweet coloured peppers was 6.595 kg/m^2, which sold by L.E. 79.14, consequently, the estimated return on capital was 38.82% per annum.

INTRODUCTION

During winter season in northern delta, Egypt, the macroclimate conditions can often be cool and cloudy. The long-term average minimum air temperature in Mansoura city, for the months of December, January, February is 7.3ºC. As a result, in this location heating is an essential requirement for the year-round efficient production of certain protected cropping such as peppers, cucumber, tomatoes, and green beans. The greenhouse industry is very important for creating a demand for sub-sectors that provide inputs for greenhouse production such as seeds, organic fertilisers, bio-pesticides, glazing materials, and so on. Nowadays, various heating systems are functioned to meet the heating requirements of the greenhouses. The conventional solution for this problem is the burning of some fossil fuel to warm up the microclimatic conditions of greenhouses during critical nights and cold days.

Owing to large heating loads and relatively high prices of fossil fuels (100-150$/barrel), alternative energy sources for greenhouse has acquired utmost interest. Some of the important alternative sources of energy are; solar collectors, heat pumps, and thermal energy storage systems using phase change materials (Benli and Durmus, 2009). As solar energy is available only during the daylight, its application requires efficient thermal energy storage systems and an auxiliary heating system. Therefore, the excess heat collected during the daylight is stored for later use at nighttime (Tiwari, 2003). Thermal heating of greenhouses have been studied by several researchers in employing different passive methods as well as active modes (Jain and Tiwari, 2003 ; Özturk and Bascetincelik, 2003 ; Abdellatif *et al*., 2007; Benli and Drmus, 2009 ; and Lu Aye *et al*., 2010). Among the active heating modes, a solar thermal system is one of the most practical and appropriate means for reducing the operating costs in a greenhouse. If heating pipes are galvanized or painted with aluminized paint, heat delivery rates will be approximately 15% less than from black pipe (ANSI/ASAE, 2003).

Protected cropping requires heat and carbon dioxide (CO_2) to enhance crop productivity (Nelson, 1998). Heat is used to adjust the indoor air temperature, while light and carbon dioxide is required for photosynthesis process. The fuel cost for providing heat energy and CO_2 represents about 28% of the operating cost of a greenhouse (BCMAFF, 2003). Specifically, heating requires improvements as it represents a quarter of operation costs depending on the energy source; oil, gas, electricity, or biomass (Chau *et al*., 2009). Within the last decade, fluctuations of fossil fuel prices have increased the necessity to explore alternative systems and this has allowed biomass heating become an economically viable option (Chau *et al*., 2009). Biomass energy has been recognised as a sustainable renewable fuel alternative that can also reduce greenhouse gas production (Raymer, 2006).

In this research work, emphasis has been given to solar thermal and biomass burning systems. Renewable energy is non-polluting and offer significant protection of the environment. Therefore, solar thermal and biomass burning systems should be employed whenever possible in order to achieve a sustainable future. The heat energy collected by solar thermal and biomass burning systems is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at nighttime and/or cloudy days (Sayigh, 2001 ; Kalogirou, 2003).

The main goal of the present study was to investigate the possibility of using the stored heat energy from the hybrid heating system (solar and biomass energies) with a heat exchanger to provide and maintain an optimum level of microclimatic conditions of the sweet coloured peppers greenhouse at nighttime during winter season. The objectives of the research work were to: (1) determine the total heat energy required to provide and maintain the microclimatic conditions of a two identical greenhouses at the desired level, (2) compare between two different heating systems, hybrid heating system (biomass energy assisted solar thermal energy) and electrical energy assisted solar thermal energy, and (3) determine the providing percentage of the total heat energy consumed during the heating season due to use the two different heating systems.

MATERIALS AND METHODS

Materials:

The latitude and longitude angles of the site (University of Mansoura, Egypt), respectively, are 31.045°N and 31.365°E, and 19.45 m above the sea level.

Experimental greenhouses

Experimental work was executed during 2010-2011 growing winter season in two identical gable-even-span single greenhouses, E-W orientated, and covered with 800μm thick corrugated fibreglass reinforced plastic. The geometric characteristics of each greenhouse are as follows: eaves height 3.25 m, height of each sidewall 2 m, rafter angle 27^{o}, width 4 m, length 8 m, floor surface area 32 m^2, and volume 87.7 m^3. The greenhouse facility used in this research work covered with the ratio of cover surface area to the total greenhouse surface area of 2.685.

Solar heating system

Two solar panels, each having a surface area of 2.0 m^2, and constructed of copper pipes with a black absorbing surface, were connected with a 32.0 m^2 sweet coloured peppers greenhouse. These solar panels arranged in one bank with a series array. The solar heating system is of the "recycling flow system" i.e. the water is continually cycled through the solar collectors. The operating fluid (water) was continually pumped so as to pass through the solar collectors under clear sky conditions. After passing through the solar collectors, it was stored in a 300 liters insulated storage tank situated inside the greenhouse. The water pump was switched on and off manually on sunny days from 1st of November 2010 until 5thof April 2011. Two different flow rates of operating fluid (12 and 15 l/min.) were functioned according to the intensity of solar radiation flux incident. It was adjusted and controlled every day using a control valve and a measuring cylinder with stop clock. For the duration of November, December, and January 12 litre/min water flow rate was used. The higher water flow rate (15 liter/min.) was functioned during February, March, and April.

The thermal performance analysis of the solar collectors was experimentally determined, by measuring the temperature increase at various water inlet temperatures, mass flow rate, and solar energy available under clear sky conditions. Using this data the solar collector area and configuration were calculated so that the water temperature at the end of day reached to over 60ºC when the solar radiation was a maximum. Under steady-state conditions, the overall thermal efficiency (η_o) can be measured and determined using the system analysis of Duffie and Beckman (1991) ; Kalogirou (2004) ; and ASHREA (2005) as follows:

$$\eta_o = \frac{F_R\ A_c\ [R\ (\tau\ \alpha) - U_o\ (T_{fi} - T_a)]}{R\ A_c}\ x\ 100\ ,\ \% \qquad (1)$$

Where, F_R, A_c, R, $(\tau\ \alpha)$, U_o, T_{fi}, and T_a , respectively, are the heat removal factor, collectors surface area (m^2) , solar radiation on a tilted surface (W/m^2), optical efficiency, overall heat transfer coefficient (W/m^2. °K), inlet water temperature (°K) and ambient air temperature (°K),. The normalized temperature rise (D_T) of the solar collector was computed from the following relation:-

$$D_T = \frac{T_{fi} - T_a}{R}\ ,\qquad {}^{\circ}K\ m^2/W \qquad (2)$$

The mathematical model of energy balance on the water storage tank was functioned to predict the water temperature at the end of each day (T_{ke}) during the heating period. This model was solved in terms of the water temperature at the beginning of each day (T_{kb}), heat energy acquired to storage (Q_{gain}), heat energy lost from the solar panels (Q_{loss}) and heat energy lost from the storage tank. It showed that, there are many factors affecting heat energy balance on water storage tank during daylight. These factors and their effect on heat energy balance were; absorbed solar energy that converted into useful heat gain, convective heat transfer coefficient, variation in the water temperatures in the storage tank during daylight, ambient air temperature surrounding the solar collectors, and air temperature surrounding the storage tank. Therefore, it is imperative to determine the water temperature in the storage tank at the end of each day to check whether there are differences between the actual heat energy stored in the storage tank and heat energy required to keep the air temperature within a greenhouse at a desired level. The equation of heat energy balance is:

$$T_{ke} = T_{kb} + \frac{3600}{M_s\ C_p}\left[\ Q_u - Q_L - U_L\ A_s\ (T_k - T_{ai})\ \right] \qquad (3)$$

Biomass burning system

Horizontal biomass combustion equipment was used, at which the biomass solid fuel took place on horizontal stationary steel grate as shown in Fig. (1). Biomass fuel is semi-continuous supplied in the batch. The furnace design has used as a stationary burning system with front-feed solid fuel burner. The biomass burner is approximately cylindrical in shape, and made of 3 mm thick double layer of steel tightly fixed together along the frame elements of the walls.

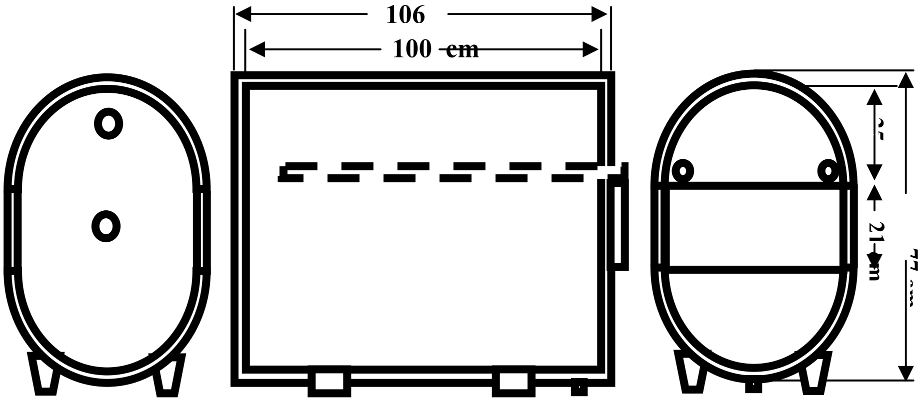

Fig. (1): Schematic diagram of biomass burning system

Overall design and installation

The solar panels were mounted individually on a movable frame outside the greenhouse at an optimum tilt angle and continually facing due south. The panels were adjusted manually to change the orientation and tilt angle once each hour, so that at that time the angle of incidence of the surface of the solar panel and the sun's rays was set at zero. The site was protected from the prevailing north-westerly winds by the greenhouse, but was not shaded from the sun. The first greenhouse was connected to a hybrid heating system (biomass burning system assisted a complete solar heating system) as shown in Fig. (2). The second greenhouse was connected to a complete solar heating system (two solar panels, storage tank, heat distributing system, and control system) with an auxiliary heater (electric heater, 3.0 kWh) to be used during the experimental period when the solar energy was insufficient to rise the water temperature in the storage tank into 60ºC (Fig. 3). The auxiliary heater was used when the stored solar energy was insufficient to provide the requirements of the heat energy supply. To provide and maintain positively a temperature of 16-18^{o}C at night time in winter months and cold days, the greenhouse was equipped with a heat exchanger using parallel flow system in order to utilize the stored energy from the storage tank for heating the indoor air of the greenhouse (Fig. 2). The heat exchanger was located on an iron stand to be above the floor surface by 35 cm (the coldest zone inside the greenhouse). The heated water from the insulated storage tank (heated by solar energy during the daylight) was pumped to be circulated through the heat exchanger. It was controlled by on-off controller to initiate heating at 16^{o}C and interrupt it at 18^{o}C (environmental control board with differential thermostat).

Four different field residues (biomass materials) were collected from different fields (corn stalks, grapes stalks, pear stalks, and wood of trees). The quantity of these four field residues represent more than 40% of the total crop residues annually produced in Egypt in which represent a large source of renewable energy. Samples of the four field residues were chemically analysed in the Chemical Labour , Faculty of science, Cairo University. Chemical analysis was used to determine the percentage of different elements contains in the field residues such as; Organic carbon (C), Hydrogen (H_2), Oxygen (O_2), Nitrogen (N_2), Sulphur (S), and Moisture content (H_2O) These percentages of different elements contain in the field residues are summarised and listed in Table (1) and used to determine the high heating value (HHV) and the low heating value (LHV) using the following equations:

$$\mathbf{HHV = 144.20\,(H_2) + 33.82\,(C) + 9.30\,(S),\quad MJ/kg\ of\ residue \quad (4)}$$

$$\mathbf{LHV = HHV - 2.453\,(9\,H_2 + MC),\quad MJ/kg\ of\ residue \quad (5)}$$

The biomass burner efficiency was computed as the ratio of heat energy output to the heat energy input. There are two methods to determine the burner efficiency (Chau *et al*., 2009):

Input-output method

$$\textbf{Burner efficiency} = \frac{\textbf{Heat energy absorbed by water}}{\textbf{Heating value of biomass}} \times 100 \quad (6)$$

Heat loss method

$$\textbf{Burner efficiency} = 1 - \frac{\textbf{Heat energy losses}}{\textbf{Heating value of biomass}} \times 100 \quad (7)$$

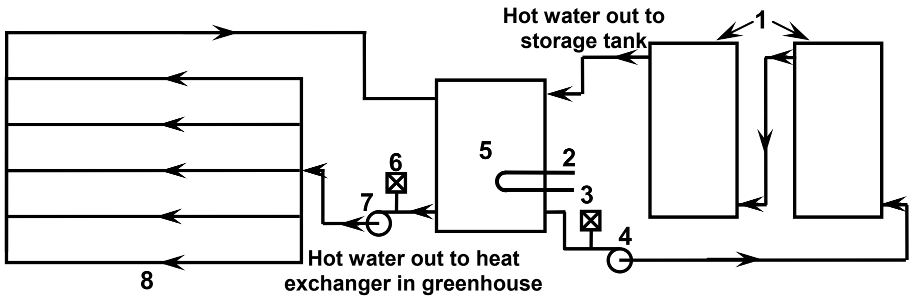

Fig. (2): Schematic diagram of solar heating system included; (1) solar collectors, (2) auxiliary electrical heater, (3) water flow control, (4) water pump for solar collectors, (5) storage tank, (6) flow control, (7) water pump for heating, and (8) heat exchanger.

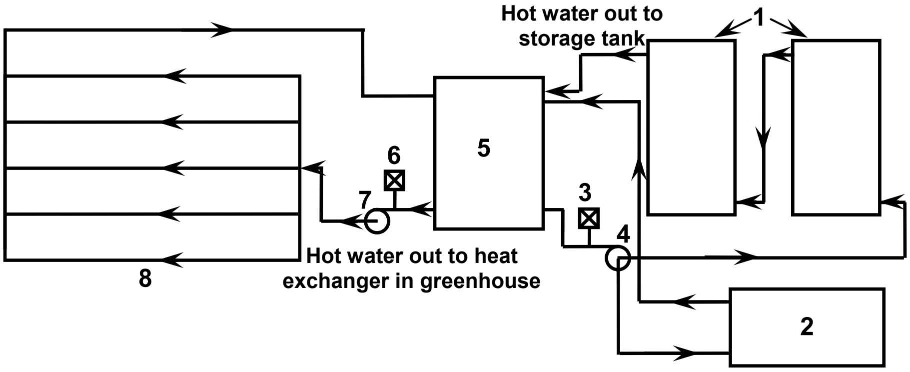

Fig. (3): Schematic diagram of hybrid heating system included solar heating system and (2) auxiliary biomass burning system.

Table (1): Chemical analysis for some field residues uses in this project as a source of renewable energy

Field residue	Organic carbon (C), %	Hydrogen (H_2), %	Sulfur (S), %	Moisture content (MC), %
Corn stalks	27.50	5.85	0.25	10.55
Grapes stalks	37.05	6.17	8.35	10.45
Pear stalks	33.38	6.93	7.60	12.60
Wood of trees	38.15	7.63	6.75	14.75

Measurements and data acquisition unit

The solar radiation, air temperature, air relative humidity, and wind speed and its direction were measured and recorded using meteorological station, which installed just above the solar panels and greenhouses. Disk solarimeters installed on the top frame of solar panels in order to measure the solar radiation flux incident on a tilted surface. A 12 channel data-logger was also used for taking and storing reading from the different sensors (thermocouples type K) situated at different location of the solar panels and the storage tank. Another data-logger was also used for taking and storing reading from the different sensors situated at different locations of the sweet coloured peppers greenhouses. The recorded data were stored in the memory for output to a printer or to a computer for storage on disk. The time interval for data recording was 5 min with data acquisition every one minute for integrated measurements. The calibration of all sensors and the logger was completed successfully at the beginning of the experimental work.

Cultivation and Watering systems

Pots system was used as an agriculture system for sweet coloured peppers. The greenhouse was equipped by 65 plastic pots (28 cm diameter and 30 cm high), which arranged in five rows (each row having thirteen pots). Drip irrigation system was used for watering pots of the crop. A 200 liters scaled plastic water supply tank was located inside the greenhouse on 1 m above the ground surface in order to provide adequate hydrostatic pressure for maximum use rate of water. Thirteen drippers (long-bath GR 4 liter/hr discharge) were uniformly alternative distributed with 50 cm dripper spacing throughout each row of plants inside the two greenhouses. Two trays of sweet colour pepper seedlings (Bravo, C.V –Enza Zaden) were brought down from a nursery. Sixty five of seedlings with an average of four true leaves were planted on the pots inside each greenhouse on 27th of August 2010 after six weeks of sowing.

RESULTS AND DISCUSSION

Thermal performance

The solar panels have been operating satisfactorily for six months without malfunction, except for a small leaking in a rubber connection between the collectors and water pump after the water had reached over 60°C. Water temperatures have been monitored for six months beginning in November 2010, and the monthly average solar energy contribution is shown in Fig. (4). During the experimental period, there were 1288 hours of bright sunshine of which 1138 hours (88.35%) were recorded and used in the thermal performance analysis and applications, slightly lower than the average due to clouds. Although on day to day figures the correlation between sunshine hours and solar energy collected was poor, nevertheless the agreement was good on a monthly average basis (Fig. 4). The discrepancies between months arise due to number of bright sunshine hours, solar altitude angles, water temperature in the storage tank at the beginning of each day, and number of operating hours.

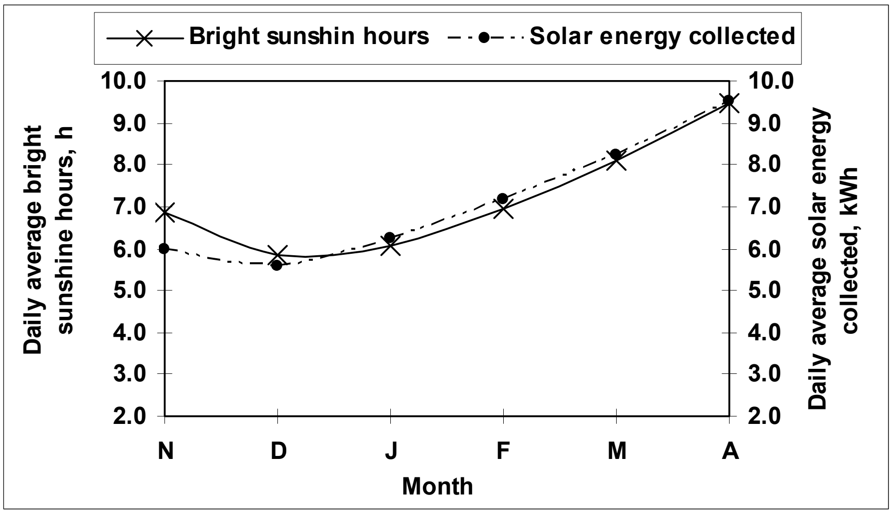

Fig. (4): Daily average solar energy collected by solar panels and daily average sunshine hours during the experimental period.

The thermal performance analysis of the solar panels is mainly determined by its overall thermal efficiency in converting solar energy into stored heat energy. A comparison between the daily average total solar radiation and the total solar energy collected was executed. The correlation between the solar energy collected (21.665 kWh) and the available solar radiation (28.344 kWh) was in agreement (92.55%) except that the solar panels appear to be more efficient in February than in other months because the mass flow rate was increased to 0.25 kg/s and the heat energy stored during daylight was consumed at nighttimes. This also due to the water temperature in the storage tank at the beginning of each day throughout the month was lower than the indoor air temperature. As the temperature difference between the absorber surface and the water passing through the solar panels are increased, the heat transfer rate between the absorber surface and the water is increased. The overall thermal efficiency is the ratio of the solar energy collected by the solar panels to the solar energy available. The daily average overall thermal efficiency of the solar panels during the experimental period was 76.39%, consequently, 23.61% of the solar energy available was lost.

The mathematical model of energy balance on the water storage tank was functioned to predict the water temperature at the end of each day (T_{ke}) during the heating period. This model was solved in terms of the water temperature at the beginning of each day (T_{kb}), heat energy gained to storage (Q_{gain}), heat energy lost from the solar panels (Q_{loss}) and heat energy lost from the storage tank. It showed that, there are many factors affecting heat energy balance on water storage tank during daylight. These factors and their effect on heat energy balance were; absorbed solar energy that converted into useful heat gain, convective heat transfer coefficient, variation in the water temperatures in the storage tank during daylight, ambient air temperature surrounding the solar panels, and air temperature surrounding the storage tank. Therefore, it is imperative to determine the water temperature in the storage tank at the end of each day to check whether there are differences between the actual heat energy stored in the storage tank and heat energy required to keep the air temperature within a greenhouse at a desired level.

The predicted water temperatures were plotted as a function of the measured water temperatures on a 45° plotting sheet during the heating period from November 2010 to April 2011(Fig. 5). The predicted water temperatures validated well with that measured during the heating period and gave a good agreement (96.62%). There were some variations in the validation of model between hour to hour and month to another due to effect of air temperature inside the greenhouse, which changed from time to time. Changing in the inside air temperature occurred due to an on-off controller system, which initiate ventilating and cooling at 28°C and interrupt it at 26°C.

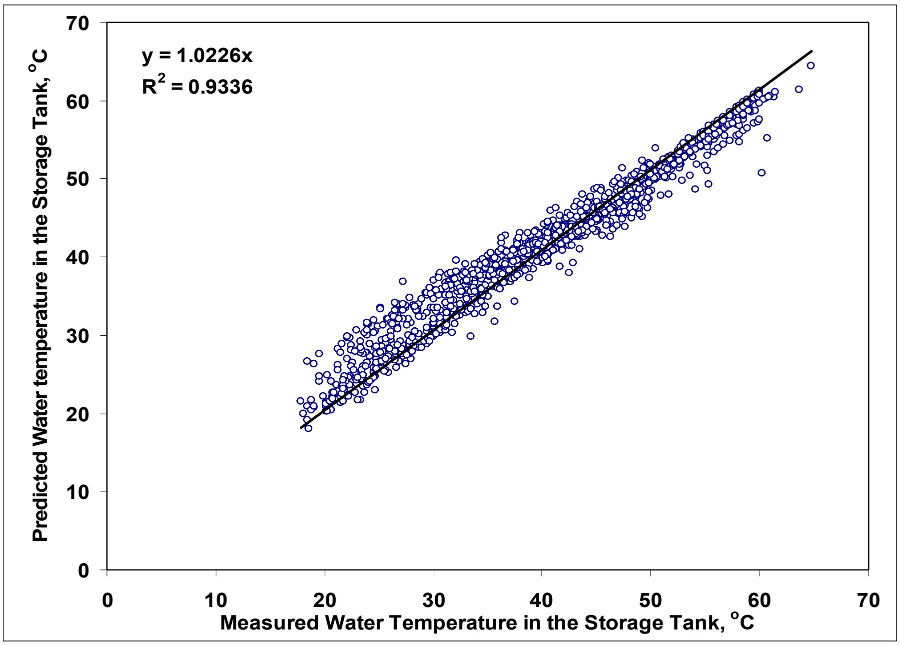

Fig. (5): Predicted water temperatures versus measured water temperatures in the storage tank during the heating period.

Heat energy providing

During the 181 day heating season the solar panels collected 3922 kWh. The daily average heat energy provided by the solar panels during this period is given in Table (2), where it is compared with total heat energy requirements for providing and maintaining optimal level of indoor air temperature. During the heating period the useful solar energy collected was 21.665 kWh of which 20.223 kWh was stored in the storage tank and consumed during the heating period for both greenhouses. During the heating season the storage tank in greenhouse 1 was taken 26.362 kWh per night as supplementary heat energy from the biomass burning system. Therefore, the renewable source of heat energy (solar energy heating system and biomass burning system) provided 46.585 kWh (85.90%) of the daily total heat energy required (54. 230 kWh). While, the storage tank in greenhouse 2 was taken 25.165 kWh per night as supplementary heat energy from the electrical heater. Thus, the solar energy system with greenhouse 2 only provided 20.223 kWh (38.32%) of the total heat energy required (52.778 kWh). If the electrical energy consumed by the water pumps has ignored because of the water pumps are one essential component of the solar collector and does not a source of heat energy addition to the greenhouse, the proportions of heat energy provided by using solar energy system for the two greenhouses (G1 and G2) are 100% and 47.74%, respectively. The potential savings form solar power was not fully realized for three main reasons: firstly, little solar power was collected in the first two hours after sunrise and the last before sunset due to low solar altitude angle and water temperature in the storage tank. As the heat energy stored in the storage tank was not continually consumed at nighttimes, therefore at the beginning of some days more than two hours of sunshine were lost.

Table (2): Daily average total heat energy normally required (kWh) during heating season (181 days).

Energy	Heat energy, kWh per day	Providing of total, %
Greenhouse 1		
Solar energy		
Total useful heat energy collected	21.665	-
Total heat energy stored in the storage tank	20.223	37.29
Electrical and biomass energy		
Total electrical energy used by water pump (4)	2.845	5.25
Total electrical energy used by water pump (7)	4.800	8.85
Total heat energy used by biomass burning system	26.362	48.61
Total energy supplied to the greenhouse 1	46.585	85.90
Total energy consumed by greenhouse 1	**54.230**	**100.0**
Greenhouse 2		
Solar energy		
Total useful heat energy collected	21.665	-
Total heat energy stored in the storage tank	20.223	38.32
Electrical energy		
Total electrical energy used by water pump (4)	2.845	5.39
Total electrical energy used by water pump (7)	4.545	8.61
Total electrical energy used by electrical heater	25.165	47.68
Total energy supplied to the greenhouse 2	45.388	86.00
Total energy consumed by greenhouse 2	**52.778**	**100**

Secondly, throughout the heating season, the auxiliary biomass and electrical heaters were switched on at the end of each day when the water temperature in the storage tank was lower than 60ºC. Therefore, some of this heat energy dissipated into the indoor air in spite of its temperature was higher than the set point temperature (18ºC) particularly with biomass burning system. This point of action resulted in extra loss of heat energy from inside to the outside atmosphere. This heat energy was ignored in computing the percentage of heat energy supplied by the solar heating system. This loss can be eliminated by installing automatic control to switch on the two auxiliary heaters when the heat energy in the water tank is insufficient to provide the desired level temperature of indoor air.

Thirdly, during the coldest month (January) the outside air temperature at night times lowered to 6.3ºC for the majority of nights resulted in great amount of heat energy loss. As the heat energy supplied into the greenhouse resides in the task of adding heat at the rate at which it is lost, accordingly, there were 8.787 and 8.388 kWh of biomass and electrical energy, respectively, added to the water in the storage tank during this month. Therefore, a movable thermal curtain should horizontally be spread at a height of 2.25 m above the floor surface at night times to reduce heat losses during this period. About 40% saving in heat energy supply can be achieved in this way (Critten and Bailet, 2002). A movable baffle should also be used to close the outside surface area of the cooling pads at the end of daylight to minimize the heat losses due to infiltration of cold air. In spite of these heat energy losses solar power is providing a significant proportion of the total heat energy required for heating the two greenhouses.

Microclimatic conditions

The air temperature inside the two greenhouses was compared with the outside air temperature as an important measure of the effectiveness of heating system. The fluctuations of air temperature surrounding the crops play an important role for their growth rate, development, and productivity. Fluctuation changes in air temperature, caused by the on-off control board, were evidently observed inside the greenhouse. A temperature gradient developed along the centerline of the greenhouses and its value varied with time during each heating cycle. The nightly average indoor air temperatures for the two greenhouses (G1 and G2) varied between 15.3ºC and 22.5ºC, and 14.4ºC and 21.7ºC, respectively, whereas the outside air temperature ranged from 6.3ºC to 21.0ºC.

The highest air temperatures inside the two greenhouses (17.8°C and 17.3, respectively) during January month (coldest month) were recorded at 19.00h, just two hours after sunset. These air temperatures were gained from the heat energy stored during the daylight, heat energy lost from the storage tanks and acquired by the indoor air during the operating of the biomass burning system and electrical heater, and the heat energy emitted from the heat gained by the concrete floor. Therefore, the heat distributing systems were not operated over this hour. The lowest air temperatures inside the two greenhouses (15.3 and 14.4°C, respectively) were also recorded during January month at 06.00h just prior to sunrise. The lowest air temperature inside the greenhouse occurred due to three reasons. Firstly, the majority of heat energy stored in the storage tanks during daylight (from solar energy system) and supplementary heat energy added after that (from biomass burning system and auxiliary electrical heater) was consumed during the heating cycles at night times. Secondly, the air temperature difference between the set point (18.0ºC) and the outside (6.3ºC) was 11.7°C, consequently greatest amount of heat energy was lost at that time. Thirdly, the fiberglass cover was able to keep the air temperature inside the greenhouse greater than that of the outside by approximately 2ºC. Under these circumstances, the two heating systems provided a heating effect of 9.0ºC and 8.1ºC, respectively.

The air relative humidity inside the two greenhouses, respectively, ranged from 62.4 to 78.8%, and 65.0 to 80.5%, whereas the outside air relative humidity was in the range of 42.2 to 75.3%.The nightly average air relative humidity inside the two greenhouses (G1 and G2) during the heating period was 72.2% and 73.7%, respectively. However, the nightly average relative humidity of the outside air was 59.3% during the heating period. This means that the air relative humidity inside the two greenhouses was greater than that of the outside by 12.9% and 14.0%, respectively. The cyclic variations in air relative humidity mainly occurred at the peak of the heating cycle in the two greenhouses. Therefore, the air relative humidity inside the two greenhouses (G1 and G2) decreased by 6.8% and 5.2% at the peak of each heating cycle, whereas at the end of the cooling down it increased by 6.4 % and 7.1%, respectively. Most protected cropping grow best within a fairly restricted range, typically 60% to 80% air relative humidity at night time for many varieties (Ozturk and Bascetincelik, 2003). High air relative humidity is the main response of pathogenic organisms. Most pathogenic spores cannot germinate at air relative humidity below 85%. Low air relative humidity increases the evaporation demand on the plant to the extent that moisture stress can occur, even when there is an ample supply of water to the roots. Normal plant growth inside the greenhouse generally occurs at air relative humidity ranged from 45 to 80% (Hanan, 1998).

The nightly average water vapour pressure deficit (VPD) of the air surrounding the sweet coloured peppers crop decreased gradually with time from 0.725 kPa (G1) and 0.628 kPa (G2) at 19.00h until they reached the minimum values (0.477 and 0.430 kPa) at 6.55h, as the indoor air temperature decreased, and the air relative humidity increased. They then increased until approached the maximum values just at and around noon. The vapour pressure deficit inside the two greenhouses (G1 and G2) showed the same trend during the heating period. When the air vapour pressure deficit is too low (VPD < 0.43 kPa) at air relative humidity too high (RH >85%) and air temperature very low (Ta < 15 °C), the water may condense out of the air onto leaves, fruits, and other plant parts causes splitting and cracking of fruits such as sweet coloured peppers and tomatoes. This can provide a medium for fungal growth and diseases. This condition can significantly downgrade the quality of vegetable crops. Higher vapour pressure deficit means that, the air surrounding the plant has a higher capacity to hold water, stimulating water vapour transfer (transpiration) into the air in this low air relative humidity conditions. Several studies (Pringer and Ling, 2004 ; Argus, 2009) that explored disease pathogen survival at different climate levels revealed two critical values of air vapour pressure deficit (0.20 – 0.43 kPa). The studies showed that fungal pathogens survive best below vapour pressure deficit of 0.43 kPa.

Due to the air temperature, air relative humidity, and vapour pressure deficit within the two adapted greenhouses were at or around the optimal levels (16.7ºC, 68.7%, and 0.61 kPa, respectively) particularly at the critical period (from 2.0 to 6.0 am) during winter season, optimal vegetative growth rate was achieved. The weekly averages increasing rate in number of leaves inside the two greenhouses, respectively, were 3.72 and 3.87 leaf/plant. As the number of leaves is increased, the green surface area is increased, and the biochemical reactions are thus increased making the photosynthesis process more active. This is in agreement with the data published by Nelson (1996). The weekly averages stem length of sweet coloured peppers plants for the two greenhouses (G1 and G2) were 4.32 and 4.04 cm/week, respectively. The maximum lengths of the plants inside the two greenhouses reached to 203.2 and 189.7 cm, respectively. Because the microclimatic conditions of the two greenhouses were almost at the same, slight variation in stem length occurred according to the reaction rates of various metabolic processes, and the number of leaves. Due to the reasons discussed previously, the numbers of fruits being seated on each plant within the two greenhouses (G1 and G2) were on the average 26.4 and 24.8 fruit, respectively. Some of these seated fruits approximately 37% were eliminated according to the breading policy of the sweet coloured peppers. Therefore, the total fresh yield of sweet colour pepper crop for the two greenhouses (G1 and G2) respectively, was 211.027 and 189.687 kg

Economic considerations

The total annual costs included the three different items (greenhouse construction, solar heating system, and operating costs) were about L.E. 1824.25. However, the total costs per square meter of greenhouse were L.E. 57.01. The fresh yield of sweet colour pepper per square meter was 6.595 kg/m^2, which sold by L.E. 79.14. Consequently, the estimated return on capital was 38.82% per annum. Since then power costs have risen and the system is achieving a return of about 60% can be obtained. The economic benefit of renewable energy utilization in agricultural applications is still marginal due to the unrealistically low price tariff for electricity power, as the government financially supporting this power. However, renewable energy systems can have a beneficial impact on the environmental, economic, and political issues of the world.

CONCLUSSION

The primary objectives of this hybrid heating system (biomass heating system assessed solar heating system) are to increase the renewable energy converted into stored thermal energy and to investigate effective uses of that stored energy for heating sweet coloured peppers greenhouses. A hybrid water heating system has been developed and installed on the roof of Agricultural Engineering Department, University of Mansoura, beside an experimentally greenhouses. The system has operated satisfactorily for over six months.

The solar panels which are continuously orientated and tilted to maintain an incident solar angle of zero from sunrise to sunset will allow maximum values of both; the absorptance of the absorber surface and the transmittance of the glass cover to be reached. The overall thermal efficiency and heat losses are mainly affected by the water inlet temperature and ambient air temperature. Over the period November 2010 to April 2011, the solar heating system collected 3922 kWh (14.119 GJ) of solar power. During the heating period the useful solar energy collected was 21.665 kWh of which 20.223 kWh was stored in the storage tank and consumed during the heating period for both greenhouses. The hybrid heating system (biomass burning system assessed solar heating system) proved to be very efficient to provide and maintain the air temperature levels required for the sweet coloured peppers. The hybrid heating system (biomass burning system assessed solar energy heating system) which connected to the greenhouse 1 provided 46.585 kWh (85.90%) of the daily total heat energy required (54.230 kWh). While, the storage tank in greenhouse 2 was taken 25.165 kWh per night as supplementary heat energy from the electrical heater. Thus, the solar energy system with greenhouse 2 only provided 20.223 kWh (38.32%) of the total heat energy required (52.778 kWh).Consequently, the hybrid heating system provided an adequate amount of heat energy required to warm the air temperature inside the greenhouse 1, in which this greenhouse is daily heated by zero energy (no any other source of heat energy is used with this greenhouse).

Due to the air temperature, air relative humidity, and vapour pressure deficit within the two adapted greenhouses were at or around the optimal levels (16.7ºC, 68.7%, and 0.61 kPa, respectively) particularly at the critical period during winter season, optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield were achieved. The total fresh yield of sweet coloured peppers crop for the two greenhouses (G1 and G2) respectively, was 211.027 (6.595 kg/m^2) and 189.687 kg (5.928 kg/m^2).
The economics of such a system remains marginal at present power prices in Egypt, although changes in power costs may drastically alter the situation.

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بحث وإستغلال نظام تسخين هجين لطاقة الكتل الحيوية المساعدة للطاقة الشمسية لتسخين بيت محمى لفلفل الألوان الحلو

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يهدف هذا البحث إلى دراسة إستغلال طاقة الكتل الحيوية الناتجة من المخلفات الحقلية المختلفة مع نظام كامل للتسخين بالطاقة الشمسية كنظام كامل للطاقة المتجددة بغرض توفير الظروف المناخية الداخلية لبيت محمى مزروع بمحصول فلفل الألوان الحلو خلال موسم الشتاء لعام ٢٠١١/٢٠١٠ م ومقارنة هذا البيت مع اخر مزود بنظام كامل للطاقة الشمسية مع سخان إضافى يعمل بالطاقة الكهربائية بغرض تحديد نسبة التوفير فى الطاقة الحرارية الإجمالية اللازمة للبيوت المحمية عند إستخدام الطاقة الجديدة والمتجددة. تم تطوير نظام مركب (طاقة شمسية وطاقة الكتل الحيوية) لتسخين الماء اللازم لتدفئة البيوت المحمية، مثبت بجوار بيت محمى تجريبى موجود فوق سطح قسم الهندسة الزراعية بجامعة المنصورة وتم تشغيله بشكل مرضى لفترة تتعدى الستة أشهر. تم توجيه المجمعات الشمسية وتغيير زاوية الميل بإستمرار للمحافظة على زاوية سقوط شمسية صفر من الشروق وحتى الغروب حتى تسمح بالوصول إلى أقصى قيمة لكلاً من معامل إمتصاص السطح الماص ومعامل نفاذية الغطاء الزجاجى. وجد أن الكفاءة الحرارية الكلية والفواقد الحرارية تتأثر بشكل رئيسى بدرجة حرارة دخول الماء ودرجة حرارة الهواء الخارجى.

خلال الفترة من نوفمبر ٢٠١٠م وحتى أبريل ٢٠١١م تم تجميع ٣٩٢٢ كيلووات.ساعة من الطاقة الشمسية (أى مايعادل ١٤.١١٩ جيجا جول) بواسطة نظام التسخين الشمسى. وخلال فترة التسخين (الستة أشهر) أضاف النظام المركب للطاقة المتجددة ٤٦.٥٨٥ كيلووات .ساعة فى اليوم بمتوسط ٨٥.٩٠ ٪ من إجمالى متطلبات الطاقة الحرارية اللازمة للمحافظة على درجة حرارة هواء البيت المحمى عند أو حول المستوى الأمثل. بينما أدى إستخدام نظام الطاقة الشمسية مع سخان كهربائى إلى توفير ٢٠.٢٢٣ كيلووات .ساعة فى اليوم بمتوسط ٣٨.٣٢٪

أدت الظروف المناخية داخل البيت المحمى والتى كانت عند أو حول المستوى المرغوب من درجات حرارة الهواء- الرطوبة النسبية – النقص فى الضغط البخارى (١٦.٧ °م ، ٦٨.٧ ٪ ، ٠.٦١ كيلو بسكال) خاصةً عند الفترة الحرجة أثناء موسم الشتاء إلى تحقيق معدل نمو خضرى أمثل وكذلك طول السلميات وعدد الثمار التى عقدت وجودة المحصول. حيث بلغ متوسط أنتاج البيت الأول والثانى من ثمار الفلفل الألوان على التوالى ٢١١.٠٢٧كجم (٦.٥٩٥ كجم/م^{٢}) و١٨٩.٦٨٧ كجم (٥.٩٢٨ كجم/م^{٢}) هذا وتظل إقتصاديات هذا النظام متماشية مع أسعار الطاقة الحالية فى مصر على الرغم من أن التغير فى تكاليف الطاقة يمكن أن يبدل الموقف بشدة.

قام بتحكيم البحث .

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