Heating greenhouses with solar energy - new trends and developments

Grafiadellis M., Traka-Mavrona E.

in

Choukr-Allah R. (ed.).
Protected cultivation in the Mediterranean region

Paris : CIHEAM / IAV Hassan II
Cahiers Options Méditerranéennes; n. 31

1999
pages 119-134

HEATING GREENHOUSES WITH SOLAR ENERGY - NEW TRENDS AND DEVELOPMENTS

Ì. GRAFIADELLIS and E. TRAKA - MAVRONA
National Agricultural Research Foundation Agricultural Research Center of Macedonia and Thrace
Thessaloniki - Greece

Abstract: The last two decades a lot of efforts have been done by the researchers in different countries in order to study the possibilities of using solar energy for heating greenhouses. From these research works hundreds of solar systems have been developed, but out of these very few found practical application. The passive solar system with the water filled plastics tubes and the system of spraying water on the top of the greenhouses are the only solar systems adapted by some growers of the greenhouses in the Mediterranean region. In Japan the earth - air heat exchange system found also some practical applications. Today many researchers have focused their interest on the improvement of the efficiency of the passive solar system, which has already passed to the growers, on the study of the response of different greenhouse crops to this solar system and on the modifications of this solar system to different climatic zones and different greenhouse structures. In this paper the problems of using solar energy for heating greenhouses and future perspectives are discussed.

INTRODUCTION

The last thirty years a rapid expansion of the plastic greenhouses in Mediterranean countries has been noticed. The majority of these greenhouses are unheated simple structures covered with plastics sheets, which make use of the favorable mild climatic conditions of some regions (Grafiadellis, 1987; Nisen et al., 1990).

In the simple Mediterranean plastics greenhouses during cold seasons large diurnal changes of air temperatures take place mainly during weather conditions of clear sky. In such conditions during night the minimum air temperatures often drop to much lower than the accepted levels and the maximum air temperatures increase above the desired levels (Stangellini, 1992; Castilla et al., 1992; Martinez, 1992). Although most of the greenhouse crops show a certain degree of adaptation to the big diurnal variations of air temperatures (Martinez, 1992); and low night temperatures are compensated to a certain degree with the increased day temperatures (Kooistra, 1984). It is widely known that lower than 12-13°C minimum air temperatures affect negatively yield and quality of the most interesting greenhouse crops (Nisen et al., 1990). Beside that in the unheated plastics greenhouses relative humidity increases and condensation on the plants and on the glazing materials often creates big problems (Grafiadellis, 1987; Hanan, 1991). The application of heating with conventional fuel into these simple greenhouses has always proved beneficial, but in many cases it has found to be uneconomical (Mattas and Grafiadellis, 1989). The main reasons for this are the short production period (November - May), the low light intensity during winter months and the inadequate control of the microclimate in the simple greenhouses (Nisen et al., 1990; Garzoli, 1989).

In order to improve temperature conditions in the simple plastics covered Mediterranean greenhouses and avoid heating, the scientists have introduced several techniques such as the double layering, the thermal screens, the use of thermic plastics films, the establishment of micro-tunnels or plastics mulch in the early stages of the plants, etc. (Grafiadellis, 1987). The investigations on the greenhouse insulation techniques have led to the conclusion that although each technique is increasing by 1-2°C the minimum air temperature of the unheated plastics covered greenhouses, the joint effect of two or more techniques has proved to be poor because in the unheated plastics greenhouses there is not enough heat in the air and in the soil to be used at night (Grafiadellis, 1987; Garzoli, 1989).

THE USE OF SOLAR ENERGY FOR HEATING GREENHOUSES

The efforts of the scientists to use solar energy have started very early in the history. The Greek philosopher Archimedes was one of the first man who has converted solar energy into mechanical power using in 209 BC bronze solar energy concentrators and burning the Roman fleet in Sicily (Grafiadellis, 1990). After the discovery of the wind power, coal and petrol the scientists left the solar energy unexplored and the 20th century found the research in the same level as it was in the time of Archimedes. After the oil crisis of 1973 a lot of efforts have been done in many research institutions in different countries in order to discover simple and efficient ways on using solar energy for heating greenhouses. The fact that the greenhouse itself is a huge solar collector encouraged the scientists to find out ways of using the heat wasted by ventilation (Grafiadellis, 1990; Ross et al., 1978; Boulard and Baille, 1986). Out of these investigations hundreds of solar systems have been developed. In some research projects the greenhouses themselves as solar collectors (Baille and Boulard, 1986; Garzoli and Shell, 1984) were used and in some others external collectors away or integrated into the greenhouses have been used (Zabeltitz, 1987).

At Rutgers University, in New Jersey of the U.S.A. a solar system was developed in which water in daytime was heated by external plastics collectors and in the night heat was distributed in the greenhouses through polyethylene film exchangers (Mears et al., 1978).

Short et al. (1978) in USA have constructed a solar pond with which heat was collected over the whole year and it was used during the cold seasons to heat a greenhouse.

Damrath (1978) in Germany has designed a solar system of collecting during daytime a part of the incoming solar radiation into the greenhouse and distributing it at night by the circulation of the water through small diameter plastics pipes.

Baille and Boulard (1987) have studied the possibility of using phase change materials inside the greenhouses in order to collect and distribute solar radiation inside the greenhouses.

Grafiadellis and Kyritsis (1980) have constructed a plastics tube heat exchanger in which water and air were simultaneously circulating and the collection at daytime and distribution at night of solar heat in the greenhouses were maintained.

Takakura and Nishina (1980) in Japan have designed a solar system for the collection and distribution of solar energy through phase change materials.

Baille and Boulard (1986) have described a solar system, which was doing use of a double translucent roof structure through which water and $CuCl_2$ were circulated for the collection of solar energy in daytime and distribution of it at night through the entire roof of the greenhouse.

At Cornell University in the USA a bench - rock heat storage solar system has been designed with which at daytime a fan drew warm air from the greenhouse to a rock bed and at night the flow was reversed (Ross et al., 1978).

Leval and Zamir (1987) in Israel have constructed a spraying tower with which in daytime the excess solar energy from the greenhouse have been collected in order to be used in the night.

Mavrogiannopoulos and Kyritsis (1987), as well as Yamamoto (1973) have constructed a system of using the greenhouse soil as a means for storing solar energy from the daytime to be used at night.

Verlodt (1987) in Tunisia has studied a radiant mulch system of black PE tubes laid on the soil of the greenhouse where water was circulated and solar energy was collected in daytime and distributed at night.

Grafiadellis (1984) has studied a system of spraying water on the top of the greenhouse while simultaneously air was circulated inside the greenhouse to absorb heat from the soil and sprayed water.

From a study done by Grafiadellis (1991) on behalf of European Community on the technical and economical aspects of the most important solar systems, which have already been introduced for practical application in the Mediterranean countries. It was proved that the solar ponds, phase change materials and heat pumps need very high investment, have very high annual running cost and with today fuel prices are not economical. Another group of solar systems, where the rock - bed solar system, the earth - air heat exchange system and the system with external flat plate plastics solar collectors belong, found also to be very expensive but not very far away from becoming economical. From the same study it was proved that the third group of solar systems, in which the passive solar system and the system of water spraying on the greenhouses belong, needs very low capital and running cost and can be introduced without any hesitation into the commercial greenhouses (Table 1).

Table 1: Technical and economical characteristics of the main solar systems introduced into the greenhouses.

Kind of solar system	Increase of temperature	Energy gained in diesel oil (liters/m^2)	Cost per m^2 of greenhouse area	
			Installations ($)	Running cost ($)
With external flat plate plastics solar collector	4 - 5^{0}C	12 - 15	6.499	3.519
The earth - air heat exchange system	5 - 8^{0}C	8 - 10	17.812	6.400
Solar ponds	10 - 15^{0}C	25 - 30	40.624	15.625
Water spraying on the greenhouse	3.5 - 5^{0}C	10	542	298
The rock - bed solar system	5 - 8^{0}C	8 -10	16.750	6.031
Passive solar system	4 - 5^{0}C	8 - 10	494	494
Phase change materials	10 - 12^{0}C	15	30.000	10.759
Heat pumps	10^{0}C	15	51.250	19.375

THE USE OF PASSIVE SOLAR SYSTEMS FOR HEATING GREENHOUSES

Solar heating systems are characterized by whether the heated water or air is distributed around the greenhouses (Fulley, 1990), by using a fan or pump (active systems) or by natural means (passive systems).

The advantages of the active solar systems are the accurate placement of the heat, the better control and the high efficiency. The disadvantages of these systems are the high cost, the need of electrical power to drive fans or pumps and the complexity.

The passive solar systems work with natural way, provide heat into the greenhouse without requiring external energy sources, are simple, easily understood, inexpensive, aesthetically more attractive than ordinary active systems and can operate even when the active systems fail (Kececioglou et al., 1988; Fulley, 1990). The principal disadvantages of the passive systems are the little or no control and the difficulty to integrate the solar collection and storage facilities into the greenhouse architecture.

One of the first works on using passive systems for the protection of vegetables under cover was that of Sondern (1967) in the Netherlands. Using small diameter PE tubes, filled with water inside low tunnels, he protected beans from -6°C air temperature and observed that daily aeration of the tunnels was not required.

El-Aidy in his thesis for the degree of PhD he did in the University of Budapest, in Hungary (personal communication), used tubes filled with water as passive system in order to improve temperature conditions in greenhouses cultivated with tomatoes.

Incalcaterra (1984) has studied the effect of using water tubes and soil mulching on the production of cantaloupe F1 Cader melon crop in greenhouses and concluded that the water tubes in PE covered greenhouses have shown beneficial effect compared to the control but they were inferior than a treatment of soil mulching.

Airhart (1984) is referring to a passive rock storage heating system consisting of a rock - bed 30cm deep that forms the greenhouse floor. He found that heat collection efficiency is not adequate since the rate of heat flux through the vertical profile mainly by conduction is very slow.

Marakami et al. (1983) have investigated the efficiency of a water bag collector consisting of transparent PVC film located on an insulated plate and found that under optimum conditions of operation, the energy collected was on an average 4mj/m^2/day in January and 10mj/m^2/day in August.

For the protection of greenhouse crops against summer frost Woolston (1985) used in Finland as solar storage systems water filled tanks, steel barrels, stones, gravel, waterfilled black film tubes and transparent film tubes containing blackened water and observed that these means were able to compensate outdoor temperatures of down to 4.2°C.

Albright (1981) is referring to the use of some simple means of passive heating applied to the commercial greenhouses.

One successful attempt to use a passive solar air heating system has been demonstrated on a small greenhouse at Bena, in Pyrannes, in Southern France (Fulley, 1990).

All the efforts of the above mentioned scientists did not find any practical application in the commercial greenhouses and have forgotten by the time.

INVESTIGATIONS ON THE PASSIVE SOLAR SYSTEM WITH THE WATER FILLED PLASTICS TUBES IN AGRICULTURAL RESEARCH CENTER OF MACEDONIA AND THRACE

One of the most important research institutions, where very intensive research on the use of solar energy for heating greenhouses was carried out, is the Agricultural Research Center of Macedonia and Thrace. The first attempts on using solar energy for heating greenhouses in this Research Center started in 1977 and until 1983 several solar systems have been developed (Grafiadellis, 1984). The first attempts on using water tubes for the collection of solar energy have started in 1978. The success of these tests was limited due to the bad quality, small diameter, and black color of the plastic tubes and to many other technical problems met.

From 1978 till 1983 the efforts of the scientists in this Research Center were focused towards solving technical problems of water leakages, developing good quality of plastics films, avoiding algae development in the water tubes and designing an efficient solar system (Grafiadellis, 1986).

From 1983, when the passive solar system with the water filled tubes took its final form (tubes from excellent quality of PE film, 1m circumference, laid on a black PE film of 75ì thickness and covering the 35% of the greenhouse soil surface) till today, a lot of experiments were carried out (Grafiadellis, 1986; Grafiadellis et al., 1990). Some of the results are as follows:

From an experiment of testing different kinds of plastics as water tube materials (PEuv, black PE, simple PE and EVA), it was found that the simple PE had the most advantages, the lowest cost and it was suggested as the most suitable material for the construction of the tubes (Grafiadellis et al., 1990).

From another experiment of testing different circumferences of water tubes (80, 90, 100, 110, 120cm), it was found that the one of 100cm (31.8cm diameter) was the most suitable for practical application (Grafiadellis et al., 1988). From other investigations it was found that under unfavorable weather conditions of low solar radiation intensity followed by low minimum air temperatures, the superiority of the big tubes over the small ones was clear. On the contrary, under conditions of high radiation levels followed by minimum air temperatures, the efficiency of the small tubes was higher (Pavlou, 1991).

It was also proved that the amounts of solar energy collected and released during a collection - release energy cycle (a day) are nearly equal. The energy balance is either positive or negative depending on the amount of energy stored in the tubes at the beginning of the cycle, the amount of solar radiation available during the collection and the weather conditions. If insufficient amounts of energy are stored at the beginning of the energy cycle in the water tubes, insufficient solar radiation is available during the day and night air temperature is low, then a negative balance occurs and the deficit is covered by energy stored during the previous cycle (Pavlou, 1991).

From experiments of testing PE films of different thickness (100, 125, 150, 175, 200, 225 and 250ì), it was proved that PE tubes of 100-125ì thickness with or without UV absorber were the most suitable for the construction of the sleeves, if they were made from the best quality of row materials (Grafiadellis et al., 1988).

From other investigations it was found that as bigger is the number of the tubes in a greenhouse as better is the effect on plant production (Fig. 1, 2). For practical reasons it is not possible to cover more than 35% of the total greenhouse area (Fig. 3, 4). In some cases bigger size tubes can replace to some extent the small size tubes (Grafiadellis et al., 1988).

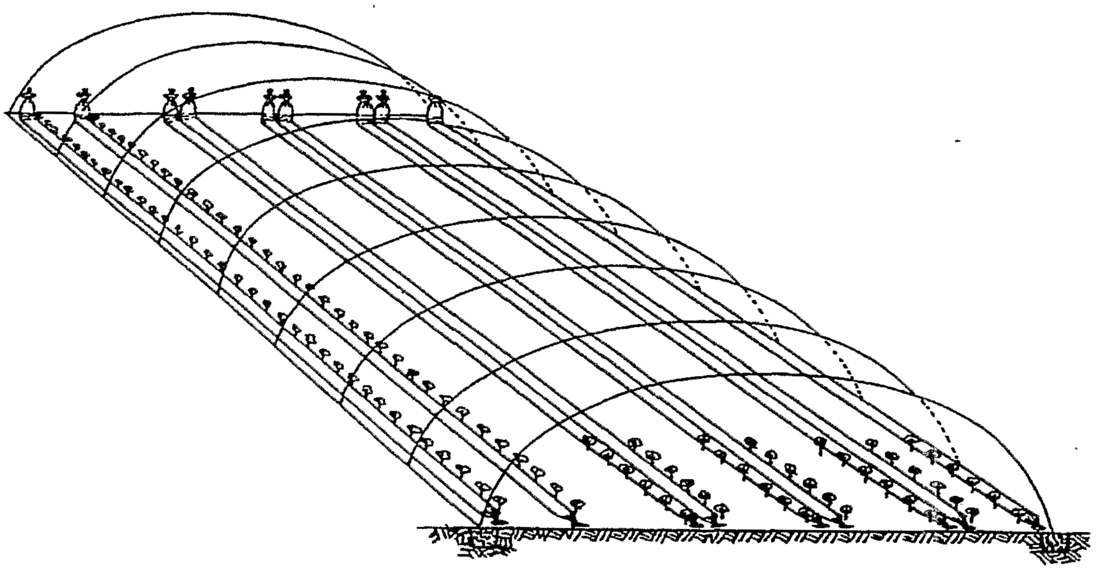


Figure 1. Arrangement of the passive solar system in a greenhouse.

Other investigations have shown that from October till May in Thessaloniki, Greece, the energy collected with the passive solar system in a 1000m^2 PEuv covered greenhouse was equivalent to 16.016-18.280 liters of gas oil and that from the solar radiation which was falling on the greenhouse, 18-19% was collected by this system (Grafiadellis et al., 1990).

From an experiment of studying the effect of the passive solar system on the minimum air temperature, it was found that when in the unheated control greenhouse covered with PE film the air temperature was 0.75°C, in the solar heated greenhouse covered with double PE film was 6.40°C, in another covered with thermal polyethylene was 6.08°C and in the greenhouse covered with a single sheet of PE film was 4.70°C (Grafiadellis, 1986). It was also observed that the passive solar system at night increases plant temperature by 2-4°C, reduces relative humidity by 6-12%, reduces considerably moisture condensation on the plants and glazing materials and increases light available at midday in the plant level by about 15% and in the morning and afternoon by 40% (Grafiadellis, 1990).

From a research work done in Chania, Greece, by Taieb and Grafiadellis (1993), it was found that by the addition of black acrylic color into the water of the tubes in the quantity of 4g per 85 liters of water an increase of the efficiency of the passive solar system by 25% was obtained.

From other experiments which were done in the Technological Educational Institute of Larissa, Greece, it was found that from a big variety of chemicals added into the water of the tubes, the $CuSO_4$ in the quantity of 600g/85l of water the highest increase of the efficiency (25%) has given.

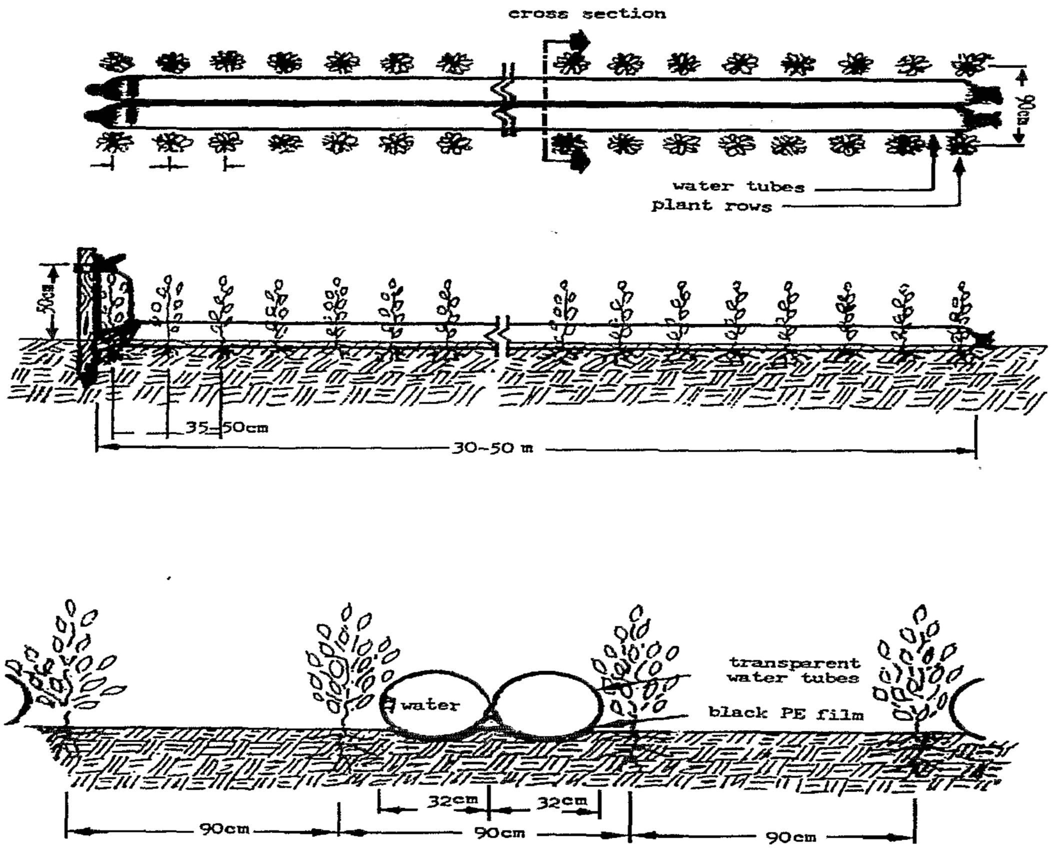


Figure 2. Cross section and details of establishing the passive solar system.

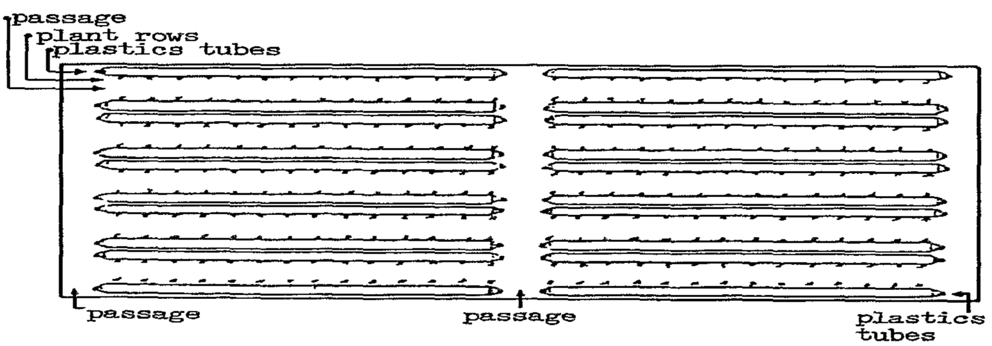


Figure 3. Arrangement of the water tubes in horizontal position along a greenhouse.

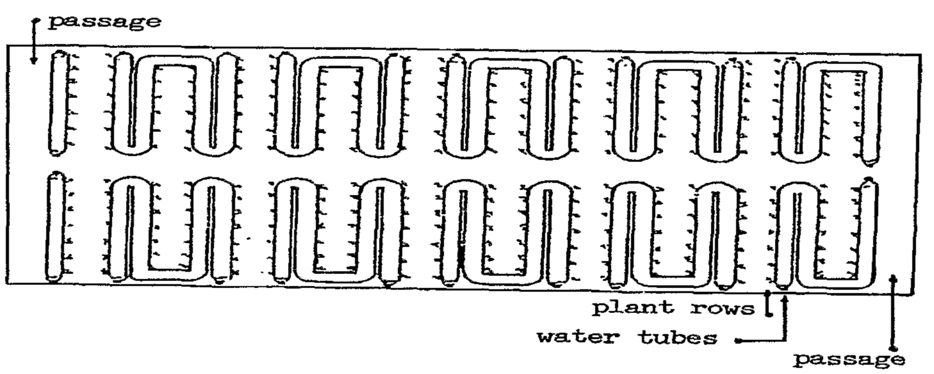
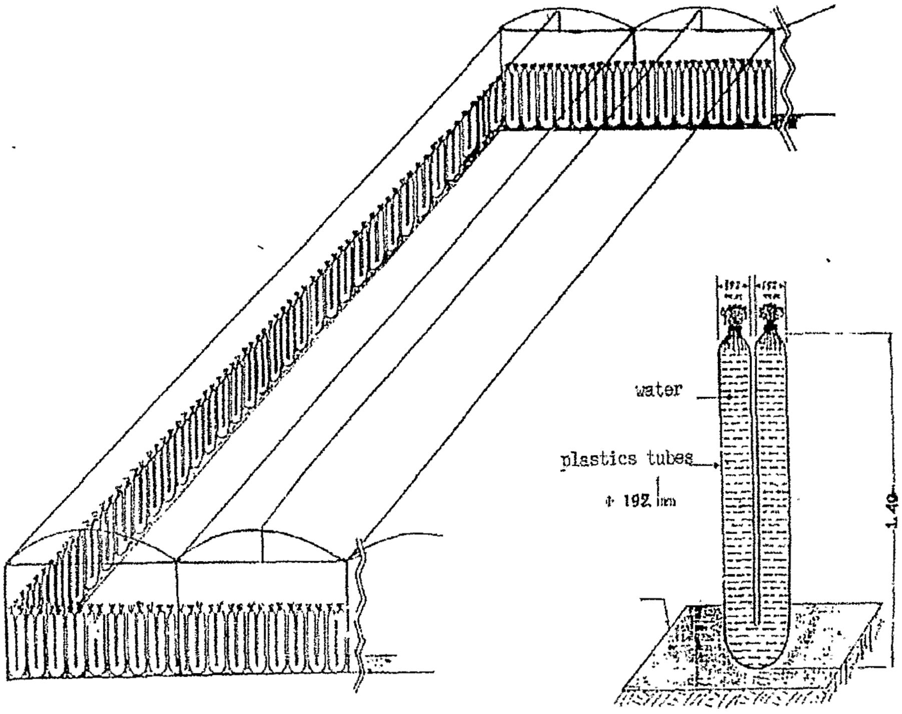


Figure 4. Other way of arranging the passive solar system in a greenhouse.

It was also found that water tubes in vertical position (Fig. 5) are effective in collecting solar energy in greenhouses, the best circumference of the tubes is that of 60cm and by adding black acrylic color into the water an increase of 38% of the efficiency of this solar system is obtained (Dimitriou, 1996).

From other investigations it was found that the passive solar system with water tubes of 1m circumference covering the 35% of the soil surface reduces by 2.9°C the maximum air temperature in a PE covered greenhouse (Grafiadellis and Taieb, 1998).



Details of arranging the water tubes vertically

Figure 5. The passive solar system with the water tubes in vertical position in the sides of a greenhouse

From a study of the effect of three heating systems on the production of four commercial tomato hybrids conducted during 1986-88 by Traka - Mavrona et al. (1992), it was found that the greenhouse with only the passive solar system and the second one heated by the warm air furnace and equipped additionally with the passive solar system, increased the total marketable production by 37 and 29%, respectively and the early marketable production by 45 and 94%, respectively compared to the nonheated control greenhouse. From the same research work it was also proved that the solar greenhouse has influenced mainly the total production through an increase in the mean fruit size, while the conventionally heated greenhouse affected more the earliness of tomatoes.

Very similar results were obtained from another research work during 1989-90 (Grafiadellis et al., 199..), when the passive solar system was found more effective in increasing the total marketable fruit production on an average of 16 tomato cultivars compared to the gas oil air furnace and the anti-frost protection. In this case the early production was not significantly differentiated between the two heated greenhouses.

From another study of the response of a melon crop as it was affected by greenhouse heating, it was found that the total production of melons in the two greenhouses heated with the passive solar system and with the warm air furnace was similar, but it was much superior to the nonheated control greenhouse (Grafiadellis et al., 1998).

In another experiment, the effect of greenhouse heating on tomato fruit quality was studied (Traka - Mavrona et al., 1993). From the results obtained, it was found that in the nonheated control greenhouse the number of malformed and reduced - weight fruits was higher. The mean fruit weight of early production was favoured by the gas oil air furnace, but later in spring, the solar system was more effective. Additionally the greenhouse with the gas oil air furnace gave higher soluble and total solids of the fruit juice, but also increased the blossom - end rot incidence. The pH of the fruit juice had a tendency to drop as the temperature increased.

An additional research study was also conducted during 1992 in the above mentioned greenhouses (Traka - Mavrona et al., 199..), regarding the tomato fruit set of six tomato hybrids and two lines as affected by the greenhouse heating with the passive solar system, compared to the conventional heating with the gas oil air furnace and the anti-frost protection with gas oil heaters. From this research work it have been found that by the application of heating by the passive solar system the number of flowers per inflorescence and the weight of individual fruits were increased. The increase of the flower number as the inflorescence order increased was similar in the three greenhouses. The corresponding number of fruits and the fruit set were similarly affected by the heating systems.

From an experiment of studying the effect of plant defoliation and the addition of black acrylic colour into the water of the passive solar system, it was found that by these treatments the mean fruit weight, the soluble solids, the firmness, the dry matter, the pH and the titratable acidity were not affected and that the severe defoliation reduced significantly the total soluble solids in the first two clusters and the dry matter in the first cluster (Antunes et al., 1993).

The effect of using black coloured water in the tubes in combination with soil mulching by milky polyethylene film on the fruit yield of four tomato hybrids (LSL and no LSL) grown in a plastics greenhouse was studied (Traka - Mavrona et al., 1996). Soil mulching by milky polyethylene film increased earliness by 12%, marketable yield by 19%, total yield by 18% and mean fruit weight by 9%.

From a research work done by Bouam et al. (1998) in the Agronomic Institute of Hania, Greece, it was found that by the application of the passive solar system in low tunnels an increase of the minimum air temperature by 3-4°C was noticed, the melon plants grew faster, became more vigorous, produced bigger fruits, of better calibrate, 54.6% higher yield and were by 10 days earlier.

Research done by different institutions and the experience of the growers have proved that in Mediterranean conditions only with the passive solar system and using additionally a thermal film or a double layer it is not possible to obtain an acceptable minimum air temperature of 12-13°C. So an additional heating system with conventional fuel is necessary (Grafiadellis, 1987).

Because of its low cost, its beneficial effect on the most important climatic parameters of the greenhouse (temperature, light and relative humidity) and its effect on the earliness and total production, from economical aspect, the passive solar system proved cost effective and can improve the farmers income by 30-100% (Mattas and Grafiadellis, 1989; Mattas et al., 1990; Martica and Papanagiotou, 1991).

RESEARCH ON THE PASSIVE SOLAR SYSTEM DONE IN OTHER INSTITUTIONS

At the second FAO-CNRE (Cooperative Network for Rural Energy Workshop) which took place in April 1986, in the Agricultural Research Center of Macedonia - Thrace, in Thessaloniki, it was decided and carried out a joint experiment in 11 countries by 13 research teams on the use of the passive solar system for heating greenhouses. The results of these experiments were presented at the third FAO-CNRE Workshop in April 1998, in Adana, Turkey (Zabeltitz, 1988).

Research done by Odysseos (1988) in Cyprus has shown that in a greenhouse heated by the passive solar system the temperature of the leaves of the plants was by 1.7°C higher than that of the control and that there were less chances of moisture condensation on the plants. In the same greenhouse an increase of light intensity by 30-40% close to the water tubes was observed which in many cases reached up to 70% in the morning and afternoon. It was also found that this solar system is keeping in daytime the maximum air temperature at lower levels than the control.

From experiments done in Tunisia, Verlodt and Mougou (1990) found that during the winter period the passive solar system is more suitable in less developed plants, the efficiency of this system is much higher in greenhouses covered with thermal films, the best results are obtained with as much as possible tubes and the application of the tubes in the long sides of the greenhouses is highly suggested.

Investigations in Israel have shown that the solar energy collection efficiency of the passive solar system was 8-20%, the solar sleeves raise soil and air temperature by 1-3°C at night, reduce maximum air temperature during the day by 2-5°C and improve significantly the microclimate around the plants (Esquira et al., 1988). Further researches have proved that the application of this solar system in melons has increased the suitable for export fruits to 70% as compared to 45% from the nonheated control greenhouse.

Photiades and Bredenbeck (1987) are reporting that in short sunshine hours and low sun angles prevailing in January the efficiency of the passive solar system was low. They are also mentioning that a tube partly filled with water performed slightly better than a tube next to it and fully filled with water (37% vs 35%) and that a tube without polystyrene under it did not perform as well as another tube with polystyrene (31% vs 43%).

Mougou and Verlodt (1988) observed that the larger diameter tubes are more efficient in the use of solar energy in greenhouses covered with EVA film than in PE covered greenhouses.

Photiades (1989) has shown that a tube, which was not shaded by plants, collected twice as much heat than one that was shaded by plants and heat, which was collected per day by the tubes increased from January to April.

Montero et al. (1988) in Spain using water tubes of 21cm diameter and covering 10-20% of the soil surface obtained 1-2°C higher air temperature than the nonheated control greenhouse.

From Israel Esquira et al. (1988) are reporting that cucumbers cultivated in a PE covered greenhouse heated with the passive solar system gave 70% yield increase, 3-10 days earliness and quality improvement by 30%.

From a research done in Egypt, Medany and Abou Hadid (1989) found that by using the passive solar system in a PEuv covered greenhouse an increase of the minimum air temperature of 2-4°C in comparison to the control was obtained.

In Czechoslovakia from a research (Jelinkova, 1988), it was observed that with the application of the passive solar system in a PE covered greenhouse the minimum air temperature was 6.3°C higher than in the ambient air and also that cucumber yields were 29% higher in the greenhouse where the solar system was installed in comparison to the other half which was the control.

Mavroyiannopoulos and Kyritsis (1989) are reporting that the heat exchange between tubes and their surroundings can be described by the equation: Q=281 I+5.3 (ta-tw), where ta and tw are the temperatures inside and outside the tubes and the connective coefficient of the tubes is 5.3 W/°C/m.

From data collected in the northern part of Greece it has been clearly proved that the adoption of the passive solar system in protected cultivation will greatly improve the income of the growers (Mattas and Grafiadellis, 1989; Martica and Papanagiotou, 1991). From the analysis of the economical results, Mattas et al. (1990) have shown that by the application of the passive solar system in the greenhouses the income of the growers is increasing by 30% in tomato and 50% in cucumbers.

Almost all the above mentioned research works on the passive solar system were carried out after the second FAO-CNRE Workshop, which took place in April 1986 in Thessaloniki, Greece on behalf of the joint experiment.

At the present time even more scientists in several countries are working intensively in order to improve the efficiency of the passive solar system and adapt it to different crops and different climatic regions.

Very interesting tests and investigations are also carried out by plastics film industries, which led to the introduction to the growers of very good quality of plastic tubes.

The last years the growers in Greece who have established the passive solar system in their greenhouses have gained very big experience and introduced very interesting developments mainly on the response of different crops, the need of adding to the solar heated greenhouses extra heat with conventional fuel, insulating the solar heated greenhouses, avoiding water leakages from the tubes, etc.

The last 4-5 years the Ministry of Agriculture of Greece with the assistance of European Community is establishing many demonstration solar greenhouses, covered mainly with plastics films and cultivated with vegetables or flowers all over the country. From the different solar systems tested in these demonstration projects, the passive solar system proved cost effective, became the most popular and replaced all other systems.

FUTURE PERSPECTIVES

As the prices of the fuel are continuously increasing, the researchers are obliged to pay more attention into the use of renewable sources of energy and mainly to the solar energy for heating greenhouses.. From the different solar systems developed, the passive system is gaining continuously popularity among the researchers and the growers, because of its simplicity, low cost and high efficiency on the use of solar energy. The messages which are coming from both sides are very promising.

All the investigations and practical applications of the passive solar system have proved that with this system it is not possible to cover all heating needs of the greenhouses, but it can add security when the main heating systems are failing and also can contribute considerably in the reduction of fuel consumption. In the Mediterranean region where the majority of the greenhouses are not heated, the passive solar system is improving very much the most important environmental factors (temperature, light and relative humidity) inside the greenhouses and this affects considerably the earliness, the production and finally the income of the growers.

Although the passive solar system looks very simple, its way of acting is very complicated. In the future further research is needed on the following topics:

1. Improvement of the quality of the plastics tubes.

2. Study of the response of greenhouse crops to the addition of black colour and $CuSO_4$ into the water tubes.

3. Study of the effect of this system on plant temperature, light reflection and moisture condensation on the covering materials and plants.

4. Use of reflectors on the north wall of the greenhouse in order to increase the solar radiation which is falling on the water tubes.

5. Contribution of this solar system on the energy saved in heated greenhouses in different regions.

6. Study of how the insulation techniques of greenhouses (thermic films, double layering or thermal screens) are affecting the efficiency of the passive solar system.

7. Study of the response of different crops to the passive solar system in different climatic conditions.

8. Study of the possibilities of removing some of the lower leaves of the plants to avoid shading on the water tubes.

REFERENCES

Airhart, D.L., 1984. Overcoming horticultural problems in solar greenhouses. Acta Hort. 148: 785-789.

Albright, L.D., 1981. Passive solar heating applied to commercial greenhouses. Acta Hort. 115: 543-551.

Amor Ben H., Salhi, M., Zid ben A. and H. Verlodt, 1990. First results of heating greenhouses by a passive solar system in Gafsa (southwest of Tunisia). Acta Hort. 263: 131-138.

Baille, A., 1988. Low temperature-heating systems in greenhouse production. Technological aspects and thermal performances. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 107-116.

Baille, A. and Th. Boulard, 1986. An overview of solar greenhouses projects in France. Contribution to the 2nd FAO CNRE Workshop on Solar Heating of Greenhouses, Thessaloniki, Greece.

Baille, A. and Th. Boulard, 1987. Phase change materials for heat storage in greenhouse. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, pp. 139-142.

Bouam, M., Gerasopoulos, D. and M. Grafiadellis, 1998. The effect of the passive solar heating system and of the kind of covering material on yield and quality of melons cultivated in low tunnels. Paper presented in Mediterranean Colloquium on Protected Cultivation, Agadir, Marocco, Oct. 6-9, 1996.

Boulard, Th. and A. Baille, 1986. Preliminary results of two solar storage systems. Contribution to the 2nd FAO CNRE Workshop on Solar Heating of Greenhouses, Thessaloniki, Greece.

Castilla N., Tognoni, F. and C. Olympios, 1992. Vegetable production under simple structures in Southern Europe. Food and Fertiliser Technology Center, Taipei, Rep. of China, Bull. 348: 25pp.

Damrath, J., 1978. Greenhouse heating with sun energy. Acta Hort. 76: 181-184.

Dimitriou, E., 1996. The passive solar system placed in vertical position in the sides of the greenhouse, M. Sci. thesis, Mediterranean Agronomic Institute of Chania, Greece.

Esquira, I., Segal, I. and A. Antler, 1988. Water sleeves for passive solar heating of greenhouses. First results of experiments and observations in Israel. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 46-49.

Fulley, R.J., 1990. Heating commercial greenhouses with solar energy. Agricultural Engineering Centre, Department of Agriculture and Rural Affairs, Werribee, Victoria, 3030, Australia.

Garzoli, K.V., 1989. Energy efficient greenhouse. Acta Hort. 245: 53-62.

Garzoli, K. and G.D.G. Shell, 1984. Performance and cost analysis of an Australian solar greenhouse. Acta Hort. 148: 723-729.

Grafiadellis, M., 1984. Development of solar systems for heating greenhouses. Acta Hort. 154: 223-232.

Grafiadellis, M., 1986. Development of a passive solar system for heating greenhouses. Acta Hort. 263: 111-119.

Grafiadellis, M., 1987. Modern greenhouses. Second ed. Thessaloniki, pp. 328.

Grafiadellis, M., 1990. The use of solar energy for heating greenhouses. Acta Hort. 263: 83-96.

Grafiadellis, M., 1991. A review of technical and economical aspects of eight solar systems used for heating greenhouses. Paper presented in FAO Consultation Workshop on Development of Greenhouses in Egypt since 1987, Egypt, March, 1996.

Grafiadellis, M. and S. Kyritsis, 1980. Heating greenhouses with solar energy. Acta Hort. 115: 553-560.

Grafiadellis, M., Spanomitsios, G. and K. Mattas, 1988. Recent experiences with passive solar system for heating greenhouses. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 21-24.

Grafiadellis, M., Spanomitsios, G. and K. Mattas, 1990. Recent developments introduced in the passive solar system for heating greenhouses. Acta Hort 263: 111-119.

Grafiadellis, M. and F. Taieb, 1998. Cooling effect of the passive solar system in greenhouses. Acta Hort. (in press).

Grafiadellis, M., Traka - Mavrona, E., Maloupa, E. and G. Spanomitsios, 199.. Influence of the passive solar system on the greenhouse climate and yield quantity and quality. ISHS International Symposium, Tunis, December 1991.

Hanan, J.J., 1991. The influence of greenhouse on internal climate with special reference to Mediterranean regions. Acta Hort. 287: 23-34.

Incalcaterra, G., 1984. Effectti della pacciamatura e dei tubolars termoregolatori sulla coltura del melone in serra fredda. Colture protette 4: 51-61, Italy.

Jelinkova, H., 1988. The Czechoslovak experience with passive solar system in greenhouses. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 18-20.

Kececioglou, T., Unsal, R. and H.A. Akadeniz, 1988. Economic comparison of solar greenhouses with classical ones. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 65-66.

Kooistra, E., 1984. Energy saving temperature regimes for vegetable growing. Acta Hort. 148: 561-566.

Levav, N. and N.M. Zamir, 1987. Hydrosolar greenhouse. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, I: 157-162.

Marakami, L., Nara, M. and K. Sakurai, 1983. The efficiency of the water bag solar collector. Acta Hort. 148: 707-710.

Martica, M. and E. Papanagiotou, 1991. Economic consequences of the system of heating on the production of protected vegetables in Northern Greece. Acta Hort. 287: 391-398.

Martinez, P.F., 1992. The influence of environmental conditions of mild winter climates on the physiological behaviour of protected crops. Acta Hort. (in press).

Mattas, K. and M. Grafiadellis, 1989. Assessing income benefits in protected cultivation when energy saving technology is introduced. Acta Hort. 245: 547-553.

Mattas, K., Grafiadellis, M., Papanagiotou, E. and M. Martica, 1990. Evaluating the effectiveness of the passive solar system for heating greenhouses. Acta Hort. 263: 97-101.

Mattas, K., Grafiadellis, M. and E. Papanagiotou, 1991. Economic consequences of the system of heating on the production of protected vegetables in Northern Greece. Acta Hort. 287: 391-398.

Mavrogiannopoulos, G. and S. Kyritsis, 1989. Passive solar sleeves for heating greenhouses. Gartenbautechnishe informationen, Bul. 30: 30-38. Institute for Horticultural Engineering of the University of Hannover and FAO.

Mavrogiannopoulos, G. and S. Kyritsis, 1987. Soil - air heat exchanger. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, I: 150-153.

Mavromatis, E., Grafiadellis, M. and E. Traka - Mavrona, 199.. A Study of the techniques which improve the efficiency of the passive solar system. Proc. of XXV Annual Meeting of ESNA (under press).

Mears, D.R., Roberts, W.J. and J.C. Simkins, 1978. Performance of a practical solar heating system. Acta Hort. 76: 193-202.

Medany, M.A. and A.F. Abou-Hadid, 1989. Studies on the heat requirement of sweet pepper plants grown under plastic houses in Egypt. Acta Hort. 287: 255-260.

Montero, J.I., Marfa, O., Serrano. L. and A. Anton, 1988. The use of passive solar sleeves in sloped tunnel greenhouses. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 31-33.

Mougou, A. and H. Verlodt, 1988. Use of passive solar heating system to improve greenhouse bio-climate. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 34-37.

Nisen, A., Grafiadellis, M., Jimener, R., La Malfa, G., Martinez, P.F., Monteiro, A., Verlodt, H., Villele, O., Zabeltitz, C.H., Denis, I.U. and W.O. Boudoin, 1990. Protected cultivation in the Mediterranean climate. FAO Division of Plant Production and Protection. Rome, Italy, pp. 313.

Odysseos, G., 1988. The passive solar system. A study of the effect on plant temperature, on reflection of light and on moisture condensation. M. Sci. thesis, Mediterranean Agronomic Institut, Chania, Greece.

Pavlou, G., 1991. Evaluation of thermal performance of water filled polyethylene tubes used for passive solar greenhouse heating. Acta Hort. 287: 89-97.

Photiades, I., 1989. Experience and results of research on passive water tube solar heating systems in Cyprus. Gartenbautechnische Informationen Bul. 30: 9-12. Institute of Horticultural Engineering, University of Hannover and FAO.

Photiades, I., and H. Bredenbeck, 1987. Passive system with water filled PE tubes. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, I: 104-105.

Ross, D.S., Roberts, W.J., Parsons, R.A., Bartok, J.W. and R.A. Aldrich, 1978. Energy conservation and solar heating for greenhouses. Northeast Regional Agricultural Engineering Service, Department of Agriculture, Bul. 3: 1-48, USA.

Short, T.H., Badger, P.C. and W.L. Roller, 1978. The solar pond as an alternative energy source for greenhouses. Acta Hort. 76: 185-192.

Sondern, J.A., 1967. Influence of the air temperature in tunnels by means of the accumulating effect of a water mattress. Acta Hort. 9: 59-60.

Stanghellini, C., 1992. Evatranspiration in greenhouses with special reference to Mediterranean conditions. Acta Hort. (in press).

Taieb, F. and M. Grafiadellis, 1993. Improvement of the efficiency of the passive solar heating system using coloured solutions. European Seminar on Business Opportunities for Energy Technologies in the Field of Greenhouse Horticulture in Southern Europe, Heraklion, Vol. I: 161-169.

Takakura, T. and H. Nishina, 1980. A solar greenhouse with phase change energy storage and microcomputer control system. Acta Hort. 115: 583-590.

Traka - Mavrona, E., Bletsos, F., Grafiadellis, M. and G. Spanomitsios, 1993. The effect of greenhouse heating on tomato fruit quality. ISHS International Symposium on the Quality of Fruit and Vegetables: The Influence of Pre- and Post - harvest Factors and Technology, Chania, September 19-23, 1993. Acta Hort. 379: 289-296.

Traka - Mavrona, E., Bletsos, F., Grafiadellis, M and G. Spanomitsios, 199.. Tomato fruit set at three different greenhouse heating conditions. 1st Balkan Symp. on Vegetables and Potatoes, June 4-7, Acta Hort. (in press).

Traka - Mavrona, E., Grafiadellis, M., Paraskevopoulou - Paroussi, G., and G. Spanomitsios, 1992. The effect of three greenhouse heating means on the production of four tomato hybrids. N.AG.RE.F. Panhellenic Congress of Agricultural Research, Thessaloniki, February 5-7, 1990. Proc., B: 855-870

Traka - Mavorna E., Grafiadellis, M. and E. Maloupa, 1995. Response of tomato production to three different heating systems. Agr. Med. 124:I

Traka - Mavrona, E., Spanomitsios G. and F. Bletsos, 1996. Effect of mulching and of adding colors into the water of the plastics tubes of the passive solar system on the production of tomatoes. Proc. of 17th Scientific Meeting of Greek Society for Horticultural Science (GSHS). pp. 293-296.

Verlodt, H., 1987. Solar greenhouse system. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, I: 179-181.
Verlodt, H., and A. Mougou, 1990. Approche sur le chauffage solaire passif des serres. Acta Hort. 263: 139-149.

Woolston, S., 1985. A survey of Finnish solar greenhouse research and development. Paper presented at CNRE FAO Workshop in Cyprus on Solar Heating of Greenhouses", FAO.

Yamamoto, Y., 1973. Temperature conditions and thermal characteristics in an earth - air heat exchange greenhouse. J. Agr. Meteorol. 29 (1): 11-15.

Zabeltitz, von Chr., 1987. Greenhouse heating with solar energy. FAO REUR Technical Series on Greenhouse Heating with Solar Energy, Rome, I: 13-21.

Zabeltitz, von Chr., 1988. Greenhouse heating with solar energy. Proc. of FAO CNRE Workshop, Adana, Turkey, Vol. 21: 9-11.