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Use of Energy-Saving Systems in Greenhouses at the Yair Research Station, Arava Valley (2008-2009)

Research Partners

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Summary

Background – To facilitate the continuation and prosperity of agriculture in the Arava, particularly against the background of global economic and climatic change, we must concern ourselves with the use of advanced, innovative technologies to protect crops against damage caused by inclement weather, while allowing continuous fruiting and optimizing fruiting per unit area, to preserve and increase the quality of the fruit or other crop product produced on each unit of cultivated area.

Goals – The testing and comparison of technologies will allow for energy savings, through the use of integrated systems that make possible improvements in the crop's growing conditions, by heating and by reducing the relative humidity (RH) inside the greenhouses, as compared with the conventional methods in use today.

Methods – The experiments were conducted in four cropping structures at the Yair Research Station in the Arava Valley in southern Israel. Each of these cropping structures had an area of 900 m^2. The following technologies were tested: 1. Control greenhouse (GH 5). The roof of this greenhouse was covered with polyethylene and the sides were covered with 50-mesh

screens. 2. The greenhouse that was equipped with a thermal screen only (GH 2) was constructed of impermeable, reflective sheeting that provided 50% shade. 3. A greenhouse equipped with a thermal screen and the Agam system (GH 3). The Agam system is based on a heat converter that can lower the RH in the greenhouse and supply the additional energy needed to heat the greenhouse. The Agam system pumps the humid greenhouse air through a concentrated salt solution flowing through a matrix of pads. The moisture in the air is then pumped through a condenser, where the latent heat present in the humid air is released into the salt solution. The solution heats up and releases warm, dry air into the greenhouse. 4. Hot-water heating (GH 9). The heater, which has an output capacity of 150,000 kilocalories, includes a heat transfer device based on the flow of hot water through a metal pipe. The heater is powered by natural gas. In this greenhouse, we also installed a thermal screen like the ones installed in buildings 3 and 2. We installed a calorimeter in each of the heated greenhouses, in order to measure the energy demand in the greenhouses. The pepper cultivars Celica (Efal) and 7158 and 7182 (Zeraim Gedera) were transplanted into the greenhouses on 10 August 2008.

Over the course of the experiment, the temperatures of two fruits from each building and the amount of moisture on the surface of the fruit were evaluated manually once a week. We evaluated green fruits approaching their final size. The evaluation was carried out before the thermal screens were rolled up, usually between 6:45 and 7:00 in the morning, and once an hour for the following three hours. The evaluation of the moisture on the surface of the fruit was done by hand and the moisture level was defined according to four levels: dry, moist, wet or very wet.

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Results and Conclusion- The thermal screen improved the night-time temperature balance and raised the night-time temperature in the greenhouses by an average of 2 to 3.5°C, without any additional energy input from any external (artificial) source. This contribution was accompanied by an increase in the amount of moisture in the building, which increased the cracking of the pepper fruit. The Agam system provided an average energy savings of 60%, as compared to the parallel heating system that used warm water to heat the greenhouse. Both of these systems involved the use of a thermal screen. The RH in the building heated using the Agam system was lower than that in the building heated using the conventional hot-water heating system. This difference between these two systems will increase the more tightly the buildings are sealed. Of the tested cultivars, cv. Celica is most resistant to cracking and cv. 7182 is most susceptible. The highest levels of cracking were observed in the greenhouse with the thermal screen (and no heater), and this corresponds to the wetness of the fruit and the high humidity observed in this building, as compared to the other buildings. The heating systems should be tested in an additional season, in order to characterize the distributions of heat and humidity associated with the different heating systems. The performance of the heating systems should also be tested over a colder winter, as this past winter was quite mild.

Background

In recent years, significant climatic changes have been felt around the world. These changes are characterized by climatic instability. One example of this is the cold snap that hit Israel in January 2008. (A similar event took place in the Arava in 1973.) Over the course of 10 nights in January 2008, an extreme cold event caused great damage to different agricultural activities. The cold weather caused damage in low areas and areas closed to the flow of air, as

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well as in relatively high areas all over the country. Affected areas include the northern valleys, the western Galilee, Emek Hefer, the Sharon region, Sheflat Yehuda, the Jordan Valley and the Arava. The damage was caused by the low temperatures and by the continuous period of temperatures below zero degrees Celsius. The crops that suffered the most damage from the cold event were in screen-houses, which provide less protection from extreme weather than structures covered with polyethylene or structures equipped with thermal screens.

Today, few cropping structures in the Arava are heated, due to the high costs of heating and the high relative humidity (RH) in heated cropping structures (which occurs as a result of closing the buildings while they are being heated), which leads to the development of fungal diseases (gray mold of pepper, downy mildew, gray mold of basil, etc.). Similarly, high humidity leads to the problem of cracked pepper fruits. The problem of cracking is particularly intense during February and March, due to the presence of high humidity, old fruit and a significant difference between day and night temperatures.

To facilitate the continuation and prosperity of agriculture in the Arava, particularly against the background of global economic and climatic change, we must concern ourselves with the use of advanced, innovative technologies to protect crops against damage caused by inclement weather, while allowing continuous fruiting and optimizing fruiting per unit area, to preserve and increase the quality of the fruit or other crop product produced on each unit of cultivated area.

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Goals

Testing and comparison of energy-saving techniques that are based on integrated systems that allow the improvement of growing conditions through heating and the reduction of the **relative humidity** inside the greenhouses. The specific techniques are described below.

Techniques

The experiments were conducted at the Yair Research Station (Chatzeva), in four cropping structures (900 m^2 each) that were covered with plastic thermal screens that contained additives to reduce the flow of IR radiation from the greenhouse, as well as an **anti-fog** additive to inhibit the dripping of condensation water (from the plastic sheets) onto the crop canopy. In each building, we set up two ventilated chambers (dry humidity chambers) that were connected to a climate monitoring and control system produced by the Eldar Company. In greenhouses 2, 5, 3 and 9, one chamber was set up above the thermal screen and the other was set up under the thermal screen, at the level of the top of the crop canopy in the center of the greenhouse. In the control greenhouse that did not have a thermal screen (greenhouse 5), we set up one chamber at the height of the top of the pepper canopy in the center of the greenhouse.

In greenhouses 3 and 9 (the heated buildings), we examined energy efficiency using a calorimeter. The calorimeter system was installed in the two buildings on 14 February by the Center for Agricultural Engineering. Each calorimeter was made up of a digital water timer attached to the hot water pipe that spanned the distance between the heater and the greenhouse, and two temperature sensors (thermocouples), A and B. Sensor A was attached to the pipe that carried hot water from the heater to the greenhouse. Sensor B was attached to the

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pipe that carried water from the greenhouse back to the heater. Measurements were recorded every 10 minutes during the periods that the heater was active and stored in a data-logger (Campbell).

Calculating energy use: If WM (water meter) represents the supply of water (in m^3) for each hour within a given time period and AT and BT are the temperatures of the water leaving the heater and returning from the greenhouse (respectively) in a given time frame, then energy demand is: I) $Q = (AT - BT)*WM$.

Q is the rate of heat transfer in thousands of kilocalories per hour. The product of Q and the coefficient 1.l6 is the heat transfer in kilowatts. (1 kilocalorie = 4180 kilojoules, dividing this number by 3600 seconds produces the coefficient 1.16.) The heat transfer coefficient of the greenhouse is calculated by dividing the thermal energy flow that enters the greenhouse (as measured by the calorimeter) by the area of the greenhouse, and then dividing this figure by the difference between the temperatures inside and outside the greenhouse. The area of the greenhouse was 900 m^2. However, in a small greenhouse, the relative area to be cooled is greater. Therefore, for these two greenhouses, we rounded the area to 1000 m^2. Dividing the heat transfer rate that was given in kilowatts per hour by an area of 1000 m^2 gives us the amount of heat lost, in terms of watts per m^2. Dividing by the difference between the indoor and outdoor temperatures gives us the heat transfer coefficient in terms of watts per m^2.

The pepper cultivars Celica, from the Efal Company, and 7182 and 7158 from Zeraim Gedera were transplanted into each of the greenhouse. In each greenhouse, harvest and fruit quality data were collected along the central gable. The pepper crop was transplanted into the greenhouses on 5 August 2008.

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Once a week, over the course of the experiment (Table 1), we manually examined the temperatures of two fruits from each greenhouse, as well as the amount of moisture on the surface of the fruit. We examined green fruits approaching their final size. The evaluations were carried out before the thermal screens were rolled up, generally between 6:45 and 7:00 in the morning, and once per hour for the following three hours. The amount of moisture on the surface of the fruit was evaluated by hand and classified according to the following four levels: dry, moist, wet and very wet. Fruit temperature was evaluated using a laser-sighted IR thermometer that allowed the measurement to be focused on the desired area. The instrument was calibrated against a thermal camera (Fluke) and was sometimes calibrated against a cup of ice water.

Table 1. Dates of Temperature and Fruit Surface Moisture Evaluations
November 25
December 3
December 8
December 17
January 7
January 14
January 20
February 11
February 18
February 25
March 3

The tested systems are described below:

A. Greenhouse 5

This control simulated the basic, window-less greenhouse commonly used in the Arava. The roof of the building was covered with polyethylene sheets. The sides of the building were covered with 50-mesh screens to keep out insects.

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B. Greenhouse 2: Retractable Ceiling (Thermal Screen)

1. This ceiling was set up in the upper portion of the building, underneath the outer cover. It is made of impermeable, reflective sheeting that is flexible enough to allow for spreading and compression and provides 50% shade. We installed internal curtains made of this material to the retractable ceiling (thermal screen) that was spread out over the building when the system was activated and rolled back when its activity finished, unlike the upper screen, which was controlled by a computer. The internal curtains were rolled up and spread out by hand when the heat was turned off and on, respectively. The times for spreading out and rolling up the screens were determined weekly using a radiation threshold based on a measurement of overall external radiation; the threshold value was 100 W/m^2.
2. This sheeting is very resistant to the passage of heat and is air-tight. These qualities inhibit condensation on the sheets that make up the external cover of the greenhouses' roofs, and significantly inhibit the escape of heat from the greenhouse, because condensation is an excellent conductor of heat, causing significant heat losses and an especially large waste of energy.
3. The use of impermeable plastic sheeting can cause an increase in the level of humidity inside the building in the area in which the crop is growing, due to the significant decrease in the condensation of excess water on the roof of the building. This can be problematic when the building does not contain any drying technology.
4. Double curtains were hung around the perimeters of the buildings, in order to minimize the loss of heat from the buildings.

5. Through work conducted and observations collected last year under laboratory and commercial field conditions, it was found that use of the impermeable thermal screens led to savings of 50-65% in heating costs for heated growth structures.
6. In a previous study, thermal screens set up in unheated greenhouses preserved temperature differences of 2 to 4 degrees Celsius, as compared to the control. The larger the difference between the indoor and outdoor temperatures, the greater the contribution of the screens.

+7. The sheets of the screens were installed so that they fit together to form a tight seal. If the screens are not fit together tightly (overlapping one another), there will be a noticeable decrease in the efficiency of the screen system.

C. Greenhouse 3

The Agam system is based on a Ventilated Latent Heat Converter (VLHC). This device converts water vapor into liquid water, thereby releasing the latent heat present in the vapor. Two main blowers move the greenhouse air across pads that are coated with a film of liquid desiccant. The moisture present in the air condenses on the liquid. This condensation heats the liquid, and the warm liquid heats the air. In this way, the cold and humid air that enters the system exits as warm, dry air.

The liquid desiccant is diluted by the condensation. The VLHC regenerator removes the condensation from the desiccant. The liquid desiccant in the device is heated by a water heater that has a capacity of 50,000 kcal/h. The heated desiccant flows through a series of pads in a compact tower.

Water vapor is removed by air flowing in a closed loop across these hot desiccant pads. The humid air then flows over a series of cold water pads in a compact tower, and the moisture in the air condenses and heats the water in the tower. The heated water then flows into a radiator

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located below the blowers, through which the heat produced through the condensation in the regenerator is transmitted to the greenhouse air. Condensation is discharged from the cooling tower at a rate of 10-20 L/h.

In this way, the air in the greenhouse is heated twice: First, it is heated by the salt solution (desiccant) that absorbs the moisture in the air and releases the latent heat. Then, in the second stage of the process, the air that was dried and heated in the first stage passes through a radiator and absorbs the heat from the heater that was transferred to the salt solution, and from the salt solution to the heated water. The heat from the natural gas-powered heater is distributed throughout the greenhouse by the fans that are part of the drying device.

D. Greenhouse 9

In this greenhouse, we installed LPG gas-powered heater with an output capacity of 150,000 kcal that included a heat transfer device based on the flow of hot water through a metal pipe. In this building, we also installed a retractable ceiling and double curtains, like those installed in greenhouses 2 and 3.

Results

Retractable Ceiling (Thermal Screen)

The thermal screen improved the night-time temperature balance and, on average, provided an additional 2 to 3.5°C over the course of the night, without the addition of energy from any external (artificial) source (Figure 1). The thermal screen inhibited the emission of some of the IR radiation from the greenhouse. At times, the temperature in the area underneath the screen was more than 5°C higher than the temperature above the screen. These data prove the efficacy of the screen in preventing the loss of heat from the building. This increase in the temperature in the pepper crop will not improve crop yield because, in most cases, including in the Chatzeva region, these higher temperatures are still 5 to 7°C lower than the temperature needed for optimal fruit production. The main advantage associated with the use of thermal screens in this region is the protection that these screens provide against chilling and freezing damage. And, in this situation, the difference between indoor and outdoor temperatures can be large.

The fruits in this treatment were significantly wetter than the fruits in the other treatments (Figure 8). Moisture accumulated on the fruits, particularly in the first two hours after the screen was rolled up in the morning. Before the screen was rolled up, the fruit was dry, like the fruit in the heated treatments. A significant difference between the wetness of the fruits in the different treatments appeared only after this point. It is possible that if there had been significant condensation on the roof of the greenhouse, the fruit inside the building would have been wetter (Figure 8).

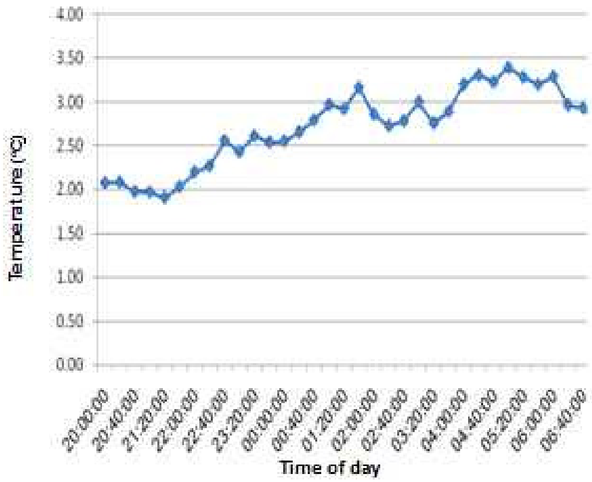

Figure 1. Average differences between the temperature in the building without a thermal screen (greenhouse 5) and the temperature in the greenhouse with a thermal screen (greenhouse 2) between 20:00 and 7:00, over 15 days between 15 January and 15 February, 2009.

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Agam System

This system addresses the issue of humidity in the greenhouse, as well as the issue of energy savings in the heating of the greenhouse. Unlike other heating systems that are based on the use of a heat transfer device to heat water by convection, in this system, the convection occurs via air that is distributed by the fan that is part of the drying device that brings warm, dry air into the greenhouse. In this way, the system is also able to dry the inner portion of the greenhouse roof.

A layer of condensation collects on the roof of the greenhouse, particularly during the overnight hours, due to the large difference between the temperature on the surface of the warm greenhouse and the cold air. This layer of condensation is one of the main causes of the loss of heat from the building, because this same layer of condensation causes the (excellent) transfer of heat from the greenhouse to the outdoors and, in this way, heat escapes from the building. The Agam system minimizes this condensation; this is one of the ways in which it provides energy savings. The system functioned properly throughout the experiment, without any technical problems. The Agam system aided the reduction of the humidity in the building (as can be understood from the data presented in Figures 2 and 3). Until 2:00 a.m., the activity of the Agam system reduced the RH by 6-7% and reduced the possibility of moisture accumulating on the fruit by increasing the difference between the temperature in the greenhouse and the dew point. This is very significant, because free water on plant organs is a catalyst for canopy diseases that appear under moist conditions.

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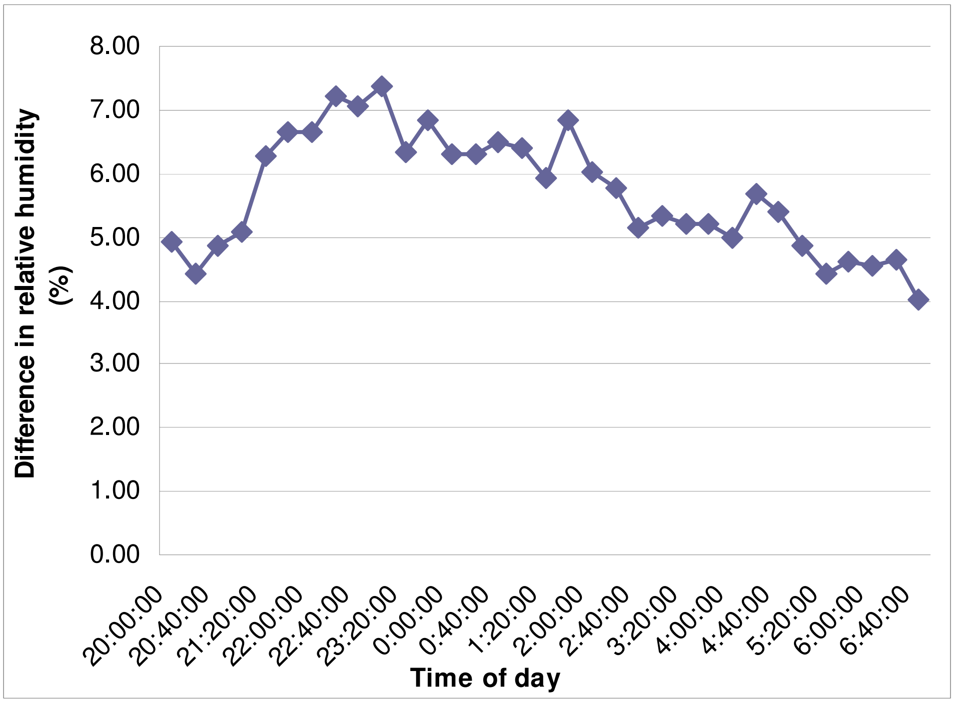

Figure 2. The average differences between the relative humidity (% RH) in the greenhouse heated using the hot-water system (greenhouse 9) and the RH in the greenhouse in which the Agam system was used (greenhouse 3). These data indicate that the RH in the greenhouse in which the Agam system was used was lower than that in the greenhouse heated using the hot-water system at different times of day. These data are averages for the hours between 20:00 and 7:00 for the following dates: Jan. 19, 23 and 27 and Feb. 3, 4, 16, 20, 23, 24, 27 and 28, 2009. These dates were chosen because, on these dates, the screens of the two greenhouses were in the same position (rolled up/spread out).

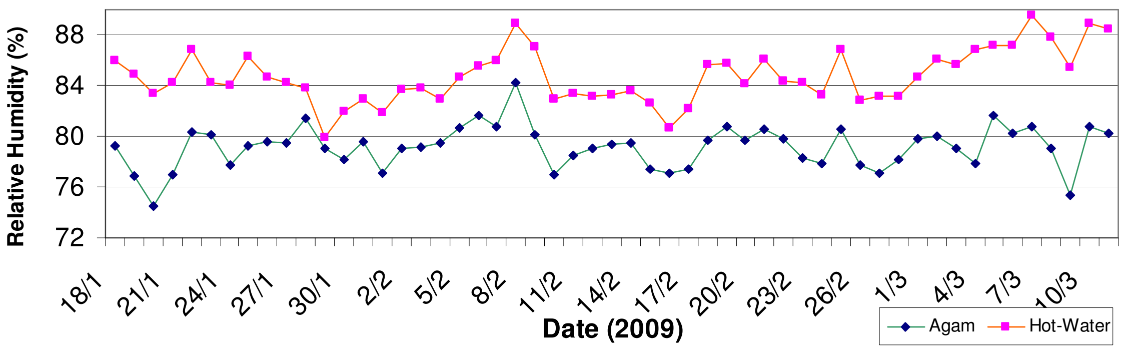

Figure 3. Comparison of the average relative humidity during the night-time hours in the greenhouse heated by hot water (pink) and the average RH during these hours in the greenhouse equipped with the Agam system (blue).

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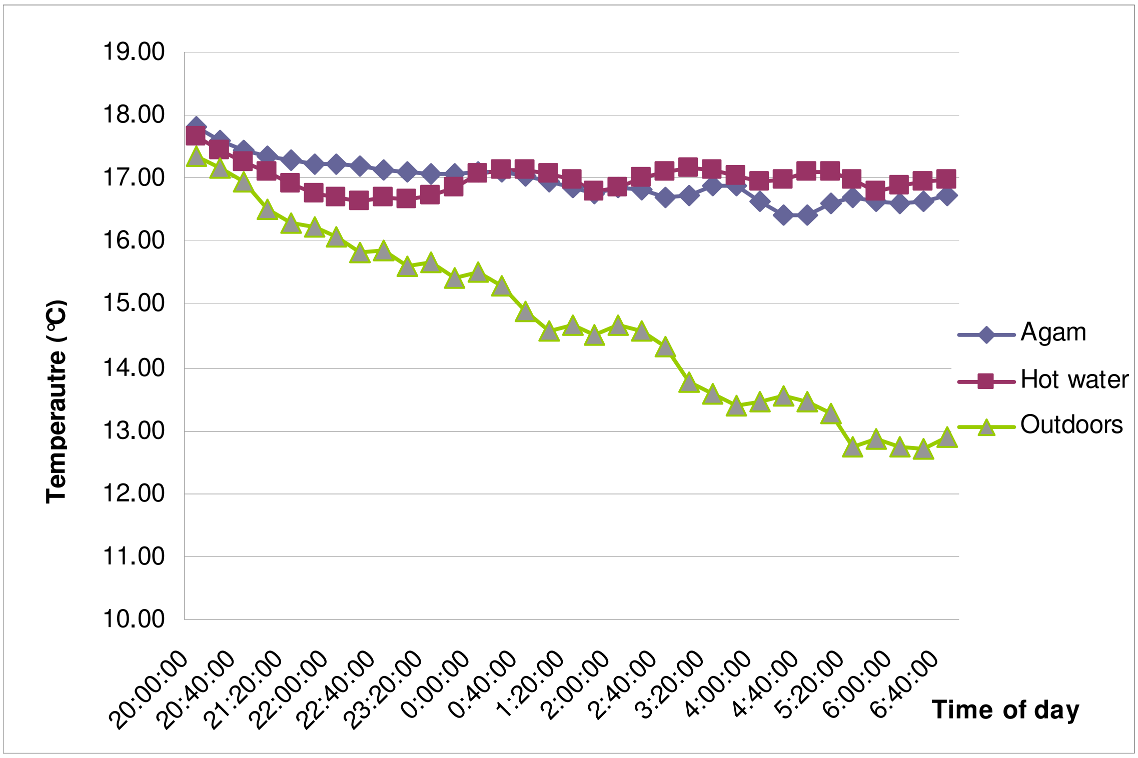

Figure 4. Comparison of the average air temperatures outside the Agam greenhouse (greenhouse 3) and those outside the greenhouse heated using the hot-water system (greenhouse 9). The data are averages for the hours between 20:00 and 7:00 on the following dates: Jan. 19, 23 and 27, and Feb. 3, 4, 16, 20, 23, 24, 27 and 28. These dates were chosen because, on these dates, the screens in the two greenhouses were in the same position (rolled up/spread out).

Energy consumption- The comparison of the energy consumption in the Agam greenhouse and the amount of energy consumed in the greenhouse heated using the hot-water system is presented in Figure 5. The average heat loss for the Agam greenhouse (greenhouse 3) is given by the transfer coefficient of $3.53\ W/(m^2 \cdot °C)$, as compared to $8.7\ W/(m^2 \cdot °C)$ for the hot-water heating system. The relationship 3.53/8.7 = 40.6% expresses the amount of energy consumed in the greenhouse equipped with the Agam dryer, as compared to the amount of energy consumed in the greenhouse heated with hot water. Heating with the Agam unit provided a 59.4% savings in the amount of energy consumed, as compared to the energy consumption in the greenhouse heated using hot water (see Figure 5). It should be noted that

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last winter was warmer than average and the heating systems did not need to work at their full capacities. The greenhouses needed to be heated to about 4 degrees above the outdoor temperatures (Figure 4), while these systems are capable of reaching much greater differences.

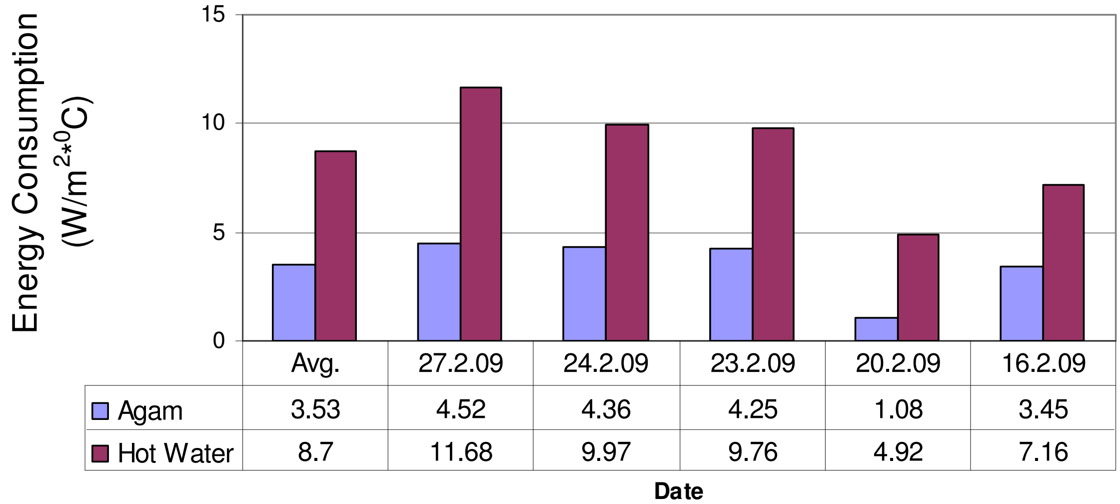

Figure 5. Energy consumption in the Agam greenhouse (drying heat), as compared to energy consumption in the greenhouse heated using hot water.

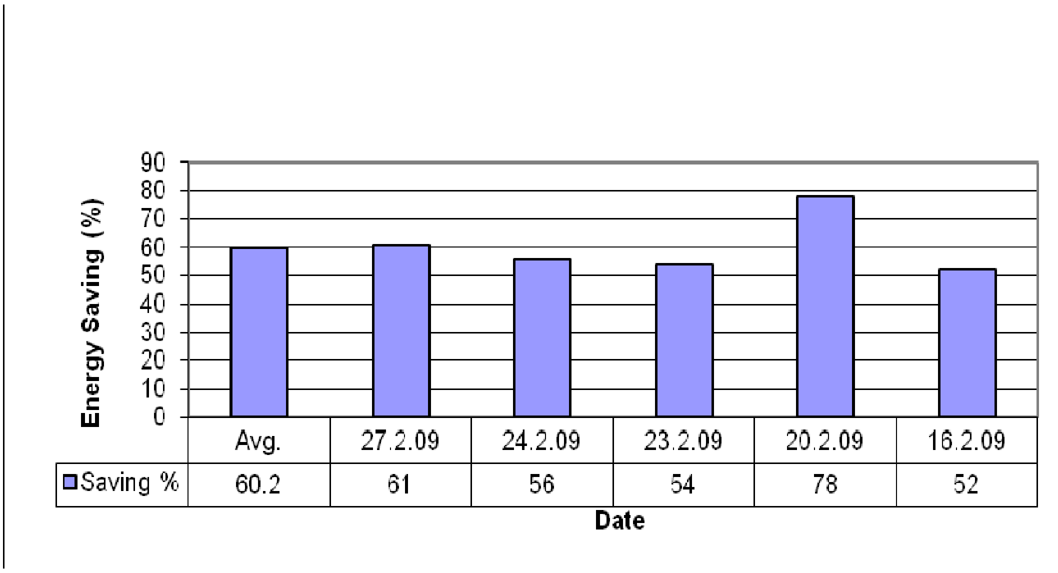

Figure 6. Energy savings (%) in the Agam greenhouse, as compared to energy use in the greenhouse heated using hot water, at different dates.

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Monitoring Fruit Surface Moisture and Temperature

The goal of the evaluation was to determine whether the relationship between fruit cracking and greenhouse technology would vary in response to the different climatic conditions associated with the different tested technologies. The problem of the cracking of the sides of pepper fruit is usually observed in the Arava in the spring, beginning in February. This cracking reduces the quality of the fruit. The problem appears when the difference between day-time and night-time temperatures becomes significant, and a thin film of water is present on the fruit as a result of increased temperature and humidity in the building, as compared to the relatively cooler temperature of the fruit in the morning (Figure 7). In this way, a layer of condensation is produced, which appears to encourage the formation of cracks. It should also be noted that the fruit that is harvested in February and March is fruit that was formed in October and November. These fruits are 90 to 100 days old. Old fruit is sensitive to weather changes, humidity and condensation that forms on it. The protocol for this evaluation is detailed in the Technologies section. It should be noted that, for a few of the initial observation points (at 7:00 a.m.), the heating systems and thermal screens had not yet been activated and the obtained results describe a situation in which this equipment was not in use.

Fruit temperature: Figure 7 presents a comparison between air temperature and fruit temperature at certain time points. These data point to a large difference between the temperature of the fruit and the temperature of the air, which decreased over time until, at three hours after the thermal screens were opened, the fruit and air temperatures were equivalent. The largest difference was observed for the first evaluation, which took place at 7:00, before the screens were rolled up. At this point in time, the difference between the temperature of the cold fruit and the air temperature reached approx. 5-6°C. The coldest fruit

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was found in the unheated, control greenhouse; the temperature of this fruit was approx. 5°C. In greenhouse 2, which was covered with a thermal screen, but was not heated, the temperature of the fruit was 7°C. The temperature of the fruit in the Agam greenhouse was 11°C, and the temperature of the fruit in greenhouse 9, which was heated using the hot-water system, reached 13°C. That is, the temperature in greenhouse 9 was two degrees higher, even though the air temperatures in the two greenhouses were the same at this time. It is very possible that this difference was due to the way in which heat was distributed in the greenhouses. While the heat in the Agam greenhouse traveled from the top of the greenhouse downward with the flow of hot air, the heat transfer devices of the hot-water heating system were located near the ground, so that the heat was distributed from the ground upward and the heat source was closer to the examined fruit. This appears to explain the difference in fruit temperatures.

The fruit in greenhouse 5 (control greenhouse) was consistently cooler than the fruit in the other greenhouses. This corresponded to the low air temperatures observed in this greenhouse both during the day and at night.

Moisture on the fruit: During the first hour of the evaluations (Figure 8), the fruits in all of the treatments were dry (Wetness level 1). The differences in wetness first appeared during the second hour after the screens were opened. The wettest fruit was found in greenhouse 2, which had a thermal screen, but no heater (Figure 9). The characterization of the relative moisture levels of the different treatments showed that this greenhouse was consistently the most humid. The control greenhouse (greenhouse 5), in which the driest fruit was found, was, of course, also the best ventilated greenhouse. The collected data (Figure 9) clearly show that the RH in greenhouse 5 was low.

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It is possible that one of the reasons for the dry conditions in greenhouse 5 (the control greenhouse) was the low-level activity of the plants in this building. In contrast to the situation in the other greenhouses, there was no activity at the meristems of the plants in this greenhouse, as a consequence of the low temperatures in this building. Whereas, in the other greenhouses, we consistently observed young, vigorous growth accompanied by high levels of transpiration, which influenced the RH in those greenhouses.

The fruits in the heated greenhouses had similar levels of surface moisture at the first evaluation point. But, later on, the fruit in the Agam greenhouse was wetter than the fruit in the greenhouse heated with hot water, despite the fact that the Agam greenhouse (greenhouse 3) was less humid, at least until 8:00. The reason for this is hidden in the fact that the temperature of the fruit in this greenhouse was lower than that of the fruit in the greenhouse heated using hot water. (The reason for this is explained in the previous section discussing temperature.) The combination of cold fruit, increasing humidity and increasing temperature led to the formation of condensation of the surface of the cold fruit (Figures 7 and 8).

Within the framework of the experiments conducted this season, we did not examine the possibility of leaving a building closed and using the Agam device to dry it out. This possibility should be examined in the coming growing season. This possibility should be tested because, in the third hour (Figures 7 and 8), the amount of moisture on the fruit decreased, and the humidity in the building decreased as well (Figure 9). Meanwhile, the fruits in greenhouse 2 (thermal screen only) remained wetter than the fruits in the other greenhouses.

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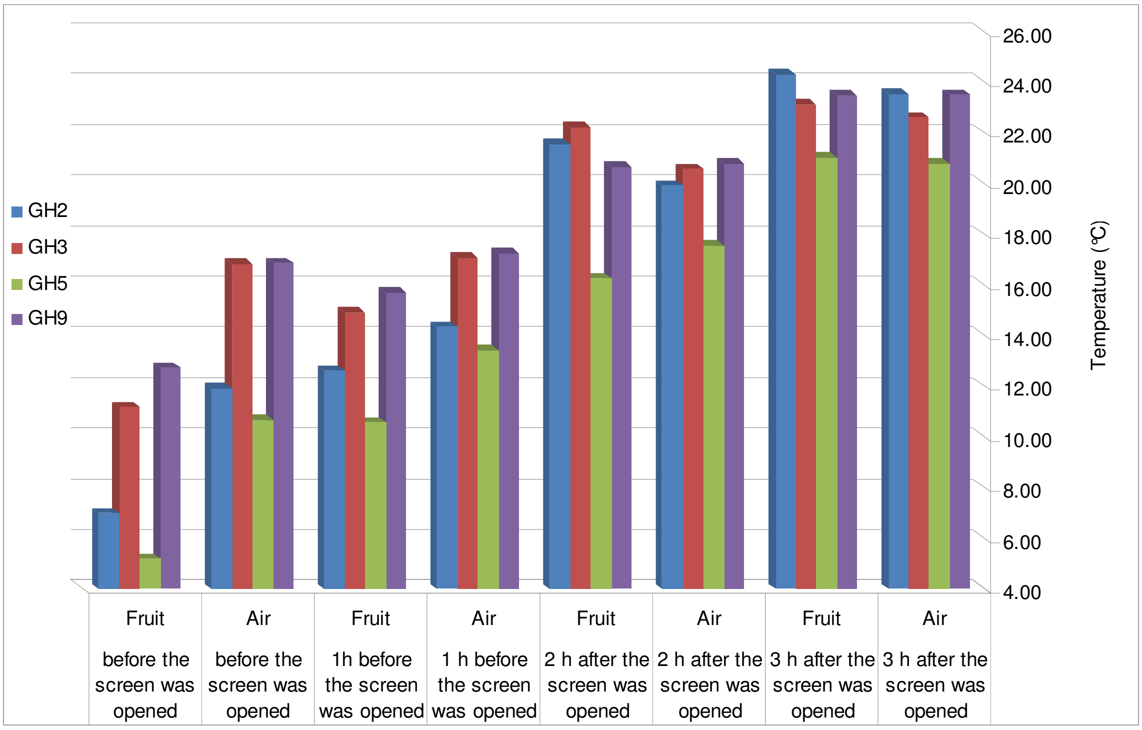

Figure 7. Fruit temperature and indoor air temperature. (Data were collected on the dates listed in Table 1.) Data were collected at four different time points during the morning. The first set of data was collected before the thermal screens were rolled up, and the rest of the data were collected over the next three hours.

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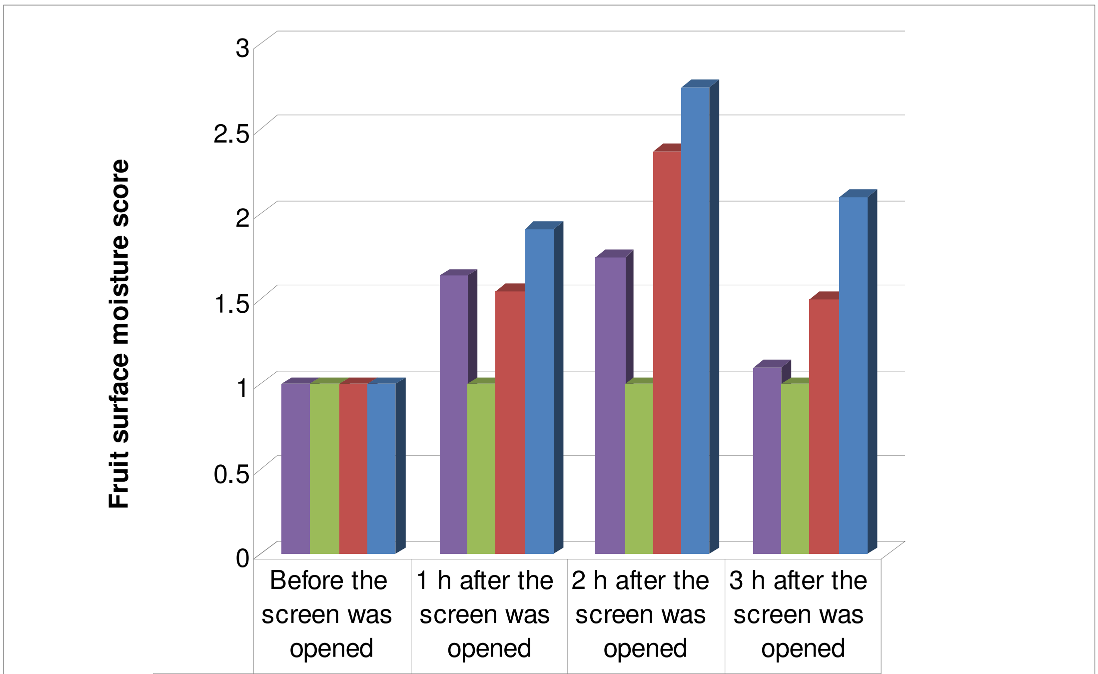

	Before the screen was opened	1 h after the screen was opened	2 h after the screen was opened	3 h after the screen was opened
GH 2	1	1.91	2.75	2.1
GH 3	1	1.55	2.37	1.5
GH 5	1	1.00	1	1
GH 9	1	1.64	1.75	1.1

Figure 8. Comparison of the levels of moisture on the surfaces of the fruits. (Data were collected on the dates listed in Table 1.) 1- dry fruit; 3- wet fruit. Data were collected at four different time points during the morning. The first set of data was collected before the thermal screens were rolled up, and the rest of the data were collected over the next three hours. (During these hours, neither the Agam system nor the heating system was running.)

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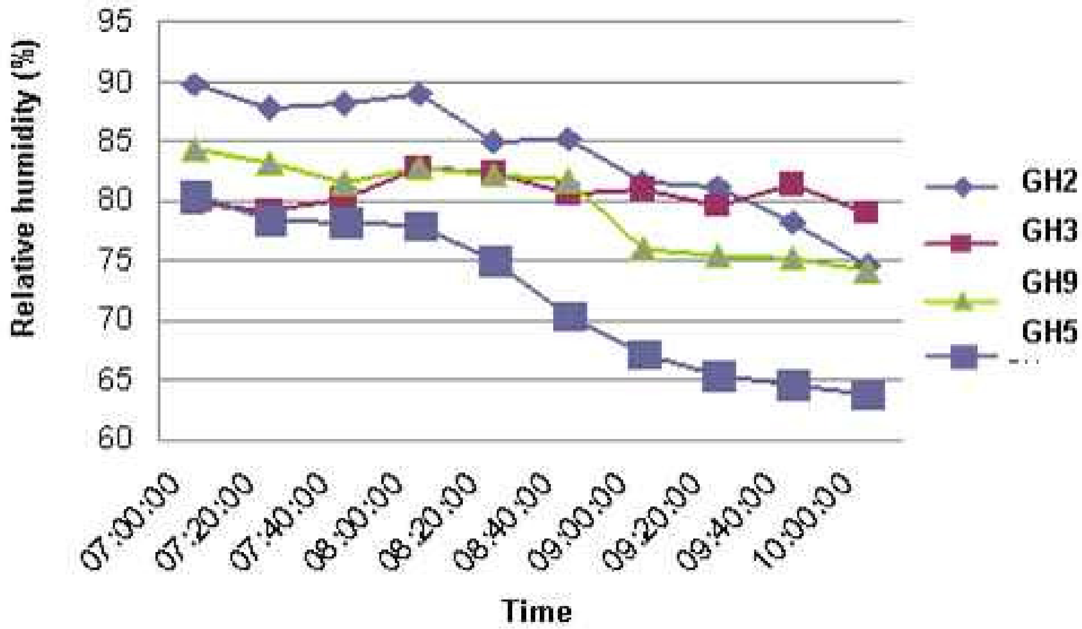

Figure 9. Average relative humidity (%) in the different greenhouses at the time of the manual evaluations of fruit temperature and surface moisture.

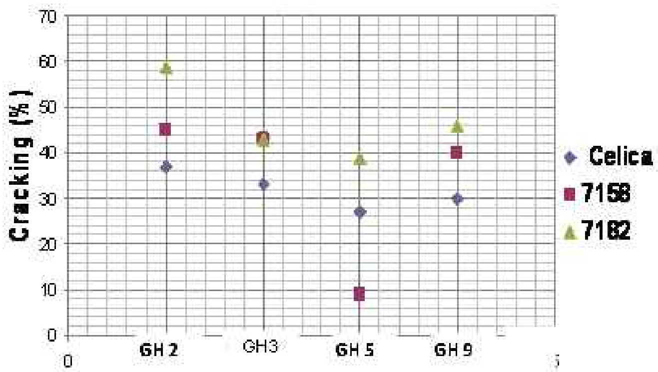

Figure 10. Seasonal fruit-cracking averages in the different greenhouses for the three cultivars Celica, 7158 and 7182. GH 2: thermal screen; GH 3: Agam system; GH 5: control; GH 9: hot-water heating.

In light of the data shown in Figure 10, it can be understood that there was a difference between the amounts of fruit cracking observed in the different cultivars, and this cultivar effect was greater than the effect of the different treatments. Of the examined cultivars, cv. Celica was the most resistant to cracking and cv. 7182 was the most susceptible. The cultivar

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7158 displayed an intermediate level of susceptibility to cracking. However, in the control greenhouse, 7158 displayed the least cracking. Similar levels of fruit cracking were observed in the greenhouse heated using the Agam system and the greenhouse heated by hot water. Despite the fact that the fruit in the Agam greenhouse was much wetter, there was no difference between the amount of cracking observed in the Agam system and the amount observed in the greenhouse heated using hot water.

Conclusions

1. The thermal screen improved the night-time temperature balance and, on average, increased the temperature inside the greenhouse by approx. 2-3°C over the course of the night, without the use of additional energy from any external (artificial) source. This contribution was accompanied by an increase in the humidity inside the building, which increased the cracking of the pepper fruits.
2. The Agam system provided an average energy savings of 60%, as compared to the commonly used hot-water heating technology. Both of these systems involve the use of thermal screens.
3. The RH in the greenhouse heated using the Agam system was lower than that in the greenhouse heated using the conventional hot-water technology. This difference will increase the more tightly the building is sealed.
4. The cultivar Celica is the most resistant to cracking, and the amount of cracking observed on these fruits was lower than that observed for the other cultivars. Of the examined cultivars, 7182 is the most susceptible to cracking. The highest level of cracking was observed in the greenhouse equipped only with a thermal screen. This

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corresponds to the amount of moisture observed on the fruit in this greenhouse and the high humidity in this building, as compared to the other greenhouses.

5. We recommend that the heating systems be tested in an additional season, in order to characterize their effects on the distribution of heat and moisture in the greenhouse. We should examine the performance of the heating systems over a colder winter, as this past winter was quite mild.

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