Greenhouse Cooling?

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There has been a great deal of interest in greenhouse cooling in the past three or four years, along with many conflicting reports about which of the many cooling systems was the best. It appeared that one of the problems was that these various cooling systems had never been compared under equal conditions of temperature and relative humidity. Another major problem existed and that was whether greenhouse cooling would be profitable to install under New York State conditions.

This experiment was designed to answer the two big problems—1. Which cooling system was the best and 2. Is greenhouse cooling profitable for New York State conditions? Both of these questions could be answered in one sentence from the experiences that we have had over the past two summers; however, some of the results should be reviewed so you can see the basis for our conclusions.

Most all of these cooling systems use evaporation of water as their cooling mechanism. Evaporative cooling has been used for many years by people living in extremely hot and dry areas to cool their homes. The principle on which evaporative cooling works is when unsaturated or dry air passes through wet media, water is evaporated. Heat energy is necessary to evaporate water (approx. 580 calories of heat to evaporate 1 gram of water) and this heat is obtained from the air. Therefore, when dry air passes through the wet media water is evaporated and heat removed from the air, thereby, cooling the air. The more water that can be evaporated by a given unit of air the cooler the air.

It is possible to measure the cooling limits of air by using wet and dry bulb thermometers. The dry bulb thermometer measures air temperature and the wet bulb thermometer measures the minimum temperature that the air can be cooled. The wet bulb reading at any given temperature varies with the amount of water that is already present in the air. If the relative humidity is high (air almost saturated with water) only a slight amount of water will evaporate and the wet bulb depression will be small. In cases where the relative humidity is low (air very dry) water evaporates rapidly and in large quantities and the wet bulb depression will be large. If we consider the wet bulb depression as a cooling potential then the drier the air the greater the cooling potential and also the warmer the air the greater the cooling potential. See

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Table 1 which shows the cooling potential of several different air temperatures and relative humidities.

Table 1. The cooling potential or maximum amount of cooling that could be obtained by evaporation at three air temperatures and three relative humidities.

Temperature	10% RH	50% RH	96% RH
60°F	18.5°F	9.5°F	0.5°F
80°F	27.0°F	13.0°F	1.0°F
100°F	36.0°F	16.0°F	1.0°F

The cooling systems, as we shall see later, differ only in that they vary in the method of making the water – air contact. The problem would be complete if it were just necessary to cool the air coming into the greenhouse; however, the sun is literally "pouring" heat into the greenhouse. On a bright summer's day the sun is applying about 300 BTU's per hour per square foot. It was estimated by Harold Gray that only about a third of this energy is affecting the temperature of the greenhouse. The other two thirds are reflected by the glass and absorbed by the plants and ground. These cooling systems must, therefore, not only cool the outside air entering the greenhouse, but also remove the heat that the sun is applying to the greenhouse.

In this experiment a number of cooling systems and combinations were run. Each of these cooling systems will be briefly described. The temperatures in each of these systems were carefully recorded and the results will be shown in the next section.

Natural Ventilation: This was the check system. For this system both the top and side vents were wide open allowing as much air as possible to pass through the compartment.

Low Pressure Mist: For this system the vents again were open wide. The mist nozzles were so located that with any one application of water the whole area of the greenhouse was covered with a film of water. The timing used in this particular setup was 10 seconds of mist every 5 minutes and the water pressure was about 80 pounds per square inch (psi).

Low Pressure Mist and Fan: The low pressure mist was also run in combination with a fan on one wall. All of the vents were closed except the side vent opposite the fan. The fan (rated to move 7.5 cubic feet of air per square foot of floor area per minute) was in continuous operation and the mist operated the same as above, that is, 10 seconds every 5 minutes.

Pad and Fan: For this system all vents were closed. The air was pulled by a fan (rated to move 7.5 cubic feet of air per square foot of floor area per minute) into the greenhouse, through a saturated (wet) pad, across the greenhouse and out the opposite side.

Outside Nozzles and Fan: This was a modification of the pad and fan system. The vents were all closed except the side vent opposite the fan (rated the same as for the pad and fan system). Instead of passing the air across the pad it was passed throught a constant mist of water. Mist nozzles were placed in the side vent and were in constant operation. Cheesecloth was placed on the inside of the vent to prevent any excess water from entering the greenhouse.

High Pressure Fog: In this system nozzles were placed uniformly in the greenhouse about 10 feet from the floor. The nozzles were spaced at the rate of one nozzle per 75 square feet of floor area. A pump was installed to give a water pressure of 450 to 500 psi. The control was by humidistat and when the relative humidity dropped below the setting on the humidistat the system turned on and when the relative humidity went above the setting it stopped. All of the vents were open. There were three high pressure fog systems used in this experiment.

High Pressure Fog—70-75%: In this system the humidistat was set so that the controls were operating at a relative humidity between 70 and 75 per cent.

High Pressure Fog—80-85%: The humidistat in this system was set to operate at a relative humidity between 80 and 85 per cent. This particular setting was high enough to cause many of the leaves and floor area of the greenhouse to be wetted similar to what would occur in the low pressure mist system.

High Pressure Fog—80-85% PLUS FAN: This system was run exactly the same as above except the air was being pulled across the greenhouse by a fan (rated to move 7.5 cubic feet of air per square foot of floor area per minute) in one wall and all of the vents, except the side vent opposite the fan, were closed.

Results

None of these houses were shaded and the temperature measurements were recorded from 8:00 am until 5:00 pm. Table 2 gives the results of the temperatures recorded for the summer of 1958.

Table 2. The adjusted mean air temperatures and the adjusted mean leaf temperatures recorded from 8:00 am to 5:00 pm for the various cooling systems during the summer of 1958. The average outside air temperature was 77.6°F and the average relative humidity was 58.4 per cent. The cooling potential was 10.5°F.

Cooling Systems	Air Temp.	Diff. out & inside temp.	Leaf Temp.
Natural Ventilation	84.4	+6.8	85.4
Low pressure mist	78.7	+1.1	77.7
Low pressure mist + fan	78.0	+0.4	76.5
Pad and Fan	74.1	—3.5	79.7
Outside nozzles + fan	77.7	+0.1	81.0
High pressure fog, 70-75%	80.4	+2.8	79.0
High pressure fog, 80-85%	78.5	+0.9	77.7
High pressure fog, 80-85% + fan	78.9	+1.3	78.8

The results given in Table 2 are adjusted figures. These figures have been obtained statistically from literally thousands of measurements. The outside air temperature (77.6°F) was the actual outside temperature last summer (1958) from the hours 8:00 am to 5:00 pm. This was recorded by a thermograph, hydro-thermograph and a thermocouple. The inside air temperatures for each of the cooling systems are the figures obtained from 4 thermographs, 2 hydro-thermographs, 6 thermocouples for the air temperature and 6 thermocouple units for the leaf temperature. These data were fed into an IBM computer and

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were statistically adjusted to the outside air temperature of 77.6°F. In other words, these figures will give a rather good indication of what could be expected with these systems.

Air Temperature:

It is possible to place these systems into three groups: 1) Natural ventilation (84.4°); 2) Low pressure mist (78.7°); low pressure mist plus fan (78.0°), outside nozzles plus fan (77.7°), high pressure fog 70-75% (80.4°), high pressure fog 80-85% (78.5°) and high pressure fog 80-85% plus fan (78.9°) and 3) Pad and fan (74.1°).

Natural ventilation represents the system that is being used and has been used for years. The pad and fan was outstanding, cooler than the natural ventilation (10.3°) and cooler than all the other systems. The pad and fan system was the only one which had a temperature below the outside air temperature. There were times when the pad and fan recorded temperatures 10 to 15 degrees below outside air temperature but the average temperature from all parts of the house from 8:00 am to 5:00 pm was 3.4° cooler than the outside temperature. With this system, more than any others, there were greater differences within the house. At the pad side it would be one temperature and at the fan side it would normally be 8 to 10 degrees warmer. However, all of this has been taken into account and averaged in the reported figure.

Leaf Temperature:

The various cooling systems do not cool the leaf temperature the same as they cool the air temperature. This can be explained by the fact that the coolest leaf temperatures were obtained in the systems that had a film of water on the leaves: the low pressure mist, low pressure mist plus fan and the high pressure fog 80-85%. In these systems the water evaporated from the leaf surfaces and not only was heat removed from the air but also from the leaf. The other cooling systems all had leaf temperatures that were cooler than the natural ventilation treatment but warmer than their air temperatures, (except the high pressure fog 80-85% plus fan which had a leaf temperature (78.8) just about the same as the air temperature (78.9°). The two low pressure mist systems and the high pressure fog 80-85% had leaf temperatures that were appreciably cooler than their air temperatures.

Which is the best Cooling System?

Although the information given by the leaf temperature measurements is interesting its value is presently only academic. The plant temperature should be the most important item to consider; however, there has been too much resistance to the system "which keep the plants wet." There are a number of valid reasons for not using these particular systems for the whole greenhouse. There are problems with leaching nutrients from the soil and probably the biggest problem is the workers; it is very uncomfortable to work under these conditions. The system which under our conditions produced the coolest air temperatures was the pad and fan system.

Now that the various cooling systems have been re-