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IN COOPERATION WITH COLORADO STATE UNIVERSITY
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Bulletin 238

March 1970

Temperature and humidity observations in CSU greenhouses

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The recent work by Carpenter and Bark (1) has shown that temperature patterns within greenhouses cannot be considered as stable. Patterns may become very complicated depending upon type and arrangement of the heating system. Installation of newer systems with constant circulation may increase temperature variations, requiring considerable effort by the grower to correct undesirable responses. Observations made at CSU suggest that the trombone, modulating pipe heating system remains as one of the better systems in terms of minimum temperature fluctuation, with the cooling system operating on separate thermostats. Carnation temperatures usually vary from the air temperature, the differences quite often becoming significant, depending upon solar radiation levels and outside air temperatures, as well as greenhouse cover and wind movement.

Methods

The observations reported here were made in conjunction with water-loss studies. During 1967-68, wet and dry bulb temperatures were measured at 10-minute intervals in various locations in an east-west oriented, glass covered greenhouse with dimensions of 36x42 feet. In 1968-69, identical measurements were made in a north-south oriented, fiberglass covered greenhouse with dimensions of 30x120 feet. The glass house was separate, attached to a central corridor on its east end. The fiberglass range was actually 2 ridge-and-furrow houses with measurements restricted to the east house. Fig. 1 shows the locations of the various thermocouple stations. Each

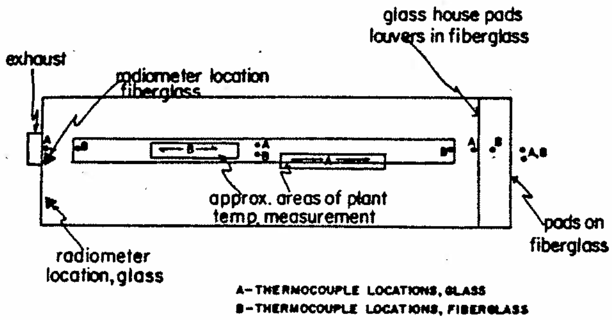

Fig. 1. Thermocouple arrangement in glass and fiberglass greenhouses. Distance between B's, ends of bench, 105'. Distance between A's, fan to pad, 41'.

wet and dry thermocouple was located in a shielded, aspirated snelter at bud height. An infrared thermometer was focused on an area of the bench in order to obtain an average value of the actual plant temperature. The south side of the east-west bench was measured in the glass house, the top of the north-south bench in the fiberglass house.

The glass house was heated by peripheral and overhead, trombone, steam pipe, controlled by a pneumatic, modulating thermostat set to operate from off to full heat over a 3° range around 60°F. Cooling operation was controlled electrically by two thermostats, one set at 65°F, the other set to operate the second of two exhaust fans at 68°F. Cooling air for the house, during cold weather, was brought in through a polyethylene tube. On demand for additional air, the corridor ventilators were raised to allow 'ull flow through the evaporative pads. Water was upplied to the pads when outdoor air temperature reached 56°F.

The fiberglass greenhouse incorporated a modified system of air control. The purpose was to permit humidification of incoming air during spring and fall when outside air temperatures were otherwise too low to permit pad operation. This would tend to reduce water stress during an otherwise excellent period for maximum growth in Colorado. The pads were located outside a louvered wall (Fig. 1). Water was run to the pads whenever temperature was high enough to avoid freezing on the pads. Control of heating and cooling was from a single thermostat, operating through a stepping, modulating system over a 10° range. Whenever some outside air was required, it was first humidified and then distributed through a 36-inch polyethylene duct extending the length of the greenhouse. With greater demand, the system operated to open the louvers in graduated steps. Heat was provided by gas-fired, overhead, modular units, blowing horizontally in one direction on one side of the greenhouse and in the opposite direction on the opposite side. At the equilibrium point, when neither heat nor cooling was required, two of the heater fan motors at opposite ends of the greenhouse remained in operation.

The data, obtained at 10-minute intervals, were subjected to a moving mean, smoothing process. In plotting, individual measurements were selected at 30-minute intervals. A total of 15 days was recorded under various conditions in the fiberglass house, 14 days in the glass house, and from these a few selected as representative of the existing conditions.

Observations and discussion

Comparisons between glass and fiberglass were made under similar conditions of total inside radiation and outside temperatures in Figs. 2 and 4. In each figure, part "A" is the <u>difference</u> between mean plant temperature and air temperature at the center of the bench, with positive values indicating a higher carnation temperature than air temperature. Part "B" indicates the temperature <u>differential</u> between exhaust fan and evaporative pad, positive values showing a higher fan-end temperature than pad-end. Part "C" shows the total inside, shortwave, solar radiation as measured with an Epply pyranometer; and part "D" is the actual air temperature, midway between pads and fan, at the center of the bench.

A number of observations were made.

Air temperature

The modular heating system in the fiberglass house resulted in greater variation in air temperature, even under supposedly stable conditions of low radiant energy and below freezing temperatures outdoors. Under similar conditions (Fig. 2, Part D) the steam system brought the air temperature up to the required value and maintained it with reasonable consistency. As cooling requirements increased (Figs. 3-4), air temperature variations increased in both glass and fiberglass houses. However, where the glass house temperature showed a steady rise, the fiberglass air temperature was lowered considerably below the desired level. Under high heating load and low radiation level, the opposite occurred, with the air temperature occasionally exceeding 74°F. In both comparisons, the thermostats were shielded and aspirated. The temperature variations from the set point under fiberglass probably resulted from the stepping mechanism employed and the wide temperature range (10°) that was necessary to avoid undesirable oscillation of the control system. The problem of flushing of white carnation varieties has been observed in the greenhouse, and it appears that the system should be modified.

Pad-to-fan temperature variation

Under conditions of high heat load and low solar radiation (Fig. 2, part "B"), temperature variations from one end of the greenhouses to the other were not remarkable, although the fiberglass greenhouse had a greater variability. As radiation load and outside air temperature increased, calling for occasional exhaust fan operation, the fan-ends tended to rise in temperature above the pad-ends. Under high radiant heat loads and moderate outdoor temperatures, the differentials in both houses were sometimes extreme. For example, in the short distance of 41 feet, the differential in the glass house exceeded 18° during the noon period (Fig. 4). Outside air temperature was between 60° and 65°F with intermittent pad operation. With low outside relative humidity, cooling by the wet pad was extreme.

A significant longitudinal temperature rise under similar conditions might be expected in the 105 feet between thermocouples in the fiberglass house. However, the outside air temperature was about 10°F lower on March 26 than on March 17. This, coupled with a high air volume required to remove the radiant heat load, resulted in louver operation. The 36-inch duct was not adequate, with the result that the pad-to-fan temperature differential sometimes exceeded 10°F.

Both glass and fiberglass present (Fig. 4) the classic situation often encountered where large volumes of cold air cannot be rapidly and efficiently dispersed through the greenhouse without extreme temperature differences. This suggests that higher capacity ducting should be installed, resorting to direct pad-to-plant operation when outside air temperatures are above 70°F during the summer.

Plant-to-air differences

With low light conditions and high heat load, plant temperatures were usually less than the air temperature. Under glass, this meant that plant temperatures were about 58° to 60°F as contrasted to an air temperature of 60° to 62°F during the conditions illus-

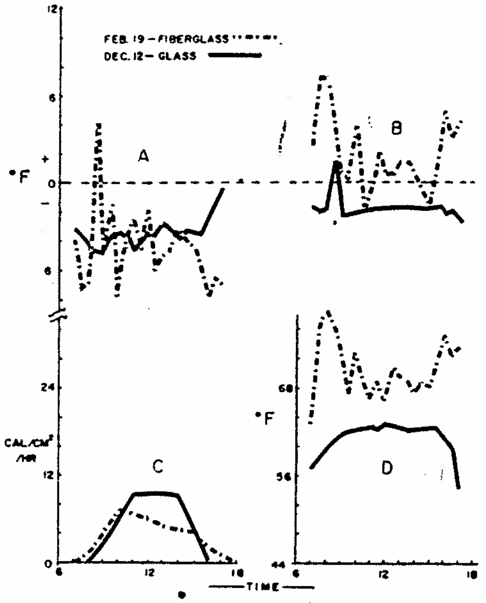

Fig. 2. Air and plant temperatures in glass and fiberglass greenhouses under conditions of low solar radiation, and outdoor air temperatures below freezing.
Part A. Plant-to-air differences, positive indicating plant temperature higher than air temperature.
Part B. Evaporative pad-to-exhaust fan differences, positive indicating exhaust end temperature higher than pad-end air temperature.
Part C. Total shortwave solar radiation within the greenhouse.
Part D. Air temperature midway between bench ends at bud height.

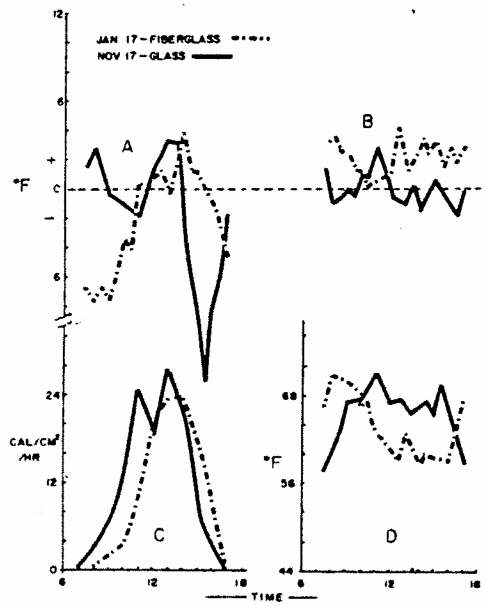

Fig. 3. Air and plant temperatures in glass and fiberglass greenhouses under conditions of moderate solar intensity and outside air temperatures ranging from slightly below freezing morning and evening to the low 40's during midday. See Fig. 2 for description of parts A, B, C and D.

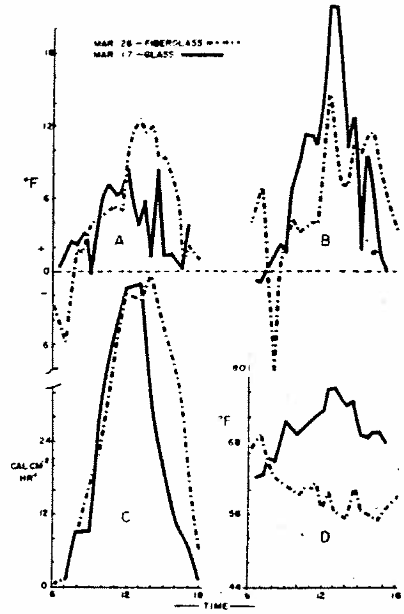

Fig. 4. Air and plant temperatures in glass and fiberglass greenhouses under high solar intensity with outside air temperatures ranging from the high 40's to middle 60's. See Fig. 2 for description of parts A, B, C and D.

trated in Fig. 2. In fiberglass, plant temperature varied more widely, usually between 64° to 71°F even though air temperature occasionally exceeded 74°F. The lower plant than air temperatures in both cases probably arose from thermal radiation of heat from the carnations to the cold roof.

As radiation load increased, there was an increasing tendency for plant temperatures to exceed the air temperature (Figs. 3 and 4). This also occurred with increasing outside air temperature. The outside air temperatures presented in Fig. 2 were consistently below freezing, those in Fig. 3 below freezing during the morning and evening hours, above freezing through the middle part of the day. On March 26 (Fig. 4), plant temperatures under fiberglass were sometimes 12°F above the air temperature. This had the effect of cancelling the low air temperature near 56°F. It is possible that fiberglass, which intercepts more radiation than glass, may tend to raise plant temperature more than what may be expected due to thermal radiation from the fiberglass to the carnation.

In any event, the results show that plant temperature may be seldom at the air temperature. A 1- or 2-degree difference may not be significant. But, from the standpoint of water loss, a 5- to 10-degree difference between plant and air for any length of time might be sufficient to adversely affect growth. As with work on flower temperatures, reported in Bulletin 226, we see that actual, mean carnation temperatures may deviate significantly from air temperatures, depending upon light intensity, outdoor air temperature, indoor air temperature, wind velocity and greenhouse cover. Unfortunately, data during maximum cooling periods and high outdoor temperatures were not obtained.

Relative humidity

Since both wet and dry bulb temperatures were obtained inside the greenhouses, it was possible to calculate relative humidities. Fig. 5 shows the results for the same periods as in Figures 2 through 4. Relative humidity in the fiberglass greenhouse was consistently higher than in the glass house. This probably resulted from the method of humidification, a tighter house, and production of water vapor by the CO_2 burners when the exhaust fans were off. These results suggest that under similar conditions, water loss from carnations grown under fiberglass would always be less than from carnations grown under glass. However, preliminary data indicate that water loss from carnations in fiberglass may equal that under glass. High water loss rates may be attributed to: 1) higher plant than air temperatures which cause water loss regardless of the relative humidity level, 2) lowered resistance to water loss from the leaf (CFGA Bulletin 233), and 3), higher wind velocities in the longer fetch of the fiberglass greenhouse, also decreasing the resistance to water loss. Attempts to reduce water loss by increasing relative humidities might not be worth the effort unless the other factors influencing water loss are adequately considered.

There is considerable information on individual features of greenhouse design, such as temperature variations, cooling and heating systems, light transmission and greenhouse coverings; but very little of this has been compiled into an integrated form whereby greenhouse construction actually takes into account the related processes of photosynthesis, water loss and plant temperatures. There is a need for a systems approach.

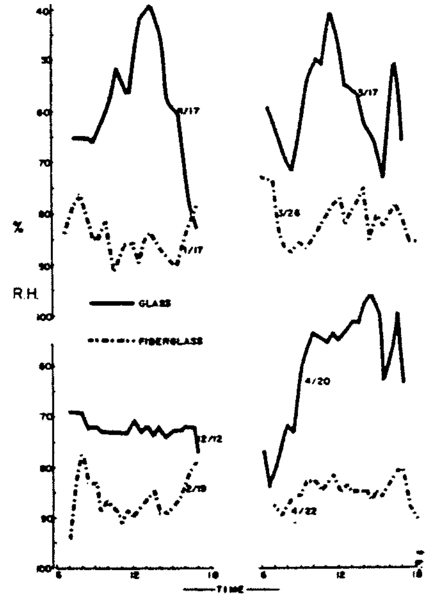

Fig. 5. Relative humidities in glass and fiberglass greenhouses for the same periods as given in Figs. 2 through 4. Values for midway between bench ends.

Literature cited

1. Carpenter, W. J. and L. D. Bark. 1967. Temperature patterns in greenhouse heating. Florist Review. 139(3613), Feb. 23.

Your editor,

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