Bulletin 461
November 1988

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research bulletin

Published by the Colorado Greenhouse Growers' Assoc., Inc. in cooperation with Colorado State University

Colorado State University

SUMMER GREENHOUSE CLIMATE IN COLORADO

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During the 1988 summer, extensive modifications in the Colorado State University computer controlled greenhouses permitted us to make some rather interesting observations on climate behavior during this period. Last Spring, 1987, we modified bench arrangement in each of the four, 20×50 ft, structures in order to approximate commercial conditions more closely (Fig. 1). Four of the five benches in each house were filled with non-wettable rockwool and one bench is soil in the ground, installed last winter. This Spring, we put a hot water system in House 2 (Fig. 1), and a second service will be installed Fall, 1988, in House 4, giving us two houses with hot water heating, and two with forced hot air. On August 1, two houses were set to humidity levels of 3 millibars vapor pressure deficit (mb, VPD)[1] and two others at 15 mb VPD. These values correspond approximately to relative humidity levels of 90-93 and 70-75% at rose temperatures of 72°F.

Carbon dioxide

CO_2 was injected at soil level in four benches, and sampling for analysis was taken from within the rose canopy of the fourth bed from the pads, about 4 ft above the soil level. A ten minute time delay for injection was provided at 2nd stage cooling since we found that injection during the cooling season immediately after the fans go off resulted in excessive CO_2 consumption. It was interesting to note that CO_2 concentration within a rose canopy during the main cooling periods will always be below the outside CO_2 level (**Fig. 2**) — sometimes as much as 5 Pascals or 60 ppm (340 versus 280 ppm). Outside CO_2 levels may vary from above 30 Pascal (357 ppm) to less than 27.5 Pa (327ppm). Under calm conditions outside CO_2 levels may exceed 400 ppm as the result of pollution in this area. Summer CO_2 injection for roses in Colorado will almost always occur in the early mornings and late afternoons with the present control system. No analysis or injection occurs at night, and all values are set to zero.

Despite high air intake of the cooling system, CO_2 can be deficient in the crop canopy during the summer and it is our belief that plant temperatures should be reduced as much as possible in order to avoid weak stems and poor quality roses. This accounts for the British effort to provide ambient CO_2 levels in greenhouse vegetables during their summers. However, most ventilation in Britain is by natural convection and, hence, the CO_2 consumption may not be excessive. We suspect, in large commercial rose ranges, the CO_2 deficit will be greater than in our small experimental houses.

Temperatures

Throughout the summer, 1988, we were always able to maintain average air temperature (average of three stations) well below 80°F during the day (**Fig. 3**), even though outside air temperature occasionally exceeded 95 F. It was not unusual to achieve 20 degrees F cooling through rigid fiber pads. The computer system was set so that if outside temperatures exceeded the inside, the cooling setpoint was reduced proportionally, tending to maintain inside air temperatures relatively low (an advantage with low CO_2 levels).

What was interesting was the fact that plant temperature was usually below the average air temperature during the main portion of the day (**Figures 3 and 4**). Sometimes the differential between canopy and air exceeded 10 degrees F. It was not until outside temperature began to approach the inside that plant temperature became more or less equal to air temperature. If air was being rapidly circulated in the greenhouse (**Fig. 4**), the plant temperature tended to remain below the air temperature to well within the night, especially since the circulated air would not be heated.

[1] VPD (vapor pressure deficit) is the difference between vapor pressure of the air at saturation (100% RH) and actual vapor pressure expressed in millibars.

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Under Colorado's cool morning conditions, the plant temperature could be above the inside air temperature, especially if the heating system came on.

The relationships between plant, inside and outside air temperatures will gradually change as the season progresses. This will be the first winter that we will have a hot water system, with natural convective air movement, to examine temperature relationships. Previous work at the Bay Farm (CGGA Bul. 408) showed that rapid movement of warm air will tend to raise plant temperature above the surrounding air, whereas cold air will decrease plant temperature below the surrounding air. The situation with a heating system which does not have forced air movement (below 10 fpm) is probably much different, and varies markedly with outside weather conditions.

Humidity

As indicated in Bulletin 460, the setting on a humidistat may have little or no effect on humidity in the greenhouse. If the setting is relatively high (80% or higher), a grower may be able to maintain that level, but the minimum (below 60% under Colorado conditions) will be determined by: 1) outside air temperature, 2) outside humidity, 3) water loss from the plants in the greenhouse, 4) the presence of evaporative pads which will add moisture to the air, and the type of heating and cooling systems installed. The result is that humidity in the summer, with evaporative fan-and-pad cooling, will generally be around 60% RH, very seldom going to 50% (**Fig. 5**). As shown in Bulletin 325, outside absolute humidity varies greatly with season, with the dew point going below the freezing point in the winter. Day-to-night variation in absolute humidity, however, will be slow and gradual, with very little difference (**Fig. 5**). The typical Colorado day-night temperature variation can cause relative humidity to change remarkably from above 70% at night to below 20% during the day. Preliminary work, reported in Bulletin 442, showed that a heavy heating load with a hot-air system can force humidity down to nearly 20% RH at night inside the greenhouse. Of course, the outside absolute humidity can be very low in the winter. The large differences one sees in percent relative humidity is more the result of temperature change than variation in absolute humidity (**Figures 5 and 6**).[2]

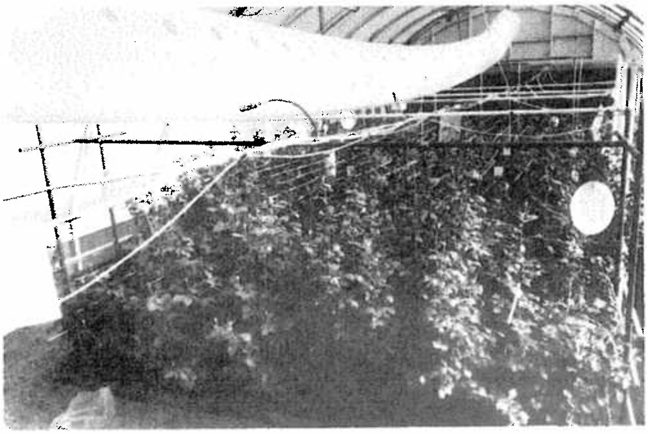
Another observation was the fact that relative humidity will increase to nearly 100% in a rose greenhouse, usually after midnight (**Fig. 5, 6**). How close to 100% is determined by the outside temperature and heating system operation. In fact, the de-humidification system frequently operated during the summer in the early morning hours as the sun began to rise and the plants began to transpire. De-humidification in the Colorado State University system requires an outside absolute humidity lower than the inside — which is almost the invariable situation in Colorado — at which point an exhaust fan and first stage heat are turned on.

The situation with a cool crop such as carnations is entirely different. Air holds much less moisture at 52 F, 100% RH, compared to a rose temperature of 62 F. The absolute humidity, 100% RH, at 52 is about 13 millibars versus 18 mb at 62 as compared to 26 mb at 72 F. Secondly, the local climatic conditions (Southern California on the coast versus Denver) will also change the greenhouse pattern. What we have observed here is applicable only to our local conditions or similar climatic regions.

Some comments on disease and pest control

The environment we have imposed on roses in the Colorado State University greenhouses is severe in terms of potential for powdery mildew. A VPD of 3 mb approximates 90% RH at 72 F, with de-humidification at 0.5 mb VPD or about 98% RH. We have not had any trace of powdery mil-

[2] Relative humidity is a ratio between actual humidity and what the air can hold at saturation (e_a/e_s*100). Since e_s varies with temperature, relative humidity will vary even though e_a (absolute humidity) does not change.



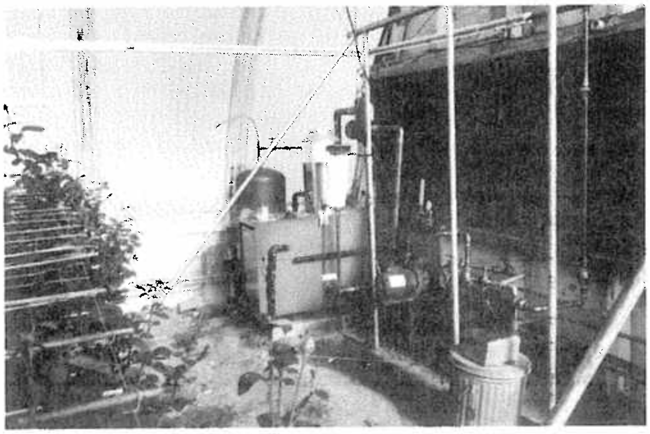


Fig. 1: *Left:* Interior of one of the four indentical greenhouses showing the new east-west benches with the yellow sticky traps arranged above the crop. We have installed a vertical, 55%, white shade cloth on the south side of the first bench in order to reduce the effect of southern exposure on the ground bench in the foreground. *Right:* Installation of the hot water boiler in House 2. This is a 206,000 BTU/hr output boiler, power vented, controlled between 180 and 200 F, with constant circulation through a 3-way, modulated mixing valve. An anticipation algorithm is in the software to turn on the boiler, based upon outside temperature, wind speed and radiation level. The mixing valve uses a non-linear algorithm that tends to return the average air temperature to the set-point. Three-quarter inch, fin tube radiation, 312 lineal feet, rated at 550 BTU/ft^2 at 180 F and 1 gpm, with lines under three of the rockwool benches, transfers the heat, with the hot-air system as a backup.

dew on 'Sonia', 'Royalty' or 'Red Success' this summer, largely due to two procedures: 1) The climate control system turns off the evaporative pads at an outside radiation level of 300 W/m^2, or when the outside temperature drops below 59 F. This allows the pad to dry out before sundown, and continued exhaust fan operation dries out the greenhouse before nightfall. This is one reason why humidities did not approach 100% until after midnight, even though the inside temperature was decreasing to the night setting. And 2), we utilized vaporized Morestan® with the dosage period for 6 hours at night, one frying pan per house (nearly 1000 sq.ft.).

We have not observed any red spider or aphids this summer, nor any thrips damage. As a supplement to Morestan® vaporization, we bought bright yellow, plastic picnic plates at the local supermarket, coated them with 90 ASE transmission oil, and installed them at the ends of each bench in each house at plant height (benches 12 ft long). The plates are wiped with paper toweling every two weeks and the oil re-applied. Thrips, fungus gnats, shore flies, plant bugs, winged aphids, etc. have been trapped, and we like to think that the use of such traps have played a significant role in eliminating insect damage. Spraying is presently limited to Orthene® every four weeks. Certainly we have reduced hazardous materials handling. Whether this practice would be suitable for a commercial establishment is open to discussion, but we think it worth looking into.

We are looking ahead to this winter for observation of greenhouse climate with two entirely different heating systems and radically different environments: no air movement versus rapid air circulation and high humidity versus a relatively low humidity. We suspect the differences will be easily observable, especially as to natural gas consumption.

Acknowledgements

This work has been supported by the American Floral Endowment and the Colorado Agricultural Experiment Station.

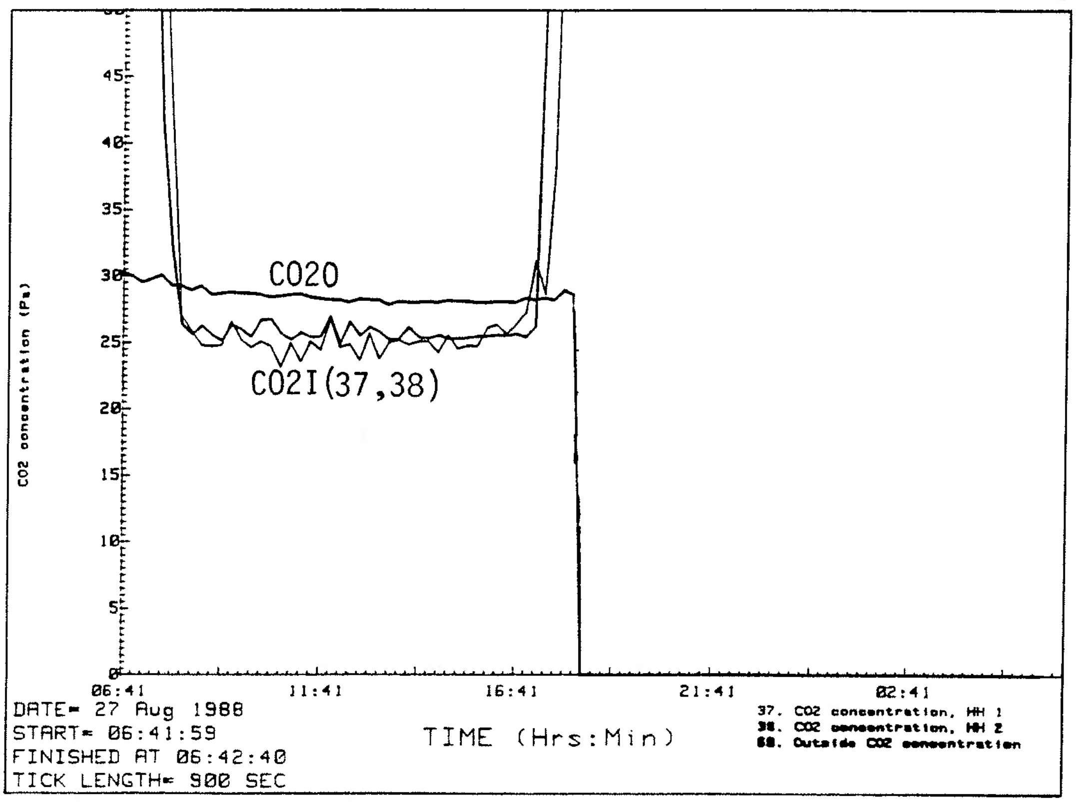


Fig. 2: Typical CO_2 levels during the day in two greenhouses compared to outside CO_2 concentration. Injection occurred in the early morning and late afternoon. As ventilation began to occur, the CO_2 level in the canopy was rapidly reduced to below the outside level. No sampling occurred at night with values set to zero.

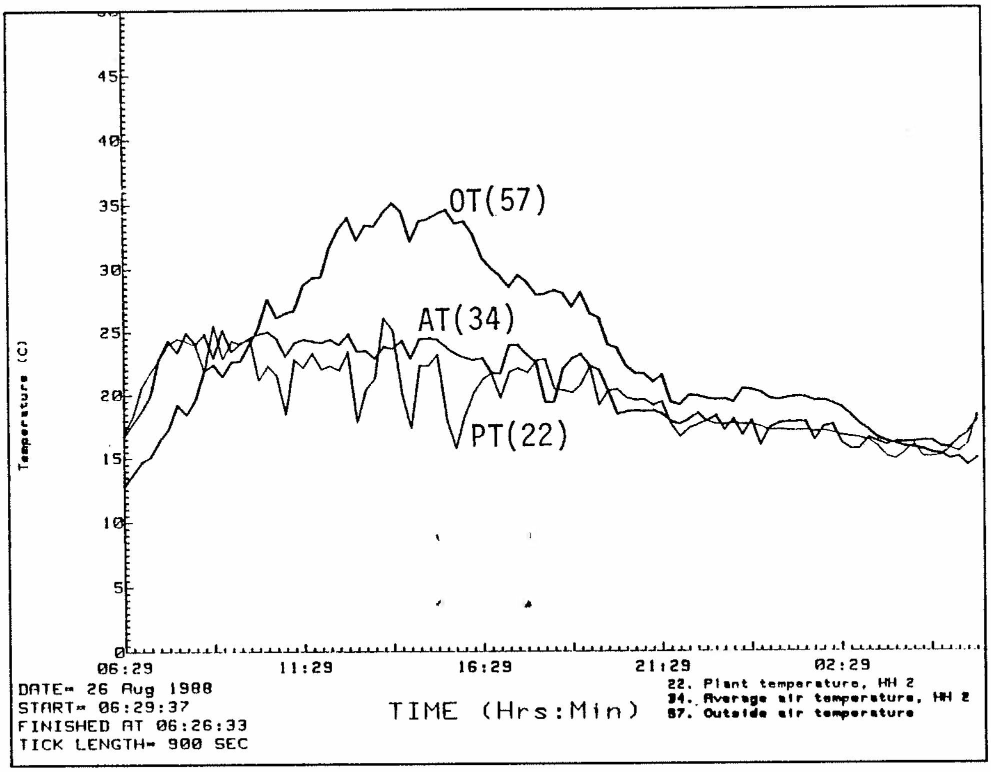


Fig. 3: Typical plant and air temperatures in one greenhouse for a 24 hr period. The plant temperature was measured with a 60° fov, infrared thermometer (PT). AT was the average air temperature from three stations in the house with outside air temperature (OT) from a sensor located on the roof of the headhouse — all shielded and aspirated. House 2 had the hot water system installed so there was no forced air circulation unless the cooling system was operating. Data were recorded at 15 minute intervals.

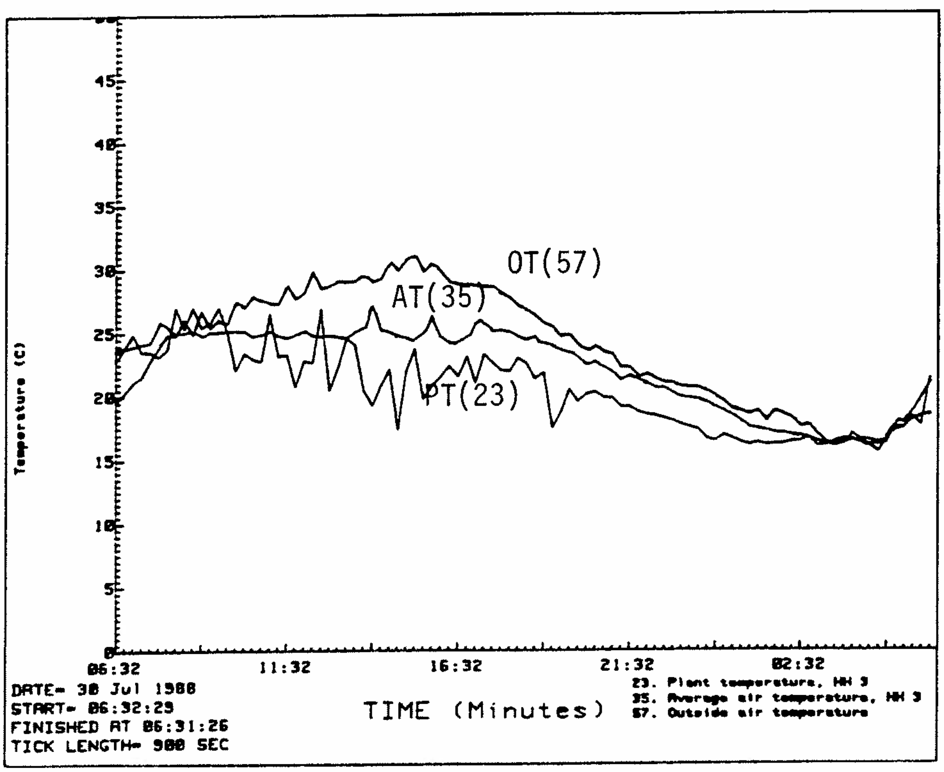
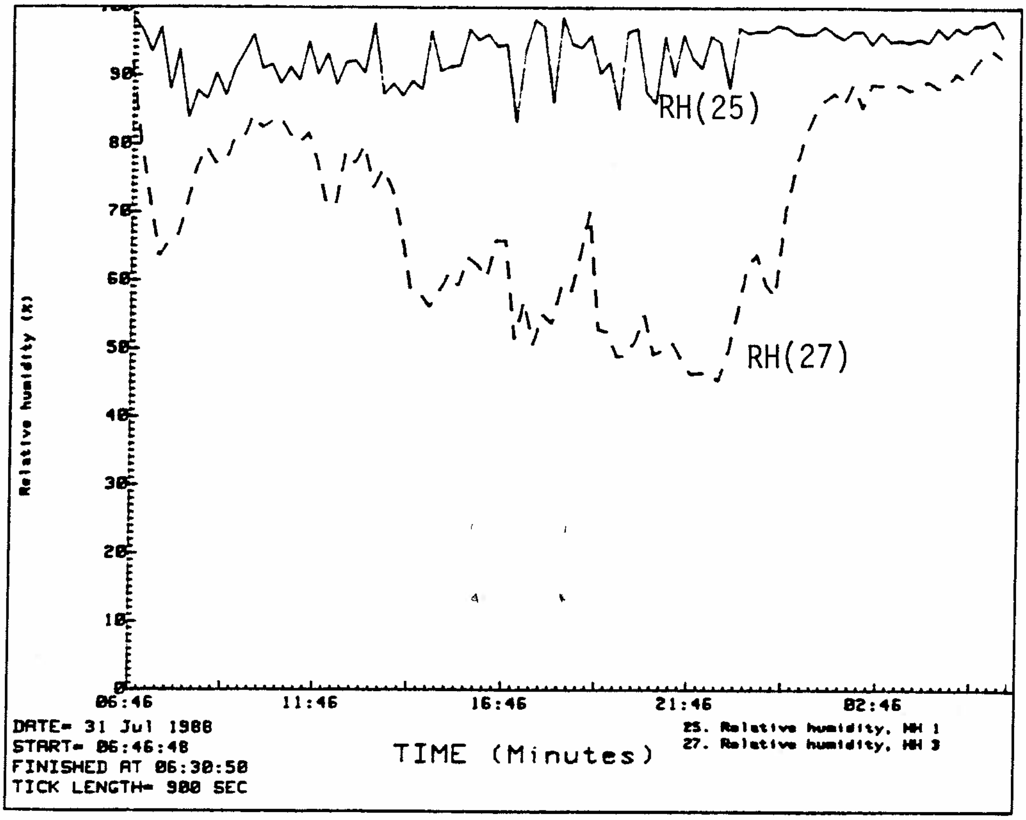


Fig. 4: Plot similar to Fig. 3, except from House 3 which was hot-air heated with the fan-jet enabled (continuous operation). Note that the plant temperature (PT) remained below the average air temperature (AT) consistently for most of the night.



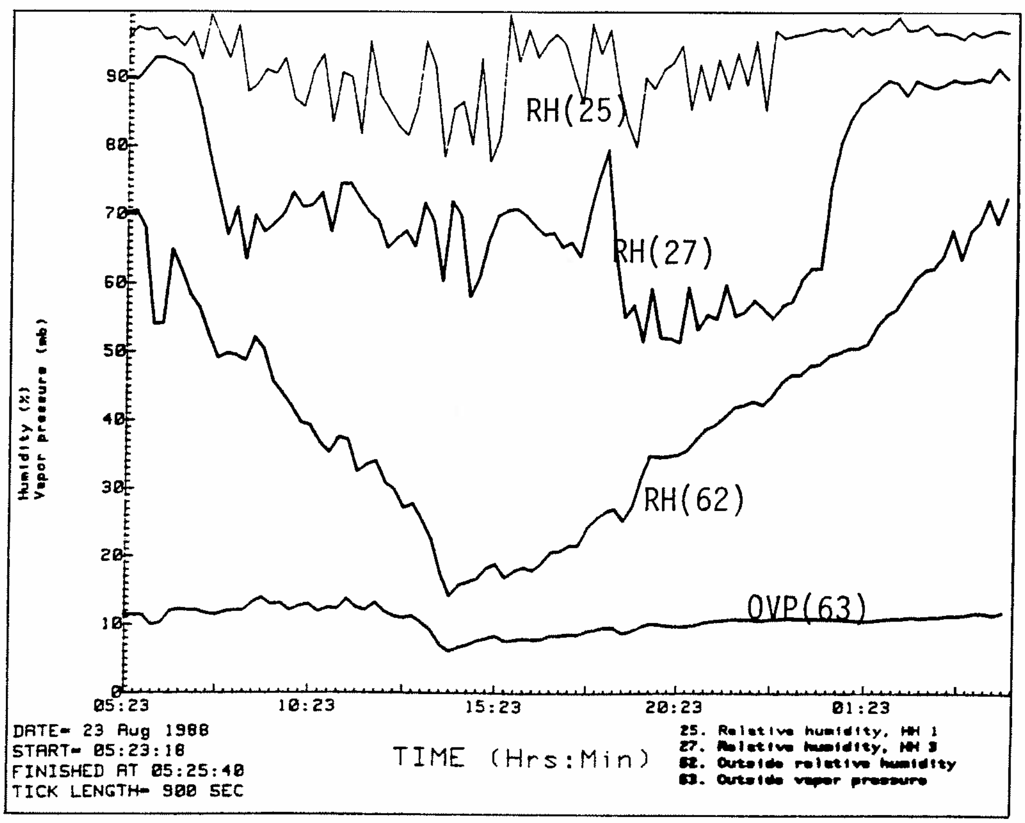
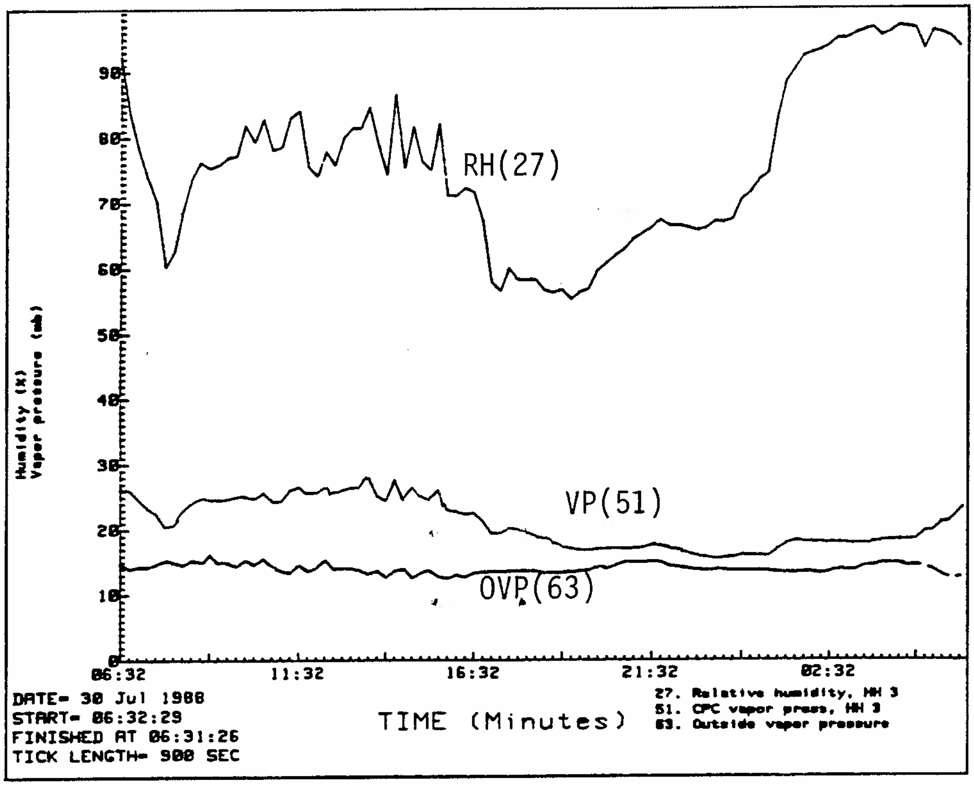


Fig. 5: Typical examples of relative humidity (RH) inside and outside two greenhouses compared with outside relative humidity and outside absolute humidity (OVP). House 1 was controlled at 3 mb VPD (ca 90% RH) whereas House 3 was set at 15 mb VPD (ca 75% RH), mist available on demand over 24 hrs. De-humidification set at 0.5 mb VPD (ca 98% RH). Both houses with hot-air heating, fan-jet enabled for continuous operation except on final cooling stages.



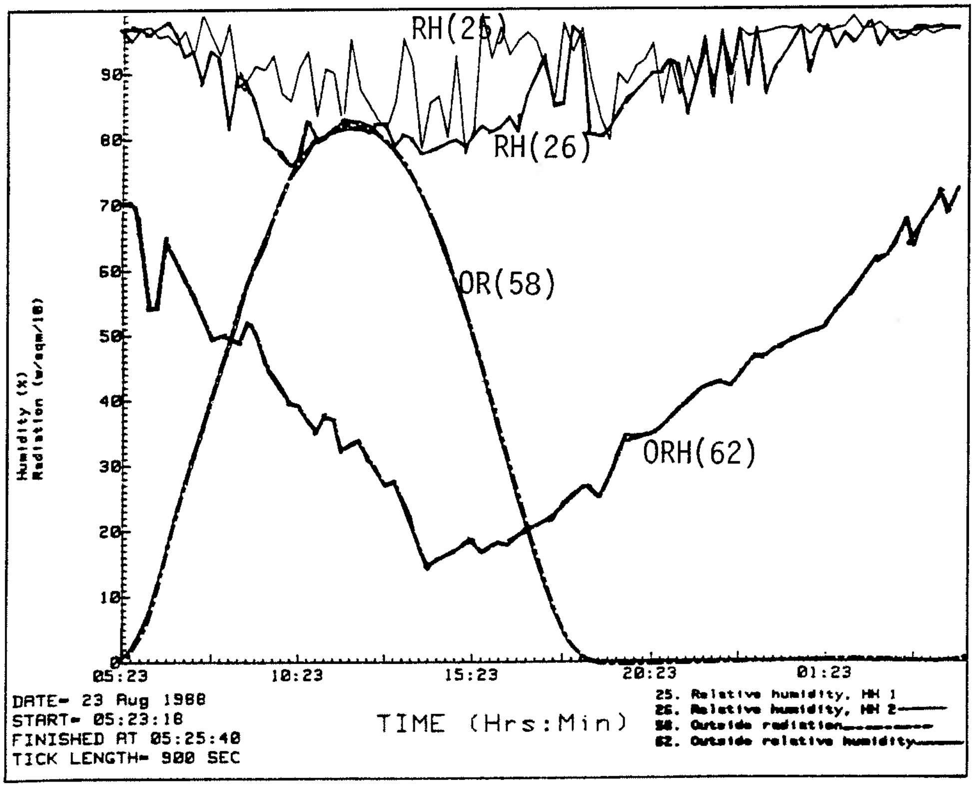


Fig. 6: Further examples of climate variation in different houses. The upper graph compares relative humidity in House 3 with actual vapor pressure and outside vapor pressure (OVP). The lower graph compares a hot-air heated house with a hot water heated house (House 2), both set for minimum humidity at 3 mb VPD. This was a perfectly clear day as shown by the outside solar radiation curve (OR). The outside relative humidity (ORH) again showed the typical Colorado variation from night to day, with the minimum RH approaching 15% then increasing to 70%. However, the upper figure shows that outside absolute humidity (OVP) may vary little, if any, over the 24 hr period.

Acknowledgement

The companies listed below have provided the Floricultural Investigations at Colorado State University with seeds and plant materials without charge. This has been a significant contribution to the total research program. We wish to express our appreciation to the best of our ability since most of our requests have been fairly small and a lot of bother. In many cases, these were donations to assist in classroom instruction, without which the teaching program would have been severely restricted. We think we have them all — we hope.

Associated Nursery Supply, Wheat Ridge, CO
Ball Seed Company, West Chicago, IL
Blue Sky Flower Farms, Broomfield, CO
Bodger Seed Ltd., El Monte, CA
Busch Greenhouses, Denver, CO
C. B. Euser Greenhouses, Denver, CO
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Colegrave Seed Company, England
Conard-Pyle, West Grove, PA
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Denver Wholesale Florists Foundation, Denver, CO
DeVor Nurseries, Pleasanton, CA
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