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Bulletin 396
June, 1983

research bulletin

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

COMPUTER CONTROL OF THE GREENHOUSE ENVIRONMENT: A Progress Report

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With the loan of equipment from Hewlett-Packard, we have written a program to control temperature in two of the CSU Temperature House compartments. A comparison between control methods in each of four compartments will be made this summer and the following winter.

Beginning last spring, the CSU Temperature House underwent rennovation with insulation, better partitions between compartments and installation of two-speed fans. The purpose is to undertake a study of different *control* systems where the *implementation* system is the same in each case. Each of the four compartments is heated by steam trombone coils with a pneumatic, modulating thermostat operating the proportional steam valve. Also located in a centrally located, aspirated shelter (Fig. 1) are two independent, fluid expansion thermostats, one for slow speed fan, the other high speed. The ventilator is opened by fast speed operation, and closes when the air pressure in the pneumatic control line drops below 12 psi. The steam valve proportions over a pressure range of 10 to 4 psi. The ventilator is timed so that operation is not continuous. To overcome the deficiency common to the usual ventilator hinged on one side (i.e., 90% of the total air flow is achieved in the first few inches of ventilator travel from the closed position), V-shaped sheet metal flanges were installed to cause a modulating effect during the initial vent travel. The thermostatic system corresponds with many commercial installations with the use of one central location for temperature sensors. The system is relatively simple, although setting of several different instruments may be required. Thirdly, the response time and differentials of these systems may vary considerably so that time must be spent in setting — assuming that each thermostat is in reasonable calibration. This system is referred to as a "thermostat control system", and it will be one of the treatments in the following year. Through the 1982-83 heating season, the compartments were run as close to the same temperature (average ≈ ± 0.5 to ± 1.0°F nights) as possible in order to determine condensate return as a function of compartment position and outside weather conditions. The pad system operates independently of the internal temperature control

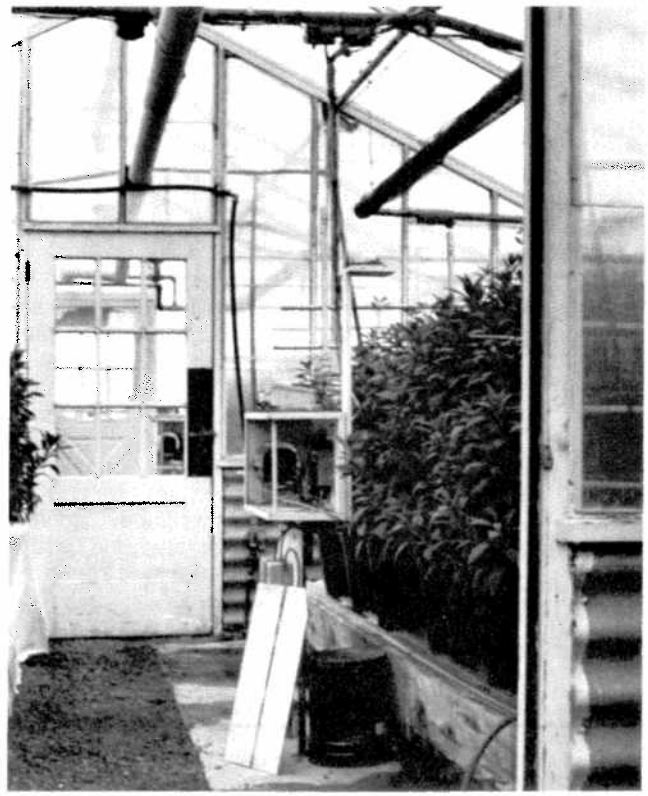

Fig. 1. Inside of one typical compartment in the CSU Temperature House, showing the centrally located, aspirated thermostat shelter with the front glass plate removed. Three thermostats separately control heating and cooling in the compartments. Temperature is monitored by two separate systems, and each compartment is fitted with its own steam condensate meter.

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system with a time clock and outside thermostat connected in series. The pad pump operates when the outside temperature exceeds 56°F during the day. Records on Alstroemeria production are being kept on several cultivars, and data collection will continue through next winter.

In January of this year, we received an HP digital acquisition and control unit, consisting of an HP 41CV, programmable calculator, a digital acquisition/control unit, thermal printer and tape cassette drive (Fig. 2). Programming of the system was completed in April, and installation and testing is presently proceeding (Fig. 3). As now programmed for two compartments, the system:

1. Reads outside temperature, inside temperature from four aspirated sensors in each compartment, and total radiation in each compartment.
2. The four air temperatures, obtained from different locations, are averaged to provide a single inside air temperature for comparison with the night or day set-points. The average outside and inside temperatures are averaged and the maximum and minimum temperatures for a given period are stored. The radiation is calculated and accumulated in storage.
3. The system switches automatically from day to night, depending upon the level set by the user. If the outside air temperature is below the set-point, ventilation will not occur at night.
4. When the switch is made to night, or day, the printer provides a summary of average, maximum and minimum temperatures and total accumulated radiation since the previous switchover. The grower has a short printed summary of system performance, as well as a record of solar radiation and outside temperatures.
5. The two compartments are controlled differently:
   A. In one unit, the control approximates the existing system. Ventilation is fixed by the user with fixed fan differentials in order to stage the system. The steam valve uses a pulsing method, based upon the difference between the set-point and the inside temperature as measured. The greater the differential, the longer the steam valve remains open. This method is called the "conventional programmed control system", and is to test the fact that one uses a computer to control temperature with minimum "bells and whistles" incorporated.
   B. The second unit program is more complex. The heating mode is not only dependent upon the difference between the set-point and measured inside temperature, but, the open time is reset to increase heating the lower the outside temperature. Also, the open time is increased each time the program is executed or run through a cycle. The attempt is to eliminate any differential from the set-point. The ventilation set-point is computed from the difference between set-point and outside air temperature. The lower the outside air temperature, the higher the temperature at which ventilation begins (see CGGA Bul. 392). Fan operation is programmed to bring the air temperature back to the ventilation set-point.
6. The system cycle time can be set by the user to vary from continuous cycling to varying off periods. This allows the system sensitivity to be varied in accordance with structure and area. This method is referred to as the "automatic re-set control system".

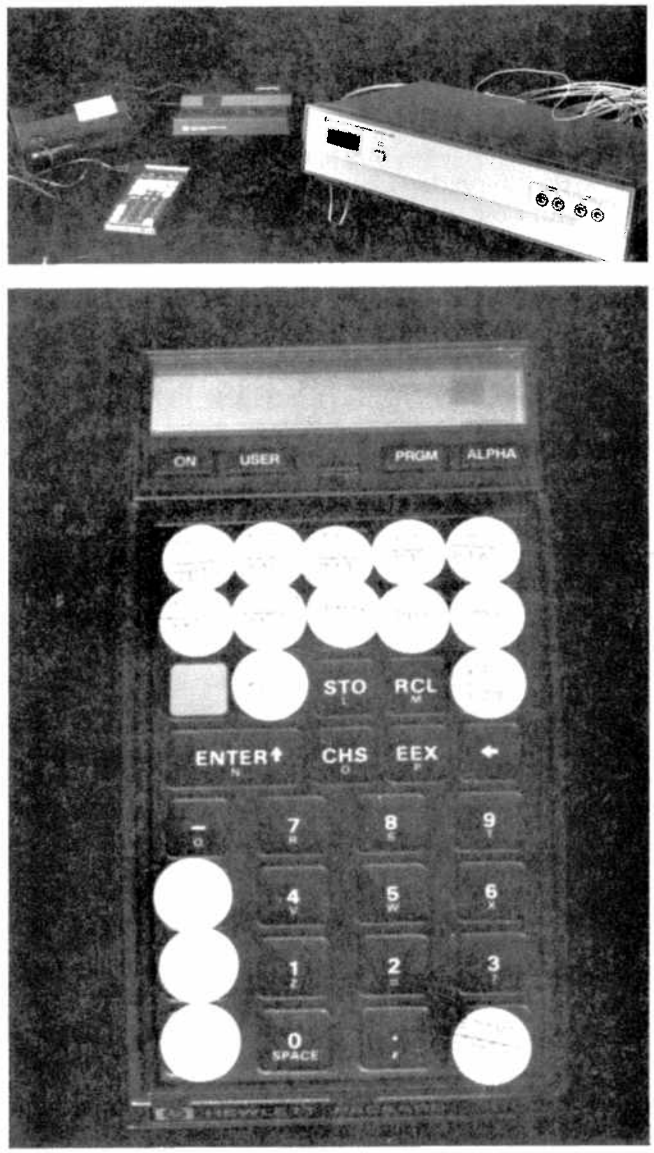

Fig. 2. The Hewlett-Packard programmable digital acquisition and control system. The small unit to the left in the upper picture is the HP 41CV hand calculator. An overlay keyboard is shown in the bottom picture. By re-defining the keyboard, one may obtain actual temperatures and set points by pressing a single key. For example, pressing R2/R1 will provide a reading of solar radiation level in each chamber. The system includes a printer and tape cassette.

The third system has yet to be selected and installed, and it may remain a thermostat control system. The programmable system has several advantages that come to mind: 1) The grower is able to determine two unambiguous set-points for day and night control. Several thermostat adjustments are unnecessary, the response time of all measurements being the same. 2) The air temperature measurement within the greenhouse is not limited to a single, critical location, and several locations may be measured and evaluated nearly simultaneously. 3) Outside weather conditions are taken into account to re-set the system as required. 4) A record is provided to the grower of system performance.

Fig. 3. Installation of the system for control in a remote, air-conditioned room. For any system of this type, protected location, and security of the controls is important. This requires suitable cabling and connections which costs might equal or excell the acquisition expense of the basic system.

There are several other possibilities which we have not attempted at this time. For example, set-points could be readjusted based upon available solar radiation (this was examined several years ago by Holley and his students, CFGA Bul. 150, 162). We do not, at this moment, consider direct implementation of available energy in the control system as highly important. CO_2 could be controlled, and the temperatures adjusted accordingly. We have not incorporated any de-humidification action or pad control, into the system, and, secondly, the basic methods for measuring humidity and CO_2, if cheap, have several limitations. It does no good to make measurements if the data is grossly in error or the instruments require expensive maintenance. The system, at present, has no fail-safe devices, although we have independent low and high temperature alarms. Also, we are able to continuously monitor air temperature in each compartment, and to obtain average, maximum and minimum temperatures digitally with yet a third, independent system. The major thrust of our tests will be to see if there are significant reductions in steam condensate as the result of the control we have incorporated, and, if there are significant improvements in crop yield and quality.

The Europeans have had much more experience than most American companies in computer implementation of greenhouse control. Several quite sophisticated methods have been published. The uses of these programs have not been published widely, and we do not know of their practicality. There have been several articles in the trade literature in the past year, and we feel that some of the information often leaves much to be desired. One of the basic problems is that we really do not know *what* is to be controlled, and *how* the *what* should be controlled. In the settings of the programs described here, we have essentially made educated guesses based upon previous experience and gut feelings. One thing we certainly want to know is the reliability of the new systems. This deals with one's ability to sleep soundly while a machine, which most people have yet to make a speaking acquaintance, holds one's profitability in a batch of silicon chips.

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DAY IS SET
                 5.111983
                18.254068

NITE  SUMMARY
 XXXXXXXXXXXXXXXXXXXXXXX
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OUTSIDE T=4.8
OUTMAX T=5.3
OUTMIN T=4.0



COMPT  ONE
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AVE T=14.7
MAX T=17.0
MIN T=13.9
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ACC RAD=56.2
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COMPT  TWO
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AVE T=14.4
MAX T=16.7
MIN T=13.5
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ACC RAD=57.3
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Fig. 4. Typical summary print-out for the preceeding night period. The date (May 11, 1983) and time (6:25 p.m.) are given, then outside average, maximum and minimum temperatures, the same values for each compartment, and the radiation level in each compartment. A similar summary is provided when the system switches to night. Temperatures are in degrees Celsius, radiation in watts per sq. meter.

Acknowledgements: This work is being supported through the loan of equipment from Hewlett-Packard, and grants from the Kenneth Post Foundation and Colorado Horticulture Research, Inc. Major expenses have been defrayed by the Colorado Agricultural Experiment Station.