Technology & Product Reports

A Low-cost Microcomputer System for Controlling Relative Humidity in Horticultural Storages

L.R. Adam[1] and

M. I.. Pritchard[2]

Additional index words. psychometrics, wet/dry bulb, refrigeration

Summary. An inexpensive system for monitoring and controlling relative humidity (RH) above 90% and for monitoring temperature was developed and tested in a storage research facility for horticultural crops. A general-purpose IBM-PC microcomputer connected to an analog/digital interface system allowed for 16 differential analog inputs and 12 digital outputs for monitoring temperature and RH in eight storage rooms. Relative humidity, measured at 2-min intervals by an inexpensive wet/dry bulb psychrometer in each room, was regulated by a cool-mist humidification system. The standard deviation of RH from set-point was ± 2.8% at 2C and ±3.1% at 10C dry bulb temperature. The software. written in BASIC, allows for additional upgrading to meet future requirements. Commercially available components were used to construct the system at a cost of about Cd$1400 (Canadian) (microcomputer and cool-mist humidification system excluded).

Department of Plant Science, University of Manitoba, Winnipeg, *Manitoba, Canada R3T 2N2.*

[1]*Technician.*

[2]*Associate Professor.*

Contribution No. 919. The cost of publisbing this paper was defrayed in part by the payment of page charges. Underpostal regulations, tbis paper therefore must hereby be marked advertisementsolely to indicate this fact.

Precise control of relative humidity (RH) and temperature is important in maintaining quality of stored horticultural crops. Proper storage temperature prevents freezing or chilling damage and condensation of water on the product, and minimizes transpiration losses and sprouting. A RH of 90% or more is desirable for most horticultural crops. However, RH close to 100% may result in free water on the product, excess growth of microorganisms, or surface cracking (Thompson, 1992).

A research facility to investigate the storage parameters required to maintain quality of horticultural crops was constructed at the Univ. of Manitoba in 1987. The facility consists of eight controlled environment rooms of 12 to 20 m^3 per room, situated in an air-conditioned building. All rooms are equipped with a thermostatically controlled refrigeration system and a computer-controlled humidification system.

Continuous measurement of RH is labor-intensive when using standard chart dataloggers. Humidification control and datalogging require a hygrometer with an output that can be read by a computer interface. Hunter and Rowe (1987) evaluated various electronic methods of RH determination in high-humidity environments. Some devices that sense RH as a function of capacitance of a thin polymer film were unreliable at a RH >90%. Commercially available RH sensors that claim accuracy of ±3% or better in the 90% to 100% RH range are costly. Psychrometer, if properly calibrated and maintained, can measure high RH accurately in horticultural crop storages and can be built at a low cost compared to other appropriate sensors.

The objective was to design and construct an inexpensive system for electronic data collection of temperature and RH that would also control RH in individual rooms of a storage research facility for horticultural crops. A modified wet/dry bulb psychrometer interfaced with a mist humidification system was used to monitor and control RH. Software was needed that allowed total control over system customization and future modifications at a low cost.

Materials and methods

Hardwave. A system was assembled that consisted of an IBM-PC (8088, 4.77 MHz) equipped with a hard drive, serial port, and analog/digital interface system (Remote Measurement Systems, Model ADC-1 + 12C, Seattle) with 16 analog inputs, 12 digital outputs, and four digital inputs (Fig. 1). Sixteen solid-state temperature transducers (AD590 J-grade, Analog Devices, Norwood, Mass.) allowed for one wet and one dry bulb temperature reading for each of the eight controlled environment rooms. The transducers were soldered onto two-conductor 0.5 -mm (24-AWG) stranded, shielded wire. They then were sealed with 6-mm-diameter heat-shrink tubing made of adhesive wall polyolefin to prevent moisture from corroding the connections. The wire spanned 15 to 30 m between the control center and the transducers in each room.

The wet/dry bulb system (Fig. 2) is similar to the conventional aspirated psychrometer described by Barber et al. (1989). The apparatus used a 100-mm-diameter, five-blade axial fan with a 48 liters-' capacity mounted on an air plenum constructed from ABS plumbing fixtures (floor flange and a 76.2-mm–50.8-mm female adapter). The adapter was machined inside to accommodate 63.5 -mm (o.d.) clear polycarbonate tubing ≈500 mm in length. Three 5-mm holes were drilled into the side of the tubing, allowing for insertion of the transducers and the wick for the wet bulb. The wick was

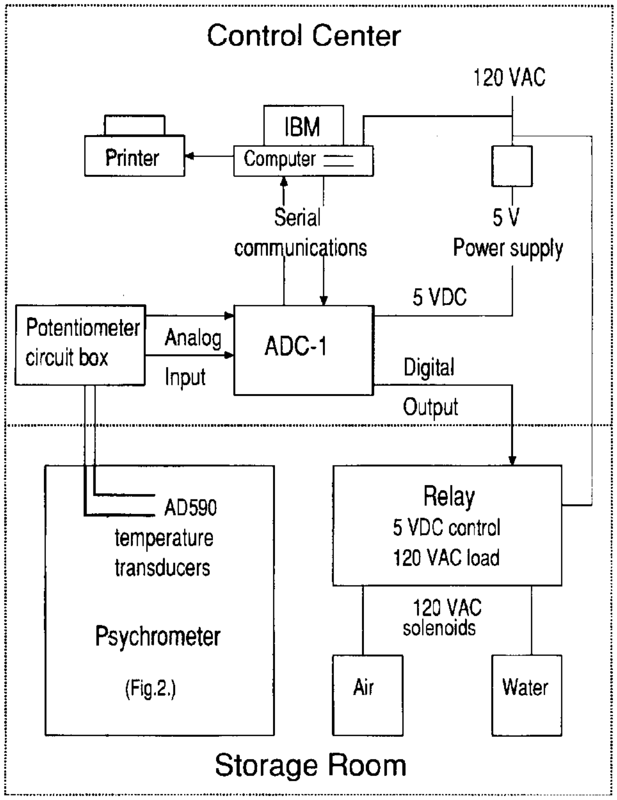

Fig. 1. ***Schematic of communication and control setup for monitoring temperature and RH, and controlling RH in a storage research facility for horticultural crops.***

made from new, washed, 8-mm-diameter 100% cotton shoelaces. One end of the wick was inserted into a 500-ml container mounted on the side of the tube, which acted as a reservoir of distilled water for the wick. The apparatus were installed on the rear wall of each room with the fan output 250 mm from the ceiling.

The humidification systems were controlled by the microcomputer

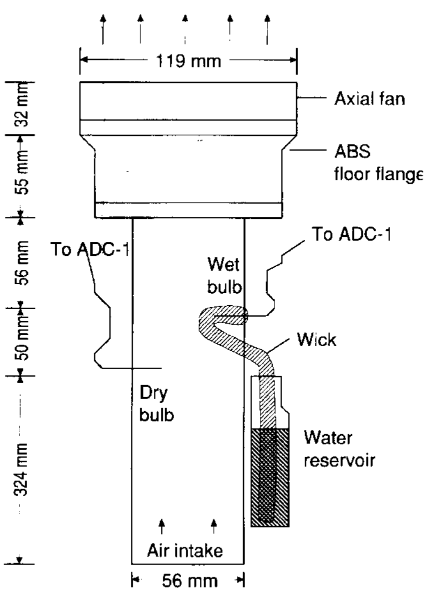

Fig. 2. ***Schematic of wet/dry bulb psychrometer for monitoring temperature and RH in a storage research facility for horticultural crops.***

through the eight digital outputs of the analog/digital interface, which activated solid-state relays (3 to 24 VDC input, 120–220 VAC load) located in junction boxes on the outside of each room. The load side of each relay was connected to a 120-VAC electric solenoid valve for air flow control and to an electric solenoid valve for simultaneous water flow control.

Air pressure of 483 kPa was supplied by a 2.2-kW DeVilbiss compressor model 44642 (DeVilbiss Canada Ltd., Barrie, Ont.) and water pressure of 414 kPa was supplied by a Hypro series 8600 plunger pump (Hypro Corp, New Brighton, Minn.) driven by a 0.36-kW/220-VAC electric motor. Air and water were piped through the solenoids and into a Spraying Systems Co. (Chicago) stainless steel nozzle assembly consisting of a model No. 2050 fluid cap and 67-6-20-70° air cap to produce a mist. The nozzles were mounted near the ceiling of the room on the opposite wall from the psychrometer to minimize condensation on the dry bulb. The nozzle assembly produced a cylindrical spray pattern ≈ 3 m in length and 0.3 m in diameter, with an output of 1.3 ml·s^{-1} (Spraying Systems Co., 1987).

The set-point temperatures in the rooms were maintained with thermostats that controlled individual refrigeration units. The refrigeration contractor supplied evaporators with oversize coil areas and adjusted suction pressures to minimize the temperature differential between the coil and room air, thereby limiting room dehumidification. Aperiodic hot-gas defrost cycle was activated when room temperature settings required that the evaporator coil be operated below 0C.

Each room was equipped with a continuously operating 12-liter·s^{-1} exhaust fan that brought in constant 21 C fresh air from within the building through an air intake vent in the wall of the room. Average air speed at the fan intake was 3 m·s^{-1}. This provided individual rooms with about two air changes every hour.

Software. The software was written in BASIC. Simple subroutines for communication, supplied with the ADC-1 manual (Remote Measurement Systems Inc., 1983), were modified and used in the system. The program cycles for 2 min between sample intervals, when it then addresses the ADC-1 and requests wet and dry bulb temperatures" from each room-.

A plot of vapor pressure (E) of water (in kiloPascals) against temperature (0–20C) (Campbell, 1986) produced a curve that is best fitted (r^2= 0.99) to the empirical equation:

$$E = 0.614e^{(0.070T)} \quad \text{[Eq. 1]}$$

where T = temperature (°C) of the dry bulb (T) or the wet bulb (T'). When the dry bulb temperature and the wet bulb temperature are substituted into the equation, it produces values for saturated vapor pressure (E_s) and vapor pressure at the wet bulb temperature (E'), respectively. Actual vapor pressure (E) is calculated using a formula (Campbell, 1986) for reduction in psychometric observation

$$E = E' - aP(T - T') \quad \text{[Eq.2]}$$

where a = psychometric constant 6.6 × 104 and P = assumed atmospheric pressure of 100 kPa.

Finally,

$$RH = (E/E_s) \times 100 \quad \text{[Eq. 3]}$$

(Woodward and Sheehy, 1983).

Temperature and RH values are kept in arrays for processing. RH values are compared to set-point values for each room. When RH drops more than 2% below the set-point, the humidification misters are actuated. Mean values of temperature and RH are calculated and logged to disk for each room every hour, along with the time. Similarly, at the end of every 24-h period, mean, minimum, and maximum values for the previous 24-h period are printed. In addition, an option can be activated that logs all data to disk. Temperatures, RH, and RH set-point control can be monitored in real time on the computer screen.

Experimental. Two storage environments consisting of empty rooms with set-points of 2C, 95% RH and 10C, 90% RH were used to determine the efficiency of the humidification system. The temperature and RH were recorded every 2 min over a 3-h period. The RH values obtained from the constructed psychrometer were compared to a Hygro-Ml optical dew-point monitor (General Eastern Instruments, Watertown, Mass.).

Results and discussion

Hardware. The IBM-PC allowed for hard-disk data storage and facilitated data transfer to other compatible computers for subsequent data manipulation and report-writing. Temperature calibration and matching of the AD590 transducers was achieved with the addition of a separate piece of hardware containing one potentiometer circuit for each of the 16 analog inputs. Outputs of the transducers were adjusted by comparison to readings taken with a Digimite electronic thermometer with type-T thermocouples and internal cold-junction reference (Thermo Electric, Brampton, Ont.). This method of calibration was chosen over an alternative method of using software to correct for variation in sensor readings. Potentiometer circuits al-allowed for easy calibration of replacement sensors without the need to edit software. Either calibration technique would result in a dry or wet bulb temperature uncertainty of less than ± 0.3C over the expected 15C operating temperature span (Remote Measurement Systems, 1983, p. D12). The ADC-1 was set at the low-speed sampling mode with a 10-ms A/D settling time offering auto-zeroing and channel readings with a 12-bit resolution. This enabled the best accuracy of readings with a minimum amount of noise (Remote Measurement Systems, 1983, p. 2).

Average air flow speed measured at the psychrometer plenum intake was 9.5 $m \cdot s^{-1}$ with the 48-liter$\cdot s^{-1}$ fan. Accurate wet bulb temperature can be achieved with speeds as low as 3 $m \cdot s^{-1}$ (ASHRAE, 1982). Wicks on the wet bulb required periodic maintenance to ensure adequate moisture around the sensor. This involved refilling the distilled water containers every 3 to 6 weeks, depending on the temperature and humidity in the room. Occasionally, 3 to 5 cm was removed from the end of the wick to ensure a clean surface and uninterrupted supply of water to the wet bulb. The frequency of wick replacement varied from 1 to 3 months, depending on the amount of dust circulating in the room.

The misting nozzles chosen had one of the smallest output volumes that was available from the supplier. Air and water pressure balancing and water flow rate adjustments gave adequate misting nozzle output. Software allowed for a variable misting time during each cycle. The misting period for each 2-rein sample cycle was 5 to 9 s. If misting time was outside of this range, an unacceptably high deviation in RH from set-point resulted.

The major advantage of this system over most commercially available systems was its low cost. Standard chart dataloggers may cost as much as Cd$900 to monitor one environment. Cost comparisons between psychrometer and high-humidity RH sensors (Table 1) show significant savings in favor of psychrometers. There also would be additional maintenance cost for replacement of high-humidity sensors.

Table 1. ***Comparisons of system costs (Canadian) for RH sensing and control of eigbt environment rooms.***

	System costs (Cd$)	
Components	Psychrometer	High-humidity sensors
ADC-1+12 C	700	700
Wire	205	205
Psychrometer plenums and fans	325	---
AD590J temperature transducers	160	---
High-humidity RH sensors with temperature	---	3600
Total	**1390**	**4505**

Software. The BASIC program operating on an IBM-PC required about 3 s to collect all temperatures, calculate RH, and update arrays. There was an additional wait of 5 to 9 s when misting was required. A batch file allowed for automatic boot in the event of a power failure. The menu was accessed through key trapping routines and a BASIC shell routine allowed system access without major interruption in program flow. An IBM-PC that may not have adequate computing power for other commonly used software packages was found to be more than adequate for the BASIC routine used in this application.

Experimental The mean temperatures of the two rooms, which were empty and were set at 2C and 10C, over the 3-h test period were 2. lC and 10.3C with a standard deviation of ± 0.4C and ±0.5C, respectively. The maximum temperature deviation for the 2.1C room without the defrost spike was ± 0.7C. Maximum temperature deviation from the 10. 3C mean was 1.3C. The mean RH of the 2.1C and 10.3C rooms were 94.6% and 91.0%, with standard deviations of ±2.8% and +3.1%, respectively (Fig. 3). Total RH fluctuation for the 2.1C and 10.3C rooms were ±6.8% and ±7.7%, respectively. The optical dew-point monitor reported mean RH values for the two rooms at 95.5% and 91.5%, with standard deviations of ±2.7% and ±2.3%, respectively. Total RH fluctuation reported by the dew-point monitor was ±6.5% and +6.4% for the 95.5% and 91.5% rooms, respectively. A sharp decrease in RH corresponded with a 1.6C increase in temperature in the 2.1C storage due to the defrost cycle, which occurred every 6 h. Atmospheric pressure variation in our area would account for < 0.1% error when working in the 90% to 100% range. A worst-case temperature error of ±0.3C would result in an error of ≈5 % RH; however, the actual comparison to the optical dew-point system shows similar means and standard deviations, verifying the reliability of this system, which was designed to operate in the 0C to 15C and 90% to 100% RH range. System operation at or slightly below 0C would result in wet bulb temperatures that would cause

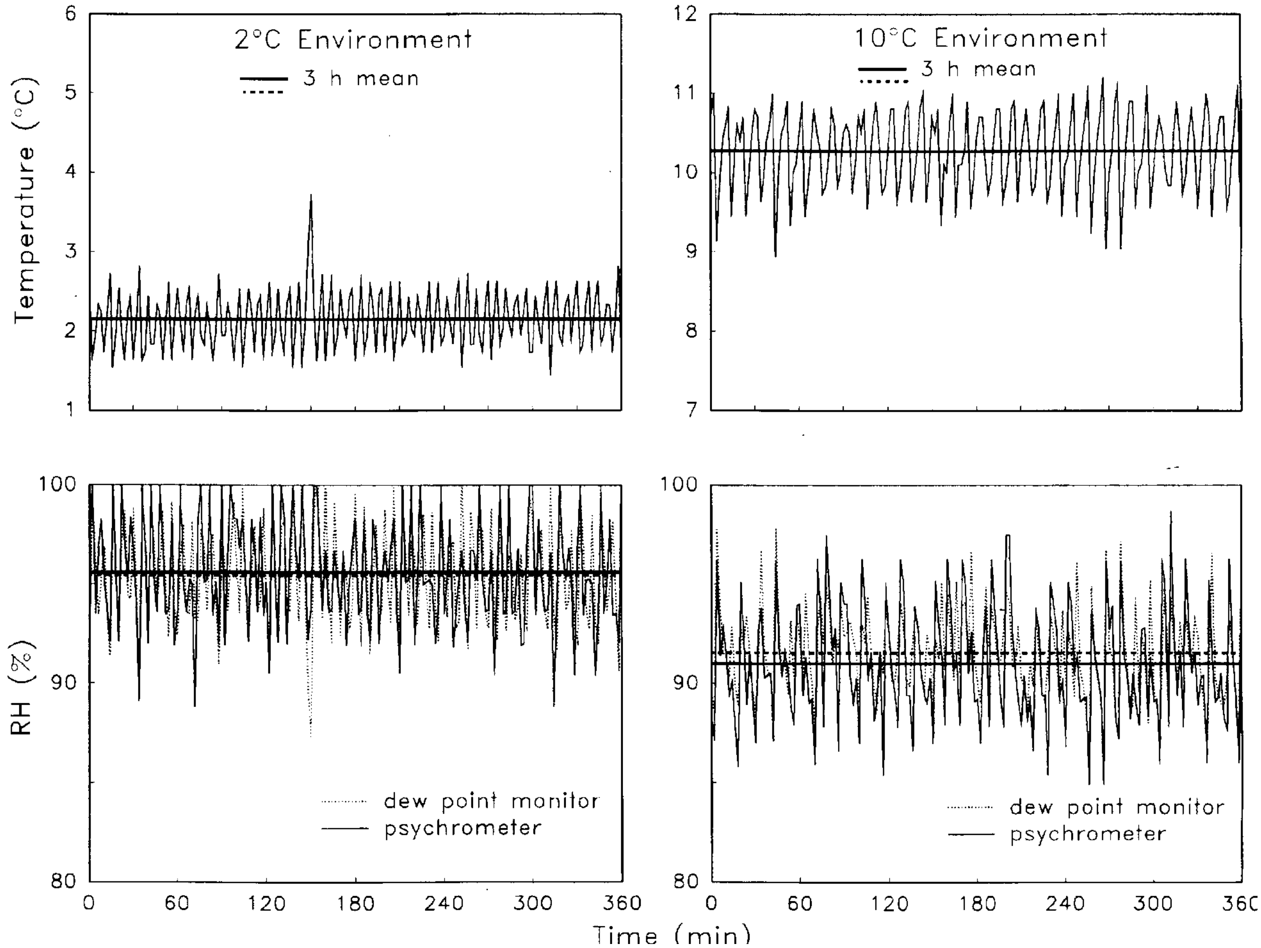

Fig. 3. ***Temperature and RH profiles over a 3-h period in a storage research facility for horticultural crops held at 2C, 95% RH and 10C, 90% RH. (RH determined by a wet/dry bulb psychometer and by an optical dew point monitor.)***

the wick to supercool or freeze. Vapor pressures derived from [Eq. 1] would be slightly overestimated, resulting in higher RH estimates. At a RH reading of 95% and 0C, the actual RH would be ≈1% lower. Operation of this system below freezing for extended periods would require the ability to heat the psychrometer, make the measurement, and convert the result to the temperature of the environment. The relatively small fluctuations in temperature and RH of the air that occurred in these empty rooms would result in negligible variations in temperature and RH around large volumes of stored product.

Conclusions

A data-logging and control system for a storage research facility of this complexity can be assembled successfully without expensive custom-made computerized equipment and without extensive computer control experience. Matched temperature sensors and routine wick maintenance are extremely important for obtaining accurate results. This low-cost system provided control of RH well within acceptable limits for storage research. The modified psychrometer proved to be an appropriate device for RH monitoring and control applications within the range of storage environments examined. The reliability and durability of this system which is available at low-cost makes it suitable for commercial applications. The ability to upgrade the software is an important asset of the system.

Acknowledgements

Funding for the construction of the storage facility by the Agri-Food Development Agreement, apart of the Canada–Manitoba Economic and Regional Development Agreement (ERDA), is gratefully acknowledged.

Literature Cited

ASHRAE. 1982. Standard method for measurement of moist air properties. ANSI/ ASHRAE Standard 41.6- 1982, Amer. Soc. of Heating, Refrig. and Air-Conditioning Eng., Atlanta.

Barber, E.M., D. Gu, and H.L. Classen. 1989. Development and testing of low-maintenance aspirated psychrometer for continuous use in livestock barns. Applied Eng. Agr. 5:601-610.

Campbell, G.S. 1986. An introduction to environmental biophysics. Springer-Verlag, New York. p. 20-24, 147-151.

Hunter, J.H. and *R.J. Rowe. 1987.* Measurement of high levels of relative humidity. ASAE Paper no. 87-4068. Amer. Soc. Agr. Eng., St. Joseph, Mich.

Remote Measurement Systems Inc. 1983. ADC-1 owners manual. Seattle.

Sp~ayin~ *Systems Co. 1987.* Industrial catalog 50, Chicago. p. E13.

Thompson, J.F. 1992. Storage systems, p. 69–78. In: A.A. Kader (ed.). Postharvest technology of horticultural crops. Agr. and Nat. Resources Publ., Div. of Agr. and Nat. Resources, Univ. of California, Berkeley.

Woodward, F.I. and J.E. Sheehy. 1983. Principles and measurement in environmental biology, Butterworths, Kent, U.K. p. 92-93.