A proportional-integral-derivative control system for heating and ventilating livestock buildings

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MacDonald, R. D., Hawton, J. and Hayward, G. L. 1989. **A proportional-integral-derivative control system for heating and ventilating livestock buildings.** Can. Agric. Eng. **31**: 45–49. A Radio Shack Colour Computer was interfaced with the heating and ventilating equipment in a hog grower room. A proportional -integral-derivative (PID) control algorithm was written in BASIC and used to stage all facets of heating and ventilating to both improve the temperature control and reduce the heating costs. The results showed that, depending on the inside and outside conditions, some on/off cycling of the equipment occurred at 2- to 6-min intervals to keep the room temperature within 0.5°C of the setpoint. From 30 Jan. to 19 Apr. 1986 the energy savings resulting from this control system totalled 3000 kWh or $150.

INTRODUCTION AND LITERATURE REVIEW

As livestock and poultry production intensifies, environmental control will play an increasingly significant role. Poor air quality and large temperature fluctuations can stress the animals, resulting in poor health which in turn costs both time and money (Kulp and Hinkle 1983). Energy may also be wasted by operating heaters and fans at the same time (Winfield and Turnbull 1980; Leonard et al. 1983). Poor ventilation and temperature control can usually be traced to poor housekeeping, a mismatch between the barn and the capacity of the installed heating and ventilating equipment or poor thermostatic controllers.

The achievement of a constant temperature in barns is challenging because of the many variables involved. These include the inside conditions such as the animal density, size and activity level and the outside conditions such as the wind speed, direction, temperature and humidity. These affect the heat and moisture generation and removal rates, respectively.

The environmental control systems used in agriculture have traditionally been one- or two-stage electromechanical switches using fluid-filled bulbs to sense temperature. These are effective in many instances (Mitchell 1984) but no readout devices. Thermostatic controllers are often not properly calibrated because they can not be adjusted easily or do not maintain their calibration.

Microprocessor control systems offer several advantages over the simple electromechanical systems (Willits et al. 1980a). These include the ability to process readings from several sensors and to record the performance of the system. The most significant advantage, however, is flexibility. Since the control strategy is implemented as a program (Mitchell and Drury 1982), it may be easily changed without rewiring the control system. Since the sensor calibration data are also stored in the memory, recalibration is also easily accomplished.

Willits et al. (1980a) also noted some potential problems with microprocessor controllers. The electronic computers are vulnerable to power line fluctuations and lightning. In addition to power failures, voltage surges can cause a computer to fail. Good line filtering and a battery backup were suggested as remedies for these problems.

Several control strategies have been used to control the temperatures of greenhouses and livestock buildings. Most have used some form of on-off control due to the high cost of proportional actuators. Willits et al. (1980b) used on-off control with a neutral zone to operate a combination of one heater, one fan and one cooler in a greenhouse. To achieve a proportional air flow over a wide range of flow rates, Cole et al. (1981) suggested that one variable-speed fan and a number of fixed-speed fans could be staged together. The sum of the flows would provide the continuous function required. Although this method is more inexpensive than a large variable speed fan, one variable speed drive is still required.

The objective of this study was to develop an inexpensive, reliable controller to provide good temperature control and optimize energy use in agricultural applications. The control strategy was based on a discrete PID (proportional-integral-derivative) algorithm adapted for staged on-off control. The output is essentially a digital to analog converter where the analog value is the heat flow rather than an electrical quantity.

FACILITY DESCRIPTION

The barn used in this study was converted from a broiler chicken facility to a multiple room hog facility in the summer of 1984. There is one dry sow area, four farrowing, one nursery and three grower rooms. Comparisons were made between grower room G2, with standard temperature controls, and grower room G3, with the microcomputer controller. Each grower room had 11 pens with the back three-quarters slatted to a manure pit as shown in Fig. 1. Each pen contained up to 15 pigs. The pigs were grouped by weight in the pens. The weights in the room ranged from 9 to 27 kg.

The computer temperature controller was installed in grower room G3. The heating and ventilation requirements for this room were calculated by NVENT (V. 84-08-28). NVENT is an Ontario Ministry of Agriculture and Food Engineering Services computer program which calculates the heating and ventilation requirements for various outside temperature with given building characteristics and livestock densities. From the results, the required heaters and fans were specified and staged as shown

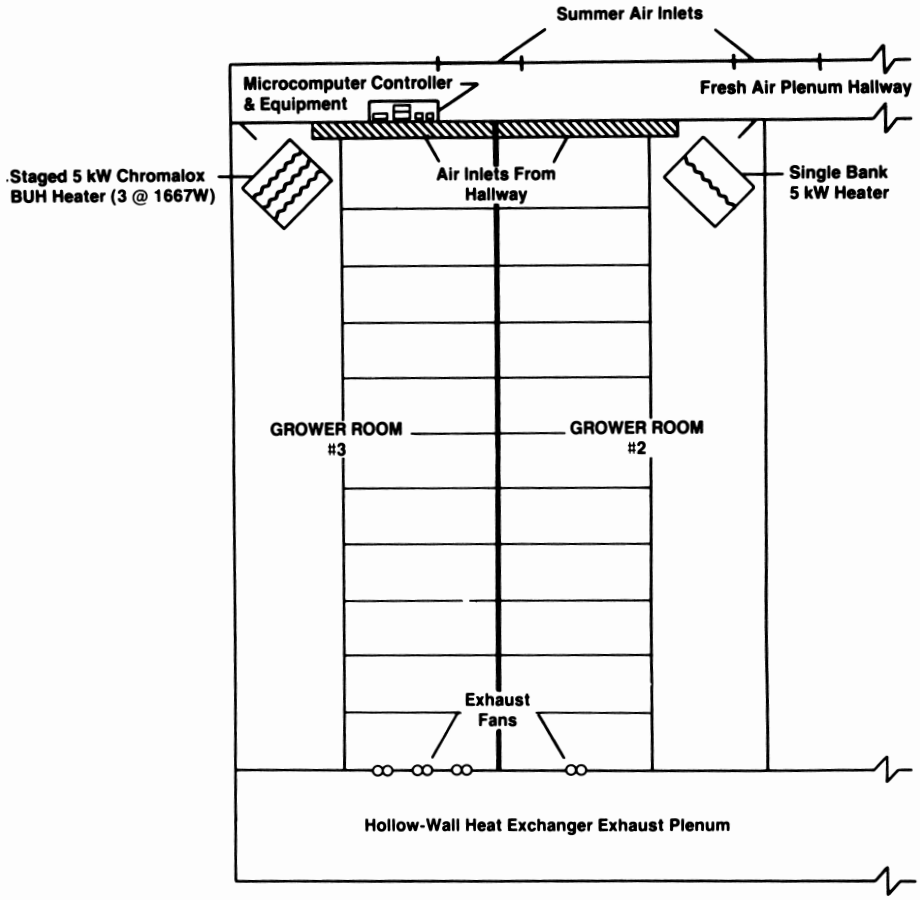

Figure 1. Plan view of grower rooms nos. 2 and 3.

in Table I. Two 300-mm two-speed fans (Fans 1 and 2) and one 5-kW Chromalox BUH fan-forced electric resistance heater with three 1.67-kW elements were installed. At the setpoint, the Fan 1 low setting provided air to the animals at about the minimum rate specified by the NVENT calculations.

The original 600-mm variable-speed fan was left in grower room G3 as a backup in case of a computer failure. Its low temperature cutoff was set about 4°C higher than the room setpoint so that it would not interfere with the computer control tests.

Grower room G2 was ventilated by a 600-mm variable-speed fan, controlled by a Ranco E-31 variable speed thermostat, with a Honeywell T-631A low temperature cut-off thermostat. Supplemental heat was provided by a 5-kW construction type heater with an internal bimetal thermostat.

Table I. Heating and ventilation equipment sequencing

Room temperature increasing	
|	Fan 1 on high + Fan 2 on high
|	Fan 1 on high + Fan 2 on low
|	Fan 1 on high
|	Fan 1 on low + Fan 2 on low
o	Setpoint — Fan 1 on low
|	1 heating element — 1.7 kW output + Fan 1 on low
|	2 heating elements — 3.3 kW output + Fan 1 on low
|	3 heating elements — 5.0 kW output + Fan 1 on low
Room temperature decreasing	

COMPUTER HARDWARE

The computer used in this ventilation controller is a Radio Shack Colour Computer II. Although a microprocessor-based controller designed for this task is desirable as the final product, a general-purpose microcomputer offers several advantages in on-site troubleshooting and software development. As a mass-produced unit, this microcomputer is available at a cost much lower than that of a custom-built unit. This computer had a full-sized keyboard and video display which allowed the control program to be modified in the field. The program was written on BASIC, a high-level language supplied with the computer. The temperature sensors used were integrated circuits which give a linear output proportional to temperature. This eliminated the linearization required by other sensor types. The sensor output was a 10-mV change per °C. Since typical barn temperatures range from 5 to 35°C the sensor output was expanded by a preamplifier. This gave a resolution of 0.1°C with an eight-bit analog to digital converter.

The fans and heaters were switched using two eight-bit digital output ports. To protect the computer from high-voltage surges from the power lines to the fans and heaters, optically-isolated solid-state relays were used. A third eight-bit port was used to drive a set of alarm lights to indicate various problems detected by the control program. These include such failures as disconnected sensors. Another continuously pulsing light indicates proper software operation.

For protection against power failures, a battery power supply was added to the Colour Computer. This, however, did not keep the program running as power line transients caused memory errors. To restart the program, a "watchdog" timer was also added. The pulses from the software operation indicator maintained the state of the timer. If pulses were missed for more than 20 s, the timer reset the computer in an attempt to restart the program. The program was run automatically after a reset occurred. The program and the control parameters were stored in an electrically alterable read-only memory. The contents of this memory could easily be altered but were not lost when the power was turned off. These measures made the controller very reliable in an electrically noisy environment.

CONTROL SOFTWARE

The discrete PID control algorithm operates by taking a sample of the barn temperature and comparing it to the desired temperature or set point. The error equation is:

$$E(n) = T\text{barn} - T\text{setpoint} \quad (1)$$

where:
$E(n)$ is the current temperature error (°C);
Tbarn is the temperature of the barn (°C); and
Tsetpoint is the desired temperature of the barn (°C).

The controller uses this error to determine the amount of correction required to return the temperature to the setpoint. To change the barn temperature, the ventilation rate or amount of heat supplied must be changed. The usual PID control equation gives the amount of heating or cooling as a function of the temperature error. It is usually more convenient, however, to calculate the change from the current heating or cooling rate. This equation (Smith 1972) may be written as:

$$dT = Kc * [(E(n) - E(n-1) + Ts/Ti * E(n) + Td/Ts * (E(n) - 2 * E(n-1) + E(n-2))] \quad (2)$$

where:
dT is the temperature change required for the system (K);
Kc is the proportional gain;
Ti is the integral time (s);
Td is the derivative time (s); and
Ts is the sample time (s).

The number n refers to the current measurement; $n-1$ to the previous measurement and $n-2$ to the one before that. The time between measurements is critical; too short a sampling time can result in excess equipment cycling while too long a sampling time can result in temperature overshoot and instability.

The constants Kc, Ti and Td must be determined experimentally. The effect of each of these on the controller performance has been described by Smith (1972). A small Kc produces large overshoot but gives good stability, while a large Kc reduces the overshoot but increases cycling. Small Ti values eliminate constant errors quickly, but result in rapid cycling of the control equipment, in this case the heaters and fans. Variations of Td have much less effect on the performance, hence its value is not as critical.

The control equation was evaluated at the end of each sampling period and a running sum of the result kept. When the sum exceeded 1.0, the room was overheated, hence either one level of heating was turned off, or one stage of cooling added. The sum was then reduced by 1.0 and the controller allowed to continue. The exact opposite procedure was carried out when the room was too cool, indicated by a sum less than −1.0. The value of +/−1.0 was arbitrarily chosen as the criterion for changing the staging. The value of Kc, in part, scales the capacities of the heating and cooling stages to match this criterion. This calculation allowed the continuous output of the PID controller to be approximated by the heating and ventilation staging arrangement.

MONITORING

The performance of the control systems in the two rooms was evaluated both on the basis of the room conditions and on the basis of the manipulations required to maintain those conditions. The conditions in each room were measured by Metra 854 weekly chart thermohygrographs. These were calibrated by the distributor.

The computer control system also recorded its operation on magnetic tape. The measured temperatures as well as the fan and heater switching were recorded. Hour meters on each heating and ventilation stage in room G3 and a kWh meter on the heater in room G2 were also installed. The readings were recorded once daily.

RESULTS

The initial controller settings were calculated from a heat balance for the room with a given livestock density. This balance calculation was done by the NVENT program. The fan and heater stages were assumed to give a 1° temperature change in 1 min. From the heater power output, a Kc value of 0.45 was calculated. The integral time was calculated to remove a 1° sustained error in 6 min.

The initial control settings for the microcomputer were: $Kc = 0.4$, $Ti = 90$ s, $Td = 5$ s, and $Ts = 15$ s. Results from the thermohygrographs showed that the stage 2 ventilation and level 1 heating were continuously cycling on and off giving 3°C temperature fluctuations over 25-min periods. These results revealed two major errors in the assumptions used in calculating the initial controller settings: fans do not move the quantity of air specified by the manufacturers under varying conditions, and the heat and moisture production from livestock is difficult to determine. To improve the controller performance, the settings were adjusted manually.

A simple "rule of thumb" tuning procedure (Coughanowr and Koppel 1965) was used since the dynamics of individual rooms can vary considerably. The procedure was easy and did not require the measurement of the room response to the heaters and fans. Since the tuning was carried out in the room, its dynamics were included implicitly.

In the first step, the integral and derivative control modes were disabled by making the integral time very large and the derivative time zero. The gain was increased until sustained oscillations were observed in the room temperature. In the room controlled in this study, this occurred at a gain of 2. The gain was set at half of this value. Next, the integral time was decreased until slight oscillations were observed in the temperature. Last, the derivative time was increased to damp these oscillations.

Figure 2A shows results obtained with the new controller settings: $Kc = 1$, $Ti = 120$ s, $Td = 10$ s, $Ts = 15$ s. The temperature in room G3 remained within 0.5°C of the setpoint. The count recorded by the computer revealed that ventilation stages 2 and 3 were active on 17 Feb. 1986 (Fig. 2A) and were cycling at 2- to 6-min intervals. The equipment cycling was also evident from the humidity record. The average relative humidity was about 10% higher than that in room G2 (Fig. 2B), indicating

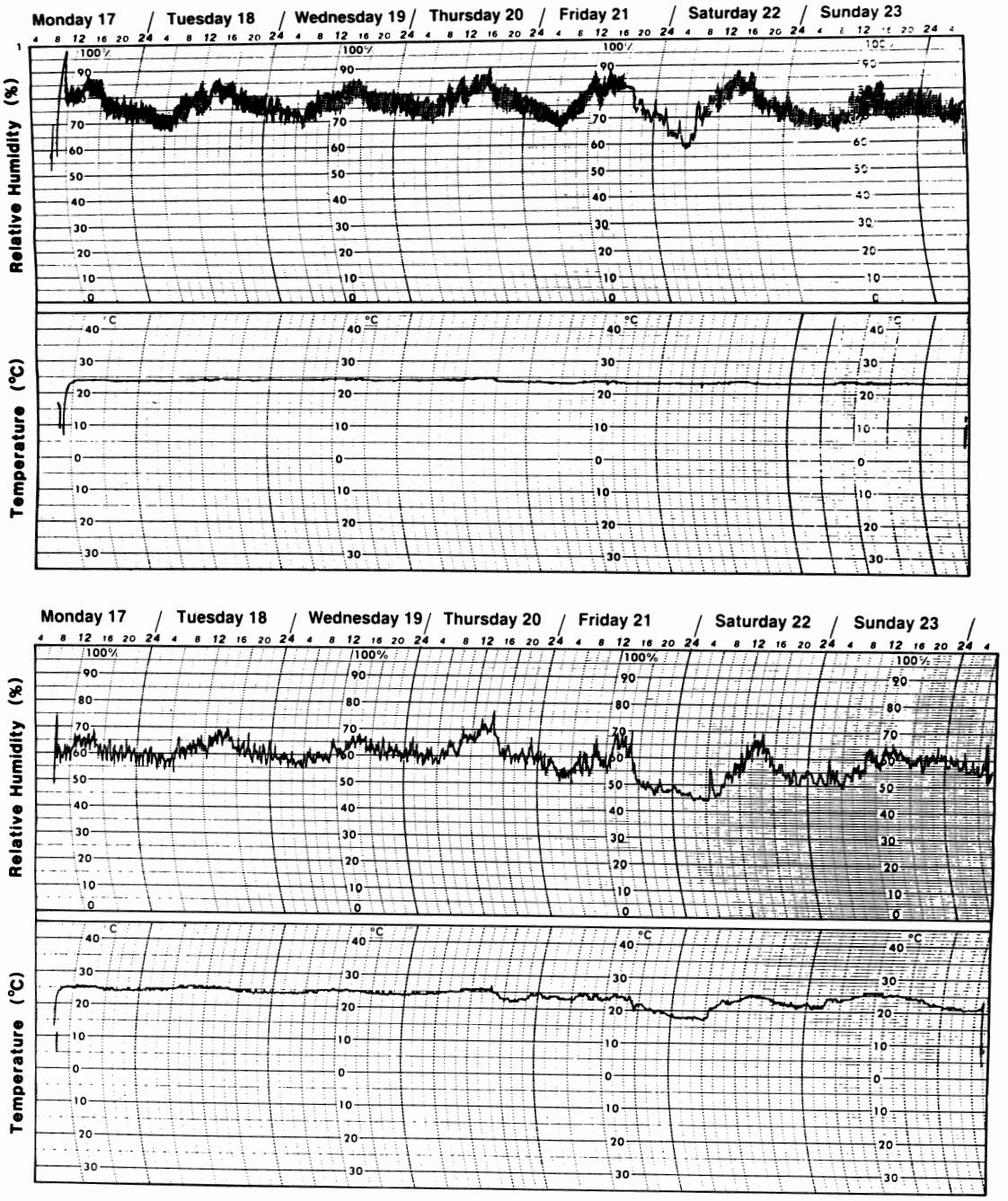

Figure 2. (a) Temperature-humidity profiles, week of 17-23 Feb. 1986; Grower room no. 3. (b) Temperature-humidity profiles, week of 17-23 Feb. 1986; Grower room no. 2.

a lower ventilation rate in room G3. No livestock health problems were noted, hence room G2 was possibly over-ventilated.

The data from room G2, shown in Fig. 2B, indicate a 5°C diurnal temperature variation at the end of the week. Fan cycling is also evident from the humidity record. The heater in room G2 was oversized, particularly for milder weather conditions. The fan may have run to cool the room resulting in unnecessary energy consumption. A poorly located internal heater thermostat may also have been responsible for the fan cycling.

Figure 3 presents a comparison between the energy consumed to heat the two rooms. The data from room (G2) with conventional temperature control were subtracted from those from room (G3) with computer control. On only a few occasions did the computer-controlled room require greater energy to maintain the temperature. The estimated cost saving resulting from the computer control from 30 Jan. to 19 Apr. 1986 amounts to 3000 kWh or $150 at $0.05/kWh. This period is approximately half of the heating season, hence the annual savings are approximately $300.

Table II gives the details of the cost of the computer control system for room G3. The total results in a simple payback period, based on the energy savings, of 5.3 yr. Much longer trials are required to assess the livestock health benefit of better temperature control.

MANAGEMENT COMMENTS

The farm operator noted that the temperature control was greatly simplified by the computer. The setpoint was chosen, set and

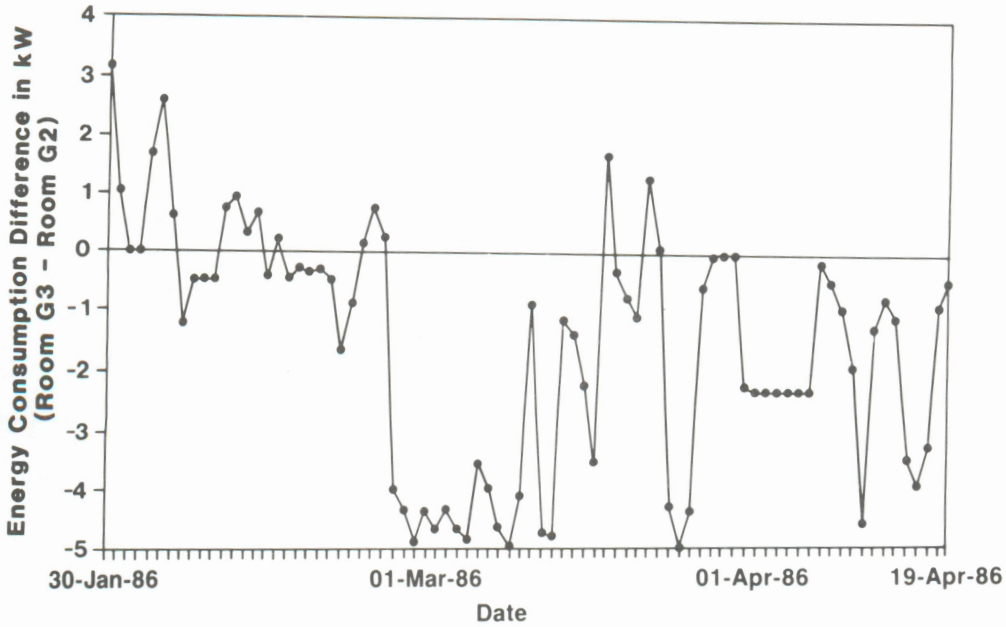

Figure 3. Energy use comparison.

Table II. Cost of computer control system with additional heating and ventilating equipment

Radio Shack Colour Computer	$190
Interface board and components	200
Hardware	50
Optically isolated relays (7 total)	210
Heater (5 kW Chromalox)	220
Two fans	300
Wiring	175
Installation	250
Total	$1595

the temperature was maintained. Grower room G2 required continued adjustment of the heater and fan thermostats. This process was aided by the monitoring thermohygrograph charts. In many cases, the room temperature dropped below that desired or the heater was operated excessively. Better cold weather control was also achieved in room G3. They attributed this partly to the installation of the smaller fans.

They did not note any differences between the health of the pigs in room G2 and those in room G3. The air in room G3, however, felt ''heavier'' because of the higher humidity due to the lower ventilation rate.

CONCLUSIONS

The results of these tests confirm the applicability of computer temperature control in livestock housing. Computer controllers improve temperature regulation and can save energy.

The PID algorithm provides good control of the temperature. A controller gain setting for all barns cannot be recommended due to the variations in the capacity of both the fans and heaters used. Fine tuning of the installed system is still required. A simple method of determining the optimum PID controller settings before installation in various livestock and poultry operations has yet to be developed.

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