A relative humidity controller for experimental turkey housing

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Hao, H. and Leonard, J.J. 1995. **A relative humidity controller for experimental turkey housing**. Can. Agric. Eng. **37**:113-117. A conventional temperature-based fan controller was modified so that it could be used to modulate fan speed on the basis of relative humidity. The thermistor in the original controller was replaced with a field effect transistor (FET) whose gate terminal was connected to an analog output port of a computer data acquisition and control board. The same board was used to acquire relative humidity signals from a thin-film-polymer humidity sensor. Software was written to control humidity in a poultry house at set points of approximately 30% RH and 60% RH. The system provided good control at both levels although, because of the air inlet and heating system, control was not as good at the higher level.

Le dispositif de contrôle d'un ventilateur conventionnel fonctionnant d'après la température a été modifié en vue de moduler la vitesse du ventilateur d'après l'humidité relative. Le thermisteur du dispositif original a été remplacé par un transistor à effet de champ (TEC) relié au port de sortie analogique d'une carte d'acquisition et de contrôle des données. La même carte a servi à capter les signaux d'humidité relative d'un détecteur d'humidité à membrane mince de polymère. Le logiciel avait été élaboré pour contrôler l'humidité d'un poulailler à des valeurs de réglage d'environ 30% H.R. et 60% H.R. Le système a fourni un bon contrôle aux deux points; cependant, à cause des circuits d'entrée d'air et de chauffage, il n'était pas aussi efficace à un niveau supérieur.

INTRODUCTION

Conventional control of ventilation systems in animal housing is based on the inside air temperature. Maintaining a heat balance in the ventilated space dictates that as the outside (ie., inlet) air gets colder the ventilation rate must be reduced to the point where heat generated by the housed animals is insufficient to counteract the effect of the cold incoming air. The outside air temperature at which this occurs depends on the housing design and on the species, number, and age of animals housed.

At lower outside air temperatures, the inside air temperature must be maintained by supplemental heating rather than ventilation control. Since temperature is not useful as a ventilation control parameter under these circumstances two alternatives exist. One is to maintain a constant ventilation rate. This will involve paying for some energy wastage in the form of supplemental heat.

The other alternative is to control ventilation rate on the basis of relative humidity (Zhang et al. 1990). In this case, the ventilation control system would seek to maintain a constant or desired maximum relative humidity (RH) instead of maintaining a constant or desired maximum temperature. The desirability of controlling ventilation rate on the basis of parameters other than temperature is well known (Albright 1990) and temperature/humidity control systems have been developed for this purpose (Vansteelant et al. 1988; Barrington and Desjardins 1989).

In the work that is the subject of this paper, a temperature-based ventilation controller was modified to work on the basis of humidity. As part of a project aimed at evaluating humidity sensors (Hao and Leonard 1994), data were obtained on the performance of the resulting humidity control system, at two humidity levels, over an extended period in an animal environment. Since the primary purpose of the work was to evaluate sensors, a complete, systematic evaluation of the control system was not attempted and the results, which were obtained under limited winter ventilation conditions in specialized research facilities, are not intended to be extrapolated to production facilities. Nevertheless, the approach used to obtain an easily-modified humidity control system could prove useful to researchers working in this area.

FACILITIES AND METHODOLOGY

Controller modification

A simple temperature-based variable-speed fan controller was modified to provide a microcomputer-based humidity control system. A modulating fan speed controller (T731A Modufan, Honeywell, Scarborough, ON) was used for the modification. This controller varies the fan speed electronically using a line-voltage rated, high-speed electronic triac which supplies a delayed phase-angle AC voltage to the controlled fan load. The phase angle delay varies in proportion to the sensed temperature. As sensed temperature increases, the RMS AC voltage supplied to the fan load increases, causing fan speed to increase. Similarly, as sensed temperature decreases, voltage supplied to the fan load will decrease. Figure 1 presents the characteristic curve of the controller operation (fan-on mode). Under the fan-on mode, the fan speed remains at a minimum rate at temperatures more than 2°C below set point.

The temperature sensor used in the controller was a thermistor. To control humidity levels based on RH signals, a relay switch was inserted between the thermistor and the controller. This allowed the thermistor to be isolated from the controller. At the same time, a field effect transistor (FET) (2N5460) was placed in parallel with the thermistor, as shown in Fig. 2. The FET was used to simulate the thermistor

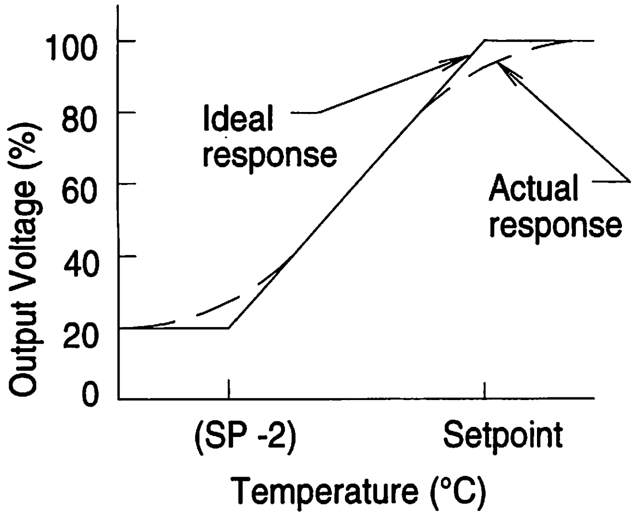

Fig. 1. Controller characteristic curve (fan-on mode).

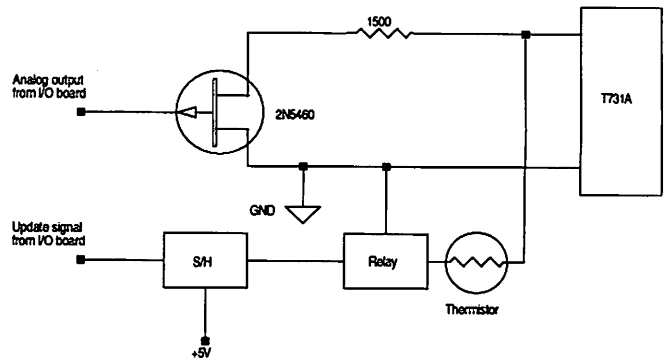

Fig. 2. Thermistor bypass circuit.

when humidity-based control was required instead of temperature-based control.

Under temperature-based control, the resistance of the thermistor changed in response to temperature. Under humidity-based control, the effective resistance of the FET was made to change by means of a computer-controlled analog signal to the gate terminal that was dependent on measured RH.

RH control system

The RH control system was a typical feedback control system. A RH sensor provided a signal via an analog-to-digital converter to a computer which compared this signal with the RH set point. A voltage, which was a function of the difference between the sensed signal and the set point (Fig. 1), was transmitted to the gate terminal of the FET to control ventilation rate. Potentially, this system is very flexible since any desired control algorithm can be implemented in software. Also, artificial time lags can be inserted into the humidity measurement loop to investigate the effects of these on system dynamics.

To maintain at least the minimum ventilation rate in the event of a computer or software failure, a failure protection scheme was required. This protection was accomplished by updating the control signal to the isolating relay every two seconds via a sample-and-hold (S/H) device (LF398) as shown in Fig. 2. In the case of a software failure or a temporary power failure, the S/H would disconnect the RH control system and the isolated thermistor would be reconnected to the controller. Under such a condition, the ventilation rate would change based on the response of the thermistor and the original temperature set point for the controller.

A preliminary test demonstrated that when the average (V_{ac}) voltage supplied to the fan load changed from the lowest value (approximately 20 V_{avg}) to the highest value (approximately 98 V_{avg}), the largest control (V_{dc}) range required was around 1.6 volts. This largest analog input range occurred at the temperature set point of 35°C. For control purposes, a large analog input signal range was desired to provide greater control sensitivity. Therefore, the temperature set point was set at 35°C for both controllers during actual tests. The 35°C set point also ensured that the fan speed would remain at the minimum value when the thermistor sensor was switched back into operation. This was convenient for winter tests but might not be practical under summer conditions.

Data acquisition and control system

An IBM PC was used to run the RH control program. An input/output (I/O) expansion board (Dascon-1, Metrabyte Corp., Taunton, MA) was used in conjunction with the computer for control and data acquisition. The I/O board had 4 analog-to-digital (A/D) input channels, 12 digital I/O ports, 2 digital-to-analog (D/A) output channels and 12-bit resolution for A/D and D/A channels. Under RH control, the ventilation rate was changed by varying the gate signal to the FET by means of an analog signal from a D/A output channel on the I/O board.

The control program implemented on the IBM PC was written in BASIC language. I/O software supplied by the manufacturer was accessed using Call statements in BASIC. The subroutines initiated A/D conversion, data transfer to memory, reading or writing data to ports and setting a programmable timer. The raw data were stored on diskette by the computer, from where they could be retrieved and processed as needed.

The control program implemented a simple proportional control algorithm. The sensed relative humidity was compared with the maximum and minimum allowable RH which had a tolerance range of ± 2% RH. If the sensed RH was out of the allowable range, the ventilation rate would be changed by varying the D/A output signals to the FET.

Experimental environment

A field test of the RH control system was conducted in two rooms of a turkey barn at the University of Alberta's Parkland Research Station in Edmonton during winter. The two rooms were equipped with a separate air temperature control system which consisted of a hot air duct with a heater installed at the air inlet so that outside air could be heated as it flowed through the air inlet duct to an attic. Air was drawn from the attic into the test rooms by ventilation fans. The ventilation fans in each room consisted of a variable speed fan (Model SD 12-EV, Canarm Ltd., Brockville, ON) and a two-speed fan (Model S 8-B2, Canarm Ltd., Brockville, ON). Each test room also had a recirculation duct. The variable speed fan in each room was controlled by a controller (T731A Modufan, Honeywell, Scarborough, ON) which was modified as described above to operate under computer control. The ambient temperature and the RH inside the test rooms were measured by RTD temperature sensors and thin-film polymer RH sensors, respectively, that were packaged together in two different units (Models HT-220 and HT-46, Rotronics Instrument Corp, Huntington, NY). The outside RH was calculated from dew point temperature measured by a dew point hygrometer (Model HYGRO-M1, General Eastern, Watertown, MA). The RH and temperature sensor units were suspended from the ceiling of the controlled air space and were located in the same position in each of the test rooms. The two RTD temperature sensors and the two thin film RH sensors were calibrated prior to each test and their dynamic response was known from previous laboratory investigations (Erdibil and Leonard 1992).

The two test rooms measured 3.4 x 4 x 2.4 m. They each had a floor area of 13.6 m^2 and could be considered identical. The recirculation duct and counter-balanced continuous slot inlet ensured complete mixing of incoming air with the resident air and the air distribution patterns were the same for both rooms. Each room contained 75 turkeys and different relative humidity levels could be achieved by controlling the ventilation rates. Figure 3 shows a cross section elevation of the experimental rooms.

During tests of humidity control performance, the air space temperature in the experimental units was nearly constant ranging from 25 to 27°C. The RH levels of the pre-heated inlet air, as measured in the attic, were quite low and ranged from 12 to 21% RH.

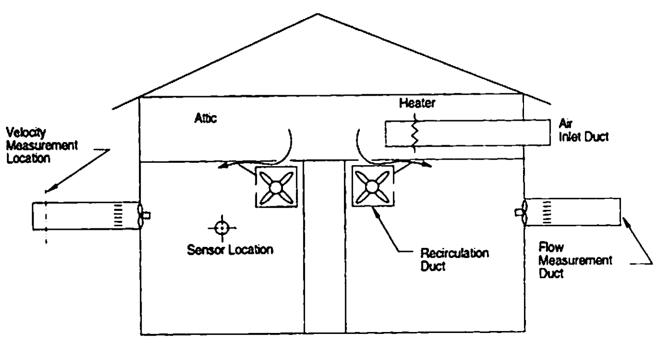

Fig. 3. Cross sectional schematic of experimental units.

Experimental design

The performance of the RH-based controller was tested for accuracy and reliability over a period of six weeks in the turkey environment.

A three-way, cross-classification analysis of variance (ANOVA) was used in this experiment to evaluate the effect of three factors: sensor type (Model HT-220 and HT-46), relative humidity level (30% RH and 65% RH), and exposure time. To evaluate the influence of these factors on the performance of the controller, a composite parameter termed a Control Performance Index (CPI) was used. Essentially, this was a time-averaged error defined as:

$$CPI = (\Sigma E \Delta t)/t \tag{1}$$

where:

E = error (%RH) observed after a time interval Δt (h), and
t = total monitoring period (h).

Thus, an error of 1% RH for two, 30-minute intervals would result in a CPI of one. Absolute values of error were used and these were measured at 30 minute intervals for a total of two consecutive days every week for a 6-week period. The half-hourly interval was selected on the basis of preliminary tests and associated work on sensor evaluation (Hao and Leonard 1994).

The experiment was conducted for a 24-h period with each RH control set point. During this time, one room was maintained at high relative humidity and the other at the lower humidity level. At the end of the 24-h period the control set points for each room were reversed and the test repeated for a further 24 h. Based on the consideration that, during the set point changing period, there could be significant influence on the controller performance index, a two to four hour interval was allowed before data were used for statistical analysis.

The statistical analysis was based on a general linear model (Eq. 2) and the three-factor interaction term was considered as the valid error for the model. The probability level of less than 0.05 was considered significant for this test.

$$Y_{ijk} = U + WK_i + RH_j + S_k + (WK{\bullet}RH)_{ij} + (WK{\bullet}S)_{ik} + (RH{\bullet}S)_{jk} + E_{l(ijk)} \tag{2}$$

where:

Y_{ijk} = predicted CPI,
U = population mean,
WK_i = effect of the ith week,
RH_j = effect of the jth RH level,
S_k = effect of the kth sensor,
$(WK{\bullet}RH)_{ij}$ = effect of interaction of week i and RH level j,
$(WK{\bullet}S)_{ik}$ = effect of interaction of week i and sensor k,
$(RH{\bullet}S)_{jk}$ = effect of interaction of RH level j and sensor k, and
$E_{l(ijk)}$ = random error within the (ijk) cell.

Hypotheses tested

The following hypotheses were tested with the ANOVA:

1. The type of RH sensor does not have a significant effect upon the CPI.
2. The RH level does not have a significant effect upon the CPI.
3. The exposure time does not have a significant effect upon the CPI.

RESULTS AND DISCUSSION

Figure 4 shows graphs of typical RH levels recorded during test periods and provides a qualitative picture of the control system performance. Table I gives the mean CPI values and standard deviations for each RH level, each sensor, and each week of the test.

The results from the ANOVA indicated that the sensor types and exposure time had no significant effect on the performance of the controller, but the effect of relative humidity levels was highly significant ($P < 0.01$).

For the high RH set point, a mean CPI of 3.14 with a standard deviation of 1.07 was observed. The results for the low RH set point showed a 54% decrease in CPI with a standard deviation of 0.53. As shown in Fig. 4, the controlled RH followed the two RH set points very well, but there was a larger RH fluctuation around the high control set point than the low set point. This can be explained by the difference in the time constants of the processes for reducing and increasing the relative humidity. Since the inlet air from the attic was quite dry, relative humidity in the room could be reduced quickly by increasing the ventilation rate and could be maintained at a low level simply by maintaining a high ventilation rate. However, increasing the relative humidity depended on the moisture generated by the birds and litter and, consequently, was a slower process than humidity reduction.

Once the relative humidity level exceeded the high set point, the ventilation rate would begin to increase and could result in over-correction. Recovery from such an overshoot was relatively slow and resulted in a correspondingly higher CPI than at the low set point. If the attic air had been more humid or if the system had included some provision for actively adding moisture to the air, the difference between the two set points would have been less pronounced.

The above explanation is, of course, conjectural in nature and would require further investigation for confirmation. A modelling approach, such as that adopted by Zhang et al. (1993), could be useful in this regard and could also be used to predict the performance of the system under summer conditions.

Table I. Summary of control performance

Source	Mean (CPI)	SD
High RH level	1.57	1.07
Low RH level	0.72	0.53
Sensor #1	1.12	0.95
Sensor #2	1.17	0.96
Week 1	1.19	1.05
Week 2	1.15	0.91
Week 3	1.16	0.92
Week 4	1.14	0.95
Week 5	1.10	0.92
Week 6	1.13	0.96

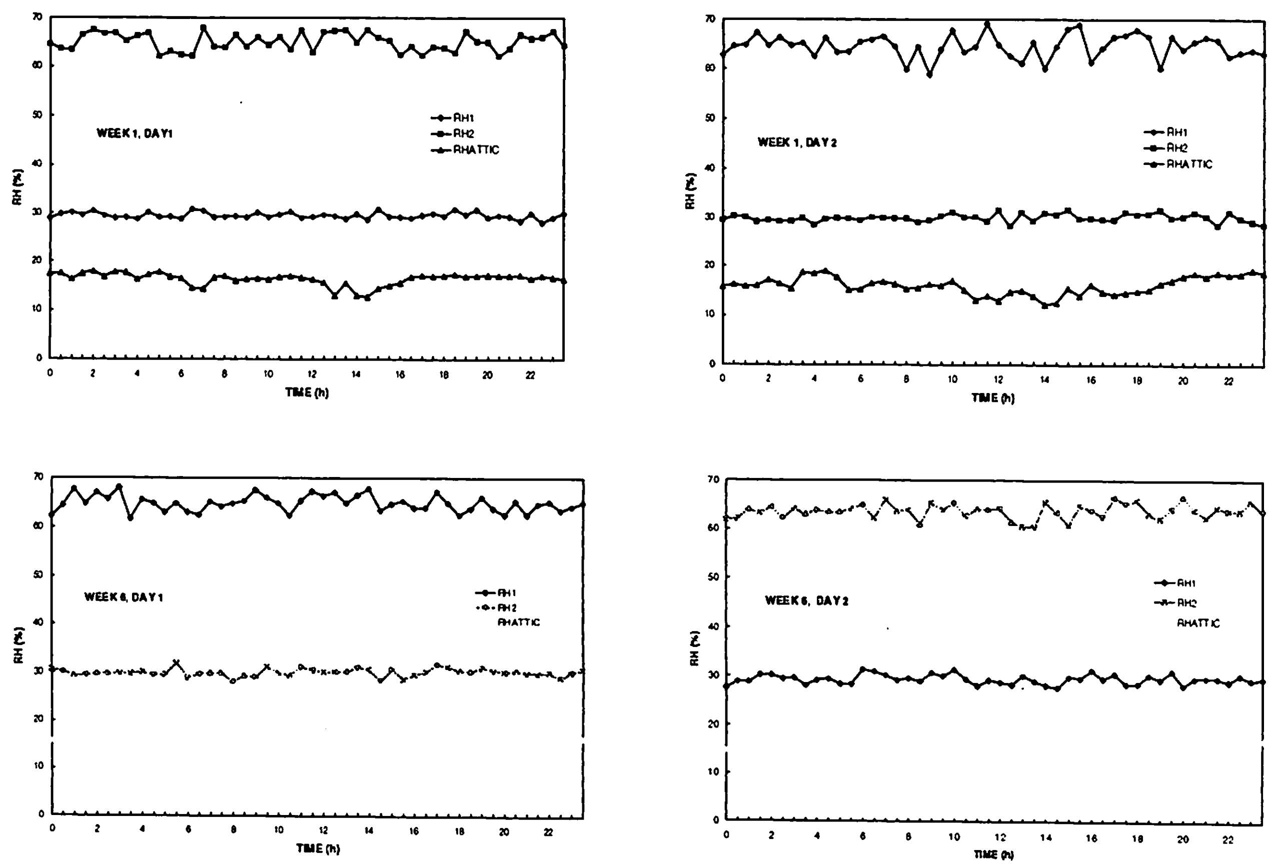

Fig. 4. Control system performance - Week 1 and Week 6.

CONCLUSIONS

Based on the results obtained in this study, the following conclusions were drawn:

1. The modified, temperature-based fan controller, used in conjunction with a computer, provided a convenient experimental system for controlling relative humidity.
2. The concept of a Control Performance Index (CPI) was useful in evaluating the performance of the humidity control system tested.
3. The tested system performed well at the two relative humidity set points. The system performed better at the low RH set point than at the high RH set point with a CPI of 1.44 for low RH and 3.14 for high RH.
4. The effects of the sensor type and exposure time on the performance of the controller were statistically insignificant.
5. The significant effect of RH levels on CPI can be explained by the different dynamics of the humidity reduction and humidity increasing processes. More humid inlet air or a means for actively adding moisture to the air could make the control system operate more effectively.

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