Development and Field Test of a Computerized Instrumentation System for Air Velocity and Temperature Measurements in Poultry Houses

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Abstract

An electronic computerized system for environmental measurements in poultry houses has been developed. Sensors were Resistant Temperature Detectors for temperature and air velocity measurements. The system admitted other auxiliary inputs such as differential pressure sensors. The accuracy for the computerized sensing system after calibration was, for air velocity measurements, better than 0.05 m/s in the range from 0.1 to 2 m/s and better than 2% in the range from 2 to 7 m/s; ±0.2ºC for air temperatures and ±5 Pa for pressure measurement. The system was tested to measure and record the environmental parameters in a real poultry building.

Keywords: Air velocity, temperature, poultry, ventilation, hot-wire anemometers

Introduction

Poultry farms with inadequate ventilation systems can suffer high mortality rates when indoor air is hot, humid, and nearly still in the animal occupied zone. Air velocity uniformity in the animal occupied zone is equally important, to prevent animal migration into better ventilated but already crowded areas, which also contributes to increase animal mortality. The issue of which air velocities are necessary to avoid chicken stress under hot conditions has been widely studied in the literature on animal farming (Simmons et al., 2003; Tao & Xin, 2003; Yahav et al., 2004). The ability of standard environmental control systems and building designs, to create suitable velocities in the animal occupied zone in poultry farms, can be evaluated from air velocity measurements in commercial farms (Boon and Battams, 1988; Lee et al., 2003; Wheeler et al., 2003). However, two main issues have to be considered. First, direct measurement with portable hand-held anemometers requires an operator, which unavoidably interferes with the air velocity and therefore distorts the measurement output. In this sense, Wheeler et al. (2003) studied temperature and air velocity uniformity in tunnel and conventional ventilation broiler houses, and stated that air velocities measured by portable hot wire anemometers were highly influenced by the operator who used the anemometer. In that work, they concluded that an automatic velocity measurement system would be an important improvement. Earlier works on airflow patterns and temperature in livestock buildings under Mediterranean conditions (Blanes Vidal et al., 2001) have also revealed the importance of having a computerized system to measure environmental parameters at many points inside livestock buildings. In this sense, commercial air velocity measurement devices from different manufactures, are able to measure air velocity at up to about 6 locations simultaneously (e.g. Testo Instruments), which in practice, is not sufficient for evaluating commercial poultry buildings in an efficient way. Secondly, the evaluation of the animal’s comfort
in commercial occupied broiler buildings has to be done from measurements taken at birds’ level. However, technicians usually take measurements at higher height above floor, out of birds reach, due to the difficulty of measuring close to animals, specially when sensitive sensors, such as hot-wire anemometers, are used. The objectives of this work are:

1. To develop a computerized system to measure and record, air velocity and temperature simultaneously at several points inside poultry building.
2. To measure air velocity and temperature in a commercial poultry house, in order to carry out a field test of the measurement system under practical conditions.

This work is focused on the development of a relatively small (16 input channels) measurement system, that can be used as a basis for the development of a measurement system with a larger number of sensors, which would be just a repetition of those used here.

**Materials and methods**

**Description of system components**
The system was composed by a portable computer, a data acquisition card (DAQ), and a configurable set of sensors and associated electronic circuits (Figure 1). Sensor instrumentation and some additional circuits were developed specifically for this application. Signals from sensors were buffered, amplified, and then, transmitted in current mode to the acquisition point, where they were converted to voltage according to the voltage range indicated in the DAQ datasheet (from 0 to 10 V).

![Figure 1. Block diagram of system components. Notation are as follows: V = Air velocity, T = Temperature, P = Differential pressure, DAQ = Data acquisition card, Ch. = Channels](image)

The data acquisition card used for the A/D conversion, was DAQCARD-6024E (National Instruments), with a resolution of 12 bits and 16 input channels. Specific software for monitoring and acquiring the data was developed based on LabView 6.0 (National Instruments). The developed software works as follows: A certain number of data \( n \) is acquired through each channel, with a sampling frequency of \( 1/t_1 \). When time \( t_2 \) is passed, the software calculates the mean and standard deviation of the \( n \) measurements. Means and standard deviations of successive periods of \( t_2 \) seconds, are collected, and can be saved at the end of the experiment. All three parameters \( (n, t_1 \) and \( t_2) \) can be defined by the user in the front panel of the software. The frontal panel of the software displays the current measurements of all 16 channels,
in independent graphs and numerical indicators. The acquisition of data can be stopped by the appropriate controller of the software. When a measurement session is stopped, all collected data is displayed automatically in a specific zone of the front panel. At that moment data can be saved, and be opened with Excel program. The system was designed to measure air temperature and air velocity, although it admitted other auxiliary inputs, such as data from differential pressure sensors. Table 1 summarizes the type, number and main characteristics of the sensors installed. The key components of the system are briefly described below.

Table 1. Number of sensors, type and characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nº</th>
<th>Sensor type</th>
<th>Measuring principle</th>
<th>Model (Manufacturer)</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>7</td>
<td>RTD (Pt100)</td>
<td>Resistance (constant current)</td>
<td>TFD</td>
<td>Calibrated resistor</td>
</tr>
<tr>
<td>Air velocity</td>
<td>5</td>
<td>RTD (Pt100)</td>
<td>Hot wire anem. (constant temperature)</td>
<td>TFD</td>
<td>Wind tunnel</td>
</tr>
<tr>
<td>Pressure (differential)</td>
<td>4</td>
<td>Silicon gauge</td>
<td>Resistance bridge</td>
<td>HCXM010D6V (SensorTechnics)</td>
<td>Liquid column</td>
</tr>
</tbody>
</table>

Temperature sensors were RTD’s (Resistant Temperature Detector) from Omega Engineering Inc. Each sensor consisted of a thin layer of platinum deposited on a small ceramic substrate, of 2x10 mm. This element complies with DIN 43760 and BS 1904 standards. Voltage difference, measured at a low constant current (auto-dissipation remains below 100µW with a current of 1mA), is related with ambient temperature. Temperature sensors were calibrated by means of a set of three standard resistors (precision of ±1mΩ) equivalent to three temperatures (0ºC, 27ºC and 40ºC), according to DIN 43760.

Air velocity was estimated by means of constant temperature hot wire anemometry. An RTD sensor was maintained at a constant temperature of 60ºC. The voltage \( U \) applied to the sensor needed to maintain this temperature under different conditions of flow, is related to air velocity \( v \), in m/s) over the sensor. The theoretical formula that describes this behaviour is the King’s Law (Equation 1).

\[
U^2 = (T_w - T) \cdot K \cdot (a + b \cdot \sqrt{v})
\]  

\(1\)

where \( T_w \) and \( T \) are temperatures of the sensor and the air (ºC), respectively; \( a \) and \( b \) are constants related to convective effect and \( K \) is a constant dependent on the electronic instrumentation. Equation 1 can be generalized using \( v^m \), with an exponent \( m \) slightly inferior to 0.5 (Zhang et al., 1996). The value of the exponent \( m \) and the other coefficients were experimentally determined for each individual sensor.

Anemometer circuit performance was calibrated in a wind tunnel. To validate velocity measurements, initial data were transformed according to the Equation (2), where \( T \) is the air temperature measured by the temperature sensors, and \( T_w \), \( K \) are constants for each sensor. Then, a linear regression was performed between X and Y variables.
\[
\begin{align*}
Y &= v^m \\
X &= \frac{U^2}{(T_w - T) \cdot K} \\
&\Rightarrow \quad Y = \frac{1}{b} \cdot X - \frac{a}{b} \\
&\Rightarrow \quad Y = A \cdot X + B
\end{align*}
\]

Differential pressure sensors consisted of an integrated silicon gauge sensor. External instrumentation was exclusively for amplifying the voltage to the level required by the data acquisition card. Pressure sensors were calibrated with a manometric system.

Field Test in a Commercial Poultry House

Air velocity and temperature in a commercial poultry house was measured with the developed system, in order to carry out a field test of the measurement system under practical conditions.

The experimental building was a commercial Mediterranean poultry farm (Figure 2a), equipped with conventional negative pressure cross-ventilation. The dimensions of the building were: length, 69.8 m; width, 15 m; side-wall height, 2.36 m, and maximum distance from floor to ceiling, 3.94 m. The animal house was provided with 56 sidewall inlets located 1.8 m above floor. Nine exhaust fans (six big fans, with a diameter of 0.63 m, and a nominal airflow rate of 36000 m$^3$/h; and three small fans, with a diameter of 0.32 m and nominal airflow rate of 10500 m$^3$/h) were placed at the opposite wall. The poultry house was occupied by broilers aged 50 days. The stocking density was of 12 animals/m$^2$ and the average weight of the animals was about 2.8 Kg. An interior view of the poultry house during the experiment is shown in Figure 2b.

The experiment was carried out under high ventilation rate conditions, which were: All big fans and one small fan running, and inlets opened 75% of the maximum (inlet slot 17.2 cm). Measurements were taken in a specific area of the farm (Figure 2a).

For all the measurements taken with the computerized sensing system, the sampling frequency was 2 Hz, so measurements were taken simultaneously from all sensors, every 0.5 seconds. In order to filter the measurement noise, the sensor readings were filtered by a moving window (low pass filter) of the length of 5 seconds (placed symmetrically around the time instant of interest), therefore the measurements were averaged every 5 seconds and the mean value was considered as the reading of the mentioned time frame.

Figure 2. Poultry building. (a) Dimensions and test zone. (b) Interior view during the field test
Three air velocity sensors and three air temperature sensors were placed in pairs, in a mobile post (Figure 3a) at three heights: (1) birds level (0.2 m); (2) the level at which air temperature and velocity sensors are usually located (0.6 m); and (3) a height where high velocities are expected (2 m). A wire cage protected the sensors (Figure 3b). The openings in the cage were 20x20 mm, and the steel wire was 2.5 mm in diameter.

The measurement post was located successively at the nine coordinates of the test zone (Figure 4), and it took data during 6 minutes (720 measurements) per location. The order of the indoor measurements (location of the measurement post) was set at random.

The remaining temperature sensors were located at two of the inlets and two of the exhaust fans, and the air velocity sensors at two inlets. The differential pressure sensors were not tested in this experiment.

Figure 3. Measurement post and sensors. (a) Sensors location in the post. (b) Wire mesh protection

Figure 4. Measurement points in the test zone and mobile post with sensors at three heights: 0.2 m, 0.6 m and 2 m (distances in meters)
Results

Calibration
Due to the narrow range of ambient temperature, a linear response for the air temperature sensors was assumed (Figure 5). The calibration line had a correlation coefficient \( r \approx 1 \). For all air velocity sensors, the regression coefficient \( R^2 \) obtained was better than 0.996 (Figure 6). Measured air velocities compared to true air velocities from one of the sensors are given in Figure 7 corresponding to velocity ranges of 0.1-1.5 m/s (a) and 1.5-7 m/s (b). Pressure measurements showed a linear correlation coefficient better than 0.9995 between differential input pressure and output voltage (Figure 8). The accuracy for the computerized sensing system after calibration was, for air velocity measurements, better than 0.05 m/s in the range from 0.1 to 2 m/s and better than 2\% in the range from 2 to 7 m/s; ±5 Pa for pressure measurements, and ±0.2°C for air temperatures.

Figure 5 Calibration line for a temperature sensor; \( p_{\beta 1} < 0.01 \), probability value for the slope; \( p_{\beta 0} \), probability value for the intercept; RSD, residual standard deviation

Figure 6. Calibration line for one of the air velocity sensors; \( p_{\beta 1} < 0.0001 \), probability value for the slope; \( p_{\beta 0} \), probability value for the intercept; RSD, residual standard deviation.

Figure 7. Measured and true air velocity from the calibration of one of the sensors, (a) range from 0.1 to 1.5 m/s; (b) range from 1.5 to 7 m/s; \( p_{\beta 1} \), probability value for the slope; RSD, residual standard deviation
Environmental Measurements in a Commercial Poultry House

Air velocity and temperature at all three heights and in the inlets and outlets were measured. When the animals are heat stressed, air velocity and temperature at 0.2 m above the floor are the most important parameters, as they define the conditions in the micro-environment around the chickens.

The results showed that in general terms, higher air velocities at birds’ level were measured close to the sidewall where the inlets were mounted (average of 0.26 m/s, Figure 9). Air velocity in the centre line of the building and close to the side wall of the fans (except in front of the biggest fan, where the air velocity was 0.38 m/s) did not exceed the minimum air velocity recommended for broilers (0.1 m/s). Regarding air temperature, the minimum temperature was of 23.5 ºC and the maximum temperature of 26.3 ºC (Figure 9). Both temperatures are higher than the recommended air temperature for 7 weeks age broilers (20ºC).

Figure 8. Calibration line for a differential pressure sensor

Figure 9. Air velocity and temperature at birds’ level (0.2 m above floor).

Figure 10 shows air velocity and temperature measured at 9 locations of the plane XY where the post was placed, at three heights (0.2 m, 0.6 m and 2 m). Air velocity at 2 m was higher than at 0.2 and 0.6 m at all points measured. Air velocities at 0.2 and 0.6 m
were very similar at all the coordinates except at points B1, C1 and D1, located close to the inlets wall. The maximum difference was 0.11 m/s.

![Air velocity measured at nine locations of the test zone, at three heights: 0.2 m, 0.6 m and 2 m](image)

**Figure 10.** Air velocity measured at nine locations of the test zone, at three heights: 0.2 m, 0.6 m and 2 m

**Conclusions**

(1) An electronic computerized system for environmental measurements in poultry houses was developed. Sensors were RTD’s for temperature and air velocity measurements. The system can acquire up to a maximum of 16 independent signals.

(2) The accuracy for the computerized sensing system after calibration was, for air velocity measurements, better than 0.05 m/s in the range from 0.1 to 2 m/s and better than 2% in the range from 2 to 7 m/s, ±0.2ºC for air temperatures and ±5 Pa for pressure measurements.

(3) The system was tested to measure and record the environmental parameters in a commercial occupied poultry building.

**References**


