Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2010 8(3), 570-579
ISSN: 1695-971-X
eISSN: 2171-9292

Development and field test of an on-line computerized instrumentation system for air velocity, temperature and differential pressure measurements in poultry houses

V. Blanes-Vidal[1]*, E. Guijarro[2], E. S. Nadimi[1] and A. G. Torres[3]

[1] *Faculty of Engineering. University of Southern Denmark. Niels Bohrs Alle, 1. 5230 Odense. Denmark*
[2] *Department of Electronic Engineering. Polytechnic University of Valencia (UPV). Camino de Vera, s/n. 46022 Valencia. Spain*
[3] *Institute of Animal Science and Technology. Polytechnic University of Valencia (UPV). Camino de Vera, s/n. 46022 Valencia. Spain*

Abstract

Experimental research on airflow patterns and thermal comfort in livestock buildings require the development of an on-line multi-point computerized system for environmental measurements. The characteristics, development and tests of such equipment are described in this article. The system was based on a laptop, a data acquisition card with 16 input channels and a set of air temperature, air velocity and differential pressure sensors. Sensors were resistance temperature detectors for temperature and air velocity measurements. The accuracy of the computerized sensing system after calibration was, for air velocity measurements, 0.05 m s^{-1} in the range of 0.1 to 1.5 m s^{-1}, and from 0.03 to 0.14 m s^{-1} in the range of 1.5 to 7 m s^{-1}; ± 0.2°C for air temperature measurements; and ± 5 Pa for pressure measurements. The system has been used in several research studies in commercial poultry buildings and the developed system has been proven to be robust and stable.

Additional key words: air velocity, measurement, poultry, temperature, ventilation.

Resumen

Desarrollo y evaluación de un sistema informatizado on-line para el registro de medidas de velocidad del aire, temperatura y presión diferencial en granjas avícolas

El desarrollo de un sistema informatizado on-line y multi-punto para la medida de parámetros ambientales en granjas es necesario para la realización de trabajos de investigación sobre ventilación y confort ambiental. En este artículo se describen las características, desarrollo y utilización de dicho equipo de medida. Éste se compone de un ordenador portátil, una tarjeta de adquisición de datos de 16 canales y un conjunto de sensores de temperatura, velocidad del aire y presión diferencial. Los sensores de temperatura y velocidad del aire son sensores de temperatura resistivos. La precisión del sistema de medida tras la calibración fue de 0,05 m s^{-1} en el rango de 0,1 a 1,5 m s^{-1}, y de 0,03 a 0,14 m s^{-1} en el rango de 1,5 a 7 m s^{-1}; ± 0,2°C para medidas de temperatura; y ± 5 Pa para medidas de presión diferencial. El sistema se ha utilizado en varios trabajos de investigación en granjas avícolas comerciales, comprobándose que es un equipo de medida robusto y estable.

Palabras clave adicionales: broilers, medida, temperatura, velocidad del aire, ventilación.

Introduction

Heat stress during the summer can cause significant economic losses in poultry housing. To avoid this, intensive poultry buildings in hot weather areas of Europe and USA, are usually provided with environmental control facilities, including: temperature, humidity and pressure variation sensors, controllers and

* Corresponding author: vbv@kbm.sdu.dk
Received: 18-09-09; Accepted: 04-06-10.

V. Blanes-Vidal and A. G. Torres are members of the SEA.

Abbreviations used: CFD (computational fluid dynamics), DAQ (data acquisition), RH (relative humidity), RSD (resistance temperature detectors).

actuators (ventilating and evaporative cooling systems).

However, when the outdoor temperature and humidity is high (*e.g.* T = 30°C, RH = 70%), the evaporative cooling systems cannot cool the incoming air adequately, the micro-environment around the birds becomes too hot and humid, and animals are heat stressed. In these conditions, a uniform and high air velocity over the animal can be very effective for increasing the convective heat losses from the animals, reducing the effective temperature and improving their thermal comfort (Loot *et al.*, 1998; Furlan *et al.*, 2000; May *et al.*, 2000; Yahav *et al.*, 2001; Yanagi *et al.*, 2002; Simmons *et al.*, 2003; Tao and Xin, 2003; Yahav *et al.*, 2004).

Poultry farms with inadequate ventilation systems suffer higher mortality rates when indoor air is hot, humid, and still in the zone occupied by animals (Tao and Xin, 2003). Air velocity and temperature uniformity in the animal occupied zone is also important to prevent animal migration into better ventilated but already crowded areas, which also contributes to increase animal mortality (Tabler *et al.*, 2002). Determining the uniformity in the vertical direction is also important to ensure that environmental control sensors (usually located about 50-70 cm above floor) reflect the conditions at bird's level (Wheeler *et al.*, 2003). However, the ability of standard environmental control systems and building designs, to create suitable air velocities in the animal occupied zone in poultry farms, is not well documented.

Air velocity distribution can be evaluated from direct aerodynamic analysis by means of air velocity measurements in commercial farms (Boon and Battams, 1988; Lee *et al.*, 2003; Wheeler *et al.*, 2003). However, several issues have to be considered when measuring air velocities in ventilated animal houses.

First, broiler buildings in Europe and USA tend to large structures housing many animals. The evaluation of these large structures must be carried out by measuring environmental variables (including air temperature and velocity) at enough points inside the indoor space. Airflow in ventilated rooms is in general turbulent and therefore it requires continuous measurement of air velocity during a certain time for subsequent calculation of averages. Therefore, simultaneous measurements at different locations in the animal building are necessary for determining the spatial distribution of these variables inside the building in an efficient way and within a reasonable time. 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 simultaneously measure environmental variables at many points inside livestock buildings.

Second, 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 air temperature and 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 study, they concluded that an automatic velocity measurement system would be an important improvement.

The differential pressure between indoor and outdoor air is the variable most commonly used in Mediterranean poultry houses, to adjust the opening of inlets, in order to get a suitable air velocity at the animals' level. Therefore, the computerized system also included differential pressure sensors. This article describes the characteristics of the developed on-line (16 input channels) measurement system, which 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 described here.

The specific objectives of this work were: (1) to develop an on-line multi-point computerized system to measure and monitor, air velocity, temperature and differential pressure inside poultry buildings; (2) to measure air velocity, temperature and differential pressure in a commercial poultry house, in order to test the measurement system under practical conditions, and to carry out a field evaluation of the climate comfort of the animals.

Material and methods

Description of system components

The measurement system was based on a portable computer, a data acquisition card (DAQ), and a configurable set of sensors and associated electronic circuits (Fig. 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

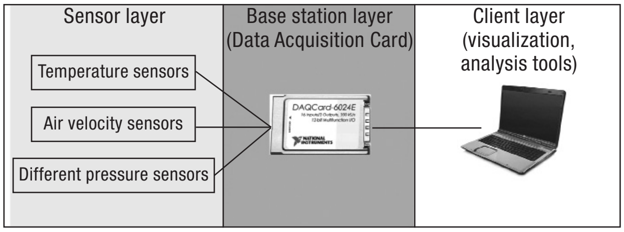

Figure 1. Diagram of system components.

to the voltage range indicated in the DAQ datasheet (from 0 to 10 V).

The system was designed to measure air temperature and air velocity, although it admitted other auxiliaries' inputs, such as data from differential pressure sensors. Table 1 summarizes the type and quantity of the key components used in the instrumentation system. They are briefly described below.

Portable computer and data acquisition card

A laptop and a data acquisition card were used for continuously recording the measured data. The basic specifications of the data acquisition card (DAQCARD-6024E) were: 16 single-ended analog input channels, 12 bits A/D converter, and maximum sampling frequency of 200 kHz.

Software development

Specific software for monitoring and acquiring the data was developed based on LabView 6.0. (National Instruments, 2004). The developed software works as follows: a certain number of data (n) is acquired through each channel of the DAQCARD, with a sampling frequency of ω. After a period of time t, the software calculates the mean and standard deviation of the n measurements. Means and standard deviations of successive periods of t seconds, are collected, and can be saved at the end of the experiment. All three parameters (n, ω and t) can be defined by the user in the front panel of the software (Fig. 2).

Table 1. Instrumentation system components

Device	No.	Description
Portable computer	1	Pentium III, 64 Mb Ram
Data acquisition card	1	National Instruments, Model 6024E
Software	1	National Instruments, Labview 6.0.
Battery	1	0-12 V
Temperature sensor	7	Omega Eng. Inc., RTD, Pt100
Air velocity sensor	5	Omega Eng. Inc., RTD, Pt100
Differential pressure sensor	4	SensorTechnics, Model HCXM010D6V

Temperature sensors

Temperature sensors were resistance temperature detectors (RTDs). Each sensor consisted of a thin layer of platinum deposited on a small ceramic substrate, of 2 × 10 mm. This element complies with DIN 43760 and BS 1904 standards. Voltage difference measured at a low constant current is related with ambient temperature. Self-heating was below 100 μW with a current of 1 mA.

Temperature sensors were calibrated by means of a set of three standard resistors (precision of ± 1 mΩ) equivalent to three temperatures (0°C, 27°C and 40°C), according to DIN 43760. Due to the narrow range of ambient temperature, a linear response for the sensor was assumed. The calibration line had a correlation coefficient equal to 1. The accuracy for the computerized sensing system after calibration was ± 0.2°C for air temperature measurements.

Air velocity sensors

Air velocity was estimated by means of constant temperature hot wire anemometry. An RTD sensor (the same as for temperature measurements) was maintained at a constant temperature of 60°C. The voltage (U) applied to the sensor needed to maintain this temperature under different conditions of flow is related to air velocity (ν) over the sensor, according to King's law (Eq. [1]):

$$U^2 = (T_w - T) \cdot K \cdot (a + b \cdot \sqrt{v}) \quad [1]$$

where T_w is the temperature of the sensor (60°C), T is the air temperature, a and b are constants related to convective effect and K is a constant dependent on the electronic instrumentation. T_w is set equal to 60°C so that the temperature difference between T_w and T under normal conditions is in the 30°C to 100°C range (Webster, 1999). Equation [1] can be generalized using ν^m, with

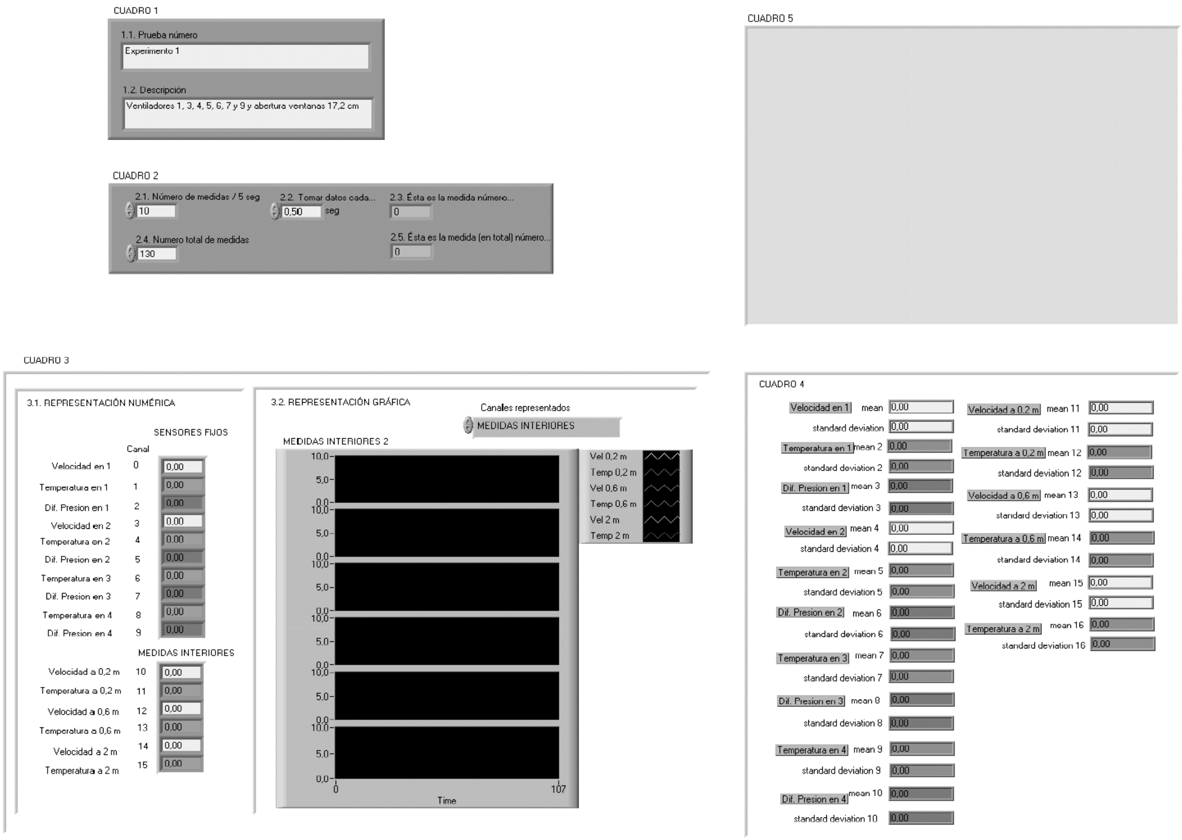

Figure 2. Front panel of the developed software.

an exponent *m* slightly inferior to 0.5 (Zhang *et al.*, 1996). The value of the exponent and the other coefficients were experimentally determined for each individual sensor and its associated circuitry.

The anemometers were calibrated in an air steady flow rig unit. The test unit included a flux generator (airflow range from 5 to 300 kg h^{-1}), regulating valves, electronic pressure gauges (Digima FP autozero, Special Instruments, maximum error 0.5%), and calibrated nozzles (ISO 5167-1). To ensure the proper formation of the velocity profile, a straight duct section was provided upstream of the anemometer location. The calibration was carried out by placing the RTD sensor in the centerline of a calibrated nozzle, measuring the voltage (U) applied to the sensor and calculating the air velocity at the centerline from the pressure drop across the nozzle (Goldstein, 1996). To validate velocity measurements, initial data were transformed according to the Eq. [2]:

$$\left.\begin{aligned} Y &= \nu^m \\ X &= \frac{U^2}{(T_w - T)\cdot K} \end{aligned}\right\} \rightarrow Y = \frac{1}{b}\cdot X - \frac{a}{b} \rightarrow Y = A\cdot X + B \quad [2]$$

where *T* is the air temperature measured by the temperature sensors, and T_w and *K* are constants for each sensor. Then, a linear regression was performed between X and Y variables. The obtained regression coefficient R^2 for each air velocity sensor was higher than 0.996 (Fig. 3). Air velocities measured by the developed system compared to reference air velocities are given in Figure 4 for two velocity ranges, 0.1-1.5 m s^{-1} and 1.5-7 m s^{-1}. The accuracy for the computerized sensing system after calibration was, for air velocity measurements, 0.05 m s^{-1} in the range of 0.1 to 1.5 m s^{-1} and from 0.03 to 0.14 m s^{-1} in the range of 1.5 to 7 m s^{-1}.

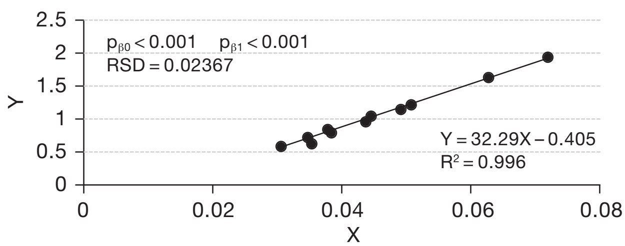

Figure 3. Calibration line for air velocity sensors. $p_{\beta1}$: probability value for the slope. $p_{\beta0}$: probability value for the intercept. RSD: residual standard deviation.

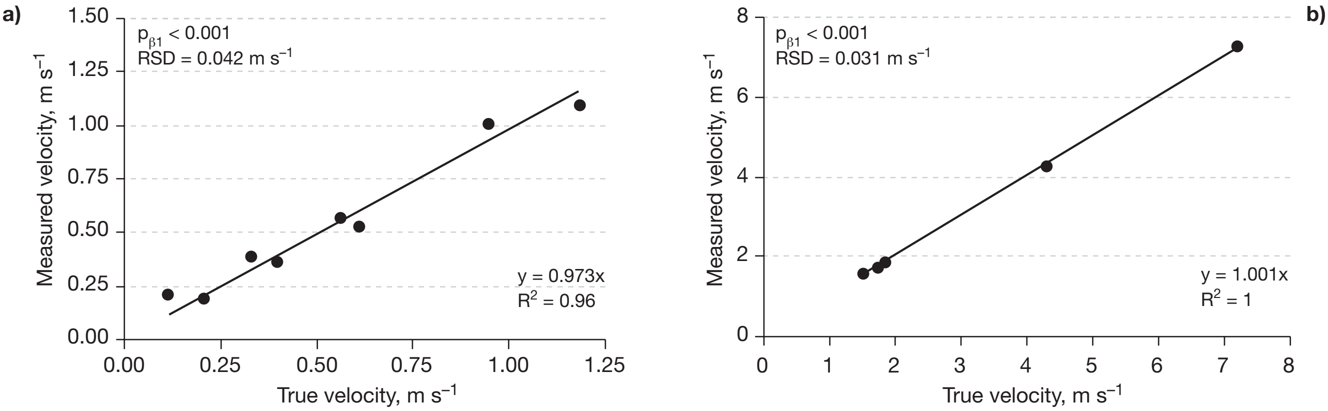

Figure 4. Measured and true air velocity from the calibration of one of the sensors. a) Range from 0.1 to 1.5 m s^{-1}; b) range from 1.5 to 7 m s^{-1}; $p_{\beta1}$: probability value for the slope; RSD: residual standard deviation.

Differential pressure sensors

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. The accuracy for the computerized sensing system after calibration was ± 5 Pa for differential pressure measurements.

Field-tests in a commercial poultry house

Experimental building and animals

Air velocity, temperature and differential pressure in a commercial poultry house located in the Valencian Community (Spain) were measured by the computerized sensing system in a field experiment carried out in summer season (June). The experimental building was a typical commercial Mediterranean poultry farm (Fig. 5), equipped with conventional cross-ventilation by negative pressure. Building dimensions 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 had 56 sidewall prefabricated inlets (Gasnet S.L., Villarreal, Spain) located 1.8 m above floor. Nine exhaust fans were located in the opposite wall: six were type *a* (Model Euroemme EM50-1.5 CV, Munters Europe, Sollentuna, Sweden) with a diameter of 0.63 m, and an airflow rate of 36,000 m^3 h^{-1}; and three were type *b* (Model FC 063-0.7 kW, Ziehl Abegg AG, Künzelsau, Germany), with a diameter of 0.32 m and ventilation rate of 10,500 m^3 h^{-1}. 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.

System setup and measurements

The experiment was carried out under high ventilation rate conditions, which were: Fans 1, 3, 4, 5, 6, 7 and 9 running, and inlets opened 75% of the maximum (inlet slot 17.2 cm). Measurements were taken in the test zone shown in Figure 5.

The animals' comfort in commercial occupied broiler buildings has to be evaluated from measurements taken at birds' level. However, measurements are usually taken at higher height above floor, out of birds reach, due to the difficulty of measuring close to animals, especially when sensitive sensors, such as hot-wire anemometers, are used. In our field test, three air velocity sensors and three air temperature sensors were placed

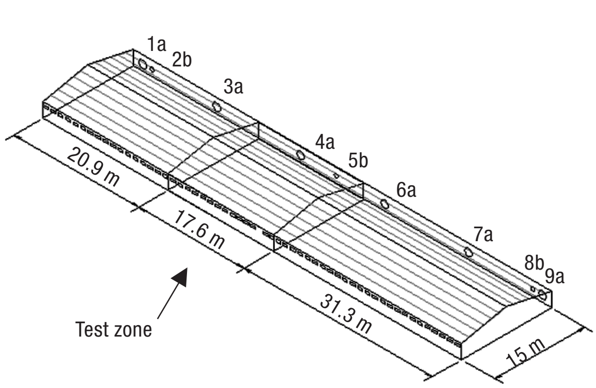

Figure 5. Commercial poultry building showing the experimental test zone, 56 wall inlets and 9 exhaust fans (six type «a» and three type «b»).

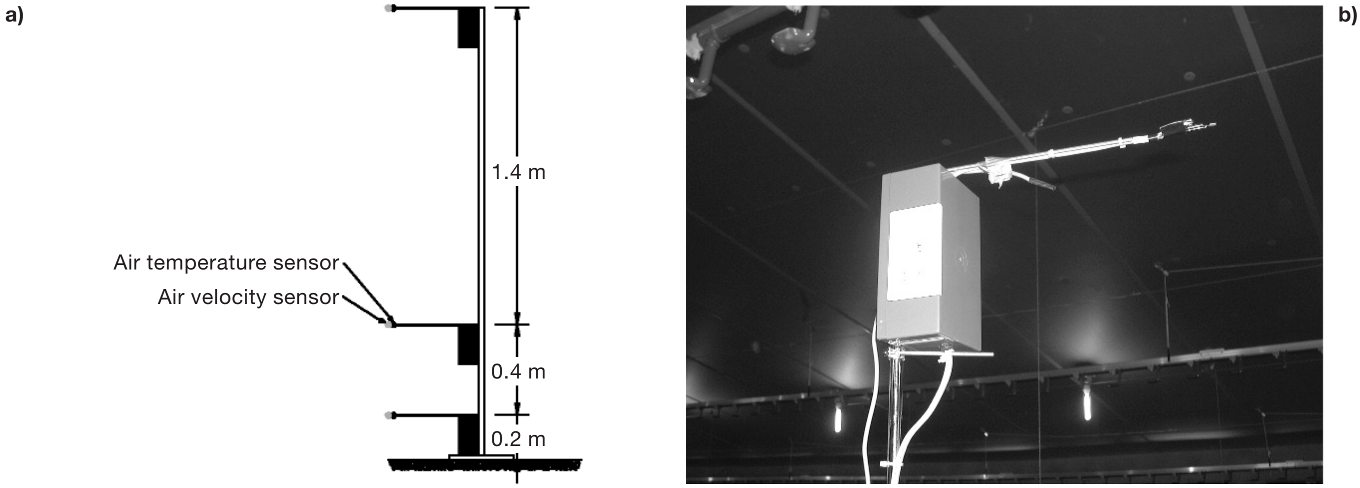

Figure 6. Measurement post showing sensors at three levels (a) and photo showing the sensors (b).

in pairs, in a mobile post (Fig. 6) at three heights: (1) birds level (0.2 m above the floor); (2) the level at which air temperature and velocity sensors are usually located (0.6 m above the floor); and (3) a height where high velocities are expected (2 m above the floor).

The measurement post was sequentially located at nine coordinates of the plane *xy* shown in Figure 7, taking measurements at one *xy* location at every time, during 6 min per location. Measurements were taken at the centreline of the building (A2, C2, D2) and aligned with the drinker lines closer to the side walls (B1, C1, D1, B3, C3 and D3) (Wheeler *et al.*, 2003). The measurement time was similar to that used by Demmers *et al.* (2000). The parameters *n*, ω and *t* were set equal to 10, 0.2 Hz and 360 s, respectively. Therefore, at each location, the measurement post took 720 measurements per sensor. The remaining temperature sensors were located at two of the inlets (points B0 and D0) and two of the exhaust fans (points B4 and D4), and the air velocity sensors at two inlets (points B0 and D0). The differential pressure sensors were placed at points B0, D0, B4 and D4.

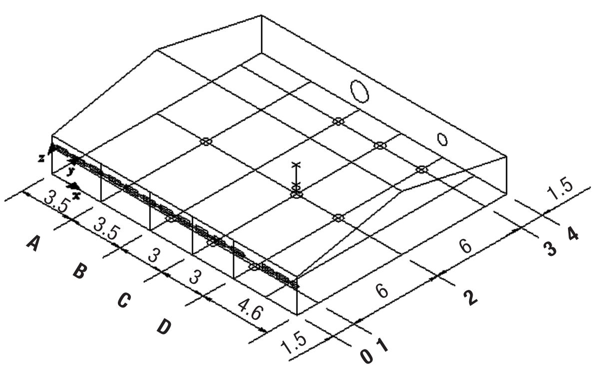

Figure 7. Measurement points in the test zone (distances in meters) and mobile post with sensors at three heights: 0.2 m, 0.6 m and 2 m.

Statistical analysis

The effect of the location in the building (x, y and z coordinates) on the indoor air velocity and temperature was evaluated by stepwise multiple regression analyses. Linear and quadratic effects were considered, and the *p*-value was set at 0.05. The analyses were carried out in MATLAB.

Results and discussion

Table 2 shows mean and standard deviation of measured air velocity at inlets, and differential pressure

Table 2. Measured air velocities (v), temperatures (T) and differential pressure (ΔP) at inlets and outlets. Means ± standard deviation

Inlets	B0	v, m s^{-1}	6.57 ± 0.13
		T, °C	22.6 ± 0.6
		ΔP, Pa	38.7 ± 1.3
	D0	v, m s^{-1}	7.14 ± 0.24
		T, °C	22.9 ± 0.4
		ΔP, Pa	14.7 ± 0.9
Outlets	B4	T, °C	24.7 ± 0.5
		ΔP, Pa	24.8 ± 1.0
	D4	T, °C	25.3 ± 0.4
		ΔP, Pa	26.5 ± 3.1

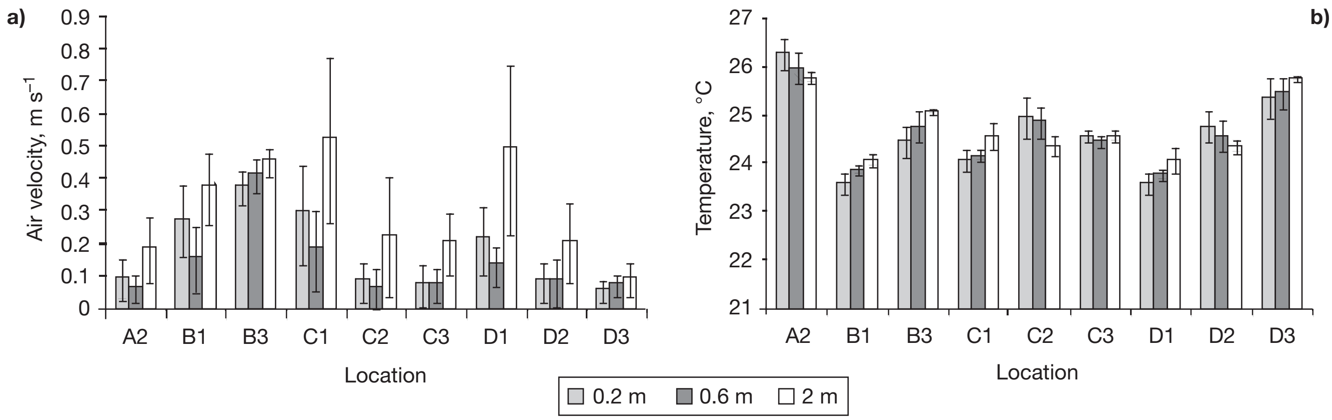

Figure 8. Air velocity (a) and air temperature (b) measured at nine locations of the test zone, at three heights: 0.2 m, 0.6 m and 2 m. Error bars show standard deviations.

and temperatures at the inlets and outlets. Air velocities and temperatures measured at the 27 points inside the test zone (nine locations of the plane XY where the post was placed, at three heights: 0.2 m, 0.6 m and 2 m) are shown in Figure 8.

The statistical analysis on air velocity showed a variation of air velocity with the distance above the floor (z^2) and the distance to the inlets (y and y^2) (Table 3). The distance along the longitudinal axis of the building (x and x^2) did not have a significant effect on the air velocity. The reason for this is the high number and uniform distribution of air inlets along the longitudinal axis of the building, as the uniformity of air distribution throughout the building, depends primarily upon the location and size of the air inlets (ASAE, 2001).

Table 3. Regression analysis relating air velocity (m s^{-1}) and air temperature (°C) with location in the building (coordinates x, y, z)

	Coefficients	Standard error	*p*-value
Air velocity			
Intercept	0.315	0.052	0.000
y	–0.057	0.017	0.003
y^2	0.003	0.001	0.011
z^2	0.043	0.011	0.001
$R^2 = 0.59$			
Air temperature			
Intercept	23.52	0.03	0.000
y	0.35	0.09	0.001
y^2	–0.02	0.01	0.007
$R^2 = 0.50$			

Regarding the vertical profiles, air velocity generally was highest at 2 m. Air velocity at 0.6 m above the floor was very similar to air velocity at bird's level when measuring at the centreline of the building (A2, C2, and D2) and close to the outlets (B3, C3 and D3) (Fig. 8). However, close to the inlets wall (B1, C1 and D1) air velocity at 0.2 m s^{-1} was higher than at 0.6 m (maximum difference of 0.11 m s^{-1}), probably due to a vortex motion (Van Brecht *et al.*, 2004). In a similar study, Wheeler *et al.* (2003) detected that in most cases, the bird level velocities were higher than their corresponding human level velocity.

Regarding the horizontal variability, air velocity did not vary along the longitudinal direction (x), but it did along the cross direction (y) (Table 3). At birds' level, air velocities were generally highest close to the sidewall where the inlets were mounted (average of 0.26 m s^{-1} from points B1, C1 and D1) (Fig. 9). Wheeler *et al.* (2003) also detected higher air velocities at birds' level

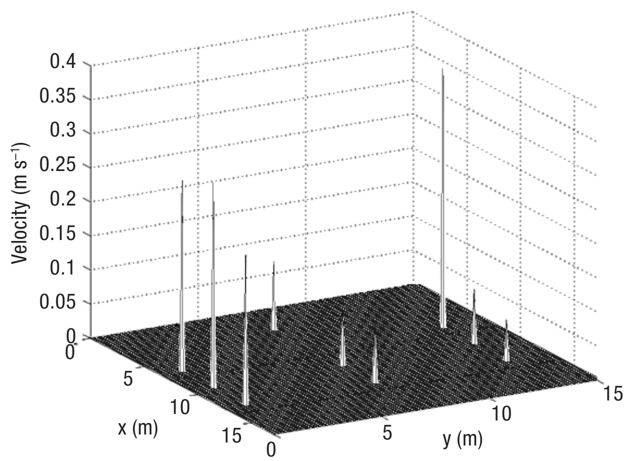

Figure 9. Air velocity at bird's levels (0.2 m above floor).

close to the inlets' wall in comparison to the centerline or points located close to the opposite (outlets) wall. Air velocity at point B3 (0.38 m s^{-1}) was higher than at C3 (0.08 m s^{-1}) and D3 (0.06 m s^{-1}), as it was highly affected by the large fan located at B4 (Fig. 8). Therefore, although both fans contributed to indoor air renewal by exhausting contaminated air from the building, only the largest fan increased the air velocity around the animals (from 0.06 m s^{-1} to 0.38 m s^{-1}).

Measured air velocities at bird's level were in general terms low in comparison to recommended values. Air velocity in the centre line of the building (points A2, C2 and D2) and close to the side wall of the fans (C3 and D3), under high ventilation rate, did not exceed the minimum recommended air velocity for broilers (0.1 m s^{-1}, according to Cedó, 2002). Furthermore, according to Dozier *et al.* (2005), broilers from 36 to 42 days of age subjected to an air temperature between 25 and 30°C, dew point temperature 23°C, and an air velocity of 2 m s^{-1} had improved BW gain, feed consumption, feed conversion, and incidence of mortality compared with broilers grown in still air at the same temperature. This velocity (2 m s^{-1}) was not reached at any point at birds' level. These results are in agreement with previous studies (Bottcher *et al.*, 1992; Wheeler *et al.*, 2003), which have revealed that in general terms, air speeds measured at bird's level in conventional (not tunnel-ventilated) broiler houses are low (from 0 to 0.5 m s^{-1}).

One of the objectives of the ventilation during summer is to mix incoming air with indoor air and remove the heat gain of the building (caused by the addition of heat transfer, thermal radiation and heat produced by the animals). As a consequence, air temperature in the building is expected to be lower at the inlets than at the outlets. The results of the statistical analysis showed that air temperature significantly varied along the y direction (Table 3), being higher at the centreline and at the outlets in comparison to the temperature at the inlets. The minimum temperature in the animal house was 23.5°C and the maximum temperature 26.3°C (Fig. 8). Air temperature at birds' level, close to the outlets (B3 and D3) was about 2°C higher than close to the inlets (B1, C1 and D1). Both temperatures were higher than the recommended air temperature for 7 weeks age broilers. In a previous experiment in a conventional ventilated house, Xin *et al.* (1994) measured a bird-level temperature gradient across the house between 1.3 to 2.1° C. Temperature uniformity is important to avoid animal migration, as birds tend to congregate in the areas where the temperature is closest to their requirements (Xin *et al.*, 1994). Overcrowded areas should be avoided, because inadequate space from that recommended means reduced rate of growth, thermal discomfort and poor welfare (McLean *et al.*, 2002). Air temperatures did not vary along the vertical direction (Table 3). In connection to this, previous authors (Xin *et al.*, 1994; Wheeler *et al.*, 2003) also found that vertical temperature gradients were negligible in cross-ventilated poultry houses under hot summer conditions. The maximum difference between temperatures at 0.2 and 0.6 m high, was 0.31 °C (at point B1).

Further implementations of the measurement system

The system has been used for measuring air velocity, temperature and differential pressure in several studies carried out with different objectives, as for example, in the evaluation of the influence of the differential pressure on indoor air velocity measured at the transverse section of a typical broiler house (Blanes-Vidal *et al.*, 2007). Furthermore, airflow computational fluid dynamics (CFD) simulations have been carried out and validated in mechanically cross-ventilated, commercial poultry buildings with multiple wall inlets by using the described system (Blanes-Vidal *et al.*, 2001, 2004a,b, 2005, 2008; Blanes-Vidal and Torres, 2005).

Conclusions

An on-line computerized system for environmental to measure environmental parameters in poultry houses was developed. The system was based on a laptop, a data acquisition card and a set of air temperature, air velocity and differential pressure sensors. Sensors were RTD's (resistance temperature detectors) for temperature and air velocity measurements. The system can acquire up to a maximum of 16 independent signals. The accuracy of the computerized sensing system after calibration was, for air velocity measurements, 0.05 m s^{-1} in the range of 0.1 to 1.5 m s^{-1}, and from 0.03 to 0.14 m s^{-1} in the range of 1.5 to 7 m s^{-1}; ± 0.2°C for air temperature measurements; and ± 5 Pa for pressure measurements.

A field test of the developed system was carried out in which air velocity, temperature and differential pressure were measured in a commercial poultry house under practical conditions. The measurements were used to analyse the air velocity and temperature variability inside the building. The results showed that air temperature at 0.6 m above floor can be used as an estimation of temperature at bird's level. However, air velocity measured at 0.6 m above the floor did not fairly represent the air velocity conditions at birds' level. Air velocity and temperature at birds' level ranged from 0.06 to 0.38 m s^{-1}, and from 23.6 to 26.3°C. Therefore, sensors for the environmental control system have to be located at suitable coordinates of the horizontal plane, in order to provide useful measurements under the experimental conditions described in this study. Air velocity under high ventilation rate conditions did not exceed the minimum air velocity recommended for 7 week poultry, and air temperature was about 5°C higher than recommended.

The field test described in this article, together with several research studies carried out in commercial poultry buildings have confirmed that the developed system is useful, robust and stable.

Acknowledgements

This work was funded by the project GV04B-511 (Consellería d'Empresa, Universitat i Ciència; Generalitat Valenciana, Spain).

References

ASAE, 2001. Design of ventilation systems for poultry and livestock shelters, EP270.5. ASAE Standards, 48th ed. American Society of Agricultural Engineers. St Joseph, MI, USA. pp. 618-635.

BLANES-VIDAL V., GARCÍA-DIEGO F.J., MILLÁN GONZÁLEZ M.C., TORRES SALVADOR A., 2001. Trayectoria y velocidad del aire en granjas avícolas de carne según sus características de diseño. Actas I Congreso Nacional de Agroingeniería. Valencia, Spain, Sept 19-22. pp. 489-494 [In Spanish].

BLANES-VIDAL V., FITAS V., TORRES A., 2007. Differential pressure as a control parameter for ventilation in poultry houses: effect on air velocity in the zone occupied by animals. Span J Agric Res 5(1), 31-37.

BLANES-VIDAL V., VILLAGRÁ V., TORRES A., 2004a. Numerical simulation of airflow in a real mechanically ventilated poultry building: validation and analysis of results. AgEng2004: International Conference on Agricultural Engineering. Leuven, Belgium, Sept 12-16. Paper no. 209.

BLANES-VIDAL V., GUIJARRO E., GONZÁLVEZ J., TORRES A., 2004b. Numerical simulation of airflow in a real mechanically ventilated poultry building: comparison of results from different boundary condition. AgEng2004: International Conference on Agricultural Engineering, Leuven, Belgium, Sept 12-16, Paper 152.

BLANES-VIDAL V., TORRES A., 2005. Air velocity and temperature distribution in an occupied commercial poultry building under high summer ventilation rate. Actas III Congreso Nacional de Agroingeniería, León, Spain, Sept 21-24, paper nº 225. [In Spanish].

BLANES-VIDAL V., GUIJARRO E., BALASCH S., TORRES A.G., 2008. Application of computational fluid dynamics to the prediction of airflow in a mechanically ventilated commercial poultry building. Biosyst Eng 100(1), 105-116.

BOON C.R., BATTAMS V.A., 1988. Air mixing fans in a broiler building - Their use and efficiency. J Agric Eng Res 39(2), 137-147.

BOTTCHER R.W., DRIGGERS L.B., CARTER T.A., HOBBS A.O., 1992. Field comparison of broiler house mechanical ventilation systems in a warm climate. J Agric Safety Health 8(4), 499-508.

BOTTCHER R.W., DRIGGERS L.B., CARTER T.A., HOBBS A.O., 2001. Field comparison of broiler house mechanical ventilation systems in a warm climate. Appl Eng Agric 8(4), 499-508.

CEDÓ R., 2002. Manejo del broiler durante la crianza. In: Producción de carne de pollo. Ed Real Escuela de Avicultura, Barcelona, Spain. pp. 107-136.

DOZIER W.A. III, LOTT B.D., BRANTON S.L., 2005. Growth responses of male broilers subjected to increasing air velocities at high ambient temperatures and a high dew point. Poultry Sci 84(6), 962-966.

FURLAN R.L., MACARI M., SECATO E.R., GUERREIRO J.R., MALHEIROS E.B., 2000. Air velocity and exposure time to ventilation affect body surface and rectal temperature of broiler chickens. J Appl Poult Res 9, 1-5.

GOLDSTEIN R.J., 1996. Fluid mechanics measurements. Taylor and Francis, Washington, USA. 701 pp.

LEE I.B., YOU B.K., CHOI K.H., JEUN J.G., KIM G.W., 2003. Study of internal climate of naturally and mechanically ventilated broiler houses. ASAE Annual International Meeting, Las Vegas, USA, Jul 27-30. Paper no. 034060.

LOOT B.D., SIMMONS J.D., MAY J.D., 1998. Air velocity and high temperature effects on broiler performance. Poultry Sci 77(3), 391-393.

MAY J.D., LOTT B.D., SIMMONS J.D., 2000. The effect of air velocity on broiler performance and feed and water consumption. Poultry Sci 79(10), 1396-1400.

MCLEAN J.A., SAVORY C.J., SPARKS N.H.C., 2002. Welfare of male and female broiler chickens in relation to stocking density, as indicated by performance, health and behaviour. Anim Welf 11(1), 55-73.

NATIONAL INSTRUMENTS, 2004, Labview programming environment. Available in http://www.ni.com/labview/optin/ [31 May, 2010].

SIMMONS J.D., LOTT B.D., MILES D.M., 2003. The effects of high-air velocity on broiler performance. Poultry Sci 82(2), 232-234.

TABLER G.T., BERRY I.L., XIN H., BARTON T.L., 2002. Spatial distribution of death losses in broiler flocks. J Appl Poult Res 11, 388-396

TAO X., XIN H., 2003. Acute synergistic effects of air temperature, humidity and velocity on homeostasis of market-size broilers. T ASAE 46(2), 491-497.

VAN BRECHT A., VRANKEN E., GUARINO M., BERCKMANS D., 2004. Optical flow algorithm to quantify the two-dimensional velocity components of a visualized air jet. T ASAE 47(3), 847-856.

WEBSTER J.G., 1999. The measurement, instrumentation, and sensors handbook. CRC Press/IEEE Press, Boca Raton, Florida, USA. 2608 pp.

WHEELER E.F., ZAJACZKOWSKI J.L., SAHEB N.C., 2003. Field evaluation of temperature and velocity uniformity in tunnel and conventional ventilation broiler houses. Appl Eng Agric 19(3), 367-377.

XIN H., BERRY I.L., TABLER G.T., BARTON T.L., 1994. Temperature and humidity profiles of broiler houses with experimental conventional and tunnel ventilation systems. Appl Eng Agric 10(4), 535–542.

YAHAV S., STRASCHNOW A., LUGER D., SHINDER D., TANNY J., COHEN S., 2004. Ventilation, sensible heat loss, broiler energy, and water balance under harsh environmental conditions. Poultry Science 83(2), 253-258.

YAHAV S., STRASCHNOW A., VAX E., RAZPAKOVSKI V., SHINDER D., 2001. Air velocity alters broiler performance under harsh environmental conditions. Poultry Sci 80(6), 724-726.

YANAGI T., XIN H., GATES R.S., 2002. A research facility for studying poultry responses to heat stress and its relief. Appl Eng Agric 18(2), 255-260.

ZHANG G., STRØM J.S., MORSING M., 1996. Computerized multi-point temperature and velocity measurement system. RoomVent'96, Fifth International Conference on Air Distribution in Rooms, Yokohama, Japan, Jul 17-19, pp. 531-538.