

# Differential pressure as a control parameter for ventilation in poultry houses: effect on air velocity in the zone occupied by animals

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## Abstract

Differential pressure between indoor and outdoor air is the parameter most commonly used to adjust the opening of inlets in mechanically ventilated poultry houses, to get a suitable air velocity at the animals' level. The aim of this work was to measure and statistically analyse the influence of differential pressure on the indoor air velocity at different locations of a transverse section of a typical broiler house. The results showed that the pressure difference (20, 30, 38 and 45 Pa) had no significant effect ( $p \geq 0.05$ ) on indoor air velocity at the animals' level. The work showed that, in all cases tested, the air velocity at level of the animals was significantly higher ( $p < 0.001$ ) at the centreline of the building ( $1.31 \text{ m s}^{-1}$ ) than at points located 1.5 m from the walls ( $0.32 \text{ m s}^{-1}$ ). These results question the efficacy of using differential pressure measurement as a sole control parameter of air velocity over the broiler chickens, and reveals that ventilation system design and the way it is operated over summer in this typical poultry house may not be appropriate for poultry farms in hot and humid climates, as it does not provide high and uniform air velocities at level of the birds.

**Additional key words:** air inlet, broilers, heat stress, mechanical ventilation.

## Resumen

**La presión diferencial como parámetro de control de la ventilación en granjas avícolas: efecto sobre la velocidad del aire en el entorno de los animales**

La depresión del aire interior es la variable que se utiliza en la regulación de la abertura de las trampillas de entrada de aire, en naves avícolas con ventilación mecánica, para obtener una velocidad del aire adecuada a la altura de los animales. El principal objetivo de este trabajo fue conocer el efecto de la depresión del aire sobre dicha velocidad, en una granja típica de producción de pollos. Los resultados del análisis estadístico indican que en la sección de la granja analizada, la depresión (estudiada a cuatro niveles: 20, 30, 38 y 45 Pa), no tuvo un efecto significativo ( $p \geq 0,05$ ) sobre la velocidad del aire sobre los animales. Por otra parte, la velocidad sobre los animales, en el centro de dicha sección, fue significativamente mayor ( $1,31 \text{ m s}^{-1}$ ,  $p < 0,001$ ) que a 1,5 m de las paredes laterales en la misma sección ( $0,32 \text{ m s}^{-1}$ ). Este trabajo muestra que la eficacia del uso de la presión diferencial como única medida para controlar la velocidad del aire sobre los animales es cuestionable. El trabajo también revela que el diseño y el modo de manejo del sistema de ventilación existente en la granja avícola de estudio no es adecuado en condiciones de clima caluroso y húmedo, ya que no proporciona una velocidad del aire suficientemente alta y uniforme a la altura de los animales.

**Palabras clave adicionales:** entrada de aire, estrés térmico, pollos, ventilación mecánica.

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## Introduction

Environmental parameters [such as temperature (T), relative humidity (RH), air velocity and air quality, i.e.

the concentration of oxygen, carbon dioxide, ammonia and other gases, dust and microbial contamination] in poultry buildings, are controlled by means of environmental control systems that consist of ventilation, heating, and cooling equipment, which are regulated automatically. In the case of mechanical ventilation, the ventilation equipment consists of inlets and exhaust fans. Ventilation control is achieved by adjusting the

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inlets and the fans (by switching fans on or off, or by adjusting fan speed).

Ventilation flow in the building influences heat, moisture and gas balance, and thus it affects the indoor T, RH and gas concentration (Blanes and Pedersen, 2005). In some Mediterranean areas, where the climate is warm and humid in the summer and cold in the winter, the ventilation fans in poultry houses are usually regulated according to temperature (for almost the whole year) or on humidity criteria (usually, in the winter).

The ventilation, together with some other factors, such as building geometry, location, number and size of the inlets and exhaust fans and the presence of indoor obstacles, determines the airflow pattern in the buildings and, therefore, air velocity in the zone occupied by the animals (Harral and Boon, 1997; Smith *et al.*, 1999; Bjerg *et al.*, 2000, 2002).

Air velocity has an important influence on animal heat loss. Consequently, under Mediterranean conditions, when the outdoor T and RH are extremely high and the efficiency of the evaporative cooling systems on the farm decreases, air velocity becomes a decisive factor in the control of animal heat stress (Lott *et al.*, 1998; Yahav *et al.*, 2001, 2004; Yanagi *et al.*, 2002; Simmons *et al.*, 2003; Tao and Xin, 2003; Dozier *et al.*, 2005). Therefore, the proper operation and control of the ventilation systems of Mediterranean poultry farms are important, not only for the control of the indoor T, RH, and gas concentration, but also to achieve a suitable air velocity over the animals, especially in the summer.

In practice, ventilation is regulated, on most farms, by setting the ventilation flow (according to air T or RH), and adjusting the inlet size (according to the pressure difference between the indoor and outdoor air). Differential pressure sensors are usually part of the environmental control equipment which control the inlets; and the slot size is adjusted so the pressure difference is almost constant and equal to set number.

The relationship between ventilation flow and indoor T, RH and air quality can be defined on a theoretical basis, by means of relatively simple heat, moisture and gas concentration balances, respectively. Therefore, by adjusting airflow rate, it is possible to obtain a T, RH, and gas concentration suitable for the birds (Schauberger *et al.*, 2000).

However, the relationship between differential pressure (the variable used for inlet slot adjustment) and air velocity in the zone occupied by the birds is uncertain, and has not been studied sufficiently in previous works.

The aim of this work was to measure and statistically analyse the air velocity in a typical poultry house, at different levels of pressure difference, under the ventilation conditions used in summer on a farm; to assess the effect of pressure variation on air velocity.

## Material and Methods

### Experimental building

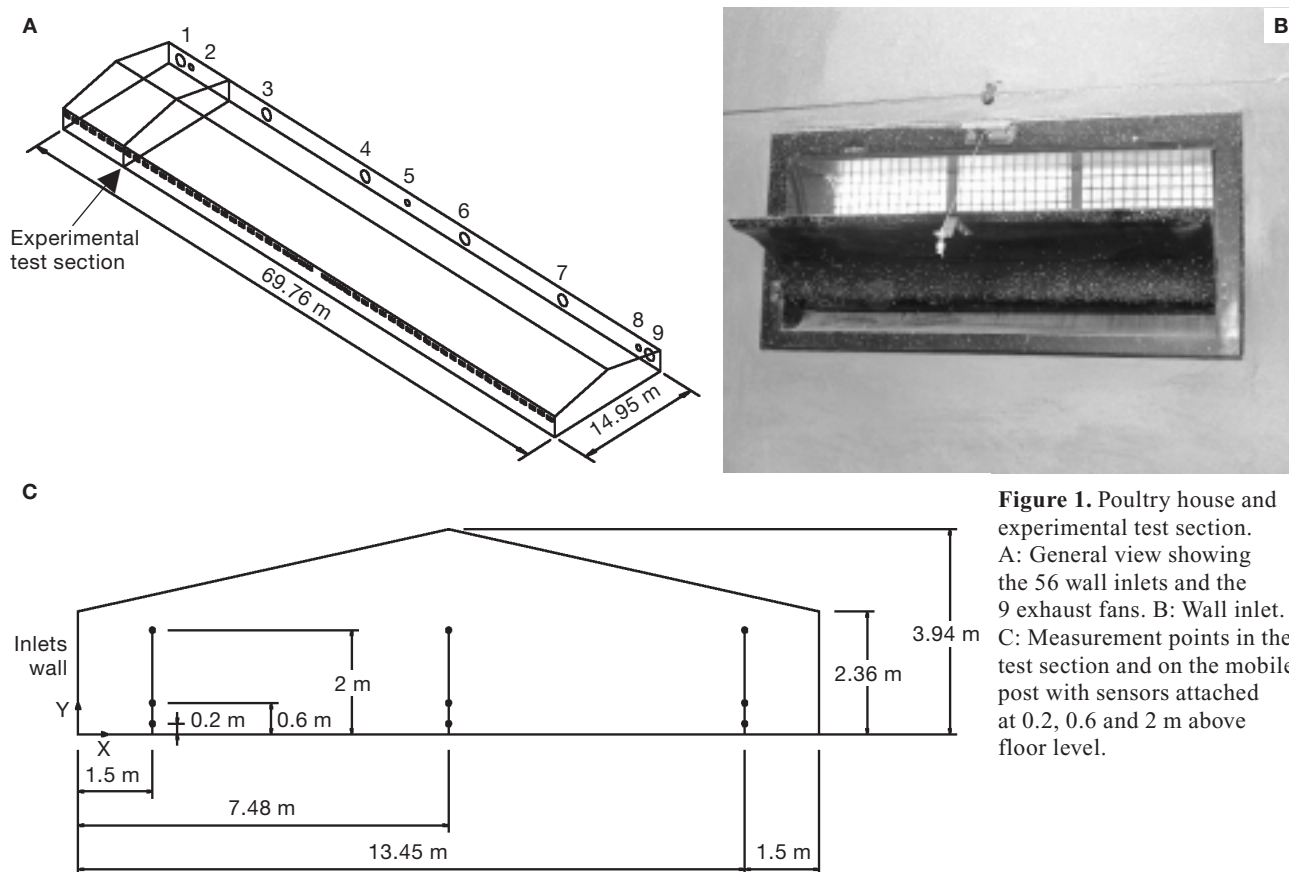
The experimental building (Fig. 1) was a typical Mediterranean poultry house, equipped with conventional cross-ventilation by negative pressure. Building dimensions were: length, 69.76 m; width, 14.95 m; side-wall height, 2.36 m, and the maximum distance from floor to ceiling, 3.94 m.

The animal house had 56 sidewall prefabricated inlets (Gasnet S.L, Villareal, Spain), which were 81 cm wide and 26.5 cm high (Fig. 1B). Their central horizontal axis was 1.79 m above floor. Opening of the inlets was controlled by bottom-hinged flaps.

Nine exhaust fans were located in the opposite wall (Fig. 1A): 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<sup>3</sup> h<sup>-1</sup>; 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<sup>3</sup> h<sup>-1</sup>.

### Instrumentation

A computerized velocity, T and pressure variation sensing system (Guijarro *et al.*, 2004) measured air velocity. The system was based on a portable computer, a data acquisition card (DAQ), and a configurable set of sensors and associated electronic circuits. Air velocity was estimated by means of constant T hot wire anemometry. Air velocity sensors were RTD's (Resistant Temperature Detectors) from Omega Engineering Inc. (2004). Each air velocity sensor consisted of a thin layer of platinum deposited on a small ceramic substrate, of 2 × 10 mm. This complies with DIN 43760 and BS 1904 standards. The RTD sensors were maintained at a constant temperature of 60°C. The voltage applied to each sensor needed to maintain this temperature under different flow conditions, was related to air velocity over the sensor, according to King's law (Zhang *et al.*, 1996).



**Figure 1.** Poultry house and experimental test section. A: General view showing the 56 wall inlets and the 9 exhaust fans. B: Wall inlet. C: Measurement points in the test section and on the mobile post with sensors attached at 0.2, 0.6 and 2 m above floor level.

The accuracy of the computerized sensing system, after calibration, was for air velocity measurements, better than  $0.05 \text{ m s}^{-1}$  in the range  $0.1$  to  $2 \text{ m s}^{-1}$  and better than 2% in the range  $2$  to  $7 \text{ m s}^{-1}$ . Differential pressure was measured with the differential pressure sensor normally used in the experimental shed (Tuffigo Avistar, Quimper, France; accuracy of  $\pm 5 \text{ Pa}$ ).

For indoor measurements air velocity sensors were placed in pairs, on a mobile post (Fig. 1C) at three heights: i) the animal occupied height ( $0.2 \text{ m}$ ); ii) the level at which air T sensors of the farm were usually located ( $0.6 \text{ m}$ ); and iii) the height where higher air velocities were expected ( $2 \text{ m}$ ).

## Experimental conditions

The trials were conducted under the ventilation conditions that are commonly used during summer on the farm, i.e. alternating operation of fans 1, 4 and 7, and of fans 3, 6 and 9, at the rate of  $1 \text{ min set}^{-1}$ . The remaining fans were not run during the trials. This ventilation procedure (alternative running of certain fan combina-

tions) is used to renew the indoor air in the house with longitudinal uniformity.

The inlets slots were adjusted to obtain the differential pressures shown in Table 1, at each level. The levels were selected based on the recommendations of the ventilation systems providers.

## Measurements

The section of the house tested was equidistant between Nos. 1 and 3. This was  $8.24 \text{ m}$  from one of the gable ends, and was expected to be a section with lower

**Table 1.** Differential pressure and inlet slot used during the experiment

| Level | Differential pressure (Pa) | Inlets slot (cm) |
|-------|----------------------------|------------------|
| 1     | 20                         | 18               |
| 2     | 30                         | 14.5             |
| 3     | 38                         | 12               |
| 4     | 45                         | 11.5             |

**Table 2.** Factors subjected to statistical analysis (ANOVA)

| Factor   | Description  | Level                              |
|----------|--|------------------------------------|
| Pressure | Differential pressure between indoor and outdoor air                 | 20 Pa                              |
|          |  | 30 Pa                              |
|          |  | 38 Pa                              |
|          |  | 45 Pa                              |
| Location | Location of the mobile post in the house test section (X-coordinate) | 1.5 m                              |
|          |  | 7.48 m                             |
|          |  | 13.45 m                            |
| Fans     | Group of fans running in the house                                   | Fans 1, 4 and 7<br>Fans 3, 6 and 9 |

air velocity. Air speed and T in the test section were monitored at nine locations. The mobile post, with the measuring equipment was placed at points 1.5 m, 7.48 m and 13.45 m from the house sidewall (Fig. 1C).

The differential pressure variable was set at 20, 30, 38 and 45 Pa. All of these values are in the normal range of adjustment used on the farm. At each pressure level, two groups of fans worked alternately: group A (Fans 1, 4 and 7) and group B (Fans 3, 6 and 9).

For each differential pressure level, set of fans running, and location of the post, the air velocity for each sensor was the average of 30 measurements.

## Statistical analysis

Analysis of variance (ANOVA) was performed, to study the effect of the factors shown in Table 2, and their interactions, on air velocity ( $\text{m s}^{-1}$ ): i) at 0.2 m above the floor ( $V_{0.2\text{m}}$ ), ii) at 0.6 m above the floor ( $V_{0.6\text{m}}$ ), and iii) at 2 m above the floor ( $V_{2\text{m}}$ ). Statistical analysis used the SAS<sup>®</sup> ANOVA procedure (SAS, 1998).

## Results

Incoming air velocity is shown in Table 3 for the different pressure levels.

**Table 3.** Air velocity of incoming air in the house

| Pressure (Pa) | Incoming air velocity      |                                     |
|---------------|----------------------------|-------------------------------------|
|               | Mean ( $\text{m s}^{-1}$ ) | Std deviation ( $\text{m s}^{-1}$ ) |
| 20            | 5.07                       | 0.21                                |
| 30            | 6.28                       | 0.32                                |
| 38            | 7.01                       | 0.38                                |
| 45            | 7.50                       | 0.73                                |

**Table 4.** Air velocity ( $\text{m s}^{-1}$ ) at bird level depending on the pressure difference and the X-coordinate; mean (standard deviation)

| Pressure (Pa) | X = 1.5 m   | X = 7.5 m   | X = 13.5 m  |
|---------------|-------------|-------------|-------------|
| 20            | 0.34 (0.19) | 1.23 (0.23) | 0.26 (0.15) |
| 30            | 0.30 (0.18) | 1.26 (0.25) | 0.41 (0.21) |
| 38            | 0.28 (0.21) | 1.37 (0.23) | 0.33 (0.19) |
| 45            | 0.32 (0.19) | 1.38 (0.20) | 0.31 (0.18) |
| Mean          | 0.31        | 1.31        | 0.33        |

With regard to indoor velocities, the measured air velocity at 0.2 m above floor level, according to pressure difference and location of the mobile post along the X-axis, are shown in Table 4. Average air velocity at the centreline of the building, for all four differential pressure levels was  $1.31 \text{ m s}^{-1}$ . The mean air velocity at 1.5 m from the side wall was much lower ( $0.31$  and  $0.33 \text{ m s}^{-1}$ ). Table 5 shows the air velocity at 0.2 m above floor level at 1.5, 7.5 and 13.5 m from the inlet wall with the two different sets of fans running.

Table 6 gives the results of the statistical analysis. The results show that «Location» had a highly significant effect ( $p < 0.001$ ) on air velocity at the animal level (0.2 m above the floor). This implies that air velocity over the animals in summer, in the test section of the house, varied significantly across the cross axis of the building (X-coordinate). The significant interaction

**Table 5.** Air velocity ( $\text{m s}^{-1}$ ) at bird level depending on the set of fans in use and the X-coordinate; mean (standard deviation)

| Fan set | X = 1.5 m   | X = 7.5 m   | X = 13.5 m  |
|---------|-------------|-------------|-------------|
| 1, 4, 7 | 0.29 (0.21) | 1.40 (0.24) | 0.35 (0.19) |
| 3, 6, 9 | 0.32 (0.19) | 1.22 (0.23) | 0.30 (0.19) |

**Table 6.** ANOVA results (probability)

| Factor              | d.f. <sup>1</sup> | Dependent variable |                   |                 |
|---------------------|-------------------|--------------------|-------------------|-----------------|
|                     |                   | $V_{0.2\text{m}}$  | $V_{0.6\text{m}}$ | $V_{2\text{m}}$ |
| Pressure            | 3                 | 0.127              | 0.056             | 0.110           |
| Location            | 2                 | 0.000              | 0.000             | 0.031           |
| Fan set             | 1                 | 0.007              | 0.081             | 0.078           |
| Pressure x Location | 6                 | 0.035              | 0.336             | 0.177           |
| Pressure x Fan set  | 3                 | 0.877              | 0.589             | 0.313           |
| Location x Fan set  | 2                 | 0.005              | 0.096             | 0.807           |

<sup>1</sup> d.f.: degrees of freedom.

«Pressure» × «Location» ( $p < 0.05$ ) implies that the effect of modifying the inlets slot, (and thus the pressure difference), differed depending on location ( $X = 1.5$  m,  $X = 7.48$  m or  $X = 13.45$  m).

The fan combination being used (factor «Fans») also had a significant effect ( $p < 0.01$ ) on air velocity at 0.2 m above the floor. However, the differential pressures did not significantly affect ( $p > 0.05$ ) air velocity at 0.2 m above floor level in the test section of the broiler house.

Fig. 2 shows the air velocity at 0.2, 0.6 and 2 m above the floor level, measured at the three X-coordinates of the test section of the poultry house and averaged over all pressure levels. Air velocity at 0.2, 0.6 and 2 m showed the same trend being higher at the centreline of the house and lower close to the ends along the transverse plane, being more noticeable at 0.2 and 0.6 m above the floor.

## Discussion

### Air velocity at 0.2 m

Air velocity at 0.2 m above the floor is the most important dependent variable in the analysis, as it is the air velocity over the birds.

Differential pressure had no effect ( $p \geq 0.05$ ) on air velocity at 0.2 m above the floor. This result brings into question the efficacy of using differential pressure measurement as the sole control parameter for setting air velocity over the broilers.

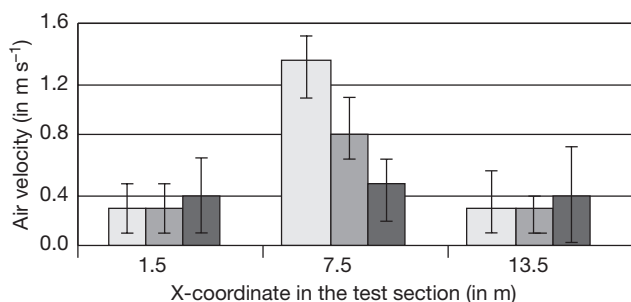
With regard to the suitability of air velocity measured to the birds' needs, Tao and Xin (2003) investigated the relative importance of air temperature, humidity and velocity on the homeostasis of market-size broilers

by developing a temperature-humidity-velocity index (THIV) during acute heat exposure. According to the index, broilers at 46 days of age and 2.8 kg body weight, subjected to a T of 35°C and an 80% RH (which can occur inside Mediterranean poultry farm houses in the summer), can be in a heat stress «alert state» in 10, 45, 90 and 120 min, when the air velocity is 0.1, 0.5, 1.0 and 1.2 m s<sup>-1</sup>, respectively. An alert situation is defined as body T rise of 1°C. When air velocity around the birds is 0.1 m s<sup>-1</sup>, an «emergency state» (a body T rise of 4°C) is reached in 90 min and in 180 min if the air velocity is 1 m s<sup>-1</sup>. Yahav *et al.* (2001) recommend velocities of 1.5 to 2 m s<sup>-1</sup> when broilers are under very hot conditions ( $\approx 35^\circ\text{C}$ ).

In this work, the air velocity at the height of the broilers in the experimental poultry house (Table 4), had low uniformity along the transverse plane, under ventilation conditions that are common in summer. The air velocity at the centre of the test section (1.31 m s<sup>-1</sup>), would provide a more comfortable environment for broilers, grown in the summer, than the air velocity achieved at 1.5 m from the inlet wall (0.31 m s<sup>-1</sup>) or the fan wall (0.33 m s<sup>-1</sup>).

This result suggests indirect negative consequences on comfort of the broilers. Differences in indoor conditions (including air velocity over the animals), inside a poultry house, can cause behavioural responses that entail the animals migrating to parts of the shed where the environment conditions are better (Tabler *et al.*, 2002). If this movement is widespread, in the flock, it can lead to environmental deterioration in those areas, due to increased heat stress associated with the high concentration of animals, as from a thermodynamic point of view, they are heat sources. Consequently, the uniformity of air velocity in the part of the house occupied by birds is important, to prevent animal moving to crowded areas, which would contribute to increase animal deaths.

With regarding the fans (Table 6), the results showed ( $p > 0.05$ ) that the air velocity in the zone occupied by the broilers in the test section of the house (which was equidistant between fans 1 and 3) varied depending on which set of fans was running. This was despite the fact that both fans were identical and were located at the same distance from the test section. Air velocity in the test section was affected by which set of fans was in use, obviously, those parts of the house which were not equidistant would be even more influenced by which group of fans was running. Thus, the results suggest that alternate fan operation would be preferable to the



**Figure 2.** Mean air velocity at □ 0.2 m, ■ 0.6 m and ■ 2.0 m, depending of the X-coordinate in the house test section. Error bars show standard deviation.

constant operation of a specific set of fans. The constant operation of a specific fan set would give low air velocity uniformity in the occupied zone, and cause bad air quality in specific zones of the house. However, running all the fans simultaneously, instead of alternating fan sets could be even more appropriate as ventilation strategy under conditions of heat stress as increasing ventilation flow at the house would decrease indoor air T and humidity and would probably increase air velocity at the level of the birds.

### Air velocity at 0.6 m

Traditionally, air velocity in commercial poultry houses has not been measured at broilers' level which is the relevant zone to evaluate bird thermal comfort, but at higher levels above the floor (about 0.6 m). This is due to the difficulty of measuring air velocity in the proximity of the animals. In this work, air velocity at 0.6 m was not uniform along the transverse plane (Fig. 2). This was the same trend as the air velocity at 0.2 m ( $R^2=0.97$ ).

### Air velocity at 2 m

Air velocity at 2 m was significantly ( $p<0.05$ ) affected by location ( $p<0.05$ ). All the factors pressure and fans and the interactions had no effect ( $p\geq 0.05$ ) on air velocity at 2 m.

### Conclusions

The following conclusions may be drawn from this work:

1. Differential pressure between indoor and outdoor air at 20, 30, 38 and 45 Pa had no effect on air velocity at the height of the broiler chickens (0.2 m above floor). This result brings into question the efficacy of using differential pressure measurement as the sole control parameter of air velocity over the animals.

2. Air velocity at 0.2 m in the centre of the test section of the poultry house was significantly higher than 1.5 m from the inlet wall or fan wall ( $1.31\text{ m s}^{-1}$  compared with  $0.31$  and  $0.33\text{ m s}^{-1}$ ), independently of pressure differences between the indoor and outdoor air. Air velocity at 0.6 m along the transverse axis of

the test section of the house varied significantly, in a similar way.

3. The fan combination being used (fans 1, 4 and 7, and fans 3, 6 and 9) also had a significant effect on air velocity at 0.2 m. Alternating fan operation is preferable to the constant operation of a specific fan set.

4. The ventilation system design and the way it is operated in summer, is not appropriate for poultry farms located in hot, humid climates, as it does not provide high and uniform air velocities at the level of the broiler chickens which is necessary to relieve bird heat stress. Running all fans simultaneously, instead of alternating fan sets could be a better ventilation strategy under conditions of heat stress.

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