Microclimate measuring and fluid-dynamic simulation in an industrial broiler house: testing of an experimental ventilation system

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Environment,
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Ventilation.

Summary

The environment in the broiler house is a combination of physical and biological factors generating a complex dynamic system of interactions between birds, husbandry system, light, temperature, and the aerial environment. Ventilation plays a key role in this scenario. It is pivotal to remove carbon dioxide and water vapor from the air of the hen house. Adequate ventilation rates provide the most effective method of controlling temperature within the hen house. They allow for controlling the relative humidity and can play a key role in alleviating the negative effects of high stocking density and of wet litter. In the present study the results of experimental tests performed in a breeding broiler farm are shown. In particular the efficiency of a semi transversal ventilation system was studied against the use of a pure transversal one. In order to verify the efficiency of the systems, fluid dynamic simulations were carried out using the software Comsol multiphysics. The results of this study show that a correct architectural and structural design of the building must be supported by a design of the ventilation system able to maintain the environmental parameters within the limits of the thermo-neutral and welfare conditions and to achieve the highest levels of productivity.

Misurazione del microclima e simulazione fluidodinamica in un allevamento avicolo industriale: test di un sistema di ventilazione sperimentale

Parole chiave
Microclima,
Pollaio,
Simulazione fluido-dinamica,
Ventilazione.

Riassunto

L'ambiente dell'allevamento avicolo è costituito da una combinazione di fattori fisici e biologici che interagiscono come un sistema dinamico complesso di interazioni tra volatili, sistema di allevamento, luce, temperatura e ambiente aereo. La ventilazione riveste un ruolo essenziale in questo contesto. Essa è essenziale per l'eliminazione di CO_2 e di vapore acqueo dall'aria del pollaio. Tassi di ventilazione adeguati sono il metodo più efficace di verifica della temperatura all'interno del pollaio e consentono anche il controllo dell'umidità relativa oltre a svolgere un ruolo chiave per alleviare gli effetti negativi dell'alta densità di allevamento e dei rifiuti umidi. Nel presente studio sono riportati i risultati di prove sperimentali effettuate in un allevamento di polli; in particolare è stata analizzata l'efficienza di un sistema di ventilazione semi trasversale in rapporto ad uno trasversale puro. Al fine di verificare l'efficienza dei sistemi sono state effettuate simulazioni fluidodinamiche utilizzando il software COMSOL Multiphysics. I risultati di questo studio mostrano che una progettazione architettonica e strutturale corretta dell'immobile deve essere accompagnata da un design meccanico e fluidodinamico del sistema di ventilazione ugualmente corretto al fine di mantenere parametri ambientali tali da garantire il benessere animale e raggiungere i massimi livelli di produttività.

Introduction

The environment in the hen house is a combination of physical and biological factors which interact as a complex dynamic system of interactions between birds, husbandry system, light, temperature, and the aerial environment (Sainsbury 2000).

Pollutants include organic and inorganic dust, pathogens and other micro-organisms as well as gases, such as ammonia, nitrous oxide, carbon dioxide, hydrogen sulphide, and methane or other compounds like endotoxins and even residues of antibiotics (Kristensen and Wathes 2000). Chronic exposure to some types of aerial pollutants – like gases, dust, and micro-organism form bio-aerosols – may exacerbate multi-factorial environmental diseases. There is strong epidemiological evidence that bioaerosols cause directly infectious and allergic diseases in farm workers and animals. In addition, air contaminants may depress the growth of the birds (Wathes 1998). The main sources of aerial pollutants are the feed, the litter, and the chickens themselves. Alle these sources are indirectly or directly influenced by factors such as season, diseases, nutrition, and the management (Wathes, 2004). It is remarkable that broiler chickens tolerate the high burden of aerial pollutants, and yet there are reasons for concerns, insofar as their welfare may be compromised by chronic exposure (Wathes 2004). Wathes (2004) suggested that the current guidelines for air quality should be revised and lower limits considered (EFSA 2012).

Carbon dioxide (CO_2) is a non-reactive gas, which is removed only by ventilation. It may interact chemically, for example, by absorption on wet building surfaces or dust particles. CO_2 is a metabolic by-product of both broiler chickens and litter processes. The EU Broiler Directive (Commission 2007) advises 3,000 ppm for carbon dioxide. However, an increase in CO_2 levels is usually accompanied by increased levels of other detrimental air pollutants such as ammonia, dust, and micro-organisms. Therefore CO_2 is used as an air quality indicator and the minimum ventilation rate is calculated on the basis of CO_2 production by the chickens and the litter (EFSA 2012).

The most important role of ventilation is to remove carbon dioxide and water vapor from the air of the hen house. Adequate ventilation rates provide the most effective method of controlling temperature within the house and also allows for controlling the relative humidity. Ventilation also plays a key role in alleviating the negative effects of high stocking density and of wet litter. Litter moisture is positively correlated with the incidence of footpad dermatitis, one of the most important welfare indicators (EFSA 2012).

The main elements that have to be considered to ensure comfort conditions are: type of animal housing, stocking density, food quantity and quality, presence or absence of litter, available space per head, micro-environment conditions (light, temperature, noise, speed, air quality, etc.), weaning technique (EFSA 2010).

The industrial breeding allows farmers to achieve good economic level by mean of mechanization, specialized employees, optimization of planimetry, high stocking rate that, of course, require specific solutions to ensure suitable air quality and temperature and humidity conditions (Kristensen and Wathes, 2000, Quaglio *et al.* 1988).

To keep body temperature stable, the heat produced by animals metabolism must be equal to the one transferred to the room. Environmental conditions with too high temperatures are deleterious (Cahaner 2008) because they reduce body heat loss, further aggravating chicken welfare, given that animal feathers inhibit internal heat dissipation (Deeb and Cahaner 1999). The optimum temperature for best performance ranges between 18 and 22 °C for growing broiler chickens (Charles 2002, Ross 2010, EFSA 2010). Birds most efficiently convert feed to meat when they are given consistently optimum environmental conditions, with temperature being the most critical factor. Broiler houses are heated as young chicks cannot maintain their body temperature. Sometimes floor heating systems are used, but in the majority of the houses local or central heating systems are utilized. If the temperature is too low, birds increase their feed intake but have to use more of that feed energy to keep their bodies warm. If temperature is too high, they reduce feed intake to limit heat production. At each stage of a bird's development, there is a narrow temperature range where maintenance energy requirements are lowest and the bird can make maximum use of feed energy for growth. If temperature goes just a few degrees outside the optimum performance zone, cooler or warmer, birds will be using a higher proportion of their feed energy for body maintenance and less for growth. For example, research conducted in the United States showed that exposing day-old chicks to an air temperature of 13 °C for only 45 minutes reduced 35 day weights by about 110 g (Ross 2010). The first day the temperature on chick level should be 30 °C. During the rearing period the temperature is lowered according to the guidelines of the breeding companies. At 27 days of age the temperature should be around 20 °C. (EFSA 2010). The target temperature for best broiler performance changes during a grow-out, typically from around 30°C on day 1 to near 20 °C or lower at harvest time, depending on bird size and other factors. (Ross 2010).

Humidity is also a very important parameter for the welfare of broilers. In the first week of life the relative humidity for a chick is particularly important because it affects the health and well-being in adulthood. A too low relative humidity during this time may lead to dehydration and uneven growth (Aviagen 1999). Usually during the first week of farming, it is recommended that relative humidity in livestock buildings is kept at 70-75% (Dobrzański and Kolacz 1996). The effect of humidity on the thermal regulation of chickens depends on age and air temperature (Lin *et al.* 2005). During the whole breeding cycle, the relative humidity should be maintained at a value between 60% and 70% (Ross 2009, Ross 2010, EFSA 2010, EFSA 2012). It depends mainly on factors within the building but also on outside humidity. Examples of important factors in the building are stocking density, live weight of the birds, ventilation rate, indoor temperature, number, type and management of drinkers, water consumption and water spillage. Birds are basically air-cooled. That is, air moving over the birds picks up their body heat and transfers it to the environment. Birds do not sweat, they do get some evaporative cooling effect through breathing and panting (Ross 2010). Temperature and relative humidity influence the thermal comfort of the birds. A relative humidity of 60-70% in the house is necessary in the first 3 days (Ross 2009). Relative humidity above 70% can occasionally be reached with high stocking densities durig Winter, when the ventilation rate may be reduced to retain heat and save energy (Ross 2009). At later ages high relative humidity causes wet litter and its associated problems. During summer, broilers may often experience discomfort due to the combined effect of high humidity and high temperature. Relative humidity below 50% leads to an increase in dust and micro-organisms, which increase the susceptibility to respiratory diseases. This situation is not very common and normally occurs only in the first or second week of life (EFSA 2012).

As a ventilation system is conceived to change the air inside the farm, it should be able to control air temperature, relative humidity, and velocity at the height of the animals, while at the same time maintaining a tolerable concentration of gas, in particular CO_2. Therefore, in addition to the global flow rate, that determines the air exchange rate, local air speed has also to be considered. Suitably ventilation design carefully considers the broiler house structure, paying particular attention to turbulence and uniformity of the air distribution. For example, a well-designed ventilation systems that helps dust removal (Banhazi *et al.* 2008), avoids high speeds close to the litter as the associated turbulence favors the suspension of particles in the environment.

Mainly 2 ventilation systems are used in a herd:

- the longitudinal system, in which the air is flowed longitudinally along the axis of livestock (today basically into disuse);
- the transverse system, in which air is fed and expelled crosswise so as to ventilate the breeding cross sections (most used today).

The 2 systems can be combined, in order to offer appropriate solutions to the selected type of ventilation.

The airflow is due to the longitudinal supply (or suction) by the fans and the control of the air speed can prevent the air back layering towards the central zone.

In the present study the results of experimental tests performed in a breeding broilers farm are shown; in particular the efficiency of a semi transversal ventilation system was studied against the use of a pure transversal one. The system under study was suitably designed for the experimentation.

Materials and methods

Poultry farming

The experimentation was conducted in a hen house located in Sant'Elia a Pianisi (Campobasso, Molise, Italy). The module of farming has a capacity of 30,000 animals per cycle: 20,500 males and 9,500 females. Each cycle lasts approximately 80 days: 60 days needed to bring the chicks to commercial size (60 for males and 35 for females) and 20 required for the underfloor space, 20 needed to the health rest. The external dimensions are: 132.00 m x 14.20 m corresponding to a gross floor area of 1,874.40 m^2, with coverage of the type pitched with a height to the eaves of 2.65 m.

The orientation of the building is North-South; the supporting structure is made of steel, the perimeter walls and the cover are made of composite panels consisting of 2 metal plates coatings between which a layer of insulating foam injected at high pressure is interposed. The natural ventilation is crosswise, made with glazing tape with polycarbonate windows and flap opening, which runs along the lateral walls parallel to the longitudinal axis (Figure 1).

In this research, however, a specific longitudinal aeration system has been realized. It consists of 14 axial fans (Figure 1, Table I), with a grid of protection placed at the outlet. Eight fans are placed in the lower part of the wall, while 6 have been positioned in the upper part.

The fan operation is regulated by a control unit regulating the temperature inside the shed and the air exchange. These 2 parameters are set by the

Figure 1. *Chicken farming in an industrial broiler house: crosswise natural ventilation with windows and flap opening, specific longitudinal aeration system.*

Table I. *Main technical data of the fans in the studied ventilation system of an industrial broiler house.*

Model	Euroemme® EM50n
Electrical motor	P = 1.0 HP; n = 1,400 rpm
Impeller	blades: 6; Φ = 1,270.0 mm; n = 368 rpm
Mass	84.0 kg
Maximum air flow	36,180 m^3/h, adjustable with 10 suction blades

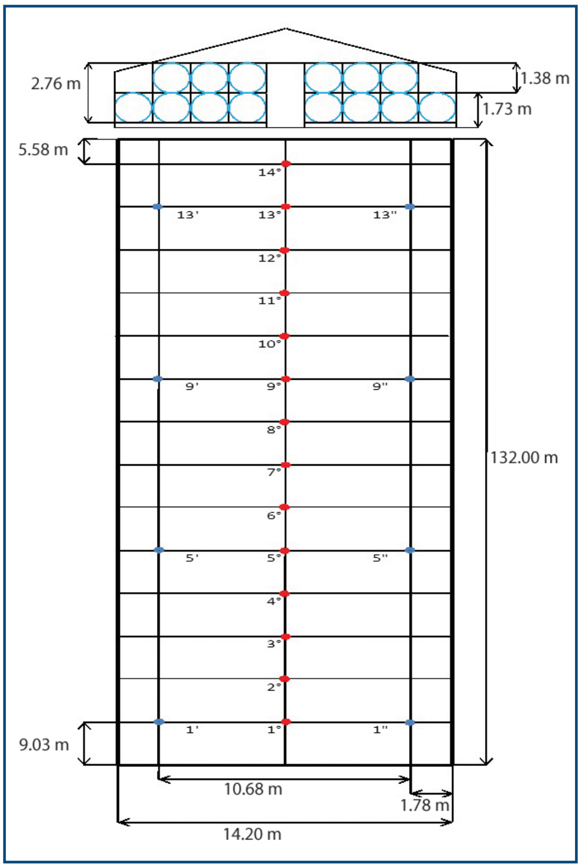

Figure 2. *Computational Fluid Dynamic in an industrial broiler house.*

farmer: the fans start at 19 °C and must provide an air change of 80% in summer and 30% in winter.

The shed is equipped with a control and high temperature protection system, which comes into operation during the warmer months. Depending on the external temperature, it can proceed in 2 ways:

a. When the outdoor temperature is higher than the tolerance limits for short periods of the day, the internal temperature rise is controlled during the coolest hours of the day, with the introduction of an air flow rate depending on the inner temperature: the greater the increase in temperature above the ideal value, the greater the air flow rate.
b. When the outdoor temperature is higher than the tolerance limits for long periods of the day, the internal temperature rise is controlled by mean of an evaporative cooling system.

Two cooling systems are placed along the lateral walls directly next to the service area (on the opposite side of the fans): in this way the air that enters through the cooling runs through the whole shed before being expelled outside. The activation of the cooling has been set as follows: on at 27 °C and off at 24 °C.

Measuring chain and related procedures

The following LSI probes were used for measurements and connected to the data acquisition system BABUC / A.

- Psychrometer BSU102 equipped with 2 thermometers, a dry bulb measuring the air temperature and a wet bulb thermometer (Temperature range: -5-60 °C ± 0.13 °C; relative humidity range: 0-100%, 2% with T = 15-45 °C. The 2 measurements were performed at an air speed of 4 m/s, imposed by a little fan housed inside the instrument.
- BSV101 hot-wire anemometer for omni-directional air speed measurement. The air speed measuring range is 0 - 45 m/s (threshold: 0.01 m/s), ±0.05 m/s (0-0.5 m/s), ±0.10 m/s (0.5-1.5 m/s), 4% (>1.5 m/s).
- BSO 103.1 probe for carbon dioxide measurement. It is an infrared absorption cell with measuring range: 0 to 3,000 ppm.

The measurements were carried out in Summer (June-July 2012), during an entire breeding cycle, when the maximum air flow rate is required. The shed was divided in the longitudinal direction in 14 areas and, for each of them, 3 measurements were made in the central part, each at a different height: 20 cm, 100 cm and 150 cm. Moreover, the positions labelled 1, 5, 9, 13, were divided into 3 subareas: lateral left, central, and lateral right, so as to obtain other 2 sets of measurements. Figure 2 shows a diagram from which it is possible to locate the position of the points where measurements were made.

In order to verify the efficiency of the longitudinal ventilation system compared with a system of transversal type, fluid dynamic simulations were performed using the software Comsol multiphysics. In such a system it is possible to define the geometry of the system, the reference equations for the specific problem (momentum and mass transport in this case) and the boundary conditions (number and type of fans turned on and their flow rate, openings for the air inlet, concentration of the trace gas in input: CO_2 in the specific case, etc.).

In this way it was possible to determine the air flow field inside the farm as well as the concentration of the trace gas. The simulation was made considering stationary conditions corresponding to the experimental ones (longitudinal ventilation system). In this way it was possible to validate the model by comparing simulated and measurement data. The same model has subsequently been used in the same hen house, once this was equipped with a cross ventilation system with the same total air flow rate.

Results and discussion

Figures 3, 4, and 5 show the trends of the measured quantities, temperature, relative humidity and CO_2 concentration of the air inside the plant at different heights. In particular, the average values recorded in each position in the test period have been reported. A general increase was observed of both of the temperature and of the CO_2 moving from the area (Figure 2 - position 1: main input of the air) opposite

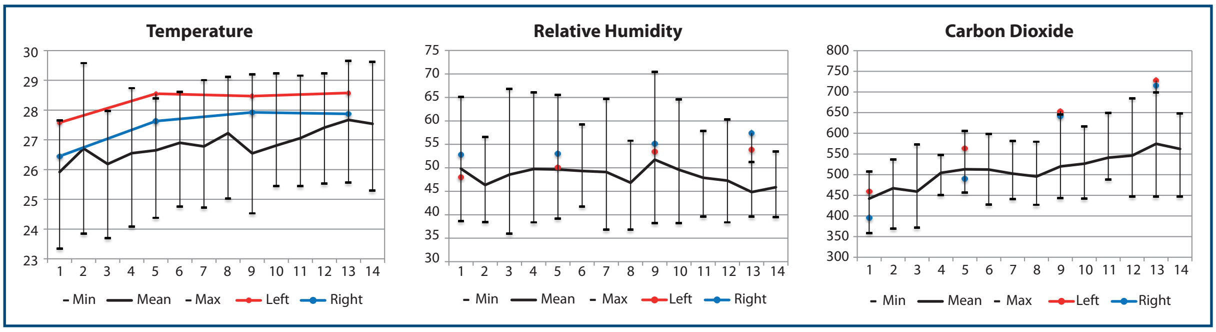

Figure 3. *Trends of the measured quantity (temperature, relative humidity and CO_2) concentration of the air inside the plant at 20 cm.*

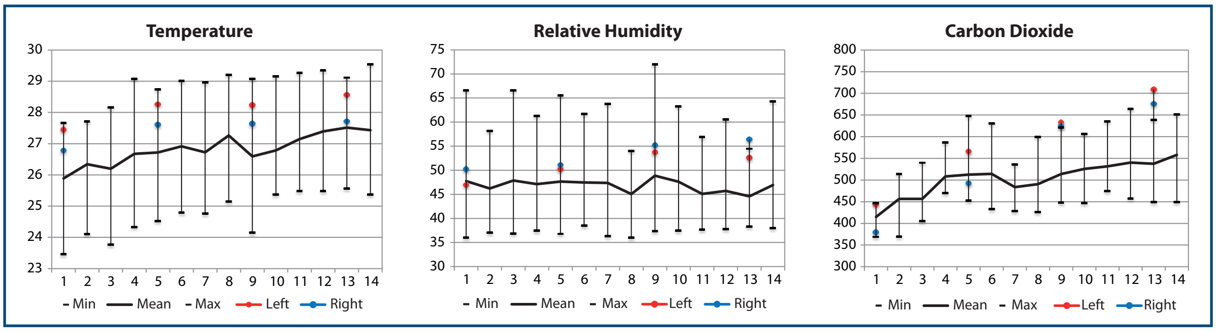

Figure 4. *Trends of the measured quantity (temperature, relative humidity and CO_2) concentration of the air inside the plant at 100 cm.*

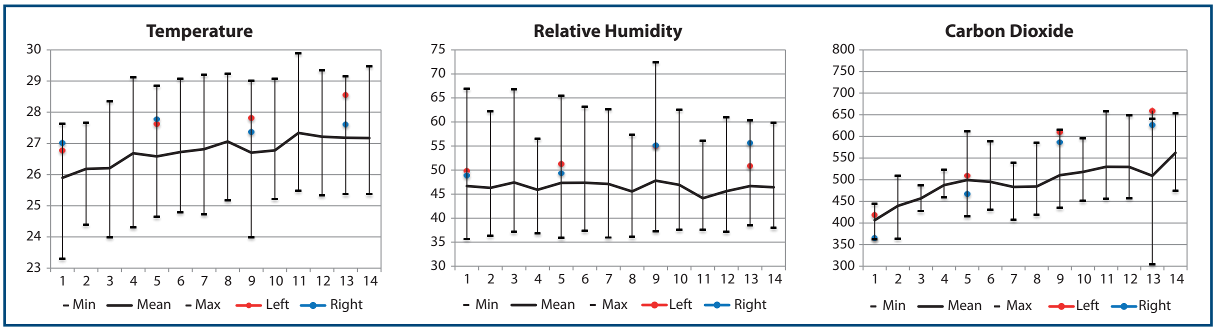

Figure 5. *Trends of the measured quantity (temperature, relative humidity and CO_2) concentration of the air inside the plant at 150 cm.*

to that of the fans to the air suction wall (Figure 2 - position 14), while the relative humidity remains almost constant. This is due to the presence of the animals and of the litter producing thermal energy and carbon dioxide.

The air temperature inside the farm varies only slightly (±1.5 °C) although it remains higher than optimal. These values, however, are not considered unreasonable because the relative humidity is kept always lower than 50%. It is also a substantial invariance of these quantities depending on the height from the litter, while the relative humidity at 20 cm from the litter is higher.

The ventilation system operates in terms of control of environmental parameters, allowing for a proper air exchange in all areas of the farming module. Trial results highlight the need for a modulated ventilation system, with the possibility of acting in a differentiated way in the layers near the floor, in which, regardless of the distance from the fans, critical environmental conditions may occur due to increased moisture, which may lead to an increased diseases risk in animals, caused by the proliferation of bacteria in the litter.

The highest concentration of moisture near the floor is due to animals respiration and manure exhalations, which are constituted by complex gas mixtures, in which the water vapor has the highest specific weight and tends to be disposed in the lower layers with respect to CO_2, other gaseous compounds based on hydrogen are also present. Moreover, in the specific case, the studied breeding module is located in a temperate climatic zone, where the Summer temperatures are not so high and, therefore, do not feel particularly the need to remove the warm air from the upper layers. The tests, however, show that this requirement is satisfied by the used ventilation system allowing a limited temperature and carbon dioxide range.

The latter two parameters, while remaining within the limits of acceptability, tend to increase in the module areas most distant from the fans, showing a limit of the longitudinal distribution compared to the transverse (Figures 6 and 7). To confirm this, it is noted that the presence of the central openings corresponding to position 7 (Figure 2) and leads to a substantial decrease in the concentration of CO_2 in the central area downstream of section 7, due to a better air circulation.

Figure 6 shows the simulated flow field, represented by the stream lines, in which the concentration of CO_2 is at 20 cm above the litter. It is observed that the stream lines are mainly concentrated in the central corridor as well as found experimentally. This fact is confirmed by the analysis of the average values both of temperature and CO_2 concentration also experimentally determined during the trial period (Figures 3, 4, and 5). These are greater in the 2 lateral corridors with respect to the central one, especially in the downstream area of the lateral openings (position 7 in Figure 2).

Therefore, the longitudinal system has the drawback of not allowing a uniform and effective air flow along the side walls, especially in those areas farther away from the fans. In this context, supplying air from side intakes lead to partially overcome this limitation, as it has been highlighted by the experimental data. Consequently, these results lead to particular design solutions such as to housing animals in the middle part of the breeding module, allocating the lateral areas to technical and/or functional operations providing only animals and operators passage.

Figure 7 reports the flow field in the case of cross ventilation, as well as the trend of CO_2 concentration

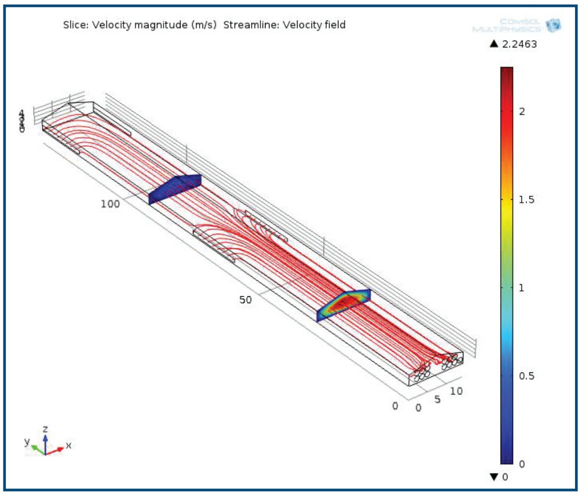

Figure 6. *Simulated flow field of the industrial broiler house considered as case study.*

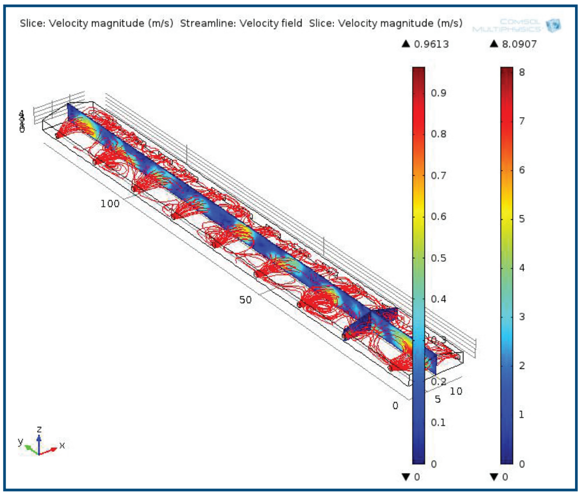

Figure 7. *Simulated flow field in the case of cross ventilation in an industrial broiler house.*

at 20 cm above the litter. Also in this case observed values are always below the aforementioned limits. However, the transverse CO_2 distribution obtained by simulation shows a more uniform air exchange.

On the one hand, the distance from the fans becomes an important technical variable that significantly influences the formation of areas of stagnant air. The hypothesized fan positioning meets the design parameters currently adopted but, in the specific case, is characterised by an excessive distance with regard to the possible stagnation that appear in the proximity of the walls between 2 successive fans.

On the other hand, a possible reduction of these distances may cause flow 'short-circuiting', which was observed in some points, especially close to the transverse walls (beginning and end of the module). These flows leave from a fan and partly carry the air towards the next fan thus reducing the efficiency of the ventilation.

This allows to state that this parameter should be determined at design time through a proper fluidynamic study, in particular a shorter distance may be accepted in the central parts of the module and should be increased to extremes, without altering the total number of fans required.

The correct positioning of the fans, as well as an adequate distribution of flows, also facilitate the control of CO_2 and moisture concentration in each volume of the breeding module, thus leading to greater flexibility. The latter is essential when the breeding cycle is all done in the same module, imposing its partitioning, both in the use of machines and spaces.

Conclusions

The buildings for broiler breeding have dimensional characteristics that set them apart in a rather marked way from buildings designed for other livestock farms. The dimensions in the horizontal plane, in fact, have a very high length / width ratio due to the high level of mechanization and automation of the feeding operations. In this context, the identification of the most suitable type of installation ensuring a uniform and regular air exchange in all areas of the building is of fundamental importance.

The results of this study show that a correct architectural and structural design of the building must be supported by an equally correct mechanical and fluid dynamics design of the ventilation system in order to maintain the environmental parameters within the limits of the thermo-neutral and welfare conditions, to achieve the highest levels of productivity.

The possibility to gain optimal thermo-hygrometric conditions, in addition to the breeding cycle and animal species, is also related to the climatic conditions of the farm location. Therefore plant solutions should be appropriately assessed by maintaining, in each case, their flexibility.

In this study, the experimental results and those of the computational fluid dynamic (CFD) simulation show that the longitudinal distribution must be supported by a specific design of spaces and facilities for the movement of the personnel, for distribution of food and water. This solution should be suitably integrated with both more lateral openings for the air inlet at the center of the module and with automatic systems controlling the fans at the different heights. With these changes, the system can also fit situations where the maintenance of optimal thermal conditions is more important than the need to control gas layering.

In contrast, the transverse distribution of the air, most frequently adopted in industrial installations, offers the best performance in terms of installed power and temperature control in warm climates, while requiring a particular fluid dynamic study, aiming to positioning the fans so as to minimize the stagnation zones and short-circuiting phenomena of the introduced air.

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