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Research Paper

# Measurement and numerical simulation of single-sided mechanical ventilation in broiler houses

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In recent years, some broiler production farms especially in Mediterranean areas, have incorporated single-sided mechanical ventilation (i.e. air inlets and fans are located in the same lateral wall). However, little scientific information on the performance of mechanical single-sided ventilation systems is available to date. This ventilation method is fitted to broiler houses because this ventilation system appears appropriate to diminish the stress and mortality of broilers during hot seasons in this climate. To analyse the single-sided ventilation method scientifically, the indoor environments of broiler houses were examined by numerical simulation using computational fluid dynamics (CFD) with validation using a range of different buildings with direct measurements using a multi-sensor system. An analysis of variation of the results of the validation tests produced to a p-value of 0.3908. Thus, the methodology employed (i.e. CFD or sensors) was not significant. The CFD simulations showed a wide range of values for air velocity: the minimum value of air velocity at broiler level was 0.52 ± 0.40 m $s^{-1}$ and the maximum was 1.29 ± 0.41 m $s^{-1}$. Two major conclusions were drawn in terms indoor air velocity: (i) excessive heterogeneity in the plane where the animals were located; and (ii) insufficient air movement to contribute to the thermoregulation of the birds and lower their internal heat and associated thermal stress in occasional periods of hot weather.



## 1. Introduction

Mechanical ventilation systems are required in warm climates for broiler production. The configuration and management of these systems has been under investigation for several decades (Charles and Walker, 2002; MWPS, 1990). Cross ventilation systems are the most frequently employed in the Mediterranean area (Blanes-Vidal, Guijarro, Balasch, & Torres, 2008; Bustamante et al., 2013) but they can create thermal problems during hot seasons. In recent years, Mediterranean broiler poultry farms have been installed single-sided mechanical ventilation and this can be considered as an emerging

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**Nomenclature**

| | |
|---|---|
| D | Diffuser |
| E | Total energy (J) |
| $E_i$ | Relative error at point *i* |
| F | External force vector (N $m^{-3}$) |
| g | Gravitational acceleration (m $s^{-2}$) |
| h | Specific enthalpy (J $kg^{-1}$) |
| H | Height (m) |
| J | Component of diffusion flux (kg $m^{-2}$ $s^{-1}$) |
| k | Turbulent kinetic energy ($m^2$ $s^{-2}$) |
| $k_{eff}$ | Heat transmission coefficient |
| M | Methodology |
| P | Pressure (Pa) |
| $S_h$ | Total entropy (J $K^{-1}$) |
| $S_m$ | Mass source (kg $m^{-3}$) |
| t | Time (s) |
| T | Temperature (K) |
| u, v, w | Velocity components (m $s^{-1}$) |
| $V_{CFD}$ | Air velocity obtained in the CFD simulations (m $s^{-1}$) |
| $V_{meas}$ | Average of the measured air velocity (m $s^{-1}$) |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | Dissipation rate of turbulent kinetic energy ($m^2$ $s^{-2}$) |
| $\rho$ | Fluid density (kg $m^{-3}$) |
| $\tau$ | Stress tensor (Pa) |

*Abbreviations and acronyms*

| | |
|---|---|
| ANOVA | Analysis of variance |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BCs | Boundary conditions |
| CFD | Computational fluid dynamics |
| FAO | Food & Agriculture Organization, United Nations |
| PDEs | Partial differential equations |
| RANS | Reynolds Averaged Navier–Stokes |
| SIMPLE | Semi-implicit method for pressure-linked equations |

technology. As its name suggests, single-sided ventilation consists of the inlets and outlets (fans) being located in the same wall. Spain is the main Mediterranean country producing broilers and it is the thirteenth leading broiler producer worldwide with ~720,000 tonnes $y^{-1}$. With ventilation systems, it is necessary to ensure the welfare of the animals, minimise pollutant emissions and consume energy and water efficiently. It is also, of course, vital to improve the working environment the farmers and increase their income.

Poultry production for meat (broilers) is one of the most important food industries, with a six-fold increase in world production in the period from 1972 to 2012 (FAO, 2015). Ventilation systems are crucial in the design in broiler houses and they are of the great importance in intensive broiler production. It is essential to explore and compare ventilation systems (e.g. cross, single-sided, tunnel) particularly because housing conditions have been shown to influence bird welfare more than the flock density (Dawkins, Donnelly, & Jones, 2004). Published research on the performance of mechanical single-sided mechanical ventilation systems is not available and the use of scientific methods to study the effectiveness of this system is essential. Earlier research on mechanical ventilation systems used CFD techniques to study the internal microclimate of poultry farms (Blanes-Vidal et al., 2008; Bustamante et al., 2013; Bustamante, García-Diego, Calvet, Torres, & Hospitaler, 2015; Mostafa et al., 2012; Osorio, Ferreira, Oliveira, Arêdes, & Oliveira, 2011; Pawar, Cimbala, Wheeler, & Lindberg, 2007). Also, there are interesting papers referring to the application of CFD techniques in naturally single-sided ventilation (Allocca, Chen, & Glicksmann, 2003; Dascalaki, Santamouris, Argirou, Helmis, & Asimakopoulos, 1996; Mokhtarzadeh-Dehghan, Telebany, & Reymonds, 1990; Papakonstantinou, Kiranoudis, & Markatos, 2000), but CFD has not been applied to single-sided mechanical ventilation for livestock buildings. Suitable control of the environmental parameters used with single-sided ventilation, e.g. air velocity, temperature, humidity and differential pressure, might lead to reductions in energy and water consumption (May, Lott, & Simmons, 2000; Yavah et al., 2004) as well as improve broiler performance (Lott, Simmons, & May, 1998; Yanagi, Xin, & Gates, 2002). The control of the air velocity, and its distribution, is the most widespread method to regulate the convective heat of broilers, which can cause stress and mortality in hot seasons.

The validation of CFD simulations by specific measurement systems is also necessary. By developing validated simulation models, it will be possible to use CFD simulations in order to build "virtual broiler buildings architectures equipped with different virtual ventilation systems". By means of these numerical simulations, it will be possible to easily explore the optimum design of the broiler building and its ventilation system and also devise more suitable management. In terms of validation, Bustamante, Guijarro, García-Diego, Balasch, and Torres (2012) developed a multi-sensor system for isotemporal measurements of air velocities and temperature that could be used to validate the CFD results. Obviously, direct measurements can only provide values at the discrete coordinates of location of sensors, whereas the CFD results can offer knowledge of the whole indoor environment. The effect on the air velocity patterns caused by the installation of diffusers in fans in a single-sided ventilation system, as their influence has not yet been analysed. Diffusers can be used to prevent direct air flow to the birds located in front of the fans, avoiding causing the birds colds or respiratory diseases, particularly when they are featherless such as in the early stages of the bird's life. Nevertheless, farmers think that diffusers can worsen the indoor environment and could increase fatal episodes in hot seasons.

Therefore, the main objectives of this work were:

(i) To study the indoor air velocity values and its distribution in mechanical single-sided ventilation on broiler farms.
(ii) To analyse the effect on the air velocity patterns caused by the installation of the diffusers at fans.
(iii) To characterise and evaluate mechanical single-sided ventilation in order to solve the problem of heat stress in broiler farms.