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Numerical study of mechanically ventilated broiler house equipped with evaporative pads

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ABSTRACT

One of the important factors to improve the broiler production is the provision of an optimum indoor environment (air quality, temperature, humidity, air velocity, gases and PMs concentration) with lower possible cost. The internal microclimate can be controlled either passively by selecting appropriate construction geometry and materials or actively by the ventilation systems and the electromechanical (E/M) equipment. In the case of broiler chamber the conditions that constitute optimum internal microclimate vary with respect the birds' age.

In the present work, the ventilation, inside a modern and fully automated broiler chamber equipped with fans and evaporative pads located in Central Greece, is simulated using Computational Fluid Dynamics (CFD) techniques. The transport phenomena inside the broiler house are described with Reynolds Averaged Navier Stokes (RANS) equations solved with the Finite Volume Method (FVM). The flow is assumed 3D, steady state and turbulent. The fans of the broiler chamber abduct air from the interior, forming inside negative pressure distribution, and are modeled as exhaust fans. The air enters the broiler house through evaporative pads which are simulated as porous media and as heat sinks, concurrently. The heat sink term is yielded analytically according to the external climatic conditions and the evaporative pads specifications. The litter and the animals are considered also as porous materials and sources of heat. The birds' thermal properties and their heat emissions are computed according to their age, the measured birds' volume, and height and meat composition. The developed CFD model is validated against measurements of temperature (16 points) and air velocity (6 points). According to the simulation results, it is drawn that the vertical temperature gradient should be taken into account when the operational sensors for the cooling devices are positioned inside the chamber since there is a deviation higher than 2 °C between the air content above and among the birds.

Also various combinations of the available five fans, operating in two possible modes of the examined poultry chamber are studied in order to assess their effect to the internal microclimate. The operation of two or three central fans are proven to be the optimum choice in terms of temperature, ventilation and air velocity. The operation of only one fan fails to preserve the required temperature, while the operation of more than three fans does not improve the ventilation rates.

1. Introduction

In a broiler house the internal microclimate affects the birds' health and productivity in terms of growth rate, the farmers' health and the public health, indirectly, through the pollutants emissions and finally, the quality of the produced meat. The microclimate control requires energy consumption and this is an additional factor that aggravates furthermore the environment through the consumption of energy sources and the release greenhouse gases. Consequently the effective control of the internal microclimate has both economic and environmental impact and is directly related with the public health (NRC, 2003).

The internal microclimate is affected by the air temperature, the relative humidity, the air speed, the air quality (CO_2, NH_3, CH_4, PMs etc concentrations) and the light levels. The desirable temperature at the birds' level ranges according to the bird age ranges of 18–32 °C, the relative humidity from 60 to 70% (Brauer-Vigoderis et al., 2014), the air velocity from 0.35 to 1 m s^{-1} depending on the air temperature (FAO, 2011), the light levels must be kept between 5 to 20 Lux (Robins and Phillips, 2014). The pollutants concentrations should be less than

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1000 ppm or 0.35% for CO_2, less than 100 ppm or 0.01% for NH_3, less than 0.75% for CH_4 and less than 1000 ppm for particulate matters (PMs) (I.H.V.E. Guide, 1965).

The study of the internal microclimate is a multi-parametric problem. It involves the simultaneous approach of many variables which are interact to each other. The internal microclimate is affected by a list of factors, and some of them are, the building geometry and construction, the installed electromechanical equipment and its operational strategy, the breeding strategy, the birds characteristics and their age, their diet, the bird kind and the external climatic conditions. All the above constitutes a complex problem that involves many disciplines and could not be addressed with simplified models. Two basic research tools have been used widely for the study of microclimate in broiler houses: (a) the field measurements and (b) the implantation of numerical methods.

Field measurements of gas and PM levels at commercial livestock barns have been previously addressed (Philips et al., 2000) as well as advances in monitoring techniques (Ni and Heber, 2001). Most of research is devoted to NH_3, as NH_3 is considered as the most bothersome emission arising from broiler houses (Casey et al., 2003). Finally the set of parameters (temperature, relative humidity, air velocity and NH_3 concentration) which structure the microclimate of a broiler house has been measured (Bartzanas et al., 2015). Measurements can be used independently for the description of microclimate or can be used for validation of a numerical tool that can supply more detail description in all over the examined flow field.

For that reason, another group of studies used CFD techniques for the prediction of microclimate in livestock building in general and in a broiler house, in particular. As a first step, those studies considered without animals in the livestock rooms (Sun et al., 2002) or with static physical animal models (Bjerg et al., 2000). This difficulty to incorporate the behavior and the emissions from the animals was later addressed (Aerts and Berckmans, 2004), since the animal modelling is crucial for the study of microclimate control. In this context, a 2D CFD model was developed for the study of microclimate in a naturally ventilated broiler house (Rojano et al., 2015) taking into account the variation of the emissions and optimum microclimate characteristics according to the birds' age. The flow around poultry house has also been studied in order to estimate the effect of pollution arise from the poultry room to the external environment (Markousi et al., 2015).

In a broiler house, the simulation treatment is further complicated, in the case of modern constructions where the electromechanical equipment should be accounted. For example, fans may impose pressure heads inside or in the boundaries of the computational domain, evaporative pads cause pressure drop and are sources of humidity and sinks of heat, heat production devices are also heat sources etc. Furthermore the operation of electromechanical equipment is neither steady, nor continuous during the broiler chamber operation. In the present work, a 3D CFD model is developed for the flow and transport phenomena simulation in a mechanically ventilated broiler house equipped with evaporative pads. In this model are simulated through to the analogous developed sub-model, the animals' heat emissions, the fans' operation and the cooling process of the evaporative pads, which are including into the computational domain. The model is validated against measurements and it is used as a conducting basis in order to be carried out a parametric study with several operational combinations of functioned fans. In the parametric study examined several cases, in which are differentiated the number and the operational modes of the worked fan or fans, serving the subject broiler house.

2. Materials and methods

2.1. Numerical model

The flow was considered to be 3D, incompressible, steady state and turbulent. The flow and transport phenomena inside the broiler house were described using the Reynolds Average Navier Stokes (RANS) equations (Ferziger and Peric, 1996), for continuity, momentum, energy conservation, turbulent kinetic energy and specific dissipation rate. In the momentum equation two source terms are added, one for the buoyancy effect and another one for the pressure drop, caused by the porous materials. The density, ρ_f, is temperature depended and is calculated in every computational cell (Bansal et al., 2005) and its value is used for the calculation of buoyancy forces, f_b.

$$\rho_f = 2.2204 - 0.353 \times 10^{-2} T \tag{1}$$

$$f_b = (\rho_f - \rho_o) g \tag{2}$$

where ρ_o [kg/m^3], stands for the reference density, g [m/s^2] for the gravity acceleration and T for the air temperature in K. The birds, the litter and the evaporative pads act as porous materials through the addition of a source term, S_i in the momentum equations. This source term is constituted by viscous (Darcy relationship) and inertial loss terms.

$$S_i = -\left(\frac{\mu}{\alpha} u_i + C_2 \rho u_i^2\right) \tag{3}$$

where μ [Pa s], is the air viscosity, 1/α [1/m^2] the viscous resistance coefficient, u_i [m s^{-1}] the local air velocity in the i direction and C_2 [1/m] is the inertial resistance coefficient. The birds and the litter are also sources of heat, adding a source term in the energy equation, while the evaporative pads absorb heat, adding a sink term in the energy equation. Finally all the porous materials contribute in the calculation of the effective thermal conductivity, k_{eff} [W/m K] (Fidaros et al., 2010). Finally the effect of porous materials to the local specific heat coefficient, C_p [J/kg K], is taken into account indirectly modifying the local air specific heat coefficient occupied by the porous media. The effect of turbulence on the flow was implemented via the high Re k-ω model (Wilcox, 1994) with wall functions.

2.2. Physical problem – geometry

In the present work, a modern broiler house is examined with total width 13.61 m, length 45.78 m, maximum height 4.45 m and side height 3.35 m. In Figs. 1 and 2 the side, front and rear views of the examined geometry are given. The broiler house is oriented from East

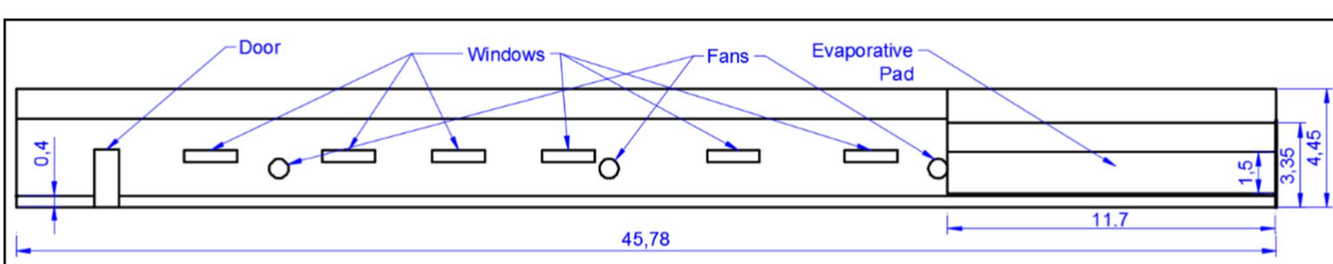

Fig. 1. Side view of broiler house.

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