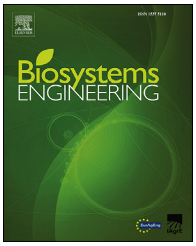
BIOSYSTEMS ENGINEERING 151 (2016) 273–285

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/issn/15375110



Research Paper

Computational modelling of thermal and humidity gradients for a naturally ventilated poultry house

Fernando Rojano [a,*], *Pierre-Emmanuel Bournet* [a], *Melynda Hassouna* [b], *Paul Robin* [b], *Murat Kacira* [c], *Christopher Y. Choi* [d]

[a] *EPHor, Environmental Physics and Horticulture Research Unit, Agrocampus Ouest, Centre d'Angers, 2, rue Le Nôtre, 49045, Angers, France*
[b] *SAS Lab., INRA 65 Rue de Saint-Brieuc, 35042, Rennes, France*
[c] *Agricultural and Biosystems Engineering, The University of Arizona, Tucson, AZ, 85721, USA*
[d] *Biological Systems Engineering, University of Wisconsin, Madison, WI, 53706, USA*

ARTICLE INFO

Article history:
Received 29 July 2015
Received in revised form
22 September 2016
Accepted 23 September 2016

Keywords:
Heat and mass transfer
Internal climate modelling
Livestock building

Natural ventilation represents a strong tool for ameliorating climate and air quality in poultry houses if the benefits of weather conditions can be maximised. To that end, this investigation analyses the impact of natural ventilation on the dynamics of the internal climate of a poultry house focussing on the role played by the outside climatic parameters except wind direction. Experimental data with prevailing North-East wind direction was considered to identify seven periods with at least 4 h of stable wind direction. Three of these periods were chosen as typical examples and used to validate a 3D computational fluid dynamics (CFD) model, to integrate the main elements determining the internal climate: animal heat and water vapour generation, radiative heat transfer, and ventilation. The three periods under analysis allowed us to deduce, from the experimental and simulated data, the influence of all the other external climatic variables (i.e. temperature, absolute humidity, solar radiation and wind velocity) that affected the internal climate. The accuracy of the CFD model at evaluating each of the three periods reached a RMSE of 1.3 °C, 1.2 °C and 0.5 °C for internal temperature and a RMSE of 0.9 g $[H_2O]$ kg^{-1} [dry air], 0.6 g $[H_2O]$ kg^{-1} [dry air] and 0.2 g $[H_2O]$ kg^{-1} [dry air] for internal absolute humidity, respectively. Then, the predictions of the 3D CFD model were analysed, using air residence-time concept to estimate ventilation rates, and also to investigate sensible and latent heat exchanges.

1. Introduction

Adequate internal climate is necessary whilst most poultry houses are in operation because the animals inside the house are susceptible to the accumulation of toxic gases, heat as well as dusts. Although the weather is highly variable in most regions, a suitable management of external climatic variables could assist in the achievement of required internal climate and air quality conditions. Also, livestock buildings that fully rely on benefits of external climate could thus, at least in

---

* *Corresponding author*. Fax: +33 (0) 2 41 22 55 53.
E-mail address: rojanoag@agrocampus-ouest.fr (F. Rojano).

http://dx.doi.org/10.1016/j.biosystemseng.2016.09.012

Nomenclature

A	Azimuth, radian
AH	Total heat generated from animals, W
AH_L	Latent heat from animals, W
AH_S	Sensible heat from animals, W
AER	Air exchange rate, h^{-1}
a	Absorption coefficient, m^{-1}
a_υ	Inlet vent area, m^2
C_p	Air specific heat, J kg^{-1} °C^{-1}
C^p_{outlet}	Tracer-gas concentration at outlet coming from a chosen point p, ppm
C^{inlet}_p	Tracer-gas concentration at a chosen point p coming from inlet, ppm
C_∞	Tracer-gas concentration when internal space is filled with homogeneous concentration, ppm
E	Elevation, radian
H	Characteristic height of the broiler house, m
h_i	Internal absolute humidity, g[H_2O] kg^{-1}[dry air]
h_o	External absolute humidity, g[H_2O] kg^{-1}[dry air]
HF_{go}	Heat flux from outdoor ground, W m^{-2}
I	Radiance, W m^{-3} sr^{-1}
k_z	Turbulence kinetic energy, m^2 s^{-2}
LH_L	Latent heat from litter, W
LH_S	Sensible heat from litter, W
RMA	Room mean age, s
LMA_p	Local mean age at any point p within the building, s
RMR	Room mean residual lifetime, s
LMR_p	Local mean residual lifetime at any point p within the building, s
m	Air flow, m^3 s^{-1}
n	Refractive index
p_o	Atmospheric pressure, Pa
Q_s	Sensible heat loss, W
Q_l	Latent heat loss, W
q	Atmospheric radiative flux, W m^{-2}
RMSE	Root-Mean-Square Error
$\bar{r}$	Position vector, m
$\bar{s}$	Unitary vector along the propagation of radiation
$\bar{s}'$	Scattering direction vector
S_R	Solar radiation, W m^{-2}
S_ϕ	Source term (i. e. buoyancy effects)
T	Air temperature, °C
T_{fi}	Temperature on indoor floor, °C
T_i	Indoor temperature, °C
T_o	Outdoor temperature, °C
t	Time, s
u_j	Velocity in direction j (i.e. for three-dimensional domain j = 1, 2, 3), m s^{-1}
u_o	Wind velocity, m s^{-1}
V	Wind velocity at curtain opening, m s^{-1}
Vol	Building volume, 158 m^3
x_j	Coordinate in direction j, m
α	Wind direction, radian
ε_r	Emissivity, [from 0 to 1]
ε_z	Turbulence energy dissipation, m^2 s^{-3}
ϕ	Denotes velocity, temperature, turbulent kinetic energy, dissipation kinetic energy and mass transport
Γ_ϕ	Diffusion coefficient of the variable ϕ
λ	Latent heat of vaporisation, 2437 J g^{-1}
σ	Stefan-Boltzman constant (5.67×10^{-8} W m^{-2} °C^{-1})
σ_s	Scattering coefficient, m^{-1}
Φ	Diffusion phase function
Ω^t	Solid angle, sr

terms of ventilation, reduce significantly the use of energy for mechanical ventilation. However, ventilation rates must be controlled since it has been found that excessive ventilation in poultry houses could augment yield of ammonia (Rong, Liu, Pedersen, & Zhang, 2014) and its discharge to the surroundings can impact the environment.

Dynamics of internal climate is determined by the ventilation rates which depend on weather, internal generated heat and the size and location of vent openings. Among the weather variables, wind direction and magnitude are of particular interest due to their crucial role to define ventilation rates. Previous studies have experimentally proved this fact in Saha et al. (2012). High thermal gradients and low wind velocities can also contribute to generate thermal buoyancy forces (Hunt & Linden, 1999) that can modify internal air motion patterns.

This work focuses on the study of internal climate dynamics looking at modelling thermal and humidity gradients by developing a comprehensive analysis about the interaction of the external and internal climate dynamics. The modelling approach is implemented using computational fluid dynamics (CFD) and taking account of the main processes about heat and mass transfer.

1.1. *Background*

Natural ventilation of buildings, as key element to investigate internal climate dynamics, is induced by convective and buoyancy forces. Both forces can be experimentally assessed through the use of tracer-gas techniques. The reliability and accuracy of the corresponding studies depend on the mixing ratio between existent gases and the tracer-gas, together with the experimental settings (i.e. external and internal climatic conditions and vents size and orientation) and accuracy of the measurements along time (Van Buggenhout et al., 2009). Advanced studies have been conducted to identify the types of tracer-gas and the rate of release to get an optimal mixing not only at the level of vents but also at different regions. Nonetheless, spatial refinement of measurements still depends on the gas analyser resolution in conjunction with stability of the external climate (Mendes et al., 2015).

Due to constraints at using tracer-gases, when spatial refinement is required, an array of sensors distributed throughout the building can serve to identify the velocity field. By means of sonic anemometers strategically placed at the interior of the building, an accurate estimation of ventilation rate can be achieved, and with advantage of providing further