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Review of live stock buildings modelled with CFD techniques

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Abstract
The control of the indoor environmental factors (air velocity, temperature, humidity) allows improving the thermal comfort area in automated farms. A deep knowledge of these factors and how they are distributed in the farm allows reducing the effects of thermal stress. In this article, the authors review the use of computational fluid dynamics (CFD) models in the climate control of livestock farms and propose recommendations obtained from different farm models. The use of CFD tools and the validation with experimental results has been widely evaluated in the literature. Both real and reduced, scaled farms were evaluated by different authors, regarding the behaviour of airflow, the appropriateness of turbulence models and the use of measurement equipment. Natural and mechanical ventilation have different challenges in practice, and therefore both have been subject of study. Occupied and empty farms were used for validation, and different CFD analysis were used to determine the distribution of air velocity, temperature and humidity. By means of these analyses the environmental parameters have been evaluated as a function of changing farm design and management: the change of building dimensions, the roof geometry, the height of the air inlet openings, the opening angle of air inlets, and the presence of equipment and animals in different sections of the farm.

Keywords: Farm; CFD; Air velocity; Real scale; Animals.

1. Introduction

The environmental factors, the design of farms and their operation have a large influence on animal production, particularly in intensive production systems. It is necessary to control the air velocity, temperature and humidity to maintain the thermal comfort area at animal level. Computational fluid dynamics (CFD) allows understanding the behaviour of gaseous fluids such as the air exchanged in the farm. It also offers valuable simulations of the heat transfer, ammonia and carbon dioxide concentrations gradients inside and outside the building [1]. Several researchers have analysed the indoor environmental conditions of livestock buildings using different available experimental data at animal level. However, CFD tools can go beyond the limitations of measurements, and therefore they constitute a valuable tool for designing and analysing the airflow behaviour and heat flux modelling at farm level. From a practical point of view, using CFD tools may allow improving the indoor environment of livestock farms in terms of building design and farm operation. Therefore, the use of CFD techniques may contribute to reduce the cost of production and to increase the productivity of the animals.

The livestock domain model is affected by the mesh design and by the turbulence model. The performance of CFD simulations is evaluated in the validation processes, which is influenced by the scale of the building and the consideration of the animals, among others. In the literature, a wide range of situations has been modelled with CFD. The objective of this review study is to analyse how CFD has been used in livestock buildings, in terms of types of buildings, model characteristics and validation.

2. Methodology

A comprehensive literature review was conducted regarding the use of CFD to model the environmental conditions of livestock farms in different animal species. Additional aspects revised in this survey related to the type of ventilation (natural or mechanical), the scale of the model (full scale or scaled experiments), the type of mesh, the turbulent model used, the validation of measurements and the recommendation of future improvements. Selection criteria of publications were the publication in indexed journals and the inclusion of most of the factors mentioned before.

The literature survey was conducted by means of the Web of Knowledge, and a summary table was obtained. Finally, summary statistics of the aforementioned factors were obtained and the results were discussed.

3. Results and discussion

As a result of the literature search, a total of 30 references were selected. These references are listed in Table 1, together with the characteristics of the study (animal species, type of ventilation, scale of the model, type of mesh, the turbulent model and the validation of measurements.

From the survey, it can be observed that most research has focused on improving the ventilation in broiler buildings, although research is also available in other species such as pigs and cows. This major interest in broiler buildings is related to the sensitivity of broilers to adverse temperatures, and is also conditioned because of the relative simplicity of broiler buildings, compared with other livestock houses.

3.1 Scales and dimensions

Both full and scaled simulations can be found in the literature. Full farm models represent the general indoor environment of a farm and provide relevant information of the airflow distribution, which may be very valuable for building design. On the contrary, representing a model of the whole farm building requires important efforts in the model design, particularly in defining the model mesh. Full farm models are therefore used in the literature to establish alternative design options or evaluating farm operation strategies.

Scaled simulations represent a particular farm region of interest. Although this analysis do not provide information of the whole farm measurement, it allows focusing on particular research aspects, for example heat transfer from the animals, animal disturbance of the air stream or modelling gaseous emissions from the animals. This is an interesting option for laboratory validation, since laboratory dimensions are normally smaller than those of commercial farms. Farm scaling is also interesting for representing a whole farm under laboratory conditions. This has been mostly used for validation of naturally ventilated buildings under controlled wind tunnel conditions.

Validation of CFD models is also essential to ensure valid applications. The scale and dimension of models also determine the possibility of validation. Measurement equipment of the most relevant parameters (air temperature, relative humidity and velocity) may interfere with the airstreams in the farm. The presence of animals may also be an obstacle for validation, as a consequence of the disturbance of animals and the installations. Some measurement devices (e.g. ultrasonic anemometers) may have relatively large dimensions, which may impede a practical installation in the farm. Validation of full scale models poses some difficulty, particularly in naturally ventilated buildings. For this reason, scaled models allow concentrating measurement efforts in particular areas of interest (e.g. the performance of fans or windows), although disturbances of measurement devices may be of higher relevance.

Table 1. Short summary of CFD studies by species.

Reference	Animal	Ventilation	Scale	CFD Code	Mesh type	Turbulent model	Measurements
Bjerg [1]	Pigs	Natural	Scaled	Fluent	Hexahedral	Standard k-ε	Temperature, air velocity, water content
Blanes-Vidal et al., [2]	Broilers	Mechanical	Full	Fluent	Unstructured (Gambit)	Standard k-ε	Temperature, air velocity, pressure
Bustamante et al., [3]	Broilers	Mechanical	Full	Fluent	Tetrahedral (Gambit)	Standard k-ε	Temperature and velocity
Bustamante et al., [4]	Broilers	Mechanical	Full	Fluent	Tetrahedral (Gambit)	RNG k-ε	Temperature and velocity
Gebremedhin and Wu [5]	Cows	Natural	Full	Phoenics	Tetrahedral hexahedral	Standard k-ε	Heat transfer
Harral and Boon [6]	Broilers	Mechanical	Scaled	Phoenics	Non-orthogonal	Standard k-ε	Velocity and turbulence energy distribution
Hoff et al., [7]	General farm	Mechanical	Scaled	In-hse	Structured	FTKE, LRKE, LBLR models	Air velocity and temperature
Kwon et al., [8]	Pigs	Mechanical	Scaled	Ansys	Hexahedron and tetra-hybrid mixed shapes (Gambit)	RNG k-ε	Ventilation rate, temperature, pressure
Li et al., [9]	Broilers	Mechanical	Scaled	Fluent	Unstructured tetrahedral	SST k-ω	Heat transfer and air velocity
Li et al., [10]	Pigs	Mechanical	Scaled	Ansys-Fluent	Unstructured tetrahedral and prismatic	SST k-ω	Airflow speed, heat transfer
Mistriotis [11]	Broilers	Natural	Full	Phoenics	Finite volume (Gambit)	Standard k-ε	Air velocity and temperature
Mostafa et al., [12]	Broilers	Natural	Full	Fluent	Hexahedron and tetra-hybrid mixed shapes (Gambit)	RNG k- ε	External wind velocity, humidity, tracer gas decay method
Norton et al., [13]	Cows	Natural	Full	Phoenics	Orthogonal	Standard k-ε	Air velocity
Norton et al., [14]	Cows	Natural	Scaled	STAR-CCM+	Hexahedron	Standard k-ε	Ventilation rate
Oliveira et al., [15]	Broilers	Natural	Full	Ansys	Tethraedral	Standard k-ε	Air velocity and temperature
Osorio et al., [16]	Broilers	Mechanical	Full	Ansys	Tethraedral	Standard k-ε	Outdoor temperature and velocity
Osorio et al., [17]	Broilers	Mechanical	Full	Ansys ICEM	Tethraedral	Standard k-ε	Air temperature

Reference	Animal	Ventilation	Scale	CFD Code	Mesh type	Turbulent model	Measurements
							and velocity
Osorio et al., [18]	Broilers	Mechanical	Full	Ansys	Tethraedral	Standard k-ε	Temperature, humidity, air velocity
Rojano et al., [19]	Broilers	Natural	Full	Ansys	Orthogonal	Realizable k-ε	Temperature, humidity, air velocity
Rong et al., [20]	General farm	Mechanical	Scaled	Fluent	Hexahedral	Standard k-ε	CO_2, emission rate and tracer gas method
Seedorf [21]	General farm	Natural	Scaled	CFD	Tetrahedral	Turbulent k-ε	Air pollutant and wind trajectories
Seo et al., [22]	Broilers	Natural	Full	Fluent	Hexahedron and tetra-hybrid mixed shapes (Gambit)	RNG k- ε	Temperature, air velocity, gas concentrations
Seo et al., [23]	Pig	Mechanical	Full	Fluent	Hexahedron mesh (Gambit)	RNG k- ε	Air and surface temperature, humidity, gas concentrations
Song et al., [24]	Broilers	Mechanical	Full	Fluent	Tetrahedron (Gambit)	LES	Air velocity
Sun et al., [25]	Pigs	Mechanical	Scaled	Fluent	Structured	Standard k-ε	Air velocity and ammonia distribution
Tong G. [26]	Pigs	Natural	Scaled	Fluent	hexahedral	S k-ε and RNG	Air velocity
Wu et al., [27]	Cows	Natural	Scaled	Fluent	Structured	Standard k-ε	Temperature, air velocity, gas concentrations
Wu et al., [28]	Pigs	Tunnel	Full	Fluent	Structured	Standard k-ε, RNG, RNS	Air velocity and CO_2 concentration
Zajicek and Kic, [29]	Broilers	Natural	Full	Ansys	Structured	RNG k-ε	Temperature, velocity

3.2 Analysis of CFD simulations

CFD simulations were performed at many different scales. The computational domain was based on an improvement of the structural characteristics of the farm and by modifying the locations of windows, fans, air ducts, heaters, humidifiers and chimneys. The improvements of poultry farms with mechanical and natural ventilation have based on the analysis of air velocity, temperature, humidity and concentrations of CO_2 and ammonia at animal level. Different results from measurements at farm were compared with those ones modified in different buildings models. The incorporation of animals in CFD models in natural farms was used in cows, pigs and broilers. Mechanical ventilated farms with broilers were analysed under the different production conditions. In a simplified way, broilers may be modelled as spheres, which can be used to calculate the convective heat loss of large number of animals under the production conditions [3].

Computational grids discretise the entire physical domain calculation for 3D and 2D studies. These studies can incorporate unstructured meshes composed by polyhedral [30], tetrahedral [18, 24, 2] hexahedral elements [26] (with the denser mesh in the inlet, outlet and walls). Furthermore, triangular prisms for ducts and roofs were used [23, 26] changing the airflow gradients for different configurations [26, 8, 24]. These different configurations included a mesh sensitivity analysis (coarser, medium, fine, and very fine mesh). In this article and for the calculation, it was selected the medium resolution in Gambit options (Ansys). Lee [31], Seo [22, 23] and Blanes-Vidal [2] concluded that hexagonal meshes have better results with less errors than tetrahedral meshes. On the contrary, Osorio[18] obtained the best results using tetrahedral meshes. In this line, tetrahedral volume elements were very useful in order to maintain the high quality in regions/volumes in different ways. These tetrahedral volume elements enabled more complex geometries in order to discretise the regions of interest, even though they are required more nodes than in hexahedral meshed. Larger file size and longer computation time and fine results were obtained using tetrahedral volume elements [15].

Unstructured tetrahedral grids were used to characterise the heat generation of a broiler. This mesh is very fine from the surface of the body [9]and to form the face, body, and legs [32]. Pig house models included a large number of pigs and only used hexahedron meshed. In this pig house models; the computational domain was divided into numerous hexahedron volumes and subdivided into corridors, pig pens, steel bars, partition walls, pigs and vent openings. Seo [23] used finer grids obtaining accurate predictions. However, more nodes and longer simulation time was required in a larger file size than the building design without animals of Guerra [32] (Figure 1).

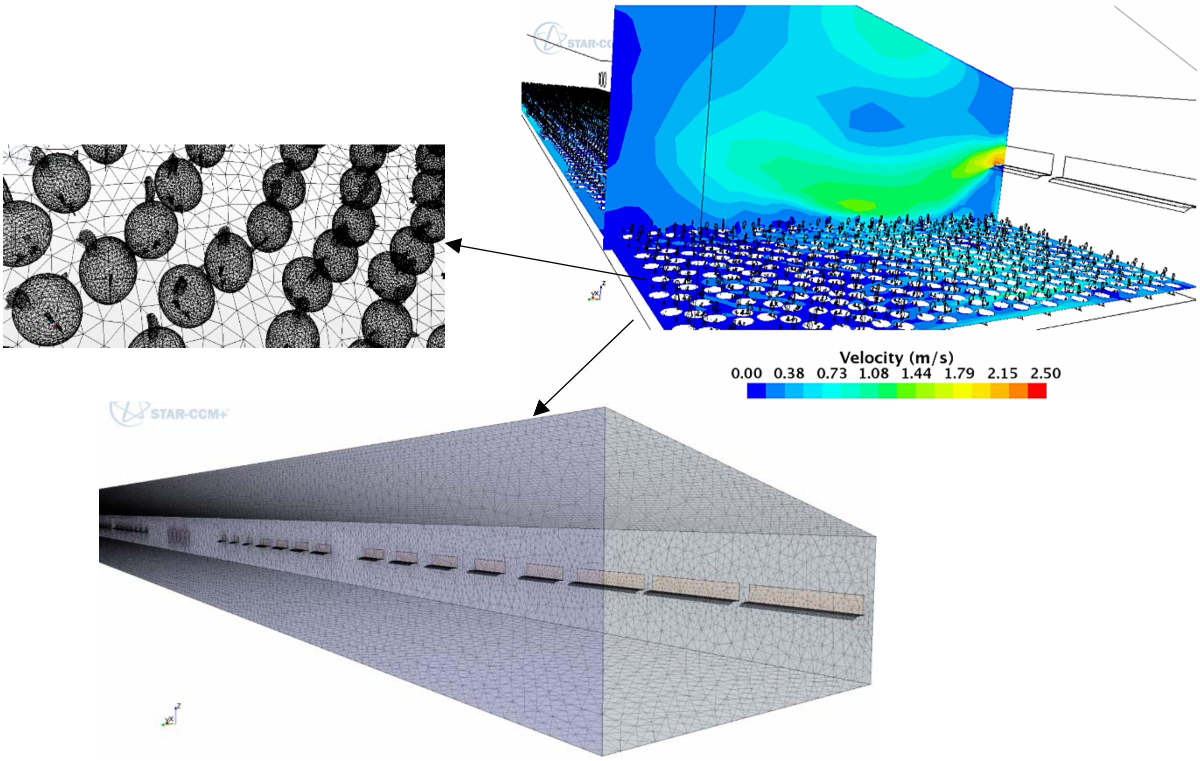

Figure 1. Fully poultry building mesh including the animals.

3.3 Turbulence models

As shown in Table 1, the turbulent models commonly used to analyse the air velocity, temperature, ammonia and carbon dioxide concentration in livestock buildings of broilers, pigs and cows are the Reynolds Averaged Navier Stokes (RANS) models. RANS use mathematical techniques to predict mean air flow conditions and to calculate the average surface from a scalar transfer [9]. In this article, the authors compare several closure turbulence models to solve these non-linear equations that affect the results of air movement and temperature. Current RANS turbulence models used for this purpose are the standard k-ε, the Renormalization-group (RNG) k-ε, the Realizable k-ε and the Reynolds stress model (RSM). The RNG k-ε and the Realizable k-ε predict well the conditions of the air flow [26] in1:12.5 scaled models. RNG and RKE models have similar results for all the meshes while standard k-ε (SKE), standard k-ω (SKW) and shear stress transport k-ω (KWSST) models are grid-dependent.

Regarding to the consulted references, the standard k-ε turbulence describes ventilating flow-field with high accuracy, easy convergence and computational stability [14]. Sometimes, this model can be inadequate because it assumes an isotropic turbulent viscosity [6] and in small scale domains it needs more simulation time for the final results. As referred, in the case of floor opening fully open a fluctuation of 16.7% is found in comparison to RKE, RNG, SKW, and KWSST models [26].

The Renormalization-group RNG k-ε turbulence model was developed to solve inaccuracies in the standard k-ε turbulence models; the dissipation rate and the effect of rotational flows on the turbulence is in this case well represented. In naturally ventilated broiler buildings, Lee [31] compared the RNG k-ε with other turbulence models. In this study [31], they quantify the different errors: a 21% in the RNG k-ε turbulence model, a 19.6% in Reynolds stress turbulence model, a 20.8% in the Standard k-ε turbulence model and 10.9% in Realizable k-ε turbulence model. Seo [22] found the highest accuracy when using the RNG k-ε turbulence model with a minimum error of -6.2% [22].The turbulence model RNG k-ε, was recommended for predicting airflow patterns, air velocities near of cold and hot wall, for the transport of pollutants in large rooms. It allows to predict flows with big streamline curvature (for example in recirculation airflow phenomena in swine buildings or cows) and to calculate the heat flux generated by the birds since it is similar to the experimental results [8, 26, 31].

As shown in Figure 1, the realizable k-ε turbulence model is the most recommended in the consulted literature to describe the turbulence and the velocity distribution [17]. This turbulence model satisfies certain mathematical constrains on the Reynolds stresses, and it is consistent with the physics of turbulent flows. Unfortunately, RSM requires additional memory and calculating time because of the increased number of the transport equations for Reynolds stresses [31].

In the different poultry building types, the effectiveness of ventilation relies on the location of inlet windows and exhaust fans, as well as the presence of air diffusers and curtains inside the building. In this way, ventilation systems and the nature of the ventilation (natural or mechanical) [33] affects the size model in the airflow patterns, in the temperature stratification. Thus, the relationship between the whole building domain and each air inlet opening is of relevant importance, a sit defines the path of the airflow streams [8].

4. Conclusion

As regards to the consulted references, many measured results that have been obtained in real and small scale. Validation in published studies show a general agreement with the CFD results. From the literature, it can be concluded that scale models may help in conducting more efficient research on farm design, because they give an idea of the structure of the farm and fluid behaviour. Scaled models also help in representing particular aspects of the farm, for example focusing on the animal heat transfer. Full scale CFD models also confirm that these analyses perform satisfactorily under real farm conditions.

5. References

[1] B. Bjerg. CFD prediction of the effective temperature in the laying area of pig pens with partly solid floor. CIGR-AgEng conference. 2016, 1-6.

[2] V. Blanes-Vidal, E. Guijarro, S. Balasch, A. G. Torres. Application of computational fluid dynamics to the prediction of airflow in a mechanically ventilated commercial poultry building. Biosyst. Eng.2008, 100 (1): 105-116.

[3] E. Bustamante, F.-J. García-Diego, S. Calvet, F. Estellés, P. Beltrán, A. Hospitaler, A. Torres. Exploring ventilation efficiency in poultry buildings: the validation of Computational Fluid Dynamics (CFD) in a cross-mechanically ventilated broiler farm. Energies. 2013, 6(5): 2605-2623.

[4] E. Bustamante, F.-J. García-Diego, S. Calvet, A. Torres, A. Hospitaler. Measurement and numerical simulation of air velocity in a tunnel-ventilated broiler house. Sustainability. 2015, 7(2):2066-2085.

[5] K. G. Gebremedhin and B. X. Wu. Characterization of flow field in a ventilated space and simulation of heat exchange between cows and their environment. J. Therm. Biol. 2003, 28(4):301-319.

[6] B. B. Harral and C. R. Boon. Comparison of predicted and measured air flow patterns in a mechanically ventilated livestock building without animals. J. Agric. Eng. Res. 1997, 66(3): 221-228.

[7] S. J. Hoff, K. A. Janni, L. D. Jacobson. Three-dimensional buoyant turbulent flows in a scaled model, slot-ventilated, livestock conhnement facility. Agric. Biosyst. Eng. 1992, 35: 671-686.
[8] K. Kwon, I. Lee, G. Q. Zhang, T. Ha. Computational fluid dynamics analysis of the thermal distribution of animal occupied zones using the jet-drop-distance concept in a mechanically ventilated broiler house. Biosyst. Eng. 2015, 136: 51-68, 2015.
[9] H. Li, L. Rong, C. Zong, G. Zhang. A numerical study on forced convective heat transfer of a chicken (model) in horizontal airflow. Biosyst. Eng. 2016, 150: 151-159.
[10] H. Li, L. Rong, G. Zhang. Study on convective heat transfer from pig models by CFD in a virtual wind tunnel. Comput. Electron. Agric. 2016, 123: 203-210.
[11] T. J. Mistriotis. Computational Fluid Dynamics as a tool for the analysis of ventilation and indoor microclimate. Netherlands J. Agric. Sci. 1997, 45: 81-96.
[12] E. Mostafa, I.-B. Lee, S.-H. Song, K.-S. Kwon, I.-H. Seo, S.-W. Hong, H.-S. Hwang, J. P. Bitog, H.-T. Han., Computational fluid dynamics simulation of air temperature distribution inside broiler building fitted with duct ventilation system. Biosyst. Eng. 2012, 112(4): 293-303.
[13] T. Norton, J. Grant, J. J. Lenehan, R. J. Fallon, D. Sun. Dynamics (CFD). 2003: 139-180.
[14] T. Norton, J. Grant, R. Fallon, D. W. Sun. A computational fluid dynamics study of air mixing in a naturally ventilated livestock building with different porous eave opening conditions. Biosyst. Eng. 2010, 106(2): 125-137.
[15] K. S. Oliveira Rocha, I. de F. Ferreira Tinôco, J. Helvecio Martins, J. A. Osorio Saraz, M. Arêdes Martins. Modeling and simulation of internal environment conditions in high-density poultry houses with ventilation using computational fluid dynamics. Ag. Eng 2014 Zurich, 2014, pp. 1-8.
[16] A. J. Osorio Saraz, I. de F. Ferreira Tinôco, K. S. Oliveira Rocha, M. Âredes Martins, M. Oliveira de Paula. Modeling and experimental validation to estimate the energy balance for a poultry house with misting cooling. Dyna, 2011, 78(170): 167-174.
[17] J. A. Osorio Saraz, M. Âredes Martins, K. S. Oliveira Rocha, N. Silva Machado, H. J. Ciro Velasques. Use of computational fluid dynamics to simulate temperature distribution in broiler houses with negative and positive tunnel type ventilation systems. Rev. U.D.C.A Atual. y Divulg. Científica. 2013, 16(1): 159-166.
[18] R. Osorio, L. Guerra, L. Barreto, Barbari Matteo. CFD modeling of the thermal environment in a negative pressure tunnel ventilated broiler barn during the first week of life. 2015, September, pp. 1-8.
[19] F. Rojano, P.-E. Bournet, M. Hassouna, P. Robin, M. Kacira, C. Y. Choi. Modelling heat and mass transfer of a broiler house using computational fluid dynamics. Biosyst. Eng. 2015, 136: 25-38.
[20] G. Rong, L. Nielsen, P.Vilhelm, T. Guohong, R.P. Zhang. Computational fluid dynamics study on the influence dioxide of in patterns on carbon distribution scaled. AgEng, 2008.
[21] J. Seedorf. Biological exhaust air treatment systems as a potential microbial risk for farm animals assessed with a computer simulation. J. Sci. Food Agric. 2013, 93(12): 3129-3132.
[22] I.-H. Seo, I.-B. Lee, O.-K. Moon, H.-T. Kim, H.-S. Hwang, S.-W. Hong, J. P. Bitog, J.-I. Yoo, K.-S. Kwon, Y.-H. Kim, J.-W. Han. Improvement of the ventilation system of a naturally ventilated broiler house in the cold season using computational simulations. Biosyst. Eng. 2009, 104(1): 106-117.
[23] I. H. Seo, I. B. Lee, O. K. Moon, S. W. Hong, H. S. Hwang, J. P. Bitog, K. S. Kwon, Z. Ye, J. W. Lee. Modelling of internal environmental conditions in a full-scale commercial pig house containing animals. Biosyst. Eng. 2012, 111(1): 91-106.
[24] C. J.-S. Song S.-H., Lee I.-B., Hwang H.-S., Hong S.-W., Seo I.-H., Bitog J.P. , Kwon K.-S. CFD analysis and comparison of forced-ventilation systems of poultry houses in Korea, XVIIth World Congr. Int. Comm. Agric. Biosyst. Eng. 2010: 1-10.
[25] H. Sun, R. R. Stowell, H. M. Keener, F. C. Michel. Two–Dimensional Computational Fluid Dynamics (CFD) Modeling of Air Velocity and Ammonia Distribution in a High–Rise Hog Building. Agric. Eng. Build. 2002, 45(5): 1-10.
[26] G. Tong, G. Zhang, D. M. Christopher, B. Bjerg, Z. Ye, J. Cheng. Evaluation of turbulence models to predict airflow and ammonia concentrations in a scale model swine building enclosure. Comput. Fluids. 2013, 71: 240-249.
[27] W. Wu, J. Zhai, G. Zhang, P. V. Nielsen. Evaluation of methods for determining air exchange rate in a naturally ventilated dairy cattle building with large openings using computational fluid dynamics (CFD). Atmos. Environ. 2012, 63: 179-188.

[28] W. Wu, G. Zhang, B. Bjerg, P. V. Nielsen. An assessment of a partial pit ventilation system to reduce emission under slatted floor – Part 2: Feasibility of CFD prediction using RANS turbulence models. Comput. Electron. Agric. 2012, 83: 134-142.
[29] M. Zajicek and P. Kic. Rural Development 2013. The Sixth International Scientific Conference Rural Development 2013. AKADEMIJA, 2013, 6: 151-156.
[30] T.Norton, J. Grant, R.Fallon, D.W.Sun. Assessing the ventilation performance of a naturally ventilated livestock building with different eave opening conditions. Comput Electron Agric. 2009:1-15.
[31] I. Lee, S. Sase, S. Sung. Evaluation of CFD accuracy for the ventilation study of a naturally ventilated broiler house. JARQ. 2007, 41(1): 53-64.
[32] E. Guerra-Galdo, S. Calvet, A. López, F. Estellés. El diseño de las instalaciones de pollos de carne y su influencia en las condiciones de confort de los animales. ITEA. 2016, 112: 405-420.
[33] G. Cao, H. Awbi, R. Yao, Y. Fan, K. Sirén, R. Kosonen, J. Zhang. A review of the performance of different ventilation and airflow distribution systems in buildings. Build. Environ. 2014, 73: 171-186.

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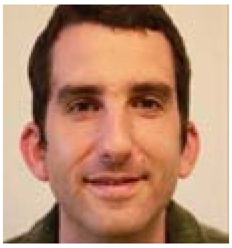

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