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Research Paper

Reliability of turbulence models and mesh types for CFD simulations of a mechanically ventilated pig house containing animals

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The use of computational fluid dynamics (CFD) to study the airflow within farm animal buildings is increasing. The choice of turbulence model within CFD is generally considered to be important due to the approximations of the turbulence in varied scales. Although some studies have been conducted on evaluations of turbulence models in simulation of airflow in ventilated rooms, knowledge of airflow in the animal occupied zone (AOZ) with airflow blockage by the animals and knowledge of thermal convection effects are still limited. In this study, five commonly used two-equation turbulence models (standard $k-\varepsilon$, realisable $k-\varepsilon$, RNG $k-\varepsilon$, standard $k-\omega$, and SST $k-\omega$) were applied to a CFD model of the airflow in a mechanically ventilated pig room with animals housed in pens. In addition to turbulence models, the effects of non-conformal meshing which combines several computational sub-domains and connects the boundary of domains using interfaces, were tested. The effect of mesh ratio on the interface (i.e. ratio of the grid number of the up and down interface) was studied based on fully structural hexahedral mesh (SH). The investigation of mesh type effect was conducted by application of an unstructured tetrahedral mesh (UT) in the AOZ and SH in the rest of the domain. The results showed that the choice of turbulence model did not have a strong effect on the main airflow pattern except for the RNG $k-\varepsilon$ model. The tested ratios of resolution at interfaces were also found not to strongly impact on the predicted airflow distributions. The use of UT in the AOZ sub domain also provided acceptable results. It was concluded that non-conformal meshes are a feasible alternative for animal buildings with complex geometries to maintain affordable grid numbers and also reduce the difficulties in mesh generation.

1. Introduction

It has been found that flow fields in pig houses are crucial for creating a thermally comfortable and healthy environment for animals. Therefore, to improve the indoor environment of animal house, the airflow distribution should be carefully studied.

In studies of ventilation systems, computational fluid dynamics (CFD) has been shown to be superior to conventional

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Nomenclature

Abbreviations

AOZ animal occupied zone
CFD computational fluid dynamics
LES large eddy simulation methods
RANS Reynolds-averaged Navier–Stokes method
RNG re-normalisation group
SH structural hexahedral mesh
SST shear stress transport
UT unstructured tetrahedral mesh

Symbols

ρ fluid density
u_i velocity component
ϕ flow variables
$\Gamma_{\phi,\mathrm{eff}}$ effective diffusion coefficient
S_ϕ source term
p fluid pressure
H fluid enthalpy
k turbulent kinetic energy
ε turbulent dissipation rate
ω turbulent specific dissipation rate
μ_t eddy viscosity
G_k generation of turbulence kinetic energy due to the mean velocity gradients
G_b generation of turbulence kinetic energy due to buoyancy
R_ε addition term in RNG k–ε models concerning the strain rate
S rate of the strain
$C_{\varepsilon 1}$, $C_{\varepsilon 2}$, $C_{\varepsilon 3}$, C_μ coefficients of the turbulence models
G_ω generation of ω
Y_k dissipation of k due to turbulence
Y_ω dissipation of k–ω due to turbulence
α_k inverse effective Prandtl number for k
α_ε inverse effective Prandtl numbers for ε
σ_k turbulent Prandtl numbers for k
σ_ε turbulent Prandtl numbers for k and ε
n measurement number in the evaluation
y experimental results
$\hat{y}$ simulated values from CFD
$\bar{y}$ average value of experimental data on measurement line

experimental methods. The main advantages of CFD are that it allows full control on the influencing factors and provides universal data in the computational domain with relatively low costs of time and expense. There is therefore an increasing tendency to use CFD methods to study of flow distributions in agricultural buildings (Bartzanas, Boulard, & Kittas, 2002; Benni, Tassinari, Sonora, Barbaresi, & Torreggiani, 2016; Bjerg, Svidt, Zhang, Morsing, & Johnsen, 2002; De Rosis, Barbaresi, Torreggiani, Benni, & Tassinari, 2014; Lee et al., 2013; Norton, Sun, Grant, Fallon, & Dodd, 2007; Rong, Nielsen, Bjerg, & Zhang, 2016; Wu, Zhang, Bjerg, & Nielsen, 2012). To better model livestock buildings, animal models with realistic geometry have been used in some CFD studies of indoor environment inside buildings (Bjerg, Zhang, & Kai, 2008; Gebremedhin & Wu, 2005; Seo et al., 2012).

Turbulence models are generally considered to be important on the results due to the approximations of the turbulence in varied scales (Rong et al., 2016; Sorensen & Nielsen, 2003). Although some studies have been conducted on the evaluation of turbulence model in simulation of airflow in ventilated rooms (Norton, Grant, Fallon, & Sun, 2010; Rong et al., 2016; Shen, Zhang, & Bjerg, 2012; Zhang, Zhai, Zhang, & Chen, 2007), knowledge of the airflow affected by animals blocking the airflow and thermal convection is still limited. Among turbulence models, generally there are Reynolds-averaged Navier–Stokes (RANS) method and large eddy simulation (LES) methods. RANS method is widely used in building ventilation research due to the sufficient high quality and low requirements for computational power (Zhang et al., 2007). Therefore, five two equation turbulence models (standard k–ε, realisable k–ε, Re-Normalisation Group (RNG) k–ε, standard k–ω, and Shear Stress Transport (SST) k–ω) which were commonly used and embedded in most CFD codes were evaluated on a ventilated pig room containing animal models in this study.

Gridding is another important factor for simulation results. In general, it is the hexahedral, tetrahedral, and hybrid meshes are the commonly applied in animal building simulation. The hexahedral mesh was the first type of mesh adopted in the CFD studies and it is commonly considered to have more accurate results compared to tetrahedral meshes (Duan et al., 2015; Hefny & Ooka, 2009). Hexahedral meshes are mainly adopted for relatively simple geometries. For a complex geometry, such as an animal, it is almost impossible to obtain suitable meshes using hexahedral grids. Tetrahedral meshes, however, are useful for boundaries with complex surfaces. In addition, using most modern grid generation codes, they can be generated automatically. However it is known that the prediction accuracy of the tetrahedral meshes may be lower than hexahedral using the same grid number. To maintain the same accuracy, the number of cells of a tetrahedral mesh need to be larger than for a hexahedral mesh with the same size cells, which means that the computation time can be longer (Duan et al., 2015; Juretic & Gosman, 2010; Yu, Yu, Sun, & Tao, 2012). Conformal hybrid meshes, as a combination of hexahedral and tetrahedral meshes, exhibit the advantages of both these kinds of mesh, and they have been applied to study air distribution in one animal house (Seo et al., 2012). However, this kind of hybrid mesh is difficult to generate, particularly with grids that have high aspect ratios.

Non-conformal meshes, which connect adjacent domain boundaries using an interface, are used when complex geometry is involved in the room space. For instance, a tetrahedral mesh can be used in the animal occupied zone (AOZ) where the geometry is complex and a hexahedral mesh can be used in the rest of the room domain. When hexahedral and tetrahedral meshes are adopted in different domains, they can be regarded as form of hybrid mesh but without requiring the full agreement of nodes at the interface boundary. Therefore, they are relatively easy to generate compared to the aforementioned hybrid mesh. However, since the nodes