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Comparison of Different Turbulent Models for Predicting Flow of Closed Spaces

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Abstract: - The paper presents a mathematical model, implemented in a general computer code that can provide detailed information for the prediction of flow field of closed spaces, using different turbulent models for the description of turbulence. For the comparison of the three models that describes the turbulent flow, the standard k-ε, the RNG k-ε and the algebraic viscosity, are used, simulating the two-dimensional International Energy Agency (IEA) Annex 20 case, with an air inlet and an air outlet. The numerical results are compared with existing experimental data.

Key-Words:-Turbulence, CFD methods, Indoor environment, Flowfield simulation, Air velocity, Temperature-

1 Introduction

Turbulence constitutes an important problem that interests natural scientists and engineers. Most researchers agree that the physics of turbulence is described by Navier-Stokes' equations. However, their direct solution for complex flows is not feasible because of large requirements of calculation power. This has as consequence the calculations of complex turbulent characteristics to be based on the turbulent models' development.

Computational Fluid Dynamics are used the last years for the simulation of flow field of air in closed spaces. The numerical methods are used for the solution of differential equations that describes heat and mass transfer phenomena which take place in the field under review.

A large number of models that describe the turbulence have been developed, but up to today the standard k-ε model is frequently used in closed spaces problems and particularly buildings. The model describes completely developed flows, therefore is placed the question: what happens when the flow isn't completely turbulent? According to Baker (1994) the air flow in closed spaces is locally turbulent and far from the systems of ventilation the flow is slight turbulent. According to Chen and Jiang (1992) the flow can be laminar, locally turbulent, in transient stage or even completely developed. Therefore is created the question of appropriateness of standard k-ε as a model for the description of air flow field of internal flows. For that reason a determined and developed application is well used for the comparison of k-ε model and two other models, RNG k-ε and the algebraic viscosity model.

For the comparison of three models of turbulent flow, the widely used, standard k-ε, in the buildings and more general in the internal cavities, the RNG k-ε and the algebraic viscosity, are used for the simulation of the two-dimensional International Energy Agency (IEA) Annex 20 case, and the numerical results are compared with existing experimental data.

2 Test Case Considered

A closed space with dimensions 9 m length and 3 m height is simulated. In the upper level of the left wall, an 0.168 m opening exists through which the air enters to the room, , while in the lower level of the right wall an 0.48 m air outlet exists. The inlet air velocity is 0.455 m/s. The external air temperature is the 20 oC. The walls are considered adiabatic. The closed space which is simulated, is given in Figure 1.

The reported results are obtained using a non - uniform grid consisting initially of 90 cells in the x-direction and 21 cells in the y-direction. The solutions are grid independent, as proved by repeating the run with even more cells.

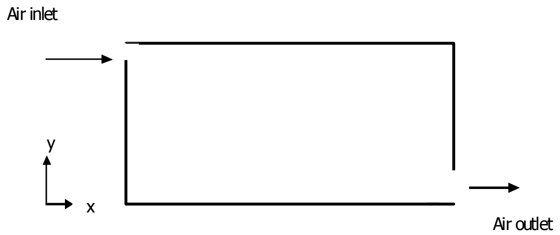


Figure 1. Examined closed space

3 Boundary Conditions

Boundary conditions are specified as follows. At the inlet a fixed mass flow rate is specified as well as the values of air velocity and temperature. At the walls, wall functions (Patankar and Spalding, 1972) are used to calculate the wall shear stress. The walls are assumed adiabatic.

4 Solution of Equations

The elements that are required for the equations that are solved for each variable φ are given in Table 1.

Equation	φ	S_φ	Γ_φ
Continuity	1	0	0
Momentum	u	$-\frac{\partial P}{\partial x_i}+\rho g_i$	m

Table 1. Source rate and effective exchange coefficient for each φ

5 Convergence

A converged solution is defined as one that meets the following criterion for all dependent variables:

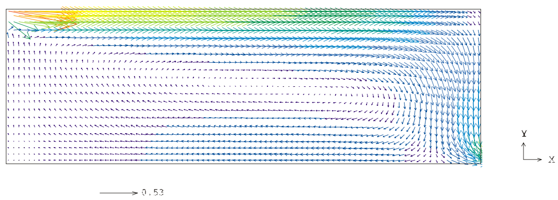
$$\max\left|\varphi^{n+1}-\varphi^{n}\right|\le 10^{-3}$$

between sweeps n and n+1. To improve convergence under-relaxation is used. Relaxation of the “false transient” type is used for the velocity components with a value of the “false time step” being 0.01. For pressure and enthalpy, “linear” relaxation was used with a value of 0.1, and 0.001 respectively.

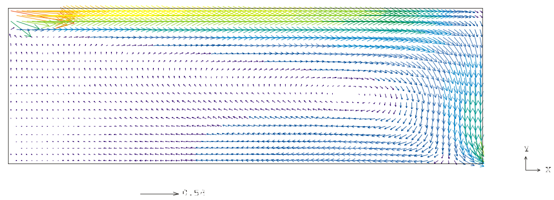
6 Results

In next Figures some representative results, are given, presenting the air flow field that result using the three turbulent models. In Figure 2 the velocity field is given for the three examined models. In Figure 3 the temperature distribution is presented near the left wall versus room height.

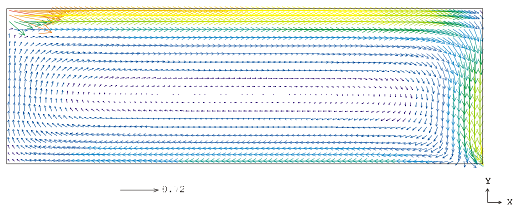
Observing Figure 2 where the air’s velocity field is given, it appears clearly that the standard k-ε model as well as the RNG k-ε model, show a similar distribution inside the closed space. For both of the models, it is observed an intense flow near the roof and close to the air inlet as well as near in the floor to the air outlet. In the rest field an air recirculation is present.



k-ε model



RNG k-ε model



Algebraic viscosity model

Figure 2. Velocity fields

This recirculation is more intense in the right half of space, while on the contrary in the left half it is almost non-existent, especially in a region until

1m from the left wall. The velocities in the lower region of the examined field are at one eighth smaller than these of the examined space air inlet. The two models describe well the turbulent fluctuations but this does not mean that they characterize with the best way the turbulent diffusion of momentum. Examining the predicted values of turbulence's viscosity and the ratio μ_t / μ_l, that is the rate of turbulence's viscosity to laminar viscosity it is observed that the rates of ratio correspond in completely developed flow (value approximately 400). These values are expected for the region of inlet as well as for the right half of room. On the contrary the turbulent diffusion in the left wall should be of lower order. The flow, there, is too low, approaching a stagnant situation. Nevertheless ratio values of turbulent viscosity to laminar viscosity are corresponding to those of the main field. Comparing those two models however, it can be conducted that the RNG k-ε is what approaches the transient flow. On the contrary the k-ε model overestimates the turbulence's values near the left wall. With regard to algebraic viscosity model it is observed that it does not describes well neither the flow field nor the turbulent diffusion of momentum inside the examined space, giving an intense recirculation near the left wall.

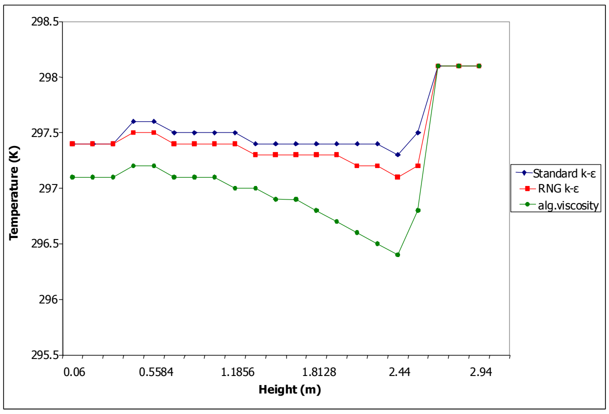


Figure 3. Temperature distribution

Figure 3 presents the temperature diagram near the left wall versus height. As is observed the RNG k-ε model gives smaller temperature values than the standard k-ε model. The algebraic viscosity model gives the most underestimated values. The sensitivity of models can be explained, examining the terms of diffusion in the energy equation. When a slight flow is observed, near the wall, then the thermal convection is small and thus the diffusion has a very important role in the energy equation. Provided that RNG k-ε model describes with a higher precision the flow field and the turbulence's diffusion it is expected to predict better than the other models, the temperature distribution inside the space. In the right part of the room, where the turbulence of the flow field is completely developed, the over-estimate of turbulence's viscosity has negligible effect.

7 Conclusions

In this paper three models for the turbulent flow modeling in the interior of closed spaces, the standard k-ε, RNG k-ε and algebraic viscosity are examined and compared between each other. For their comparison, a two-dimensional flow field with an air inlet and outlet is examined. As results, the RNG k-ε model predicts better the flow' field compared with the other two models, due to better calculation of turbulence's viscosity, in regions where the turbulence is not completely developed. The other two models overestimate the turbulence's viscosity having as a consequence the calculation with a higher fault of thermal diffusion in the regions with low flow. The phenomenon is local and it does not affect considerably field's regions where the flow is completely developed.

References

[1] K. Papakonstantinou, C. Kiranoudis and N. Markatos. *Mathematical Modelling of environmental conditions inside Historical Buildings. The case of the Archaeological Museum of Athens.* Energy and Buildings, 31:210–220 2000

[2] Q. Chen and Z. Jiang. *Significant Questions in Predicting Room Air Motion.* ASHRAE Transactions, 98(1):929–939, 1992

[3] A. Baker, P. Williams and R. Kelso. *Numerical Calculation of Room Air Motion-Part 1: Math, Physics and CFD Modelling.* ASHRAE Transactions, 100(1):514–530, 1994

[4] P.V. Nielsen. *Specification of a two-dimensional test case. IEA Annex 20.* Research Item 1.45 Technical Report. University of Aalborg Denmark, 1990

[5] V. Yakhot and S.A. Orszag. *Renormalization Group Analysis of Turbulence.* J. Sci. Comput., 1:3, 1986

[6] S.V. Patankar, and D.B. Spalding, *A calculation procedure for heat, mass and momentum transfer in parabolic flows.* Int. J. Heat Mass Transfer, 21, 1972