

Simulation with different turbulence models in an annex 20 room benchmark test using Ansys CFX 11.0

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DCE Technical Report No. 46

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by

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September 2008

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Published YYYY by
Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57,
DK-9000 Aalborg, Denmark

Printed in Aalborg at Aalborg University

ISSN 1901-726X
DCE Technical Report No. 46

1. Introduction of annex 20 two dimensional isothermal case

The simulations are performed in a well known two dimensional isothermal annex 20 room benchmark test described by Nielsen (1990). The sizes of the annex 20 room are specified as:

$$L=9\text{m}, H=3\text{m}, h_1=0.168\text{m}, h_2=0.48\text{m}$$

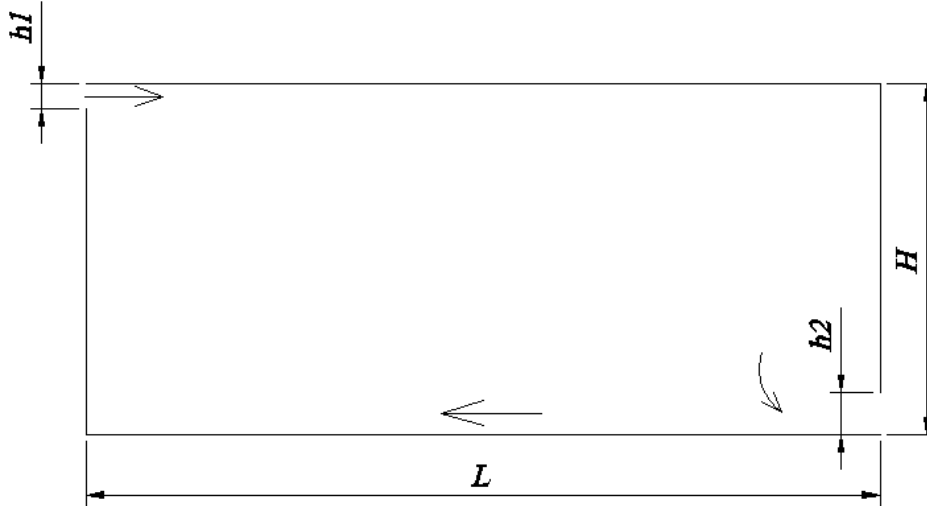


Figure 1 schematics of annex 20 2-D isothermal case

The air is supplied from left top with velocity in 0.455m/s and exhausted from right bottom. The inlet conditions are listed in the following:

$$u_0 = 0.455\text{m/s}$$

$$k_0 = 1.5[(0.04u_0)^2]$$

$$\varepsilon_0 = k_0^{1.5}/l_0$$

Where $l_0 = h/10$

According to Nielsen (1990), the inlet conditions correspond to a turbulence intensity of 4%. It is difficult to stipulate ε_0 but variation of the length scale l_0 within a reasonable level shows only a very small influence on the flow in the room.

The inlet condition for the specific dissipation rate w_0 is adopted the following relation:

$$w_0 = \varepsilon_0/0.09k_0$$

The experimental results for the flow are available along the four lines:

$$x=3.0, x=6, y=0.084 \text{ and } y=2.916$$

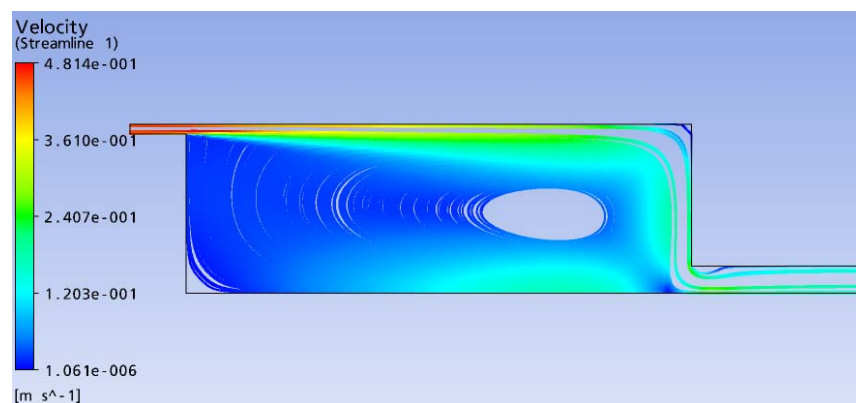
2. simulation results with $k-\varepsilon$, $k-w$, BSL and SST model

The following simulations are performed in Ansys CFX11.0 with standard $k-\varepsilon$, standard $k-w$, BSL and SST model. The simulations included the following steps:

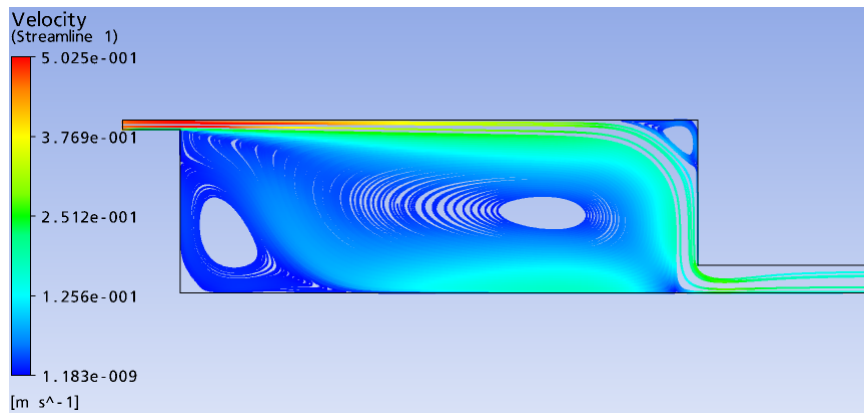
- (1) According to different requirements for y^+ with four turbulence models, find out the first grid distance to the wall. $k-\varepsilon$ model require $y^+ > 11.0$ and the other three turbulence models require $y^+ < 1.0$. More details can be referred to Voigt (2000).
- (2) To do grid independent study. The grid independent study is shown in Appendix.
- (3) Post simulation results and compare them with measurements.

2.1 Streamlines with using four turbulence models

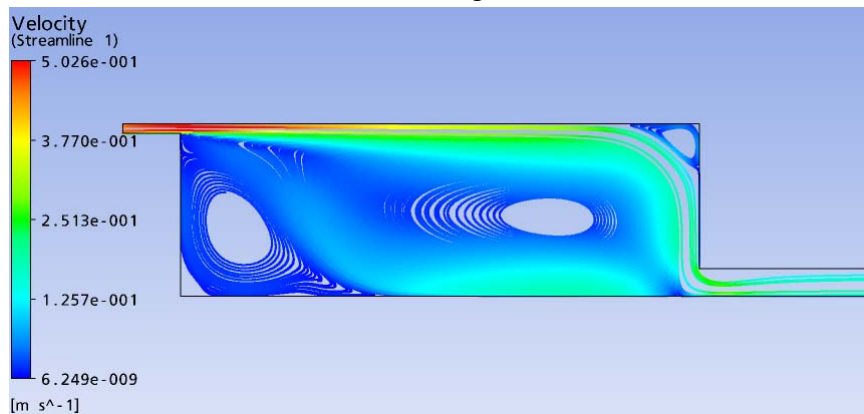
Figure 2 shows streamlines with using four turbulence models. It is seen that there are two bigger eddy corners with using $k-w$ model and BSL model than $k-\varepsilon$ model. In $k-w$ model and BSL model, the jet flow from the inlet cannot move along the ceiling so far as in $k-\varepsilon$ model and the return flow close to the floor is separated earlier than in $k-\varepsilon$ model. The streamline with using SST model is quite different from the others. Figure 3 shows the streamline in experiment. It is seen that there are two eddy recirculation at the upper right corner and lower left corner, but it is hard to say which turbulence model is better in this case according to Figure 3.



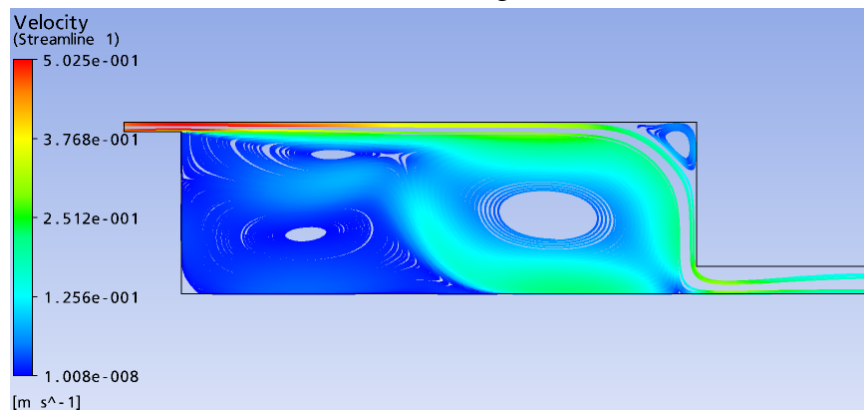
(a) streamline with using standard $k-\varepsilon$ model



(b) streamline with using standard $k-w$ model



(c) streamline with using $k-w$ BSL model



(d) streamline with using $k-w$ SST model

Figure 2 streamline with using different turbulence model

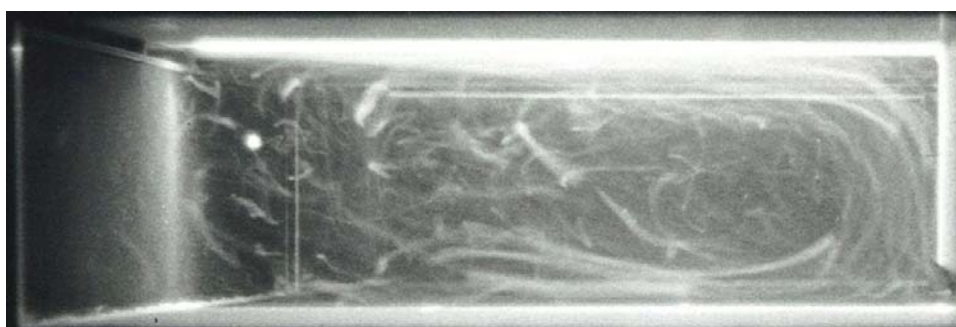


Figure 3 streamline in experiment (Peter V. Nielsen PhD thesis, 1974)

2.2 comparison of non-dimensional velocity between simulations and measurements along two horizontal lines

Figure 4 shows four lines location where simulations are compared with measurements. Figure 5 ~ Figure 8 shows comparison of non-dimensional velocity between simulations and measurements along two horizontal lines with four turbulence models. It is seen that the simulations are in good agreements with measurements for $k-\varepsilon$ model and $k-w$ model, but it is in better agreement with measurements at points close to the floor for $k-\varepsilon$ model than $k-w$ model. With BSL model, the simulations along the line of $x=3.0$ is deviated from measurements below $y=0.5\text{m}$ because the flow separated from the floor earlier, see Figure 2(c).

While in SST model, the simulations are quite different from the measurements except for the points close to the ceiling along the line of $x=3.0$. The simulations above $y=0.5$ is in agreement with measurements along the line of $x=6.0$.

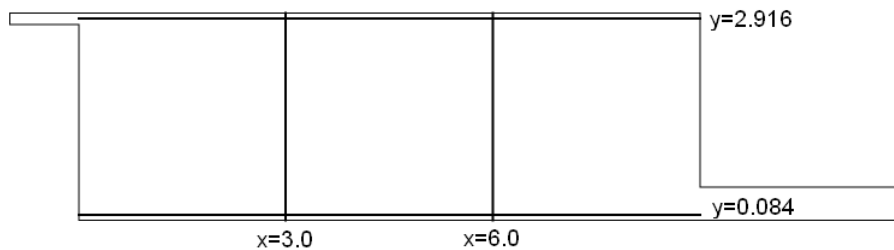


Figure 4 four lines location used to compare simulations with measurements

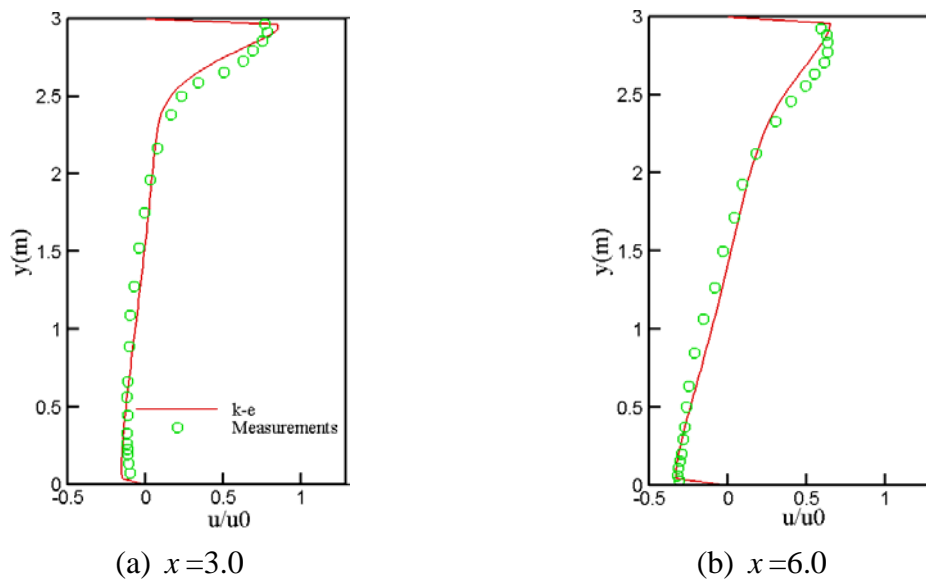
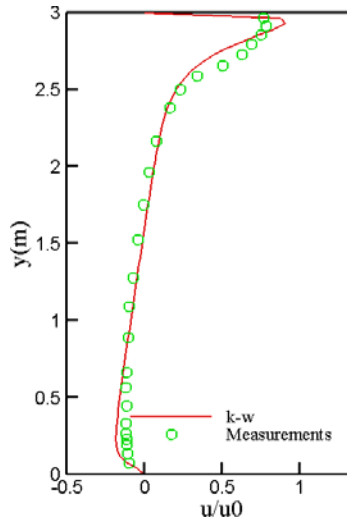
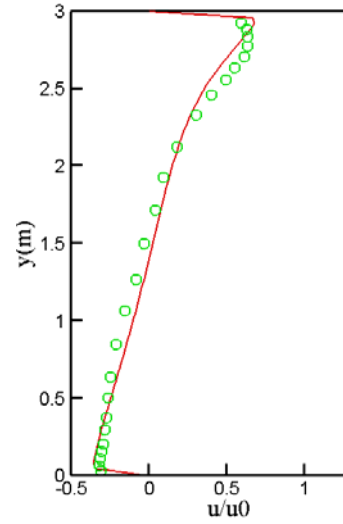


Figure 5 comparison of non-dimensional velocity between simulations and measurements for $k-\varepsilon$ model

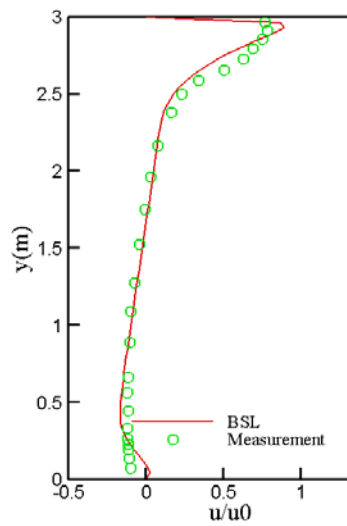


(a) $x=3.0$

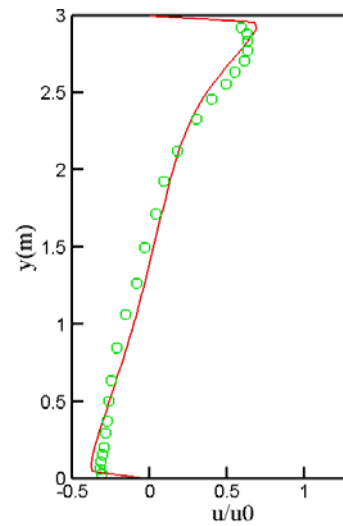


(b) $x=6.0$

Figure 6 comparison of non-dimensional velocity between simulations and measurements for $k-w$ model



(a) $x=3.0$



(b) $x=6.0$

Figure 7 comparison of non-dimensional velocity between simulations and measurements for BSL model

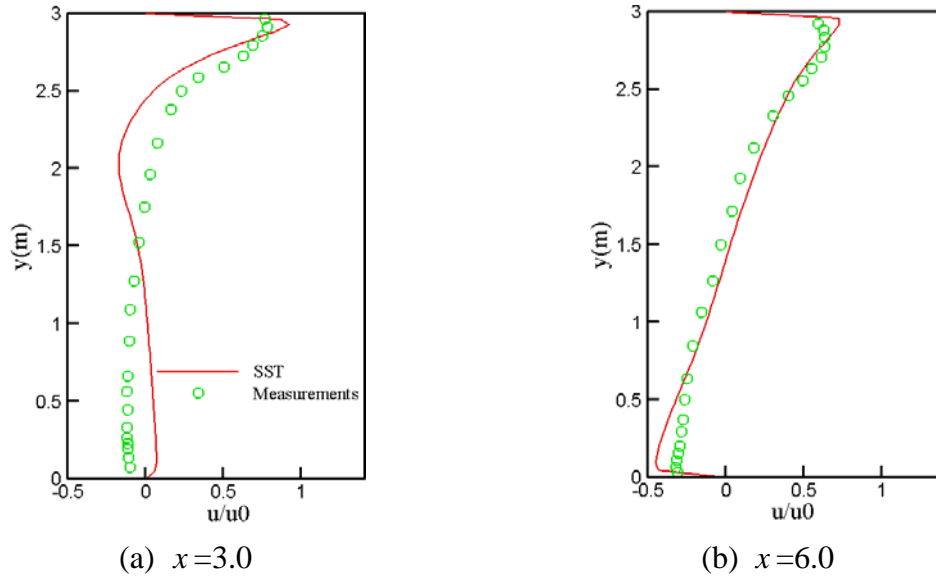


Figure 8 comparison of non-dimensional velocity between simulations and measurements for SST model

2.3 Comparison of non-dimensional velocity between simulations and measurements along two vertical lines

Figure 9 ~ Figure 12 shows the comparison of non-dimensional velocity between simulations and measurements along two vertical lines with four turbulence models. It is seen that there are no models which can predict the upper right corner well among four turbulence models. It is impossible for $k-\varepsilon$ model to predict the eddy recirculation in the upper right corner from Figure 9(b) while other three models underpredict the velocity there. However, $k-\varepsilon$ model can predict the velocity the best on line of $y=2.916$ except for the upper right corner. Along line of $y=0.084$, $k-\varepsilon$ model also is the best one to predict the velocity among the four turbulence models and SST model gets the biggest difference from measurements.

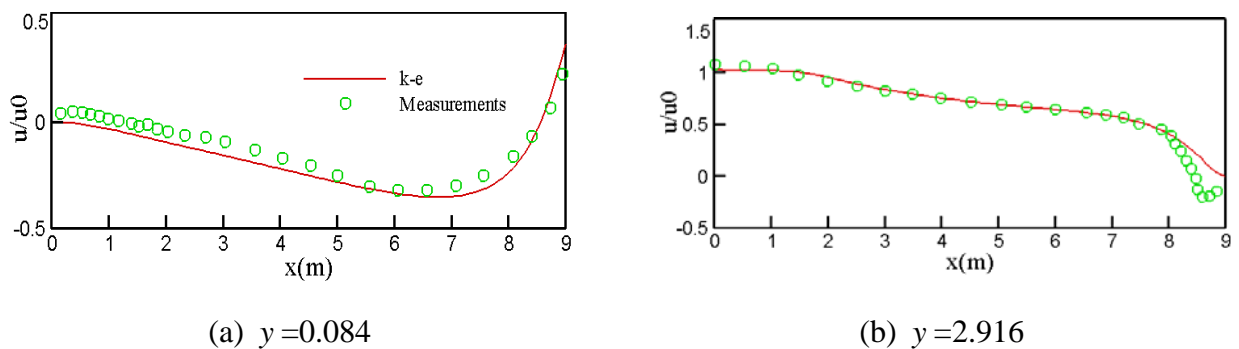
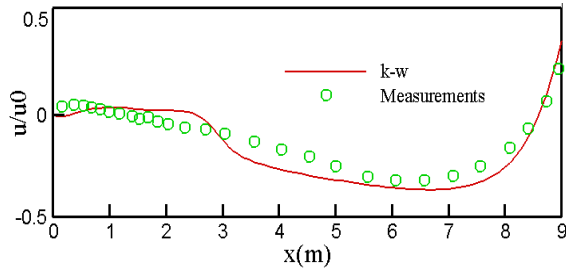
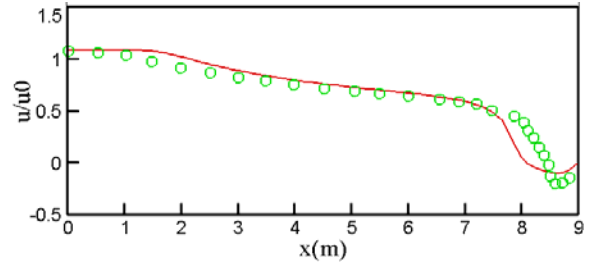


Figure 9 comparison of non-dimensional velocity between simulations and measurements for $k-\varepsilon$ model

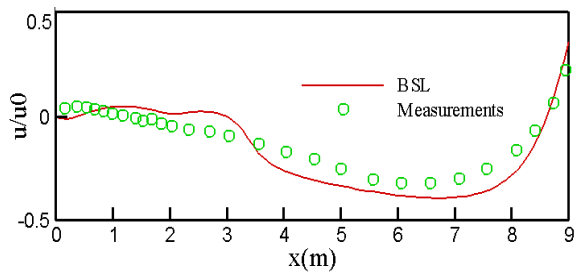


(a) $y=0.084$

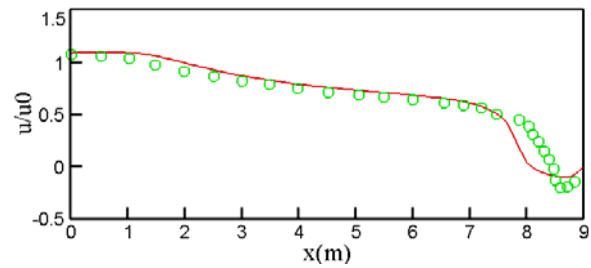


(b) $y=2.916$

Figure 10 comparison of non-dimensional velocity between simulations and measurements for $k-w$ model

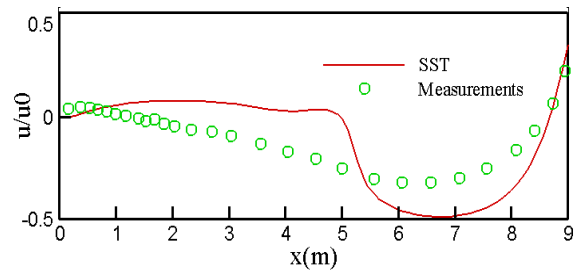


(a) $y=0.084$

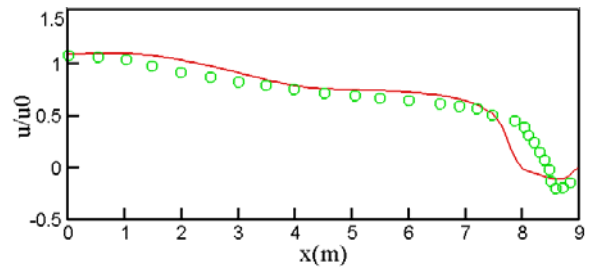


(b) $y=2.916$

Figure 11 Comparison of non-dimensional velocity between simulations and measurements for BSL model



(a) $y=0.084$



(b) $y=2.916$

Figure 12 Comparison of non-dimensional velocity between simulations and measurements for SST model

3. Conclusion

In this paper, we did simulations in a well known annex 20 room benchmarks with Ansys CFX11.0 to study how different turbulence models predict the velocity distribution in a room ventilation system. The results showed that $k-\varepsilon$ model, $k-w$ model and BSL model can give a reasonable agreement with measurements in the main stream area which is away from the solid wall. For $k-\varepsilon$ model, it is difficult to predict the wall bounded place well while the other three models can predict the eddy recirculation on the upper right corner but underpredict the velocity.

The flow close to the floor is separated earlier with $k-w$ model and BSL model than with $k-\varepsilon$ model from the streamline distribution while the SST model give quite different streamline distribution from the other three models. However, it is difficult to tell which turbulence model is better according to the streamline in experiments.

From the simulations results, we can see that it is important to understand various turbulence models and it is better to have measurements compared with simulations since different turbulence models will give various results in a specific case.

Reference

Lars Koellgaard Voigt. *Comparison of Turbulence Models for Numerical Calculation of Airflow in an Annex 20 Room*. International Center for Indoor Environment and Energy Department of Energy Engineering. Technical University of Denmark. ISBN 87-7475-225-1.

Peter V. Nielsen. *Specification of a Two-dimensional Test Case*. Department of Building Technology and Structure Engineering. Aalborg University, 1990. ISBN 0902-7531 R9040.

Peter V. Nielsen. *Flow in Air Conditioned Rooms: Model experiments and numerical solution of the flow equations*. PhD thesis, Technical University of Denmark, 1974.

Appendix grid independent study

The grid number of grid1 is 4736, the grid number of grid2 is 18944 and the grid number of grid3 is 28800.

1. $k-\varepsilon$ model

The simulations with $k-\varepsilon$ model adopted grid1.

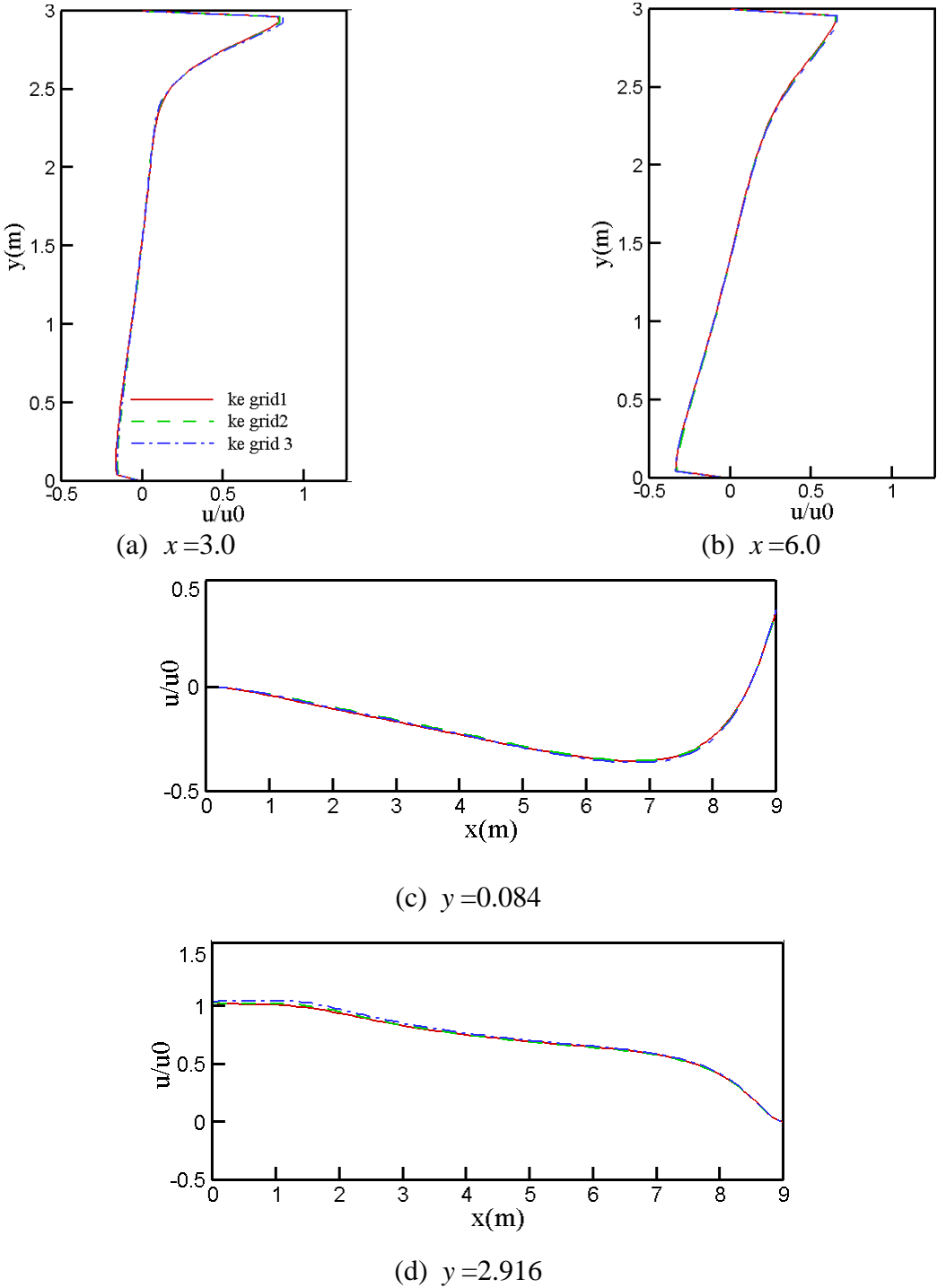


Figure 1 Grid independent study with $k-\varepsilon$ model

2. $k-w$ model

The simulations with $k-w$ model adopt the grid2.

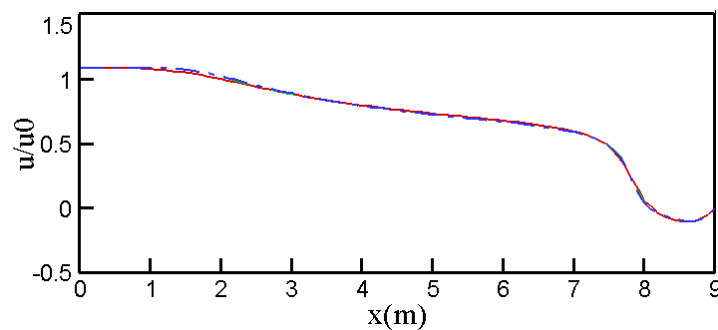
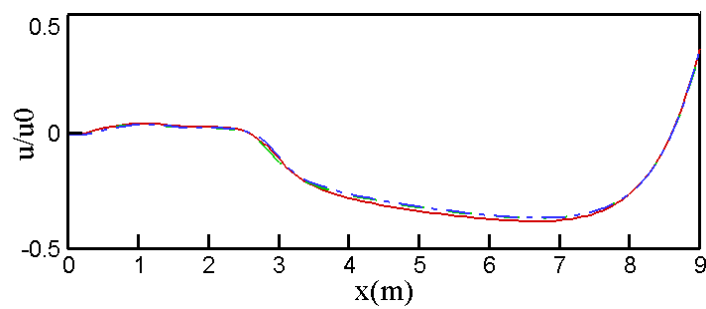
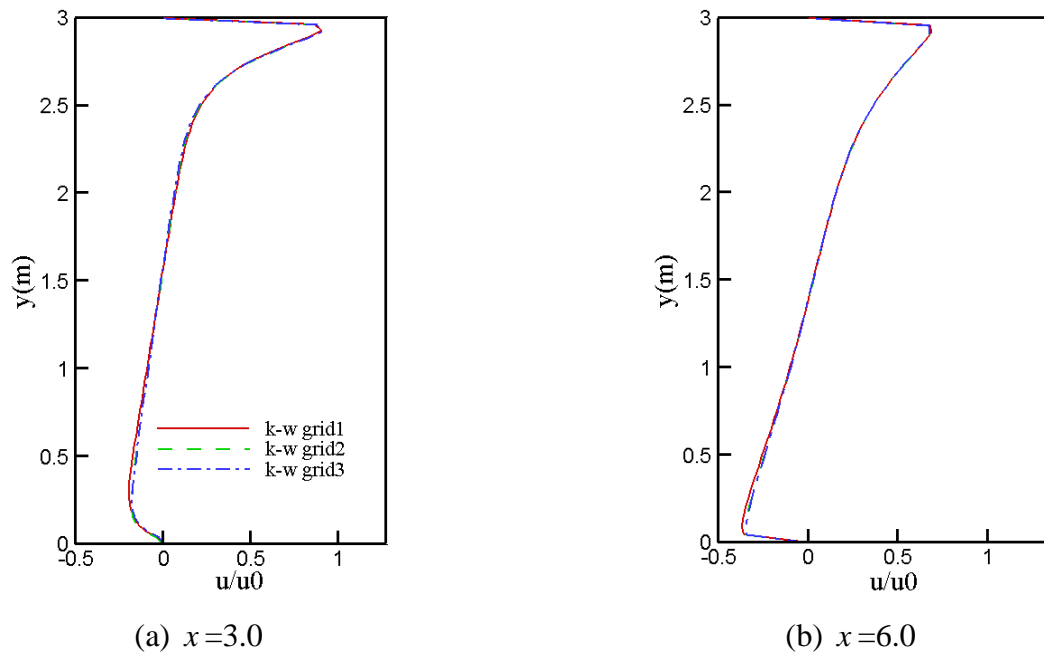


Figure 2 Grid independent study with $k-w$ model

3. BSL model

The simulations with BSL model adopted grid2.

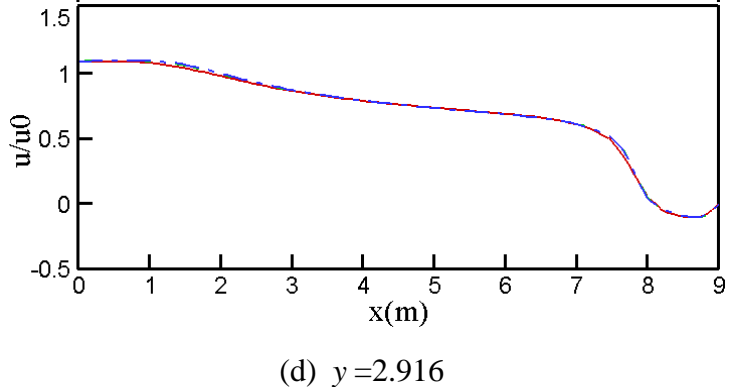
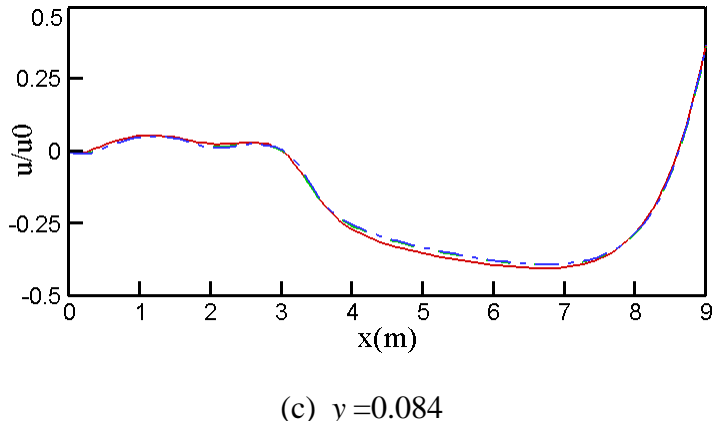
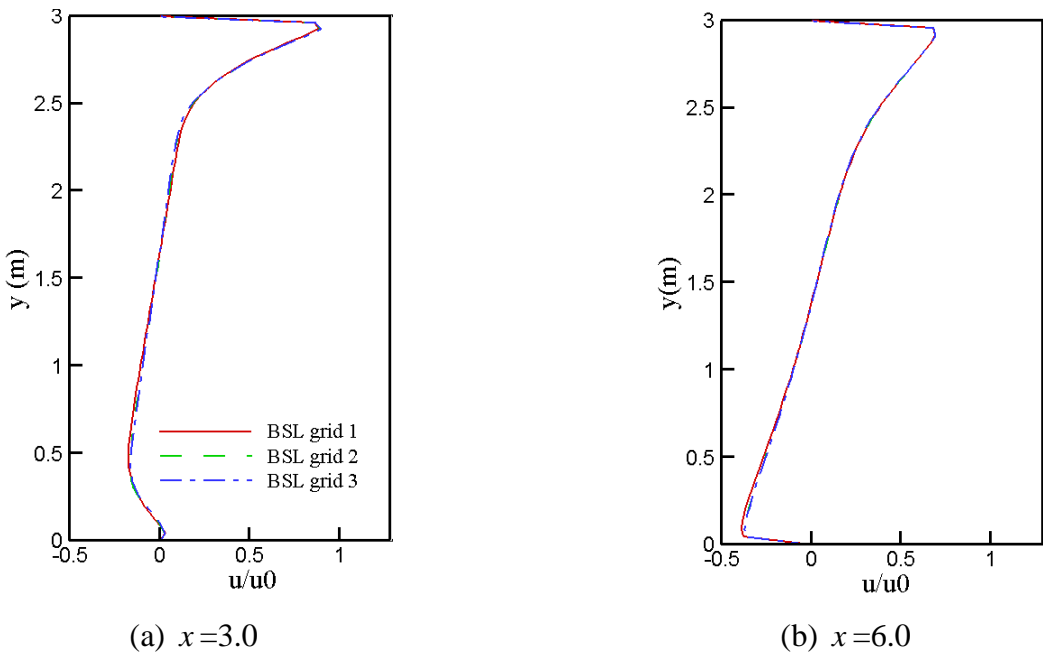


Figure 3 Grid independent study with BSL model

4. SST model

The simulations with SST model adopt grid.

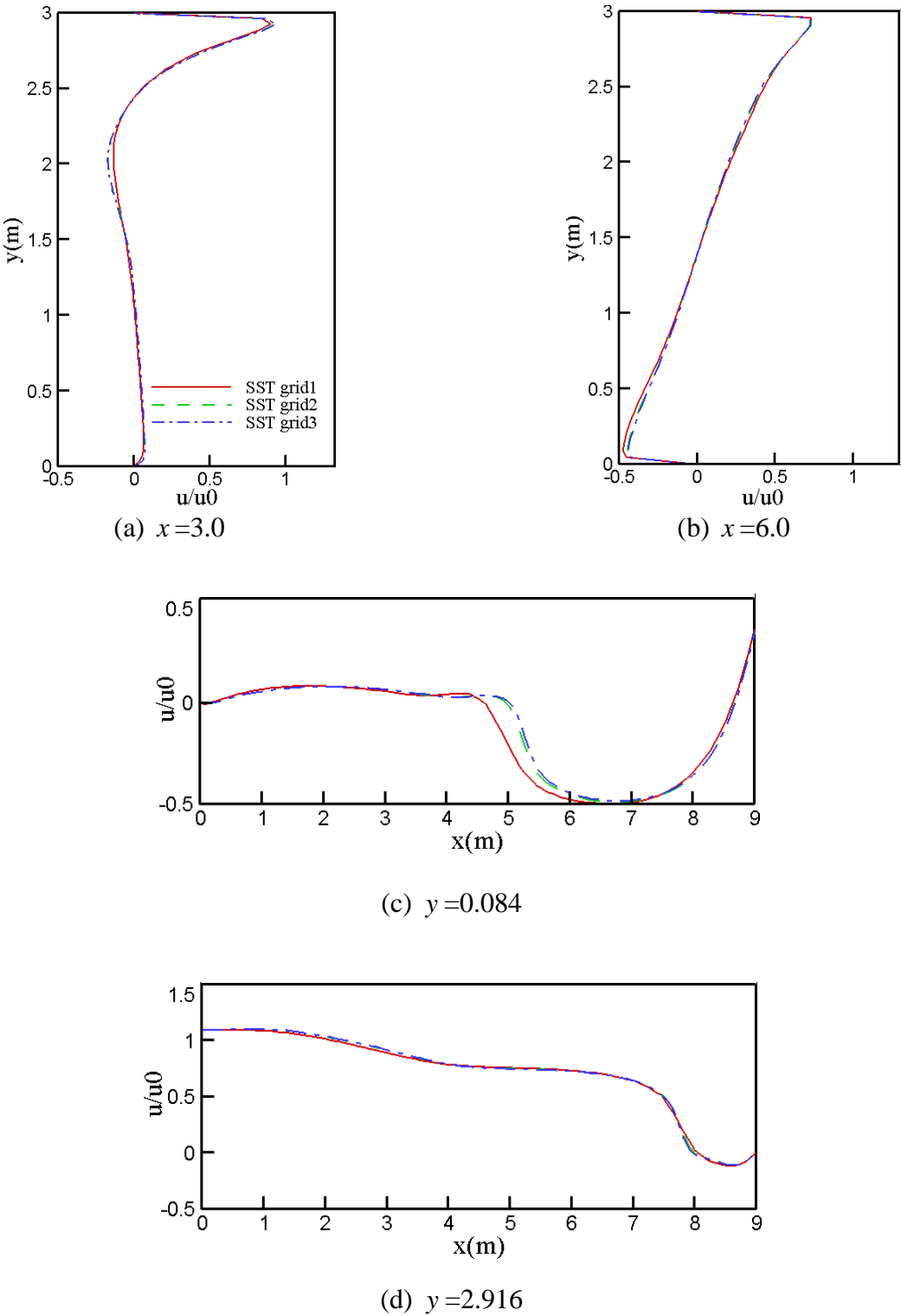


Figure 4 Grid independent study with SST model

