REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

Address:
Rue Washington 40
1050 Brussels
Belgium

- **www.rehva.eu**
- **info@rehva.eu**
- **Tel: +32 2 514 11 71**
- **Fax: +32 2 512 90 62**

Use of REHVA Guidebook Power Point Presentations

- **This Power Point Presentation can be freely used for training purposes by REHVA members.**
- **It is prepared by the main author to the REHVA Guidebook.**
- **Please refer the original author always when making the presentation.**
- **Inform REHVA secretariat each time the presentation is used: info@rehva.eu**

CFD in Ventilation Design

by

Peter V. Nielsen,

Aalborg University

The Audience

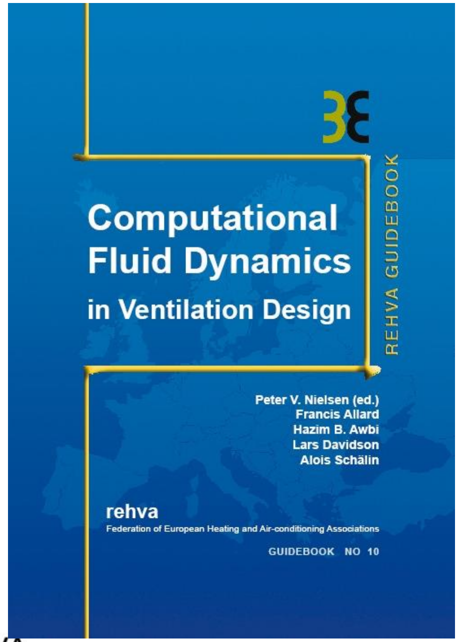
The user of the design book is mainly considered to be a consulting engineer who has to:

- order a CFD prediction
- consider and work with a CFD prediction
- discuss CFD and the CFD quality with a supplier of a CFD prediction

In principle the book is not written for engineers who are making CFD predictions already

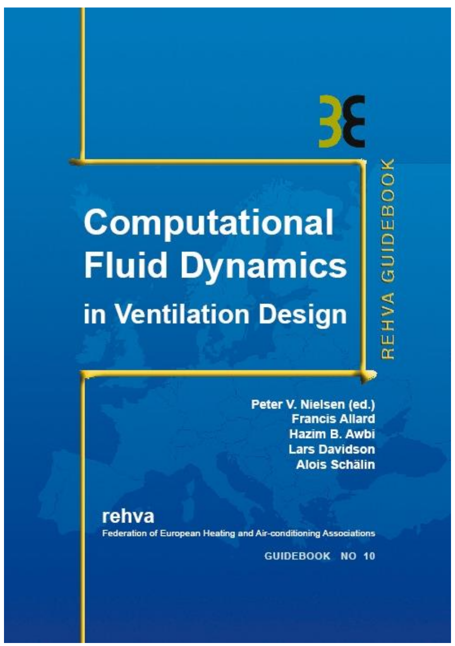
CFD in Ventilation Design

Authors: Francis Allard, Hazim B. Awbi
Lars Davidson, Alois Schälin and Peter V. Nielsen



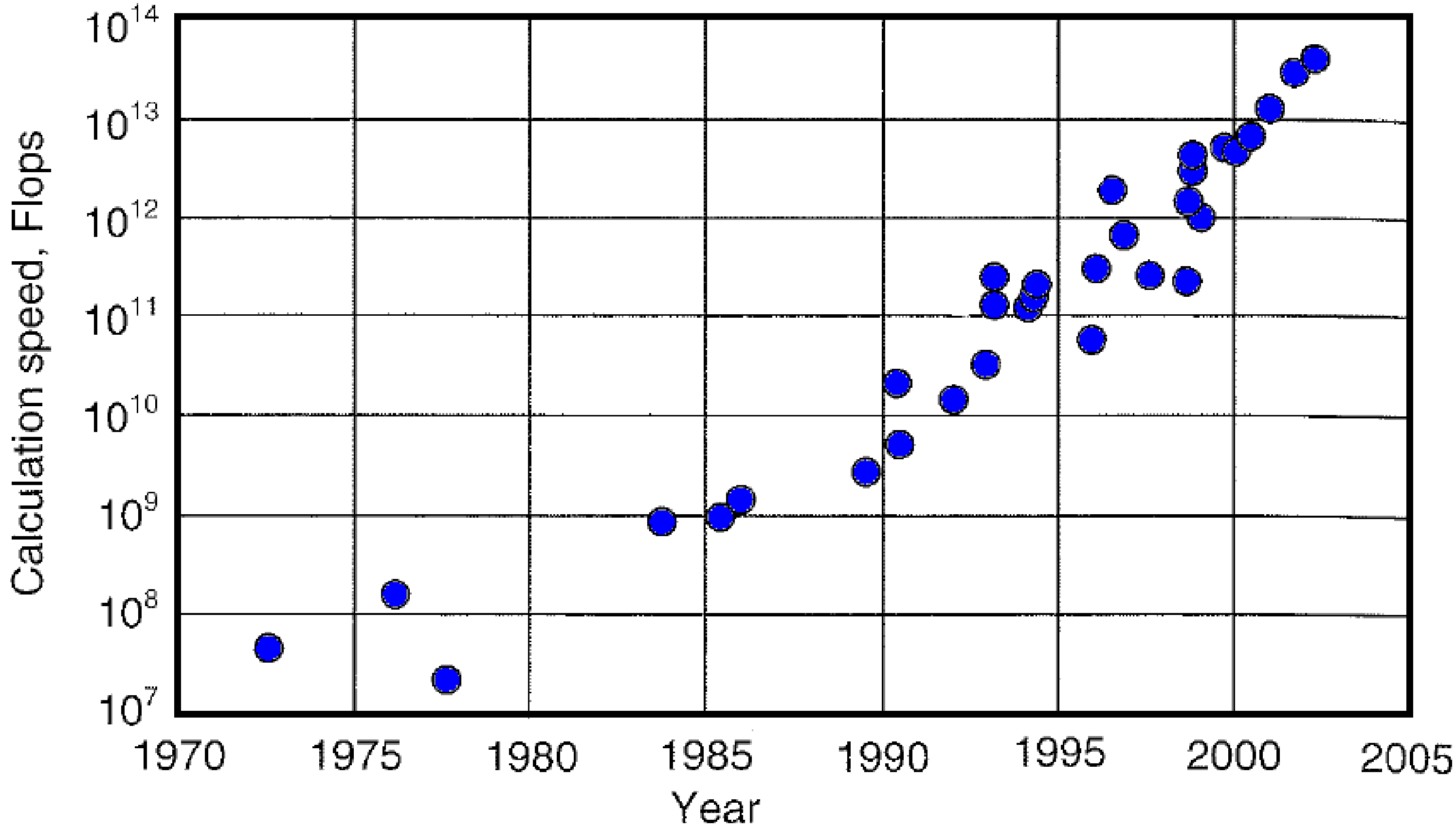
Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

CFD in Ventilation Design

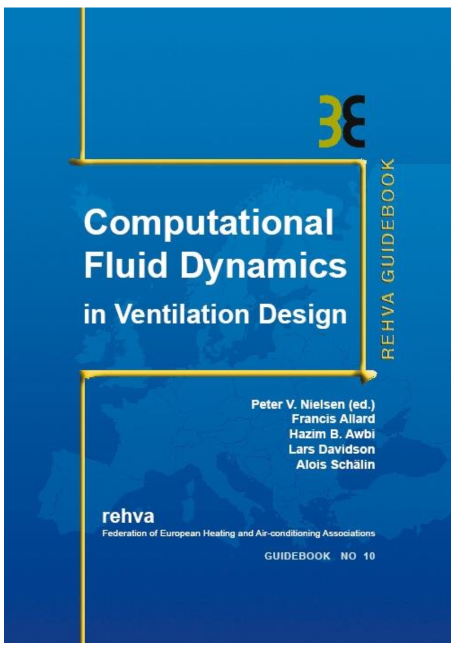


Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Development in Computer Cost



CFD in Ventilation Design



Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Mathematical Background

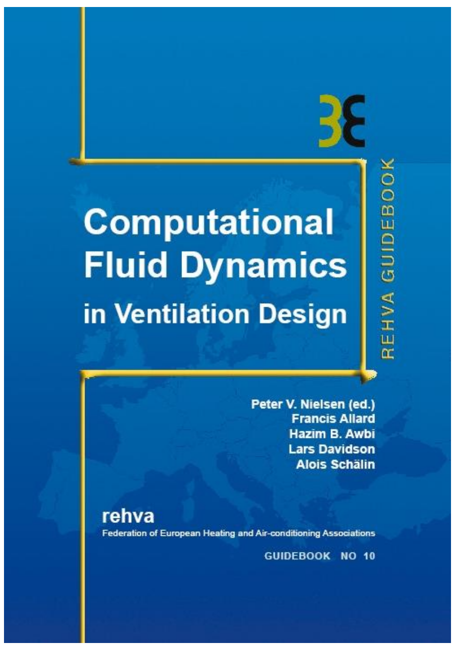
From the general description

$$\frac{\partial(\rho\Phi)}{\partial t} + div(\rho\vec{V}\Phi) = div(\Gamma_\Phi \overrightarrow{grad}\,\Phi) + S_\Phi$$

to a two-dimensional time dependent transport equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right)$$

CFD in Ventilation Design

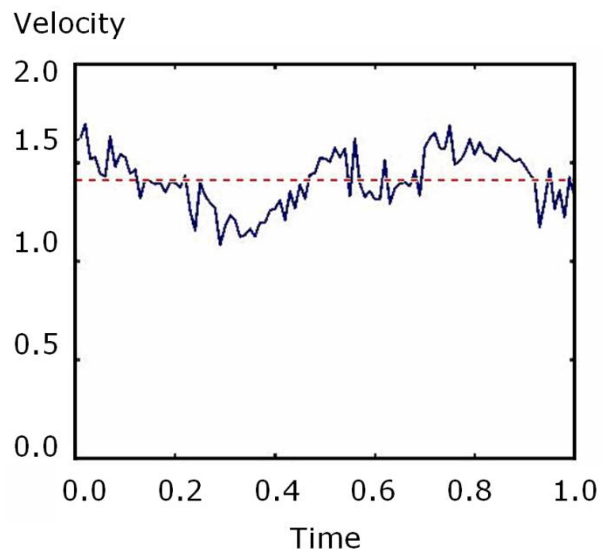


Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Turbulence Models

Laminar flow/turbulent flow
2D steady state

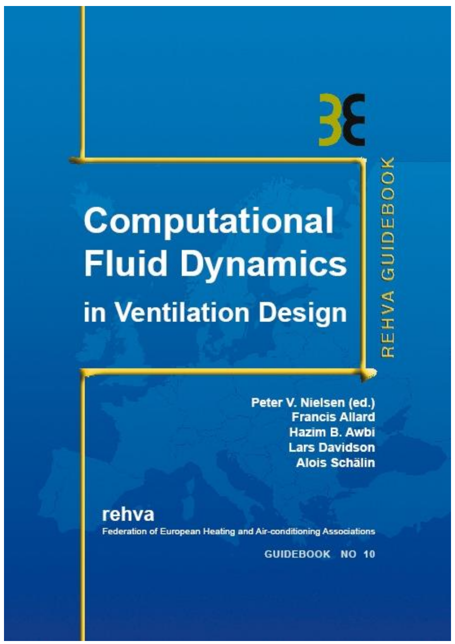
$$\rho u \frac{\partial c}{\partial x} + \rho v \frac{\partial c}{\partial y} = \Gamma_c \frac{\partial^2 c}{\partial y^2} + S_c$$



A discussion of different turbulence models as e.g. the *k-ε* model, the *k-ω* model, the *SST* model and the Reynolds Stress model

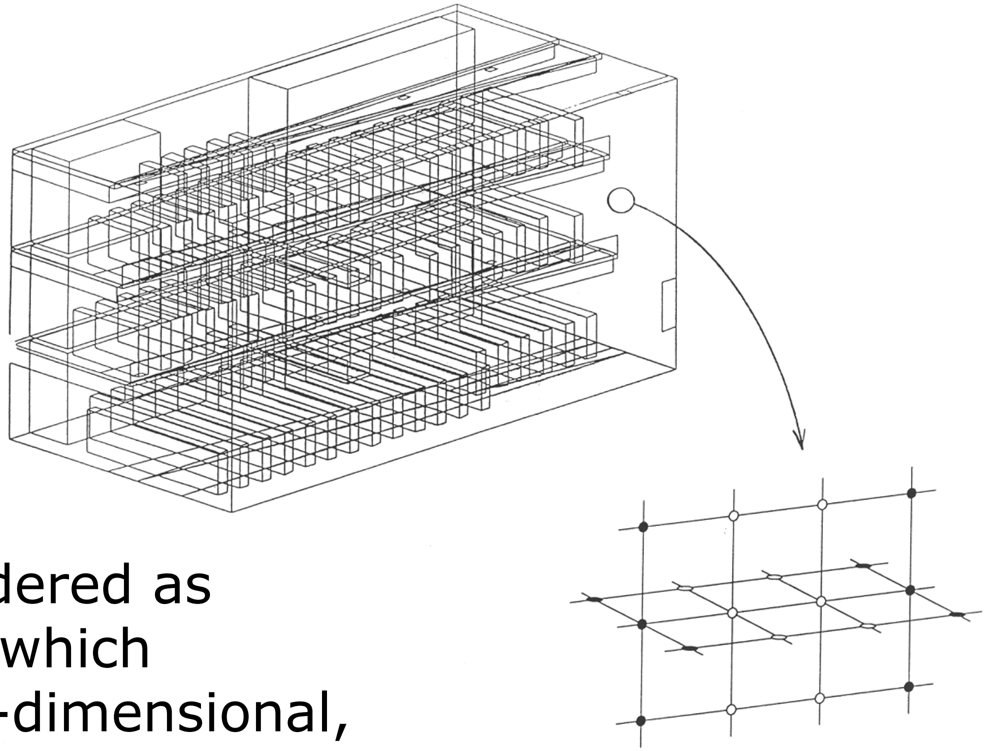
The Large Eddy Simulation is also discussed

CFD in Ventilation Design



Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

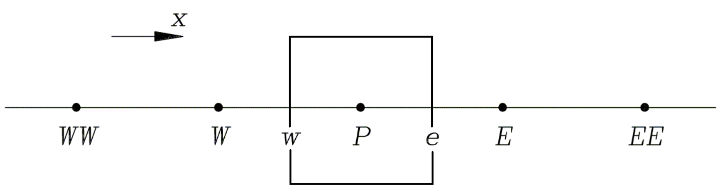
One-Dimensional Case



The case can be considered as a small part of a flow, which in certain areas is one-dimensional, parallel with grid lines and steady.

$$\rho u \frac{dc}{dx} = \Gamma_c \frac{d^2 c}{dx^2} + S_c$$

One-Dimensional Discretization Equation



Control volume formulation:

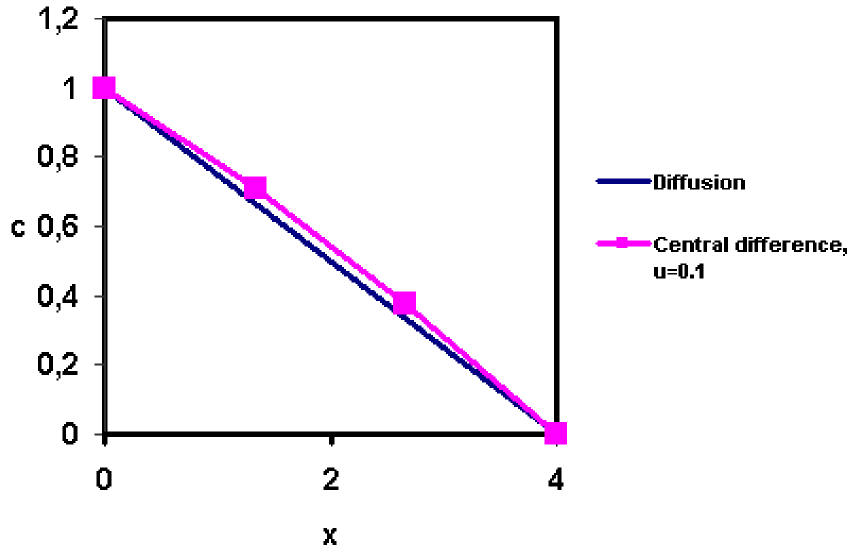
$$\rho\left(u_e c_e - u_w c_w\right) = \Gamma_c\left[\left(\frac{dc}{dx}\right)_e - \left(\frac{dc}{dx}\right)_w\right] + S_P \Delta x$$

It is necessary to replace values at the cell surfaces *e* and *w* with values from the grid points *WW*, *W*, *P*, *E* and *EE* to have a final version of the discretization equation.

Different Discretization Equations, 1

The flow is studied in a case where the length x is equal to 4. The boundary values c_o and c_3 are equal to 1.0 and 0.0.

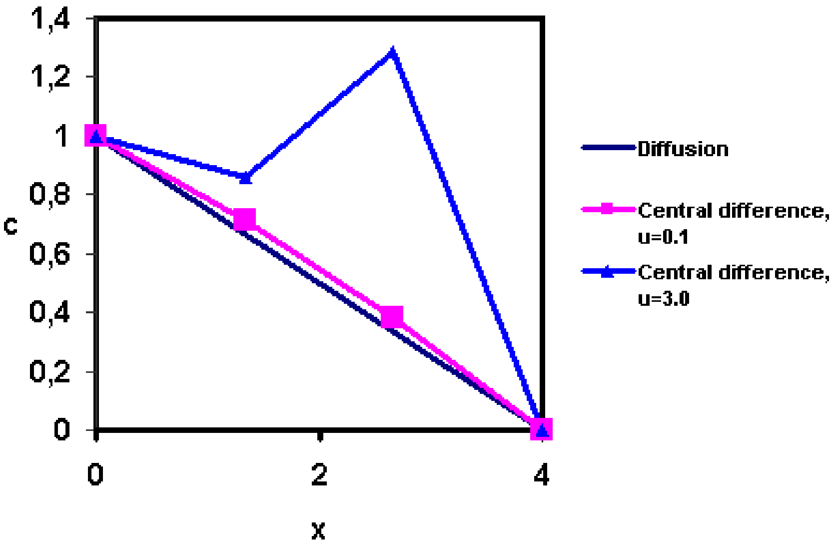
Central differences is e.g. $c_e = (c_P + c_E)/2$ and $u = 0.1$



Different Discretization Equations, 2

Central differences e.g. $c_e = (c_P + c_E)/2$ and $u = 3.0$

Wiggly for $Pe = \frac{\rho \Delta x u}{\Gamma_c}$ larger than 2



History and Numerical Schemes, 1

The sixties
The central difference scheme becomes unstable (wiggly) when the Peclet number is large. The cure is to decrease the grid size.

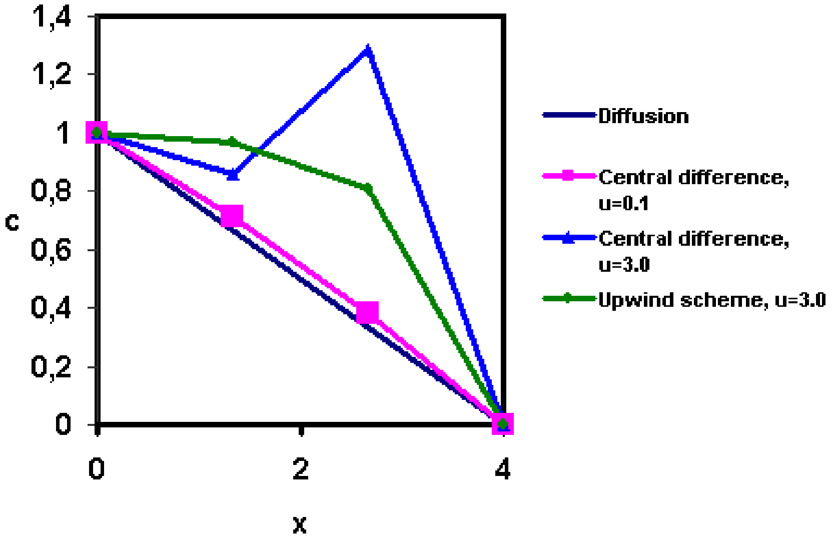
The seventies
Upwind difference opened the way for infinitely high Reynolds numbers, but false diffusion could in many cases be larger than diffusion of physical kind.

The eighties and the nineties
Second order schemes decreased the effect of false diffusion.

Different Discretization Equations, 3

The flow is studied in a case where the length x is equal to 4. The boundary values c_o and c_3 are equal to 1.0 and 0.0.

Upwind scheme e.g. $c_e = c_P$ and $u = 3.0$



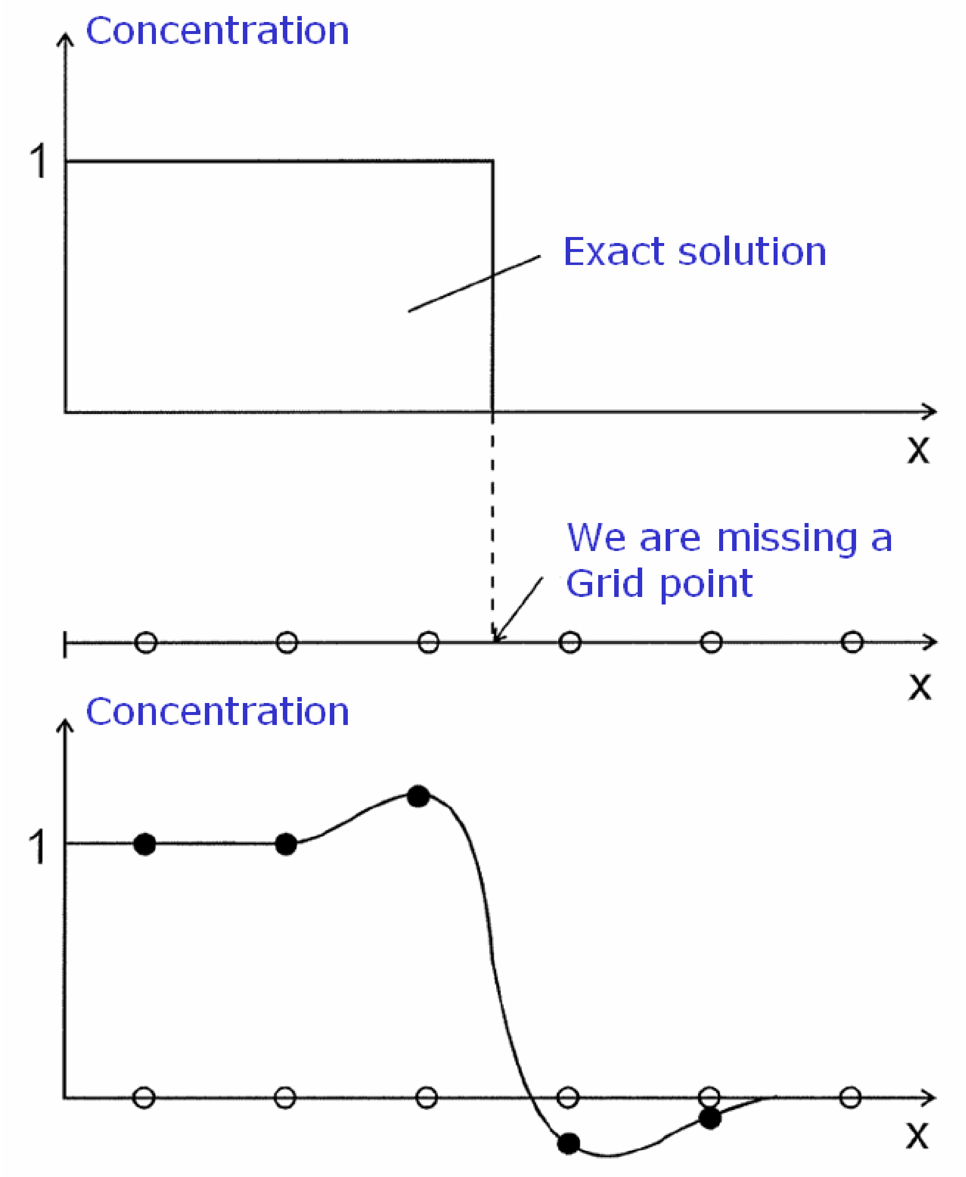
History and Numerical Schemes, 2

The sixties
The central difference scheme becomes unstable (wiggly) when the Peclet number is large. The cure is to decrease the grid size.

The seventies
Upwind difference opened the way for infinitely high Reynolds numbers, but false diffusion could in many cases be larger than diffusion of physical kind.

The eighties and the nineties
Second order schemes decreased the effect of false diffusion.

False Diffusion



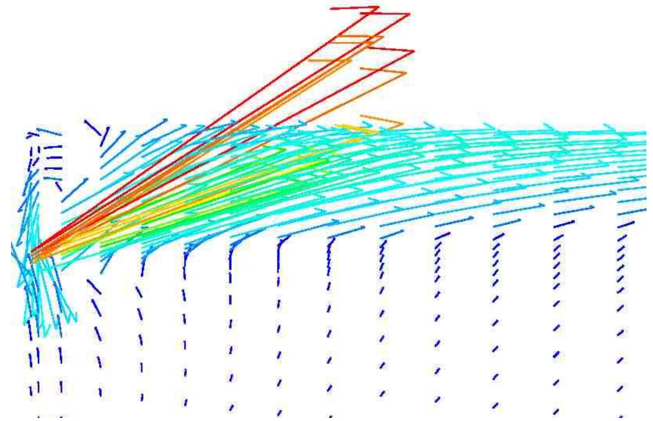
Higher Order Schemes

Second order upwind scheme is an example of a new scheme developed in the middle of the seventies.

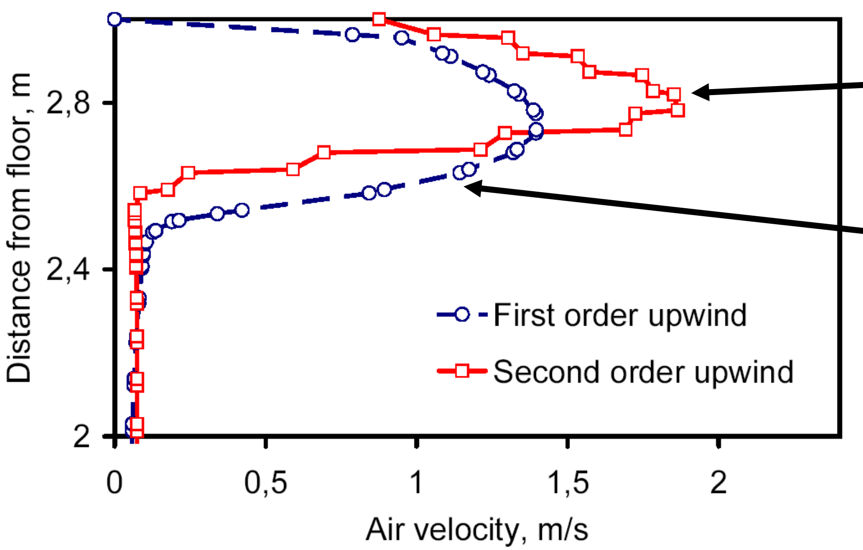
The one-dimensional case with the velocity u = 3.0 and 1st and 2nd order upwind scheme

False Diffusion and Order of the Schemes

Flow from an opening, which is inclined at ~30 deg. to the mesh. Three-dimensional flow.



Profile at the upper surface at a distance of 1 m from the opening.



Dispersive error

Diffusive error

Svidt

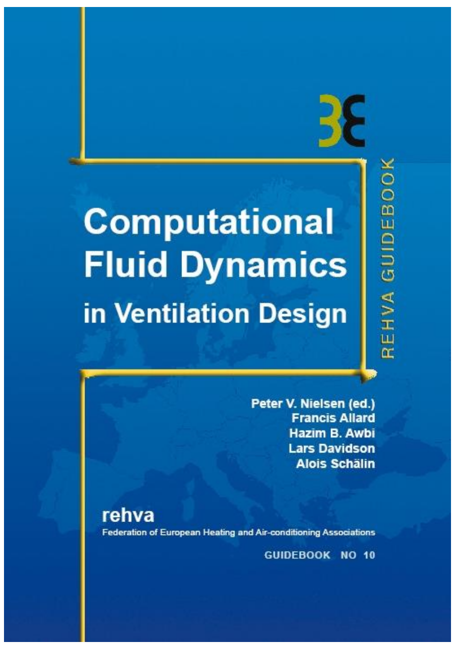
History and Numerical Schemes, 3

The sixties
The central difference scheme becomes unstable (wiggly) when the Peclet number is large. The cure is to decrease the grid size.

The seventies
Upwind difference opened the way for infinitely high Reynolds numbers, but false diffusion could in many cases be larger than diffusion of physical kind.

The eighties and the nineties
Second order schemes decreased the effect of false diffusion.

CFD in Ventilation Design

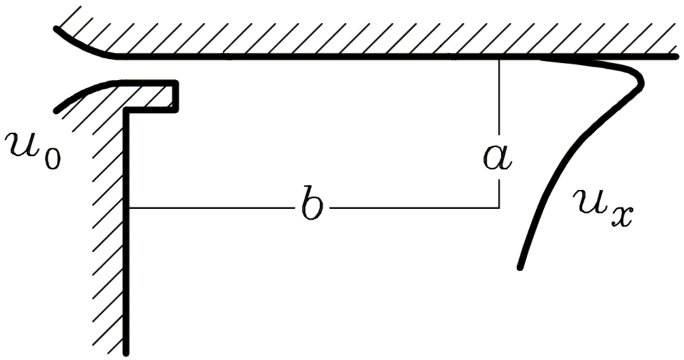


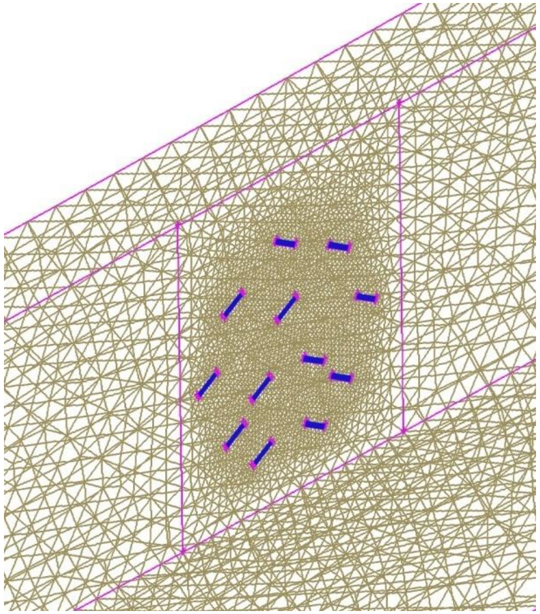
Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Boundary Conditions

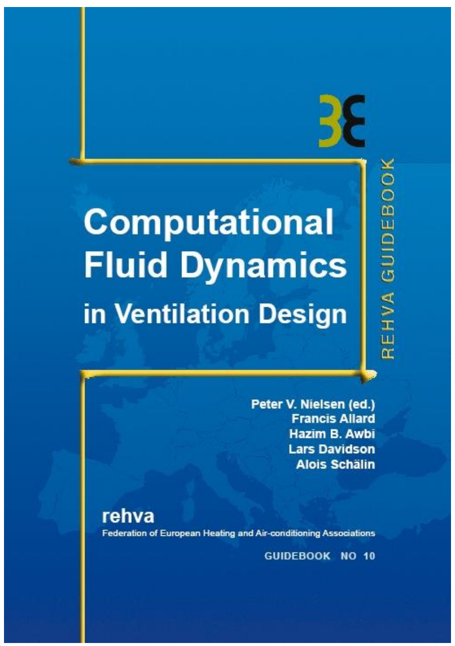
- Wall boundary
- Free boundary
- Plane of symmetry
- Air supply opening
- Air exit opening
- Obstacle boundary

Air supply opening





CFD in Ventilation Design



Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Quality Control

Quality control consists of these major steps:

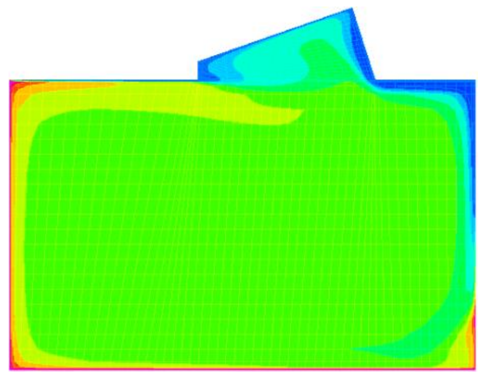
- recognize possible sources of errors
- check for these errors in your own simulations
- estimate the accuracy of the simulations
- improve the simulations, if possible

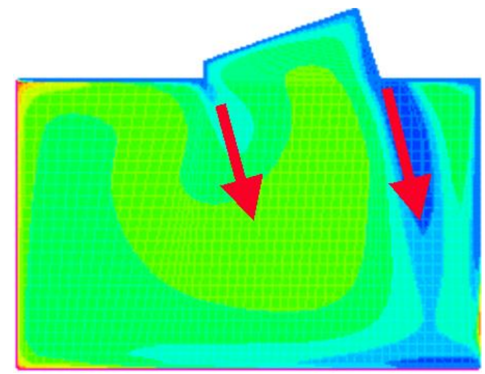
Main items in this chapter are:

- Steps in a CFD simulation
- Sources of errors and uncertainties
- How to ensure high quality predictions (recommendations)
- Questions to ask the CFD engineer as regards the work reported
- Additional advice and remarks
- A short check list

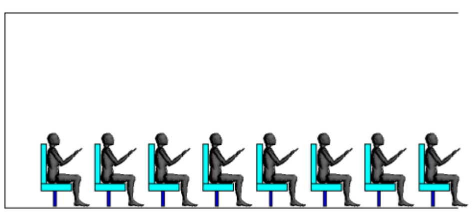
Quality Control, Sources of Errors and Uncertainties

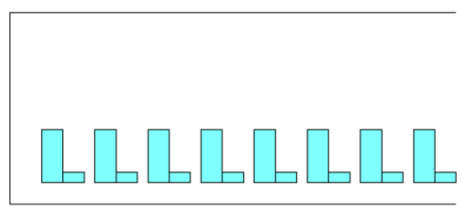
Some examples: 2D treatment instead of 3D

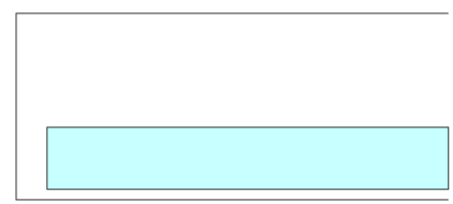




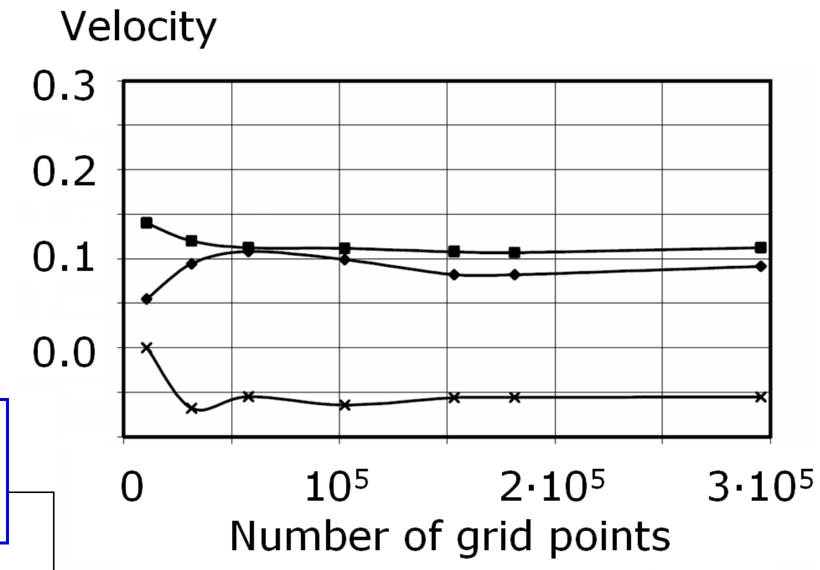
Simplification, modelling level



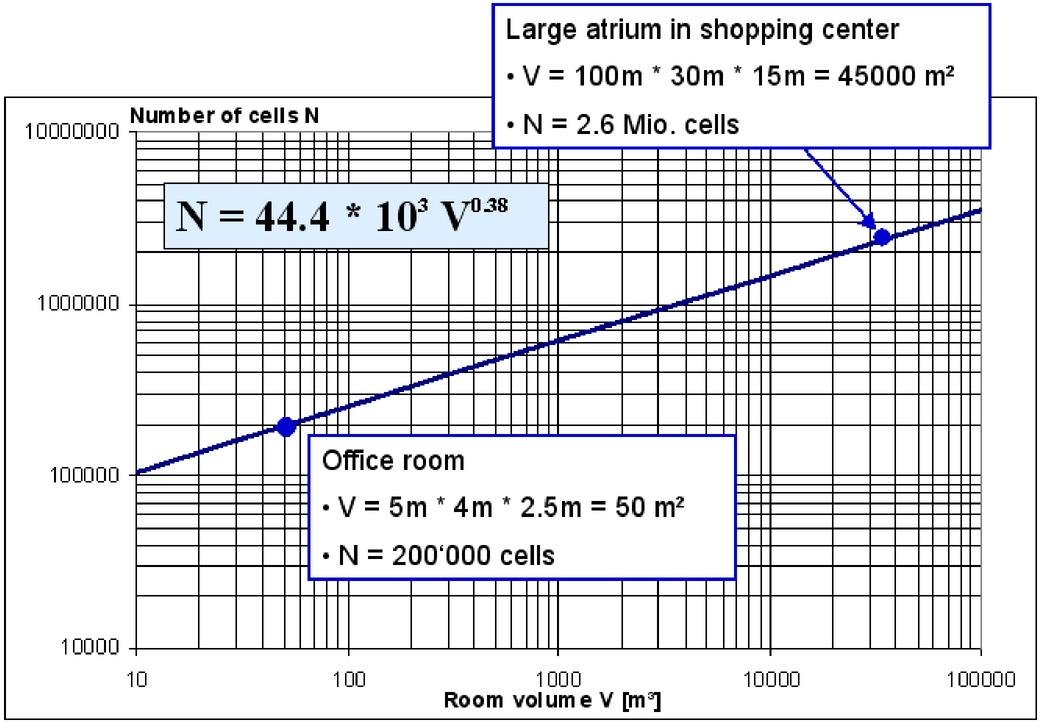




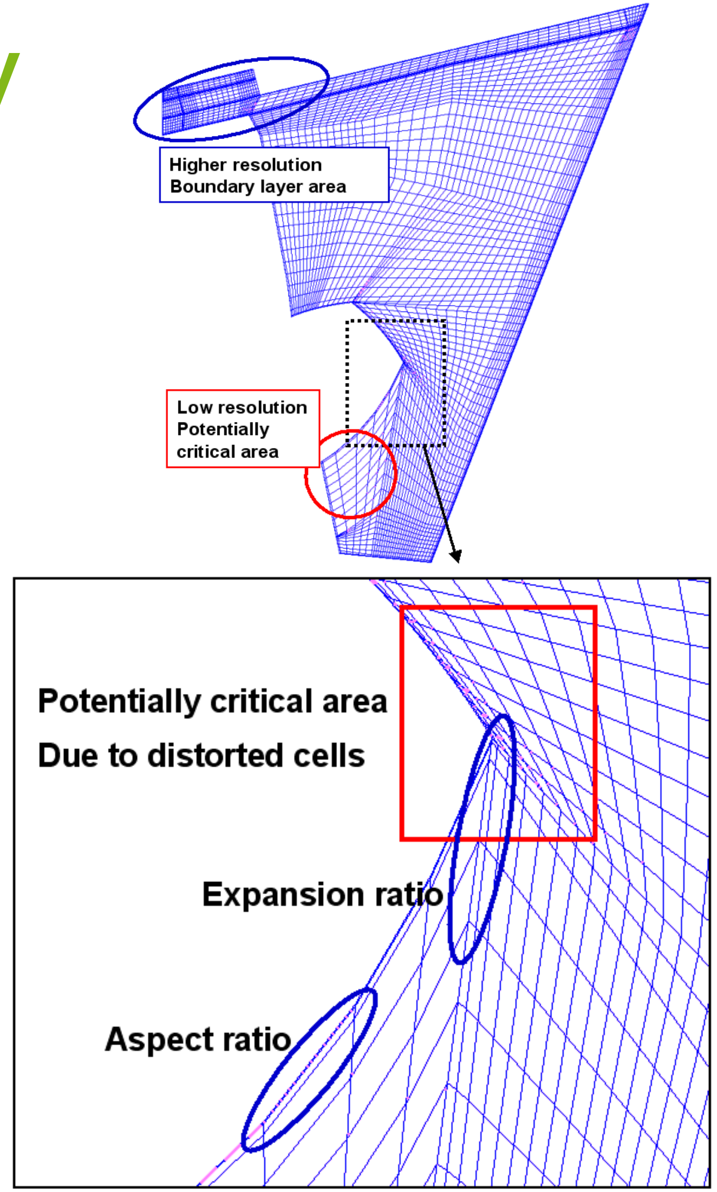
Cell Quality



Monitoring velocities versus number of cells in the prediction

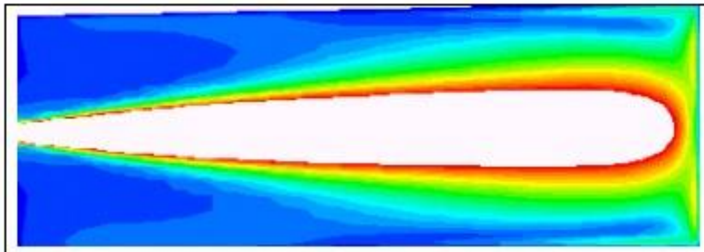


Cell Quality

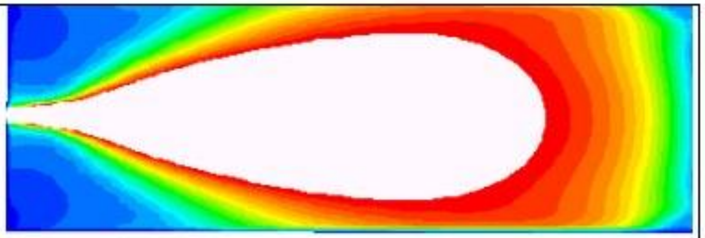


Turbulence Model

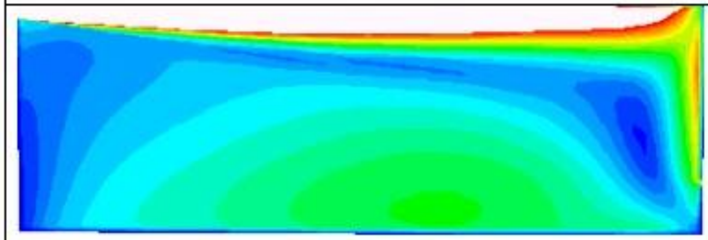
3D wall jet in a room simulated by a *k-epsilon Model* and a *Reynolds Stress Model.*



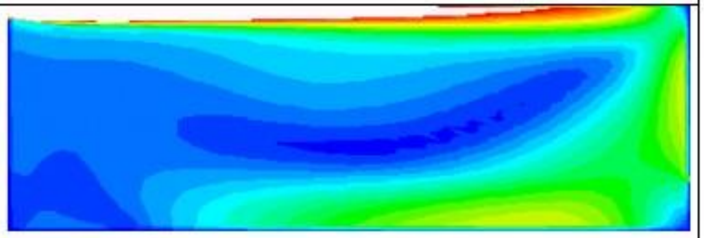
Profile near ceiling seen from above. k-ε-model. White core: velocities > 3.5 m/s.



Profile near ceiling seen from above. RSM model. White core: velocities > 3.5 m/s.



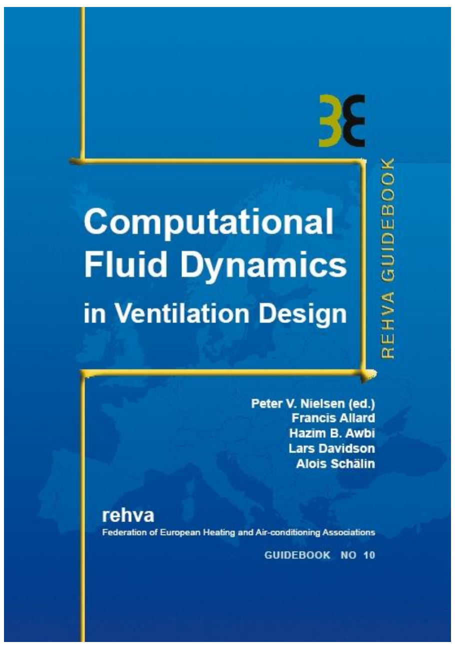
Side view of profile in mid-plane. k-ε-model. White core near ceiling: velocities > 3.0 m/s.



Side view of profile in mid-plane. RSM model. White core near ceiling: velocities > 3.0 m/s.

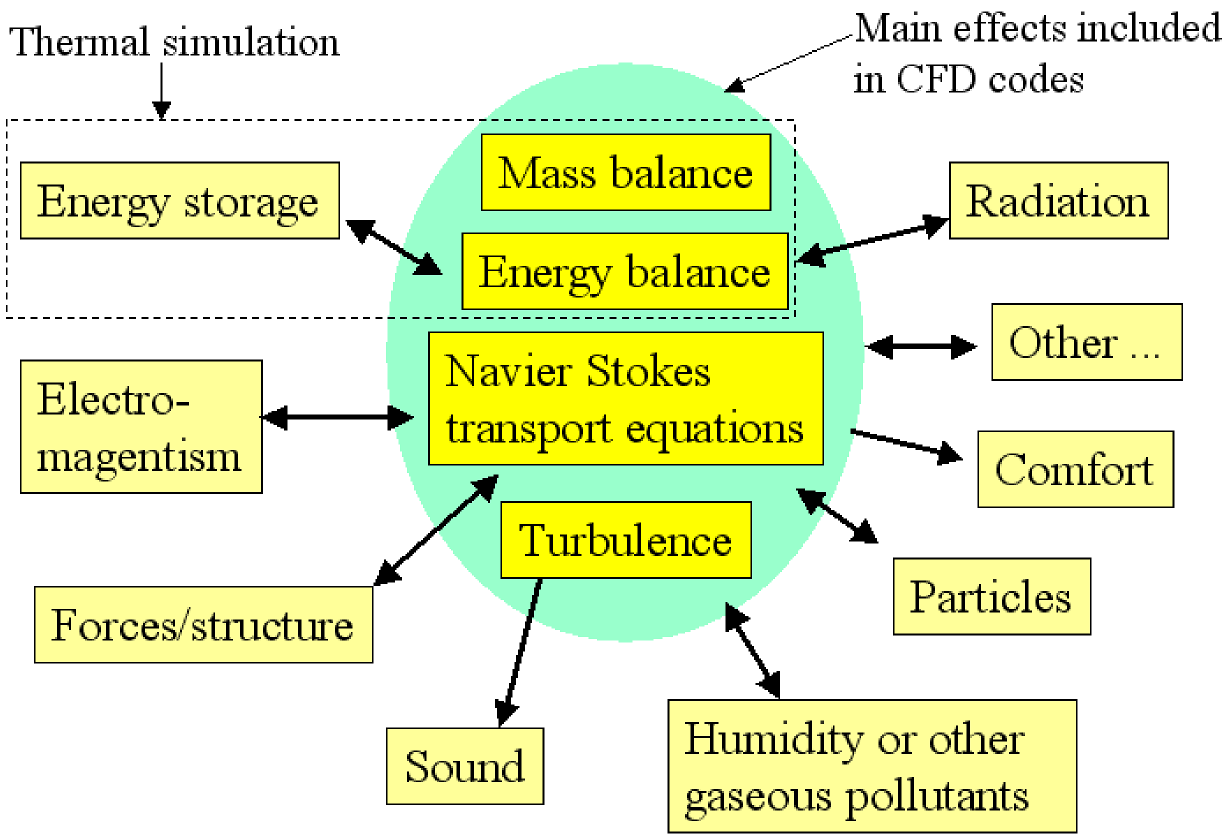
Schälin and Nielsen

CFD in Ventilation Design

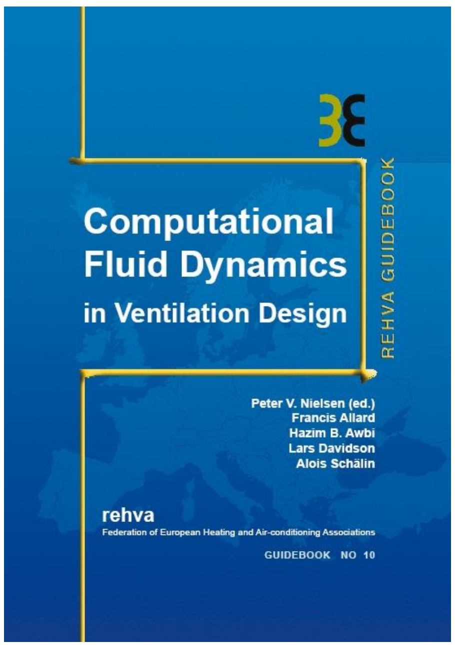


Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

CFD Combined with Other Prediction Models



CFD in Ventilation Design



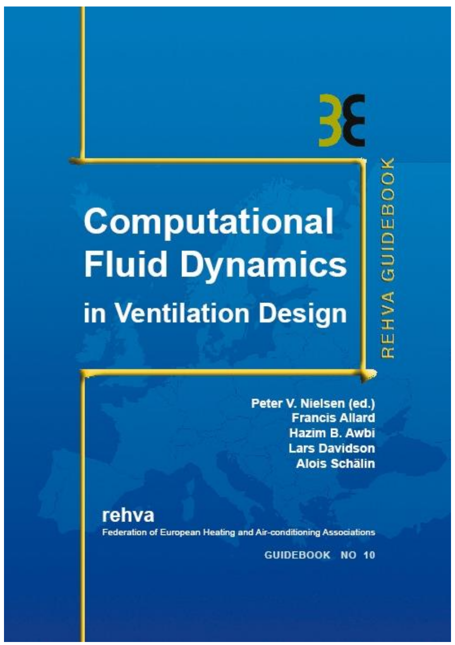
Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

Application of CFD Codes in Building Design

The applications of CFD in buildings may be grouped under the following headings:

- Prediction of air jet diffusion
- Analysis of Room air movement
- Prediction of contaminant dispersal
- Modelling emission from materials and equipment in buildings
- Indoor air quality prediction
- Thermal comfort assessment
- Mean age of air and ventilation effectiveness predictions
- Prediction of fire and smoke spread
- Wind flow around buildings

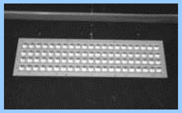
CFD in Ventilation Design



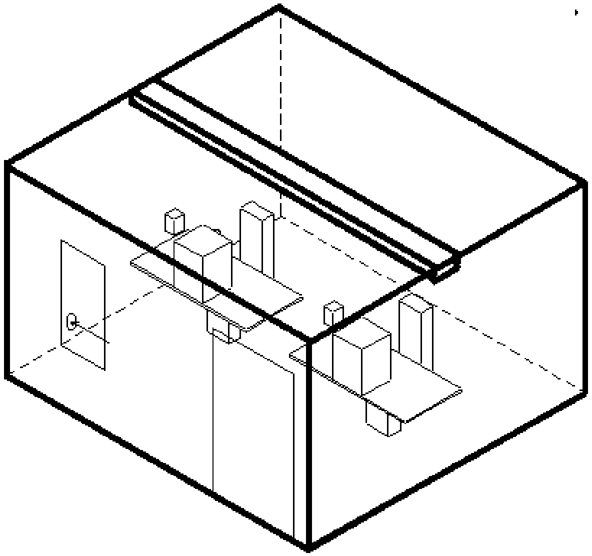
Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

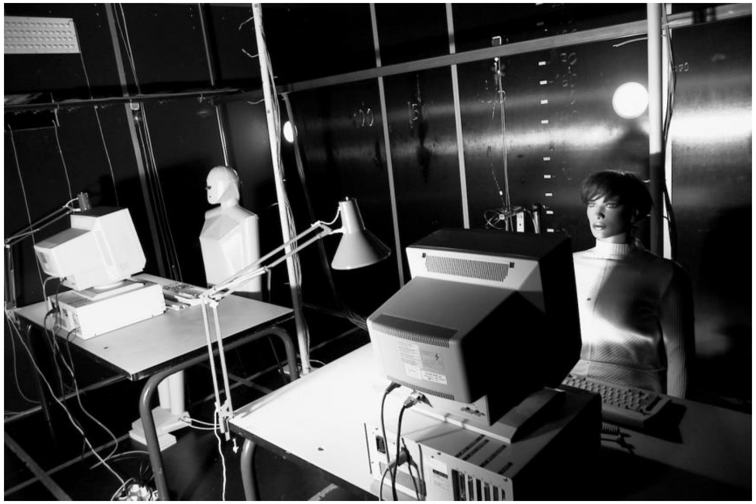
Case Studies on Different Air Distribution Systems

Five air distribution systems are compared with each other. They are all installed in the same room, and they all handle the same situation and the same load.

Mixing ventilation with end wall mounted diffuser.	
Vertical ventilation with a textile terminal..	
Displacement ventilation. End wall mounted low velocity diffuser.	
Mixing ventilation generated by a ceiling mounted radial diffuser.	

The Test Room

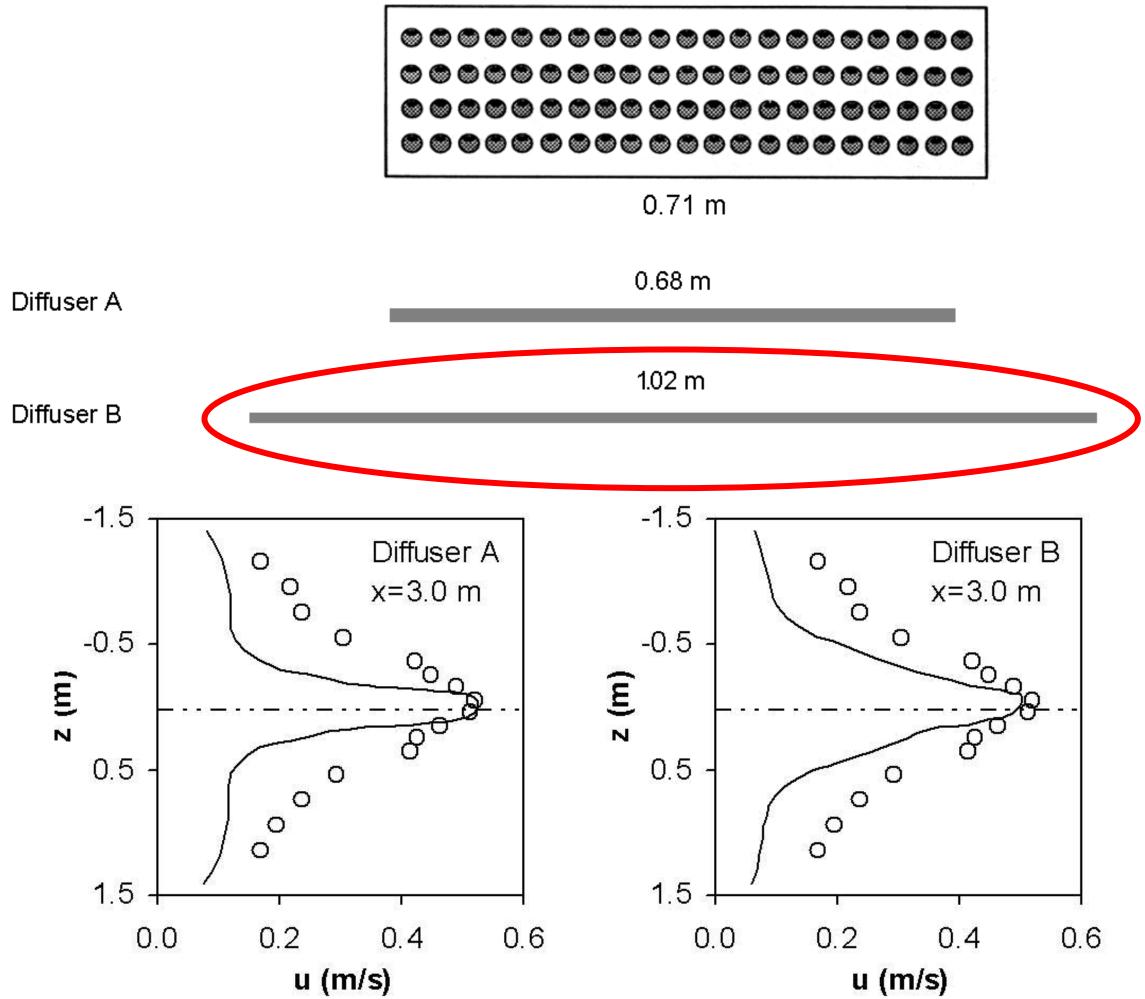




The test room is the IEA Annex 20 room with length, width and height equal to 4.2 m, 3.6 m and 2.5 m.
The heat load consists of two PCs, two desk lamps and two manikins producing a total heat load of 480 W. One work place is used in some of the experiments (240 W).

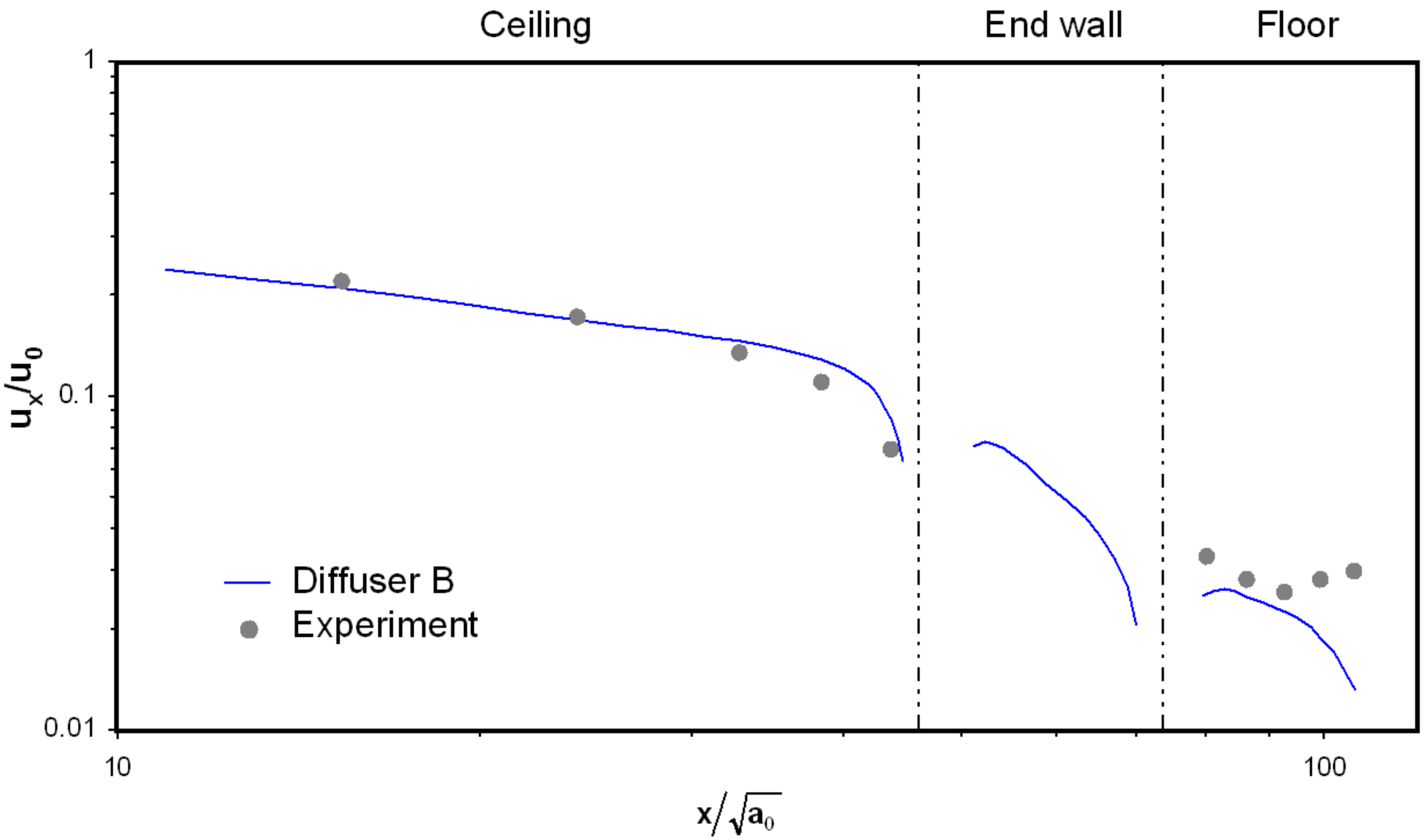
Case Study, Mixing Ventilation with Wall Mounted ATD

Simulation of the Diffuser



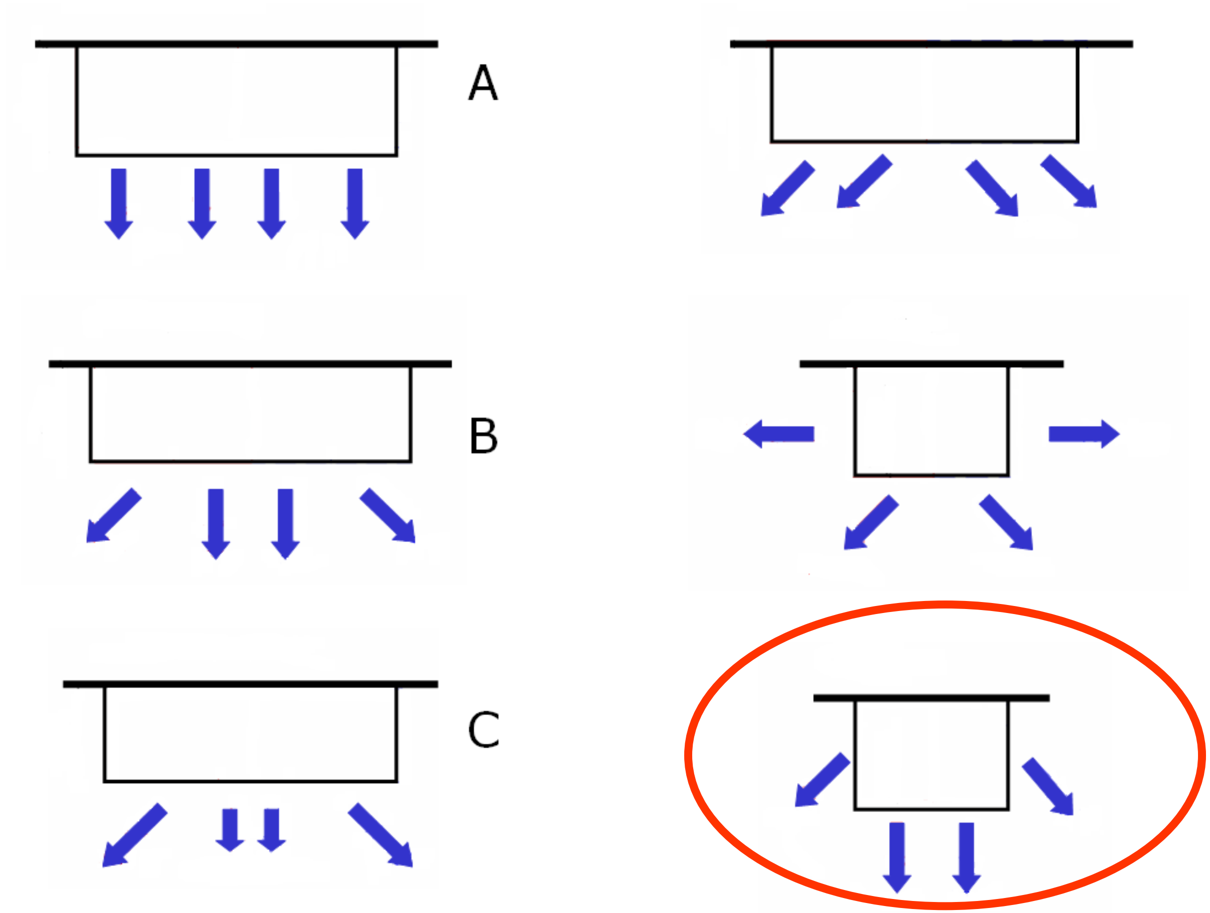
REHVA

Mixing Ventilation with End Wall Mounted Diffuser



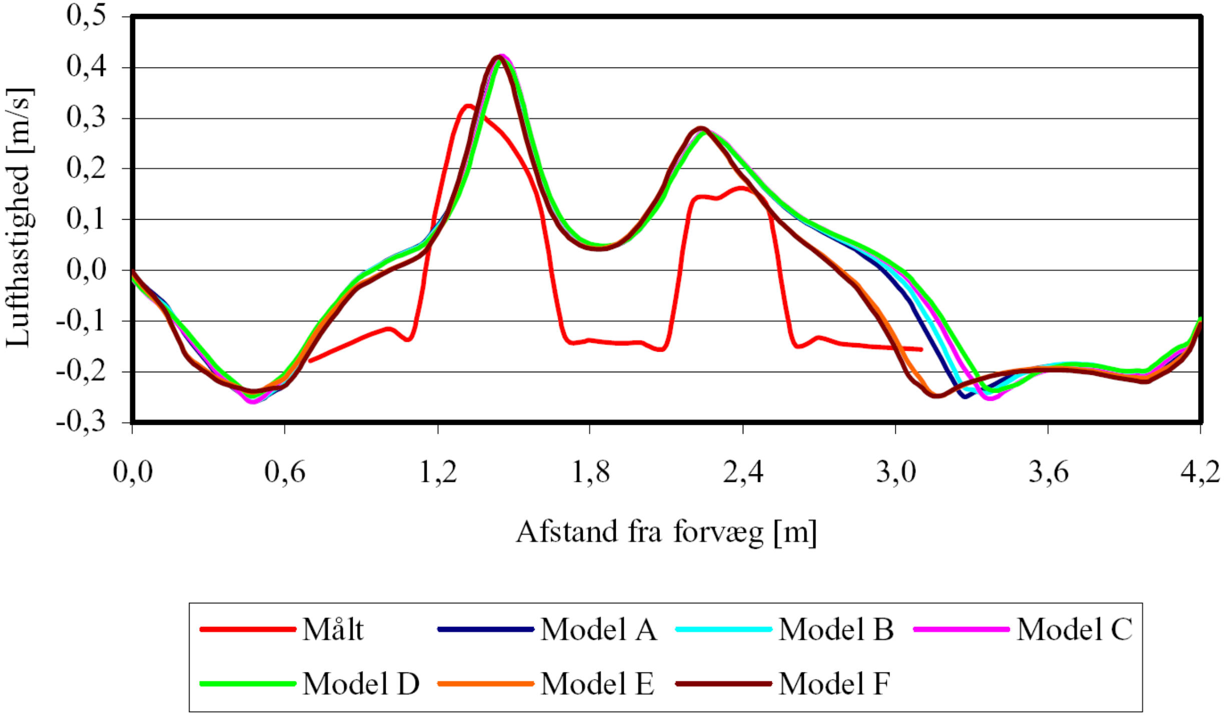
Case Study, Vertical Ventilation

Vertical Ventilation, Diffuser

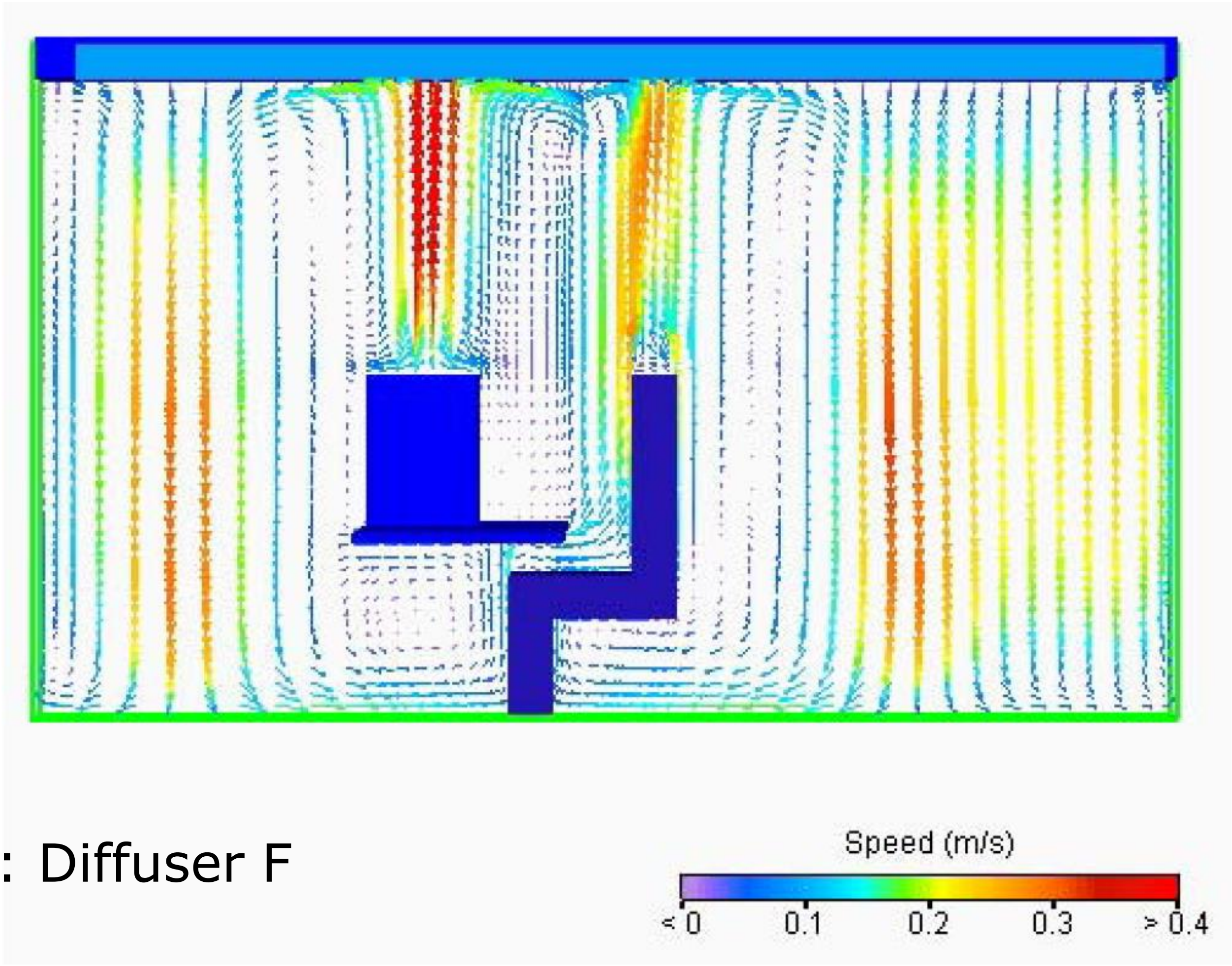


Vertical Ventilation, Diffuser

1st order steady state equations, *k-ε* turbulence model, 300,000 cells

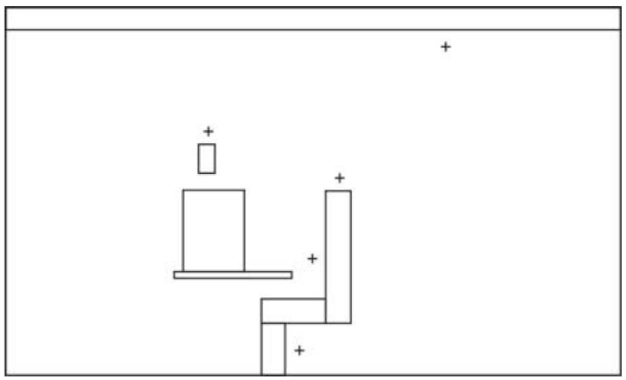


Vertical Ventilation

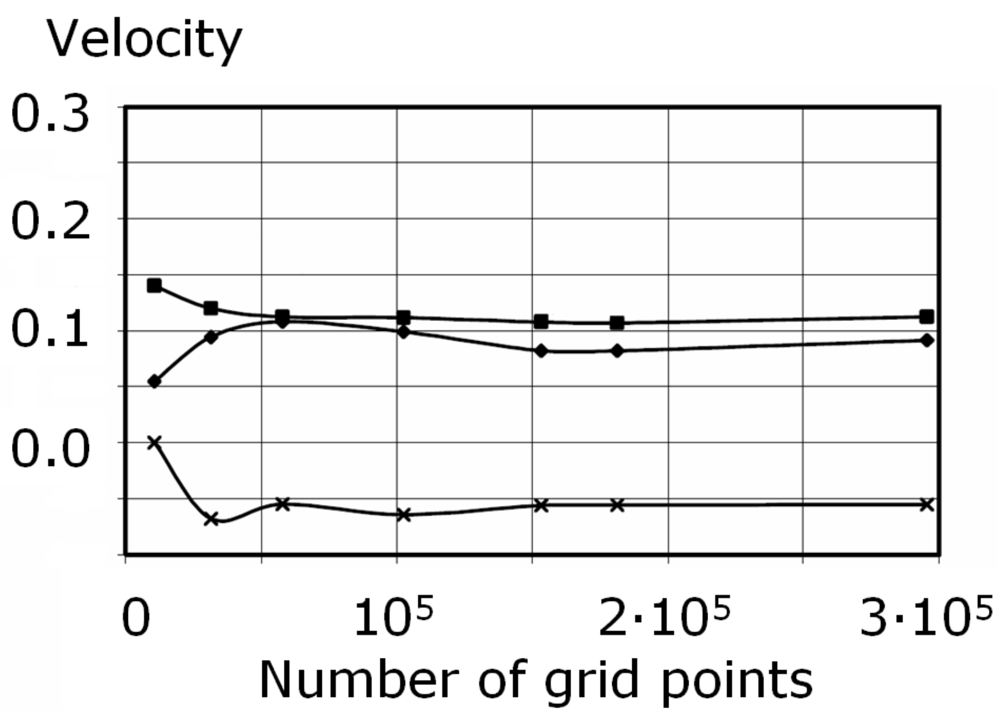


BC: Diffuser F

Vertical Ventilation, Quality Control

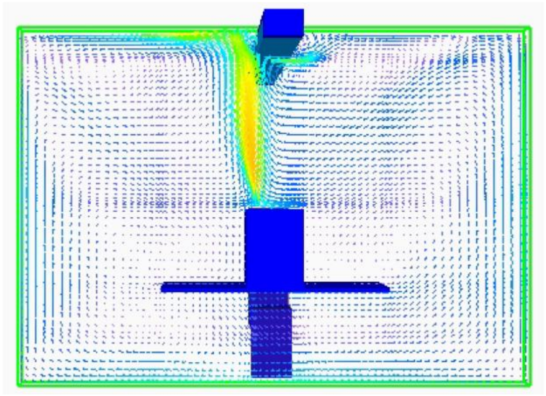


Monitoring points

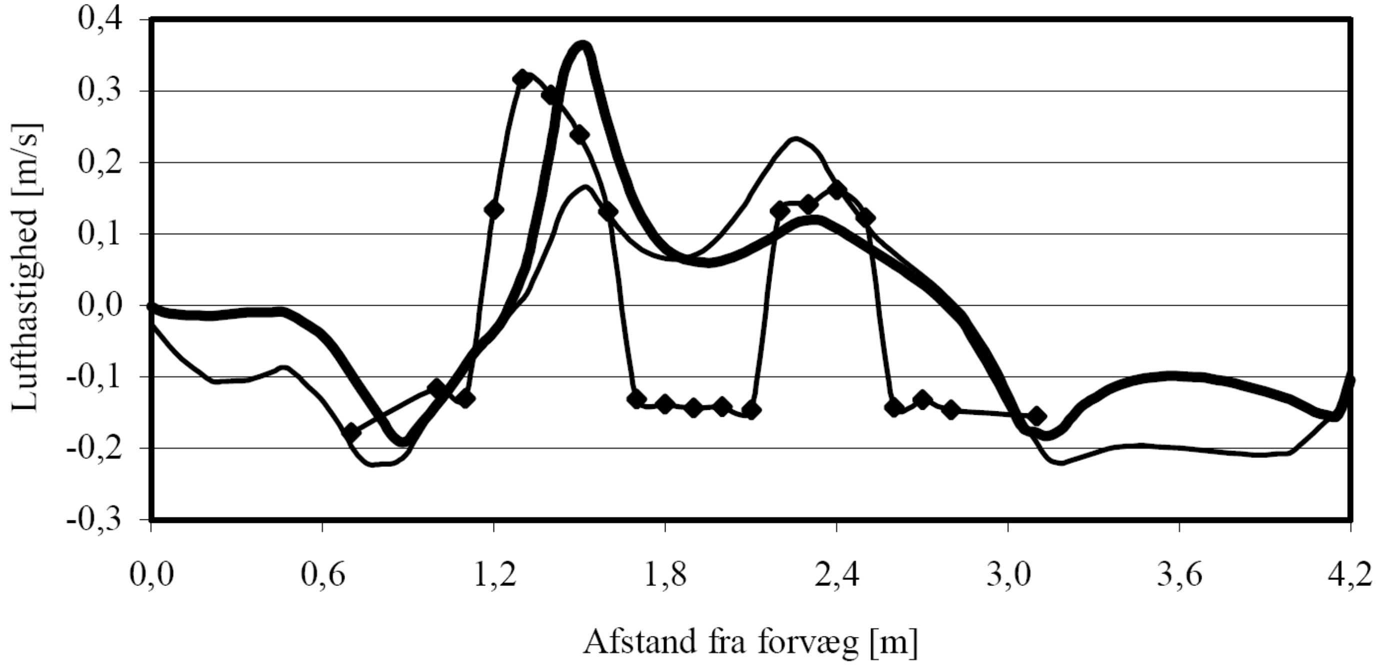


Velocity in y-direction

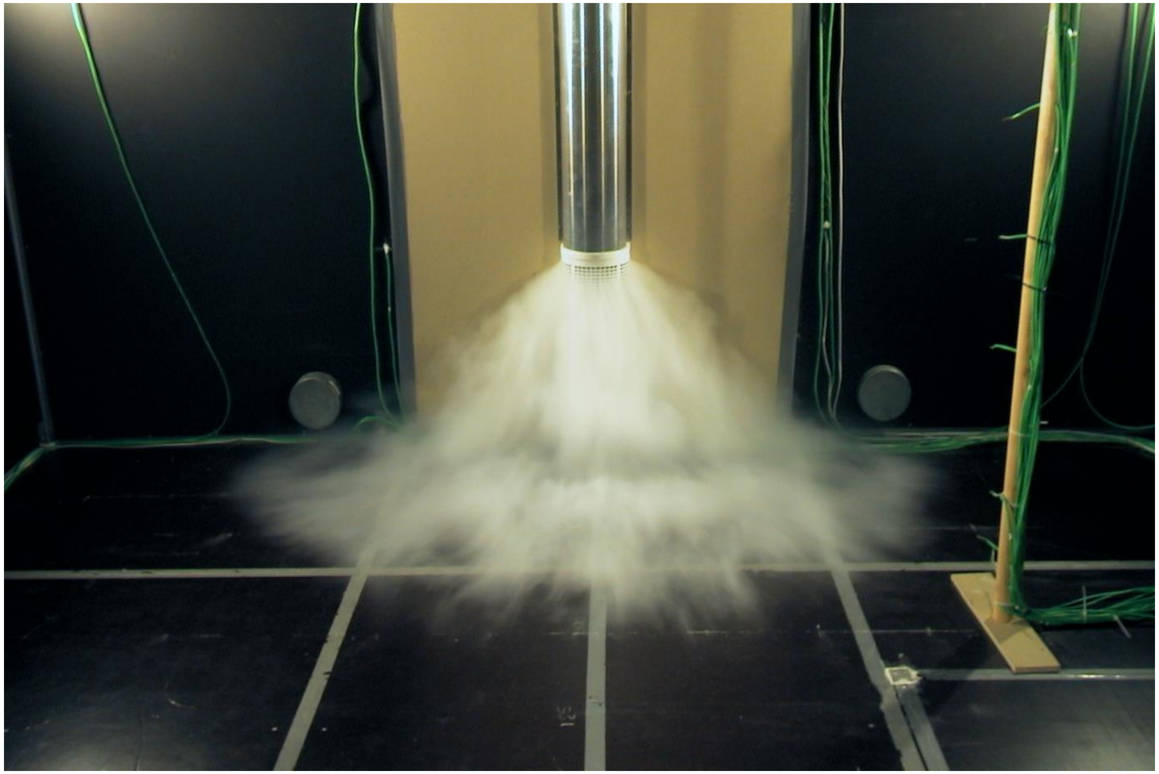
Vertical Ventilation



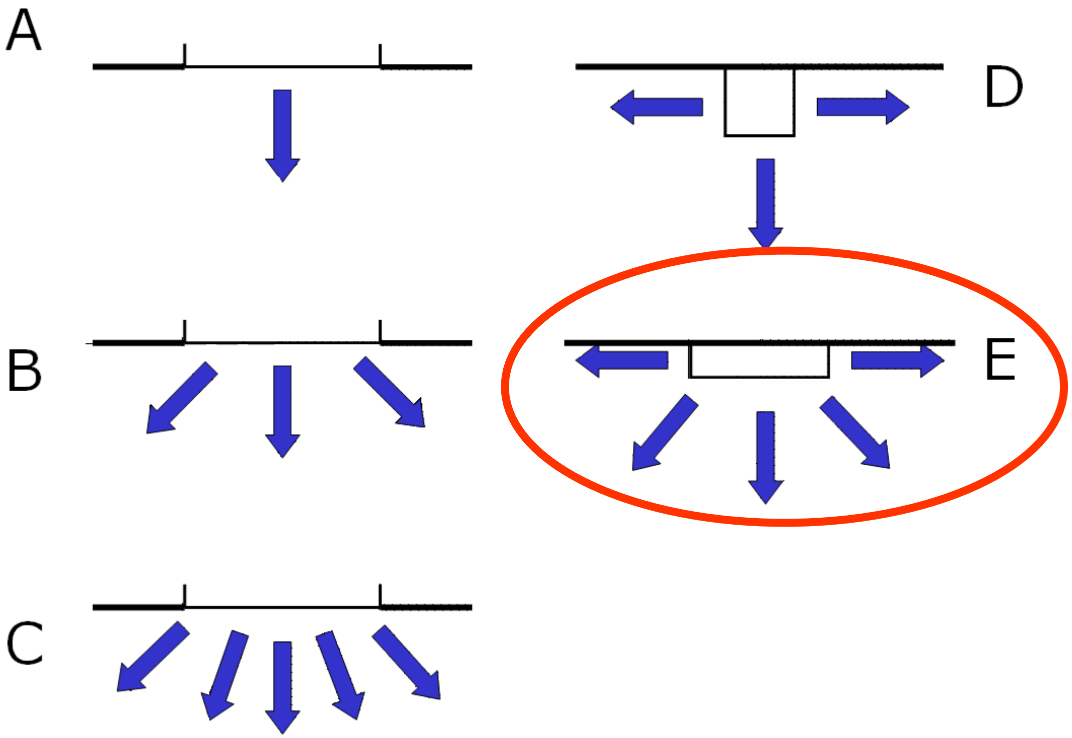
Predictions in the **whole** room
n = 5 h^{-1}
218.400 grid points



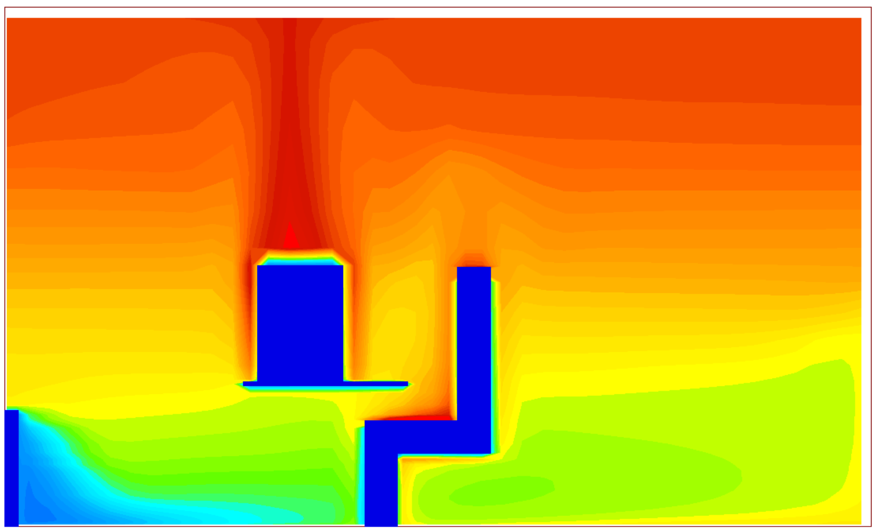
Case Study, Displacement Ventilation

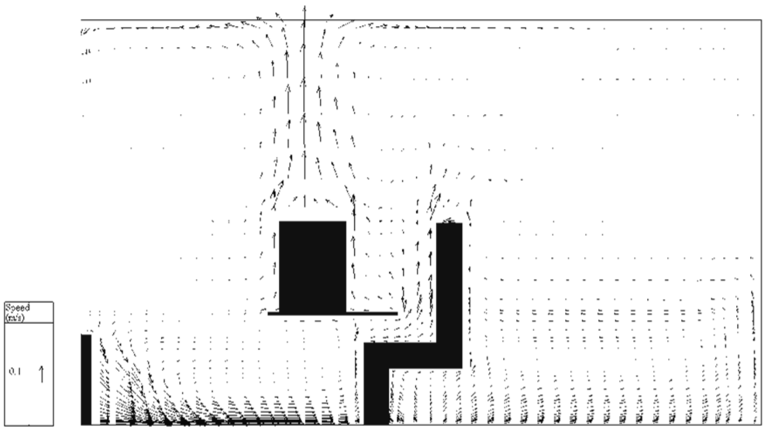


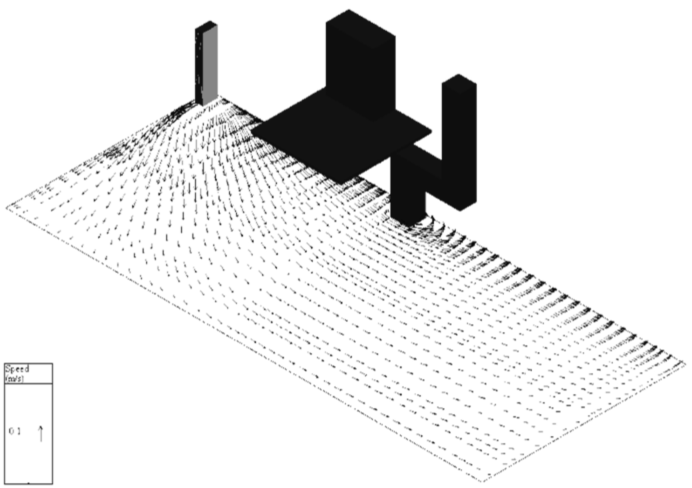
Diffuser for Displacement Ventilation



Displacement Ventilation

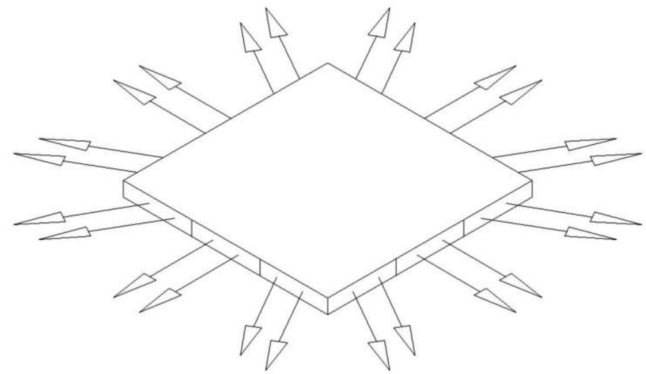




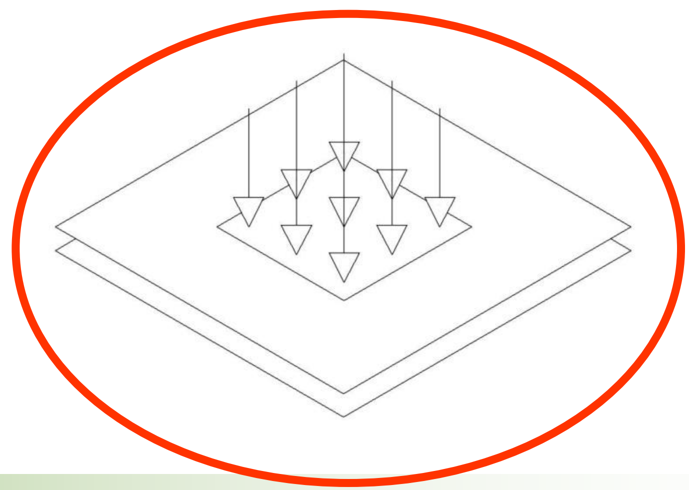


Case Study, Mixing Ventilation with Ceiling Mounted ATD

Mixing Ventilation with Ceiling Diffuser, Diffuser Models

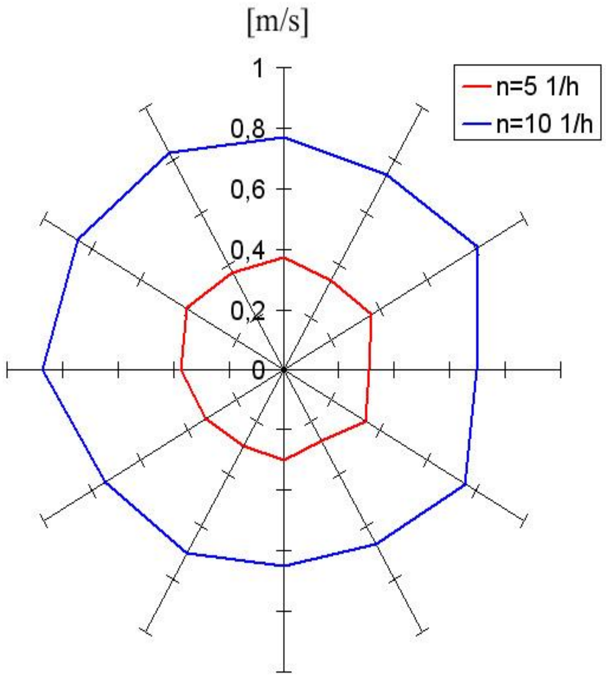


- Fixed-flow diffuser
- Diffuser with horizontal surface

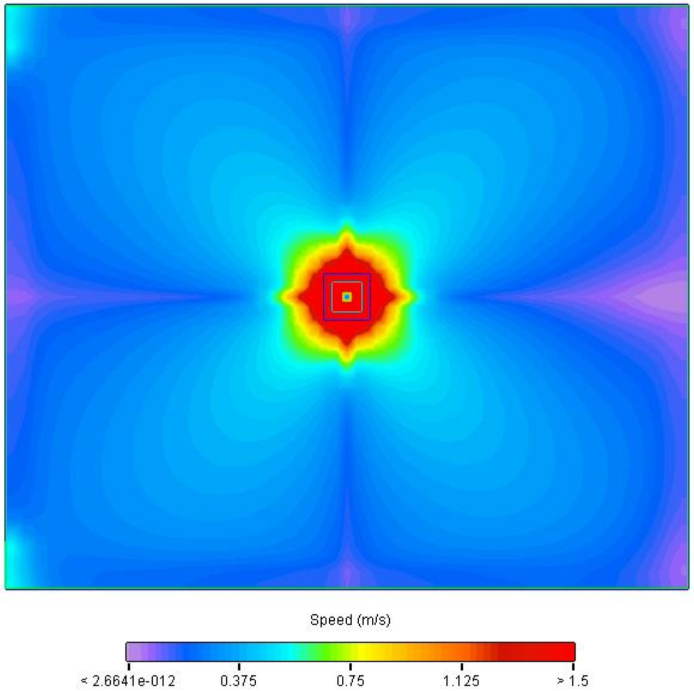


Diffuser Model

Measurements

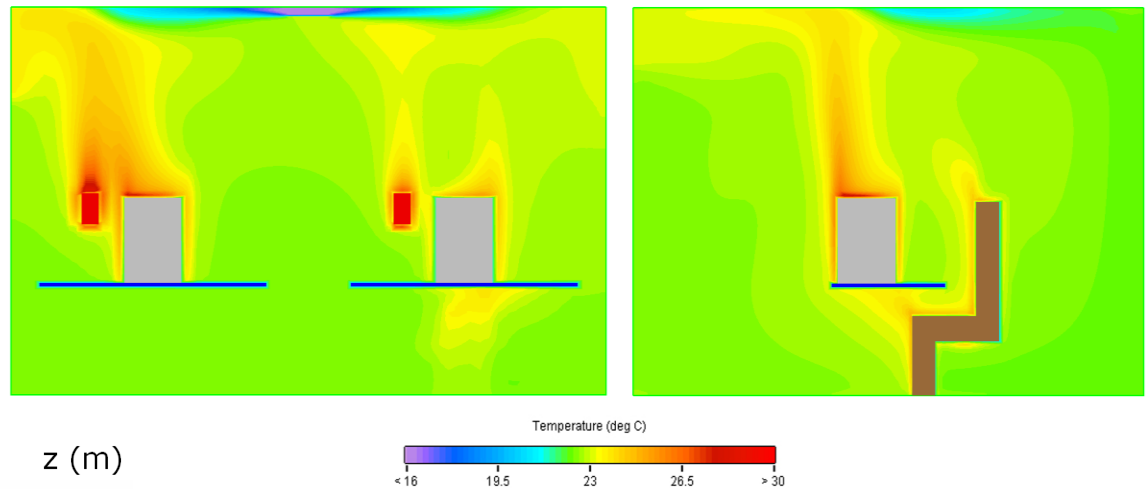


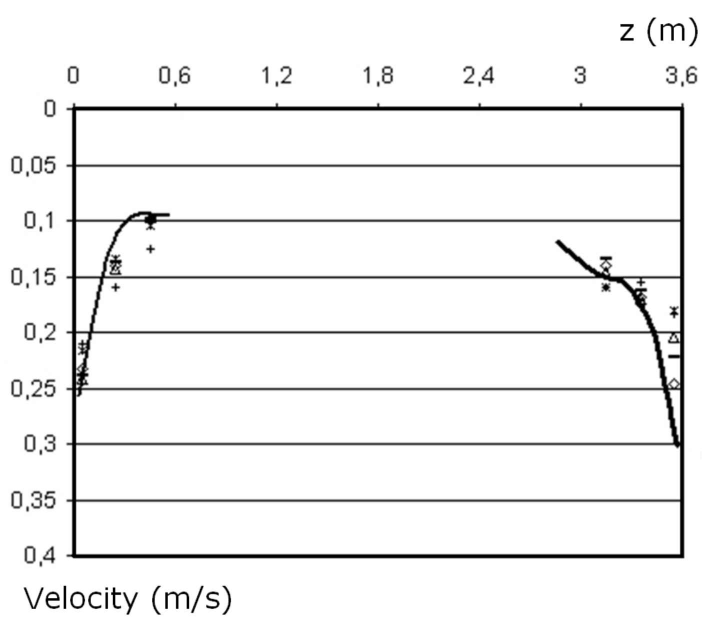
Diffuser with horizontal surface



CFD Simulations

Temperatures

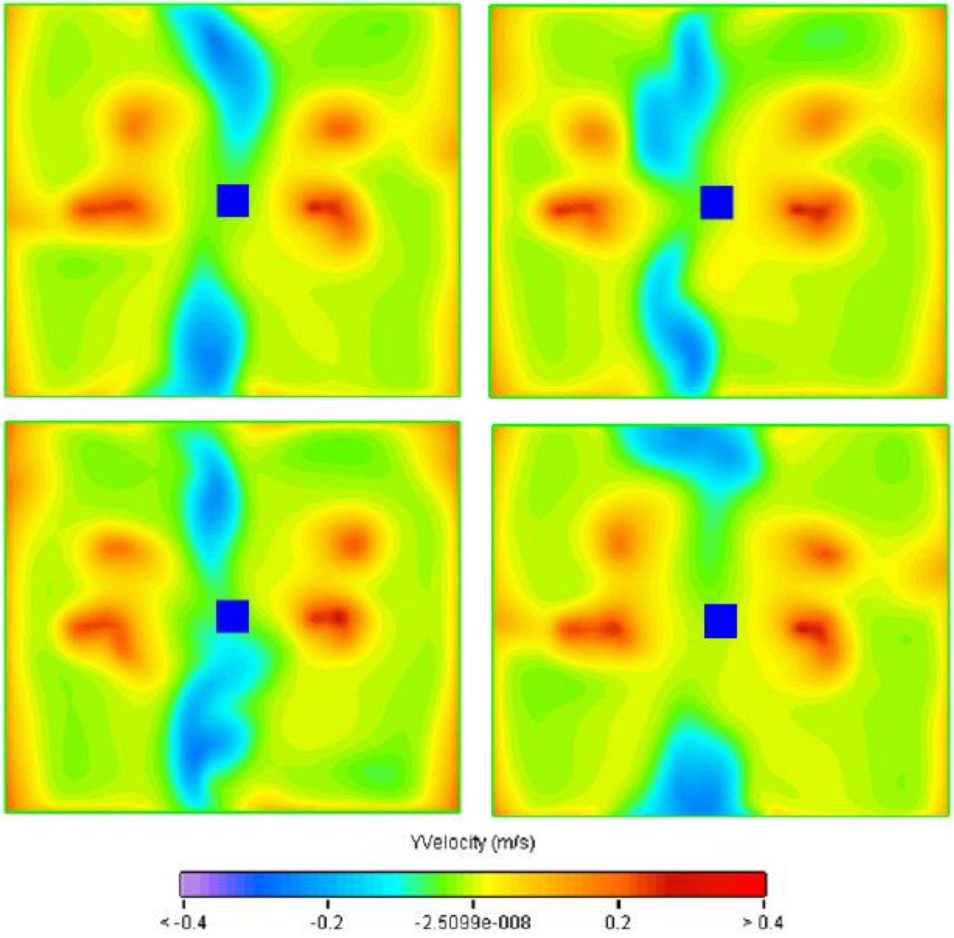




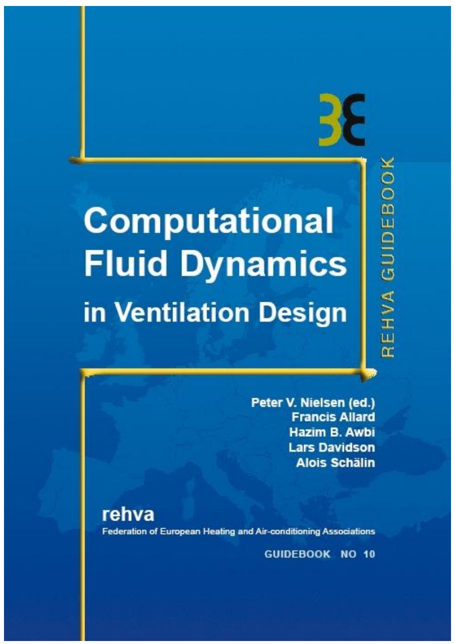
Velocities at the the height of 1.80 m close to the side walls

Simulation of Unsteady Flow

(Time Dependent Equations)

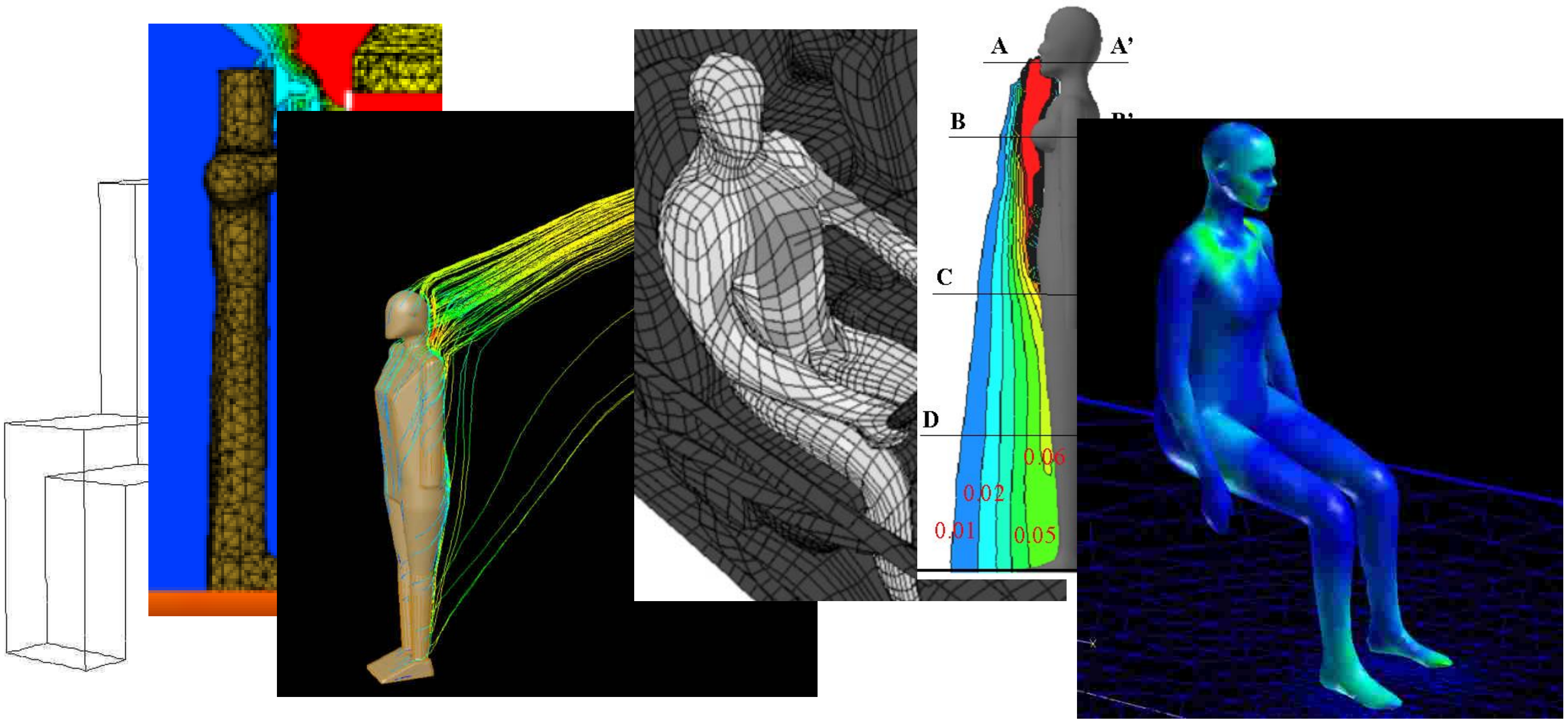


CFD in Ventilation Design



Computational fluid dynamics in a nutshell
Symbols and glossary
Mathematical background
Turbulence models
Numerical methods
Boundary conditions
Quality control
CFD combined with other prediction models
Application of CFD codes in building design
Case studies
Benchmark tests

CFD Manikins



Benchmark test for different CFD manikins:

www.cfd-benchmarks.com

Additional literature

P. V. Nielsen, The Selection of Turbulence Models for Prediction of Room Airflow. ASHRAE Transactions. 1998; Vol. 104, Part 1B. pp. 1119-1127. ISSN 0001-2505.

D. N. Sørensen and P. V. Nielsen, Quality Control of Computational Fluid Dynamics in Indoor Environments. International Journal of Indoor Environment and Health, Vol. 13, no. 1, pp. 2-17, March 2003.

D. N. Sørensen and P. V. Nielsen, Guest editorial: CFD in Indoor Air. International Journal of Indoor Environment and Health, Vol. 13, no. 1, p. 1, March 2003.

P. V. Nielsen, Computational Fluid Dynamics and Room Air Movement. Indoor Air, International Journal of Indoor Environment and Health, Vol. 14, Supplement 7, pp. 134 – 143, 2004.

Thank you for your attention

To order the REHVA guidebooks :
www.rehva.eu / section Bookstore
or through your national member