Good use of CFD for wind discomfort simulations

Fabien van Mook
Adviesburo Nieman

IBPSA NVL
Interessegebied CFD
25 oktober 2007
Katwijk/Cuijk

Contents

- motivation
- wind discomfort
  NEN 8100
- recommendations for good practice
- conclusion

Motivation

during the drink after the presentations of 8th of March

- ... quality of measurements and cfd ...
- ... for wind discomfort there exist recommendations ...
- ... workshop on cfd ...

Wind discomfort

TU Eindhoven

Wind discomfort

World Port Center
(hoogbouw.info)

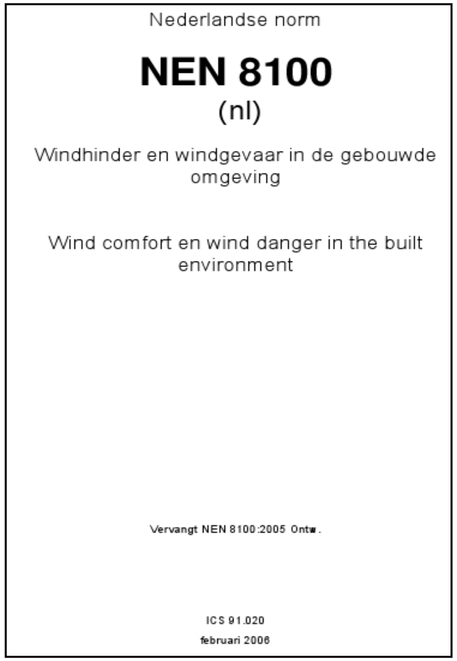
Wind effects

- forces:
  - on persons: wind discomfort and wind danger
  - on claddings and structures: wind pressures
- dispersion:
  - pollutants, dust, humidity
  - heat
  - rain, snow
  - sound
- noise

Criteria of NEN 8100

- mechanical effects on pedestrians
- wind discomfort
  - disturbance of hair, clothing and umbrellas
  - hourly average >5 m/s (3-4 beaufort) at head height
  - 3 activity classes for “traversing”, “strolling”, “sitting”
  - quality is “good” for <10%, <5% and < 2,5% of time resp.
- wind danger
  - (almost) falling
  - hourly average >15 m/s (7-8 beaufort) at head height

Determination methods of NEN 8100



Nederlandse norm

NEN 8100

(nl)

Windhinder en windgevaar in de gebouwde omgeving

Wind comfort en wind danger in the built environment

Vervangt NEN 8100:2005 Ontw.

ICS 91.020

februari 2006

- wind tunnel simulation
- numerical simulation (CFD)

common requirements:

- model upto 300 m; blockage <5-10%
- atmospheric boundary layer; KNMI statistics
- ≥12 wind directions; mean velocities
- technical form (resume of methods and results per project)
- quality report in English on laboratory and personnel (every 5 years)

- references to literature on good practice

CFD guidelines for wind discomfort

- mentioned in NEN 8100:
  - J. Franke et al., “Recommendations on the use of CFD in predicting pedestrian wind environment”, COST Action C14, 17-5-2004.
  - M. Bottema, “Wind climate and urban geometry”, PhD thesis, TU Eindhoven, 1993.
- other:
  - VDI (in progress)
  - Architectural Institute of Japan (AIJ) (in progress)

Recommendations on the Use of CFD in Wind Engineering

J.Franke

C. Hirsch, A. Jensen, H. Krüs, S. Miles, M. Schatzmann,
P. Westbury, J. Wisse, N. Wright

COST Action C14
„Impact of Wind and Storm on City life and Built Environment"
Working Group 2

Recommendations

- physical equations
- computational domain
- boundary conditions
- computational mesh
  - mesh and wall functions
- numerical approximations and solution
- validation

Physical equations

- neutral atmospheric boundary layer: N-S equations
- time-averaged
  - **standard k-epsilon model**: overestimation of k in stagnation regions
  - realizable and RNG k-epsilon models: more realistic stagnation region
  - non-linear eddy viscosity models and Reynolds stress model: anisotropy of Reynolds stresses but fine mesh needed

preferably, take anisotropy in account and evaluate different models

- unsteady
  - LES: very fine mesh and open issues (wind profile statistics, subgrid scale models, wall function modelling)

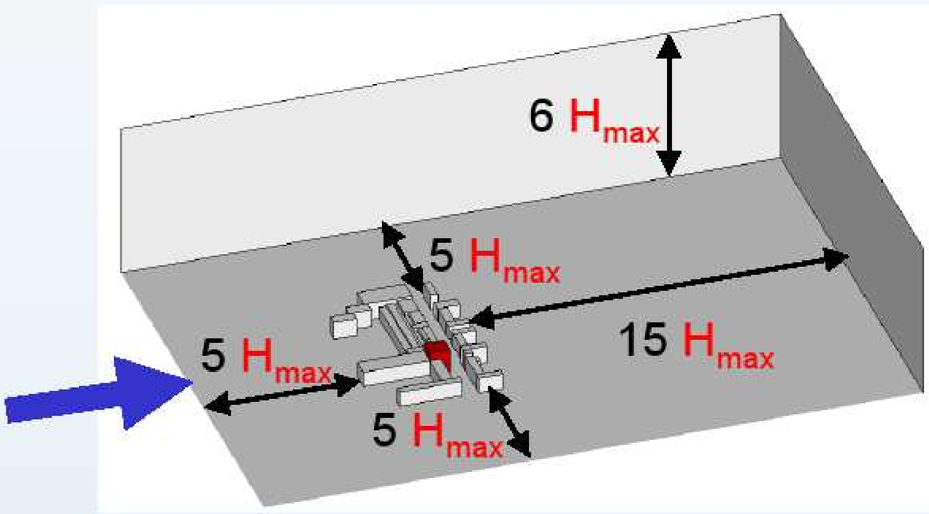
Computational domain

- in accordance to wind tunnel simulations:
  - explicit geometry upto a radius of 300 m
  - inclusion of a building at distance of 6 to 10 times its height
- domain size

- inlet ≈ 5 H_{max}
- outlet ≈ 15 H_{max}

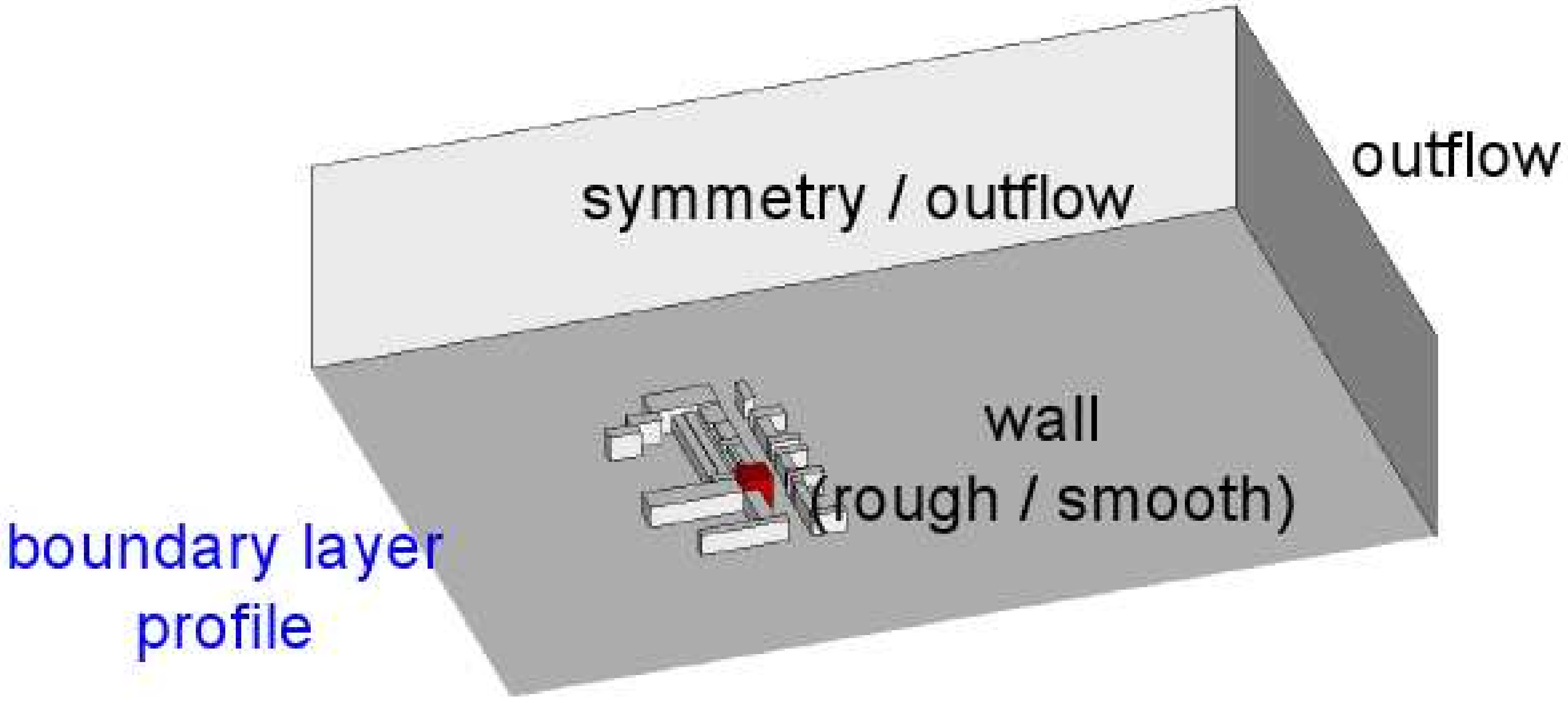
- lateral ≈ 5 H_{max}
- top ≈ 5 H_{max}

⇒ blockage ratio below 3 %



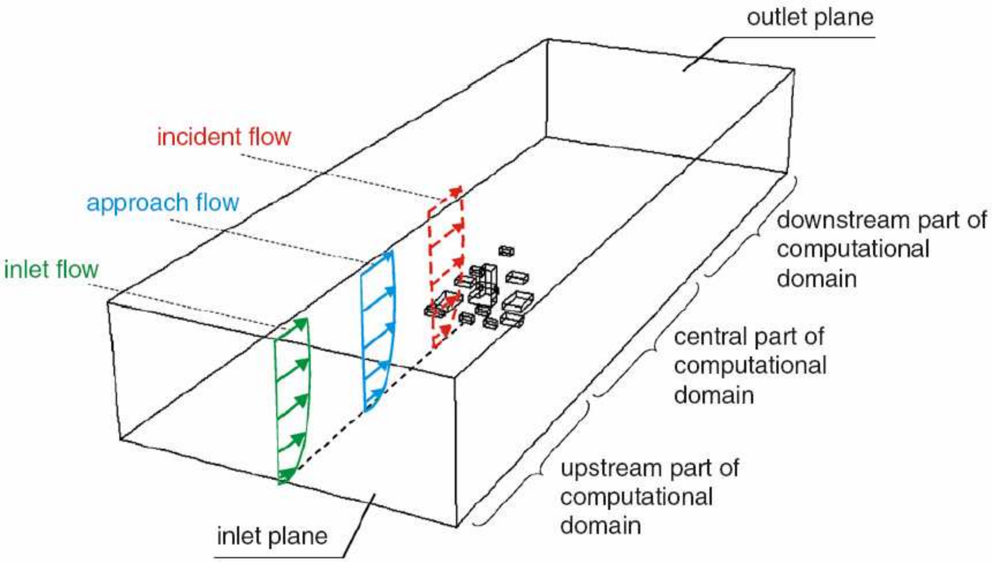
- geometric symmetry can produce asymmetric flows

Boundary conditions



- building faces: rough or smooth surface (wall function)
- use of smooth surfaces for simulation of wind tunnel

Wind profile



- ABL (z0 = roughness length)

$$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

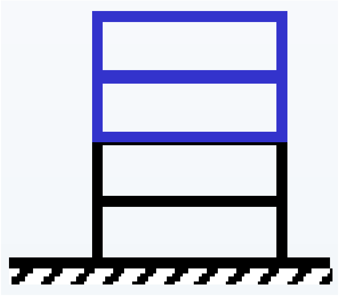
- K-epsilon model

$$K(z) = \frac{u_*^2}{C_\mu^{0.5}} \qquad \varepsilon(z) = \frac{u_*^3}{\kappa(z + z_0)}$$

- law-of-wall (“fully rough”, ks = sand-grain roughness)

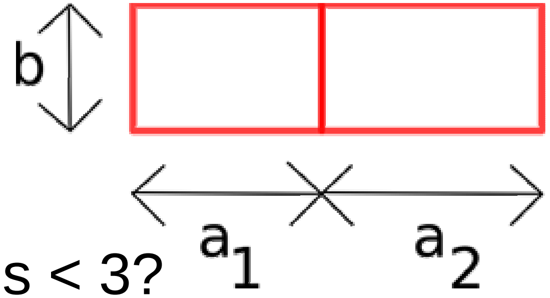
$$\frac{u(z)}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z}{k_s}\right) + 8.5 \qquad k_{s;\mathrm{ABL}} \approx 30 z_0$$

Mesh



- position of interest in 3rd or 4th cell from surface
- preferably hexahedral cells

  if tetrahedral mesh, use prisms/wedges at surfaces though



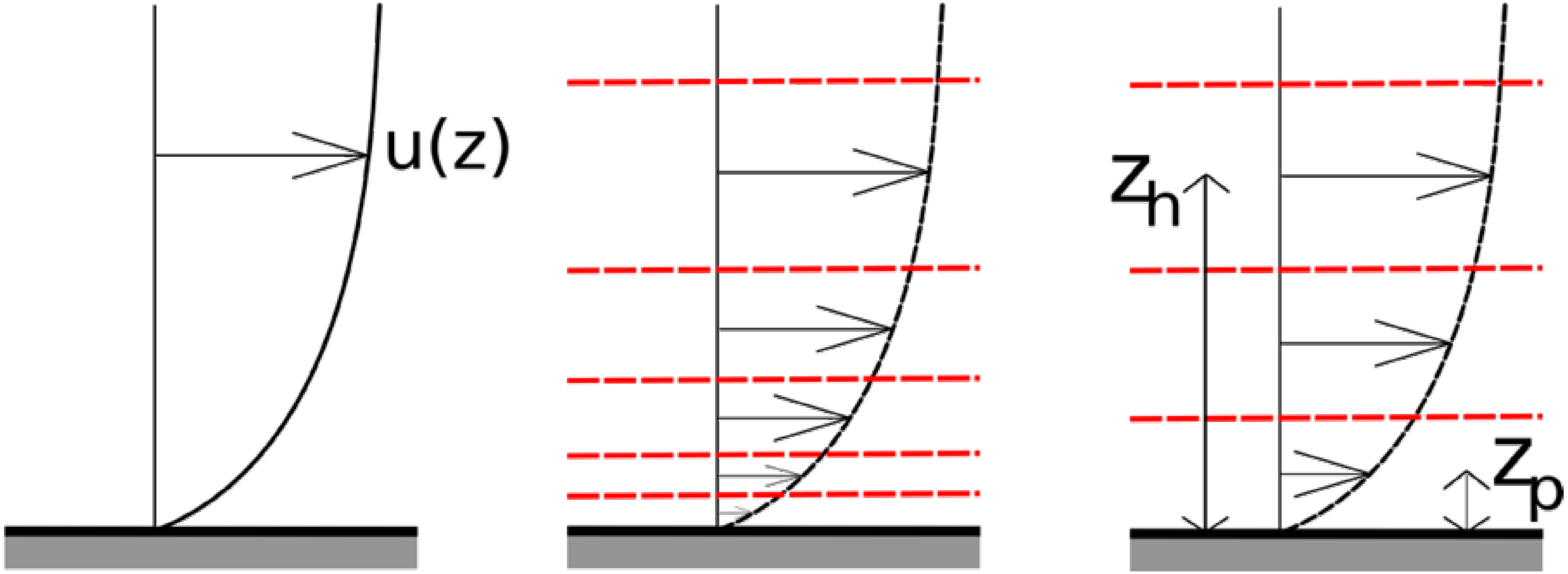
- small stretching in regions of large gradients

  a2/a1 < 1,3

  Franke et al. does not mention a/b ratio; perhaps < 3?

- minimal resolution
  - 10 cells per cube root of the building volume
  - 10 cells per building separation

Mesh and wall functions (1)



- b.l. is formally modelled with “wall functions”, so that a coarser mesh can be used
- conditions for the mesh:
  - 2 to 3 cells between surface and point of interest (zh)
  - homogeneous wind profile in upstream and downstream regions
  - zp > ks (due to the wall function)
  - ks = 30 z0

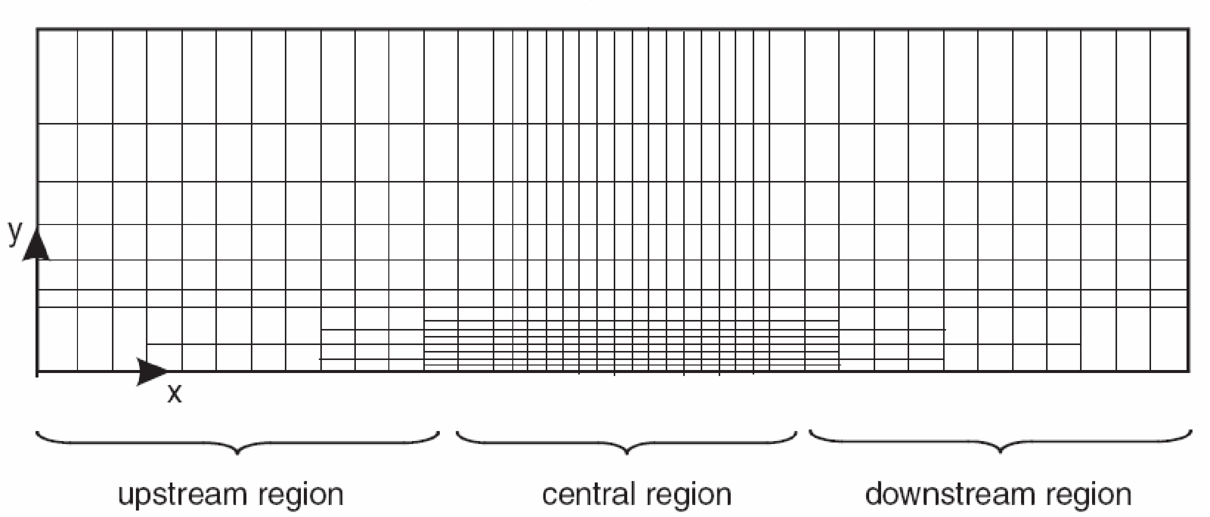
(Blocken et al. 2007; Hargreaves & Wright 2007)

Mesh and wall functions (2)

for $z_h = 1.75$ m

$z_p \geq 0.35$ m

$$z_0 = \frac{k_s}{30} \leq \frac{z_p}{30} = 0.01 \text{ m}$$



$z_p > 30$ m (for $z_0 = 1$ m)

over whole empty domain, profiles of u and k should not change

Numerical methods

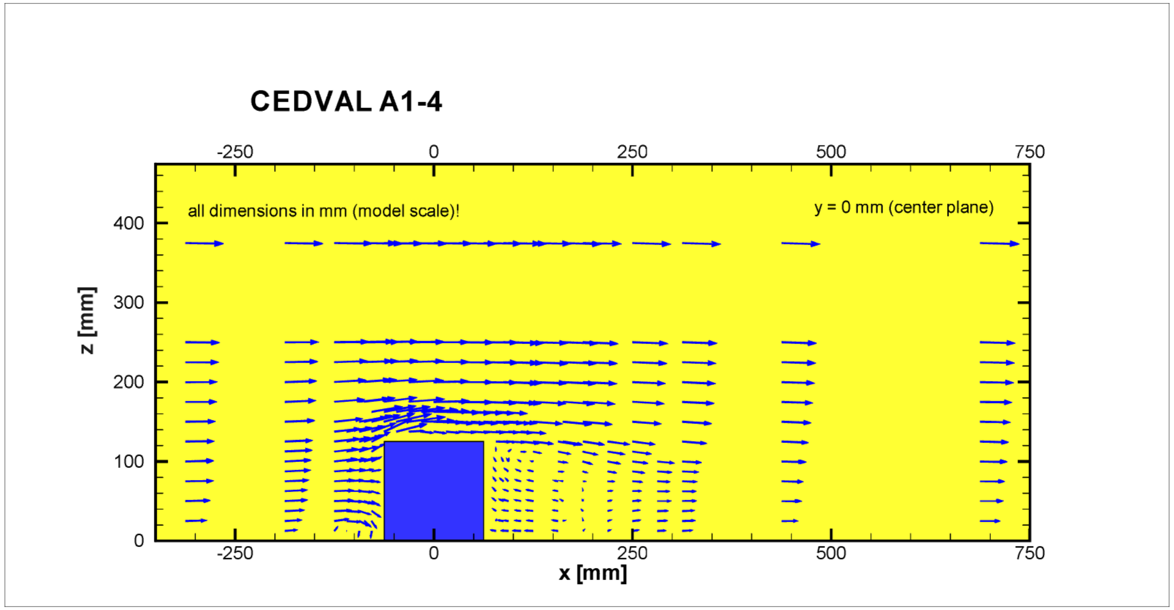
- do not use first-order numerical approximations

  but use them only at the beginning of the calculations, and switch to a higer-order scheme after some iterations

- check limitations of variables by the code
- stop when the scaled residuals reach $<10^{-5}$
- monitor some local flow variables
- check the mesh dependency by 3 consecutive mesh refinements

Validation

- more validation data is needed
- data of wind tunnel experiments is preferred because of “better” (easier) repeatability with steady-state boundary conditions than full-scale experiments
- example of data set: www.mi.uni-hamburg.de/cedval/



Validation

one has more possibilities than Franke et al. suggest:

- make cfd simulations of cases published in literature or in CEDVAL

    evaluate mesh refinement, turbulence models, wall models etc.

- compare the results, numerically and qualitatively, and for different quantities, e.g. also:
    - pressures on building faces
    - reattachement and recirculation regions
- learn from the cases for your projects

Conclusion

- good practice of cfd for wind discomfort includes especially:
  - blockage < 3% and outflow boundary far from wake
  - check of the wind profile and the terrain roughness
  - sensitivity analysis for mesh (and poss. turbulence model)
  - solution based on higher-order approximation schemes
  - good documentation
- extention of validation data set is necessary

Conclusion

- in a project it is often difficult to follow all the recommendations ideally
- especially compromises on the mesh
- future:
  - turbulence models and roughness modelling of terrains and walls are still open issues
  - are the recommendations of Franke et al. sufficient for better quality?
  - recommendations for other fields, e.g. indoor air flows?

References

- “NEN 8100 – Windhinder en windgevaar in de gebouwde omgeving”, Delft: NEN, februari 2006.
- Franke et al. (2004), “Recommendations on the use of CFD in predicting pedestrian wind environment”, COST Action C14, 17-5-2004.
- Blocken et al. (2007), “CFD simulation of the atmospheric boundary layer: wall function problems”, *Atmospheric Environment,* 41, p. 238-252.
- Hargreaves & Wright (2007), “On the use of the k-epsilon model in commercial CFD software to model the neutral atmospheric boundary layer”, *Journal of Wind Engineering and Industrial Aerodynamics,* 95, p. 355-369.