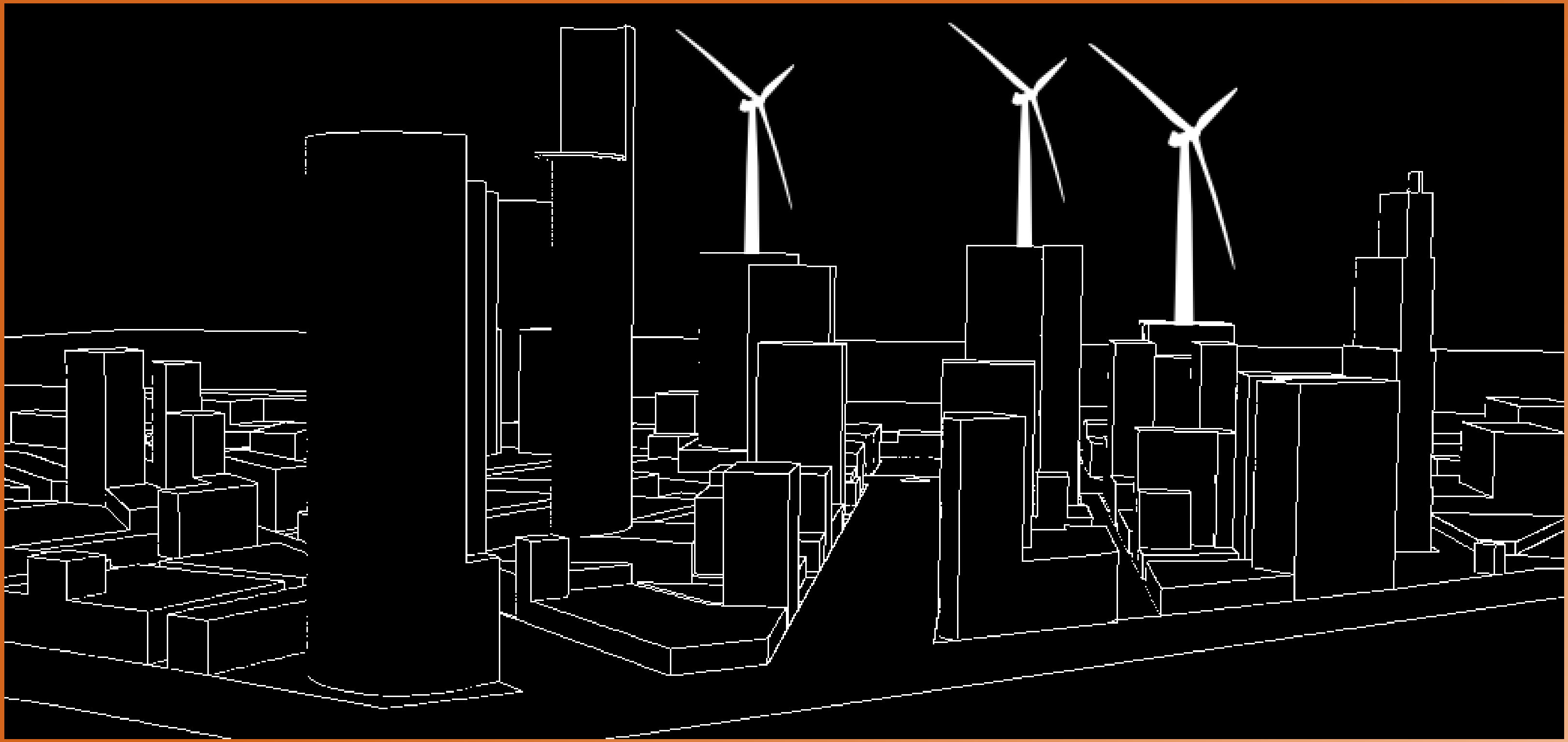
Computational Fluid Dynamics for Assessing Urban Wind Energy Potential in Vietnam

18.12.2015



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Workshop Clean energy in Vietnam after COP21, 17-18 December, Hanoi

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Agenda

- Introduction
- Statistical Meteorological Data
- Numerical Parameters
- Results
- Conclusions & Outlook

Introduction

- Urban areas responsible for large energy consumption
- Their contribution will increase with urbanization
- Local generation of electricity from renewables
  - Reduce load on grid
  - Reduce energy losses in grid
- Urban wind energy with (mainly) two problems
  - Wind turbines often not suited for urban wind conditions
  - Location of turbines at non optimum positions
- Wind in urban areas
  - Lower mean wind speed than in rural areas
  - High building induced turbulence
- Urban wind localisation
  - Measurements are localized and expensive
  - National wind atlases too inaccurate in urban areas

Introduction

Urban Wind Energy

- Power in the wind

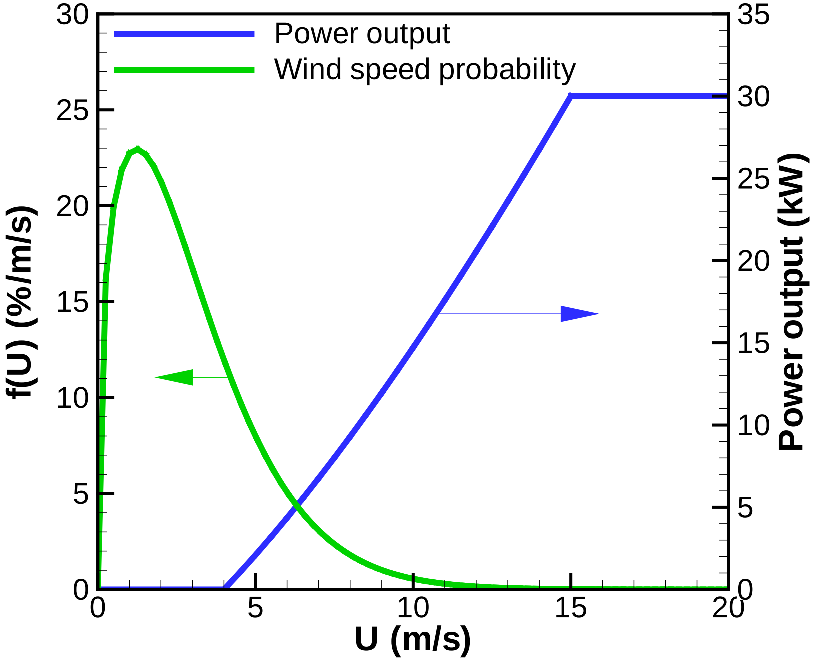
$$P_w = \frac{\rho}{2} A U^3$$

- Mechanical power output less than 30% of P_w
- Average power in the wind

$$P_{w,ave} = \int_0^\infty P_w(U) f(U) dU = \frac{\rho}{2} A U_{ref}^3 \frac{\Gamma(1+3/b)}{[\Gamma(1+1/b)]^3}$$

- Probabiliy function of wind speed – Weibull distribution
  - a: scale parameter
  - b: shape parameter

$$f(U) = \frac{b}{a}\left(\frac{U}{a}\right)^{b-1} \exp\left[-\left(\frac{U}{a}\right)^b\right]$$

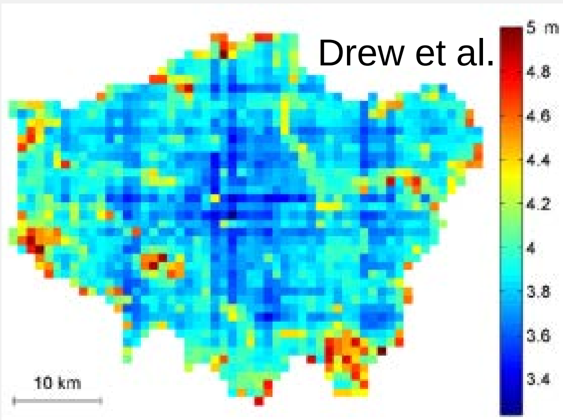


Introduction
Estimation of wind resource

Statistical meteorological data – Wind Atlas
Long term measurements OR mesoscale simulations

Internal Boundary Layer Modeling

- *Only 1 x 1 km² grid*
- *Only wind speed at 5 m above mean building height*

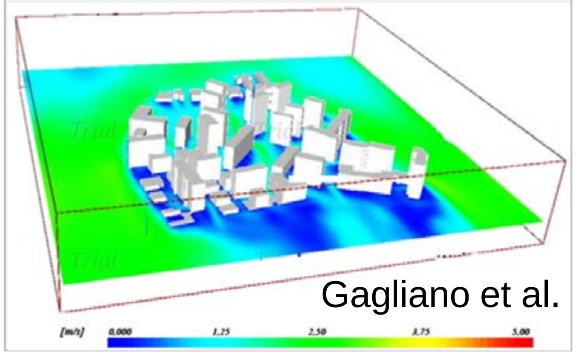


Physical Wind Tunnel Simulation

- Detailed building models
- *Only point data of wind speed*

Computational Fluid Dynamic Simulation

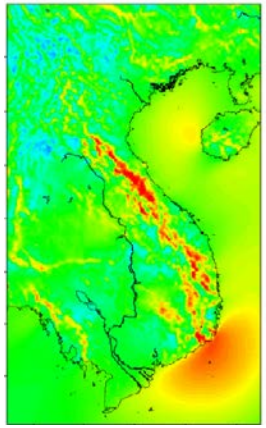
- Detailed building models
- Wind speed in entire domain with high resolution
- *Only a numerical model*



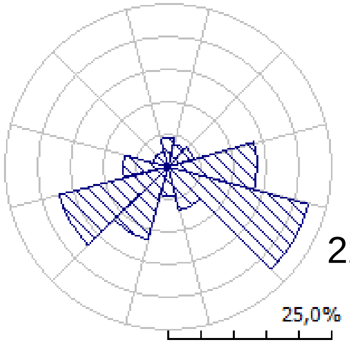
„Local“ wind climate

Statistical Meteorological Data

Interim ESMAP Wind Atlas (Badger et al., 2015)

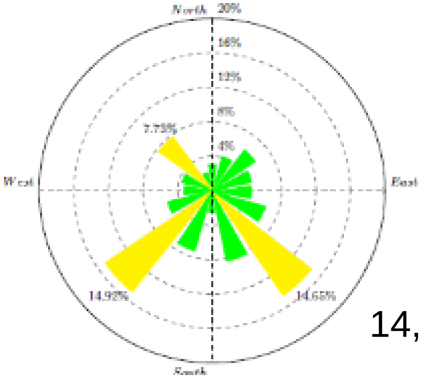


- Mesoscale simulation
- 5 km resolution
- 8 years of simulation (2003-2010)
- Velocities generalized for different terrain and heights



22,3%

- Location close to HCMC chosen
- Dominant wind direction 120˚
- **Yearly mean velocity 2,96 m/s at 10 m and z_0 = 0,04 m**
- Probability distribution of yearly velocities available



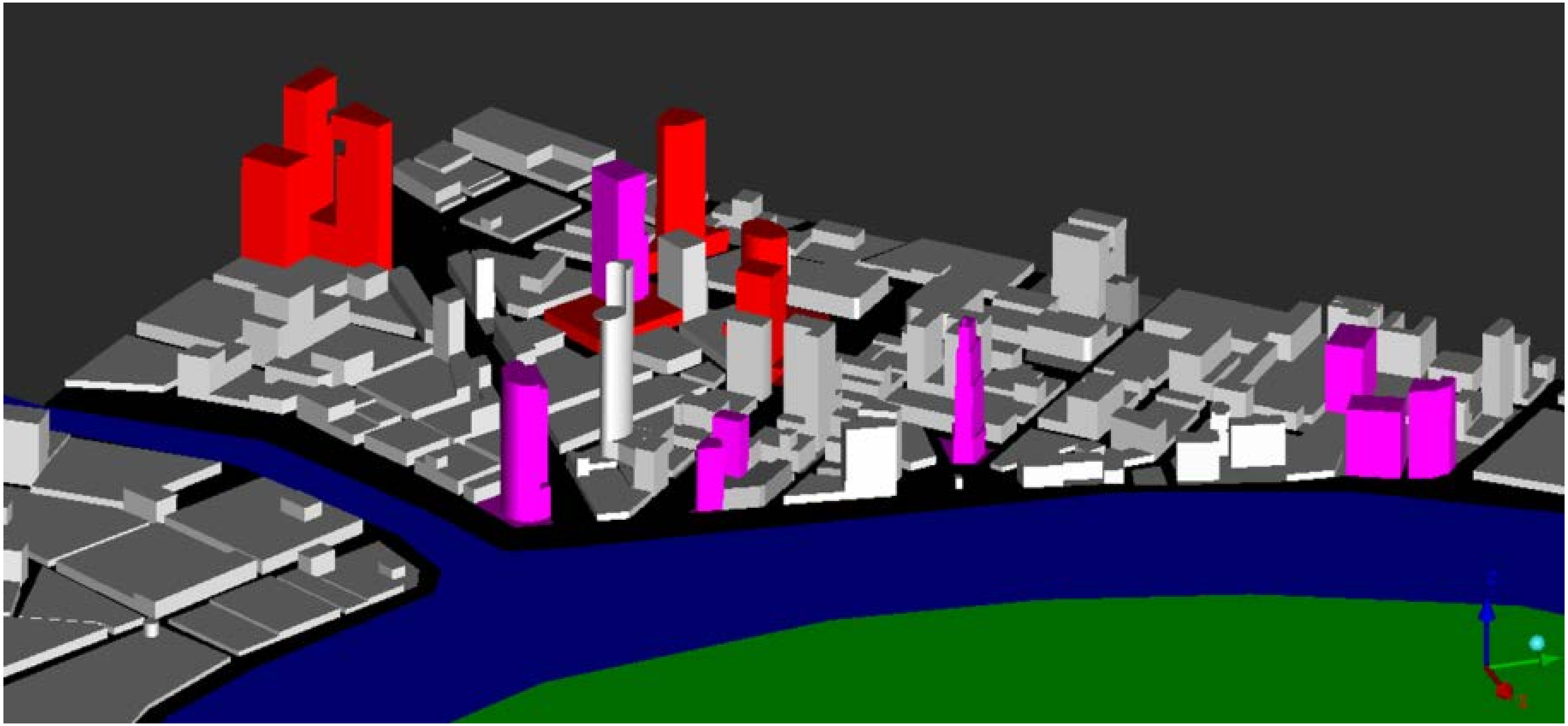
14,7%

- Measurement data from HCMC airport available (Bao, 2013)
- **Dominant wind direction 135˚**
- Yearly mean velocity 2,08 m/s
- No probability distribution of velocities available

Numerical Parameters

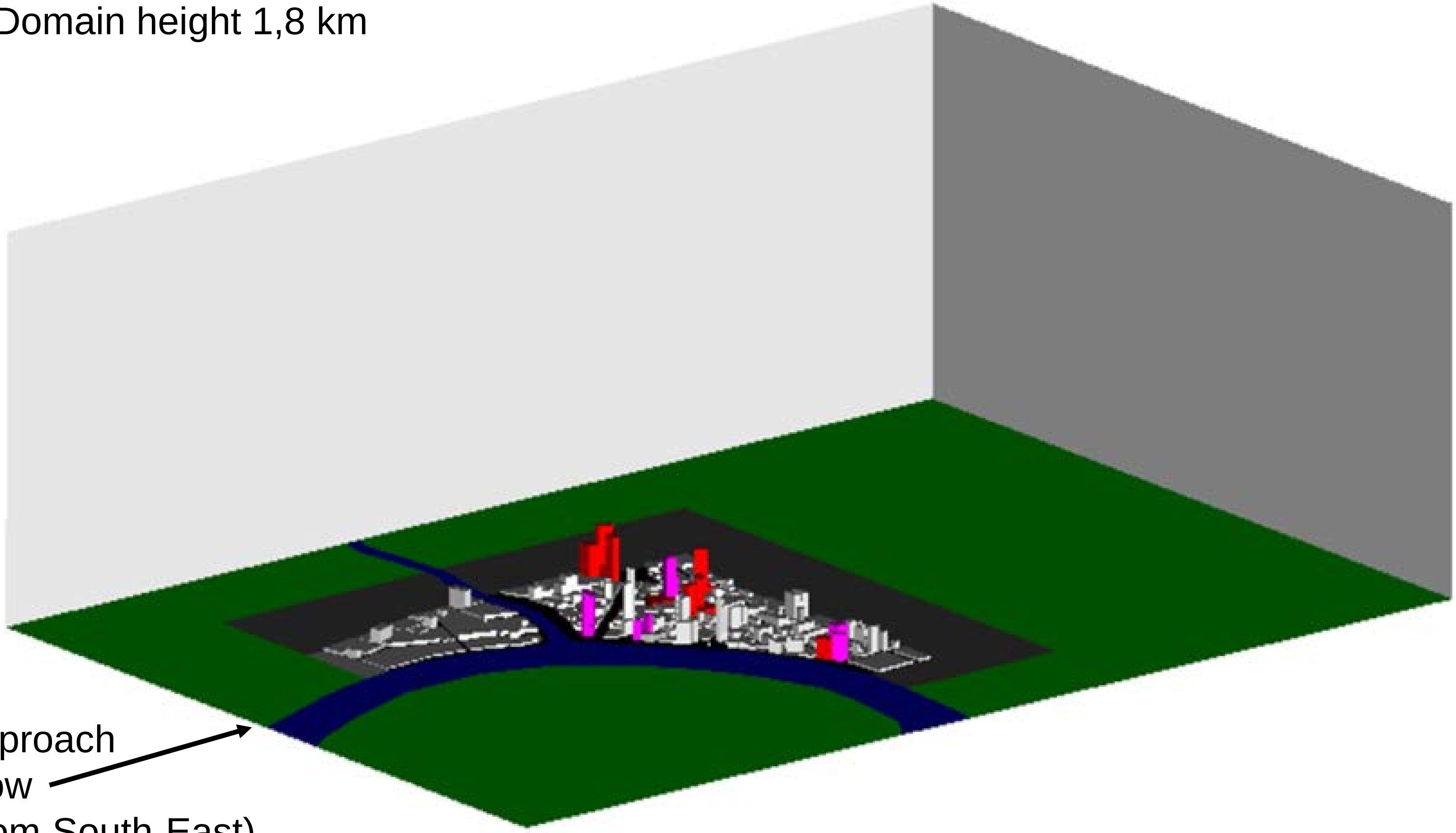
Simplified buildings for part of Ho Chi Minh City's District 1

- Buildings' CAD geometry from public information
- Under construction – Planned



Numerical Parameters
Computational domain

- 6,3 x 6,3 km^2 area
- Domain height 1,8 km



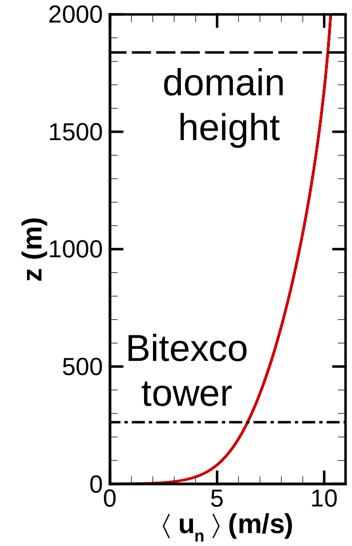
Approach
Flow
(from South-East)

Numerical Parameters

Boundary conditions

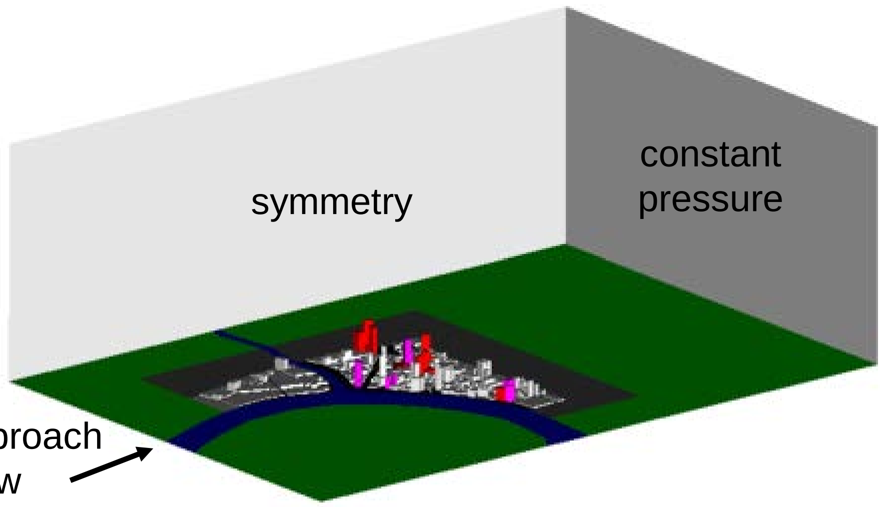
- Yearly wind statistics for z_0 = 0,4 m at z = 10 m height Above Ground Level (AGL)
- U_{ref} = 2,96 m/s
- Logarithmic inflow velocity profile from Deaves and Harris model

$$\langle u_n(z)\rangle = \frac{u_*}{\kappa}\left[\ln\left(\frac{z+z_0}{z_0}\right)+5.75\left(\frac{z}{\delta}\right)-1.88\left(\frac{z}{\delta}\right)^2-1.33\left(\frac{z}{\delta}\right)^3+0.25\left(\frac{z}{\delta}\right)^4\right]$$



- Boundary layer height δ = 2,5 km
- Turbulent kinetic energy and its dissipation from Richards and Hoxey model

- All walls with roughness
- Constant pressure at outflow
- Symmetry at lateral sides and top



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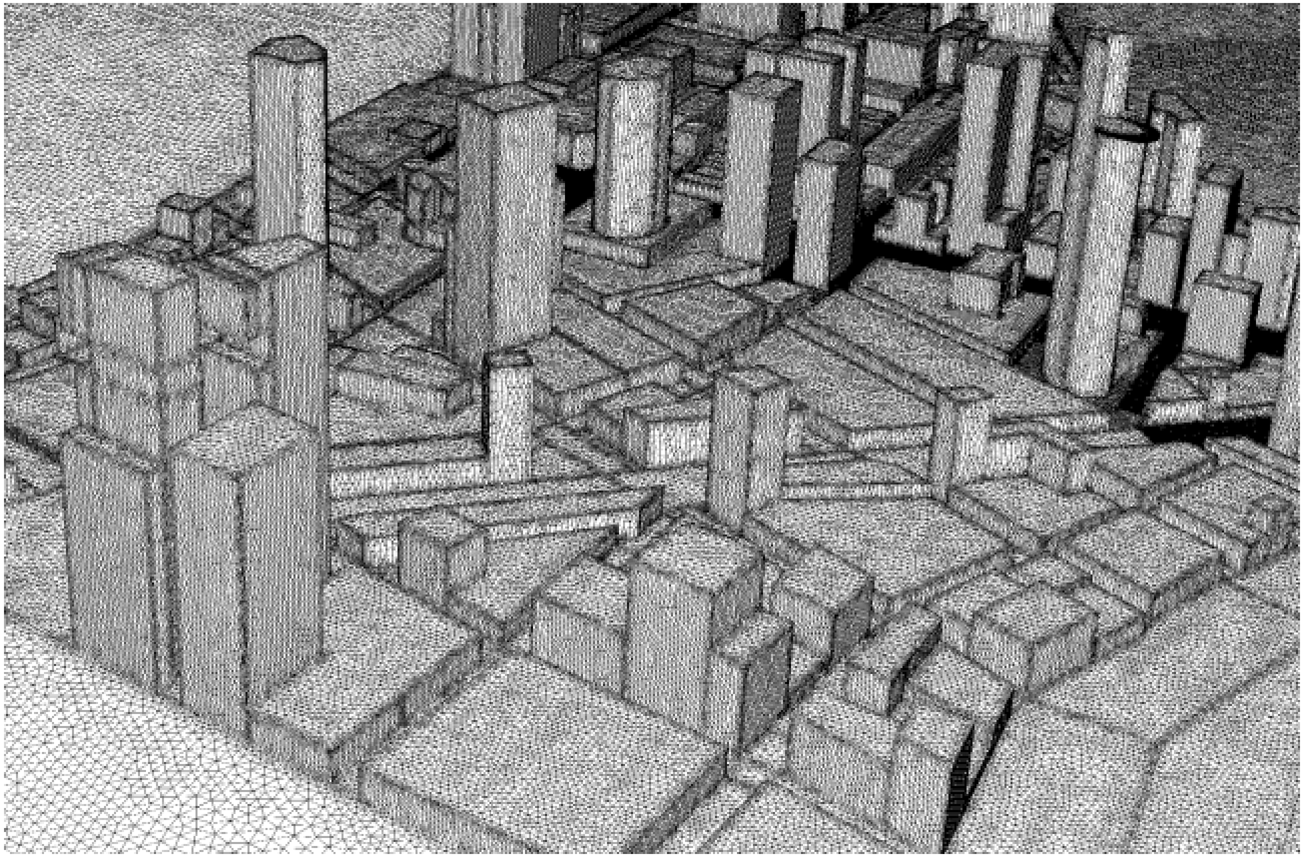
Numerical Parameters

Computational grid

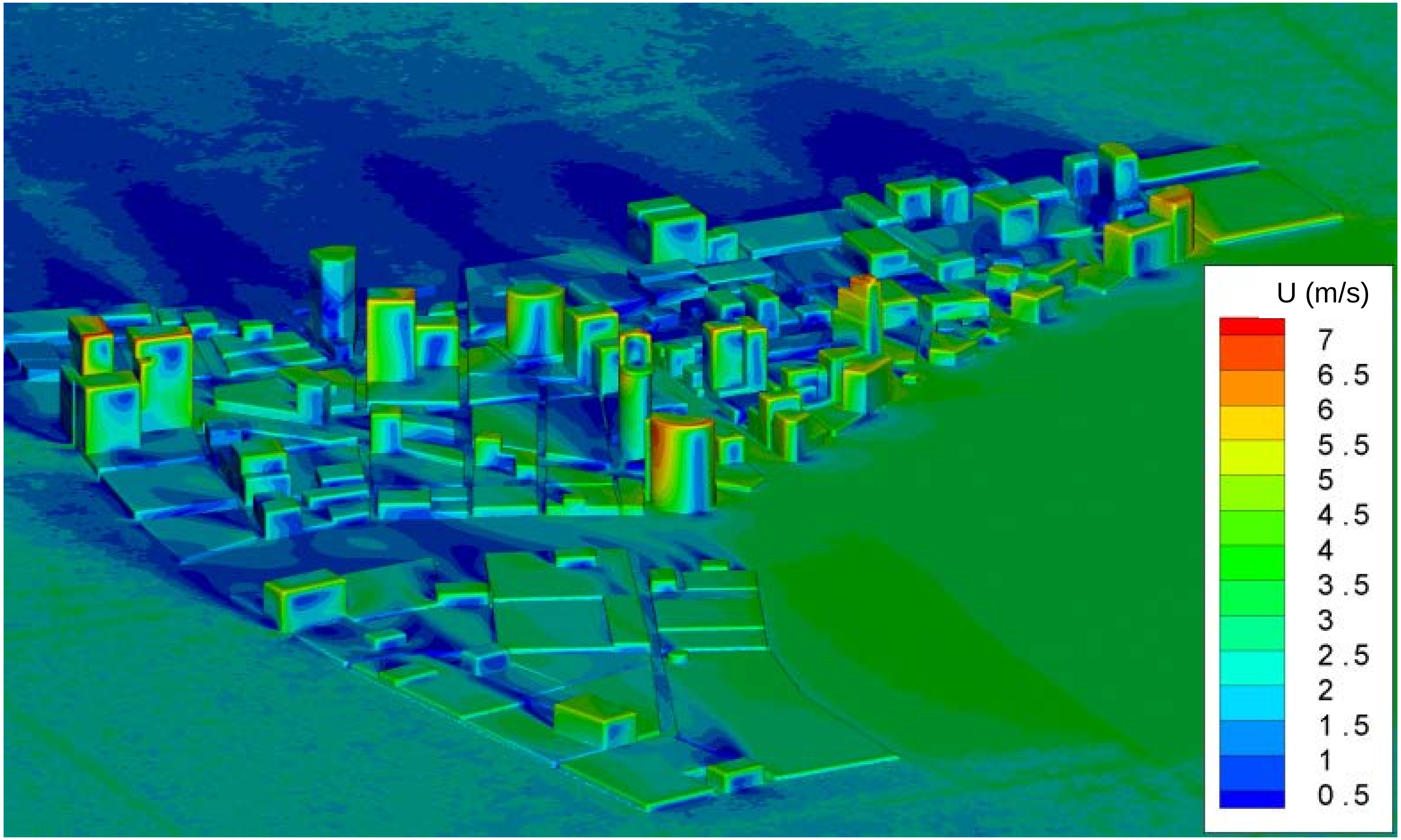
- Tetrahedral mesh
- Nearly 34 million cells



Results

Velocity magnitude at 5 m distance from building walls

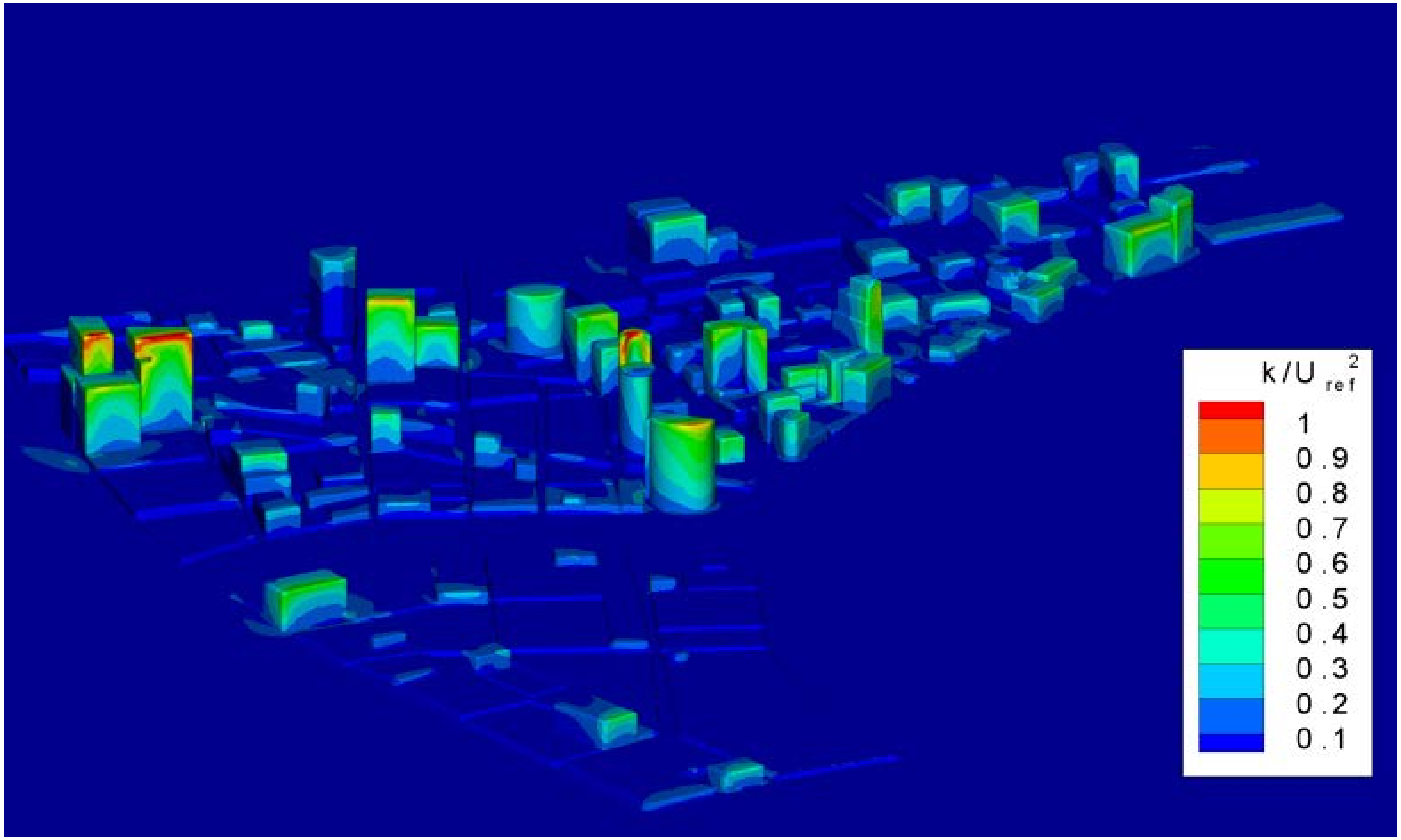
- Only high velocities above tall buildings



Results

Non-dimensional turbulent kinetic energy at 5 m distance from building walls

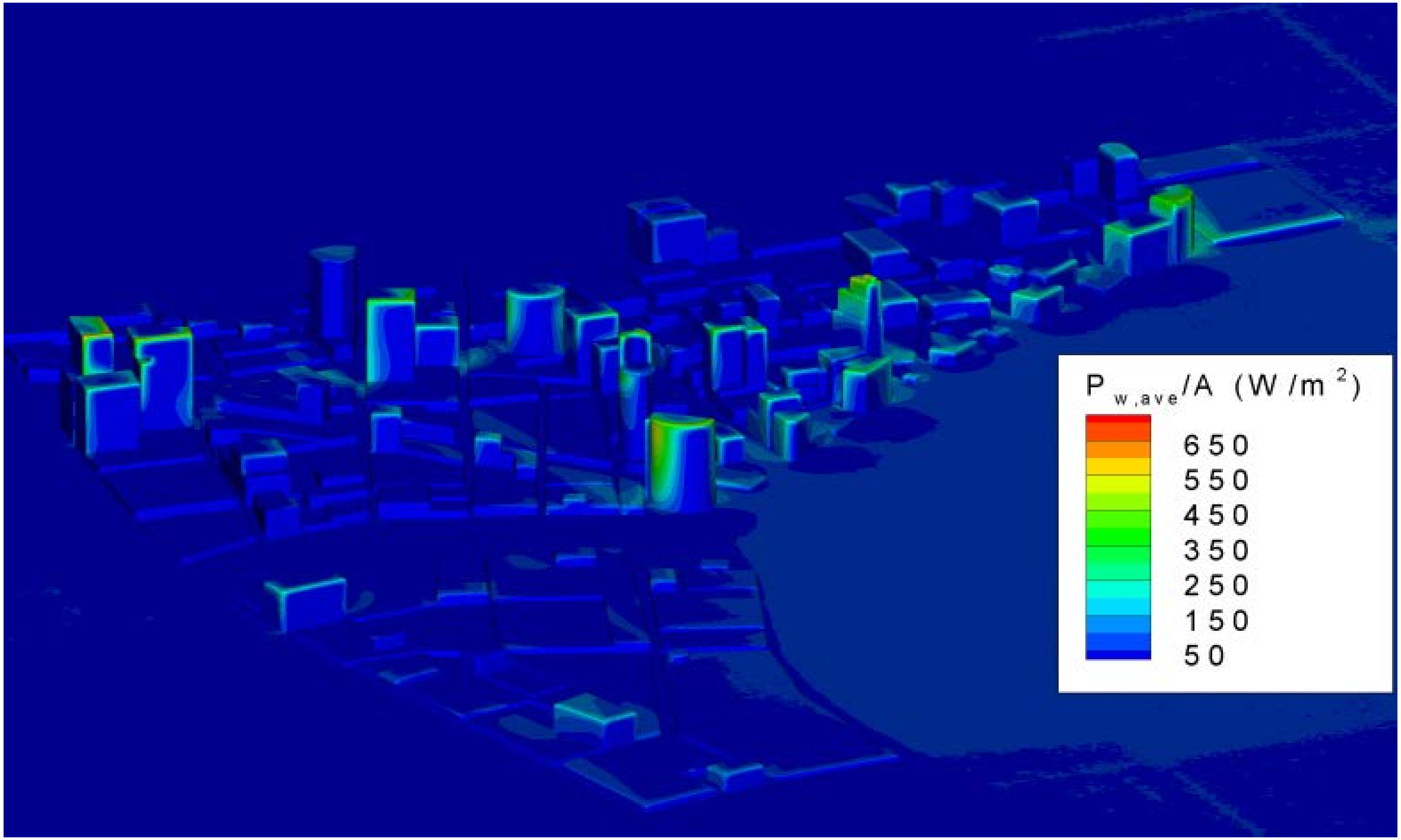
- Also highest values above tall buildings



Results

Available power in the wind at 5 m distance from building walls

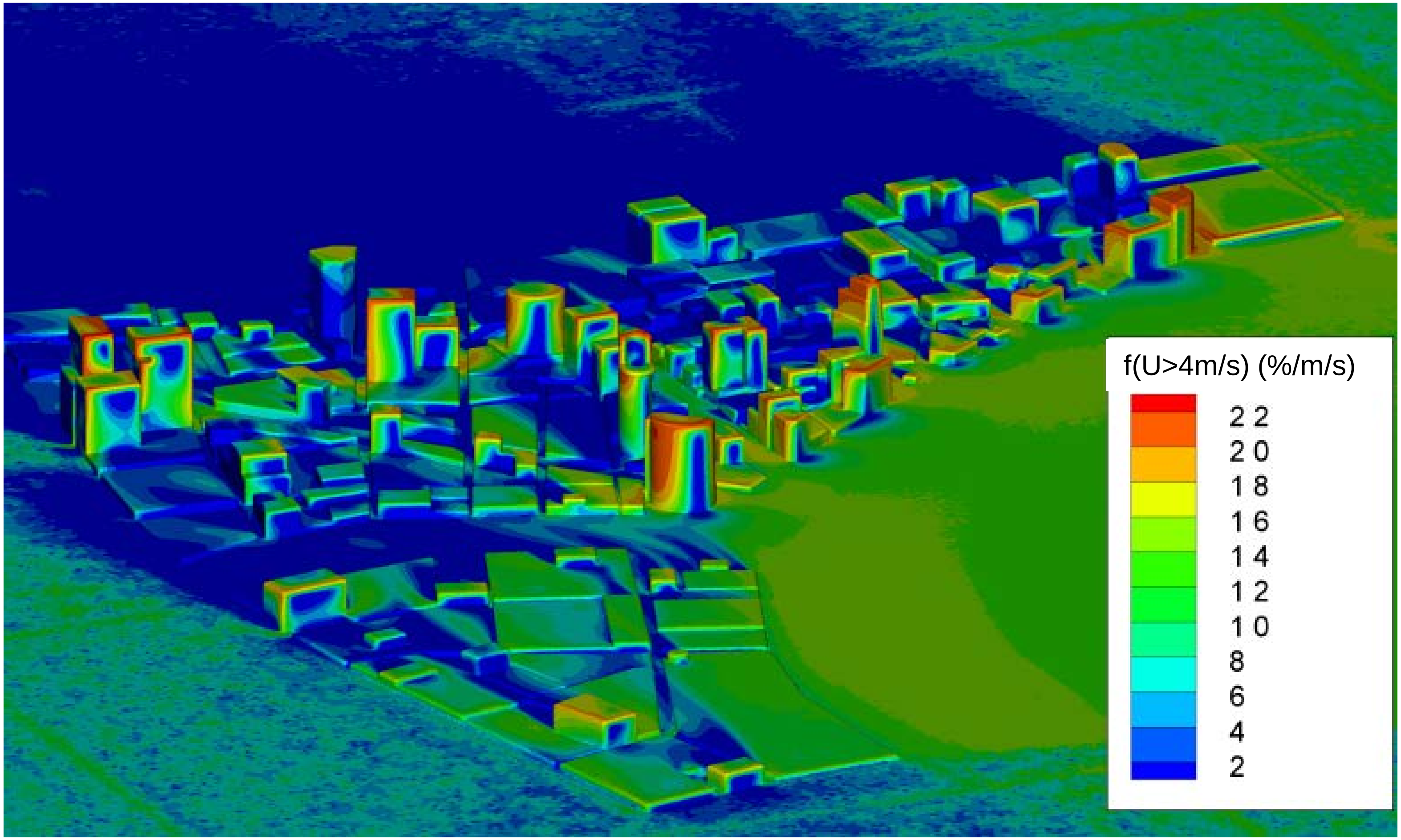
- Maximum power in the wind over a year 6,1 MWh/m^2



Results

Probability of wind speed > 4 m/s at 5 m distance from building walls

- Remember: investigated wind direction accounts only for 22,3 % in a year



Conclusion
and Outlook

- Suitable mean wind speeds at roof level of high rise buildings
- Probability function of wind speeds leads to low percentage of usable wind speeds
- Wind turbines with lower cut in speed needed

Outlook

- Districts of HCMC as GIS data set available
- Simulation for 12 wind directions
- Local wind cllimate of HCMC
  - Natural ventilation
  - Pedestrian wind
  - Pollutant dispersion
  - Emergency preparedness

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Numerical Parameters

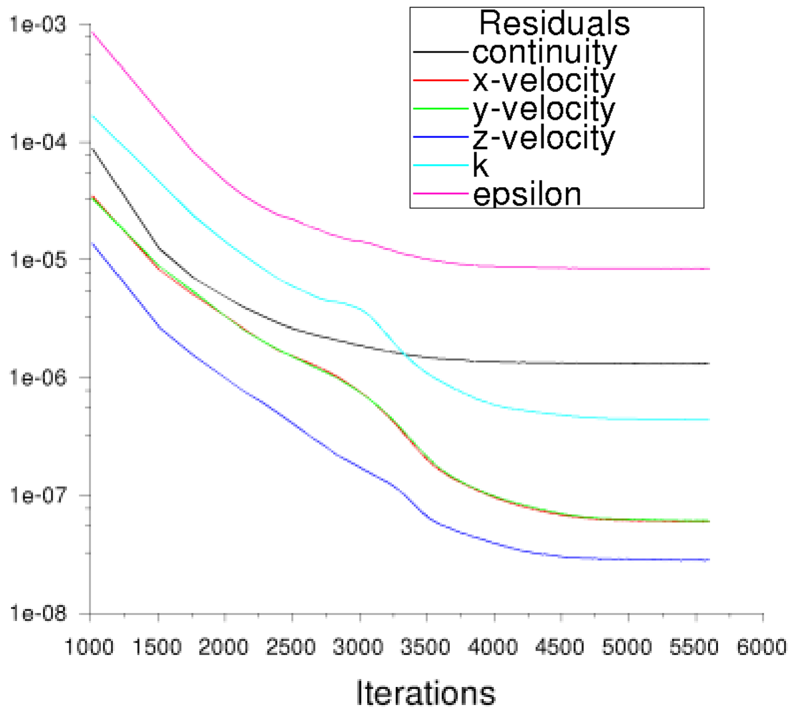
Simulation Setup

- Single precision solver Ansys Fluent v14.5.0

- Statistically steady simulation with Reynolds Averaged Navier Stokes (RANS) equations
- Standard k-ε turbulence model
- Standard rough wall functions

- Discretization
  - 2^{nd} order upwind scheme for advective fluxes
  - Least squares method for reconstruction gradient
  - Diffusive fluxes with central differences and cross-diffusion

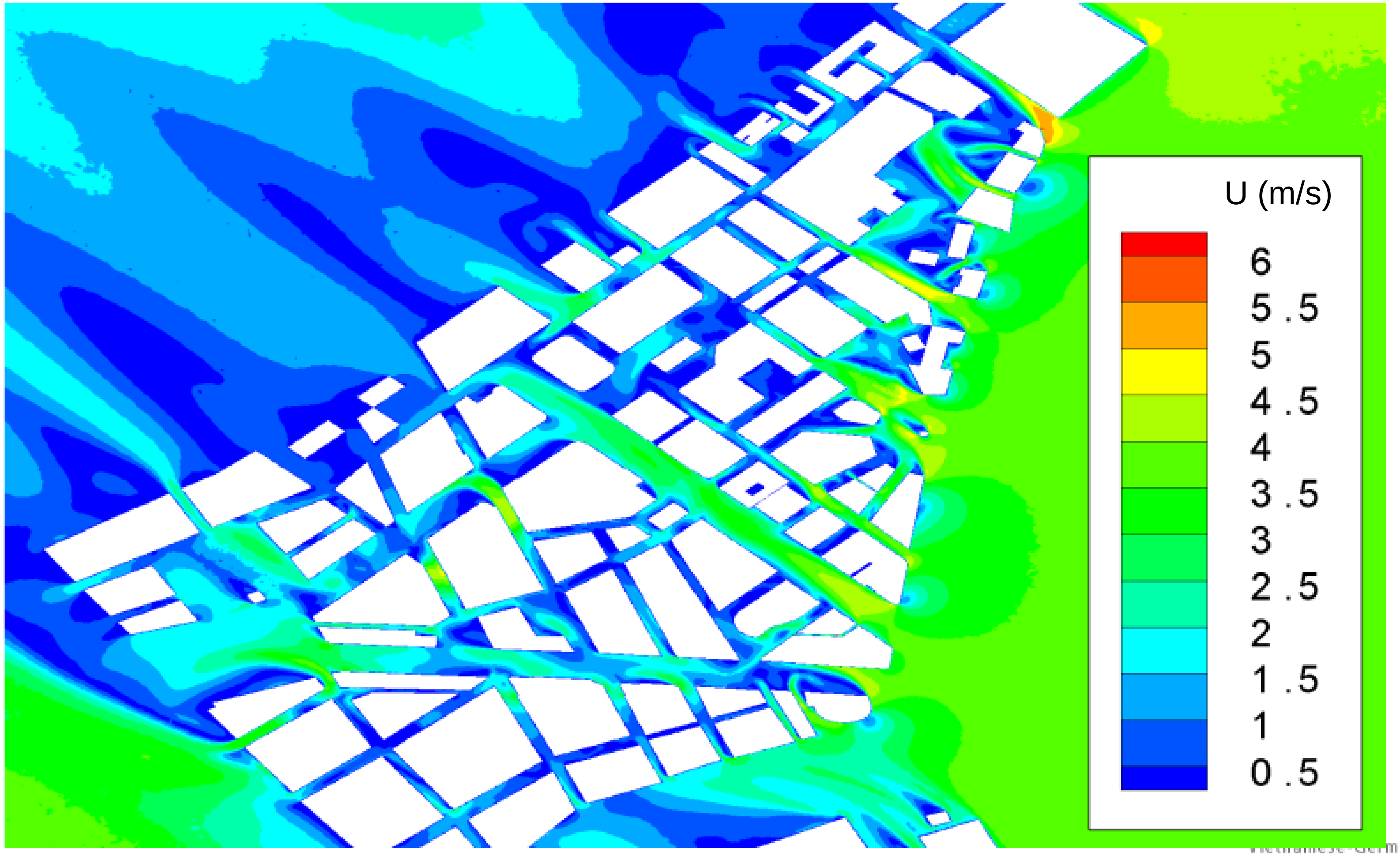
- Iterative solution with 5600 iterations



Results

Velocity magnitude at 10 m AGL

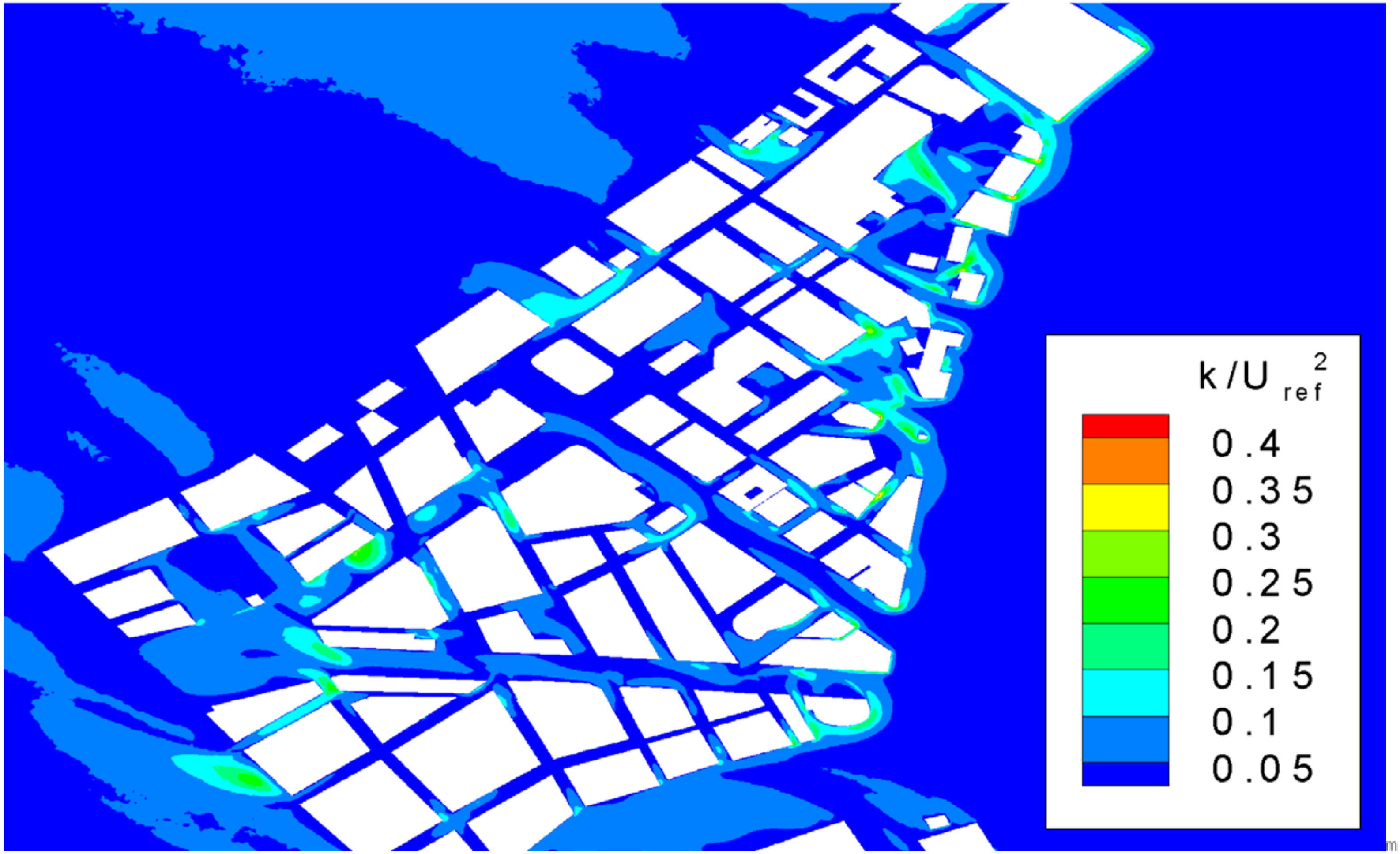
- Highest velocities around (still) unobstructed high rise buildings



Results

Non dimensional turbulent kinetic energy at 10 m AGL

- Highest turbulence also around (still) unobstructed high rise buildings



Results

Probability of wind speed > 4 m/s at 10 m AGL

- Remember: investigated wind direction accounts only for 22,3 % of a year