

WIND TUNNEL MEASUREMENT AND NUMERICAL SIMULATION OF POLLUTANT DISPERSION IN URBAN ENVIRONMENT

Tamás LAJOS

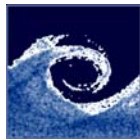
István GORICSÁN

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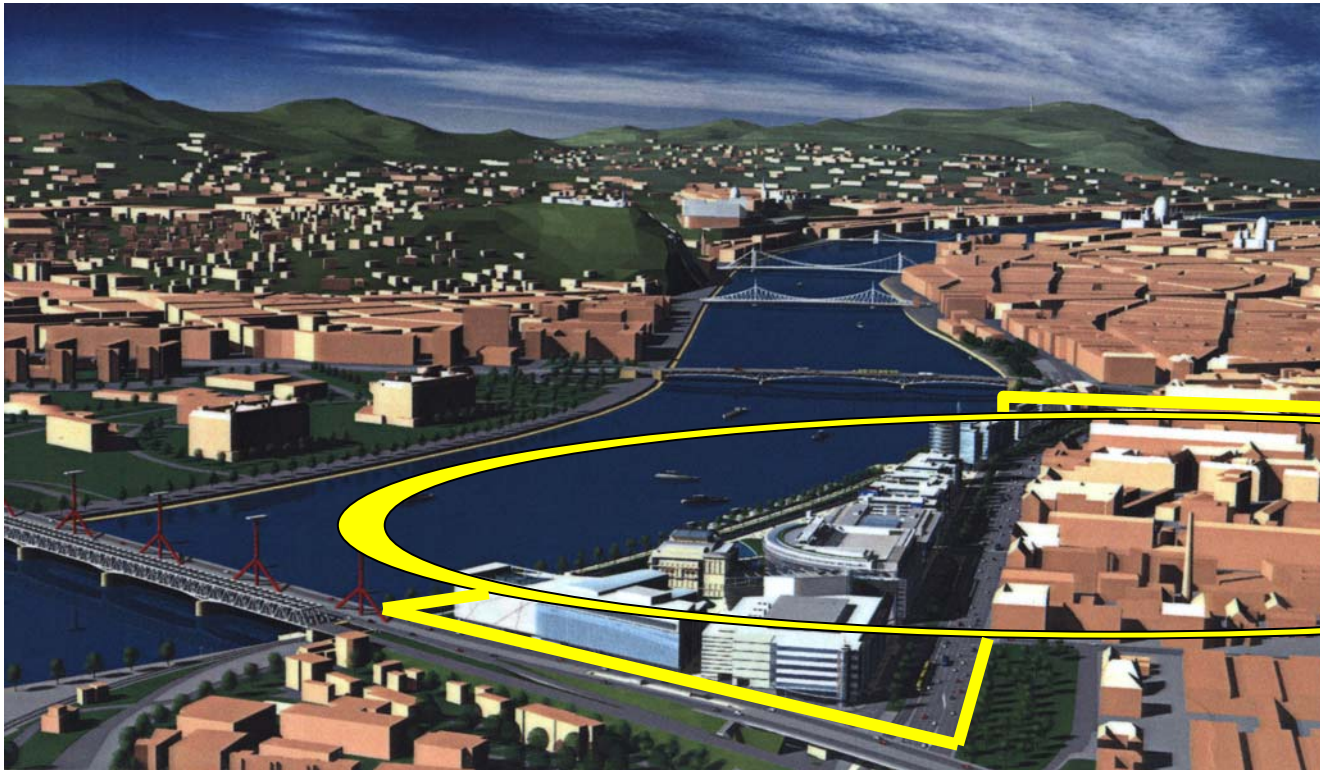
Department of Fluid Mechanics

PHYSMOD 2005

Investigated area

Millennium City Centre and neighboring district

- planned since 2000
- **wind tunnel and numerical study 2002-2003**
- full completion planned: 2007



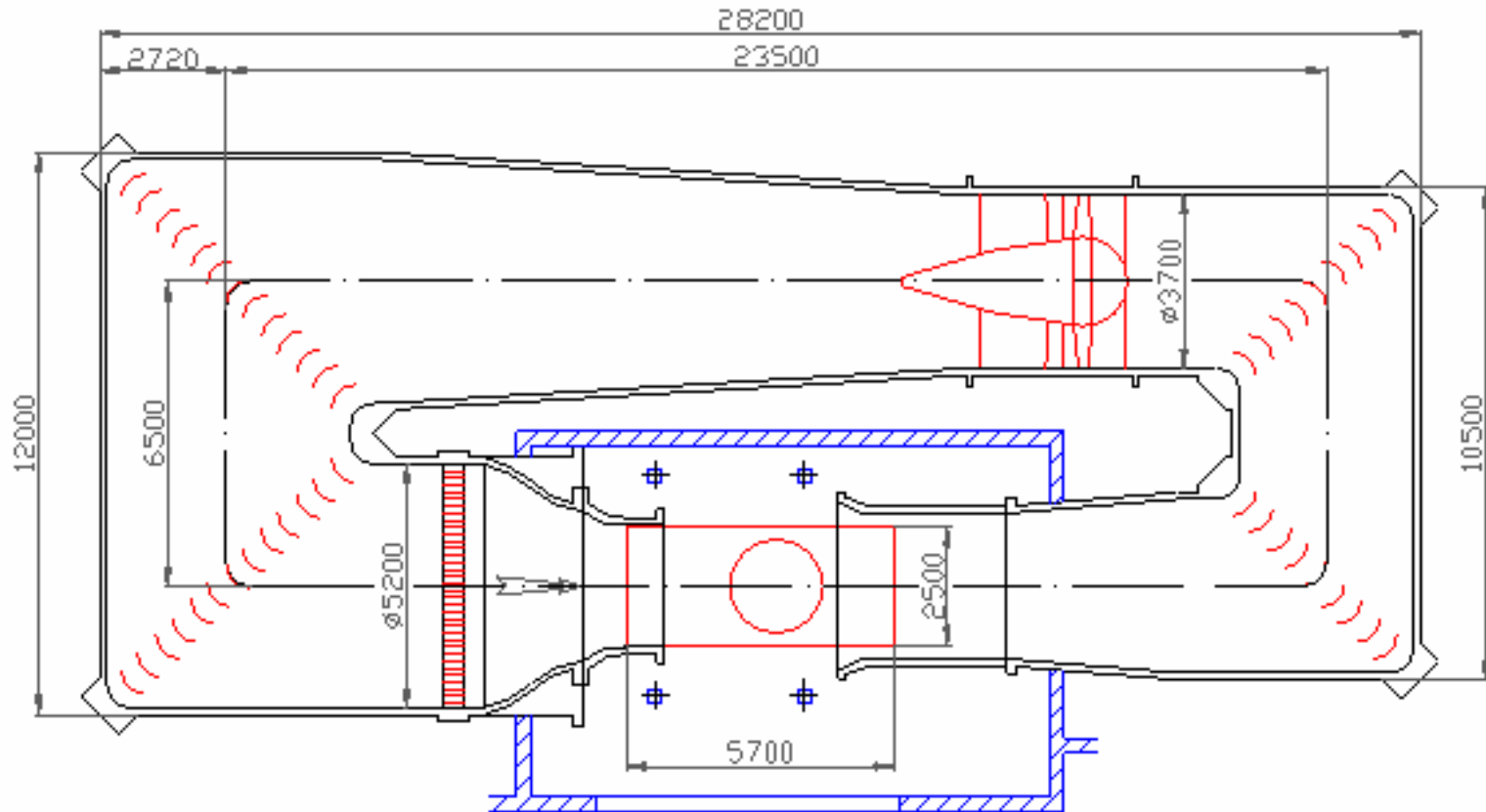
Objectives of the investigations

- Analyses of impact of Millennium City Centre on the air pollution in and ventilation of the neighboring district.
- Comparison of results of numerical simulations (Miskam, FLUENT) and wind tunnel measurements in prediction of pollutant dispersion.
- Classification of pollutant sources and flow structures with respect to their impact on the air pollution in sampling points.
- Development of more realistic wind tunnel and numerical model for introduction of tracer gas.
- Developing quantitative method to determine the average ventilation of investigated area using sand erosion.

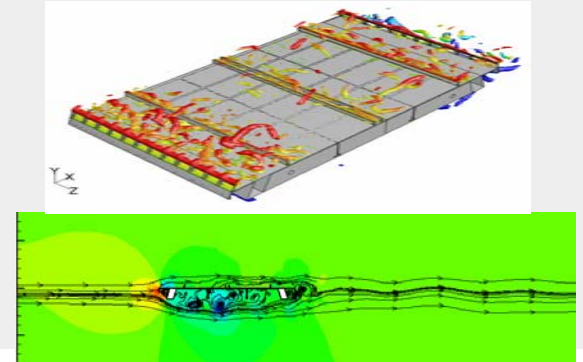
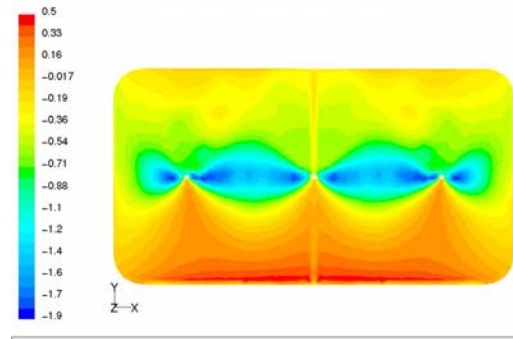
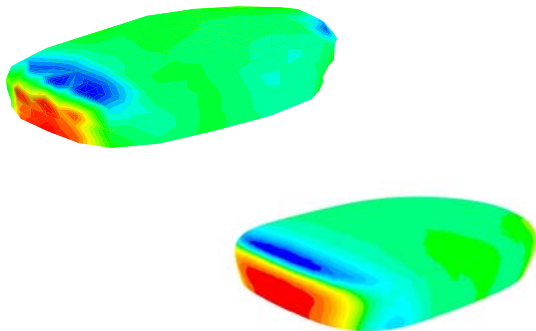
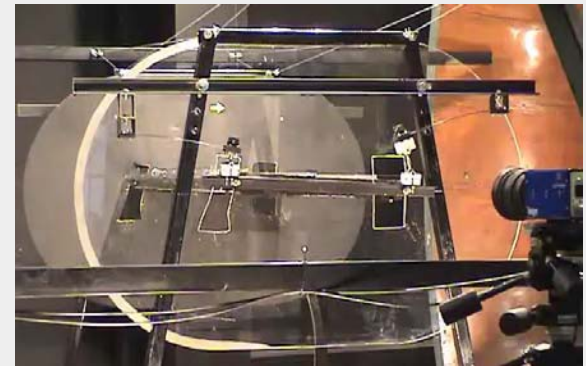
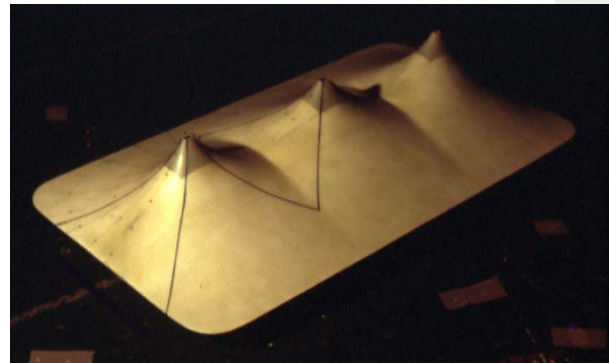
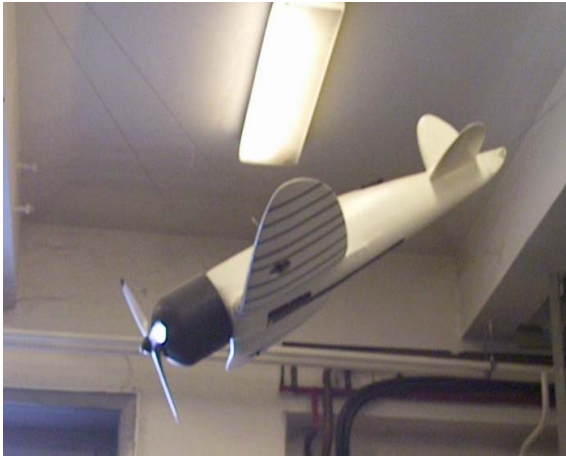
Experimental methods

The wind tunnel

- Re-circulating, horizontal wind tunnel
- Test section: 2.6 m x 5.7 m
- Wind speed: max. 200 km/h

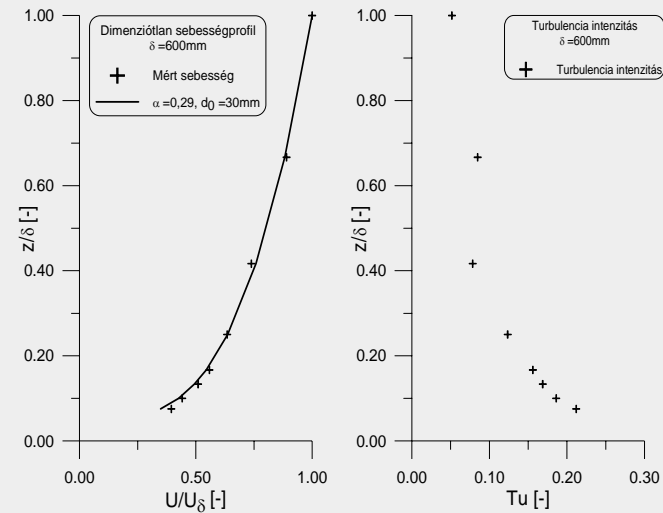
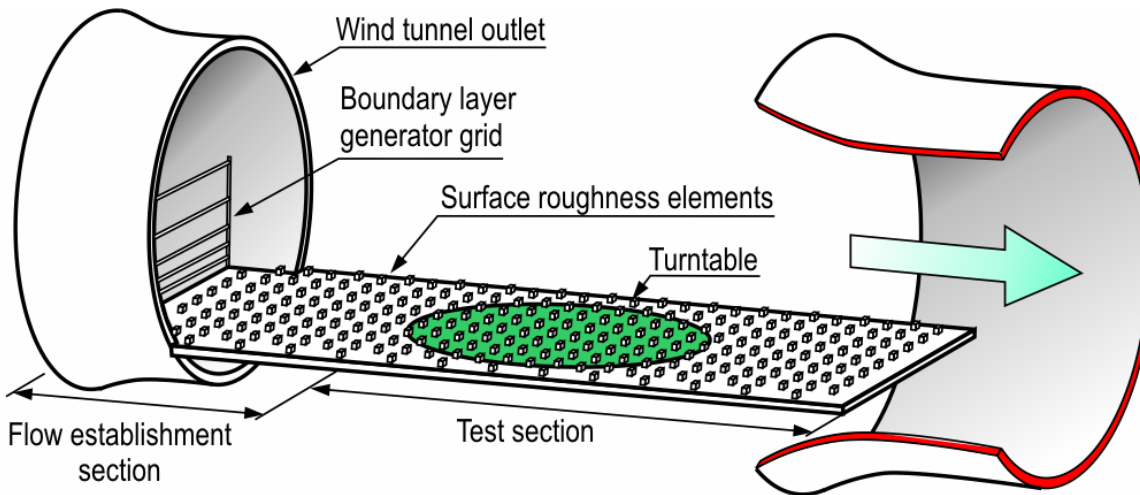


Wind tunnel applications



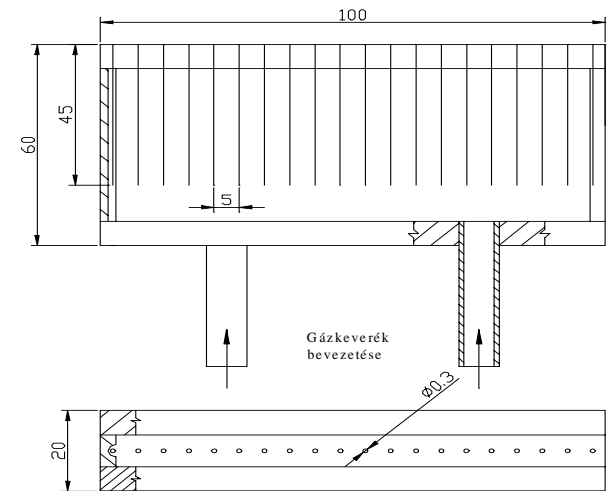
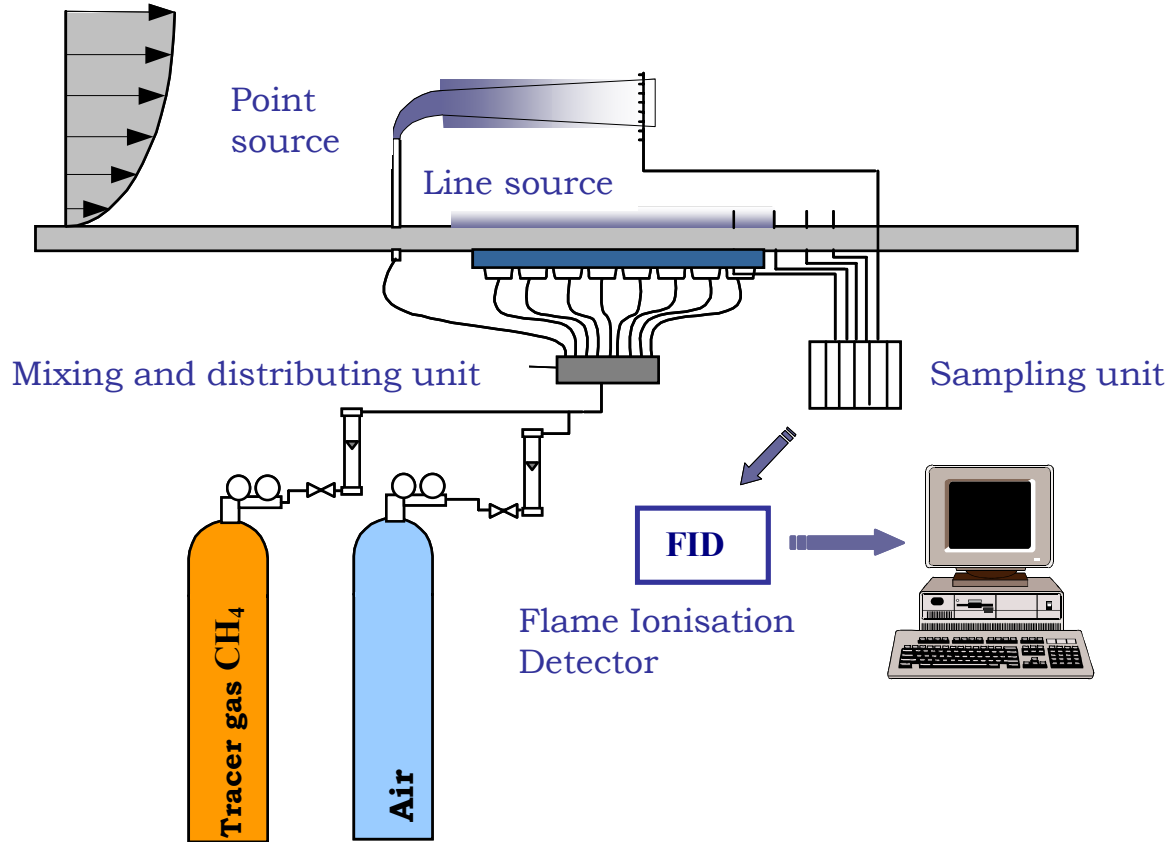
Modelling atmospheric boundary layer

- Modelling the atmospheric boundary layer
- Grid and roughness elements in the test section



Dimensionless velocity and turbulence intensity profiles

Tracer gas release, sampling, measurement



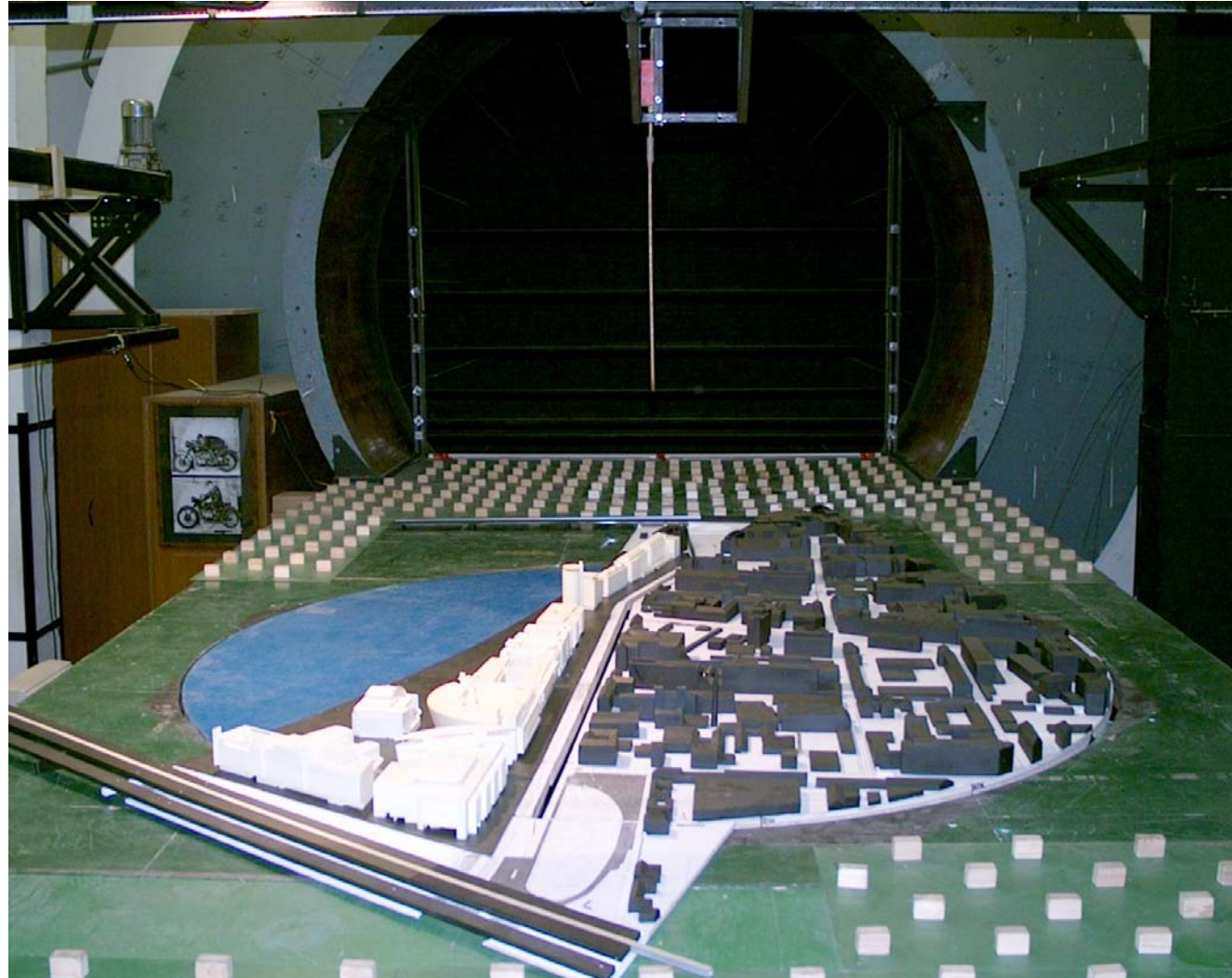
Model in the wind tunnel (NW-NNW)

Model scale: **1:500**

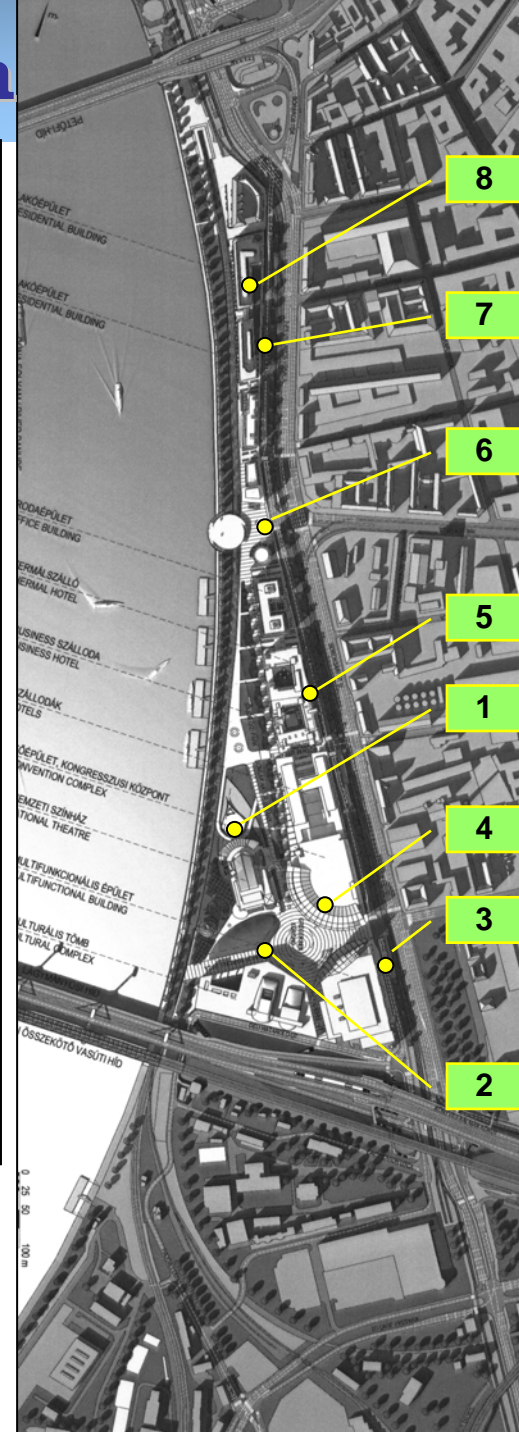
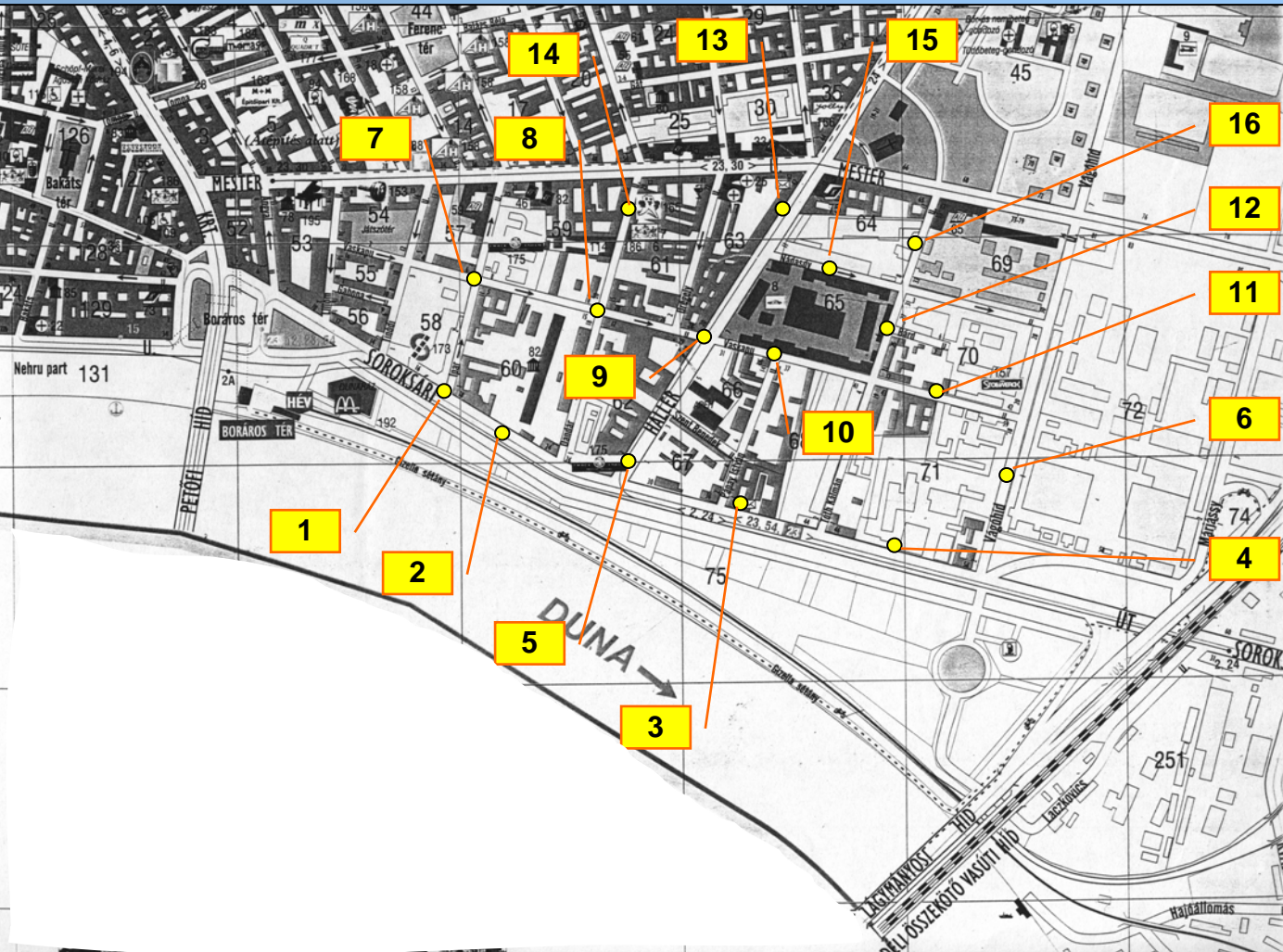
Diameter of the rotating table: **2 m**

Modelled area:
1x1.5 km

$Re_H > 20,000$



Wind tunnel measurement program



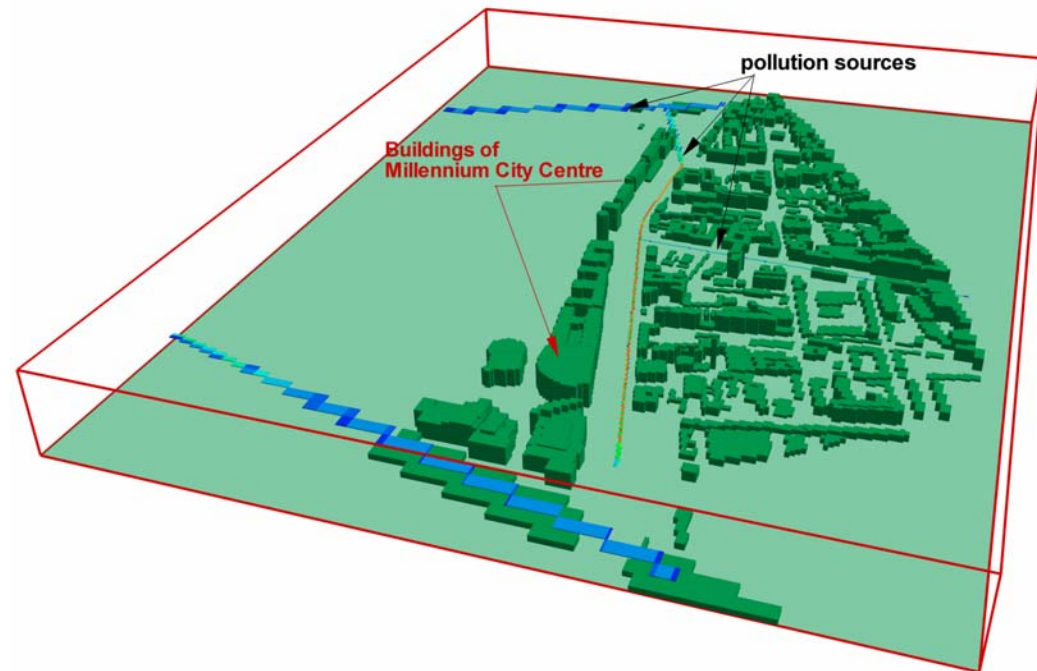
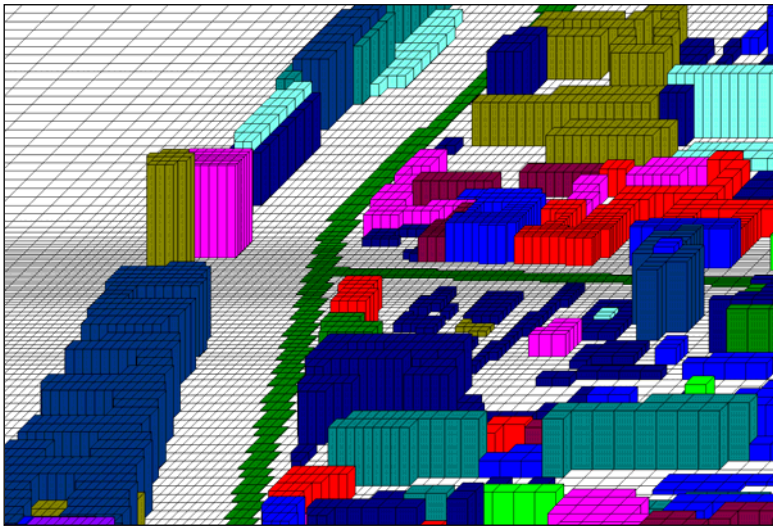
- 24 sampling points
- 5 wind directions ($22.5^\circ, 90^\circ, 214^\circ, 270^\circ, 326^\circ$)
- 2 configurations (without and with City Centre)

Numerical simulation of pollutant dispersion

MISKAM 4.22 / WinMISKAM

developed for modeling micro scale urban dispersion by Dr. J. Eichhorn, University of Mainz/Lohmeyer Engineers

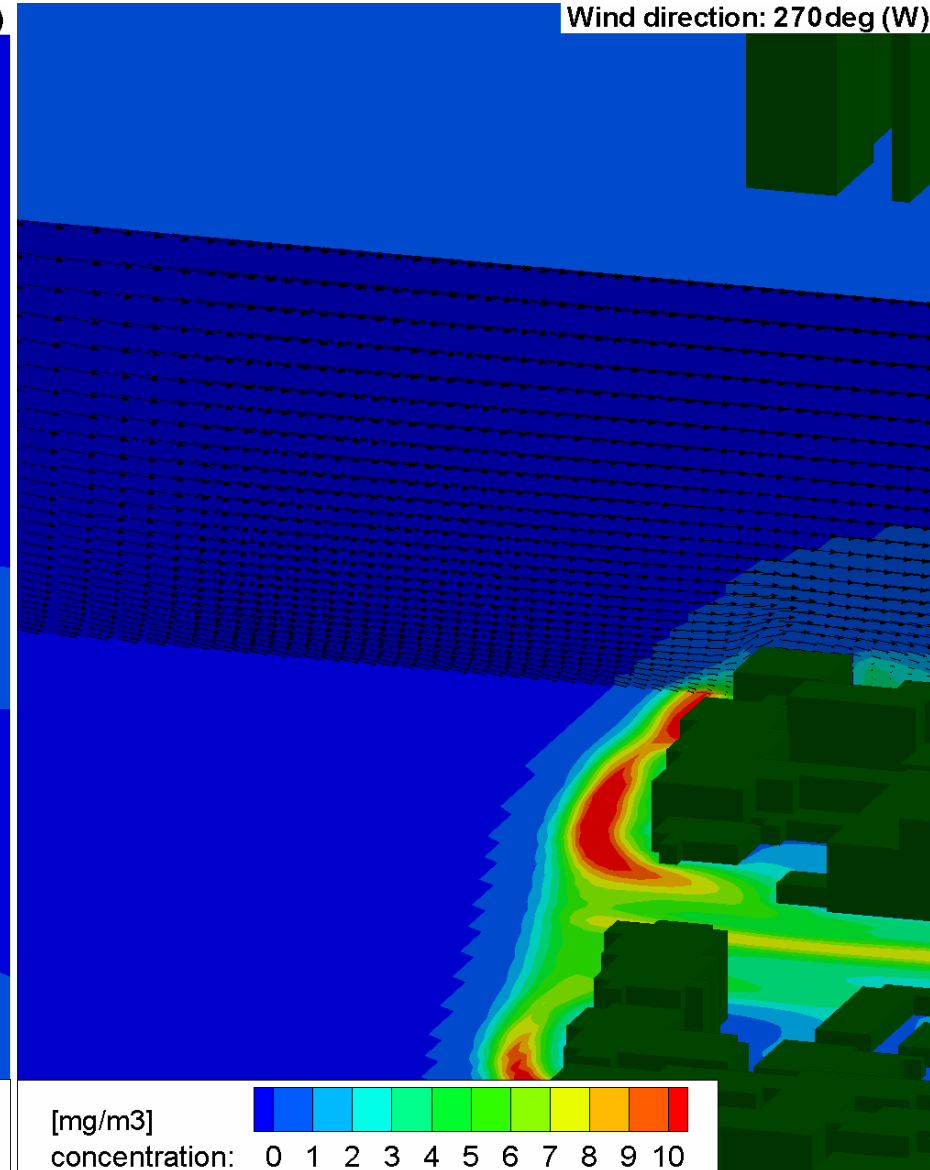
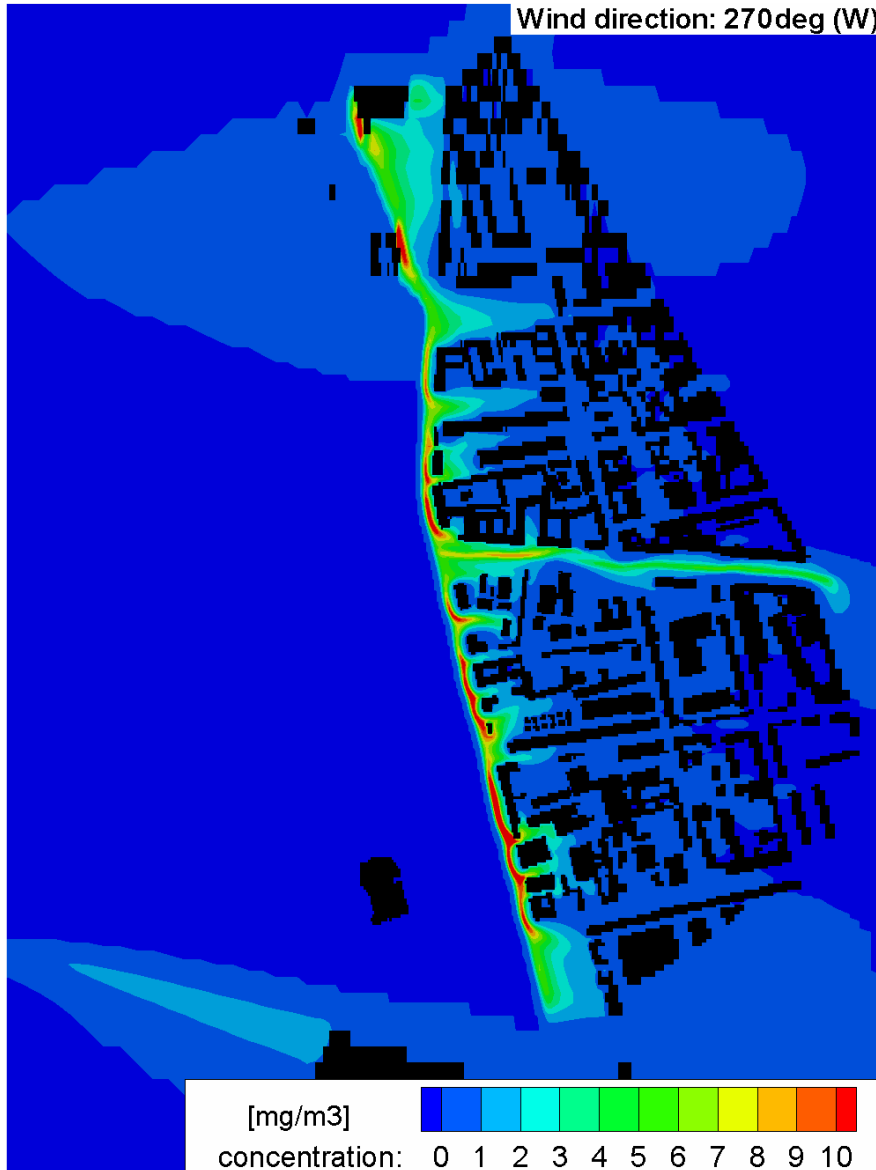
- Non-equidistant Cartesian grid, $k-\varepsilon$ turbulence closure
- Limitations for easier use (predefined boundary conditions, geometry)
- Two meshes: 900 000 and 2 million cells, 5 wind directions, 2 configurations)



Modeling of buildings:
the grid consists of bricks,
all roofs are flat

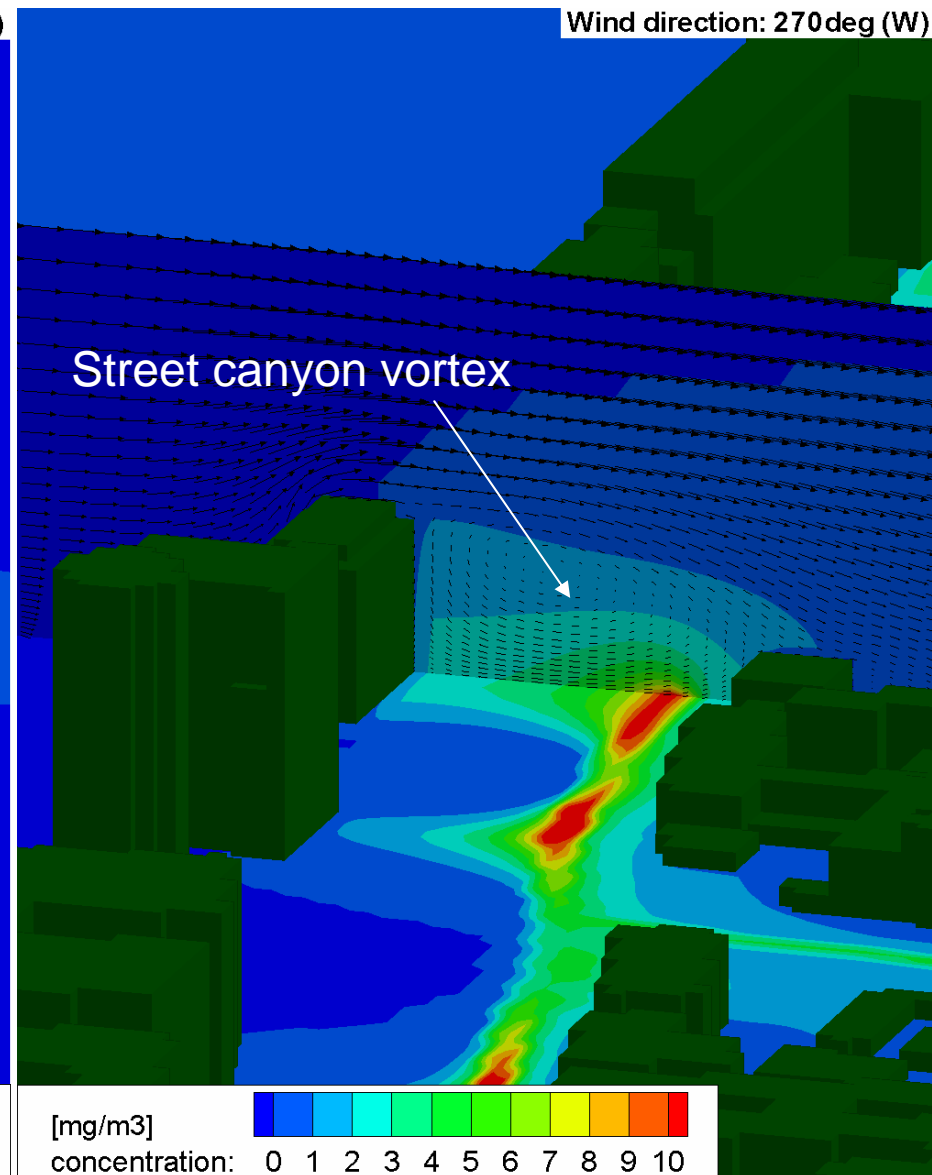
MISKAM Results I.

Concentration at 1.65m height **without new buildings**, wind direction: **West**



MISKAM Results II.

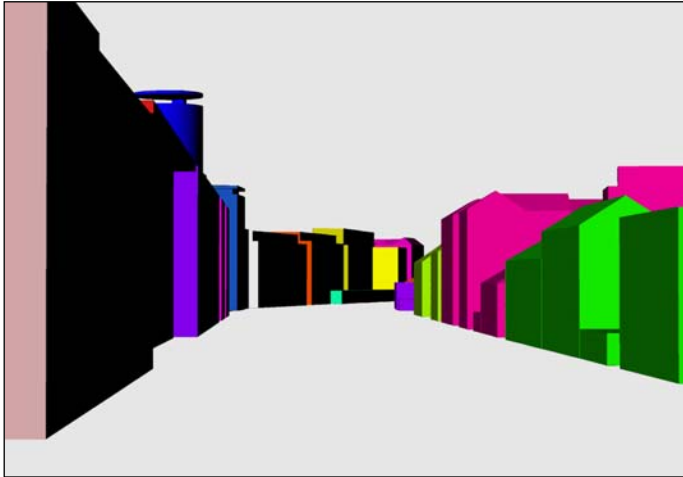
Concentration at 1.65m height **with new buildings**, wind direction: **West**



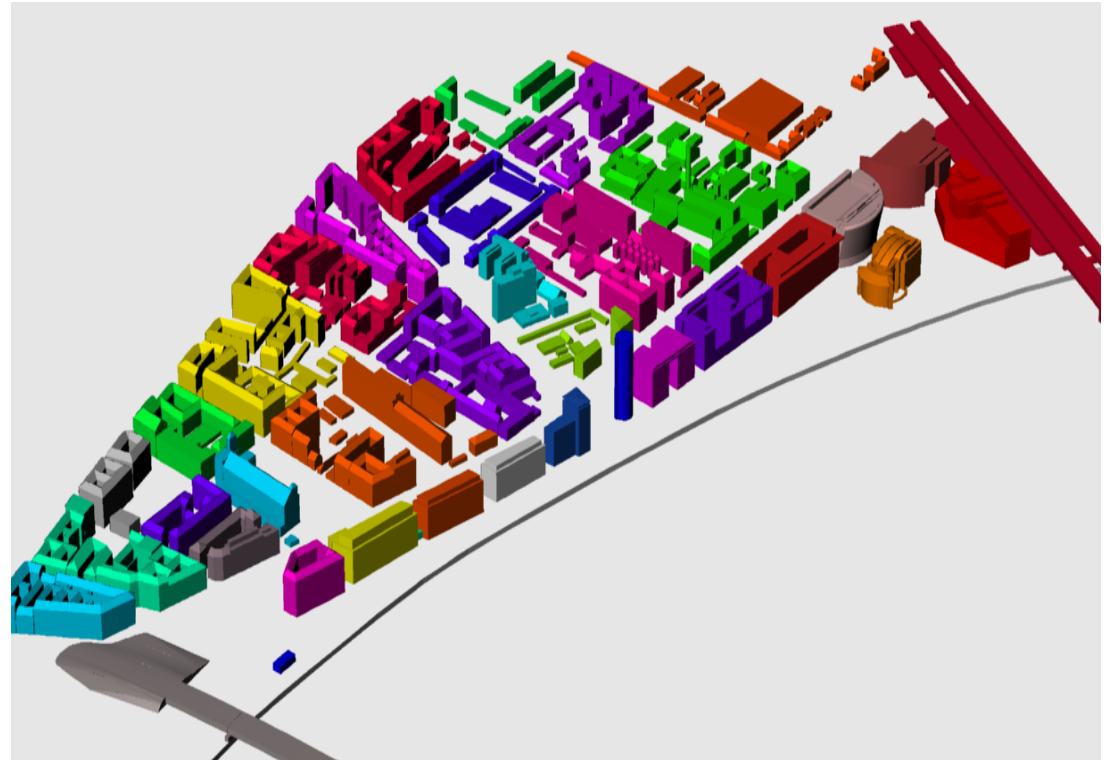
FLUENT version 6.1.

general purpose CFD software

- „realizable” k - ϵ turbulence model
- inlet boundary conditions from the wind tunnel test
- tetrahedral mesh, 1 million cells, 5 wind directions, 1 configuration)

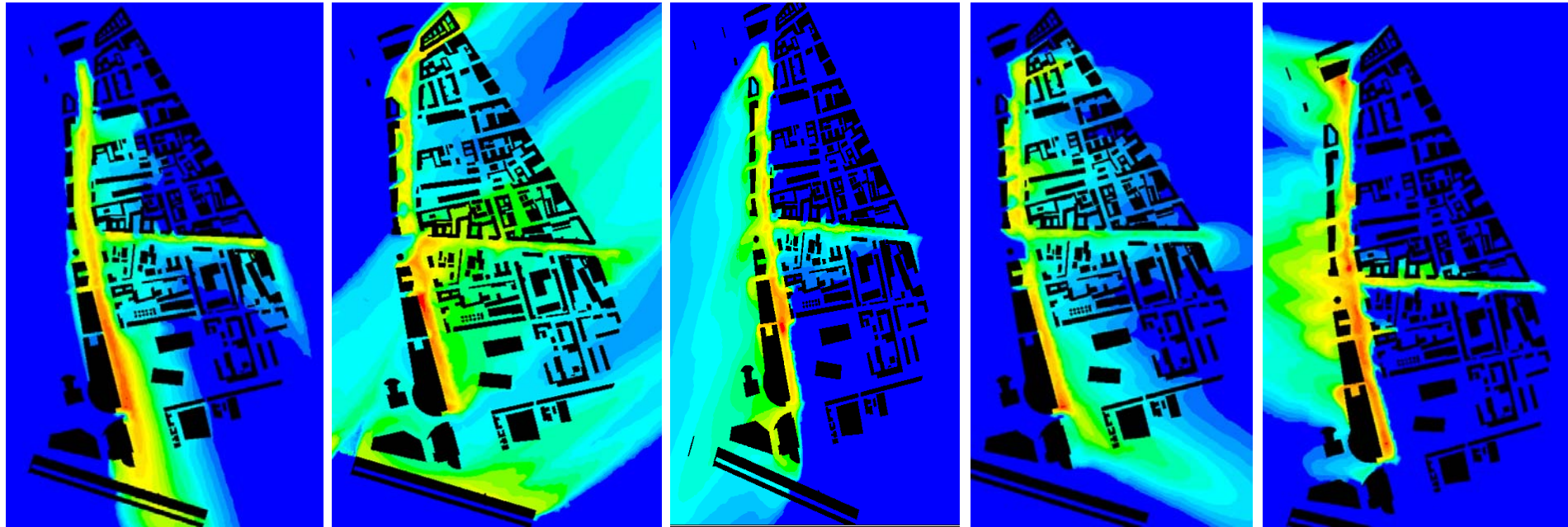


More accurate and
time consuming modelling
of buildings



FLUENT results

Concentration at 1.65m height **with new buildings**, at 5 wind directions



NW-NNW

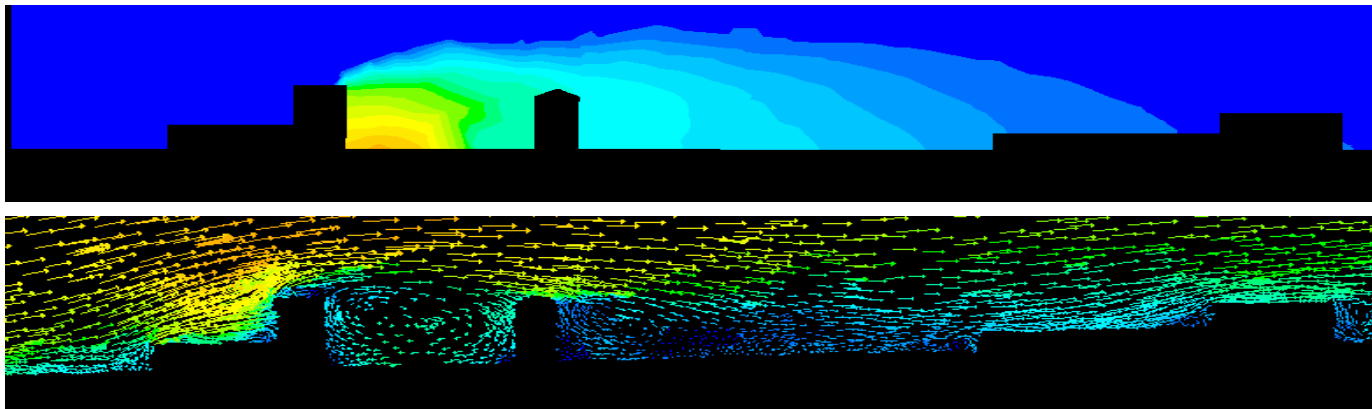
SW-SSW

N-NE

W

E

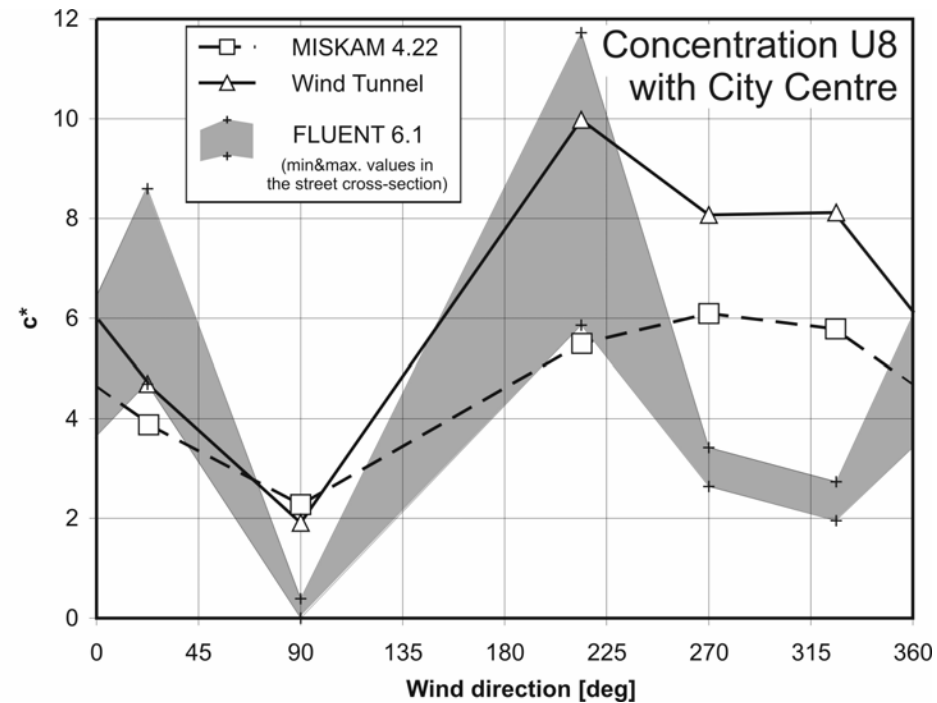
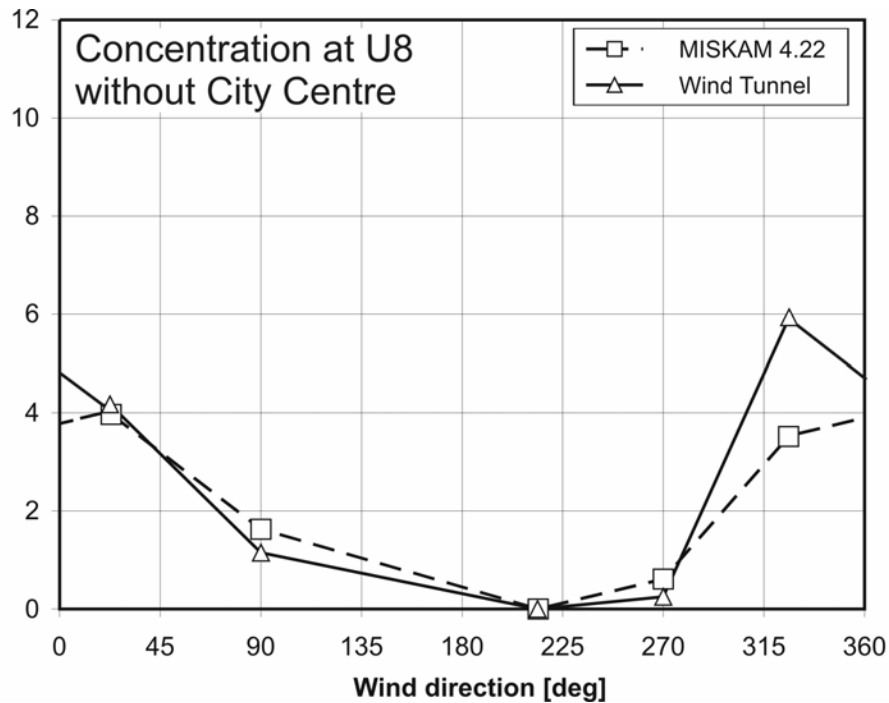
W



Comparison of wind tunnel and CFD results

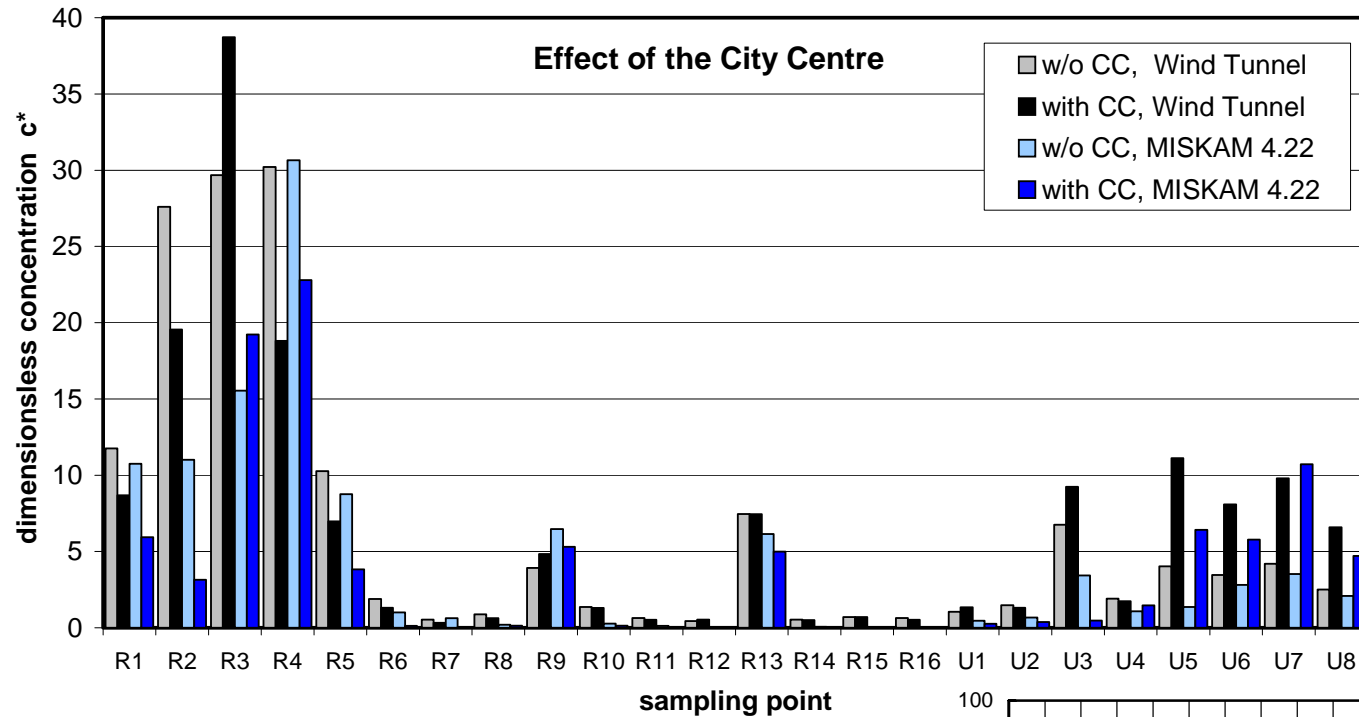
Calculated and measured values
as a function of wind direction

Example: point U8



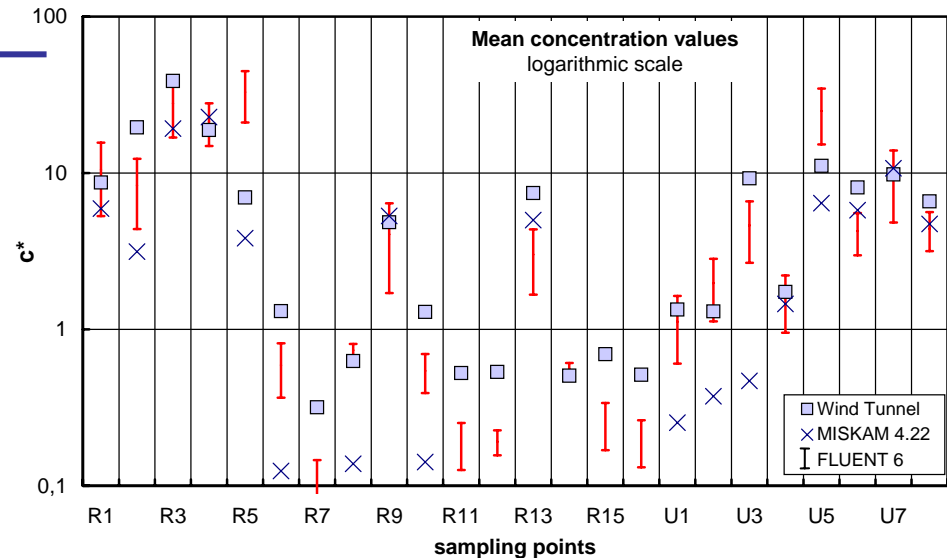
Wind tunnel / MISKAM 4.22 / FLUENT 6.1

Comparison of annual mean concentration

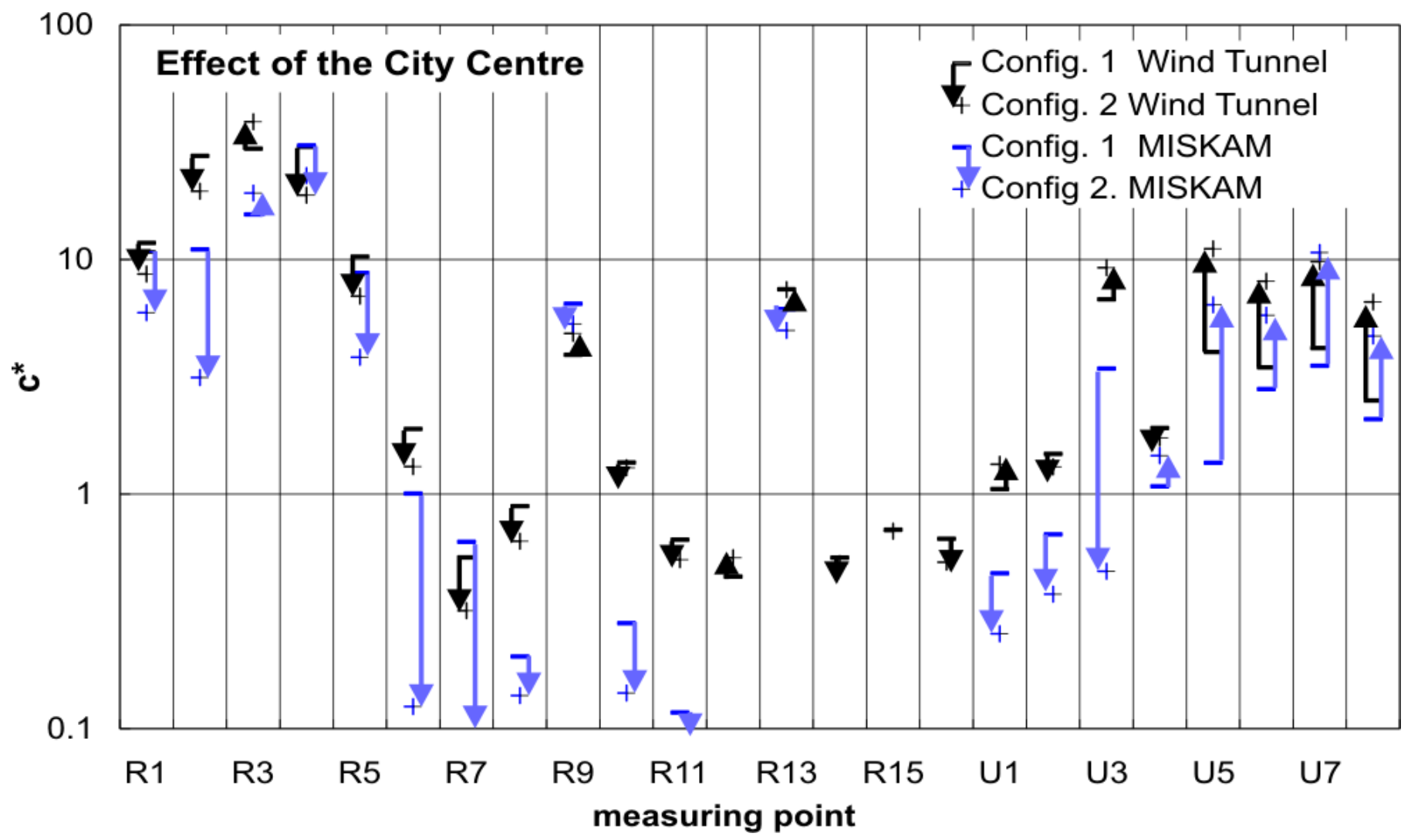


- MISKAM and wind tunnel results in all sampling points
- With and without City Centre

- wind tunnel, MISKAM and FLUENT results in all sampling points
- with City Centre
- logarithmic scale

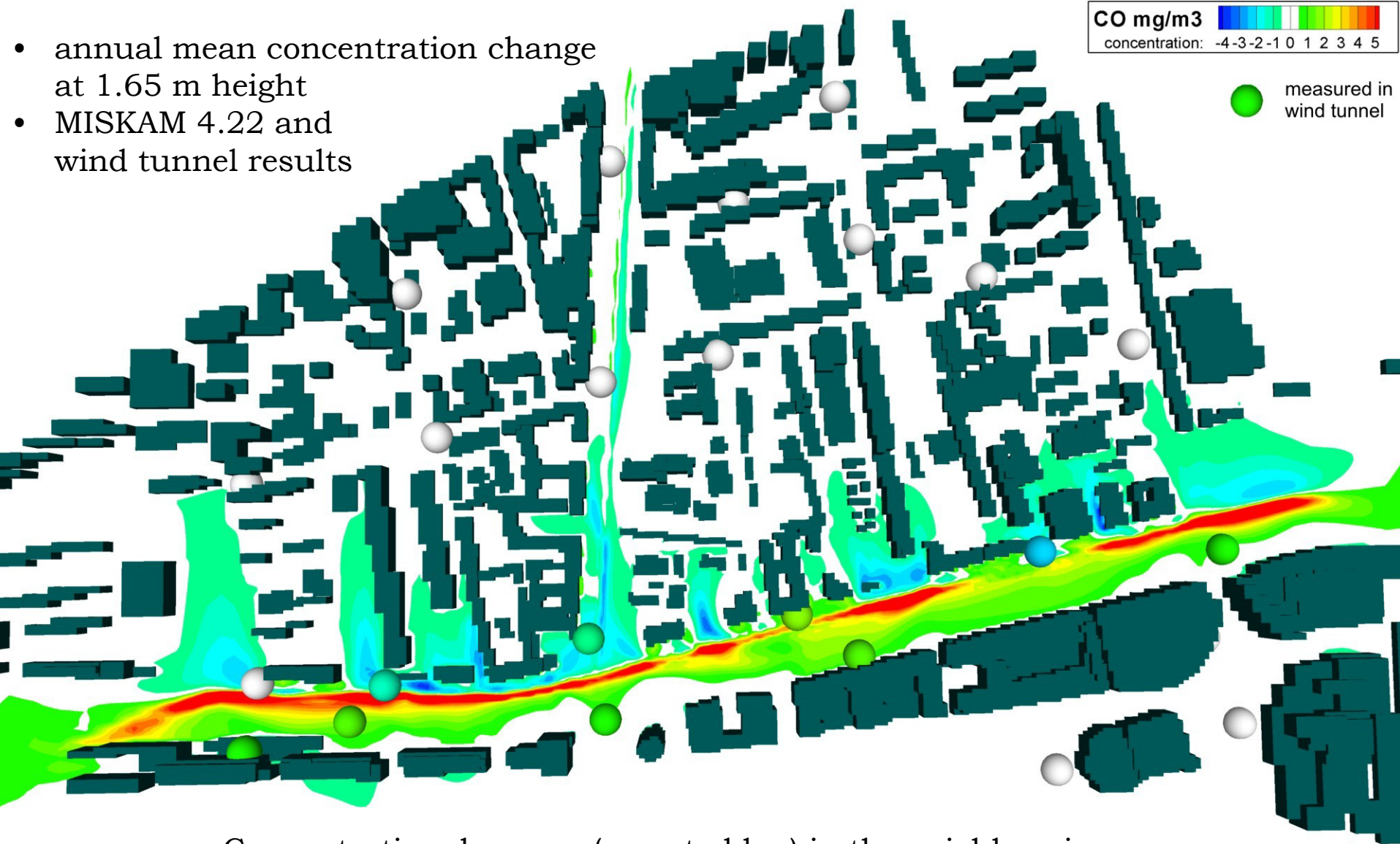


Prediction of change of annual mean concentration I.



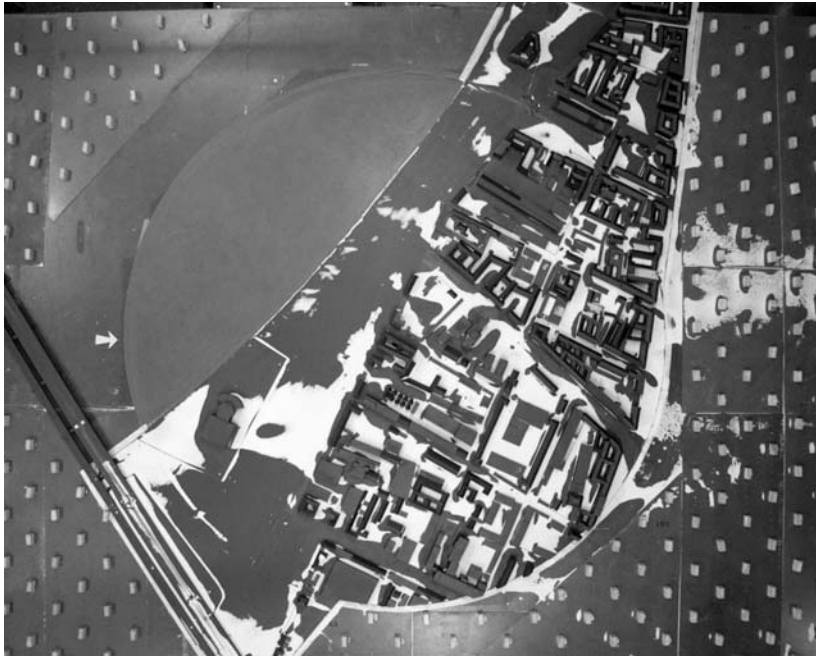
Prediction of change of annual mean concentration II.

- annual mean concentration change at 1.65 m height
- MISKAM 4.22 and wind tunnel results



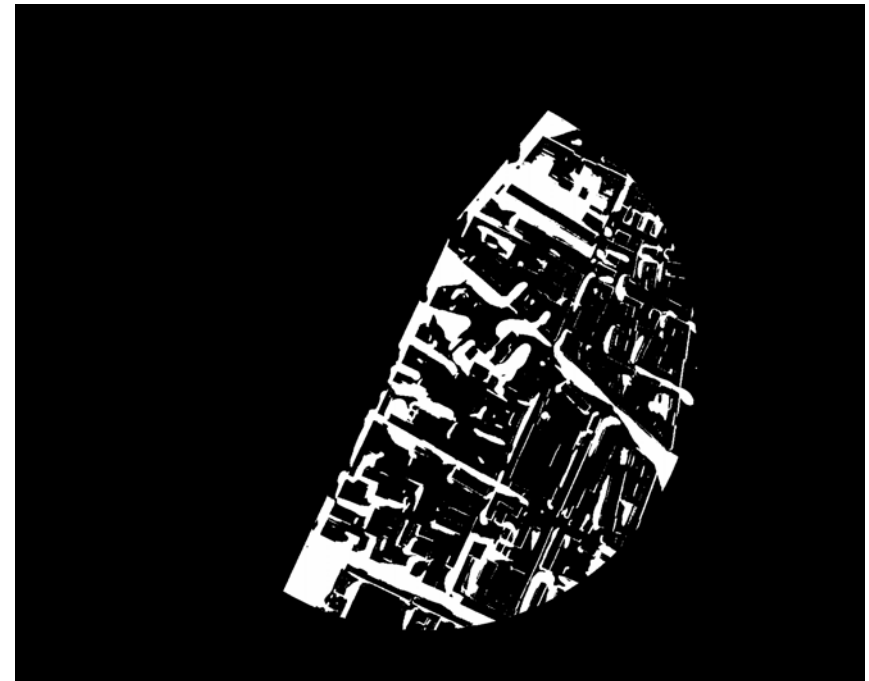
- Concentration decrease (cyan to blue) in the neighbouring area
- Concentration increase (green to red) in the street cross section (due to the 20% traffic growth, and the street canyon)

Determination of wind climate with sand erosion I.

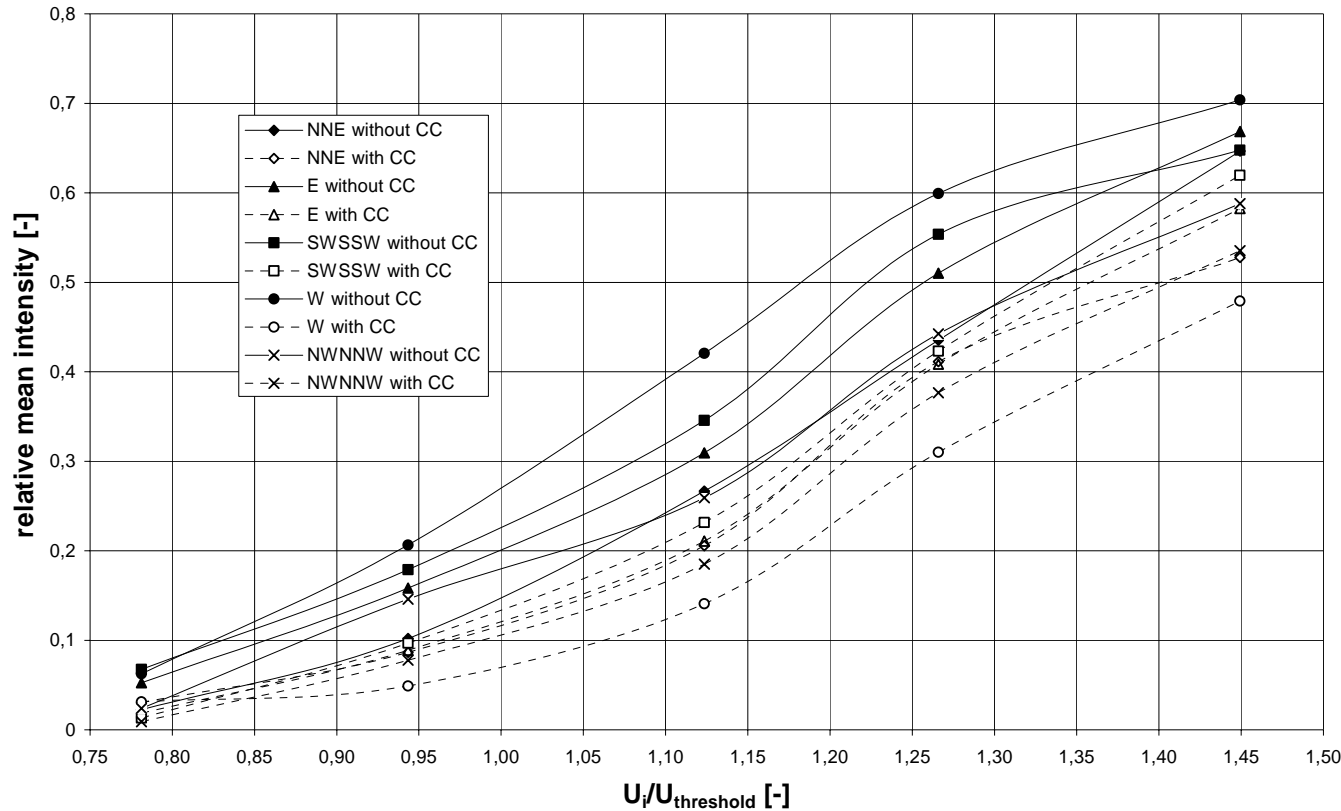


- Pictures taken at different wind velocity from the same position and same size and resolution \Rightarrow black and white image
- Mask: streets and squares are transparent roofs are black (colour code: $I_{cc} = 0$)

- Difference image (ref - $v \neq 0$ m/s, buildings and area covered by sand are black, $I_{cc} = 0$, streets and squares where the sand particles are removed became white $I_{cc} = 255$)
- The mean and relative mean intensity (RMI) can be calculated



Determination of wind climate with sand erosion II.



$$\overline{I_{DP}} = \frac{\sum_{i=1}^{N_{pixel}} I_{cc_i}}{N_{pixel}}$$

$$RMI = \frac{\overline{I_{DP}}}{I_{ref}}$$

Equal relative mean intensity means equal wind comfort (equal area covered by sand).

Wind direction	Annual incidence of wind direction	Variation of wind velocity
NWNNW	19 %	-4.5 %
NNE	16 %	-2.7 %
E	14 %	-6.4 %
SWSSW	13 %	-8.5 %
W	9 %	-19 %
Annual mean		-7 %

Conclusions

- Numerical simulation of flow and dispersion processes is promising method for prediction of air pollution. FLUENT and Miskam provided results of similar accuracy.
- Increase in accuracy is necessary, it needs further improvement, particularly in proper modeling of pollutant emission.
- CFD can be used reliably for defining the position of sampling points of WT measurement and for qualitative prediction of direction of changes of air pollution.
- Combination of sand erosion method with image processing can be effectively used for determining the change is average ventilation of a district.

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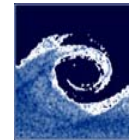
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Thank you for your attention



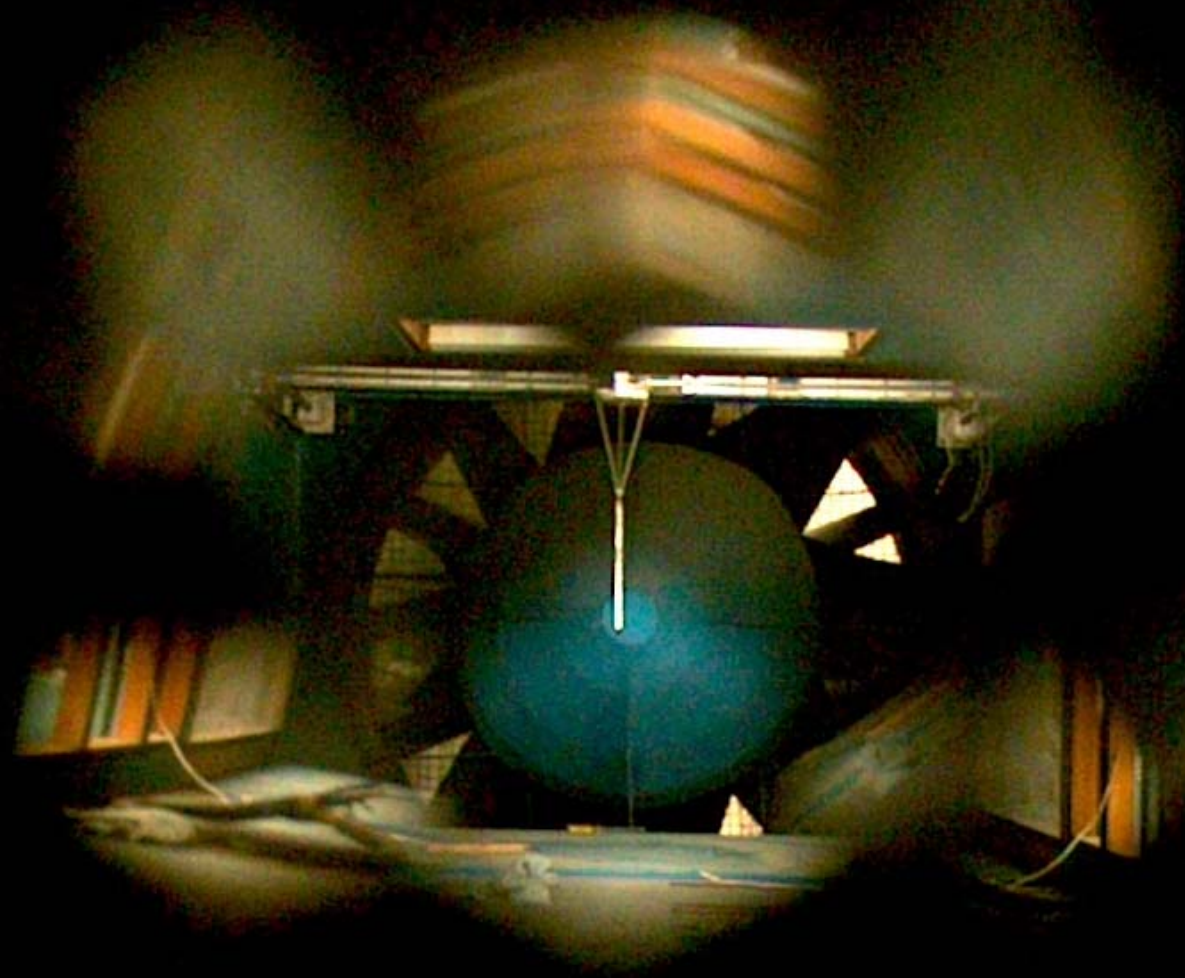
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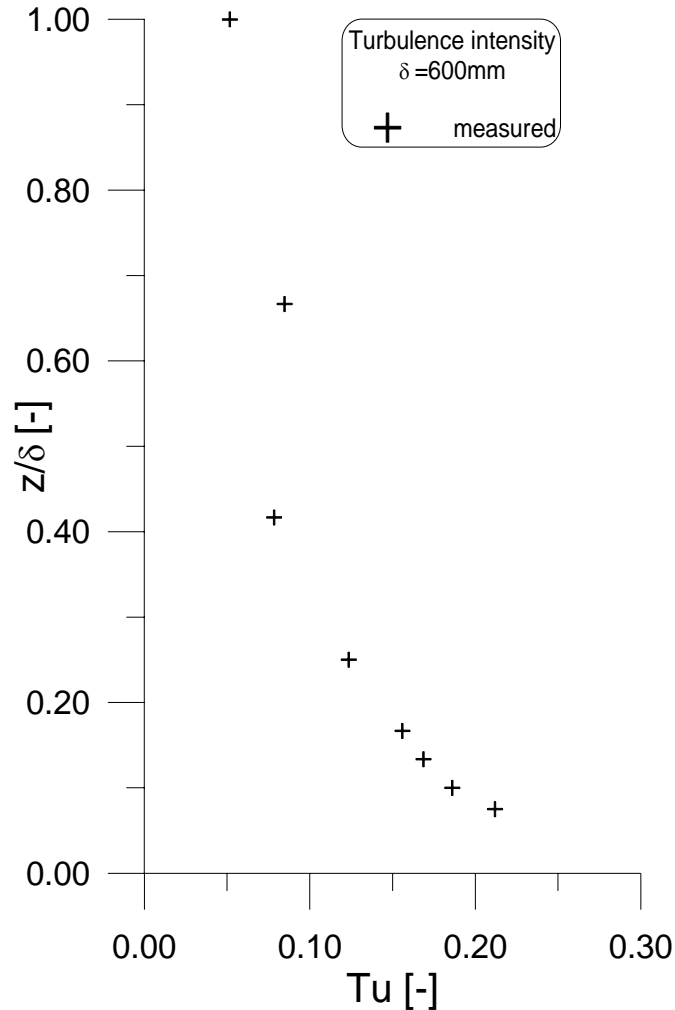
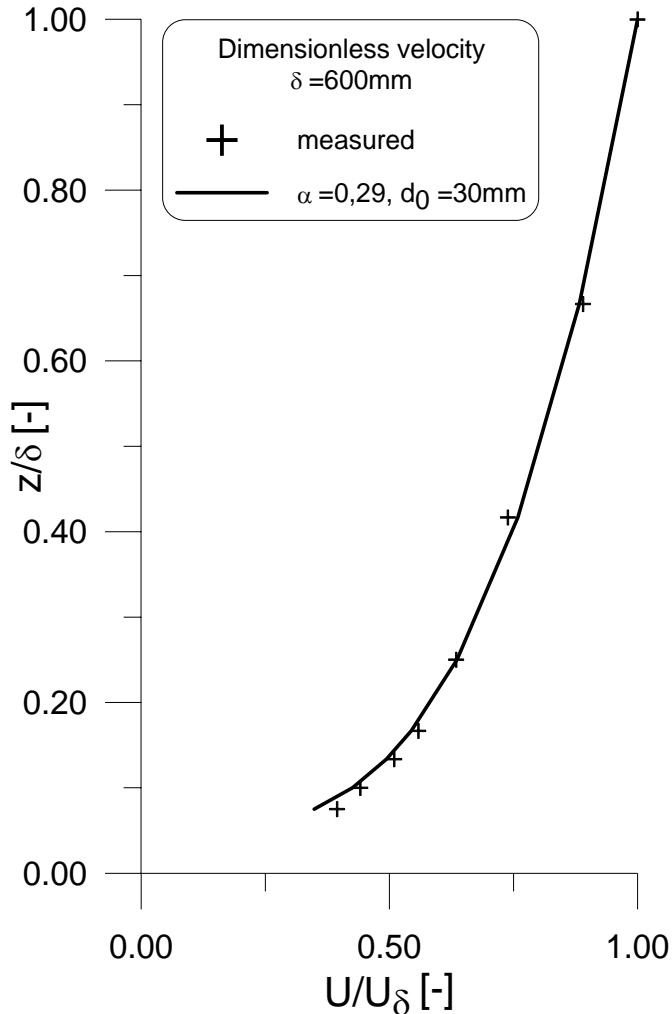


Boundary layer parameters

Velocity and turbulence profile measured with CTA

$$\frac{U(z)}{U_{\text{ref}}} = \left(\frac{z - d_0}{z_{\text{ref}} - d_0} \right)^\alpha$$

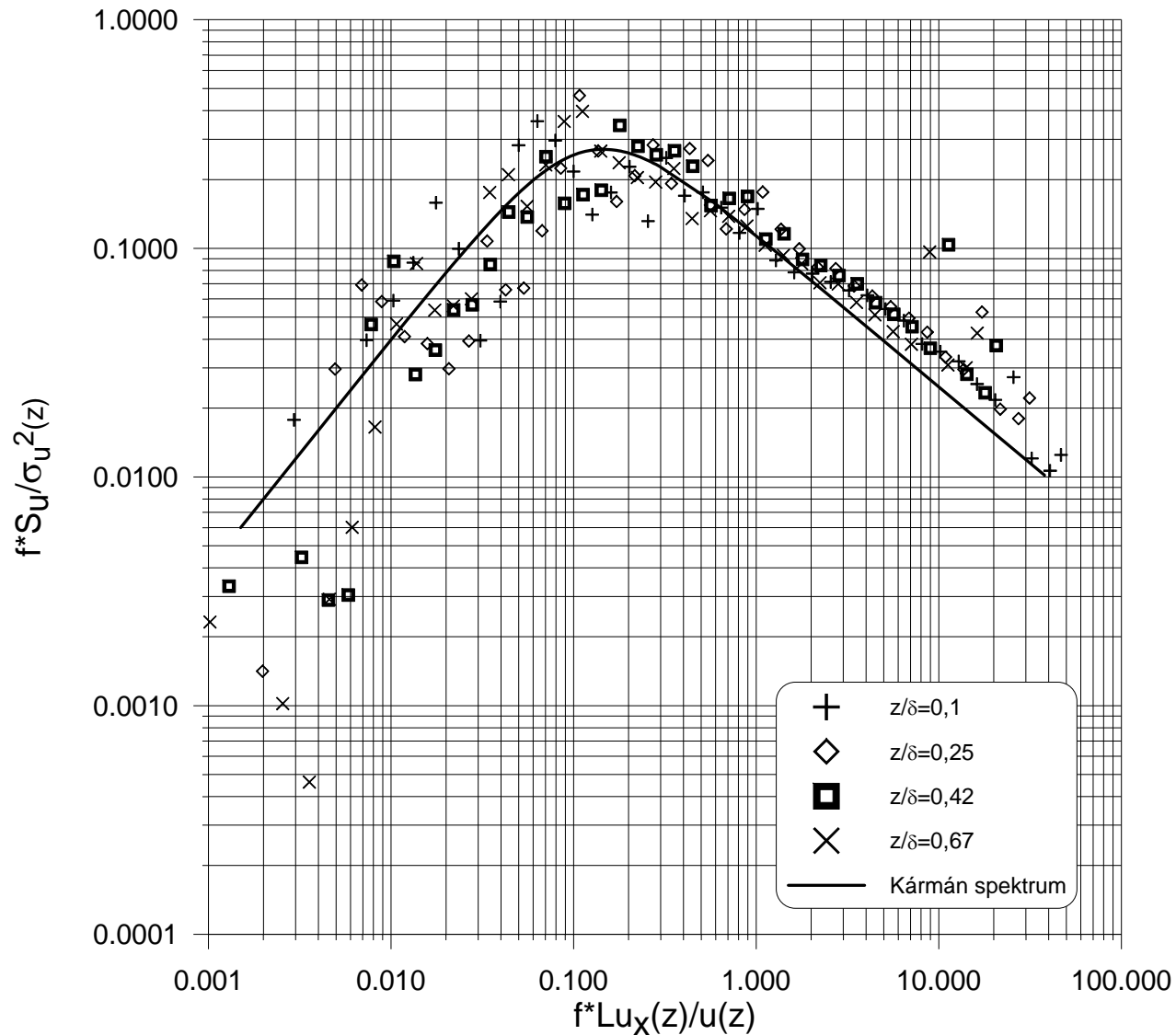
$$\frac{U(z)}{u_*} = \frac{1}{\kappa} \ln \left(\frac{z - d_0}{z_0} \right)$$



	Urban boundary layer
Roughness height z ₀ [mm]	6,56
Displacement height d ₀ [mm]	30
Profile exponent [-]	0,29
Boundary layer thickness, δ [m]	0,6
Model-scale	1:500

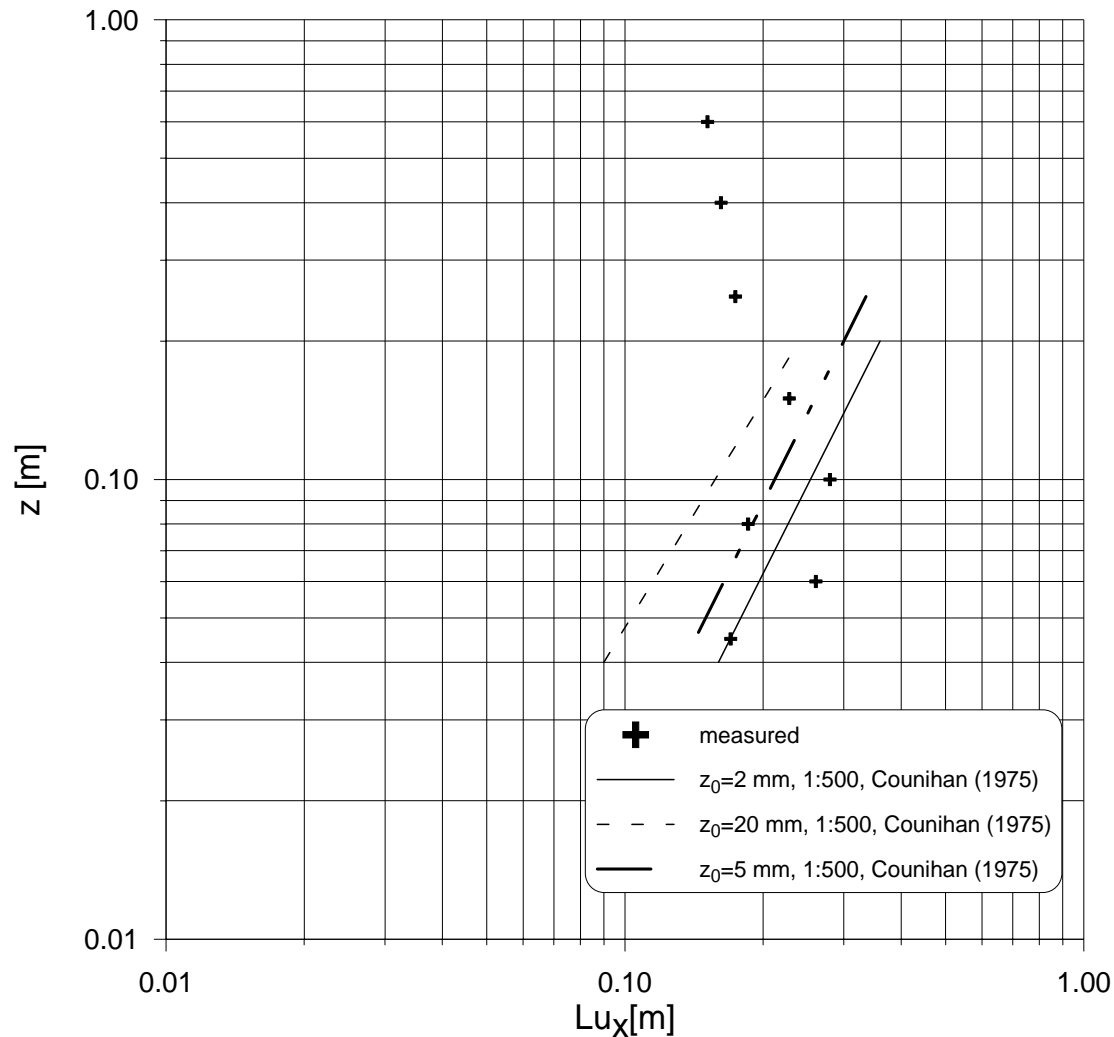
Boundary layer parameters

Turbulent kinetic energy spectrum



Boundary layer parameters

Length scale
distribution



Counihan, J. (1975) Adiabatic atmospheric boundary layers: A review and analysis of data from the period 1880-1972, *Atmospheric Environment*, vol 9. pp. 871-905

VDI 3783 Part 12. Environmental meteorology, Physical modelling of flow and dispersion processes in the atmospheric boundary layer, Application of wind tunnels