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

Tamás LAJOS

István GORICSÁN ***Márton BALCZÓ***

MŰEGYETEM 1782

Budapest University of Technology and Economics

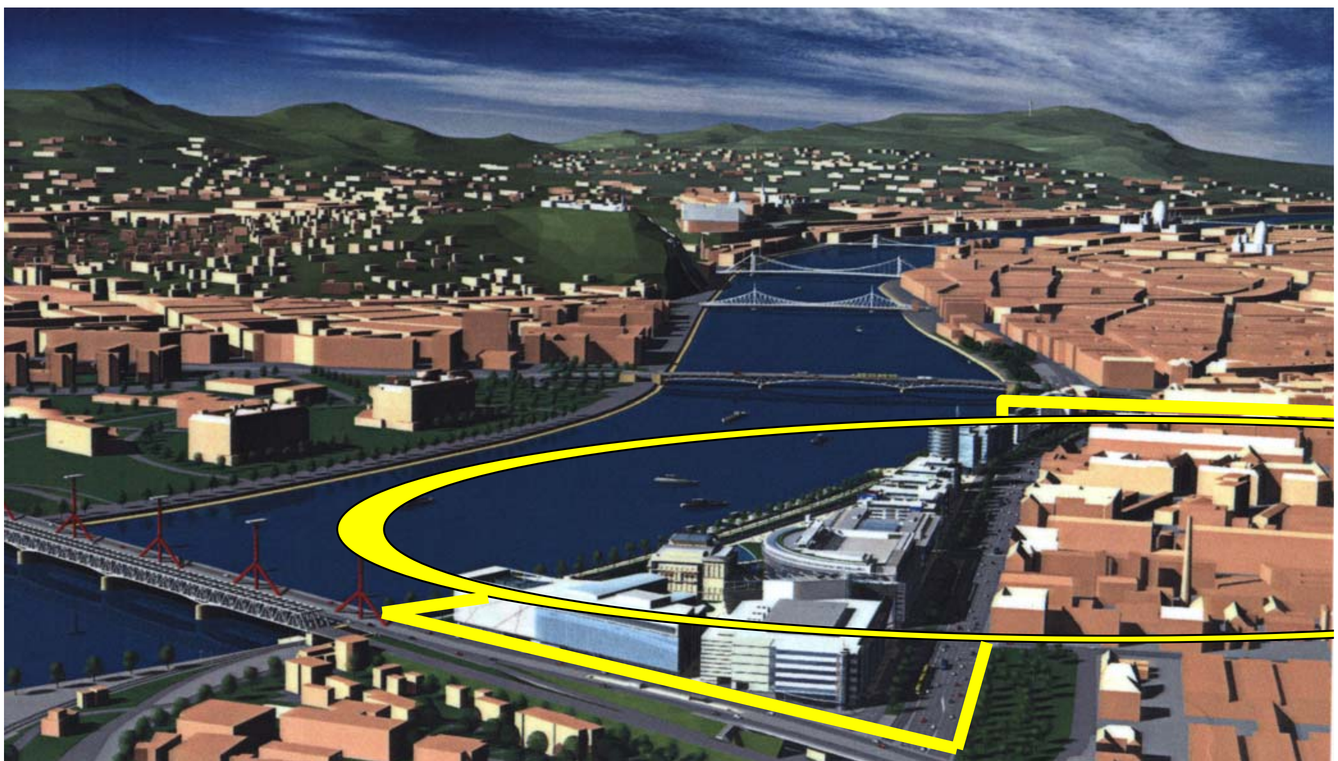
Department of Fluid Mechanics

PHYSMOD 2005

Investigated area

Millennium City Centre and neighboring district

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



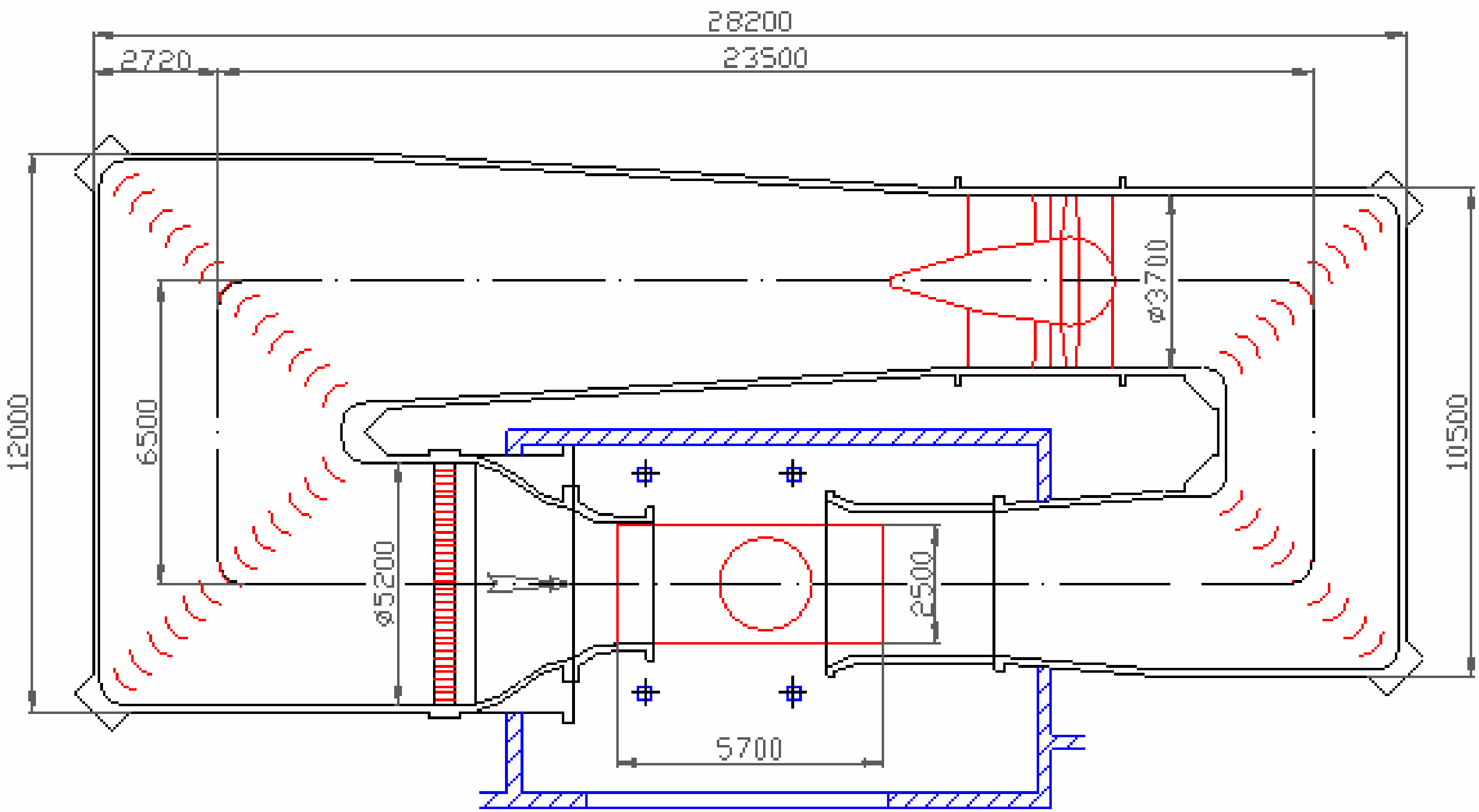
Objectives of the investigations

- 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.

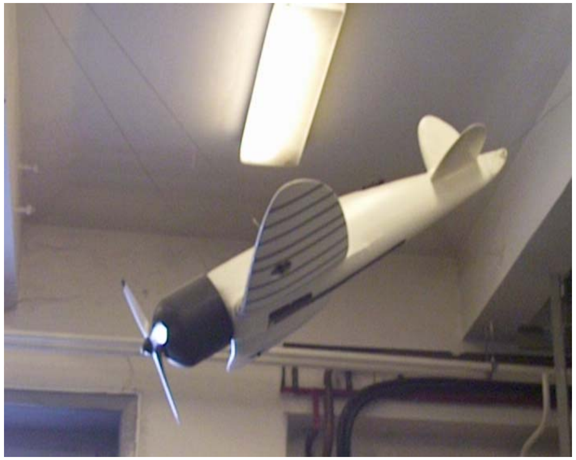
Experimental methods

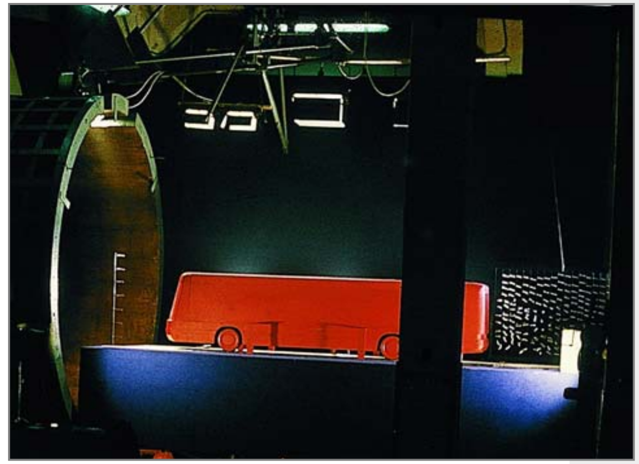
The wind tunnel

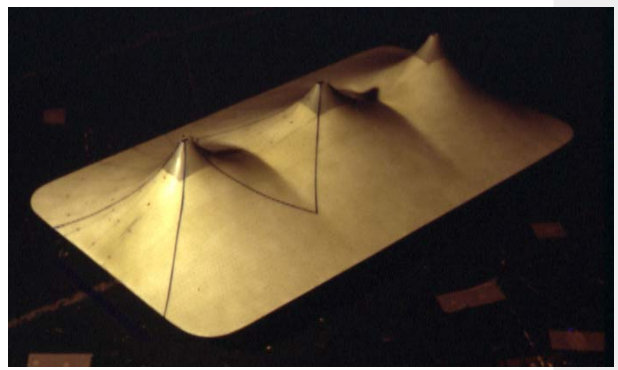
- Re-circulating, horizontal wind tunnel
- Test section: 2.6 m x 5.7 m
- Wind speed: max. 200 km/h

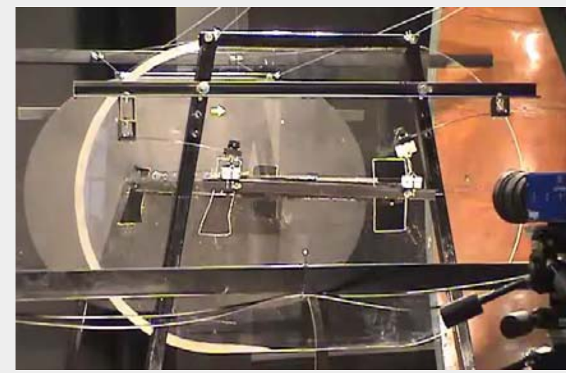


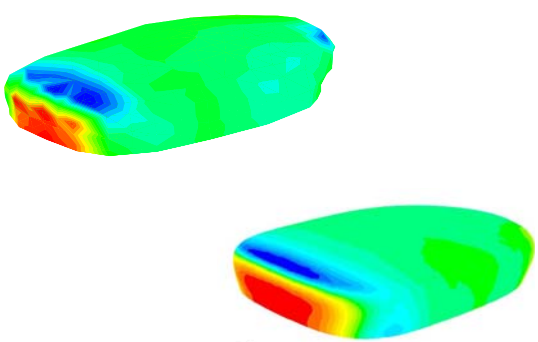
Wind tunnel applications

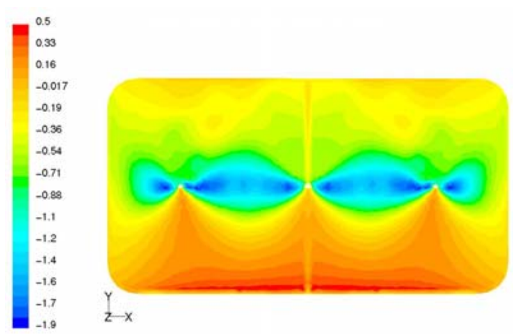


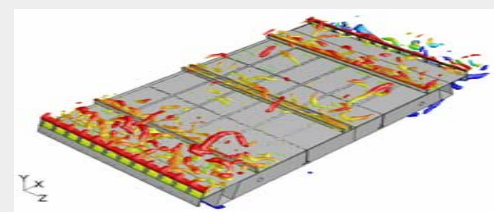


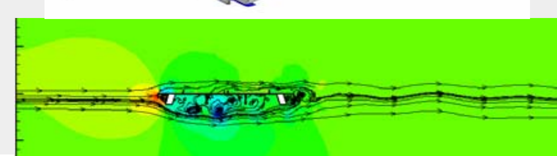




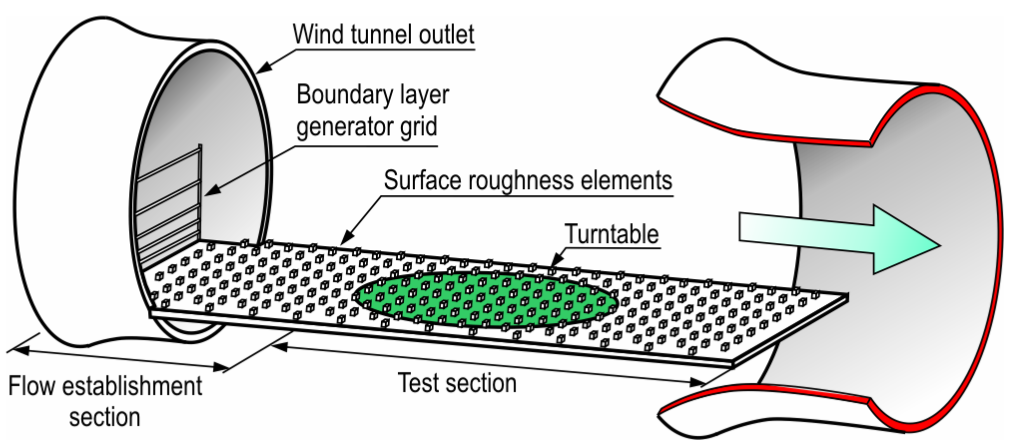


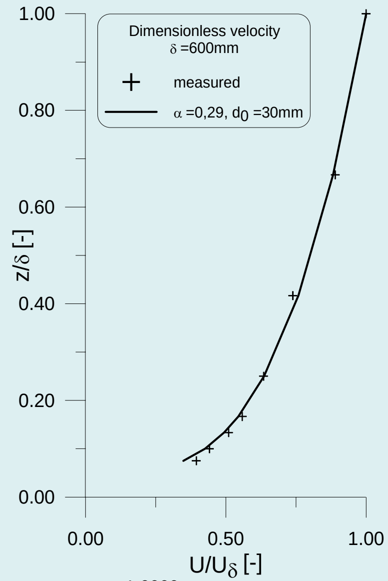


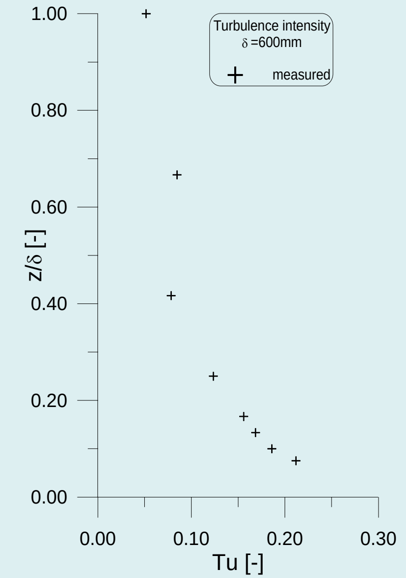


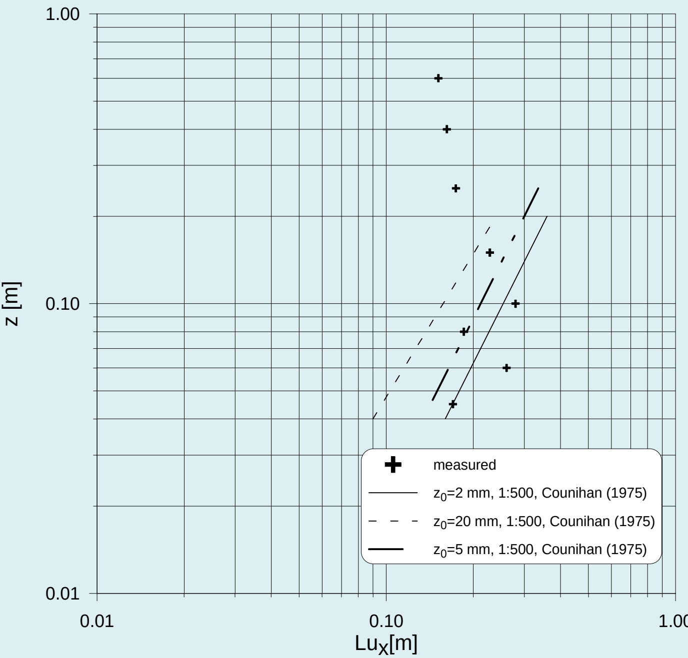


Modelling atmospheric boundary layer



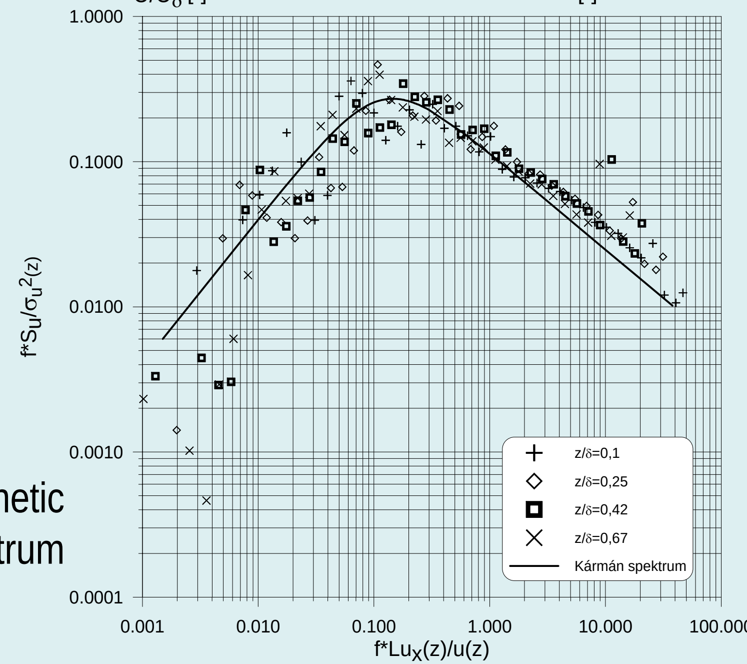




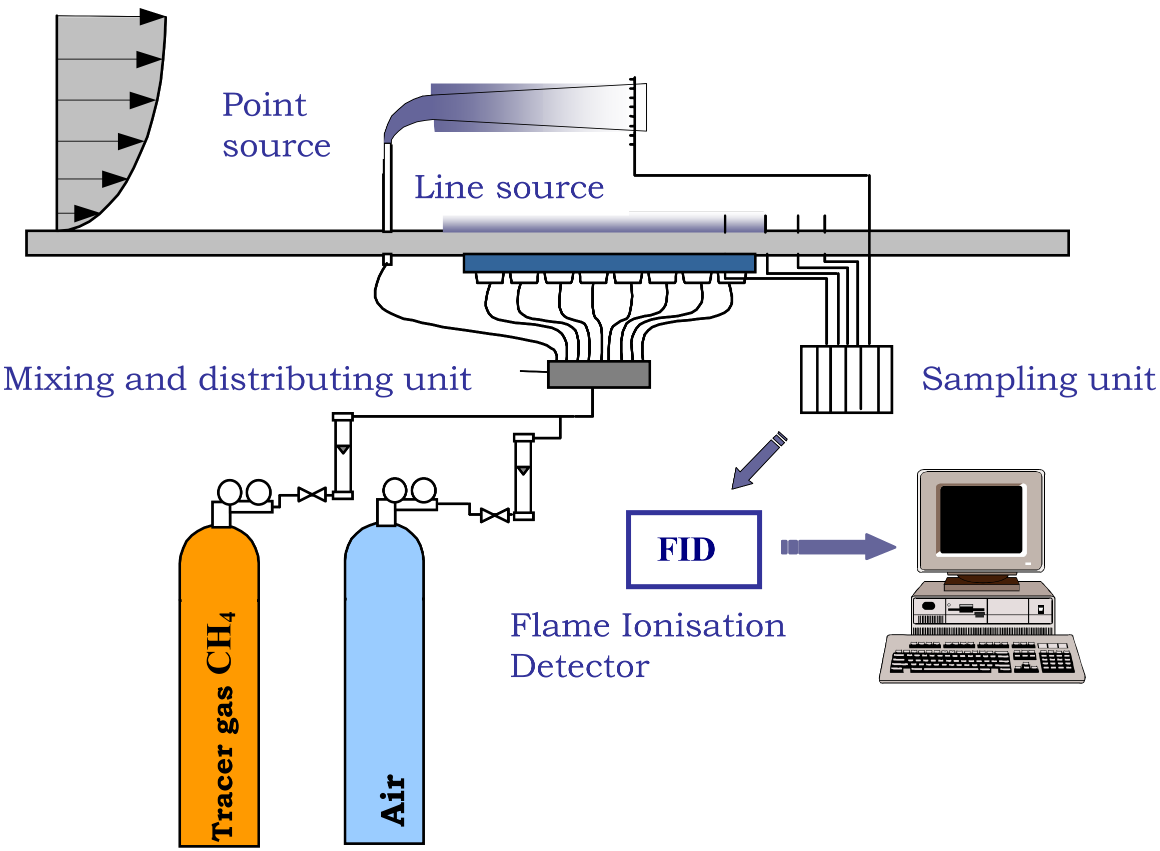


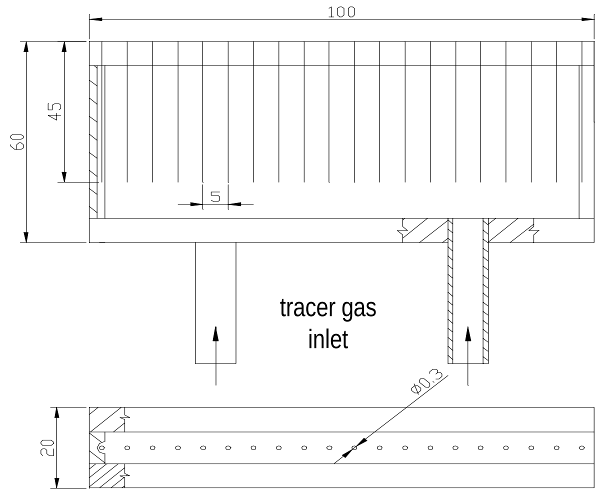
Length scale distribution

Turbulent kinetic energy spectrum



Tracer gas release, sampling, measurement





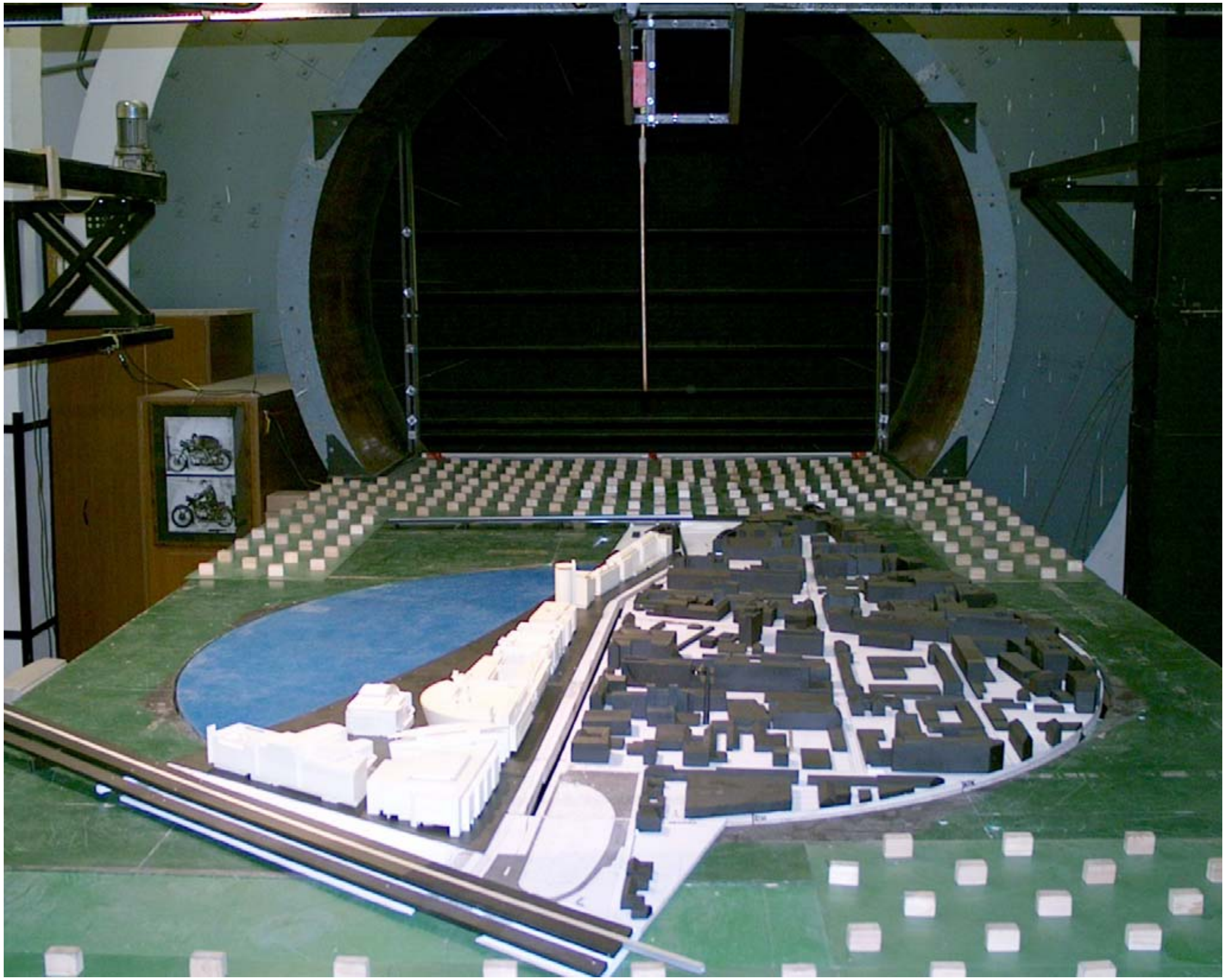
Model in the wind tunnel (NW-NNW)

Model scale: **1:500**

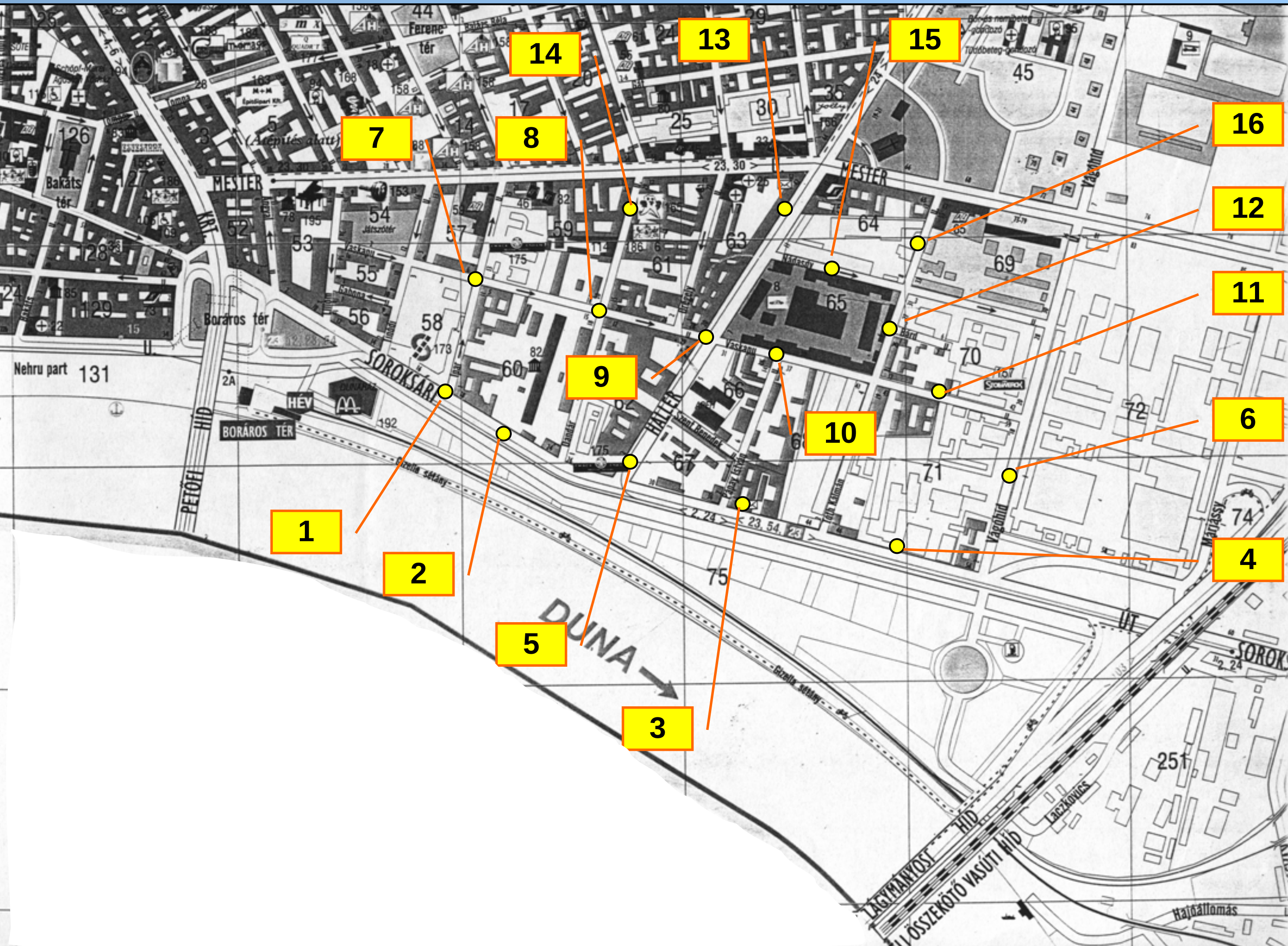
Diameter of the rotating table: **2 m**

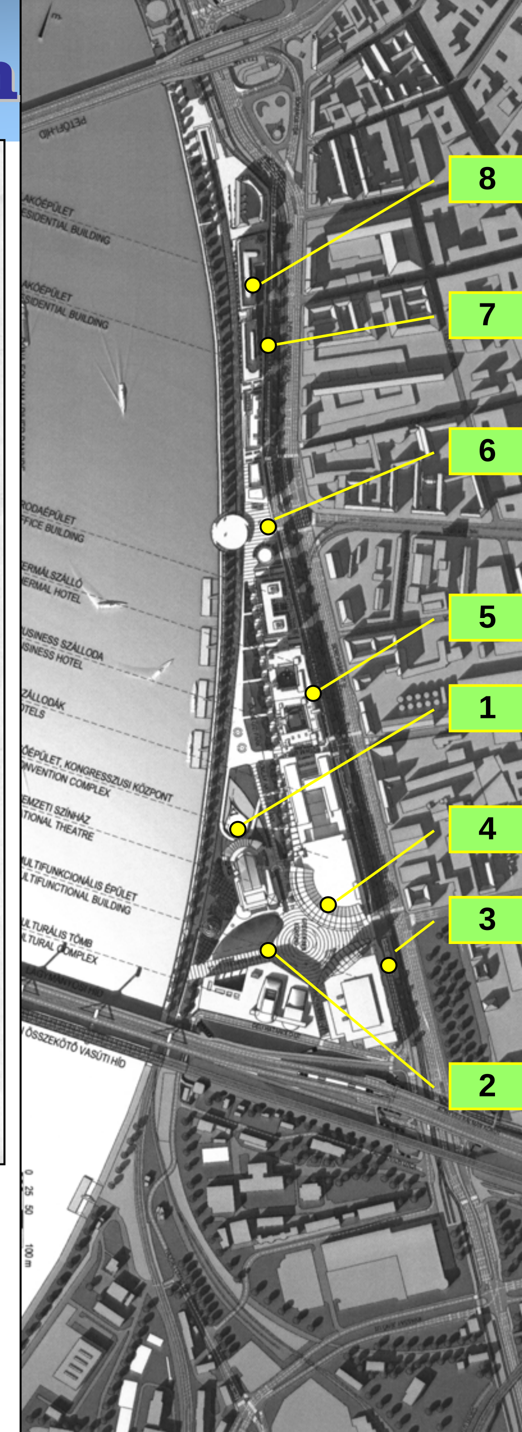
Modelled area: **1x1.5 km**

Re_H> 20,000



Wind tunnel measurement program





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

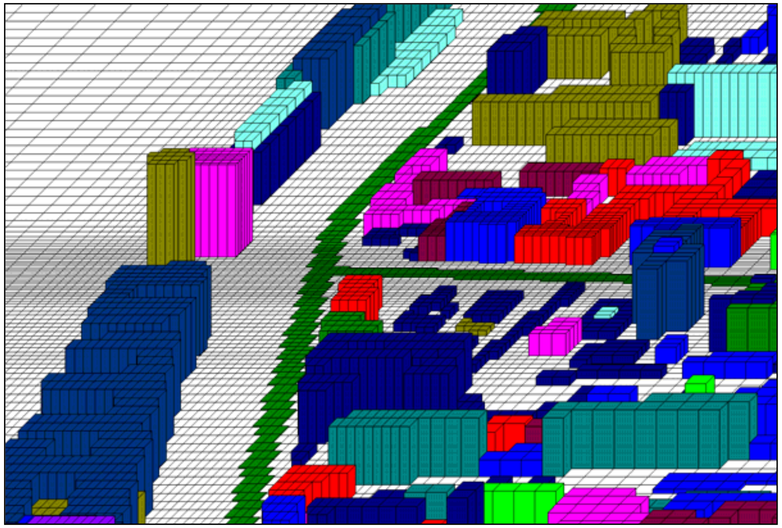
Numerical simulation of pollutant dispersion

MISKAM 4.22 / WinMISKAM

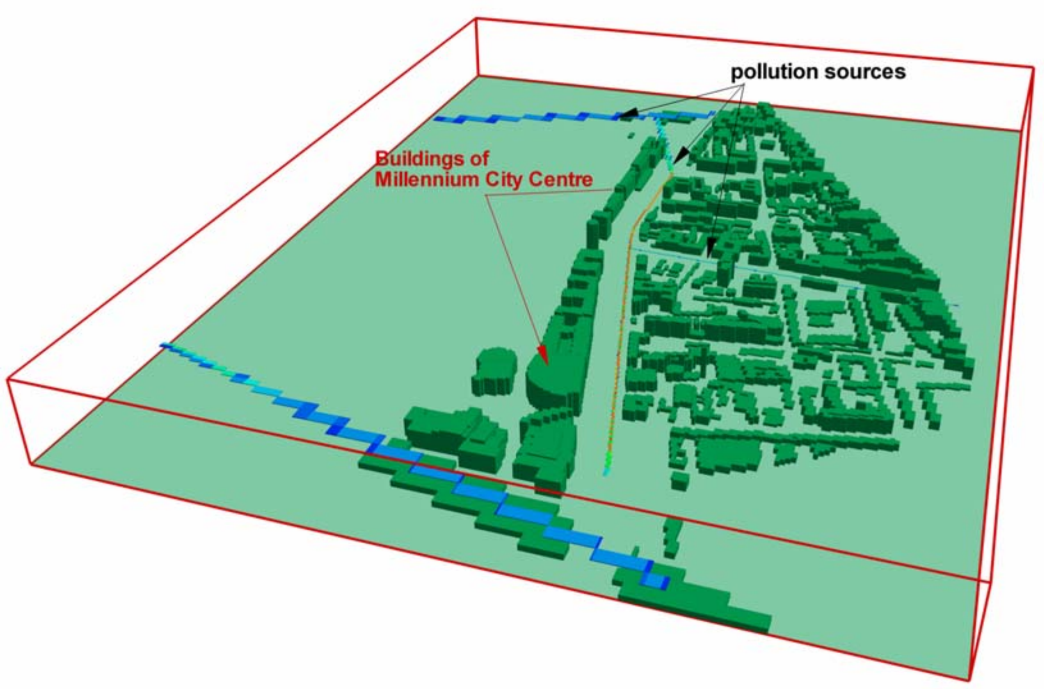
developed for modeling micro scale urban dispersion by Dr. J. Eichhorn, University of Mainz/Lohmeyer Engineers

- Non-equidistant Cartesian grid, k-ε turbulence closure
- Limitations for easier use (predefined boundary conditions, geometry)

- Two meshes: 900 000 and 2 million cells, 5 wind directions, 2 configurations)

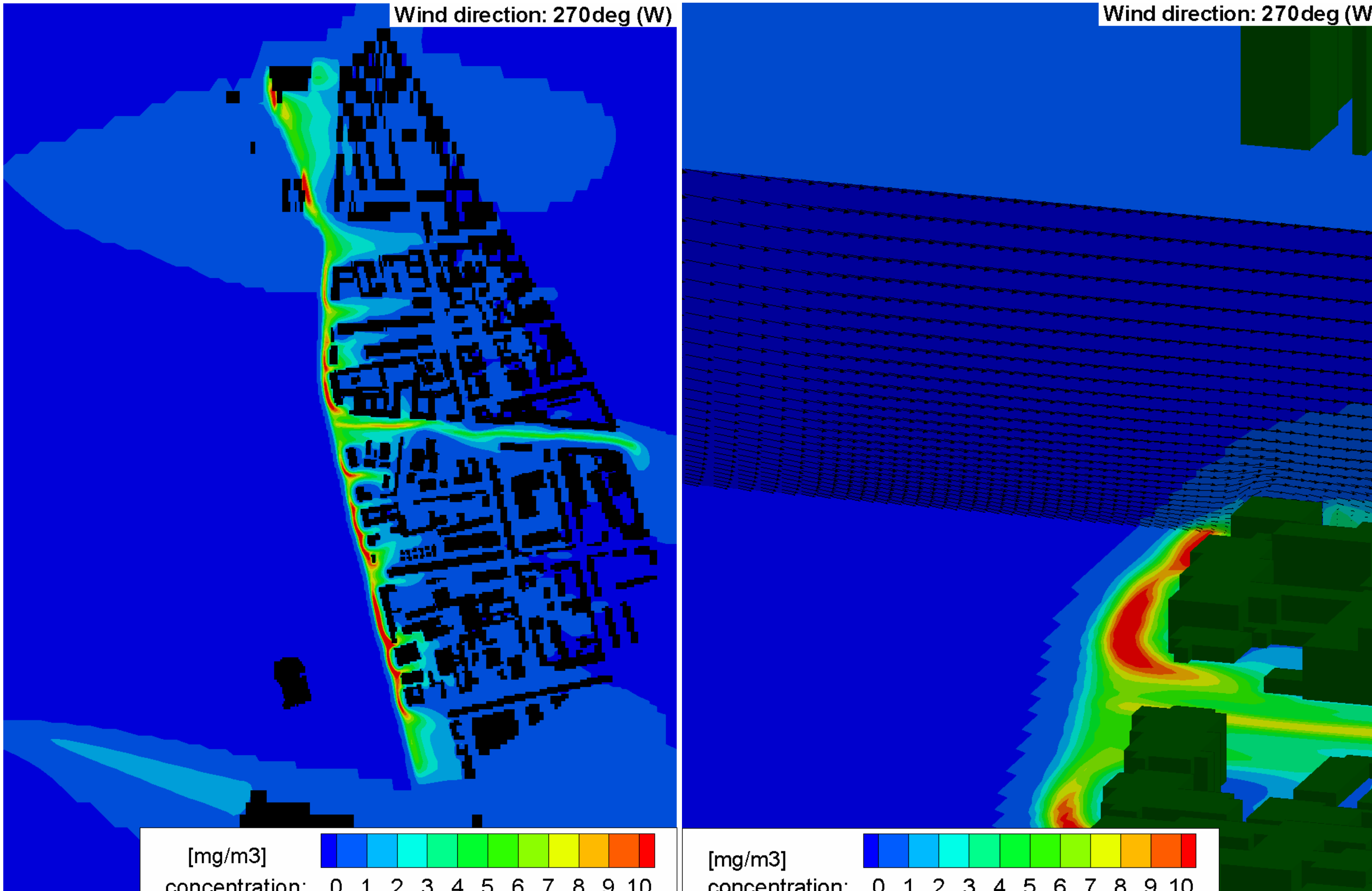


Modeling of buildings:
the grid consists of bricks,
all roofs are flat



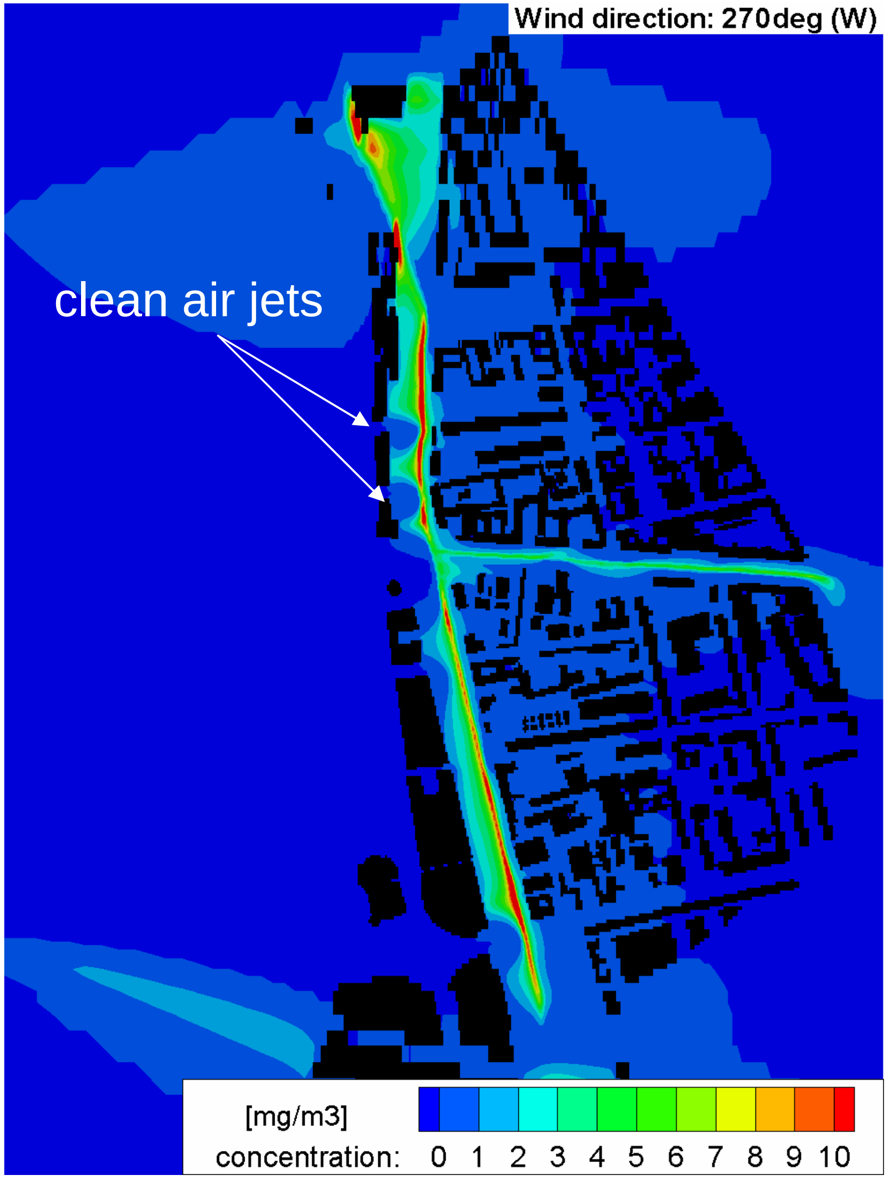
MISKAM Results I.

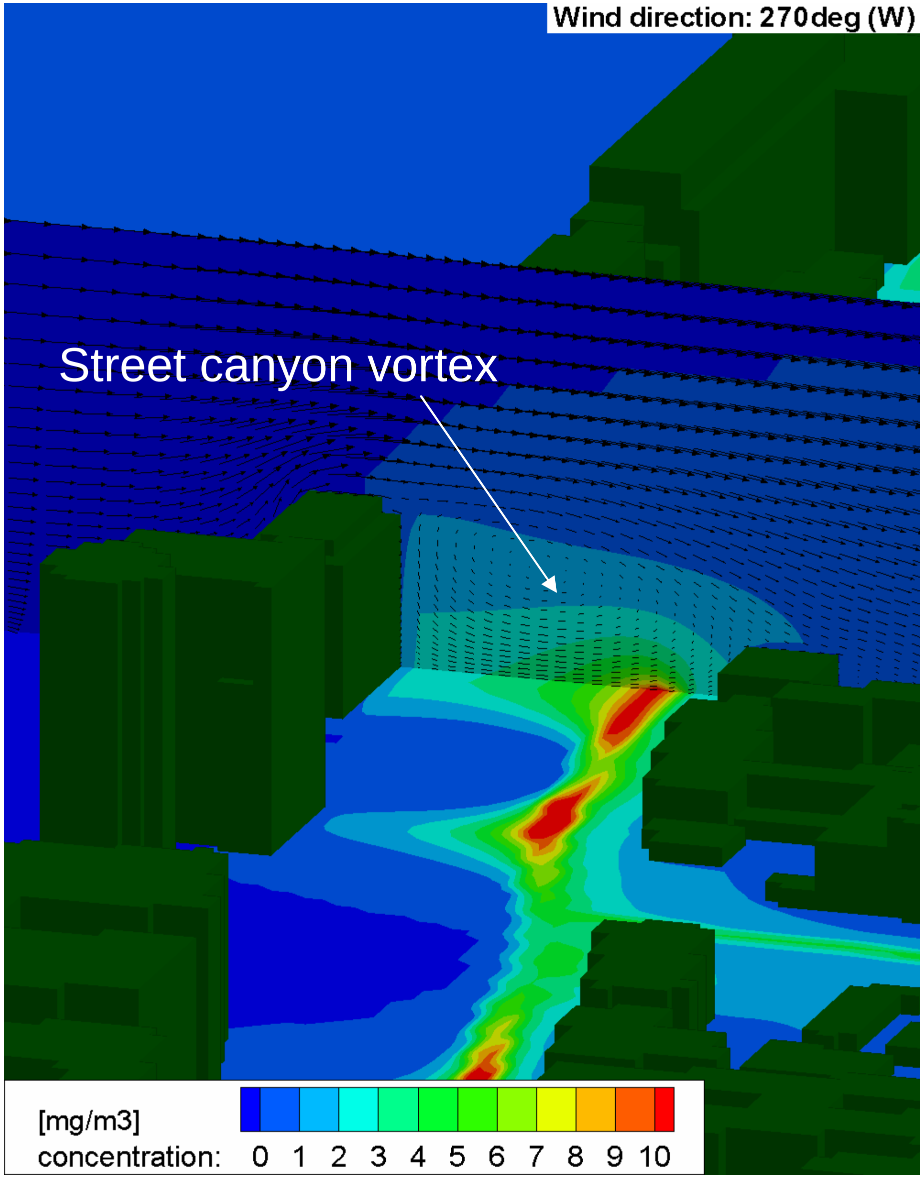
Concentration at 1.65m height **without new buildings, wind direction: West**



MISKAM Results II.

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



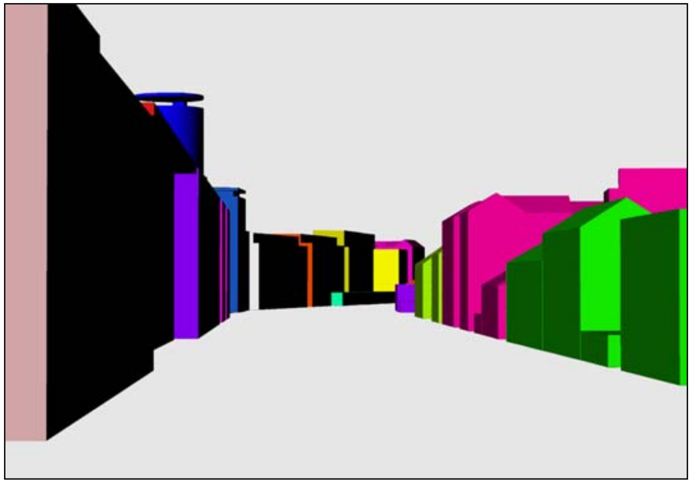


FLUENT version 6.1.

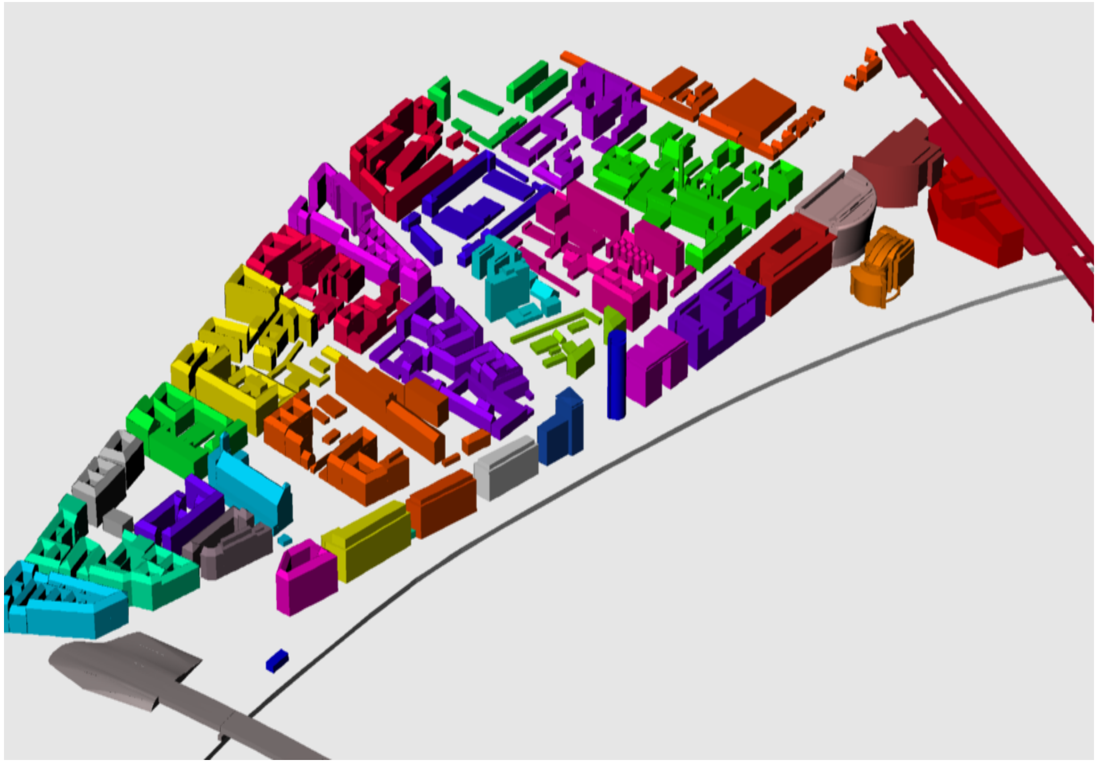
general purpose CFD software

- „realizable” k-ε turbulence model
- inlet boundary conditions from the wind tunnel test

- tetrahedral mesh, 1 million cells, 5 wind directions, 1 configuration)

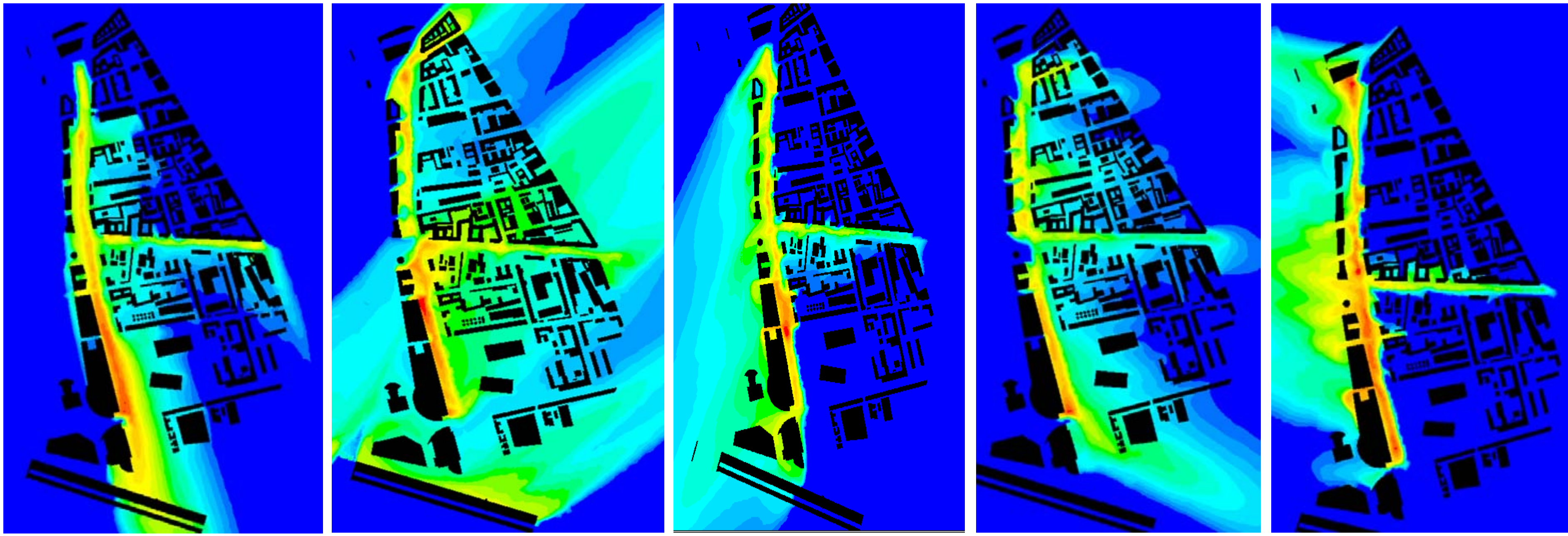


More accurate and
time consuming modelling
of buildings



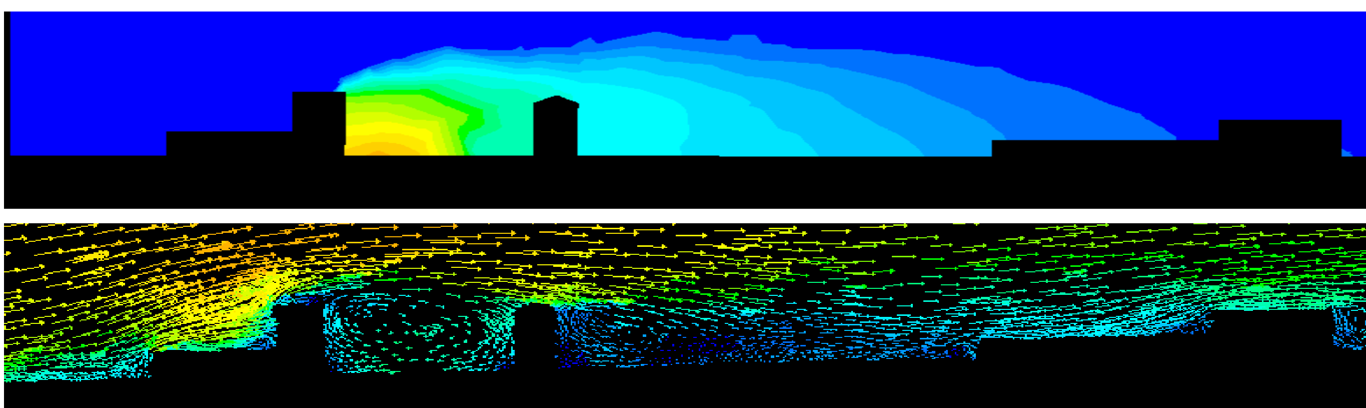
FLUENT results

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



NW-NNW SW-SSW N-NE W E

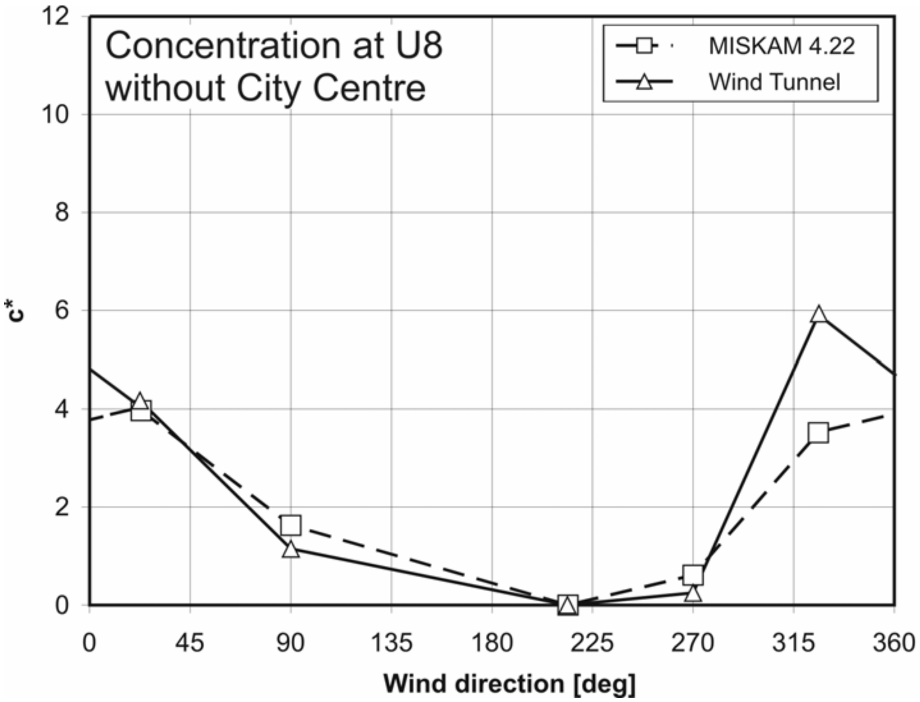
W

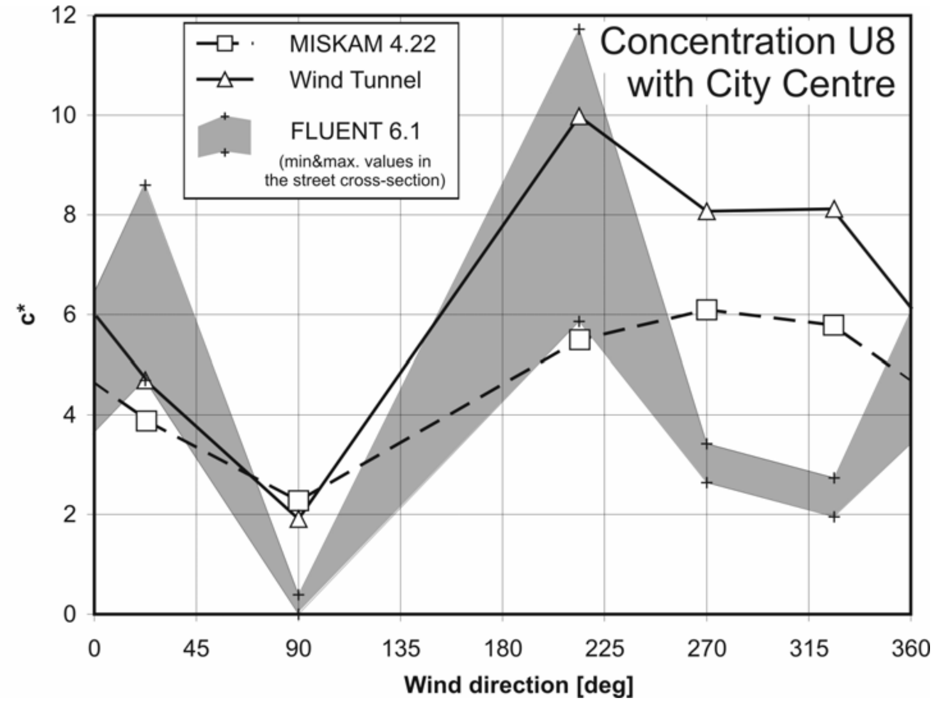


Comparison of wind tunnel and CFD results

Calculated and measured values
as a function of wind direction

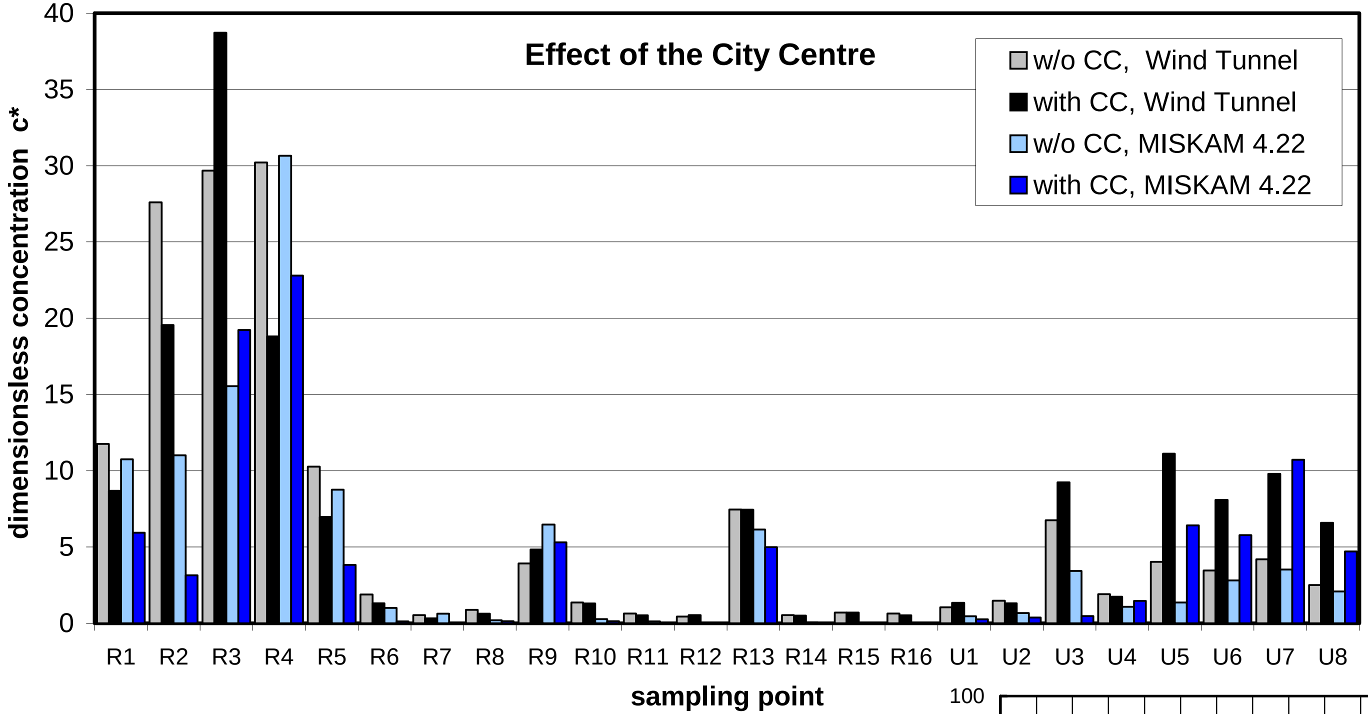
Example: point U8



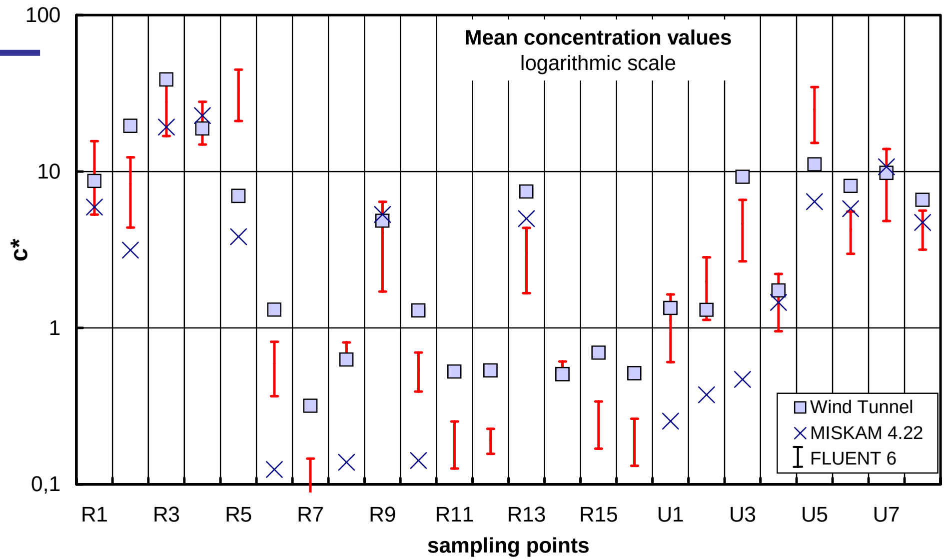


Wind tunnel / MISKAM 4.22 / FLUENT 6.1

Comparison of annual mean concentration

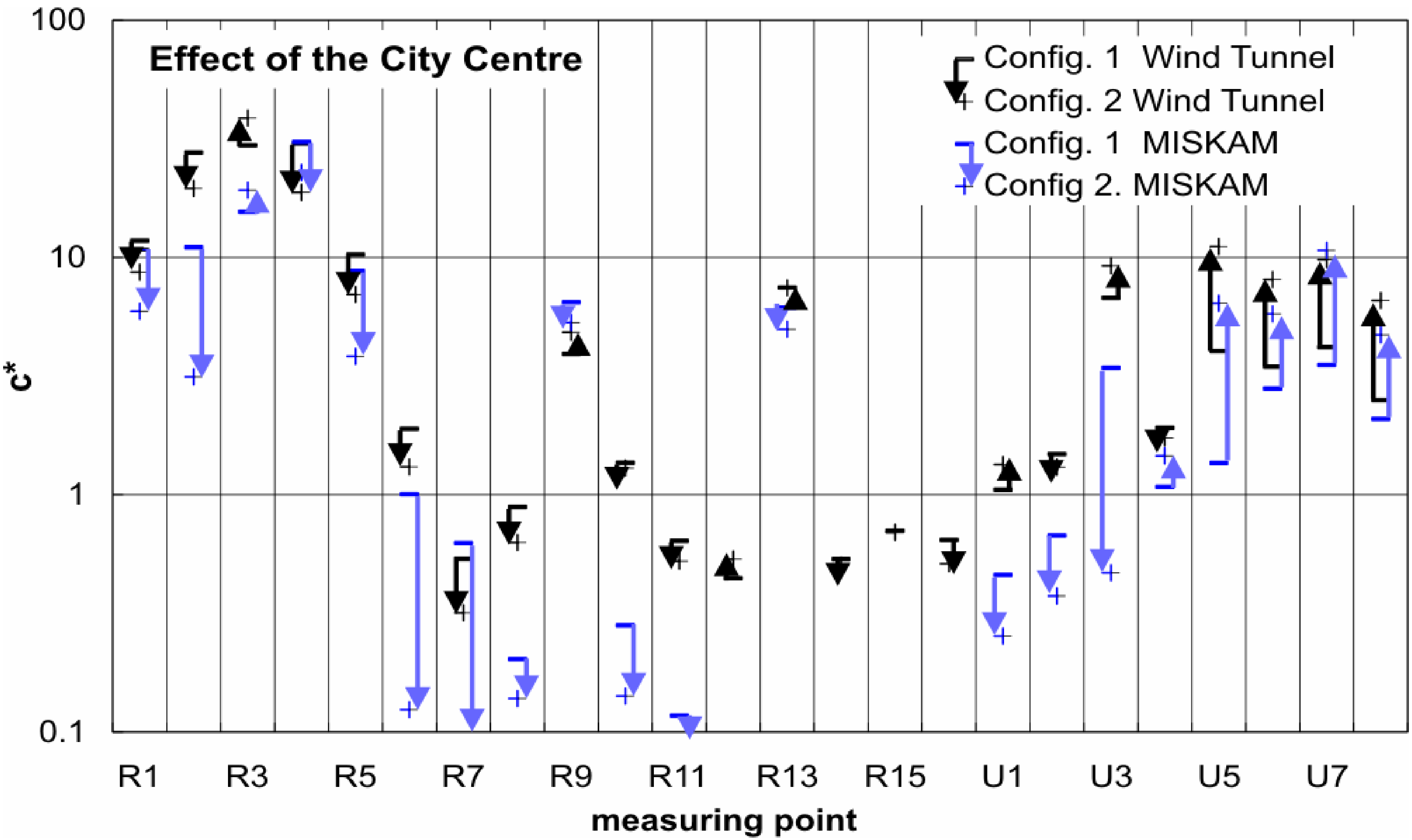


- MISKAM and wind tunnel results in all sampling points
- With and without City Centre



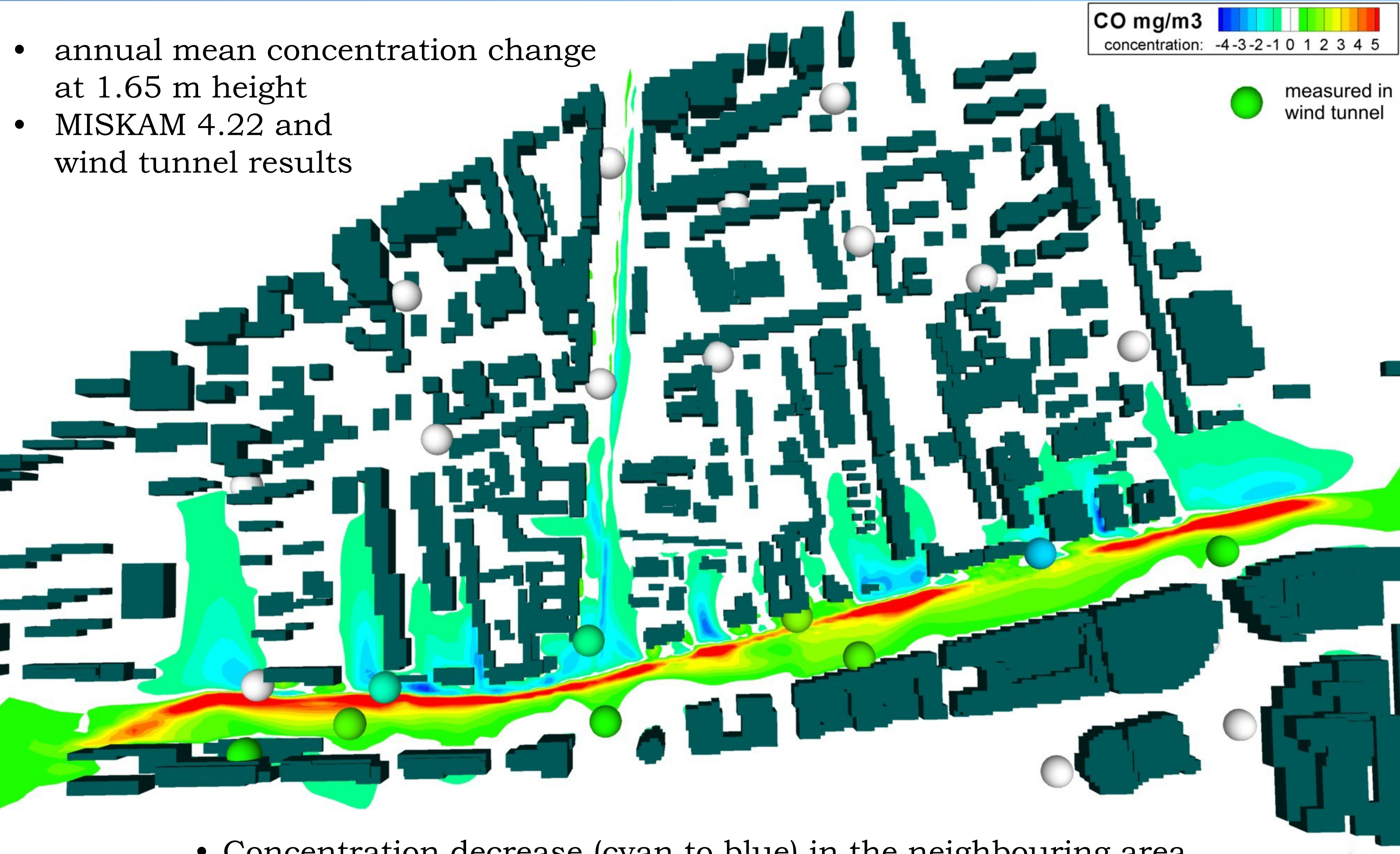
- wind tunnel, MISKAM and FLUENT results in all sampling points
- with City Centre
- logarithmic scale

Prediction of change of annual mean concentration I.



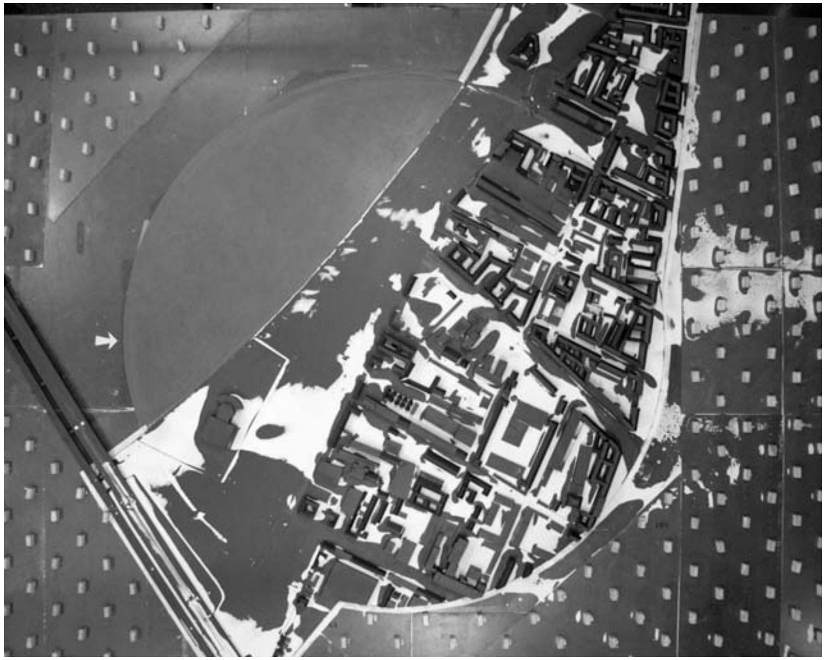
Prediction of change of annual mean concentration II.

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



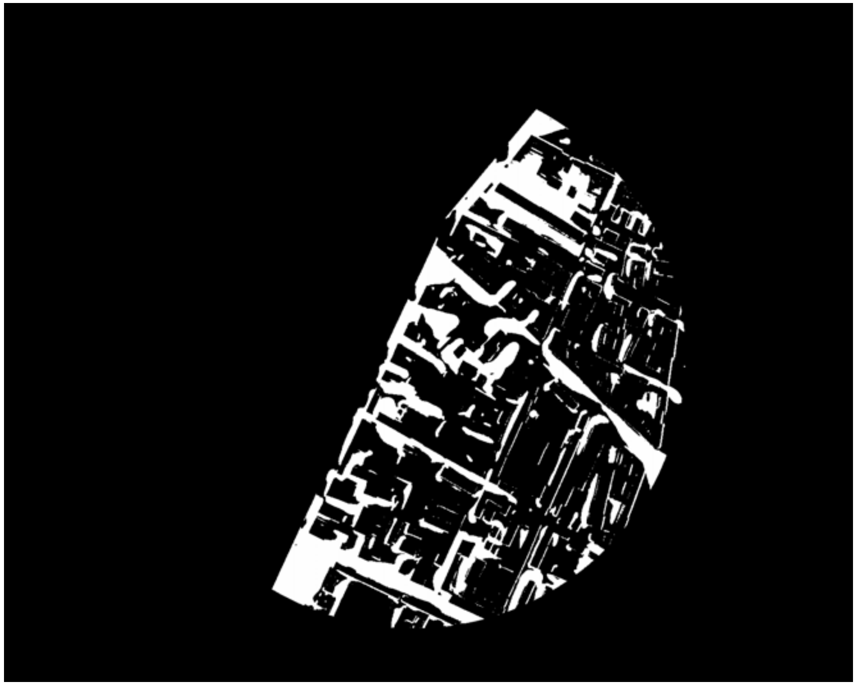
- Concentration decrease (cyan to blue) in the neighbouring area
- Concentration increase (green to red) in the street cross section (due to the 20% traffic growth, and the street canyon)

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

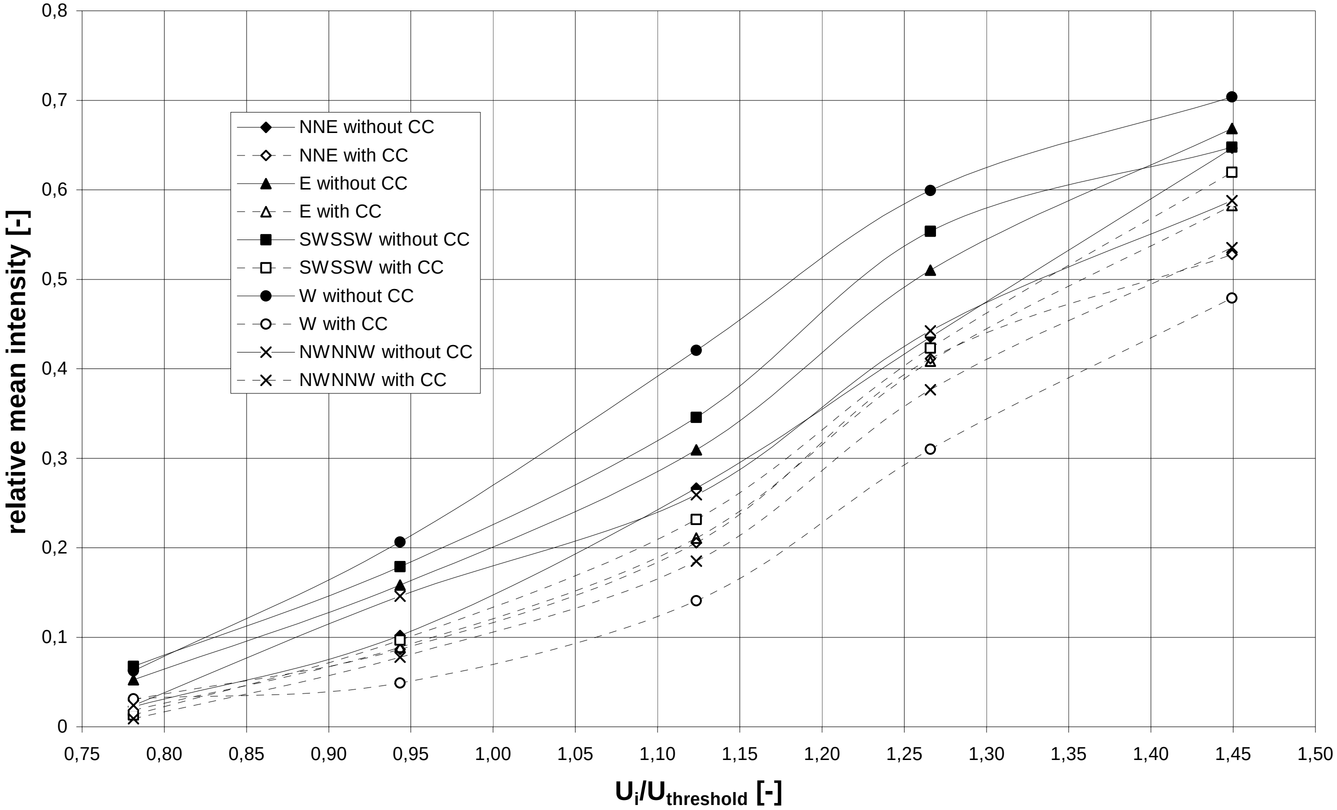
•Mask: streets and squares are transparent roofs are black (colour code: Icc= 0)



•Difference image (ref - v≠0 m/s, buildings and area covered by sand are black, Icc= 0, streets and squares where the sand particles are removed became white Icc= 255)

•The mean and relative mean intensity (RMI) can be calculated

Determination of wind climate with sand erosion II.



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

$$RMI = \frac{\overline{I}_{DP}}{\overline{I}_{ref}}$$

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 of average ventilation of a district.

Acknowledgement

Authors acknowledge the support of the following OTKA (Hungarian Scientific Research Fund) projects:

- T037651 - Simulation of turbulent flows
- T 037730 - Theoretical and experimental investigation on dispersion of pollutants emitted by ground vehicles in urban and natural environment
- T049573 - Modelling of development and methods of control of heat islands by using computational fluid dynamics.

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

Tamás LAJOS, István GORICSÁN, Márton BALCZÓ

Thank you for your attention

MŰEGYETEM 1782

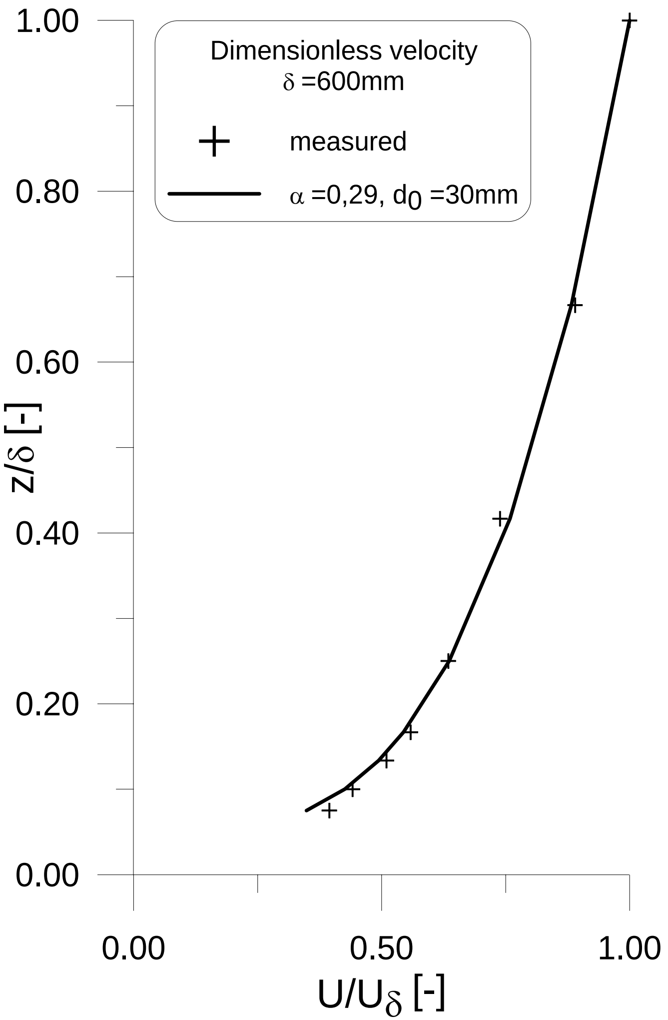
Budapest University of
Technology and Economics

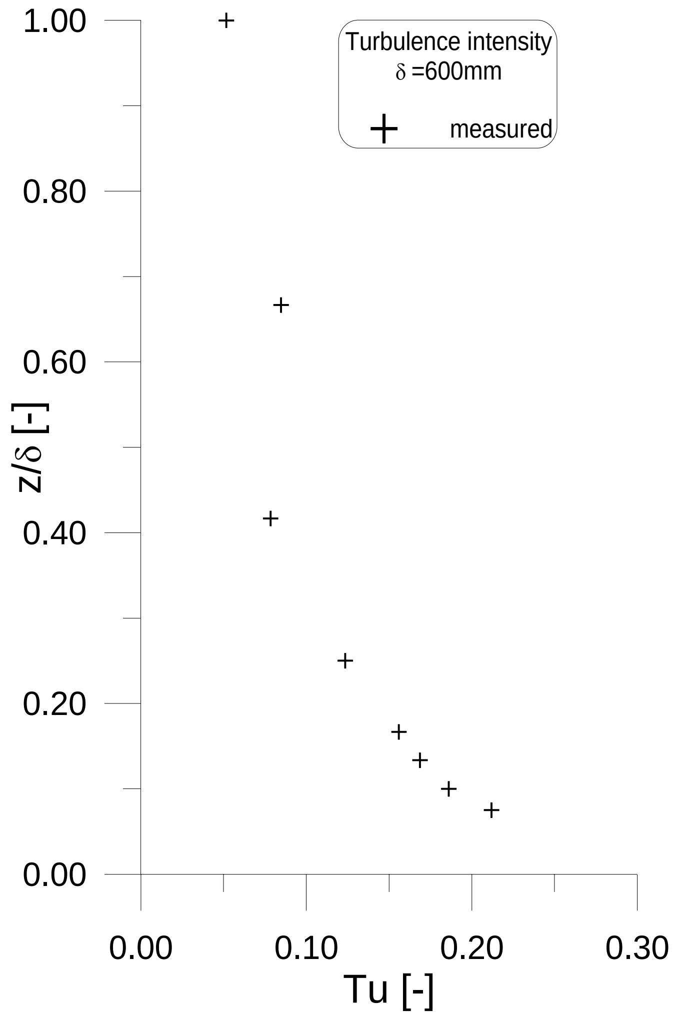
Department of
Fluid Mechanics

PHYSMOD 2005

Boundary layer parameters

Velocity and turbulence profile measured with CTA



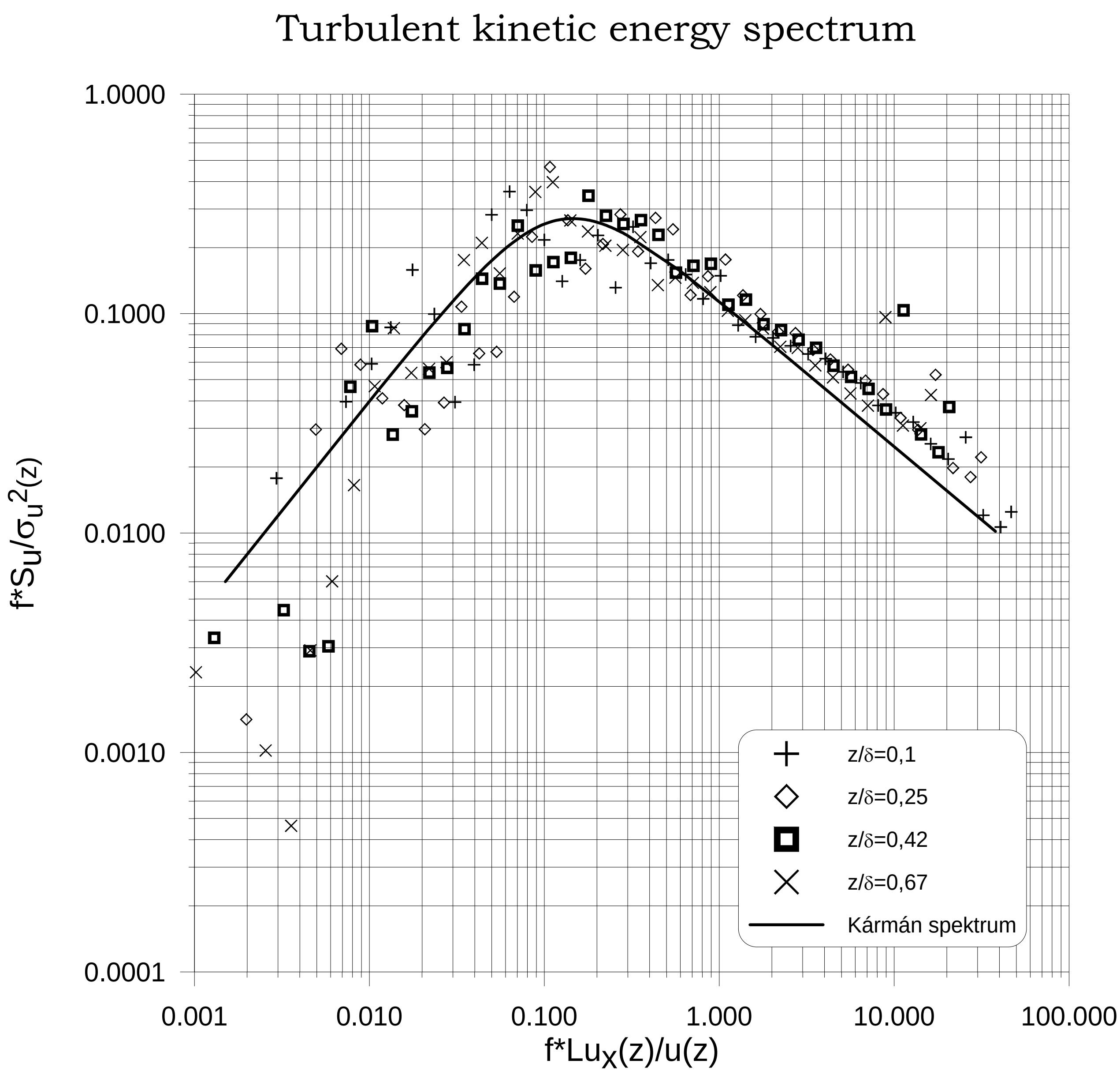


$$\frac{U(z)}{U_{ref}} = \left(\frac{z - d_0}{z_{ref} - d_0} \right)^{\alpha}$$

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

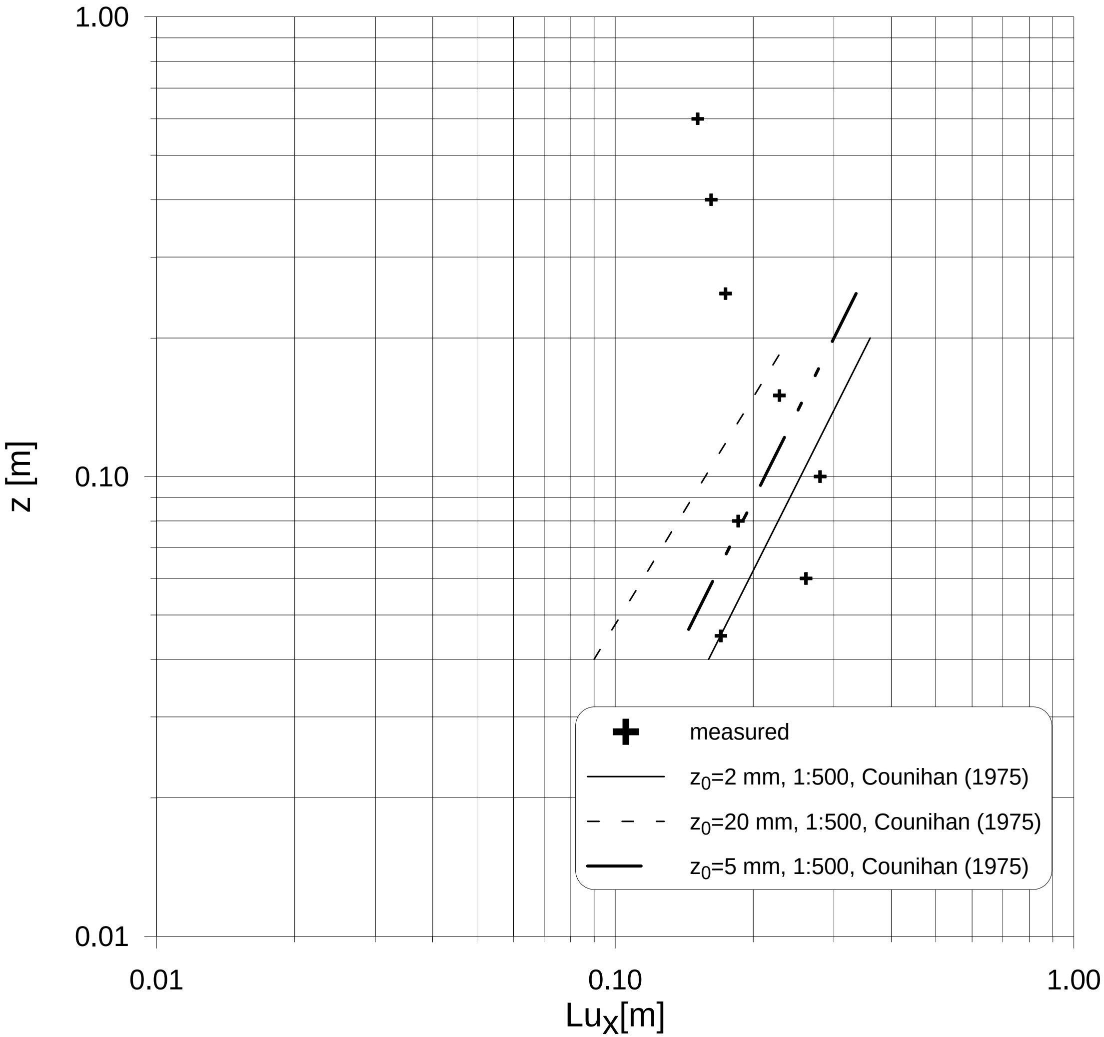
	Urban boundary layer
Roughness height z_0 [mm]	6,56
Displacement height d_0 [mm]	30
Profile exponent [-]	0,29
Boundary layer thickness, δ [m]	0,6
Model-scale	1:500

Boundary layer parameters



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