WIND TUNNEL MODELLING OF VENTILATION AROUND AN URBAN SQUARE

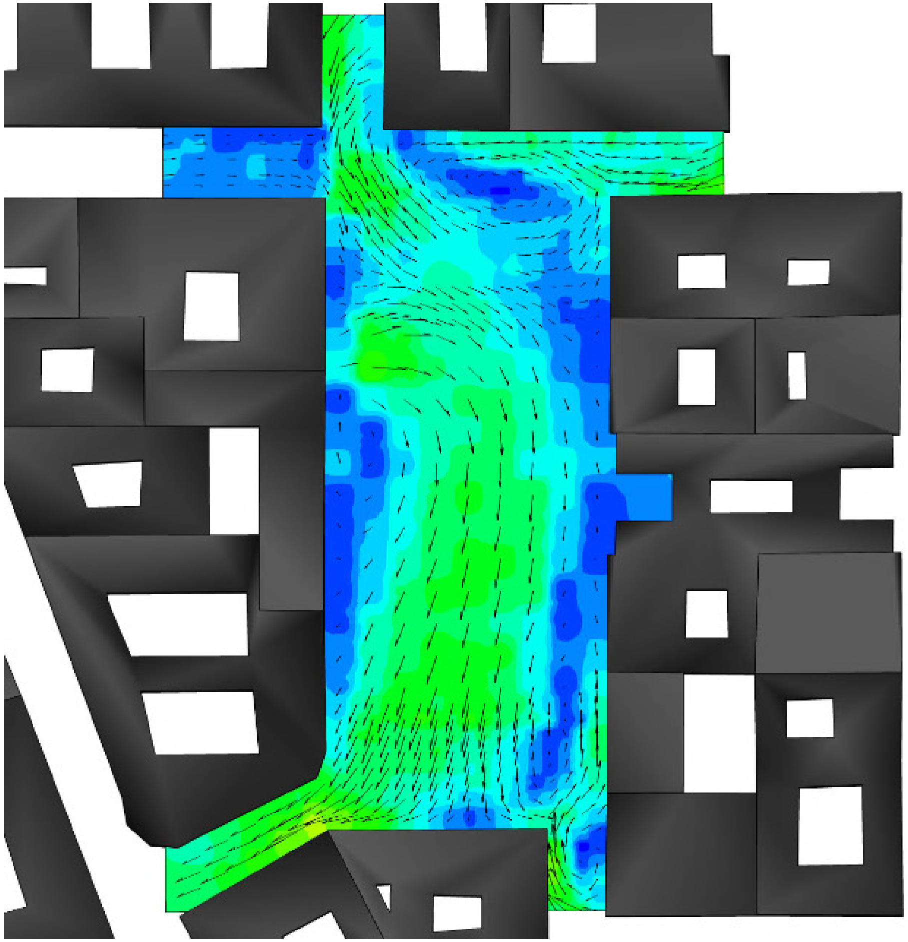
MultiScience - XXVIII. microCAD International Multidisciplinary Scientific Conference

10-11 April 2014

András Tomor
MSc student

Márton Balczó
assistant research fellow

Budapest University of Technology and Economics (BME)



Theodore von Kármán Wind Tunnel Laboratory

BME Department of Fluid Mechanics

Air quality of large cities

- Traffic pollution
- Concentration of contaminants – busy roads (nearby **squares**)
- Pollutant dispersion – flow characteristics affected by the nearby buildings
- Is the ventilation of a street or a square satisfactory?

⇓

Investigation of ventilation around urban squares

Air pollution and flow phenomena at urban squares were hardly ever dealt with

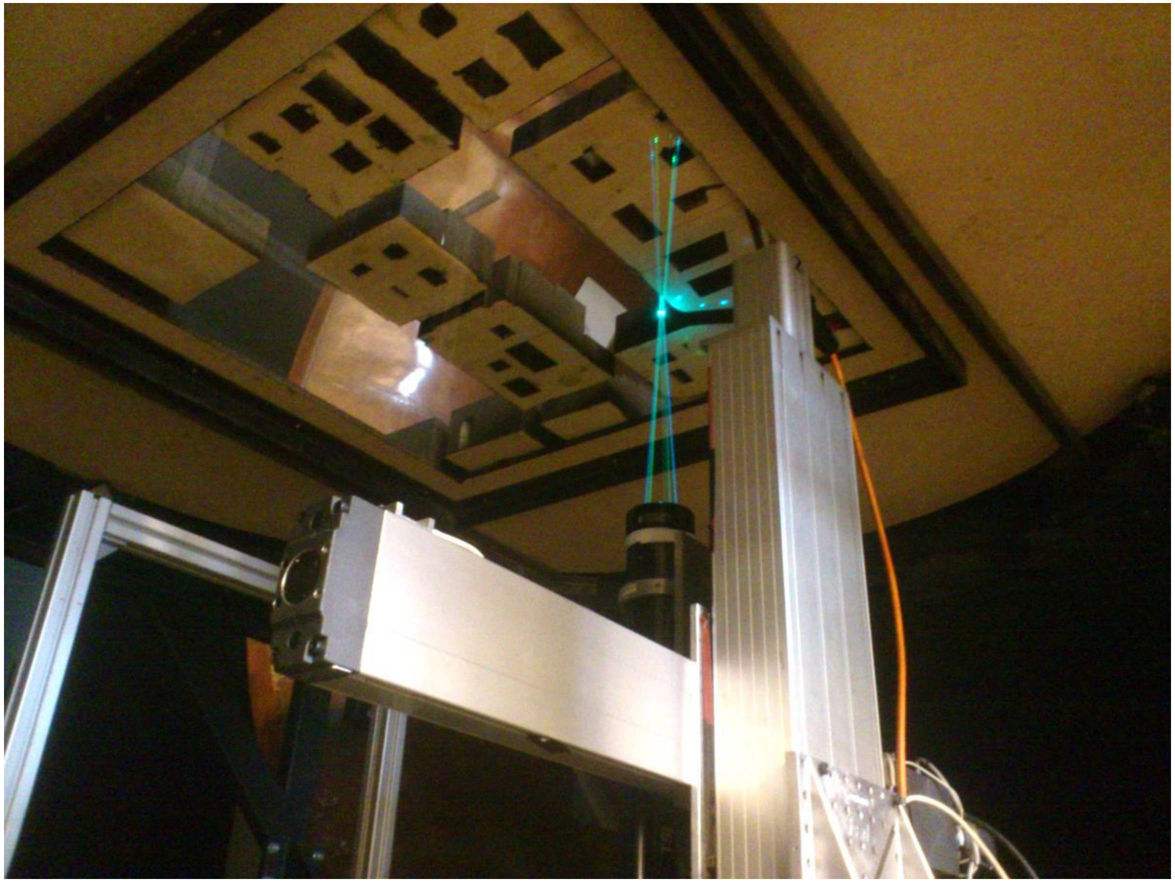
József Nádor Square in downtown Budapest – next to the extremely busy József Attila Street

Underground car park → **Department of Fluid Mechanics**, simulations (former studies)

Main objective: Investigation of ventilation around József Nádor Square with wind tunnel measurements (in the Large Horizontal Wind Tunnel)

Model construction and measurements

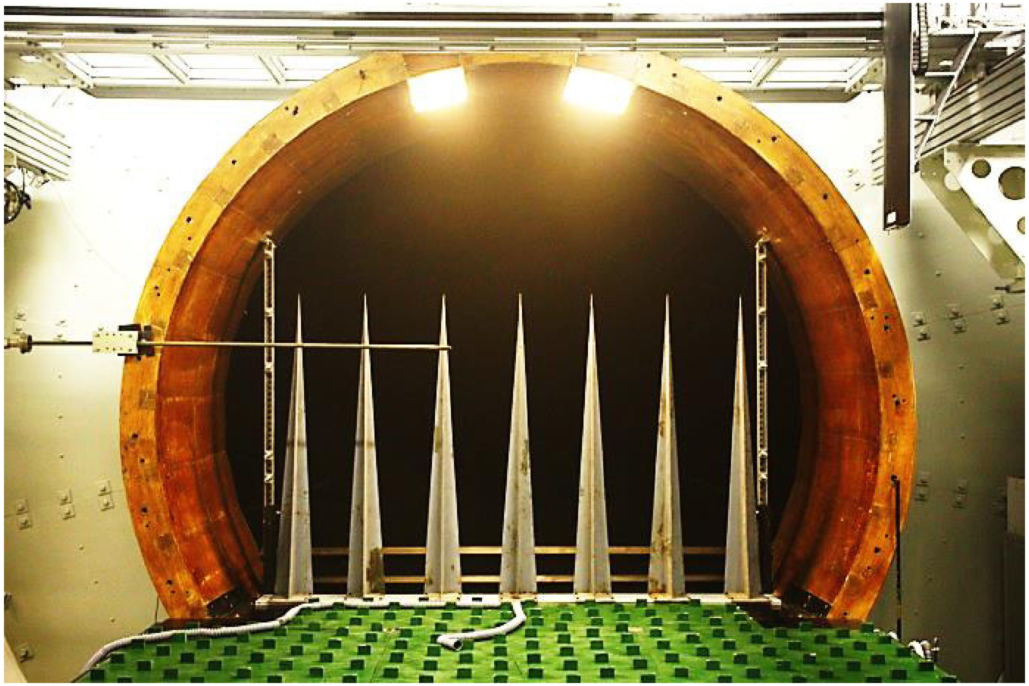
- Wind tunnel model of a quarter – modeling an **urban-type atmospheric boundary layer** → drawing correct conclusions
- Boundary layer measurements: setting the parameters of the boundary layer (urban-type)
- Determining the proper **model scale** (according to the boundary layer measurements
- Model construction
- Flow measurements on the wind tunnel model of József Nádor Square



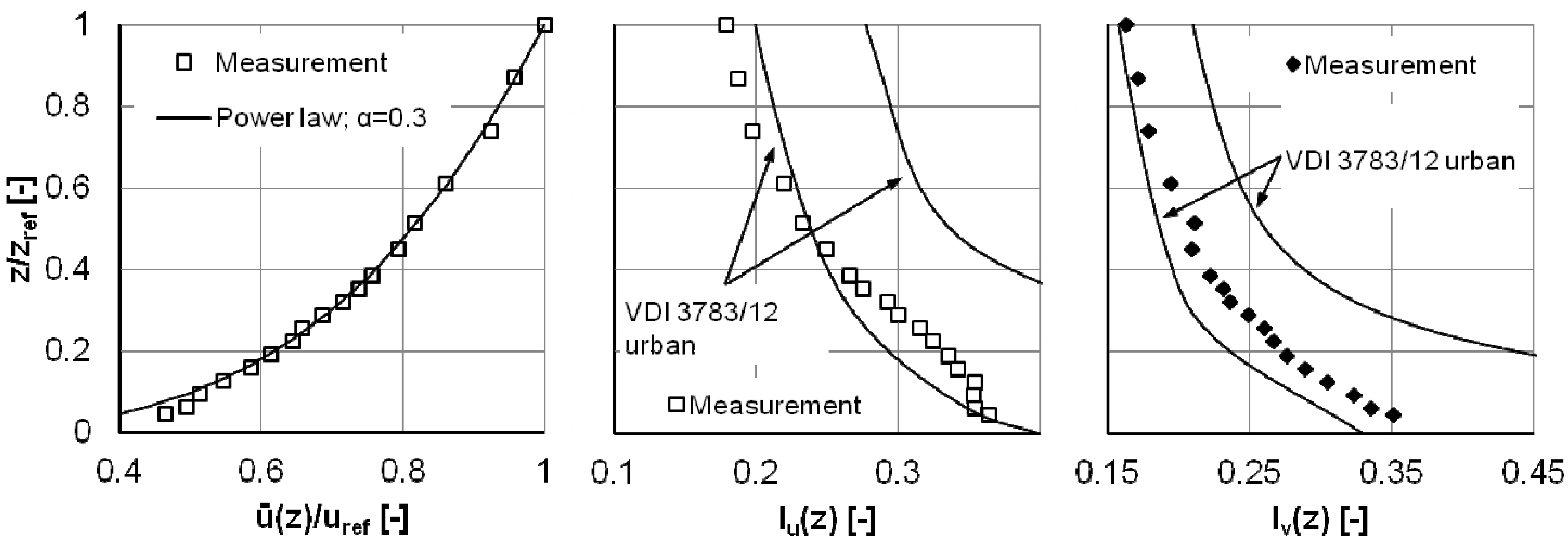
Measurements: using **LDV**

Special arrangement:
The fiber-optic LDV probe accessed to the flow **from below through** a pane of **glass** ⇒ the flow is absolutely not disturbed

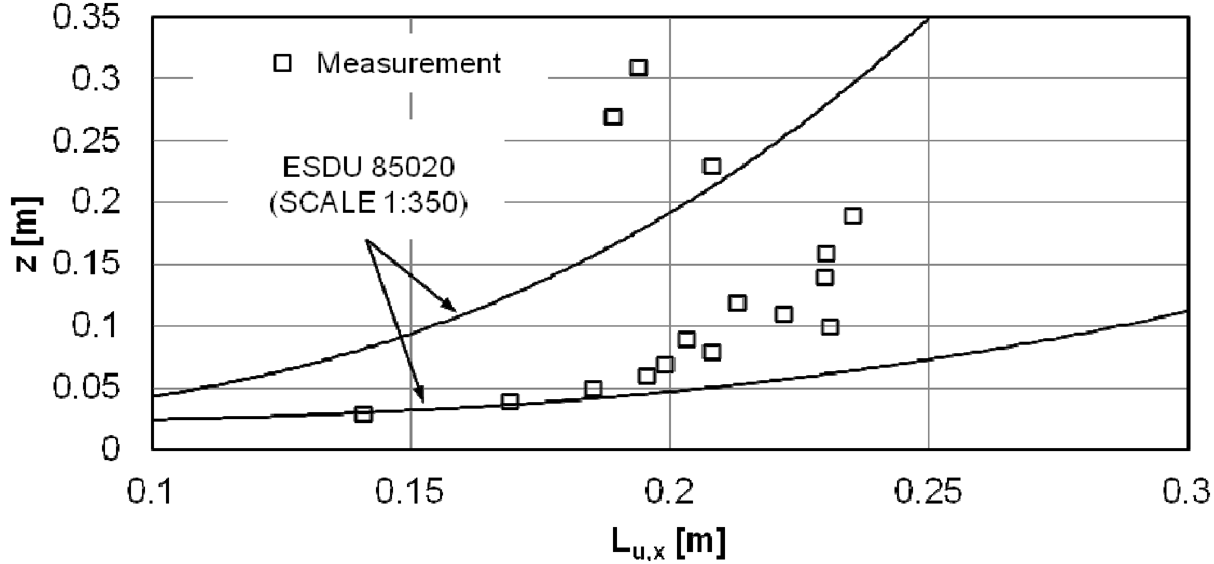
Modeling an urban-type atmospheric boundary layer



Vortex generators, crossbars and roughness elements in an appropriate arrangement ⟶ into the **preparatory section** of the wind tunnel

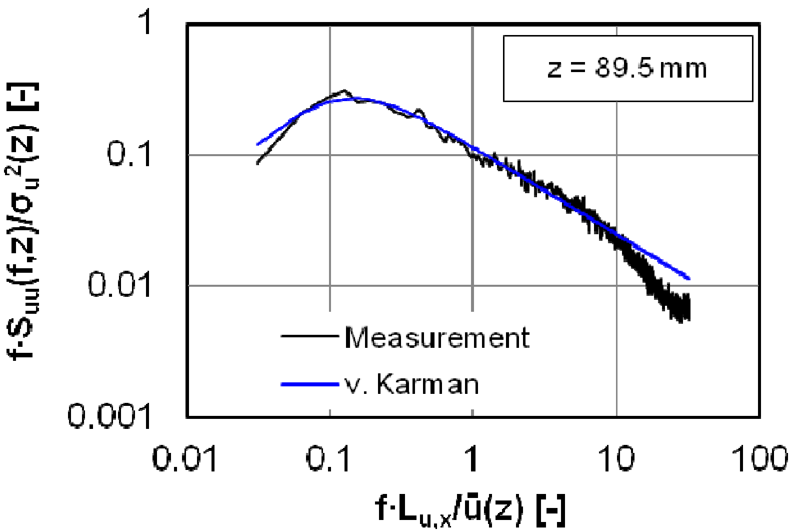


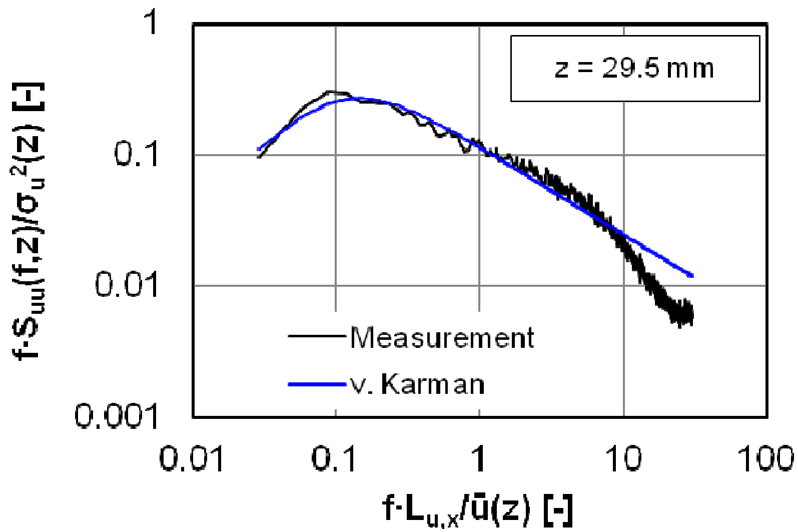
Modeling an urban-type atmospheric boundary layer



$$L_{u,x} = \int_0^\infty R_{uu}(\Delta x)\, d\Delta x$$

$$\sigma_u^2 = \int_0^\infty S_{uu}(f)\, df$$

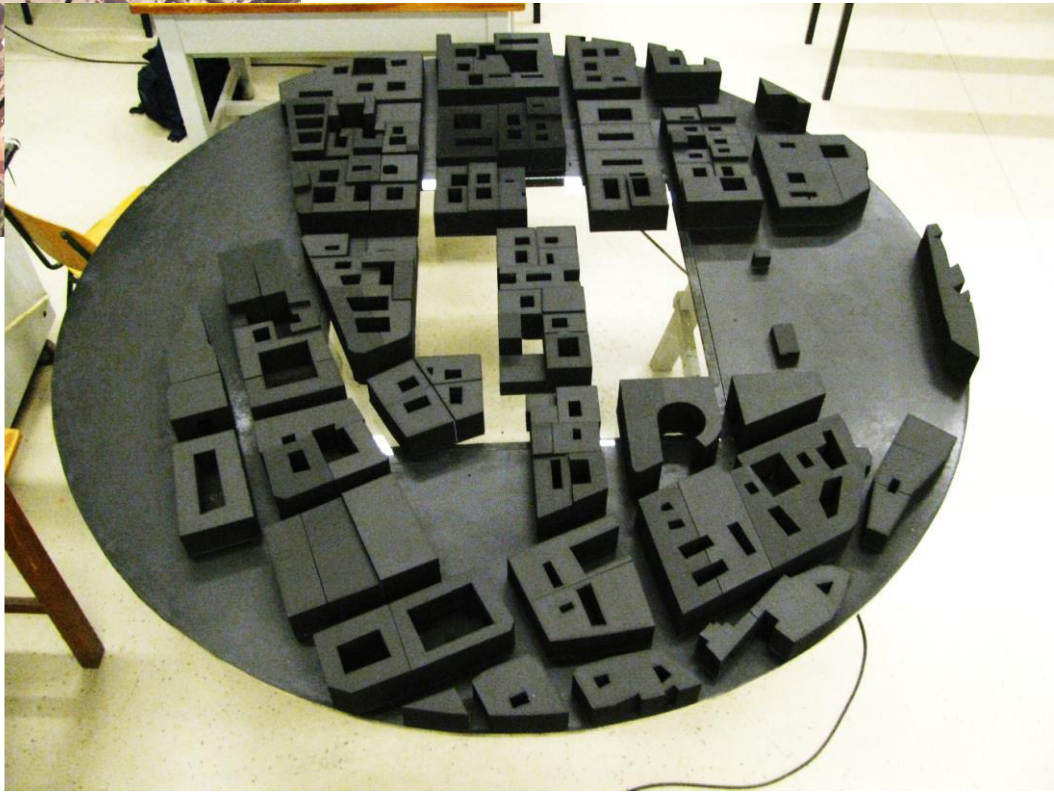




Model construction

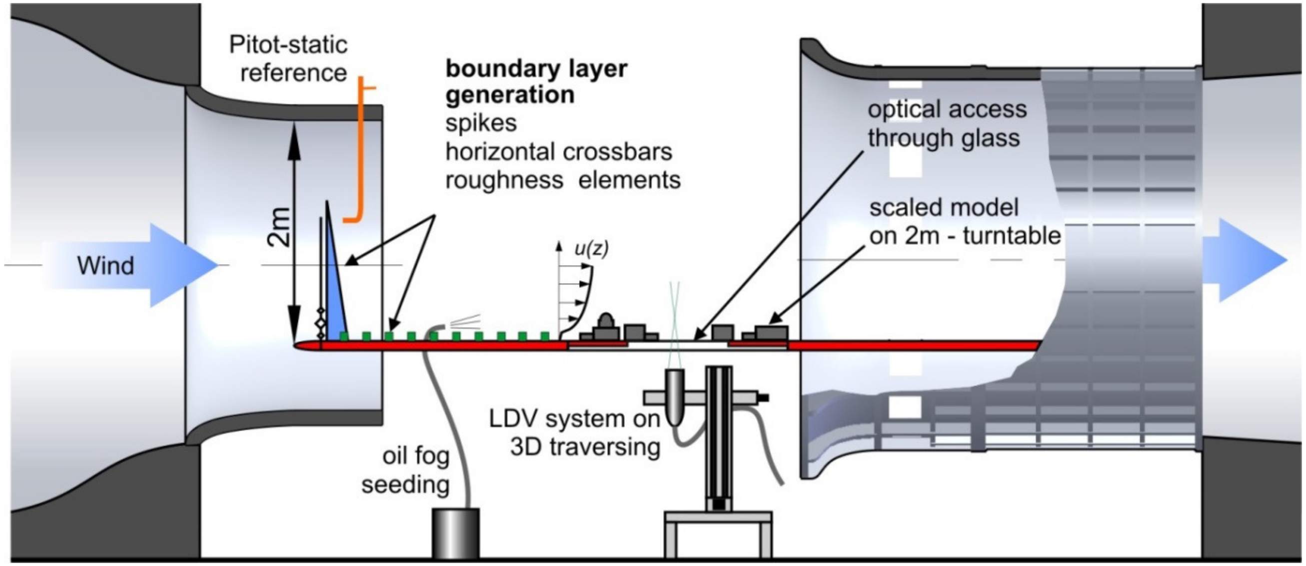
- **Model scale: 1:350**
- Wooden circular plate with a diameter of **2 m** → **all the buildings** were modelled within a circular domain with a diameter of **700 m**

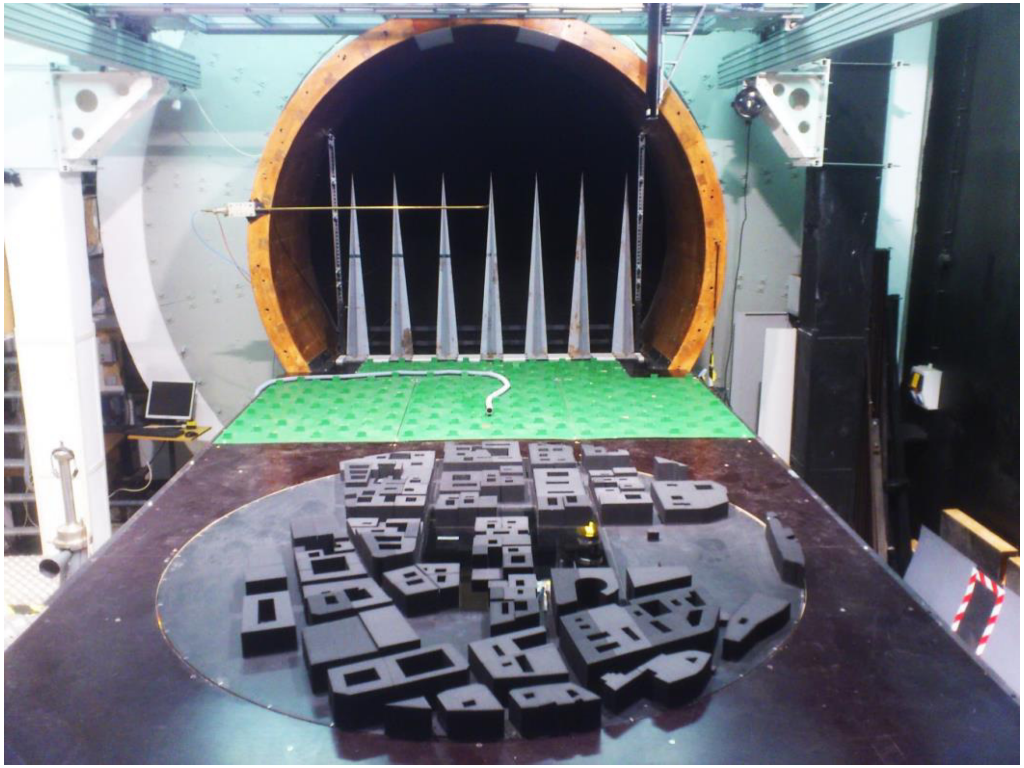
- Precise model
- Slightly simplified geometry → optimized for CFD validation



Measurements on the wind tunnel model of József Nádor Square

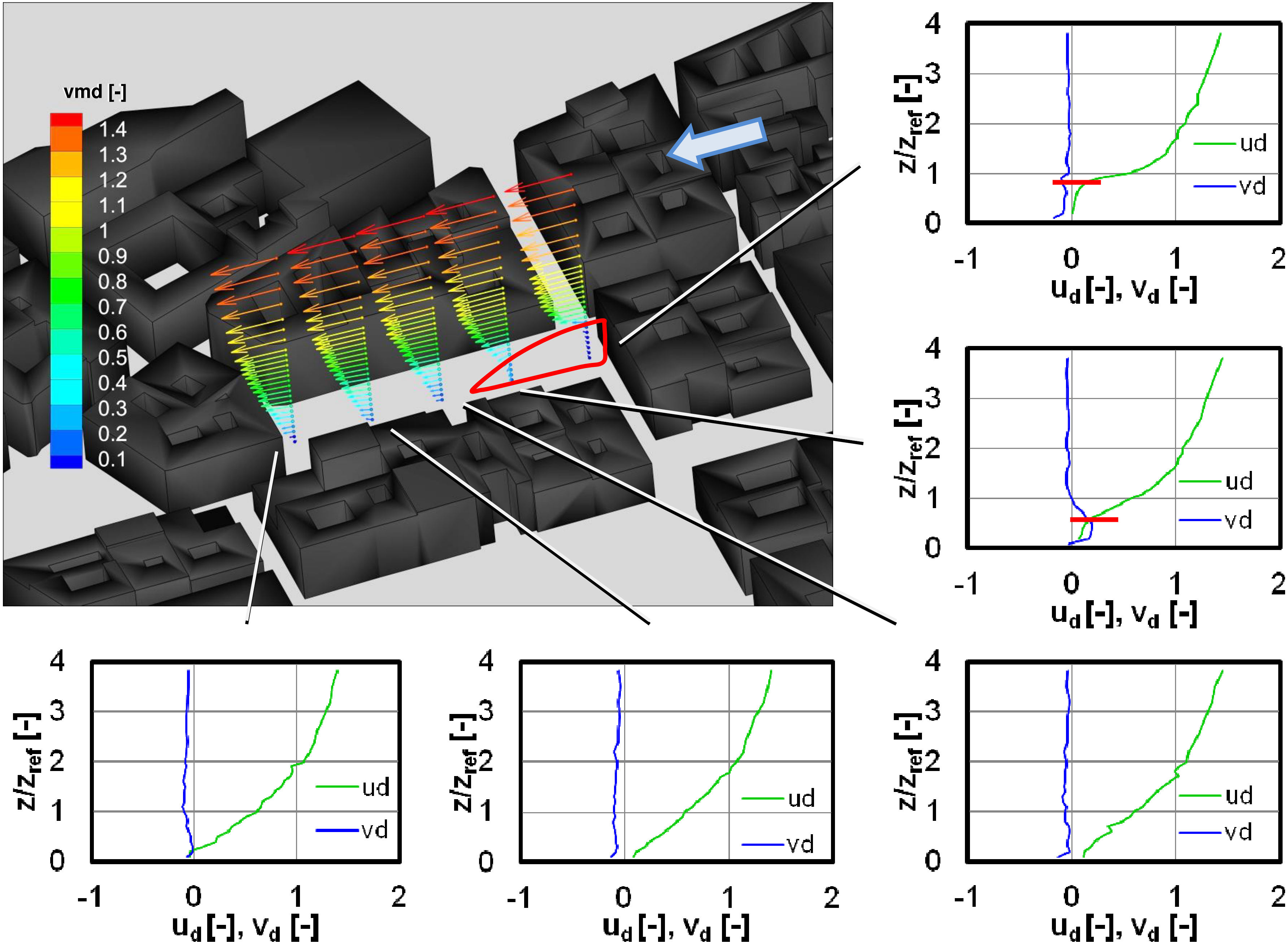
- **Vertical profile** measurements – **10 profiles** at the square and in the streets crossing the square
- **Horizontal planes** – **3 planes**:
  - **0.25h** (20 mm)
  - **0.5h** (40 mm)
  - **h** (80 mm)
  - 568 measurement points/plane
- Wind direction: **northern**
- Wind speed (at the Pitot-Static probe): 12 m/s



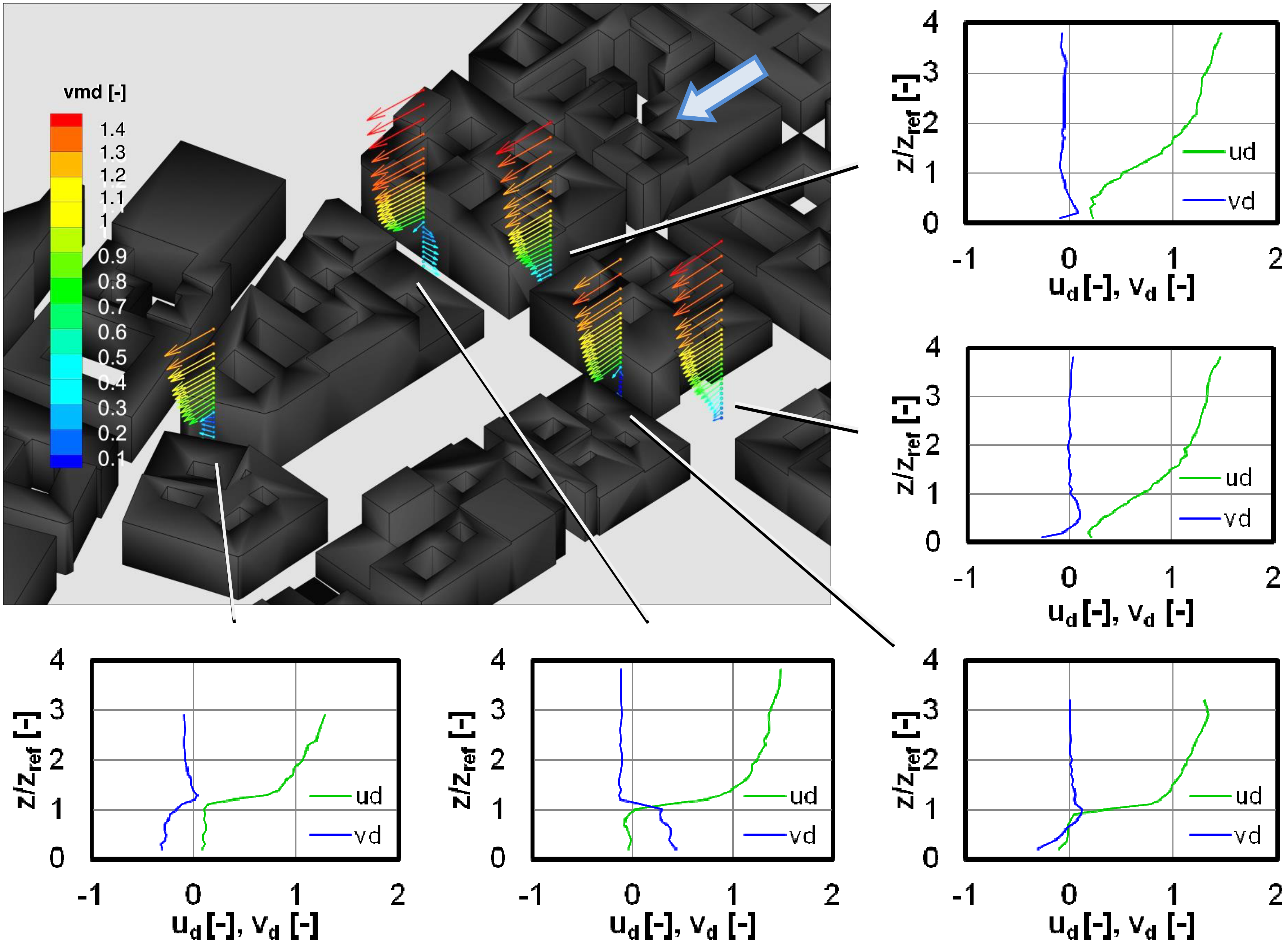


h: mean building height in model scale, **h=80 mm**
(mean building height in full scale: **H=28 m**)

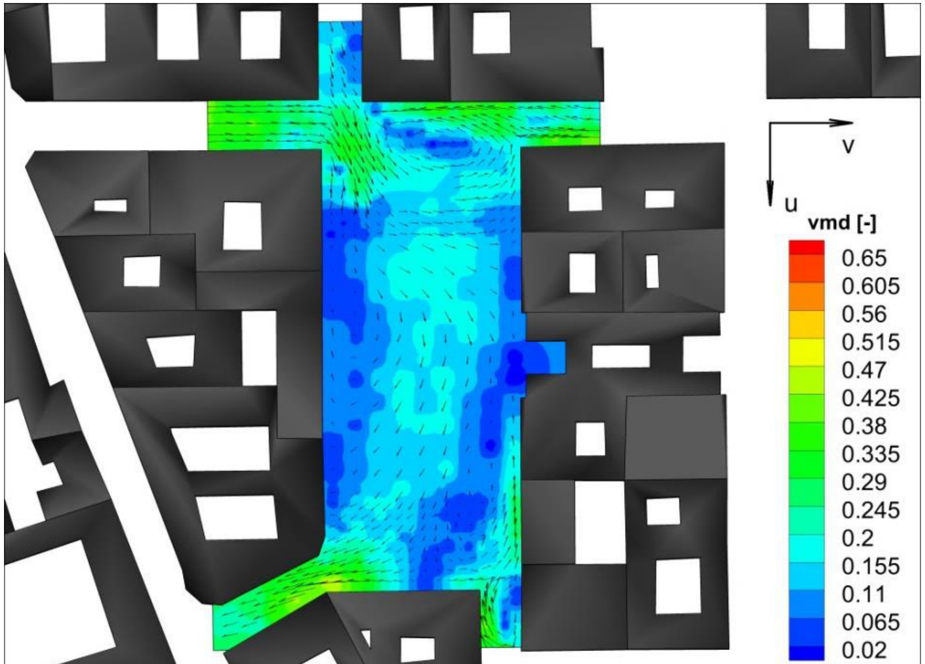
Vertical profile measurements – József Nádor Square



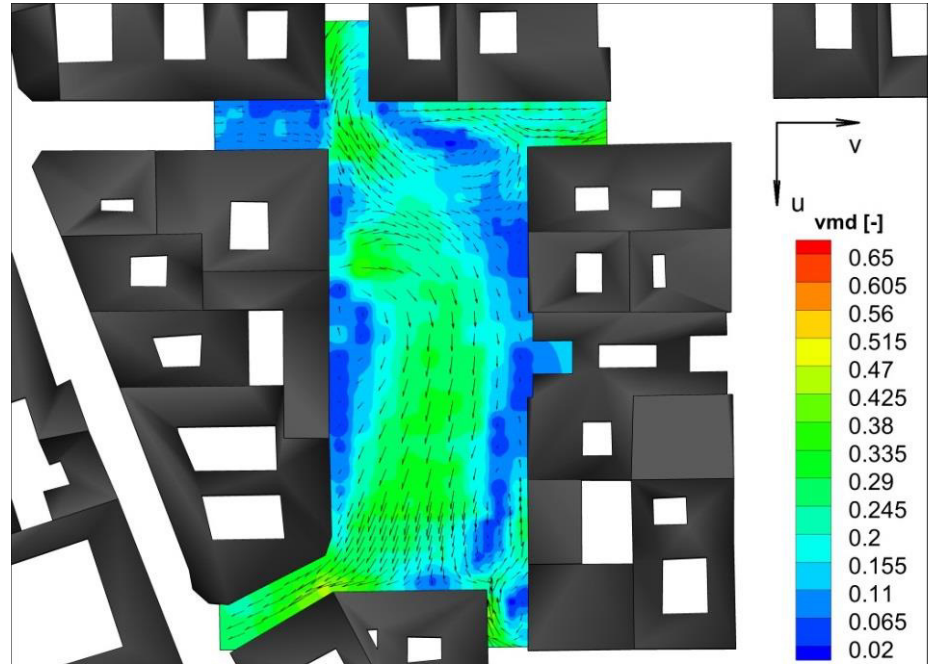
Vertical profile measurements – surrounding streets



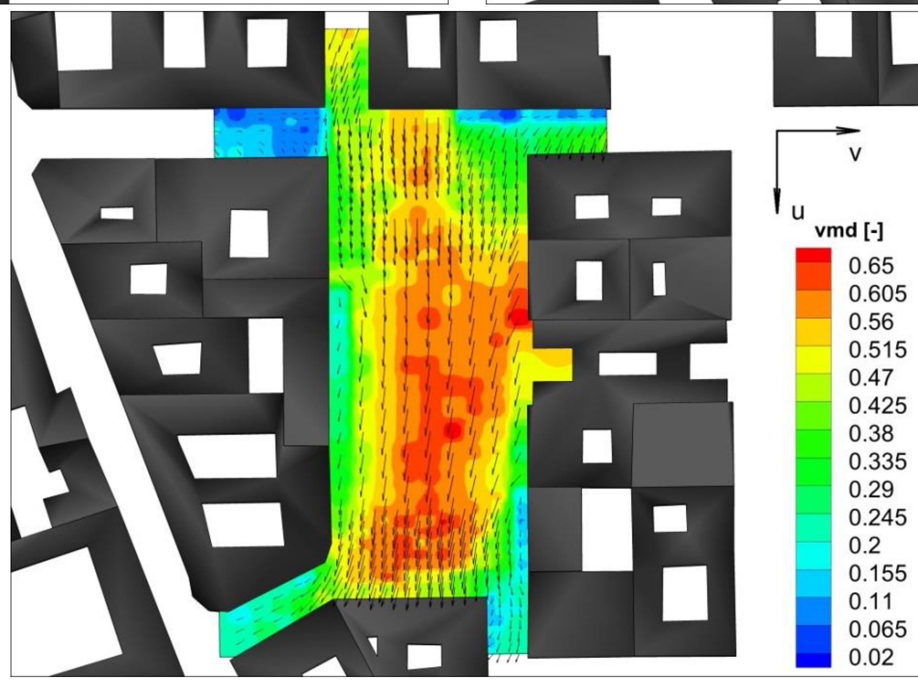
Horizontal planes



z=20 mm (0.25h)



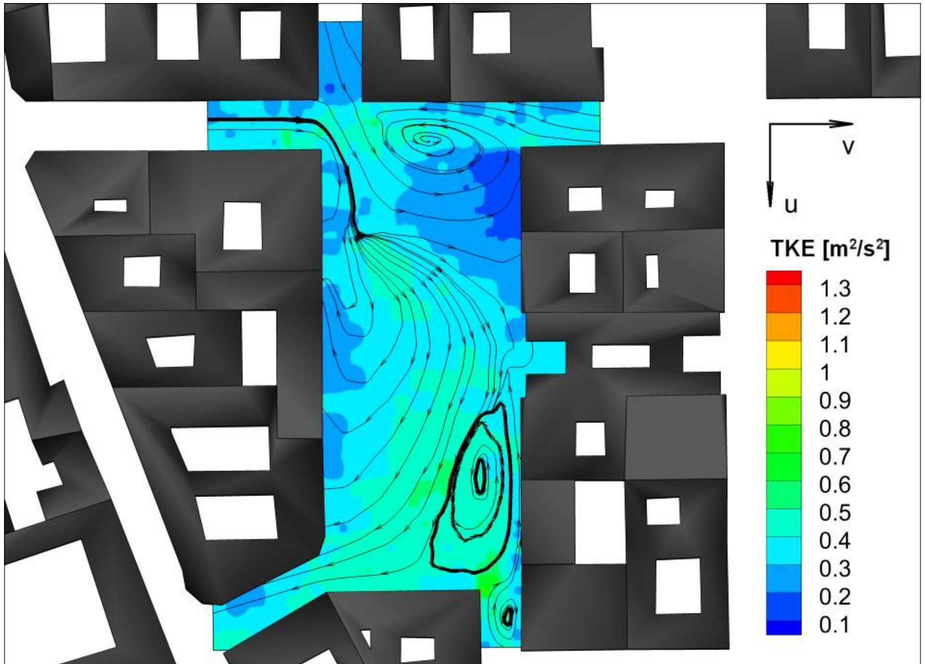
z=40 mm (0.5h)



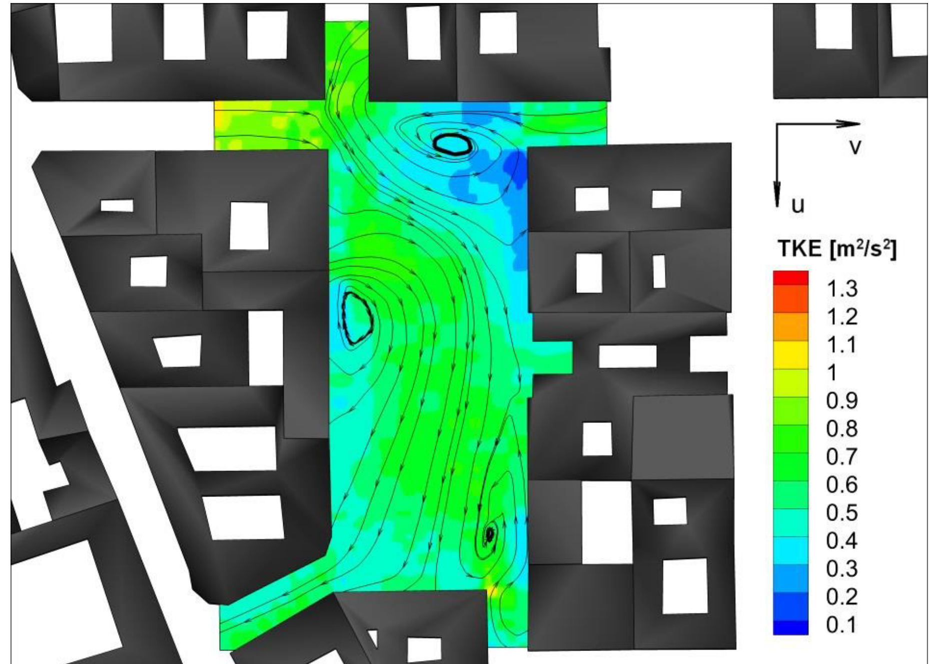
z=80 mm (h)

h=80 mm (mean building height in model scale)

Horizontal planes

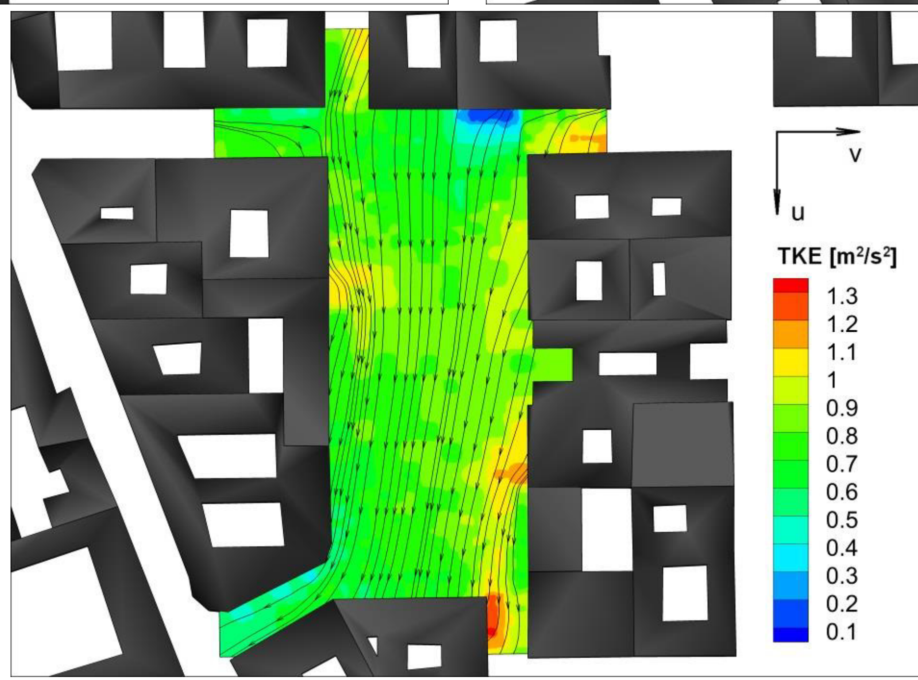


z=20 mm (0.25h)



z=40 mm (0.5h)

h=80 mm (mean building height in model scale)



z=80 mm (h)

Future plans

- Comprehensive flow field measurements with **more wind directions**
  - Velocity and turbulent kinetic energy distributions on planes at **ground level** and **at 0.75h** (60 mm)
  - Velocity and turbulent kinetic energy distributions on the **full 800 x 800 mm plane** at least at one height (flow field in the **surrounding streets**)
  - Measurements in the **quadrangles** (inner yards) and in the **passage** located between József Nádor Square and Erzsébet Square
  - **Additional wind directions**: **north-western** and **western** (the most frequently occuring wind directions in this region)
- **Concentration** measurements
- **Sand erosion** measurements
- The fiber-optic LDV probe is mountable on the large positioner → measurements can be carried out from above → their results can be compared to the results of the measurements carried out from below → the intrusiveness of the probe can be exactly determined.

Acknowledgements

The support of the project K 108936 "Flow and dispersion phenomena in urban environment" of the Hungarian Scientific Research Fund is gratefully acknowledged. This work is connected to the scientific program of the "Development of quality-oriented and harmonized R+D+I strategy and functional model at BME" project. This project is supported by the New Széchenyi Plan (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002).

Thank you for your attention!

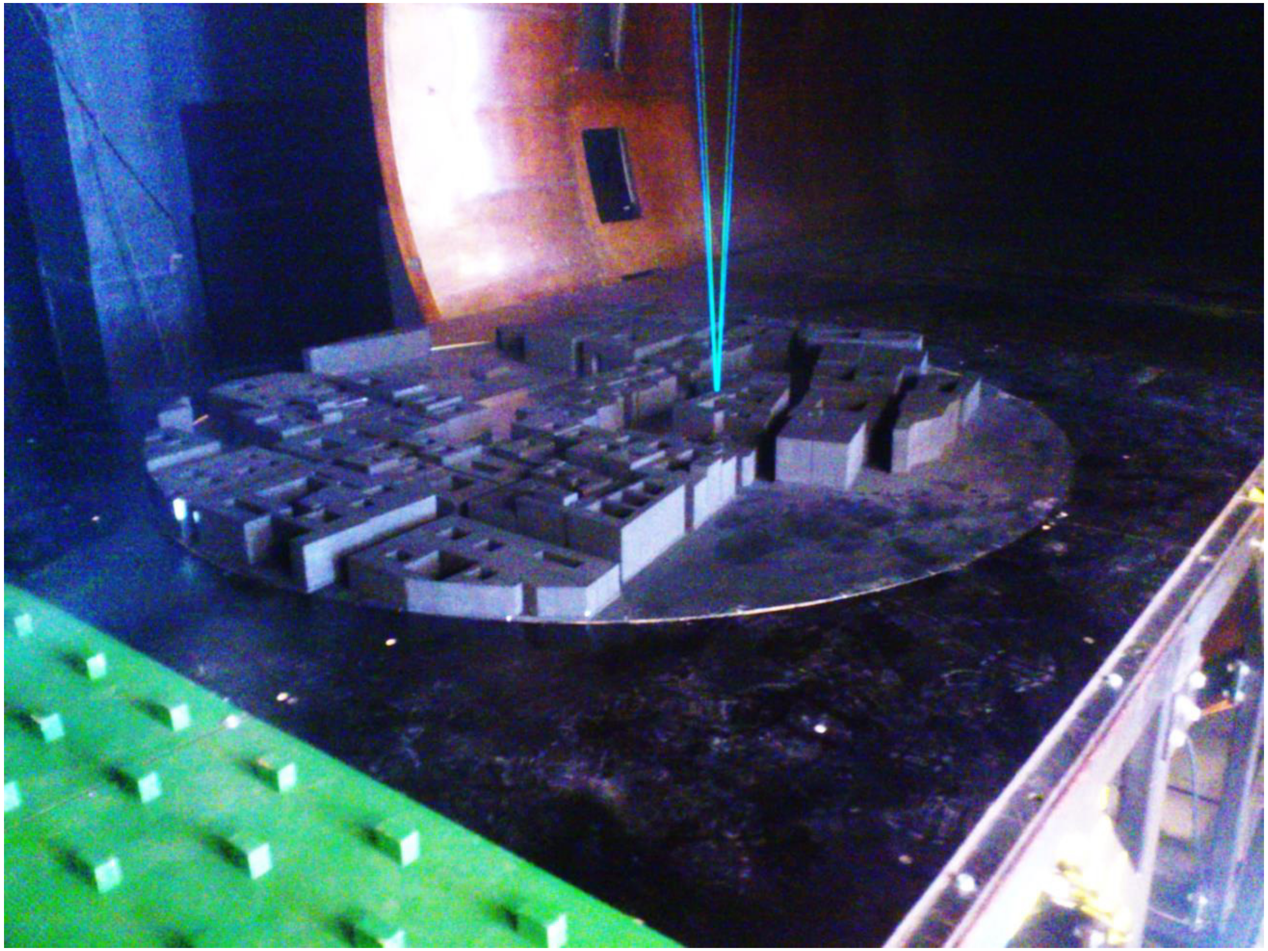
MultiScience - XXVIII. microCAD International Multidisciplinary Scientific Conference

10-11 April 2014

András Tomor
MSc student

Márton Balczó
assistant research fellow

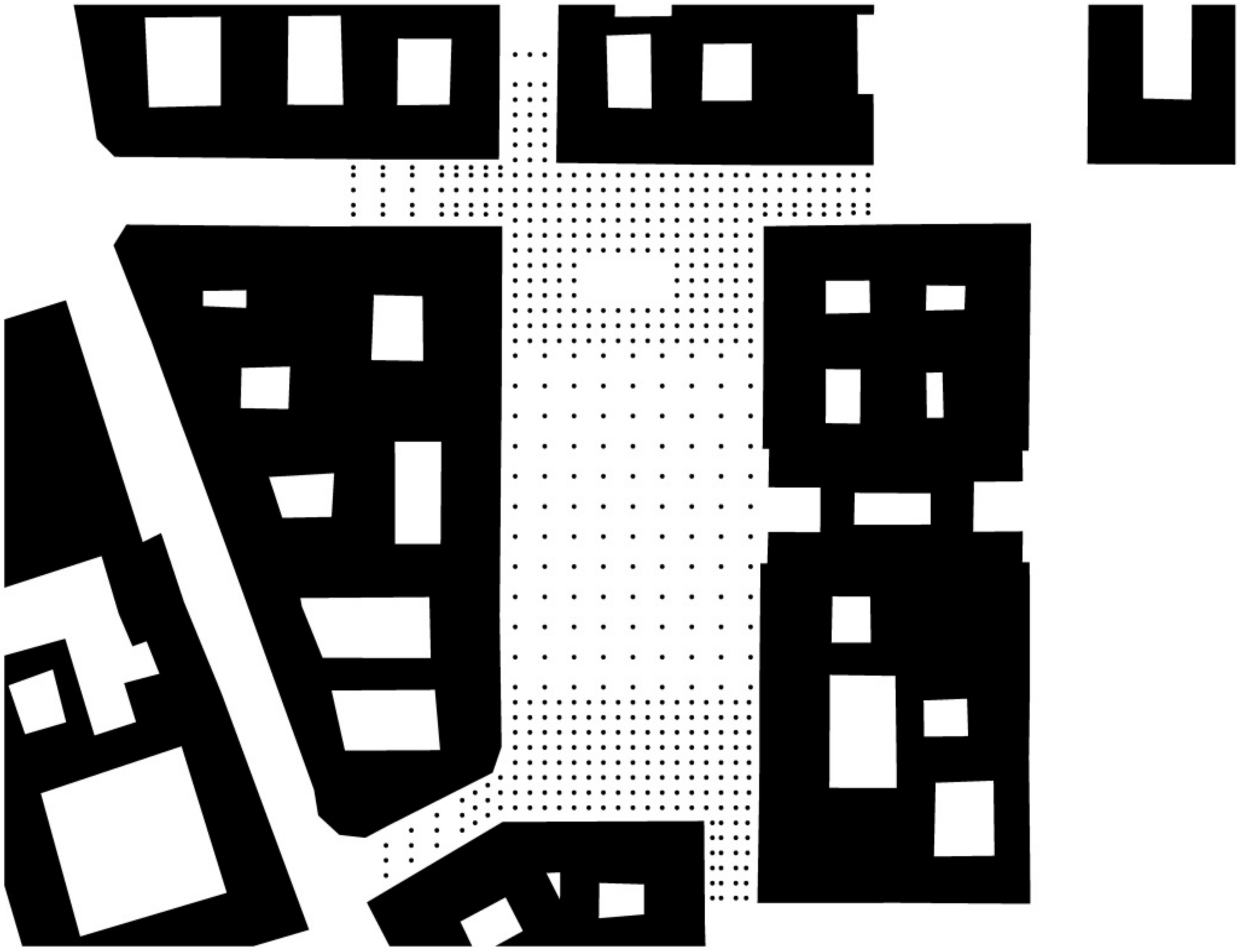
Budapest University of Technology and Economics (BME)



Theodore von Kármán Wind Tunnel Laboratory

BME Department of Fluid Mechanics

Questions



Questions

$$\bar{u}(z) = \frac{1}{T}\int_0^T u(t)dt$$

$$u_{c,d} = \frac{\bar{u}(z)}{u_{ref}} \cdot \frac{u_{\Pr andtl,ref}}{\bar{u}_{\Pr andtl}}$$

$$\bar{v}(z) = \frac{1}{T}\int_0^T v(t)dt$$

$$u_d = \frac{\bar{u}}{u_{href}} \cdot \frac{u_{P,ref}}{\bar{u}_P}$$

$$I_u(z) = \frac{\sigma_u(z)}{\bar{u}(z)}$$

$$v_d = \frac{\bar{v}}{u_{href}} \cdot \frac{u_{P,ref}}{\bar{u}_P}$$

$$I_v(z) = \frac{\sigma_v(z)}{\bar{u}(z)}$$

$$v_{md} = \sqrt{u_d^2 + v_d^2}$$

$$\frac{f \cdot S_{uu}(f,z)}{\sigma_u^2(z)} = \frac{A \cdot f_{red}}{\left(E + B \cdot f_{red}^C\right)^D}$$

$$f_{red} = \frac{f \cdot L_{u,x}}{u_{ref}}$$

$$TKE = \frac{1}{2} \cdot \left(\sigma_u^2 + \sigma_v^2\right)$$

Questions

VDI 3783 PART 12 (2000): Environmental meteorology, Physical modelling of flow and dispersion processes in the atmospheric boundary layer, Application of wind tunnels, VDI/DIN-Handbuch Reinhaltung der Luft, Band 1b

ESDU (1985): Characteristics of wind speed in the lower layers of the atmosphere near the ground. Part II: single point data for strong winds (neutral atmosphere), Engineering Sciences Data Unit 85020.