CWE-8
June 7-11, 2026
London, ON, Canada

A Wind Tunnel Study of Urban Pollution Dispersion – Benchmark Data from the ValUr Project

S. Gillmeier [a], A.K.R. Jayakumari [a], P.O. Hristov [b], M. Pantusheva [b], R. Mitkov [b], V. Naserentin [c], A. Logg [c]

[a]*Eindhoven University of Technology, Eindhoven, the Netherlands, s.g.gillmeier@tue.nl*
[b]*GATE Institute, Sofia University "St. Kliment Ohridski", Sofia, Bulgaria*
[c]*Chalmers University of Technology, Gothenburg, Sweden*

SUMMARY

Detailed urban air quality modelling relies on accurate validation of computational fluid dynamics (CFD) simulations. The ERIES–ValUr project addresses this need through a controlled wind tunnel campaign designed to generate an open-access database for urban pollutant dispersion studies. A heterogeneous district in central Sofia, Bulgaria, is modelled at a 1:350 scale and tested under atmospheric boundary layer conditions. Two point sources are sequentially used to release a passive tracer gas. Concentrations are measured at 76 pedestrian-level locations using a fast-response flame ionization detector. The setup ensured source strength and Reynolds number independency. Initial results provide normalized, time-averaged concentration fields for one release scenario.

Keywords: *Urban pollution dispersion modelling, Urban air quality, Passive scalar, Wind tunnel experiment, Experimental database, Pollutant concentration measurements*

1. INTRODUCTION

Urban air quality is a major concern due to its impact on public health. Dense city districts often exhibit pollutant accumulation and slow dispersion, creating exposure hotspots. Understanding these processes is essential for designing mitigation strategies and informing urban planning. While computational fluid dynamics (CFD) has advanced significantly, its predictive accuracy in heterogeneous urban environments depends on rigorous verification and validation (Harms et al., 2011). Field campaigns offer insights but suffer from variable meteorology and sparse data. In contrast, wind tunnel experiments enable systematic investigation under reproducible conditions, providing critical benchmarks (Schatzmann & Leitl, 2011). For instance, Klein et al. (2011) replicated pollutant dispersion in Oklahoma City to measure concentration fluctuations and flow structures at microscale resolution. Similarly, the "Michelstadt model", an idealized central European urban layout developed at the University of Hamburg, serves as a benchmark for CFD validation (Berbekar et al., 2013). These efforts highlight the need to couple physical modelling with computational tools. Building on this foundation, and emphasising the need for case-specific validation, the ValUr project delivers a well-documented experimental datasbase for pollutant dispersion in a representative European urban district to support CFD validation.

2. METHODOLOGY

This section describes the experimental setup, including the urban geometry, geometric scaling, pollutant source modelling and result normalization.

2.1. Experimental setup

The experiment is conducted in the atmospheric boundary layer (ABL) wind tunnel at Eindhoven University of Technology. The urban model is mounted on a 2.6 m turntable and represents a heterogeneous district in central Sofia, Bulgaria. The choice of the geometric scaling factor is always a compromise: it must balance reproducing the approaching atmospheric boundary layer as realistically as possible at scale, modelling a sufficiently large urban area to capture relevant surroundings, and meeting practical constraints such as manufacturing limits, while ensuring the overall blockage ratio remains below 5% (VDI-3783-12, 2000). As a result, the selected urban area is modelled at 1:350, resulting in an urban surrounding spanning 910 m in diameter at full scale (Figure 1). Building geometry is simplified to Level of Detail (LoD) 2.2 for inner regions and LoD 1.3 for the outer zone (Biljecki et al, 2016; Figure 1). Terrain is idealized to a flat base, and the cleaned geometry was 3D-printed in PLA at ≥1 mm resolution and mounted on an engraved PMMA base plate.

Figure 1: Top view of selected urban area, wind direction, pollutant source locations, as well as regions of varying LoD (a) and experimental setup in the ABL wind tunnel (b).

The approaching wind flow is simulated by means of vortex generators and surface roughness elements. Flow characteristics are discussed in section 3.1. Two point sources (*S1* and *S2*) are used to sequentially release a passive tracer mixture of ethane and synthetic air to simulate pollutant dispersion at two indicated locations along a busy road (Figure 1). Each source is modelled as a 6 mm ground opening with a 10 mm lid positioned 3 mm above to ensure source strength independence at relatively high emission velocities. Concentration levels are recorded at 76 pedestrian-level locations (1.75 m full-scale height) using a fast-response flame ionization detector at 85 Hz for 300 seconds. Concentration levels are normalized using equation 1.

$$C^* = \frac{(C_x - C_b)U_{ref}L_{ref}^n}{Q} \qquad (1)$$

with C_x the tracer gas concentration at each measurement location, C_b the tracer gas concentration in the approach flow, U_{ref}, the streamwise velocity at L_{ref}, L_{ref} a representative height (tallest building height = 0.33 m at model-scale), $n = 2$ for a point source, and Q the emission volume rate [m^3/s].

3. RESULTS

This section discusses approach flow characteristics and provides a first insight into obtained time-averaged concentration levels for one of the two point source release locations.

3.1. Approach flow conditions

The full-scale height profile of time-averaged streamwise velocities is presented in Figure 2. By fitting the logarithmic law of the wall and the power law, an aerodynamic roughness length of z_0 = 0.23 m (full-scale) and a profile exponent of $\alpha = 0.19$ is found to match time-averaged approach flow conditions well (VDI-3783-12, 2000). Also, turbulence intensities (Figure 2) fall within the suburban roughness category (classified as 'rough'). Corresponding, energy spectral densities and integral length scales of turbulence (e.g., $L_{u,x}$) have also been analysed. $L_{u,x}$ values ranges from ~150 m to ~250 m between 20 m to 100 m height (full-scale).

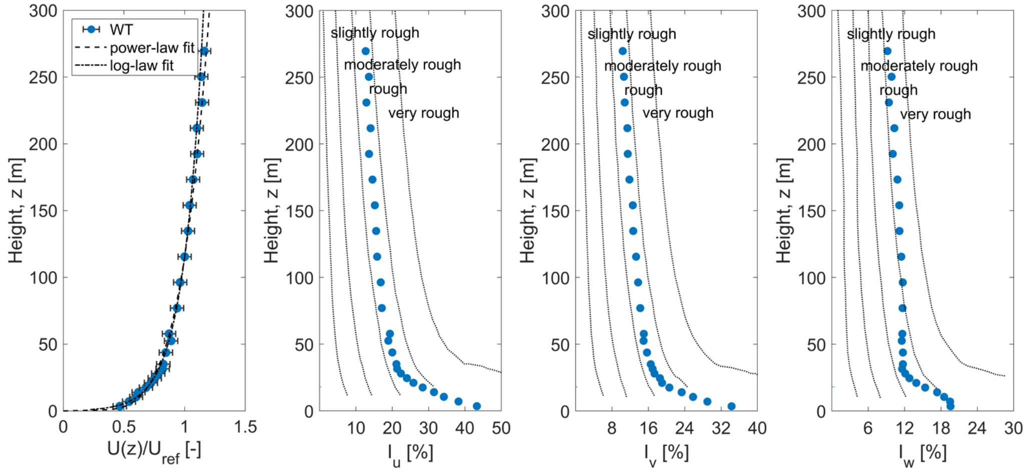

Figure 2: Height profile of time-averaged streamwise velocities ($U_{ref} = U(z = 115.5\text{ m})$) incl. logarithmic law and power law fits and height profiles of streamwise (I_u), lateral (I_v) and vertical (I_w) turbulence intensities.

3.2. Time-averaged concentration of pollutants for dispersion scenario *S1*

Figure 3 illustrates the dispersion of emissions released from point source *S1* by means of time-averaged normalized concentrations.

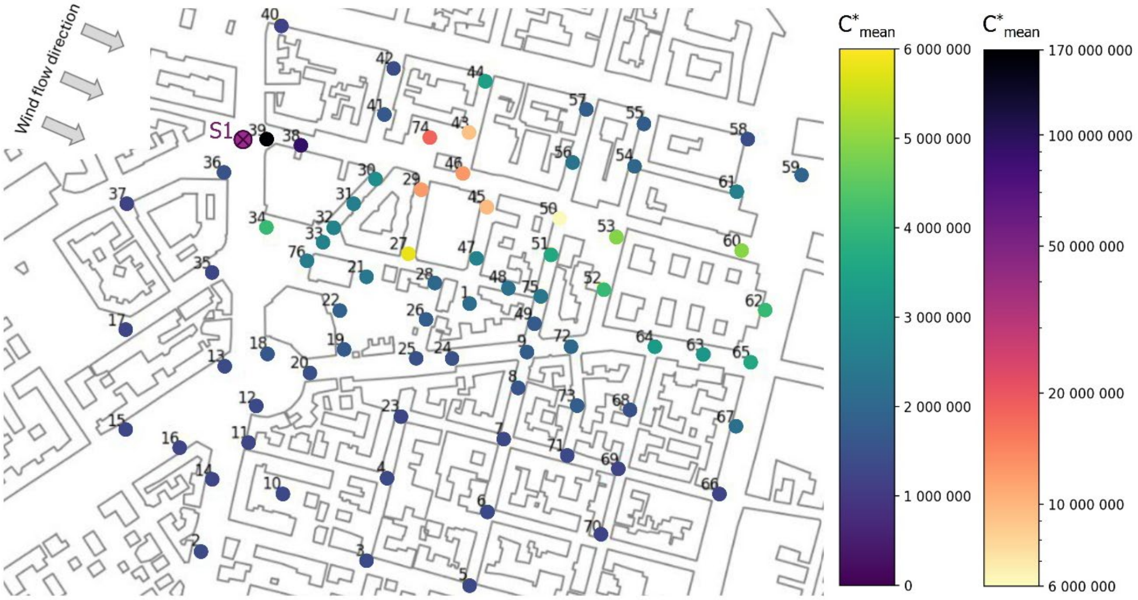

Figure 3: Time-averaged normalized concentrations of dispersed pollutants released from *S1*.

Reynolds number and source strength independency tests are conducted to prove the reliability of the model results, but are not presented here for brevity.

Elevated concentrations occur near the source location and along adjacent street canyons, with values decreasing toward peripheral streets. The gradient illustrates the influence of local geometry and flow patterns on pollutant dispersion. For the sake of brevity, only time-averaged concentrations are presented, while higher-order statistics that give insights into the turbulent nature of such dispersion processes are not part of this extended abstract.

4. CONCLUSIONS

The ERIES–ValUr wind tunnel campaign provides a high-quality, open-access database for validating CFD models of urban pollutant dispersion. By replicating a heterogeneous district in Sofia at a 1:350 scale and modelling controlled passive tracer releases, the experiments ensure reproducible conditions and repeatable measurements at pedestrian level. Initial results demonstrate the capability of the setup to capture spatial variability in pollutant dispersion, offering critical benchmarks for microscale modelling. Through rigorous validation, this dataset will support improved predictive reliability of CFD simulations of urban pollution dispersion and will contribute to the development of mitigation strategies for complex urban environments. Future work will include analysis of additional release scenarios the validation effort itself.

ACKNOWLEDGEMENTS

This work is part of the transnational access project “ERIES – ValUr”, supported by the Engineering Research Infrastructures for European Synergies (ERIES) project (www.eries.eu), which has received funding from the European Union’s Horizon Europe Framework Programme under Grant Agreement No. 101058684. This is ERIES publication number C113. Further, the research is supported by the GATE project funded by the Horizon 2020 WIDESPREAD-2018-2020 TEAMING Phase 2 programme under grant agreement no. 857155 and the programme "Research, Innovation and Digitalization for Smart Transformation" 2021-2027 (PRIDST) under grant agreement no. BG16RFPR002-1.014-0010-C01 and partially by the Swiss National Science Foundation and the Bulgarian Ministry of Education and Science under Grant Agreement No. IZPYZ0_228861 for the project “Automatic maximally rigorous uncertainty quantification to enable design for certification” (unCertify).

REFERENCES

Berbekar, E., Harms, F., Lübcke, M., Leitl, B. (2013). Validation data set for local-scale emergency response models. PHYSMOD 2013 – International Workshop on Physical Modeling of Flow and Dispersion Phenomena EnFlo Laboratory, University of Surrey, UK, 16th – 18th September 2013

Biljecki, F., Ledoux, H., & Stoter, J. (2016). An improved LOD specification for 3D building models. Computers, Environment and Urban Systems, 59, 25–37. https://doi.org/10.1016/j.compenvurbsys.2016.04.005

Harms, F., Leitl. B., Schatzmann, M., Patnaik, G. (2011). Validating LES-based flow and dispersion models. Journal of Wind Engineering and Industrial Aerodynamics 99, 289–295

Klein, P., Leitl, B. & Schatzmann, M. Concentration fluctuations in a downtown urban area. Part II: analysis of Joint Urban 2003 wind-tunnel measurements. Environ Fluid Mech **11**, 43–60 (2011). https://doi.org/10.1007/s10652-010-9195-7

Schatzmann, M., & Leitl, B. (2011). Issues with validation of urban flow and dispersion CFD models. Journal of Wind Engineering and Industrial Aerodynamics, 99(4). 169-186. https://doi.org/10.1016/j.jweia.2011.01.005

VDI 3783-12 (2000). Environmental meteorology – Physical modelling of flow and dispersion processes in the atmospheric boundary layer – Application of wind tunnels. Verein Deutscher Ingenieure.