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Simulation of atmospheric boundary layer and pollutant dispersion in the wind tunnel facility at University of Bristol

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Simulation of atmospheric boundary layer and pollutant dispersion in the wind tunnel facility

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2nd -3rd April 2025

National Wind Tunnel Facility Conference (NWTF)

The Exchange, Birmingham.

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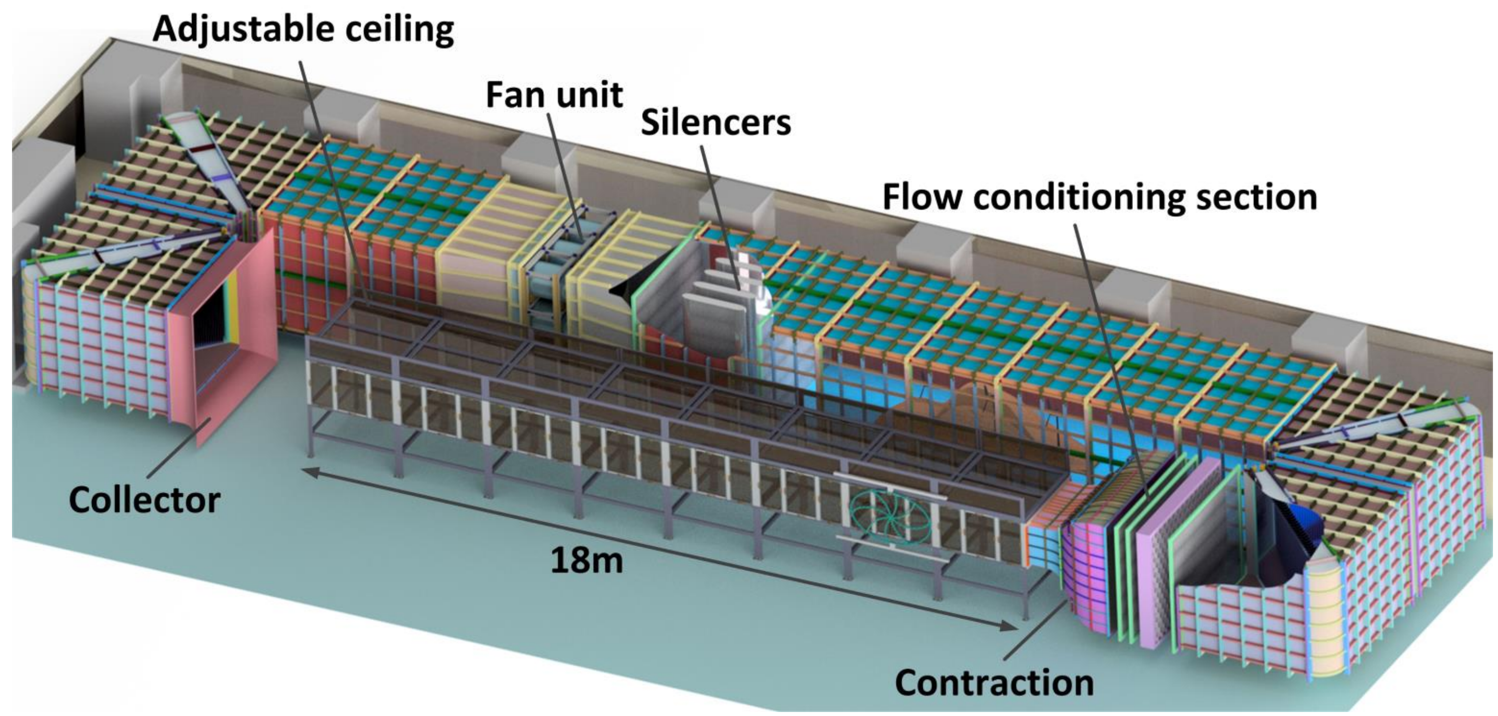
Facility Overview

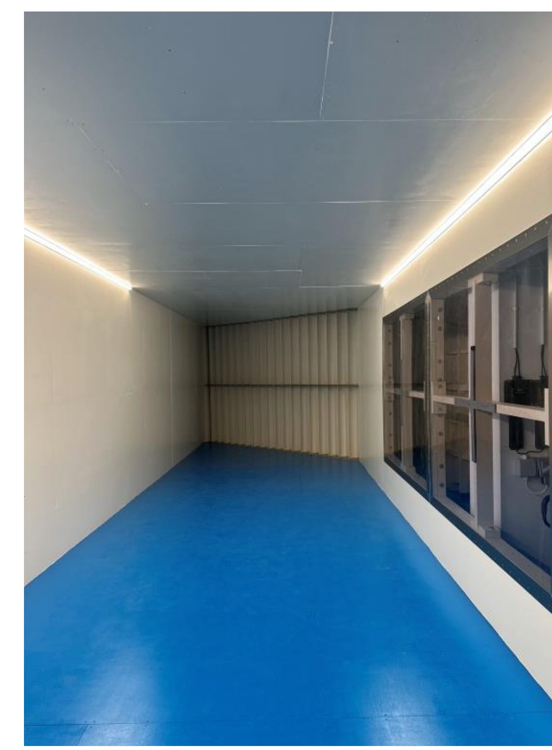
Specifications:

- Total Length: 30 m
- 9 axial fans, 240 kW power requirement
- Velocity range: 0.5 m/s – 35 m/s
- Test section: 2 m (W) × 1 m (H) × 18 m (L)
- Free-stream turbulence intensity (~0.13%)



HMI Control Panel

Test Section



Return Section

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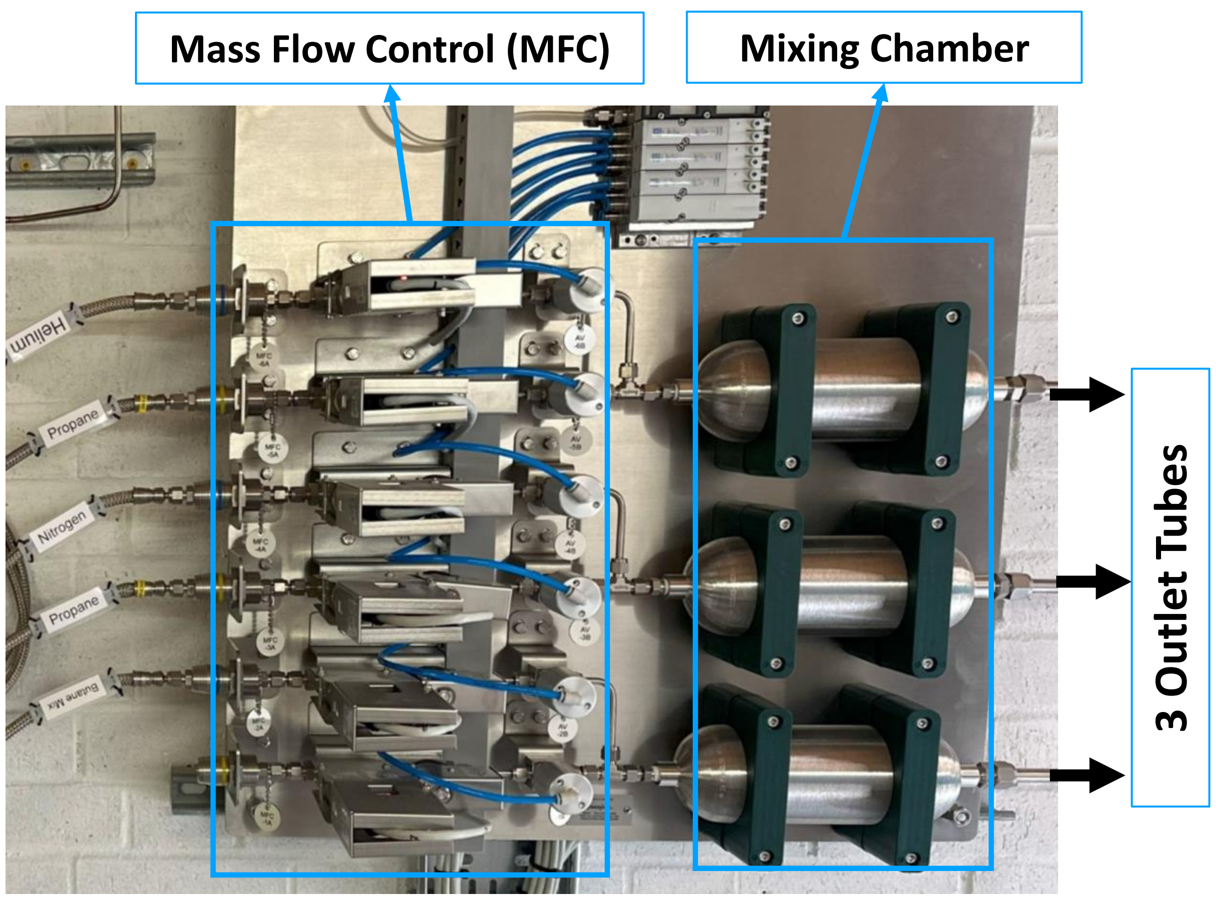
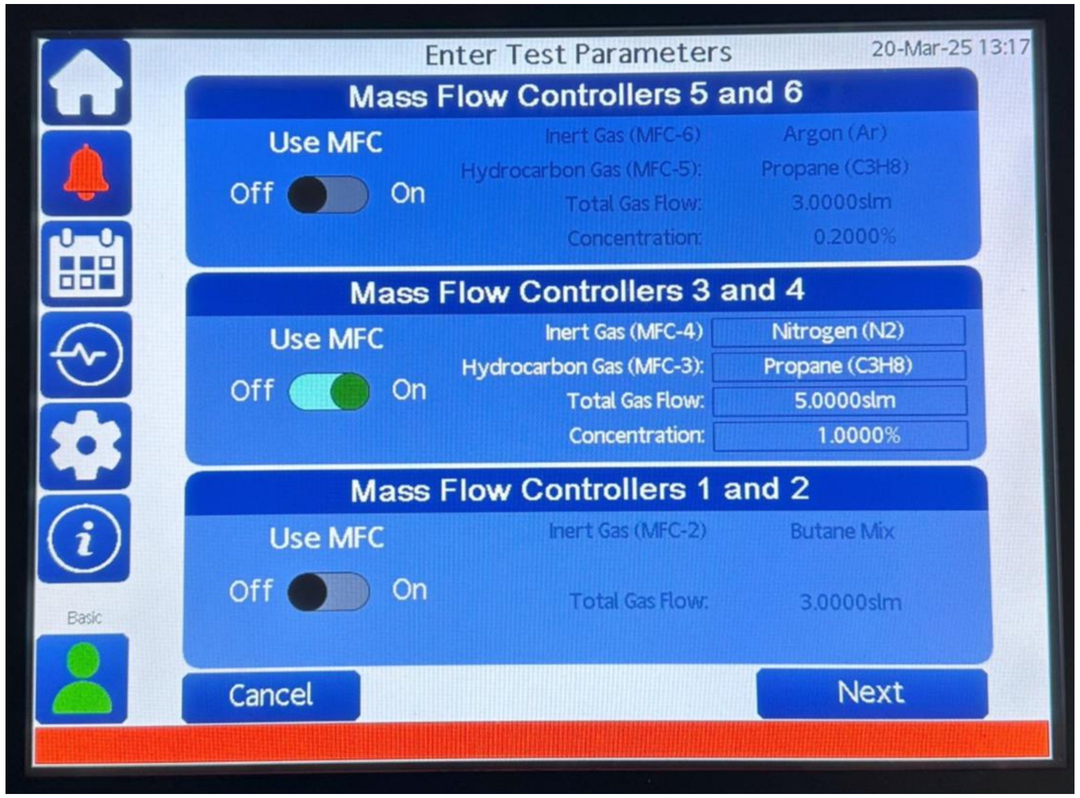
Equipped with:

- **Gas Injection** Systems mixing:
  - Inert (Nitrogen, Argon, Helium)
  - Hydrocarbon Gas (Ethane, propane, Butane)
- **3-Axis Traverse** Systems
- New **High-Speed Stereo PIV** Systems



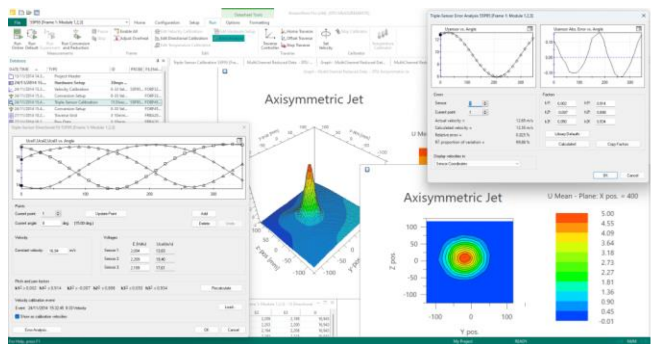
Gas Mixing Components



HMI Control Panel

Wind Tunnel Measurement Capabilities

Hot-Wire Measurement

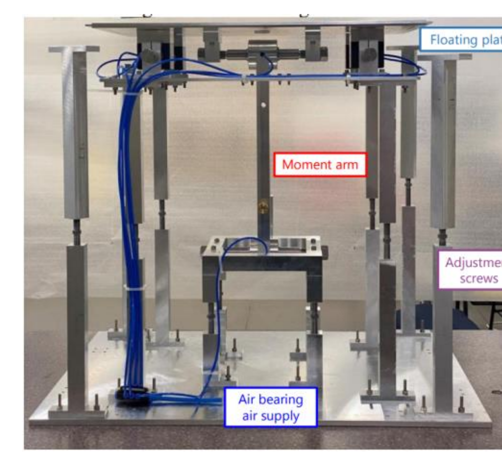
Fast Flame Ionization Detector (FFID)


Particle Image Velocimetry (PIV)

Pressure Sensors

Smoke Flow Visualisation

Drag Balance



Background

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Air pollution poses a major threat to health and climate. (World Health Organization, 2025)

2nd
highest risk factor for noncommunicable diseases

Burden of Disease
6.7 million
deaths in 2019 from exposure to ambient and household air pollution

Ambient Exposure
99%
of the world's population live in places where air pollution levels exceed WHO guideline limits

A fundamental boundary layer simulation in a wind tunnel is necessary to accurately replicate environmental flows through the systematic characterisation of boundary layer profiles.

Current Research Focus Areas In Bristol Wind Tunnel	• Environmental Flows • Pollutant Dispersion • Ventilation Study

Wind Tunnel Characterisation

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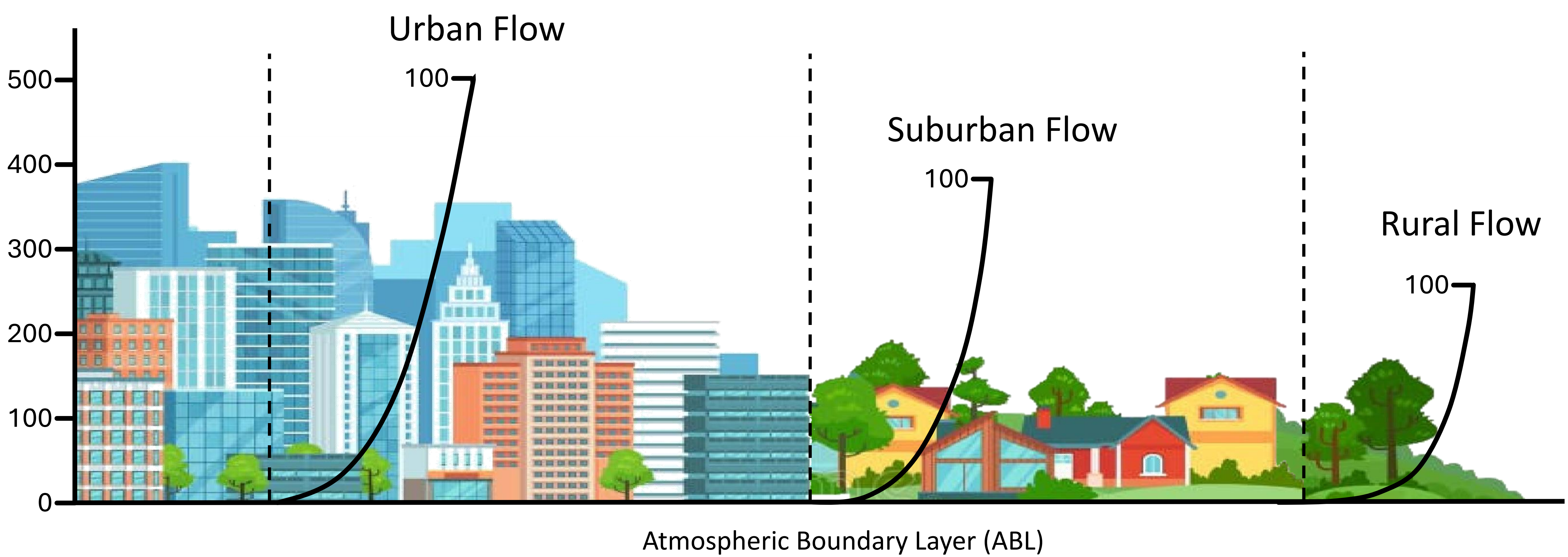
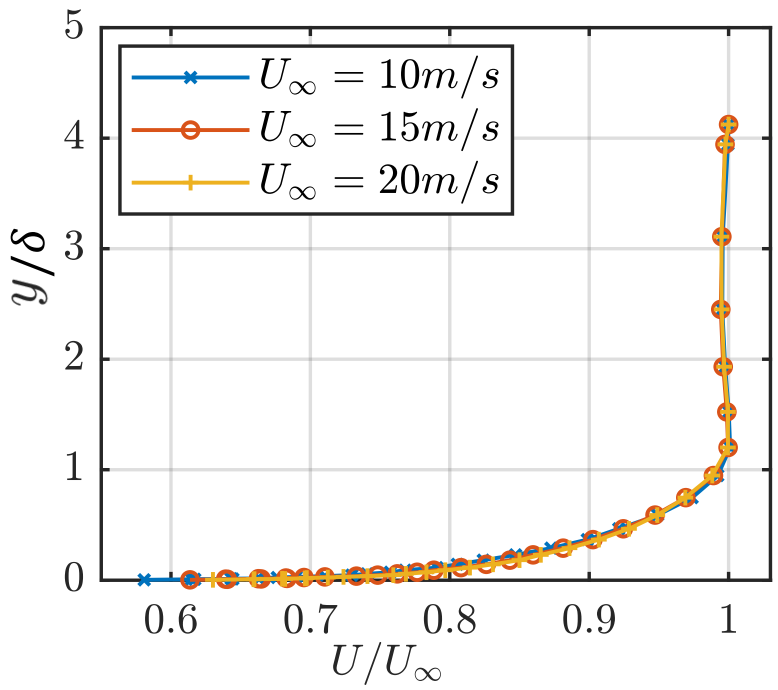
- Empty Wind tunnel
  - Assess flow in the empty tunnel (smooth wall)
- Atmospheric Boundary Layer (ABL) simulation
  - Analysis of urban, suburban and rural flow conditions

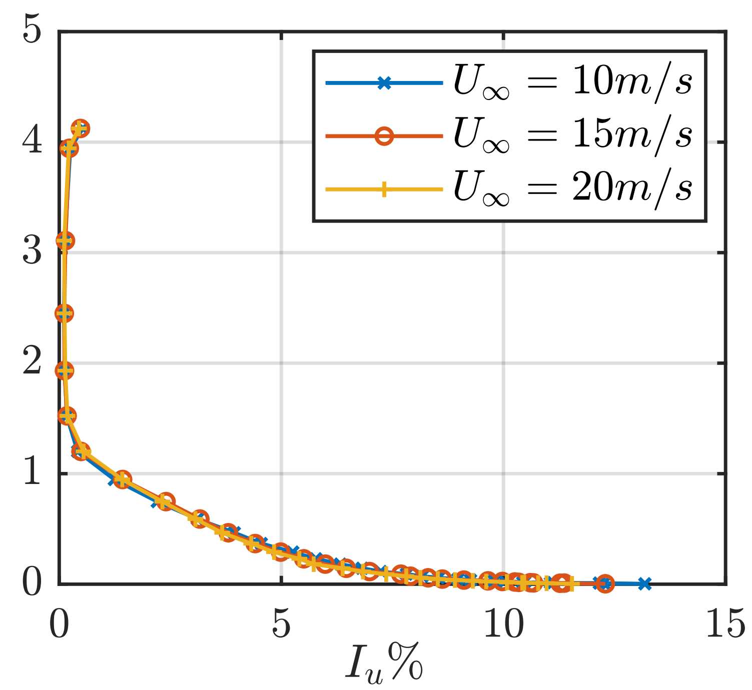


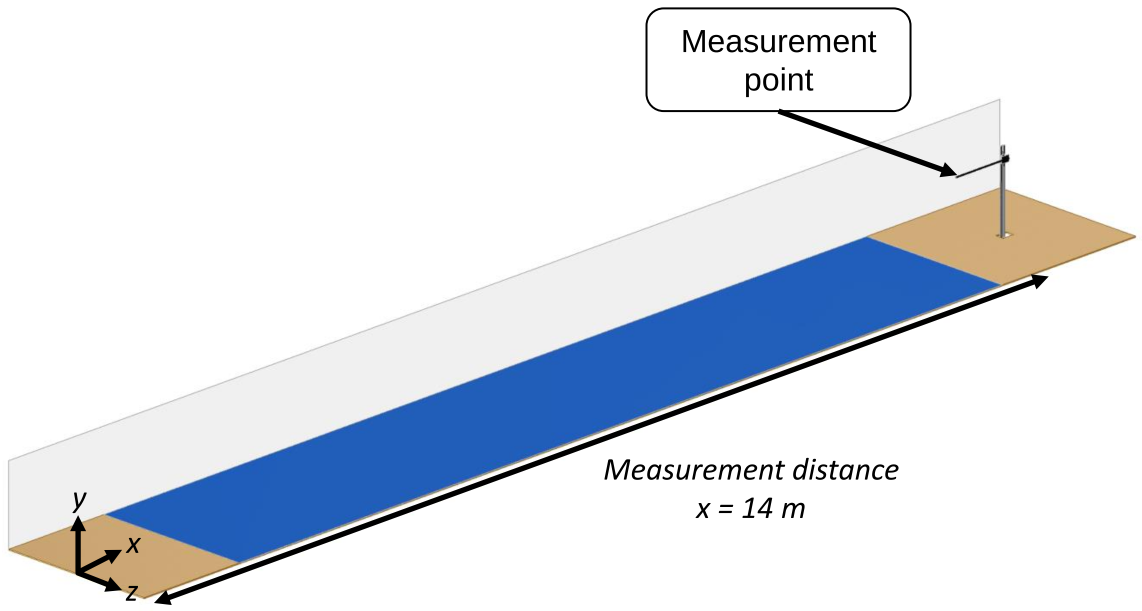
Empty Wind Tunnel Flow

(a) Mean velocity

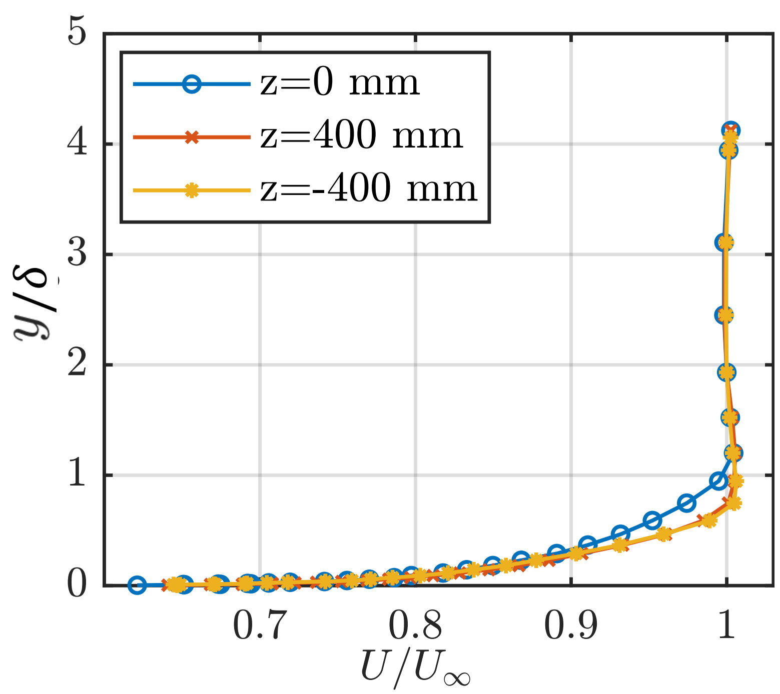


(b) Turbulence intensity





(c) Mean velocity in spanwise positions



- The turbulence intensity in the freestream is less than 0.13%.
- The maximum deviation in spanwise direction of flow uniformity is less than 3%

Simulation Setup for ABL Flow

Implement and evaluate ABL using Counihan's method (Counihan, 1969)

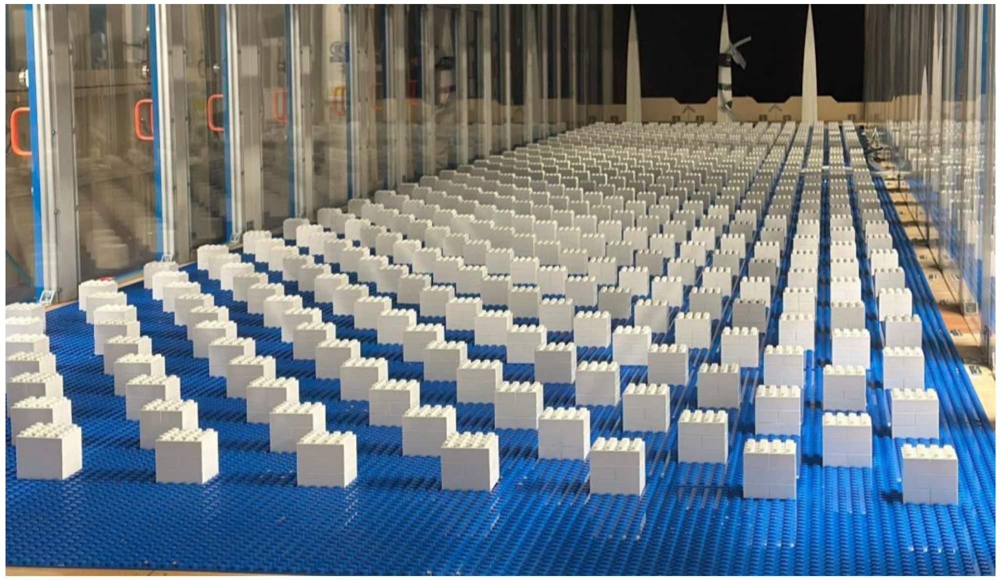
ABL Simulation Setup

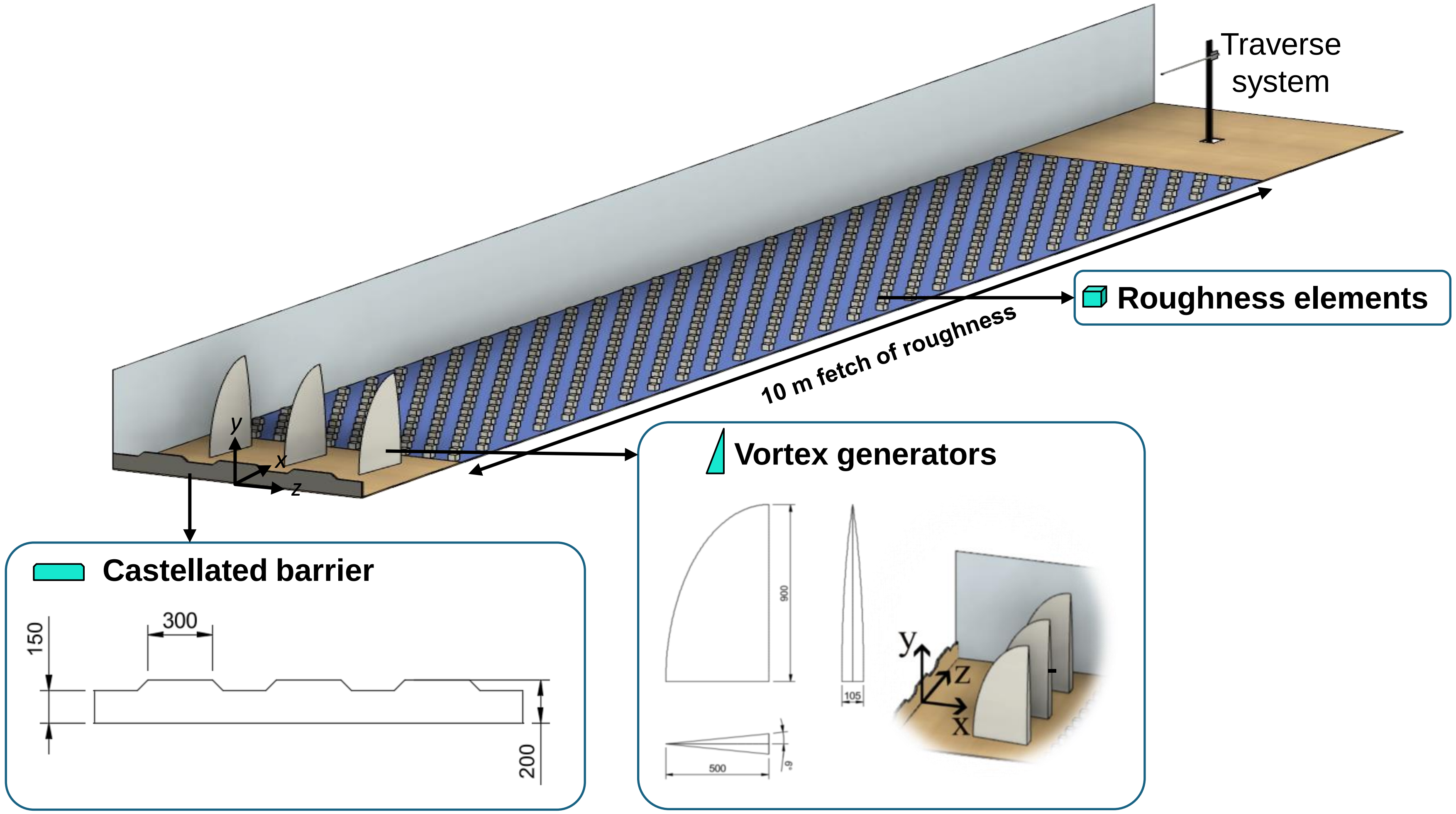
Castellated Barrier:
- Height = 200 mm
- Counihan's design

Vortex Generators:
- Height, H = 900 mm, Spacing = 0.6H

Roughness Elements:
- Staggered spacing = 140 mm
- Cube height = 63 mm

Acquisition Parameters:
- Hot-wire measurements
- Sampling Time = 100s
- Sampling Rate = $2^{16}\ Hz$





Urban Flow Simulation

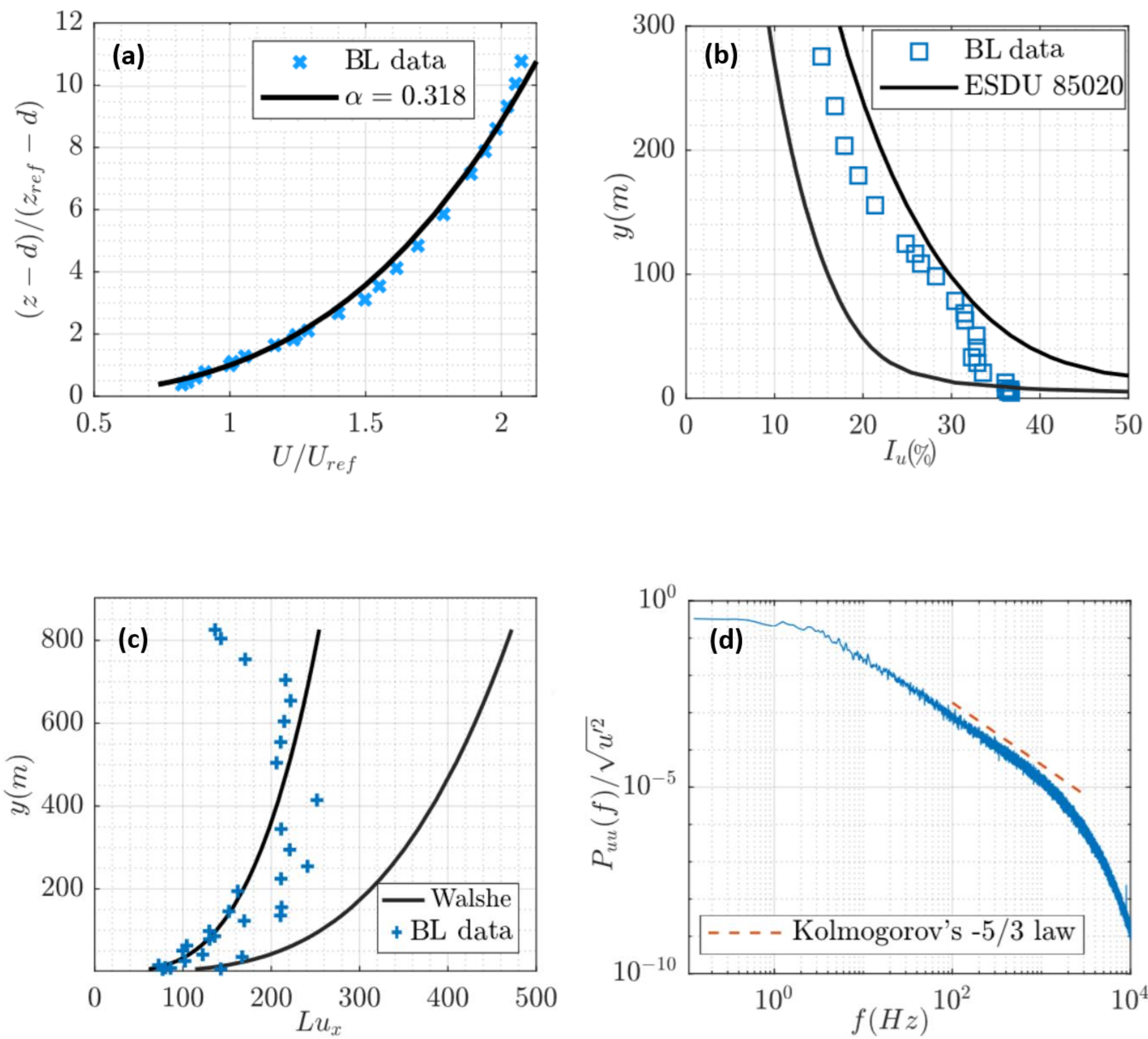
Power law:

$$\frac{U}{U_{ref}} = \left(\frac{y-d}{y_{ref}-d}\right)^{\alpha},$$

*U_{ref}: the mean velocity
y_{ref}: the height at a reference point
d: zero-displacement height
α: Power law exponent

Urban Flow Setup Configuration:
Roughness Elements Lego Block:
Spacing $= 140\ mm$
Height $=\ 63\ mm$

Power Law Equations Parameters:
Power Law exponent, $\alpha = 0.318$
Aerodynamic roughness height, $(ESDU)\ y_0 = 2\ m$

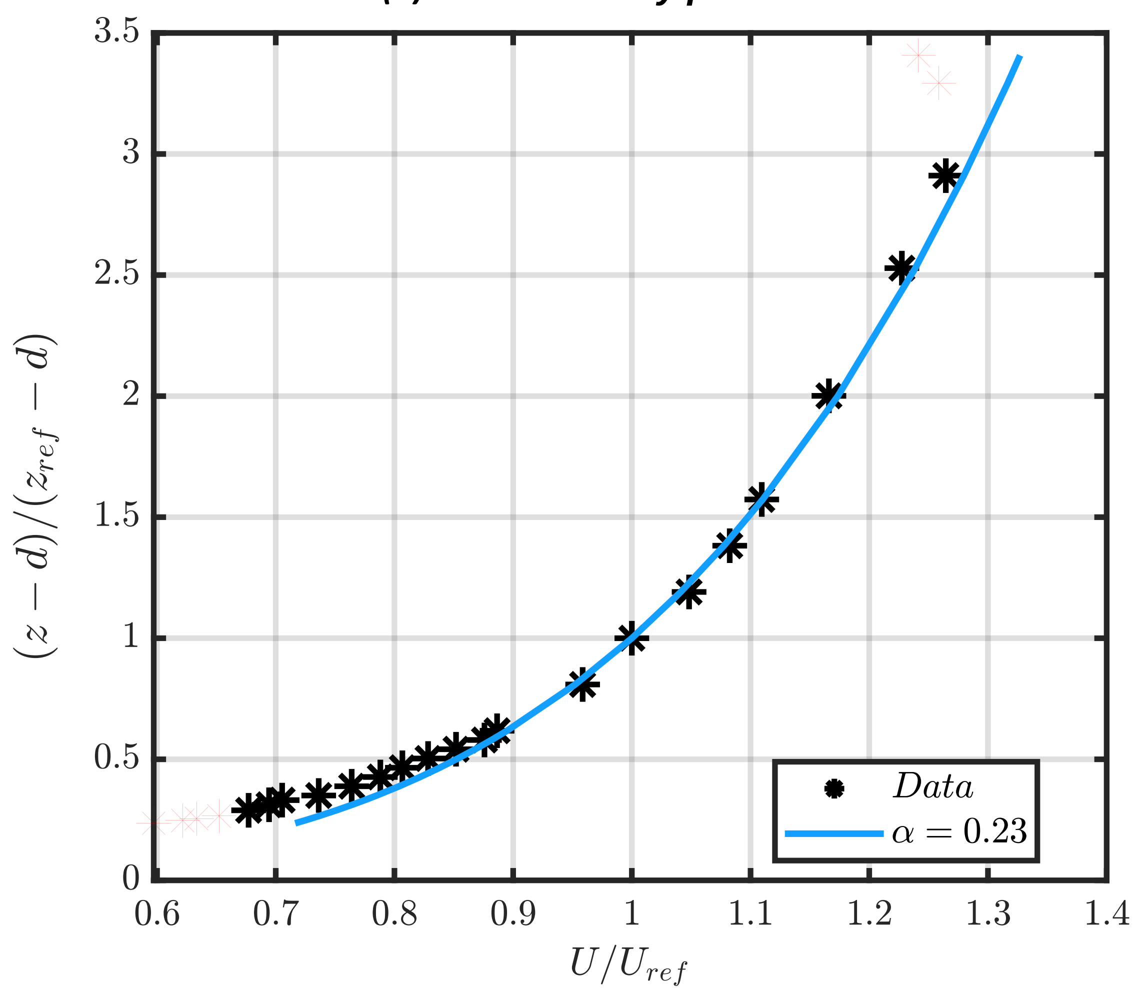


Suburban Flow Simulation

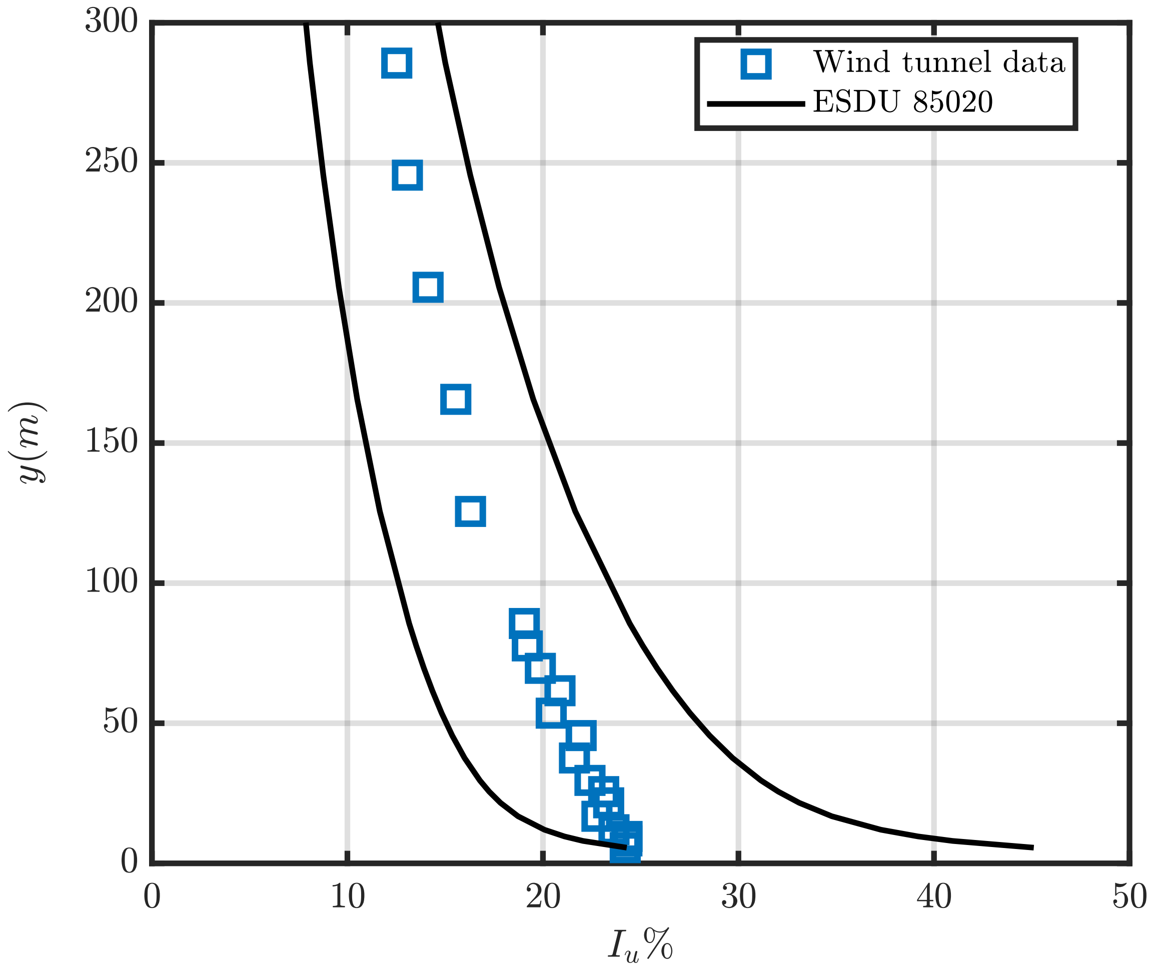
Suburban Flow Setup Configuration:
Roughness Elements Lego Block:
Spacing $= 140\ mm$
Height $= 43\ mm$

Power Law Equations Parameters:
Power Law exponent, $\alpha = 0.23$
Aerodynamic roughness height, $(ESDU)\ y_0 = 0.5\ m$

(a) Mean velocity profile



(b) Turbulence intensity compared to ±30% ESDU 85020

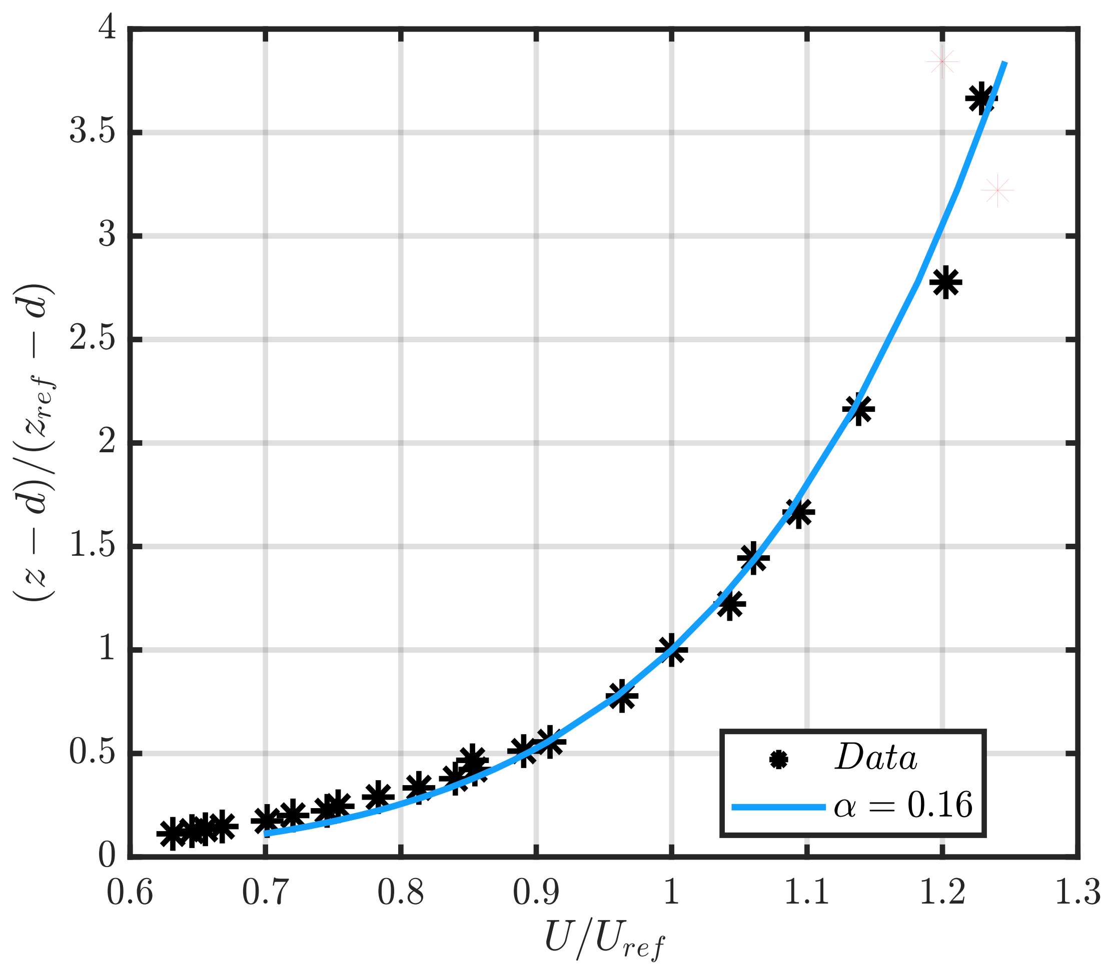


Rural Flow Simulation

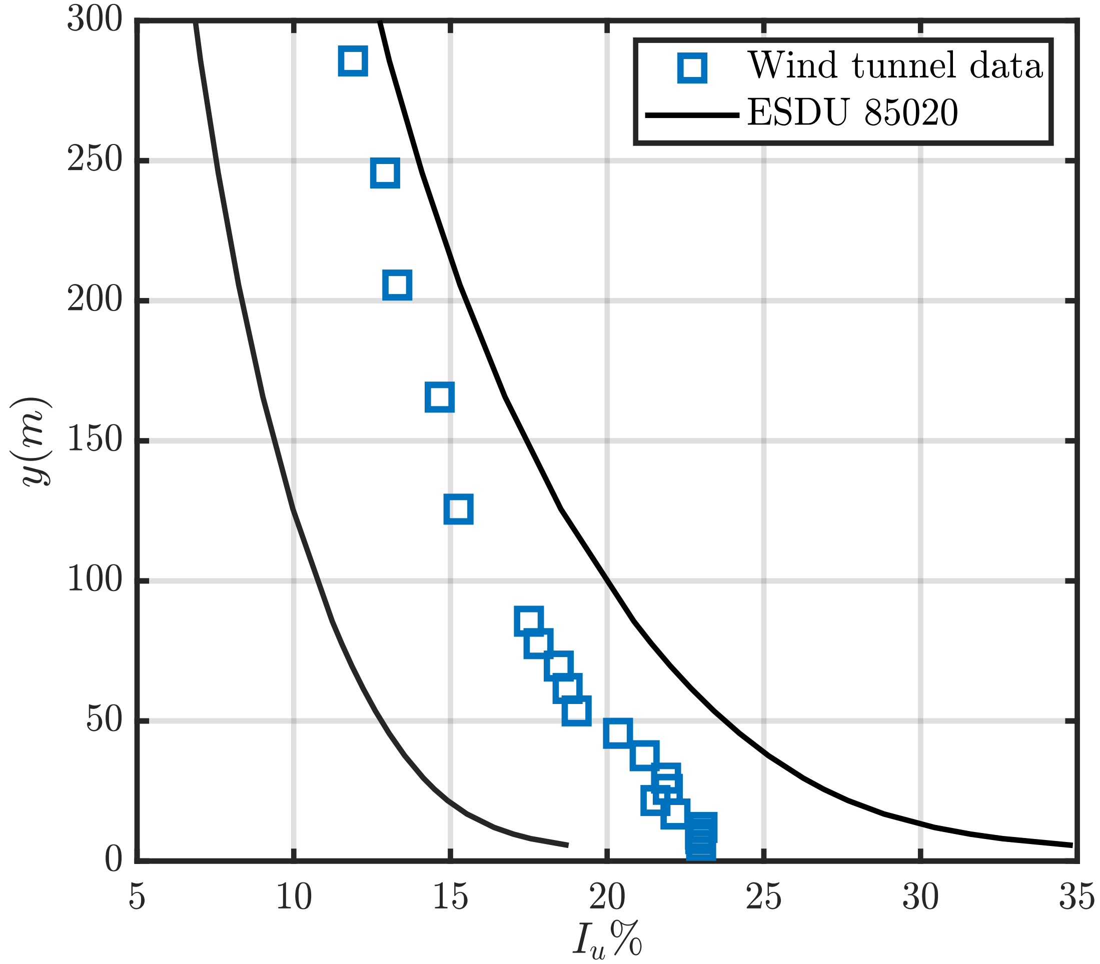
Rural Flow Setup Configuration:
Roughness Elements Lego Block:
Spacing $= 280\ mm$
Height $= 23\ mm$

Power Law Equations Parameters:
Power Law exponent, $\alpha = 0.16$
Aerodynamic roughness height, $(ESDU)\ y_0 = 0.3\ m$

(a) Mean velocity profile



(b) Turbulence intensity compared to ±30% ESDU 85020



Active Research Project

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Pollutant Dispersion in Urban Environments

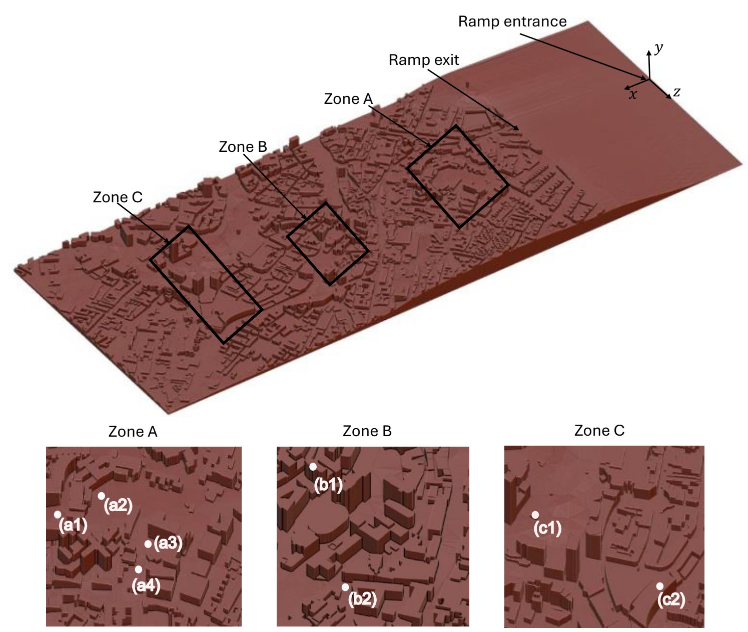
MODELAIR

Objectives

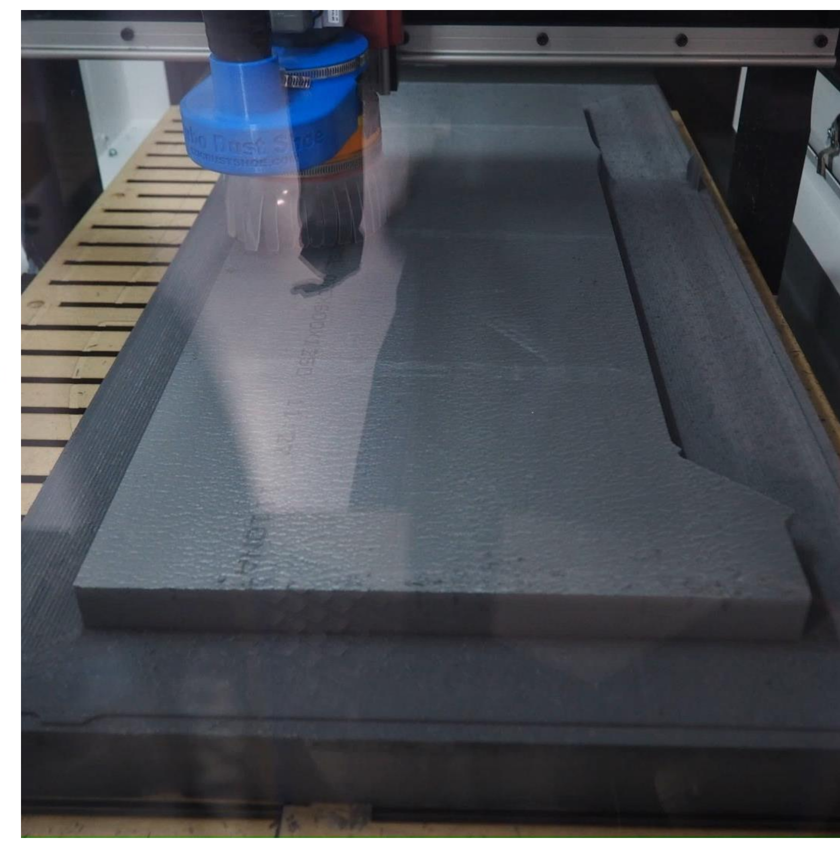
- Investigation of air pollutant dynamics under controlled wind conditions.
- Application in urban planning and pollution control strategies.

Contact: Nada Taouil, *vv23404@bristol.ac.uk*

Bristol City Model
scale of 1:800



Velocity measurement's locations
on the city model



CNC Process conducted in the Rapid Prototyping Teaching Lab, University of Bristol.

Building Wake Interaction with The Pollutant Dispersion

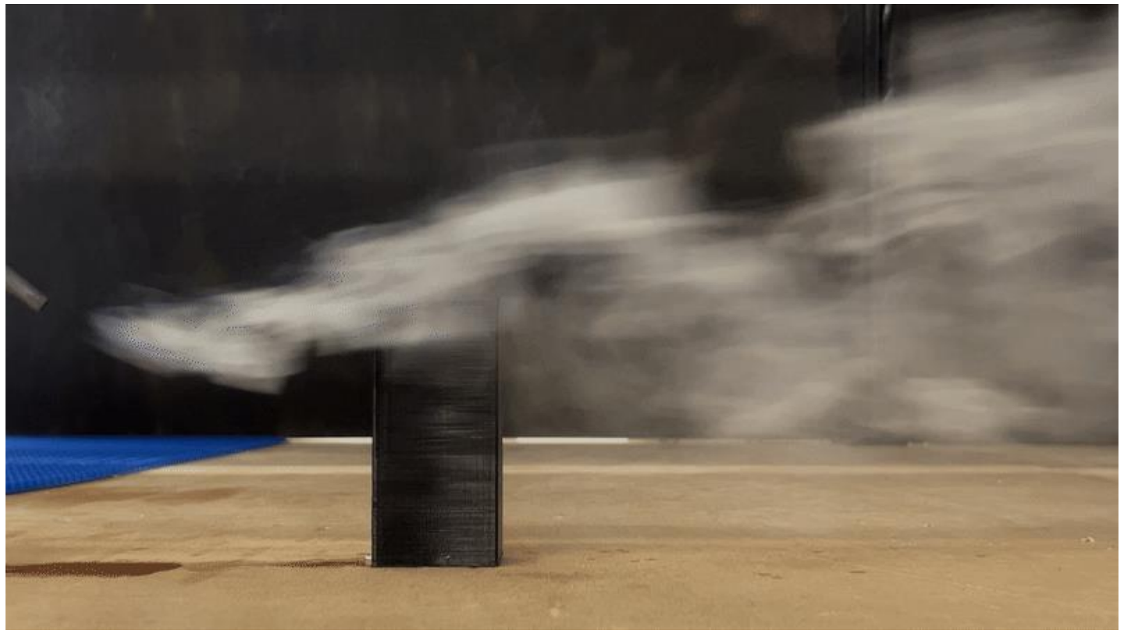
Objectives

- Analysis of wake structures and correlation with pollutant dispersion.
- To improve the building design and structures for sustainable urban development.

Contact: Matheus R. M. D. Almeida, *nh24027@bristol.ac.uk*

Building Model

Pressure taps installed on the building Model



Flow visualization on the building models

Indoor-Outdoor Air Interaction Study

Objectives

- Analysis of inlet and outlet configurations influence on the indoor air quality.
- Develop intricate (HW-FID) coupled measurement setup for the indoor setting.
- Strategies for energy-efficient and health-promoting ventilation.

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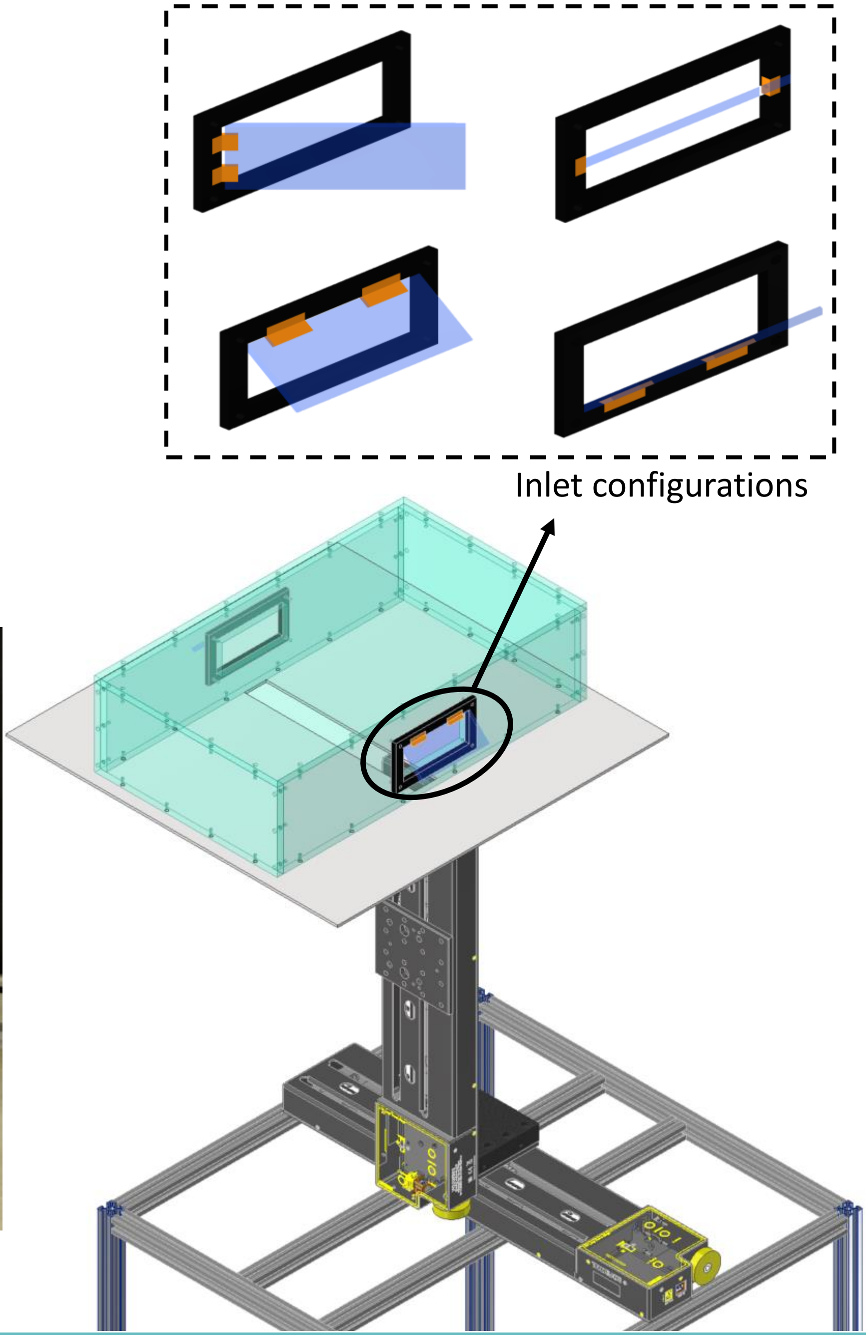
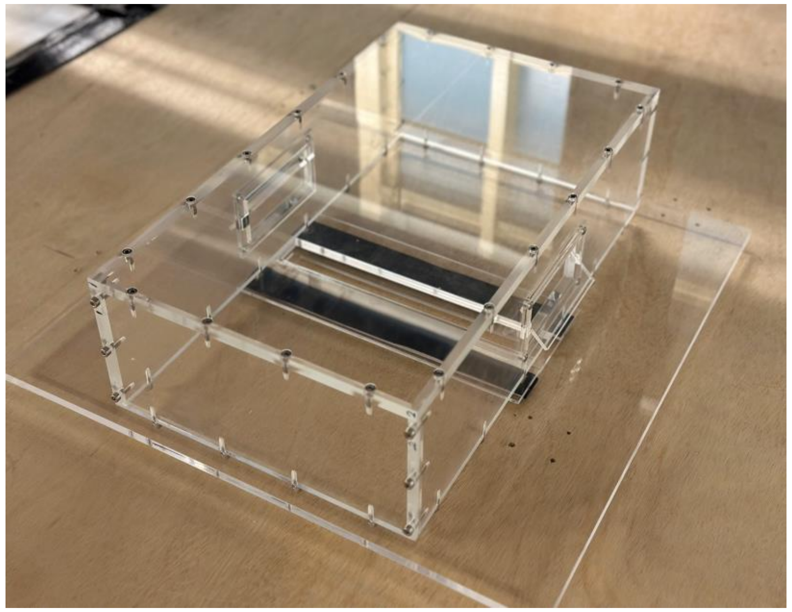
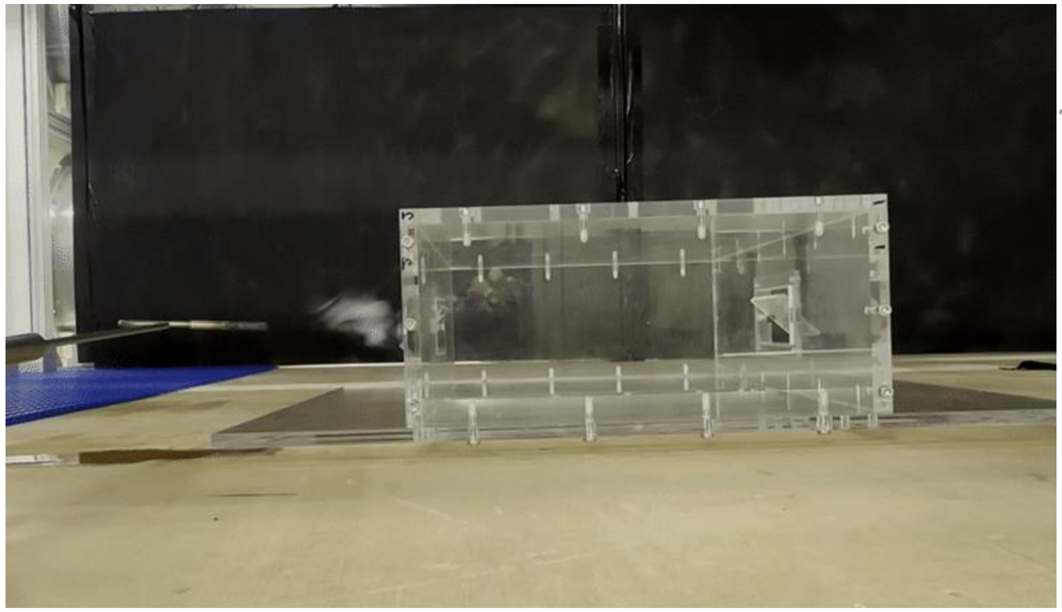



The classroom model


Flow visualisation of the classroom model

Conclusion

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The characterisation of the wind tunnel:

- Validated the stability of the smooth-wall flow conditions and successfully implemented ABL simulations for urban, suburban and rural environments
- These findings ensure that our experiments provide realistic and reliable data for pollutant dispersion analysis
- Gas injection characterisation for a range flow conditions underway

Future Research Directions:

- Further Refinement of BLWT characterisation techniques to enhance the simulations accuracy.
- Expansion of pollutant dispersion studies with more complex urban configurations.
- Improve our understanding of indoor-outdoor pollutant transport and its implications for building ventilation design.

Thank you

This project has received funding from

- The European Union's Horizon Europe research and innovation programme under MODELAIR project grant agreement No 101072559.
- University of Bristol Research Training Support Grant.

I would like to extend my sincere thanks to the conference organizers for their hard work and dedication in making this event possible.

References

[1] World Health Organization. (2025). Air Pollution. World Health Organization: WHO. https://www.who.int/health-topics/air-pollution#tab=tab_2

[2] Cook, N. J. (1978). “Wind-tunnel simulation of the adiabatic atmospheric boundary layer by roughness, barrier and mixing-device methods”, Journal of Wind Engineering and Industrial Aerodynamics, 3(2-3), 157–176.

[3] Counihan, J. (1969). “An improved method of simulating an atmospheric boundary layer in a wind tunnel”, Atmospheric Environment, 3(2), 197–214.

[4] Hohman, T. C., Buren, T. V., Martinelli, L. & Smits, A. J. (2015). “Generating an artificially thickened boundary layer to simulate the neutral atmospheric boundary layer”, Journal of Wind Engineering and Industrial Aerodynamics, 145, 1–16.