MAGIC

Envisaging a world with greener cities

Managing Air for Green Inner Cities

The Challenge:

Can we develop cities with no air pollution and no heat-island effect by 2050?

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ARUP

Breathing Buildings

CERC

Duvas Technologies

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Foster + Partners

EC Harris LLP

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FFI Forsvarets forskningsinstitutt
Norwegian Defence Research Establishment

IAP

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New Circle Members

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Air Monitor
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Develop, create, research, learn...
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- 14 Inaugural partners
- 48 Non-academic organisations
- 20 Universities (8 overseas)

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About

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Envisaging a world with greener cities

Imagine a city with no air pollution or heat island

– Current HVAC system is carbon intensive

We need to think differently

– Natural ventilation in buildings
– Integrated green and blue spaces
– Diluted air pollution levels
– Increased albedo
– Public education and policy change

How

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- What will this look like?
  - Fully integrated suite of models
  - Management tools
  - Decision support tools
- Comprised of:
  - Fully resolved air quality model with data assimilation
  - Reduced order models
  - Cost-benefit analysis

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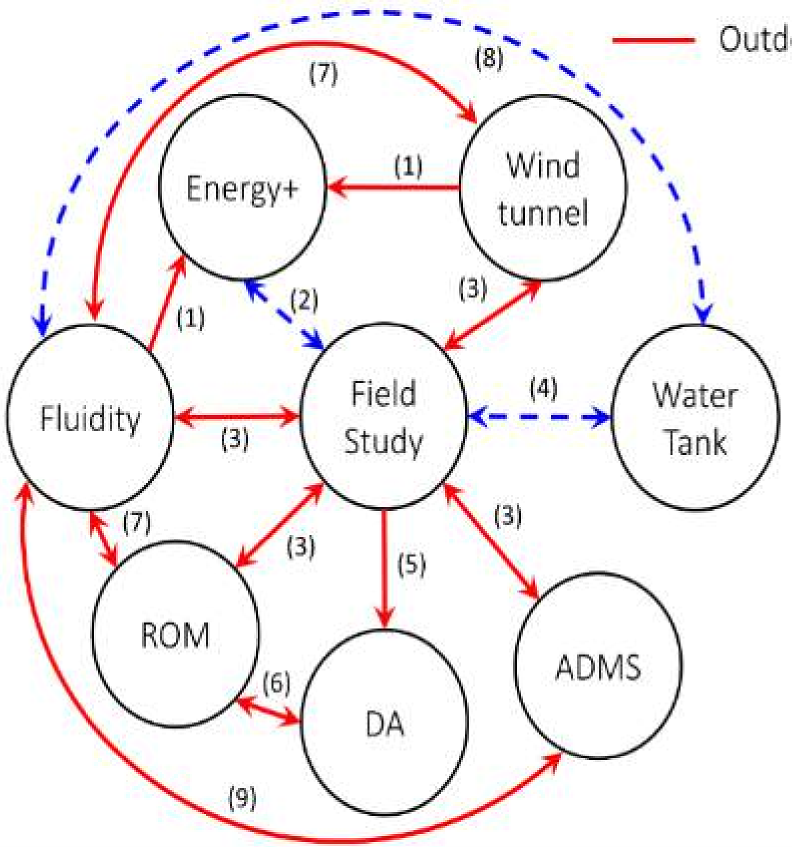

Outdoor condition — Indoor condition

ADMS: Urban flow model
DA: Data Assimilation
ROM: Reduced order model
Energy+: EnergyPlus

(1) Outdoor boundary conditions
(2) Comparison of indoor temperature and pollutant concentration
(3) Comparison of outdoor tracer gas concentration
(4) Comparison of profiles of indoor temperature
(5) Incorporate sensor data into models for increased accuracy of predictions
(6) Improved accuracy of ROM predictions
(7) Comparison of outdoor velocity field and tracer gas concentration distribution
(8) Comparison of indoor tracer gas concentration distribution
(9) Comparison of outdoor pollution

Progress

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- Test sites
- Fluidity development
- Wind tunnel studies
- Ventilation studies
- Energy calculations
- Traffic emissions
- Integration
- Future work

Progress

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London field study 2017

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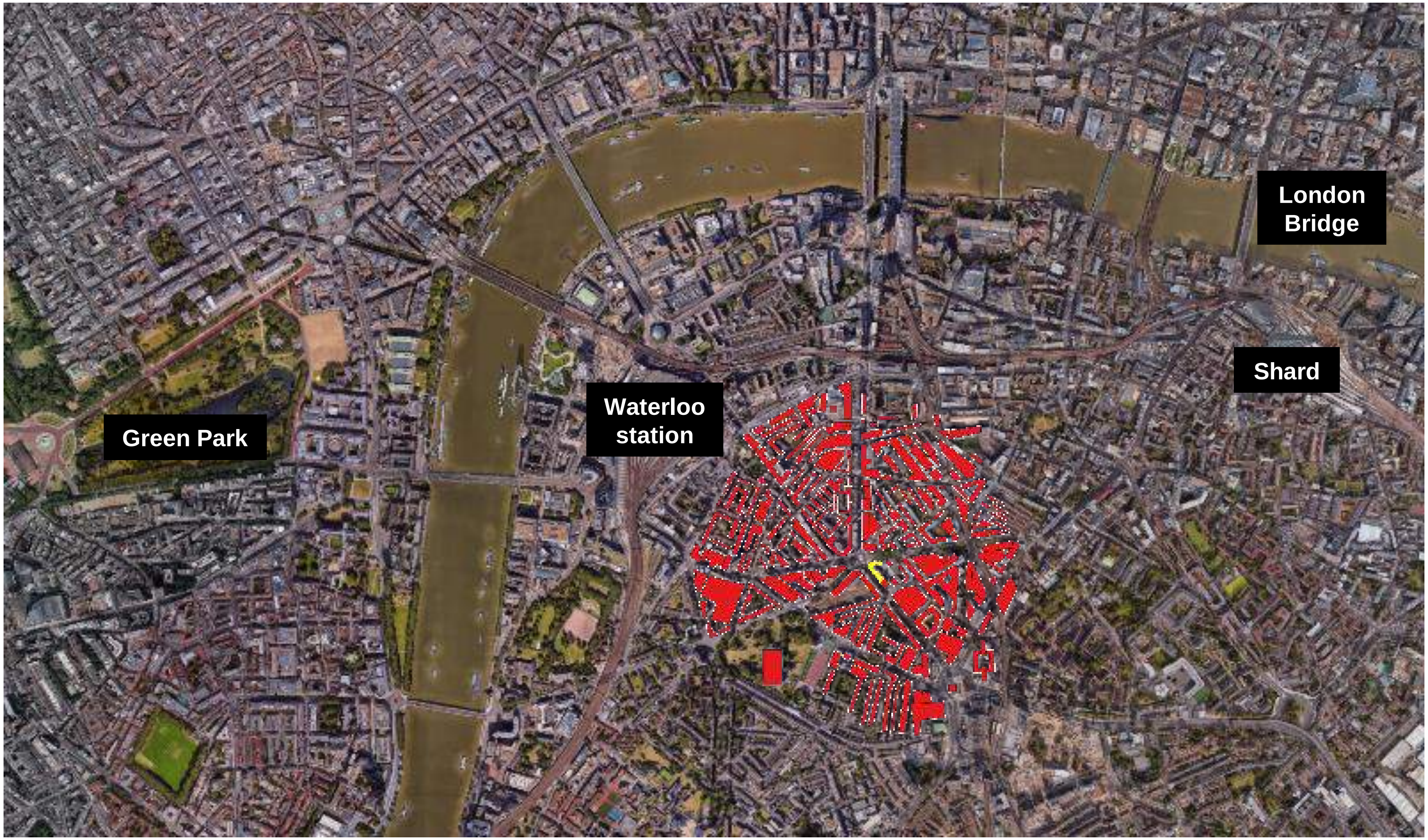

Test site

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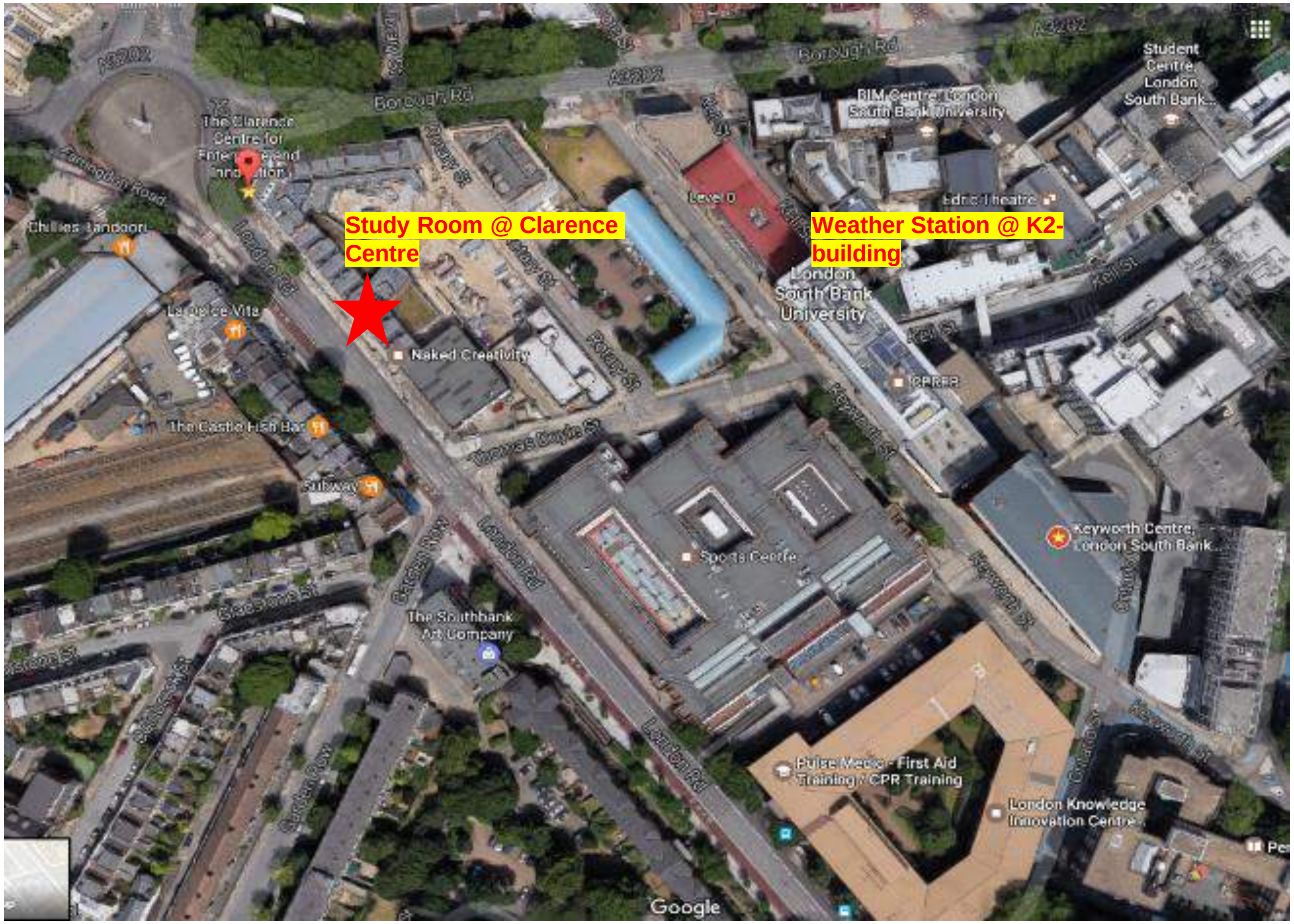

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Case study room

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London Road Side

Courtyard Side

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Indoor CO_2 – Single-sided Ventilation

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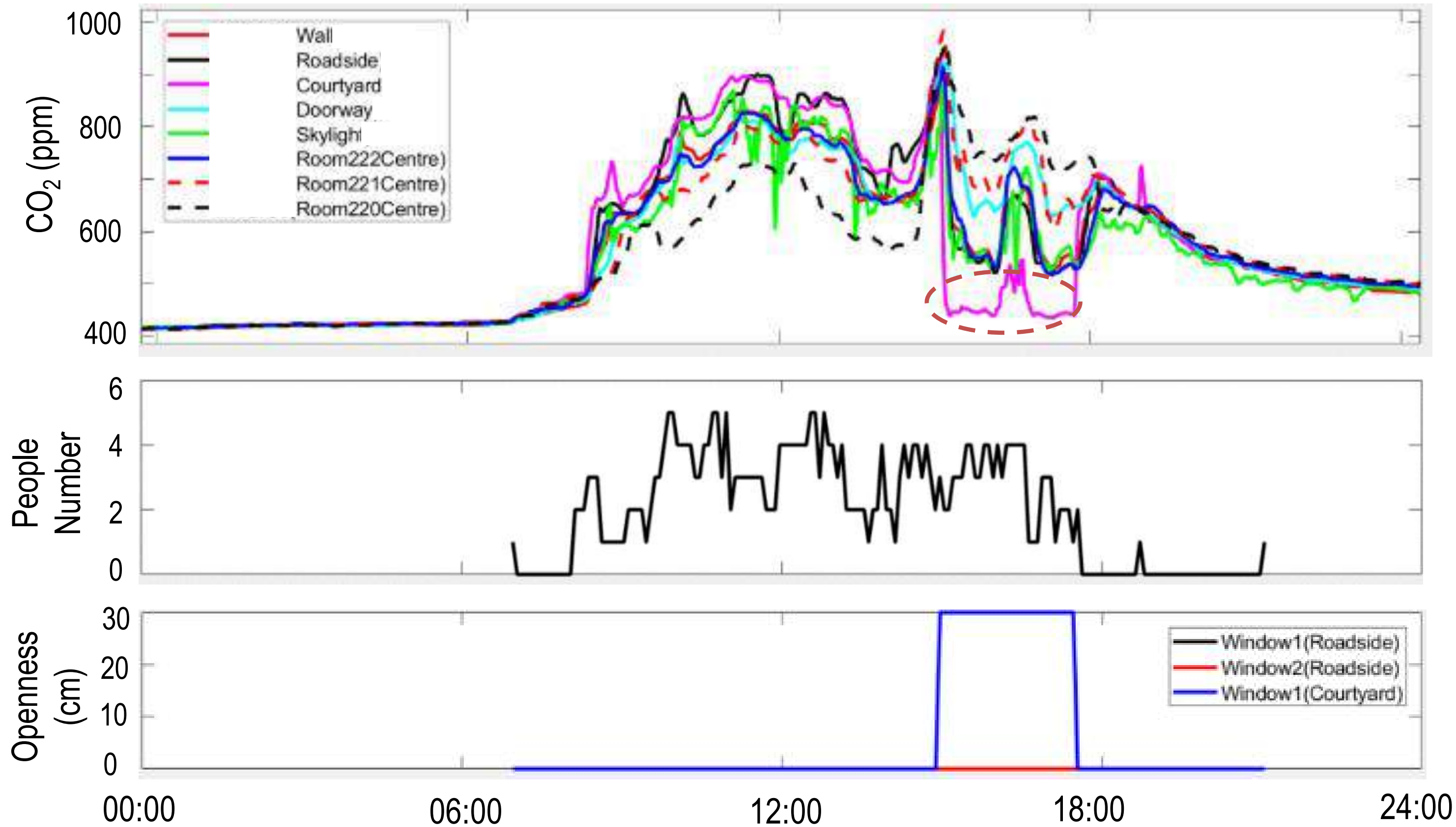

- CO2 highly correlates to the number of occupants in the room
- CO2 reduction is clear when the window is open and CO2 by the window is close to outdoor
- CO2 spatial variation is observed

Indoor CO_2 Vertical Stratification

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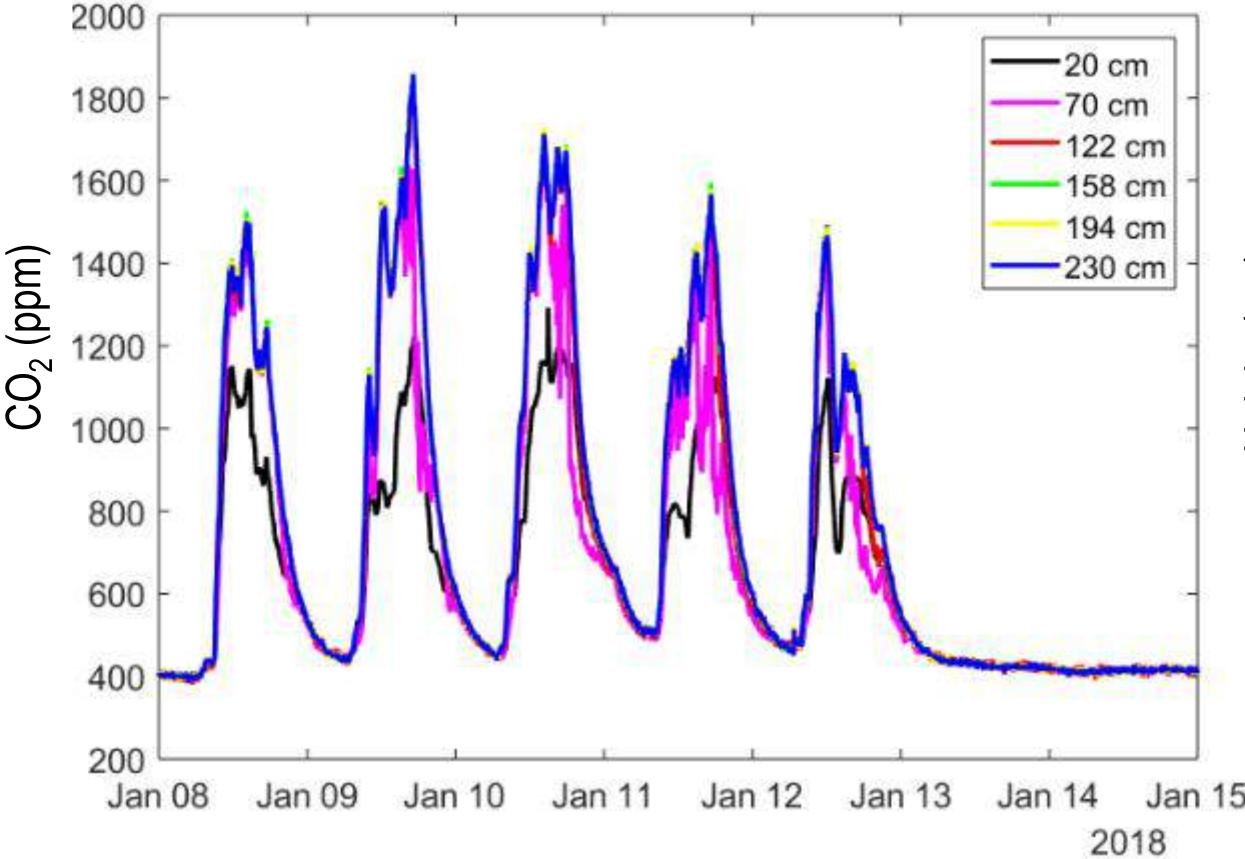

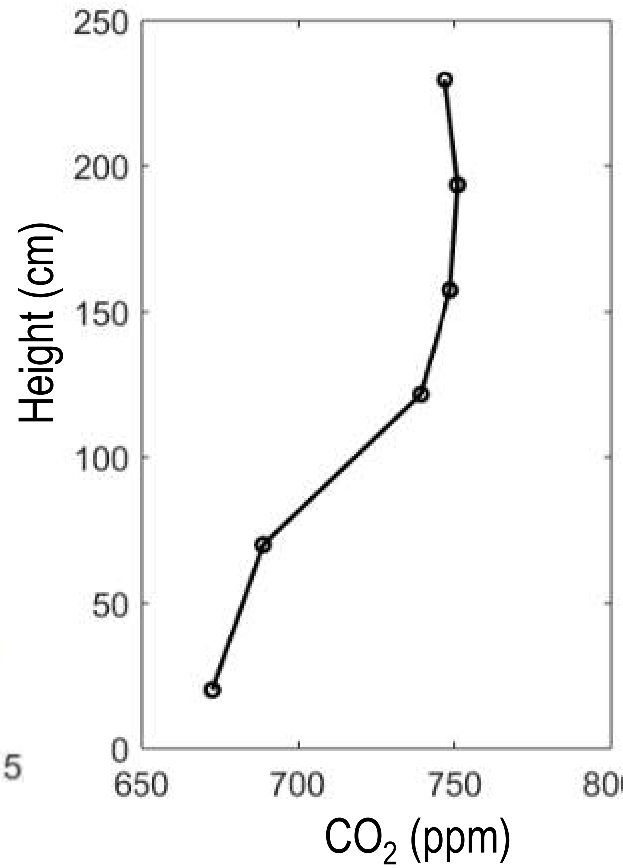

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Outdoor monitoring

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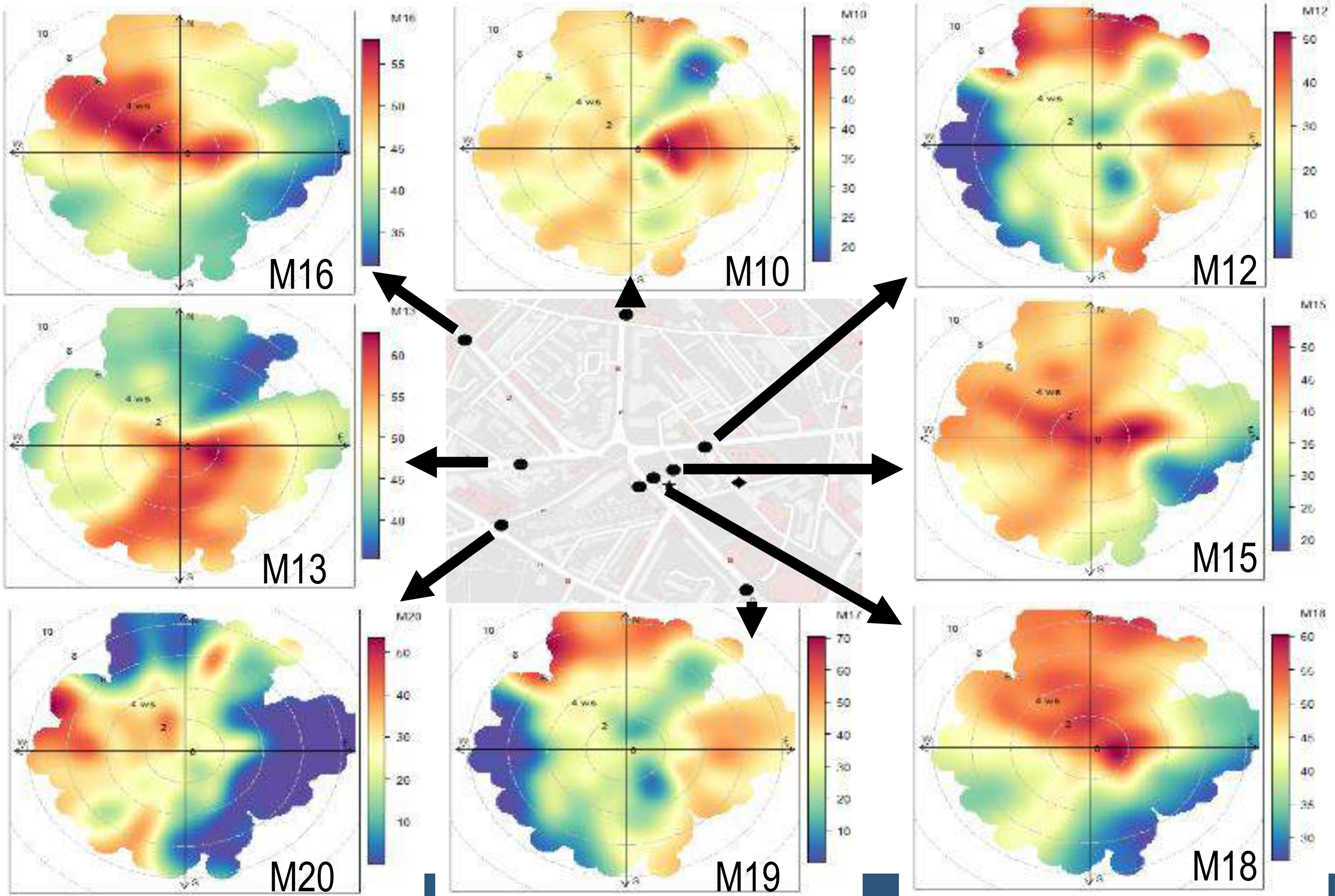

Cambridge field study 2018

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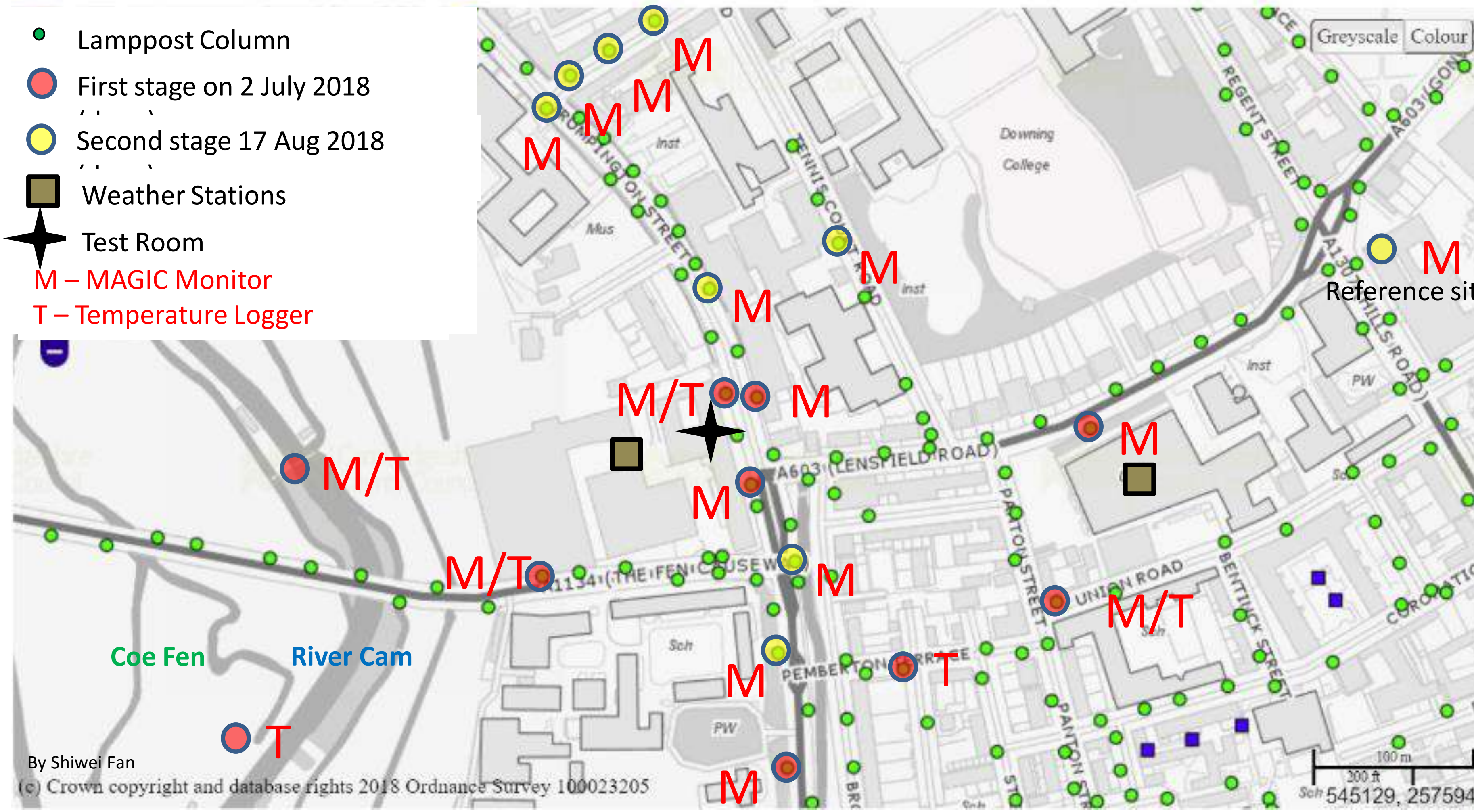

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Cambridge Study

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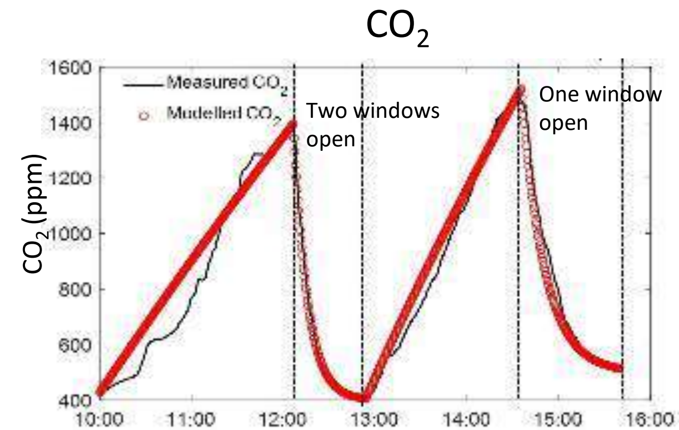
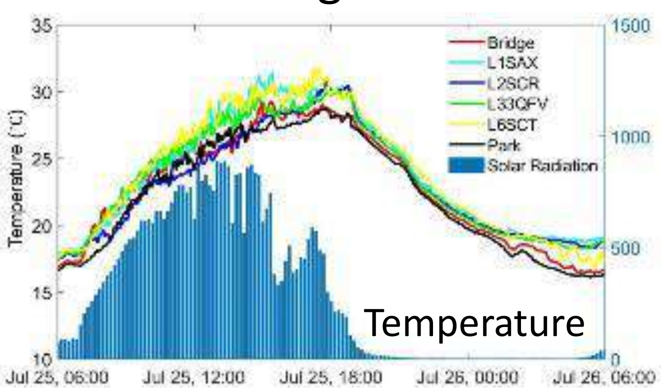
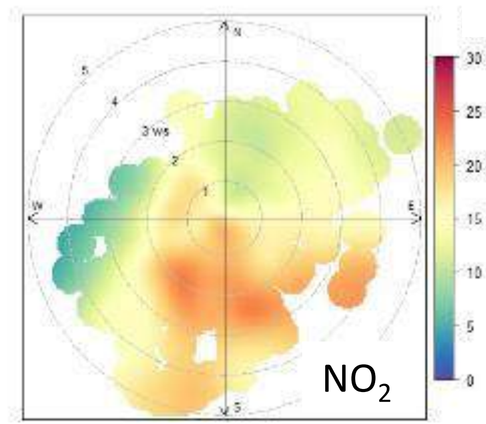
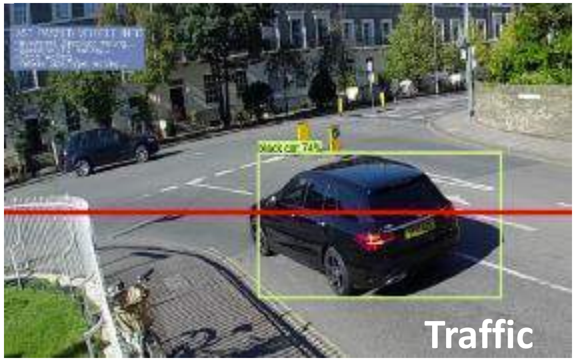
- Operated from July 2018 and completed in Feb 2019
- Indoor: ventilation/pollutants, thermal stratification
- Outdoor: pollutants, temperatures in green/blue spaces and urban areas
- Others: reference wind speed/direction, and solar radiation
- Controlled ventilation tests with traffic monitoring









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Progress

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Fluidity development

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- **Urban Terreno**
  - Purpose: automatic generation of unstructured and 3D mesh for complex urban environment. Developed to be as generic as possible and run in parallel. ✓
  - Topography of the terrain can be considered. ✓
  - Identify and remove automatically topological problem. ✓
  - Identify buildings, roads, green and blue spaces region (needed to assign proper boundary conditions). ✓

- **LSBU test site**
  - Comparison with wind tunnel data
    - Mean velocities, reynolds stresses, pollutant concentration and pressure coefficients ✓
  - Data Assimilation
    - Link Fluidity and DA ✓
    - Wind tunnel data to be assimilated ✓
  - Comparison between Fluidity results and NIROM results ✓

- **Cambridge test site**
  - Implementation of thermal effect ✓
    - Conduction through walls and ground ✓
    - Convection between air and urban setting ✓
    - Radiation: direct and diffuse ✓
  - Implemention of near wall log-law function ✓
  - Comparison with wind tunnel experiment ✓

Numerical modelling

Laetitia Mottet

Carolanne Vouriot

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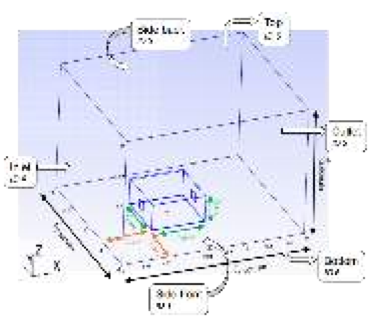
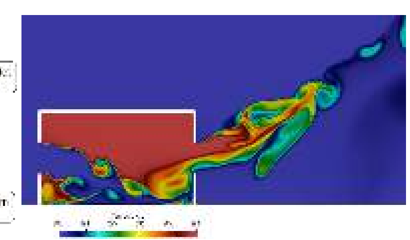
- **Fluidity manual based on indoor-outdoor exchange (with Carolanne Vouriot)**





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Fluidity development

Laetitia
Mottet

Carolanne
Vouriot

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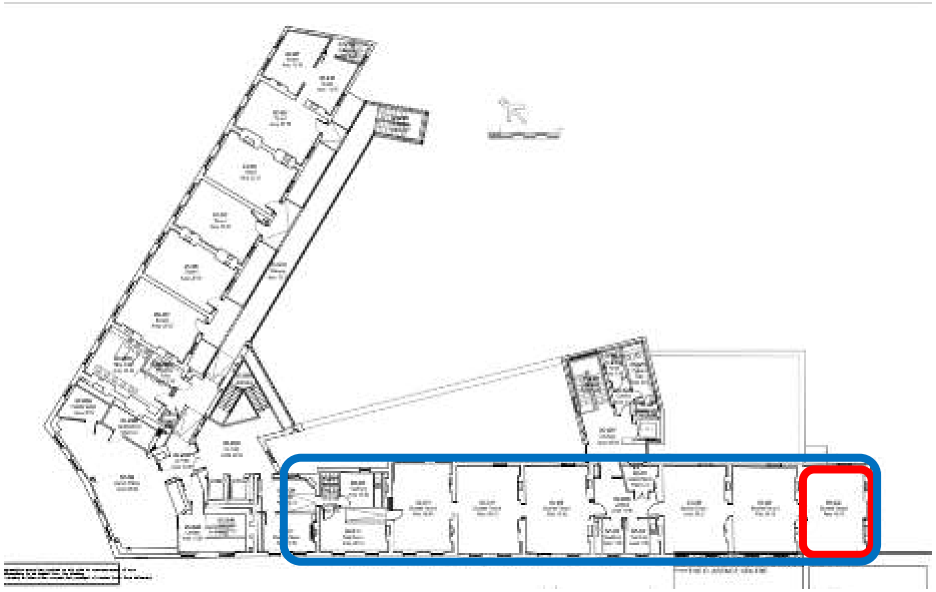
- **Indoor modelling**
  - Fluidity is tested to be used for complex indoor modelling ✓
    - LoHCool project: test of adaptation scheme to enhance natural ventilation.
  - Indoor modelling of Clarence Center (Carolanne Vouriot) ✓



Only that part of the **building** will be modelled + the **room** + the **building next** to the test room

Fluidity development

Laetitia Mottet

Carolanne Vouriot

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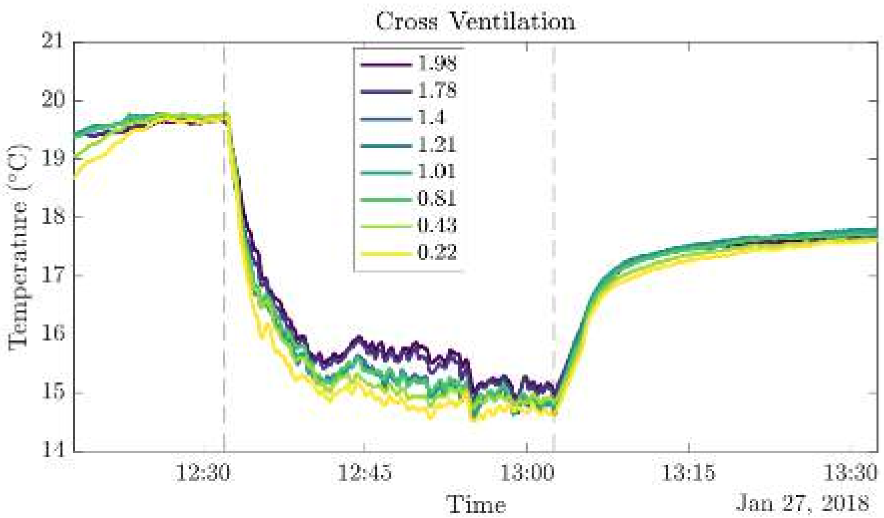
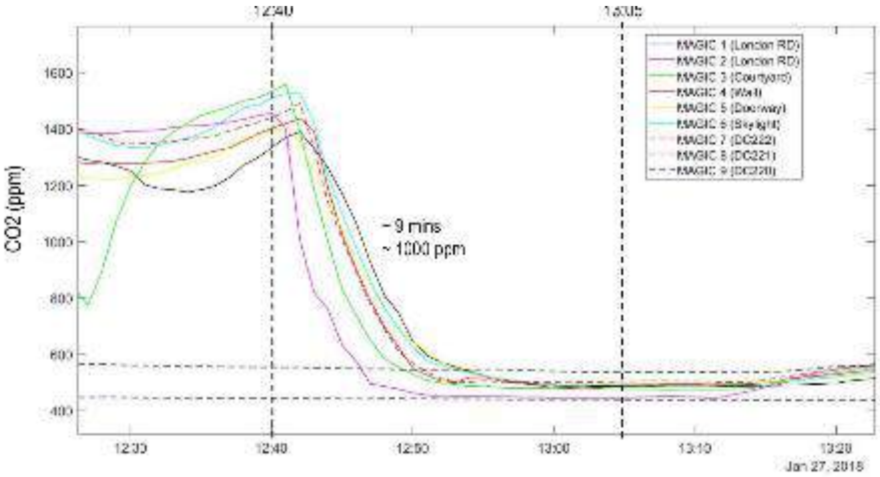
Envisaging a world with greener cities

- **Indoor modelling**
  - Fluidity is tested to be used for complex indoor modelling ✓
    - LoHCool project: test of adaptation scheme to enhance natural ventilation.
  - Indoor modelling of Clarence Center (Carolanne Vouriot) ✓
    - Temperature field and CO2 decay will be compared for the cross ventilation controlled experiment (25 minutes) made in January 2018.





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Fluidity development

Laetitia Mottet

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- **More physics**
  - Implementation of thermal effect ✓
    - Conduction through walls and ground ✓
    - Convection between air and urban setting ✓
    - Radiation: direct and diffuse ✓

- Objective: Compute the **air temperature** field in the domain
  - Advection-Diffusion equation

$$\rho_{air} c_{p,air} \frac{\partial T_{air}}{\partial t} + \rho_{air} c_{p,air} (\mathbf{u}.\nabla T_{air}) = \nabla(k_{air} \nabla T_{air}) + S$$

- Need to determine correct **boundary condition**, i.e. surface temperature of buildings, ground using a

SURFACE ENERGY BALANCE

$$\underbrace{\rho_s c_{p,s} d_s}_{\text{Properties and thickness of the surface}} \frac{dT_s}{dt} = \underbrace{K}_{\text{Net shortwave radiation}} + \underbrace{L}_{\text{Net longwave radiation}} - \underbrace{H}_{\text{Sensible heat flux}} - \underbrace{E}_{\text{Latent heat flux}} - \underbrace{G}_{\text{Ground heat flux}}$$

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Fluidity development


Laetitia Mottet

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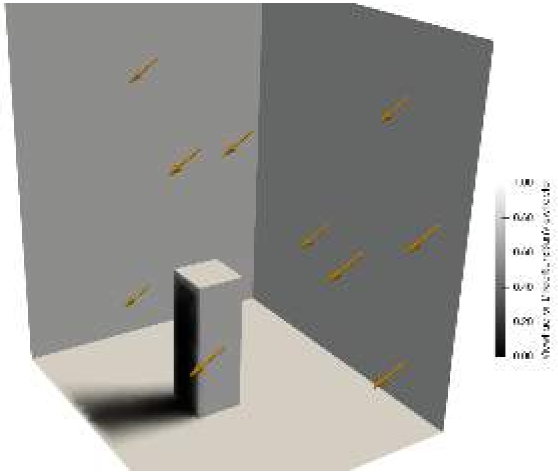
Envisaging a world with greener cities

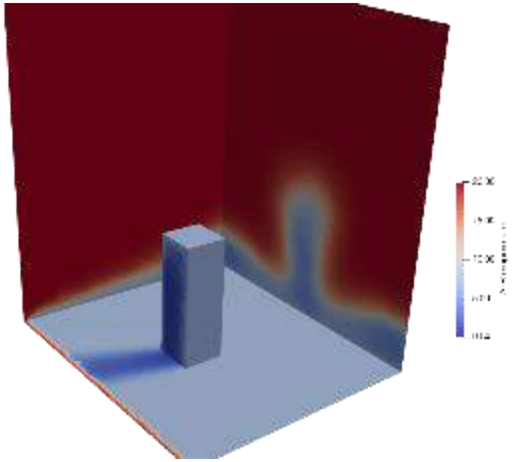
- **More physics**
  - Implementation of thermal effect ✓
    - Conduction through walls and ground ✓
    - Convection between air and urban setting ✓
    - Radiation: direct and diffuse ✓

Example of results: Assuming direct solar radiation of the net shortwave radiation

$$\rho_s c_{p,s} d_s \frac{dT_s}{dt} = K$$



Value of K: direct solar radiation only.



Surface temperature computed.

Fluidity development

Laetitia Mottet

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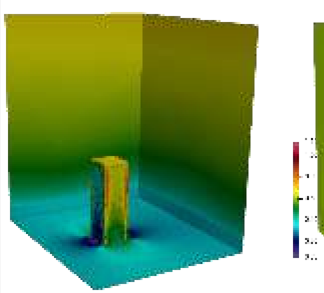
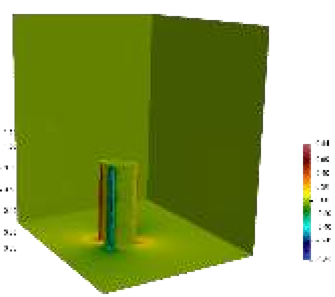
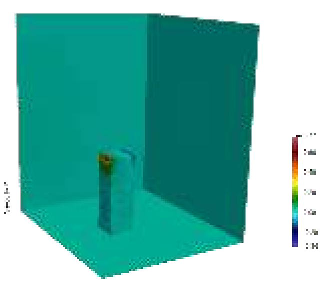
- **More physics**
  - Implementation of thermal effect ✓
    - Conduction through walls and ground ✓
    - Convection between air and urban setting ✓
    - Radiation: direct and diffuse ✓
  - Implemention of near wall log-law function associated with a slip BC ✓



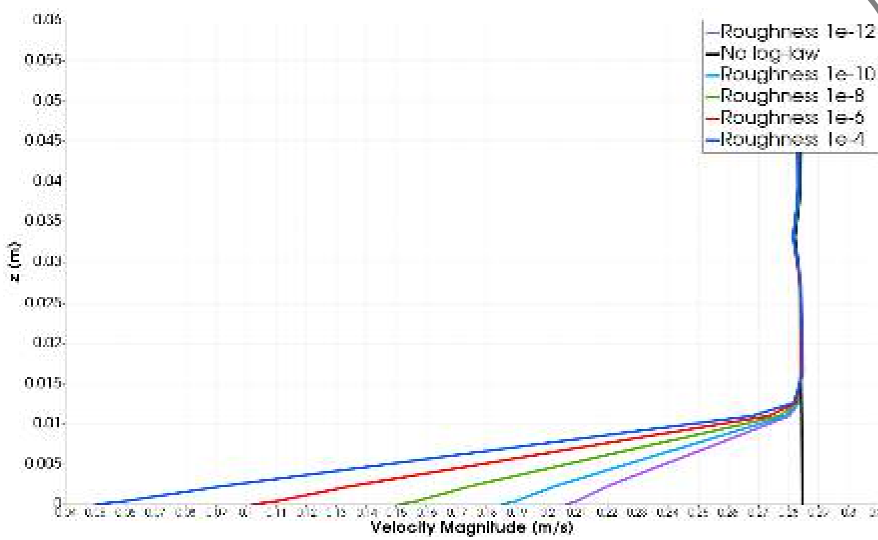
x-component



y-component



z-component



Vertical profile of the velocity near the ground using different roughness value.

Simulation of trees in London Road

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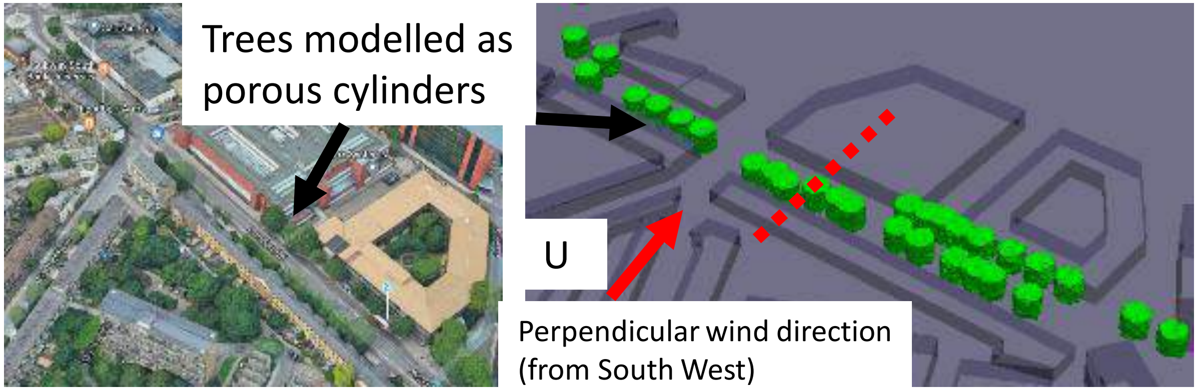
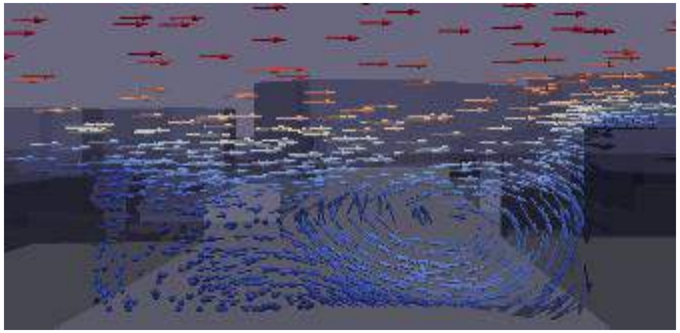


Momentum sink due to tree:

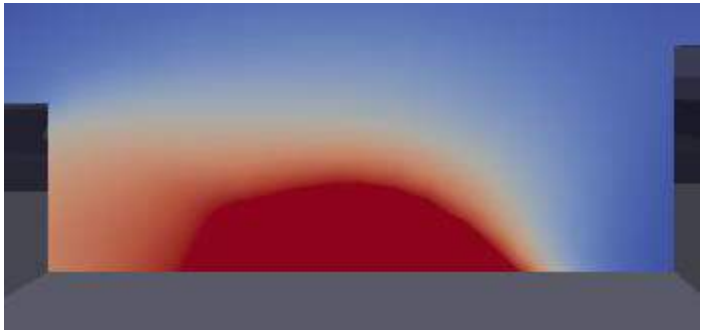
$$S = -C_D.LAD.\frac{1}{2}(\rho u|u|)$$

$$C_D = drag\ coeff.$$
$$LAD = Leaf\ Area\ Density$$

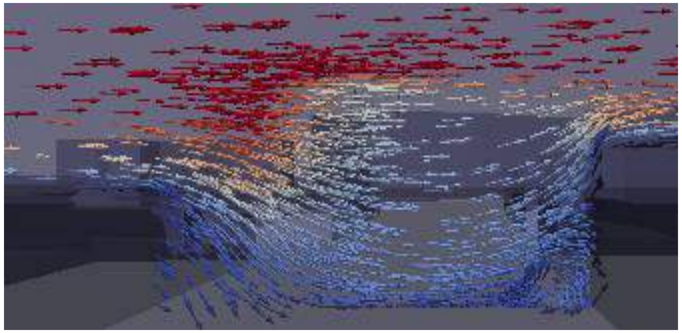
No trees – vortex in street canyon



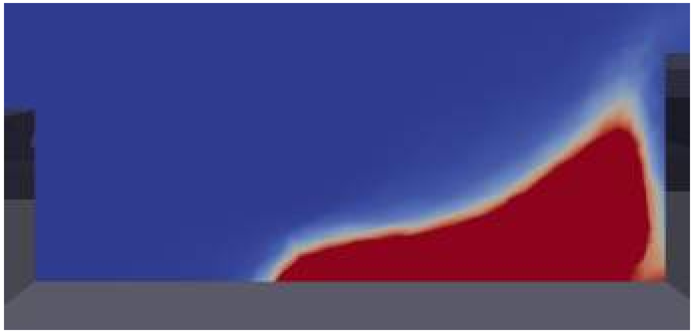
No trees – tracer dispersed to leeward side



With trees – no street canyon vortex



With trees – tracer dispersed to windward side



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Progress

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- Test sites
- Fluidity development
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Wind tunnel model studies
Update on LSBU site

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Activities
- Measured velocity and concentration fields for a range of wind directions
- Measured surface pressures on Clarence House
- Joint measurements of all three fields

Motivation
- To provide data for evaluating performance of computational methods (e.g. Fluidity).
- To understand flow and dispersion physics in complex urban environments.
- To compare behaviour with previous studies in the Marylebone Road area of London.

Wind tunnel highlights

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- Studied the effect of model scaling
  - Compared 1:500 model against 1:200 model
  - Small blockage effect observed (< 10% speed-up in larger model)

500x smaller than actual London

200x smaller than actual London

Wind tunnel highlights

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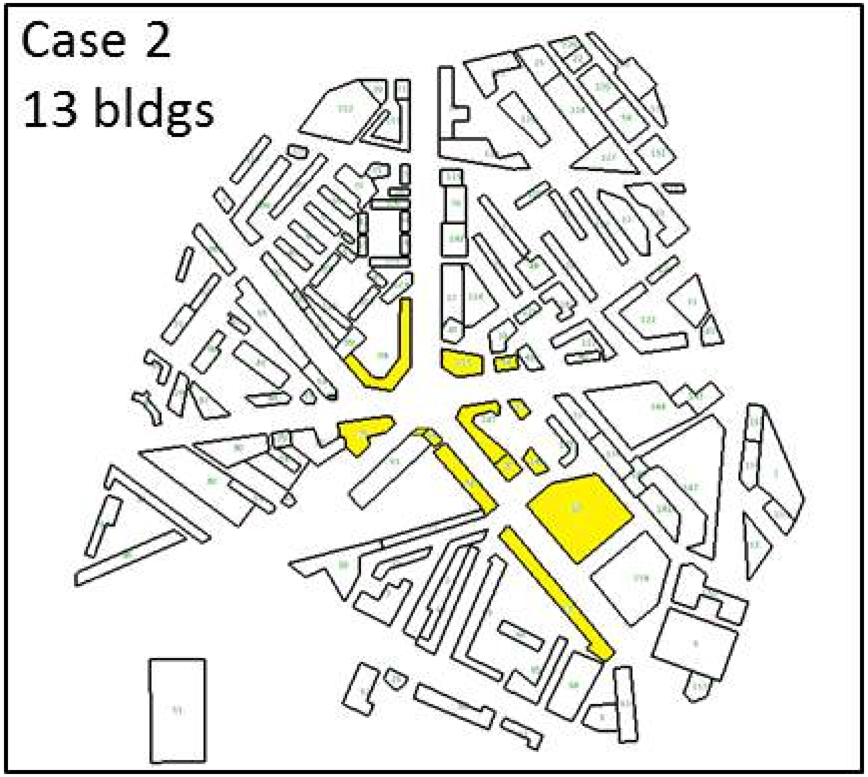
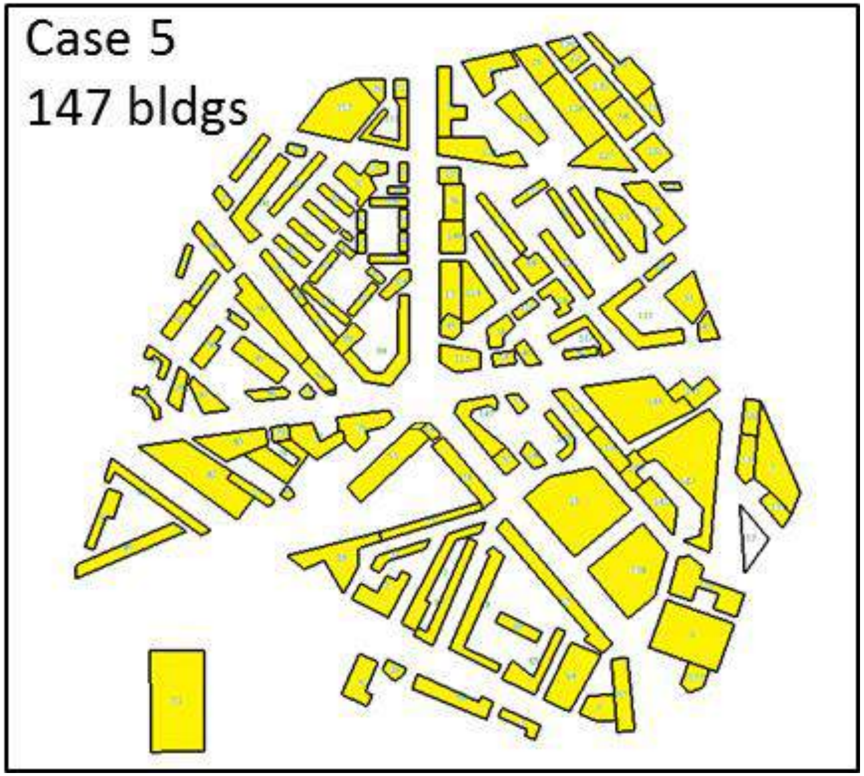
- Studied the effect of model extent
  - Compared 13-building model against 147-building model
  - Moderate differences in velocities (generally < 15% of reference)





Wind tunnel highlights

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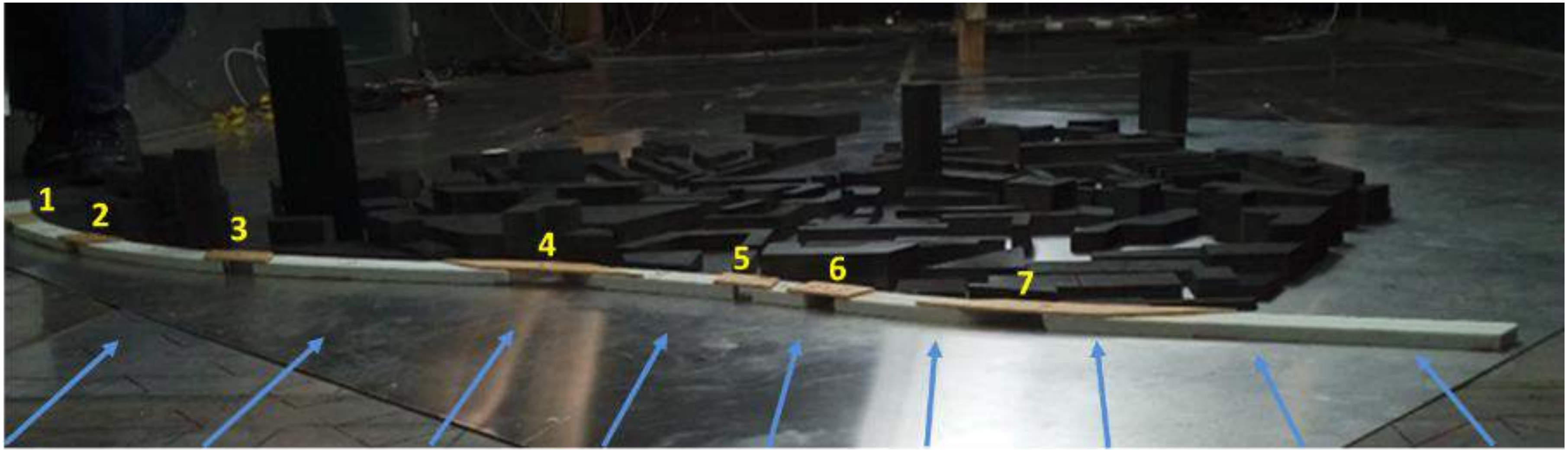
- Studied the effect of SE features
  - Added rail viaduct and 8 additional buildings
  - No observed change to flow at Clarence Centre / London Rd
  - Channelling effects appear to be mostly localised around viaduct road passages



Progress

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Water-bath experiments

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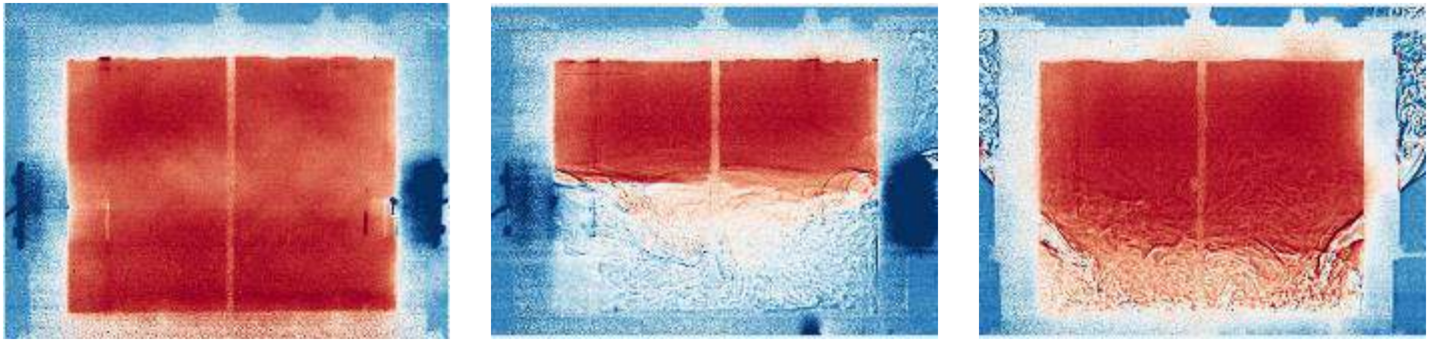
Wind-dominated cross-ventilation: Model as wind only with reduced room volume.

Buoyancy-dominated cross-ventilation: Model as exchange flow with a Froude number correction.



Future plans: EnergyPlus model, single-sided ventilation.

Cross-ventilation

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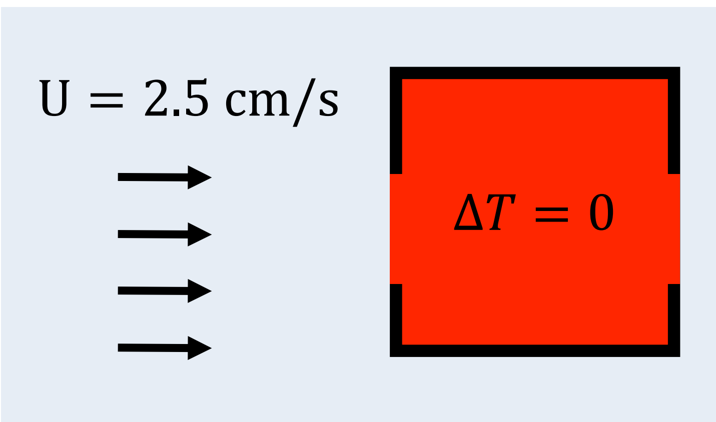

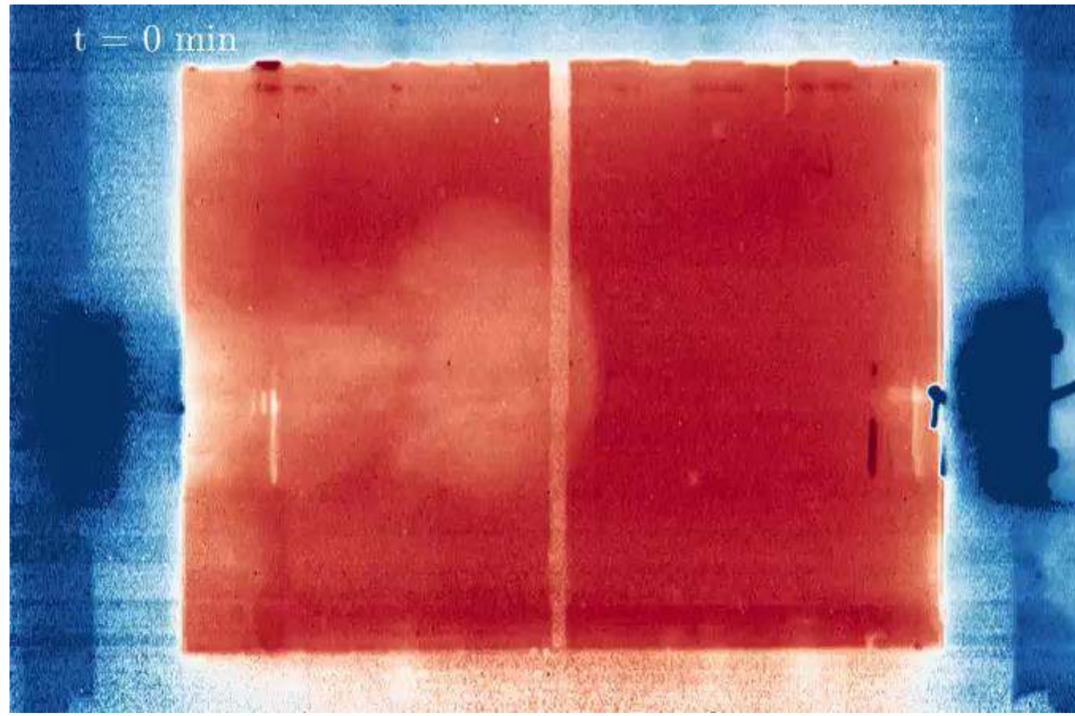

Wind and buoyancy

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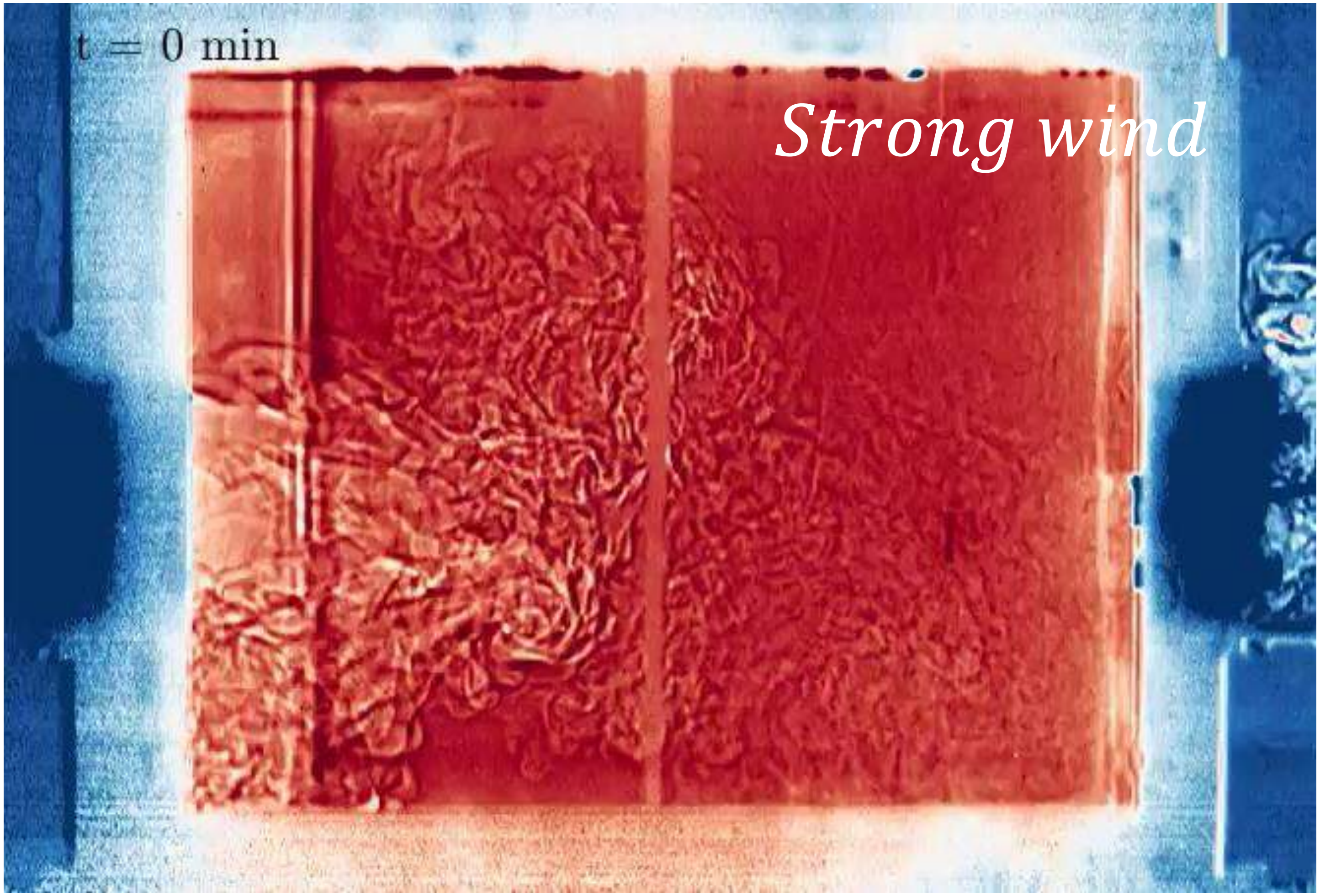

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EnergyPlus simulation

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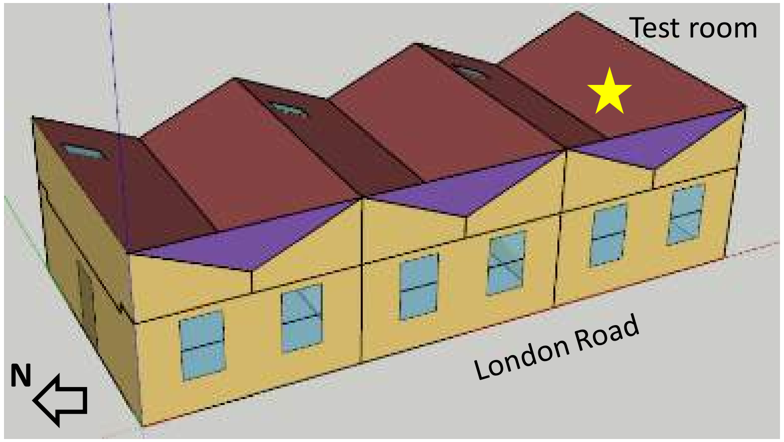
London test room



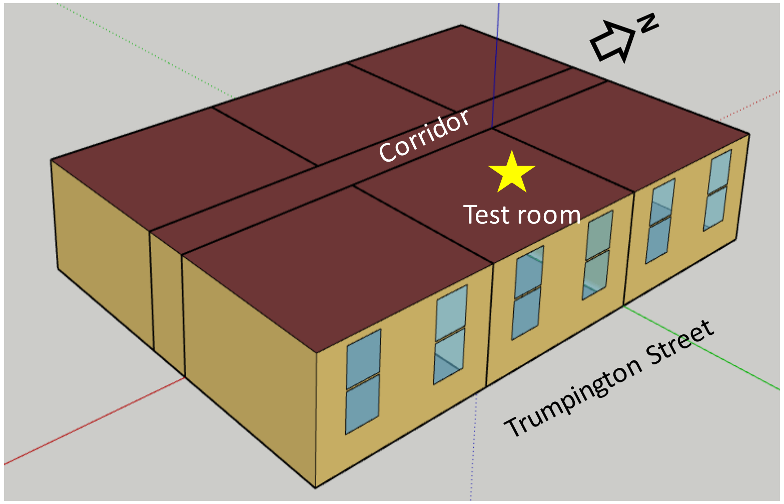
Finished:

- ✓ Worked on my LSBU E+ paper (Enriched Introduction and Methods & study room part, polished & replotted figures);
- ✓ Simulated the LSBU room by using two sets of Cp data with original and twice London Road width, compared the results and added the discussions into the LSBU E+ paper.
- ✓ Submitted a EnergyPlus contribution proposal of Cambridge Cross Ventilation Model with MDW to EnergyPlus development group for review.

To do:

- ➢ Keep on working on my LSBU E+ paper by polishing figures, results, discussions and conclusions.
- ➢ Develop a new module in E+ if the proposal is approved.

Cambridge test room



Finished:

- ✓ Worked on the occupancy schedules of people number, door & window & blind status for the Cambridge test room;
- ✓ Finished E+ simulation of temperature and CO_2 for the Cambridge test room by incorporating realistic occupancy schedules of 2 weeks (Jul 16-26) in July 2018 and 2 weeks (Sep 17-30) in September 2018.

To do:

- ➢ Model traffic pollution (CO, NO) effects on indoor environment;
- ➢ Incorporate Cp results from CFD and WT to improve E+ results.

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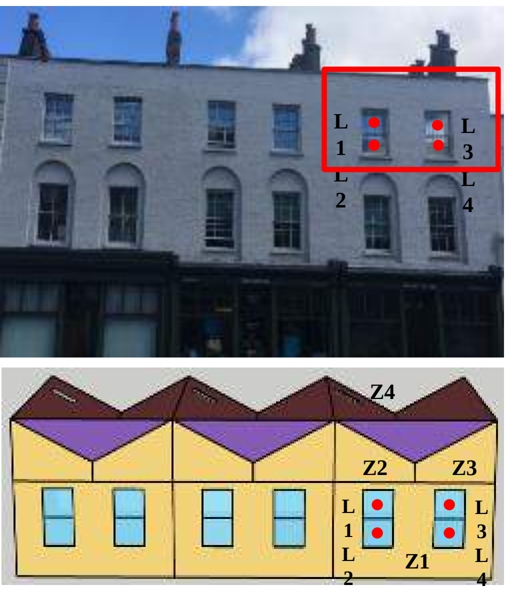
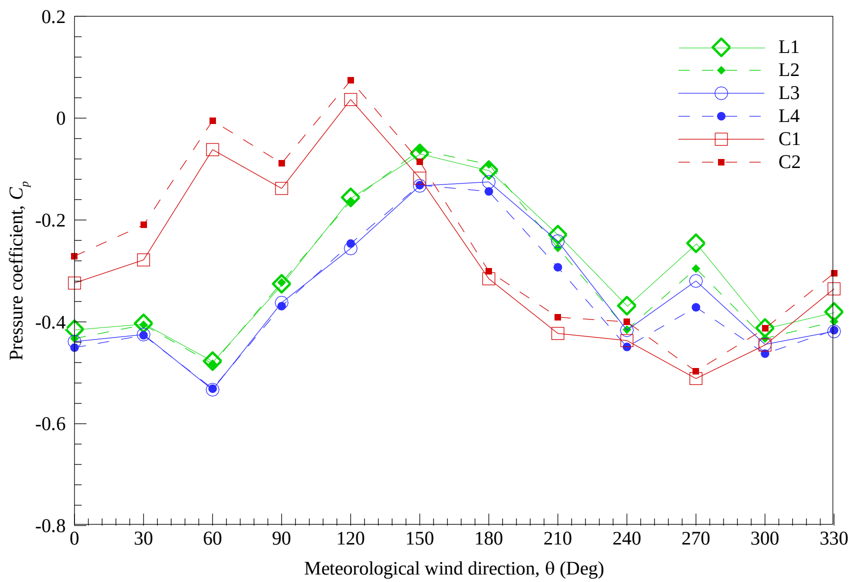
EnergyPlus model with 6 external AFN nodes

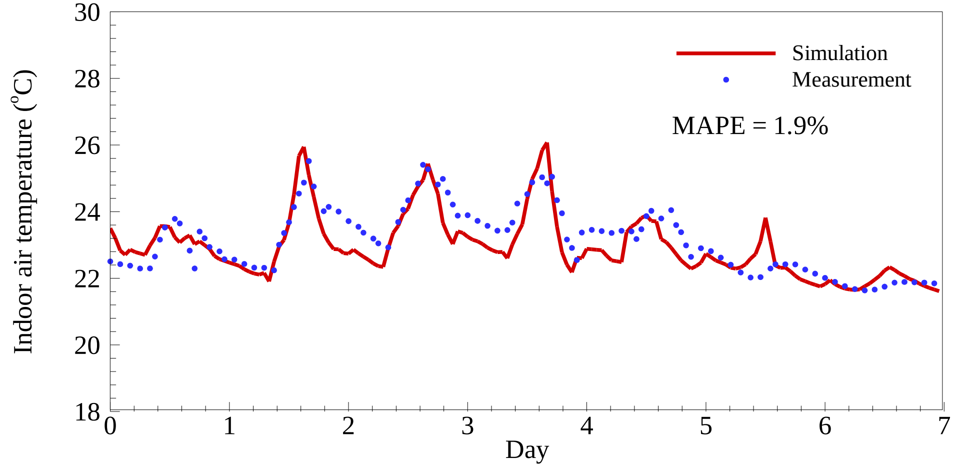
(a) London Road side

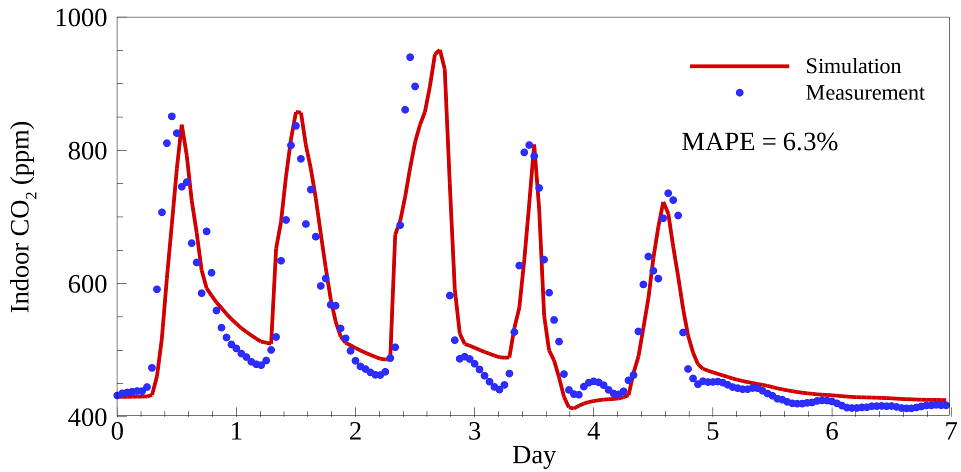


(b) Courtyard side



Comparison between measurement and simulation of indoor air temperature and CO_2 in LSBU test room from Sep. 25 to Oct. 01, 2017 (Mon-Sun).





MAPE:
Mean absolute percentage error

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{mea - sim}{mea}\right| \cdot 100\%$$

The impact of urban form changes with widened London Road

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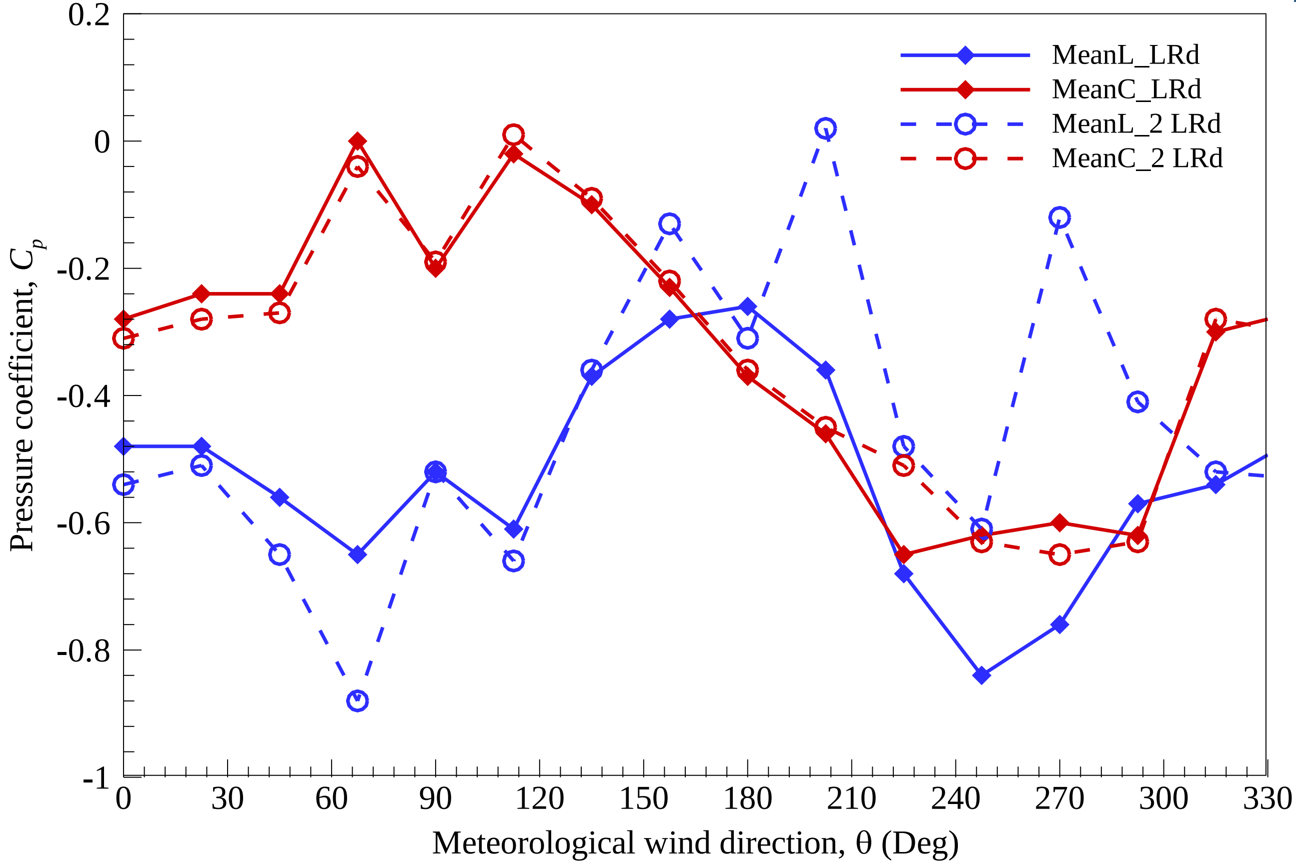

MeanL: Cp averaged over the 4 windows on the London Road side
MeanC: Cp averaged over the 2 windows on the Courtyard side

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Progress

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- Test sites
- Fluidity development
- Wind tunnel studies
- Ventilation studies
- Energy calculations
- Traffic emissions
- Integration
- Future work

Vehicle emissions modelling
(Anna Schroeder)

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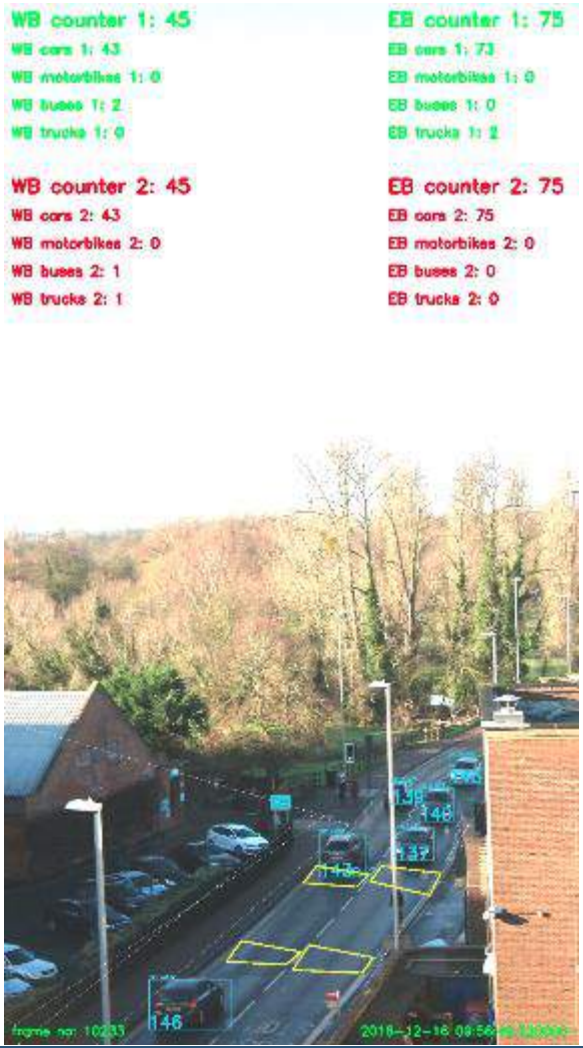

- Computer vision algorithm working
  - Detects and tracks vehicles
  - Highly accurate count values
  - Gives speed and acceleration estimates
- Study conducted to compare on-road PM measurements with observed vehicle behaviour (results in preparation)

Vehicle emissions

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- Study on Fen Causeway, Cambridge:
  - measurement of PM and filming of road traffic completed (3 weeks of data, Dec 18)
  - initial code for detecting, tracking, counting and extracting positional data (for speed and acceleration) of vehicles is working

- Next steps:
  - improve code and analyse video footage
  - predict emissions based on video footage and compare with measurements
  - extract number plate information if possible to get better vehicle emission estimates

Progress

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The OPAL framework

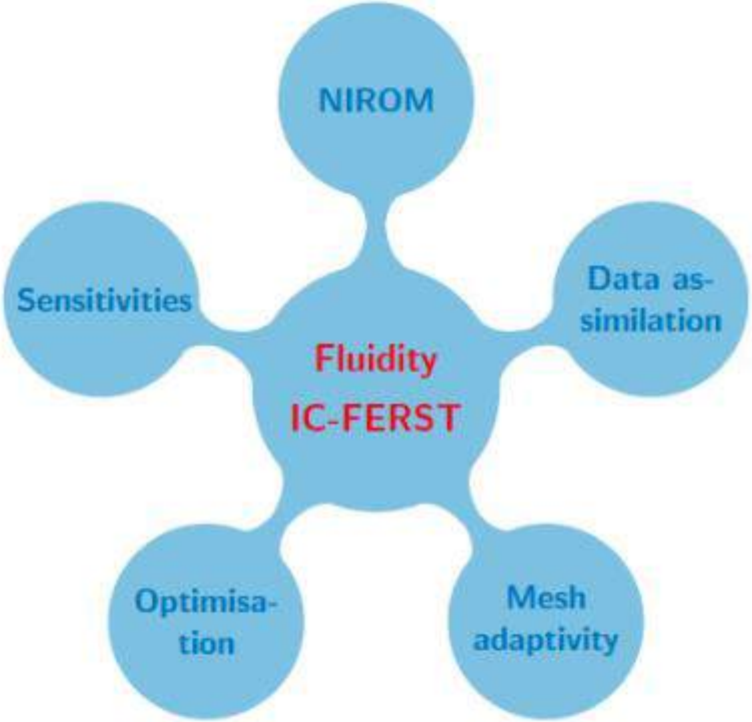
OPAL is collection of functions and scripts written in Python that

- generate input files for Fluidity or IC-FERST,
- run Fluidity or IC-FERST,
- access and manipulate the solutions (in the (p)vtu files).

Within OPAL it is currently possible to

- perform non-intrusive reduced order modelling,
- calculate ensemble-based sensitivities,
- perform ensemble-based data assimilation,
- optimisation (with a genetic algorithm).

The OPAL framework



Progress

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Future work

- More controlled tests with traffic monitoring added are planned
  - Simultaneous indoor and outdoor pollutants monitoring
  - Controlled indoor tests with window openings to estimate ventilation rates
  - Indoor and outdoor exchange during window opening events
  - Collect traffic data for traffic modelling

Doppler LIDAR wind measurements

Prof Janet Barlow, Dr Hannah Gough (Uni of Reading)

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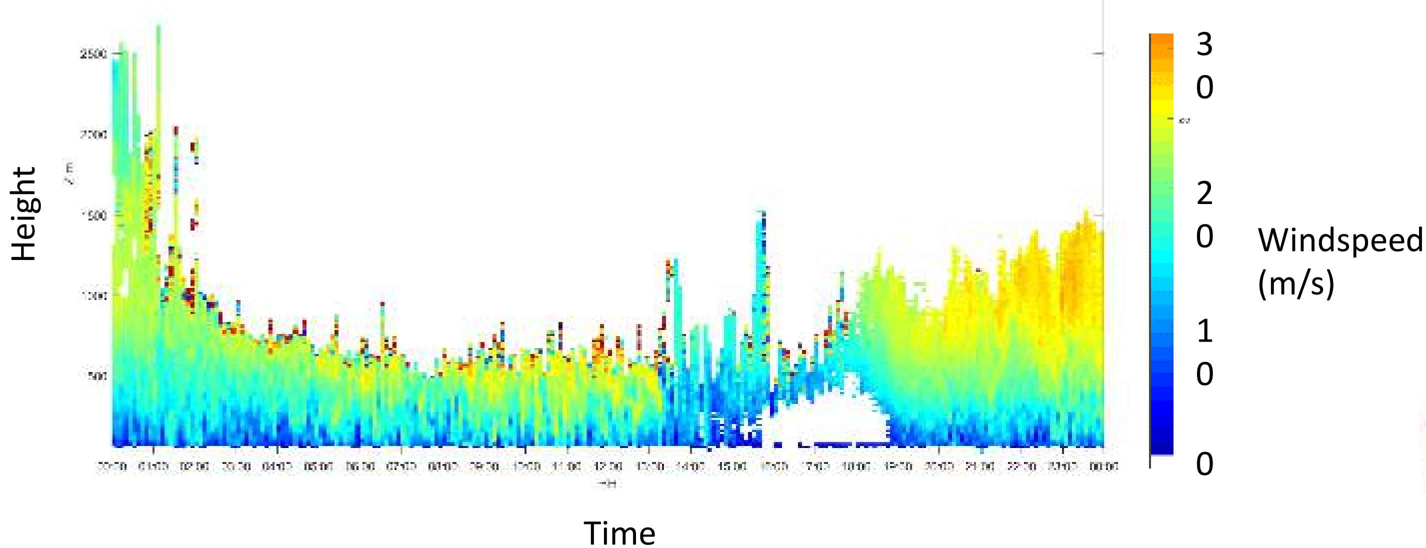
- Halo Photonics Streamline Doppler LIDAR
- Uses 1.5 micron pulses (20kHz) of laser light to measure pollution particle backscatter and velocity every second
- Lidar scans give wind profiles, pollution mixing heights, building wake lengths



HALO Photonics

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Location

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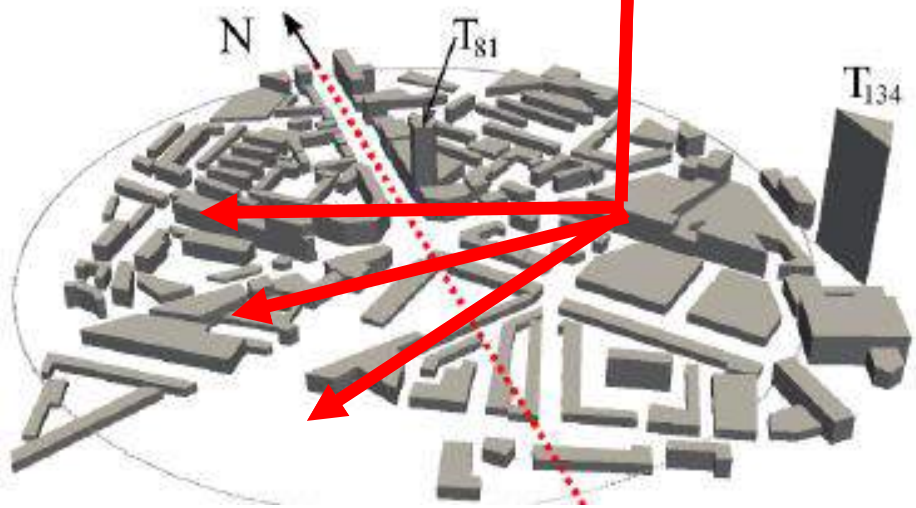
- London South Bank K2 building
- Building 26.5 m high
- Good view for scanning tall building wakes, flow above Clarence Centre
- Compare with wind tunnel and CFD simulations



Thanks to Dr Elsa Aristodemou at LSBU

London South Bank University

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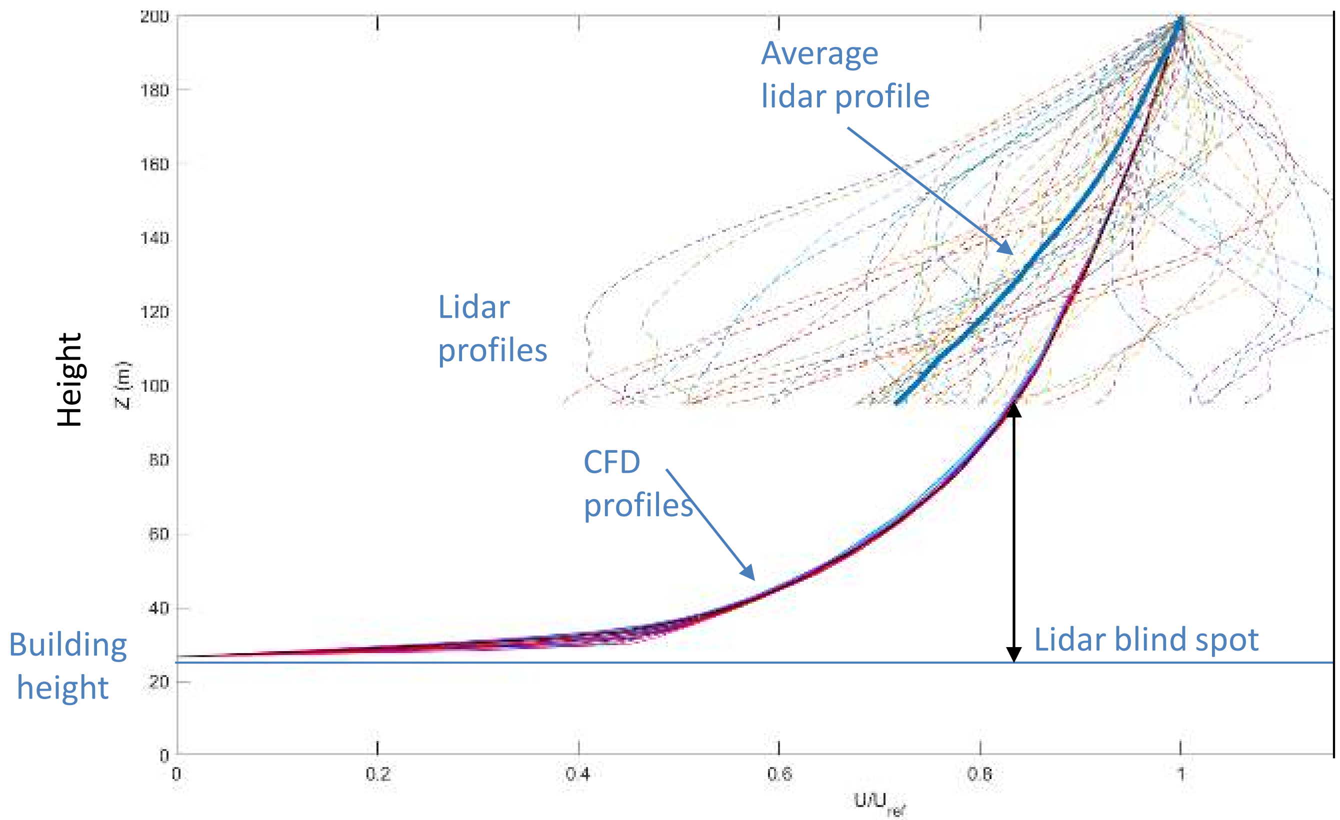
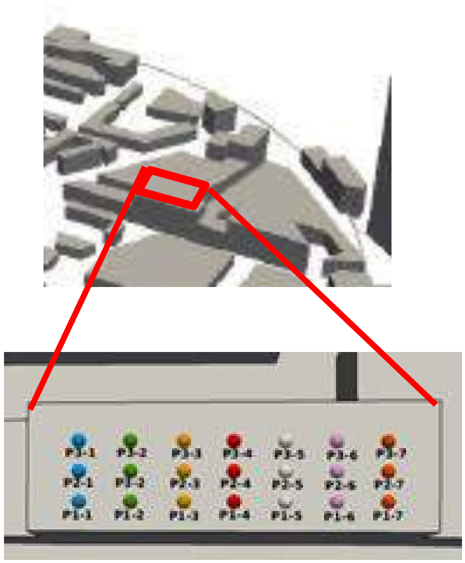
Preliminary CFD comparison - NW direction

Wind profile more sheared (slowed down) by city roughness than in simulations



Windspeed normalised by windspeed at 200m height



CFD profiles on roof

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Comparison with lidar

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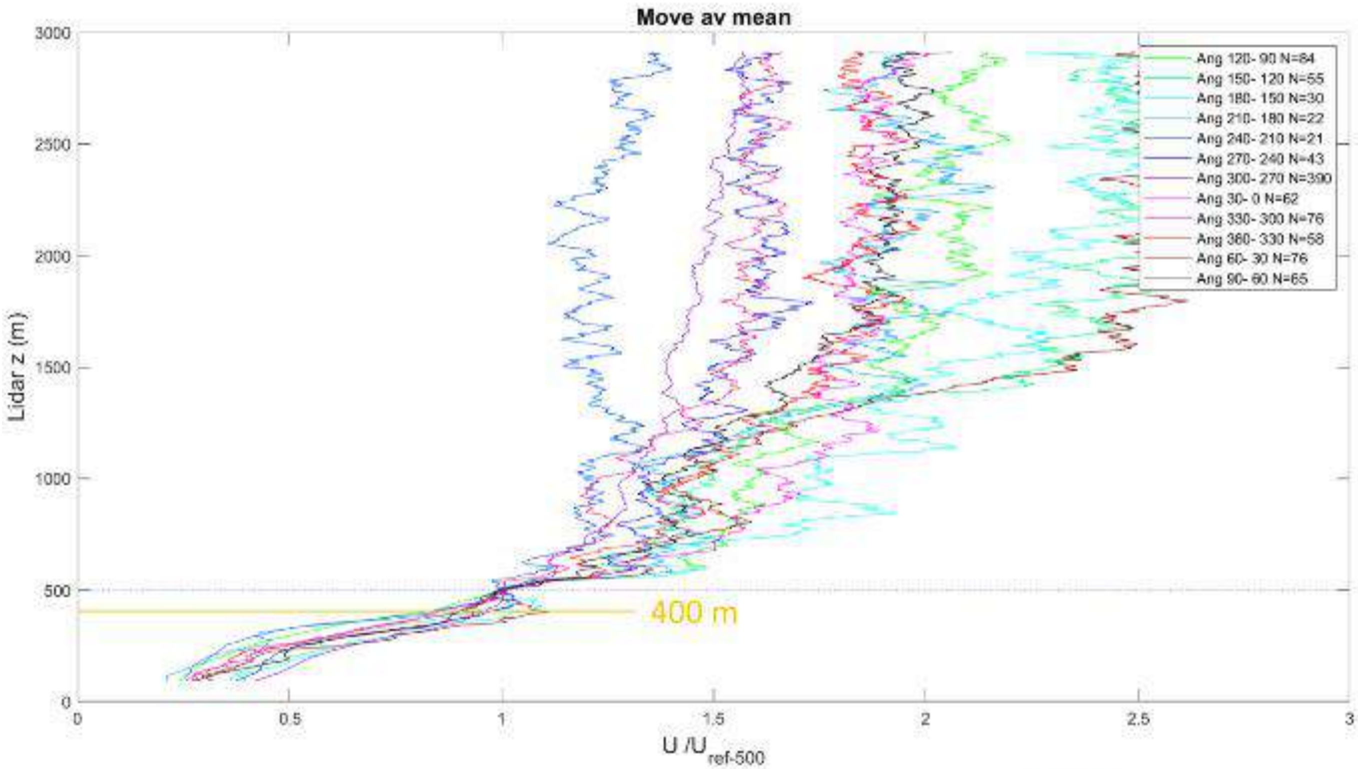
- Lidar mounted on K2 Bldg roof
  - Initial comparisons show promising agreement on profile shape



Lidar data courtesy of H Gough & J Barlow

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Plans for 2019

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- Complete Fluidity development and testing
- Link with ROM and DA
- Conduct further room ventilation studies
- Choose 2019 test site(s) for Case Study
- Develop a cost-benefit model

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