

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?





Partners



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ARUP









Foster + Partners

EC Harris LLP



FFI Forsvarets forskningsinstitutt Norwegian Defence Research Establishment

WWW m





🐯 The University of Reading









New Circle Members

MAGIC

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Imperial College



MAGIC Circle



Envisaging a world with greener cities

- 14 Inaugural partners
- 48 Non-academic organisations
- 20 Universities (8 overseas)





About



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



Envisaging a world with greener cities

- 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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- (8) (7) Wind (1) Energy+ tunnel 1 (3)(2) (1) Field (4) Water Fluidity (3) Study Tank (3) (7) (3) (5) ROM ADMS (6) DA (9)
 - 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

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



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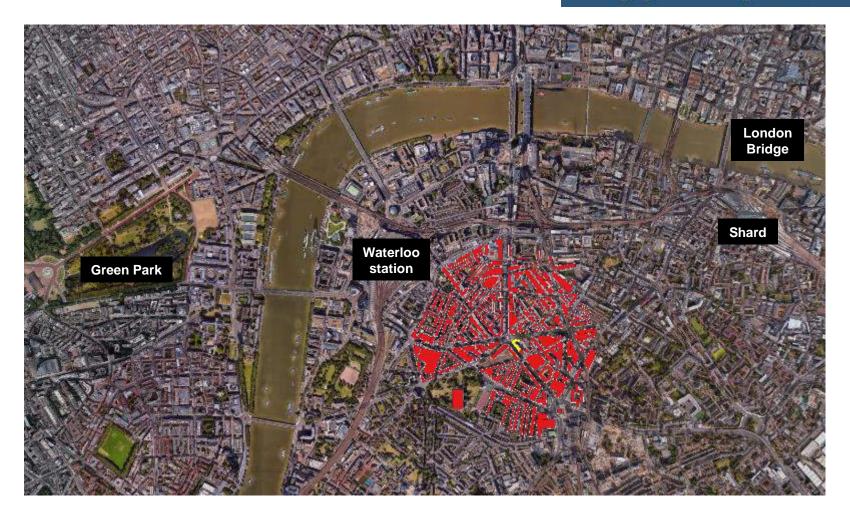




London field study 2017

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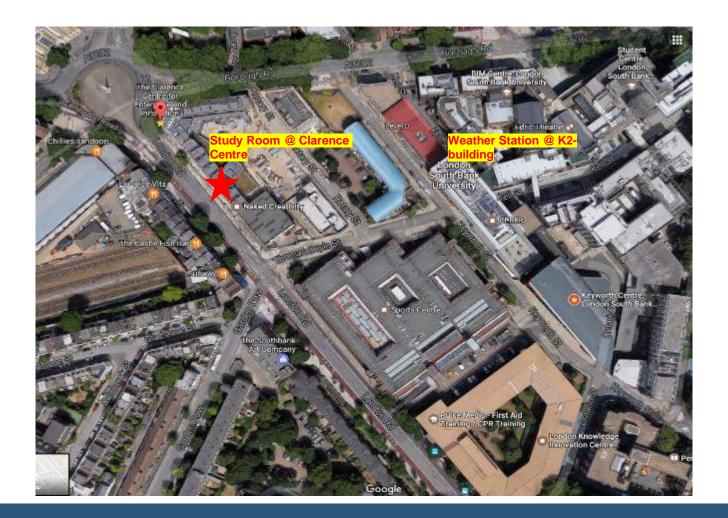




Test site



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Case study room



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London Road Side



Courtyard Side



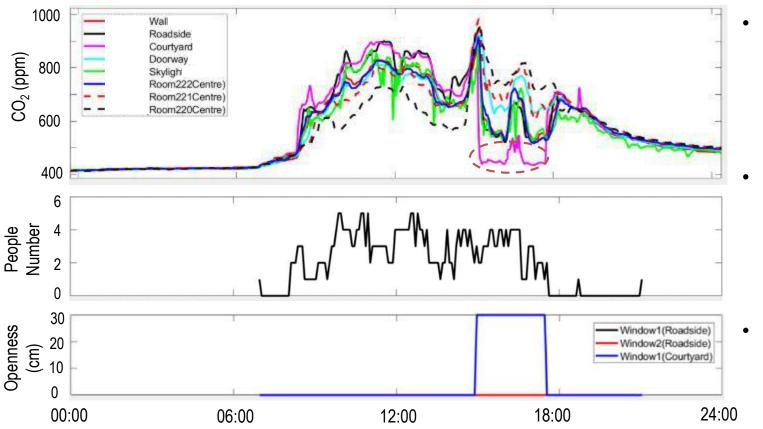




Indoor CO₂ – Single-sided Ventilation

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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

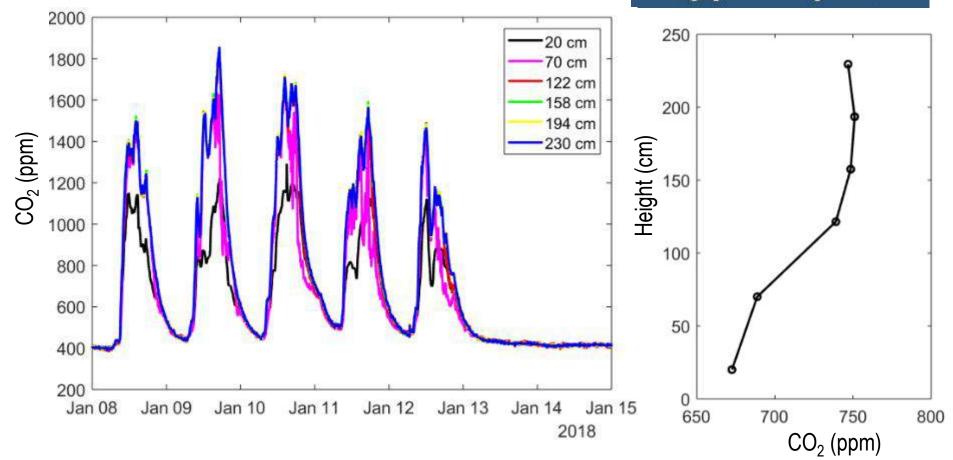




Indoor CO₂ Vertical Stratification

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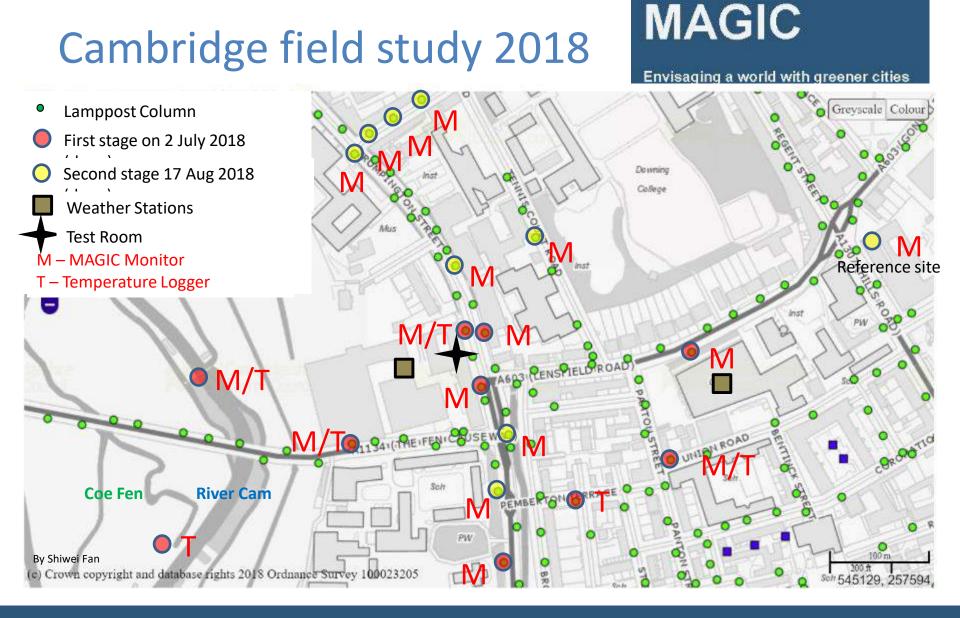






Outdoor monito MAGIC

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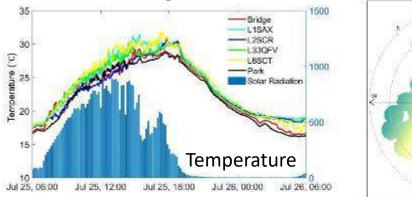


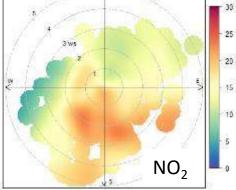


Cambridge Study



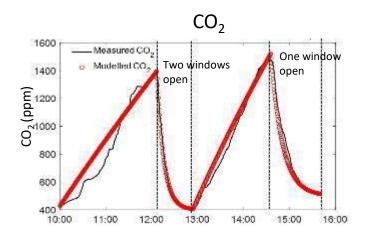
- Operated from July 2018 and completed in Feb 2019
- Indoor: ventilation/pollutants, thermal stratification
- Outdoor: pollutants, temperatures in green/blue spaces and urban areas
- Others: reference wind speed/direction, and solar radiation
- Controlled ventilation tests with traffic monitoring

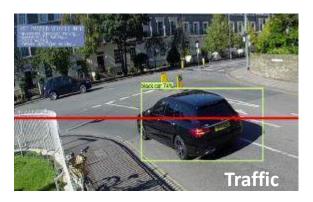






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Urban Terreno

- 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. \checkmark
- Identify and remove automatically topological problem. \checkmark
- 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 \checkmark
 - Wind tunnel data to be assimilated \checkmark
- Comparison between Fluidity results and NIROM results √

Cambridge test site

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





Numerical modelling

Laetitia Carolanne Mottet Vouriot

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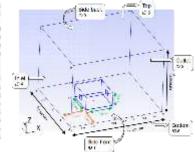
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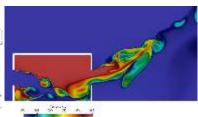
Fluidity manual based on indoor-outdoor exchange (with Carolanne Vouriot)

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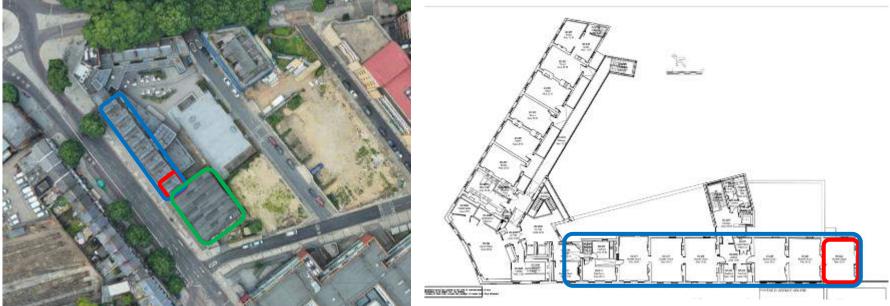
Fluidity development MAGIC

Laetitia Mottet

Carolanne Vouriot

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)



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





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Laetitia
Mottet
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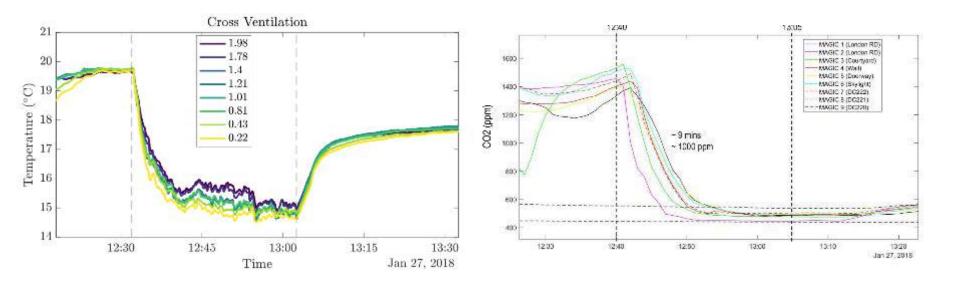
Carolanne Vouriot Envisaging

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Indoor modelling

- Fluidity is tested to be used for complex indoor modelling \checkmark
 - 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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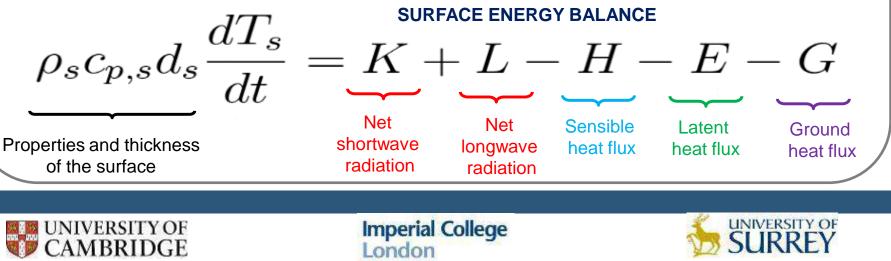
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- More physics
 - Implementation of thermal effect
 - Conduction through walls and ground \checkmark
 - Convection between air and urban setting ✓
 - Radiation: direct and diffuse
 √
- Objective: Compute the air temperature field in the domain
 - Advection-Diffusion 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





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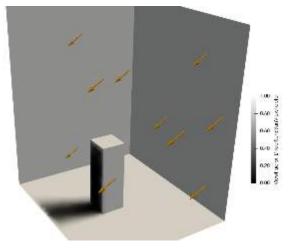
• More physics

Implementation of thermal effect

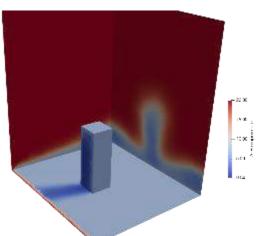
- Conduction through walls and ground \checkmark
- Convection between air and urban setting ✓
- Radiation: direct and diffuse ✓

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

$${}^{\text{on}}_{\rho_s c_{p,s} d_s} \frac{dT_s}{dt} = K$$



Value of K: direct solar radiation only.



Surface temperature computed.







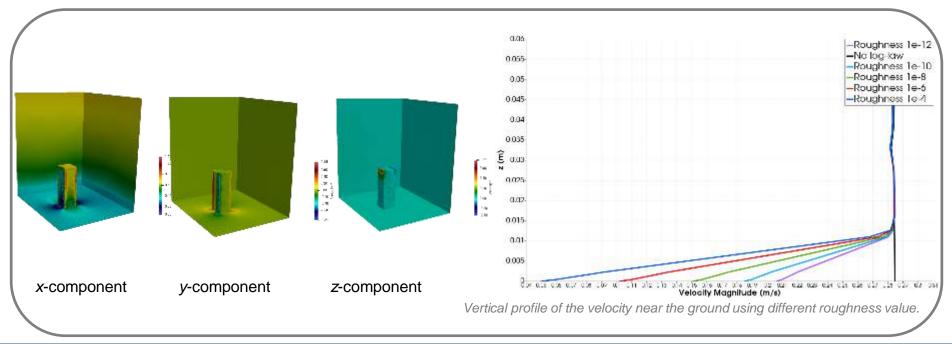
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- More physics
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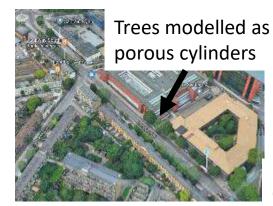
– Implemention of near wall log-law function associated with a slip BC \checkmark

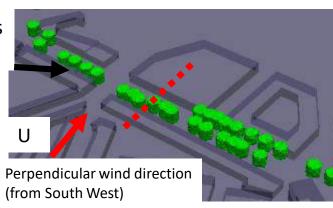






Simulation of trees in London Road





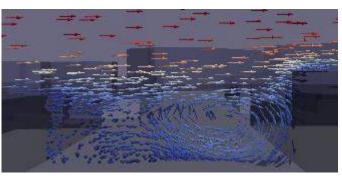
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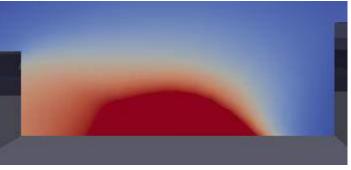
Momentum sink due to tree: $S = -C_D. LAD. \frac{1}{2}(\rho u|u|)$

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

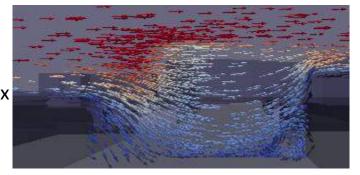
No trees – vortex in street canyon



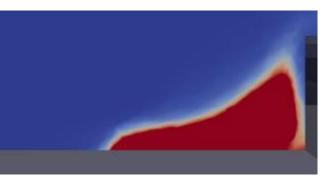
No trees – tracer dispersed to leeward side



With trees – no street canyon vortex



With trees – tracer dispersed to windward side







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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





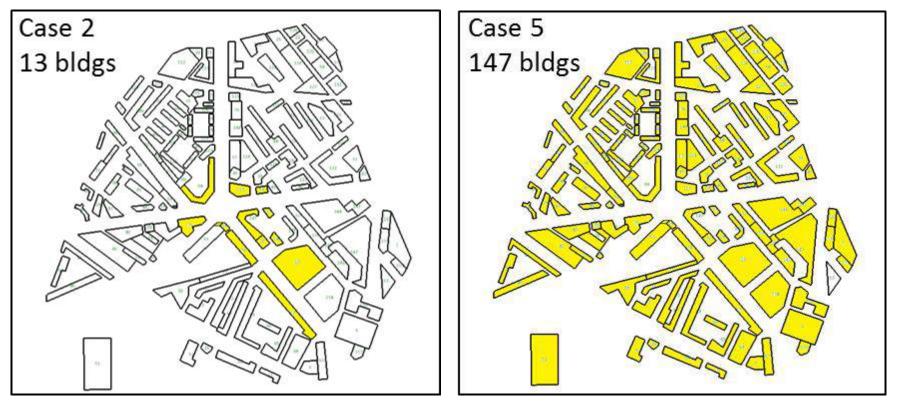
Wind tunnel highlights

Studied the effect of model extent



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







Wind tunnel highlights

Studied the effect of SE features



- No observed change to flow at Clarence Centre / London Rd
- Channelling effects appear to be mostly localised around viaduct road passages





Imperial College London



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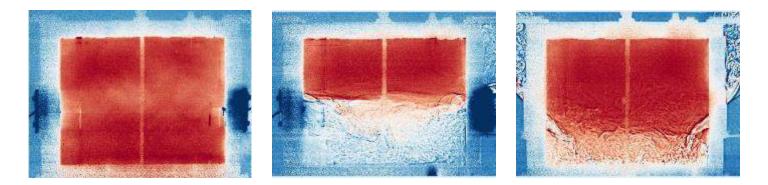
Water-bath experiments



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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.

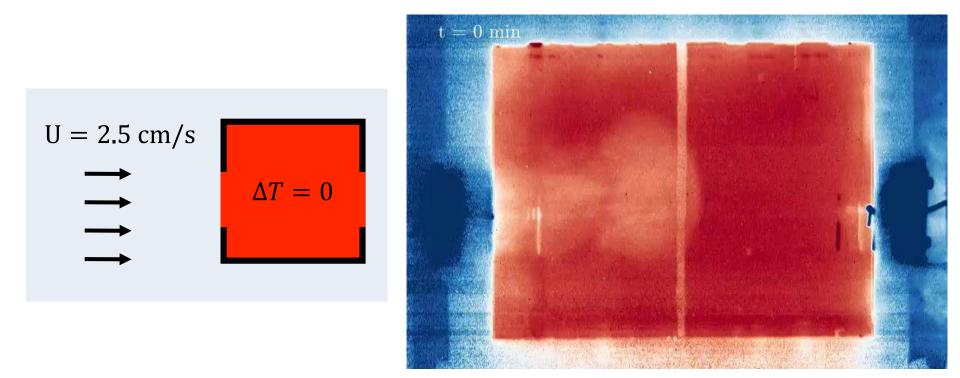




Cross-ventilation



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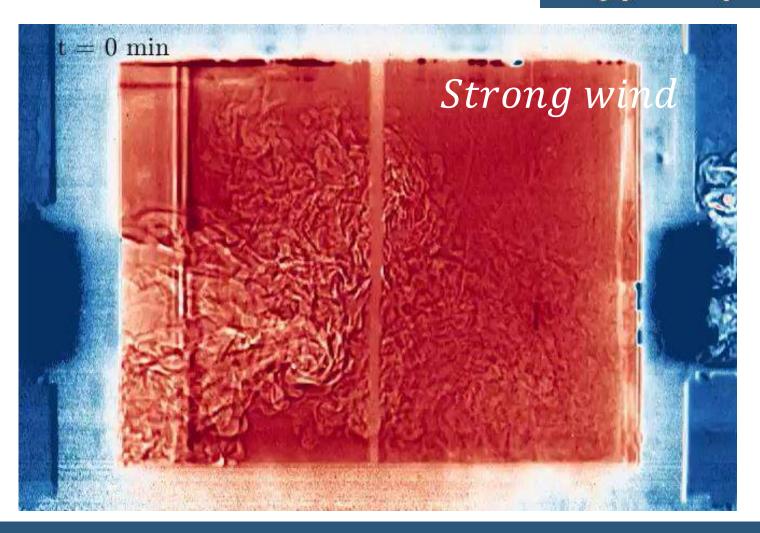




Wind and buoyancy



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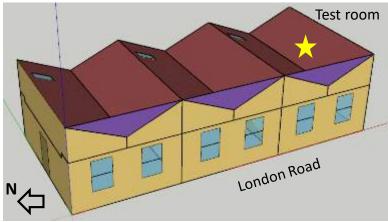


EnergyPlus simulation

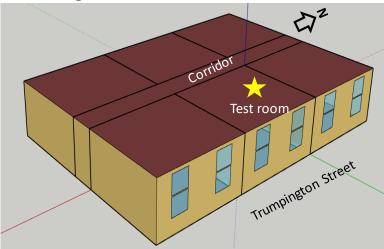
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London test room



Cambridge 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.

<u>To do:</u>

- 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.

Finished:

- ✓ Worked on the occupancy schedules of people number, door & window & blind status for the Cambridge test room;
- ✓ Finished E+ simulation of temperature and CO₂ 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.

<u>To do:</u>

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

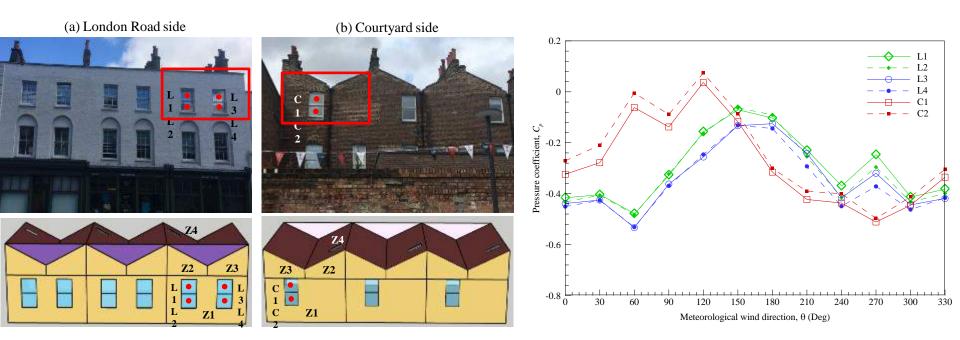






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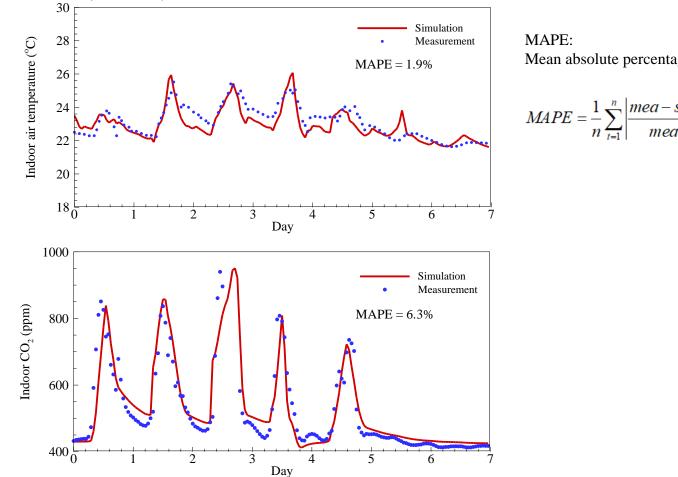
EnergyPlus model with 6 external AFN nodes





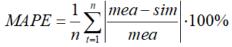


Comparison between measurement and simulation of indoor air temperature and 22nvisaging a two flowith greener cities from Sep. 25 to Oct. 01, 2017 (Mon-Sun).





Mean absolute percentage error



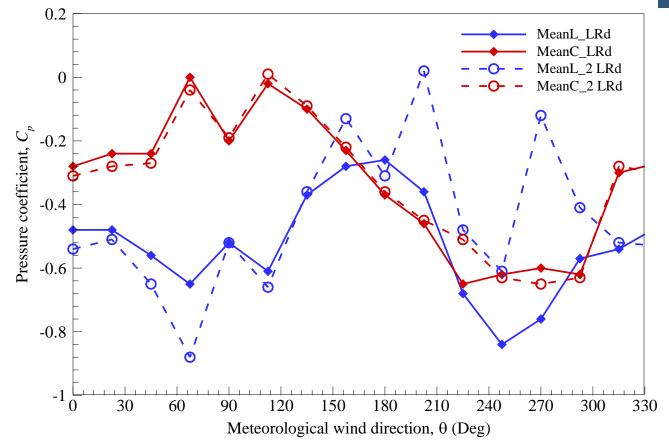




The impact of urban form changes with widened London Road

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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





Progress

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



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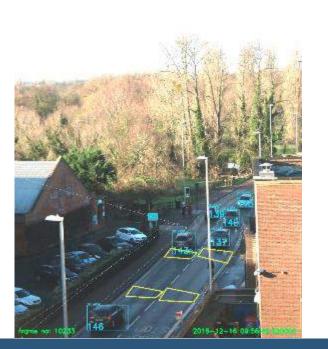




Vehicle emissions modelling (Anna Schroeder)

- WB counter 1: 45 WE cons 1: 43 WE motortilies 1: 0 WE trucke 1: 0 WB counter 2: 45 WB cons 2: 43 WB motorbikes 2: 0
- WB motorbikes WB buses 2: 1 WB trucks 2: 1

EE counter 1: 75 EB one 1: 73 EB motorbitae 1: 0 EB trucke 1: 1 EB counter 2: 75 EB cons 2: 75 EB motorbikes 2: 0 EB trucke 2: 0 EB trucke 2: 0



Computer vision algorithm working

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





Vehicle emissions

- 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

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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).





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The OPAL framework NIROM Data as-Sensitivities similation Fluidity **IC-FERST** Mesh Optimisaadaptivity tion





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





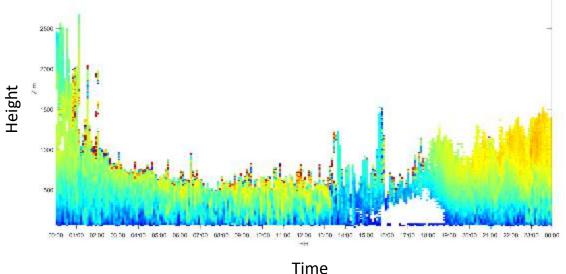




Doppler LIDAR wind measurements

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

- 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





Imperial College London



University of

Reading



0

2

0

1 0

0

Windspeed

(m/s)

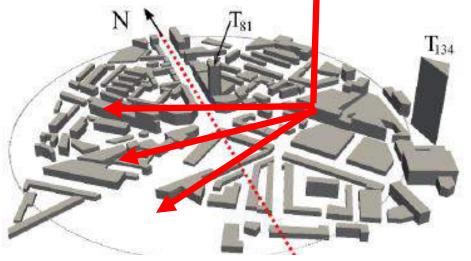


Location



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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

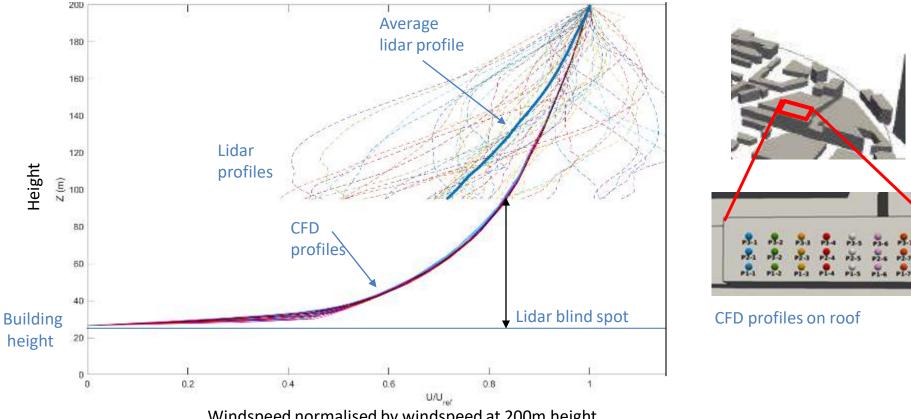






MAGIC Preliminary CFD comparison - NW direction with greener cities

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



Windspeed normalised by windspeed at 200m height



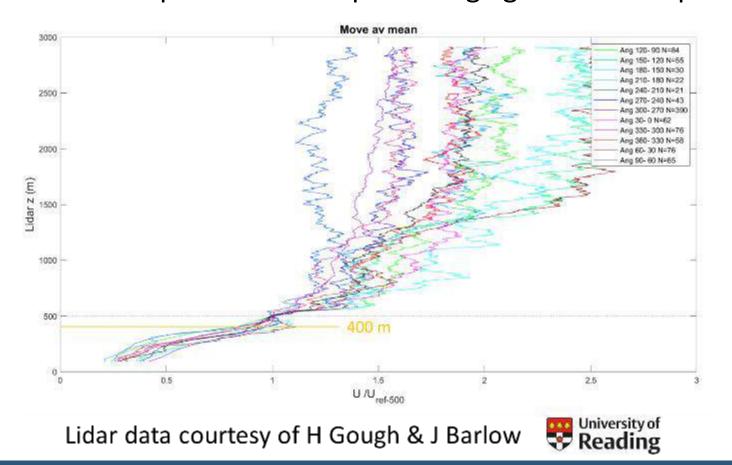


Comparison with lidar



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







Plans for 2019



- 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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