Department of Meteorology

University of Reading

EFFECTS OF METEOROLOGICAL CONDITIONS ON BUILDING NATURAL VENTILATION IN IDEALISED URBAN SETTINGS

EPSRC Engineering and Physical Sciences Research Council

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- Refresh: Remodelling Building Design Sustainability from a Human Centred Approach
- *Explore the impact of urban microclimate on building ventilation for optimal performance of occupants.*
- EPSRC Challenging Engineering project, 2013-18
- www.refresh-project.org.uk

UNIVERSITY OF LEEDS

UNIVERSITY OF Southampton

UNIVERSITY OF BIRMINGHAM

UNIVERSITY OF SURREY

EPSRC

Engineering and Physical Sciences Research Council

RESEARCH NEEDED

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- How does the urban area influence the pressure distribution on a building and thus the natural ventilation rates?

- How do the effects of limited and expansive arrays differ?

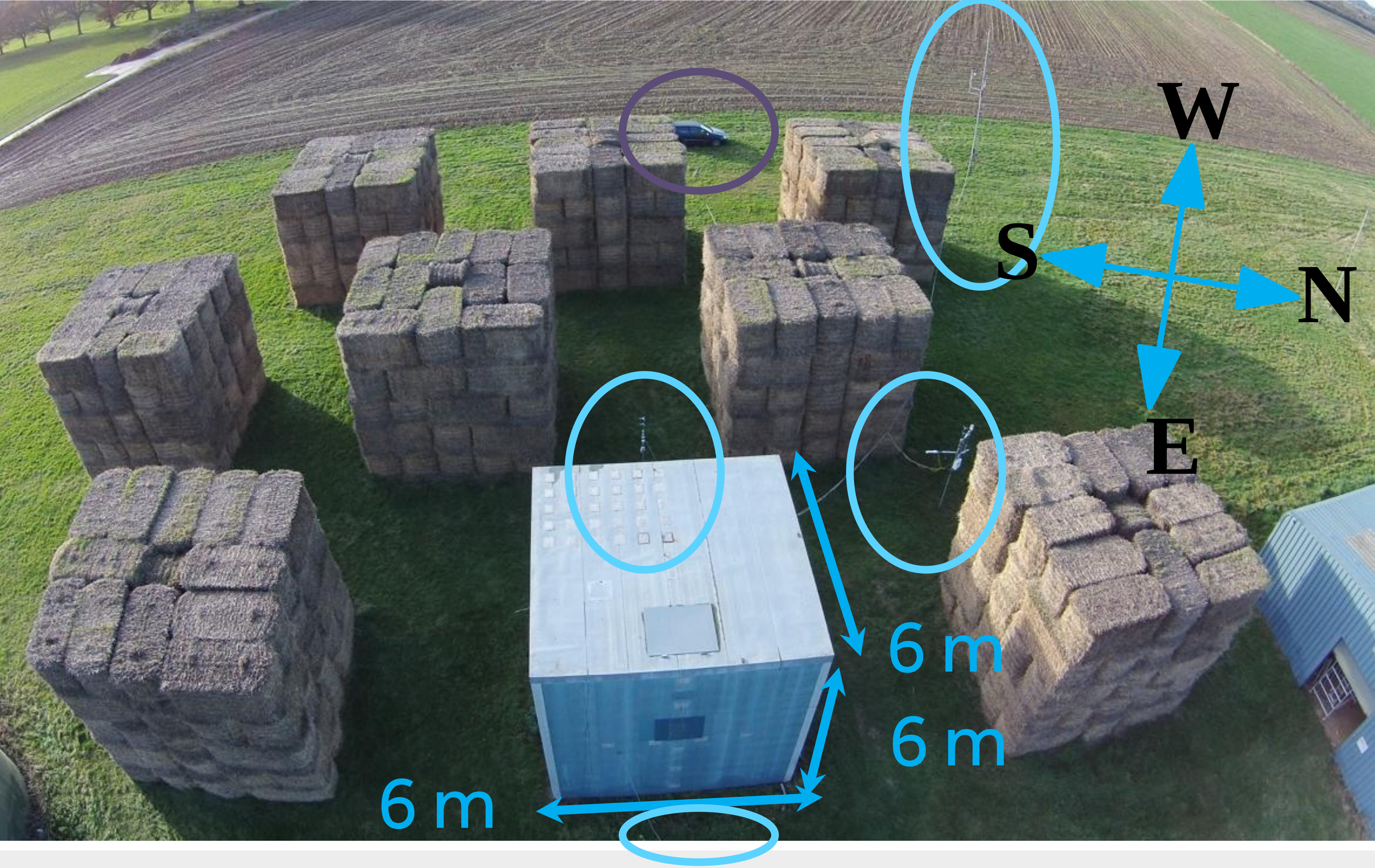
- How do current ventilation models perform against a large, varied dataset?

- How do different ventilation measurement techniques perform under different conditions?



Studied previously by:
Hoxey, Richards, Straw, Robertson, Yang (1990-2015)

Measuring:
Rainfall, Radiation, Wind speed , Wind direction, Temperature, Pressure, CO_2 concentration (30 minute averages)



Measuring:

Rainfall, Radiation, Wind speed , Wind direction, Temperature, Pressure, CO_2 concentration

INTERNAL EQUIPMENT

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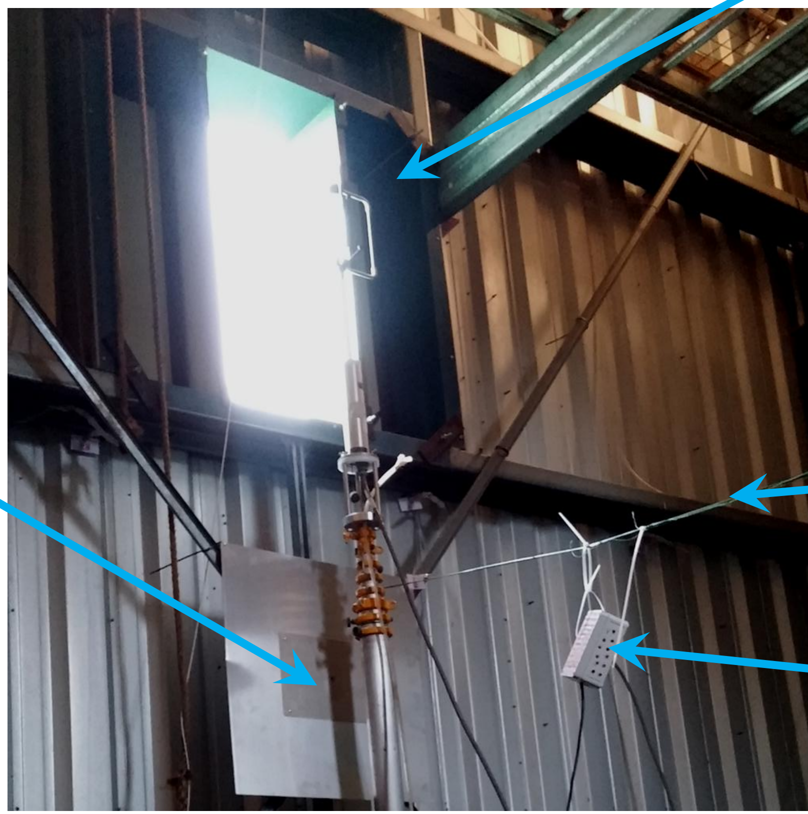
Sonic anemometer (10 Hz)



Pressure taps (10 Hz)

Thermocouples (10 Hz)

CO_2 sensor (2 Hz)

7

TIME LINE

- Sept 2014: Set up
- Oct 2014: Experiment start
- Oct 2014- April 2015: Array case
- May 2015- July 2015: Isolated cube




TIME LINE

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- Sept 2014: Set up
- Oct 2014: Experiment start
- Sept 2014- April 2015: Array case
- May 2015- July 2015: Isolated cube
- April 2016: Site decommissioned


GBM
www.gbmuk.com
VOLVO
GBM
GBM

WIND TUNNEL MODEL

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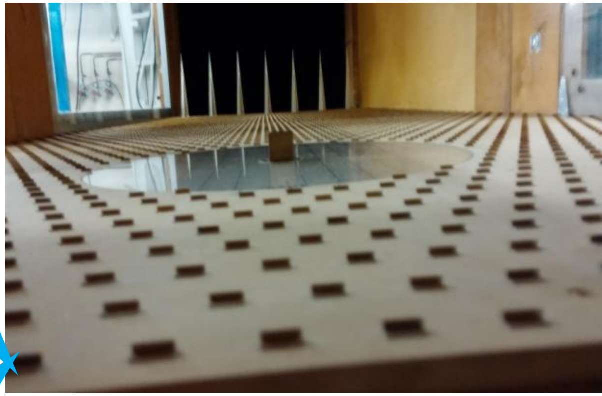
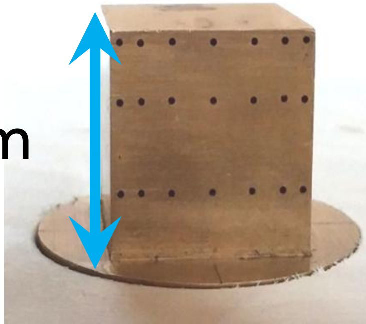
- ‘A’ Tunnel, Enflo lab UNIVERSITY OF SURREY
- Controlled conditions
- 1:300 scale model
- 100 Hz sampling rate: pressure taps.



2 mm



20 mm

ARRAY EXTENSION

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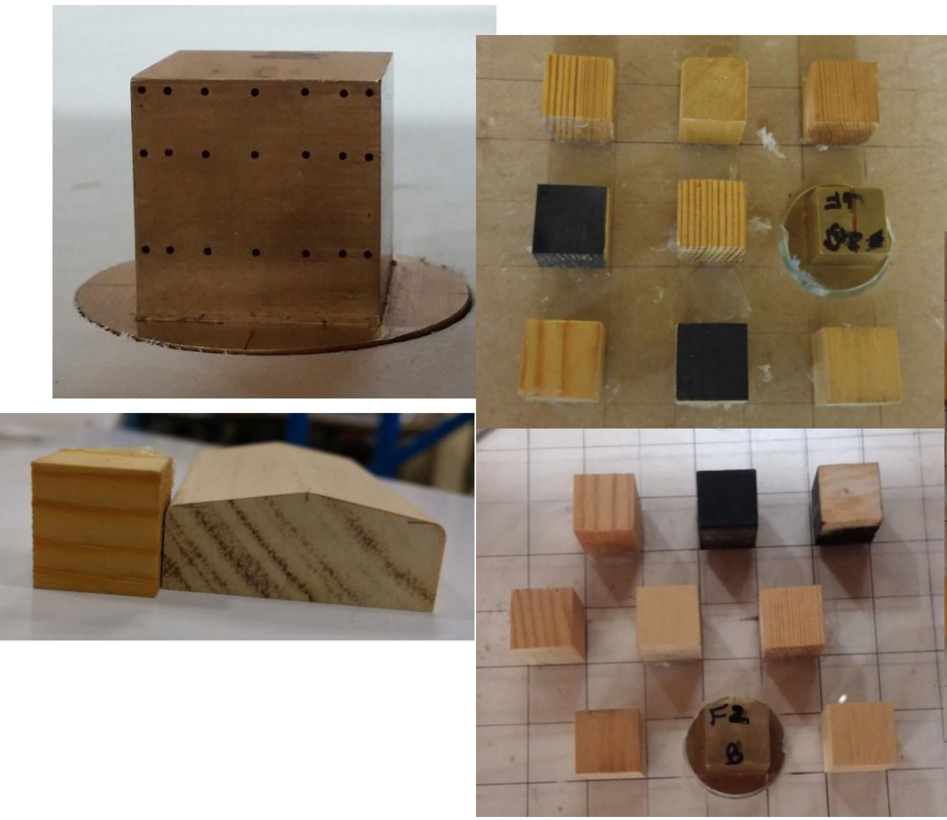

Increasing size

SILSOE ARRAY

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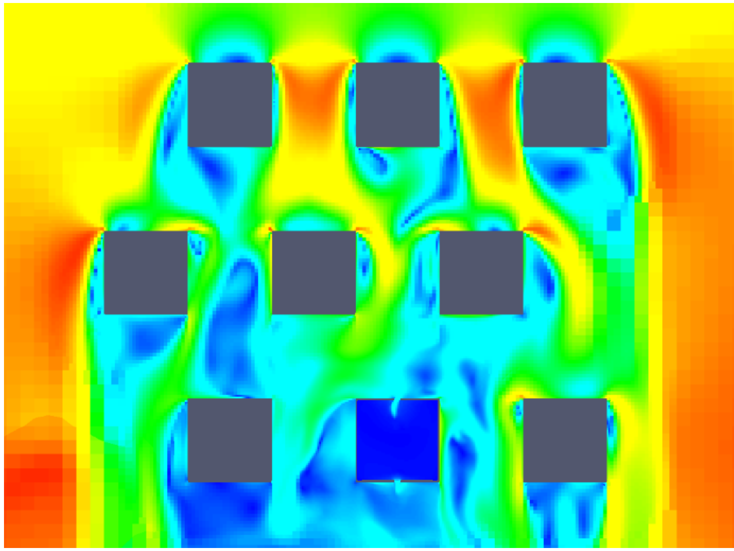
Full scale

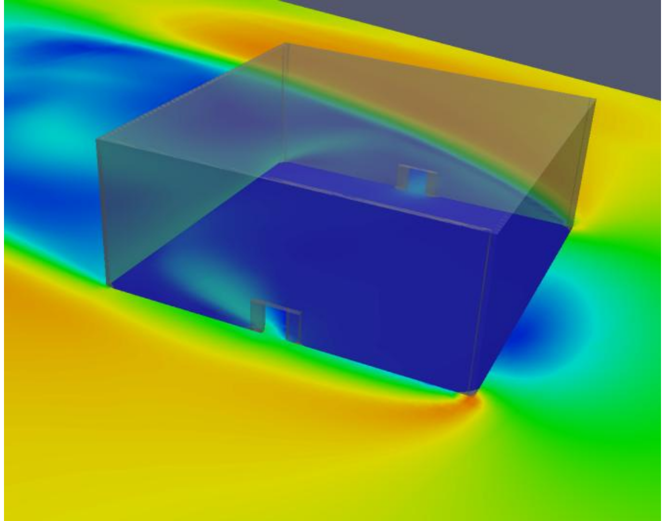
Wind tunnel

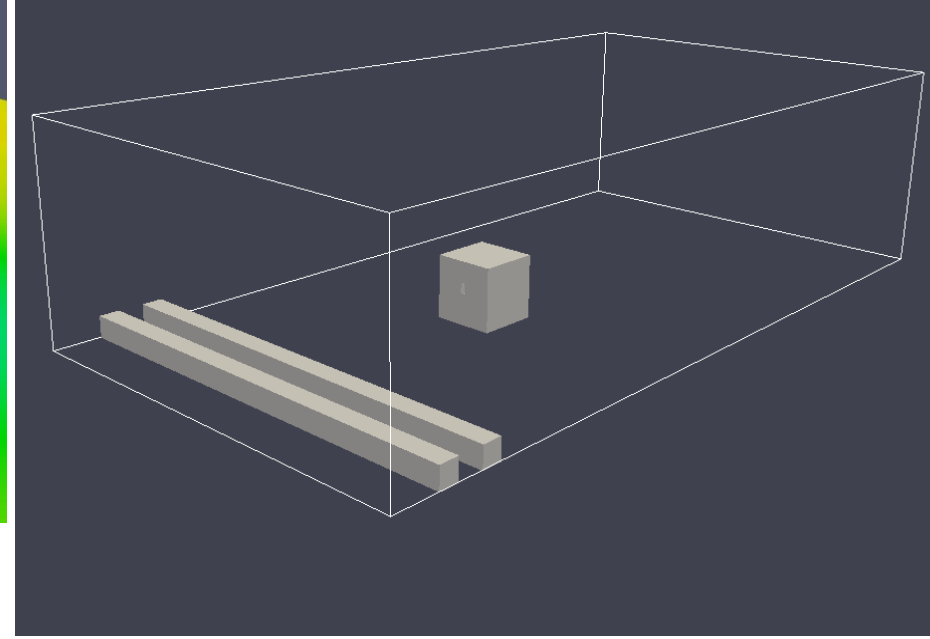


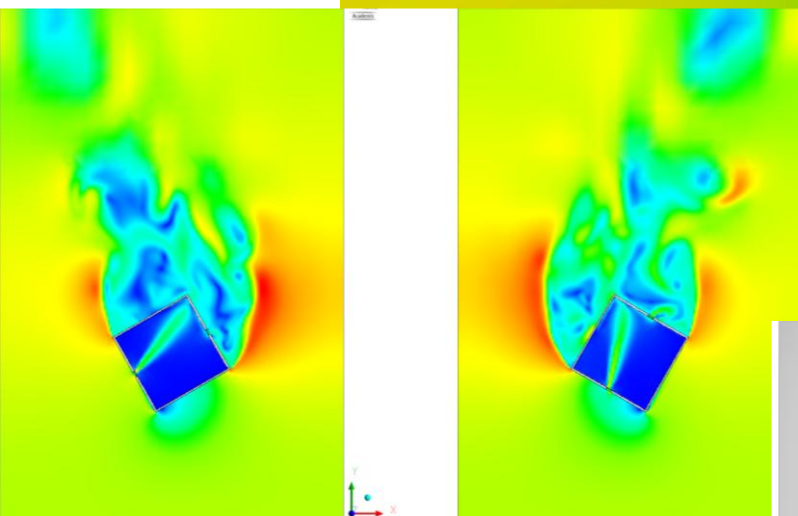
CFD

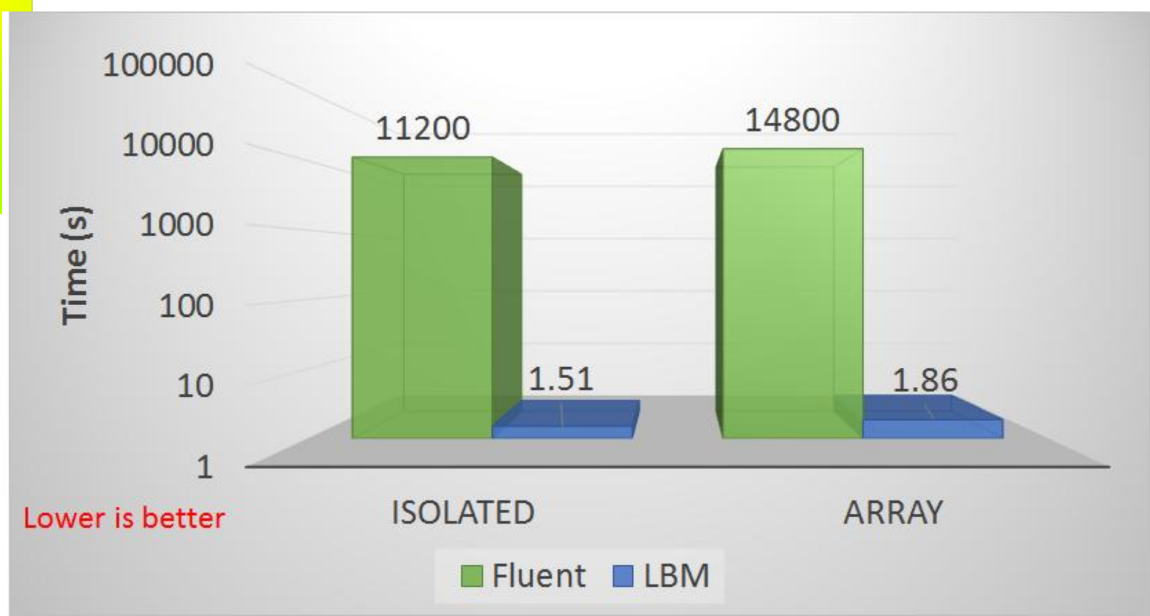
(King, 2017)

CFD









King et al. (2017)

NOTATION

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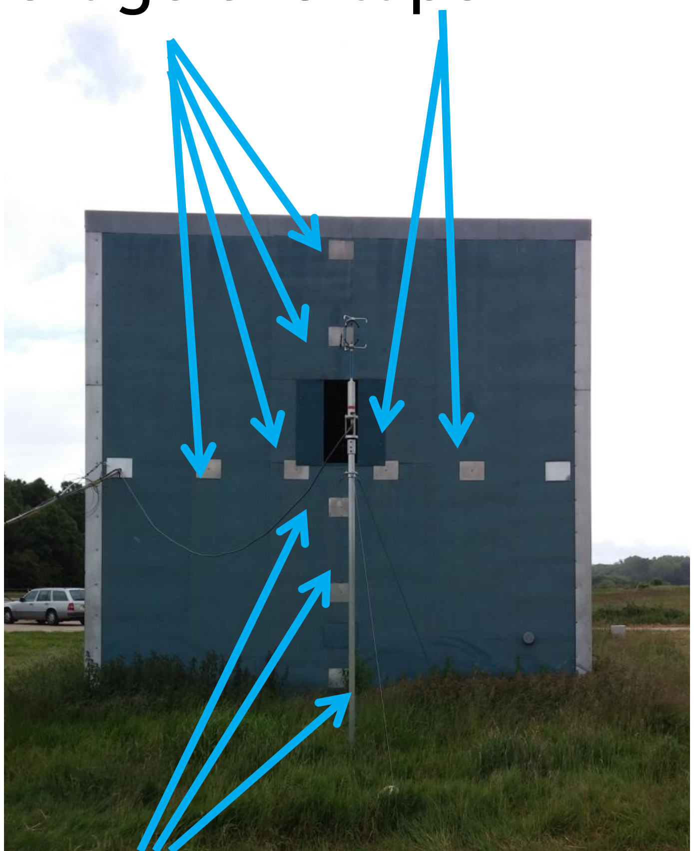
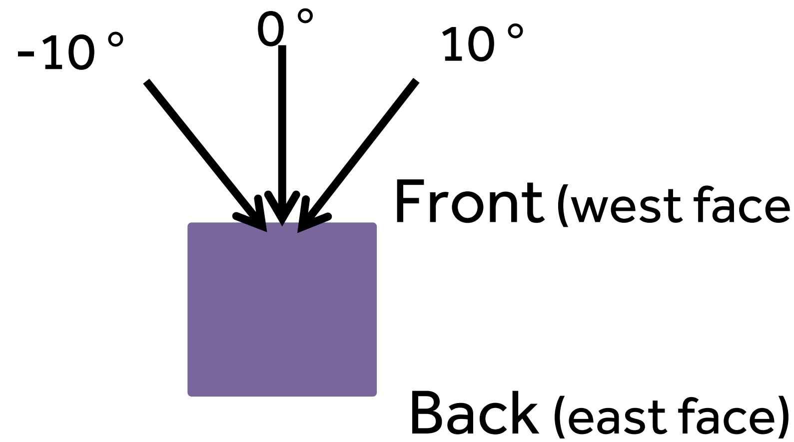
$$C_p = \frac{\Delta p}{0.5 \rho U_{ref}^2}$$

Front Face C_p:

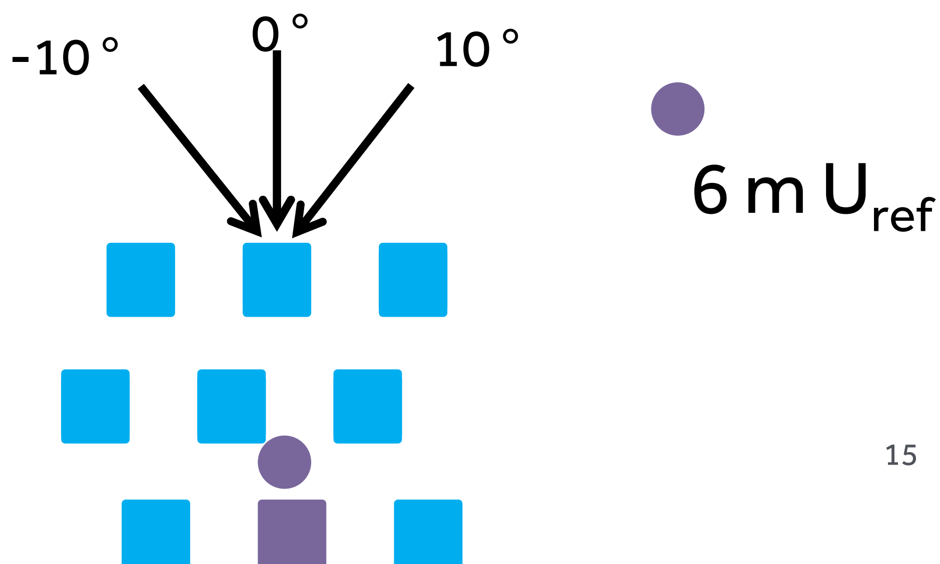
Average of 9 taps



Perpendicular

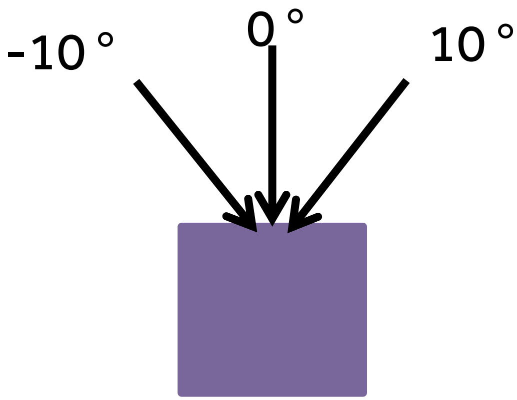


Perpendicular



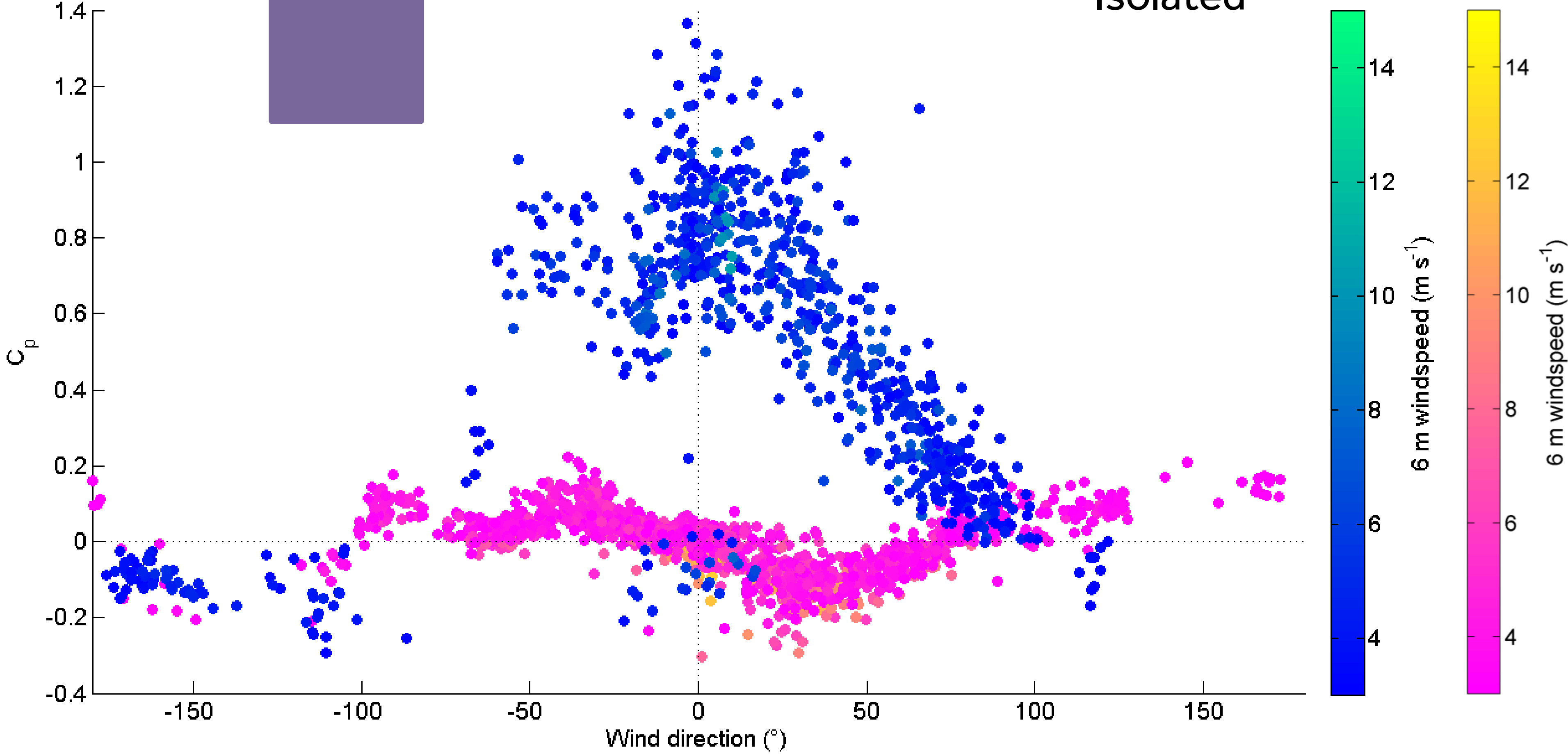
FRONT FACE C_p

$$C_p = \frac{\Delta p}{0.5\rho U_{ref}^2}$$



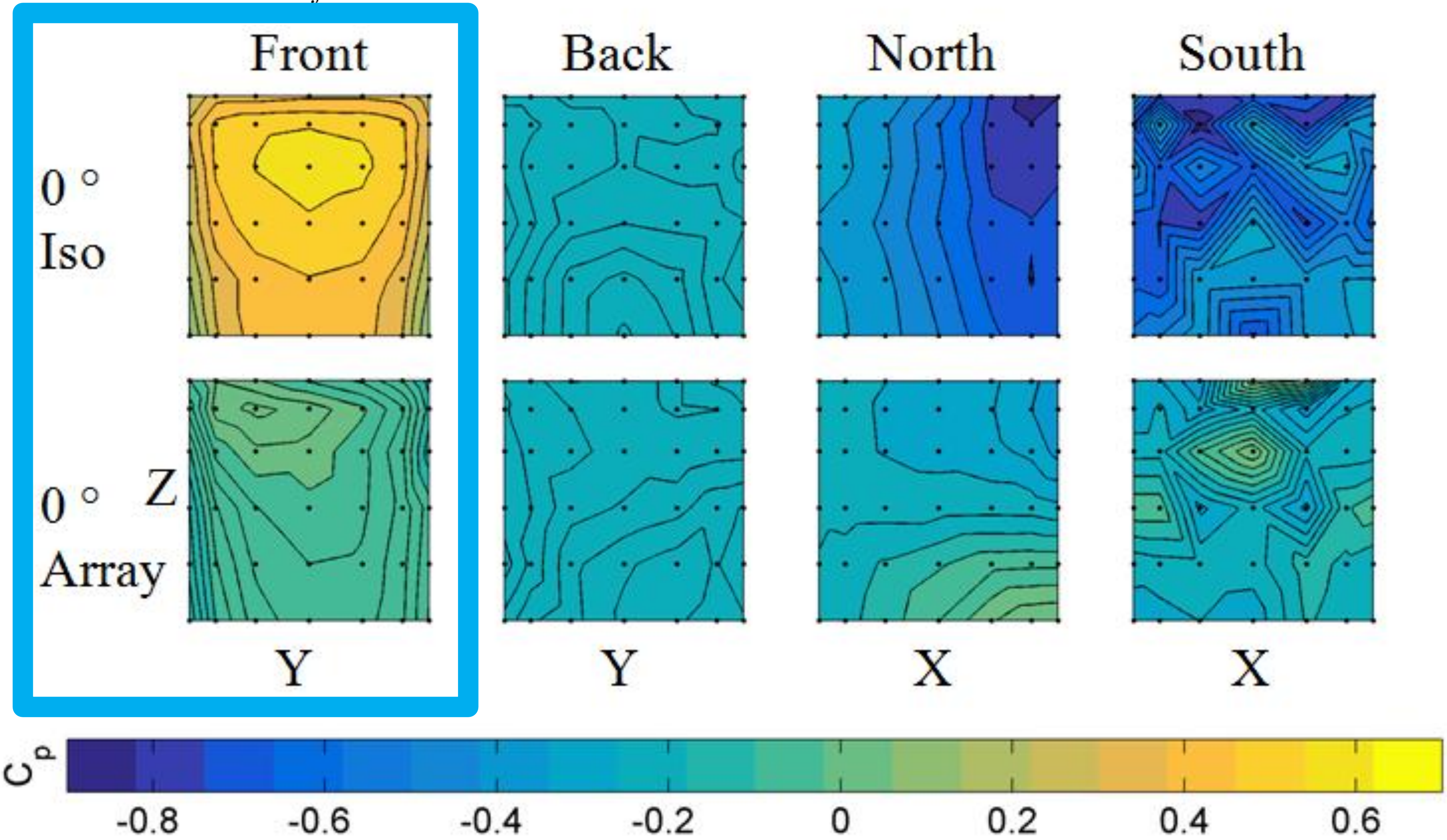
Isolated

Array



• Sheltering effects C_p distribution on the cube (WT)

$$C_p = \frac{\Delta p}{0.5 \rho U_{ref}^2}$$



EXISTING C_p MODELS

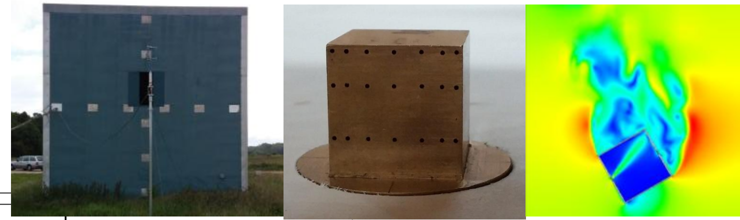
- Based on wind tunnel data (Bowen, 1976 & Wiren , 1985)
- No errors or methods listed

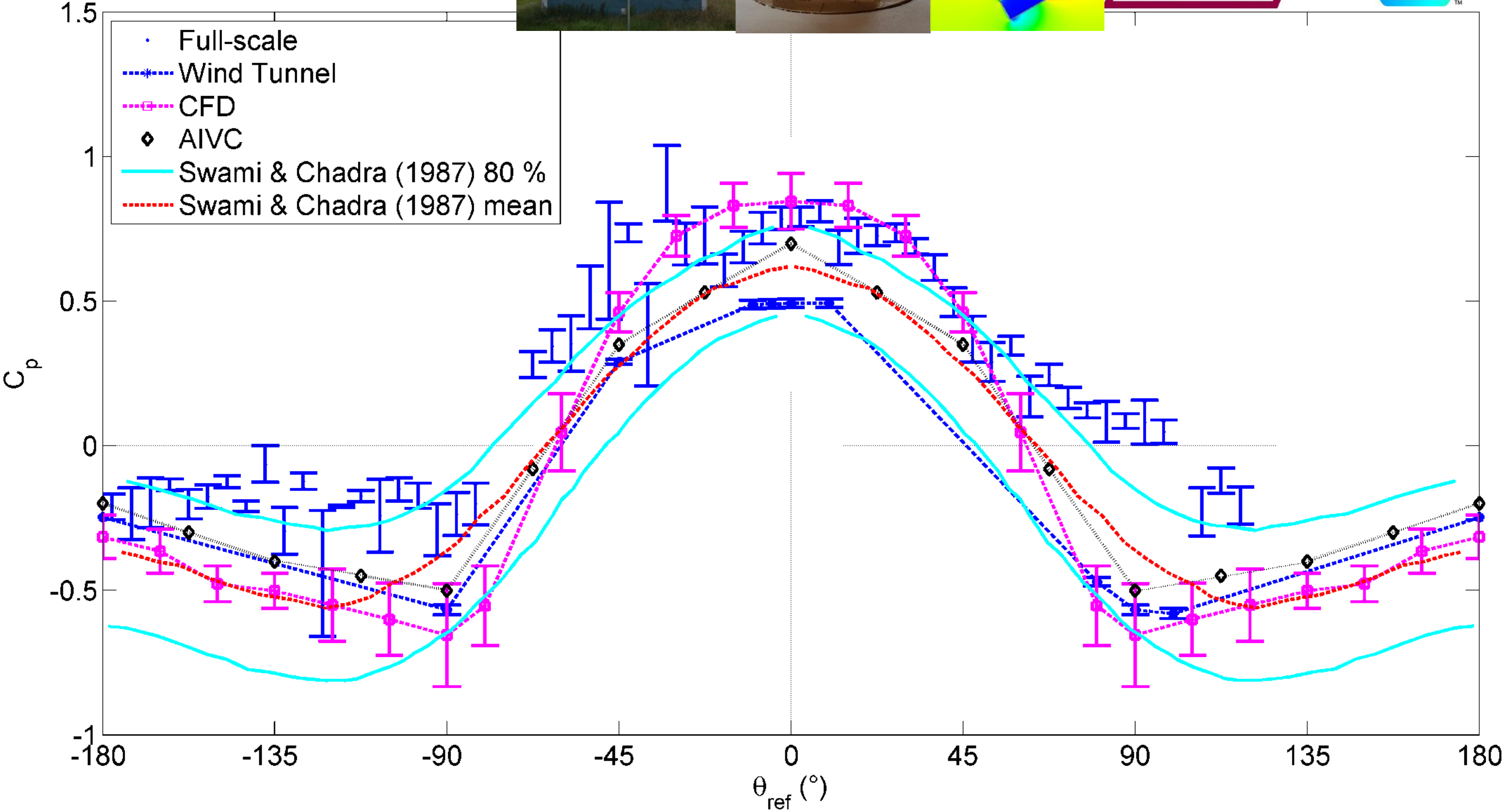
- **Caution: Approximate data only. No responsibility can be accepted for the use of data presented in this publication**
- Warning is often ignored…

- AIVC 1:1 aspect ratio, sheltered conditions, flat roof

ISOLATED CUBE C_p

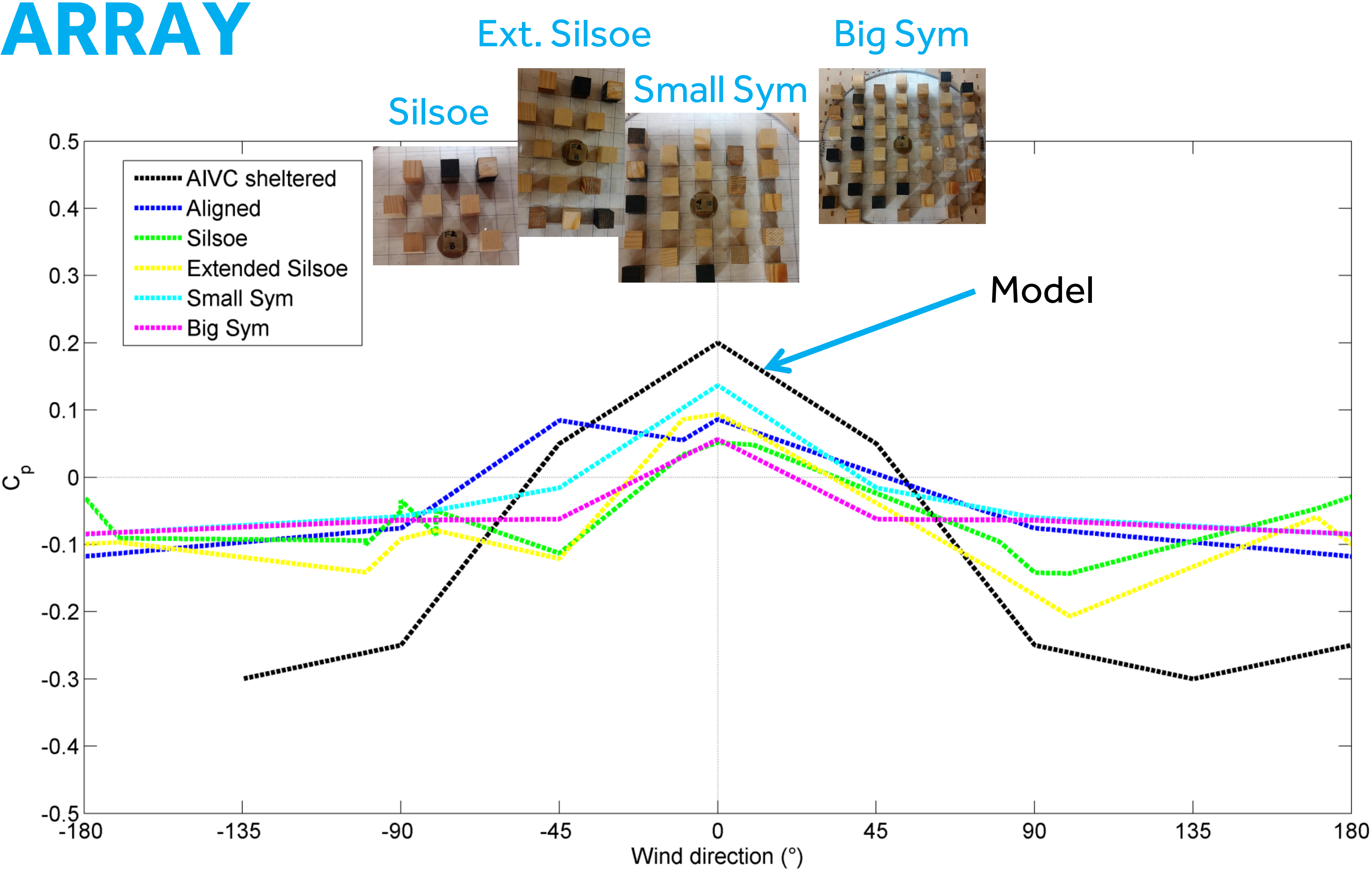
$$C_p = \frac{\Delta p}{0.5 \rho U_{ref}^2}$$



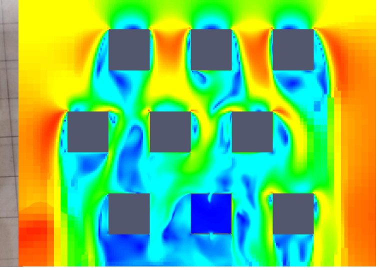


C_p MODEL & WIND TUNNEL: ARRAY

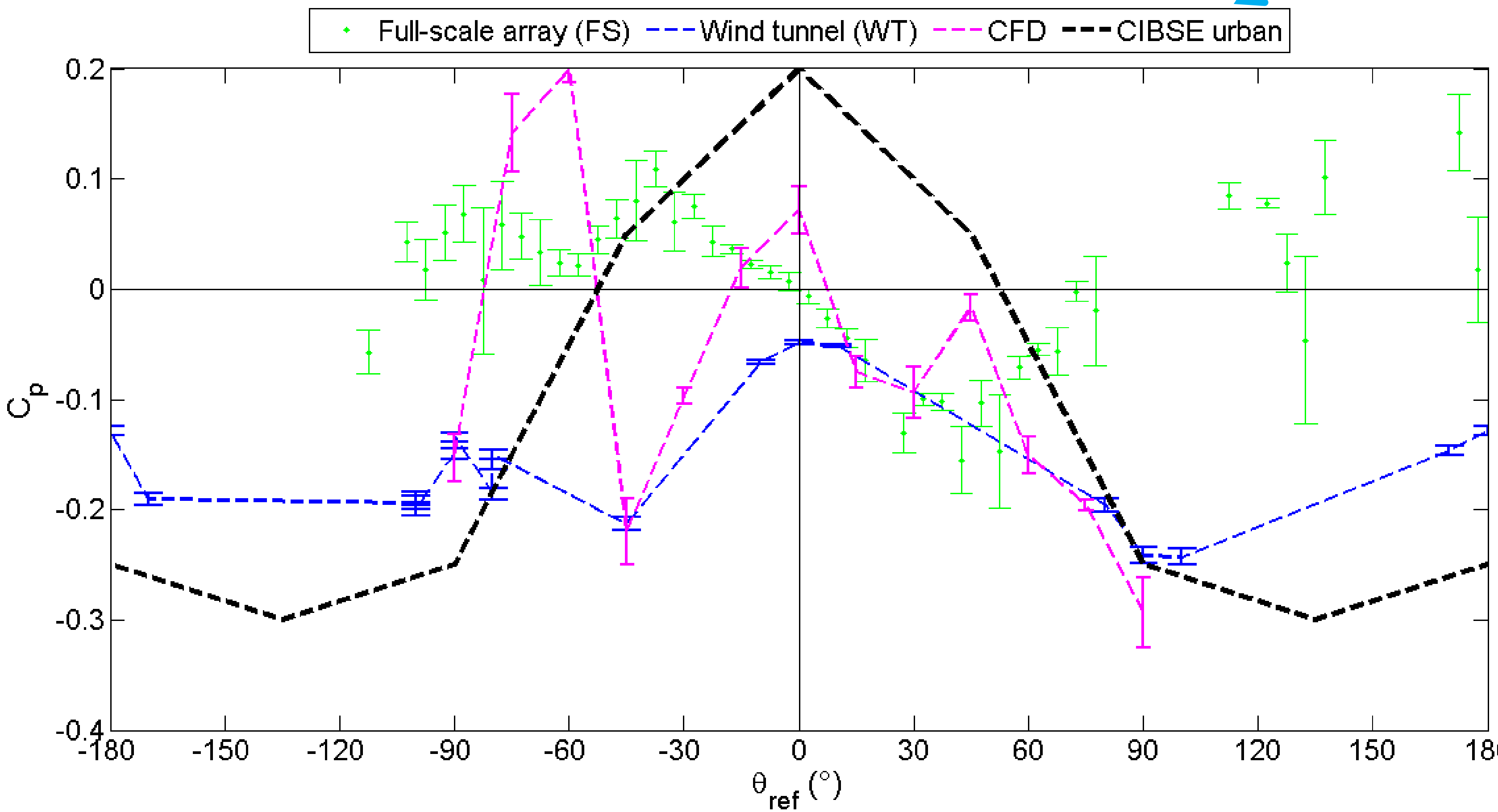
$$C_p = \frac{\Delta p}{0.5 \rho U_{ref}^2}$$



ARRAY C_p



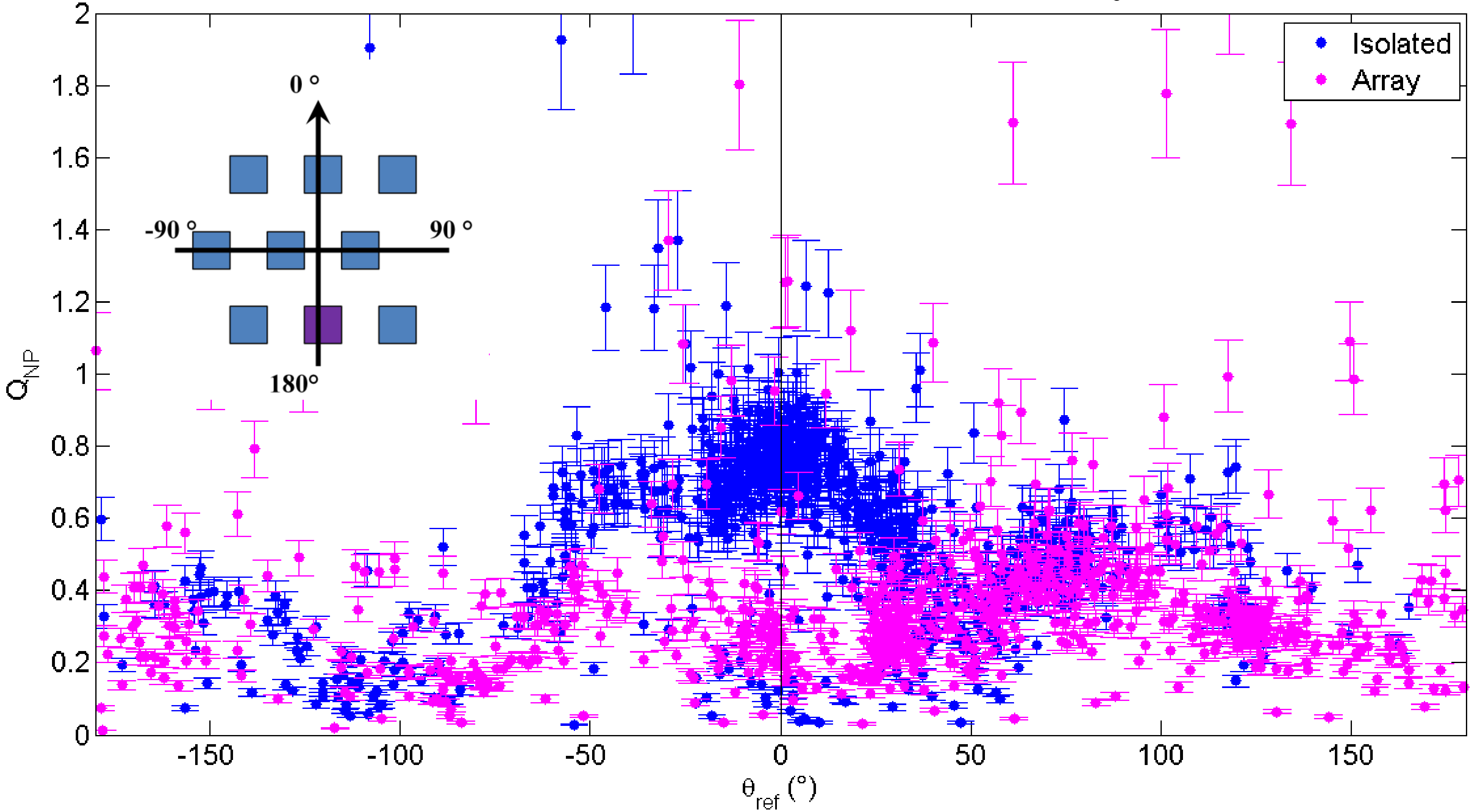
CIBSE urban = AIVC sheltered



ARRAY, CROSS VENTILATED

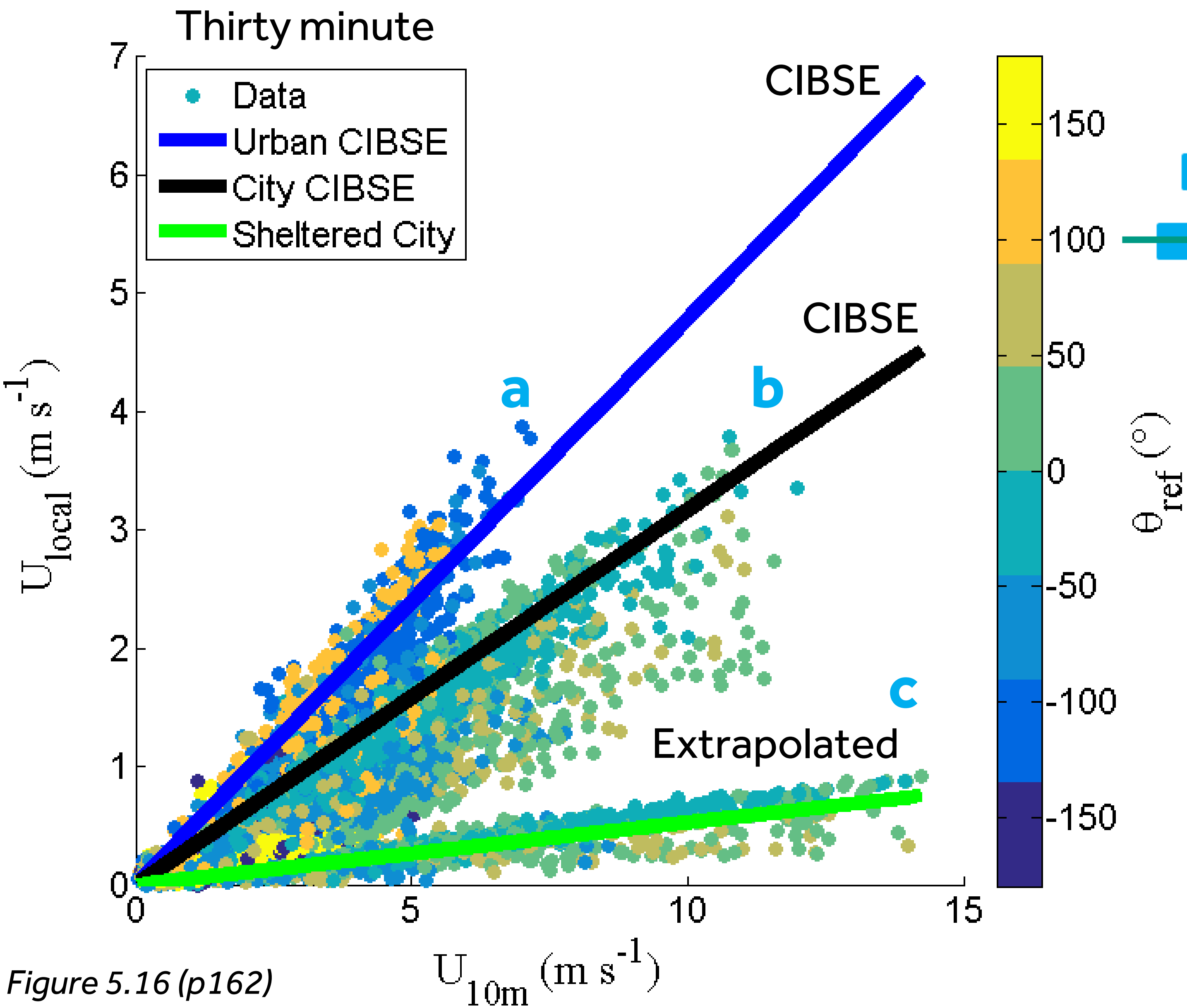
- Effect of array is non linear for cross ventilation

$$Q_N = \frac{Q}{U_{ref} A}$$



- Relation between local and reference wind speed is not captured by CIBSE models

$$U_z = U_R k_c z^a$$



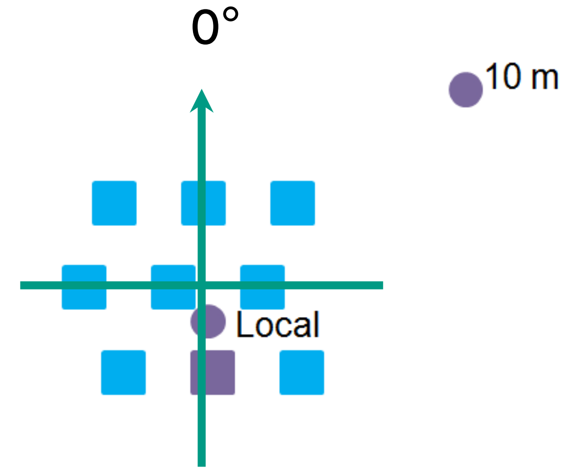
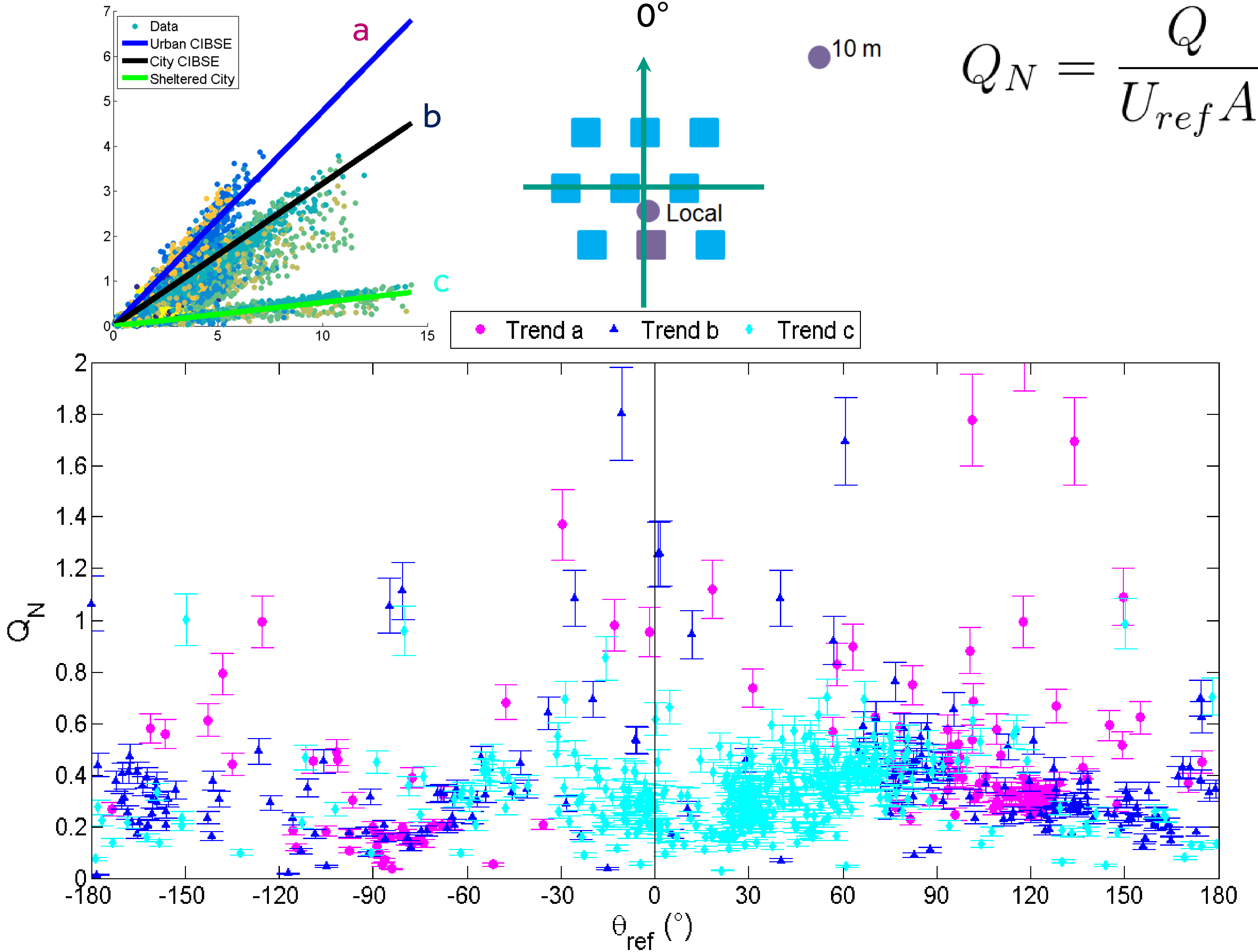


Figure 5.16 (p162)



Data
Urban CIBSE
City CIBSE
Sheltered City
a
b
c
0°
10 m
Local
$Q_N = \frac{Q}{U_{ref} A}$
Trend a
Trend b
Trend c
Q_N
θ_{ref} (°)

SUMMARY OF KEY CONTRIBUTIONS: THESIS

- Existing models for C_p do not fully capture the effect of sheltering or the spread of data in 'real' conditions
- Scaled models can be representative of full-scale as long as all main upstream roughness features are captured
- Wake and channelling flow behaviour within the array cannot be predicted with existing over-simplistic models
- Flow around simple cubes is complex, but can provide insight into even more complex geometry flow behaviours

ONGOING WORK

Thesis: http://centaur.reading.ac.uk/71951/1/19004951_Gough_thesis.pdf

King et al. (2017) Investigating the influence of neighbouring structures on natural ventilation potential of a full-scale cubical building using CFD.

https://doi.org/10.1016/j.jweia.2017.07.020

King et al. (2017) Modelling urban airflow and natural ventilation using a GPU-based lattice-Boltzmann method (accepted)

Gough et al. (in review) Effects of variability of local winds on cross ventilation for a simplified building within a full-scale asymmetric array: The Silsoe field campaign.

Hoxey et al. (in review) Static pressure fluctuations in the atmospheric boundary layer.

Gough et al. (in progress) Influence of neighbouring structures on building façade pressures: A full-scale, wind-tunnel, CFD and practitioner guidelines comparison.

Gough et al. (in progress) A comparison of tracer gas, pressure derived and volumetric methods for measuring ventilation rate in an isolated and sheltered full-scale cube.

Snow et al. (in progress) A review of the impact of temperature, ventilation and carbon dioxide upon human performance in the workplace

SIMILAR ONGOING PROJECTS

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ReFRESH
Remodelling Building Design Sustainability From A Human Centred Approach

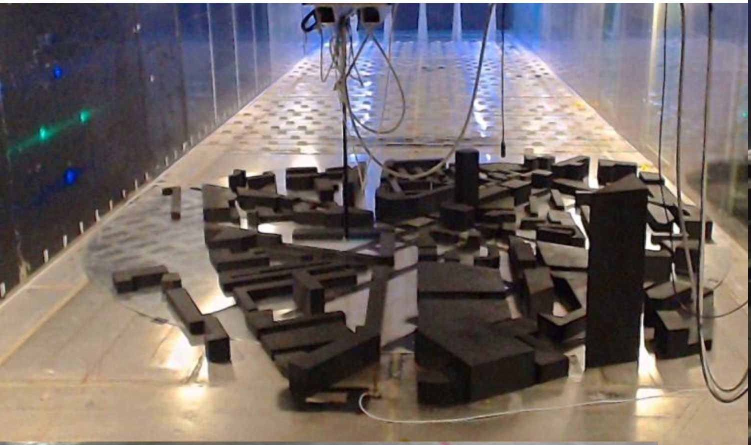
diplos

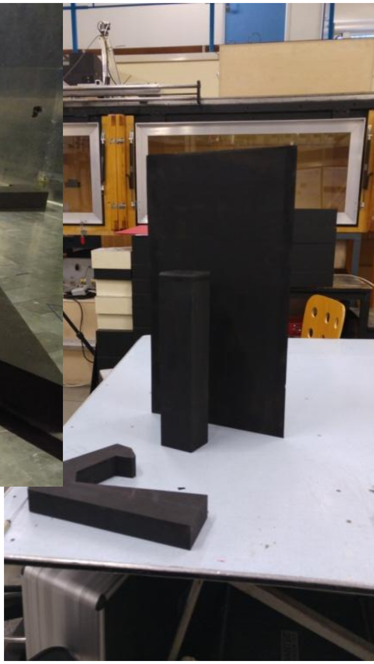
MAGIC
Envisaging a world with greener cities

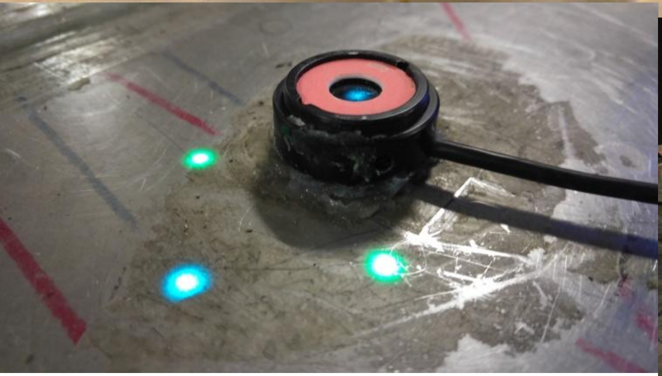
- **ReFRESH -** http://www.refresh-project.org.uk/
- **DIPLOS-** Dispersion of Localised Releases in a Street Network http://www.diplos.org/
- **MAGIC-** Air pollution, dispersion and Urban heat islands http://www.magic-air.uk
- **AIRPRO-** An integrated study of air pollution processes in Beijing http://aphh.org.uk/project/index/airpro

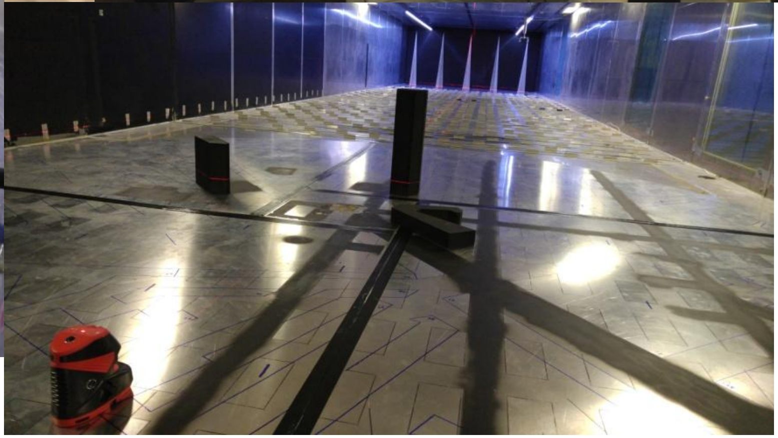
AIRPRO & MAGIC WORK

- Effect of tall buildings on dispersion and wind flow in a built up urban area.









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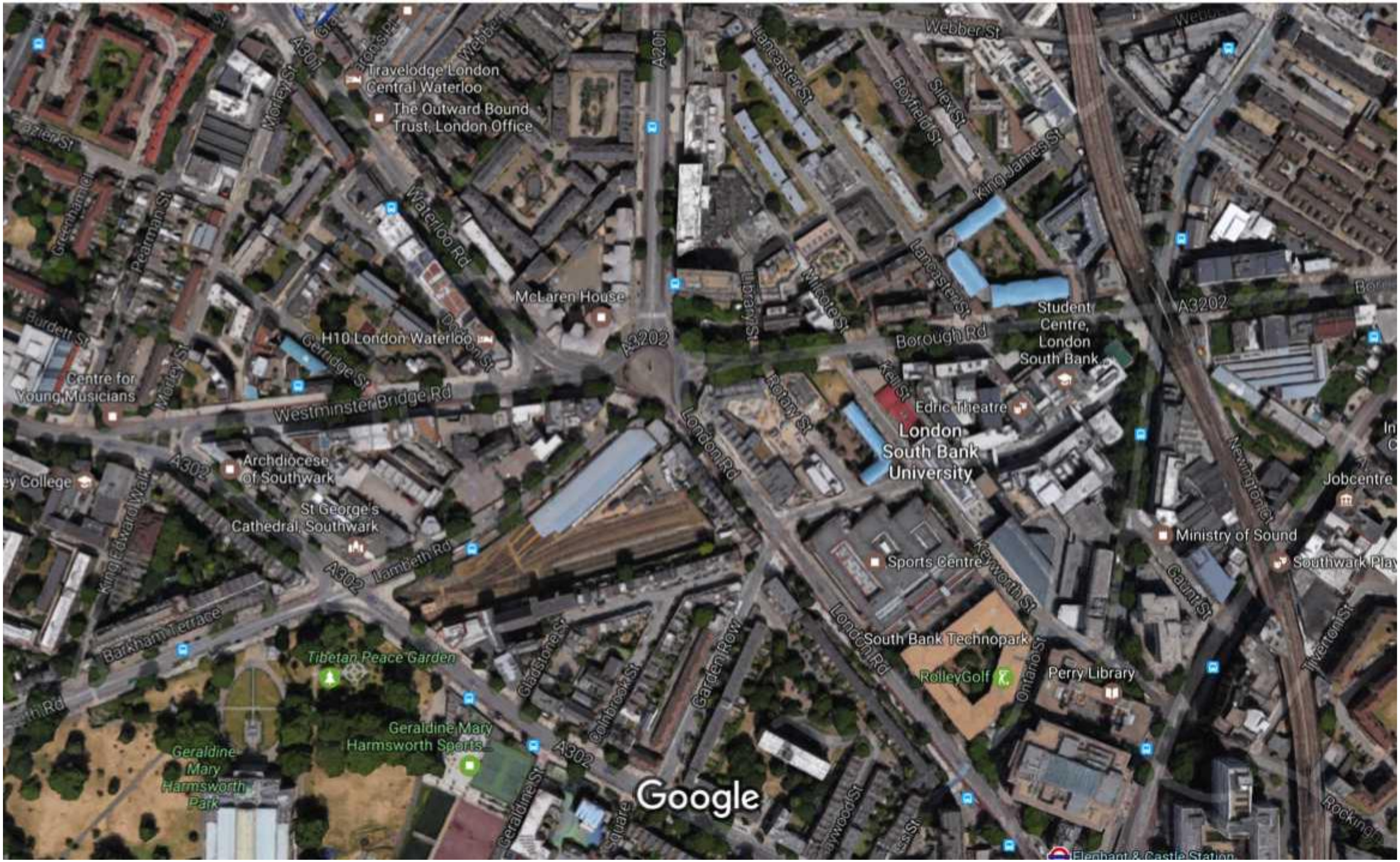

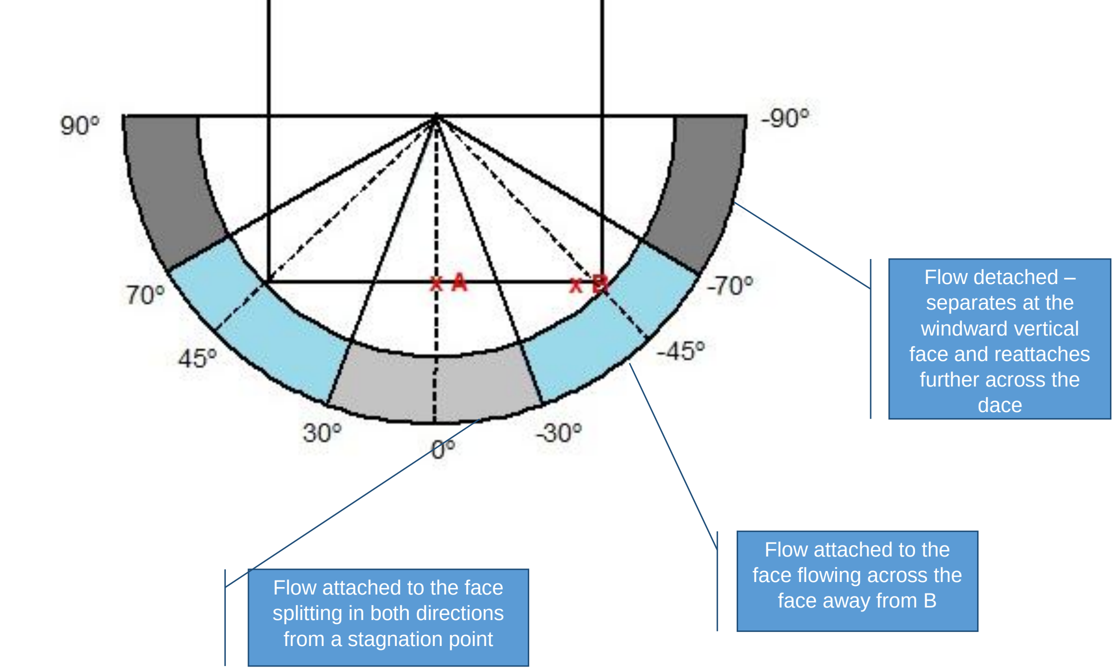

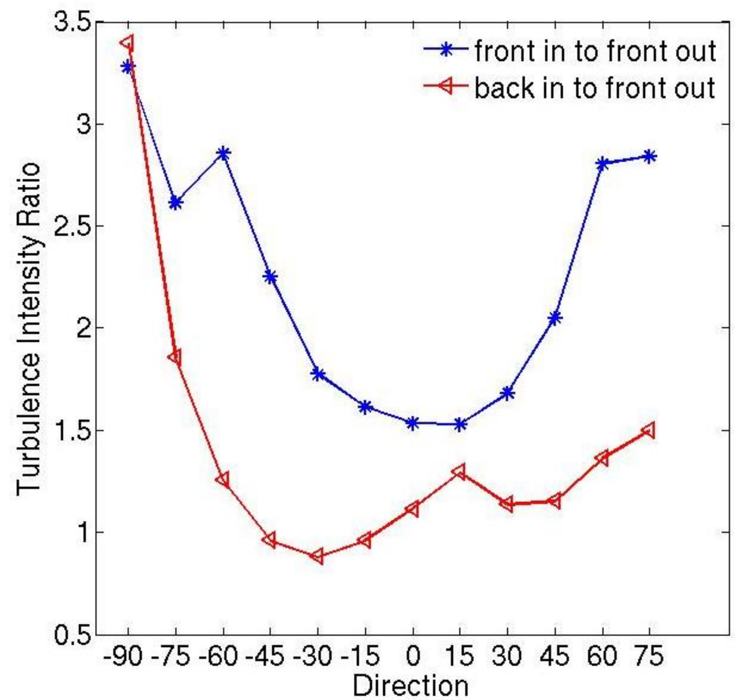

Flow fields (0 °, 45 °, 90 °)

- Sonic anemometer data are shown as **1-minute** mean wind vectors and **half hourly** mean vectors (black lines).
- **Turbulence intensities** are shown for every anemometer.