Fluid dynamics of Urban Tall-building clUsters for Resilient built Environments

Wake Scaling Behind Cluster of Tall Buildings

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FUTURE Programme

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Objectives

- To understand the magnitude and spatial scale of the effects of a cluster of tall buildings.
- To identify the main parameters that govern the extent and character of the near and far fields within the wake.
- To assess what can be said generically and what remains site specific.
- To develop fast analytical models that describe the behaviour of wakes downstream of groups of tall buildings.
- To collate this information within a set of guidelines and tools publicly available to professionals, regulators, and policymakers.

Work Packages

✓ Idealised clusters in neutral atmospheric conditions

✓ Idealised clusters in non-neutral atmospheric conditions

✓ Realistic clusters in all atmospheric conditions.

Timeline

Sept 2022 → April-May, 2023 → Sept-Oct, 2023

Work Package 1

Sept 2022

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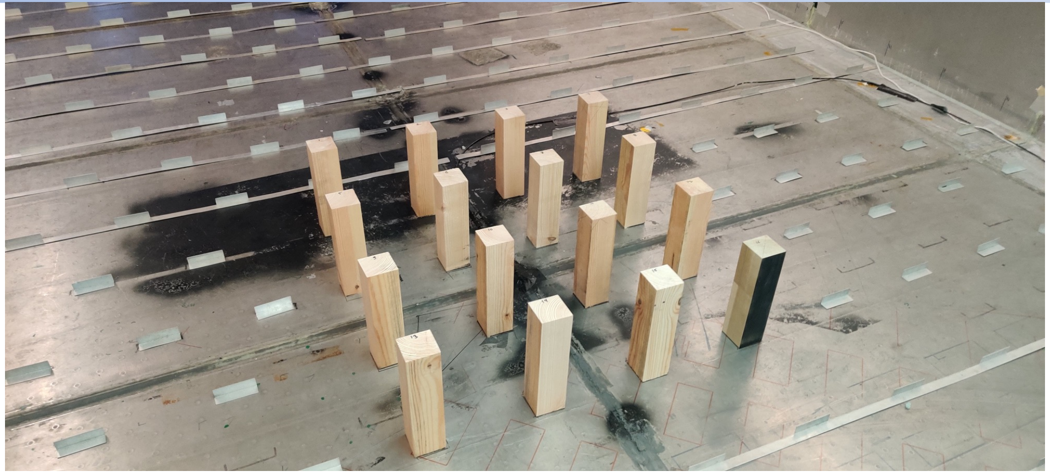
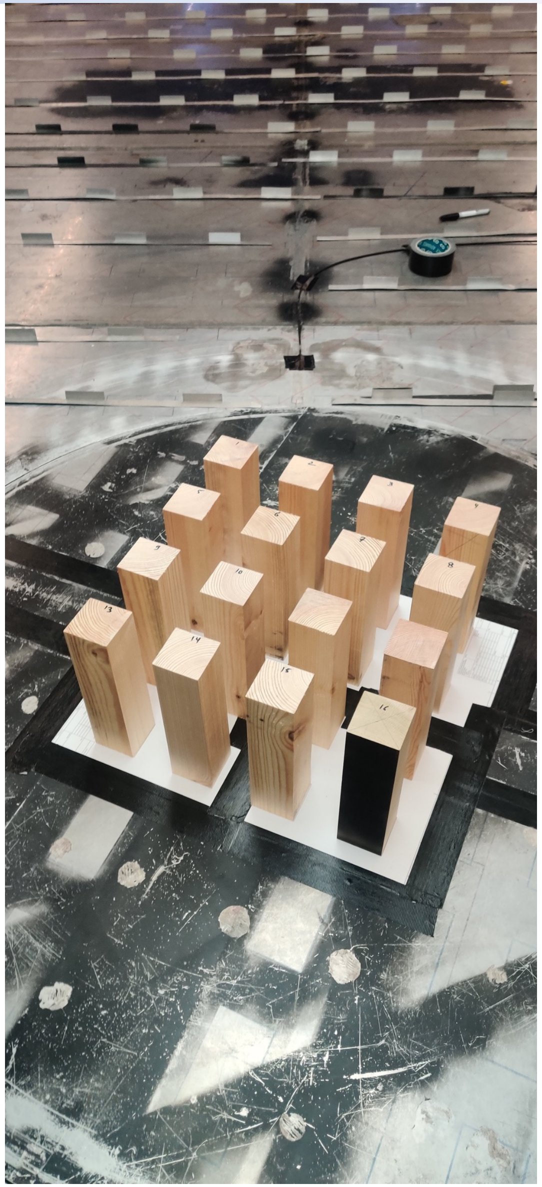
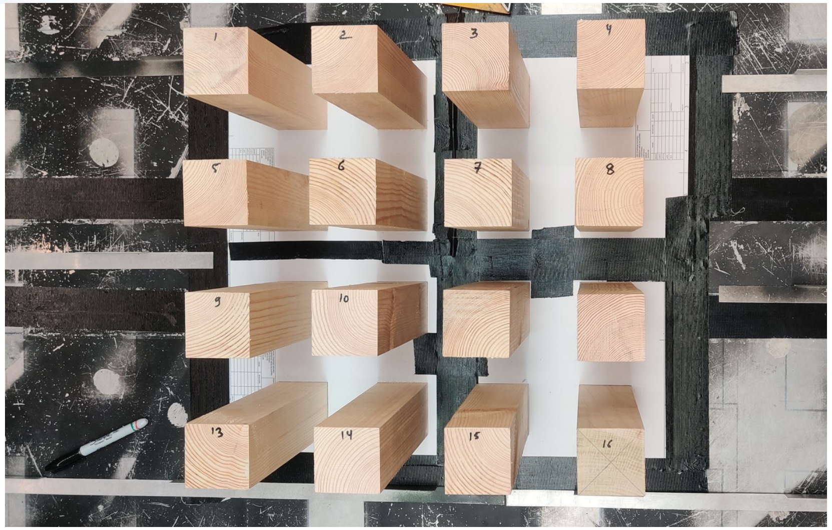
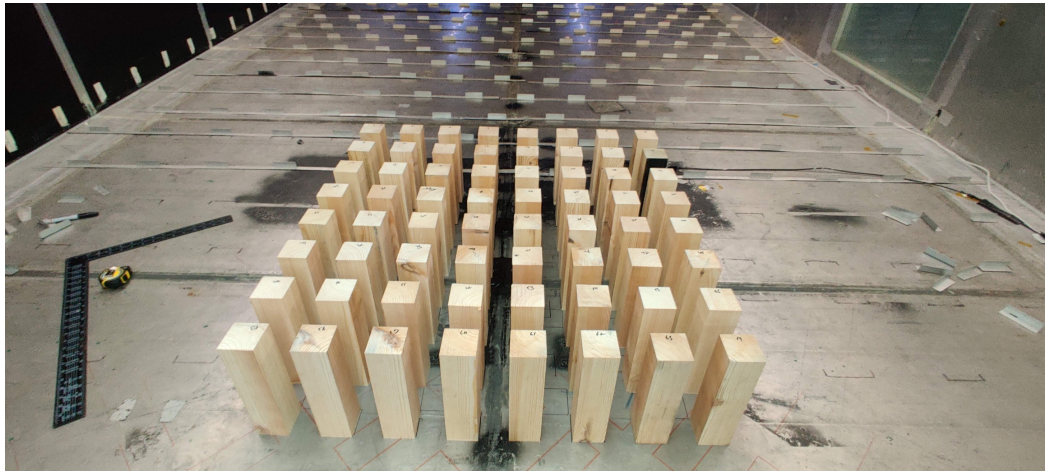
Topic	No of cases	WT
No buildings	1	One source location
Standard arrays (h/b = 4, d/b = 1)	4 (1x1, 2x2, 4x4, 8x8)	4 source locations – upwind, within, downwind, further downwind.
Number of orientations	3 (0, 22.5, 45°)	4x4 array; 22.5° gives side force and breaks wake symmetry; 4 source locations
Spacing, d/b	4 (d/b = 0.5, 1, 2, 3)	4x4 array, one wind direction, 0°, one source location (array centre)
Height ratio, h/H	3 (h/H = 0.125, 0.25, 0.5)	4x4 array, one wind direction, one source location (array centre)
Building height non-uniformity	3 (Dh/h = 0, 1/3, 1/2)	4x4 array, h = 240 mm, one wind direction, one source location (array centre), normal distribution of heights.
Array shape	2 (8x1, 1x8)	Spacings, d/b =1, 2
Reynolds number	2 (U_{ref} = 2, 1 m/s)	4 x 4 array, 0° wind direction. Needed as precursor to stable/unstable cases.
Extended measurements	3	4 x 4 array, 0° wind direction, velocity field only, see above.
Approach flow	2 Roughness elements, DIPLOS blocks	4 x 4 array, one wind direction, one source location (array centre) - standard roughness, as above; DIPLOS blocks hxhx2h, d/h = 1, h = 70 mm

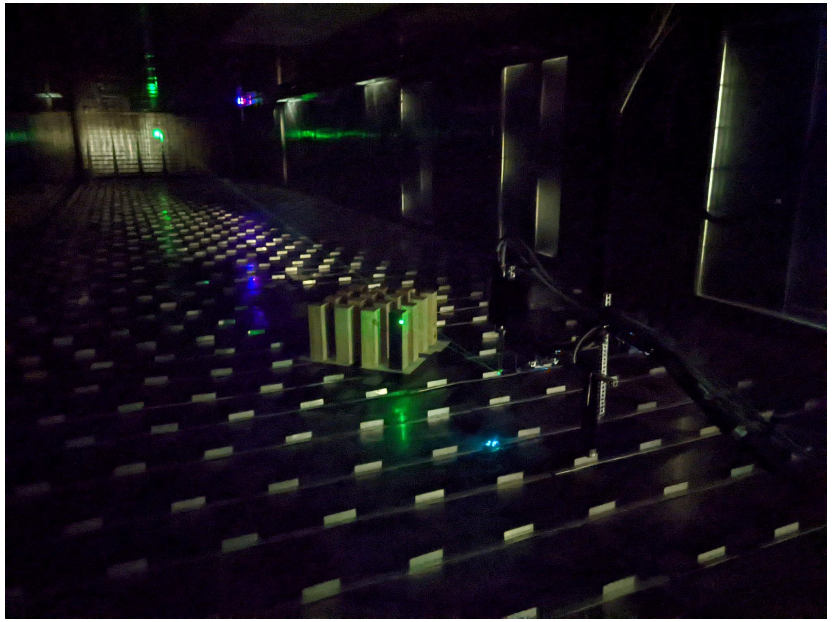
Work Package 1





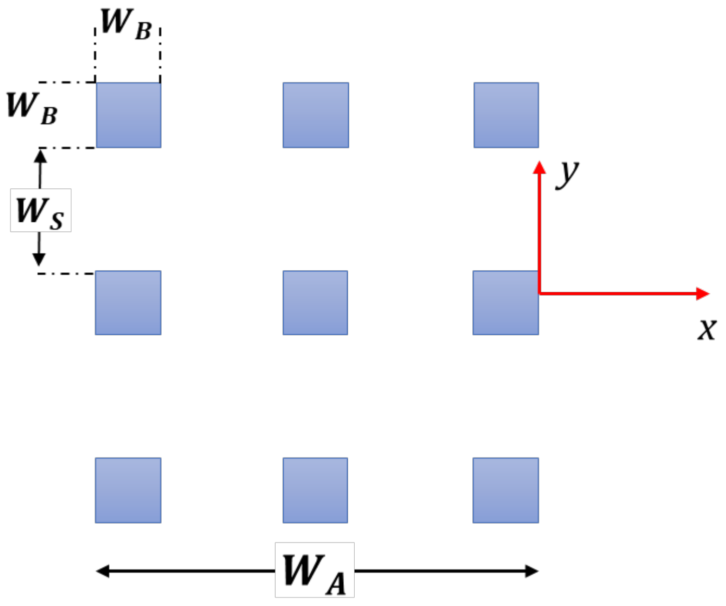






Test Cases

Case no	Array Size (N x N)	Building Width, W_B (mm)	W_S/W_B	Building height, H_B (mm)	Array Width, W_A (mm)
1	1 x 1 (SB)	10	-	60	10
2	5 x 5	10	1	60	90
3	4 x 4	10	1	60	70
4	3 x 3	10	1	60	50
5	5 x 5	10	0.5	60	70
6	5 x 5	10	2	60	130
7	5 x 5	10	4	60	210
8	5 x 5	10	1	80	90
9	5 x 5	10	1	40	90



x: streamwise distance

y: spanwise distance

z: vertical distance

$\delta = 223$ mm

$Re_\delta = 1.39\times10^5$

Test Cases

Case no	Array Size (N x N)	Building Width, W_B (mm)	W_S/W_B	Building height, H_B (mm)	Array Width, W_A (mm)
1	1 x 1 (SB)	10	-	60	10
2	**5 x 5**	10	1	60	90
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5	5 x 5	10	0.5	60	70
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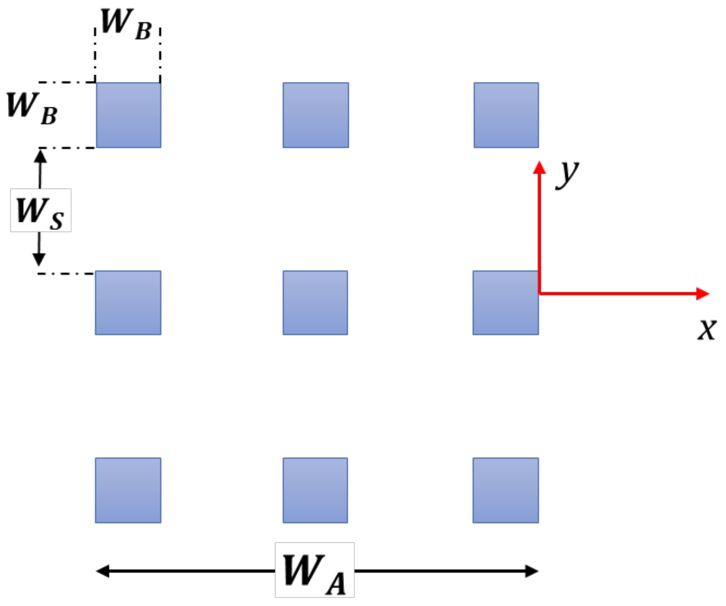

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Array size

Test Cases

Case no	Array Size (N x N)	Building Width, W_B (mm)	W_S/W_B	Building height, H_B (mm)	Array Width, W_A (mm)
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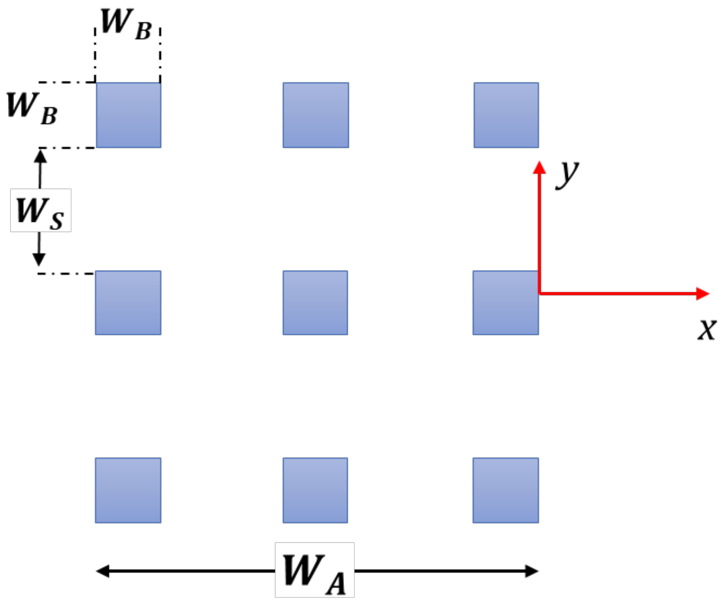

x: streamwise distance

y: spanwise distance

z: vertical distance

$\delta = 223$ mm

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Building Spacing

Test Cases

Case no	Array Size (N x N)	Building Width, W_B (mm)	W_S/W_B	Building height, H_B (mm)	Array Width, W_A (mm)
1	1 x 1 (SB)	10	-	60	10
2	**5 x 5**	10	1	**60**	90
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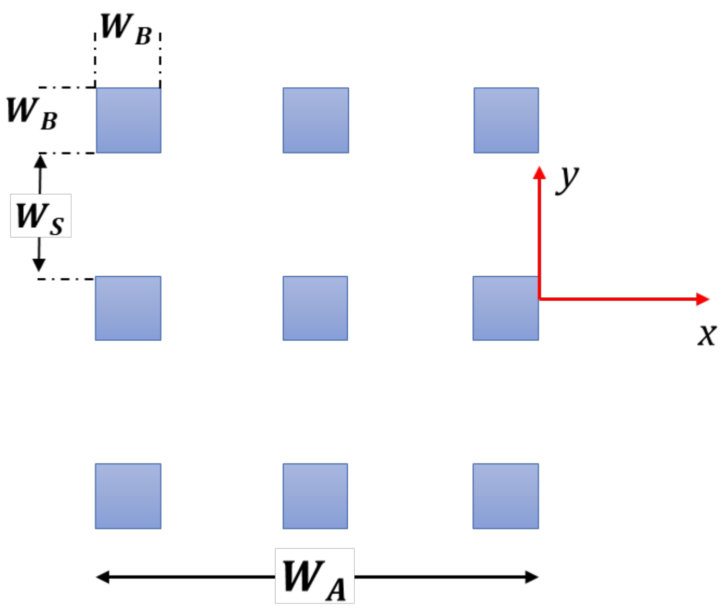

x: streamwise distance

y: spanwise distance

z: vertical distance

$\delta = 223$ mm

$Re_\delta = 1.39\times10^5$

Aspect Ratio

Test Cases

Case no	Array Size (N x N)	Building Width, W_B (mm)	W_S/W_B	Building height, H_B (mm)	Array Width, W_A (mm)
1	1 x 1 (SB)	10	-	60	10
2	5 x 5	10	1	60	90
3	**4 x 4**	10	1	60	**70**
4	3 x 3	10	1	60	50
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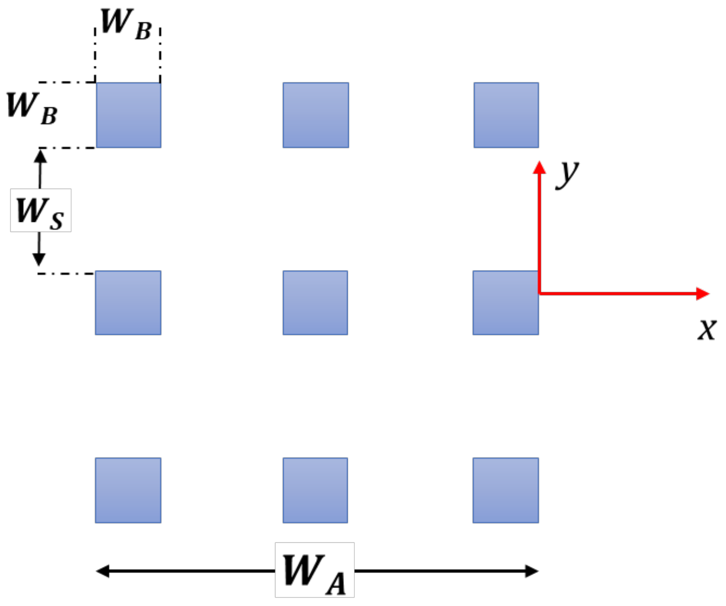

x: streamwise distance

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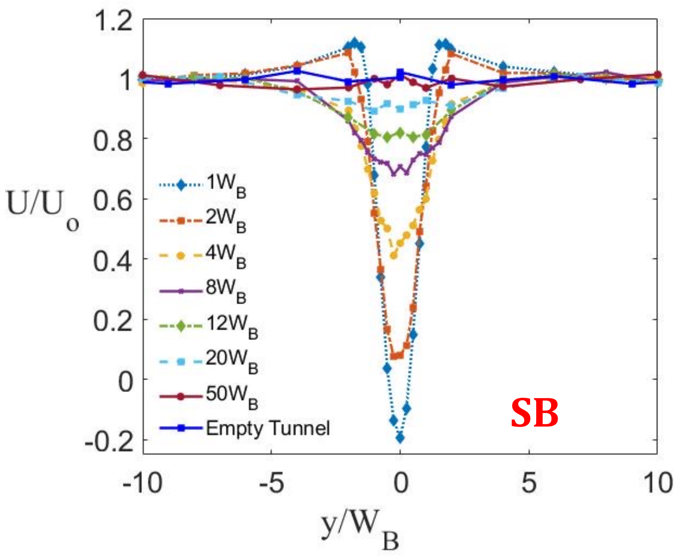
z: vertical distance

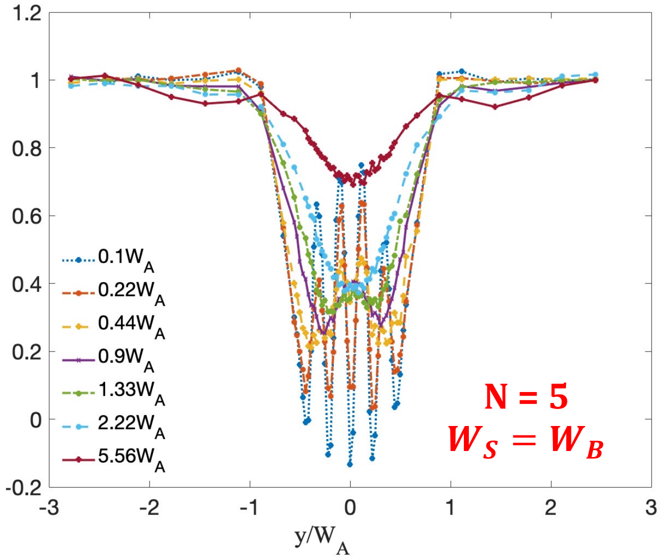
$\delta = 223$ mm

$Re_\delta = 1.39{\times}10^5$

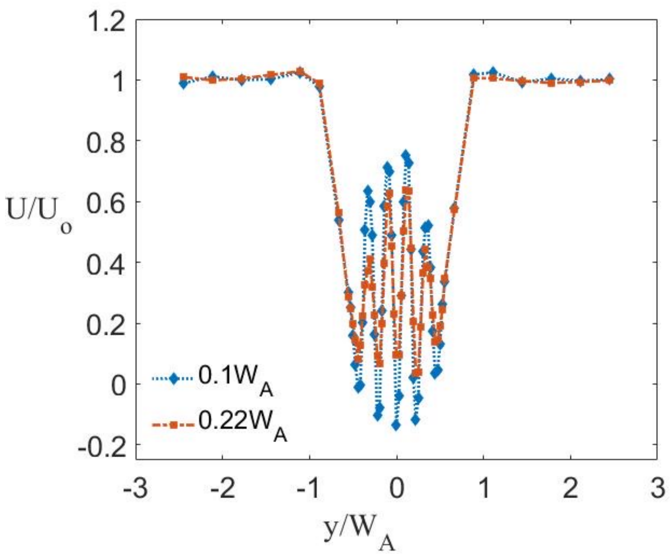
Packing Density

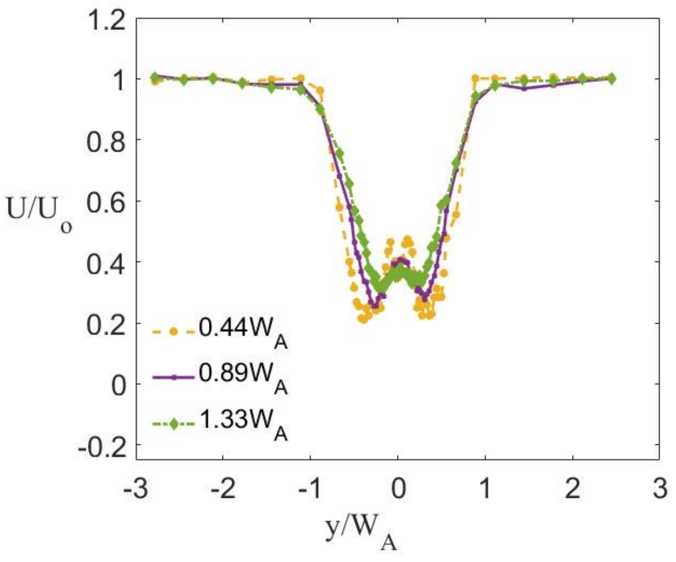
Cluster vs isolated building - regimes

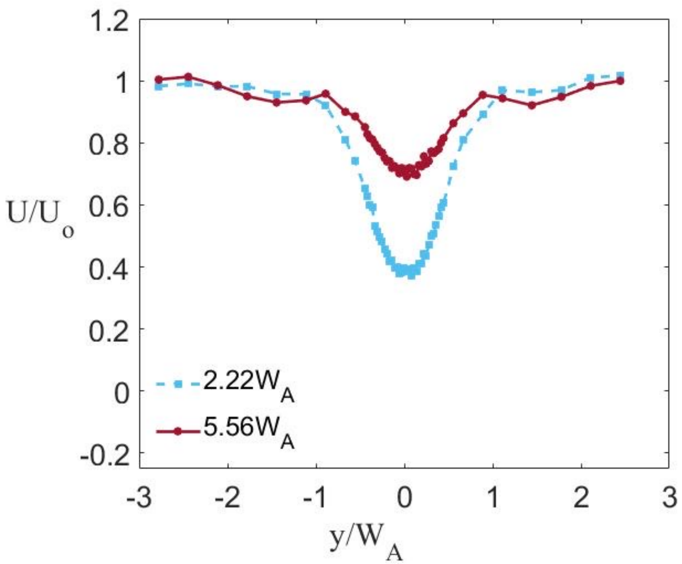




- Near wake regime: Distinct wake behind individual buildings; $x/W_A = 0.1, 0.22$
- Transition wake regime: Individual wakes merge together; $x/W_A = 0.44, 0.9, 1.3$
- Global wake regime: Single wake similar to behind a single building; $x/W_A = 2.2, 5.56$







Effect of N, W_S, and AR in near wake regime

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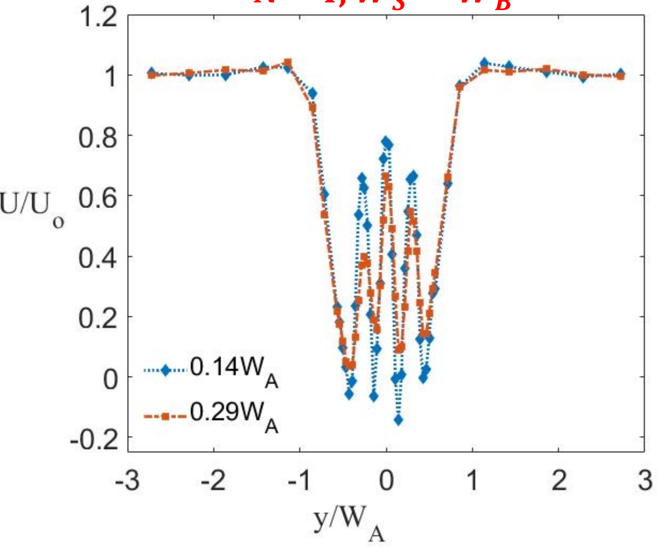
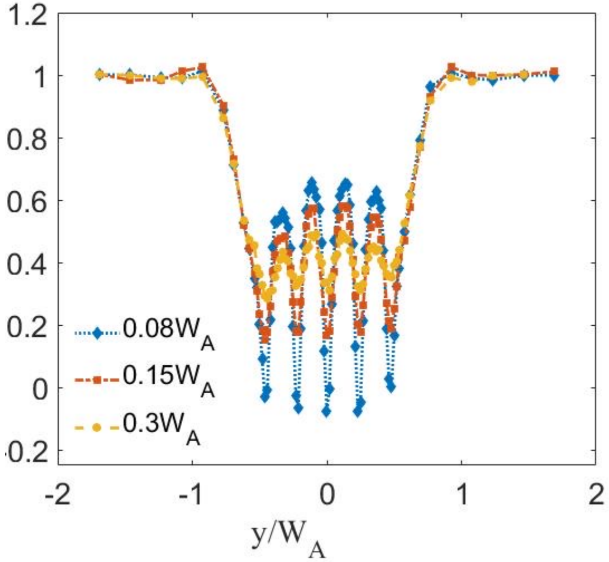
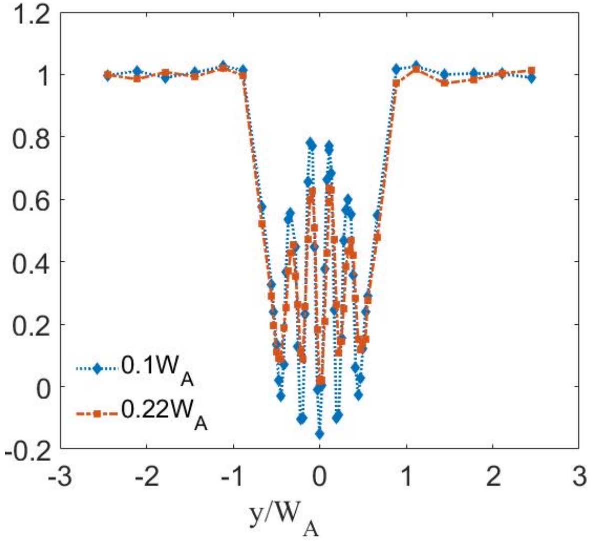
N = 4, $W_S = W_B$



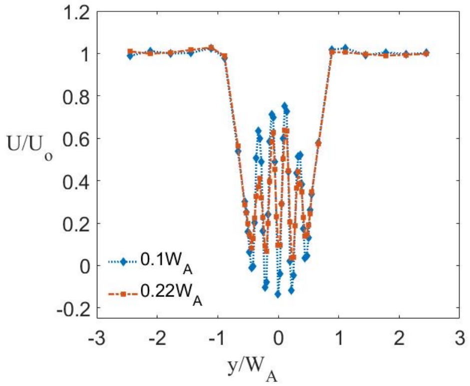
N = 5, $W_S = 2W_B$



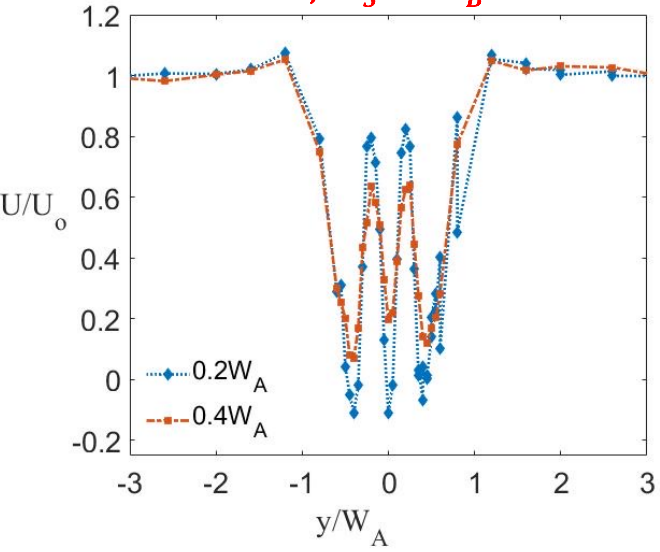
N = 5, AR = 8



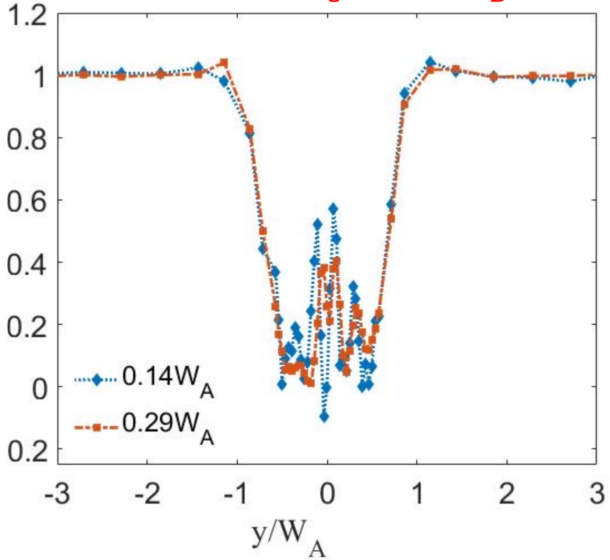
N = 5, $W_S = W_B$



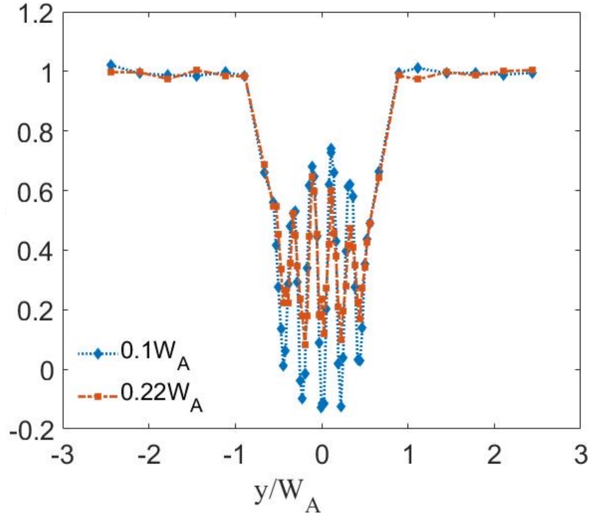
N = 3, $W_S = W_B$



N = 5, $W_S = 0.5W_B$



N = 5, AR = 4



Effect of N, W_S, and AR in global wake regime

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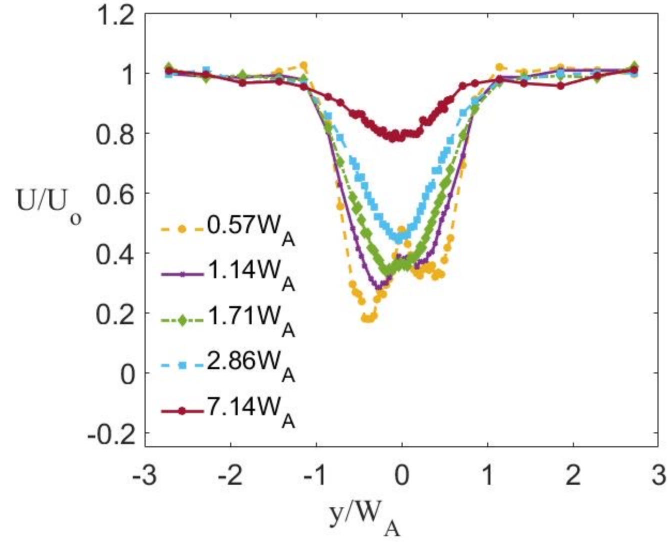
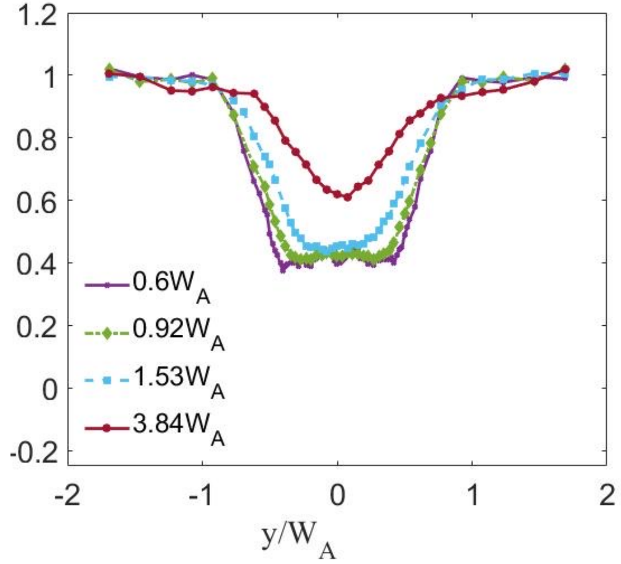
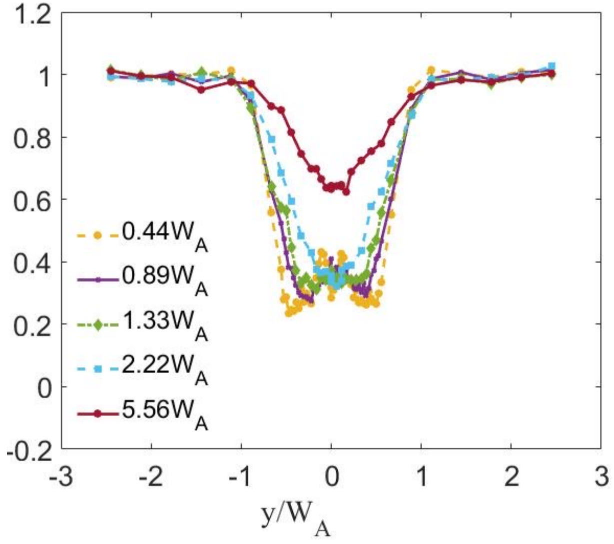
N = 4, $W_S = W_B$

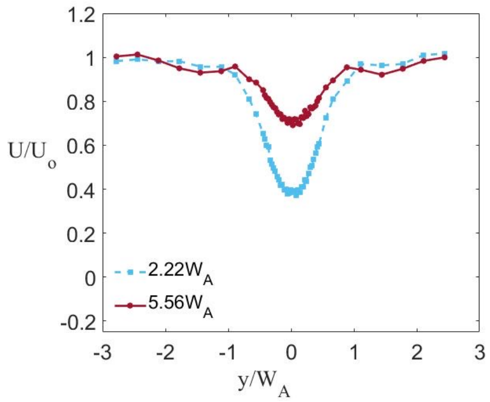


N = 5, $W_S = 2W_B$

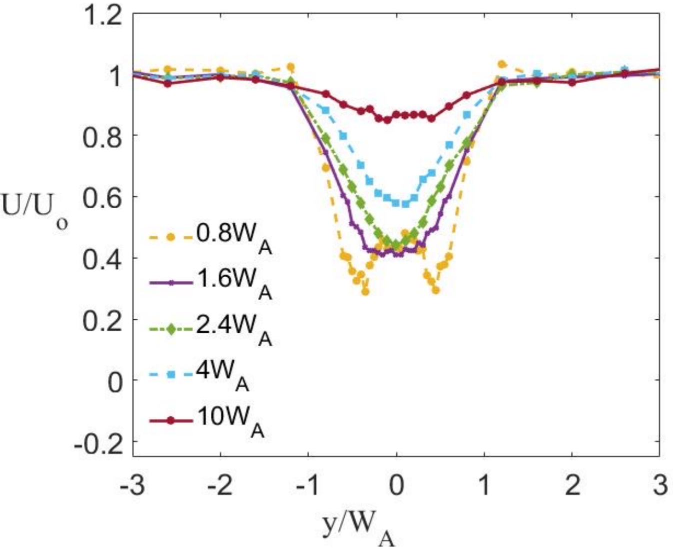


N = 5, AR = 8

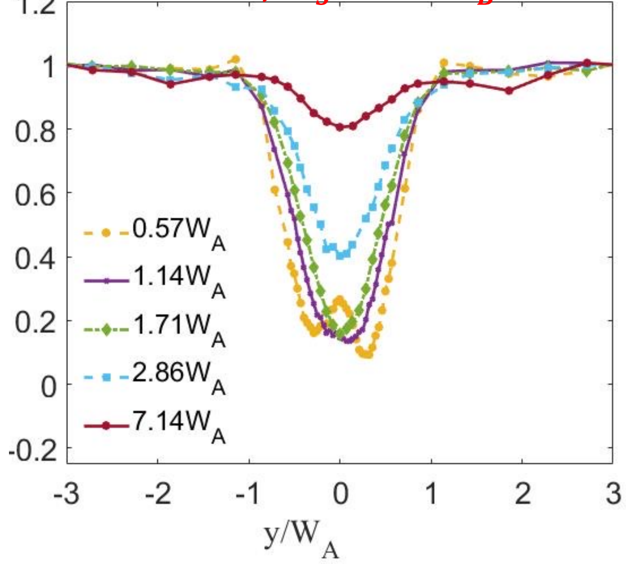




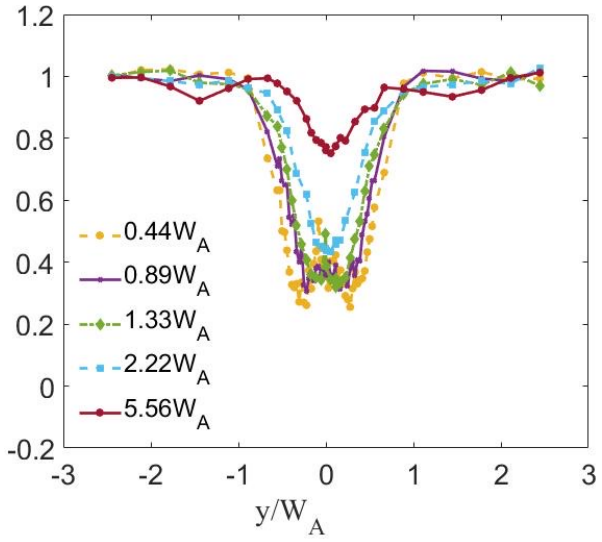
N = 3, $W_S = W_B$



N = 5, $W_S = 0.5W_B$



N = 5, AR = 4



- Near Wake:

  $x \le 0.5W_A$

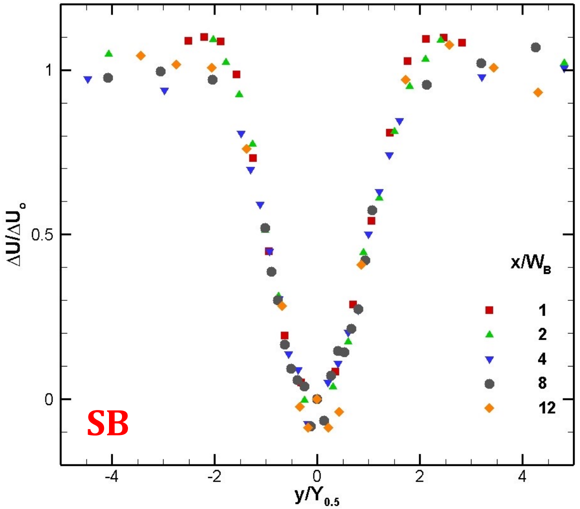
- Transition Wake:

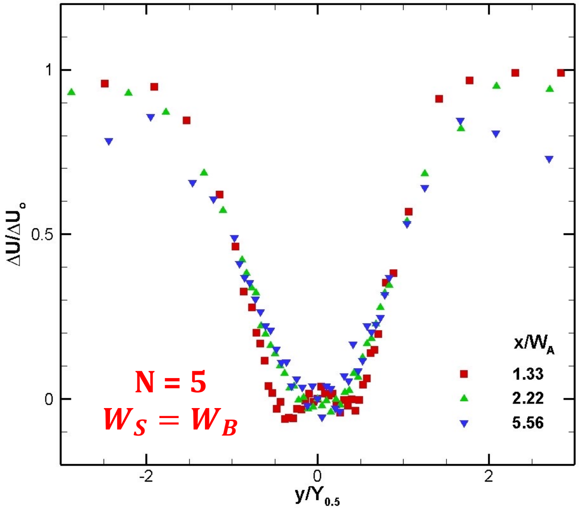
  $0.5W_A \le x \le 1.5W_A$

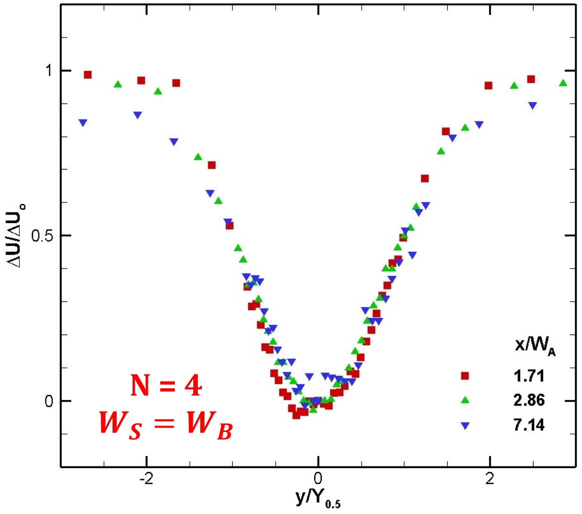
- Global Wake:

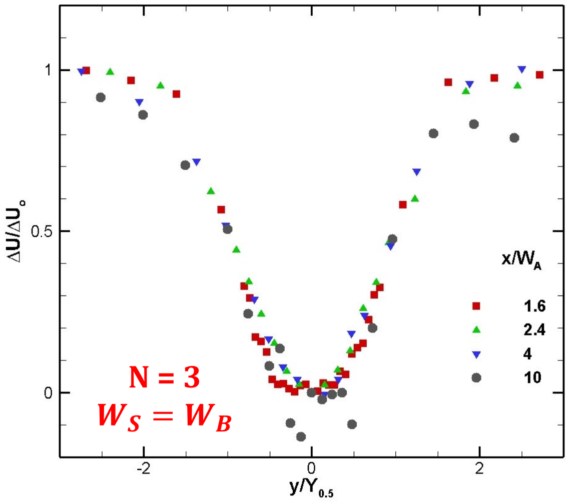
  $x \ge 1.5W_A$

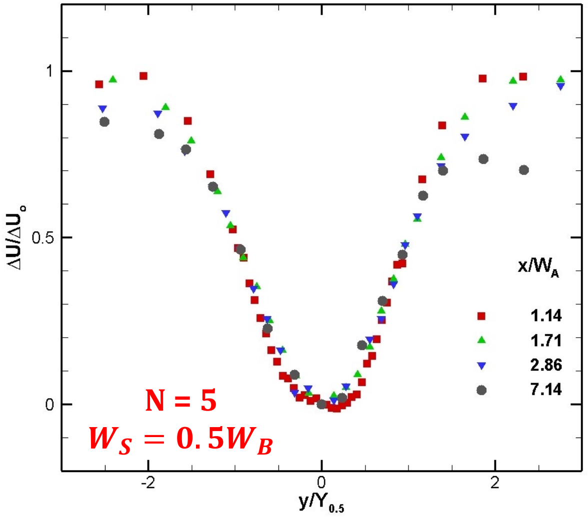
Flow in global wake regime

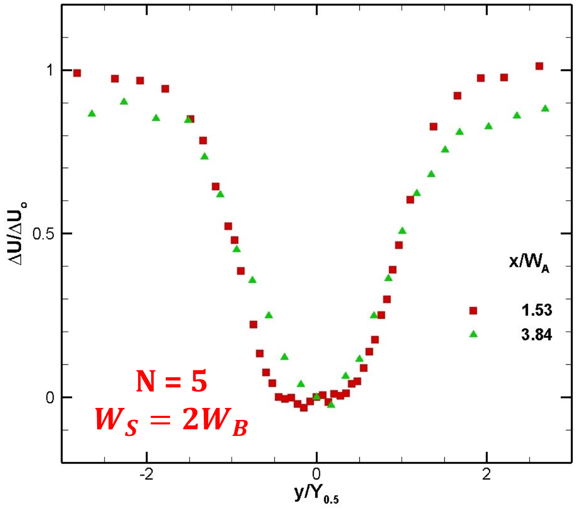








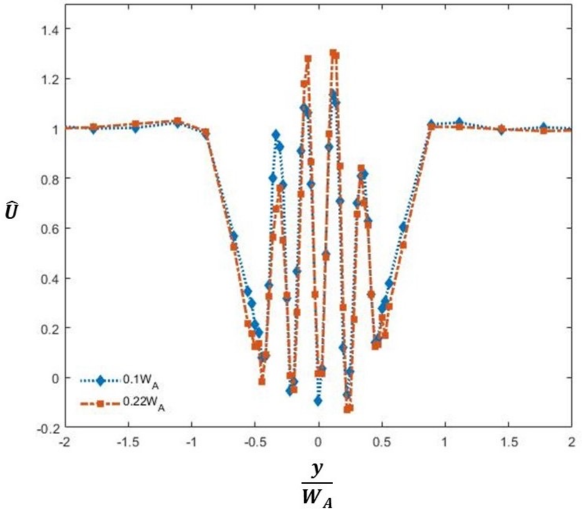




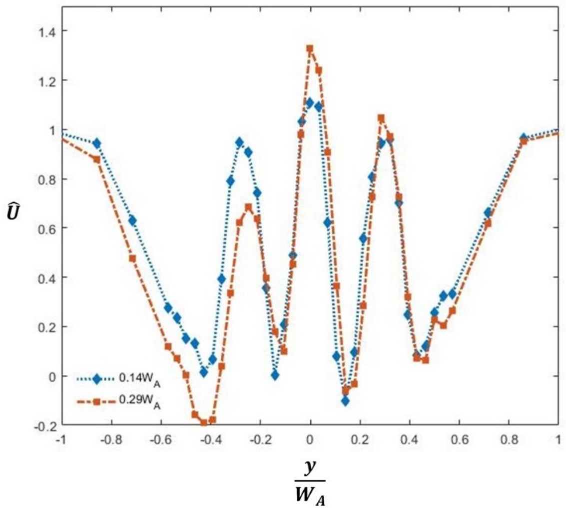
- Global wake regime behaves same as that of the wake behind a single building.
- In the global wake regime, the wake is characterised by wake half width and maximum velocity deficit.
- Effect of individual buildings are subdued.

Flow in near wake regime

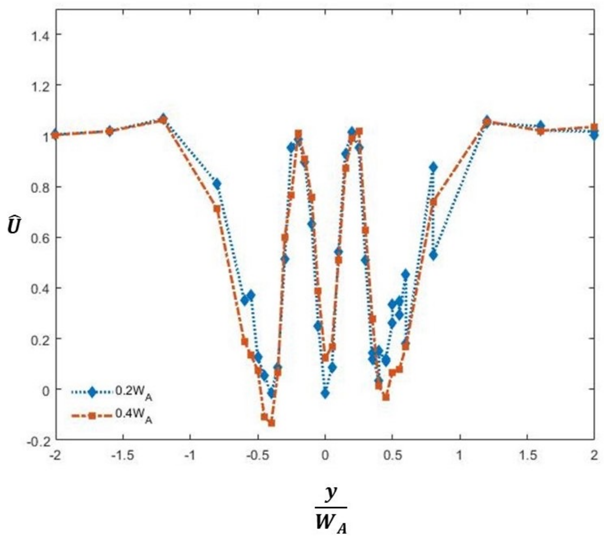
N = 5; $W_S = W_B$



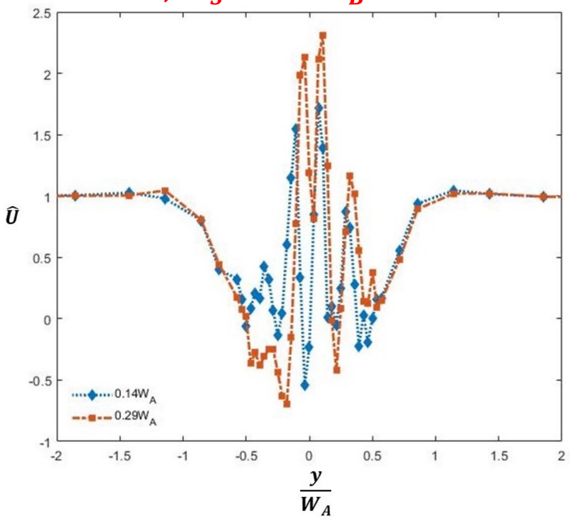
N = 4; $W_S = W_B$



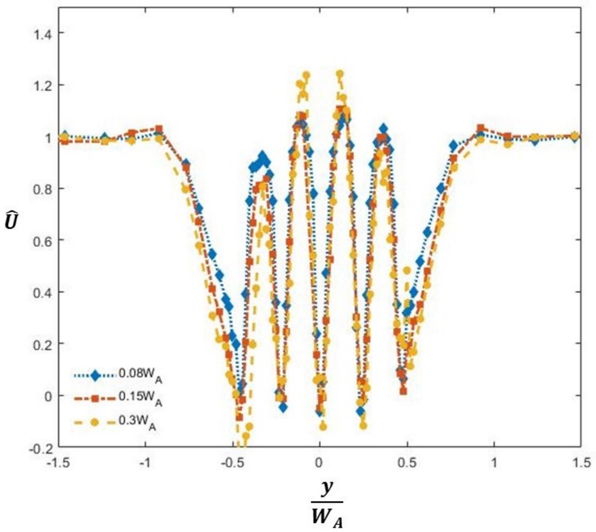
N = 3; $W_S = W_B$



N = 5; $W_S = 0.5W_B$



N = 5; $W_S = 2W_B$



$$\hat{U} = \begin{cases} \dfrac{U - U_{cl}}{U_{loc} - U_{cl}} & |y| \leq 0.5W_A \\ \\ \dfrac{U - U_{cl}}{U_o - U_{cl}} & |y| > 0.5W_A \end{cases}$$

U_{cl} = average velocity at individual building center at a given x location

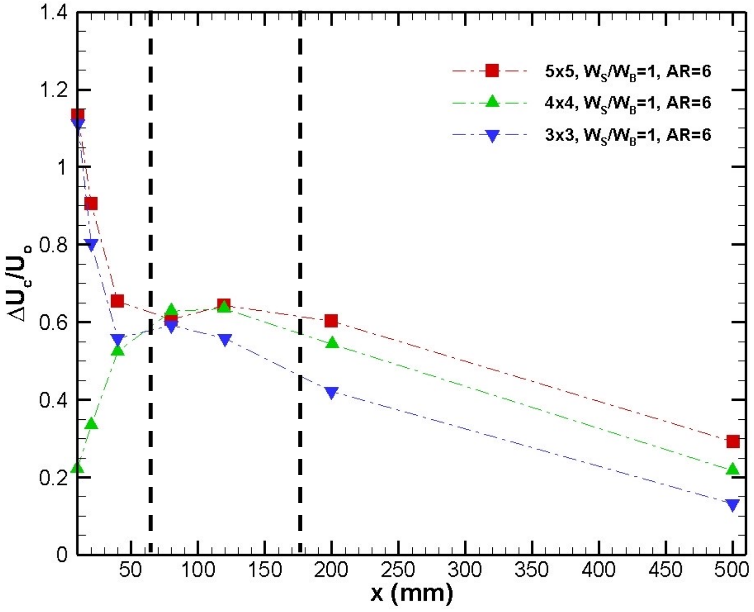
U_{loc} = average velocity at the center of the channels at a given x location

- Effect of individual wakes behind each building is prominent in the near wake regime.
- Wake is characterised by local velocity in the channels between the buildings.

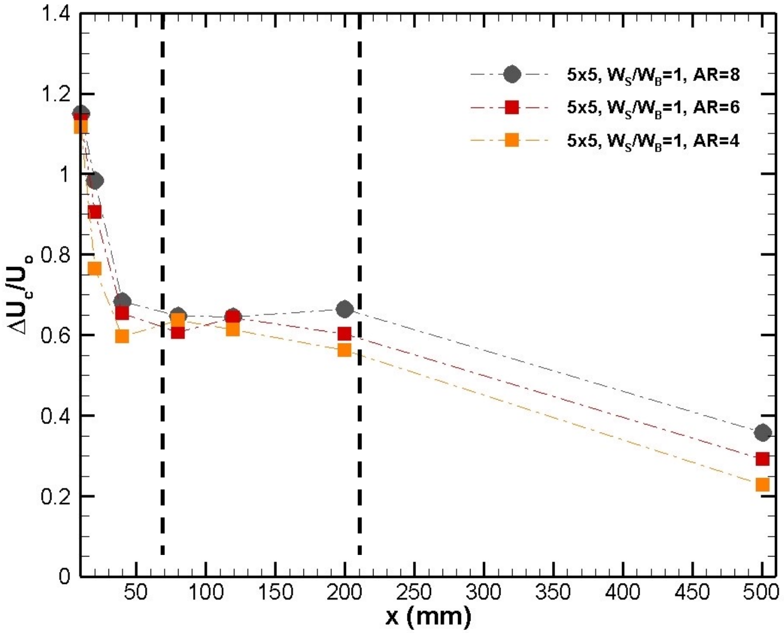
Wake recovery behind building cluster

The velocity decay depends on:

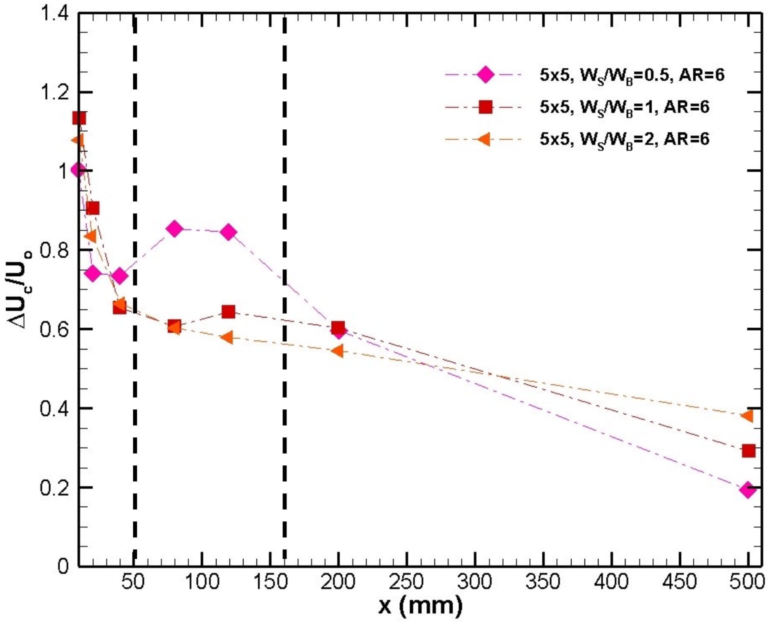
- Array Size: **ΔU** decay faster with decrease in the size of the array

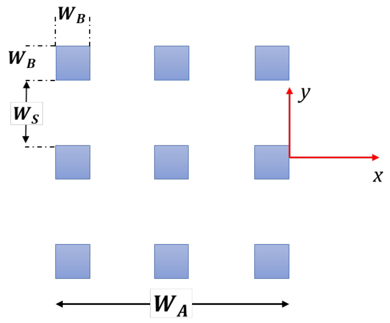


- Aspect ratio: **ΔU** decay faster with decrease in aspect ratio

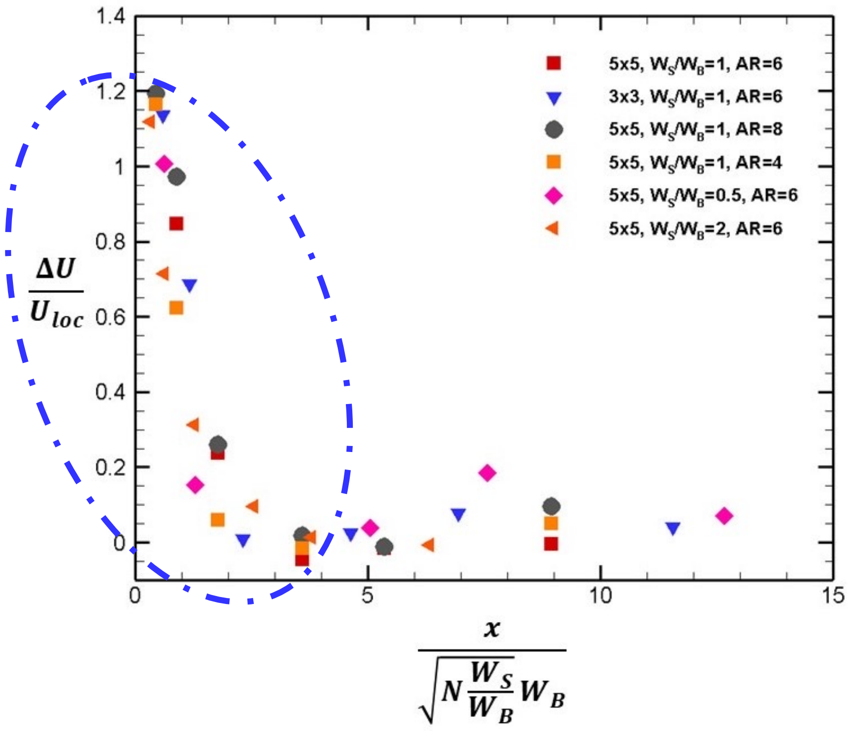


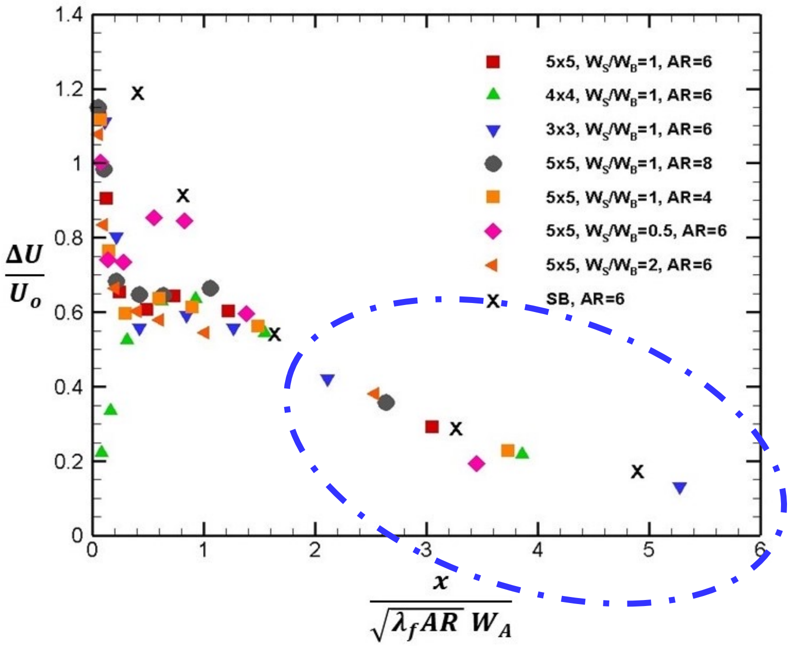
- Spacing between buildings

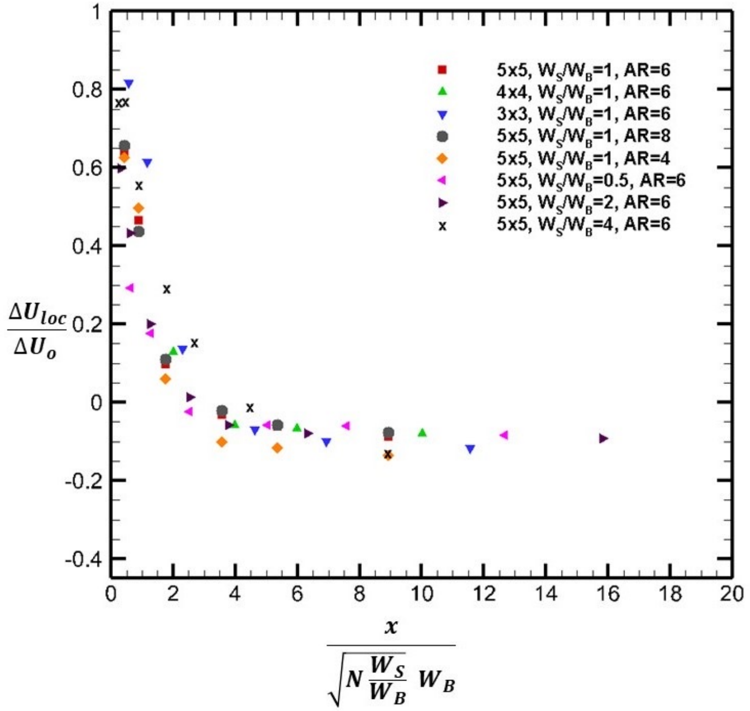




Wake recovery behind building cluster





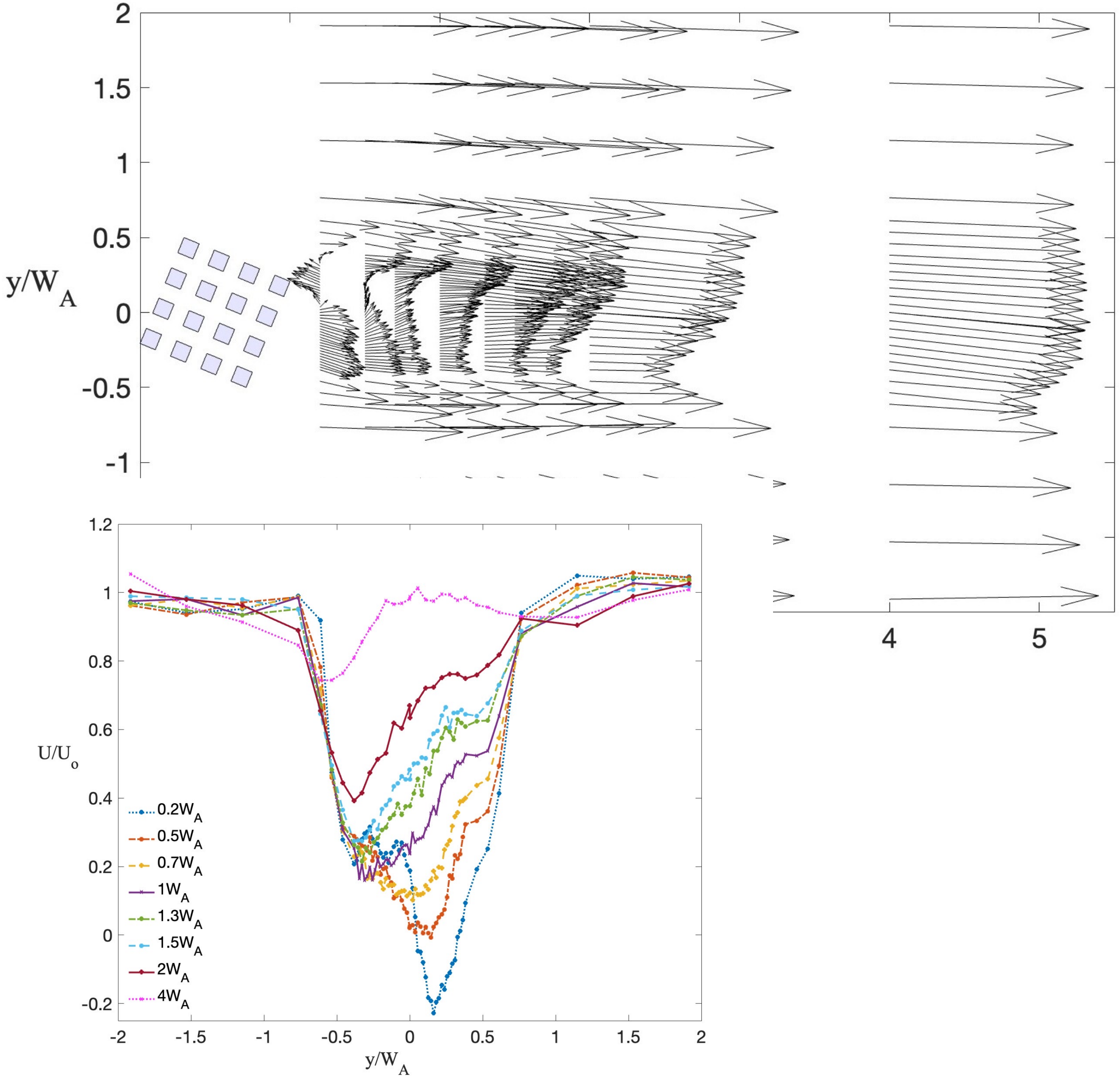


- The decay of velocity deficit is governed by :
  - N, W_S, and W_B in the near wake regime
  - λ_f, AR, and W_A in the global wake regime

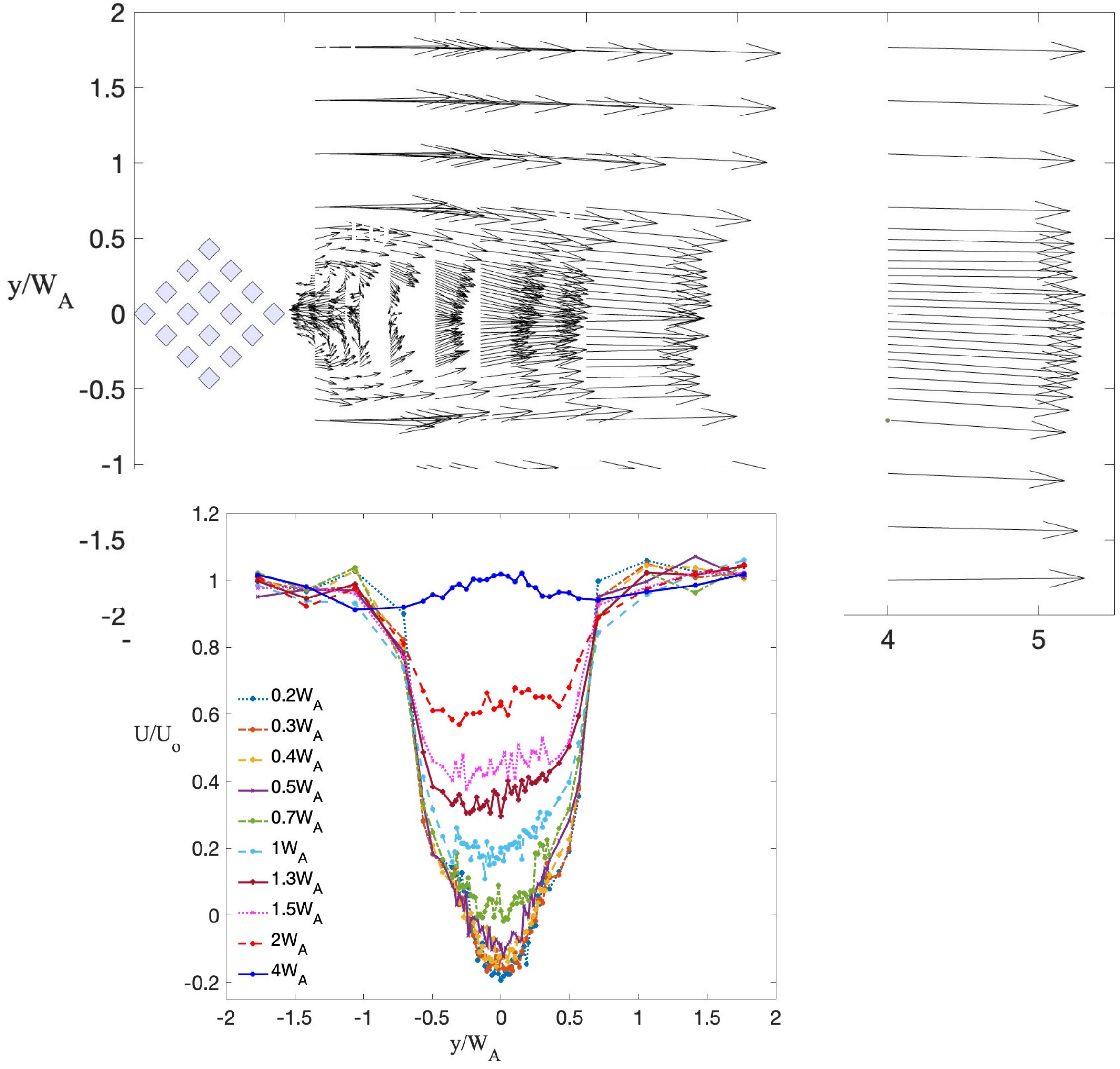
- AR = H_B / W_B
- $\lambda_f = \frac{N * H_B * W_B}{H_B * W_A}$ (frontal blockage)

Effect of Wind Angle

22.5^o



45^o



Work Package 2

April-May, 2023

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- WP 2 includes idealized building cluster in **thermally stratified boundary layer** conditions.

Topic	No of cases	WT
No buildings	1	One source location
Standard arrays (h/b = 4, d/b = 1)	4 (1x1, 4x4, 8x8)	2 Source location: centre and upstream
Number of orientations	3 (0, 22.5, 45˚)	4x4 array; 22.5˚ gives side force and breaks wake symmetry;
Spacing, d/b	4 (d/b = 0.5, 1, 3)	4x4 array, one wind direction, 0˚, one source location (array centre)
Approach flow	2 Roughness elements, DIPLOS blocks	4 x 4 array, one wind direction, one source location (array centre) - standard roughness, as above; DIPLOS blocks hxhx2h, d/h = 1, h = 70 mm
Reynolds number	2 (U_{ref} = 2, 1 m/s)	4 x 4 array, 0˚ wind direction.
Height ratio, h/H	3 (h/H = 0.125, 0.25, 0.5)	4x4 array, one wind direction, one source location (array centre)

Work Package 3

Sept-Oct, 2023

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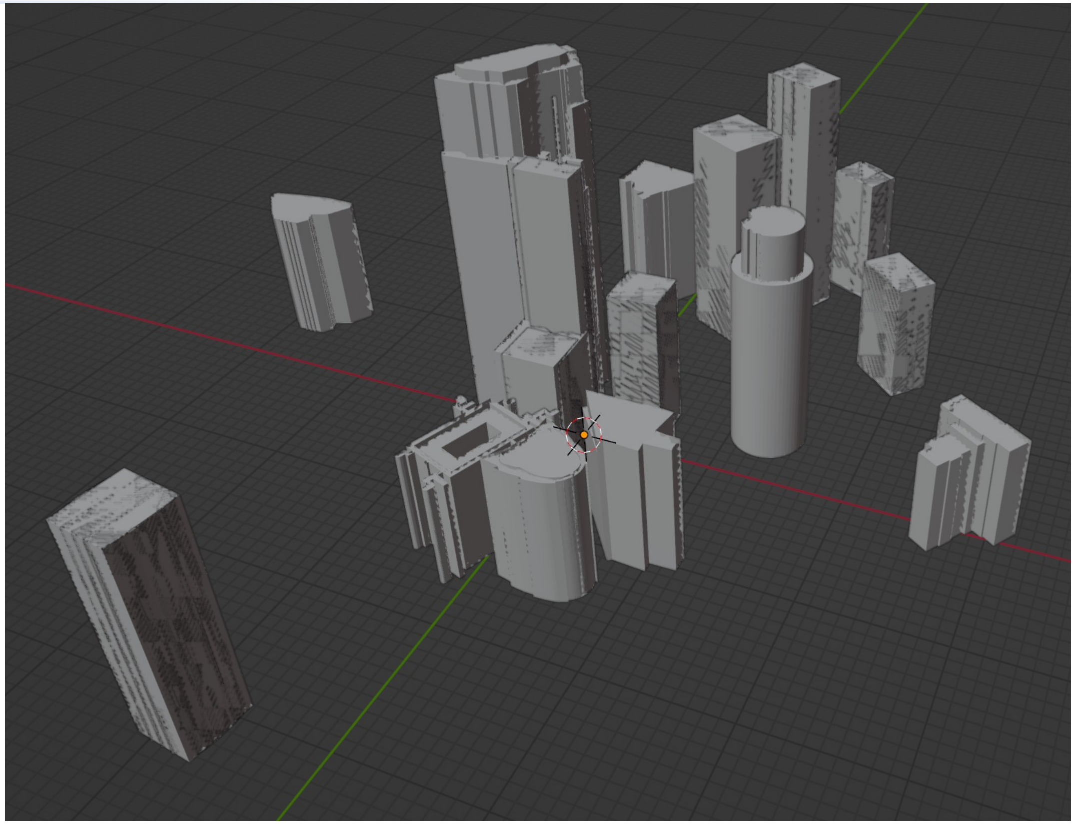

Work Package 3

Sept-Oct, 2023

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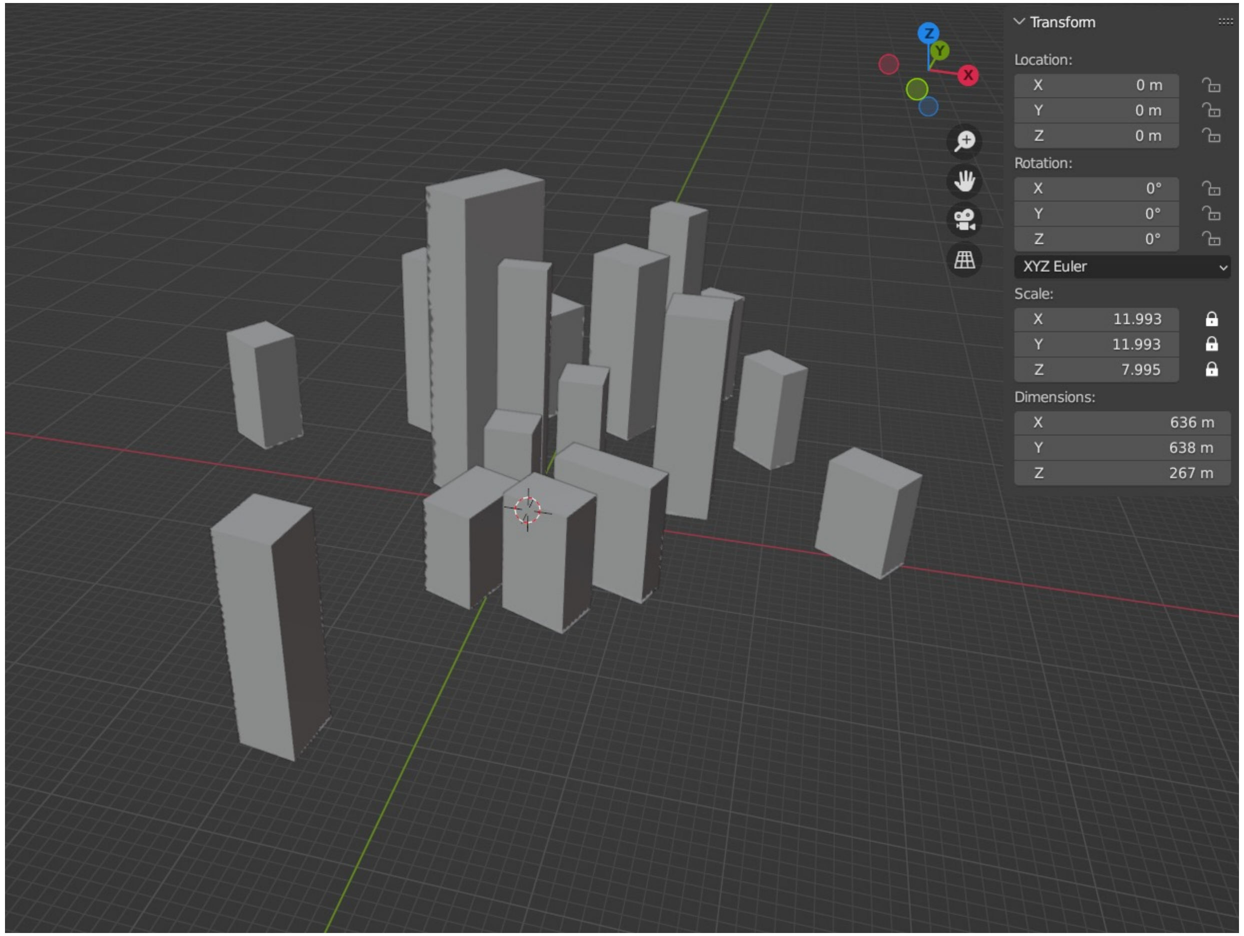

Key Observations in WP1

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- ✓ Different wake regimes behind cluster of buildings
- ✓ Extent of wake regimes depend on cluster width.
- ✓ The wake structure in global wake regime is similar to that of single building with same width.
- ✓ Geometry and orientation of individual buildings is governing parameter in near wake region.

Thank You