Parramatta Over and Adjacent Station Development

Addendum Pedestrian Wind Assessment

May 2024

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20/05/24	F	Response to Sydney Metro comments	Eugene Cullity

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Contents

List of Figures

List of Tables

Glossary

Term	Definition
BoM	Bureau of Meteorology
CBD	Central business district
Concept and Stage 1 CSSI Application	Application SSI-10038 including all major civil construction works between Westmead and The Bays, including station excavation and tunnelling, associated with the Sydney Metro West line
Concept SSDA	A concept development application as defined in Section 4.22 of the EP&A Act, as a development application that sets out concept proposals for the development of a site, and for which detailed proposals for the site or for separate parts of the site are to be the subject of a subsequent development application or applications.
CoPC	City of Parramatta Council
CSSI	Critical state significant infrastructure
DCP	Development control plan
DPE	Department of Planning and Environment
DPHI	Department of Planning, Housing and Infrastructure
EP&A Act	Environmental Planning and Assessment Act 1979
GFA	Gross floor area
NZS	New Zealand Standard
PDCP	City of Parramatta Development Control Plan
Pedestrian Wind Assessment	Parramatta Over and Adjacent Station Development Pedestrian Wind Assessment (Appendix Y), submitted with the original Concept SSDA
SSDA	State Significant Development Application
SSI	State Significant Infrastructure
Stage 2 CSSI Approval	SSI-19238057, approved 24 August 2022, including major civil construction works between The Bays and Sydney CBD including station excavation and tunnelling, associated with the Sydney Metro West railway line
Stage 3 CSSI Approval	SSI-22765520, approved 25 January 2023, including rail infrastructure, stations, precincts and operation of the Sydney Metro West line
Sydney Metro West	Construction and operation of a metro rail line and associated stations between Westmead and the Sydney CBD as described in Section 1.1
TfNSW	Transport for New South Wales
The site	The Parramatta Over and Adjacent Station Development site

Executive Summary

This addendum to the Pedestrian Wind Assessment supports a Concept State Significant Development Application (Concept SSDA) submitted to the Department of Planning and Environment, now Department of Planning, Housing and infrastructure (DPHI) pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Sydney Metro is seeking to secure approval within the meaning of section 4.22 of the EP&A Act, for over station development (OSD) and adjacent station development (ASD). The Concept State Significant Development Application (Concept SSDA) is seeking consent for maximum building envelopes, proposed land uses, maximum building heights, maximum Gross Floor Area (GFA) and car parking. The proposed development comprises four buildings (Buildings A, B, C and D), consisting of three new commercial office buildings (Buildings A, C and D) and one residential accommodation building (Building B).

The Concept SSDA was lodged with the DPHI on 10 November 2022 and was placed on public exhibition for 28 days between 16 November 2022 and 13 December 2022. In total, advice was received from 11 State and local government agencies and 15 submissions were received from key stakeholders, community organisations and the community.

DPHI issued a letter to Sydney Metro on 16 December 2022 requesting a response to the issues raised during the public exhibition of the application. DPHI also issued a further Request for Further Information (RFI) on 6 February 2023. The Submissions Report provides a response to the issues raised.

The City of Parramatta Council (CoPC) provided advice relating to the realignment of Horwood Place. CoPC recommended that the alignment of Horwood Place be straightened with a 14m street reservation width to accommodate parking, footpaths and tree planting along both sides of the street and to ensure Kia Ora has an appropriate curtilage and setting.

In response to the agency advice from CoPC, the design of Horwood Place has been refined to straighten the alignment of Buildings A and D and reduce the buildings setbacks. As a result of these design refinements, additional wind assessment was required to ascertain the wind comfort and safety impacts along Horwood Place.

Wind impacts on pedestrian areas throughout and surrounding the development were assessed using Computational Fluid Dynamics (CFD) simulations combined with statistical analysis of nearby meteorological observations. To accurately capture local flow behaviour, the effects of nearby buildings were modelled within a sufficient radius and to sufficient accuracy, as outline din the Australasian Wind Engineering Society Quality Assurance Manual (2019). The local wind environment was represented statistically using twenty years of meteorological data from Bankstown Airport, scaled according to AS/NZ 1170:2021 methods. The design refinements were assessed against the City of Parramatta Development Control Plan (PDCP) 2023 criteria.

The results of the addendum are summarised as follows:

Wind conditions at pedestrian level in general are appropriate for the intended use of areas of the precinct, according to PDCP (2023) criteria.

Areas of the development where the criteria are exceeded are:

The laneway between Buildings A and D

Around half of the area fronting to Buildings A and D (Horwood Place)

There are no safety exceedances for any areas within and immediately surrounding the development.

The introduction of fixed or retractable canopies or awnings and/or porous screens, architectural screening in critical positions such as balustrading, and trees and landscaping or roughing elements would provide a wind break to exposed facades and could reduce wind speeds sufficiently to achieve the desired comfort criteria.

1 Introduction

1.1 Purpose and Scope

This addendum to the Pedestrian Wind Assessment supports a Concept State Significant Development Application (Concept SSDA) submitted to Department of Planning, Housing and Infrastructure (DPHI) pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Sydney Metro is seeking to secure approval within the meaning of section 4.22 of the EP&A Act, for an over station development (OSD) and adjacent station development (ASD). The Concept SSDA is seeking consent for maximum building envelopes, proposed land uses, maximum building heights, maximum Gross Floor Area (GFA) and car parking. The proposed development comprised four buildings (Buildings A, B, C and D), consisting of three new commercial office buildings (Buildings A, C and D) and one residential accommodation building (Building B).

Previously, wind impacts were assessed as part of the Pedestrian Wind Assessment, prepared to support the Concept SSDA. The assessment found that satisfactory wind comfort was achieved in all areas other than the two areas as noted below:

> *"The two areas where the required criteria are not achieved are the east-west pedestrian link and footpath/frontages along the eastern side of Buildings A and D. In both of these areas, conditions suitable for retail streets or sitting for longer periods of time will require design refinements. However, the wind conditions are categorised as more suitable for major pedestrian streets, parks, or areas where people are expected to site or stand for shorter periods."*

The Concept SSDA was lodged with the DPHI on 10 November 2022 and was placed on public exhibition for 28 days between 16 November 2022 and 13 December 2022. In total, advice was received from 11 State and local government agencies and 15 submissions were received from key stakeholders, community organisations and the community.

DPHI issued a letter to Sydney Metro on 16 December 2022 requesting a response to the issues raised during the public exhibition of the application. DPHI also issued a further Request for Further Information (RFI) on 6 February 2023. The Submissions Report provides a response to the issues raised.

Advice from NSW Government agencies have been received in response to the Concept SSDA EIS.

This addendum report is broken down into the following chapters:

Chapter 1 – outlines an introduction to the project and this report.

Chapter 2 – outlines the scope of the assessment.

Chapter 3 – provides the methodology adopted to complete the updated assessment.

Chapter 4 – outlines the results of the updated assessment.

Chapter 5 – provides a conclusion to the report, summarising the outcomes within the report.

This report should be read in conjunction with the Parramatta Over and Adjacent Station Development Pedestrian Wind Assessment (Appendix Y) submitted with the original Concept SSDA. This addendum report assesses the safety and amenity impacts arising from the design refinements to Buildings A and D and in particularly to the retail frontage which front Horwood Place.

2 Scope of Assessment

The scope of this addendum to the wind impact assessment is as follows:

- Conduct additional wind modelling to demonstrate that there will be no safety or amenity impacts arising from the proposed design refinements to PTA Buildings A and D. This will include modelling of the proposed envelope and providing commentary on whether wind speeds, particularly at the retail frontages to Buildings A and D, which front Horwood Place, will be acceptable. The proposed design refinements include:
  - Amended massing (Figure 2-1).
  - A reduced separation between Buildings A and D (3 m setback as opposed to 6 m).
- Establish whether there will be any safety or amenity issues arising from these refinements.
- Provide potential mitigation measures.
- Computational Fluid Dynamics modelling will be used to carry out this assessment.

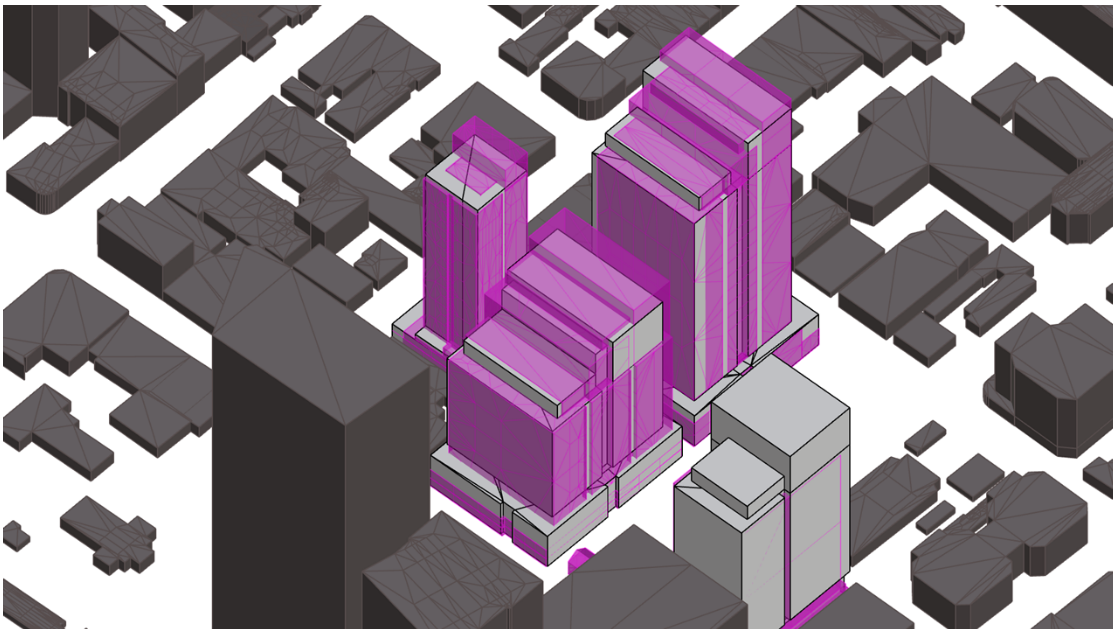


Figure 2-1: Illustration of current CFD massing model (pink), compared with massing model from Pedestrian Wind Assessment (light grey)

3 Methodology

3.1 Assessment Criteria

In the Pedestrian Wind Assessment, assessment is made against the Lawson (2001) criteria for wind comfort and safety, as the criteria in the 2011 PDCP do not mention the averaging duration or probability of occurrence for each category's threshold wind speed.

The 2023 PDCP has subsequently been published, including averaging durations and probabilities of occurrence for comfort thresholds (see Figure 3-1). Additionally, a separate criterion is defined for safety.

It is noted that the Lawson criteria for comfort are the same as the PDCP 2023 criteria, other than the PDCP's additional category for outdoor restaurant dining (0-2 m/s). For this reason, the PDCP 2023 criteria will be used for this assessment, including assessment against the safety criterion.

Further detail on the PDCP 2011, Lawson and PDCP 2023 criteria sets can be found in Appendix A.

C.01 To ensure comfort in and around new buildings, the wind speeds in Table 9.8.9.1 below must be exceeded for less than 5% of the time around new buildings for both hourly mean and gust equivalent mean wind speeds:

< 2 m/s	Outdoor restaurant dining
< 4 m/s	Sitting (such as café style dining), or scheduled outdoor events
< 6 m/s	Standing, generally supports outdoor planting
< 8 m/s	Walking in retail areas / active street frontages?
< 10 m/s	Walking / non-active street frontages (objective walking from A to B or for cycling)

Table 9.8.9.1 – Wind speeds

C.02 To ensure public safety, a 3 second moving average gust wind speed of 23 metres/second must be exceeded for less than 0.1% of time.

Figure 3-1: PDCP criteria for wind mitigation

3.2 Target Criteria

The target PDCP (2023) comfort criteria for this study are unchanged from the Pedestrian Wind Assessment report, shown below in Figure 3-2. It is noted that there are no areas specifically designated for outdoor restaurant dining (0-2 m/s) as opposed to café dining (0-4 m/s).

Figure 3-2: Target comfort criteria throughout the precinct

3.3 Meteorological Data

Historical weather data was used for the analysis and obtained from the Bureau of Meteorology weather station at Bankstown Airport, which is required by the PDCP (2023). Daytime (6am - 9pm) hours were used for the comfort assessment as recommended by the PDCP (2023), with all hours considered for pedestrian safety.

From 2000 to 2019, 10-minute wind observations were converted to hourly means using methods outlined in Grange (2014). Scaling to correct for the difference in terrain roughness surrounding the site (i.e., due to buildings, trees, and other obstructions) was made as detailed in Appendix B.1. Details of the statistical methods used and coefficients describing the wind probability distributions can also be found in Appendix B.2.

The scaled data is presented in the wind rose plot below, Figure 3-3. Here, the length and colour of the spoke sections represent the frequency and amplitude of recorded wind events, respectively.

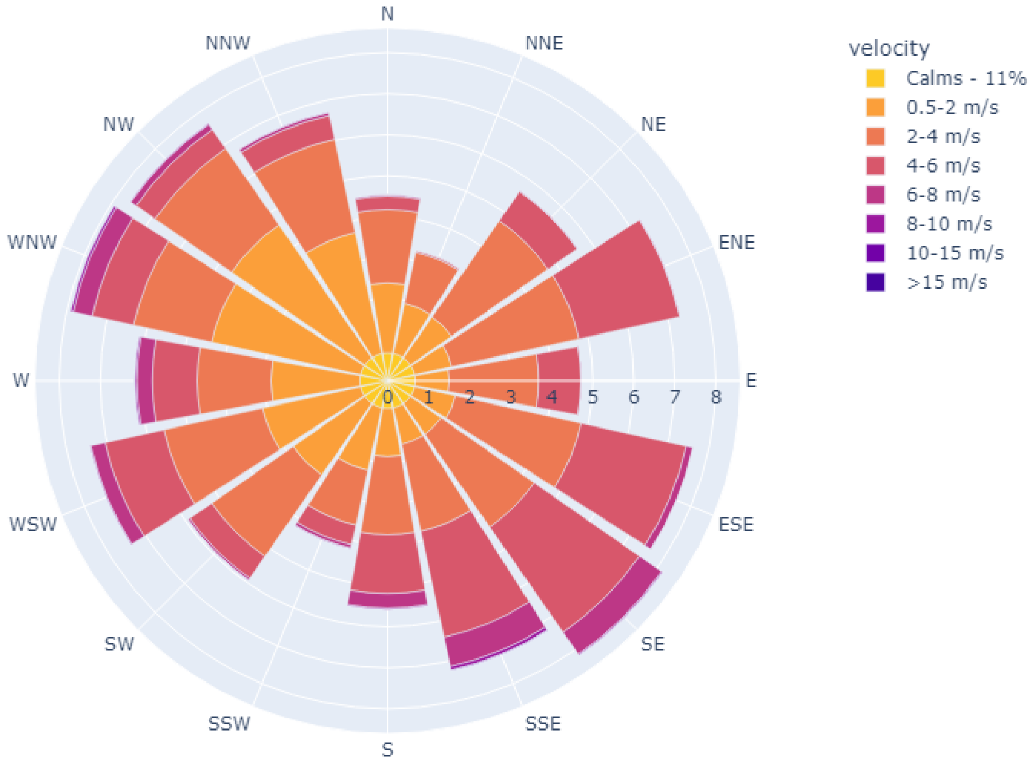


Figure 3-3: Wind rose plot of Bankstown Airport BoM Data, 2000-2019, 6am-9pm (as used for comfort assessment)

3.4 Computational Model

Surrounding physical features which influence the near field flow, such as significant buildings, structures, or topography, are essential to accurate wind modelling. The development, surrounding buildings and topography within 500 m radius were modelled to sufficient accuracy, following the Australasian Wind Engineering Society Quality Assurance Manual (2019) guidelines. Images of the simplified model are provided below in Figure 3-4 and Figure 3-5. Further detail on the CFD methodology is provided in Appendix C.

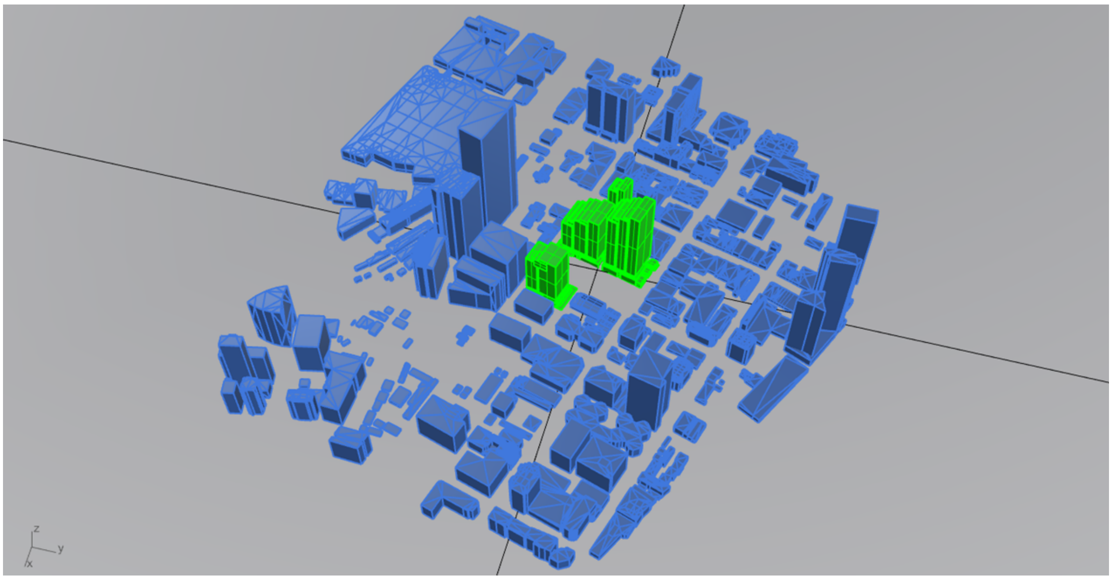


Figure 3-4: Model geometry, showing extents and detail of the surrounding buildings

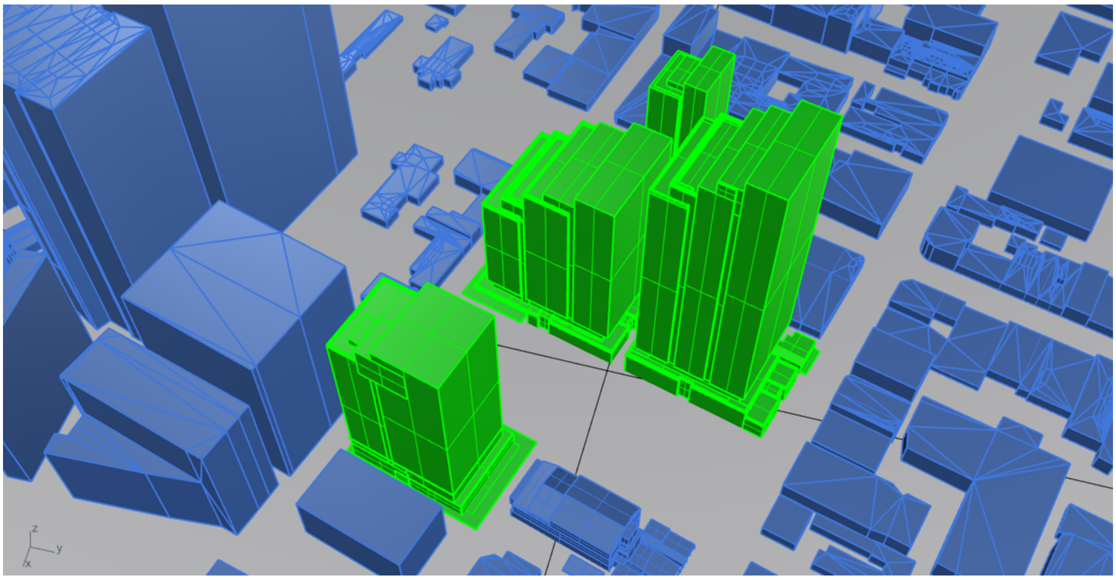


Figure 3-5: Model geometry, showing detail of the proposed development

3.5 Statistical analysis

The methods used to assess CFD results against the PDCP (2023) criteria are as follows:

CFD was used to determine the mean wind speed ($\overline{U}$) and turbulent kinetic energy (k) at a height of 1.5 m for 16 wind directions relative to a reference wind speed of 10 m/s.

For the PDCP *comfort* criteria, gust-equivalent mean wind speeds, U_{GEM}, were calculated using:

$$U_{GEM} = \max\left(\overline{\mathrm{U}}, \frac{\overline{U} + 2.6\sqrt{k}}{1.85}\right)$$

where 2.6 is the peak factor corresponding to a 3-second gust relative to a 10-minute mean. The gust factor of 1.85 has been used based on the research published by Lawson (2001).

Comfort wind speeds were calculated using a Weibull statistical analysis (see Appendix B.2) of the gust-equivalent mean wind speed results, resulting in wind speeds with a 5% probability of exceedance from all directions.

For the PDCP (2023) *safety* criteria, gust wind speeds, $\hat{U}$, were calculated using:

$$\hat{U} = U_{GEM} \times 1.85$$

It is noted that this is a conservative approach where $U_{GEM} = \overline{U}$.

Safety wind speeds were also calculated using a Weibull statistical analysis, using the gust wind speed results, resulting in wind speeds with a 0.1% probability of exceedance from any direction.

4 Results

4.1 Comfort

Wind comfort results are displayed in Figure 4-1. These plots can be considered as a weighted average of wind events occurring from all directions (i.e., taking into consideration the relative probability of wind speeds from each direction). Results are presented against the PDCP (2023) criteria across an assessment surface 1.5 m above ground level.

Unscaled gust-equivalent mean wind speeds for each wind direction are displayed in Appendix D, illustrating the wind conditions produced by each wind direction and providing some indication of their relative contribution (without scaling for strength or frequency of winds from each direction).

The results of the assessment indicate that wind speeds are generally compliant with the requirements for standing, when assessed against the PDCP (2023) criteria (aligning with the Lawson Criteria). However, the target comfort criteria for sitting (café-style dining, outdoor events) for the lane between Buildings A and D and for the Horwood Place frontages to these buildings is not achieved. Further discussion is provided below.

Table 4-1: Summary of wind comfort assessment

Area	Comfort Wind Speed (m/s)	Target Criteria Achieved?	Description of Results
Laneway between buildings A and D	4-6	No	Downwash and funnelling effects are present at both ends of the laneway, particularly from WSW, WNW, NE wind directions. Awnings will likely provide acceptable mitigation. Landscaping and porous screens at either end of the laneway are options if awnings are undesirable.
Laneway between buildings B and D	2-6	Yes	A combination of downwash and funnelling is evident from several wind directions (NNW, NW, WNW, SSW), however the overall result is suitable for the intended use
Frontages to buildings A and D (Horwood Pl)	4-6	No	Approximately half of the frontage area meets the target category (suitable for outdoor café seating). Winds washing down the eastern facades of Buildings A and D, from NE through to SE winds, are driving the exceedances in other areas. Landscaping as per or like the proposed plan may provide adequate mitigation if tree canopies are of a suitable height and density. Alternatively, awnings and perforated screens could provide adequate mitigation.
Civic Link	4-6	Yes	Wind conditions are suitable for standing, outdoor planting but exceed those recommended for outdoor events or café-style dining.
George Street	4-6	Yes	Wind conditions are suitable for standing
Macquarie Street	2-4	Yes	Wind conditions are generally suitable for outdoor café seating, which is below the target criteria of 4-6 m/s (standing)
Macquarie Lane	2-4	Yes	Wind conditions are generally suitable for outdoor café seating; well-below the target criteria of 6-8 m/s (strolling)

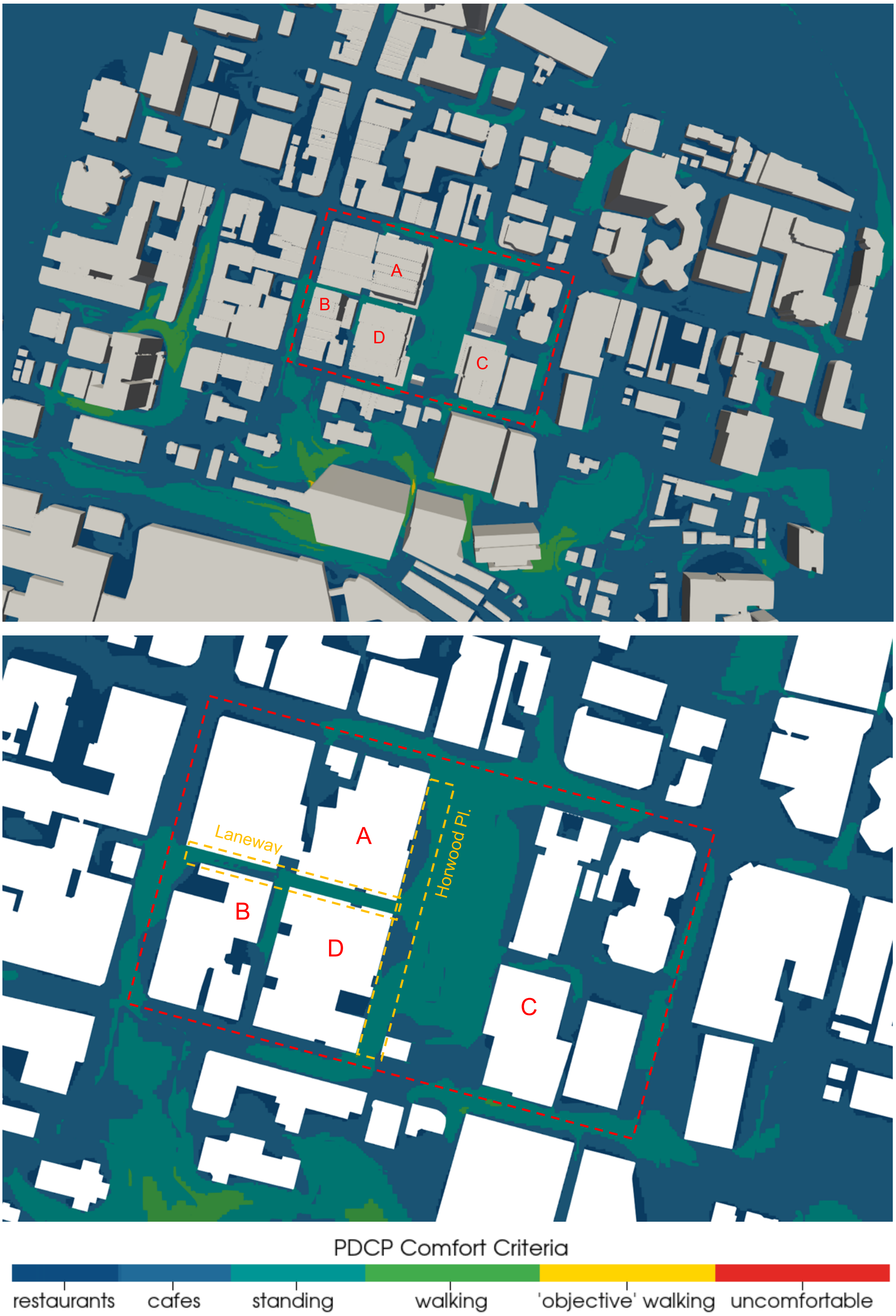


Figure 4-1: Wind comfort results: surrounding wind environment and buildings (top) and 1.5 m plane results throughout the development, buildings omitted (bottom)

4.2 Safety

Safety results are displayed in Figure 4-2: . As with the comfort contours above, the results represent wind events from all directions. There are no exceedances of the

PDCP (2023) wind safety criteria in any areas throughout or surrounding the development. The exceedances shown below are due to existing tall buildings.

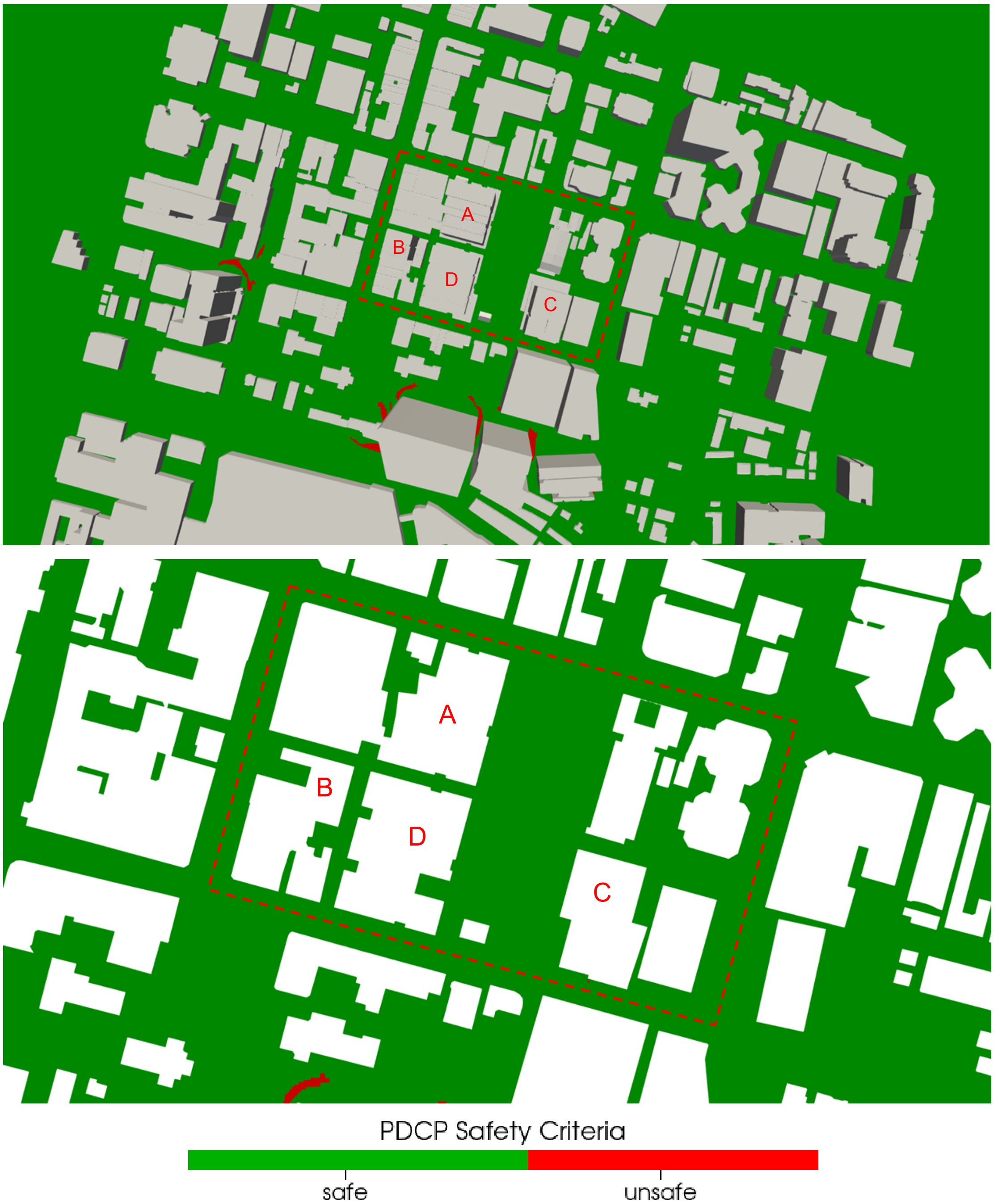


Figure 4-2: Safety results: surrounding wind environment and buildings (top) and 1.5 m plane results throughout the development, buildings omitted (bottom)

4.3 Potential Mitigation Strategies

Wind mitigation is required in two locations: the laneway between Buildings A and D, and the Frontages to buildings A and D (Horwood Pl).

At the laneway between buildings A and D, adequate mitigation may be provided by a combination of:

Retractable awnings running the full length and covering the full length of the laneway.

- A dense tree canopy, from ~2 to 4+ m height, at the intersection of the two laneways
- Dense shrubbery or porous screens, from the ground up to ~3m height, at the eastern (Horwood Pl) end of the laneway.
- Movable porous screens or planter boxes with dense shrubbery ~2 m height adjacent to any outdoor café seating

At the Frontages to buildings A and D (Horwood Pl), adequate mitigation may be provided by a combination of:

- Tree canopy cover in proposed landscaping design
- Tree canopy cover in amended landscaping design, where dense canopies meet facades of Buildings A and D
- Awnings (fixed or retractable) above any outdoor café seating
- Movable porous screens or planter boxes with dense shrubbery ~2 m height adjacent to any outdoor café seating

Figure 4-3: Potential mitigation strategies: movable planter boxes with dense shrubbery (left) and retractable awnings (right)

5 Conclusion

This addendum to the Pedestrian Wind Assessment has been prepared to support the Concept SSDA and to respond to the agency advice and submissions.

In response to the agency advice from CoPC, the design of Horwood Place has been refined to straighten the alignment of Buildings A and D and reduce the buildings setbacks. The assessment addresses the design refinements to Buildings A and D along Horwood Place and their impacts on pedestrians at ground level, particularly at the retail frontages to Buildings A and D.

The assessment was completed using a combination of CFD simulations and statistical analysis of meteorological observations to calculate comfort and safety wind speeds at pedestrian height. The assessment was carried out against the City of Parramatta DCP (2023) controls for wind mitigation.

Wind conditions throughout the precinct are generally suited for the intended uses of most areas, with conditions suitable for standing achieved in all areas. The results of the addendum indicate that wind speeds are generally compliant with the intended usage of each area of the proposed development (when assessed against the PDCP (2023) criteria). However, the target comfort criteria of sitting (outdoor café seating) for the lane between Buildings A and D and for the Horwood Place frontages to these buildings is not achieved.

There are no exceedances of the PDCP (2023) wind safety criteria in any areas considered in this study.

The current simulation did not include the effects of trees and other landscaping features. It is possible that including those will reduce the wind speeds sufficiently to achieve the desired comfort criteria. Alternatively, adequate wind mitigation can likely be provided by awnings and/or porous screens. Such mitigation measures can be considered in the future Detailed SSDAs.

6 References

AS/NZS 1170.2:2021, "Structural Design Actions", Part 2: Wind Actions.

AS/NZS 1170.2:1989, "Minimum design loads on structures" (known as the SAA Loading Code), Part 2: Wind Loads.

Australasian Wind Engineering Society, (2019), AWES-QAM-1-2019, "Quality Assurance Manual: Wind Engineering Studies of Buildings".

City of Parramatta Council, (2011), "Parramatta Development Control Plan", pp. 57.

City of Parramatta Council, (2023), "Parramatta Development Control Plan".

Grange, S, (2014), "Technical note: Averaging wind speeds and directions", 10.13140/RG.2.1.3349.2006.

Holmes, J, (2021), "The Wind Climate of The Melbourne Metropolitan Area - wind speed and directional probabilities at four stations", 10.13140/RG.2.2.16175.66725.

Lawson, T, (2001), "Building Aerodynamics", Imperial College Press, U.K. pp. 117-137.

Appendix A Comparison of Assessment Criteria

Detail is provided below on the three assessment criteria discussed in this addendum: the 2011 PDCP criteria, 2023 PDCP criteria and Lawson (2001) criteria.

A.1 2011 PDCP Criteria

The 2011 PDCP provides some limits for appropriate wind speeds in different areas, stating:

"To ensure public safety and comfort the following maximum wind criteria are to be met by new buildings:

10 m/s in retail streets

13 m/s along major pedestrian streets, parks and public places

16 m/s in all other streets."

However, the averaging duration and probability of occurrence for each threshold are not provided. I.e., results for the median hourly mean wind speeds or annual maximum gusts could be compared against these thresholds, providing drastically different results.

A.2 2023 PDCP Criteria

The 2023 PDCP Criteria provide comfort categories suited to various use cases and one acceptability threshold for safety, reproduced below.

C.01 To ensure comfort in and around new buildings, the wind speeds in Table 9.8.9.1 below must be exceeded for less than 5% of the time around new buildings for both hourly mean and gust equivalent mean wind speeds:

< 2 m/s	Outdoor restaurant dining
< 4 m/s	Sitting (such as café style dining), or scheduled outdoor events
< 6 m/s	Standing, generally supports outdoor planting
< 8 m/s	Walking in retail areas / active street frontages?
< 10 m/s	Walking / non-active street frontages (objective walking from A to B or for cycling)

Table 9.8.9.1 – Wind speeds

C.02 To ensure public safety, a 3 second moving average gust wind speed of 23 metres/second must be exceeded for less than 0.1% of time.

Figure 6-1: PDCP 2023 criteria for wind mitigation

A.3 Lawson (2001) Criteria for Wind Comfort and Safety

Comfort wind speeds are defined as the exceedance of threshold wind speeds occurring less than 5% of the time (i.e., 95th percentile wind speeds). The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category. Note that the Lawson Criteria are defined in terms of equivalent mean wind speeds, which account for the impact of turbulent/gusty conditions on comfort.

Table 6-1 Lawson comfort criteria

Comfort rating	Description	Wind speed	Appropriate usage	Description of wind effects
C1+ - Uncomfortable	Uncomfortable for all users	> 10 m/s	Uncomfortable for all users	Umbrellas difficult to use. Hair blown straight
C1 – Fast walking	Fast or business walking	8 – 10 m/s	Areas where people are not expected to linger	Force of wind felt on body
C2 - Strolling	Leisurely walking	6 – 8 m/s	General walking or sightseeing	Dust and papers raised. Hair disarranged
C3 - Standing	Short period sitting/standing	4 – 6 m/s	Bus stops, building entrances	Light leaves and twigs in motion. Lightweight flags extend
C4 - Sitting	Long period sitting/standing	0 – 4 m/s	Reading a newspaper, eating a drinking	Light wind felt on face. Leaves rustle

Appendix B Statistical Analysis of Meteorological Data

B.1 Scaling Methods

Modelling of local wind effects requires accurate representation of the surrounding terrain and built environment. The influence of terrain and built environment over the development length is incorporated into AS/NZS 1170.2:2021 as different terrain categories. Based on the terrain category, a suitable model of the atmospheric boundary layer (change in velocity and turbulence intensity with height) is given, which accounts for nearby structures and terrain (roughness). This model uses a logarithmic law to describe the mean wind speed profile in terms of roughness length.

Wind data from Bankstown was corrected to open terrain (category 2) using methods outlined in Holmes, 2021. To scale to the terrain roughness surrounding the site (category 3), scaling was applied using mean wind speed terrain/height multipliers from AS/NZS 1170.2:1989; i.e., multiplying by 0.44/0.6 = 0.733.

B.2 Weibull Analysis

To accurately account for the relative contributions of wind events from different directions, comfort exceedance probabilities were defined using a Weibull distribution. The probability of the wind speed at a certain location, U_i, exceeding a speed, V, for any given direction, θ, is given by:

$$p(U_i > V,\theta) = A(\theta\,)e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]}$$

Here $k(\theta)$ and $C(\theta)$ are Weibull coefficients for the azimuth sector, θ, and $A(\theta)$ is the marginal probability of the wind direction being within the azimuth sector. Therefore, the sum of all the marginal probabilities will be equal to one and the following will hold true:

$$\sum_{all\ sectors} A(\theta) = 1$$

Consequently, the exceedance probability is given by:

$$p(U_i > V) = \sum_{all\ sectors} A(\theta)e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]}$$

The coefficients obtained from the Bankstown Airport BoM data for hours between 6am and 9pm are shown below in Table B-2.

Table B-2: Weibull coefficients for all 16 assessment directions

Direction	A	C	k
N	0.039	2.84	2.07
NNE	0.026	2.43	2.62
NE	0.050	3.36	2.70
ENE	0.066	4.29	3.35
E	0.040	3.84	2.88
ESE	0.069	4.70	2.91
SE	0.075	5.26	2.75
SSE	0.066	5.26	2.47
S	0.049	4.31	2.09
SSW	0.035	3.07	1.82
SW	0.053	2.99	2.05
WSW	0.067	3.56	1.85
W	0.055	3.60	1.72
WNW	0.072	3.19	1.59
NW	0.070	2.67	1.79
NNW	0.060	2.75	1.90

Appendix C Detailed CFD Methodology

C.1 Numerical Methods

The analysis uses a Computational Fluid Dynamics (CFD) model which predicts fluid flows by mathematically modelling the Reynolds Averaged Navier-Stokes equations; fundamental equations which describe fluid motion. OpenFOAM software was used; its reliability well validated by academic researchers and independent organisations.

CFD simplifies estimates of turbulence, models average flow conditions well and random flow conditions with less accuracy. The turbulence closure scheme used for the modelling in this report was the realisable k-ε model. This model has been extensively validated for urban flows and has been shown to have superior performance for highly separated flows when compared with the standard k-ε model.

C.2 Computational Domain and Meshing

A cylindrical computational domain was used for the analysis. The domain size was selected to allow at least 10h from the extents of significant geometry to the, where h is the height of the tallest building, following COST recommendations. An outflow length of 7h was used and mesh refinements were made down to a minimum 0.16 m edge length.

C.3 Approach Flow and Boundary Conditions

Accurate CFD simulations require appropriate modelling of conditions at the model boundaries. Of particular importance are the inlet velocity and turbulence conditions, which were modelled using the AS/NZS 1170.2:1989 boundary layer profiles for mean velocity and turbulent kinetic energy. The ground plane roughness was modelled to ensure the boundary layer profile remained constant (neutrally stable) throughout the approach and far-field.

Additional boundary definitions were:

- the top boundary having a shear stress and vertical gradient in epsilon following the recommendations of Richards and Hoxey,
- outflow boundary with zero gradient in pressure,
- side boundaries based on a mixed inlet/outlet condition,
- bottom (ground) boundary as a no-slip wall with wall roughness function applied, and
- building surfaces as no-slip walls.

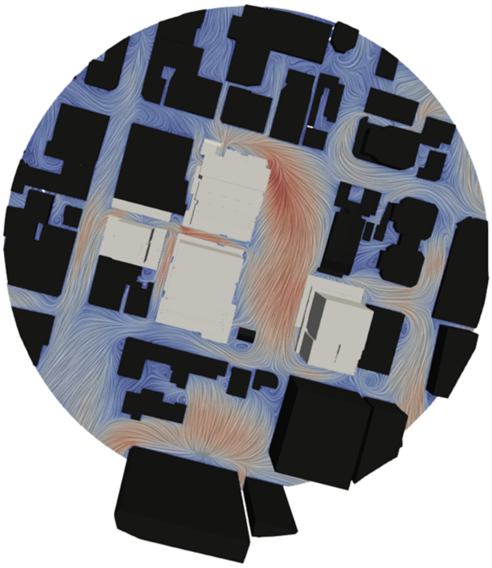
Wall functions were used to model the viscous sublayer flows near no-slip walls to accurately model wall friction effects. Changes in wind speed with direction were accounted for in postprocessing calculations using Weibull distribution parameters.

$$p(U_i > V, \theta) = A(\theta)\, e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]} \quad \sum_{all\ sectors} A(\theta) = 1 \quad p(U_i > V) = \sum_{all\ sectors} A(\theta)\, e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]}$$

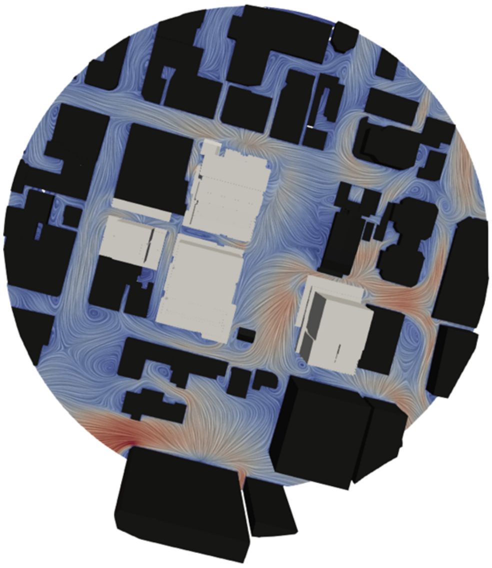
Appendix D Unscaled Gust-equivalent Mean Wind Speeds from Individual Wind Directions

Wind speeds presented in the following images are unscaled gust-equivalent mean wind speeds, relative to a reference mean wind speed of 10 m/s at 10 m height. No scaling has been applied to account for the relative strength and frequency of winds from the different directions.

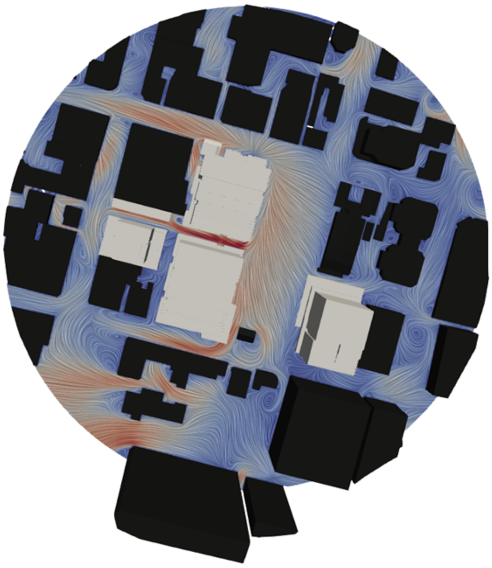
N



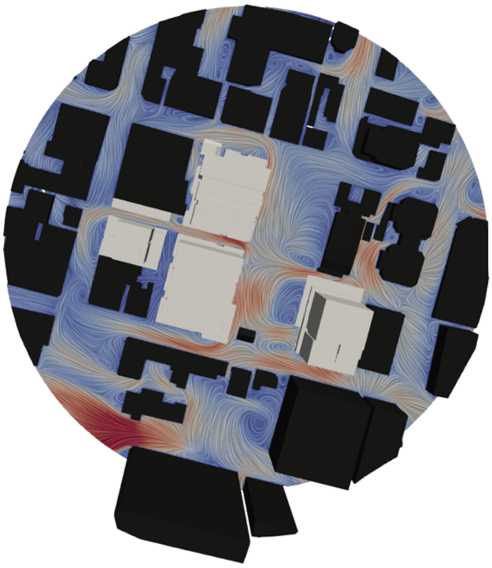
NNE



NE



ENE



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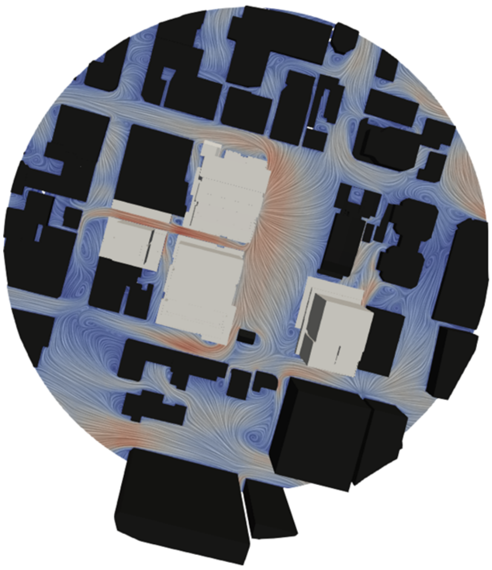
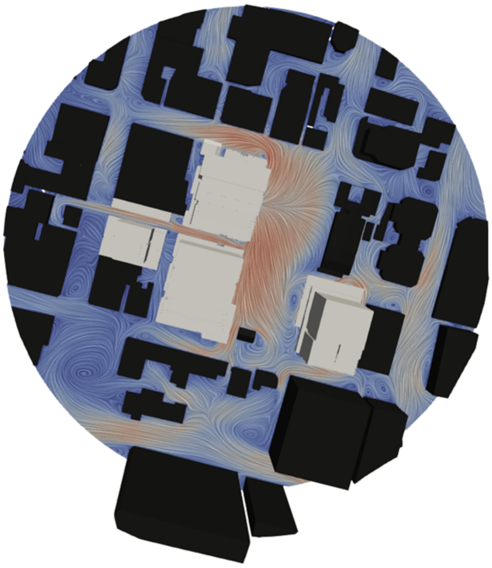
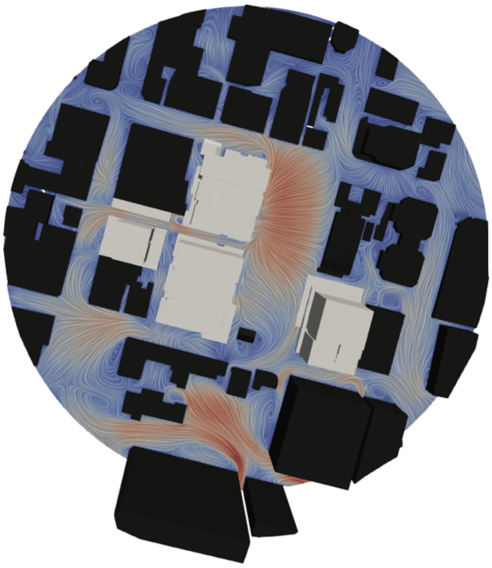


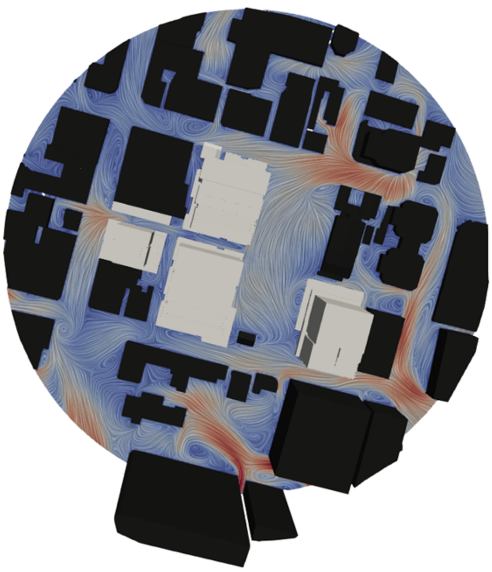
ESE



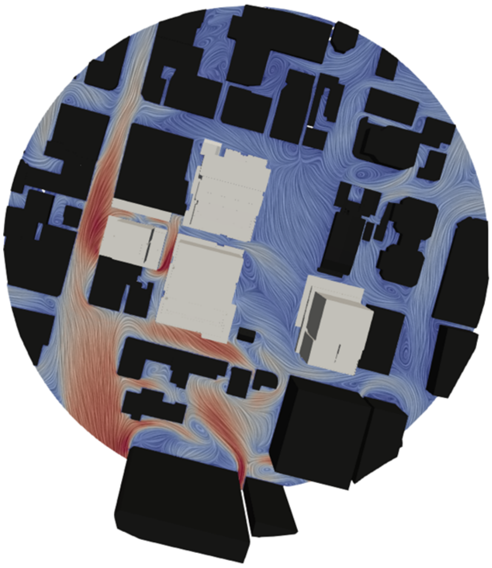
SE



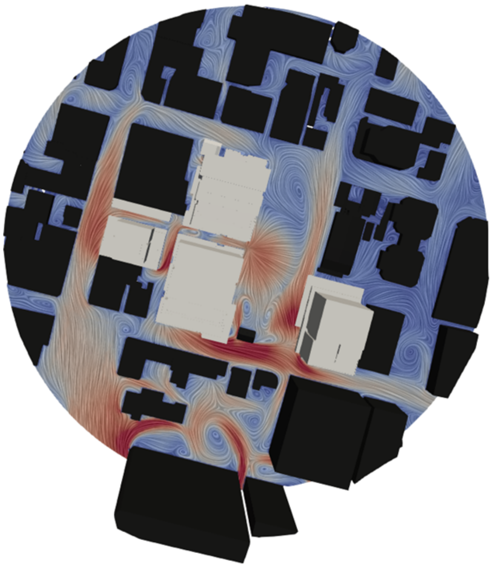
SSE



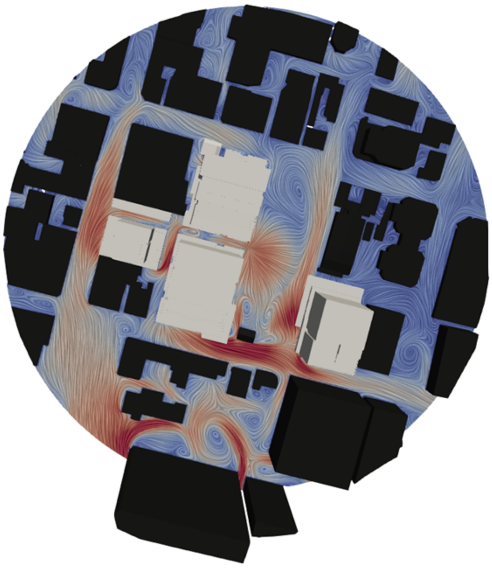
S



SSW



SW



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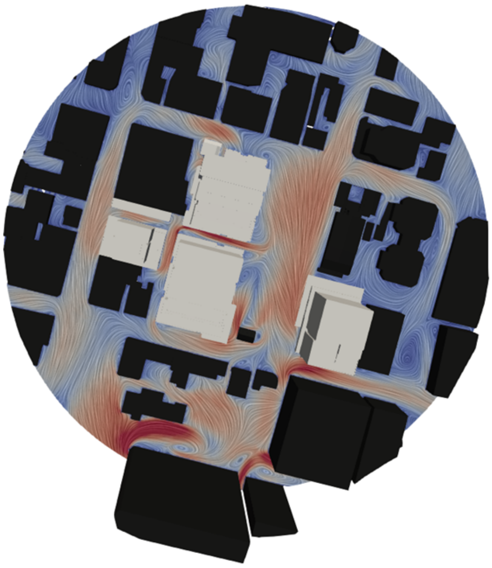

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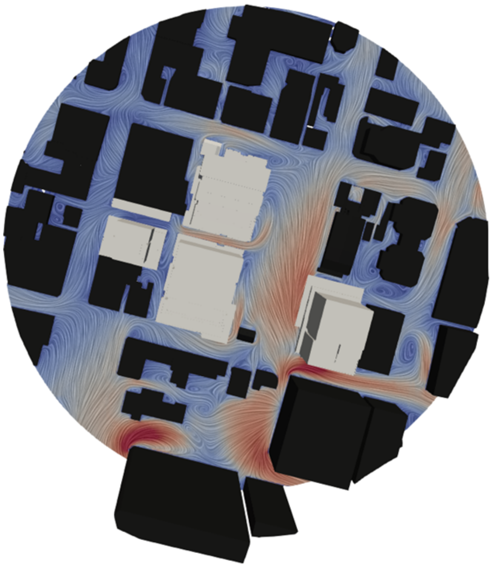

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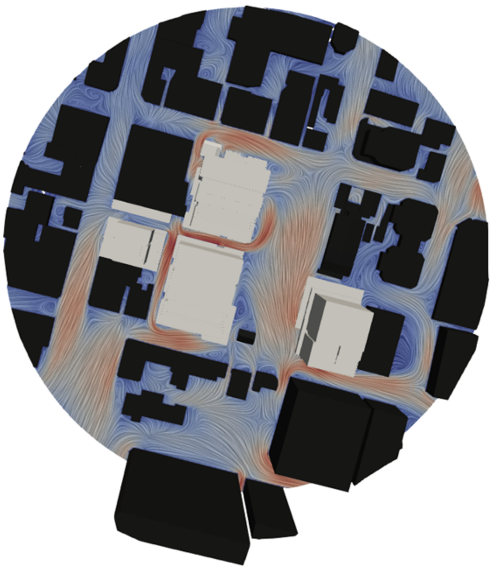
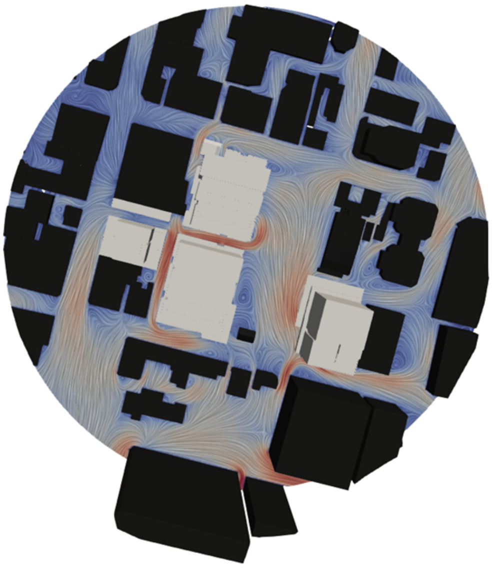


NW



NNW