53 SAINT PAULS TERRACE, SUITE 16
GROUND FLOOR
SPRING HILL, QLD 4000
AUSTRALIA
M: +61-(0)481-263-324
E: cochran@melconsultants.com

15 July 2022

Central Precinct Renewal
Wind Analysis Executive Summary
(MEL#64/20)

In October 2020 the Department of Planning issued Study Requirements for the proposed Central Precinct State Significant Precinct (SSP). Transport for NSW (TfNSW) is seeking to renew the precinct as it is an exceptional opportunity to deliver development with far reaching urban renewal outcomes that benefit Sydney and NSW. Renewal will allow Central Station to reach its full potential, address existing connectivity issues, make Central a new destination, support Sydney's economic competitiveness and revitalize significant heritage assets.

The Study Requirements outlined for Central Precinct are intended to guide Transport for NSW's investigations into new planning controls for the Central SSP Study Area. A key part of these Study Requirements is the need to undertake a detailed wind analysis of land within the Precinct and in affected adjacent areas including surrounding streets, Railway Square, Prince Alfred Park and Belmore Park, particularly the future City's Third Square – the area including the current railway Square, Lee Street and the Western Forecourt. The wind study must be supported by wind modelling which may include computer modelling and/or wind tunnel testing with physical models. The criteria used for assessing the ambient wind conditions are based on directionally averaged approach for comfort conditions, described by Lawson (1990), and adopted by the Central Sydney Planning Strategy.

MEL Consultants have been engaged by Transport for NSW to assist with addressing the wind study requirements. In doing so we have undertaken detailed analysis of the anticipated wind conditions in and around Central Precinct, which itself is a large southward expansion of the Sydney CBD. Specifically, wind impacts and performance of the proposed future renewal of Central Precinct have been investigated by using two different, but symbiotic, fluid mechanics technologies, these being:

(i) Computational Wind Engineering (or CWE, an atmospheric-based subset of the broader field on Computational Fluid Dynamics, CFD) and,

(ii) physical modelling with a scaled representation of the site in a large boundary-layer wind tunnel.

For assessing the environmental pedestrian-wind conditions the former is a new approach gaining confidence in the wind-engineering community and the latter is a well-established approach used with success since the 1970s.

The CWE approach is computationally intensive as it solves the turbulent Navier-Stokes equations of fluid motion and the continuity equation over the domain of interest. As the modelling of mechanical turbulence has improved in recent years the determination of the resulting flow field within a complex cityscape has also improved using CWE; with the results moving closer to reality. The CWE output of principle interest has been mean velocity contours at 1.5 m above the surface (nominal chest height) where people walk. This presentation of the data is more intuitive to most end users and, in fact, much more information is presented than the discrete locations of the wind-tunnel studies.

The physical model in the wind tunnel (at a scale of 1:400) in these Central Station studies used a well-established research device called a hot-wire anemometer (generally attributed to Schubauer and Klebanoff, 1946) to measure gust wind speeds at about 130 discrete locations on and around the project.

There are a number of reasons and benefits to using two different fluid mechanics technologies, these being:

- Use of the CWE approach enabled MEL Consultants to test and retest wind performance of the Indicative Masterplan for the Central Precinct. The ability to quickly analyse and report wind performance results back to Transport for NSW and the design team has been vital to informing an iterative design process for the Precinct. This allowed the design team to test and retest massing scenarios for the Central Precinct to understand the wind implications of the site layout and built form, and adjust accordingly to maximise the Precinct's wind performance.
- The CWE test is able to present wind information in a clearly discernible and easy to understand form, using colour coded maps to show wind performance across the precinct and its surroundings. It is also very effective at illustrating wind trajectories and highlighting the reasons why certain wind conditions are occurring. This enabled MEL Consultants to quickly understand the cause and effect of wind conditions so that we could provide high quality advice to the Central Precinct team in a timely manner to assist with the design evolution process.
- Once the Indicative Masterplan was refined using the CWE approach, MEL Consultants has then used a physical model in the wind tunnel to confirm and better understand the performance of the proposed design for the Precinct. This step provided us with more wind data that has enabled us to verify the performance of the Indicative Masterplan, but importantly also enabled us to identify which areas within the Precinct that still require continued investigations and potentially the use of localised wind mitigation measures.
- The wind-tunnel results have a better ability to confidently obtain peak gust data which has enabled the design team to get a more comprehensive understanding of likely future wind performance and conditions within the Precinct.

Following this two-step process, we have been pleased to see a high level of general agreement between the CWE results and the wind-tunnel modelling results. This agreement has given us good confidence in exploring "what if" scenarios using CWE regarding OSD building shapes and orientations as the general massing design evolved. For example, the northmost tall tower, labelled A1, was originally a bluff rectangular shape. By refining its shape to a rounded triangle and adjusting slightly its east-west position the flows down the Avenue were greatly diminished for the important northeast winds (conceptually the new A1 tower acted like the bow of a ship for key northeast winds). The existing configuration (i.e., no OSD or towers, but with the Western Gateway buildings) was explored using CWE since the verification with the wind-tunnel data (noted above) was in good agreement. Lastly, this existing configuration was studied with a physical model in the wind tunnel and the results presented in the wind-tunnel report along with data for the proposed Precinct massing ("64-20-WT-ENV-03", dated 14 July 2022, attached herein). The results suggest good agreement with CWE effort and show that public areas around the site are generally comparable (in some cases slightly improved) with the development present. Some windy areas around the Western Gateway buildings are present in both configurations; albeit moved in location.

The symbiotic nature and benefits of the two broad approaches described above is also best illustrated in the sequence of events used in this large Central Station study. The initial study in late 2020 (report "64-20-WT-ENV-00") showed that a generic, tall, massing model created wind conditions that were not desirable in many locations. In order to explore methods of refining the general massing of the many buildings on the OSD and elsewhere to improve these likely conditions, the CWE approach proved to be much more efficient whilst still providing a high degree of accuracy in understanding mean flows and the resulting wind performance conditions.

The alternative approach of building multiple wind-tunnel models and exploring the results via hot-wire anemometry and flow-visualization techniques (a methodology that would have been required in the quite recent past) was not used. Such an approach would not be effective at supporting an iterative design development process due to the extensive time to update physical models, test, update models again, and so on. The extensive and iterative CWE approach is described in a report "64-20-CFD-ENV-03", dated 12 July 2022, (attached herein) and it outlines the full history of the building shape changes and location adjustments used to guide the multiple building massing. This document shows the extensive iterative testing that the CWE testing enabled and that some ideas explored made conditions worse and were "dead ends", but the ultimate sequence was beneficial to the design process.

Once the CWE had shown a preferred design path, these choices were confirmed in a second wind-tunnel study (report "64-20-WT-ENV-03", dated 14 July 2022, attached herein). That work has shown that some locations within the proposed new Precinct that may result in potentially unsafe wind conditions in their current configuration without any localised mitigation. Specifically:

- The area at the top of the escalators and stairs at the intersection with the elevated Avenue (Section 4.18 of wind-tunnel report), and
- The raised pedestrian bridges connecting the OSD to the east (Section 4.22 of the wind-tunnel report).

Both these locations have subsequently had mitigation ideas explored using CWE to show that local ameliorative measures in problem areas can be used to improve these conditions, and in doing so deliver acceptable future wind environments.

In the case of the pedestrian bridges the standard porous (say, 50 to 60% solid) tall safety balustrading has been identified as being an effective solution. While in the central part of the north-south Central Avenue, strategic placement of some architecturally acceptable porous screens and avenue-side gazebos were shown to be effective at delivering improved wind environments.

Future wind-tunnel work will be used to confirm the efficacy of these localised amelioration measures. That said, the results of this computational mitigation effort are outlined in the attached CWE report (Addendum A to "64-20-CFD-ENV-03"), with the data from this further analysis, demonstrates that localized solutions will assist with delivering improved wind conditions around each building, depending on proximate intended pedestrian use, as its own individual design evolves during each DA process.

In the same Addendum A of the CWE study, further investigation has also been caried out to explore the influence of trees on the northern plaza (i.e., Central Green), noting the intention that this space is planned to be characterised by such vegetation. In undertaking this analysis consideration was also given to the types of trees being proposed for the area (e.g., species, height, density etc.). The CWE testing shows that the trees had the effect of improving the ambient conditions in many locations consistent with the "walking" criterion and the "stationary criteria" (standing and sitting in various locales, depending on wind direction).

The end result of these symbiotic wind-engineering studies is that the current architectural proposal can be made devoid of unsafe wind conditions on the highly-trafficked OSD pedestrian corridors. Similarly, the wind conditions locally around individual buildings can also be improved for specific purposes (say, standing conditions for waiting/entry areas or sitting conditions for cafes) when individual building designs and DAs are being assessed. The consequence of this long iterative process is that the conditions at the base of these new tall buildings is much improved from the original conceptual design and is, in fact, better than the aerodynamically unplanned and unstudied CBDs that constitute most cities.

In reviewing all the wind results contained in the attached wind reports, it is important that consideration is also given to the context of the Central Precinct, as it is a significant factor in shaping the wind conditions and wind performance of the proposed Central Precinct. For example, the relatively elongated north-south tall-building character of the Sydney CBD has long been known to foster a windy pedestrian environment (e.g., Sydney City Council study in the 1980s resulting in a paper by Cochran and Howell entitled "Wind Tunnel Studies for the Aerodynamic Shape for Sydney, Australia", JWE&IA, October 1990) and in many ways the proposed renewal of Central Precinct represents a continuation of that tall-building environment to the south.

The Central Precinct is located on the southern edge of the CBD, and its redevelopment will form a new perimeter to the CBD. In this regard it is naturally more exposed than, say, a new building situated within the core of CBD area surrounded by other existing tall buildings.

In addition to the Precincts inherent spatial proximity on the edge to the established CBD, the creation of a cluster of new tall buildings on an elevated platform (OSD at about RL30) has the potential to both draw winds down from above and accelerate horizontal winds up over the "hill" created by the new built form of the OSD.

Lastly, the straight sight lines desired along the main pedestrian thoroughfares (i.e., Central Avenue and the Devonshire Link), some aligned with dominant wind azimuths, can serve to encourage accelerated horizontal flows. With these constraints in mind the Transport for NSW and their design team have embarked on a highly iterative process, using the two wind-engineering tools noted above, to achieve a remarkably usable result for the important pedestrian spaces in and around the project.

Leighton C

Leighton Cochran, PhD CPEng FIEAust NER RPEQ MASCE
MEL Consultants Pty Ltd

Transport for NSW

Central Precinct Renewal

Environmental Wind Speed Measurements on a Wind Tunnel Model of the Central Precinct Renewal Masterplan, Sydney

July 2022

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The wind-engineering effort for the Central Precinct Renewal has focused, since late 2020, on the likely environmental pedestrian-wind comfort and safety conditions expected in and around this substantial expansion of the Sydney CBD southward. Numerous meetings were held with the design team, led by the architects and Transport NSW, during much of 2021 and early 2022. The massing of the multiple OSD buildings, and others off the station, was guided by many design parameters. However, by merging the dual skill sets of physical modeling in the wind tunnel and sensible use of Computational Wind Engineering (CWE) an optimized aerodynamic approach to the shapes, gaps and orientations of the OSD buildings was achieved. This symbiotic approach was discussed with two review groups (Project Working Group and Design Review Panel) via Microsoft Teams meetings in late 2021 and early 2022. Specifically:

- PWG on 02 March 2022, 09 March 2022 and 06 April 2022.
- DRP on 03 September 2021 and 28 October 2021.

This document presents the boundary-layer wind-tunnel results of the aerodynamically optimized design of the project; as it evolved from an initial wind-tunnel study in late 2020 combined with the subsequent CWE efforts.

ENVIRONMENTAL WIND SPEED MEASUREMENTS ON A WIND TUNNEL MODEL OF THE CENTRAL PRECINCT RENEWAL MASTERPLAN, SYDNEY

By
Y. Padayatchy
E. Chong
L. S. Cochran

SUMMARY

Wind-tunnel tests have been conducted on a 1/400 scale model of a revised massing (April 2022) of the Central Precinct Renewal Masterplan, Sydney. The revisions from the previous masterplan study (late 2020) evolved from a series of iterative Computational Wind Engineering studies during late 2021 and early 2022. The resulting physical model, examined herein, encompassed the proposed Western Gateway developments (Dexus Fraser, Atlassian and Toga projects) and the revised massing layout of the likely tall building developments over the Station (generally referred to as the Over the Station Development (OSD)) along with some peripheral buildings to the east and south. The model of the Development within surrounding buildings was tested in a simulated upstream boundary layer of the natural wind to determine likely environmental wind conditions. These wind conditions have been primarily (i.e., focus of Chapter 4 herein) related to the locally mandated Central Sydney Planning Strategy – Implementation guidelines and assessed with respect to the Safety Standard as well as the Walking, Standing and Sitting Comfort Standards (derived from Lawson, 1990). Additionally, criteria based on gust wind speeds which are commonly used in other domestic and international jurisdictions are presented in Appendix A and discussed where appropriate in Section 4 of this report to expand the directional understanding of the likely wind conditions.

An assessment based on the comfort criteria outlined in the Central Sydney Planning Strategy has shown some general trends presented herein: (i) the wind conditions are better at the south end of the OSD than at the north end, (ii) the surrounding streets (except

west side of Lee Street from Dexus Fraser and northwest corner of Toga) and OSD areas (except east side of Atlassian on the avenue) generally satisfy Walking Comfort Standard or better, and (iii) nearby parks and public spaces satisfy the Walking Comfort Standard or better.

However, for Configuration April 2022 it has also been shown that wind conditions at several locations, especially on the west side of Buildings B, C and F (top of stairs/escalator at central avenue), centre of the east side bridges, locally on west side of Lee Street from the Dexus Fraser building and locally at the northwest corner of Toga building have not satisfied the Safety Standard, i.e., unsafe for pedestrians. It should be noted that no safety fences along the bridges were included in this study and if these are included (say, minimum 50% solidity and over 1.8 m high), wind conditions on the bridges would be expected to improve to be within the Safety Standard.

The central avenue safety observation, noted above, indicates that when the OSD buildings are going through concept design (as opposed to the current massing study) some specific ameliorative studies, including built form changes, may be required. In Section 4.18, for example, some specific ideas to be explored are suggested for the conditions at the top of the stairs/escalators. In the same manner, any local areas associated with an individual building (say, entry-level outdoor café) may benefit from local protection to achieve a “sitting” standard.

The wind conditions for the Existing Configuration, including the proposed Western Gateway developments, in the surrounding streetscapes and platform areas have been presented for comparison.

Report 64-20-WT-ENV-03
July 2022

CENTRAL PRECINCT RENEWAL MASTERPLAN, SYDNEY
ENVIRONMENTAL WIND TUNNEL MODELLING

MEL CONSULTANTS REPORT NO: **64-20-WT-ENV-03**

PREPARED FOR:
Transport NSW
Level 3, 18 Lee Street
Chippendale NSW 2008

Contact: Hugh Thornton
Ph: +61 (0)410 342 264

PREPARED BY:
MEL Consultants Pty Ltd
22 Cleeland Road
South Oakleigh VIC 3167

Contact: Yogen Padayatchy
Ph: +61 (0)3 8516 9680

PREPARED BY:

Y. Padayatchy
Senior Engineer
Date: 12 July 2022

REVIEWED BY:

L. S. Cochran
Director
Date: 13 July 2022

RELEASED BY:

M. Eaddy
Managing Director
Date: 14 July 2022

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0	06 November 2020	Initial issue
1	10 May 2022	Revised Massing (Apr 2022)
2	23 May 2022	Updated report without MEL logos
3	14 July 2022	Updated report with Existing Configuration

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CONTENTS

1. INTRODUCTION

The proposed development at Central Precinct Renewal Masterplan will consist of 15 new buildings ranging from ~30 m to ~150 m in height located near and on the Central Railway Station between Pitt and Elizabeth Streets in Sydney. The immediate surrounding terrain is dominated by low-rise to mid-rise buildings and in the far field the surrounding terrain includes the tall buildings of the Sydney Central Business District (CBD) to the north and suburban housing for the other directions, as shown in Figure 1.

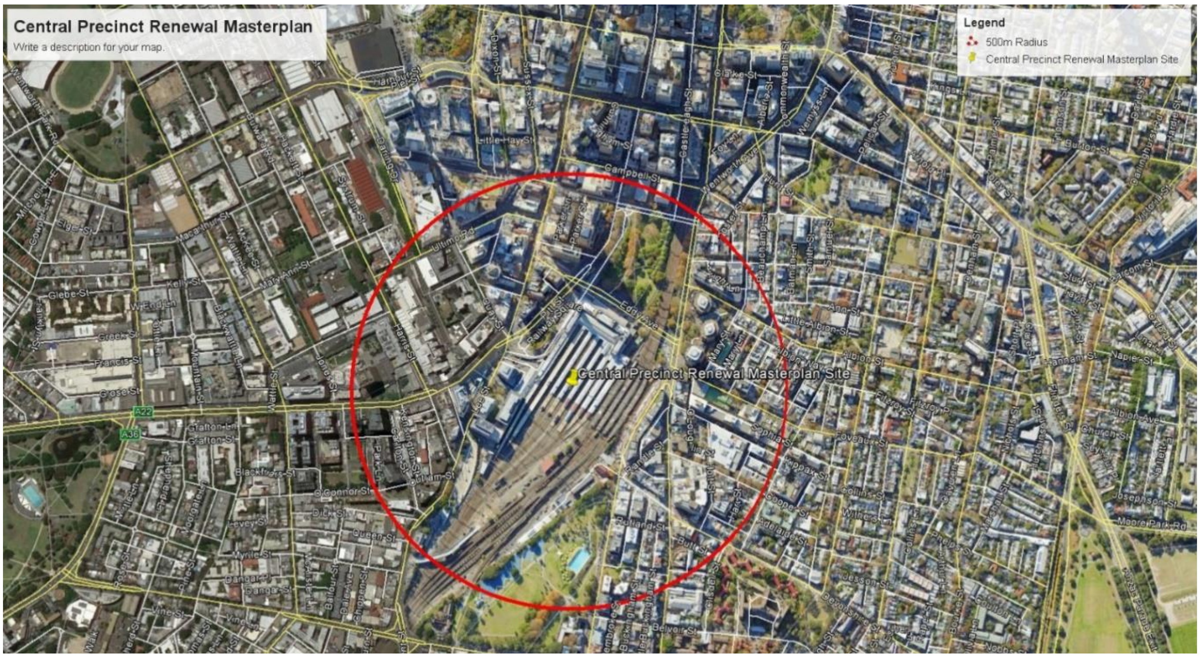

Figure 1. Central Station (yellow pin) with a red circle showing a 500 m radius centred around the development site (after Google Earth)

The extensive wind-tunnel model study was commissioned by Transport NSW to provide environmental wind conditions in and around the Development. These building envelopes are a massing estimate by Architectus of what may be expected to be built over the platform areas of Central Station given a multitude of design constraints, such as shading of the park to the south. This massing is the result of an extensive series of computation wind engineering (CWE) studies in late 2021 and early 2022. These subsequent wind-tunnel tests, discussed herein, were carried out in one of MEL Consultants' two 400 kW Boundary Layer Wind Tunnels during April 2022 and July 2022 (Existing case for comparative purposes). The data from those wind-tunnel tests were reduced and presented herein using the historic wind record at Sydney Airport from BoM; discussed further in Section 2.

2. ENVIRONMENTAL WIND CRITERIA

The advancement of wind-tunnel testing techniques, using large boundary layer flows to simulate the natural wind, has facilitated the prediction of wind speeds likely to be induced around a development. To assess whether the predicted wind conditions are likely to be acceptable or not, some forms of criteria are required. In the case of Sydney, a set of criteria are defined for that jurisdiction, with an associated statistical data-reduction rationale (mean velocity or Gust Equivalent Mean (GEM) velocity approaches), that have an academic history with a British researcher (Lawson, 1990) and have been adopted by some other cities (e.g., the Boston Redevelopment Authority, BRA, in Massachusetts). The resulting Central Sydney Planning Strategy – Implementation guidelines has defined wind comfort standards for the assessment of the wind conditions in Sydney City. The definitions of the standards are as follows:

Wind Safety Standard is an annual hourly maximum peak 0.5 second gust wind speed measured between 6am and 10pm Eastern Standard Time of 24 meters per second*.

**Equivalent to 23 meters per second for an annual maximum peak 3 second gust wind speed, which is the traditional Safety Criterion for the gust wind speed based criterion.*

Wind Comfort Standard is an hourly mean wind speed (defined below) for each wind direction, with probability of exceedance less than 5% per annum (averaged over all wind directions) measured between 6am and 10pm Eastern Standard Time (equivalent to 292 hours per annum), of equal to or less than:

- 4 metres/second for sitting areas
- 6 metres/second for standing areas
- 8 metres/second for walking areas

Mean wind speed means the maximum of:

- Hourly mean wind speed, or
- Gust equivalent mean wind speed (gust wind speed divided by 1.85)

It is noted that the above Safety Standard is assessed for each wind direction while the above Comfort Standards are pass/fail criteria as they only assess the summation of probabilities of exceedance across all wind directions to determine whether a location passes or fails the threshold criterion (see Tables in Section 4). There may be cases that a Test Location passes the all directions combined criterion (i.e., averaged over all azimuths) but fails the criterion when applied for a particular wind direction(s). This is an important distinction that may result in acceptance of wind conditions for comfort/usage that may not actually reflect a desirable locale for, say a long-term restaurant venue. Thus, for completeness, this report will provide data for each Test Location as a function of wind direction in Appendix A and some discussion of any conditions of interest in Section 4.

The Central Sydney Planning Strategy – Implementation guidelines uses the definition of mean wind speed based on the hourly wind speed so that the probabilities will be determined from the hourly wind data for an applicable automatic weather station representing the City of Sydney. The probability data used have been corrected for the approach terrain at the location of the automatic weather station (in this case at Sydney Airport) and referenced to 10 m in Terrain Category 2. This is the standard reference height of AS/NZS1170.2:2021.

2.1 Suggested Pedestrian Comfort Criteria.

The following wind criteria are suggested on and around the Development:

- Pedestrian transit areas	Walking Comfort Standard
- Building entrances	Standing Comfort Standard
- Outdoor seating areas	Sitting Comfort Standard
- Terraces	Walking Comfort Standard *

*Some terraces may be deemed elective use areas – areas where usage is at the discretion of the authorised users of the space. However, if these terrace areas are intended as outdoor corporate meeting areas, pools, BBQ venues or are associated with a commercial venture then the Walking Comfort Standard may not be appropriate and Standing or Sitting Comfort Standards may be required.

The activation of the public realm external to the site would depend on the existing wind conditions in the streetscapes that are often beyond the control of the proposed development. For cases where the existing wind conditions in the public realm external to the site are on the walking criterion, then the proposed development should not have any adverse wind effects in these areas.

3. MODEL AND EXPERIMENTAL TECHNIQUES

A 1/400 scale model of the proposed Central Precinct Renewal Masterplan (April 2022 Massing), Sydney was constructed from digital 3D model and communications provided by Architectus Sydney up to April 2022. For the OSD portion of the digital and physical model the intent is to represent the generic and constrained building envelopes (latter guided by wind-engineering knowledge gained during 2021 and 2022 CFD/CWE studies) that, when each building is individually designed, would contain a more detailed and, perhaps, smaller building within this architectural envelope that responds to the findings of this report.

The scale model of the development and surrounding buildings (including the three proposed buildings of the Western Gateway Development – Dexus Fraser, Atlassian and Toga Project) was tested in a model of the natural wind generated by flow over roughness elements augmented by vorticity generators at the beginning of the wind-tunnel working section. The surrounding buildings include all built and under construction buildings in the immediate vicinity. The basic natural wind model was for flow over suburban terrain, the characteristics of which are given in Figure 2. The surrounding wind-tunnel model of all significant buildings, out to a minimum radius of 300 m (AWES-QAM-1-2019 requirement), modified the approach wind model for the presence of the surrounding buildings. Photos of the wind tunnel model for the Proposed and Existing Configurations are shown in Figures 3 and 4, respectively.

The technique used to investigate the environmental wind conditions entailed the use of hot-wire anemometry. The method of determining the local criteria is given in detail in the Central Sydney Planning Strategy – Implementation guidelines, Section 2 above, and Reference 3. Additionally, further data reduction and site commentary were performed based on gust wind speeds (directional assessment) described in Reference 2 and shown in Appendix A. Thus, the one set of hot-wire data were reduced in two ways to gain a fuller understanding of the likely conditions on and around the Central Station Precinct. In this study measurements in the Development areas may well be inside separated regions and peak velocity squared ratios were helpful to make conclusions about likely gust wind conditions (beyond the CSPS criteria) that may form part of the commentary in Section 4, as noted above. In summary, measurements were made of the peak gust wind velocity with a hot-wire anemometer at various locations and expressed as a squared ratio with the mean wind velocity at a scaled reference height of 300 m. This gives the peak velocity squared ratio

$$\left(\hat{V}_{local} / \overline{V}_{300m}\right)^2$$

as shown in Figure A1.

Wind-tunnel velocity measurements were made for an equivalent 1-hour period in full scale and filtered to provide an equivalent full-scale, 3-second gust wind speed. Photographs of the models as tested in the wind tunnel are shown in Figures 3 and 4. The Test Locations in and around the Development are shown in Figure 5.

4. DISCUSSION OF RESULTS

Velocity measurements were made at many locations around the Central Precinct Renewal Masterplan (April 2022 Massing), Sydney for different wind directions at 22.5° intervals. The model was constructed from digital 3D models and communications provided by Architectus Sydney up to April 2022 and will be referred as ***Configuration April 2022*** in this report. For the purpose of discussion, the buildings within the Development have been referred as Buildings A – O as shown in Figure 5. The ***Existing Configuration*** is defined as the Central Station that currently exists on the site with the inclusion of confirmed pending development (Western Gateway Development – Dexus Fraser, Atlassian and Toga Project), adjacent and west of the proposed site.

As discussed in Section 2, the Central Sydney Planning Strategy – Implementation guidelines wind comfort standards are pass/fail criteria based on an assessment of the summation of probabilities for all wind directions combined. Therefore, to assess the wind conditions the exceedances will be presented in tabular form in Tables 1 to 33. For completeness the data are also reduced in a directional format (as opposed to the CSPS methodology, discussed above) and presented in Appendix A to compare with the pedestrian criteria based on gust wind speeds.

The following sections detail the results for the various pedestrian areas tested.

4.1 Summary of Results

To assist with the assessment of the Existing Configuration and Configuration April 2022 wind conditions, summaries of the wind criteria achieved for all wind directions at each Test Location in the surrounding streetscapes, on the OSD, covered and open platforms and nearby parks have been provided using a colour code system presented in Figures 6a and 6b, respectively.

Different colours have been used to represent the wind comfort standard achieved (legend on Figures 6a and 6b) at each test location. Note again that the Central Sydney Planning Strategy Implementation guidelines use an omnidirectional presentation for comfort conditions (green, yellow, blue) and directional results for the safety criterion (red).

4.2 Building A (Figure A2)

For Configuration April 2022, Table 1 indicates that the wind conditions around Building A (Test Locations 1, 2 and 3) have been shown to satisfy the Walking Comfort Standard, with Test Locations 2 and 3 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 1, 2 and 3 have been shown to all pass the Safety Standard.

Table 1: Pedestrian Wind Comfort and Safety – Building A

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
1	Configuration April 2022	20.6%	7.2%	2.3%	Pass	7.41
2	Configuration April 2022	16.3%	4.5%	1.0%	Pass	6.91
3	Configuration April 2022	14.6%	3.9%	0.9%	Pass	6.59
All Building A	Configuration April 2022				**average**	**6.97**

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A2 in Appendix A. Inspection of these directional data in Appendix A show the same pass/fail Safety Standard in Table 1, as one would expect. However, in each of the three wind roses multiple cases where the Walking Comfort Criterion is directionally exceeded have been shown; the azimuth-averaged data in Table 1 all satisfy the walking criterion even if for some specific directions this does not hold true. Thus, one should note that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 1.

4.3 Building B (Figure A3)

For Configuration April 2022, Table 2 indicates that the wind conditions around Building B (Test Locations 8 and 9) have been shown to satisfy the Walking Comfort Standard, with Test Location 9 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Location 8 been shown to fail the Safety Standard and pass the Safety Standard at Test Location 9.

Table 2: Pedestrian Wind Comfort and Safety – Building B

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
8	Configuration April 2022	20.1%	7.4%	2.6%	Fail	7.89
9	Configuration April 2022	6.6%	1.2%	0.1%	Pass	4.81
All Building B	Configuration April 2022				average	6.35

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A3 in Appendix A. Again, the directional data in these plots concurs with the Safety Standard results in Table 2, as essentially the same methodology has been applied. However, the success of the Walking Comfort Standard in Table 2 for Test Location 8 is not reflected in Figure A3, as there are many wind directions that exceed the gust wind speeds based Walking Comfort Criterion. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 2 and, in fact, this is a trend of the two data reduction techniques (i.e., directional comfort criteria typically exceed the average values in the tables and the comfort criteria may be satisfied in an omnidirectional sense while still failing the safety criterion). The following discussion will typically not continue to emphasize this interesting observation, except to point out when some specific design attribute may be influenced by such commentary.

4.4 Building C (Figure A4)

For Configuration April 2022, Table 3 indicates that the wind conditions around Building C (Test Locations 11 and 12) have been shown to satisfy the Walking Comfort Standard, with Test Location 12 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 11 and 12 have been shown to pass the Safety Standard.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A4 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 3.

Table 3: Pedestrian Wind Comfort and Safety – Building C

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
11	Configuration April 2022	20.1%	7.3%	2.4%	Pass	7.68
12	Configuration April 2022	13.7%	4.2%	1.2%	Pass	6.34
All Building C	Configuration April 2022				average	7.01

4.5 Building D (Figure A5)

For Configuration April 2022, Table 4 indicates that the wind conditions around Building D (Test Locations 4, 5, 6 and 112) have been shown to satisfy the Walking Comfort Standard, with Test Location 6 and 112 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 4, 5, 6 and 112 have been shown to pass the Safety Standard.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A5 in Appendix A. As expected, the Safety Standard in Figure A5 and Table 4 are satisfied, as discussed before. However, the Standing Comfort Criterion (i.e., short term stationary activities criterion) at Test location 6 in Figure A7 is exceeded for many azimuths which disagrees with the omnidirectional Standing Standard in Table 4. That said, one could expect that any outdoor cafes or other long-term commerce between Buildings D and E may suffer due to the impact of wind. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 4. This is a consistent theme that should guide the design team.

Table 4: Pedestrian Wind Comfort and Safety – Building D

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
4	Configuration April 2022	23.0%	8.1%	2.8%	Pass	8.04
5	Configuration April 2022	14.5%	5.1%	1.6%	Pass	6.60
6	Configuration April 2022	9.1%	2.8%	0.8%	Pass	5.55
112	Configuration April 2022	7.0%	1.6%	0.2%	Pass	4.89
All Building D	Configuration April 2022				average	6.27

4.6 Building E (Figure A6)

For Configuration April 2022, the wind conditions around Building E (Test Locations 10 and 13) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at Test Locations 10 and 13 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 5.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A6 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 5.

Table 5: Pedestrian Wind Comfort and Safety – Building E

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
10	Configuration April 2022	13.1%	3.7%	0.8%	Pass	5.57
13	Configuration April 2022	13.5%	3.6%	0.8%	Pass	5.80
All Building E	Configuration April 2022				average	5.68

4.7 Building F (Figure A7)

For Configuration April 2022, the wind conditions around Building F (Test Locations 15, 16, 19 and 20) have been shown to satisfy the Walking Comfort Standard, with Test Locations 15, 16 and 20 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 15, 16 and 20 have been shown to pass the Safety Standard and fail the Safety Standard at Test location 19. This safety condition is discussed in detail in the Central Plaza results of Section 4.18, as Locations 19, 55 and 96 are all influenced by the same accelerated westerly flows over the elevated stair/escalator corridor between the Atlassian and Dexus buildings. Some amelioration concepts are discussed in that part of the report.

The criteria achieved have been presented in Table 6.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A7 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 6.

Table 6: Pedestrian Wind Comfort and Safety – Building F

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
15	Configuration April 2022	16.5%	4.9%	1.2%	Pass	6.94
16	Configuration April 2022	10.7%	2.9%	0.7%	Pass	5.96
19	Configuration April 2022	13.0%	5.0%	1.8%	FAIL	6.40
20	Configuration April 2022	10.8%	3.1%	1.0%	Pass	5.95
All Building F	Configuration April 2022				average	6.31

4.8 Building G (Figures A8)

For Configuration April 2022, the wind conditions around Building G (Test Locations 21, 23 and 24) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at Test Locations 20, 23 and 24 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 7.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A8 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 7.

Table 7: Pedestrian Wind Comfort and Safety – Building G

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
21	Configuration April 2022	4.1%	0.6%	0.0%	Pass	4.36
23	Configuration April 2022	11.5%	2.4%	0.6%	Pass	5.74
24	Configuration April 2022	10.3%	1.8%	0.3%	Pass	5.64
All Building G	Configuration April 2022				average	5.25

4.9 Building H (Figures A9 & A10)

For Configuration April 2022, the wind conditions around Building H (Test Locations 17, 18, 22, 25 and 27) have been shown to satisfy the Walking Comfort Standard, with Test Locations 17, 22, 25 and 27 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 17, 18, 22, 25 and 27 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 8.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A9 and A10 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 8.

Table 8: Pedestrian Wind Comfort and Safety –Buildings H

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
17	Configuration April 2022	9.9%	2.4%	0.6%	Pass	5.88
18	Configuration April 2022	21.8%	7.4%	2.1%	Pass	7.58
22	Configuration April 2022	6.4%	1.1%	0.2%	Pass	4.55
25	Configuration April 2022	5.6%	0.8%	0.1%	Pass	4.70
27	Configuration April 2022	9.3%	1.9%	0.4%	Pass	5.07
All Building H	Configuration April 2022				average	5.56

4.10 Building I (Figure A11)

For Configuration April 2022, the wind conditions around Building I (Test Locations 28 and 29) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at Test Locations 28 and 29 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 9.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A11 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 9.

Table 9: Pedestrian Wind Comfort and Safety – Building I

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
28	Configuration April 2022	11.6%	2.6%	0.4%	Pass	5.82
29	Configuration April 2022	9.6%	2.8%	0.6%	Pass	5.71
All Building I	Configuration April 2022				average	5.77

4.11 Building J (Figure A12)

For Configuration April 2022, the wind conditions around Building J (Test Locations 30 and 31) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at Test Locations 30 and 31 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 10.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A12 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 10.

Table 10: Pedestrian Wind Comfort and Safety – Building J

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
30	Configuration April 2022	5.9%	1.5%	0.3%	Pass	4.52
31	Configuration April 2022	15.9%	4.3%	0.8%	Pass	6.19
All Building J	Configuration April 2022				average	5.35

4.12 Building K (Figure A13)

For Configuration April 2022, the wind conditions around Building K (Test Locations 32 – 34) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at Test Locations 32 – 34 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 11.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A13 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 11.

Table 11: Pedestrian Wind Comfort and Safety – Building K

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
32	Configuration April 2022	8.7%	1.9%	0.4%	Pass	5.46
33	Configuration April 2022	9.6%	2.7%	0.7%	Pass	5.48
34	Configuration April 2022	13.8%	3.1%	0.6%	Pass	6.24
All Building K	Configuration April 2022				average	5.73

4.13 Building L (Figure A14)

For Configuration April 2022, the wind conditions around Building L (Test Locations 35 – 37) have been shown to satisfy the Walking Comfort Standard, with Test Location 35 and 56 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 35 – 37 have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 12.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A14 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 12.

Table 12: Pedestrian Wind Comfort and Safety – Building L

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
35	Configuration April 2022	15.1%	4.6%	1.3%	Pass	6.56
36	Configuration April 2022	9.5%	2.5%	0.7%	Pass	5.66
37	Configuration April 2022	22.7%	9.6%	3.2%	Pass	7.65
All Building L	Configuration April 2022				average	6.62

4.14 Building M (Figures A15 & A16)

For Configuration April 2022, the wind conditions around Building M (Test Locations 38 – 42) have been shown to satisfy the Walking and Standing Comfort Standards, with Test Location 39 also satisfying the Sitting Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 38 – 42 have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 13a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A15 & A16 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 13a.

The wind conditions for the Existing Configuration at Test Locations 38 – 41 have been provided for comparison in Table 13b and Figure A15.

Table 13a: Pedestrian Wind Comfort and Safety – Building M

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
38	Configuration April 2022	9.1%	2.4%	0.6%	Pass	5.39
39	Configuration April 2022	0.3%	0.0%	0.0%	Pass	2.84
40	Configuration April 2022	8.6%	2.4%	0.7%	Pass	5.35
41	Configuration April 2022	5.9%	1.2%	0.2%	Pass	4.72
42	Configuration April 2022	7.3%	1.3%	0.2%	Pass	5.23
All Building M	Configuration April 2022				average	**4.71**

Table 13b: Pedestrian Wind Comfort and Safety for Existing Configuration – Building M

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
38	Existing Configuration	19.3%	6.0%	1.6%	Pass	7.15
39	Existing Configuration	3.6%	0.3%	0.0%	Pass	3.66
40	Existing Configuration	26.0%	10.1%	3.1%	Pass	8.49
41	Existing Configuration	18.1%	5.5%	1.3%	Pass	7.24
All Building M	Existing Configuration				**average**	**6.64**

4.15 Building N (Figure A17)

For Configuration April 2022, the wind conditions around Building N (Test Locations 43, 44 and 98) have been shown to satisfy the Walking Comfort Standard, with Test Location 43 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 43, 44 and 98 have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 14a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A17 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 14a.

The wind conditions for the Existing Configuration at Test Locations 43 and 44 have been provided for comparison in Table 14b and Figure A17.

Table 14a: Pedestrian Wind Comfort and Safety – Building N

Test Location	Configuration	Wind Comfort Standard			Safety	wind speed (m/s)
		Sitting	Standing	Walking		
43	Configuration April 2022	15.5%	4.7%	1.1%	Pass	6.55
44	Configuration April 2022	19.9%	6.6%	1.7%	Pass	7.45
98	Configuration April 2022	18.2%	6.3%	1.8%	Pass	7.20
All Building N	Configuration April 2022				average	7.07

Table 14b: Pedestrian Wind Comfort and Safety for Existing Configuration – Building N

Test Location	Configuration	Wind Comfort Standard			Safety	wind speed (m/s)
		Sitting	Standing	Walking		
43	Existing Configuration	19.0%	6.7%	1.9%	Pass	7.43
44	Existing Configuration	14.9%	3.5%	0.8%	Pass	6.44
All Building N	Existing Configuration				average	6.93

4.16 Building O (Figure A18)

For Configuration April 2022, the wind conditions around Building O (Test Locations 45, 46, 47 and 62) have been shown to satisfy the Walking Comfort Standard, with Test Locations 45, 46 and 62 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at Test Locations 45, 46, 47 and 62 have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 15a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A18 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 15a.

The wind conditions for the Existing Configuration at Test Locations 45 – 47 have been provided for comparison in Table 15b and Figure A18.

Table 15a: Pedestrian Wind Comfort and Safety – Building O

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
45	Configuration April 2022	13.1%	3.6%	1.0%	Pass	5.77
46	Configuration April 2022	11.2%	2.1%	0.3%	Pass	5.46
47	Configuration April 2022	19.6%	6.4%	1.8%	Pass	7.32
62	Configuration April 2022	5.4%	1.3%	0.2%	Pass	4.46
All Building O	Configuration April 2022				average	5.75

Table 15b: Pedestrian Wind Comfort and Safety for Existing Configuration – Building O

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
45	Existing Configuration	8.0%	1.5%	0.2%	Pass	5.40
46	Existing Configuration	15.3%	3.7%	0.6%	Pass	6.49
47	Existing Configuration	14.2%	3.3%	0.7%	Pass	6.16
All Building O	Existing Configuration				**average**	**6.02**

4.17 North Plaza (Figures A19 & A20)

For Configuration April 2022, the wind conditions within the North Plaza (Test Locations 48 – 52) have been shown to satisfy the Walking Comfort Standard, with Test Locations 48, 49 and 52 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved for Configuration April 2022 have been presented in Table 16a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A19 & A20 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 16a.

The wind conditions for the Existing Configuration at Test Locations 48 have been provided for comparison in Table 16b and Figure A19.

Table 16a: Pedestrian Wind Comfort and Safety – North Plaza

Test Location	Configuration	Wind Comfort Standard			Safety	wind speed (m/s)
		Sitting	Standing	Walking		
48	Configuration April 2022	5.6%	1.0%	0.1%	Pass	4.59
49	Configuration April 2022	15.4%	4.5%	1.1%	Pass	6.55
50	Configuration April 2022	21.3%	7.2%	2.2%	Pass	7.60
51	Configuration April 2022	25.6%	10.5%	3.5%	Pass	8.32
52	Configuration April 2022	12.4%	3.5%	0.9%	Pass	5.93
All Test Locations	Configuration April 2022				average	6.60

Table 16b: Pedestrian Wind Comfort and Safety for Existing Configuration – North Plaza

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
48	Existing Configuration	0.3%	0.0%	0.0%	Pass	2.72
All Test Locations	Existing Configuration				average	2.72

4.18 Centre Plaza (Figures A21 & A22)

For Configuration April 2022, the wind conditions within the Centre Plaza (Test Locations 53 – 57 and 96) have been shown to satisfy the Walking Comfort Standard, with Test Locations 56 and 57 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard with the exception of Test Locations 55 and 96 which have been shown to fail the Safety Standard.

The criteria achieved for Configuration April 2022 have been presented in Table 17.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A21 & A22 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 17.

Table 17: Pedestrian Wind Comfort and Safety – Centre Plaza

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
53	Configuration April 2022	20.0%	6.6%	1.7%	Pass	7.40
54	Configuration April 2022	18.2%	5.9%	1.7%	Pass	6.82
55	Configuration April 2022	27.7%	11.2%	3.9%	FAIL	8.76
56	Configuration April 2022	12.3%	3.9%	1.3%	Pass	6.04
57	Configuration April 2022	7.9%	2.6%	1.0%	Pass	5.22
96	Configuration April 2022	18.8%	6.4%	2.2%	FAIL	7.51
All Test Locations	Configuration April 2022				**average**	**6.96**

Flow visualization has indicated that winds from the western azimuths are accelerating through the gap between the Atlassian and Dexus buildings; augmented by the increase in elevation from ground level to OSD level (stairs, escalator and lift provide pedestrian assistance over the elevation change along this major public thoroughfare). The wind flow influencing Location 55 then splits north (Location 96) and south (Location 19, discussed earlier in Section 4.7) along the Avenue spine. Mitigating this safety condition at the top of the stairs/escalator may not be straightforward in an architecturally acceptable manner, but some exploration of solutions is required. For example, an elevated porous screen (artistic element, perhaps) over the public thoroughfare between the two Western Gateway towers at the OSD edge may mitigate the strength of the flow to eliminate the safety concern. Any such ameliorative device must absorb turbulent flow energy rather than redirect winds under the screen and, perhaps, make the local wind conditions worse or not improve the local environment. Ongoing iterative work is required with the architectural team either at this stage of the design process or when the design of the proximate OSD buildings is better established.

4.19 South Plaza (Figure A23)

For Configuration April 2022, the wind conditions within the South Plaza (Test Locations 58, 59 and 99) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard.

The criteria achieved have been presented in Table 18.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A23 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 18.

Table 18: Pedestrian Wind Comfort and Safety – South Plaza

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
58	Configuration April 2022	8.8%	2.1%	0.6%	Pass	4.95
59	Configuration April 2022	16.6%	4.8%	1.3%	Pass	6.80
99	Configuration April 2022	15.3%	4.3%	0.9%	Pass	6.58
All Test Locations	Configuration April 2022				average	6.11

4.20 Belmore Park (Figure A24)

For Configuration April 2022, the wind conditions in Belmore Park (Test Locations 78 and 111) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 19a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A24 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 19a.

The wind conditions for the Existing Configuration at Test Locations 78 and 111 have been provided for comparison in Table 19b and Figure A24.

Table 19a: Pedestrian Wind Comfort and Safety – Belmore Park

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
78	Configuration April 2022	16.6%	5.0%	1.2%	Pass	6.59
111	Configuration April 2022	12.9%	2.6%	0.4%	Pass	6.19
All Belmore Park	Configuration April 2022				average	6.39

Table 19b: Pedestrian Wind Comfort and Safety for Existing Configuration – Belmore Park

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
78	Existing Configuration	15.2%	4.8%	1.1%	Pass	6.46
111	Existing Configuration	12.1%	2.4%	0.4%	Pass	6.00
All Belmore Park	Existing Configuration				average	6.23

4.21 Central Station (Figure A25 & A26)

For Configuration April 2022, the wind conditions around Central Station (Test Locations 70 – 75) have been shown to satisfy the Walking and Standing Comfort Standards, with Test Location 70 also satisfying the Sitting Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 20a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A25 & A26 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 20a.

The wind conditions for the Existing Configuration at Test Locations 70 - 75 have been provided for comparison in Table 20b and Figures A25 and A26.

Table 20a: Pedestrian Wind Comfort and Safety – Central Station

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
70	Configuration April 2022	1.7%	0.1%	0.0%	Pass	3.50
71	Configuration April 2022	6.7%	1.4%	0.2%	Pass	5.01
72	Configuration April 2022	9.6%	2.1%	0.3%	Pass	5.16
73	Configuration April 2022	10.9%	3.4%	0.9%	Pass	5.80
74	Configuration April 2022	10.2%	2.0%	0.3%	Pass	5.62
75	Configuration April 2022	10.9%	2.9%	0.6%	Pass	5.38
All Test Locations	Configuration April 2022				**average**	**5.08**

Table 20b: Pedestrian Wind Comfort and Safety for Existing Configuration – Central Station

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
70	Existing Configuration	2.3%	0.2%	0.0%	Pass	3.75
71	Existing Configuration	7.4%	1.2%	0.1%	Pass	4.83
72	Existing Configuration	10.4%	2.6%	0.5%	Pass	5.08
73	Existing Configuration	5.7%	1.1%	0.1%	Pass	4.74
74	Existing Configuration	2.7%	0.4%	0.0%	Pass	3.63
75	Existing Configuration	8.3%	1.6%	0.2%	Pass	5.17
All Test Locations	Existing Configuration				average	**4.53**

4.22 Bridges (Figures A27 & A28)

For Configuration April 2022, the wind conditions on the bridges (Test Locations 60, 61, 63, 64 and 105) have been shown to satisfy the Walking Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard with 2 exceptions. The exceptions were at Test Locations 61 and 64 which have been shown to fail the Safety Standard. It should be noted that *no balustrades* along the bridges were included on the model in this study. Wind conditions on the bridges would be expected (based on both experience and the companion CWE study) to improve with the addition of porous safety fences (say, 50% solidity ratio and taller than 1.8 m) at a minimum.

The criteria achieved have been presented in Table 21.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A27 & A28 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 21.

Table 21: Pedestrian Wind Comfort and Safety – Bridges

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
60	Configuration April 2022	19.3%	6.4%	1.6%	Pass	7.36
61	Configuration April 2022	26.8%	12.4%	4.9%	FAIL	8.43
63	Configuration April 2022	20.8%	7.2%	2.4%	Pass	7.28
64	Configuration April 2022	26.6%	11.2%	4.4%	FAIL	8.52
105	Configuration April 2022	18.2%	5.3%	1.2%	Pass	7.11
All Test Locations	Configuration April 2022				average	7.74

4.23 Suburban Platforms (Figures A29 & A30)

For Configuration April 2022, the wind conditions at the Central Platforms (Test Locations 65 – 69) have been shown to satisfy the Walking and Standing Comfort Standards, with Test Locations 67 and 68 also satisfying the Sitting Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 22a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A29 & A30 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 22a.

The wind conditions for the Existing Configuration at Test Locations 65 – 69 have been provided for comparison in Table 22b and Figure A29 and A30.

Table 22a: Pedestrian Wind Comfort and Safety – Suburban Platforms

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
65	Configuration April 2022	8.2%	2.0%	0.4%	Pass	4.51
66	Configuration April 2022	5.2%	0.9%	0.1%	Pass	3.88
67	Configuration April 2022	3.3%	0.3%	0.0%	Pass	4.03
68	Configuration April 2022	2.3%	0.2%	0.0%	Pass	3.75
69	Configuration April 2022	8.9%	1.8%	0.2%	Pass	5.17
All Test Locations	Configuration April 2022				average	4.27

Table 22b: Pedestrian Wind Comfort and Safety for Existing Configuration – Suburban Platforms

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
65	Existing Configuration	6.0%	0.8%	0.1%	Pass	4.78
66	Existing Configuration	5.3%	0.9%	0.1%	Pass	4.51
67	Existing Configuration	7.0%	0.9%	0.1%	Pass	4.94
68	Existing Configuration	14.3%	3.3%	0.5%	Pass	6.25
69	Existing Configuration	7.9%	1.2%	0.1%	Pass	5.14
All Test Locations	Existing Configuration				average	5.12

4.24 Prince Albert Park (Figures A31 & A32)

For Configuration April 2022, the wind conditions within Prince Albert Park (Test Locations 82 – 84 and 106 – 108) have been shown to satisfy the Walking and Standing Comfort Standards with the exception of Test Location 82 which only satisfied the Walking Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 23a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A31 & A32 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 23a.

The wind conditions for the Existing Configuration at Test Locations 82 – 84 and 106 – 108 have been provided for comparison in Table 23b and Figure A31 and A32.

Table 23a: Pedestrian Wind Comfort and Safety – Prince Albert Park

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
82	Configuration April 2022	19.8%	6.5%	1.6%	Pass	7.26
83	Configuration April 2022	17.0%	4.5%	0.8%	Pass	6.74
84	Configuration April 2022	17.7%	4.8%	0.9%	Pass	6.83
106	Configuration April 2022	11.6%	2.4%	0.4%	Pass	5.89
107	Configuration April 2022	14.7%	3.5%	0.7%	Pass	6.37
108	Configuration April 2022	12.3%	2.4%	0.4%	Pass	6.14
All Test Locations	Configuration April 2022				average	6.54

Table 23b: Pedestrian Wind Comfort and Safety for Existing Configuration – Prince Albert Park

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
82	Existing Configuration	15.3%	4.1%	0.8%	Pass	6.54
83	Existing Configuration	18.1%	5.2%	1.1%	Pass	6.93
84	Existing Configuration	16.4%	4.2%	0.7%	Pass	6.71
106	Existing Configuration	13.5%	3.0%	0.5%	Pass	6.19
107	Existing Configuration	9.3%	1.3%	0.1%	Pass	5.62
108	Existing Configuration	7.0%	0.8%	0.1%	Pass	5.04
All Test Locations	Existing Configuration				average	6.17

4.25 Chalmers Street (Figure A33)

For Configuration April 2022, the wind conditions along Chalmers Street (Test Locations 81, 109, 121 and 122) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 24a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A33 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 24a.

The wind conditions for the Existing Configuration at Test Locations 81, 109, 121 and 122 have been provided for comparison in Table 24b and Figure A33.

Table 24a: Pedestrian Wind Comfort and Safety – Chalmers Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
81						
	Configuration April 2022	7.9%	1.1%	0.1%	Pass	5.27
109						
	Configuration April 2022	7.9%	1.5%	0.3%	Pass	5.26
121						
	Configuration April 2022	9.3%	2.7%	0.6%	Pass	5.44
122						
	Configuration April 2022	9.6%	2.2%	0.3%	Pass	5.64
All Test Locations					average	
	Configuration April 2022					**5.40**

Table 24b: Pedestrian Wind Comfort and Safety for Existing Configuration – Chalmers Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
81	Existing Configuration	6.2%	1.3%	0.3%	Pass	5.02
109	Existing Configuration	13.9%	4.2%	1.1%	Pass	6.51
121	Existing Configuration	12.2%	3.3%	0.7%	Pass	6.12
122	Existing Configuration	13.1%	3.6%	0.8%	Pass	6.44
All Test Locations	Existing Configuration				average	6.02

4.26 Elizabeth Street (Figure A34)

For Configuration April 2022, the wind conditions along Elizabeth Street (Test Locations 79, 80 and 110) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 25a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A34 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 25a.

The wind conditions for the Existing Configuration at Test Locations 79, 80 and 110 have been provided for comparison in Table 25b and Figure A34.

Table 25a: Pedestrian Wind Comfort and Safety – Elizabeth Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
79	Configuration April 2022	8.6%	2.7%	0.9%	Pass	5.45
80	Configuration April 2022	9.3%	2.3%	0.6%	Pass	5.67
110	Configuration April 2022	9.9%	2.0%	0.4%	Pass	5.61
All Test Locations	Configuration April 2022				average	5.58

Table 25b: Pedestrian Wind Comfort and Safety for Existing Configuration – Elizabeth Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
79	Existing Configuration	8.4%	2.0%	0.5%	Pass	5.41
80	Existing Configuration	8.2%	1.8%	0.3%	Pass	5.25
110	Existing Configuration	11.6%	2.5%	0.4%	Pass	5.93
All Test Locations	Existing Configuration				average	5.53

4.27 Railway Colonnade Dr (Figure A35)

For Configuration April 2022, the wind conditions along Railway Colonnade Drive (Test Locations 76, 77 and 114) have been shown to satisfy the Walking Comfort Standard, with Test Locations 77 and 114 also satisfying the Standing Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 26a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A35 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 26a.

The wind conditions for the Existing Configuration at Test Locations 76, 77 and 114 have been provided for comparison in Table 26b and Figure A35.

Table 26a: Pedestrian Wind Comfort and Safety – Railway Colonnade Dr

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
76	Configuration April 2022	19.1%	6.5%	1.9%	Pass	7.01
77	Configuration April 2022	15.0%	4.1%	0.9%	Pass	6.55
114	Configuration April 2022	14.4%	3.7%	0.7%	Pass	6.08
All Test Locations	Configuration April 2022				average	**6.54**

Table 26b: Pedestrian Wind Comfort and Safety for Existing Configuration – Railway Colonnade Dr

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
76	Existing Configuration	18.7%	6.5%	2.0%	Pass	6.77
77	Existing Configuration	17.6%	5.2%	1.3%	Pass	6.77
114	Existing Configuration	17.2%	5.2%	1.5%	Pass	6.44
All Test Locations	Existing Configuration				average	**6.66**

4.28 Ambulance Avenue (Figure A36)

For Configuration April 2022, the wind conditions along Ambulance Avenue (Test Locations 115 and 116) have been shown to satisfy the Walking and Standing Comfort Standards, with Test Location 115 also satisfying the Sitting Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 27a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A36 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 27a.

The wind conditions for the Existing Configuration at Test Locations 115 and 116 have been provided for comparison in Table 27b and Figure A36.

Table 27a: Pedestrian Wind Comfort and Safety – Ambulance Avenue

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
115						
	Configuration April 2022	3.2%	0.4%	0.0%	Pass	3.85
116						
	Configuration April 2022	11.1%	2.6%	0.5%	Pass	5.86
All Test Locations					average	
	Configuration April 2022					4.86

Table 27b: Pedestrian Wind Comfort and Safety for Existing Configuration – Ambulance Avenue

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
115	Existing Configuration	4.8%	0.6%	0.1%	Pass	4.71
116	Existing Configuration	10.2%	2.0%	0.4%	Pass	5.75
All Test Locations	Existing Configuration				average	5.23

4.29 Lee Street (Figures A37 – A39)

For Configuration April 2022, the wind conditions along Lee Street (Test Locations 85 – 88 and 100 – 104) have been shown to satisfy the Walking Comfort Standard, with most Test Locations also satisfying the Standing Comfort Standard. With the exception of Test Location 87 which has failed the Safety Standard (both Proposed and Existing), the wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 28a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A37 & A38 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 28a.

The wind conditions for the Existing Configuration at Test Locations 85 – 88 and 100 – 104 have been provided for comparison in Table 28b and Figures A37 to A39.

Table 28a: Pedestrian Wind Comfort and Safety – Lee Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
85	Configuration April 2022	10.7%	2.0%	0.2%	Pass	5.57
86	Configuration April 2022	15.7%	4.5%	1.1%	Pass	6.59
87	Configuration April 2022	16.7%	5.8%	2.1%	FAIL	6.98
88	Configuration April 2022	8.6%	1.8%	0.3%	Pass	5.53
100	Configuration April 2022	11.1%	1.8%	0.2%	Pass	5.79
101	Configuration April 2022	12.6%	2.8%	0.6%	Pass	6.23
102	Configuration April 2022	12.6%	2.7%	0.6%	Pass	6.29
103	Configuration April 2022	10.7%	1.8%	0.2%	Pass	5.96
104	Configuration April 2022	16.6%	4.6%	0.9%	Pass	6.72
All Test Locations	Configuration April 2022				average	6.18

Table 28b: Pedestrian Wind Comfort and Safety for Existing Configuration – Lee Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
85	Existing Configuration	14.5%	3.6%	0.7%	Pass	6.29
86	Existing Configuration	14.9%	4.0%	0.9%	Pass	6.31
87	Existing Configuration	16.3%	5.2%	1.7%	FAIL	6.62
88	Existing Configuration	6.4%	1.2%	0.2%	Pass	5.06
100	Existing Configuration	15.6%	4.4%	0.8%	Pass	6.42
101	Existing Configuration	8.4%	1.2%	0.1%	Pass	5.30
102	Existing Configuration	12.3%	2.7%	0.5%	Pass	5.89
103	Existing Configuration	10.0%	2.1%	0.4%	Pass	5.60
104	Existing Configuration	16.6%	4.5%	1.0%	Pass	6.65
All Test Locations	Existing Configuration				**average**	**6.01**

4.30 Railway Square (Figure A40)

For Configuration April 2022, the wind conditions at Railway Square (Test Locations 119 and 120) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 29a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A40 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 29a.

The wind conditions for the Existing Configuration at Test Locations 119 and 120 have been provided for comparison in Table 29b and Figure A40.

Table 29a: Pedestrian Wind Comfort and Safety – Railway Square

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
119	Configuration April 2022	12.7%	4.0%	1.2%	Pass	6.25
120	Configuration April 2022	6.4%	1.2%	0.2%	Pass	4.81
All Test Locations	Configuration April 2022				average	5.53

Table 29b: Pedestrian Wind Comfort and Safety for Existing Configuration – Railway Square

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
119	Existing Configuration	19.0%	6.0%	1.5%	Pass	7.07
120	Existing Configuration	10.2%	2.3%	0.4%	Pass	5.34
All Test Locations	Existing Configuration				average	6.20

4.31 George Street (Figure A41)

For Configuration April 2022, the wind conditions along George Street (Test Locations 93 and 94) have been shown to satisfy the Walking and Standing Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 30a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A41 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 30a.

The wind conditions for the Existing Configuration at Test Locations 93 and 94 have been provided for comparison in Table 30b and Figure A41.

Table 30a: Pedestrian Wind Comfort and Safety – George Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
93	Configuration April 2022	13.9%	3.2%	0.5%	Pass	5.98
94	Configuration April 2022	12.9%	3.5%	0.9%	Pass	5.91
All Test Locations	Configuration April 2022				average	5.95

Table 30b: Pedestrian Wind Comfort and Safety for Existing Configuration – George Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
93	Existing Configuration	8.7%	1.4%	0.2%	Pass	5.07
94	Existing Configuration	13.9%	3.6%	0.7%	Pass	6.11
All Test Locations	Existing Configuration				average	5.59

4.32 Toga (Figure A42)

For Configuration April 2022, the wind conditions near Toga Development (Test Locations 89, 90, 95 and 97) have been shown to satisfy the Walking Comfort Standard, with Test Location 89 also satisfying the Sitting Comfort Standard and Test Location 97 satisfying both the Standing and Sitting Comfort Standards. With the exception of Test Location 90 which has failed the Safety Standard (Figure A42 indicates that this occurs for northeast winds only, and is only marginally exceeded), the wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 31a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figure A42 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 31a.

The wind conditions for the Existing Configuration at Test Locations 89, 90, 95 and 97 have been provided for comparison in Table 31b and Figure A42. Note that the Safety Standard is exceed for more locations and directions in the Existing case.

Table 31a: Pedestrian Wind Comfort and Safety – Toga

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
89	Configuration April 2022	17.1%	4.9%	1.0%	Pass	6.75
90	Configuration April 2022	17.6%	5.9%	2.0%	FAIL	7.06
95	Configuration April 2022	24.3%	9.1%	2.8%	Pass	7.98
97	Configuration April 2022	2.3%	0.4%	0.0%	Pass	3.11
All Test Locations	Configuration April 2022				average	**6.22**

Table 31b: Pedestrian Wind Comfort and Safety for Existing Configuration – Toga

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
89	Existing Configuration	12.2%	2.7%	0.5%	Pass	5.97
90	Existing Configuration	10.5%	2.8%	0.8%	Pass	5.66
95	Existing Configuration	25.0%	10.4%	3.7%	FAIL	7.94
97	Existing Configuration	25.7%	10.6%	3.8%	FAIL	7.98
All Test Locations	Existing Configuration				average	6.89

4.33 Pitt Street (Figures A43 & A44)

For Configuration April 2022, the wind conditions along Pitt Street (Test Locations 91, 92, 113, 117 and 118) have been shown to satisfy the Walking and Standing Comfort Standards, with Test Location 118 also satisfying the Sitting Comfort Standard. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 32a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A43 and A44 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 32a.

The wind conditions for the Existing Configuration at Test Locations 91, 92, 113, 117 and 118 have been provided for comparison in Table 32b and Figure A43 and A44.

Table 32a: Pedestrian Wind Comfort and Safety – Pitt Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
91	Configuration April 2022	8.8%	2.0%	0.3%	Pass	5.44
92	Configuration April 2022	15.3%	3.9%	0.7%	Pass	6.27
113	Configuration April 2022	12.1%	3.1%	0.6%	Pass	5.97
117	Configuration April 2022	13.4%	3.5%	0.9%	Pass	6.24
118	Configuration April 2022	4.0%	0.4%	0.0%	Pass	4.13
All Test Locations	Configuration April 2022				average	5.61

Table 32b: Pedestrian Wind Comfort and Safety for Existing Configuration – Pitt Street

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
91	Existing Configuration	11.9%	2.6%	0.6%	Pass	6.06
92	Existing Configuration	15.4%	4.1%	1.0%	Pass	6.27
113	Existing Configuration	9.1%	1.9%	0.3%	Pass	5.43
117	Existing Configuration	15.1%	3.8%	0.7%	Pass	6.49
118	Existing Configuration	5.0%	0.5%	0.1%	Pass	4.54
All Test Locations	Existing Configuration				average	5.76

4.34 Platforms Under the OSD (Figures A45 & A46)

For Configuration April 2022, the wind conditions at the platforms under the OSD (Test Locations UP1 – UP5) have been shown to satisfy the Walking, Standing and Sitting Comfort Standards. The wind conditions for Configuration April 2022 at the above Test Locations have been shown to pass the Safety Standard. The criteria achieved have been presented in Table 33a.

The wind conditions as a function of wind direction based on the gust criteria for Sydney are presented in Figures A45 and A46 in Appendix A. It is noted that at each Test Location the directionally-specific comfort wind conditions may be higher than those of the tabulated results for all wind directions in Table 33a.

The wind conditions for the Existing Configuration at Test Locations UP1 – UP5 and 123 have been provided for comparison in Table 33b and Figure A45 and A46.

Table 33a: Pedestrian Wind Comfort and Safety – Platforms Under OSD

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
UP1	Configuration April 2022	0.0%	0.0%	0.0%	Pass	2.02
UP2	Configuration April 2022	0.7%	0.1%	0.0%	Pass	2.76
UP3	Configuration April 2022	1.3%	0.1%	0.0%	Pass	3.18
UP4	Configuration April 2022	3.3%	0.4%	0.0%	Pass	3.40
UP5	Configuration April 2022	1.8%	0.2%	0.0%	Pass	2.80
All Test Locations	Configuration April 2022				average	2.83

Table 33b: Pedestrian Wind Comfort and Safety for Existing Configuration – Platform Under OSD

Test Location	Configuration	Wind Comfort Standard				wind speed (m/s)
		Sitting	Standing	Walking	Safety	
UP1	Existing Configuration	1.3%	0.0%	0.0%	Pass	3.51
UP2	Existing Configuration	3.5%	0.5%	0.1%	Pass	4.15
UP3	Existing Configuration	6.7%	1.7%	0.5%	Pass	4.81
UP4	Existing Configuration	4.0%	0.4%	0.0%	Pass	4.39
UP5	Existing Configuration	5.8%	0.7%	0.1%	Pass	4.80
123	Existing Configuration	12.2%	2.4%	0.3%	Pass	6.10
All Test Locations	Existing Configuration				average	4.63

5. CONCLUSIONS

Wind-tunnel tests have been conducted on a 1/400 scale model of a revised massing (April 2022) of the Central Precinct Renewal Masterplan, Sydney. The revisions from the previous masterplan study (late 2020) evolved from a series of iterative Computational Wind Engineering studies during late 2021 and early 2022. The resulting physical model, examined herein, encompassed the proposed Western Gateway developments (Dexus Fraser, Atlassian and Toga projects) and the revised massing layout of the likely tall building developments over the Station (generally referred to as the Over the Station Development (OSD)) along with some peripheral buildings to the east and south. The model of the Development within surrounding buildings was tested in a simulated upstream boundary layer of the natural wind to determine likely environmental wind conditions. These wind conditions have been primarily (i.e., focus of Chapter 4 herein) related to the locally mandated Central Sydney Planning Strategy – Implementation guidelines and assessed with respect to the Safety Standard as well as the Walking, Standing and Sitting Comfort Standards (derived from Lawson, 1990). Additionally, criteria based on gust wind speeds which are commonly used in other domestic and international jurisdictions are presented in Appendix A and discussed where appropriate in Section 4 of this report to expand the directional understanding of the likely wind conditions.

An assessment based on the comfort criteria outlined in the Central Sydney Planning Strategy has shown some general trends presented herein: (i) the wind conditions are better at the south end of the OSD than at the north end, (ii) the surrounding streets (except west side of Lee Street from Dexus Fraser and northwest corner of Toga) and OSD areas (except east side of Atlassian on the avenue) generally satisfy Walking Comfort Standard or better, and (iii) nearby parks and public spaces satisfy the Walking Comfort Standard or better.

However, for Configuration April 2022 it has also been shown that wind conditions at several locations, especially on the west side of Buildings B, C and F (top of stairs/escalator at central avenue), centre of the east side bridges, locally on west side of Lee Street from the Dexus Fraser building and locally at the northwest corner of Toga building have not satisfied the Safety Standard, i.e., unsafe for pedestrians. It should be noted that no safety fences along the bridges were included in this study and if these are included (say, minimum 50% solidity and over 1.8 m high), wind conditions on the bridges would be expected to improve to be within the Safety Standard.

The central avenue safety observation, noted above, indicates that when the OSD buildings are going through concept design (as opposed to the current massing study) some specific ameliorative studies, including built form changes, may be required. In Section 4.18, for example, some specific ideas to be explored are suggested for the conditions at the top of the stairs/escalators. In the same manner, any local areas associated with an individual building (say, entry-level outdoor café) may benefit from local protection to achieve a “sitting” standard.

The wind conditions for the Existing Configuration, including the proposed Western Gateway developments, in the surrounding streetscapes and platform areas have been presented for comparison.

Prepared by

Y. Padayatchy

MEL Consultants Pty Ltd
July 2022

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2. W.H. Melbourne, Wind environment studies in Australia, Journal of Industrial Aerodynamics, Volume 3, 1978, pp. 201-214

3. T.V. Lawson, The Determination of the Wind Environment of a Building Complex before Construction, Report Number TVL 9025, Department of Aerospace Engineering, University of Bristol, 1990

FIGURES

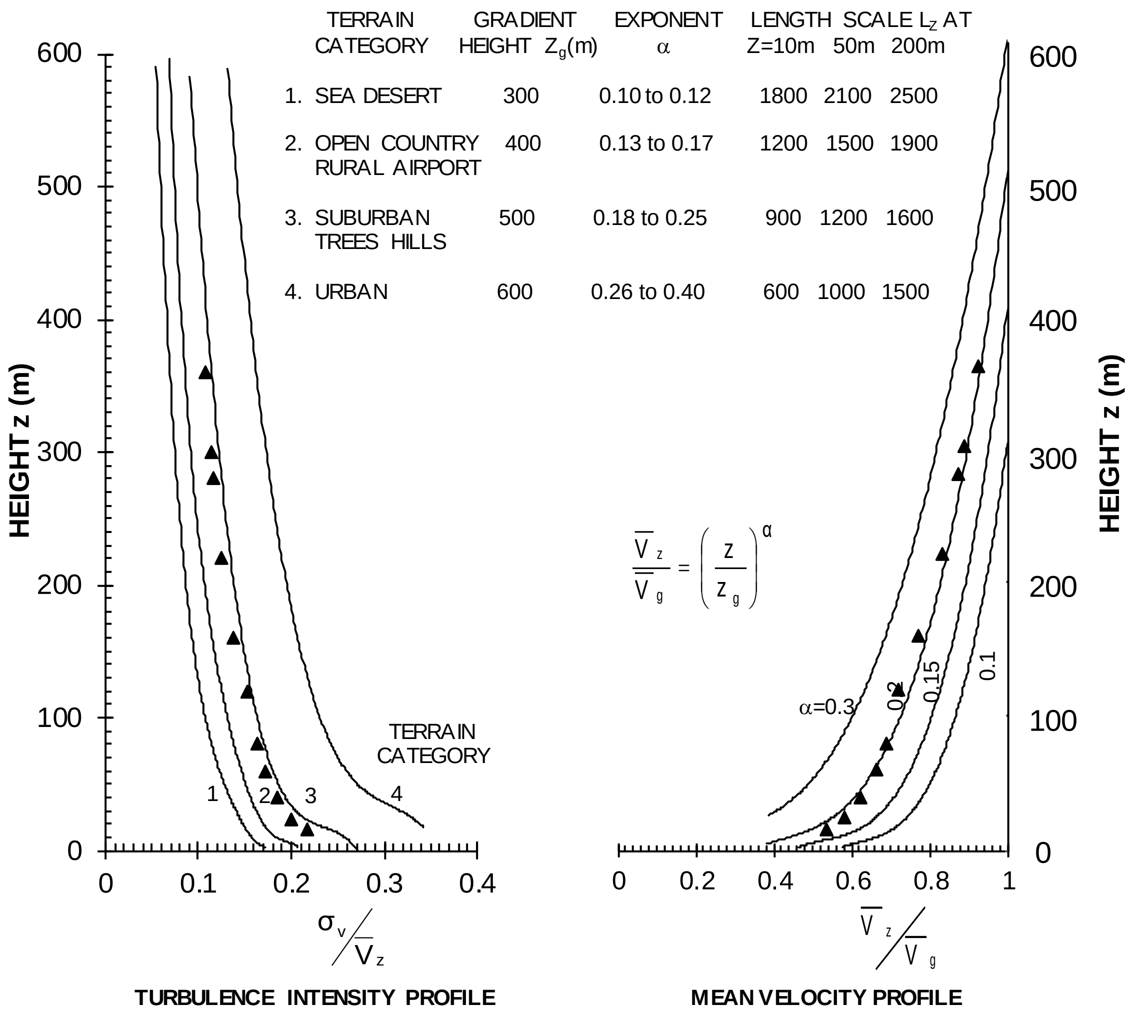


Figure 2 – 1/400 scale TC3 boundary layer turbulence intensity and mean velocity profiles in the MEL Consultants Boundary Layer Wind Tunnel 4.8 m x 2.2 m working section, scaled to full-scale dimensions.

Figure 3a – View from the north of the 1/400 scale model of the Central Precinct Renewal Masterplan – Configuration April 2022 in the wind tunnel.

Figure 3b – View from the southeast of the 1/400 scale model of the Central Precinct Renewal Masterplan – Configuration April 2022 in the wind tunnel.

Figure 4a – View from the northeast of the 1/400 scale model of the Central Precinct Renewal Masterplan – Existing Configuration in the wind tunnel.

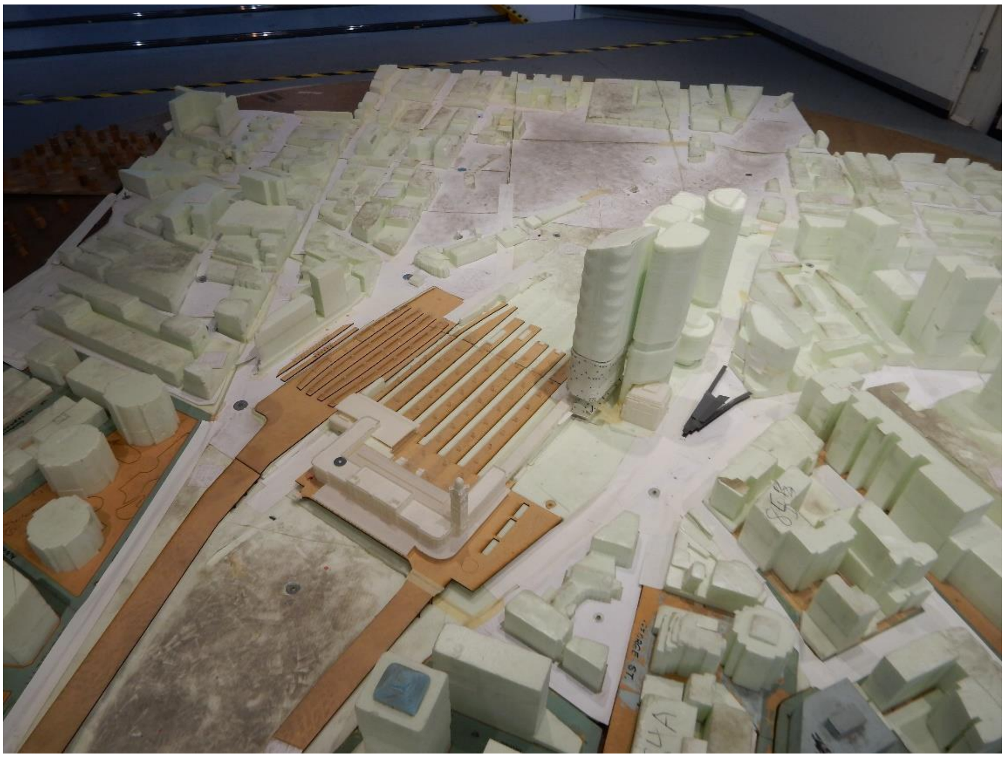


Figure 4b – View from the north of the 1/400 scale model of the Central Precinct Renewal Masterplan – Existing Configuration in the wind tunnel.

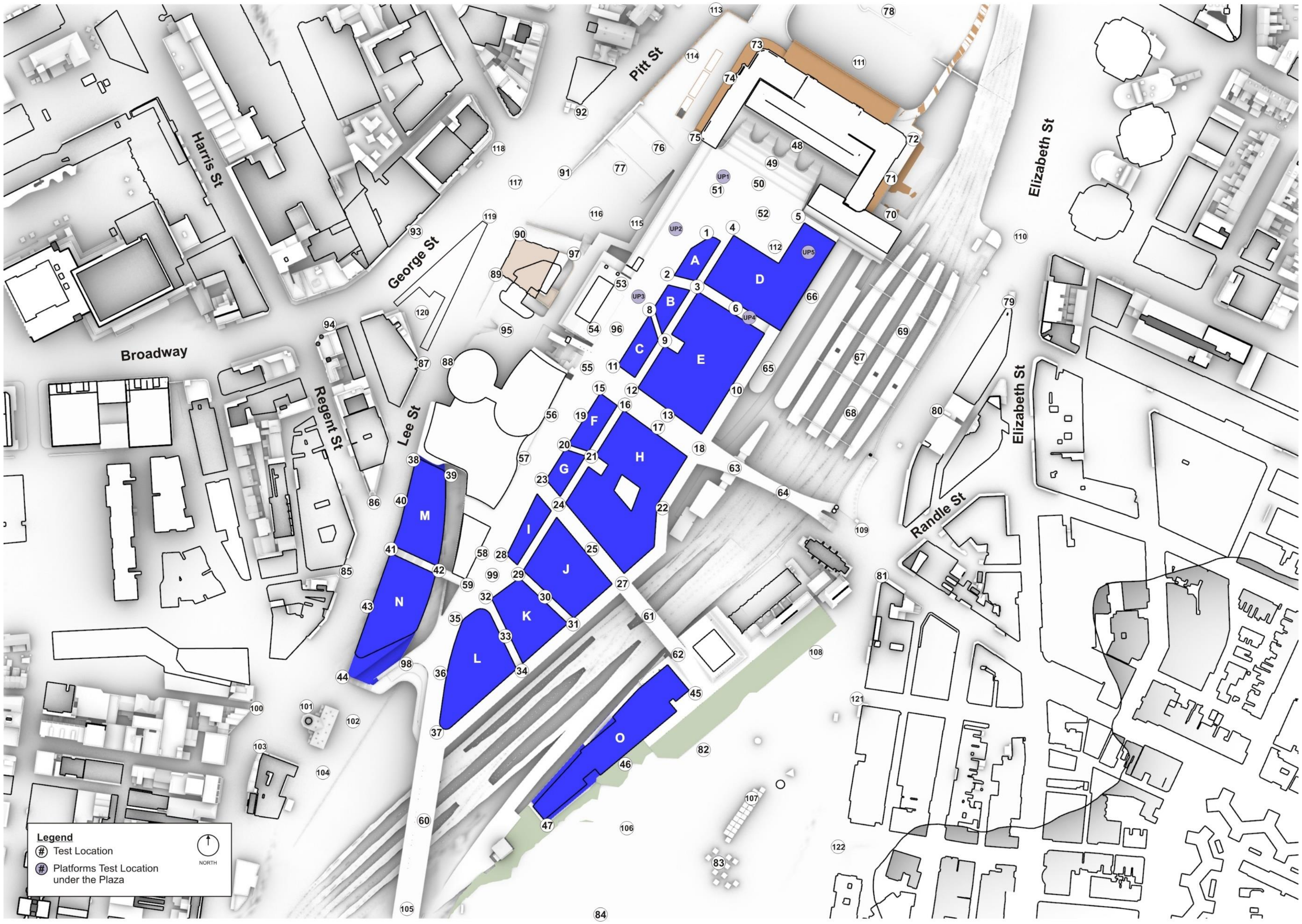


Figure 5 - Test Locations around the Central Precinct Renewal Masterplan, Sydney for Configuration April 2022

Figure 6a – Summary of wind conditions for Existing Configuration for 360° of wind direction

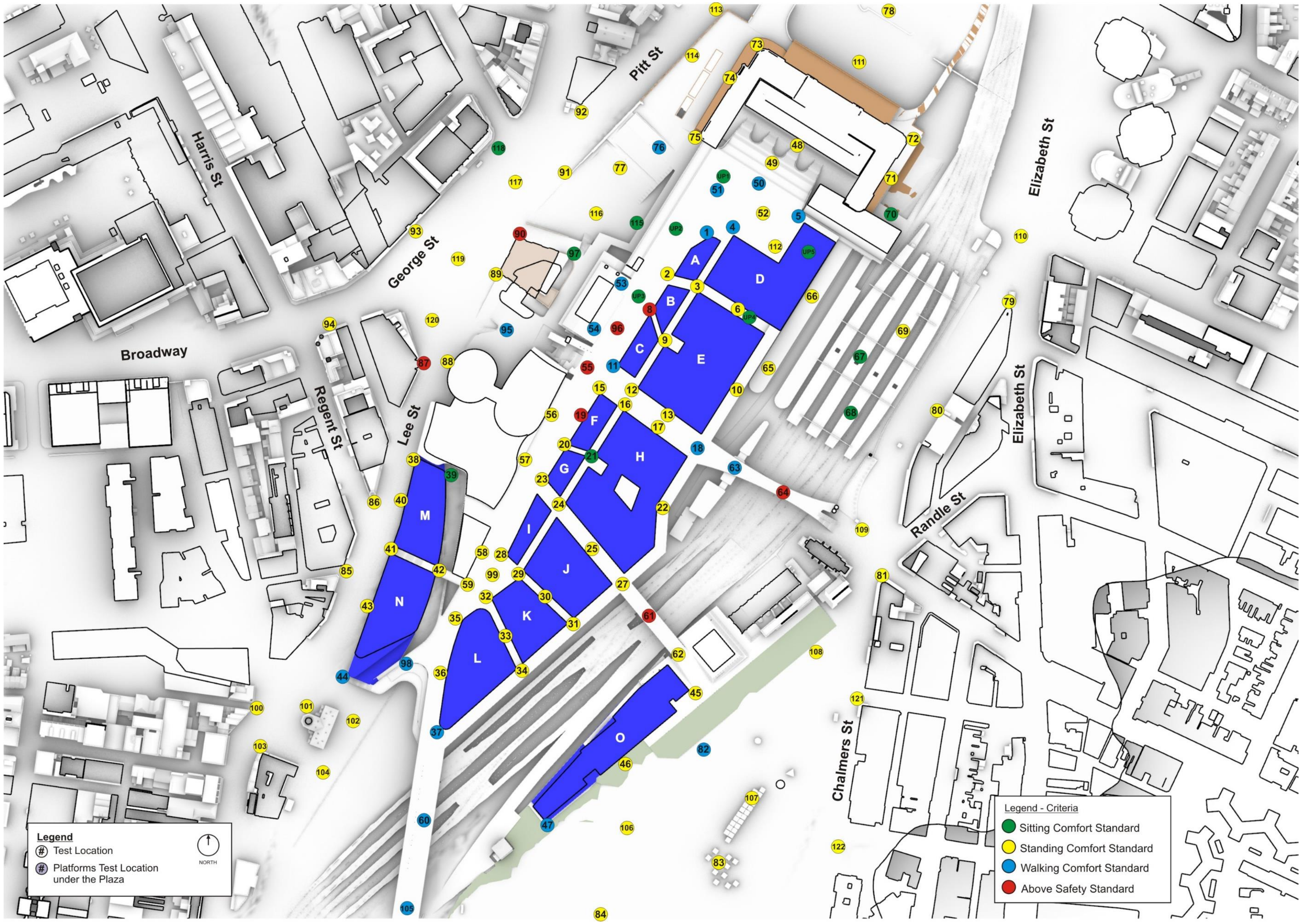


Figure 6b– Summary of wind conditions for Configuration April 2022 for 360° of wind direction

Appendix A

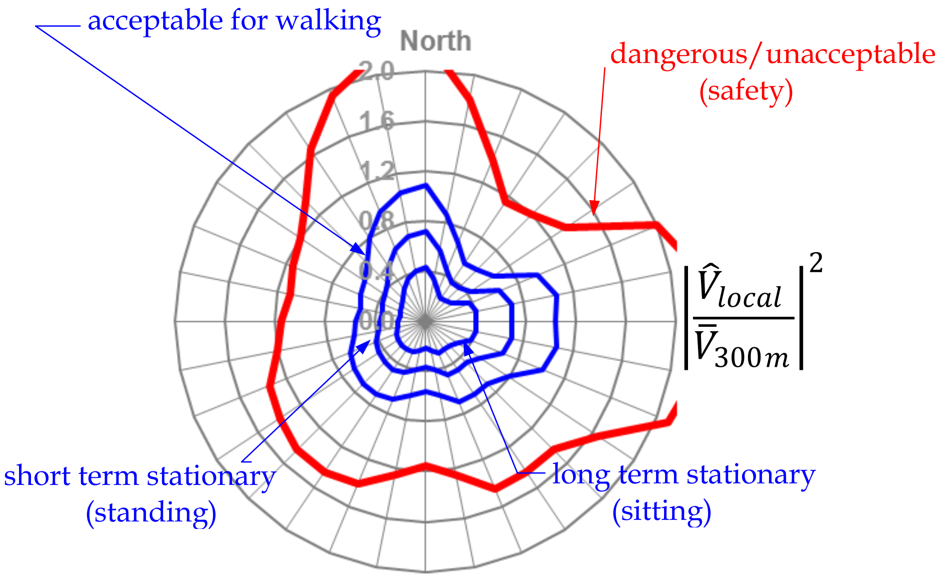
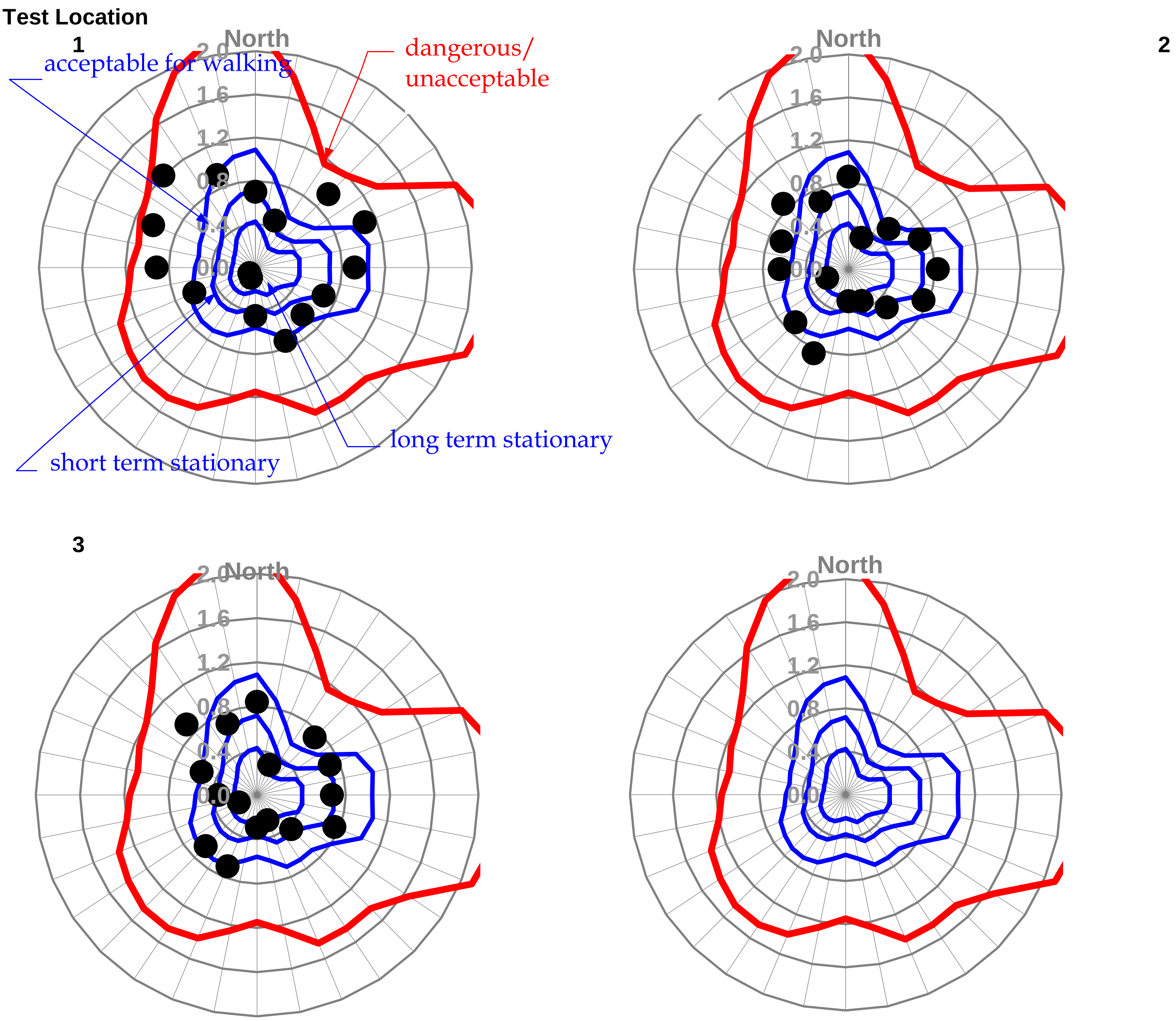


Figure A1 - Environmental wind criteria for Sydney as a function of wind direction expressed in terms of peak velocity pressure ratio.



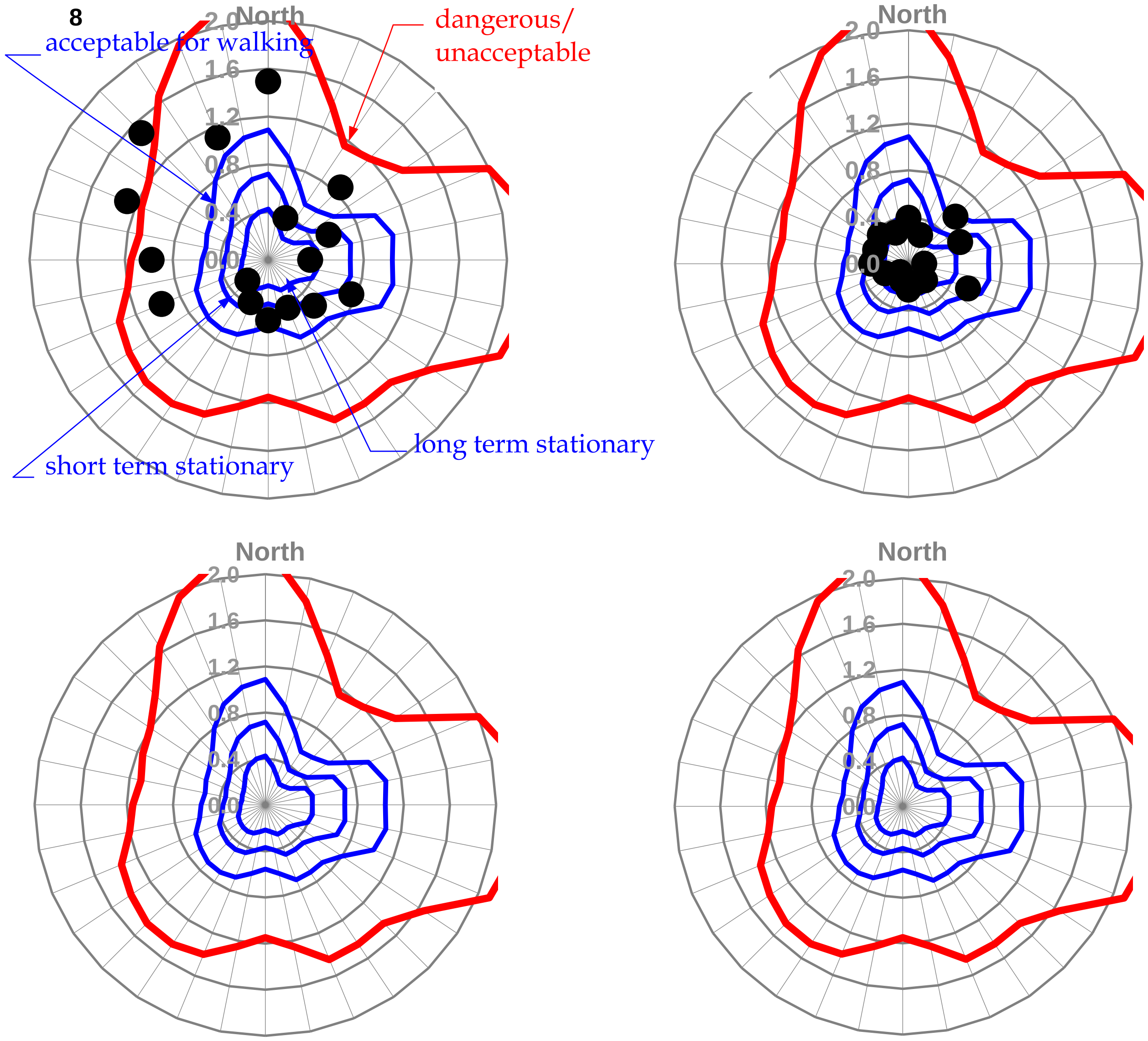
Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A2 - Building A

Test Location

8 9

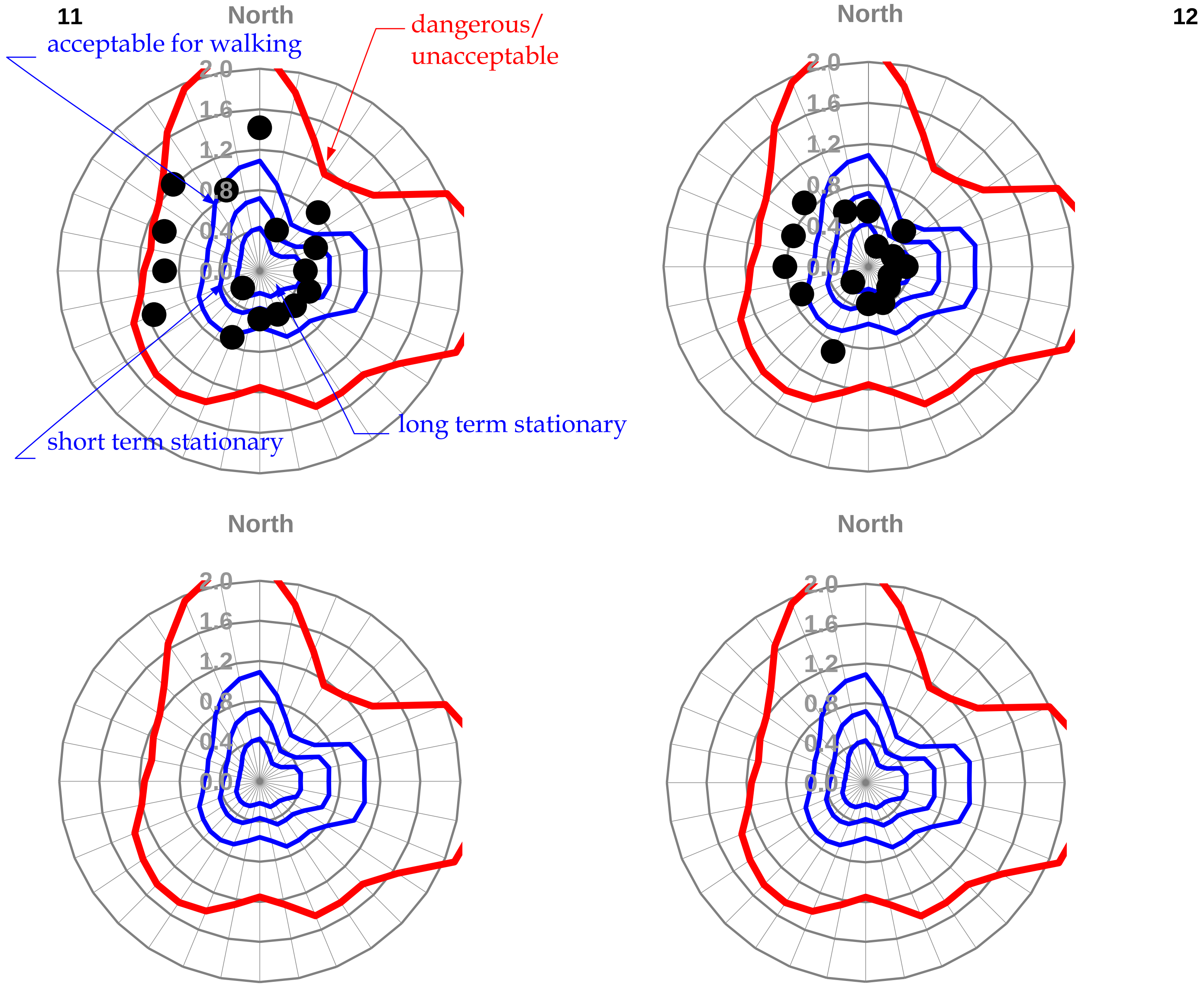


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A3 - Building B

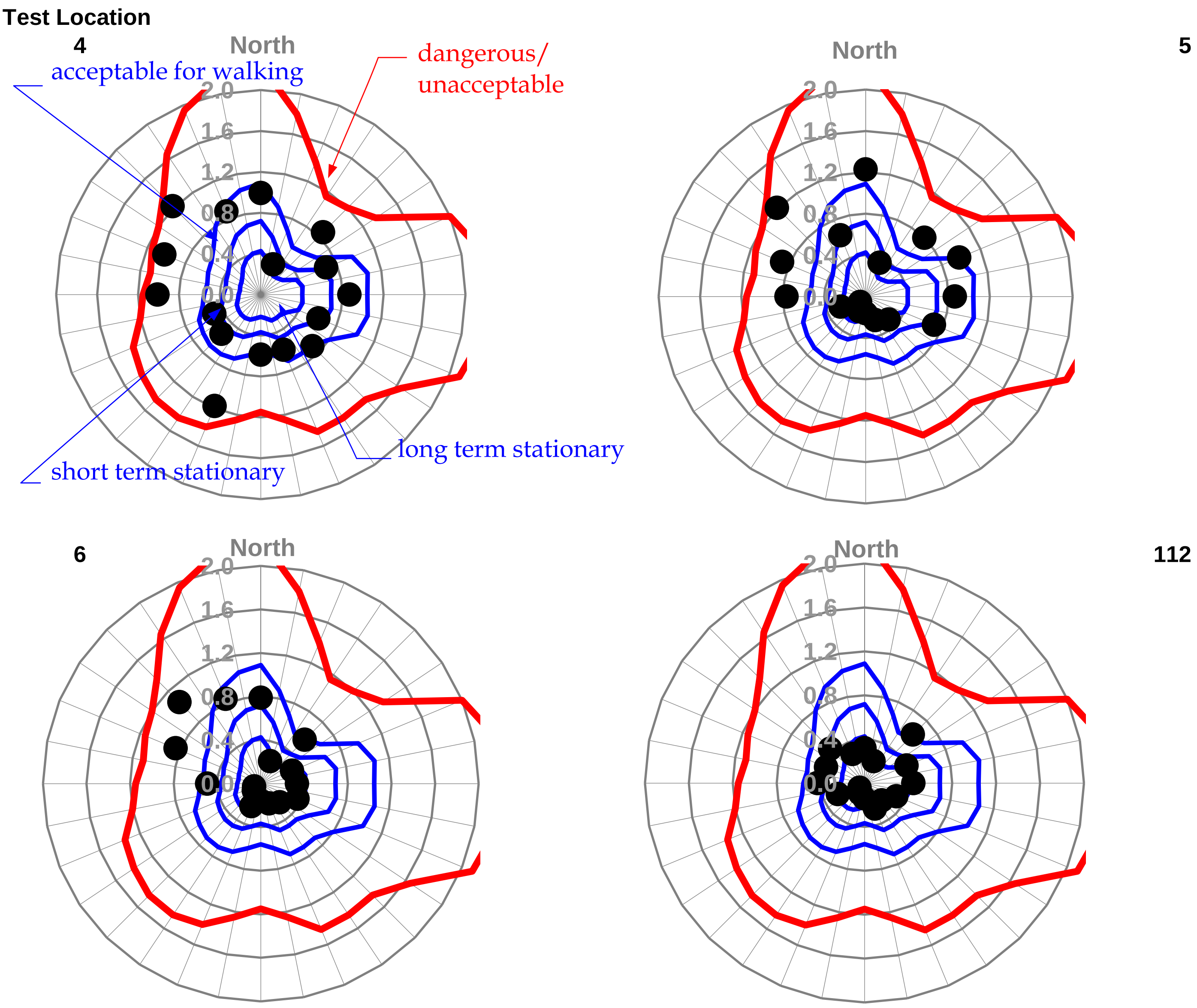
Test Location



Peak velocity squared ratio $\left|\dfrac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^{2}$ as a function of wind direction

Configuration April 2022	●

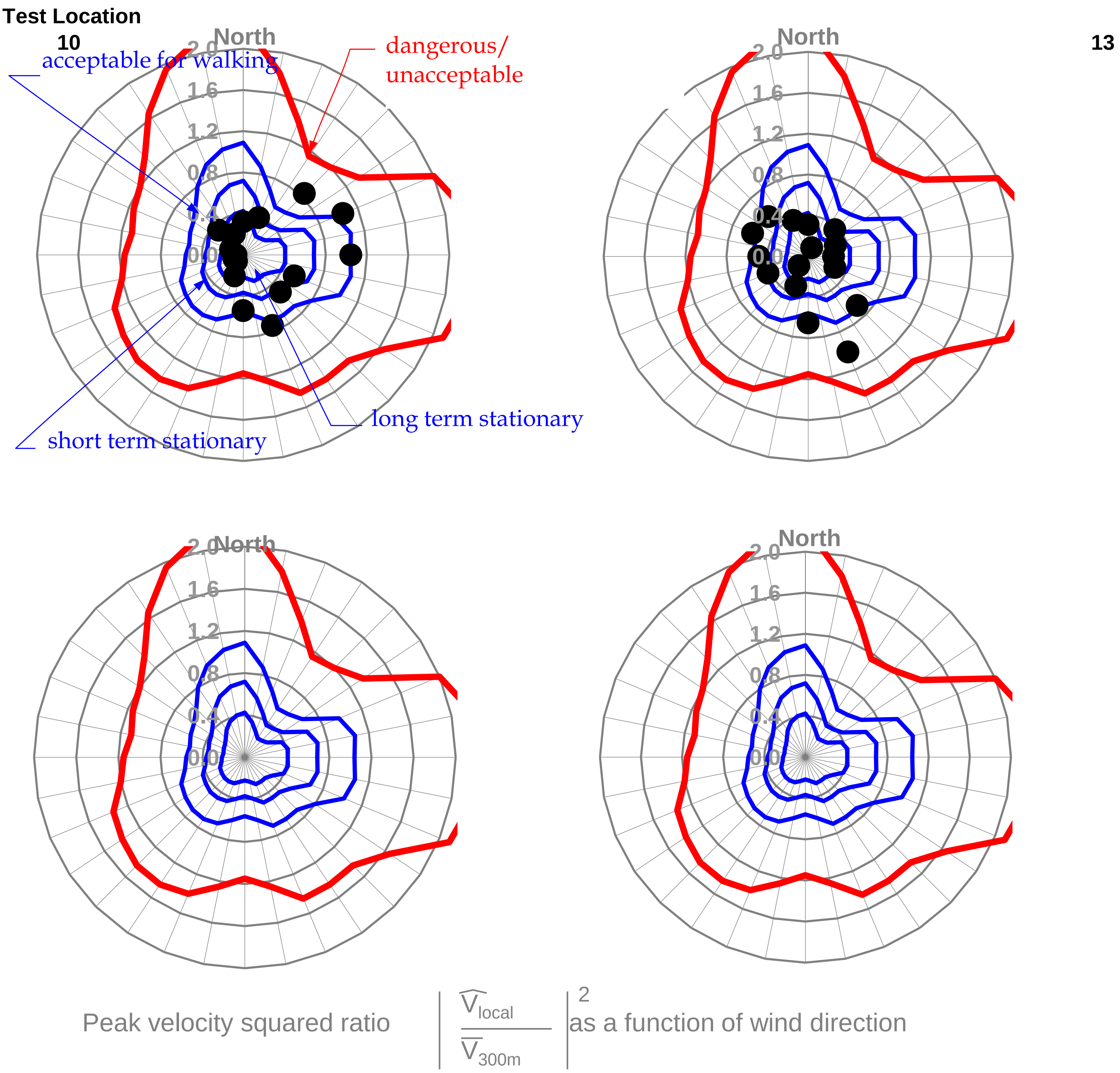
Figure A4 - Building C



Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

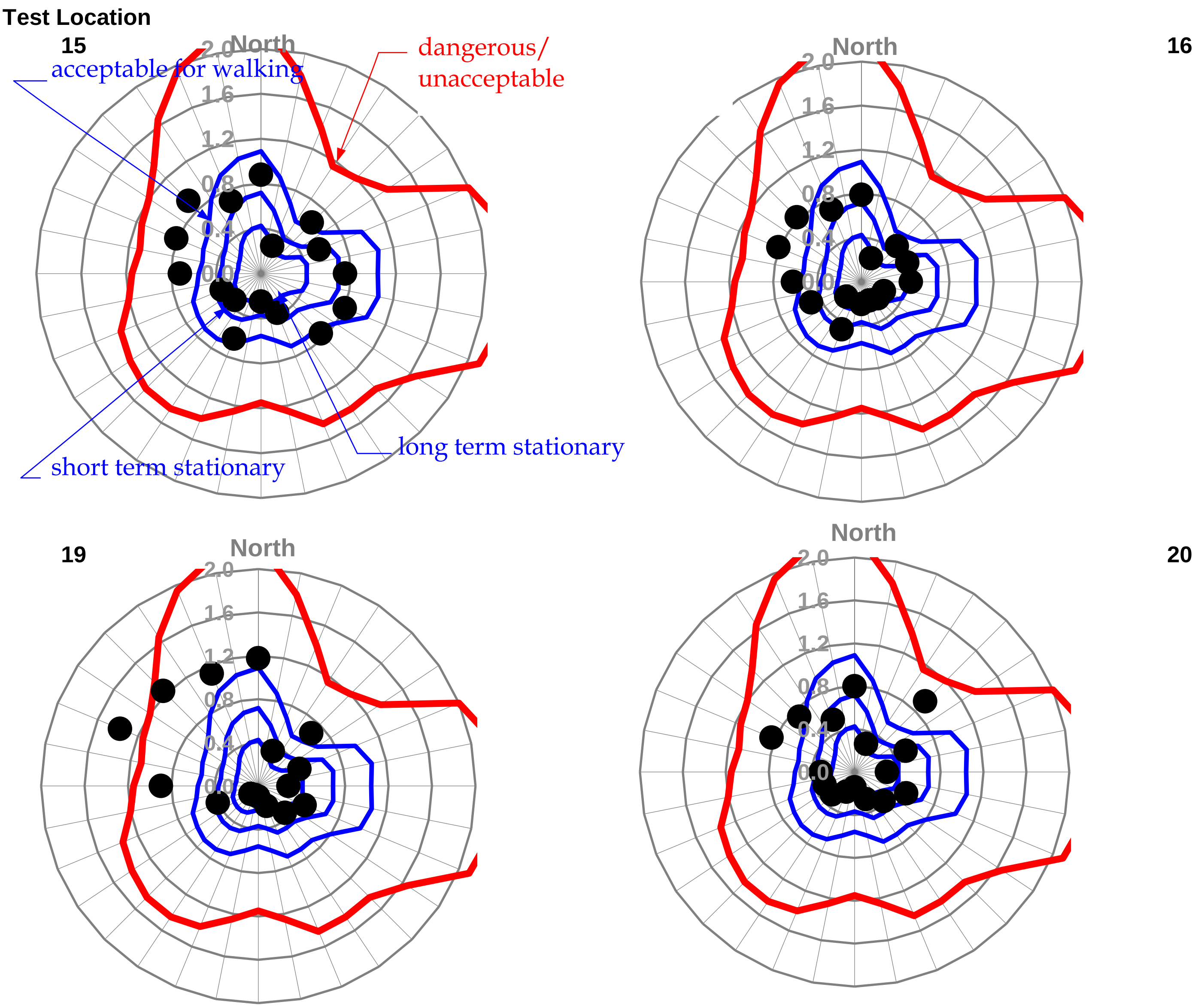
Configuration April 2022	●

Figure A5 - Building D



Configuration April 2022 ●

Figure A6 - Building E

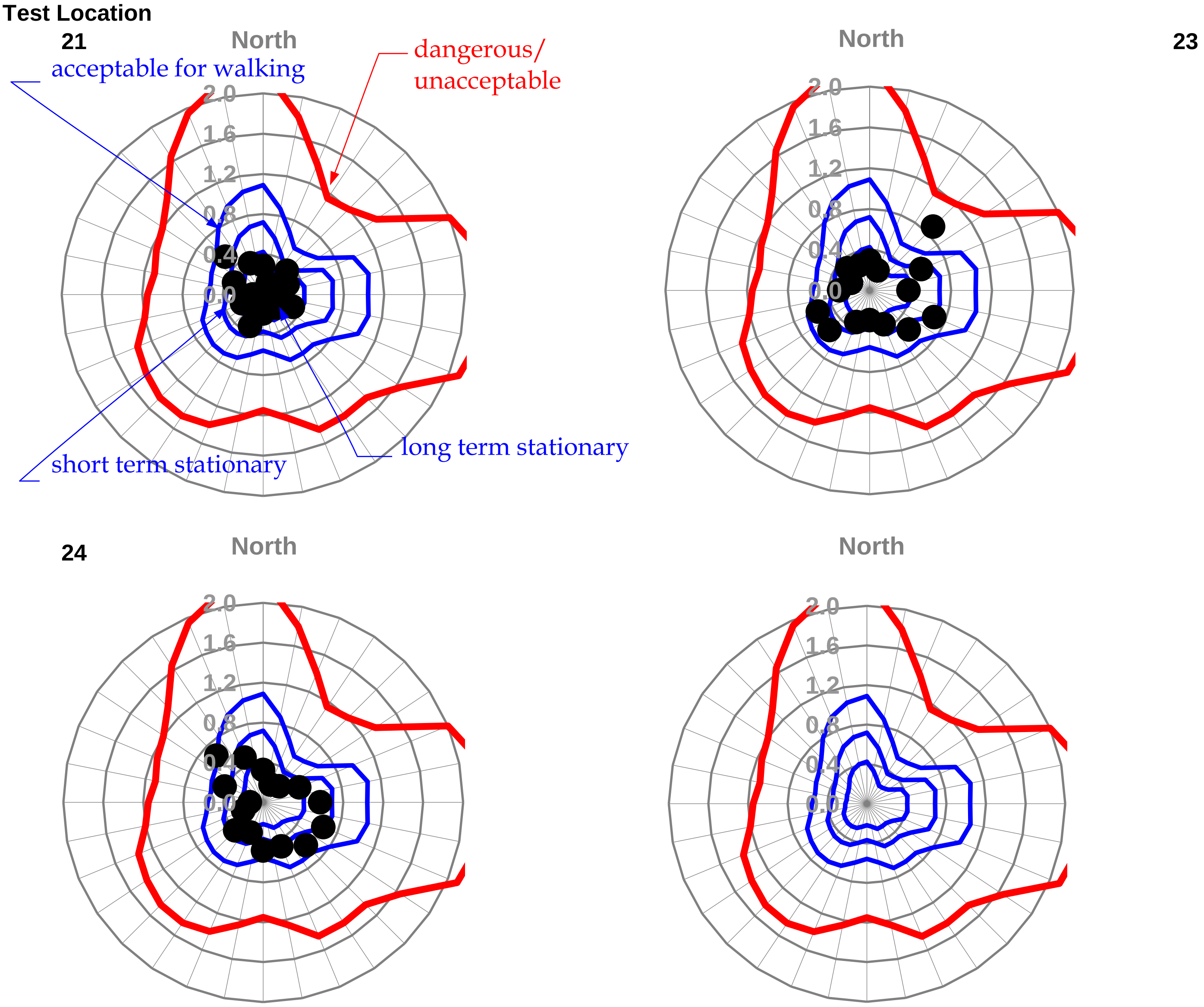


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A7 - Building F

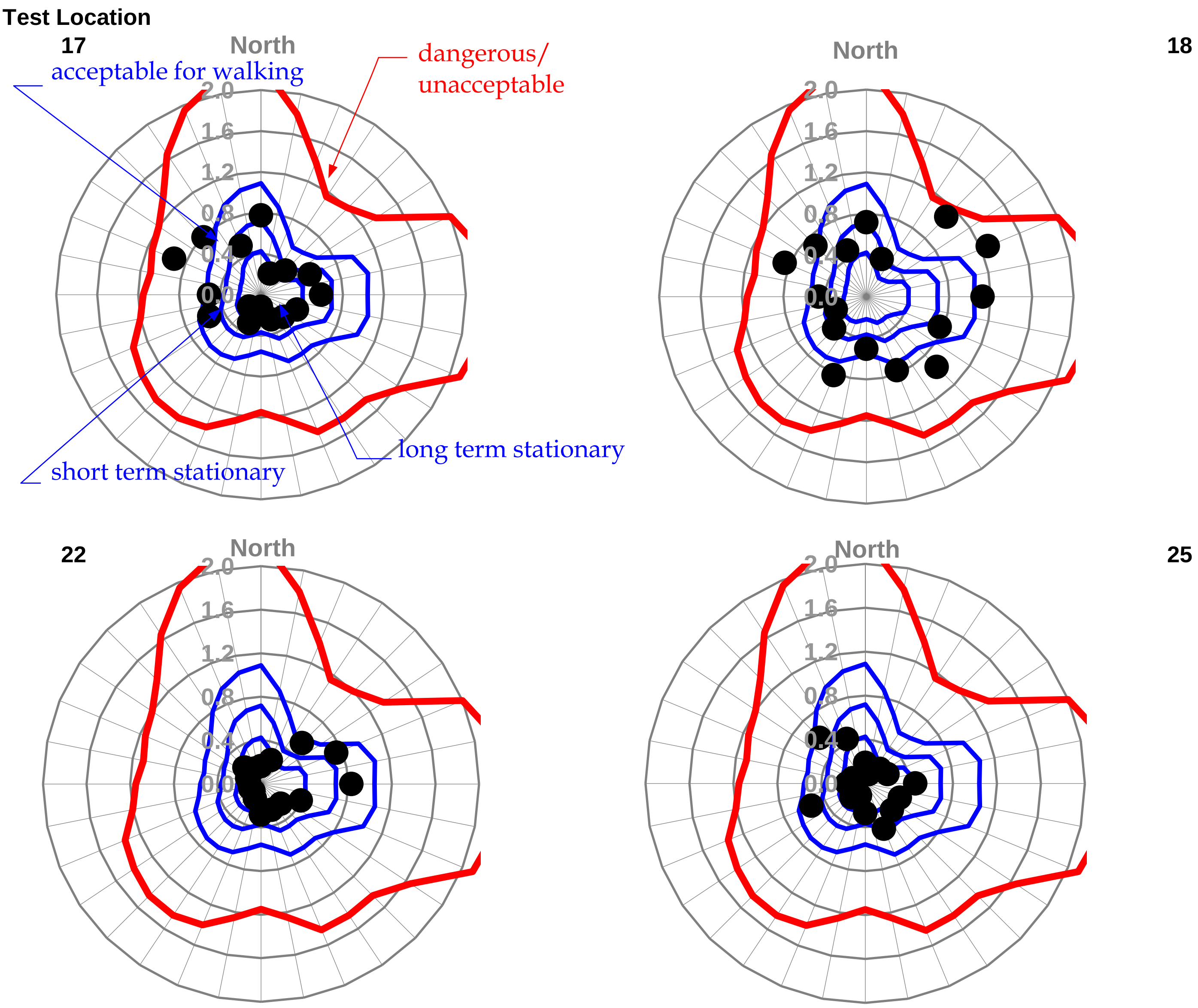
Test Location



Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●

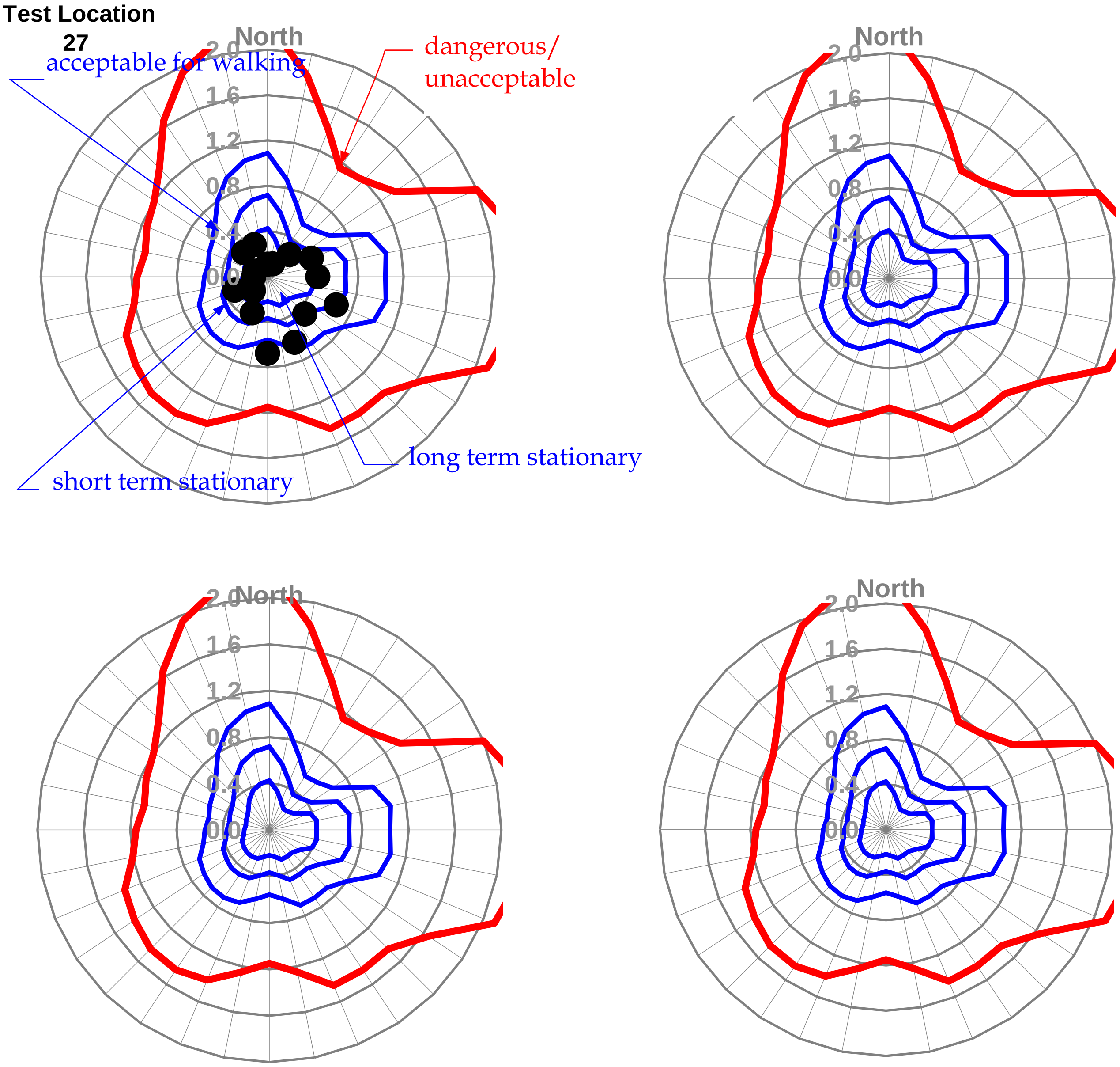
Figure A8 - Building G



Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A9 - Building H

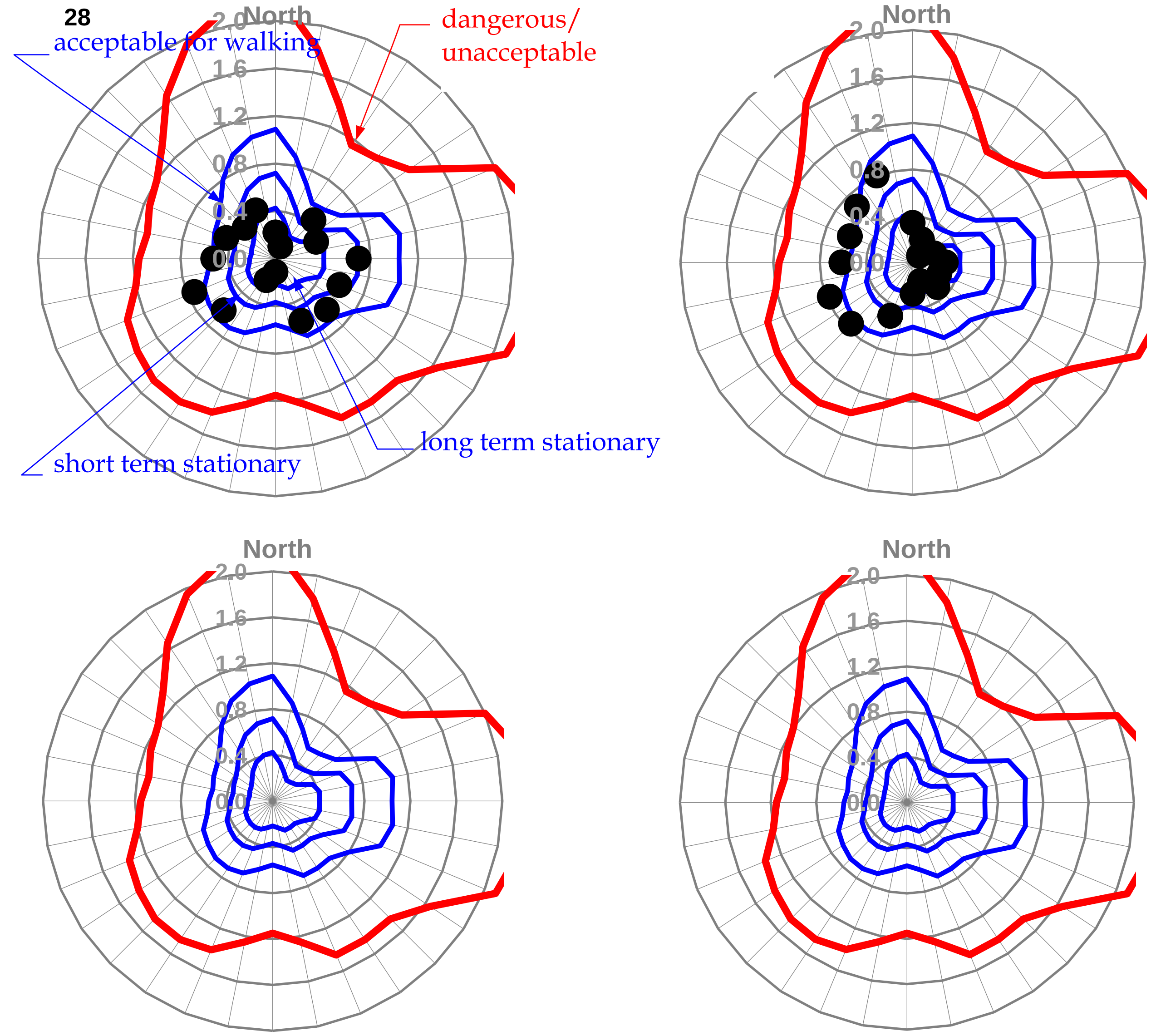


Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A10 - Building H (continued)

Test Location



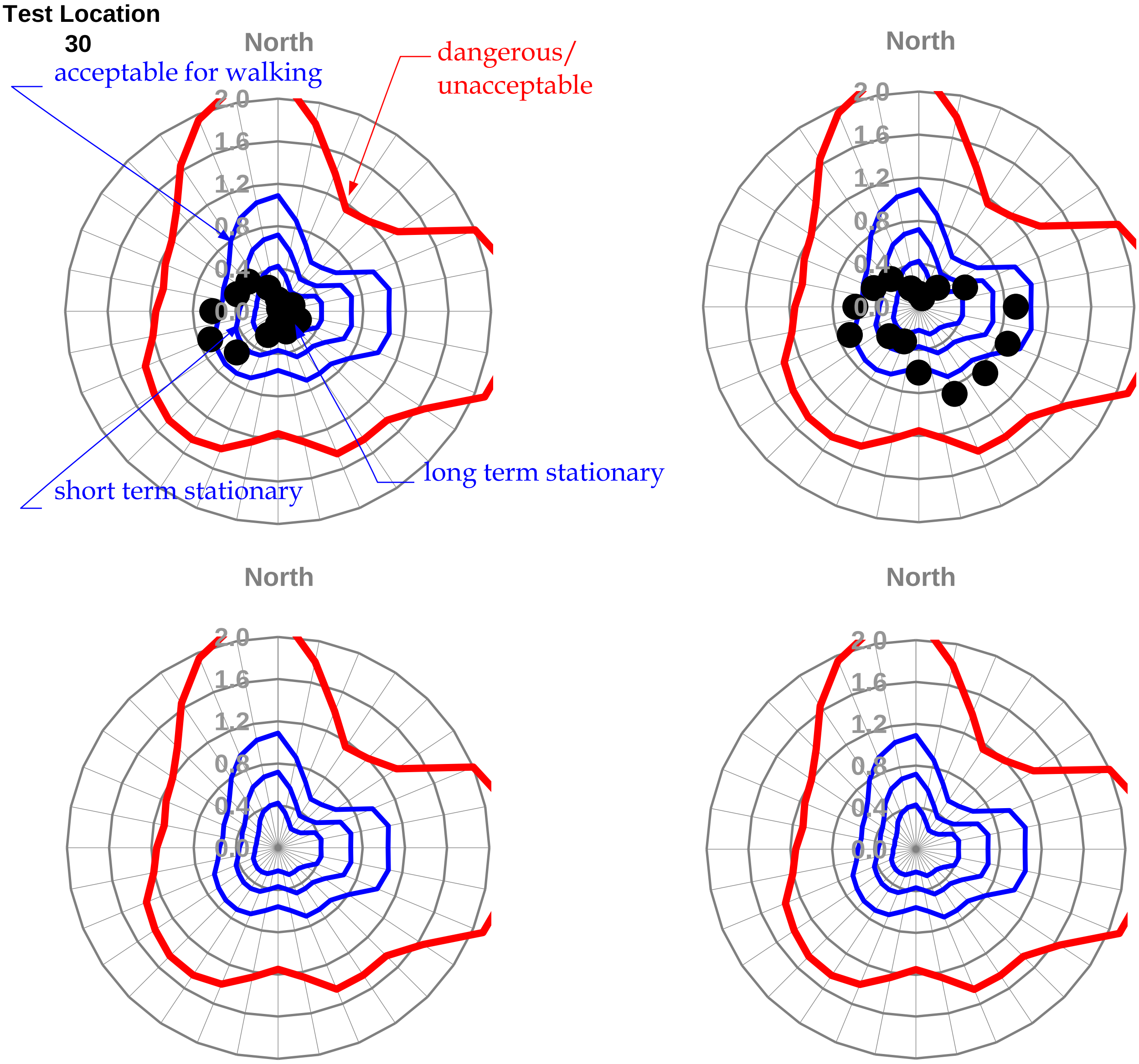
Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A11 - Building I

Test Location

30 **31**

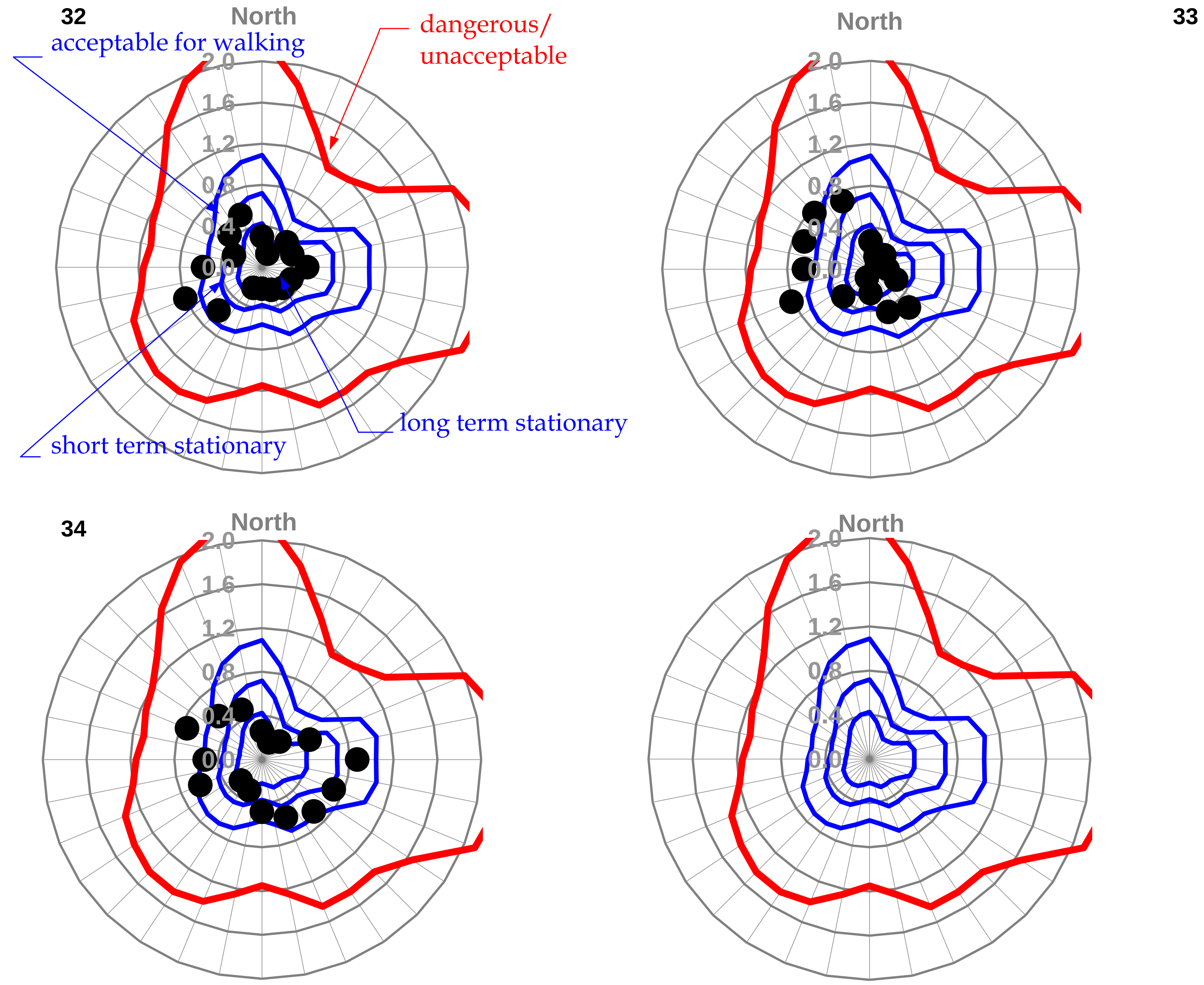


Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A12 - Building J

Test Location



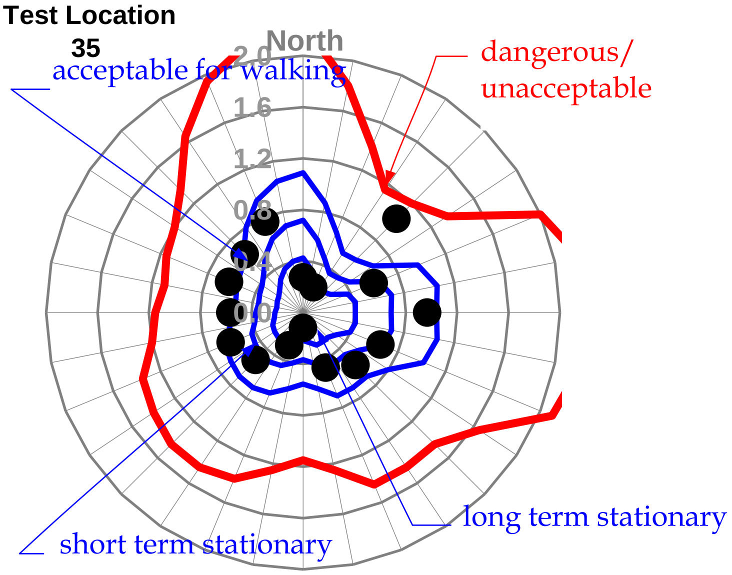
Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022 ●

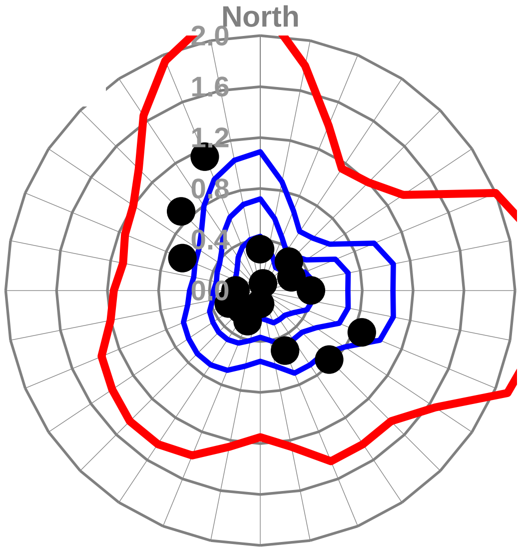
Figure A13 - Building K

Test Location

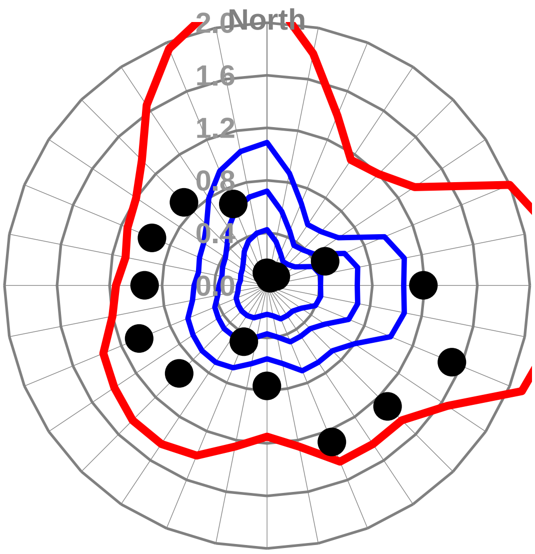
35

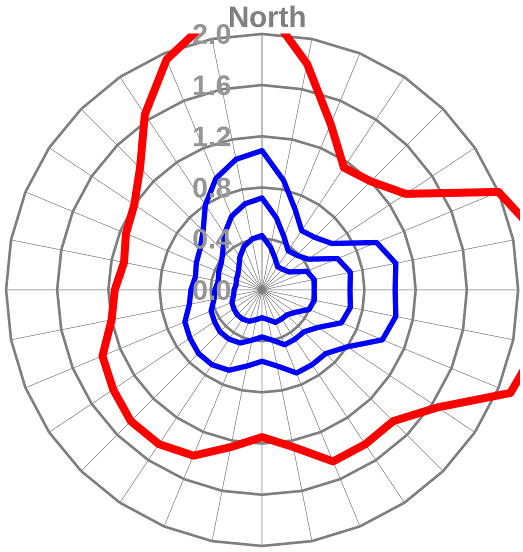


36



37





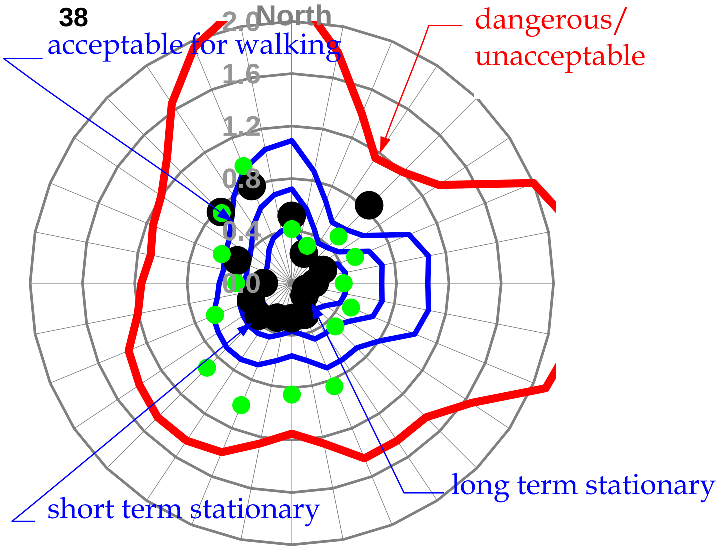
Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●

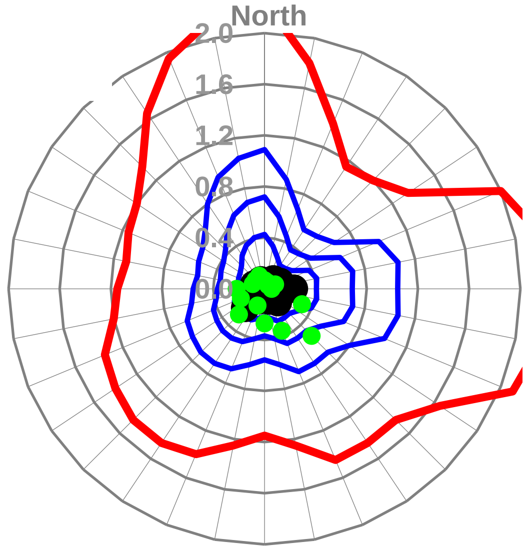
Figure A14 - Building L

Test Location

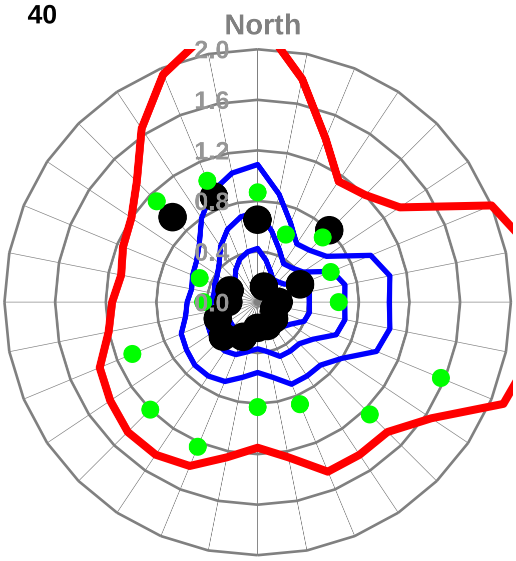
38



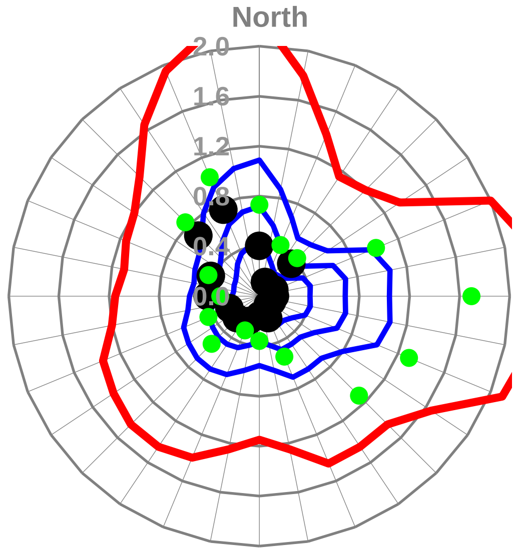
39



40



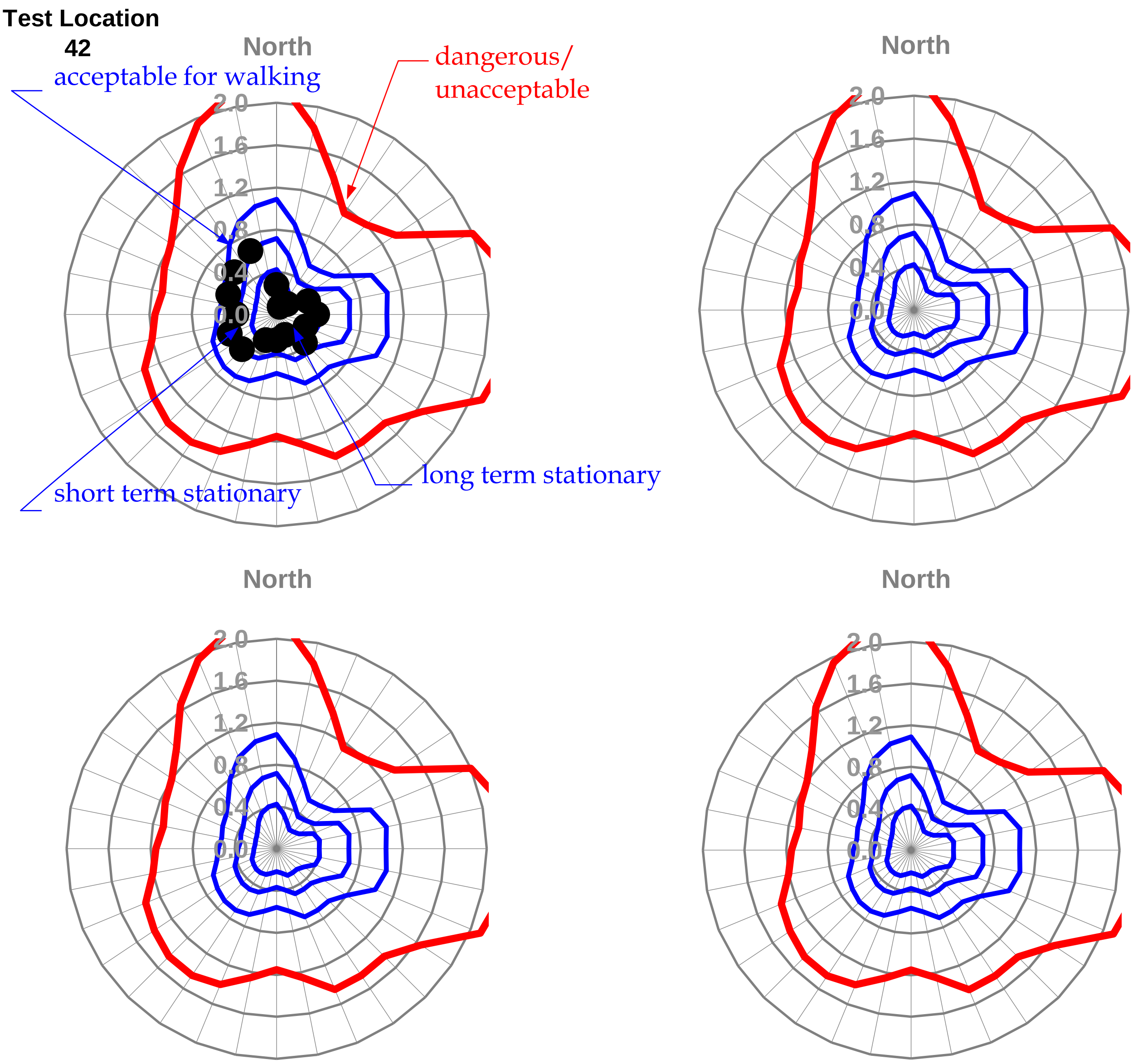
41



Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^{2}$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

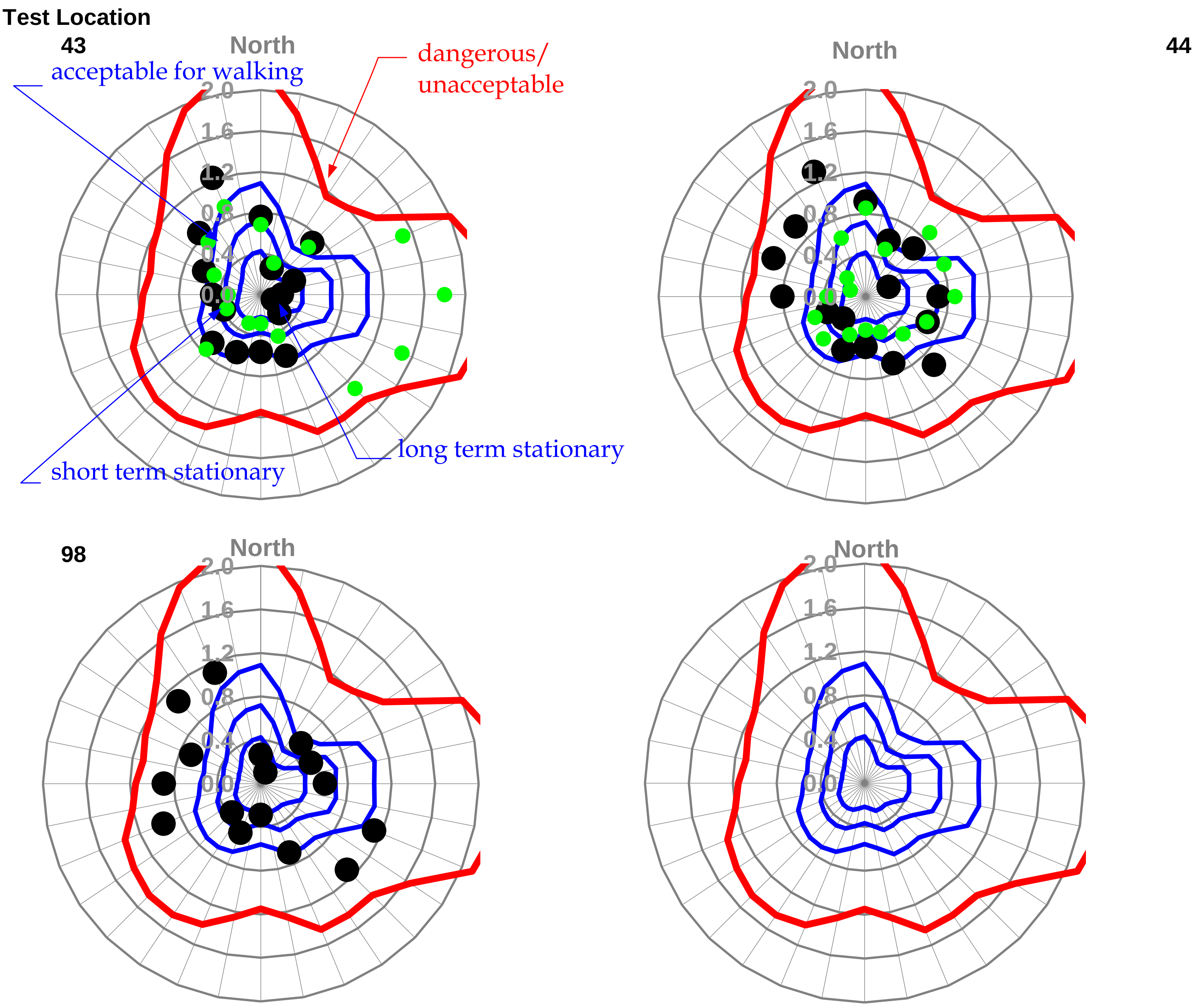
Figure A15 - Building M



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A16 - Building M - continued

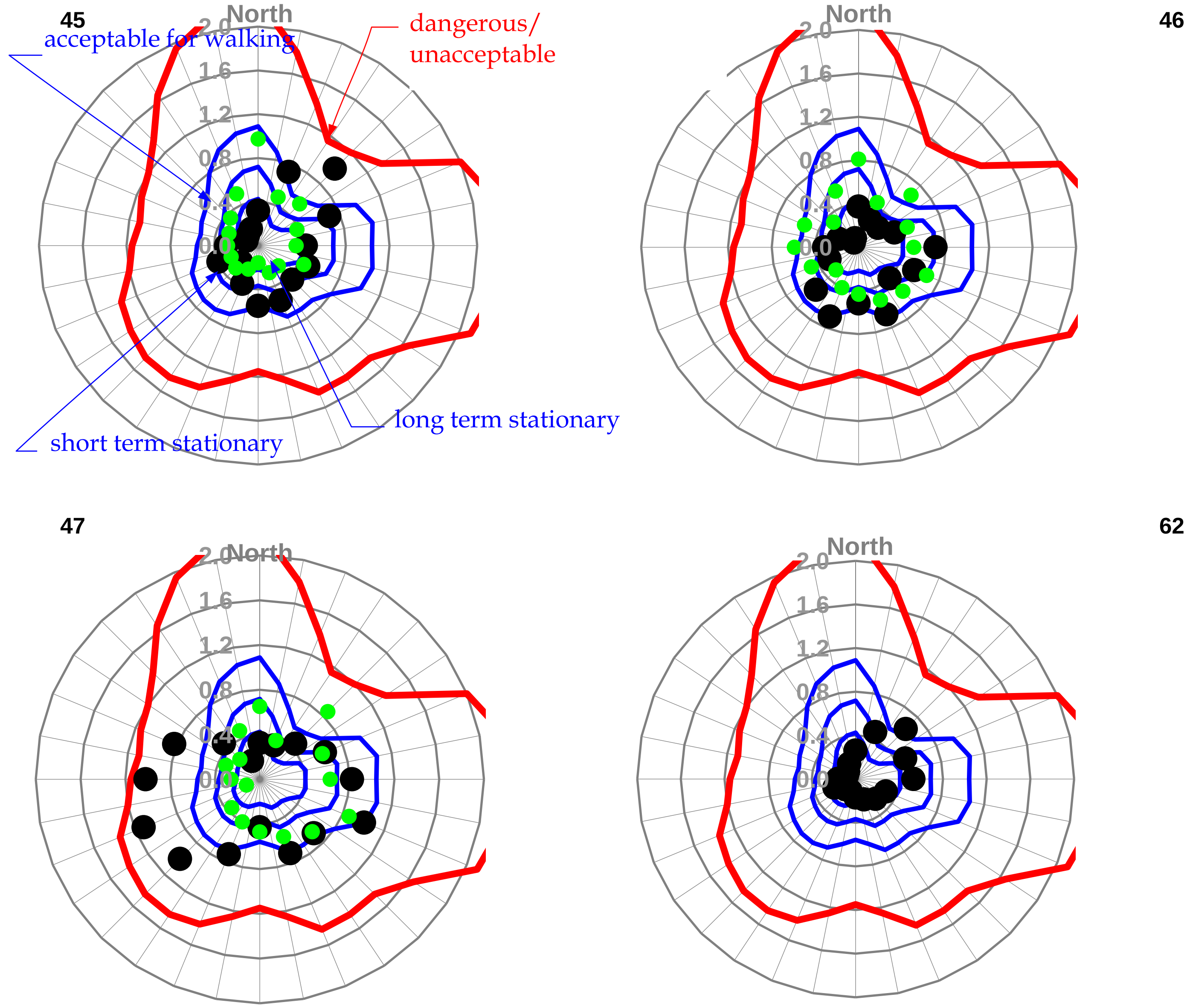


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A17 - Building N

Test Location



Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A18 - Building O

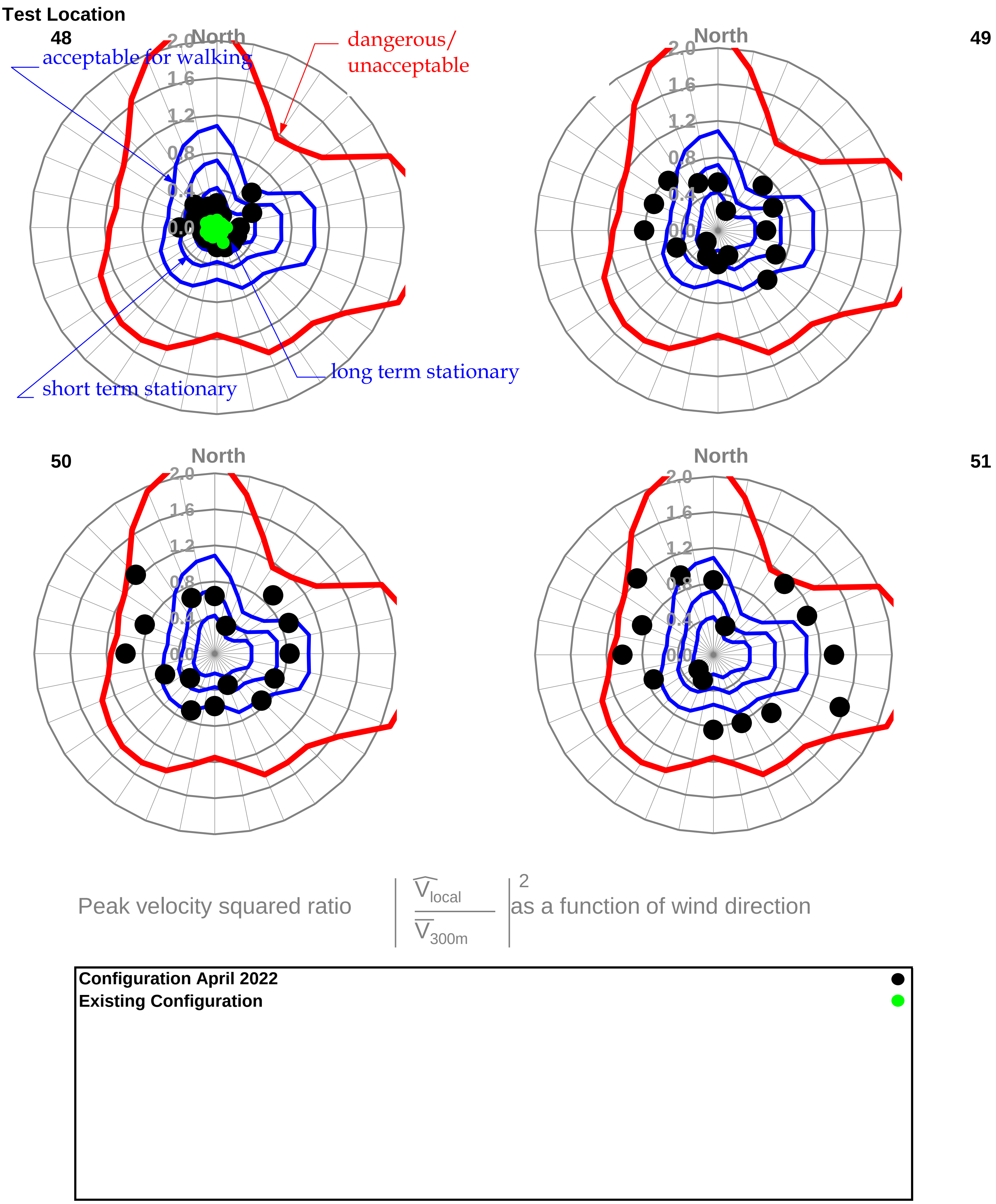
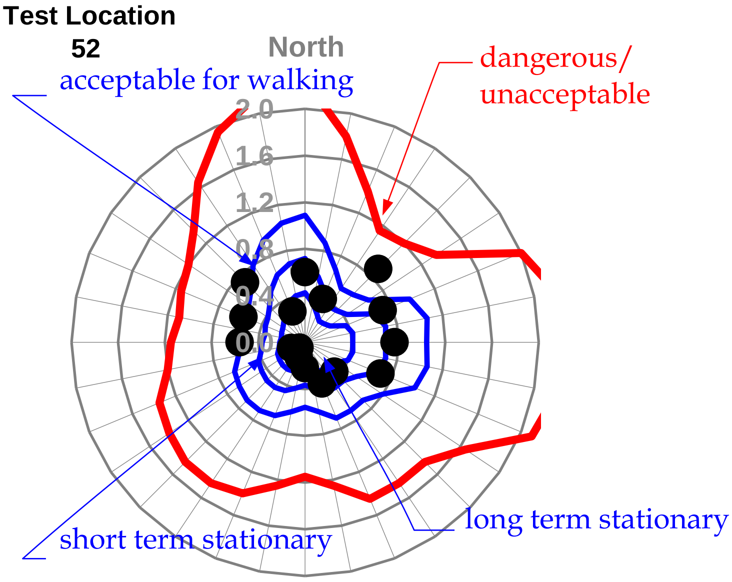
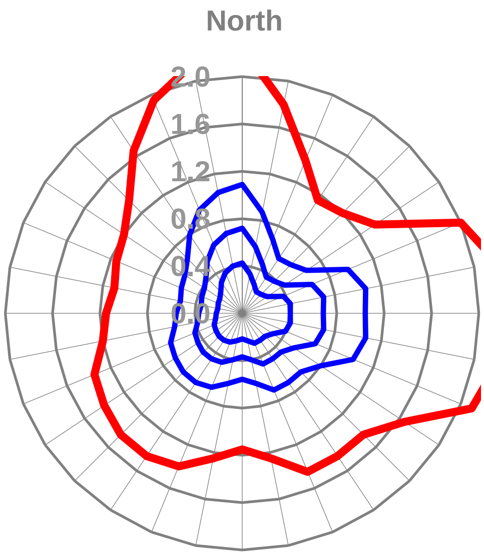
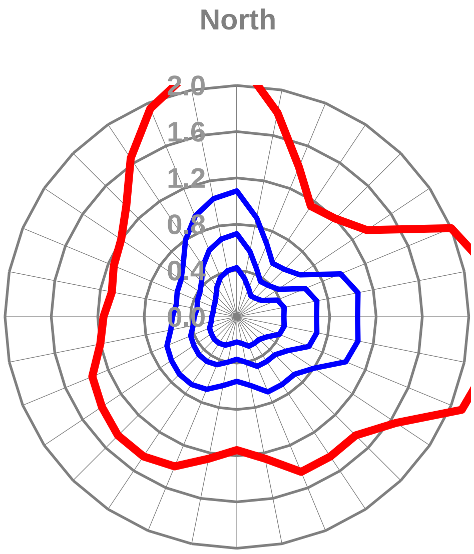
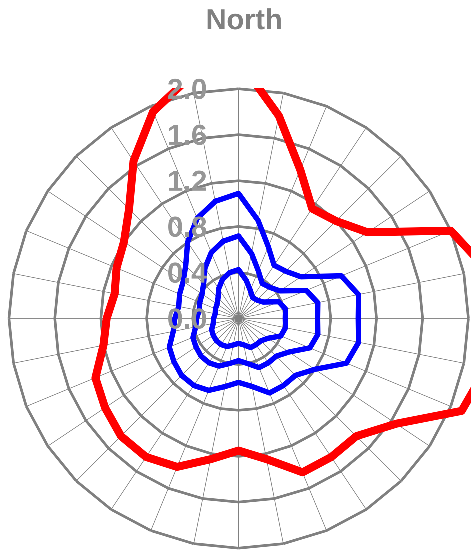


Figure A19 - North Plaza







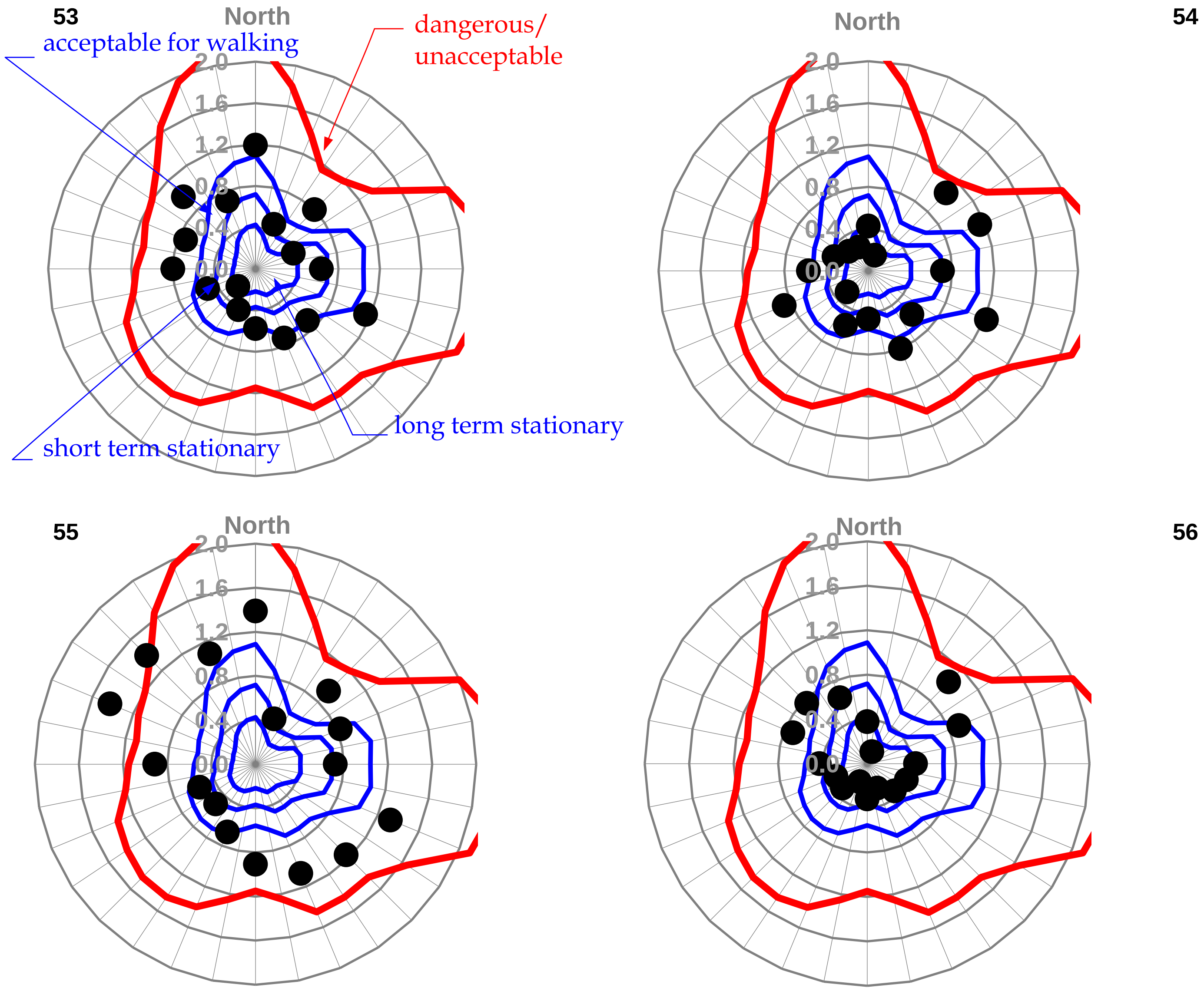


Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A20 - North Plaza - continued

Test Location

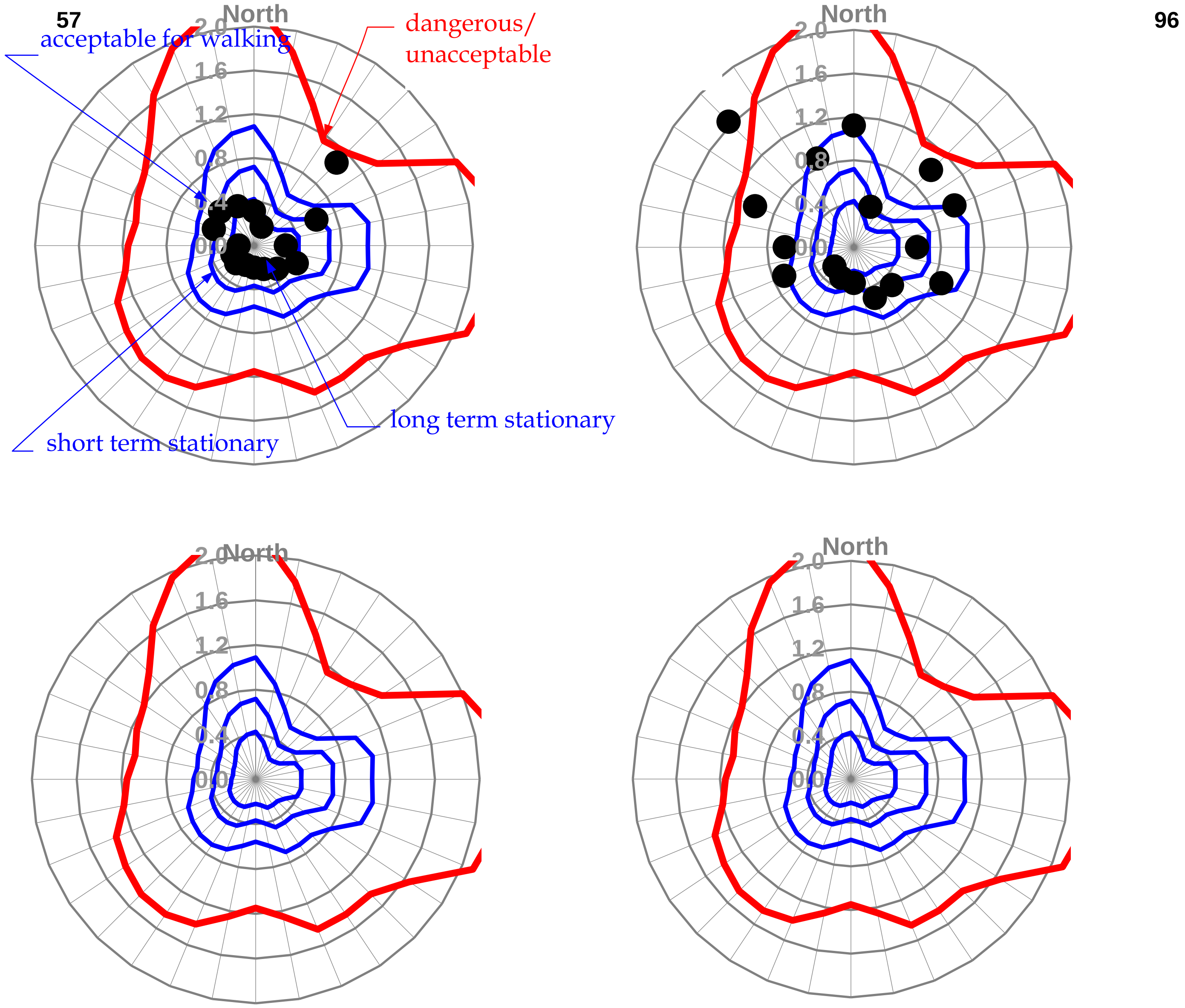


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A21 - Centre Plaza

Test Location

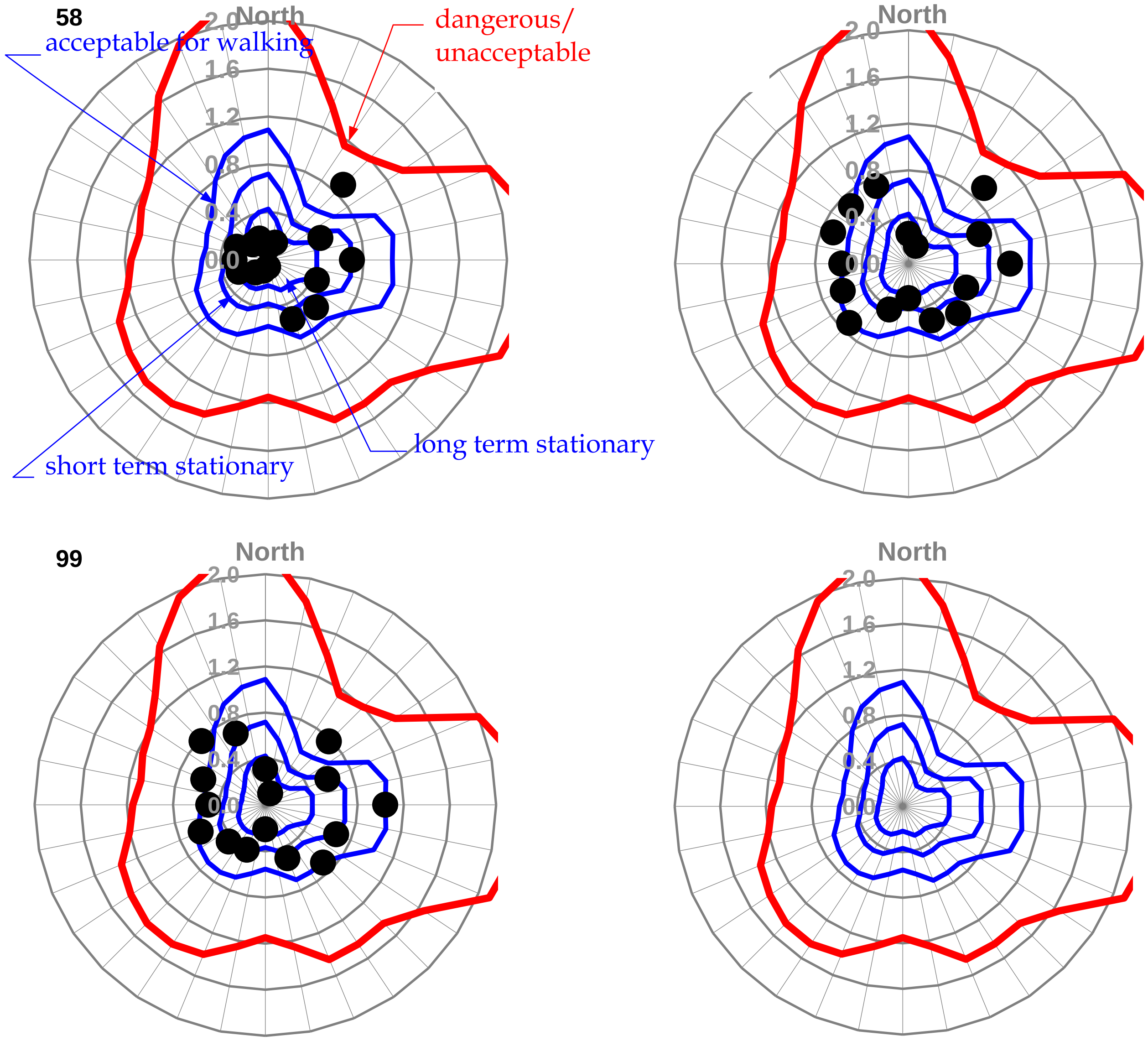


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A22 - Centre Plaza (continued)

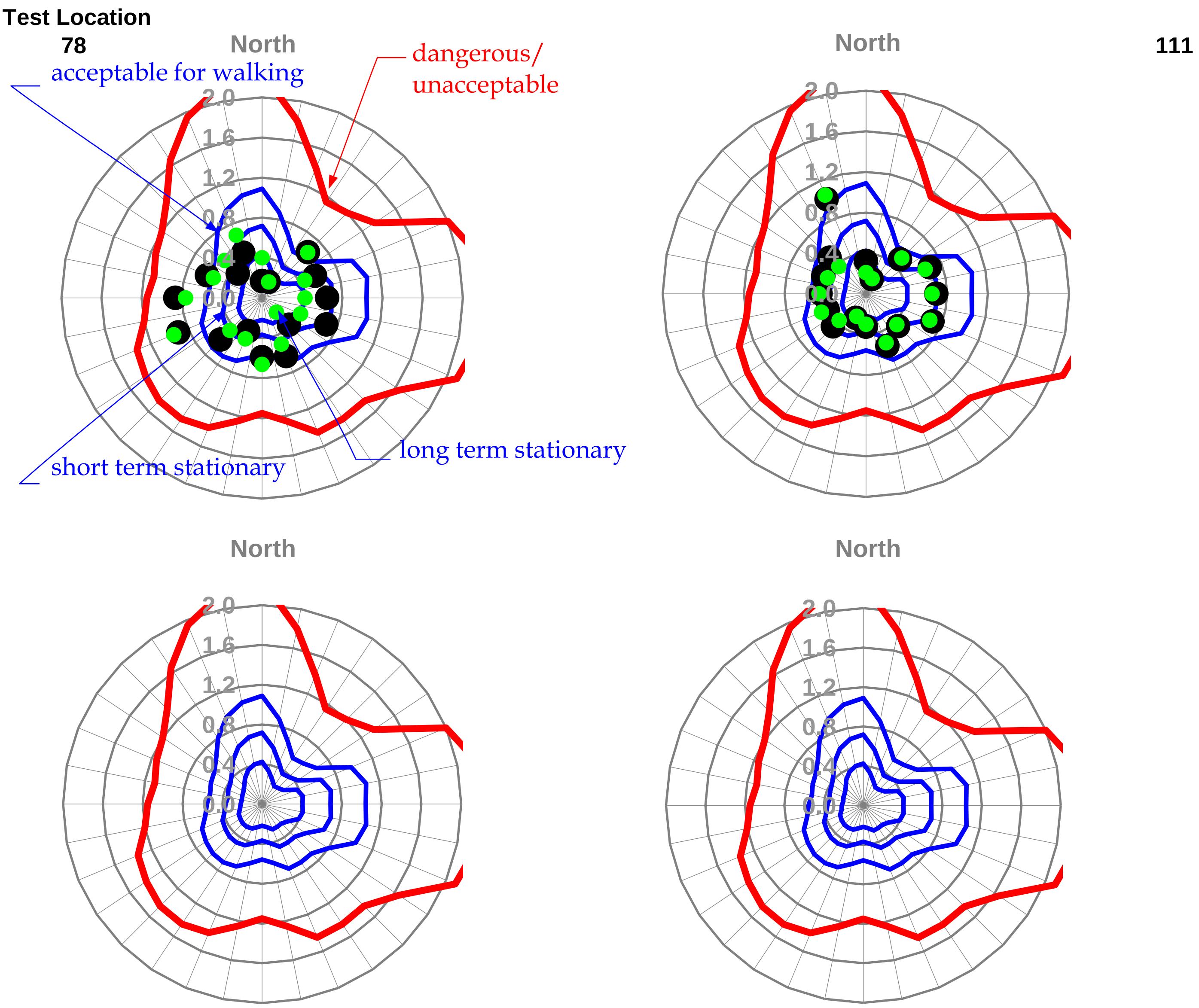
Test Location



Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●

Figure A23 - South Plaza

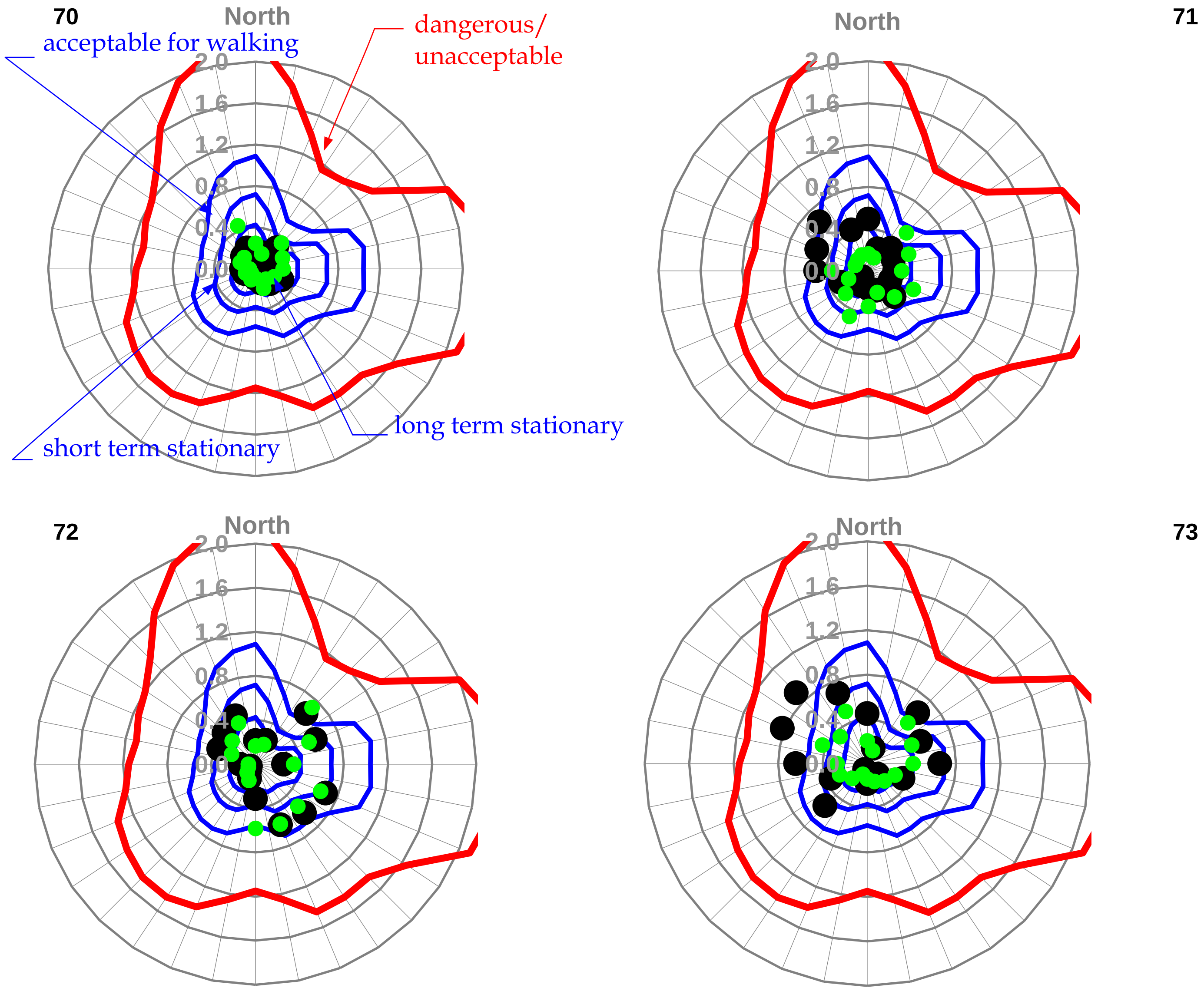


Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A24 - Belmore Park

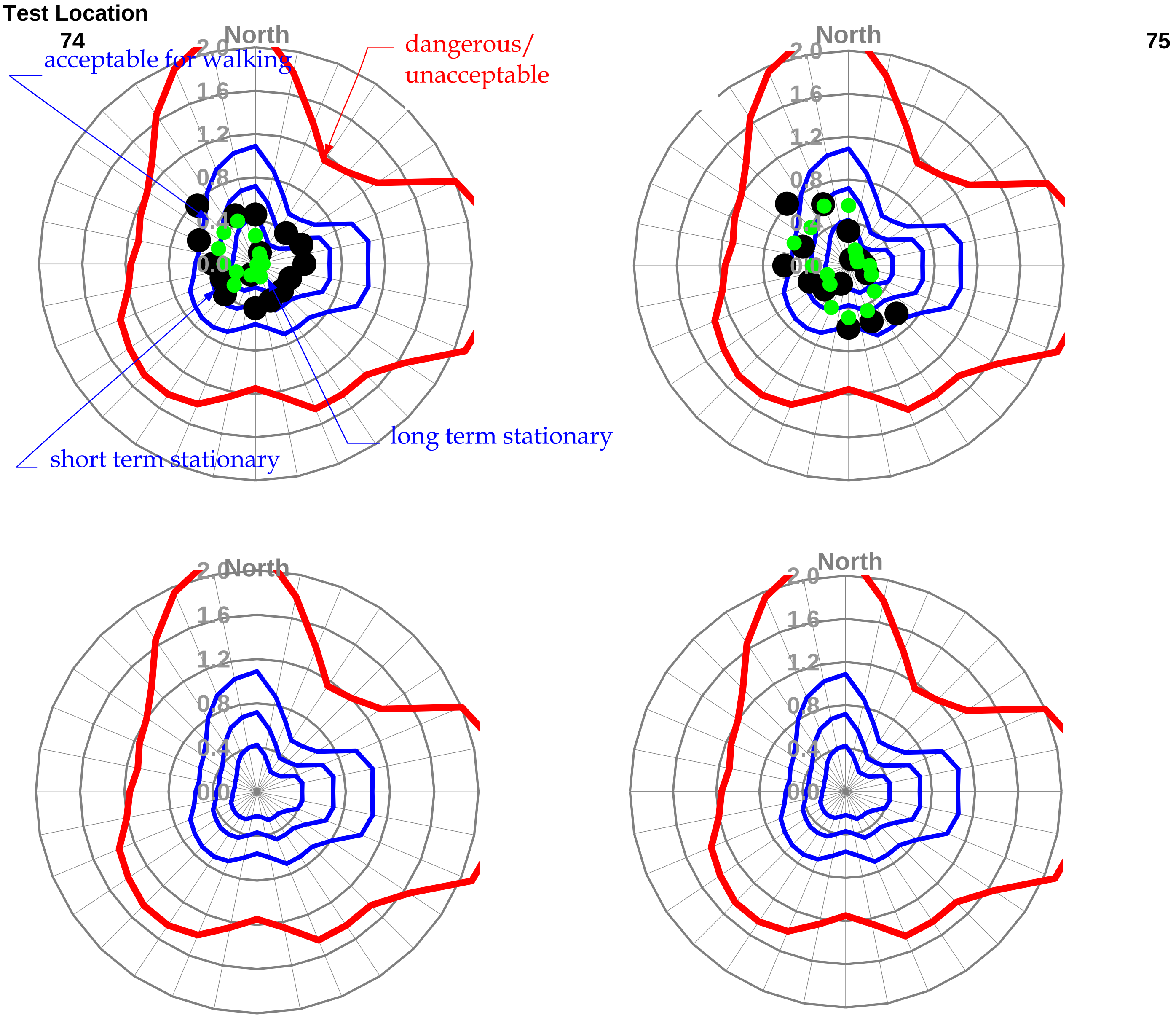
Test Location



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

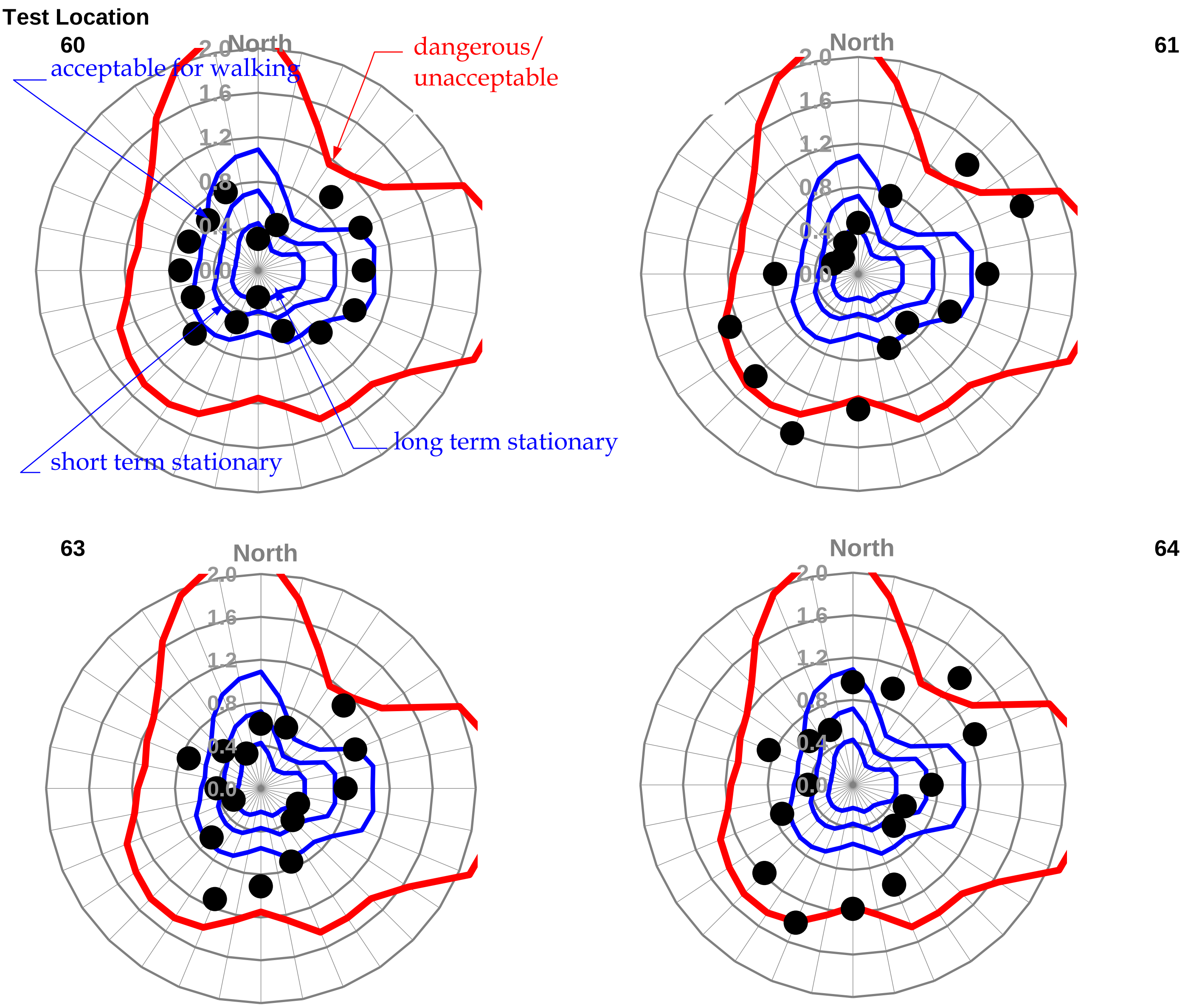
Figure A25 - Central Station



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

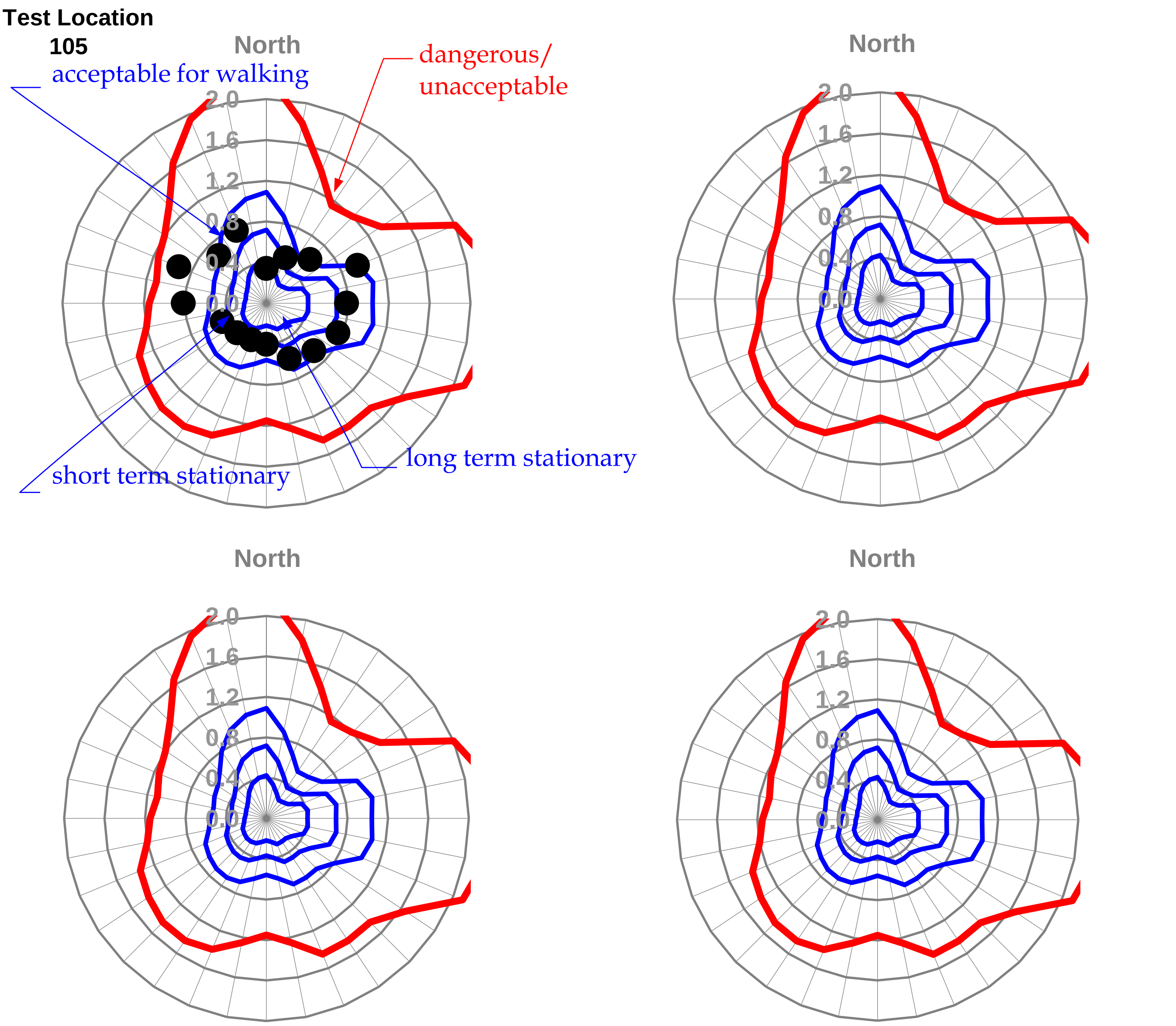
Figure A26 - Central Station (continued)



Peak velocity squared ratio $\left| \frac{\hat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A27 - Bridges

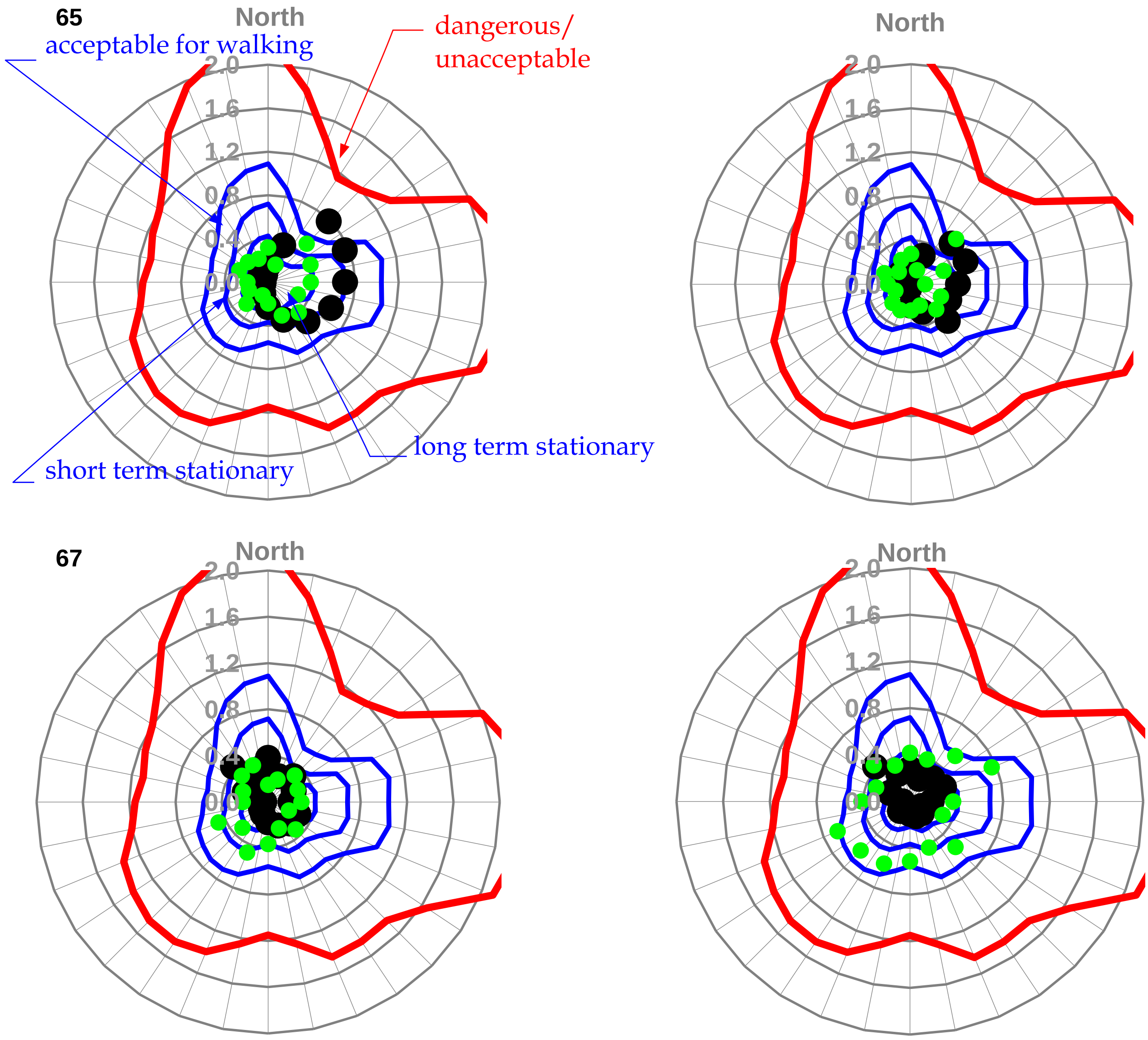


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022 ●

Figure A28 - Bridges (continued)

Test Location



Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^{2}$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

Figure A29 - Suburban Platforms

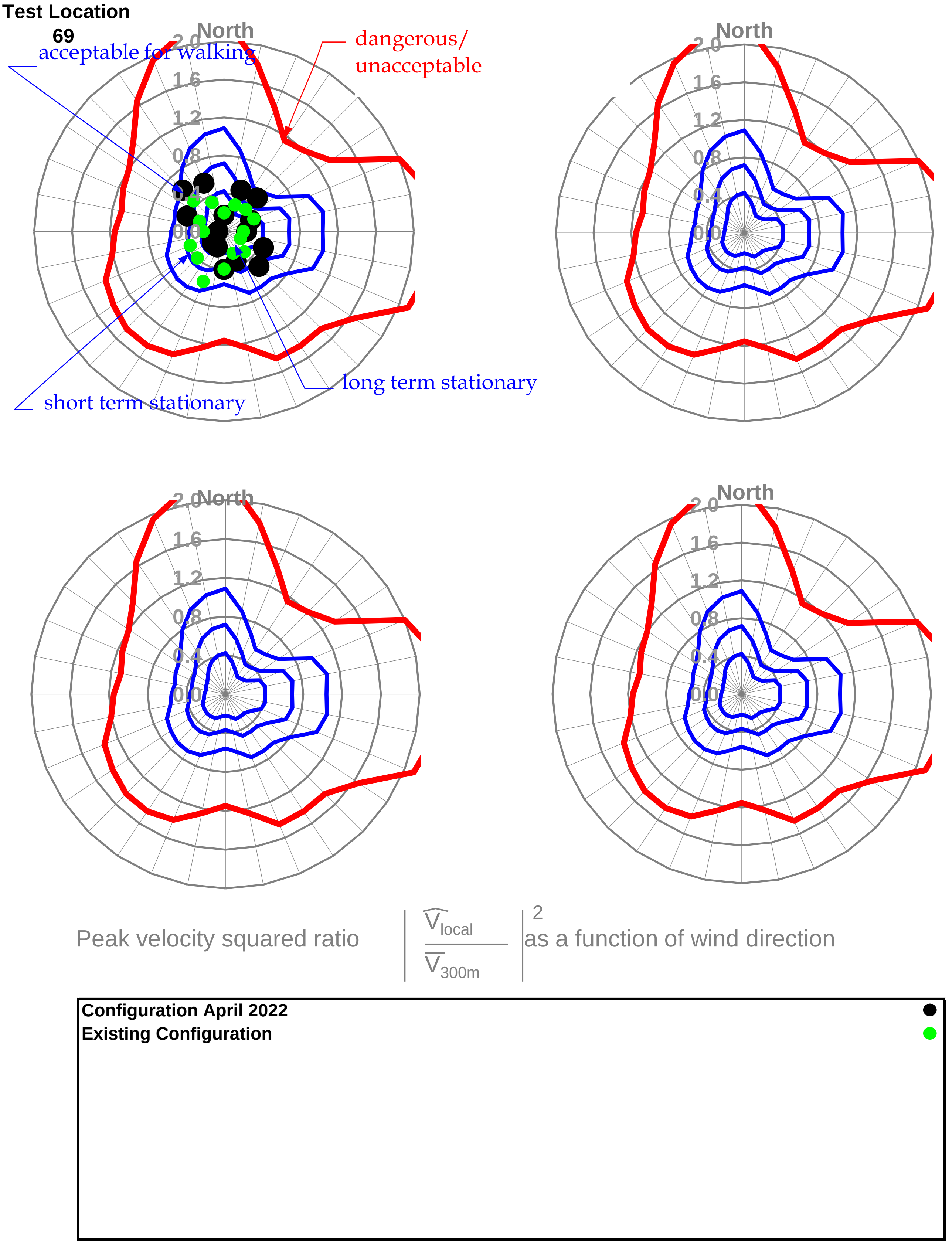
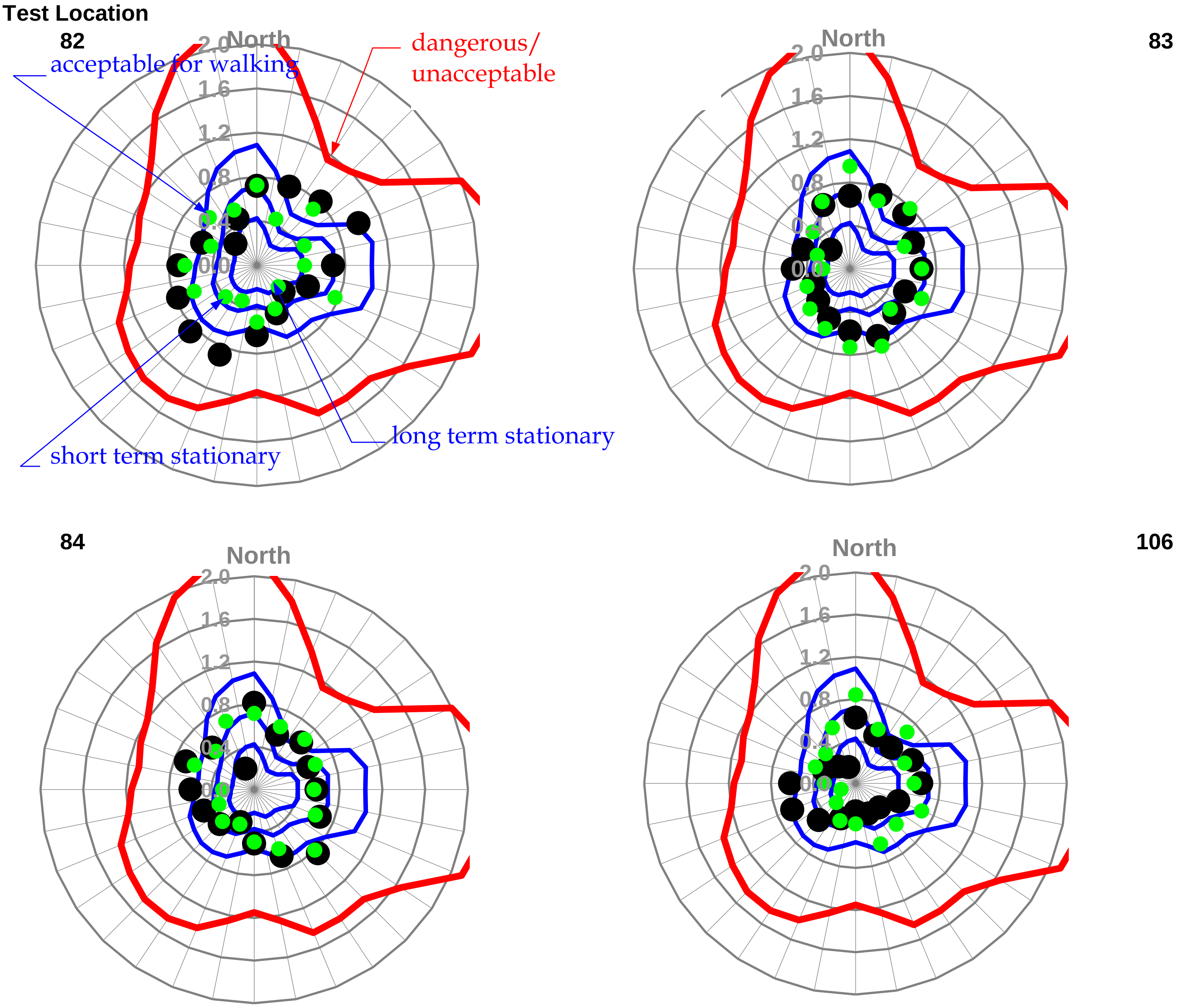


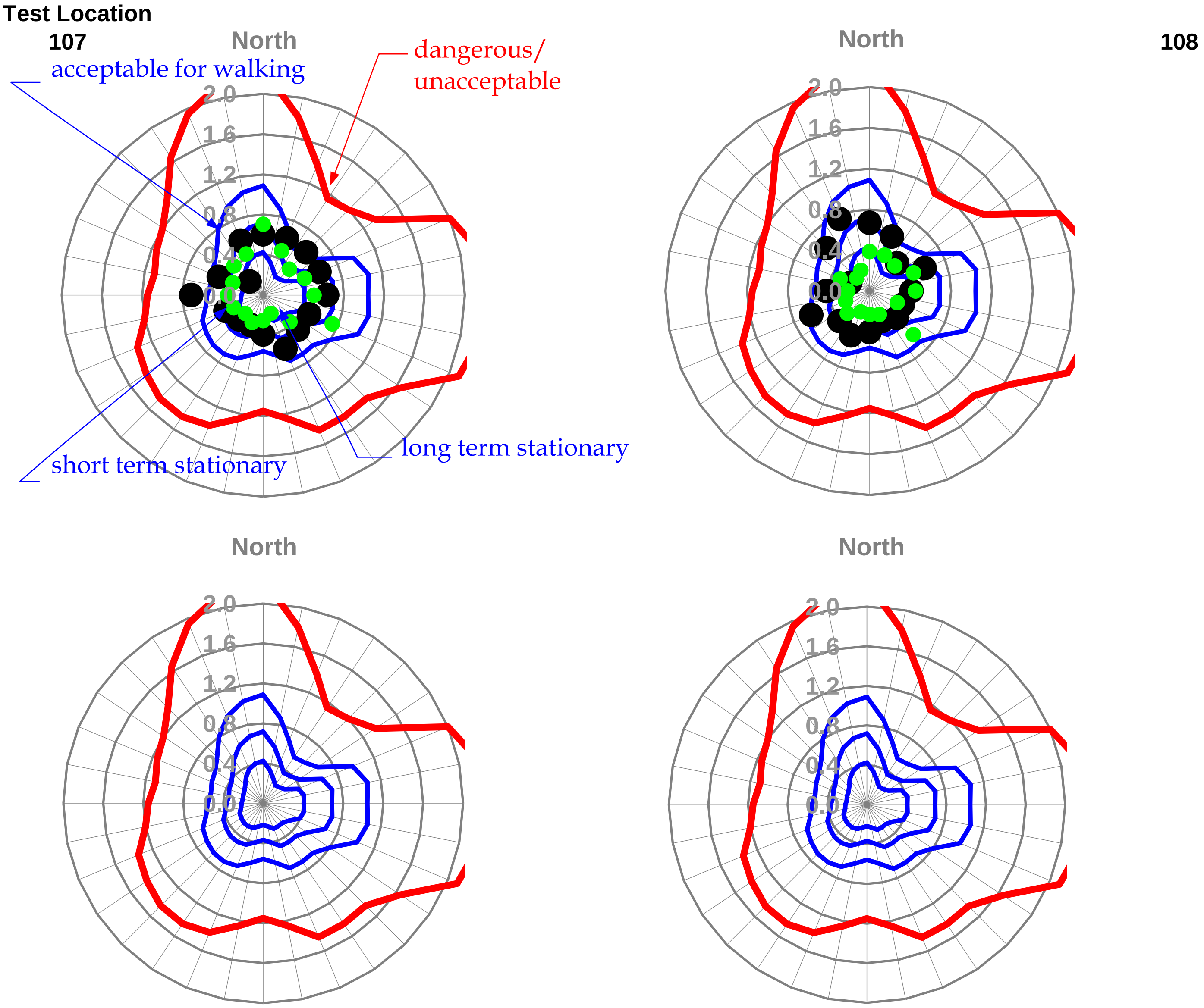
Figure A30 - Suburban Platforms (continued)



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

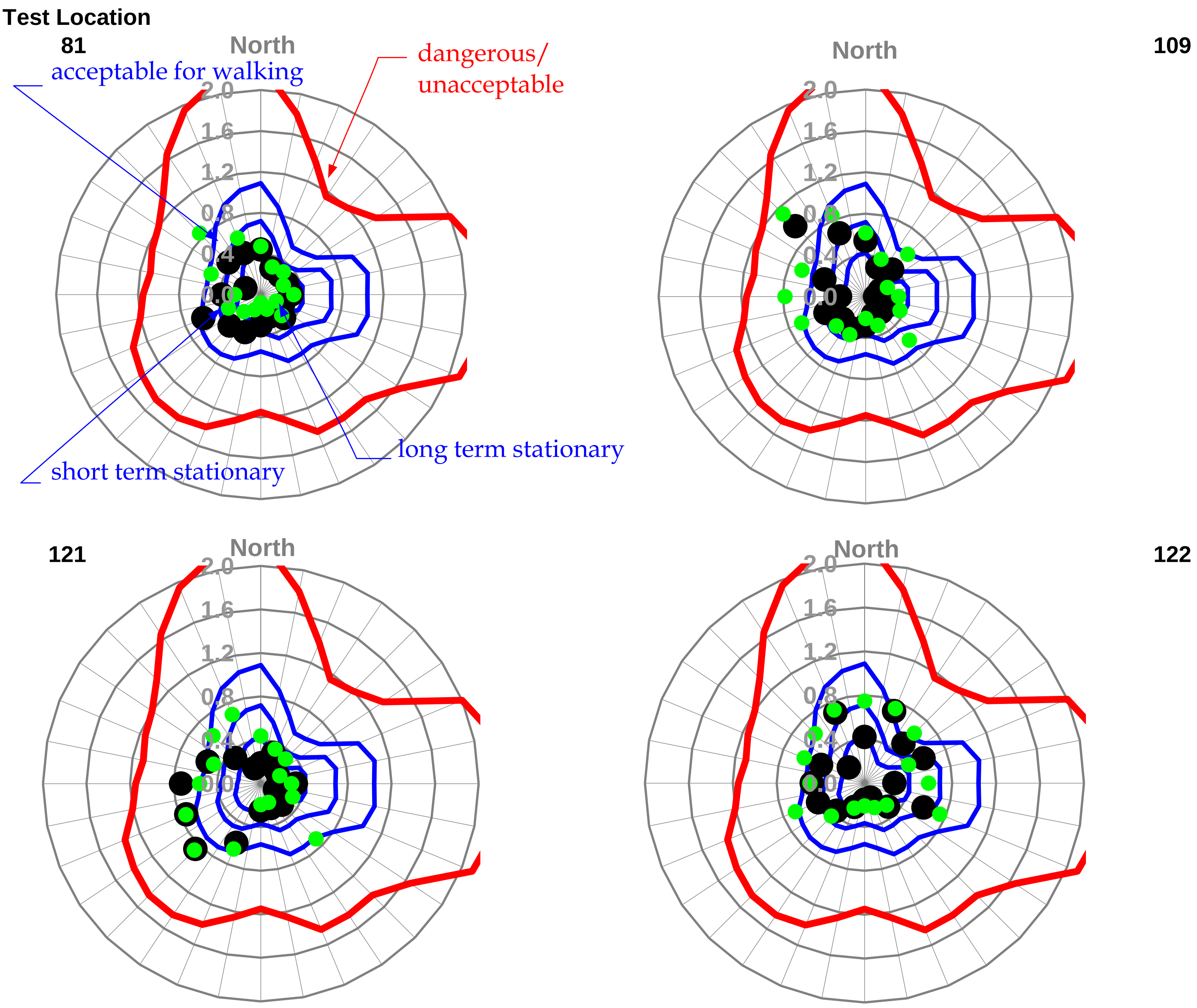
Figure A31 - Prince Albert Park



$$\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$$

Configuration April 2022	●
Existing Configuration	●

Figure A32 - Prince Albert Park (continued)

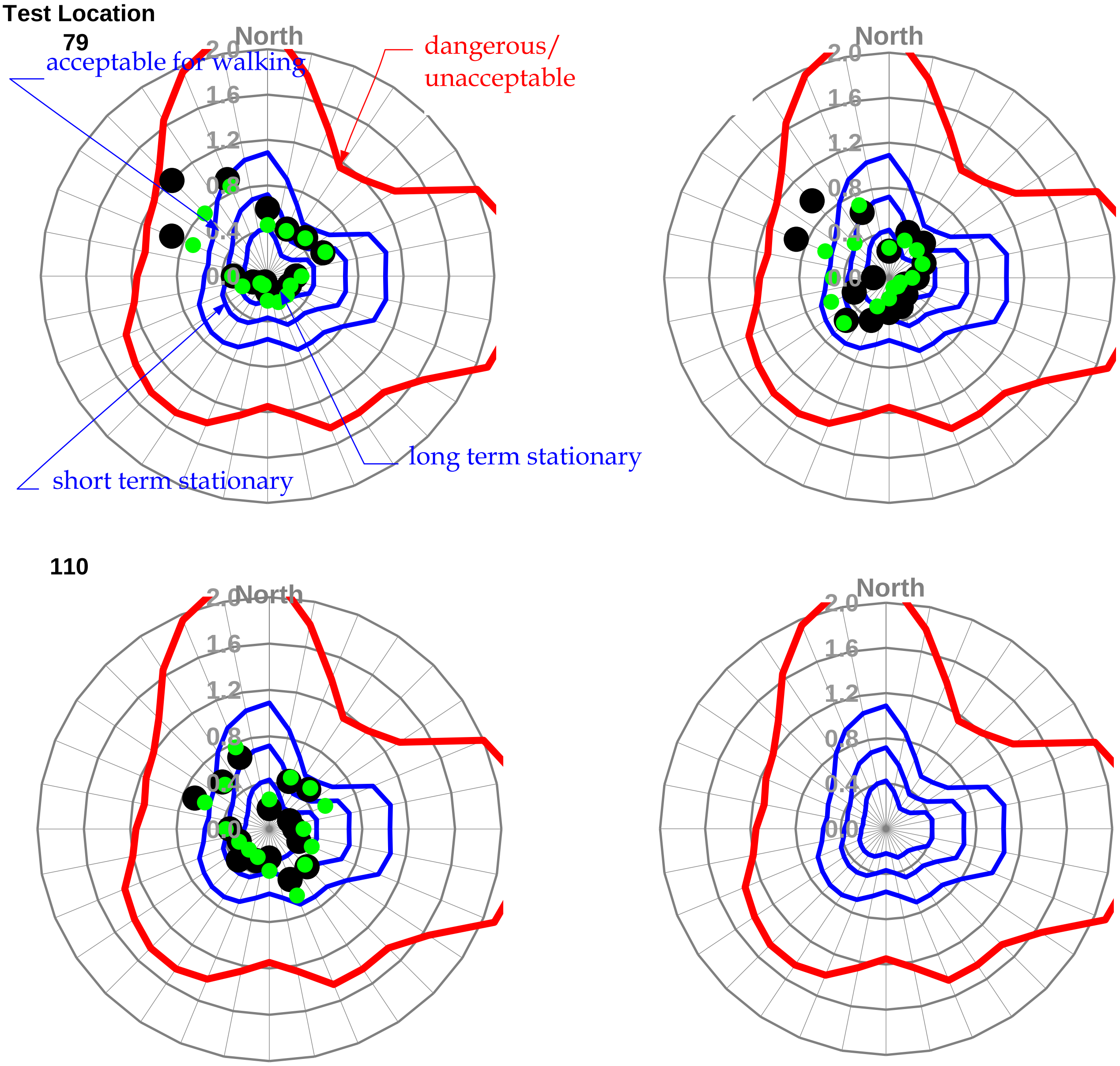


Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

- Configuration April 2022 ●
- Existing Configuration ●

Figure A33 - Chalmers Street

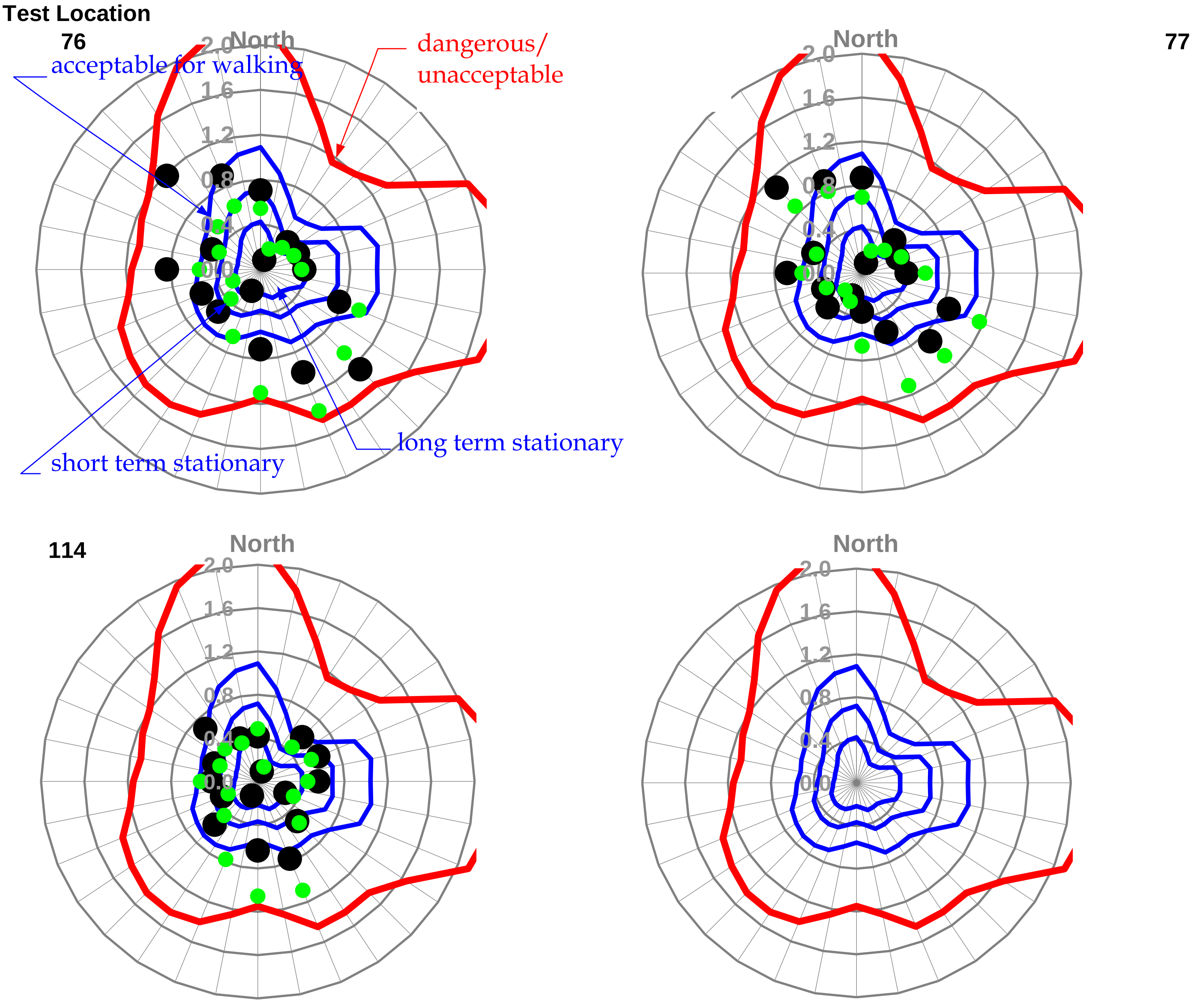
Test Location



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

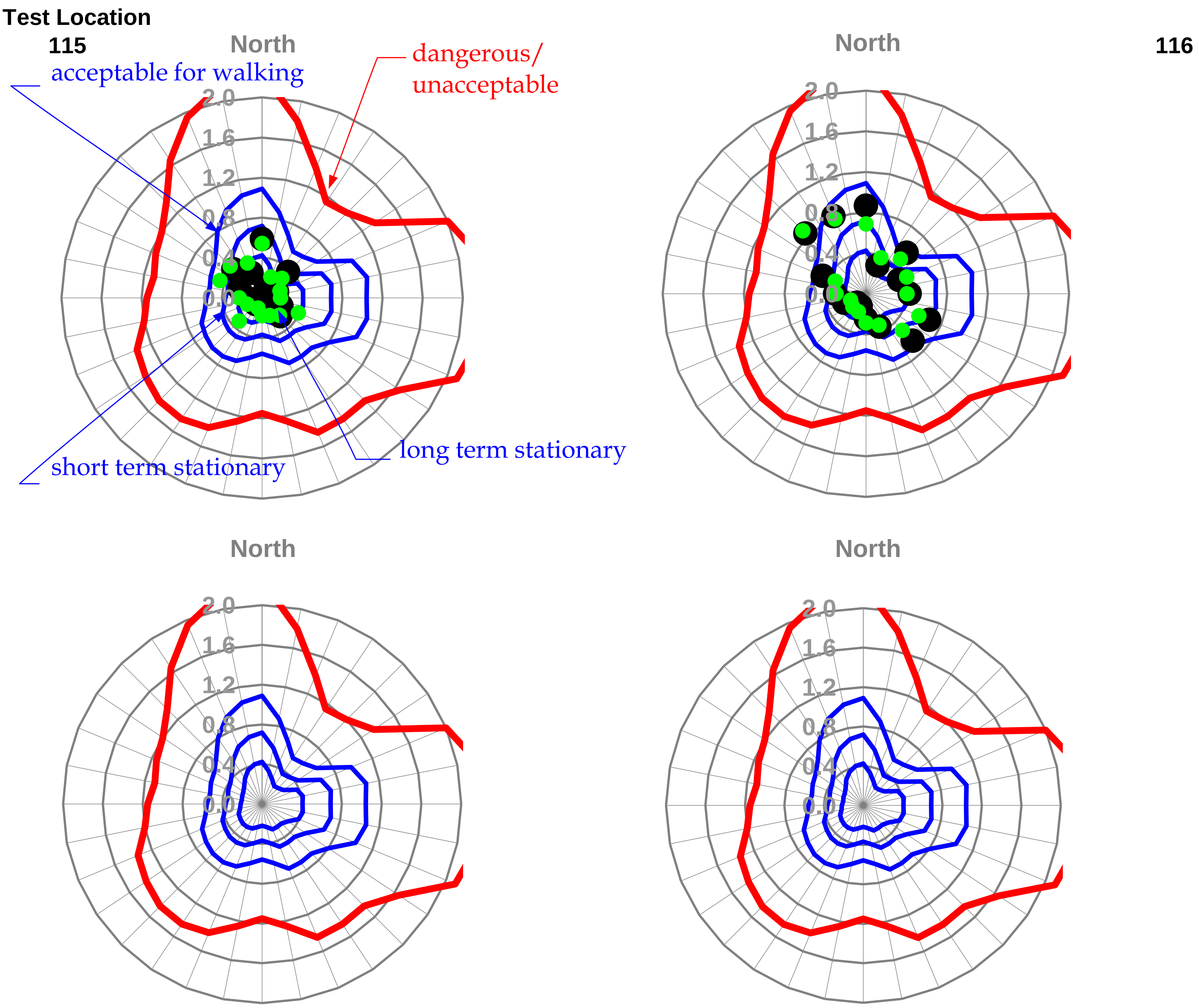
Figure A34 - Elizabeth Street



Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

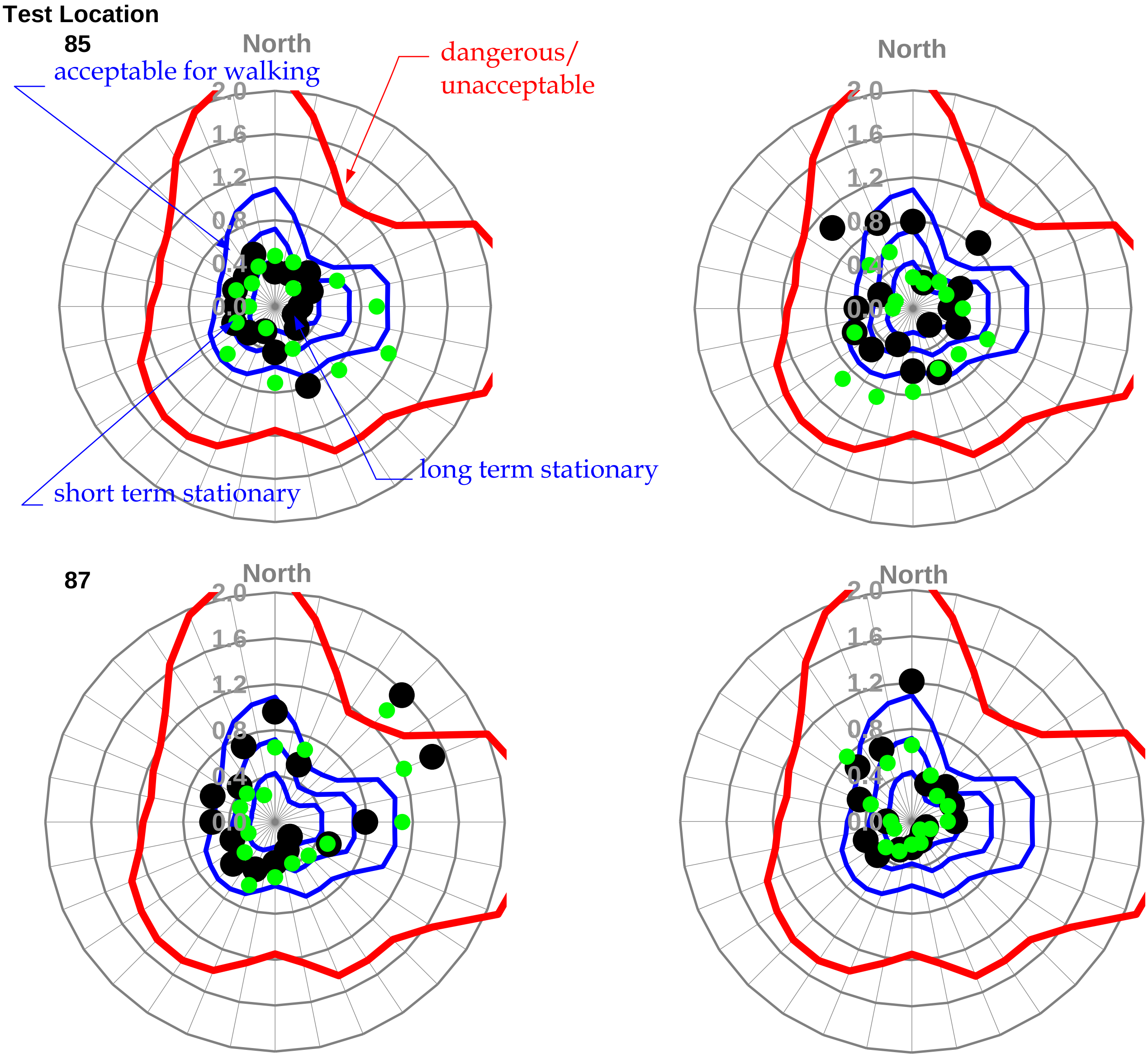
Figure A35 - Railway Colonnade Dr



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\bar{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	● (green)

Figure A36 - Ambulance Avenue



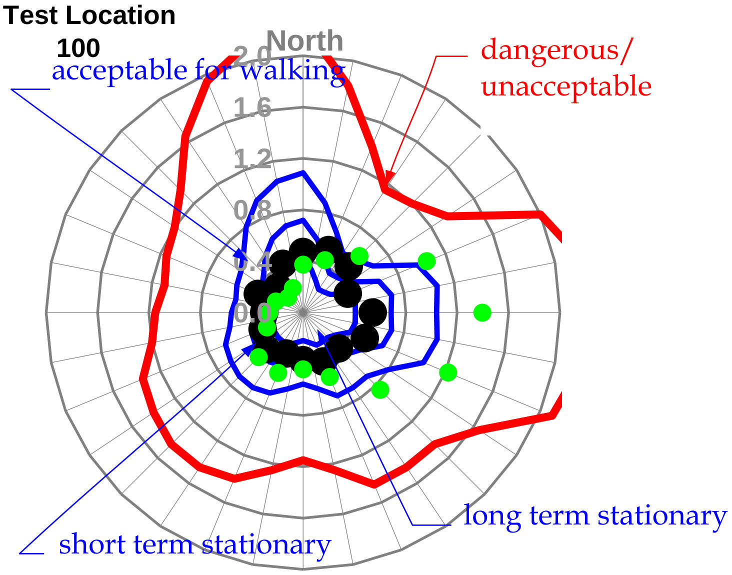
Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^{2}$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

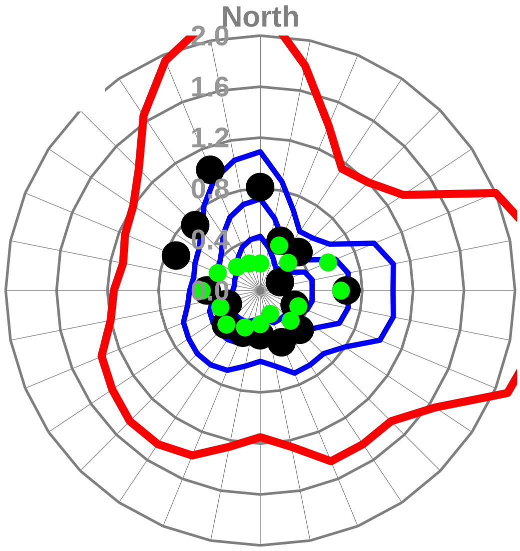
Figure A37 - Lee Street

Test Location

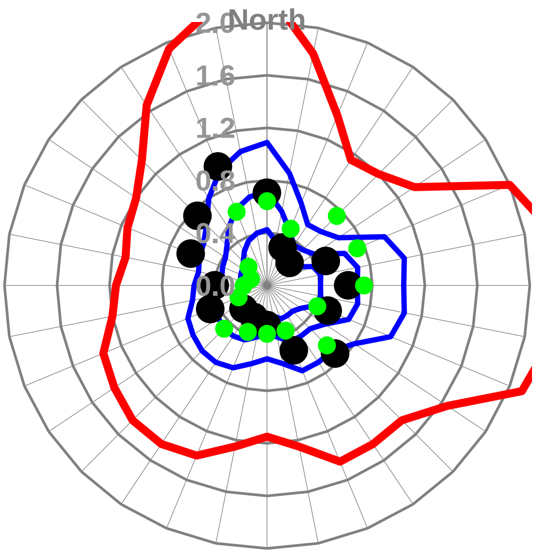
100



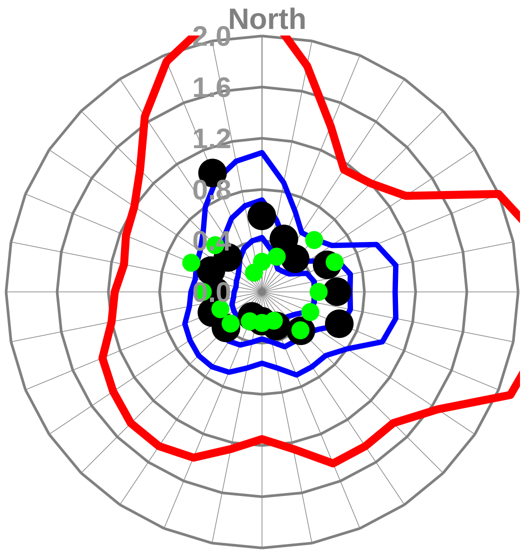
101



102



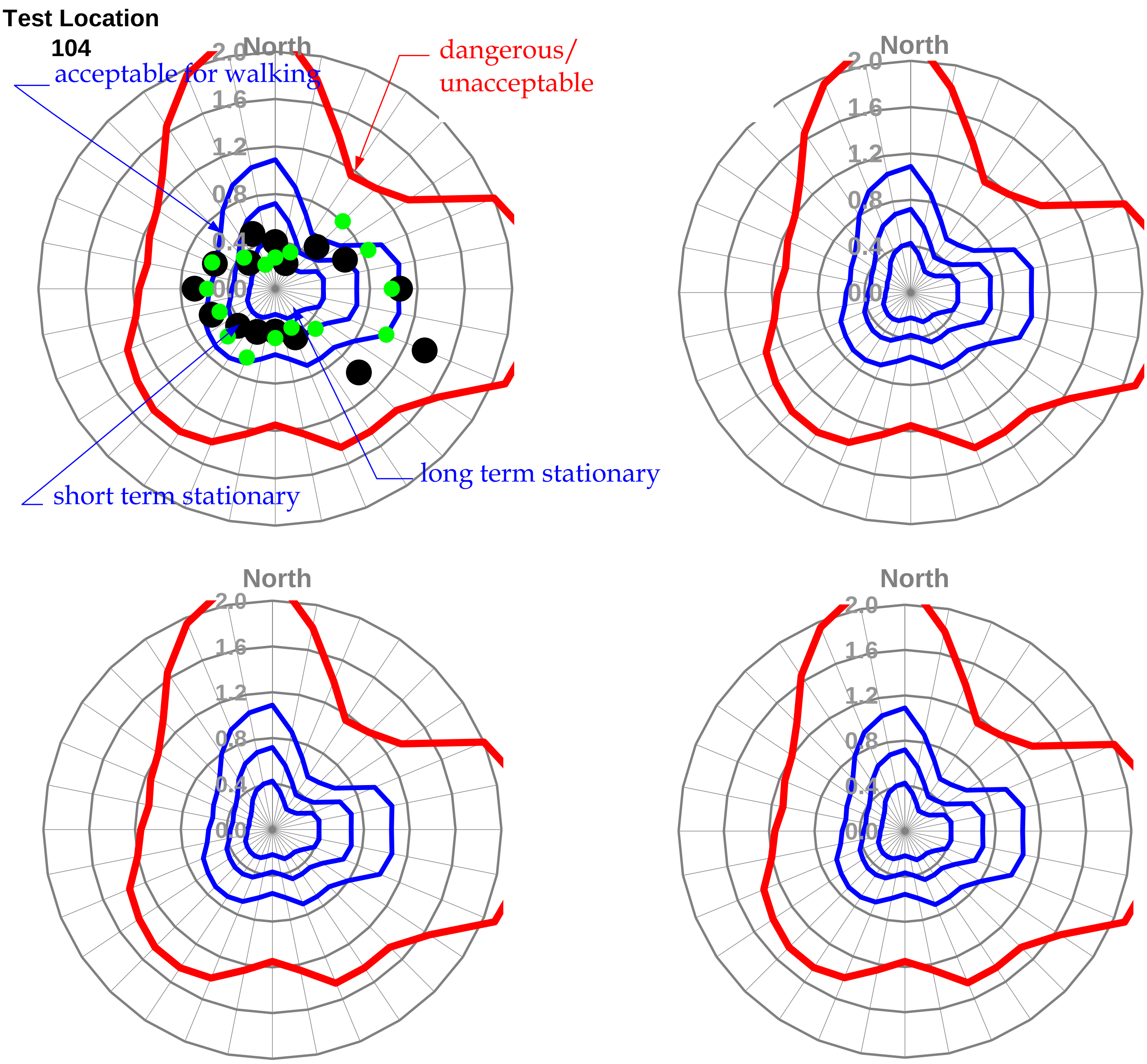
103



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	● (black)
Existing Configuration	● (green)

Figure A38 - Lee Street (continued)



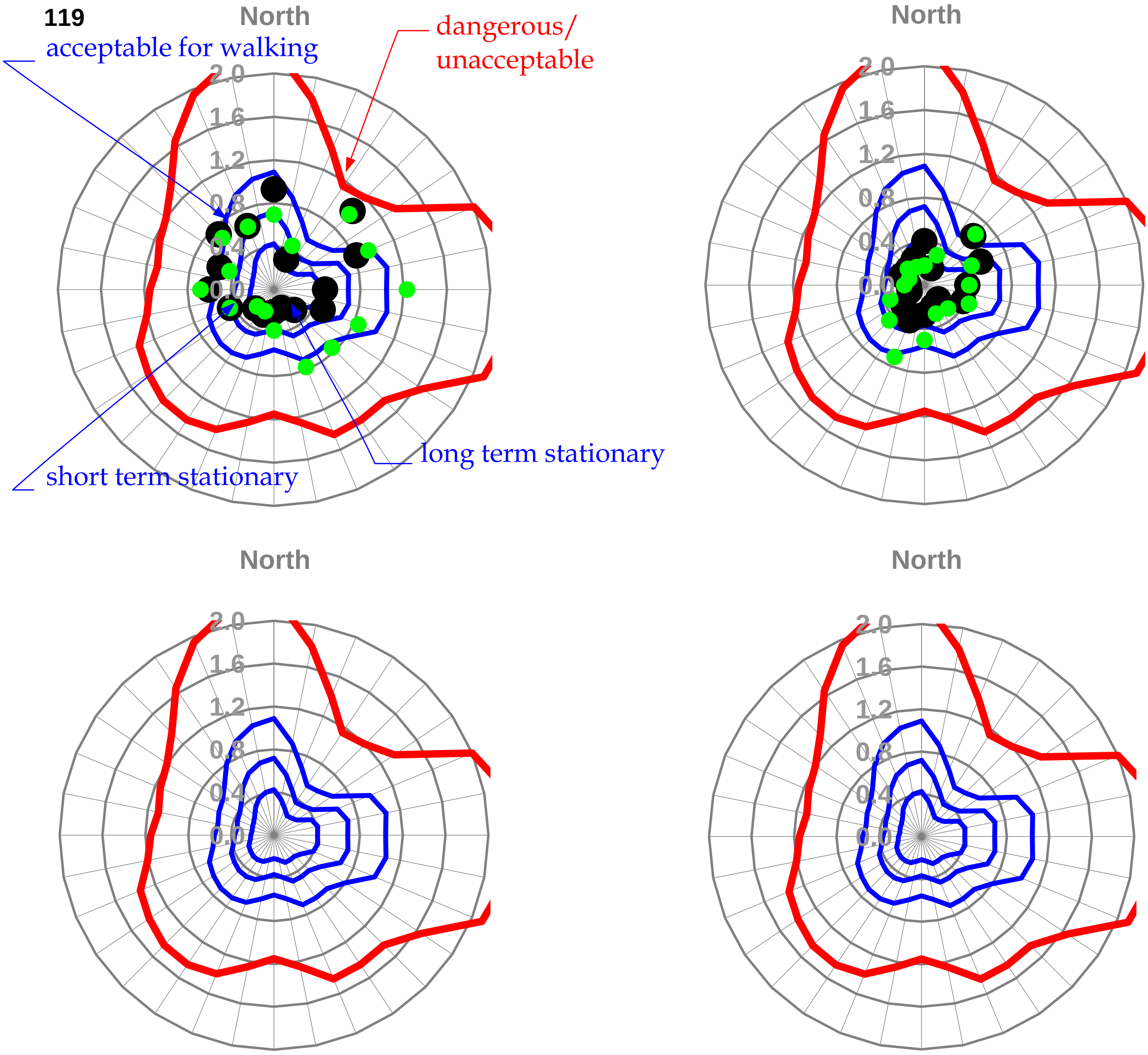
Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A39 - Lee Street (continued)

Test Location

119 **120**



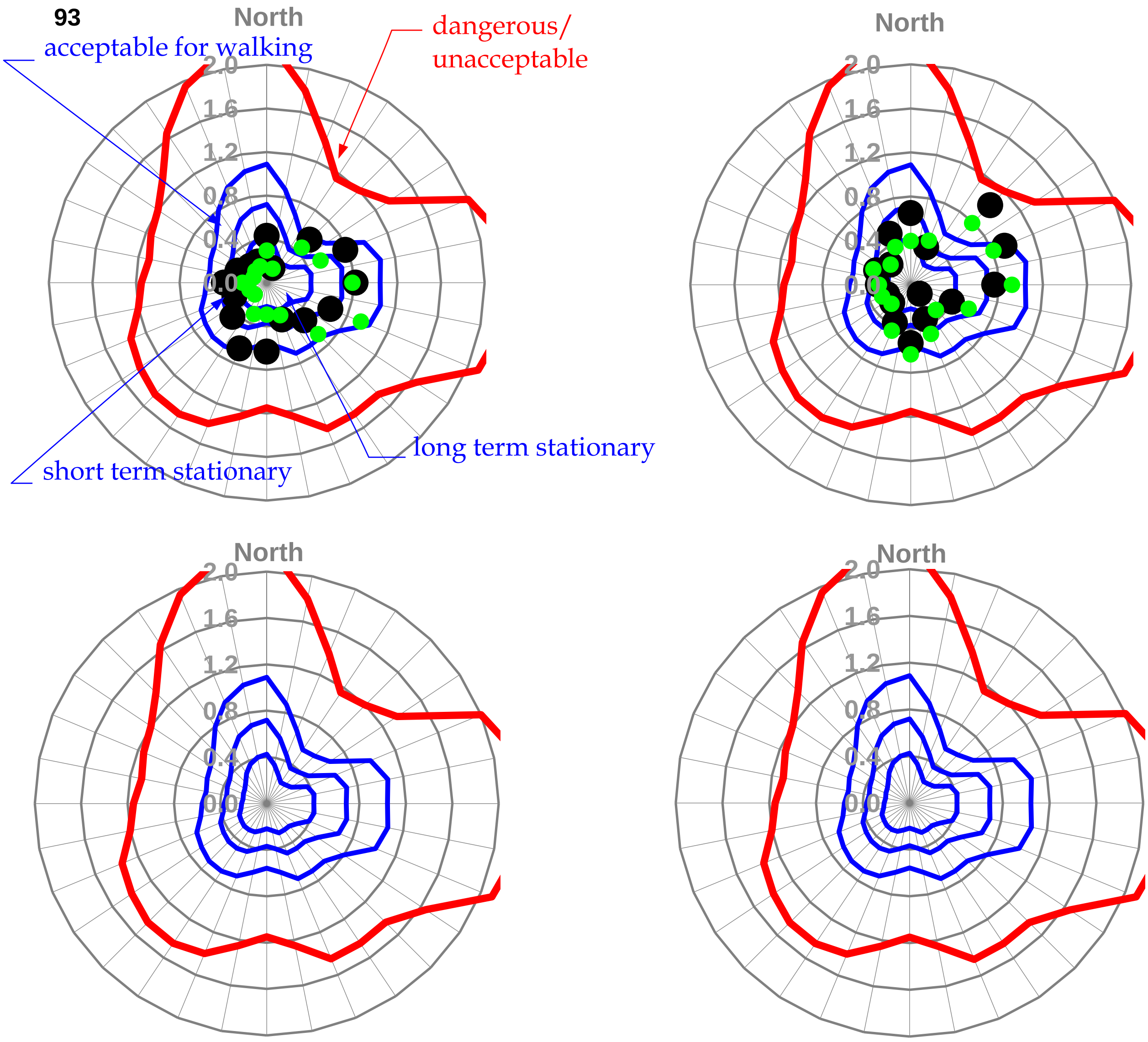
Peak velocity squared ratio $\left|\dfrac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A40 - Railway Square

Test Location

93 **94**

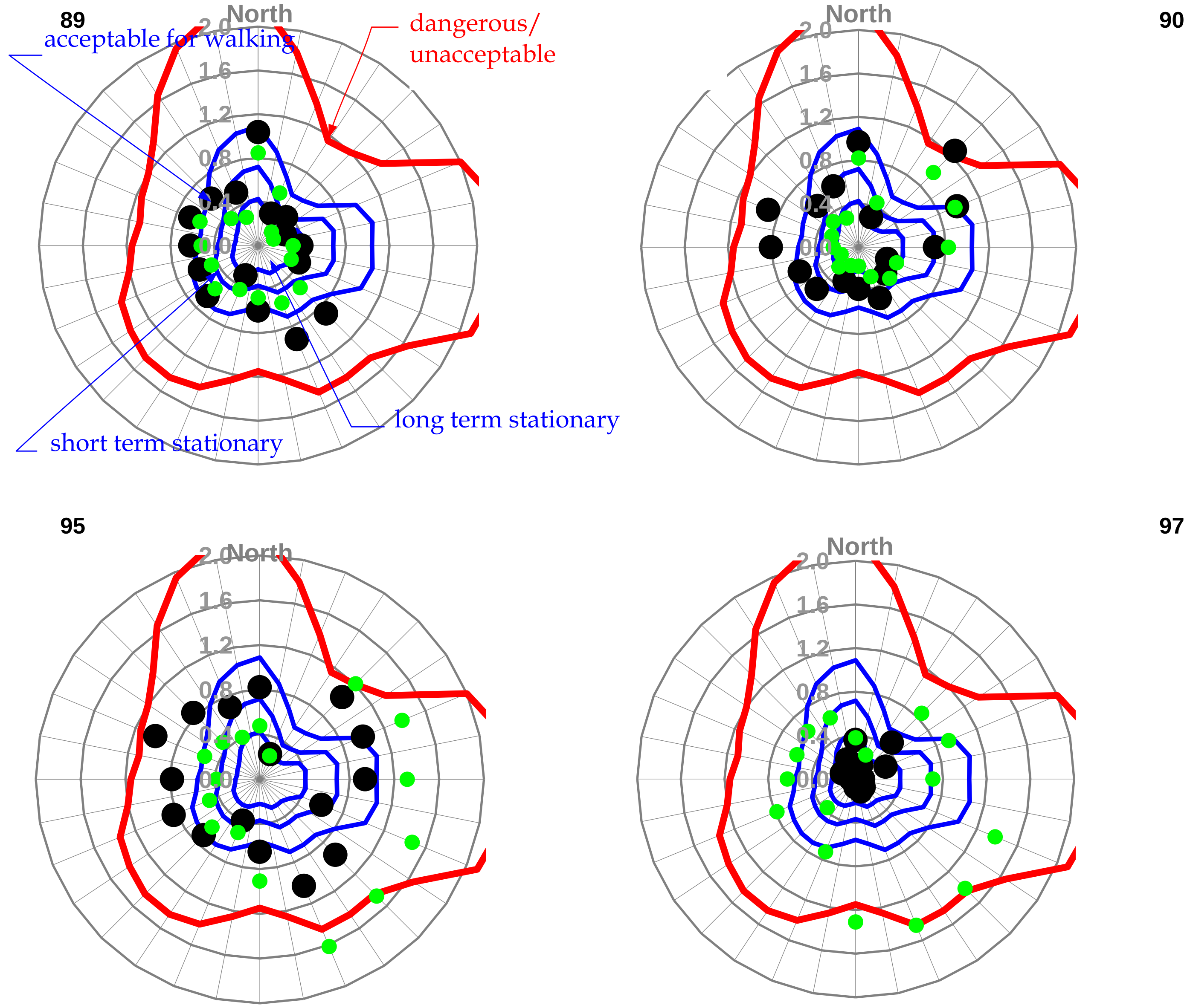


Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A41 - George Street

Test Location

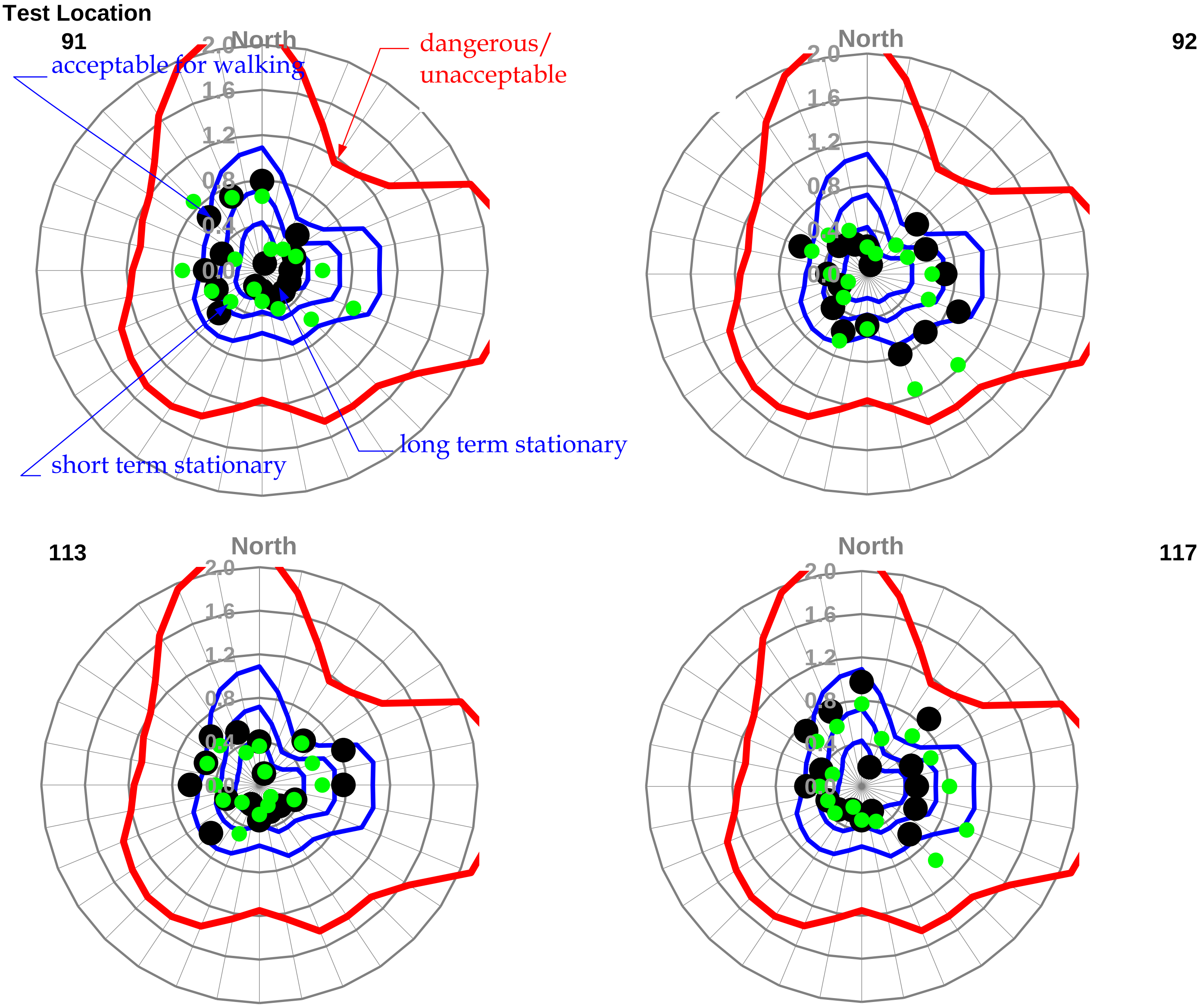


Peak velocity squared ratio $\left| \frac{\widehat{V}_{local}}{\overline{V}_{300m}} \right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A42 - Toga

Test Location

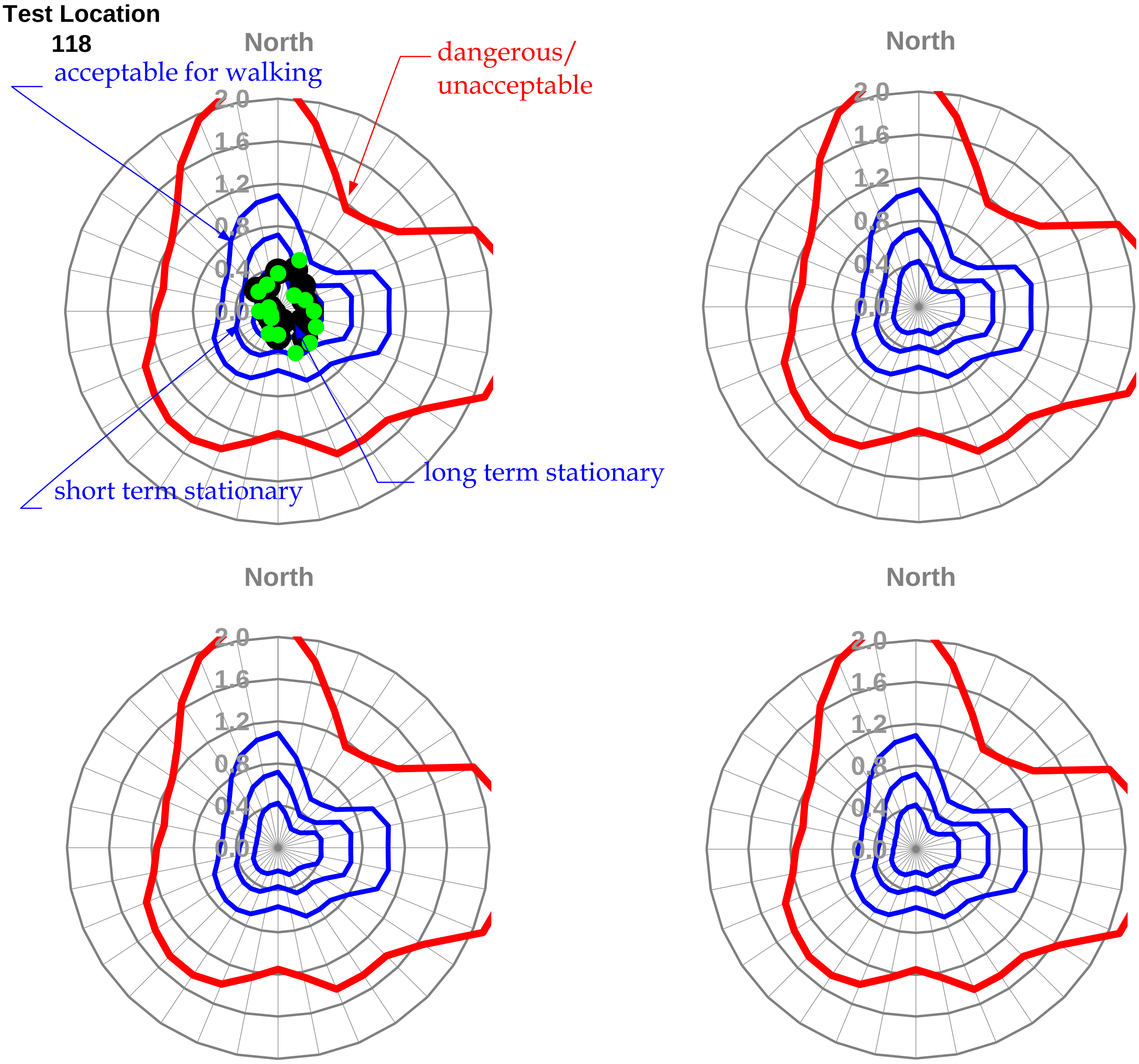


Peak velocity squared ratio $\left|\frac{\widehat{V}_{local}}{\overline{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022	●
Existing Configuration	●

Figure A43 - Pitt Street

Test Location
118



Peak velocity squared ratio $\left|\frac{\hat{V}_{local}}{\bar{V}_{300m}}\right|^2$ as a function of wind direction

Configuration April 2022 ●
Existing Configuration ●

Figure A44 - Pitt Street (continued)

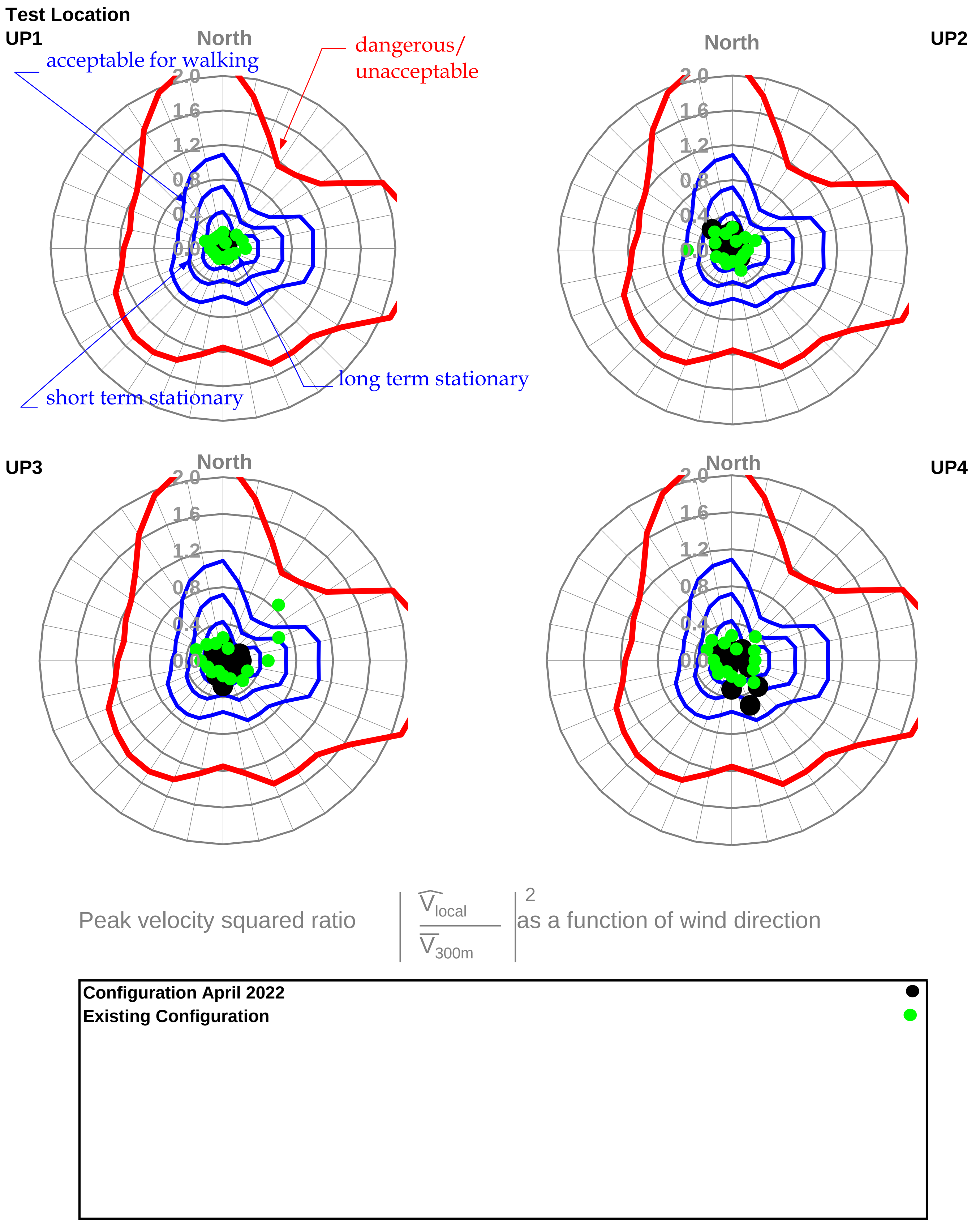
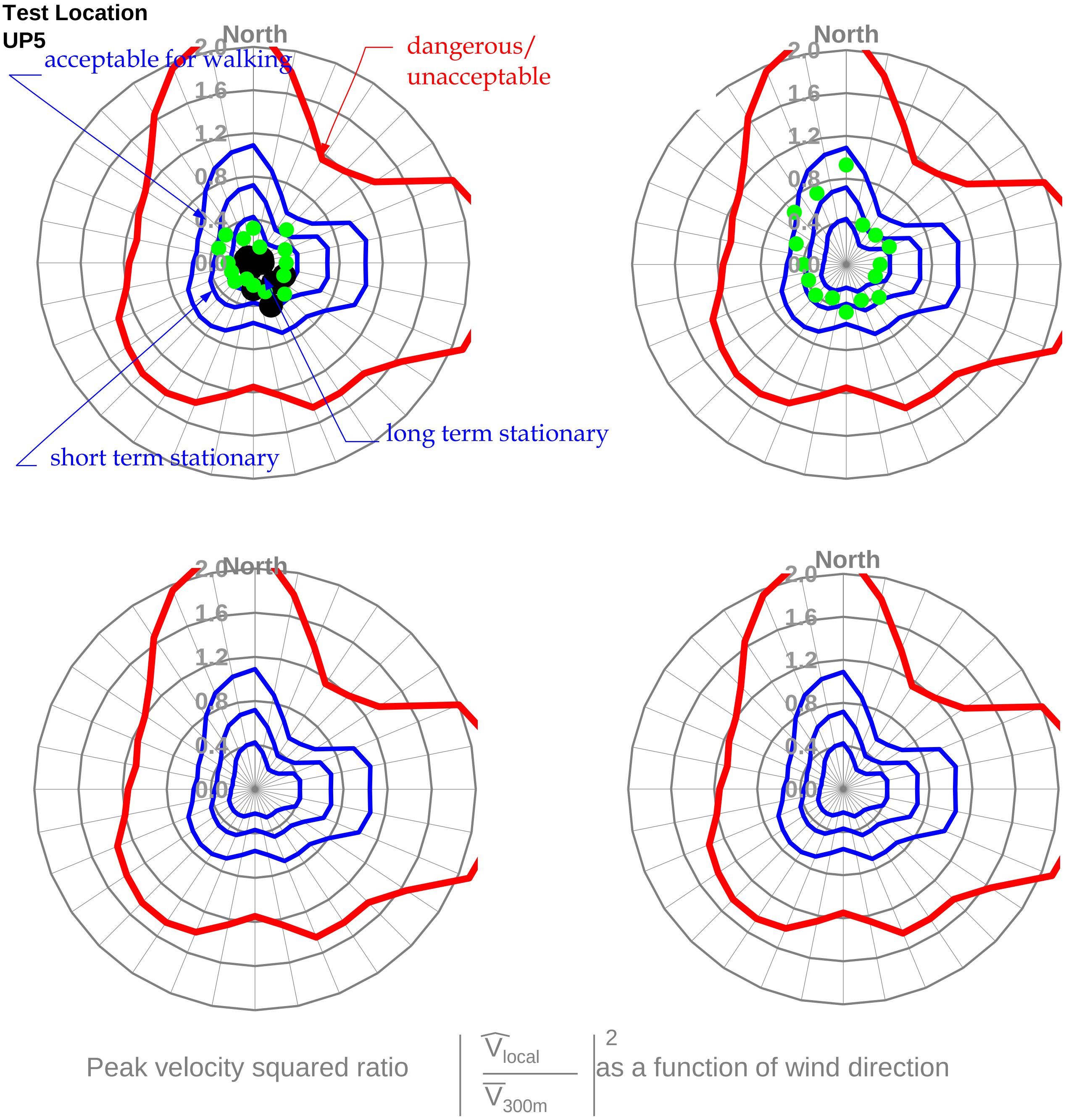


Figure A45 - Platforms under the OSD

Test Location
UP5

123



Configuration April 2022	●
Existing Configuration	● (green)

Figure A46 - Platforms under the OSD (continued)

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Paper 12

CRITERIA FOR ENVIRONMENTAL WIND CONDITIONS

W.H. MELBOURNE

Department of Mechanical Engineering, Monash University, Clayton, Victoria 3168 (Australia)

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Summary

Since 1971 a number of authors have published criteria for the acceptability of environmental wind conditions for human comfort for a range of activities.

This paper notes that it is the forces caused by peak gust wind speeds and associated gradients which people feel most and discusses the relation between peak gust and mean wind speeds. Melbourne's criteria, which have been stated in terms of maximum gust speeds per annum, are shown to define a range of wind-speed probabilities, in particular, the frequency of occurrence of mean wind speeds, which then facilitates comparison between the various published criteria.

It is shown that, in spite of the apparent numerical differences in published wind speed criteria and the various subjective assumptions used in their development, there is remarkably good agreement when they are compared on a proper probabilistic basis.

1. Introduction

In recent literature and at the 4th International Conference on Wind Effects on Buildings and Structures, London, 1975, there has been some debate as to the quantitative values of wind speed to be used in criteria for environmental conditions around new building developments. It was noted by several of the authors at the above-mentioned conference, that in spite of the seeming numerical differences in wind-speed criteria quoted by a number of authors, the differences were, in fact, relatively small [1]. The problem is that the phenomenon of wind and frequency of occurrence is very complex and the numerical values developed for these criteria depend on the statistical framework in which they are set.

It is the purpose of this paper to discuss the physical nature and effect of wind on people in respect of the relationship between mean wind speeds and peak gusts produced in turbulent conditions and the statistical inference of the various ways of expressing the frequency of occurrence of given wind speeds, and hence to permit a comparison of the various published environmental wind criteria.

2. The reason for needing environmental wind-speed criteria

Whilst involved in the technical argument about criteria, it is important to remember the reason for trying to establish environmental wind-speed criteria.

Briefly, the need has arisen because unacceptable wind speeds can be induced around building developments and one way of avoiding these problems is to conduct wind-tunnel tests from which wind speeds around a proposed development can be estimated. Having obtained the facility for predicting likely wind conditions in a given area, it becomes necessary to develop some criteria as to the frequency of occurrence of wind speeds which are acceptable and unacceptable for a variety of activities.

3. How people feel the effects of wind

There seems little doubt that wind speed and rate of change of wind speed are the primary parameters in any assessment of how wind affects people, Melbourne [2], Hunt et al. [3]. There are, of course, other factors such as temperature, humidity, degree of shade and mode of dress, which are also significant; however, these are factors which can be superimposed on or used to modify the effects of wind speed and as such will not be dealt with here.

Wind gustiness, or fluctuation of wind speed with time, is a random process and whilst the mean wind speed is a meaningful and simple parameter to obtain, the rate of change of wind speed is not. Fortunately, the effect of rate of change of wind speed can be covered generally by the parameter of turbulence intensity of wind speed, that is the standard deviation over the mean of wind speed. Further, in terms of what people feel, it is often convenient to talk in terms of a gust wind speed, that is a wind speed averaged over the smallest periods of time to which a person can respond, of the order of seconds. The mean 2- or 3-second-gust wind speed has become a useful reference in this respect, because it is roughly equivalent to the peak gust speed recorded by the Dines anemometer and the larger cup anemometers.

The wind force felt by a person is related to dynamic pressure. Hence, whilst it may be convenient in one sense to relate criteria directly to wind speed, it must be appreciated that the force felt by a person is proportional to wind speed squared. For this reason a more rational feel for the problem is gained if comparative data are presented in terms of velocity pressures rather than velocities. However, the referring of criteria to wind speed has gained popular acceptance and values of wind speed are more easily remembered than numbers based on the square of wind speed, hence, criteria will be discussed in terms of wind speed.

In concluding this section, it is worth re-casting the opening sentence by now saying that it is the peak gust wind speeds and associated gradients which people feel most.

4. Relationships between peak gust and the mean wind speeds

The peak gust wind speed $\hat{u}$ is dependent on turbulence intensity and can be given in terms of the mean $\overline{u}$ and standard deviation σ_u as

$$\hat{u} = \overline{u} + 3.5\,\sigma_u \tag{1}$$

For example, for a turbulence intensity ($\sigma_u/\overline{u}$) of 15%, $\hat{u} = 1.5\,\overline{u}$, and for 30%, $\hat{u} = 2.0\,\bar{u}$, etc.

As noted, it is the peak gust wind speeds and associated gradients which people feel most and as such it is of interest to know under what conditions they occur. The observations of Melbourne and Joubert [4] indicated that the areas in full scale which have been classed as having unpleasant or unacceptably high wind speeds were all associated with high mean wind speeds. Later, model- and full-scale measurements by Isyumov and Davenport [5] and Melbourne [6] continued to show that the windiest areas were associated with high mean wind speeds, but that the turbulence intensity was important in determining the peak gust wind speeds. In the case of the former, the ratio of peak gust wind speed over mean wind speed $\hat{u}/\overline{u}$ for the three windiest conditions respectively were 1.5, 2.7 and 2.8 and for the latter 1.9, 1.9 and 2.4. For areas and wind directions with lower wind conditions, and obviously for much greater turbulence intensities, this ratio was typically as high as 5.0. This means that to get an accurate prediction of peak gust wind speeds from wind-tunnel model tests, it is essential that mean and rms or peak values for a given probability level be actually measured.

Although it is possible to have unpleasant areas with low mean wind speeds and high turbulence intensities, the evidence to date does seem to indicate that for areas likely to have unacceptably high wind conditions, such as near corners, in narrow alleys and in arcades, the turbulence intensity is relatively low and that in these areas it would be reasonable to assume that the peak gust wind speeds will be about twice the mean wind speed. This means that wind-tunnel investigations, in terms of exploring and improving likely areas of high wind conditions, can often be reasonably based on very simple and inexpensive model measurements of mean wind speed. However, this does not mean that the need to model the turbulence characteristics of the incident wind stream can be overlooked, as a low turbulence stream would produce quite different flow fields and erroneous information.

5. Melbourne's criteria for environmental wind speeds

Notwithstanding the usefulness of the above very simple tests, to maintain flexibility in the application of environmental wind-speed criteria to all levels of turbulence, the author believes it is necessary to frame the definition in terms of gust wind speeds related to some meaningful return period or frequency of occurrence. Criteria which are defined only by mean wind speeds need to be qualified with respect to turbulence to have any general application.

Melbourne's criteria [2, 7] were based on two levels of wind speed, an unacceptable level at which wind gusts would be strong enough to knock people over and a level generally acceptable in main public access-ways based on conditions which had existed in the main Australian cities during the first half of the 20th century, when building was dense but heights restricted to about 30 m. Temperatures are typically between 10° C and 30° C with people appropriately dressed for the outside temperature conditions. These criteria simply state that in main public access-ways wind conditions are

(a) completely unacceptable if the annual maximum gust exceeds 23 m/s (the gust speed at which people begin to get blown over),

(b) generally acceptable if the annual maximum gust does not exceed 16 m/s (which results in half the wind pressure of a 23 m/s gust). Along the lines of Davenport's [8, 9] suggestions for comfort for activities less than walking in a main public access-way, two additional comfort criteria have been added to the original criteria as follows:

(c) generally acceptable for stationary short-exposure activities (window shopping, standing or sitting in plazas), if the annual maximum gust does not exceed 13 m/s,

(d) generally acceptable for stationary, long-exposure activities (outdoor restaurants, theatres), if the annual maximum gust does not exceed 10 m/s.

From these basic criteria a probability distribution, or frequency of occurrence, can be developed to suit any turbulence conditions. An example of such a distribution is given in Fig.1, for a turbulence intensity of 30%, where the distributions of the maximum gust speeds per annum, of 23 m/s, 16 m/s, 13 m/s and 10 m/s are shown as normal distributions back to the maximum hourly mean wind speed per annum (i.e. $\hat{u} = 2.0\,\overline{u}$ for $\sigma_u = 0.3\,\overline{u}$, which as discussed in Section 4 is a very typical situation). The upper part of Fig.1 shows the distribution of hourly mean wind speeds for these conditions using a Rayleigh distribution, and the expected maximum wind speeds for periods of a day, week, month and year have been calculated using a method by Davenport [10].

Davenport showed that the number of storms, on occasions during which a wind speed $\overline{u}$ is exceeded, can be expressed as

$$N_u = \sqrt{2\pi}\,\nu T\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^2\left(1+\frac{1}{k}\right)\right]^{1/2} k\left\{-\ln P_{(>\overline{u})}\right\}^{(k-1)/k} P_{(>\overline{u})} \tag{2}$$

where $P_{(>\overline{u})}$ is the probability of exceeding the mean wind speed $\overline{u}$ (based on the Weibull distribution), k is one of the Weibull parameters, Γ is the Gamma function and νT is the number of independent events per annum. The value of k varies about 1.5 to 2 and νT varies between 500 and 1000, depending on the local wind climate. From an evaluation of Davenport's eq. (2) [5] the ranges given in Table 1 can be obtained which express the relation between probability of exceeding a certain hourly mean wind speed and the number of storms per annum during which that mean wind speed is exceeded. Apart from

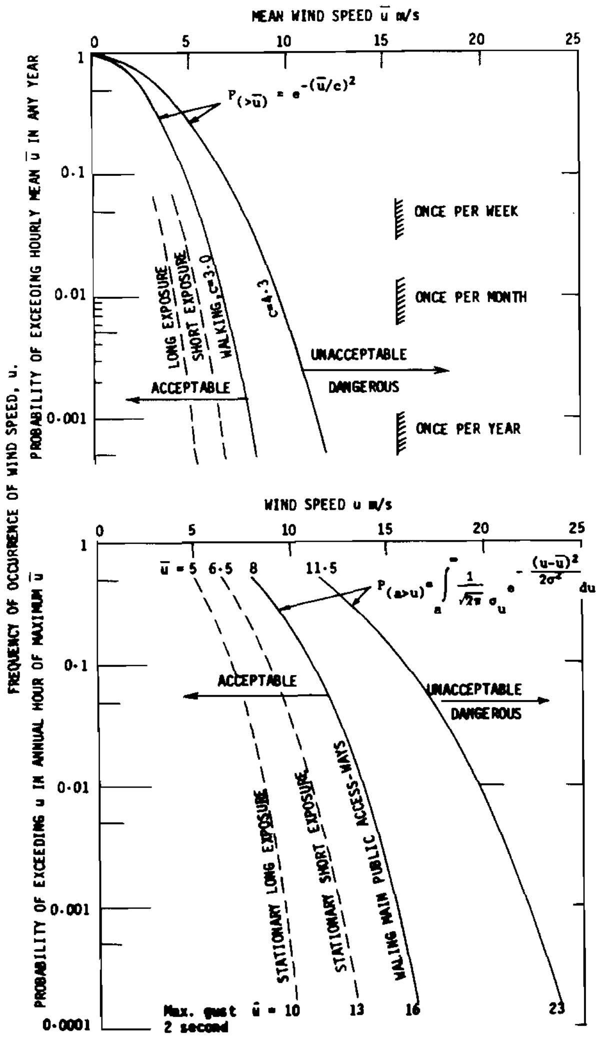

Fig. 1. Probability distributions of Melbourne's criteria for environmental wind conditions for daylight hours, for a turbulence intensity of 30%. $\sigma_u = 0.30\bar{u}$, $\hat{u} = 2.0\bar{u}$.

providing a very important link to give information about the maximum wind speeds likely to occur on average for various periods, such as once per year, once per month, etc., this also provides the necessary link to enable the various environmental wind speed criteria to be compared.

One other complication arises in respect of the number of storms per annum which are relevant to the assessment of environmental wind conditions for human comfort. It is obviously conservative to include winds which blow for all hours of the year, day and night, when most areas under consideration will only be occupied for half of the time or less. Although it does not make

TABLE 1

Relationship between probability of exceeding a mean wind speed and the average number of storms per annum during which that mean wind speed is exceeded

Number of storms per annum during which $\bar{u}$ is exceeded ($N_{\bar{u}}$)	Probability of exceeding an hourly mean wind speed $\bar{u}$ ($P_{(>\bar{u})}$)	
	All hours	Daylight hours
1, once per annum on average	0.00025—0.0005	0.0005—0.001
12, once per month on average	0.003—0.006	0.006—0.012
52, once per week on average	0.015—0.03	0.03—0.06

a great deal of difference, the author prefers to relate criteria and assessment to approximately half the total time, by relating the probability of exceedence to half the yearly cycling rate (i.e. 250—500 independent events per annum) and calling this procedure an assessment of environmental wind conditions relating to "daylight hours"; these ranges are also given in Table 1. Strictly speaking, the cycling rate and evaluation of the wind speed probability distributions should be related to the relevant occupancy times (i.e. daylight hours, afternoon hours, etc.), and in many parts of the world seasonal distributions are also significant. However, for the purposes of this comparison of criteria the simplistic assumptions above described as relating to "daylight hours" will be used in this paper.

6. Comparison of various criteria

Since 1971 several forms of criteria for environmental wind conditions have been published. The criteria developed by Wise [11], Penwarden [12, 13] Davenport [8,9], Lawson [14] and one by Hunt, Poulton and Mumford [3] are given in terms of mean wind speed at some stated or implied level of turbulence intensity between 15% and 20%. Comparison of these criteria can be made in Fig.2 with Melbourne's criteria which have been plotted for a turbulence intensity of 15%, i.e. for $\sigma_u/\bar{u} = 0.15$ and from eqn. (1) $\bar{u} = \hat{u}/1.5$.

Wise [11], in 1971, commented in relation to the Beaufort scale "that wind speeds much above about 5 m/s are likely to give unpleasant disturbance to clothing and hair" and "making reasonable assumptions about metabolic rate, and the thermal resistance of body layers and clothing, speeds of some 5 m/s appeared tolerable at 10° C in normal winter clothing". Penwarden [12] in 1973 and again in collaboration with Wise [13] in 1975 prepared a summary of wind effects on people based on a modified version of the Beaufort Scale from which the following three points can be extracted

discomfort begins $\bar{u}$ = 5 m/s
unpleasant $\bar{u}$ = 8—10 m/s
dangerous $\bar{u}$ = 15—20 m/s.

Penwarden and Wise [13] quoted a criterion which they had used at the Building Research Station, that conditions were regarded as acceptable, or no remedial action was required, if $\bar{u} < 5$ m/s for 80% or more of the time and vice versa, that remedial action would be taken if $\bar{u} > 5$ m/s for more than 20% of the time. In probability terms this criterion is interpreted as being acceptable if $P_{(\bar{u} > 5)} \leqslant 0.2$.

Davenport [8, 9] in 1972 amalgamated work by Wise, Melbourne and Joubert and suggested criteria for a range of activities; these were related to a Beaufort scale for open-country mean wind speeds at 10 m. These criteria also noted that the relative comfort level might be expected to be reduced by one Beaufort number for every 20° C reduction in temperature. In particular Davenport nominated the following hourly mean wind speeds (converted to 2 m) conditions as being tolerable if not exceeded more than once per week, which in probability terms are interpreted as being acceptable for

walking fast if $P_{(\bar{u} > 10)} \leqslant 0.05$
strolling, skating if $P_{(\bar{u} > 7\frac{1}{2})} \leqslant 0.05$
standing, sitting, short exposure if $P_{(\bar{u} > 5\frac{1}{2})} \leqslant 0.05$
standing, sitting, long exposure if $P_{(\bar{u} > 3\frac{1}{2})} \leqslant 0.05$

Lawson [14] in 1973 used the same Beaufort scale as Penwarden and developed a figure to take into account the effects of turbulence. A value of $\hat{u} = 1.7\,\bar{u}$ was used, which from eq. (1) implies a turbulence intensity of about 20%. Lawson quotes Beaufort 4 wind speeds (6—8 m/s) as being tolerable if not exceeded for more than 4% of the time; and Beaufort 6 wind speeds (11—14 m/s) as being unacceptable if exceeded for more than 2% of the time. In probability terms these criteria are interpreted as being

acceptable if $P_{(\bar{u} > 6-8)} \leqslant 0.04$
unacceptable if $P_{(\bar{u} > 11-14)} \geqslant 0.02$

Hunt, Poulten and Mumford [3] in 1976 described a range of wind-tunnel tests which were conducted to show how wind affects people's abilities to perform simple tasks, including a simulation of turbulence. Two criteria were developed, firstly that if wind conditions are to be tolerable and for most kinds of performance to be unaffected

$$\bar{u} < 9/(1 + 3 \text{ turbulence intensity})$$

for turbulence intensity of 15% this becomes $\bar{u} < 6.2$ m/s, and secondly, for safe and sure walking that there must be a low probability (say 1%) of a gust lasting over a few paces (say 5—10 m) exceeding 13 m/s. For a turbulence intensity of 15% the 13 m/s gust becomes a mean wind speed of 13/1.5 = 8.7 m/s. (Hunt used a conversion from Durst to give 9 m/s.) In probability terms

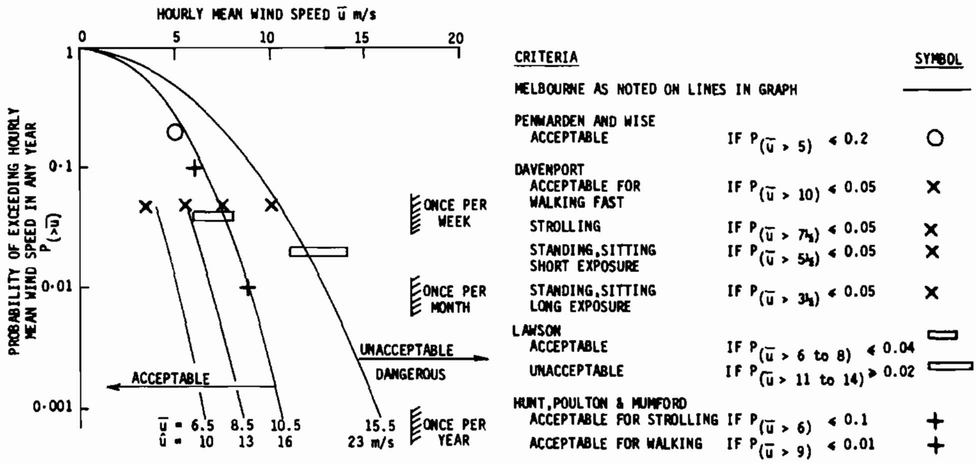

Fig. 2. Comparison of various criteria for environmental wind conditions for daylight hours for a turbulence intensity of 15%. $\sigma_u = 0.15\overline{u}$, $\hat{u} = 1.5\overline{u}$.

for 15% turbulence intensity, this is interpreted as being

acceptable for strolling if $P_{(\overline{u} > 6)} \leqslant 0.1$
acceptable for walking if $P_{(\overline{u} > 9)} \leqslant 0.01$

These criteria in probability terms have been compared in Fig.2 with Melbourne's criteria plotted for a turbulence intensity of 15%.

7. Conclusions

It remains to conclude that the degree of agreement between the criteria when presented in probabilistic terms is quite remarkable for a phenomenon which relies almost completely on subjective assessment. This is particularly so for the earlier attempts by Wise, Melbourne and Penwarden where the criteria were developed entirely independently and in quite different ways. The agreement of the later published criteria, whilst supportive, is not quite so remarkable as there has been a certain amount of influence from the earlier attempts. It seems reasonable to conclude that assessments based on any of these criteria could be said to be made with some consensus of international opinion. However, assessment of the viability of any area in terms of wind environment still relies heavily on the assessment of the use to which the area is to be put and the cost-effectiveness of providing protection from the wind.

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Paper 9

WIND ENVIRONMENT STUDIES IN AUSTRALIA

W.H. MELBOURNE

Department of Mechanical Engineering, Monash University, Clayton, Victoria 3168 (Australia)

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Summary

The assessment of prospective environmental wind conditions about proposed building developments in Australia has been discussed. Assessment techniques, making use of wind tunnel studies, have been illustrated with examples from a study of two possible building configurations for a very exposed site on the north side of the City of Melbourne.

A method of predicting the probability of occurrence of a given wind speed at a particular location has been detailed, and examples have been given of the integration of model measurements of local velocities with the wind speed probability distribution for the geographic area. The comparisons of these probabilistic estimates with environmental wind speed criteria have been discussed and illustrated.

A method of measuring peak gust wind speeds at model scale in situations of high turbulence intensity has been given and a comparison is given with a full scale situation.

1. Introduction

An assessment of prospective environmental wind conditions is now carried out for virtually all major building developments in Australia; for several of the major cities it is a mandatory requirement of the licensing authority. Some of the proposed developments become the subject of wind tunnel studies because of their size and particular exposure to strong wind directions, or when the architect wants an evaluation of several possible schemes, or where the development of a particularly well protected recreational area or shopping precinct is required. Because of a steady build-up of experience in architects' offices of how to design to avoid undesirable environmental wind conditions, there has been a significant reduction in the number of wind tunnel studies required and most are now occasioned by an architect or client wanting to create configurations with better than average environmental wind conditions.

Feedback from developments which have been the subject of wind tunnel tests, and some full scale studies, have permitted the development of the criteria discussed by Melbourne [1]. Much of the techniques used in conducting these wind tunnel tests in Australia by Melbourne at Monash University and Vickery at the University of Sydney have been reported in the text Architectural Aerodynamics [2]. This text concentrated more on examples for architects, in particular how environmental wind problems are caused and how they can be avoided. Hence it would seem to be more appropriate in this paper to discuss the probabilistic techniques used in Australia to assess prospective environmental wind conditions about a proposed development from wind tunnel tests. To illustrate these techniques, examples will be drawn from an investigation carried out at Monash University on the relative merits of two possible configurations for a very exposed site on the north side of the City of Melbourne, one proposal was made up of rectangular building towers and the alternative proposal was based on towers with a circular planform.

2. Wind tunnel techniques

As discussed in both Refs. [1] and [2], it is the wind pressures caused by peak gust wind speeds and associated gradients which people feel most. Although it is possible to have unpleasant areas with low mean wind speeds and high turbulence intensities, the evidence to date does seem to indicate that in areas likely to have unacceptably high wind conditions, such as near corners, in narrow alleys and in arcades, the turbulence intensities are relatively low (20 to 30%) and that in these areas it is reasonable to assume that the peak gust wind speeds will be about twice the mean wind speed. In many cases these problems can be assessed adequately through measurements of local mean wind speeds referenced to a probability distribution of wind speeds for the area. Measurements of mean wind speeds can be simply made with either small pitot static tubes or hot wire anemometers. The exception can occur when assessment is required of an area, such as a recreational plaza for long exposure, which is surrounded by buildings. The turbulence intensity in these situations can be high and the criteria for comfort very strict and in these cases it is necessary to measure peak gust wind speed with a hot wire anemometer.

The measurement of mean velocity pressures with a pitot static tube and the measurement of mean wind speeds with a hot wire both have advantages and disadvantages. The hot wire technique has problems in that the measurement of mean and standard deviation in turbulence intensities above 20% become increasingly suspect and eventually meaningless. However, if only peak gust wind speeds without local directional information are required, then the hot wire technique is relatively satisfactory. The peak gust wind speeds can be obtained from an on line probability analysis of the signal from the hot wire equipment. If the equivalent to a 2 to 3 second gust, as measured by a cup or Dines anemometer in full scale is required, the signal must be appropriately filtered and the velocity with a probability of exceedance of about 2×10^{-4} (i.e. 3.5 standard deviations above the mean for a normally distributed process) taken as the equivalent gust wind speed.

For the majority of wind tunnel investigations the author prefers to use the technique of measuring mean velocity pressures with pitot static tubes as shown diagramatically in Fig.1. The mean velocity pressure can be simply

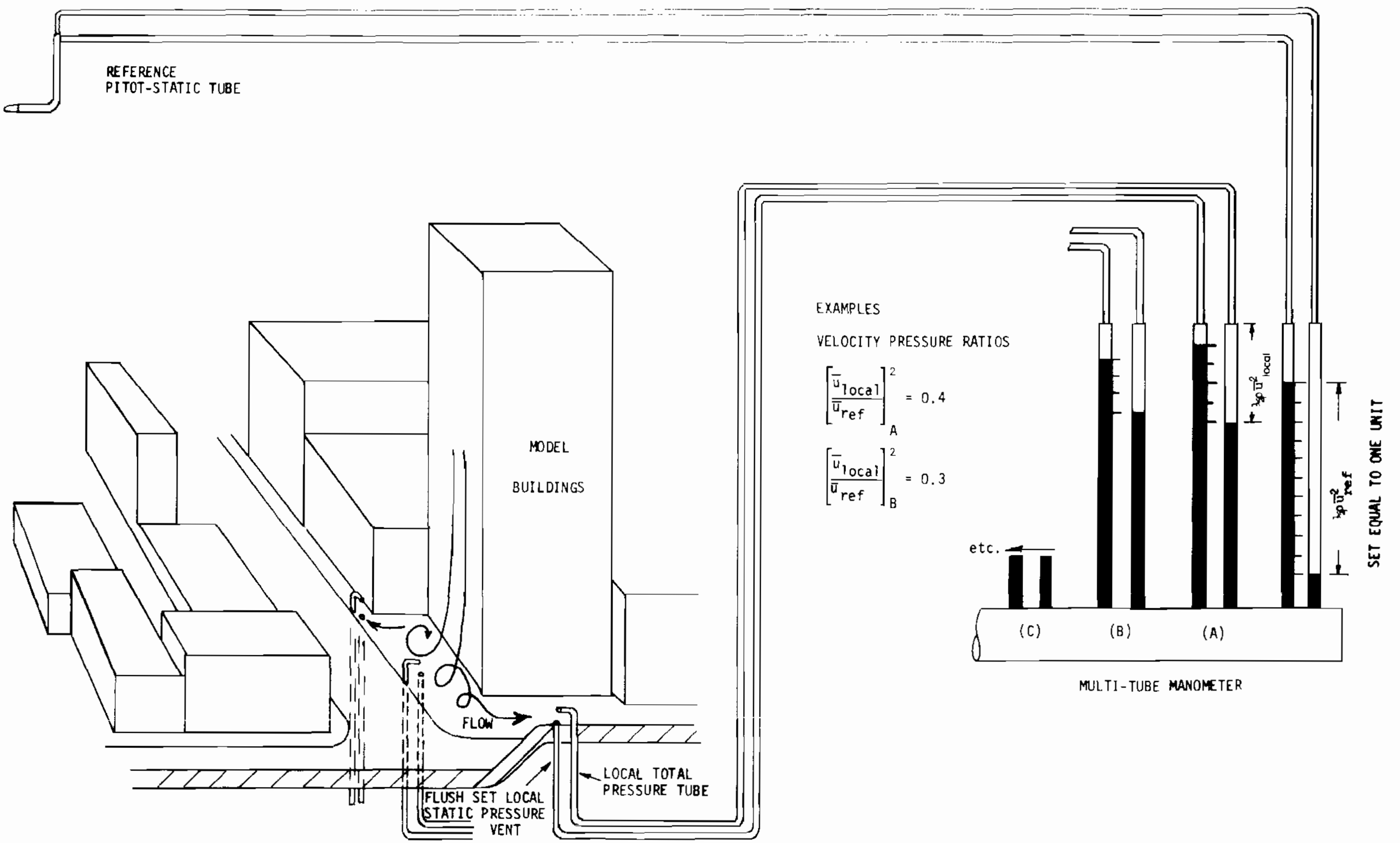

Fig.1. Experimental arrangement for measuring mean velocity pressure ratios.

measured by using a length of small diameter tubing bent in the horizontal plane to measure total pressure in conjunction with a surface static vent. The mean velocity pressures at a number of stations can be measured at the same time by displaying the velocity pressure on a multitube manometer. The disadvantage of this technique is that the total pressure tubes have to be aligned to face directly into wind to get the maximum reading (which does have the benefit of indicating the local wind direction), and peak gust wind speed readings cannot be satisfactorily obtained even if a pressure transducer is used. It is more satisfactory to use a hot wire anemometer to measure peak gust wind speed.

Both techniques require that measured local velocity pressures or wind speeds be referred as a ratio to some reference velocity pressure or wind speed, such as at or near gradient height, which can in turn be related to a full probability distribution of wind speeds for the area. These techniques and probabilistic analysis will be illustrated in the following example.

3. Assessment of prospective environmental wind conditions

The assessment of prospective environmental wind conditions about a proposed development in Australia goes through a series of stages of which the following are typical:

(i) The client and architect discuss broad principles with a number of specialist consultants, one of whom is the wind enginner or aerodynamicist.

(ii) Several configurations or themes on one configuration are developed for the assessment of environmental wind conditions.

(iii) A probability distribution of wind speeds with direction, relative to the site, is compiled.

(iv) Wind tunnel tests are made on the various configurations and modifications developed at the time the models are in the wind tunnel.

(v) The wind tunnel data are integrated with the wind speed data to facilitate a final assessment of the environmental wind conditions.

In practice, the integration of the wind tunnel and wind speed data is done continuously throughout the wind tunnel test programme, to facilitate continuous assessment and decisions by the client and architect to dictate the direction of the test programme. The author will only conduct wind tunnel tests of this type when senior client and architect representation at the wind tunnel can be guaranteed. There are some very simple ways in which the wind tunnel data can be assessed with respect to the wind speed data and these will be illustrated in the following example.

3.1 Example of wind tunnel testing and initial assessment procedure

The example chosen is that of a major development proposal to be located on the northern edge of the Central Business District of the City of Melbourne. The architects were particularly aware of the fact that such a development would be exposed to the wind directions from which come the strongest and most frequent winds. Similarly, they were aware that there was little likelihood of any significant shielding being developed for these directions in the foreseeable future. Accordingly, they developed two proposals for assessment of environmental wind conditions. The first was based on three rectangular tower buildings with extensive canopy arrangements near ground level and the second was based on three circular towers of similar size and arrangement with the ground level area left completely open. Photographs of these two models are shown in Fig.2.

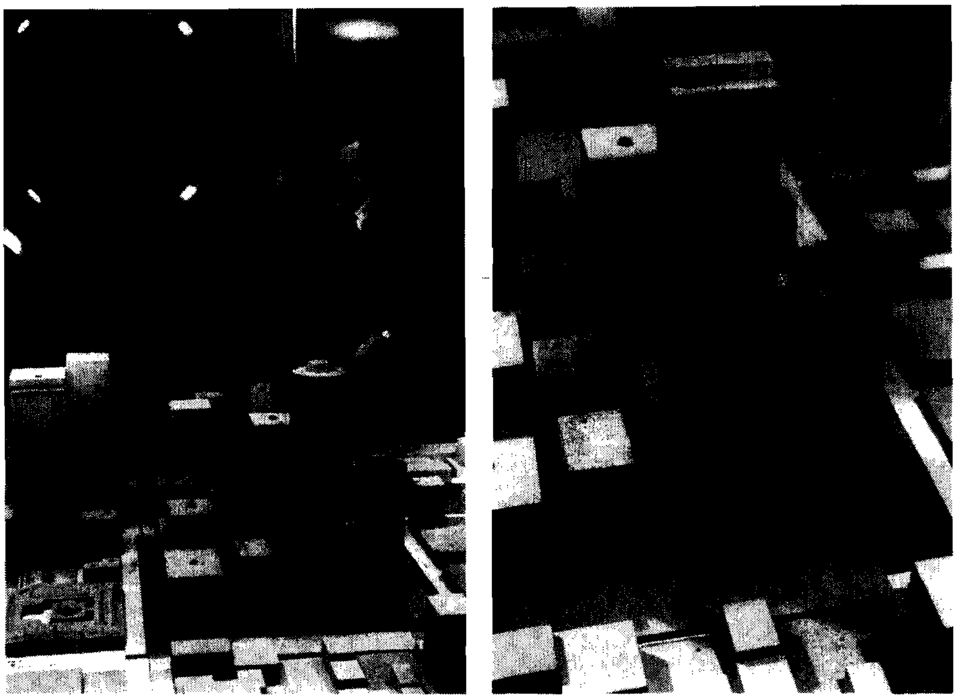

Fig.2. 1/400 scale models of a development proposed for the City of Melbourne.

Before the commencement of the wind tunnel test, it is necessary to prepare a probability distribution of wind speeds. An example of such a distribution is given in the first part of Table 1 in the form of the raw data as were obtained from records of measurements made with a Dines anemometer located at a height of 10 m at Essendon Airport some 10 km north of the City of Melbourne. The cumulative probability distribution for each of the 16 wind directions (θ) can be fitted to a Weibull distribution, which takes the form,

$$P_{(>\overline{u})\theta} = A_\theta \exp-(\overline{u}/c_\theta)^{k_\theta} \qquad (1)$$

which then can be presented in a polar plot with lines of constant probability

TABLE 1

Probability distribution of hourly mean wind speeds measured at 10 m height in open country terrain at Essendon Airport, Melbourne, Australia, 1959—71 for daylight hours 0730 to 1930, and environmental wind criteria per 22½° sector

	Band of wind speeds, $\overline{u}$ (m/s)					
$\overline{u}$ at 10 m over open country terrain	0.5 to 2.1	2.1 to 3.6	3.6 to 5.65	5.65 to 8.75	8.75 to 11.3	11.3 to 14.4
$\overline{u}$ at 300 m over suburban terrain*	0.8 to 3.2	3.2 to 5.5	5.5 to 8.6	8.6 to 13.4	13.4 to 17.3	17.3 to 22.0
Wind direction	Probability of being in band × 10^6					
N	11973	15323	37400	64368	31085	15543
NNE	3900	4340	8238	12468	4943	2800
NE	6535	3185	2855	1538	440	110
ENE	5218	1813	660	165	55	
E	7800	2800	1098	330		
ESE	4340	2690	2088	1318	330	
SE	9008	7745	9720	7635	1593	440
SSE	8733	11698	16423	12138	933	165
S	18948	32898	64753	68543	9063	933
SSW	9338	10490	18180	17630	3680	1043
SW	11080	12633	20485	18508	6205	2418
WSW	5823	6700	11588	14280	5548	2965
W	9555	11040	7963	21968	7690	2528
WNW	4558	5273	7963	7360	1703	715
NW	6480	7853	10215	12578	7223	1868
NNW	5878	8073	12633	17025	7280	2418
Calm	88788					
Total	1000000					

$${}^{*}\overline{u}_{300,\,\text{suburban}} = \overline{u}_{10,\,\text{open country}} \left[\frac{400}{10}\right]^{0.15} \left[\frac{300}{500}\right]^{0.25} = 1.53\,\overline{u}_{10,\,\text{open country}}.$$

**For a lower turbulence intensity of $\sigma_u = 0.15\overline{u}$, $\hat{u} = 1.5\overline{u}$, the numerical criteria become Unacceptable/dangerous, annual maximum $\overline{u} > 15.5$; Acceptable/walking, annual maximum $\overline{u} < 10.5$.

		Average annual hourly maximum wind speed at 300 m for each sector from line with $P_{(>\bar{u})} = 0.001$ in Fig.3	Environmental wind criteria based on Melbourne's criteria for $\sigma_u = 0.3\bar{u}$, $\hat{u} = 2.0\bar{u}$**			
			Unacceptable/ dangerous annual maximum $\bar{u} > 11.5$ m/s		Acceptable for walking annual maximum $\bar{u} < 8.0$ m/s	
14.4 to 17.5	17.5 to 21.1		For $\bar{u}_{local} = 11.5$		For $\bar{u}_{local} = 8.0$	
22.0 to 26.7	26.7 to 32.3		$\dfrac{\bar{u}_{local}}{\bar{u}_{300}}$	$\left[\dfrac{\bar{u}_{local}}{\bar{u}_{300}}\right]^2$	$\dfrac{\bar{u}_{local}}{\bar{u}_{300}}$	$\left[\dfrac{\bar{u}_{local}}{\bar{u}_{300}}\right]^2$
2910	275	24	0.48	0.23	0.33	0.11
330		20	0.58	0.33	0.40	0.16
		12	0.96	0.91	0.67	0.44
		6	1.9	3.7	1.3	1.8
		6	1.9	3.7	1.3	1.8
		10	1.2	1.3	0.8	0.64
		14	0.82	0.67	0.57	0.33
		14	0.82	0.67	0.57	0.33
55		18	0.64	0.41	0.44	0.20
110		17	0.68	0.46	0.47	0.22
165		19	0.61	0.37	0.42	0.18
605	55	20	0.58	0.33	0.40	0.16
440		20	0.58	0.33	0.40	0.16
165		18	0.64	0.41	0.44	0.20
165	55	19	0.61	0.37	0.42	0.18
330		20	0.58	0.33	0.40	0.16

level as shown in Fig. 3. In this particular plot the mean hourly wind speed has been factored to refer to a height of 300 m over suburban terrain by the relationship,

$$\bar{u}_{300\text{, suburban}} = \bar{u}_{10\text{, open country}} \left[\frac{400}{10}\right]^{0.15} \left[\frac{300}{500}\right]^{0.25}$$

$$= 1.53\, \bar{u}_{10\text{, open country}} \qquad (2)$$

In the wind tunnel model tests, the local velocity pressures, or local wind

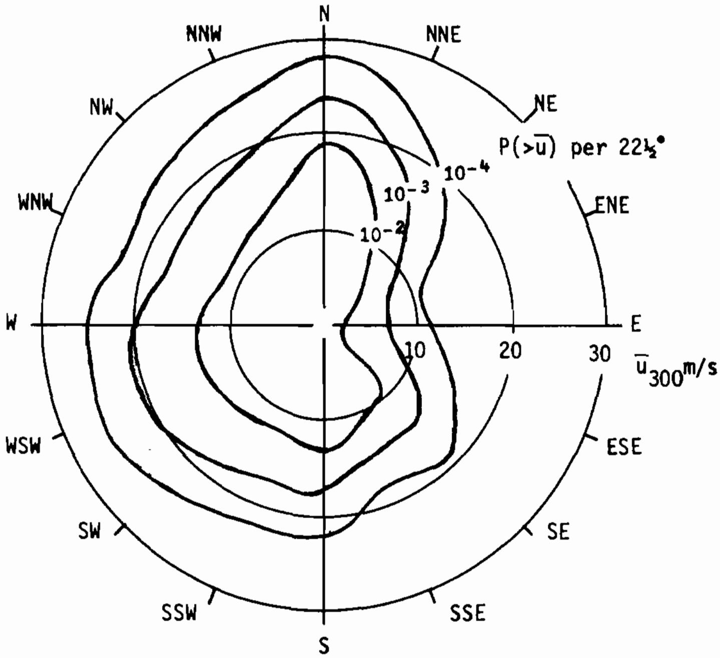

Fig. 3. Probability distribution of hourly mean wind speeds at 300 m over suburban roughness at Essendon Airport Melbourne for daylight hours 0730 to 1930.

speeds, will be measured as a ratio with the similar measurement at 300 m over the model suburban approaches. Hence, if the annual maximum hourly wind speeds at 300 m can be obtained for each wind direction sector, then Melbourne's criteria [1] can be expressed for each sector as a ratio against which any measurements can be directly compared at the time of measurement. The annual maximum hourly wind speed for each sector can be obtained using the probabilities given in [1] and in this case, where the distribution is for daylight hours, the average maximum hourly wind speed can be approximated by reading around the contour with a probability $P_{(> \overline{u})} = 10^{-3}$ in Fig.3 as tabulated in Table 1. With this information the criteria, in ratio form, can be calculated as shown in the last part of Table 1 for the most general case of the peak gust wind speed equal to twice the hourly mean wind speed ($\hat{u} = 2\overline{u}$) for two levels as defined in [1] as being

(a) unacceptable/dangerous if the annual maximum gust wind speed, $\hat{u} > 23$ m/s;

(b) acceptable/for walking if the annual maximum gust wind speed, $\hat{u} < 16$ m/s.

The curves of these two criteria can then be plotted as background information on the data sheets on which the wind tunnel measurements are directly recorded as shown in Fig.4. Obviously this information forms the background for any test series and once it has been obtained for an area, it serves for tests

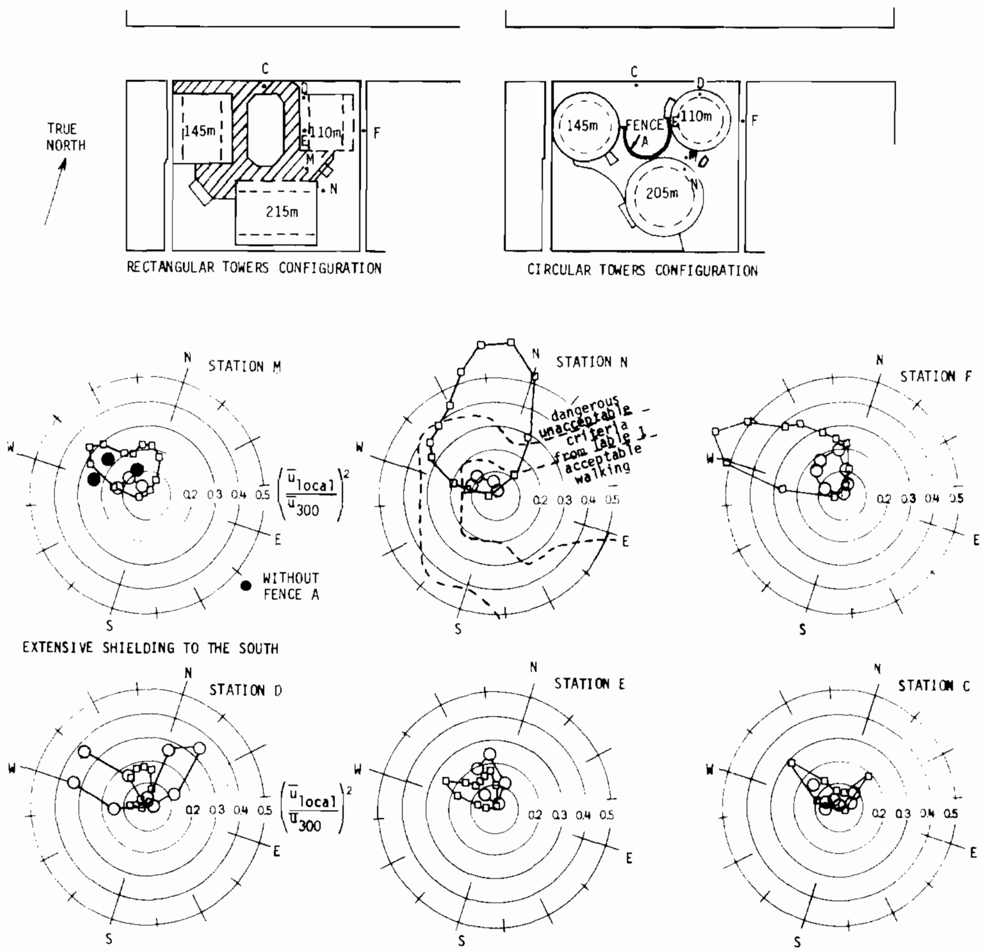

Fig. 4. Mean velocity pressure ratios from wind tunnel model tests.

on all projects in that area. In this particular case, some small modification has to be made to reduce the effect of topographical funnelling which peaks the distribution for northerly wind directions at Essendon Airport, but the effect of which reduces further south over the downtown area of the City of Melbourne and southern suburbs.

Examples of polar plots of velocity pressure ratio as a function of wind direction are given in Fig.4, for 6 of about 30 stations, at which measurements were made to facilitate the assessment of environmental wind conditions for these two configurations. At Stations M, N and F, the very adverse effects of the rectangular buildings inducing flow down to ground level is shown to result in quite unacceptably high velocity pressure ratios (for this geographic region) in critical points of public access. These adverse effects can be offset to some extent by the use of local wind break fences or overcome completely by providing air locked connections under the canopy between the main towers at ground level. The circular tower configuration is shown to induce much less wind flow at ground level and to provide conditions within the "acceptable criterion" at Stations M and N. However, in the absence of surrounding buildings over 30 m height to the north and west, there is still a need for the local protection provided by the 50% porous Fence A shown in Fig.1 and 4. Similarly, wind conditions at Stations D, E and C, for the completely open circular tower configuration, are shown to border on unacceptable levels (and certainly are well in excess of acceptable levels). These very local conditions can be ameliorated with the use of porous wind breaks (planter boxes of shrubs and trees) or by the planned layout of architectural features and main access-ways which keep pedestrian traffic away from local regions where high wind speeds are likely to occur.

In concluding this example of how, during wind tunnel testing, a very quick assessment can be made of prospective environmental wind conditions for various configurations, a word of caution must be made in respect of interpreting the measurements.

First of all, the criteria shown in Fig.4 are for each 22½ degree sector; that is if the velocity pressure ratio (or wind speed ratio, whichever approach is being used) reaches, for example, the criterion for unacceptable/dangerous conditions for one sector, it means that once per annum, on average, the peak gust wind speed of 23 m/s will be exceeded. If the criterion is reached for two sectors, it means the probability of exceeding the criterion will double and so on. To make a proper assessment of the probability of exceeding certain wind speeds for all wind directions, a full analysis for all wind directions must be compiled, as shown in Section 3.2.

Secondly, an assessment has to be made by the experimenter as to when the local turbulence intensity reaches a level which invalidates the use of mean velocity pressures or mean wind speeds, whichever technique is being used. If this stage is reached, the simple technique of relying on mean measurements has to be abandoned and the more sophisticated technique of measuring peak gust wind speeds has to be used. A further word of warning here is that it is not sufficient to rely on mean and standard deviation readings from a hot wire anemometer to indicate when a turbulence level of say 25% is reached, because the errors inherent in the hot wire tend to increase the mean and reduce the standard deviation, hence lulling the unwary into thinking that the turbulence intensity is not all that high. A much safer way to determine whether high turbulence, low mean velocity conditions are present, is to observe the signal on a cathode ray oscilloscope and run out a probability distribution to check on the peak values. One consolation, in a sense, of relying on mean wind speeds measured with a hot wire anemometer to higher turbulence intensities is that the mean wind speeds measured are high, and in most cases excessively conservative decisions are more likely to be made on the basis of this incorrect information. An example of the measurement of peak gust wind speeds will be given in Section 3.3.

3.2 Probability distributions of wind speed for all wind directions

In the majority of situations, high wind speeds induced at a particular station are confined to a relatively narrow band of wind directions and an assessment can be made on the basis of criteria for a given sector as described in Section 3.1. For situations where either a more accurate assessment is required (perhaps for a marginal situation), or high wind speeds occur for a broad range of wind directions, it becomes necessary to prepare a full probability distribution of wind speeds which accounts for all, or all the significant, wind directions. Such a distribution can be prepared as follows:

(a) From a distribution such as given in Table 1, a cumulative probability distribution of wind speeds at the reference point (in this case 300 m over suburban terrain) can be prepared which expresses the probability of exceeding a given wind speed for a given wind direction sector, $P_{(>\bar{u})\,\theta,\,\mathrm{reference}}$. One convenient method of doing this is to use the Weibull distribution noted previously.

(b) For each station an average value of the wind speed ratio, $\bar{u}_{\mathrm{local}}/\bar{u}_{\mathrm{ref.}}$ can be obtained from the model tests for each wind direction sector. Using this wind speed ratio, the cumulative probability distribution can be prepared expressing the probability of exceeding a given wind speed for a given wind direction sector at the local station, $P_{(>\bar{u})\theta,\,\mathrm{local}}$.

(c) The value of $P_{(>\bar{u})\,\theta,\,\mathrm{local}}$ must be obtained for all or all significant wind directions and integrated to give the total probability of exceeding a given mean wind speed for all directions, i.e.

$$P_{(>\bar{u})\,\mathrm{all\ directions,\ local}} = \int_0^{360} P_{(>\bar{u})\,\theta,\,\mathrm{local}}\,\mathrm{d}\theta \tag{4}$$

(d) The whole process can be done conveniently with a digital computer, but it is not a particularly long task to do it manually for a few stations, simply because if the relatively coarse 22½° sectors are used, it is very unusual in practice to have to do the integration of more than three or four sectors. An example of the final stages of this process is given in Table 2 for Station M of the previous example.

(e) Finally, a graph of the probability of exceeding a given wind speed can be superimposed on criteria expressed in the same probabilistic form such as given in [1] and an example of which is given in Fig.5, for several of the stations from the previous example. Whilst such a presentation confirms just how unacceptable conditions would be at Stations M and N for the Rectangular Towers proposal, it is more useful in quantitatively indicating how acceptable the conditions at Station C are likely to be, which can only be very generally assessed from observing the information in Fig.4.

3.3. Measurement of peak gust wind speeds

If, as described in Section 3.1, it is deemed necessary to make an assessment of an area subjected to wind flows with high turbulence intensities, a

TABLE 2

Example of last part of the development of the probability distribution of mean wind speeds at Station M, Rectangular Towers Configuration (Fig.4)

Wind direction	$\overline{u}_{local}$ (m/s)	4	6	8	10	12
	$\frac{\overline{u}}{\overline{u}_{300}}$ frim Fig.4	Probability of being greater than $\overline{u}$ for 22½° sectors of wind direction $P_{(>\overline{u})\theta} \times 10^6$				
N	0.42	80,000	45,000	11,000	1,300	100
NNW	0.47	20,000	12,000	3,000	500	50
NW	0.47	20,000	12,000	3,000	500	50
WNW	0.57	13,000	6,000	2,000	600	150
W	0.40	18,000	7,000	1,000	50	
All other wind directions	< 0.2	Not significant				
Total $P_{(>\overline{u})}$ *		0.15	0.082	0.020	0.0029	0.00035

*These values are plotted in Fig.5.

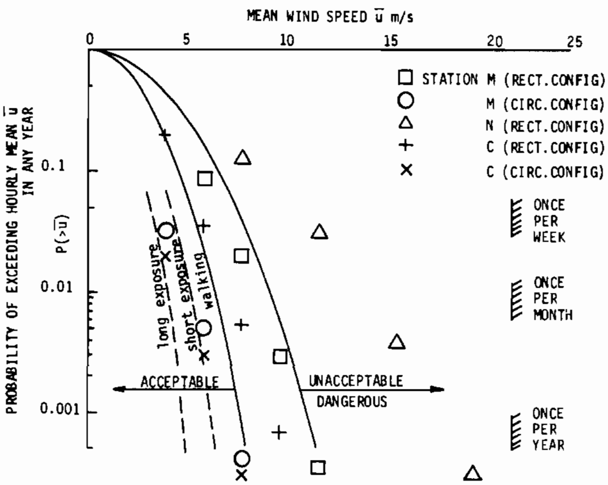

Fig.5. Probability distributions of mean wind speeds at several stations compared with Melbourne's criteria for environmental wind conditions (Daylight hours, $\sigma_u = 0.3\overline{u}$, $\hat{u} = 2\overline{u}$).

measurement of the peak gust wind speeds can be made using a hot wire anemometer as follows:

(a) If it is required to compare model scale peak wind speed measurements with criteria [1] based on peak gusts measured over two to three seconds in full scale, it is first necessary to low-pass filter the hot wire anemometer linearised output, so that it looks like the scaled down version of the output from a typical cup or Dines anemometer.

(b) The next step in the process is to obtain a probability distribution of the filtered hot wire anemometer signal; this can be conveniently obtained using on-line digital analysis techniques.

(c) It is then necessary to determine the probability level equivalent to 2—3 second peak gust in full scale. Many observers of wind data collected from cup or Dines anemometers in open country situations have observed that the peak gust wind speeds are between 1.5 and 1.8 times the mean, and from a knowledge of the turbulence intensities in these situations, it is possible to deduce that the 2—3 second mean wind gust wind speed is approximately 3.5 standard deviations above the mean, i.e.

$$\hat{u}_{2-3\,\mathrm{sec}} = \overline{u} + 3.5\,\sigma_u \tag{4}$$

For a normally distributed process, the probability of exceeding 3.5 standard deviations above the mean is 2.3×10^{-4}. It is suggested that the value of the velocity with a probability of exceedance of 2.3×10^{-4} is an appropriate approximation to use as being equivalent to a 2—3 second mean maximum gust wind speed.

(d) The gust wind speed so obtained can then be expressed as a ratio with the reference mean wind speed and compared with the environmental wind criteria as previously outlined.

The measurement of peak gust wind speeds can be illustrated by the following comparison of a full scale measurement at a city corner, at an intersection near, but not directly adjacent, to tall buildings, and a model measurement for the same situation. The model measurements were made using a hot wire anemometer and the procedure as outlined above.

		Full scale	Model scale
$\dfrac{\text{local peak gust wind speed}}{\text{local mean wind speed}}$,	$\dfrac{\hat{u}}{\overline{u}}$	4.1	1.8
$\dfrac{\text{local mean wind speed}}{\text{reference mean wind speed}}$,	$\dfrac{\overline{u}}{\overline{u}_{300}}$	0.21	0.50
$\dfrac{\text{local peak gust wind speed}}{\text{reference mean wind speed}}$,	$\dfrac{\hat{u}}{\overline{u}_{300}}$	0.8	0.9

It can be seen that the model measurement of the mean wind speed is a very significant overestimate and on its own would be quite misleading. The reason is apparent when one observes that the ratio of local peak to mean wind speed is over four, indicating very high turbulence, and which the hot wire anemometer records at less than two. However, when only the peak gust wind speed is used from a hot wire anemometer in this situation, the comparison between peak and reference mean wind speed ratios compares relatively well.

4. Conclusions

The assessment of prospective environmental wind conditions about a typical proposed building development in Australia has been discussed. Measurement techniques have been described and illustrated with examples. In particular, examples of the probabilistic assessment of local wind speeds and comparison with environmental wind speed criteria have been given in detail. A method of measuring peak gust wind speeds in situations of high turbulence intensity has been given.

Acknowledgements

The author wishes to acknowledge the kind permission of Meldrum and Partners to include examples from studies on one of their projects. The author is indebted also to the Australian Bureau of Meteorology for the full scale wind data made available, not only for this report, but for countless studies of a similar kind in various Australian locations.

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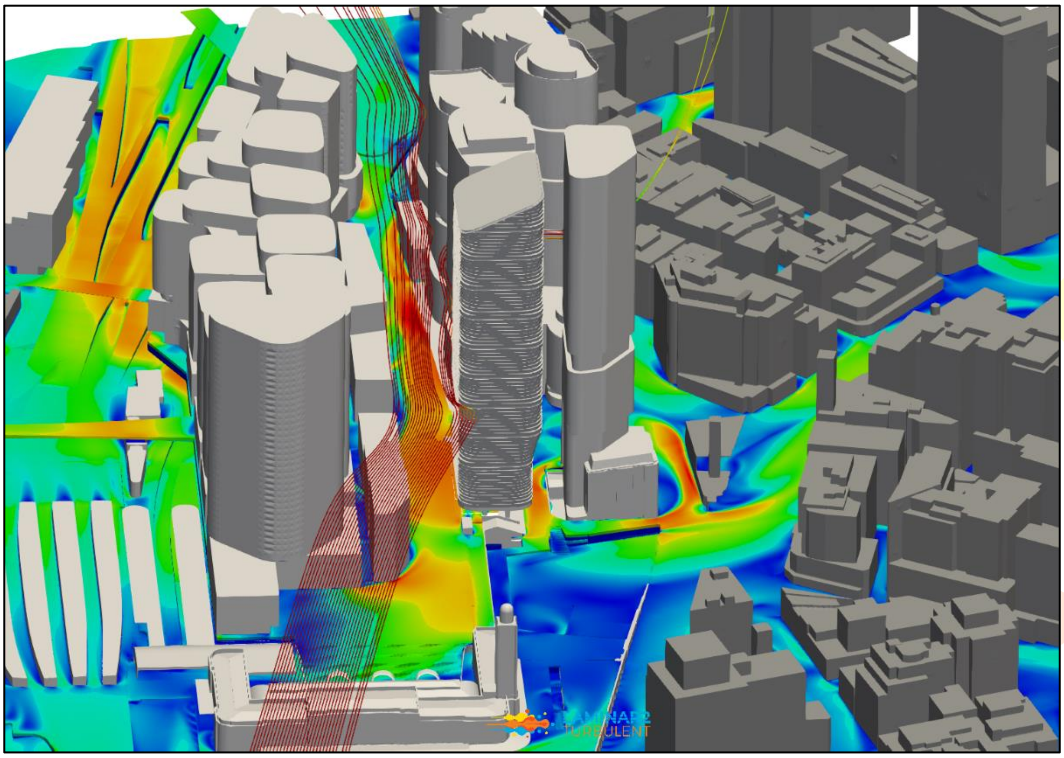
REPORT 64-20-CFD-ENV-03b

CENTRAL PRECINCT RENEWAL SYDNEY

CFD ENVIRONMENTAL WIND STUDY



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Central Precinct Renewal Sydney
CFD Environmental Wind Study

By T. McQueen, B. Gilhome and L. Cochran

SUMMARY

An environmental wind study to assess the wind conditions in the public realm for the Central Precinct Renewal in Sydney was conducted using Computational Fluid Dynamics (CFD). The CFD model of the proposed development, within surrounding buildings, with no existing or future ground level trees, was simulated in a natural wind boundary layer to determine likely local environmental wind conditions. Indication of the risk of exceeding pedestrian environmental safety and comfort criteria as a function of wind direction was presented for each design configuration. A Baseline configuration and six additional design iterations consisting of multiple design options were simulated. Key design configurations were simulated for eight wind directions (45^{o} increments).

For each iteration of the project wind mitigation strategies were investigated to reduce the risk of wind safety issues, reduce pedestrian wind levels in surrounding streetscapes and achieve target activation. Significant reduction in the risk of exceeding pedestrian level safety and comfort criteria compared to the initial Baseline proposal was achieved. The *Iteration 6 – Revised Preferred Massing* configuration was identified as the overall lowest-risk option. Further local refinement may be required to achieve target wind comfort criteria based on the intended pedestrian activation in the precinct streetscapes.

Report 64-20-CFD-ENV-03
July 2022

WEST MELBOURNE WATERFRONT
CFD ENVIRONMENTAL WIND STUDY

MEL CONSULTANTS REPORT NO: **64-20-CFD-ENV-03**

PREPARED FOR:
Transport for NSW
680 George Street, Level 43
Sydney, NSW 2000

Contact: Hugh Thornton
e: hugh.thornton@transport.nsw.gov.au

PREPARED BY:
MEL Consultants Pty Ltd &
Laminar2 Turbulent Pty Ltd
22 Cleeland Road
Oakleigh South VIC 3167

Contact: Leighton Cochran
Ph: +61 (0) 481 263 324

PREPARED BY:

T. McQueen
Fluid Dynamics Engineer,
L2T

Date: 04th July 2022

REVIEWED BY:

B. Gilhome
Founder and Principal,
L2T

Date: 04th July 2022

RELEASED BY:

L. Cochran
Director, MEL Consultants

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CONTENTS

1 INTRODUCTION

The proposed Central Precinct Renewal development consists of several towers located near and on the Central Railway Station between Pitt and Elizabeth Streets in Sydney. There is significant pedestrian activation within the site and in the surrounding streetscapes. The immediate surrounding terrain consists of low- to medium-rise commercial buildings. In the far-field, the surrounding terrain includes the Sydney Central Business District to the north and low-rise suburban housing in other directions. The proposed development will be exposed to the prevailing winds from the north-east, south, and west wind directions.

The CFD environmental wind study was commissioned to provide feedback on pedestrian-level wind conditions in the surrounding streetscapes and indicate areas that are at risk of not satisfying the target pedestrian comfort and safety criteria. Mitigation strategies to achieve target wind criteria, based on the intended pedestrian activation, were developed and incorporated into the masterplan during the iterative CFD development process. The CFD environmental wind study results guided many of the changes to the masterplan and resulted in significantly improved pedestrian wind conditions which have now been confirmed in the environmental wind tunnel study.

The CFD environmental wind study was carried out on the Laminar2 Turbulent computer cluster between September 2021 and January 2022.

2 ENVIRONMENTAL WIND CRITERIA

The advancement of CFD techniques within the discipline of wind engineering (Computational Wind Engineering, CWE), including computational capabilities, simulation of boundary layer flows of the natural wind, and ongoing correlation with wind tunnel studies, has facilitated the prediction of wind effects induced by proposed developments on the surrounding streetscapes.

Wind conditions are commonly required to be assessed using a set of generally accepted environmental wind criteria. The criteria used in this study are based on those proposed by Melbourne (Reference 1). It is important to note that Melbourne (Reference 1) found people are most sensitive to the peak gust wind speed and its associated gradient. Hence, gust wind speeds have traditionally been used to develop environmental wind criteria.

However, due to the nature of the CFD analysis technique implemented – which is not capable of resolving instantaneous gust effects – these criteria need to be defined in terms of an hourly mean wind speed. Furthermore, the criteria used in this study are assessed for a range of wind directions independently. This contrasts with definitions of some other criteria which consider all wind directions combined in their evaluation.

These directional criteria based on gust wind speeds can be presented as follows:

For public safety, the criterion is as follows:

- Unacceptable and unsafe if the hourly mean with a probability of exceedance of 0.1% in any wind direction exceeds a mean wind speed equivalent to a three-second gust wind speed of 23 ms^{-1} – the wind speed at which people begin to get blown over.

For pedestrian comfort, the criteria are as follows:

- Generally acceptable for walking in urban and suburban areas if the hourly mean wind speed with a probability of exceedance at any wind direction in any 22.5° wind direction sector does not exceed 8 ms^{-1} for a probability of exceedance of 0.1% (gust = 16 ms^{-1}).

- Generally acceptable for stationary short exposure activities (window shopping, standing, or sitting in plazas) if the hourly mean wind speed with a probability of exceedance in any 22.5° wind direction sector does not exceed 6.5 ms^{-1} for a probability of exceedance of 0.1% (gust = 13 ms^{-1}).

- Generally acceptable for stationary, long exposure activities (outdoor restaurants, theatres), if the hourly mean wind speed with a probability of exceedance in any 22.5° wind direction sector does not exceed 5 ms^{-1} for a probability of exceedance of 0.1% (gust = 10 ms^{-1}).

The probability of exceedance of 0.1% relates approximately to the annual maximum mean wind speed occurrence for each wind direction. The safety criterion should be satisfied for each wind direction since it is reasonable to err on the side of caution when considering public safety.

These criteria, their derivation in terms of probability of occurrence, and the effects of turbulence on the relationship between gust and mean wind speeds in highly turbulent urban wind environments are discussed in References 1 and 2.

Since this CFD analysis does not assess the gust wind speeds, particularly for pedestrian safety, the CFD data is presented in terms of risk levels of not achieving the target criteria. For example, *low-risk* indicates less than 50% likelihood of not achieving the target criterion and *high-risk* indicates more than 50% likelihood of not achieving the target criterion. The wind effects of the proposed development will need to be quantified by a wind tunnel model study undertaken to the requirements of the Australasian Wind Engineering Society (AWES) Quality Assurance Manual (AWES-QAM-1-2019) and the requirements of the responsible authority.

3 CFD MODEL AND TECHNIQUES

The wind flow around the development was modelled using OpenFOAM CFD software. Figure 1 shows the computational domain and coordinate system used for this study. The proposed development and surrounding buildings were modelled at full-scale. The computational domain was initially set to 2000 m in the X-direction, 3332 m in the Y-direction, and 2000 m in the Z-direction. For *Iteration 6* extended surrounds were included in the model and the domain was extended to 3000 m in the X-direction, 4500 m in the Y-direction, and 2000 m in the Z-direction. The large computational domain ensured that the blockage ratio of the CFD model was less than 3%. It also ensured that the domain boundaries were sufficiently far from the proposed development and surrounding buildings to have a negligible effect on the wind flow in the area of interest. The proposed development (shown in red) was laterally centred in the domain and was located approximately 1416 m (2000 m for *Iteration 6*) downstream of the *inlet* (transparent blue plane). The surrounding buildings (shown in yellow) and topography (shown in green) were modelled out to a radius of 890 m from the site including all existing or under construction buildings and approved future buildings as of June 2021. Additional buildings, out to a radius of 1060 m, were included to the northeast of the development for *Iteration 6*. Beyond the 890 m radius, a flat ground plane with a rough wall function applied was included to simulate the atmospheric boundary layer. Different wind directions were simulated by rotating the proposed development, the surrounding buildings, and the topography within the CFD domain.

The wind flow enters the domain at the *inlet* and exits the domain at the *outlet* (transparent red plane). For all wind directions, the approach mean velocity boundary layer profile was modelled as Terrain Category 3 (TC3) – as defined in

AS/NZS 1170.2:2021. For the quality assurance process, a CFD simulation without the building model was performed to verify a TC3 boundary layer was achieved throughout the computational domain. Figure 2 shows the simulated boundary layer and the equivalent AS/NZS 1170.2:2021 and ISO 4354:2009 profiles. The simulated boundary layer profile had a deviation of less than 3.5% from the AS/NZS 1170.2:2021 and ISO 4354:2009 profiles. The boundary layer turbulence intensity profiles are also provided in these standards. However, as a steady-state Reynolds-averaged Navier-Stokes (RANS) turbulence model was used for the simulation, which considers the mean flow and does not simulate the turbulent fluctuations, turbulence intensity profiles were not relevant.

The domain was meshed with both hexahedra and split-hexahedra cells using SnappyHexMesh. Smaller mesh cells were used near the proposed development and surrounding buildings out to a radius of 520 m, and near the topography surface across the whole domain. The meshes generated for the study were comprised of approximately 60 million cells.

The fluid (wind) flow was solved using a customised version of OpenFoam-v2012 using the standard k-epsilon turbulence model. OpenFOAM uses the Finite Volume Method to discretise the governing equations, which are then solved using the OpenFOAM SIMPLE algorithm. Second-order discretisation schemes were used for all variables, except for k and epsilon divergence terms where a first-order upwind scheme was used. The Laplacian terms were discretised using a linear limited scheme with a blend factor of 0.5. During the solve the flow solution was monitored at critical points in the domain. The simulation was iterated until the velocity at these points had stabilised to a constant value, or if flow oscillation was observed then the oscillation was about a steady value. Typically, the solutions required between 5000 to 6000 iterations.

The CFD parameters used have been correlated with wind tunnel data for consistency of results. The quality assurance correlation study investigated different RANS turbulence models to determine their influence on the simulated wind speeds around buildings. The standard k-epsilon model predicted very similar wind speeds compared to others (Realizable k-epsilon and k-omega Shear Stress Transport) and was more robust in its solution. Therefore, the k-epsilon turbulence model was used in this study. The quality assurance correlation study showed that the error in pedestrian level mean velocities between the wind tunnel and CFD was ≤ 10% of the reference velocity, using the k-epsilon model.

The CFD environmental wind studies undertaken satisfy, and in most cases exceed, all applicable AWES-QAM-1-2019 guidelines and AWES Guidelines for Pedestrian Wind Effects Criteria. Although vegetation can improve pedestrian wind comfort, this study assumed no vegetation except where specifically applied for amelioration in Appendix A.

4 INTERPRETATION OF CFD RESULTS

The CFD results presented in the following sections are based on steady-state flow fields (time-averaged). The pedestrian wind conditions do not include or account for natural wind flow unsteadiness/gustiness that is provided by the wind tunnel studies. However, the CFD results show the wind flow over a large area with high spatial resolution. Compared to the discrete points of a wind tunnel study, the CFD results assist with understanding the general environmental wind flow around the buildings and identifying the elements of the proposed development that impact pedestrian level wind conditions. This hybrid computational/physical modelling approach provides the best of both techniques (Cochran and Derickson, 2011).

The CFD simulation results presented aim to provide a qualitative analysis of the pedestrian wind environment and do not intend to replace wind tunnel environmental wind studies. The CFD study results provide the risk of exceeding a target pedestrian comfort criterion or exceeding the pedestrian wind safety criterion. Using CFD allows for a better understanding of the environmental wind flow field and the sensitivity of the wind impacts to building massing configurations. This understanding enables the development of targeted mitigation strategies that contribute to more refined and ultimately greater value/higher quality development. Undertaking a CFD study prior to a wind tunnel study can also improve the effectiveness of the wind tunnel study, particularly for complex and challenging projects.

The CFD pedestrian wind study results presented in this report provide individual wind direction contour plots for the risk of exceeding the pedestrian comfort and safety criteria, as well as contour plots amalgamating the results of all the wind directions analysed. Note that all the contour plots presented are taken at a 1.5 m elevation (nominal chest height) above the local pedestrian surface.

5 DISCUSSION OF RESULTS

The wind directions, for which each configuration, were tested are listed in Table 1.

	N	NNE	NE	ENE	E	SE	S	SW	W	NW
BASELINE (Wind tunnel correlation)	✓		✓		✓	✓	✓	✓	✓	✓
ITER 1	✓		✓		✓	✓	✓	✓	✓	✓
ITER 2 – OPT 1			✓				✓			✓
ITER 2 – OPT 2			✓				✓			✓
ITER 3 – OPT 3			✓				✓			✓
ITER 3 – OPT 4			✓							
ITER 3 – OPT 5			✓							
ITER 3 – OPT 6			✓							
ITER 4 - OPT 4			✓				✓			✓
ITER 4 - OPT 5			✓				✓			✓
ITER 5 - OPT 1		✓	✓				✓			✓
ITER 5 - OPT 2			✓				✓			✓
ITER 5 – WITH DECK			✓				✓			✓
ITER 5 – WITHOUT DECK			✓				✓			✓
ITER 5 – OPT 1 NO A1 TOWER			✓							
ITER 6 – WITHOUT DECK	✓		✓		✓	✓	✓	✓	✓	✓
ITER 6 – REVISED PREFERRED MASSING	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ITER 6 – 8M SETBACK	✓		✓		✓	✓	✓	✓	✓	✓
ITER 6 – 8M SETBACK ALTERNATIVE	✓		✓		✓	✓	✓	✓	✓	✓

Table 1: Wind directions at which design configurations were tested.

A short summary of the intent and results for each configuration is presented in this section. Diagram 1 shows building designations referenced in this section.

Diagram 1: Building Designations

Figures showing the results are presented in Section 8 and Figure 3 shows the intended streetscape activation areas.

5.1 BASELINE

The *Baseline* configuration was simulated for 8 wind directions (north, northeast, east, southeast, south, southwest, west, and northwest). The results are shown in Section 8.1. The *Baseline* configuration was also separately tested in a boundary-layer wind tunnel by MEL Consultants. A comparison between the CFD and Wind Tunnel pedestrian level winds for all wind directions combined is shown in Figure 19.

The outcomes of this analysis are as follows:

- The proposed development is at high risk of exceeding the safety criterion in the following areas:
  - Between building A1and B1, A3 and B3, C1 and C2.1,
  - North and west corners of building A1, and
  - Northwest corner of Dexus Fraser building, along Lee St.
- The individual pedestrian level wind risk contour plots show that the northeast, south, and northwest wind directions result in the most adverse wind conditions.
- Generally good agreement is observed between the CFD and wind tunnel results for the combined wind directions pedestrian level environmental wind risk contour plot.

5.1.1 Wind Mitigation Strategies

The proposed development has little shielding provided by the surrounding buildings for the prevailing wind directions (northeast, south, and west). The primary mitigation strategies proposed are as follows:

1. Improve building shapes to reduce wind effects from the northeast and northwest wind directions by encouraging wind to move around the buildings rather than being directed to podium/ground level.
2. Avoid large continuous build forms so wind can permeate through the development more freely, rather than being directed down to ground.
3. Round and/or break-up podium corners to reduce local wind speed increases.

5.2 ITERATION 1

This configuration was simulated for 8 wind directions (north, northeast, east, southeast, south, southwest, west, and northwest). The results are shown in Section 8.2. The *Iteration 1* massing was significantly altered from the *Baseline* design.

The outcomes of this analysis are as follows:

- Neighbouring tall towers: Atlassian, TOGA and Dexus-Fraser generally increase pedestrian wind speeds.
- Relative to the *Baseline,* the updated proposal has reduced the risk of exceeding the Safety wind criterion.
- Elevated wind speeds are expected along the main avenue, at aligned wind directions, and in the exposed plaza to north of the proposed development.
- Localised high wind speeds are observed due to building detailing.
- Three key wind directions for development were identified as northeast, south and northwest. These wind directions produced most adverse pedestrian wind conditions.

5.2.1 Wind Mitigation Strategies

- Wind mitigation of likely safety issues:
  - Continue to increase wind permeability of northern development towers, e.g., height, width, streamlining, rounding etc.
  - Rounding/chamfering and refinement of critical buildings to reduce local wind accelerations.

5.3 ITERATION 2 – OPTION 1 AND OPTION 2

The *Iteration 2 - Option 1* and *Iteration 2 – Option 2* configurations were simulated for 3 wind directions (northeast, south, and northwest). These three wind directions were identified in Iteration 1 as the most challenging for the development as they produce the most adverse pedestrian wind conditions. The results for *Iteration 2 - Option* 1 are shown in Section 8.3, and *Iteration 2 - Option 2* in Section 8.4. Figure 37 shows design variation between *Iteration1* and *Iteration 2 – Option 1*. Figure 46 shows design variation between *Iteration1* and *Iteration 2 – Option 2*. In *Iteration 2 – Option 1* tower A1 was modified to a more streamlined triangular design, and in *Iteration 2 – Option 2* tower A1 was updated to an elliptical design. For both options, changes to the design of other towers were also made increasing permeability between towers and refining tower forms.

The outcomes of this analysis are as follows:

- The plaza northwest of the development is expected to see high wind speeds with wind from multiple directions.
- The revised tower A1 for *Iteration 2 – Option 1* has generally reduced wind speeds long the main avenue and in the plaza to the northwest of the proposed development.
- Pedestrian wind conditions over the railway to the south of the development have degraded. These changes need to be assessed against target pedestrian activation in this area.
- Additional localised safety issues have emerged for both options, especially for the south wind direction.

5.4 ITERATION 3 – OPTION 3, OPTION 4, OPTION 5 AND OPTION 6

The *Iteration 3 - Option 3* configuration was simulated for 3 wind directions (northeast, south, and northwest). The *Iteration 3 - Option 4, 5,* and *6* configurations were only simulated for the northeast wind direction as these investigated northern massing sensitivities to inform future development directions. The results for *Iteration 3 - Option 3, 4, 5,* and *6* are shown in Sections 8.5, 8.6, 8.7, and 8.8, respectively.

Figure 55 shows design variation between *Iteration 2 – Option 1* and *Iteration 3 – Option 3*. Figure 56 shows design variation between *Iteration 2 – Option 2* and *Iteration 3 – Option 3*. In *Iteration 3 – Option 3,* tower A1 was reverted to a rectangular design, albeit with rounded corners and massing of towers A2 and A3 increased. The corners of all other towers were also rounded. A tower was also removed at the south of the development.

In *Iteration 3 – Option 4, 5,* and *6* the following isolated design changes were made to test the sensitivity of *Iteration 3 – Option 3*:

- Option 4: Position of tower A1 shifted to west.
- Option 5: Position and massing of towers A4, A5, and A6 altered.
- Option 6: Rail platform canopy to the north of tower A1 removed.

The outcomes of this analysis are as follows:

- The *Iteration 3 – Option 3* configuration was generally a backward step relative to *Iteration 2*. The following areas were identified at high risk of exceeding the safety criterion at the following locations:
  - Northern region of the proposed development.
  - Along the central avenue of the development.

5.4.1 Wind Mitigation Strategies

- Reduction of massing and streamlining of towers A1, A2 and A3 is suggested to reduce risk of exceeding pedestrian safety wind speeds surrounding the development. The positioning and streamlining of tower A1 are of particular importance to achieve the desired wind outcomes.
- Reduce tower A3 massing presented to southerly winds.
- Tower A4/A5/A6 height is relative insensitive to all wind directions and moderate increased height may offer south wind direction plaza protection.
- Movement of tower A4/A5 to west and moderate size increase may protect main avenue from northeast winds and offer plaza protection from south wind direction. Care also needs to be taken to avoid creating issues from northwest wind direction.
- Removal of rail platform canopy is relatively insensitive and can be removed if not required.

5.5 ITERATION 4 – OPTION 4 AND OPTION 5

These configurations were simulated for 3 wind directions (northeast, south, and northwest). *Iteration 4* further explored the block A and B tower massing to achieve best pedestrian wind outcomes at the three key wind directions. The results for *Iteration 4 - Option 4* are shown in Section 8.19. The results for *Iteration 4 - Option 5* are shown in Section 8.10. Figure 74 shows design differences between *Iteration 4 - Option 4* and *Iteration 4 – Option 5*. Towers A1, A2, A3, and B1 were altered between options. In *Iteration 4 - Option 5*: the footprints of towers A1 and A2 were increased; tower A3 was split into two separate towers on a single podium; and the radius on one corner of tower B1 was removed.

The outcomes of this analysis are as follows:

- *Iteration 4 - Option 5* delivers the best overall pedestrian level wind conditions. It provides several improvements in pedestrian level wind conditions for the northeast, south, and northwest wind directions.
- However, a few locations are still at high risk of exceeding pedestrian safety wind speeds, namely:
    - At the southern end of the main avenue near towers C4 and C5 for the northeast wind direction.
    - In the pedestrianised area between the Atlassian Tower and building to the south for the south wind direction.

5.6 ITERATION 5 – OPTION 1, OPTION 2, BASELINE WITH DECK, AND BASELINE WITHOUT DECK

Building on improvements of *Iteration 4 - Option 5, Iteration 5 - Option 1* configuration was simulated for 4 wind directions (north-northeast, northeast, south, and northwest). Block C and buildings A4, A5 and A6 massing were modified to improve wind flow through development and further improve pedestrian wind conditions. The *Iteration 5 - Option 2* was an updated current city configuration, With Deck and Without Deck configuration, and were simulated for 3 wind directions (northeast, south, and northwest). The results for *Iteration 5 - Option 1* are shown in Section 8.11, *Iteration 5 - Option 2* in Section 8.12, *Iteration 5 - With Deck* in Section 8.13, and *Iteration 5 - Without Deck* in Section 8.14. Figure 90 shows design variation between *Iteration 5 - Option 1* and *Iteration 5 - Option 2*. Towers A1, A2, A3, A4, A5, and A6 are altered between the two options. In *Iteration 5 - Option 2*: the footprint of tower A1 was decreased; the footprints of towers A2 and A3 were increased; and towers A4, A5, and A6 were adjusted accordingly to align with changes to towers A1, A2, and A3.

The outcomes of this analysis are as follows:

- *Iteration 5 - Option 1* and *Iteration 5 - Option 2* Comparison:
    - Option 1 delivers the best overall pedestrian level wind conditions.
    - Northwest wind direction produces isolated area at risk of exceeding the safety limit. It is suggested building A6 is reverted to the previous configuration (Iteration 4 – Option 5).

- Comparison to site with development (*Iteration 5 - Option 1* or *Iteration 5 - Option 2*) to the existing (*Iteration 5 - Without Deck*) configuration:

- The proposed development degrades the pedestrian level wind conditions at these locations and wind directions:
    - Railway Square, George St, Lee St (northeast wind).
    - Laneway to the west of the Atlassian building (northeast wind).
    - Coach terminal, Railway Colonnade Dr (northwest wind).
    - Chalmers St (northwest wind).
- The proposed development generally improves the pedestrian level wind conditions at these locations and wind directions:
    - Atlassian building, Dexus Frasers building (south wind).
    - Coach terminal, Railway Colonnade Dr (south wind).
    - Regent St (northwest wind).
    - Devonshire St (northwest wind).

- *Iteration 5 - With Deck* and *Iteration 5 - Without Deck* Comparison:
    - The *Iteration 5 - With Deck* configuration degrades wind conditions for the south and northwest wind directions in comparison to the *Iteration 5 - Without Deck* configuration.

5.7 ITERATION 5 – OPTION 1 WITH NO A1 TOWER

This configuration was simulated for the northeast wind direction. The results are shown in Section 8.15.

The outcomes of this analysis are as follows:

- Removing tower A1 significantly degrades the pedestrian level wind conditions along the central avenue for the northeast wind direction

5.8 ITERATION 6 – REVISED PREFERRED MASSING, 8M SETBACK, 8M SETBACK ALTERNATIVE & BASELINE WITHOUT DECK

These four configurations were simulated for 8 wind directions (north, northeast, east, southeast, south, southwest, west, and northwest). In addition, the *Iteration 6 - Revised Preferred Massing* configuration was simulated for the north-northeast and east-northeast wind directions. The results for the *Iteration 6 - Baseline Without Deck* are shown in Section 8.16, the *Iteration 6 - Revised Preferred Massing* in Section 8.17, the *Iteration 6 - 8m Setback* in Section 8.18, and the *Iteration 6 - 8m Setback Alternative* in Section 8.19. Figure 142 and Figure 155 show wind flow streamlines for the prevailing northwest wind direction and how the Western Gateway conditions the wind entering the proposed development site. Figure 142 and Figure 155 show the design variation between the *Iteration 6 - Revised Preferred Massing* and the *Iteration 6 - 8m Setback* and *Iteration 6 - 8m Setback Alternative* configurations, respectively.

For the *Iteration 6 - 8m Setback* configuration, towers A2, A3, B1, B2, C1, C2, C3, D1, and D2 have all been altered from the *Iteration 6 - Revised Preferred Massing* configuration and GFA significantly reduced.

For the *Iteration 6 - 8m Setback Alternative* configuration (equivalent GFA to *Iteration 6 - 8m Setback* configuration), the shorter towers in the central avenue of the development have been removed and the footprint of the taller towers (A2, A3, B1, B2, and C1) extends further west into the central avenue. Towers A2, A3, B1, and B2 have been rotated 90 degrees so that the alleyways between A2 and A3, and B1 and B2 run parallel to the central avenue.

The outcomes of this analysis are as follows:

- In comparison to the existing *Iteration 6 – Baseline Without Deck* configuration, the *Iteration 6 - Revised Preferred Massing*:
  - Improves wind conditions to the west of the development, including around the Atlassian, Dexus Fraser, and Toga towers.
  - Wind conditions to the east of the development are generally degraded along rail lines.
- The *Iteration 6 - Revised Preferred Massing* configuration delivers the best overall pedestrian level wind conditions.
- The *Iteration 6 - 8m Setback* and *Iteration 6 - 8m Setback Alternative* configurations have isolated areas at risk of exceeding the safety criterion.

6 CONCLUSIONS

An environmental wind study to assess the wind conditions in the public realm for the Central Precinct Renewal in Sydney was conducted using Computational Fluid Dynamics (CFD). The CFD model of the proposed development, within surrounding buildings, with no existing or future ground level trees, was simulated in a natural wind boundary layer to determine likely local environmental wind conditions. The results were assessed against pedestrian environmental safety and comfort criteria as a function of wind direction. A Baseline configuration and six additional design iterations consisting of multiple design options were simulated. Key design configurations were simulated for eight wind directions.

For each iteration of the project wind mitigation strategies were investigated to reduce the risk of wind safety issues, reduce pedestrian wind levels in surrounding streetscapes and achieve target activation. Significant reduction in the risk of exceeding pedestrian level safety and comfort criteria compared to the initial Baseline proposal was achieved. The *Iteration 6 – Revised Preferred Massing* configuration was identified as the overall lowest-risk option. Further local refinement may be required to achieve target wind comfort criteria based on the intended pedestrian activation in the precinct streetscapes.

7 REFERENCES

1. Melbourne W. H., 1978, Criteria for environmental wind conditions, *Journal of Industrial Aerodynamics*, Volume 3, pp. 241-249
2. Melbourne W. H., 1978, Wind environment studies in Australia, *Journal of Industrial Aerodynamics*, Volume 3, pp. 201-214
3. Cochran, L.S. and Derickson, R.G., 2011, A Physical Modeler's View of Computational Wind Engineering, *Journal of Wind Engineering and Industrial Aerodynamics*, Volume 99, Number 4, pp 139-153.

8 FIGURES

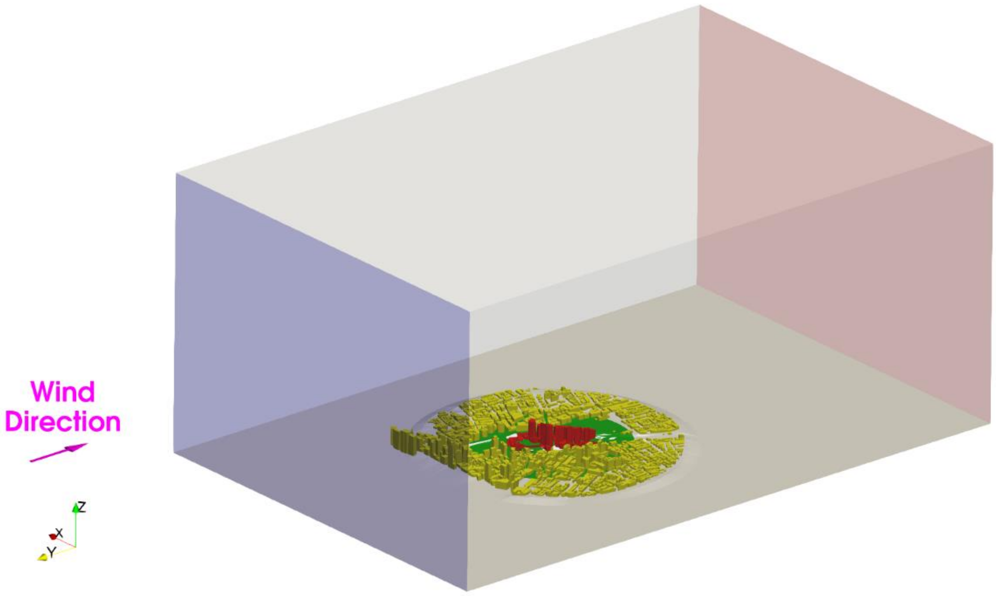

Figure 1: CFD Domain

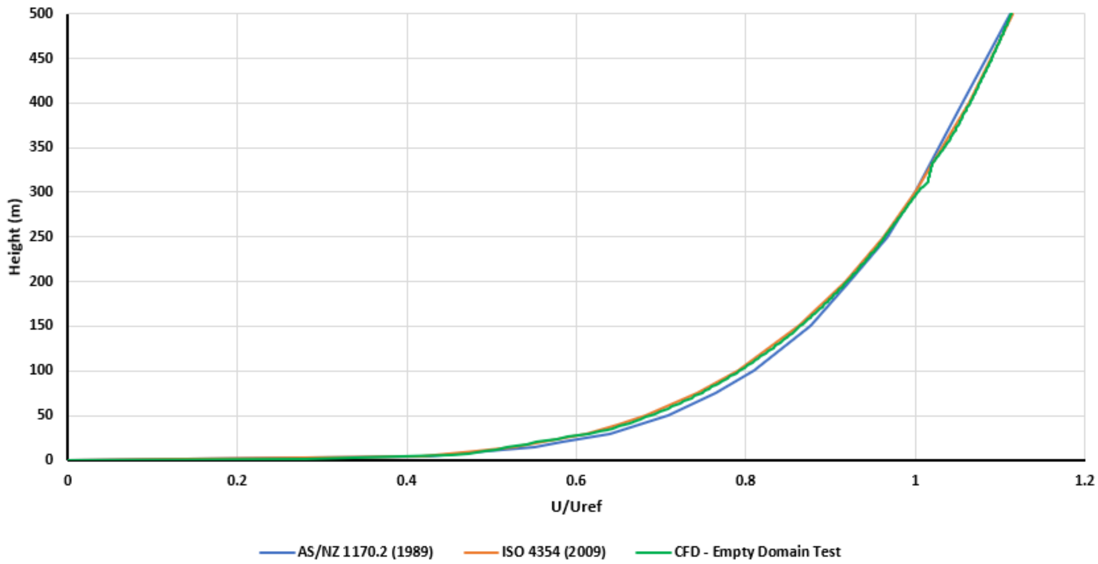

Figure 2: Full scale TC3 boundary layer mean velocity profile for all wind directions

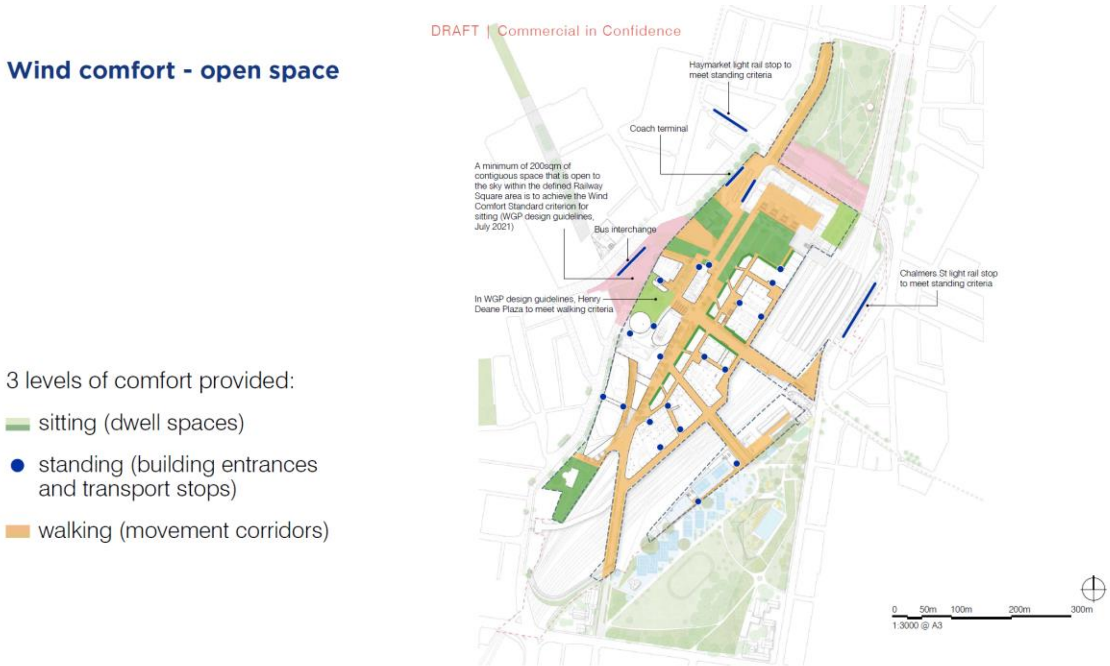

Figure 3: Streetscape activation areas

8.1 BASELINE

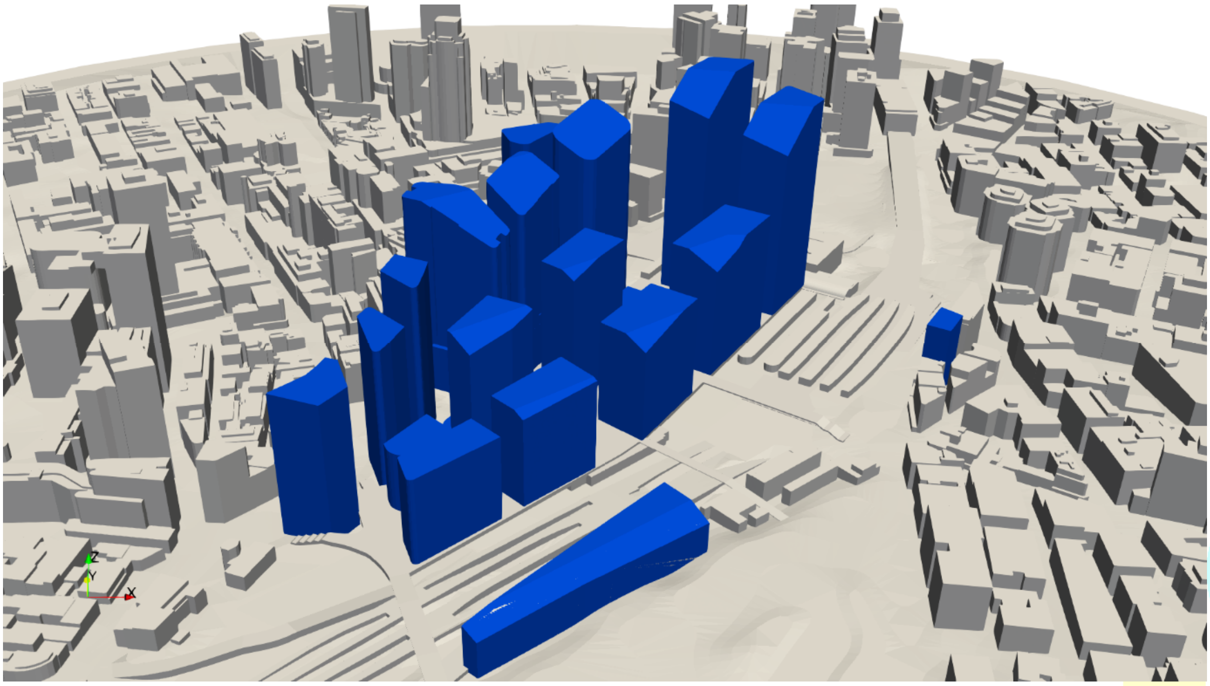

Figure 4: South View of the Proposed Baseline Massing

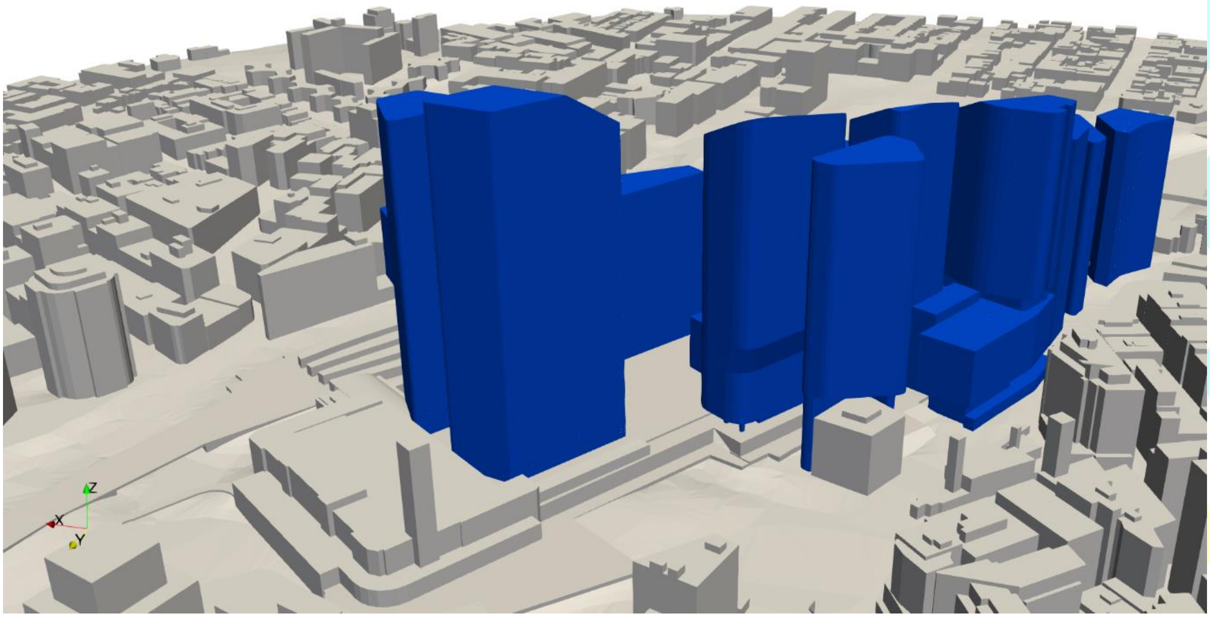

Figure 5: North View of the Proposed Baseline Massing

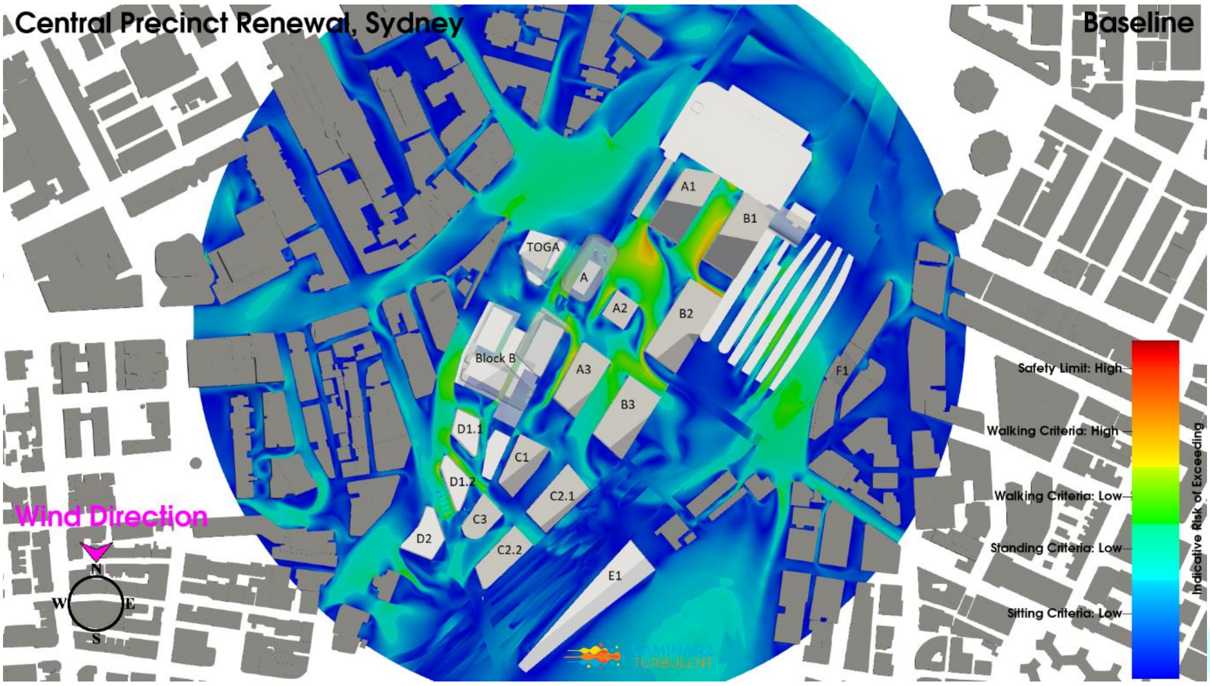

Figure 6: Baseline Configuration, North Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

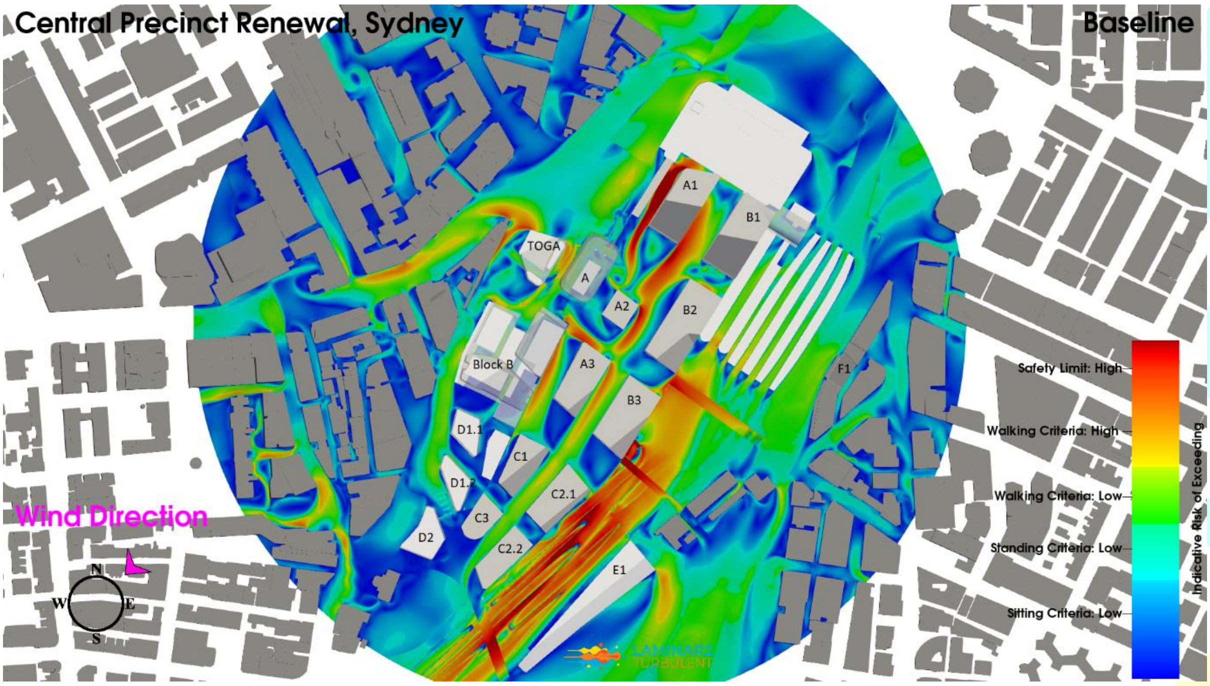

Figure 7: Baseline Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

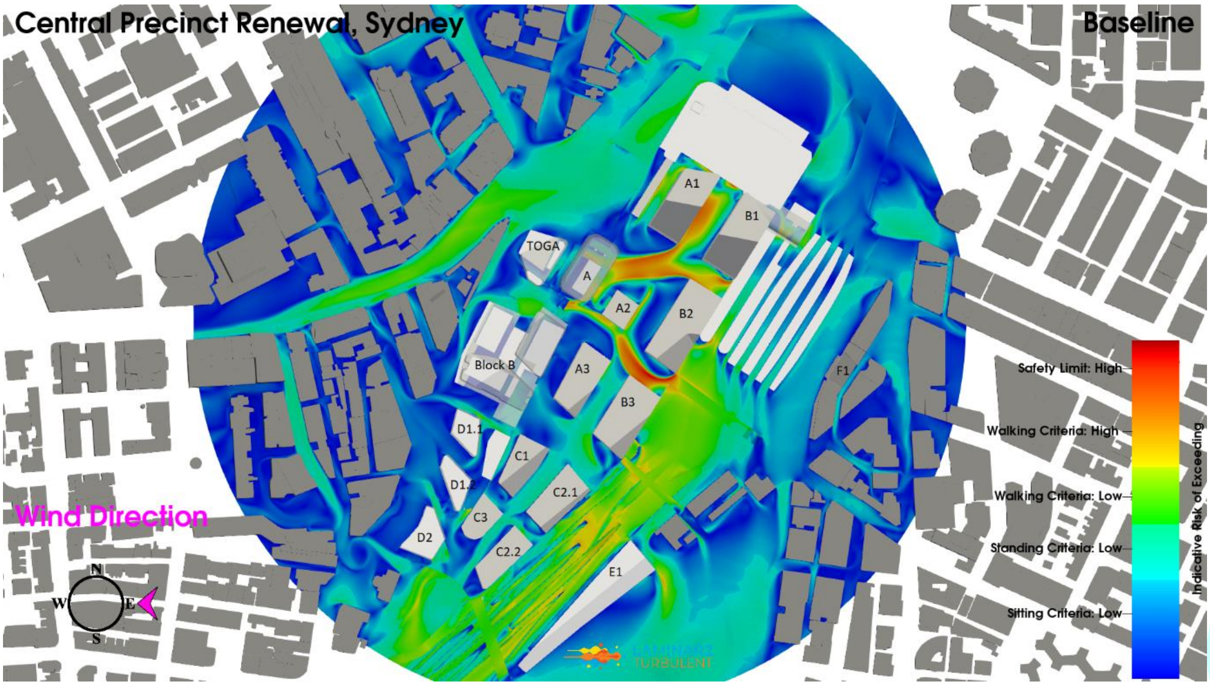

Figure 8: Baseline Configuration, East Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

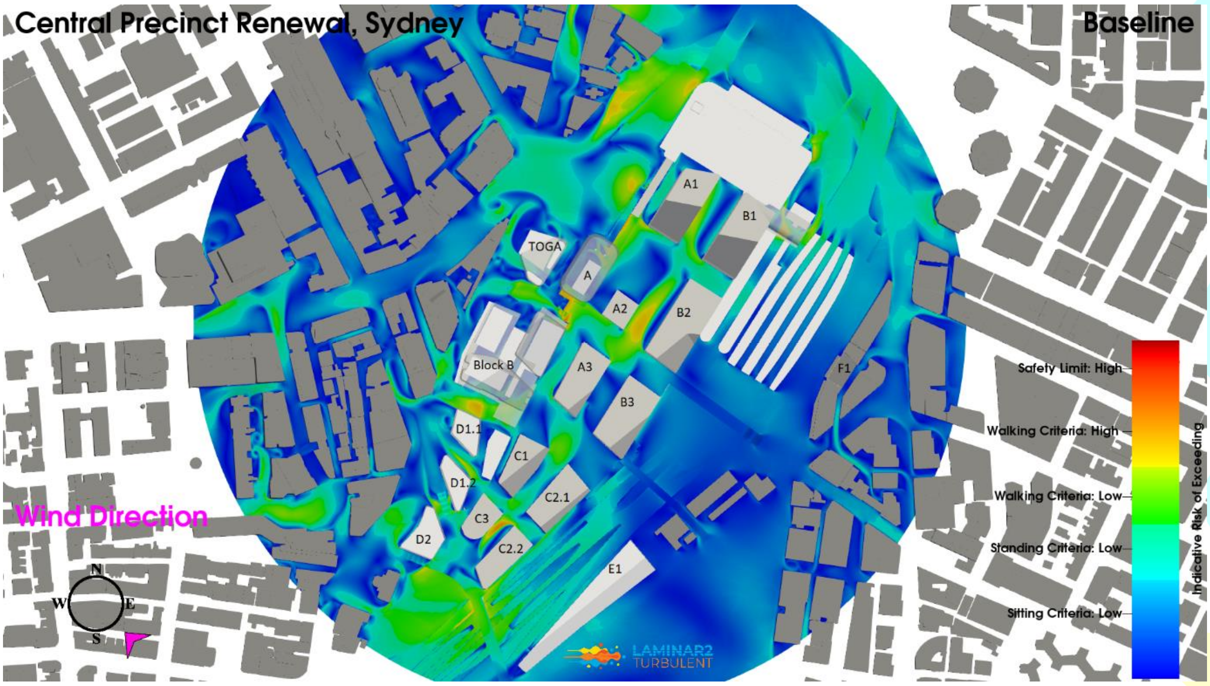

Figure 9: Baseline Configuration, Southeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

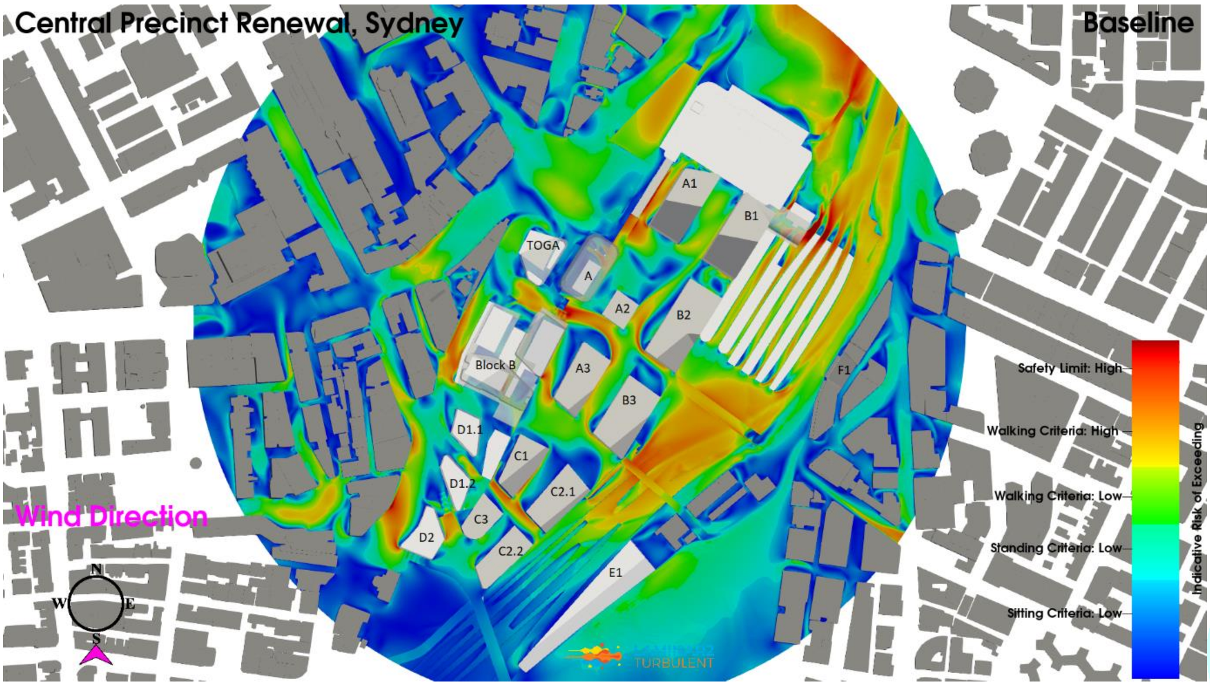

Figure 10: Baseline Configuration, South Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

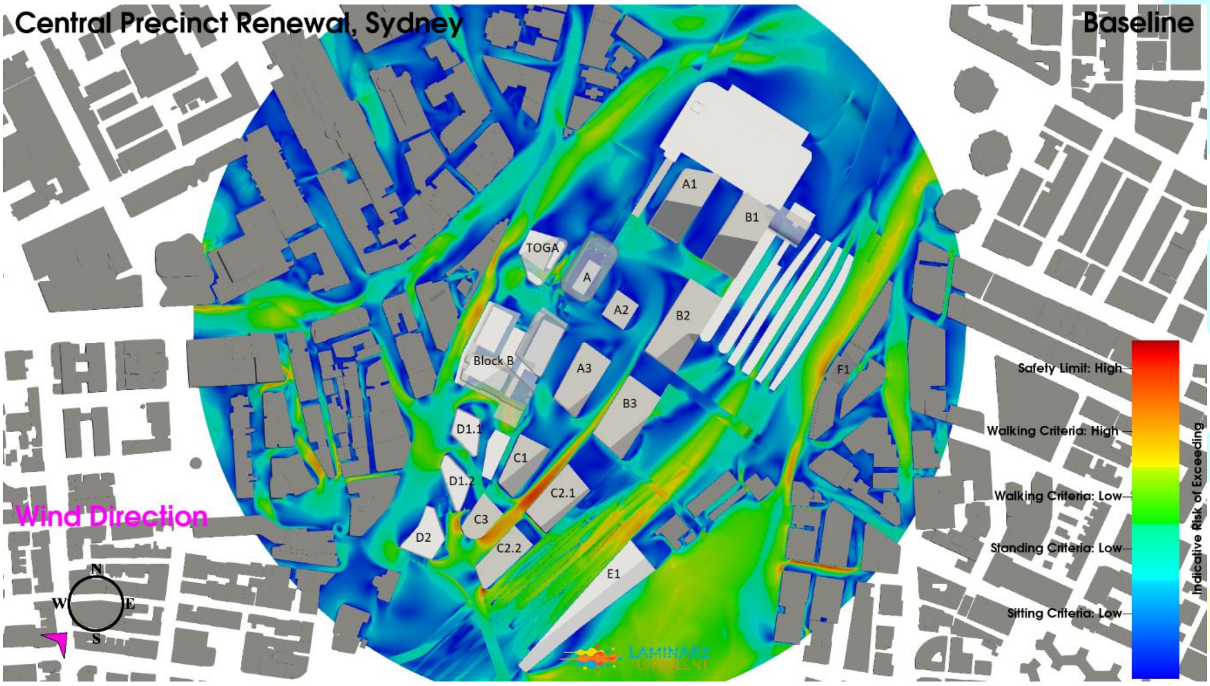

Figure 11: Baseline Configuration, Southwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

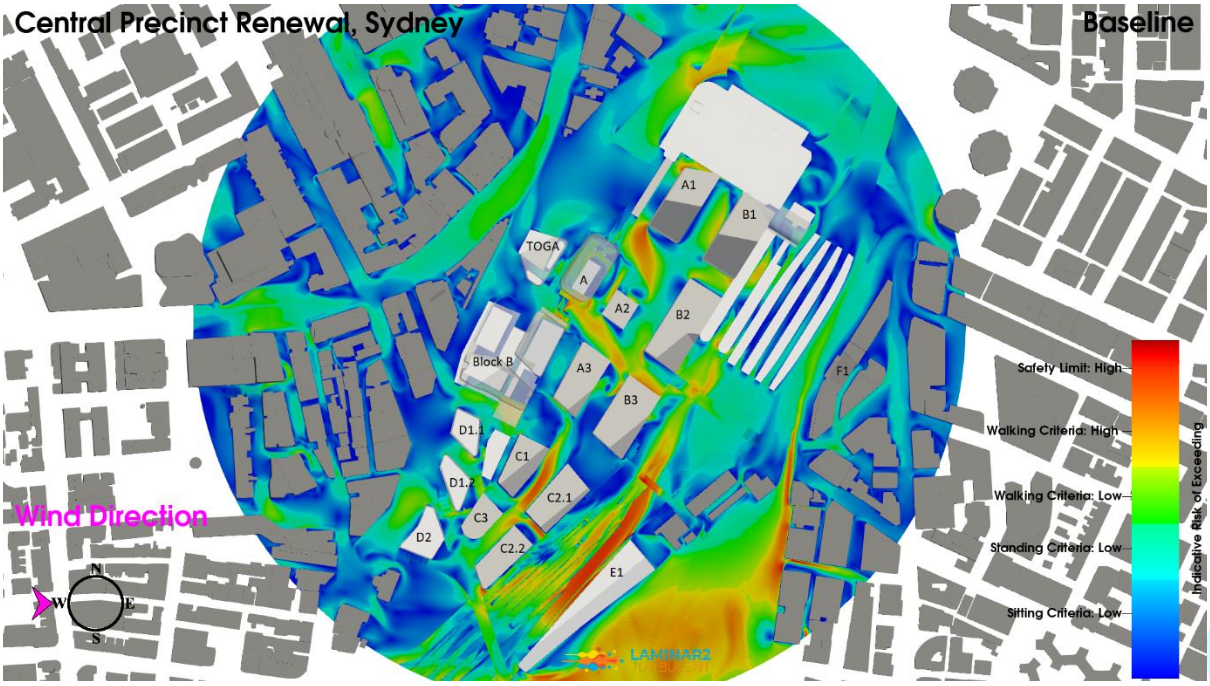

Figure 12: Baseline Configuration, West Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

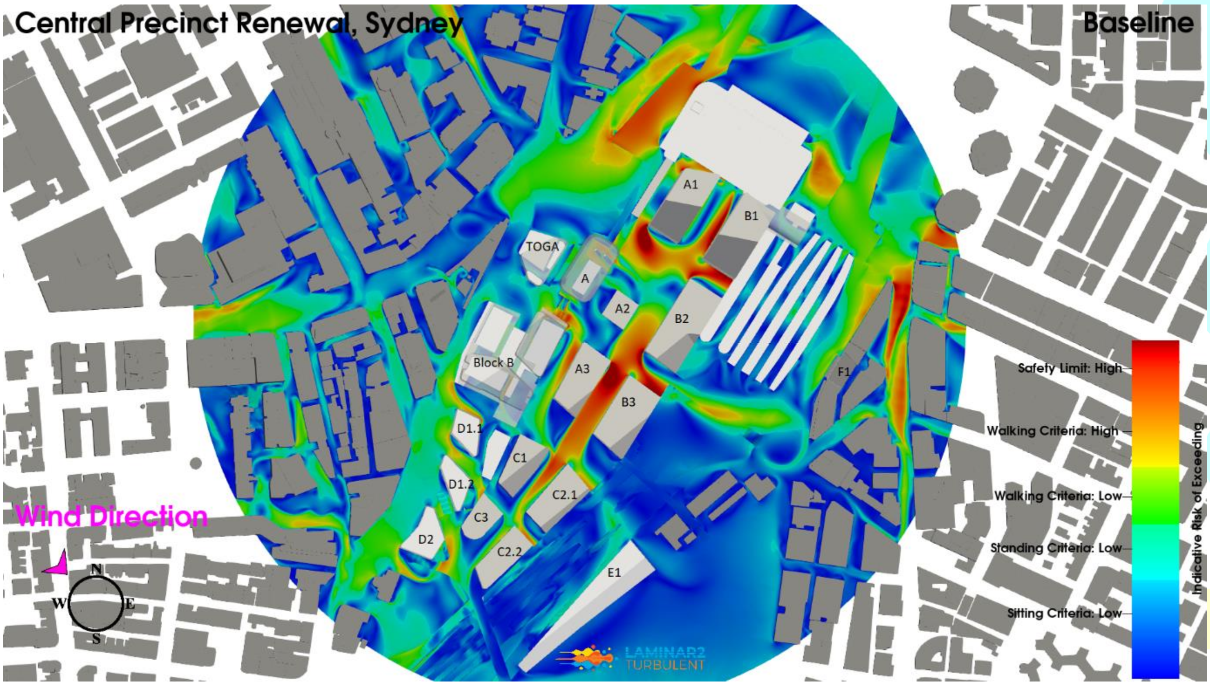

Figure 13: Baseline Configuration, Northwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

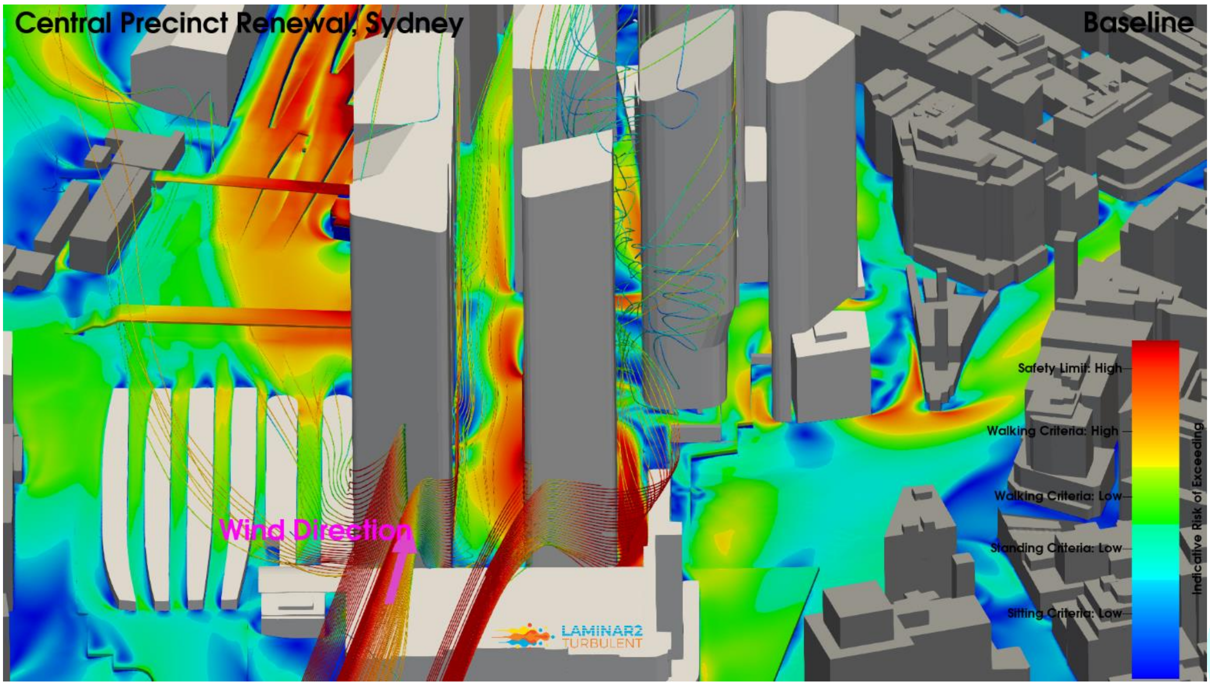

Figure 14: Baseline Configuration, Northeast Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

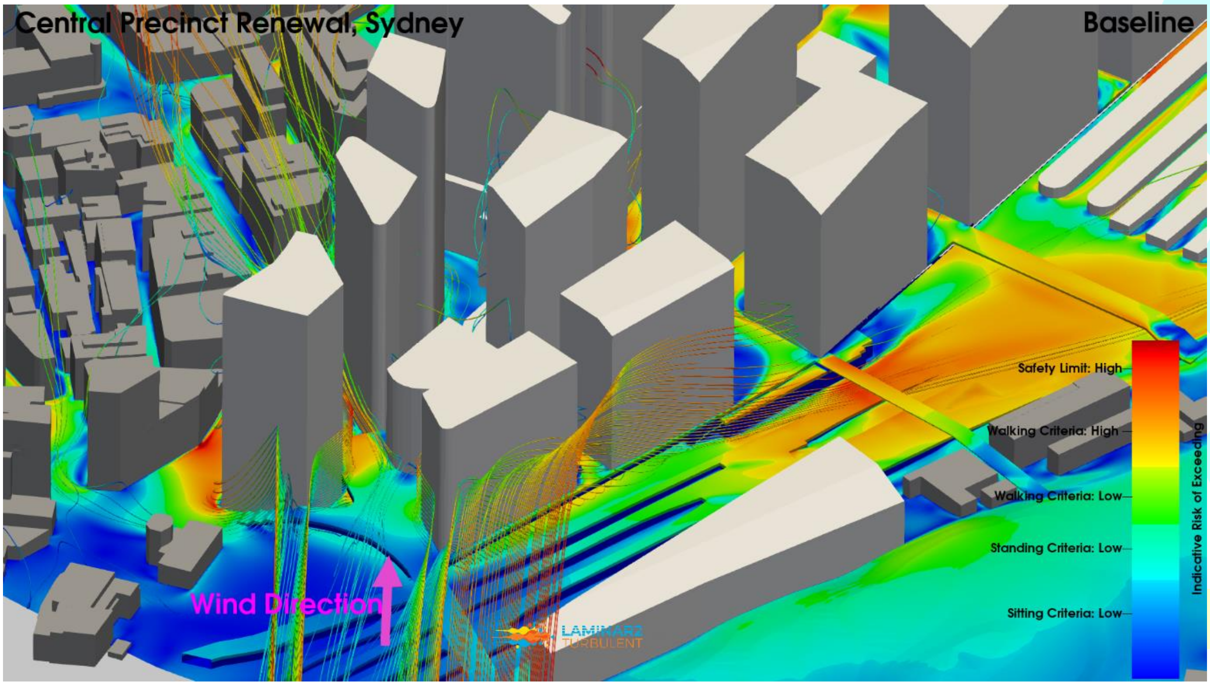

Figure 15: Baseline Configuration, South Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

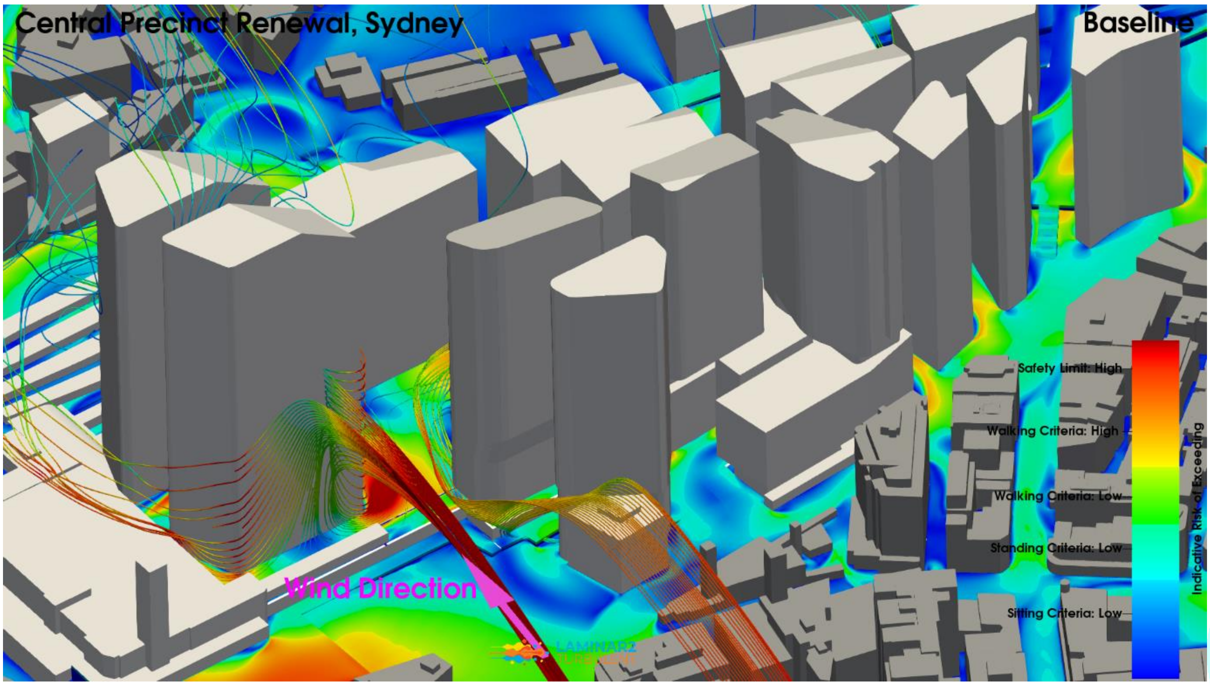

Figure 16: Baseline Configuration, Northwest Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

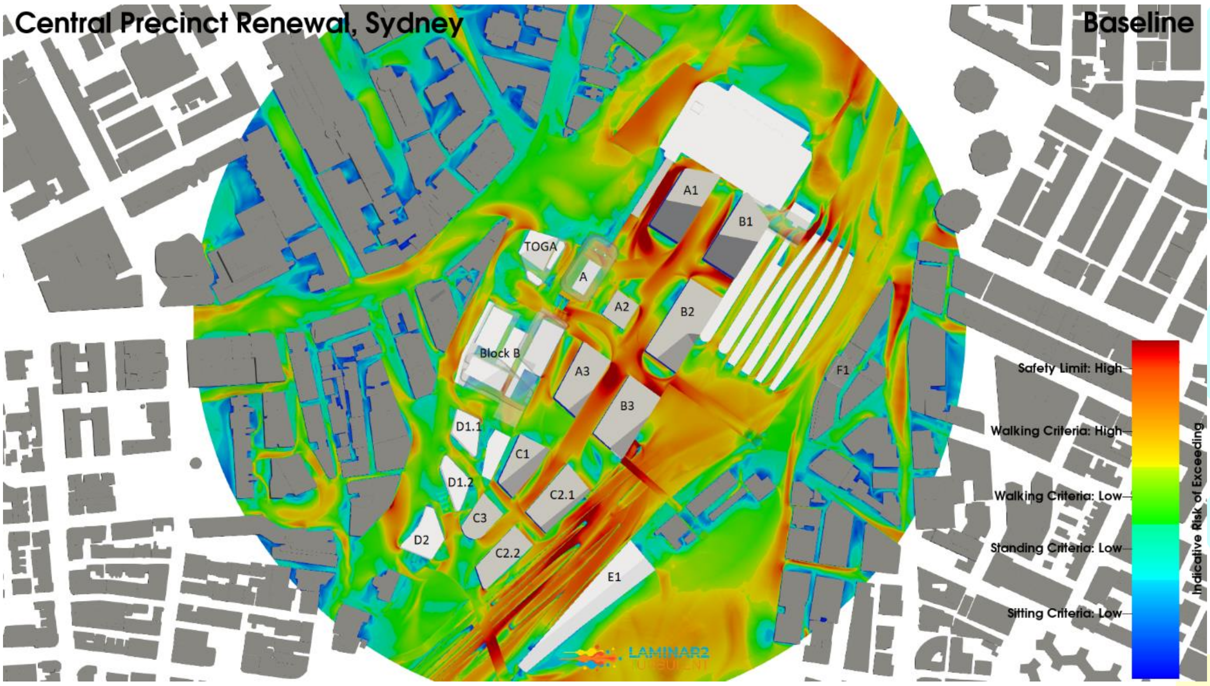

Figure 17: Baseline Configuration, Combined Wind Directions, Planview, Ground Level Maximum Pedestrian Environmental Wind Risk Contour Plot

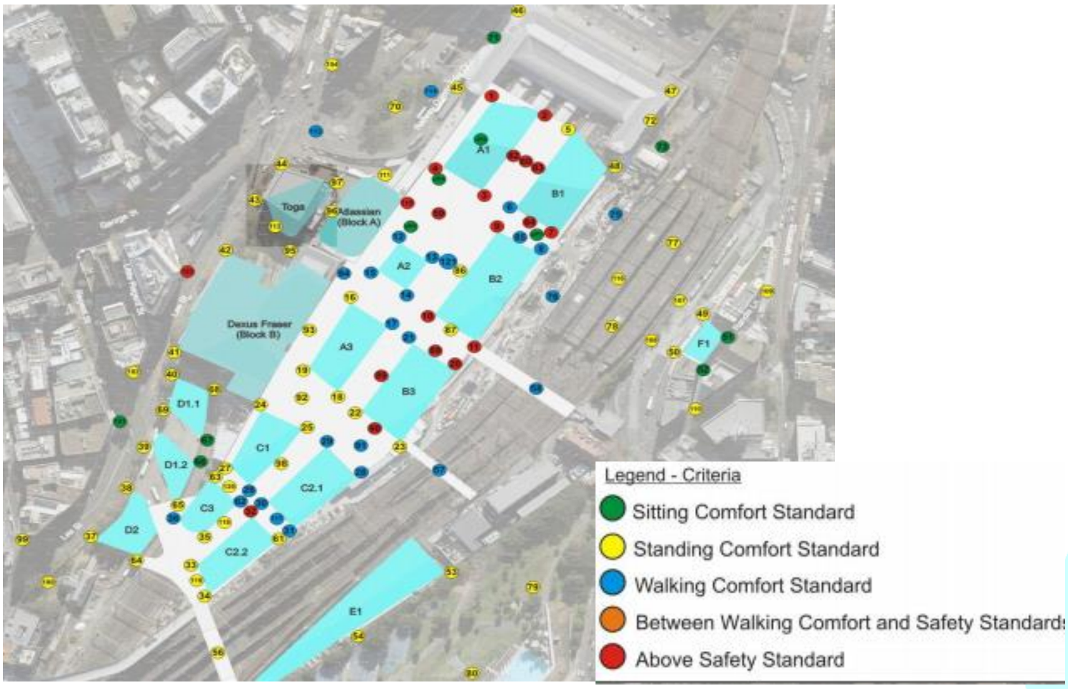

Figure 18: Wind Tunnel Results, Baseline Configuration, Combined Wind Directions, Planview, Ground Level Maximum Pedestrian Environmental Wind Risk Contour Plot

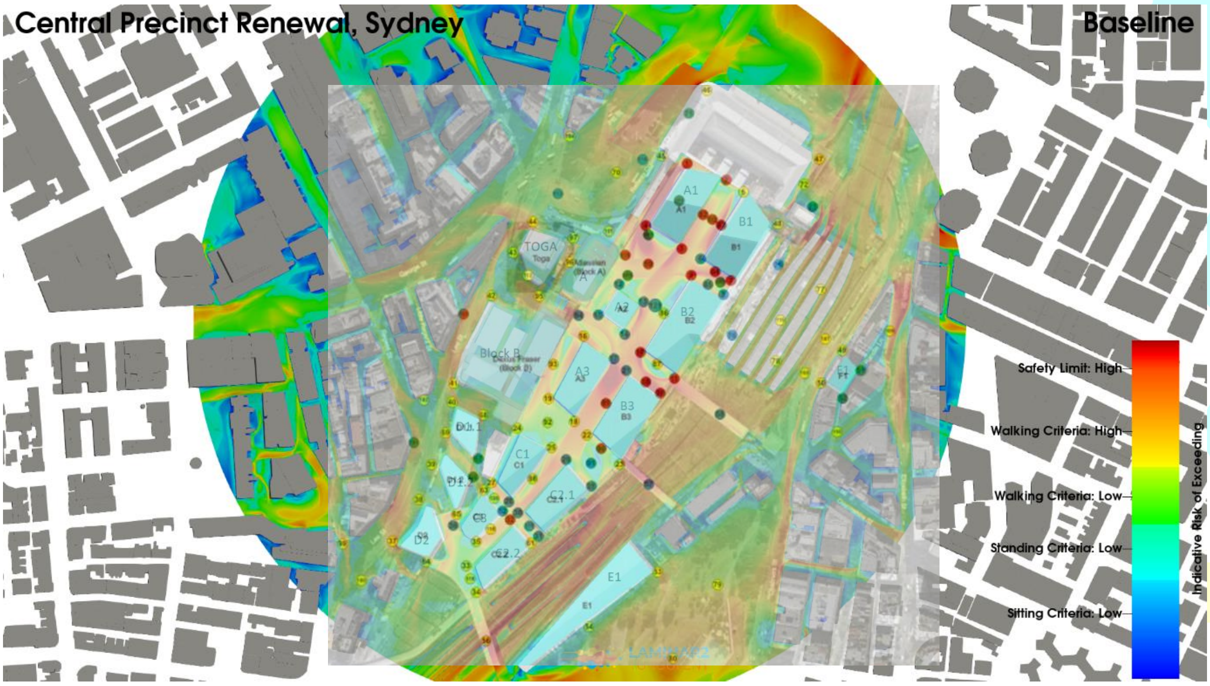

Figure 19: Comparison Between Baseline CFD and Wind Tunnel Results, Combined Wind Directions, Planview, Ground Level Maximum Pedestrian Environmental Wind Risk Contour Plot

8.2 ITERATION 1

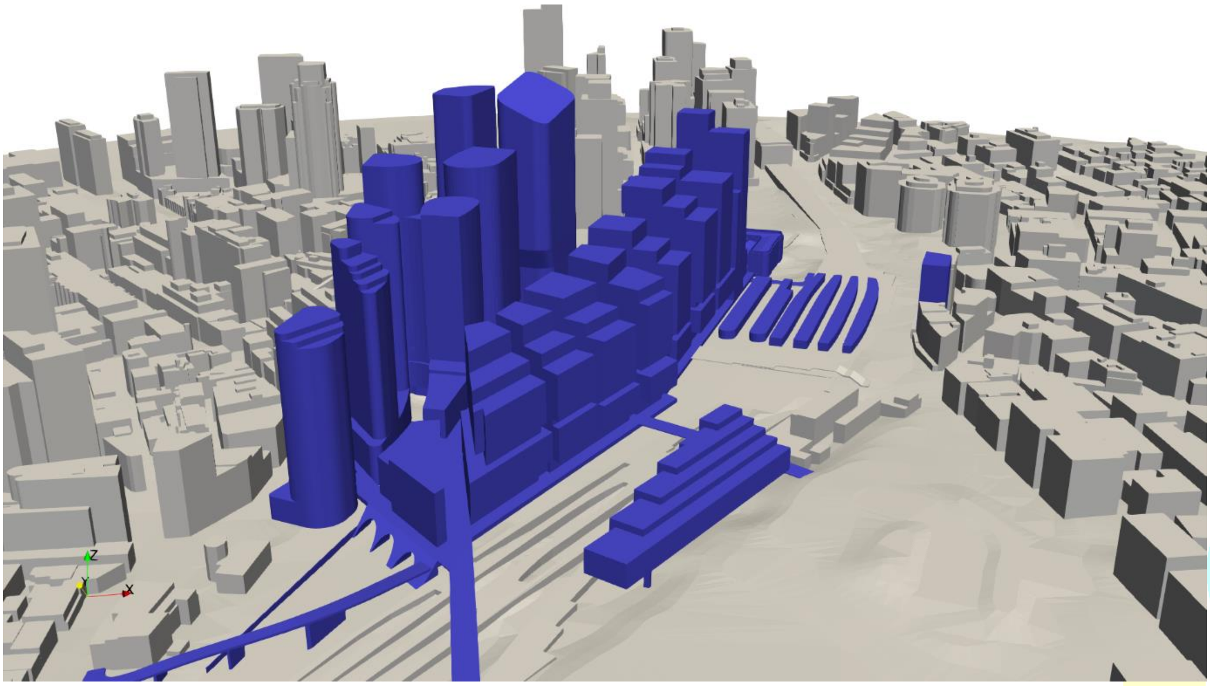

Figure 20: Southeast View of Proposed Iteration 1 Massing

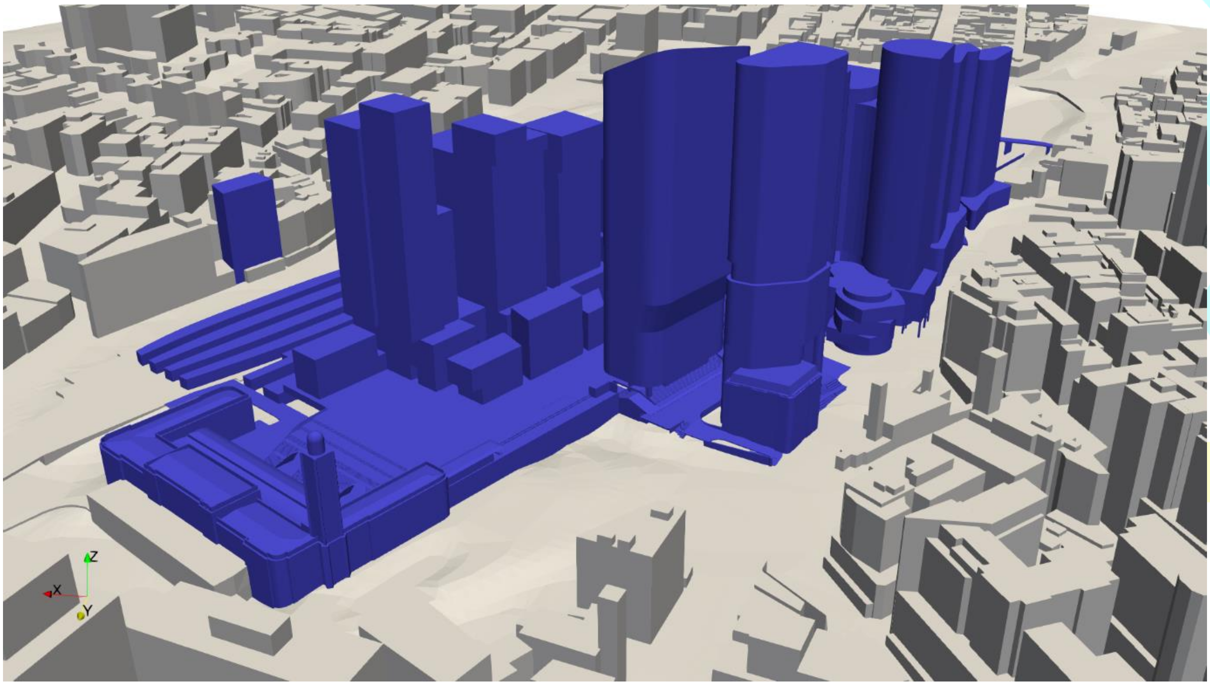

Figure 21: Northwest View of Proposed Iteration 1 Massing

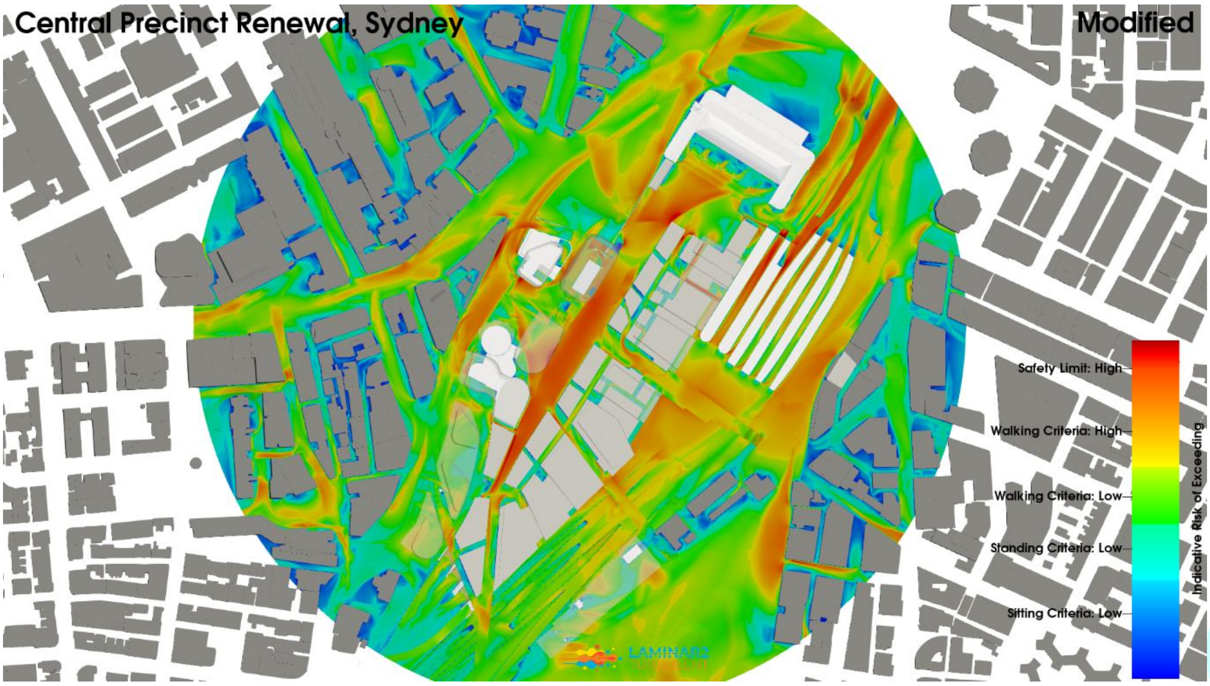

Figure 22: Iteration 1 Configuration, Combined Wind Directions, Planview, Ground Level Maximum Pedestrian Environmental Wind Risk Contour Plot

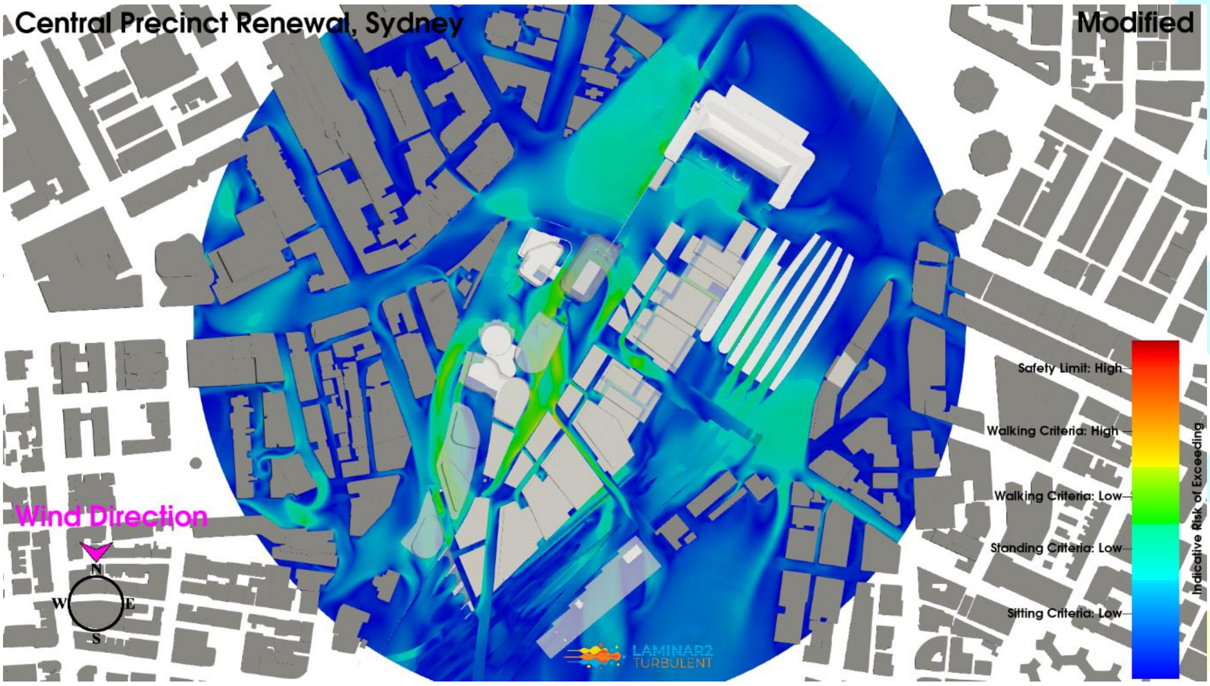

Figure 23: Iteration 1 Configuration, North Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

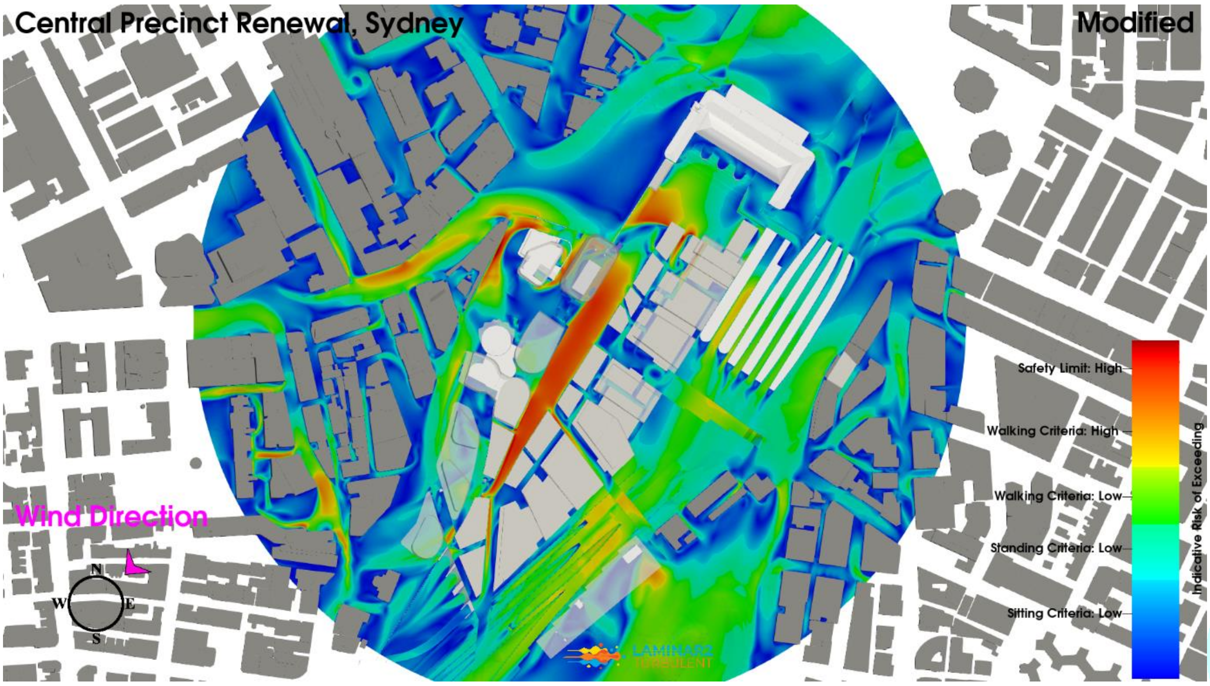

Figure 24: Iteration 1 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

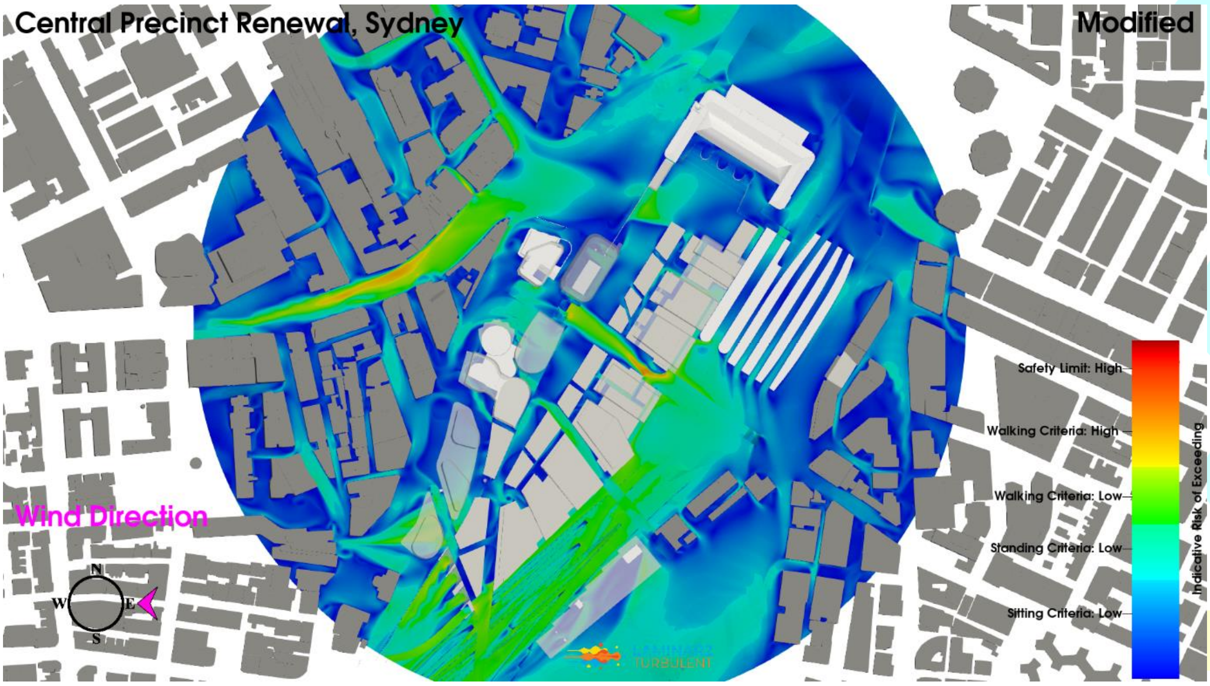

Figure 25: Iteration 1 Configuration, East Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

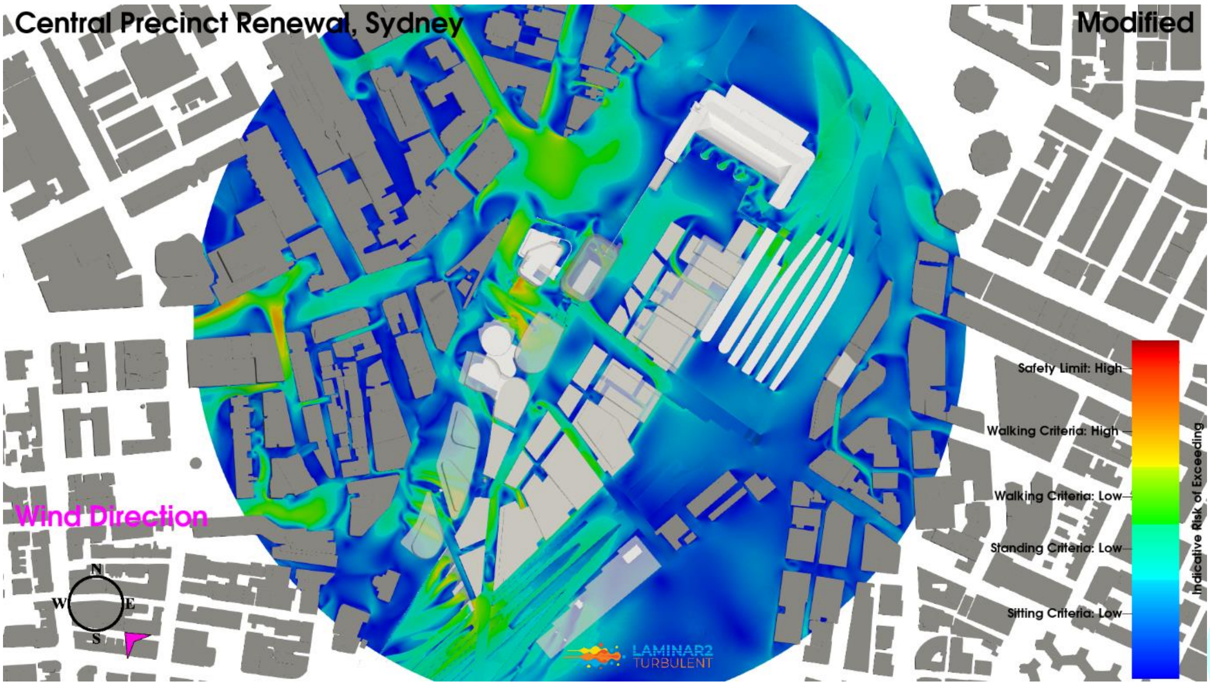

Figure 26: Iteration 1 Configuration, Southeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

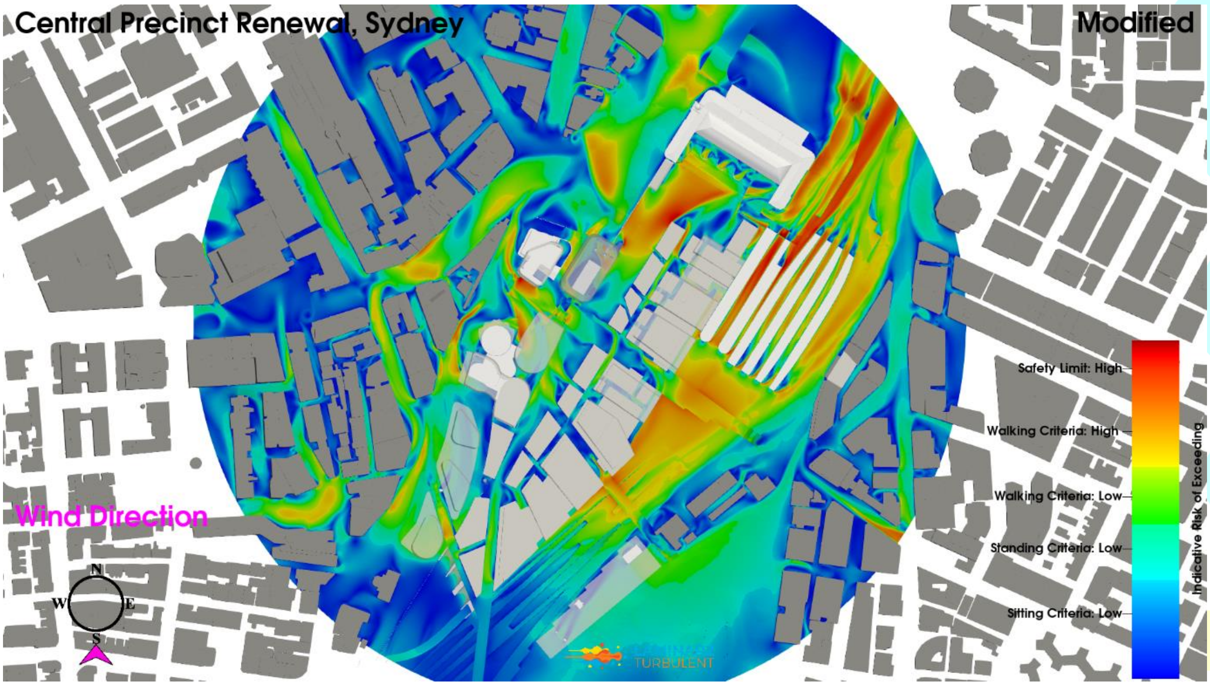

Figure 27: Iteration 1 Configuration, South Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

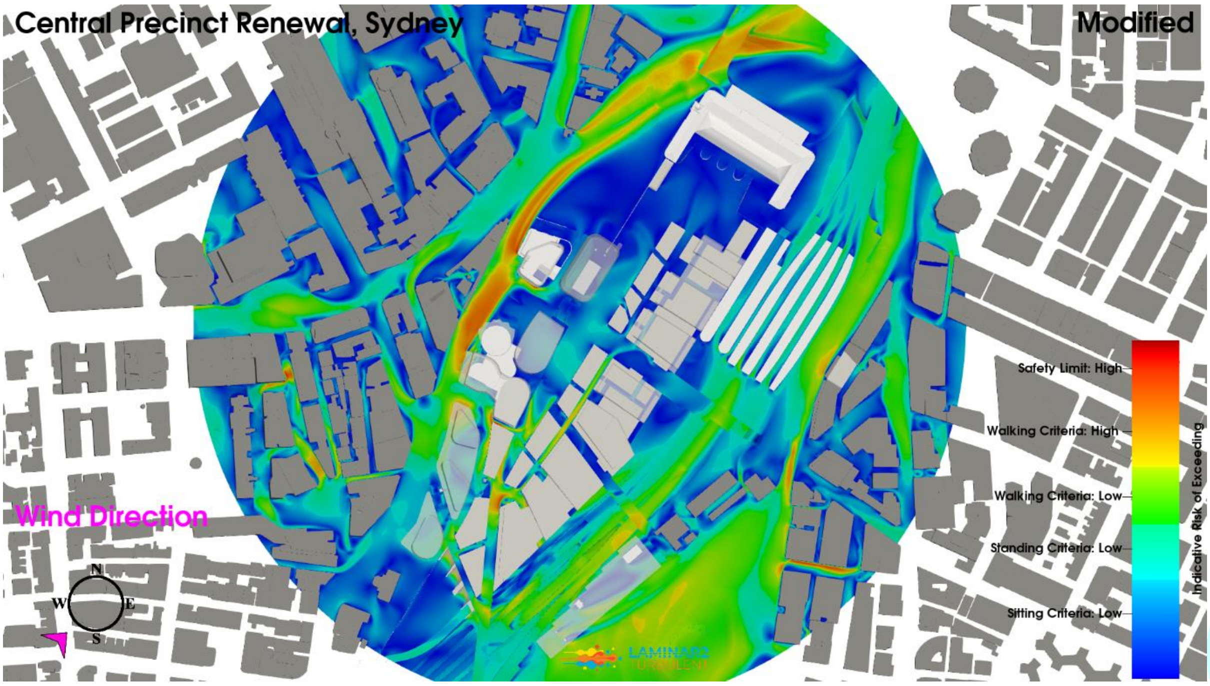

Figure 28: Iteration 1 Configuration, Southwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

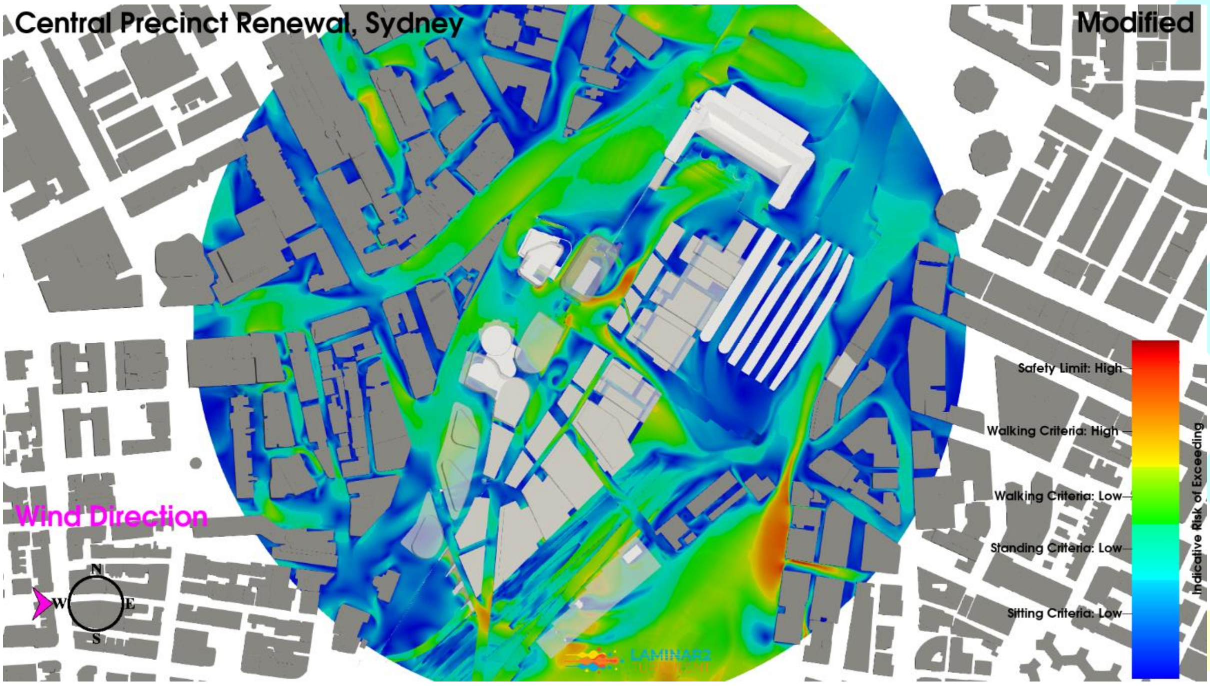

Figure 29: Iteration 1 Configuration, West Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

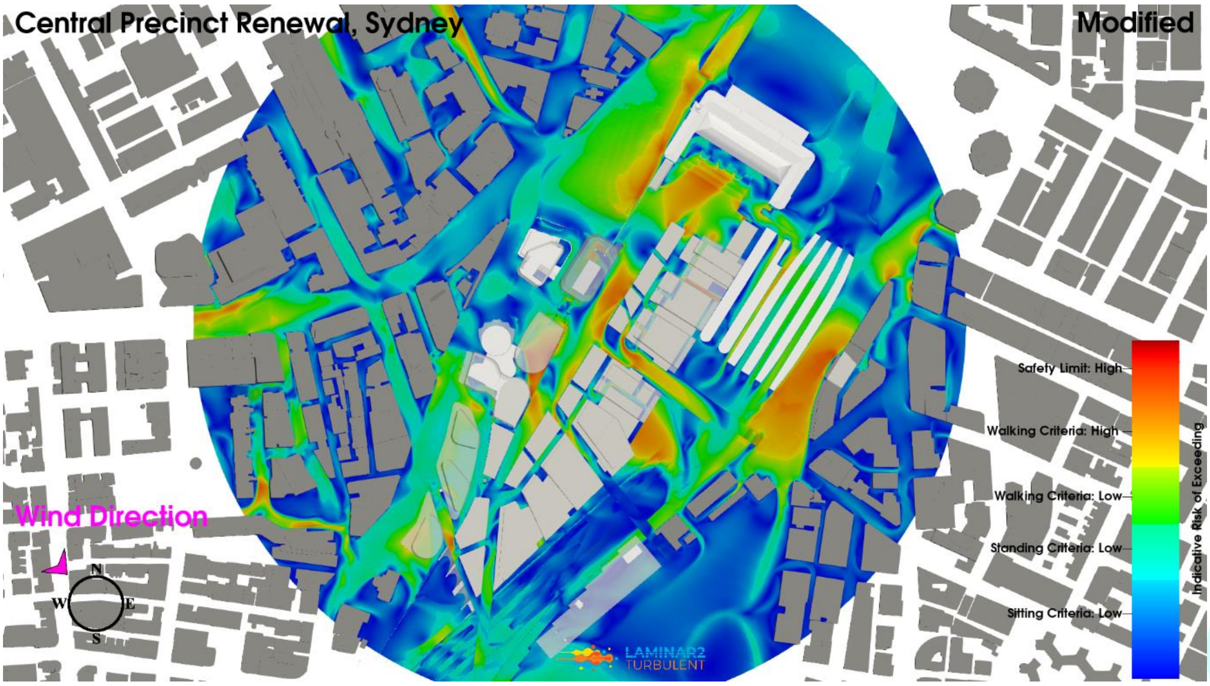

Figure 30: Iteration 1 Configuration, Northwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

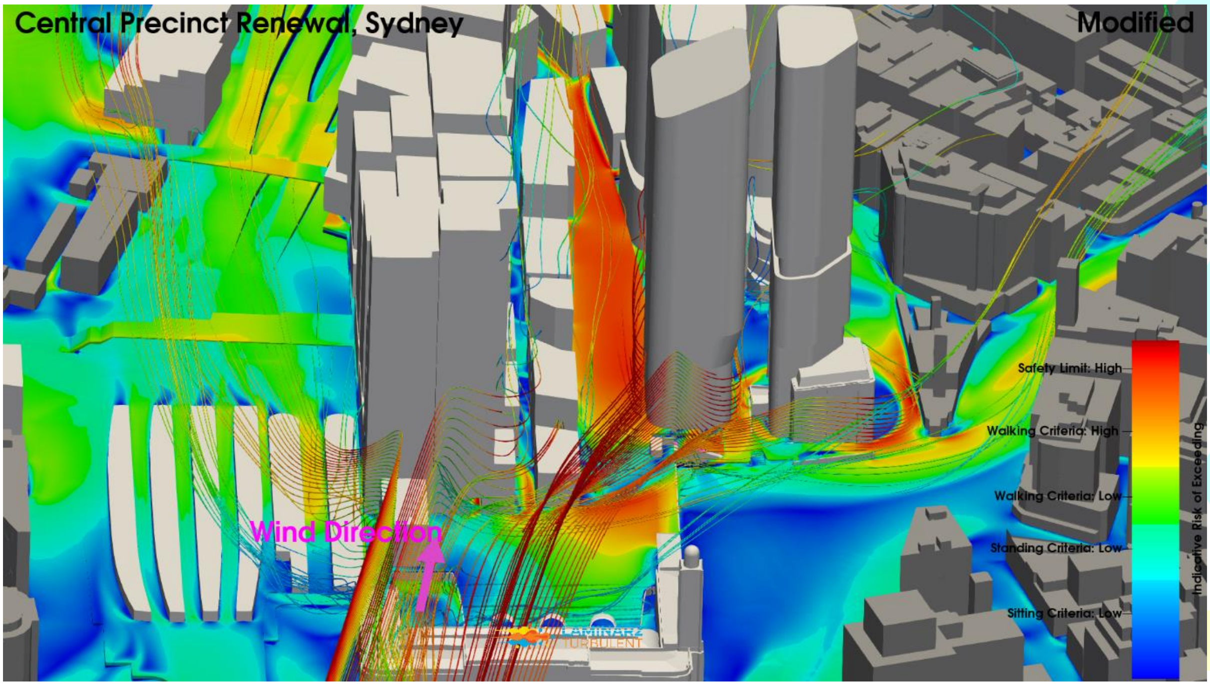

Figure 31: Iteration 1 Configuration, Northeast Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

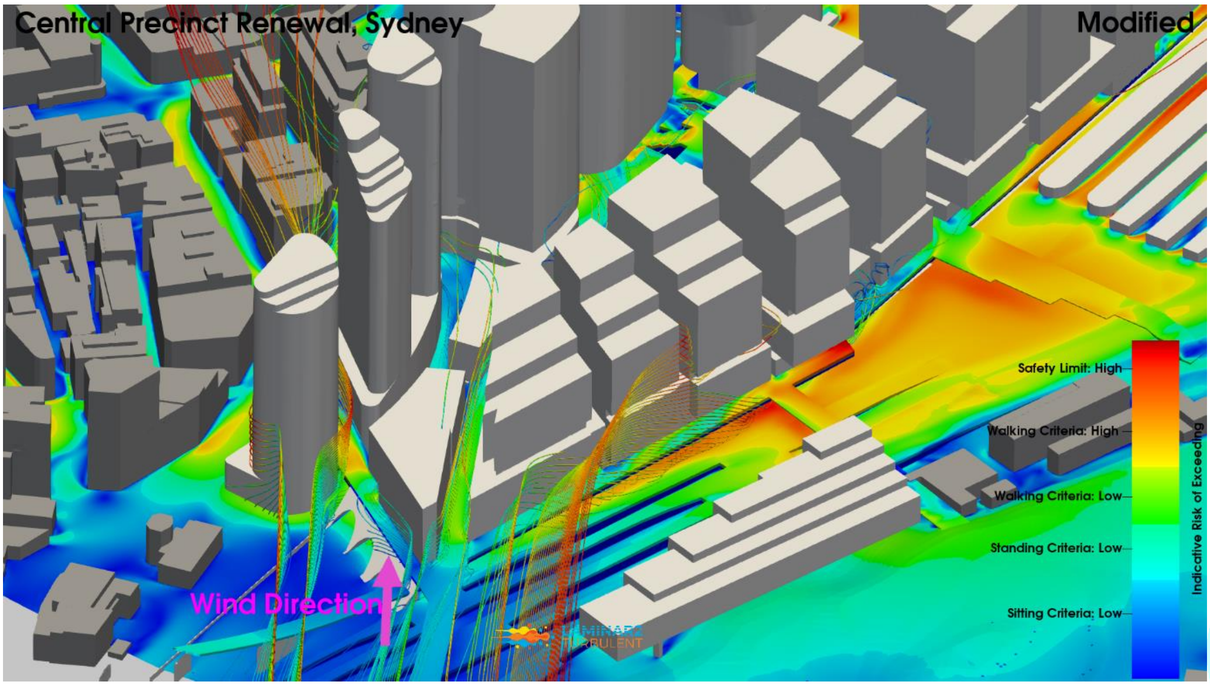

Figure 32: Iteration 1 Configuration, South Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

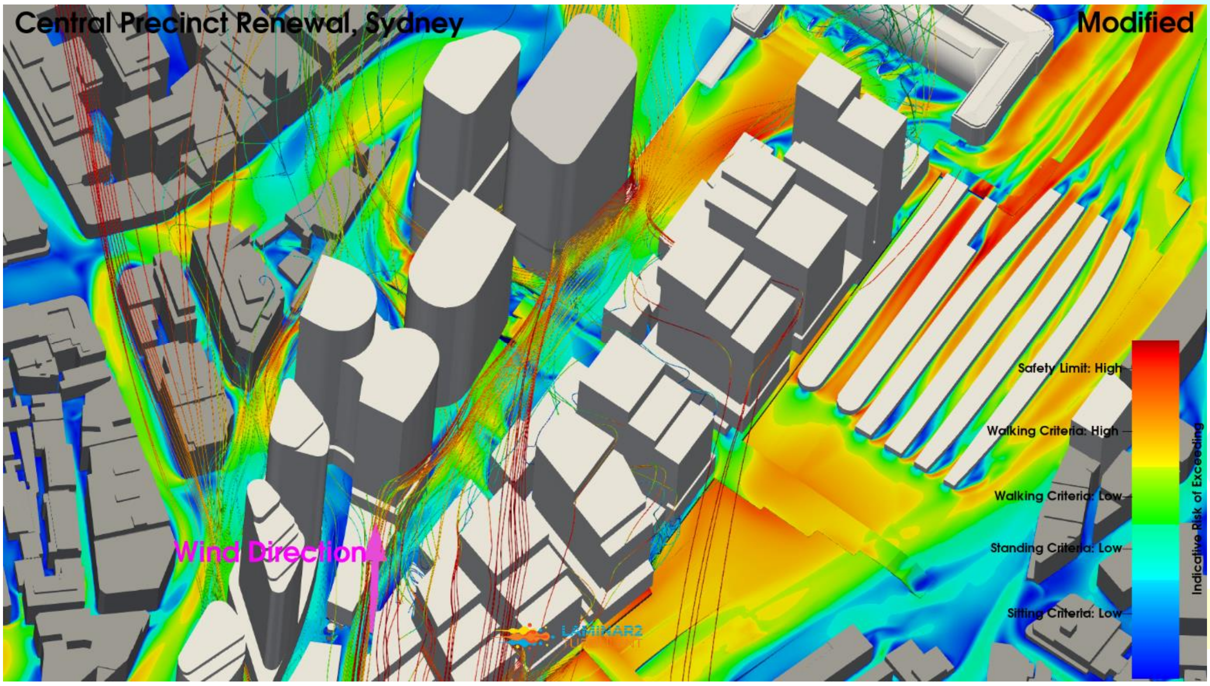

Figure 33: Iteration 1 Configuration, South Wind Direction (alternate view), Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

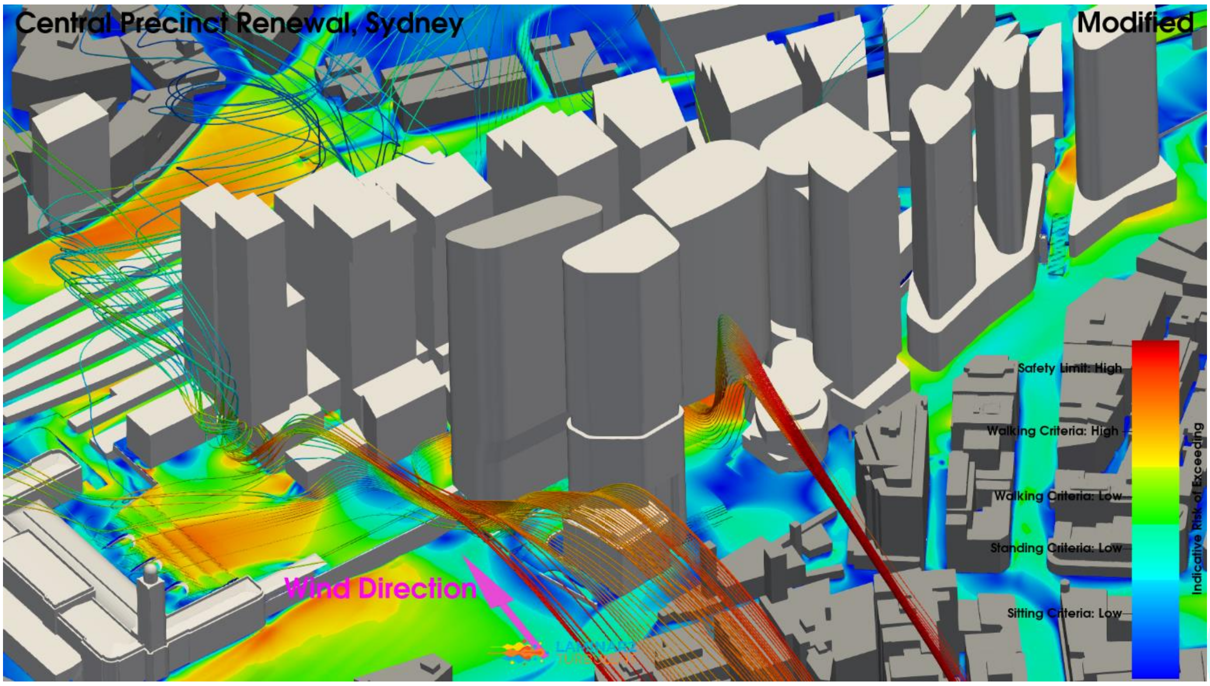

Figure 34: Iteration 1 Configuration, Northwest Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

8.3 ITERATION 2 – OPTION 1

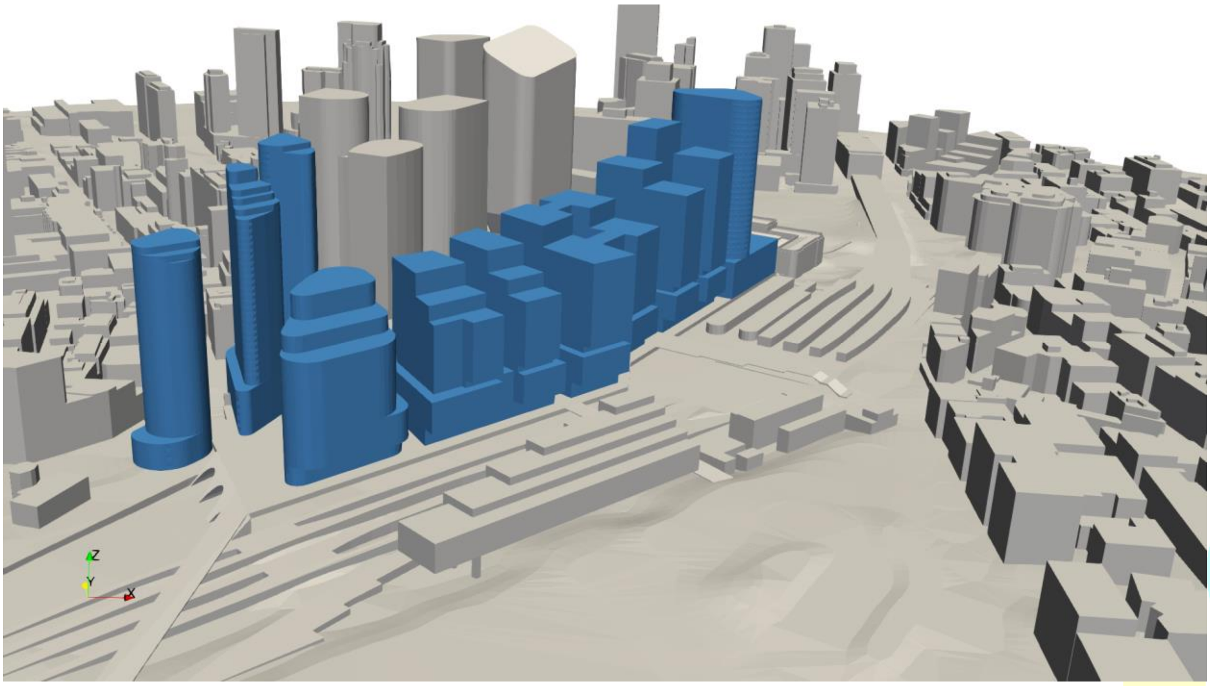

Figure 35: Southeast View of Proposed Iteration 2 – Option 1 Massing

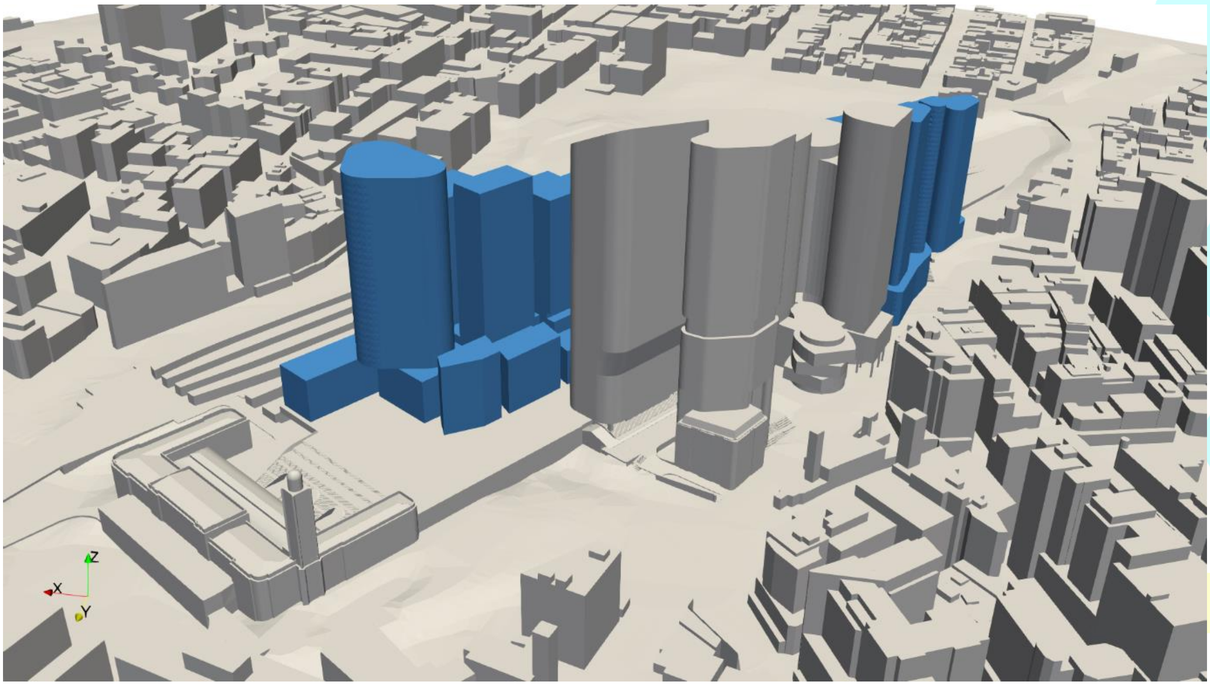

Figure 36: Northwest View of Proposed Iteration 2 – Option 1 Massing

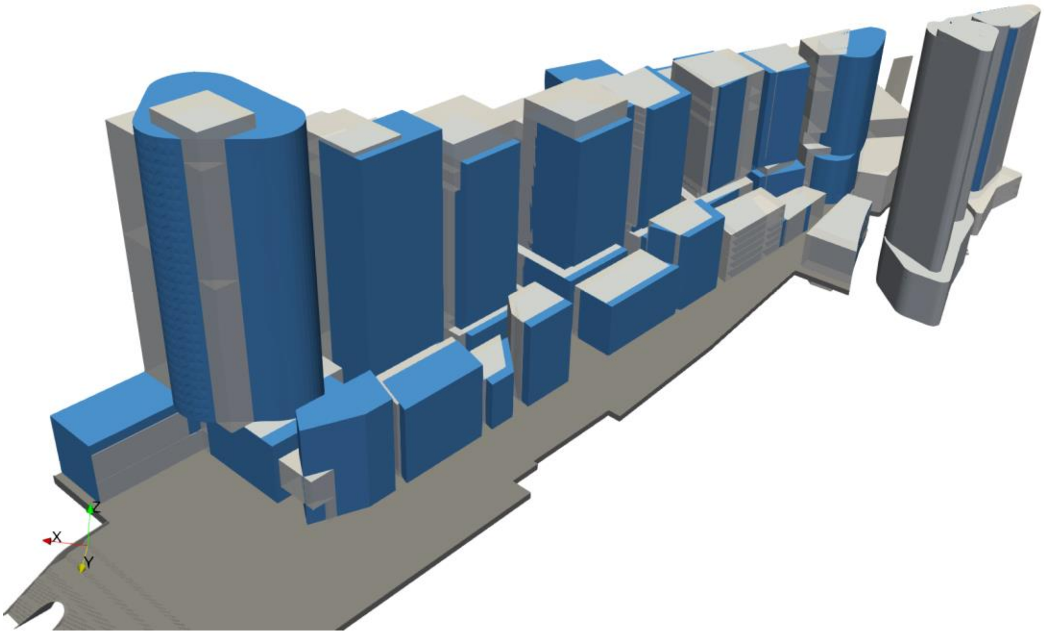

Figure 37: Iteration 1 (White) and Iteration 2 – Option 1 (Blue) Comparison

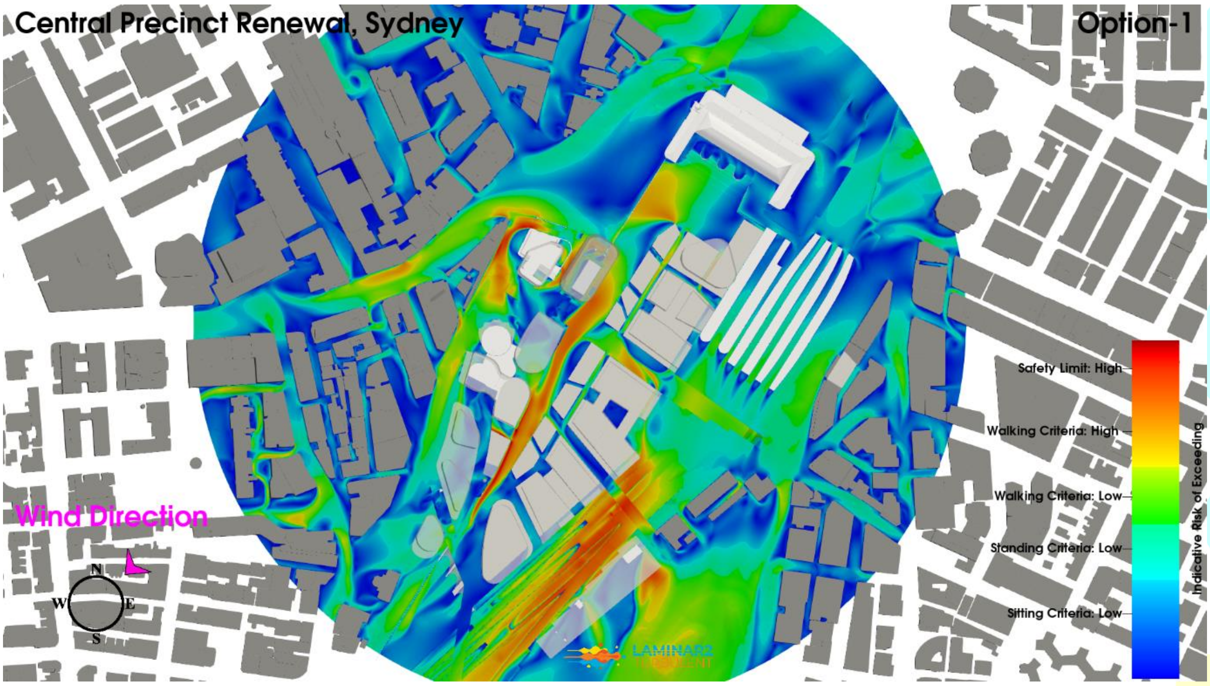

Figure 38: Iteration 2 – Option 1 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

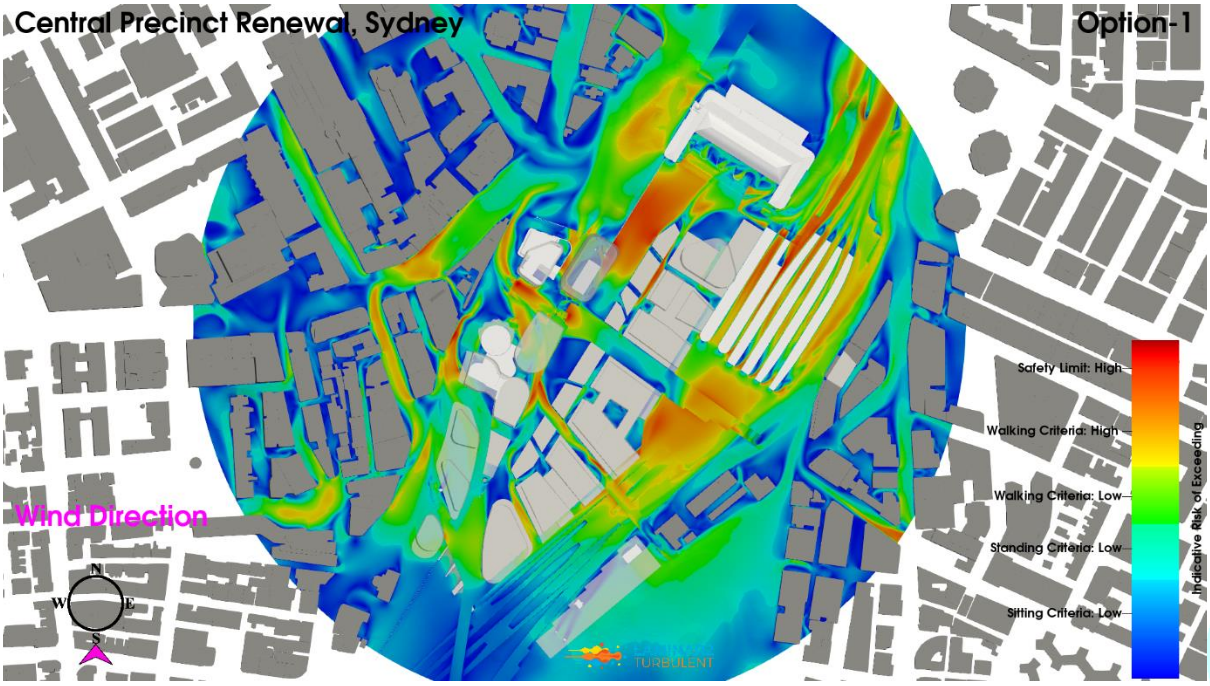

Figure 39: Iteration 2 – Option 1 Configuration, South Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

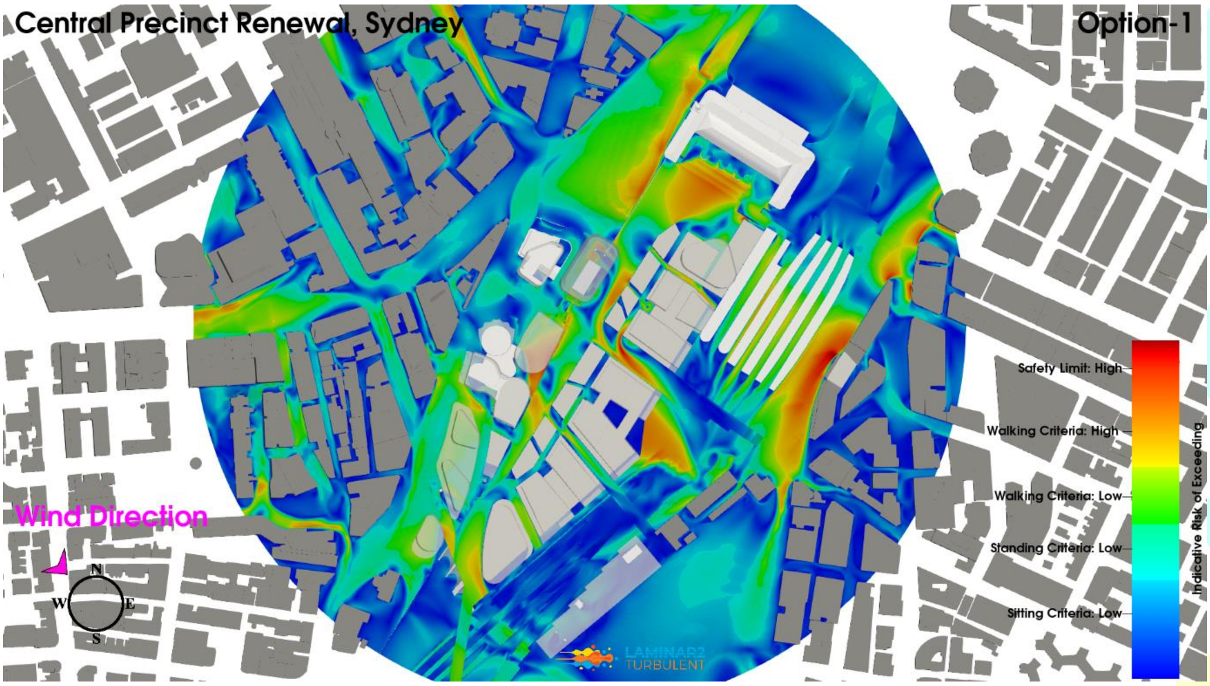

Figure 40: Iteration 2 – Option 1 Configuration, Northwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

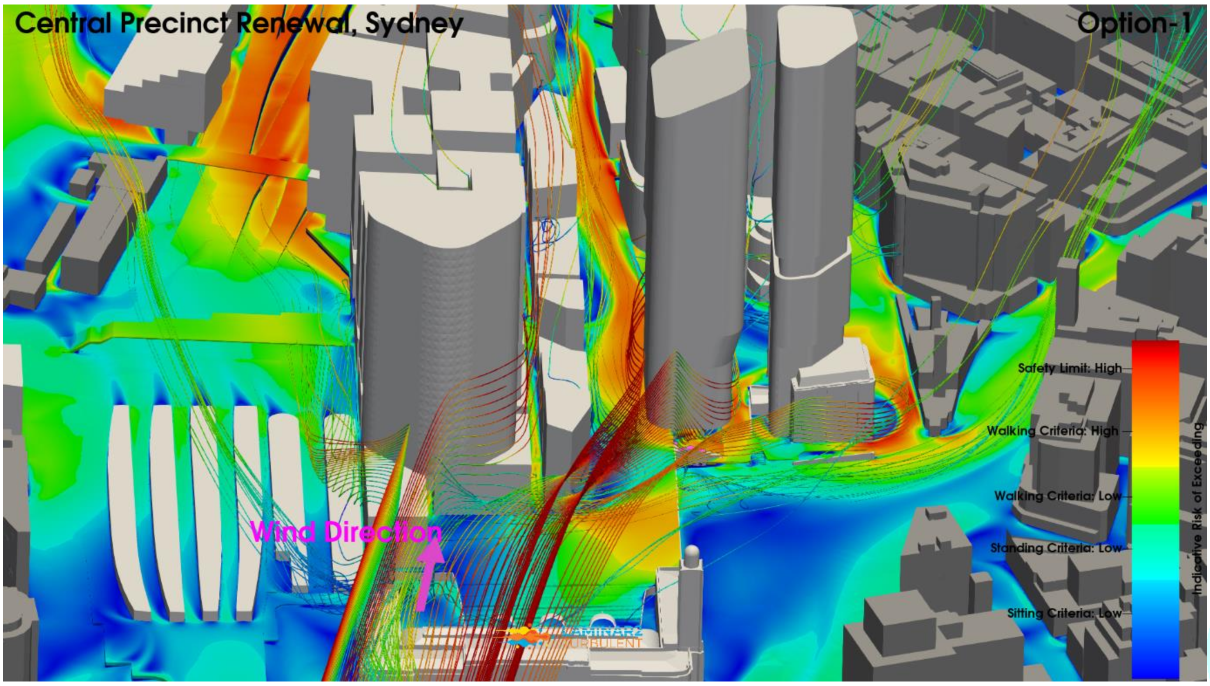

Figure 41: Iteration 2 – Option 1 Configuration, Northeast Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

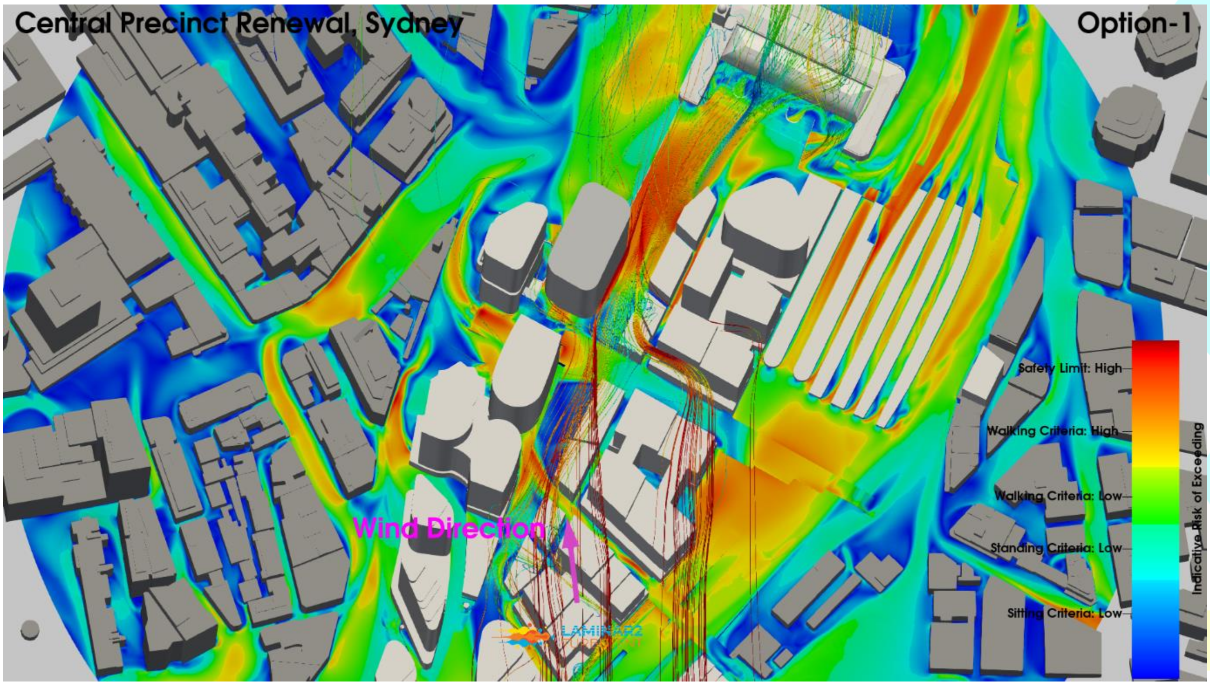

Figure 42: Iteration 2 – Option 1 Configuration, South Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

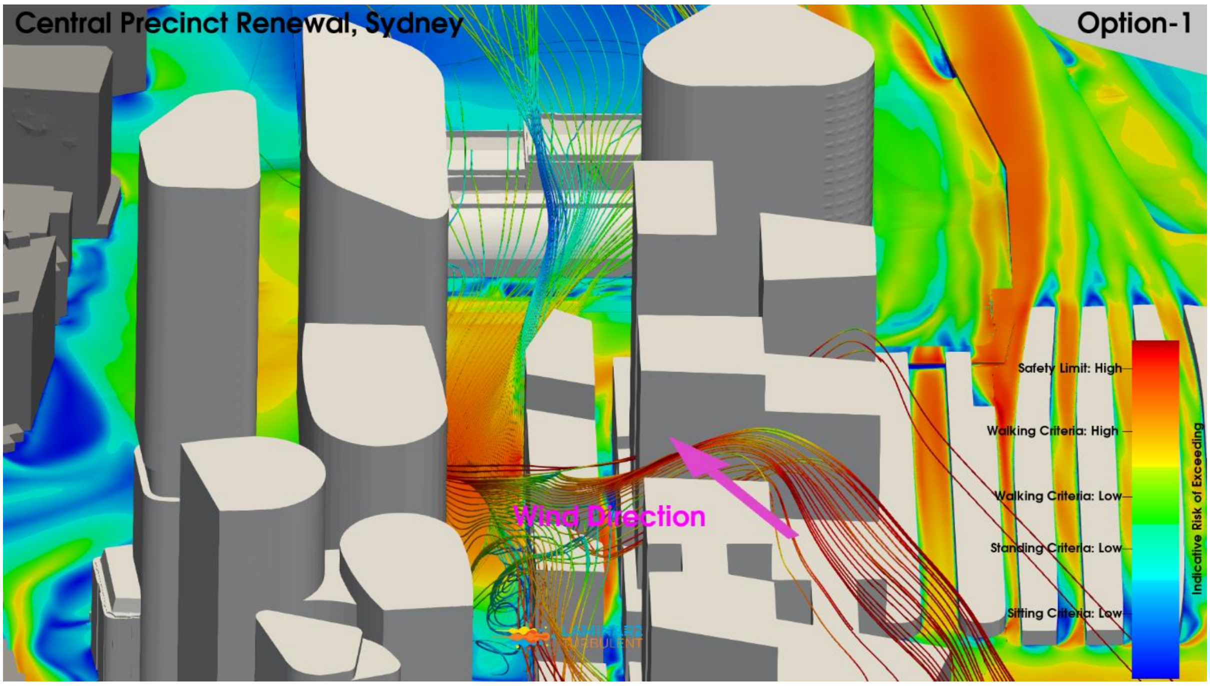

Figure 43: Iteration 2 – Option 1 Configuration, South Wind Direction (zoom view), Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

8.4 ITERATION 2 – OPTION 2

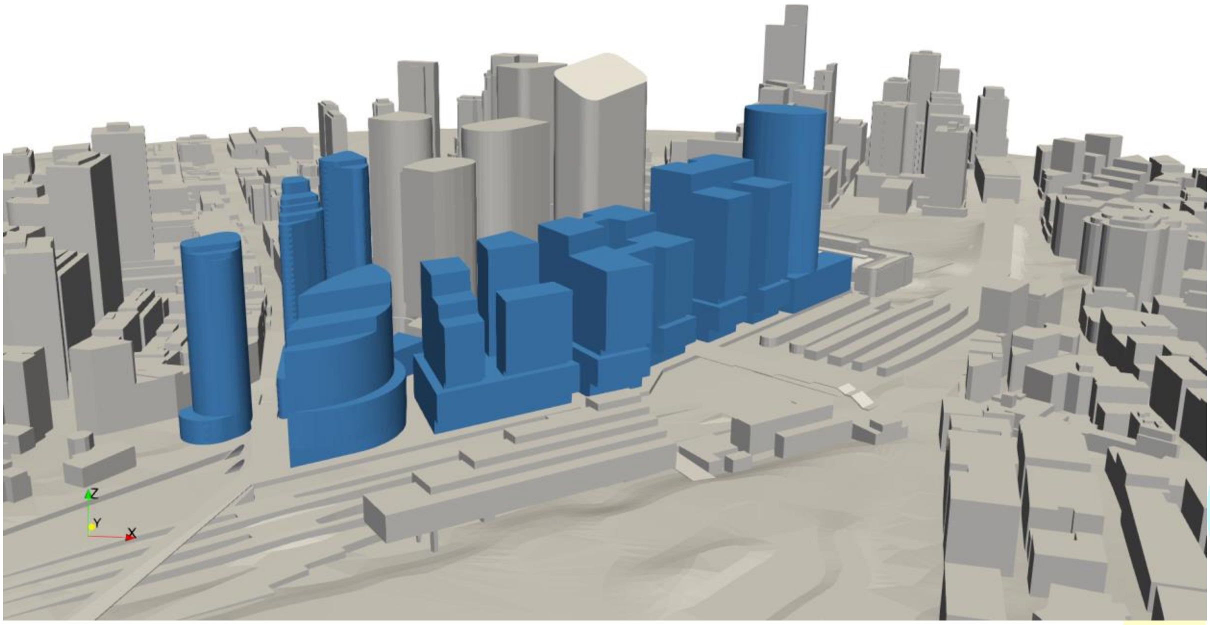

Figure 44: Southeast View of Proposed Iteration 2 – Option 2 Massing

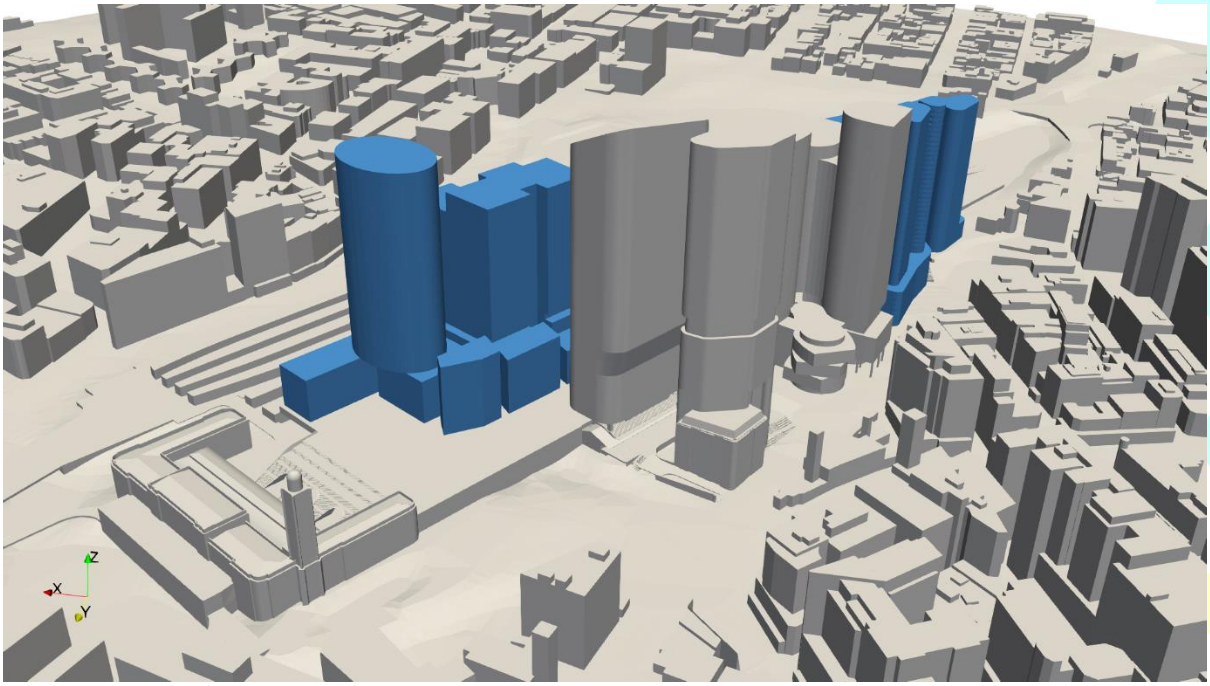

Figure 45: Northwest View of Proposed Iteration 2 – Option 2 Massing

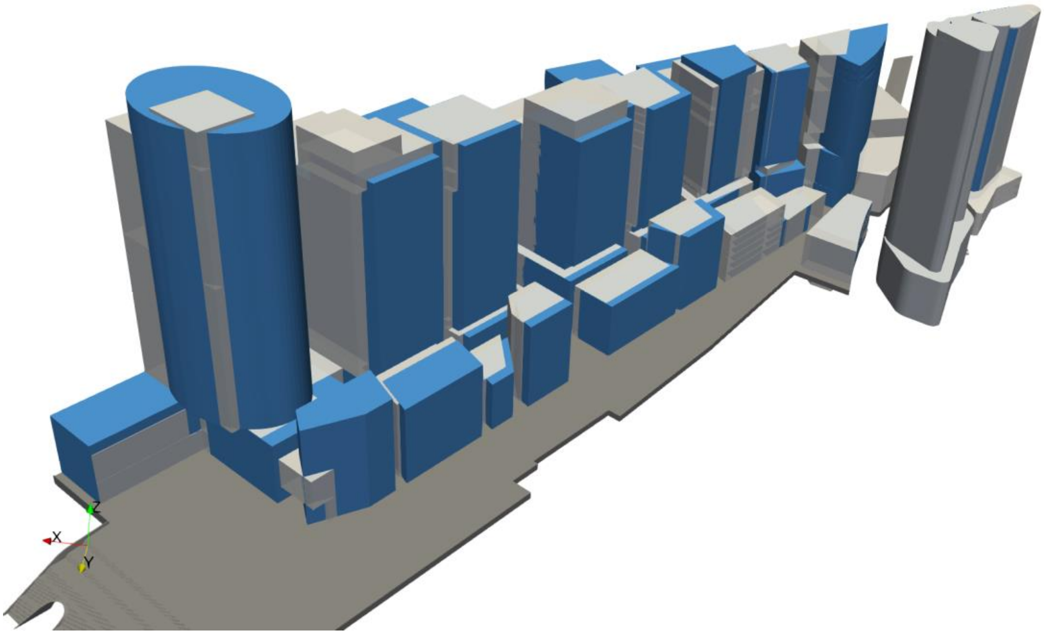

Figure 46: Iteration 1 (White) and Iteration 2 – Option 2 (Blue) Comparison

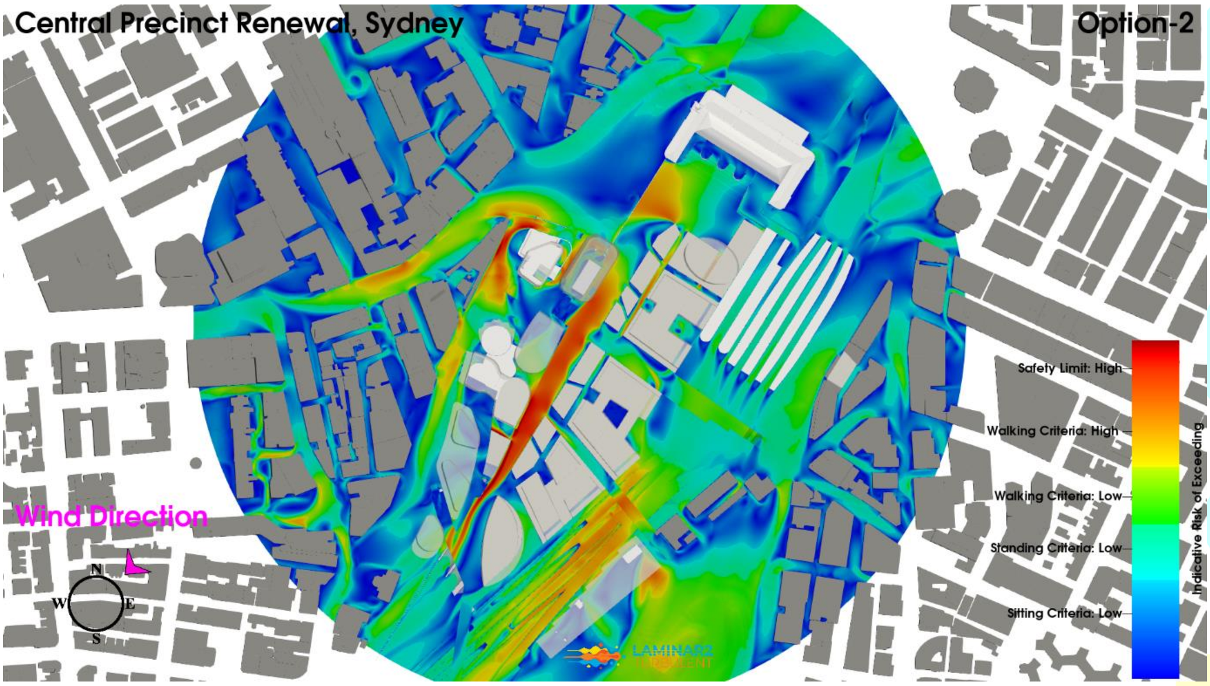

Figure 47: Iteration 2 – Option 2 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

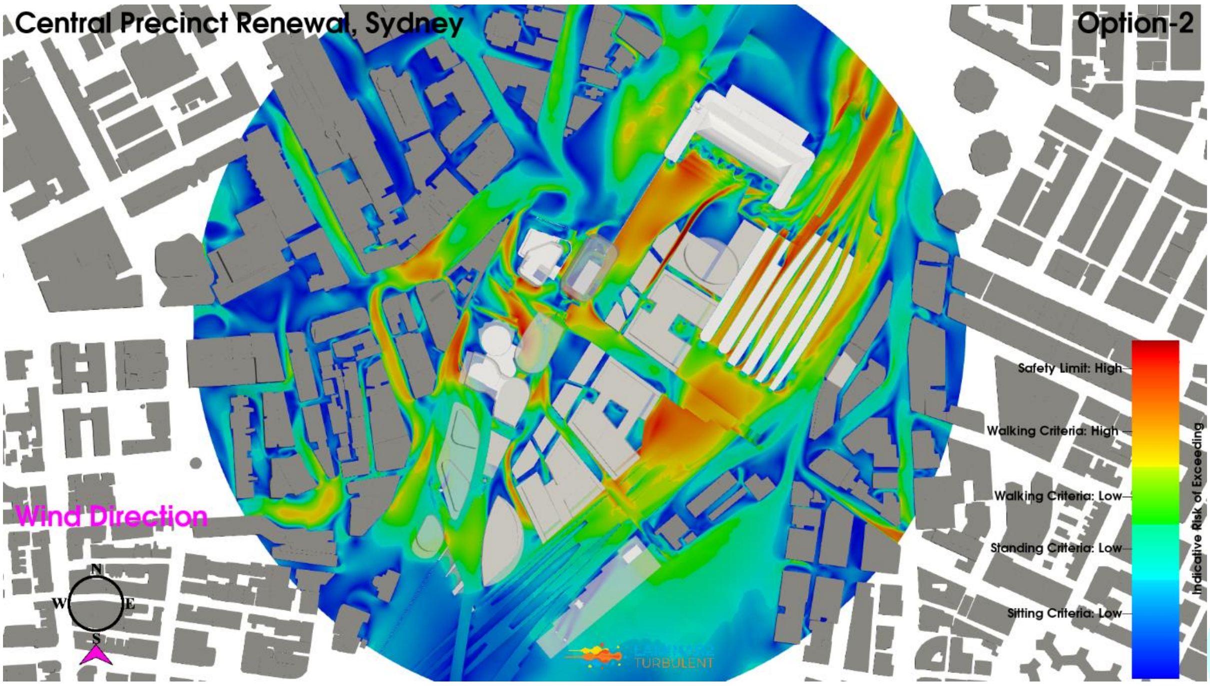

Figure 48: Iteration 2 – Option 2 Configuration, South Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

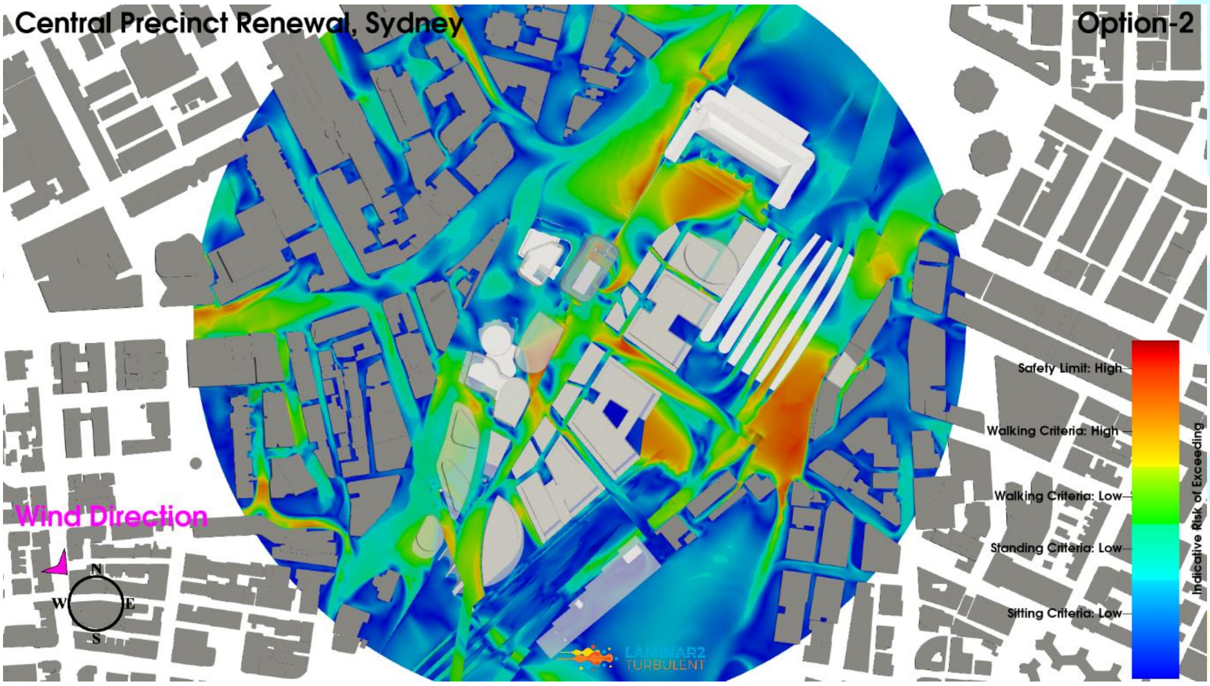

Figure 49: Iteration 2 – Option 2 Configuration, Northwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

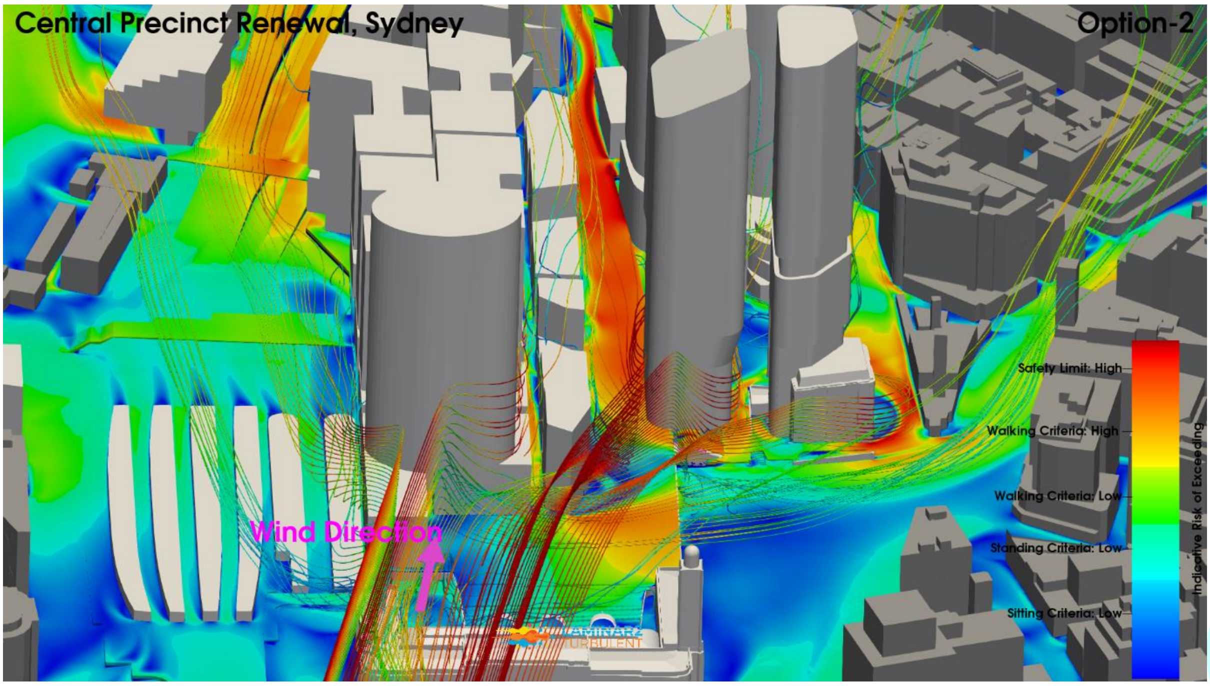

Figure 50: Iteration 2 – Option 2 Configuration, Northeast Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

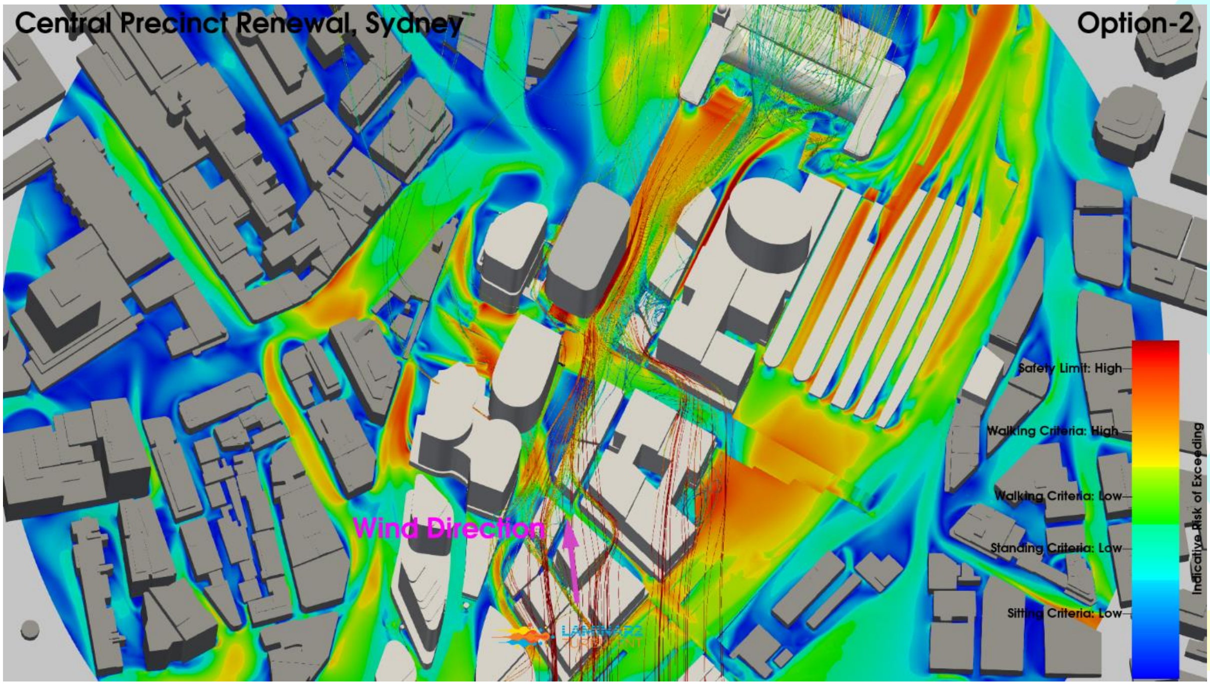

Figure 51: Iteration 2 – Option 2 Configuration, South Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

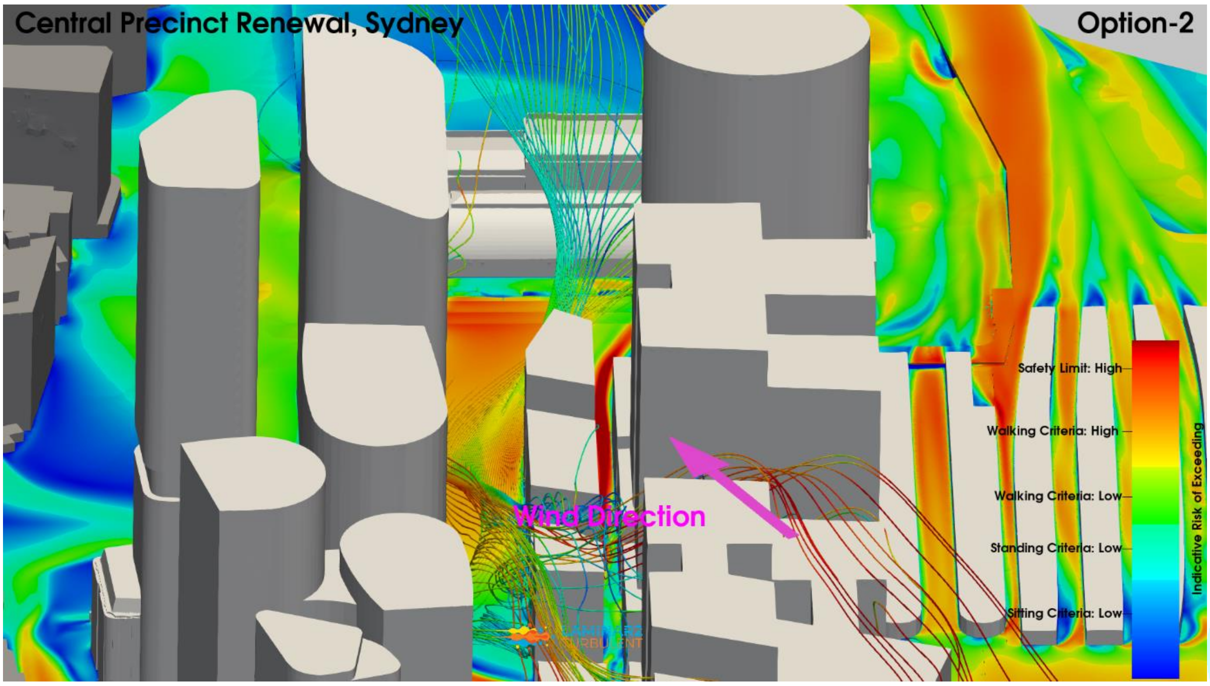

Figure 52: Iteration 2 – Option 2 Configuration, South Wind Direction (zoom view), Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

8.5 ITERATION 3 – OPTION 3

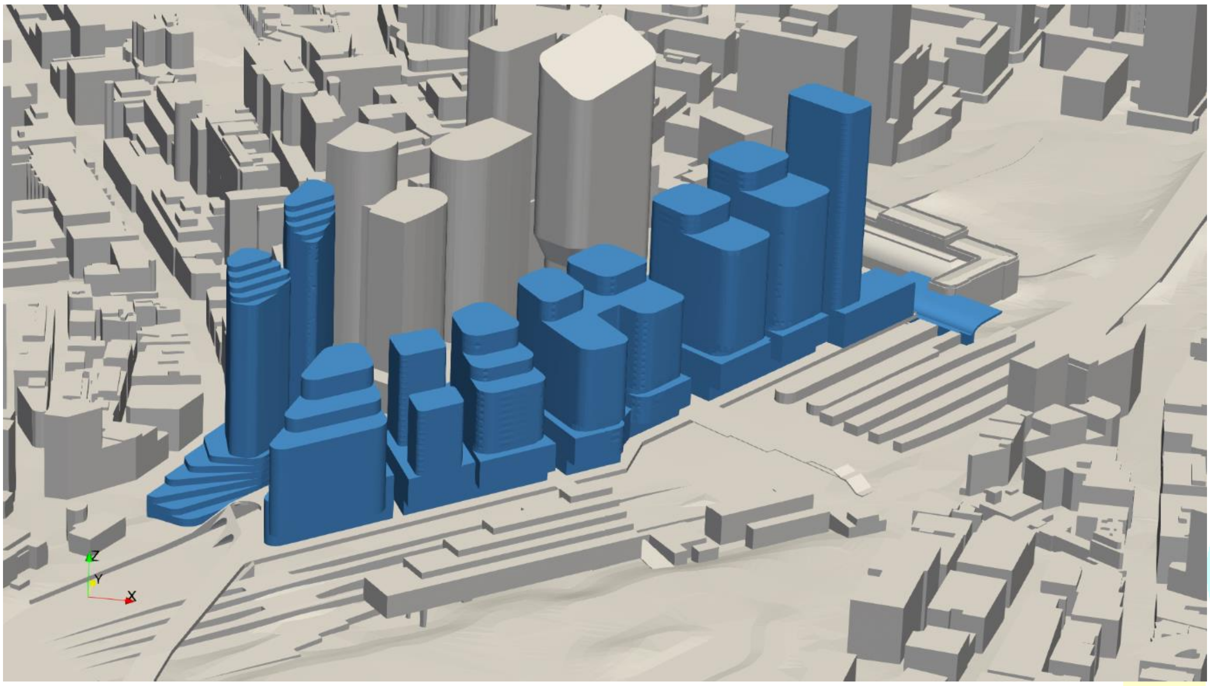

Figure 53: Southeast View of Proposed Iteration 3 – Option 3 Massing

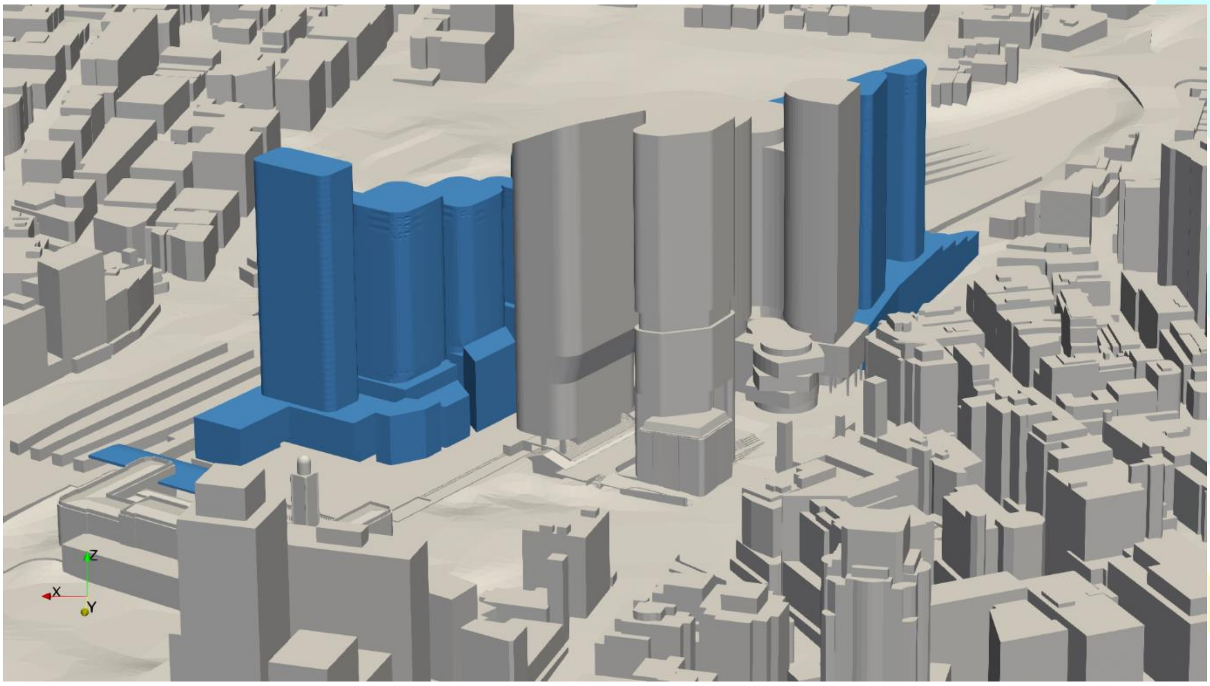

Figure 54: Northwest View of Proposed Iteration 3 – Option 3 Massing

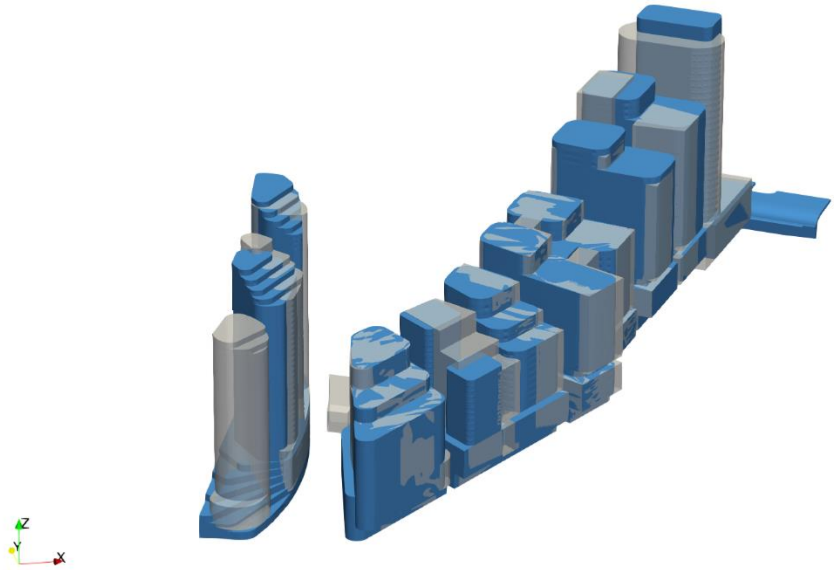

Figure 55: Iteration 2 – Option 1 (White) and Iteration 3 – Option 3 (Blue) Comparison

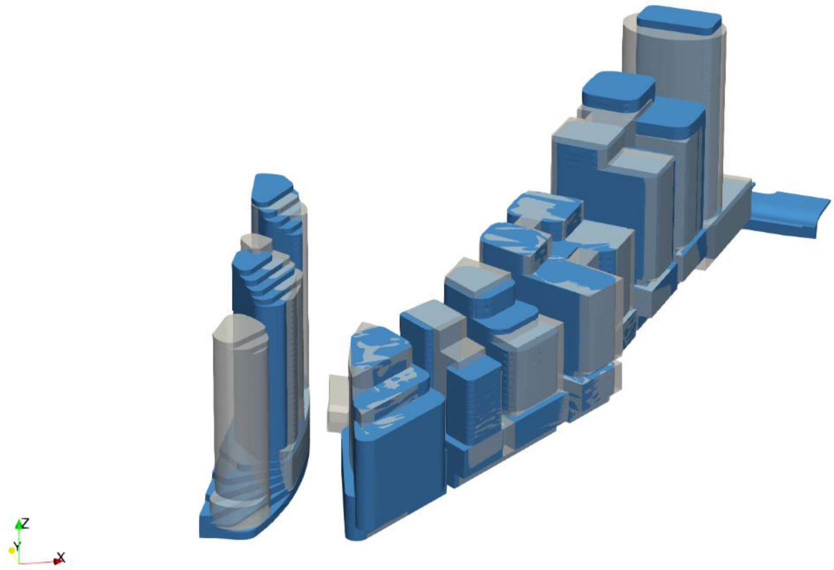

Figure 56: Iteration 2 – Option 2 (White) and Iteration 3 – Option 3 (Blue) Comparison

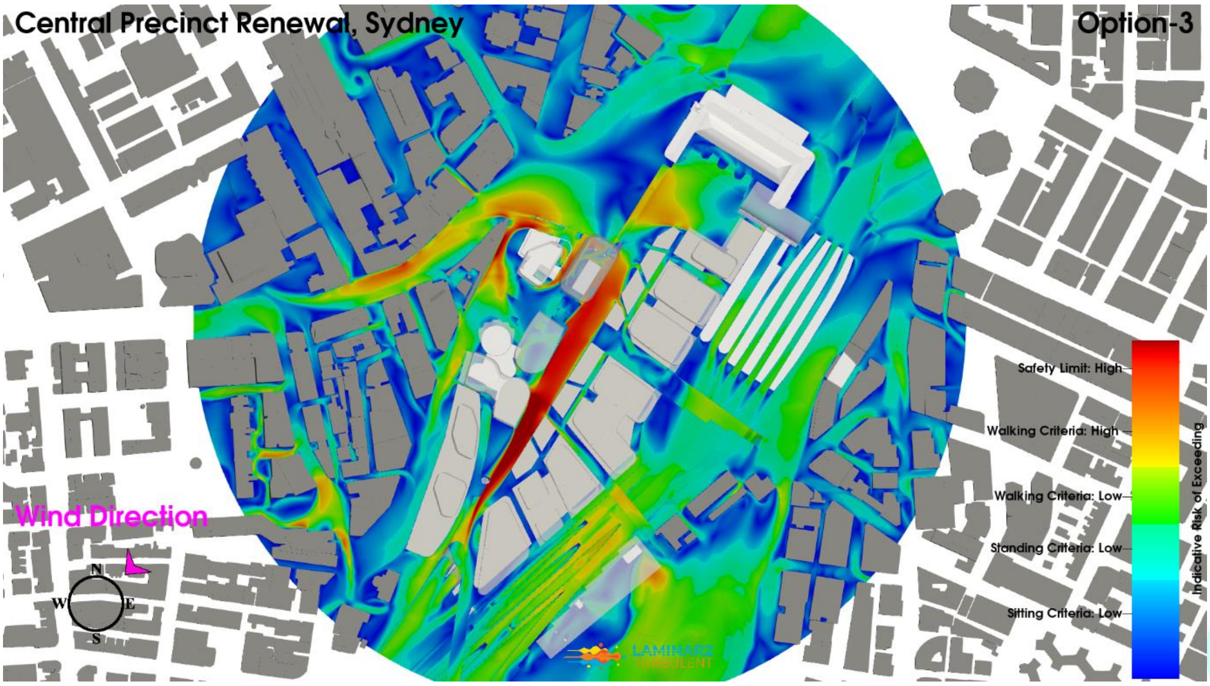

Figure 57: Iteration 3 – Option 3 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

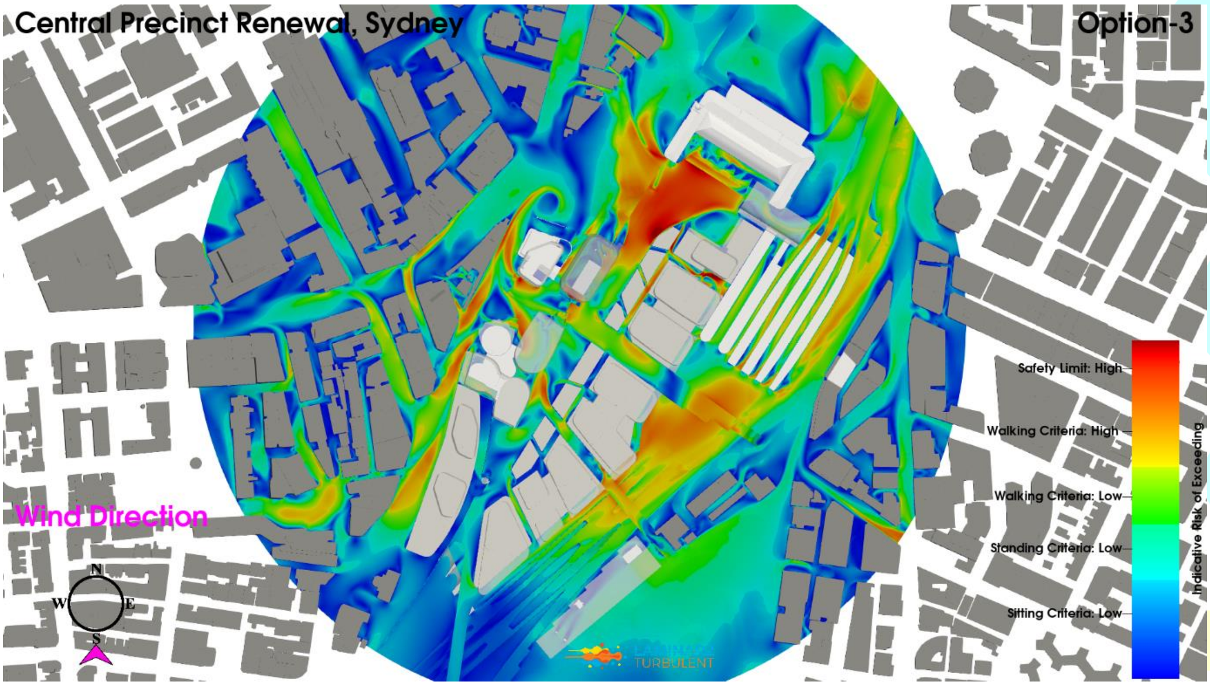

Figure 58: Iteration 3 – Option 3 Configuration, South Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

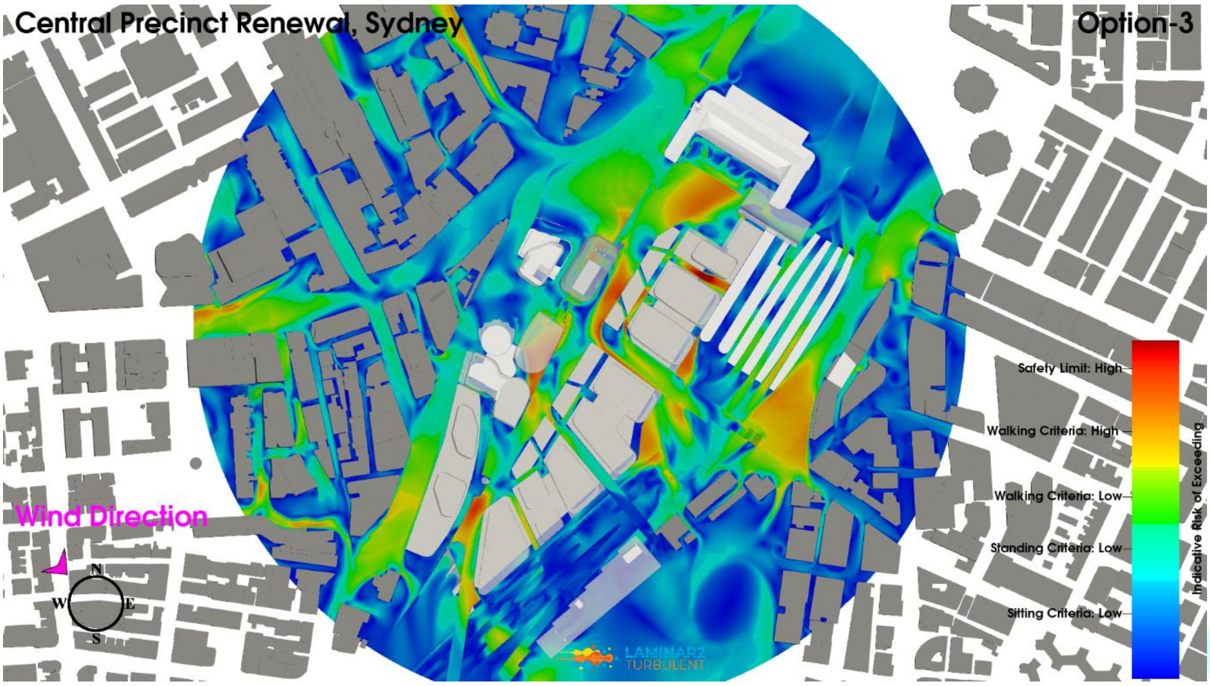

Figure 59: Iteration 3 – Option 3 Configuration, Northwest Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

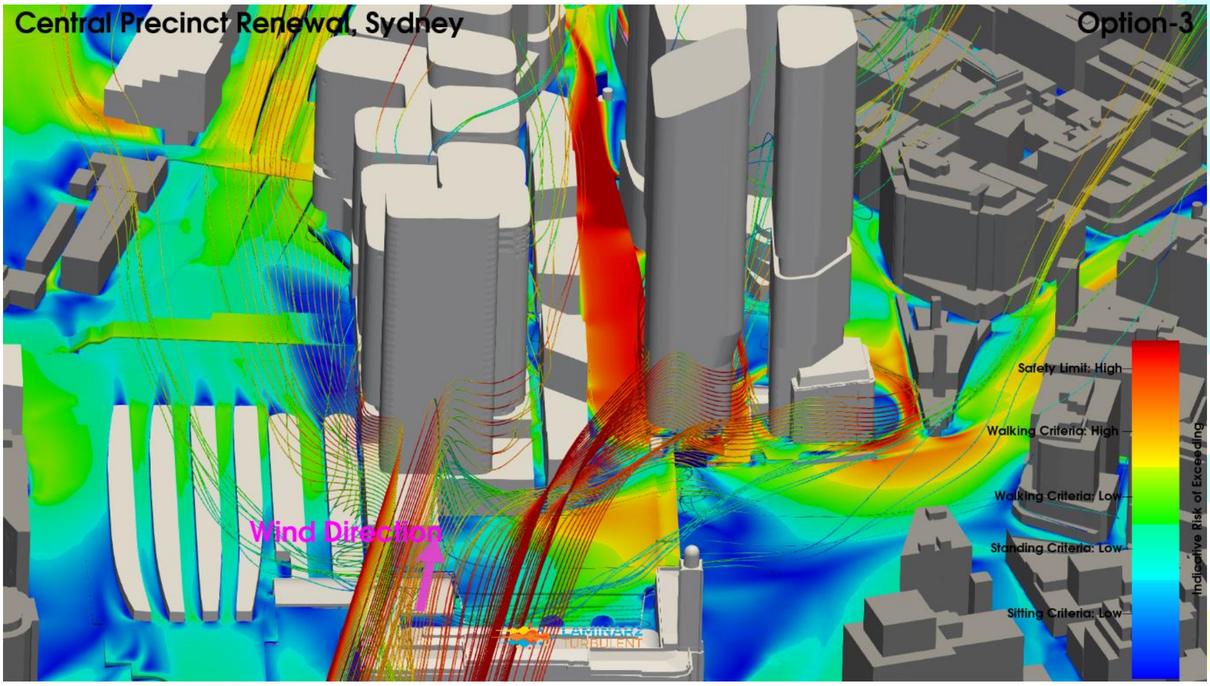

Figure 60: Iteration 3 – Option 3 Configuration, Northeast Wind Direction, Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

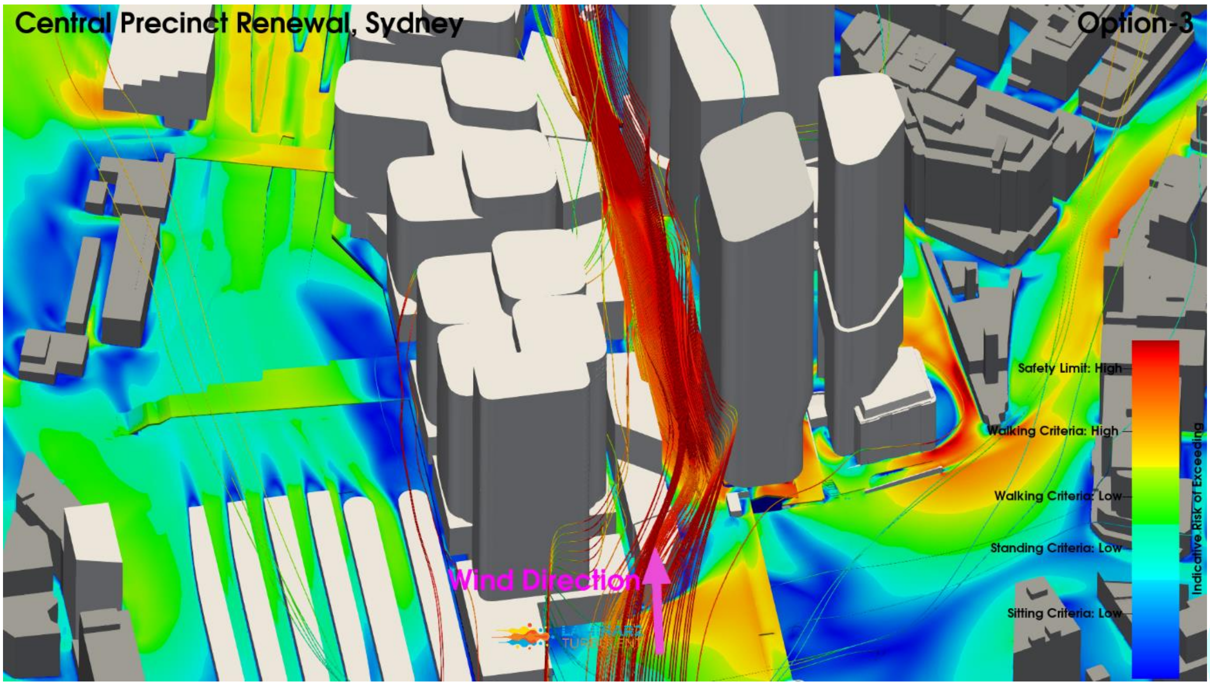

Figure 61: Iteration 3 – Option 3 Configuration, Northeast Wind Direction (zoom view), Streamlines, Pedestrian Level Environmental Wind Risk Contour Plot

8.6 ITERATION 3 – OPTION 4

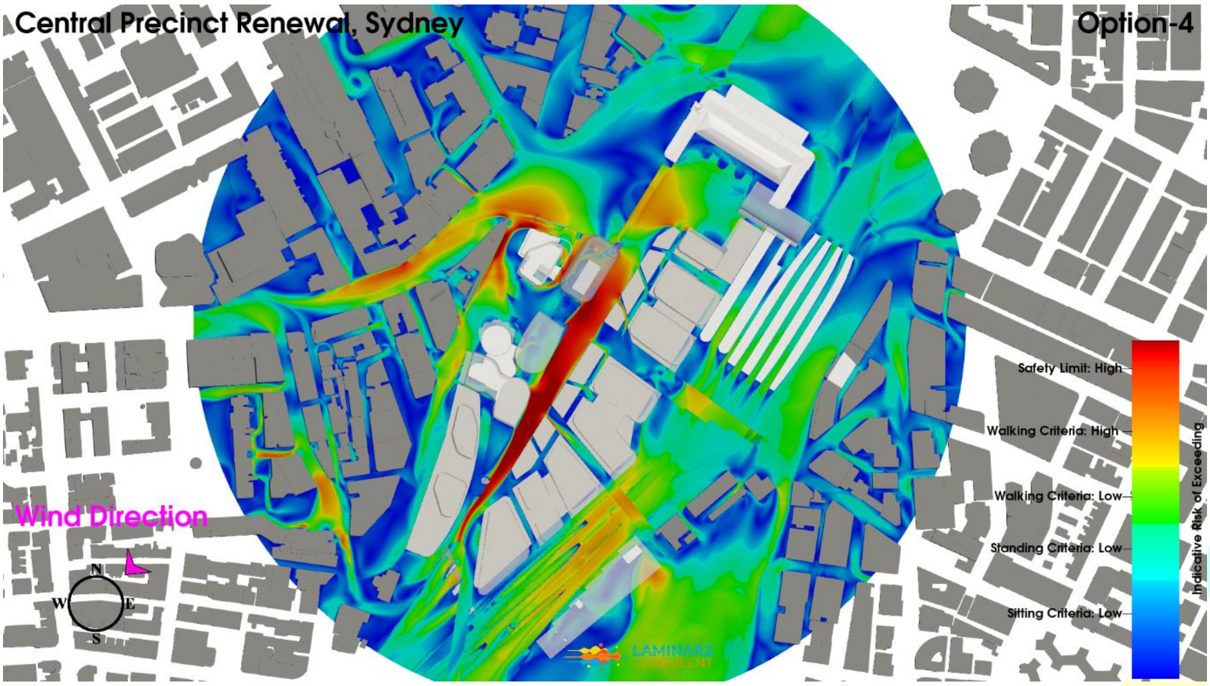

Figure 62: Iteration 3 – Option 4 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

8.7 ITERATION 3 – OPTION 5

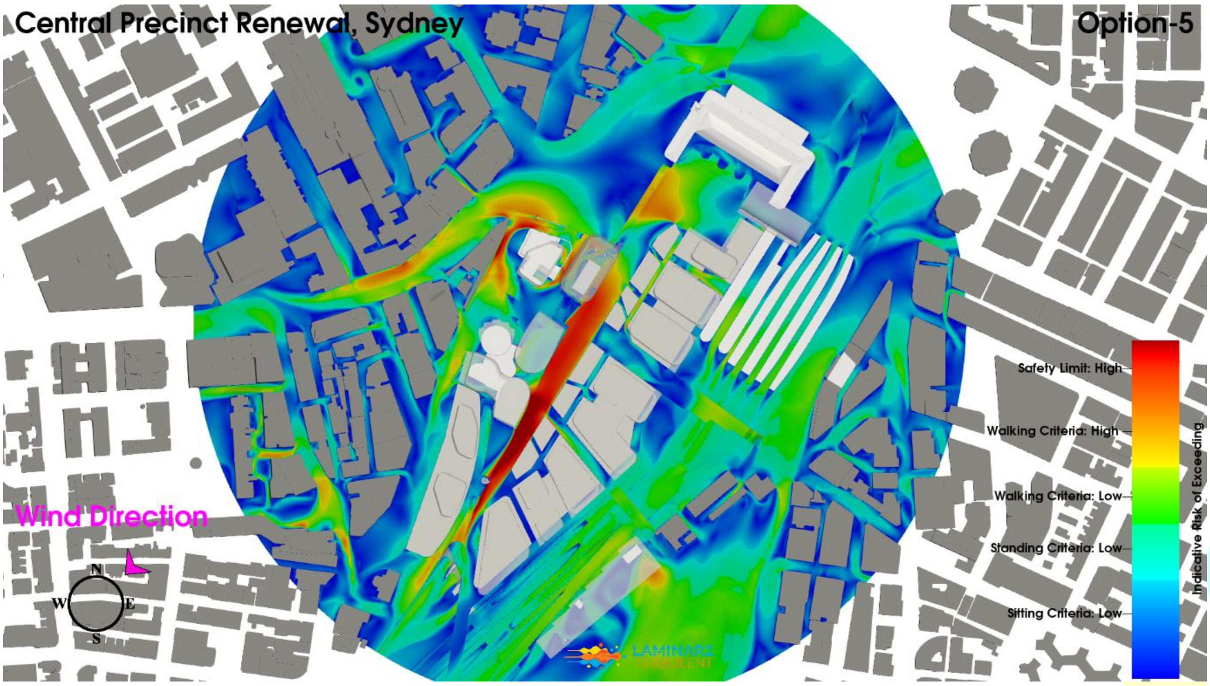

Figure 63: Iteration 3 – Option 5 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

8.8 ITERATION 3 – OPTION 6

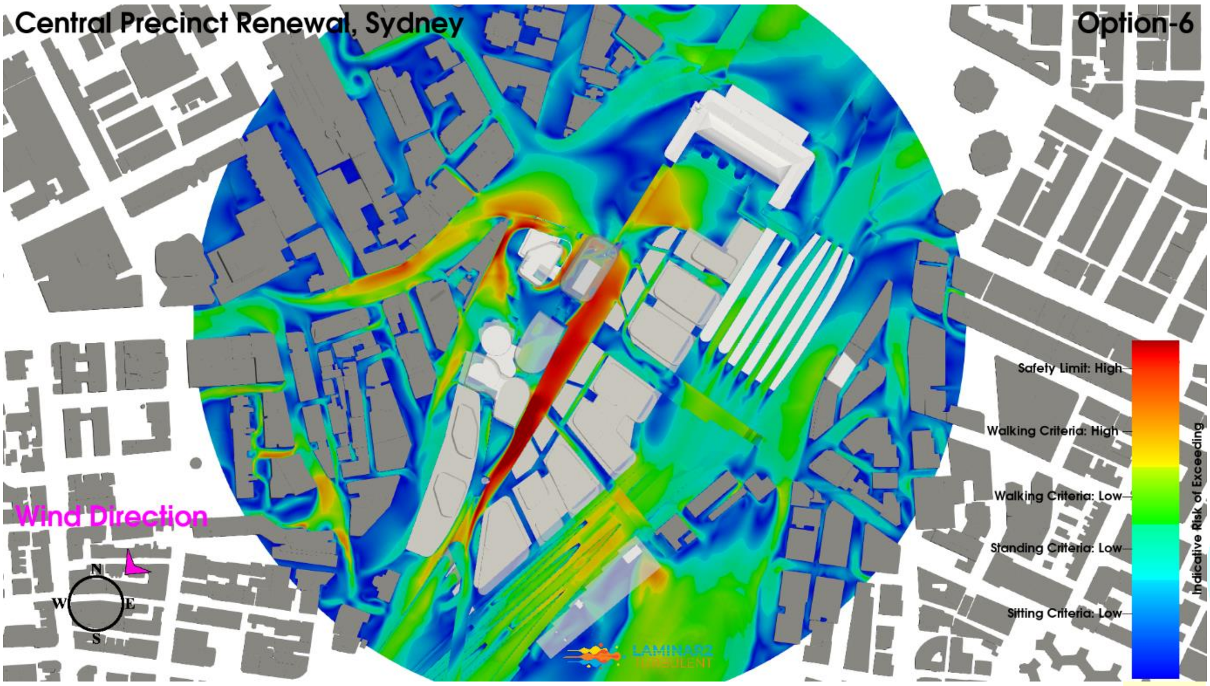

Figure 64: Iteration 3 – Option 6 Configuration, Northeast Wind Direction, Planview, Ground Level Pedestrian Environmental Wind Risk Contour Plot

8.9 ITERATION 4 – OPTION 4

Figure 65: North View of Proposed Iteration 4 – Option 4 Massing

Figure 66: South View of Proposed Iteration 4 – Option 4 Massing

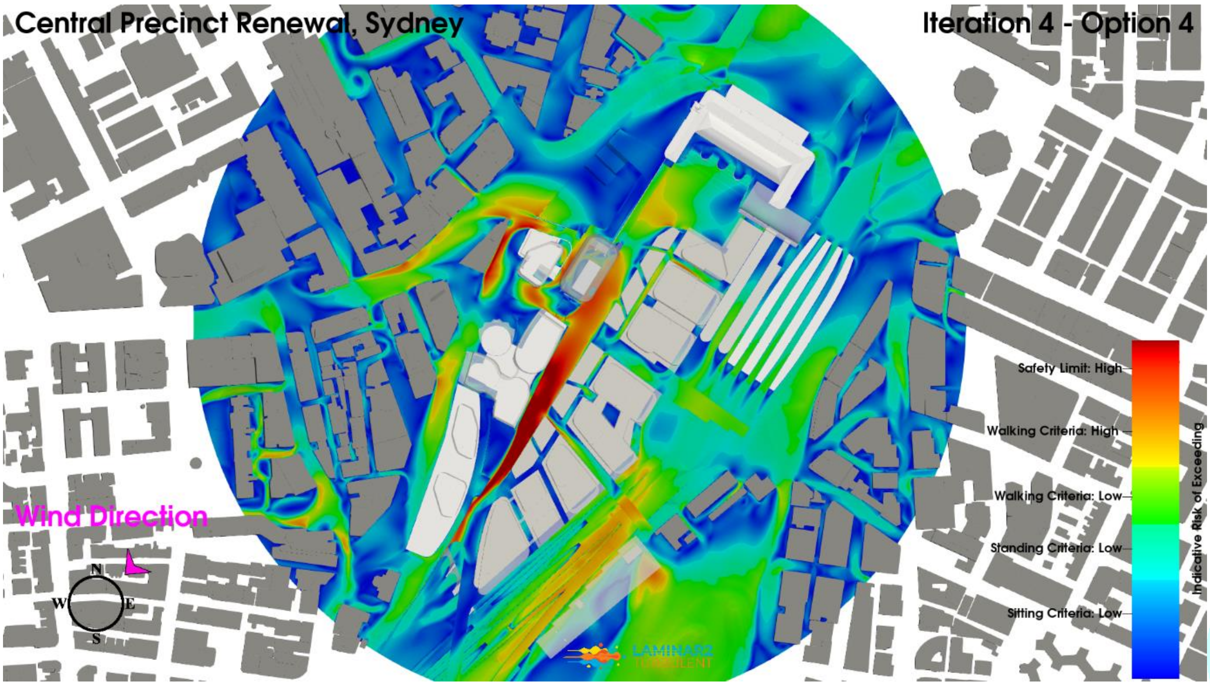

Figure 67: Iteration 4 – Option 4 Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

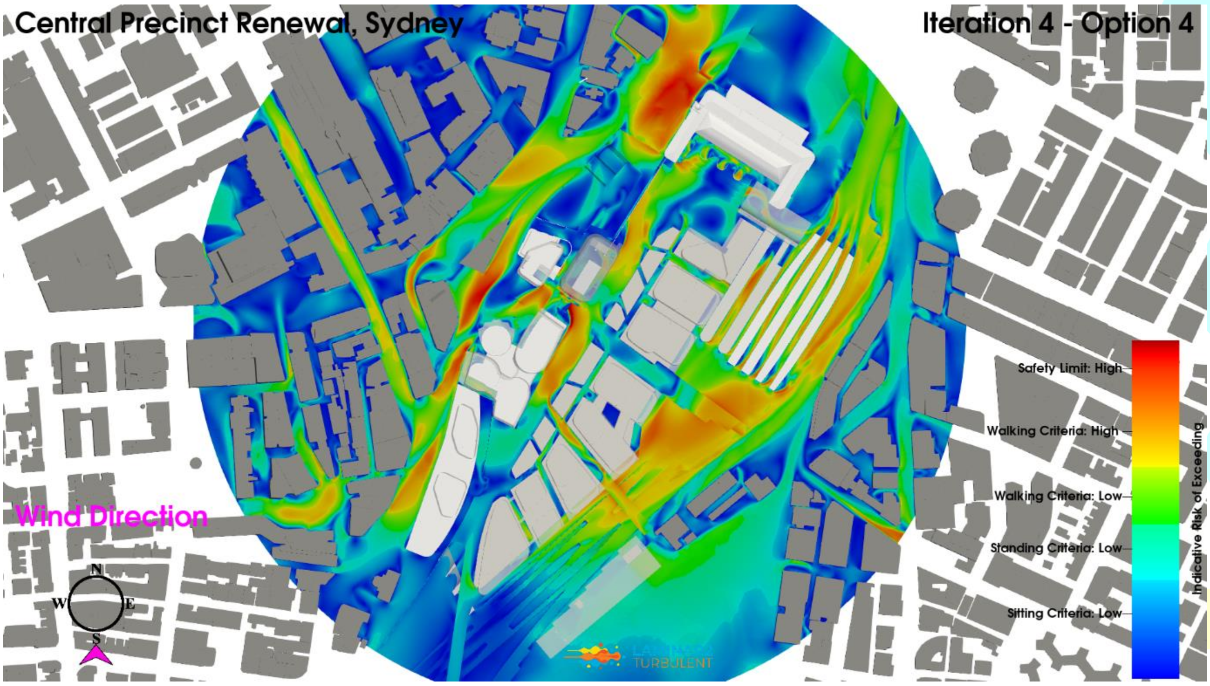

Figure 68: Iteration 4 – Option 4 Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

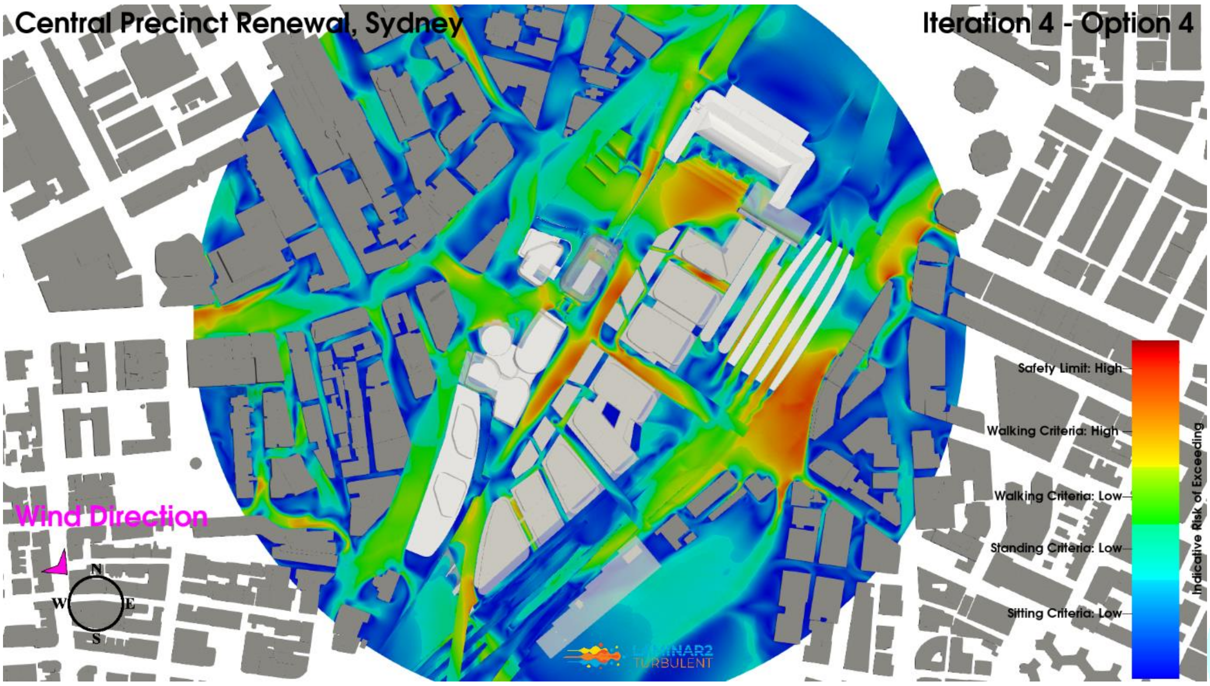

Figure 69: Iteration 4 – Option 4 Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

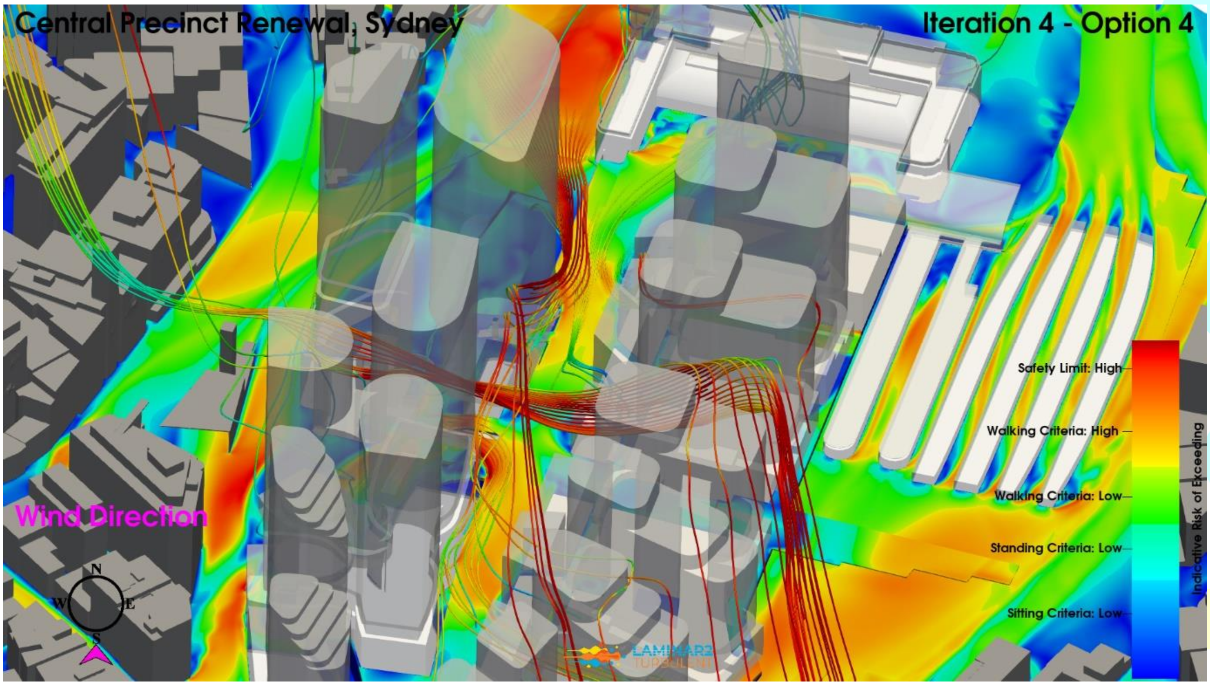

Figure 70: Iteration 4 – Option 4 Configuration, South Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

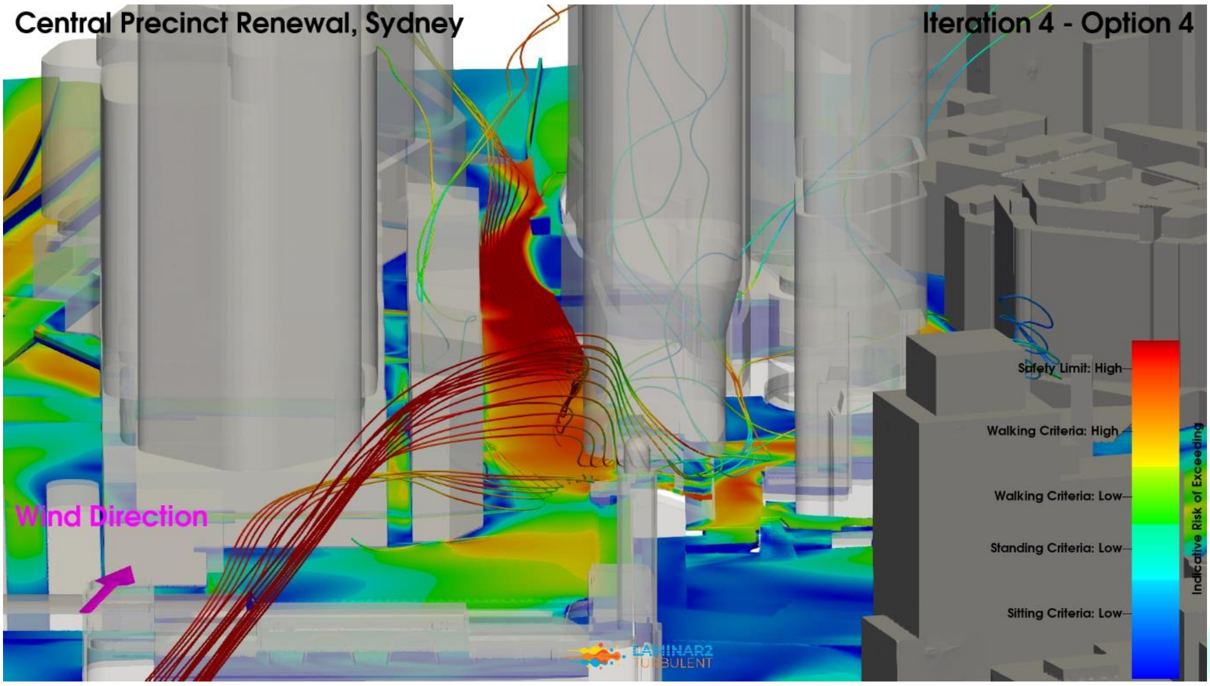

Figure 71: Iteration 4 – Option 4 Configuration, Northeast Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

8.10 ITERATION 4 – OPTION 5

Figure 72: North View of Proposed Iteration 4 – Option 5 Massing

Figure 73: South View of Proposed Iteration 4 – Option 5 Massing

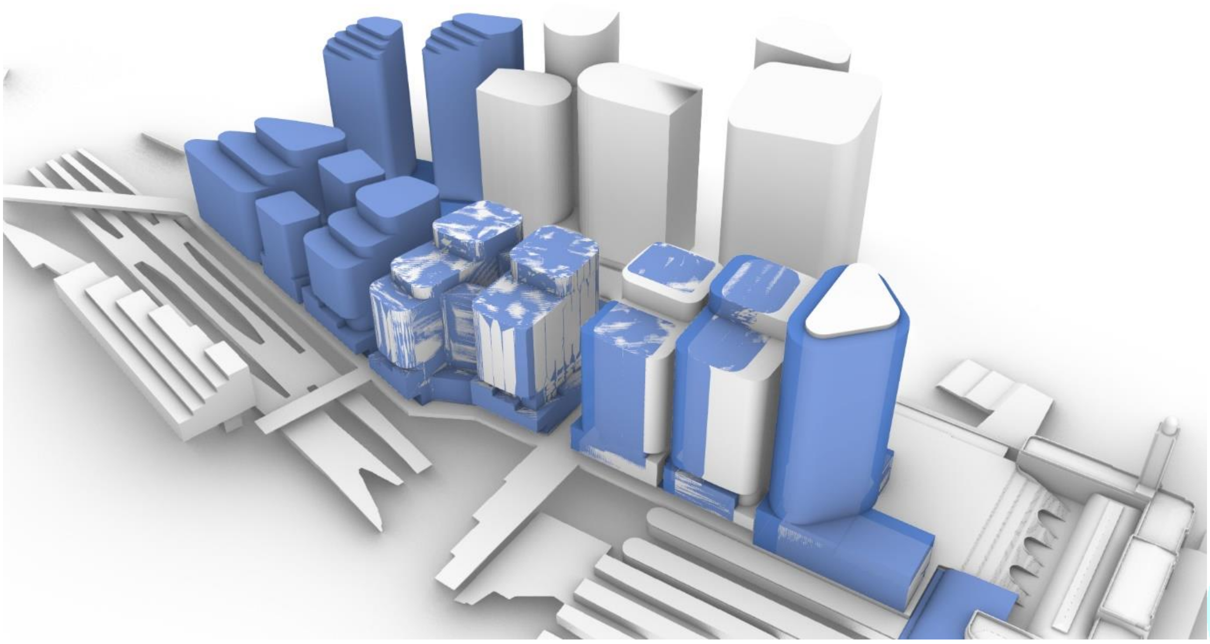

Figure 74: Iteration 4 – Option 4 (white) and Iteration 4 – Option 5 (blue) Comparison

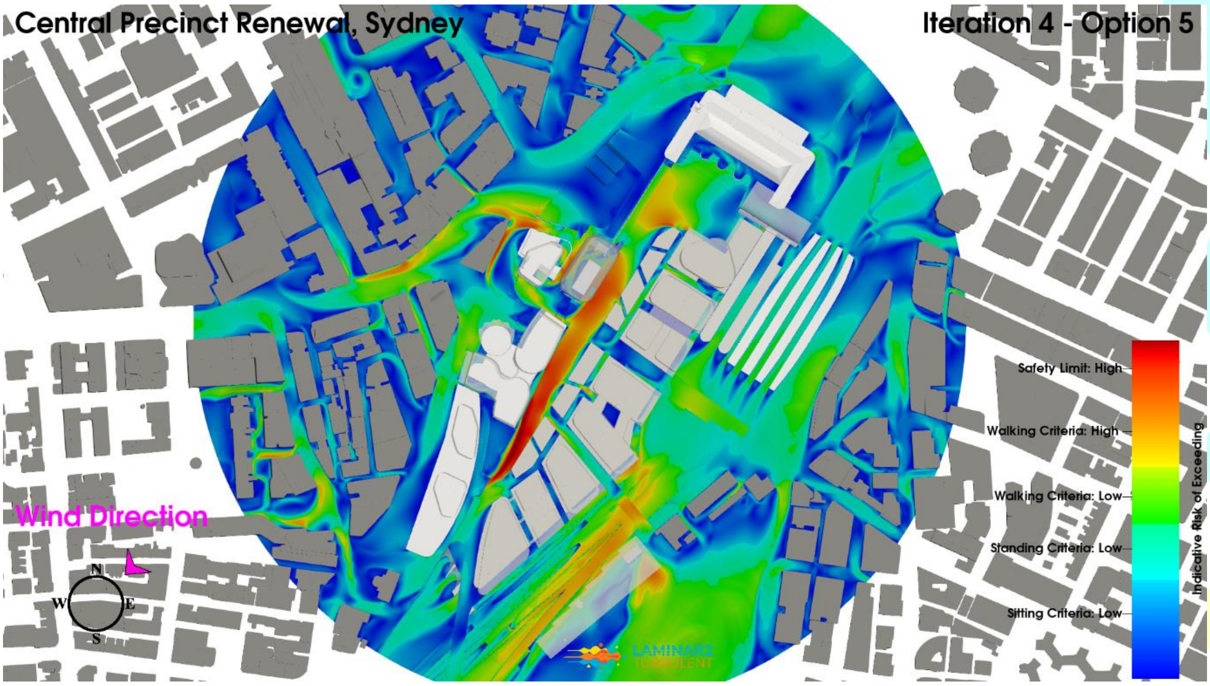

Figure 75: Iteration 4 – Option 5 Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

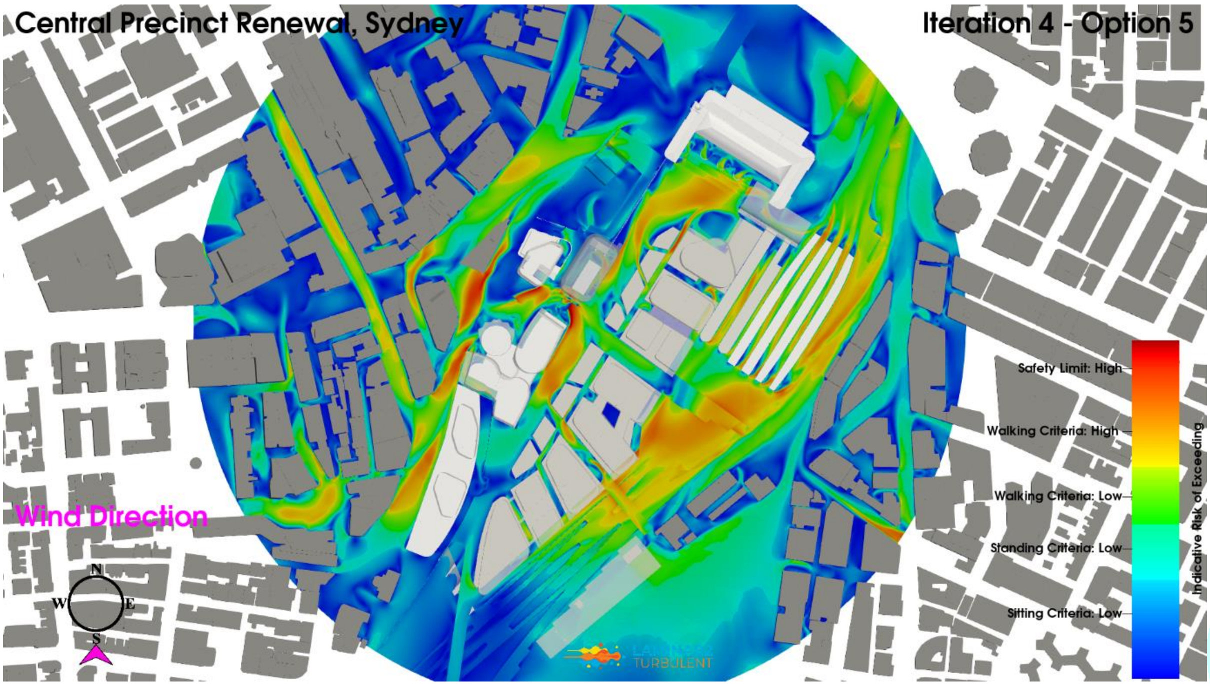

Figure 76: Iteration 4 – Option 5 Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

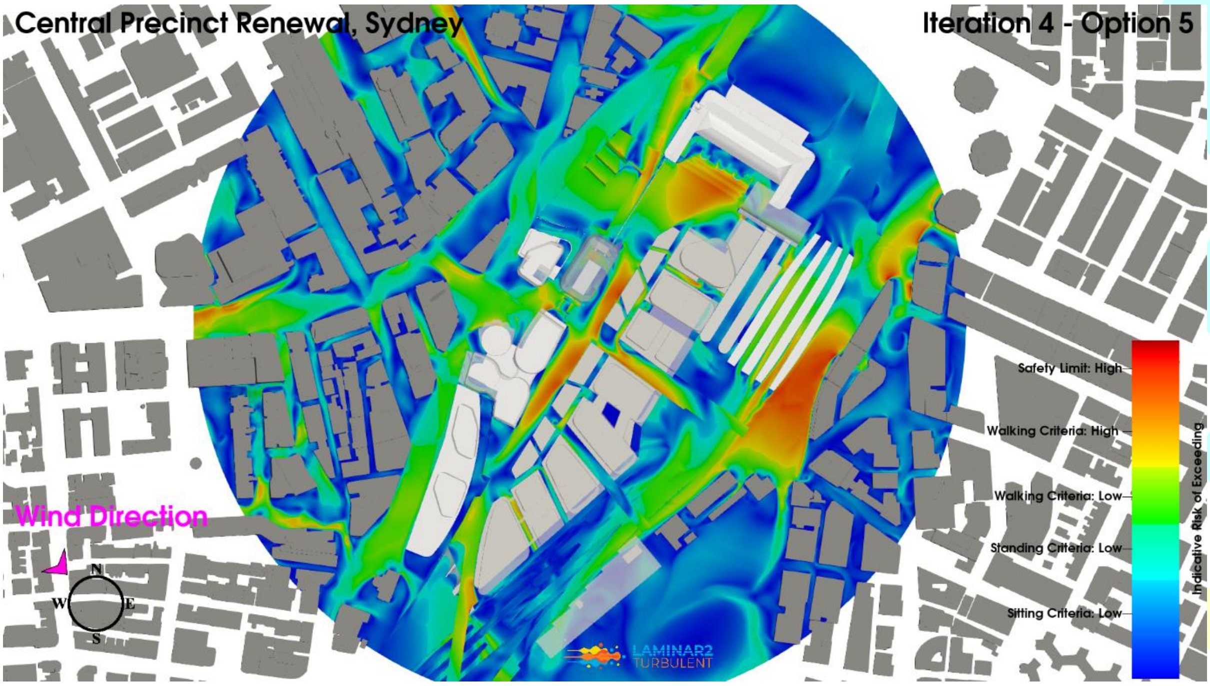

Figure 77: Iteration 4 – Option 5 Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

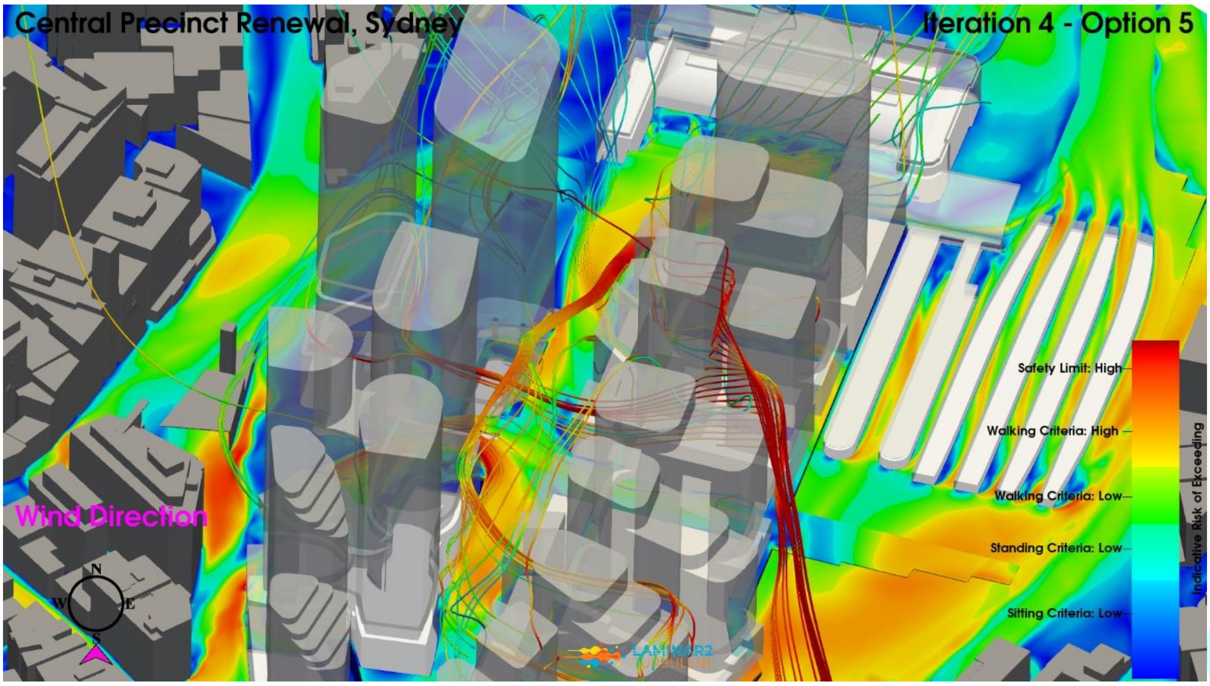

Figure 78: Iteration 4 – Option 5 Configuration, South Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

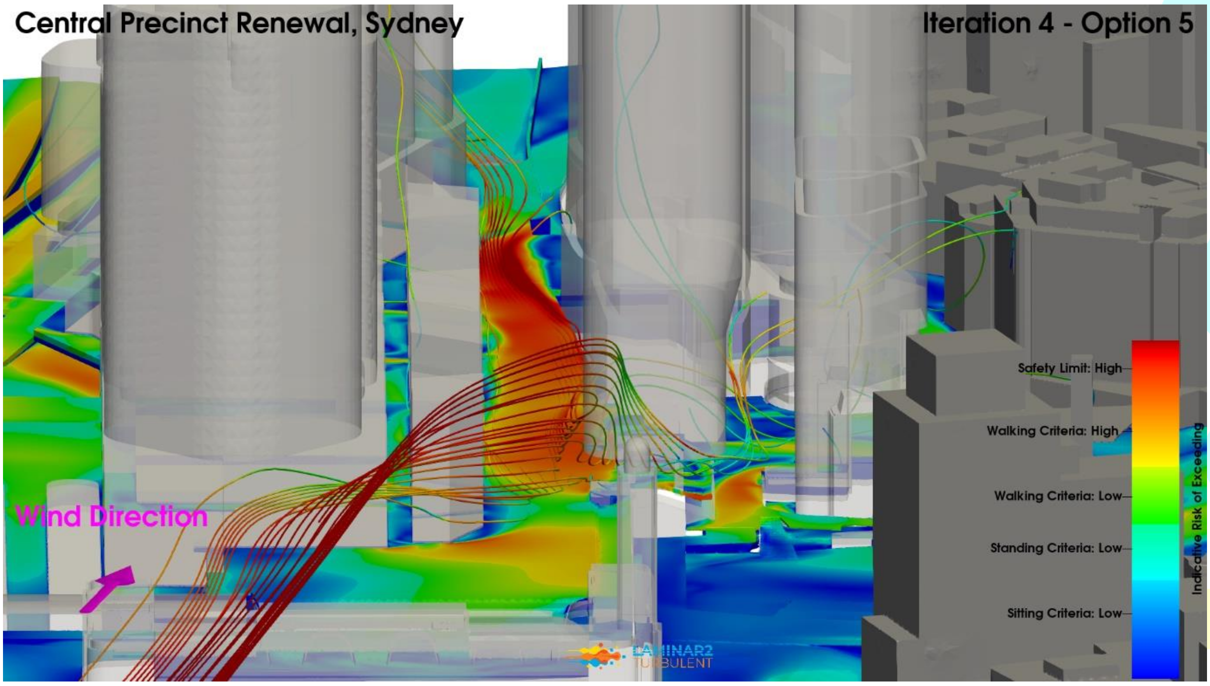

Figure 79: Iteration 4 – Option 5 Configuration, Northeast Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

8.11 ITERATION 5 – OPTION 1

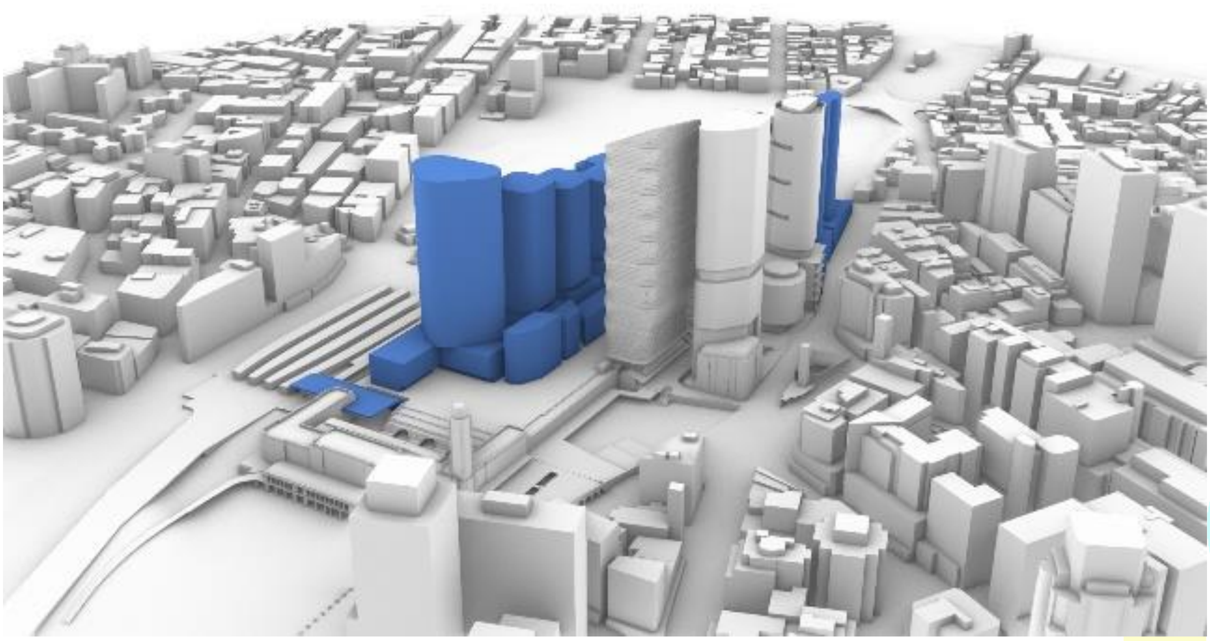

Figure 80: North View of Proposed Iteration 5 – Option 1 Massing

Figure 81: South View of Proposed Iteration 5 – Option 1 Massing

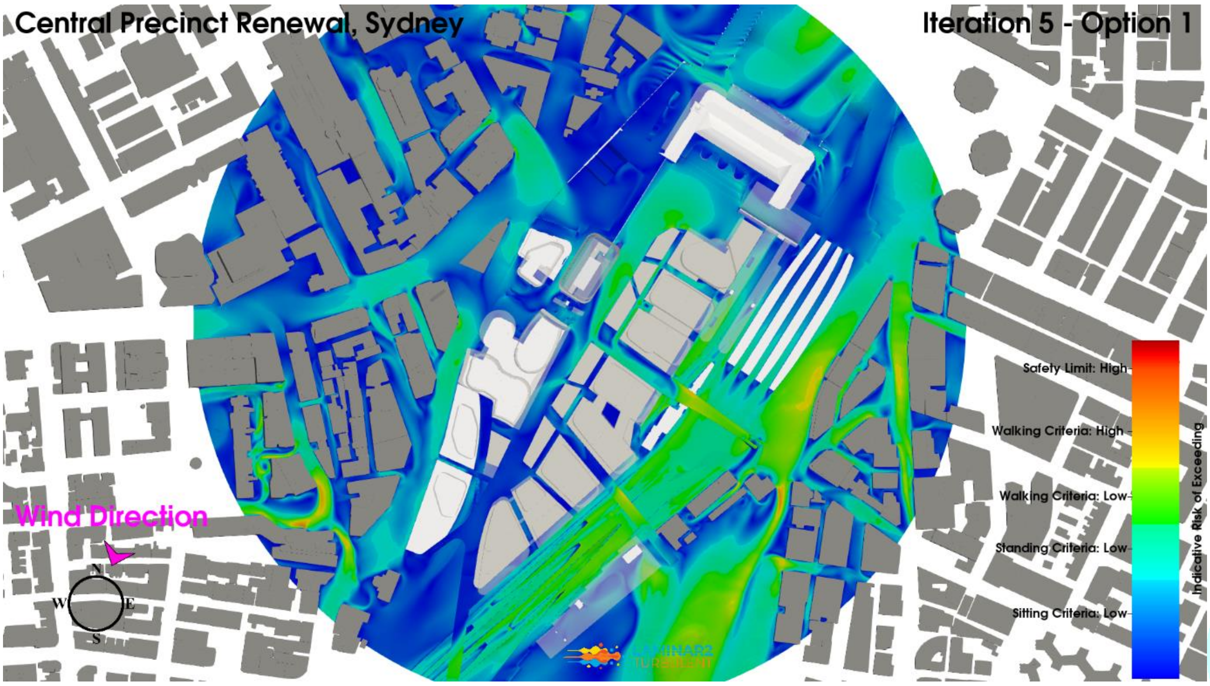

Figure 82: Iteration 5 – Option 1 Configuration, North-northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

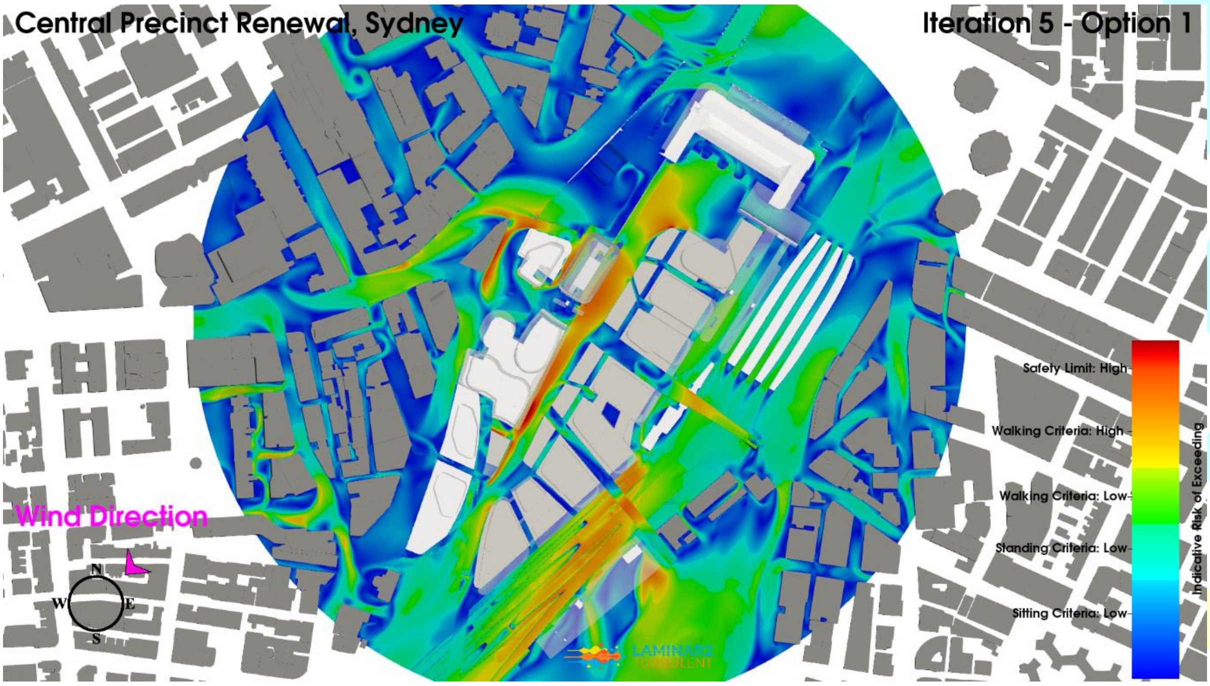

Figure 83: Iteration 5 – Option 1 Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

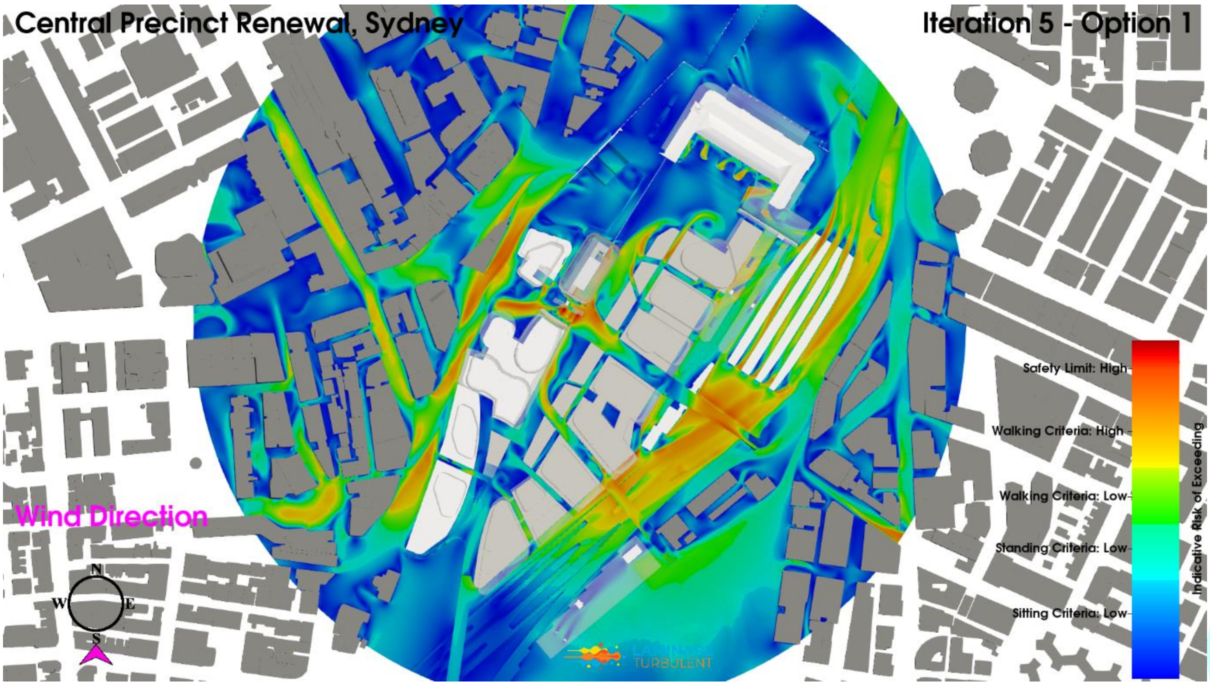

Figure 84: Iteration 5 – Option 1 Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

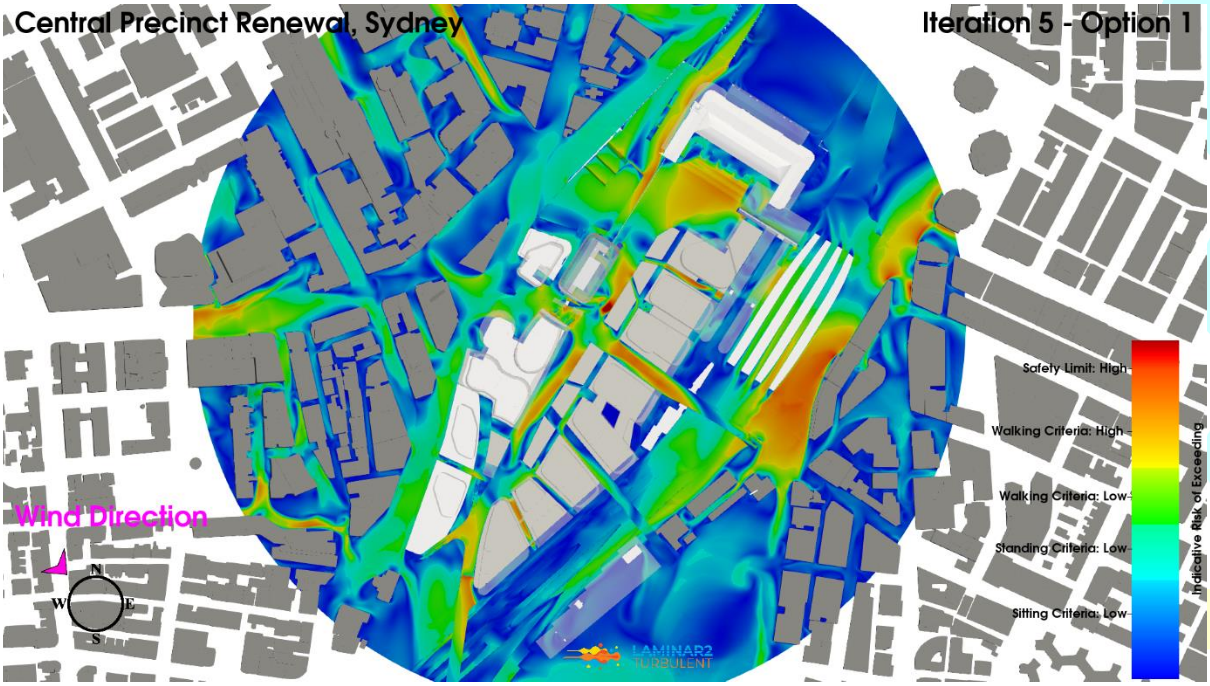

Figure 85: Iteration 5 – Option 1 Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

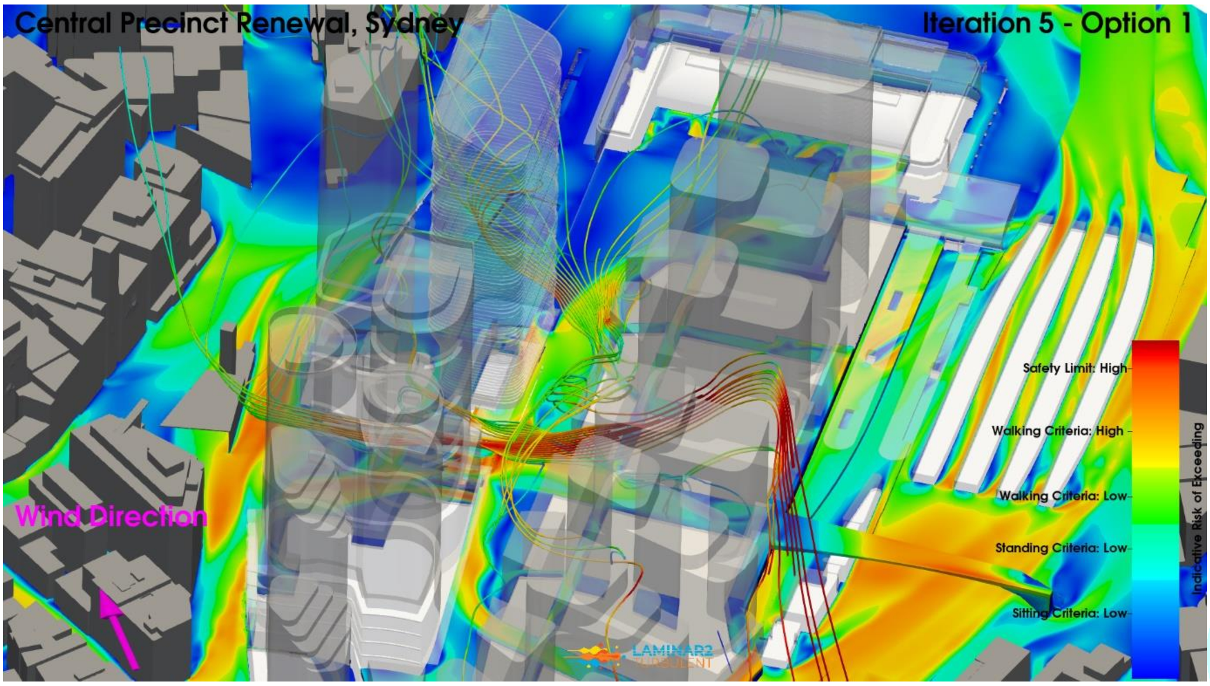

Figure 86: Iteration 5 – Option 1 Configuration, South Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

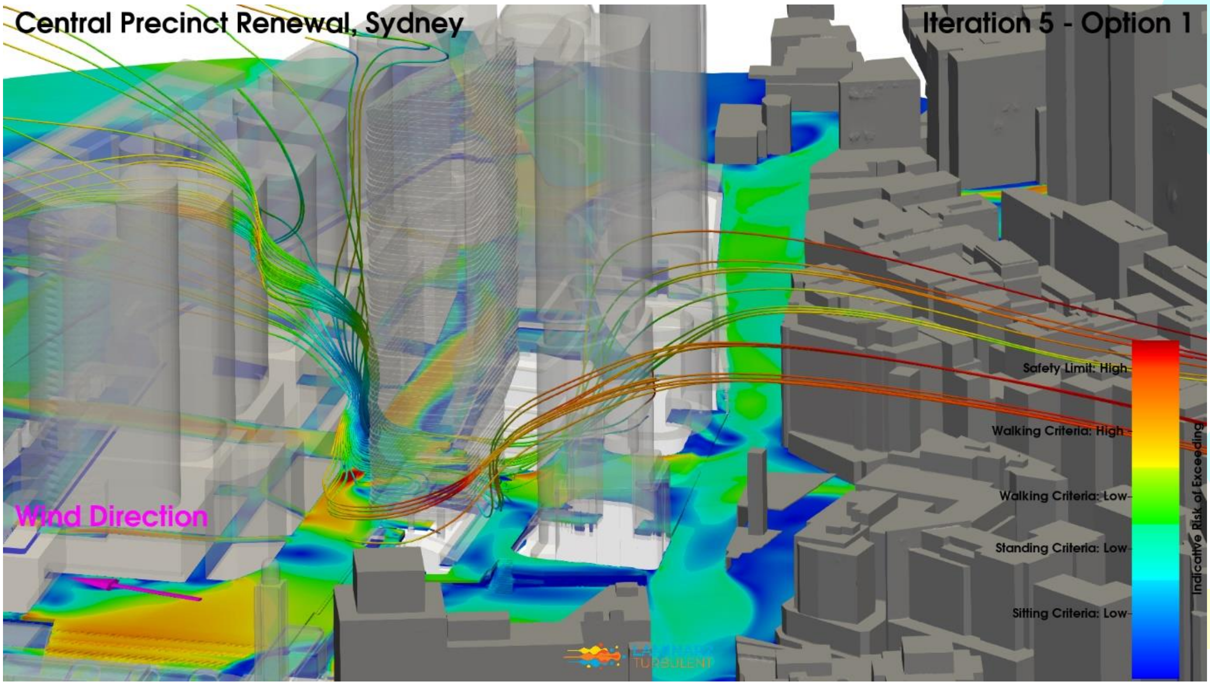

Figure 87: Iteration 5 – Option 1 Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

8.12 ITERATION 5 – OPTION 2

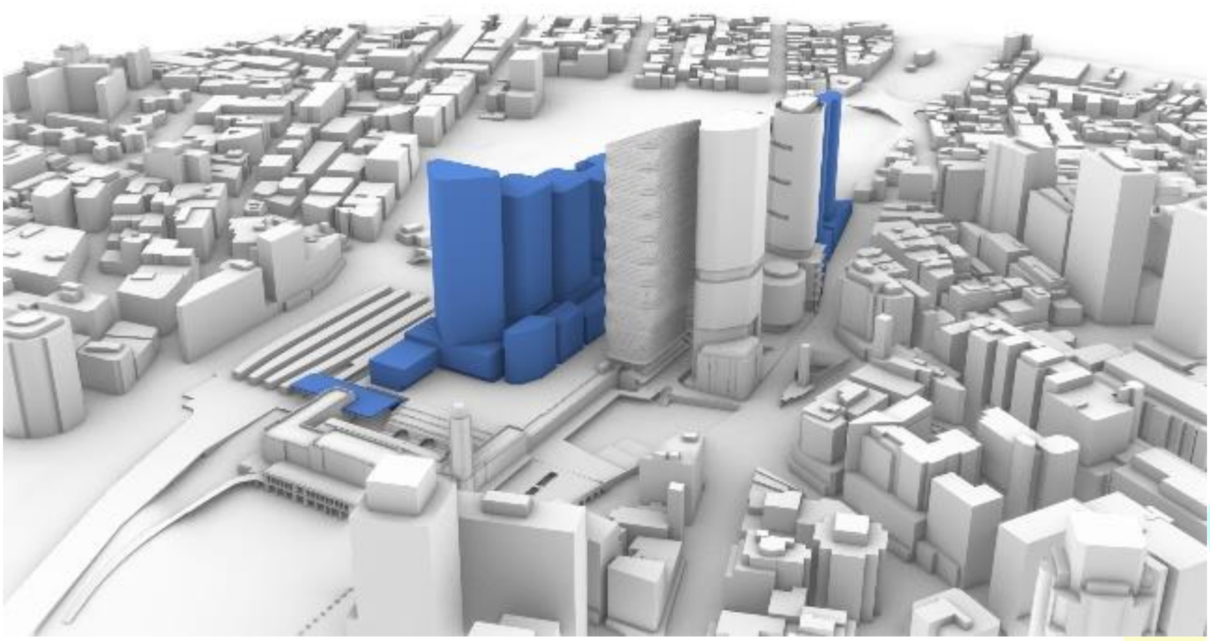

Figure 88: North View of Proposed Iteration 5 – Option 2 Massing

Figure 89: South View of Proposed Iteration 5 – Option 2 Massing

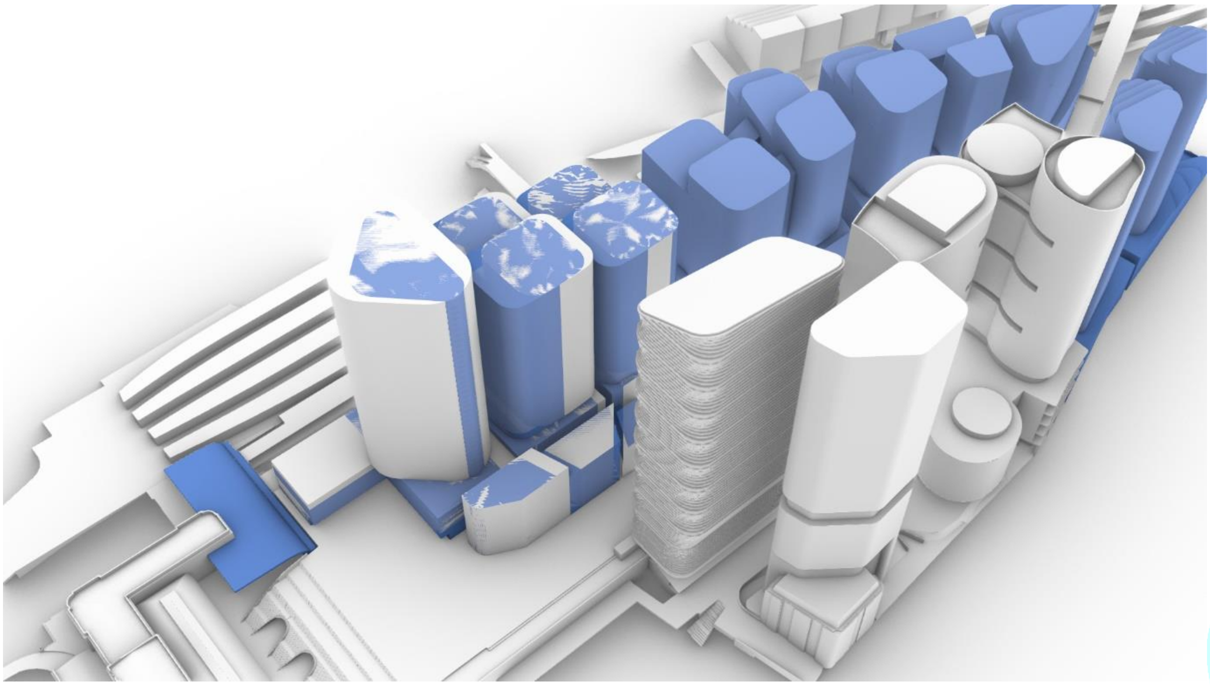

Figure 90: Iteration 5 – Option 1 (white) and Iteration 5 – Option 2 (blue) Comparison.

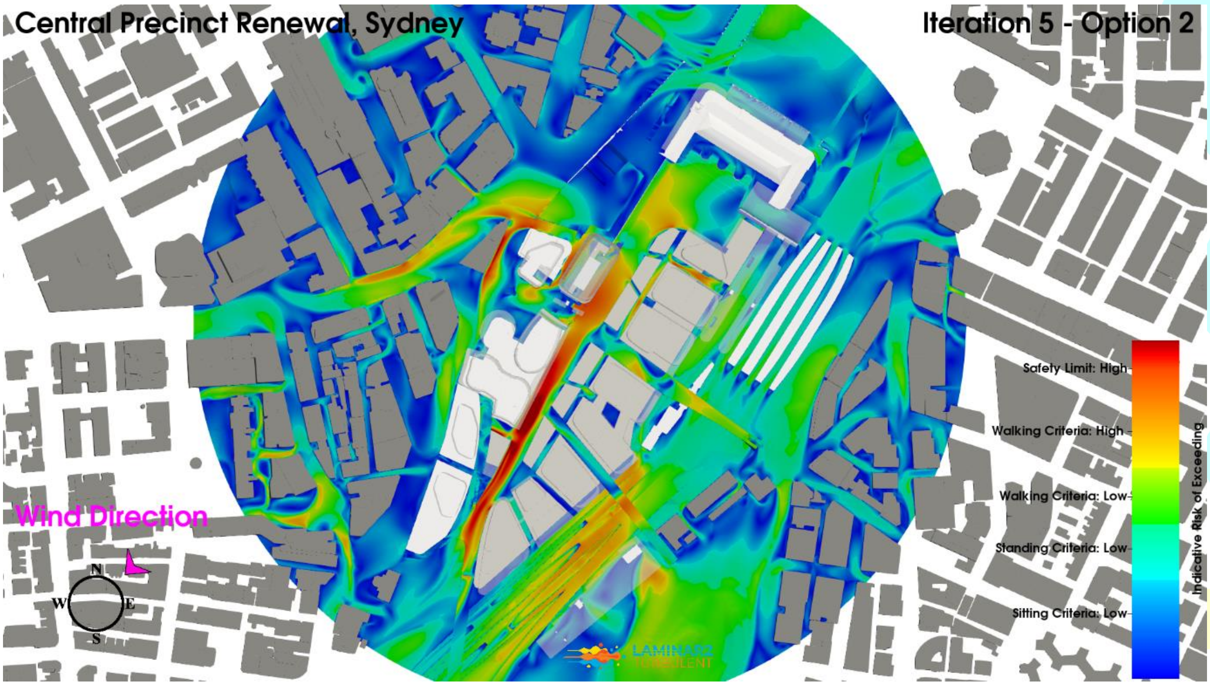

Figure 91: Iteration 5 – Option 2 Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

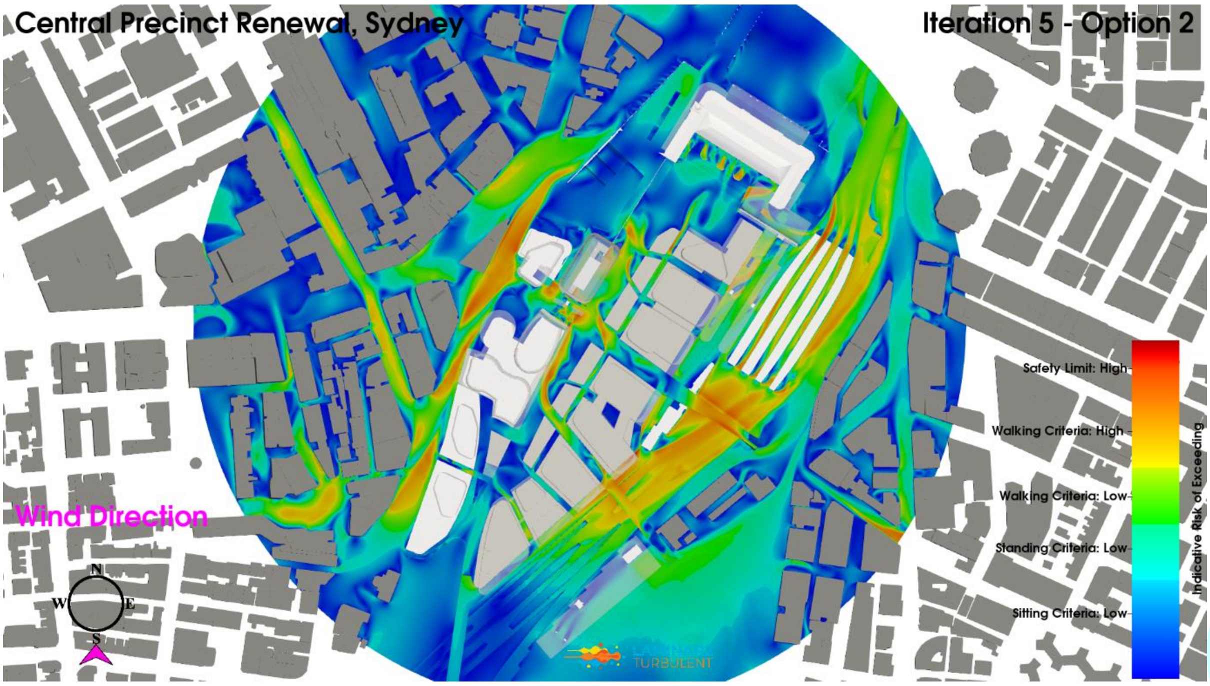

Figure 92: Iteration 5 – Option 2 Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

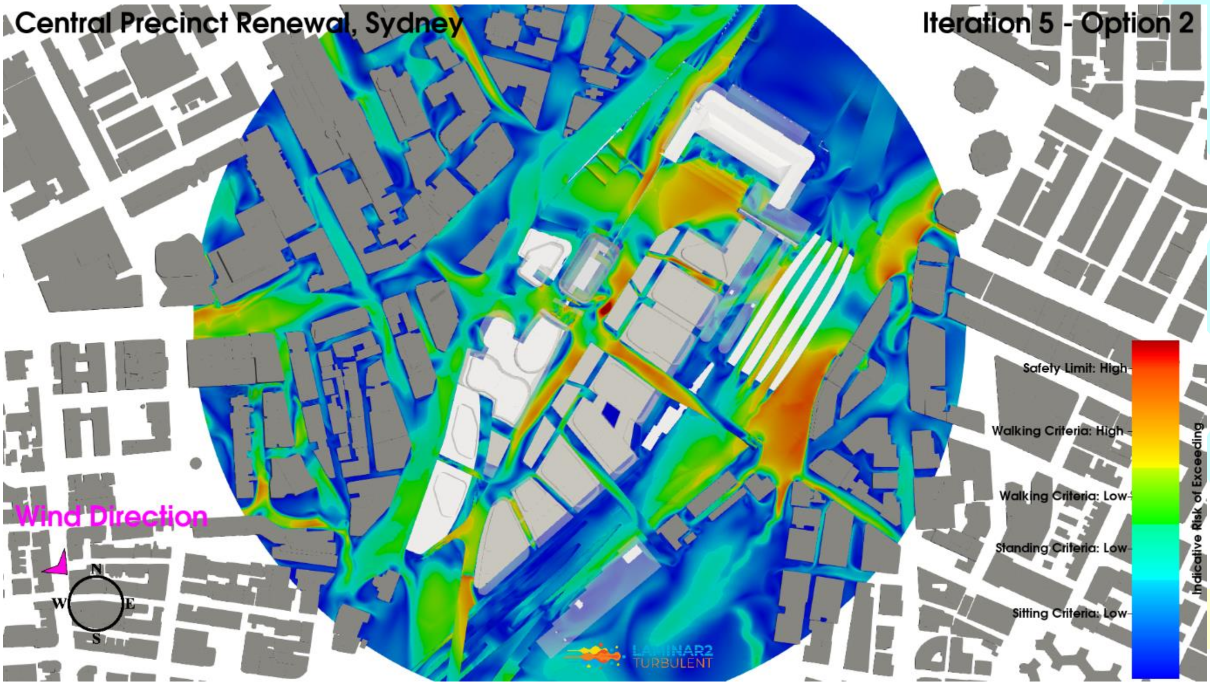

Figure 93: Iteration 5 – Option 2 Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

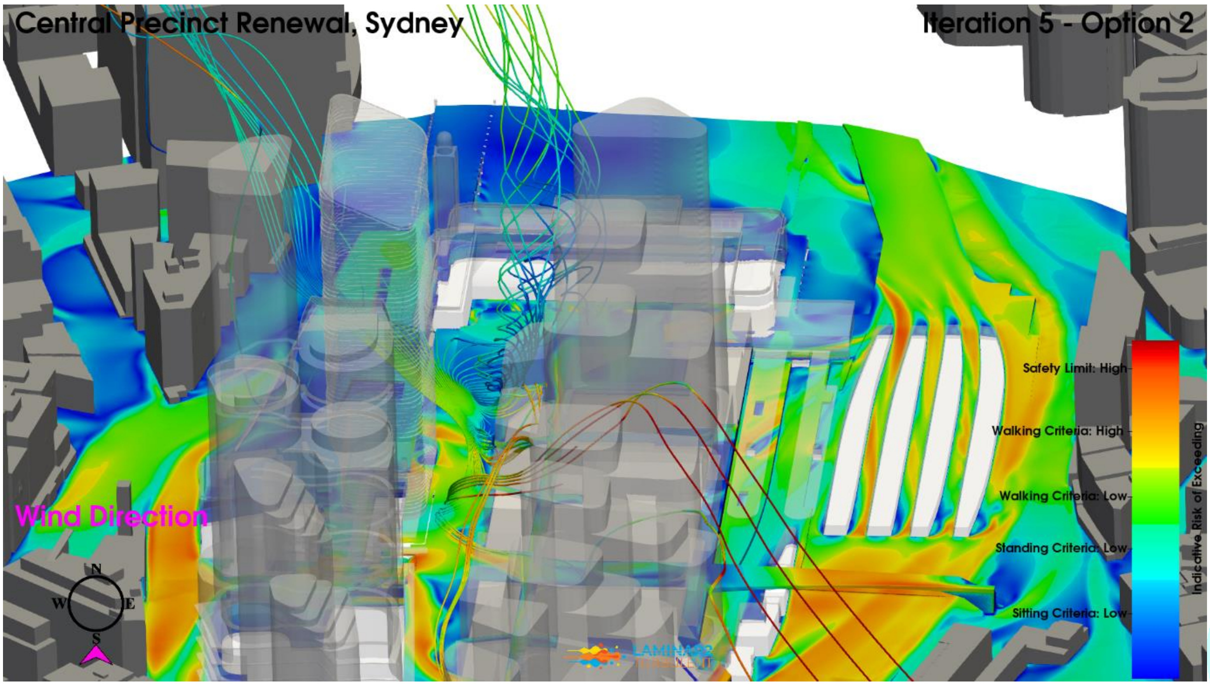

Figure 94: Iteration 5 – Option 2 Configuration, South Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

8.13 ITERATION 5 – BASELINE WITH DECK

Figure 95: North (left) and south (right) views of proposed Iteration 5 – Baseline with Deck

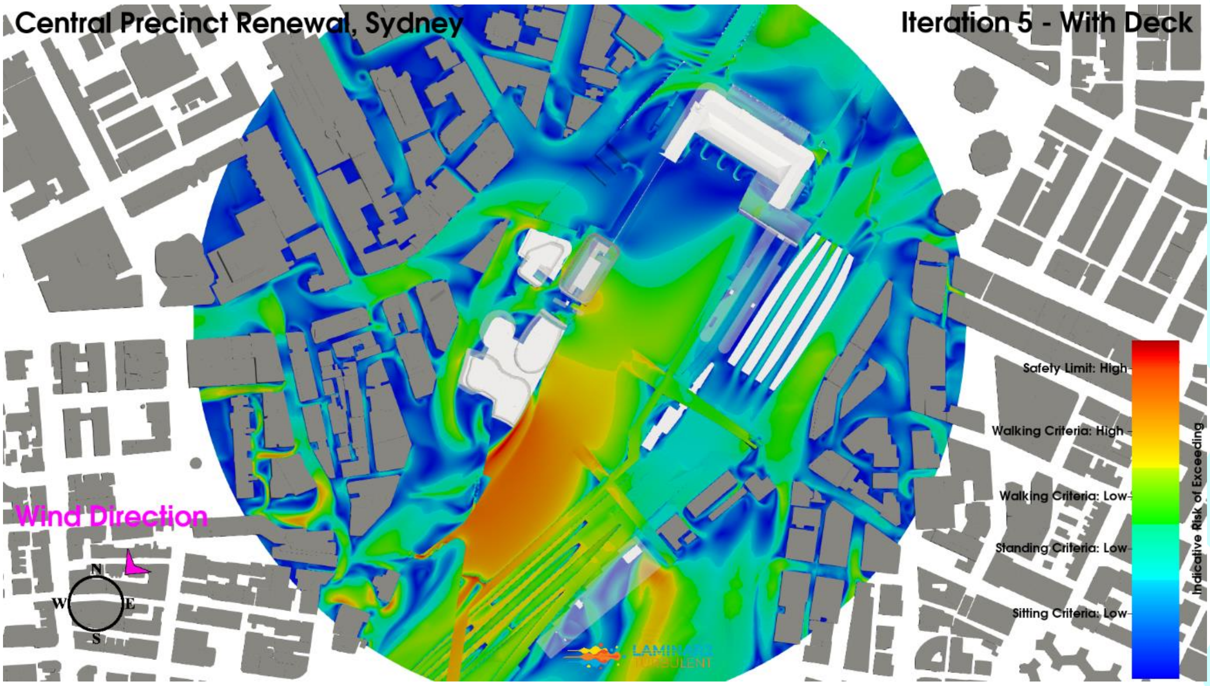

Figure 96: Iteration 5 – Baseline With Deck Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

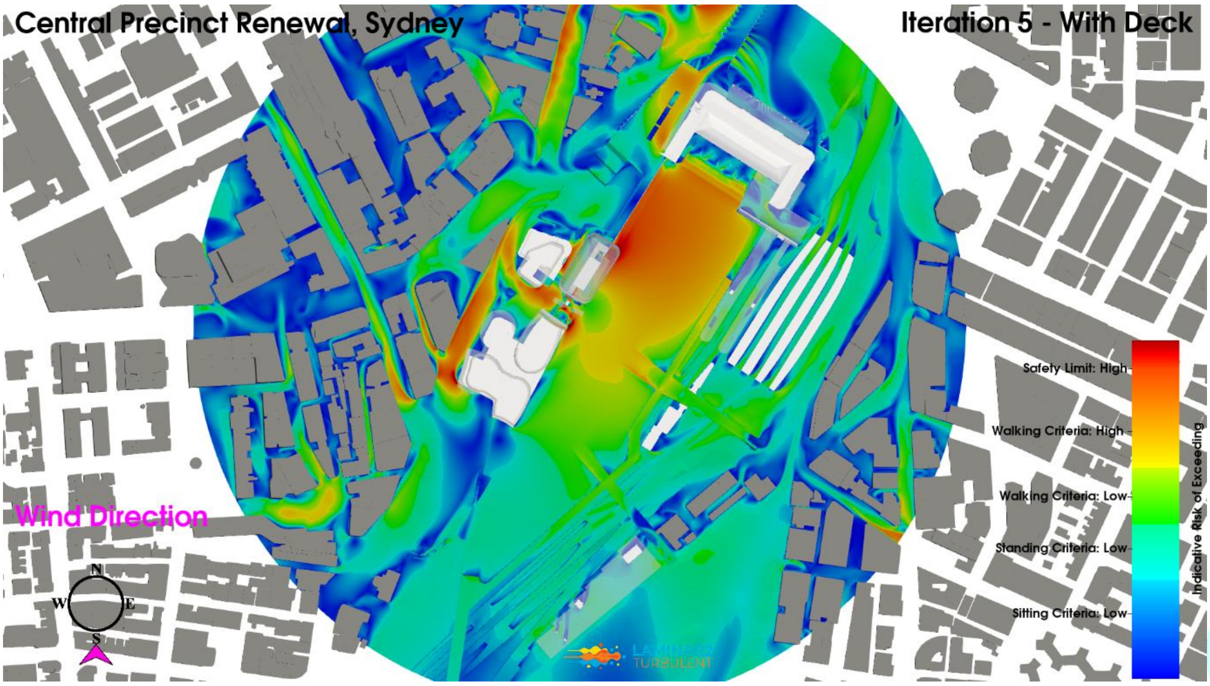

Figure 97: Iteration 5 – Baseline With Deck Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

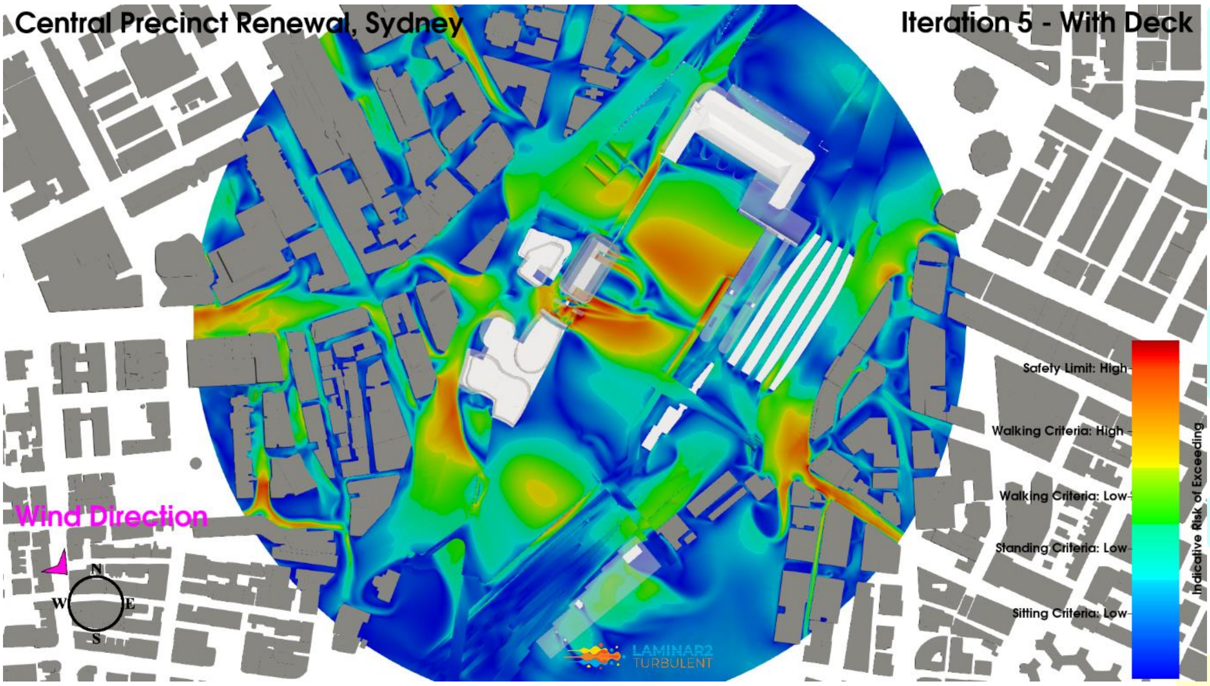

Figure 98: Iteration 5 – Baseline With Deck Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

8.14 ITERATION 5 – BASELINE WITHOUT DECK

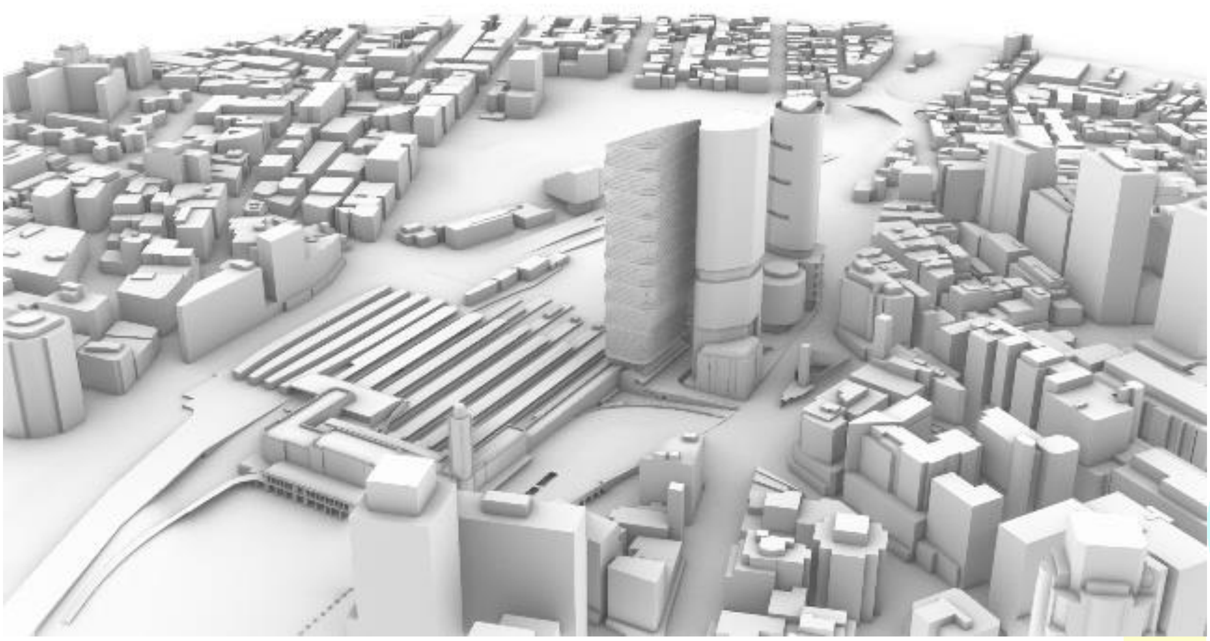

Figure 99: North View of Proposed Iteration 5 – Baseline Without Deck

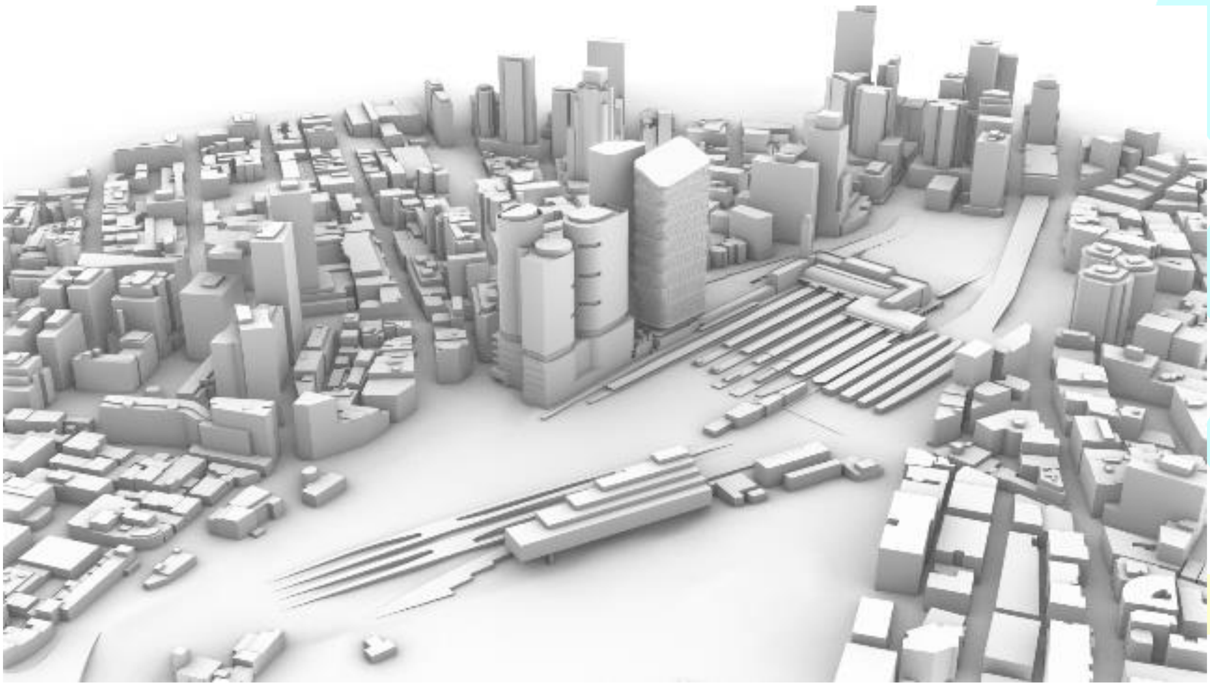

Figure 100: South View of Proposed Iteration 5 – Baseline Without Deck

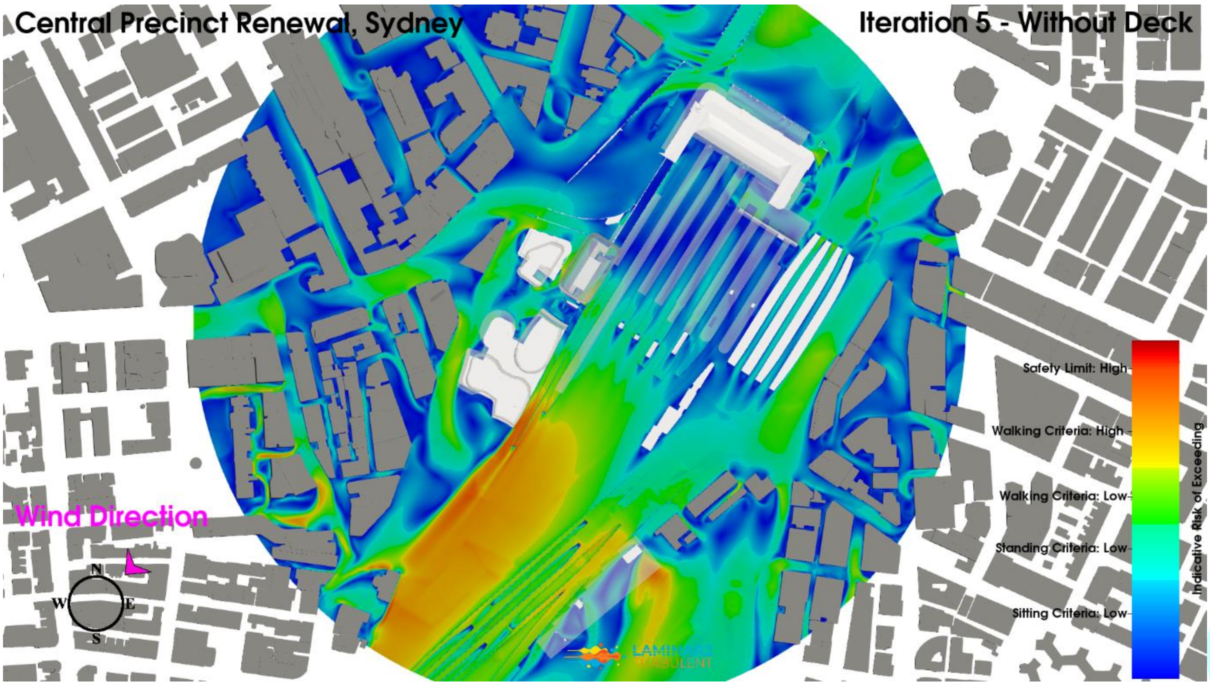

Figure 101: Iteration 5 – Baseline Without Deck Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

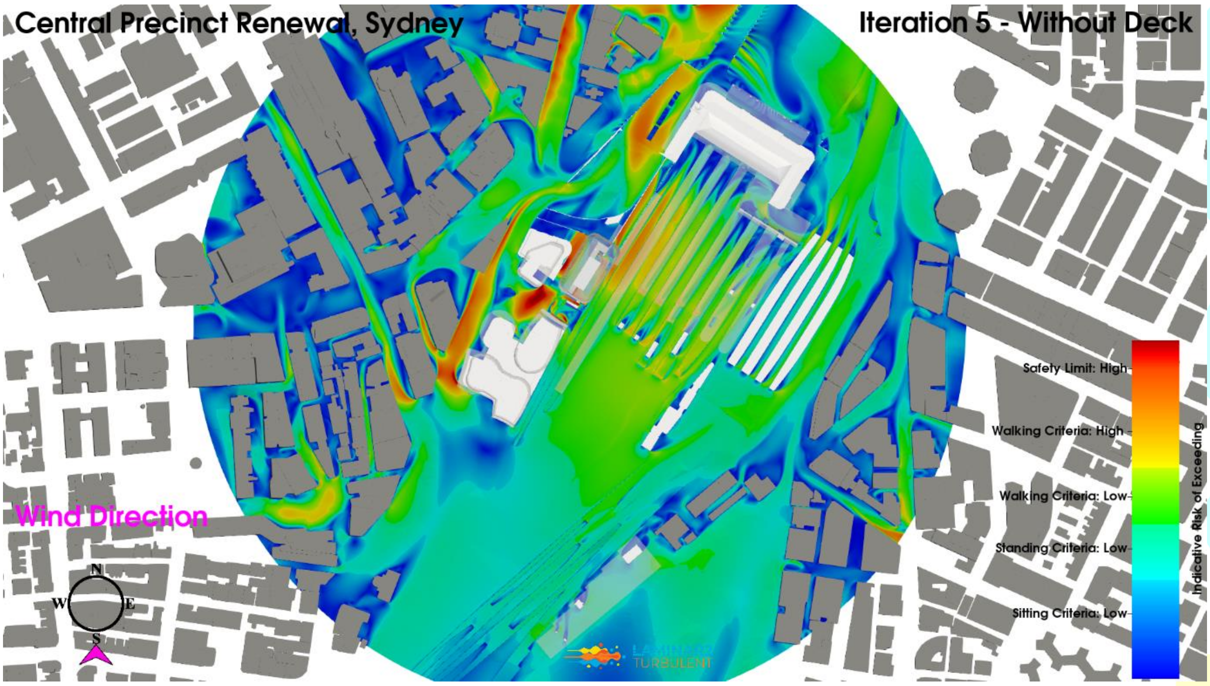

Figure 102: Iteration 5 – Baseline Without Deck Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

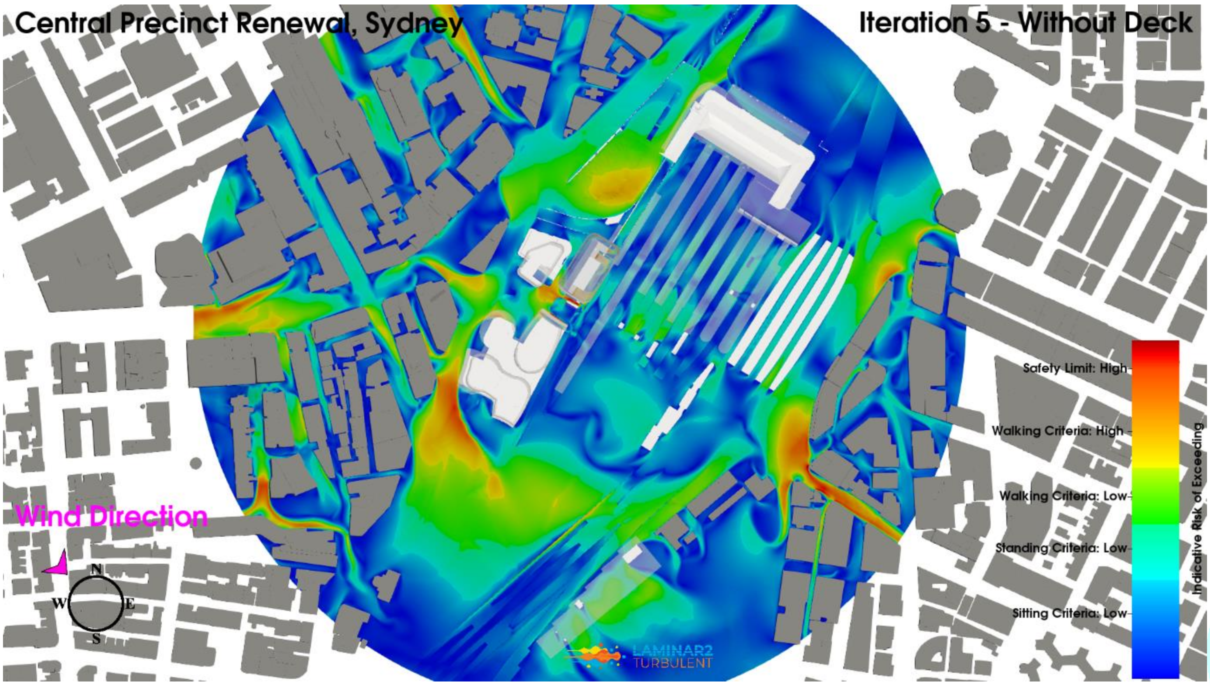

Figure 103: Iteration 5 – Baseline Without Deck Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

8.15 ITERATION 5 – OPTION 1 WITH NO A1 TOWER

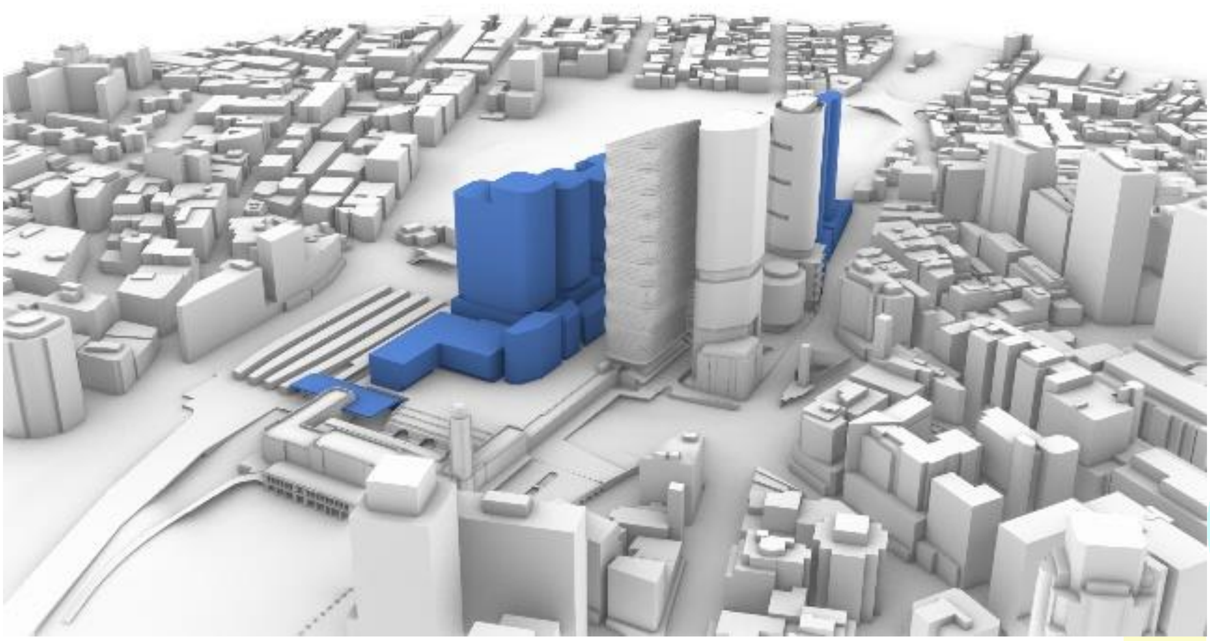

Figure 104: North view of proposed Iteration 5 – Option 1 with no A1 tower massing

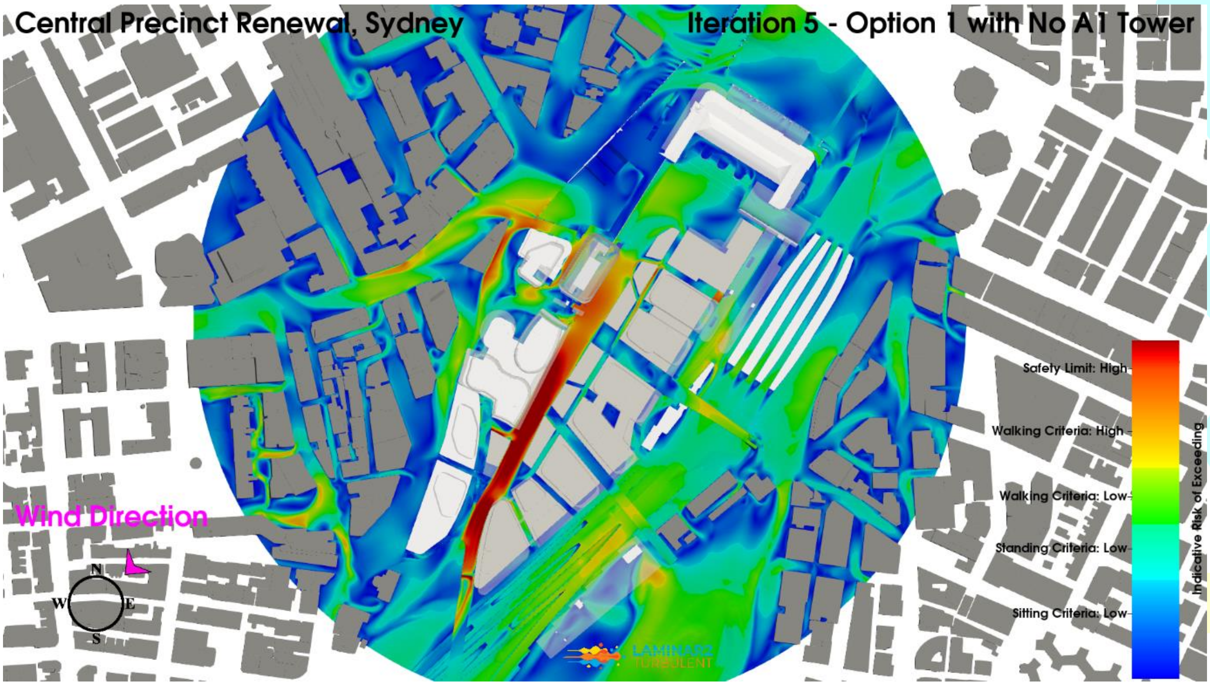

Figure 105: Iteration 5 – Option 1 With No A1 Tower Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

8.16 ITERATION 6 – BASELINE WITHOUT DECK

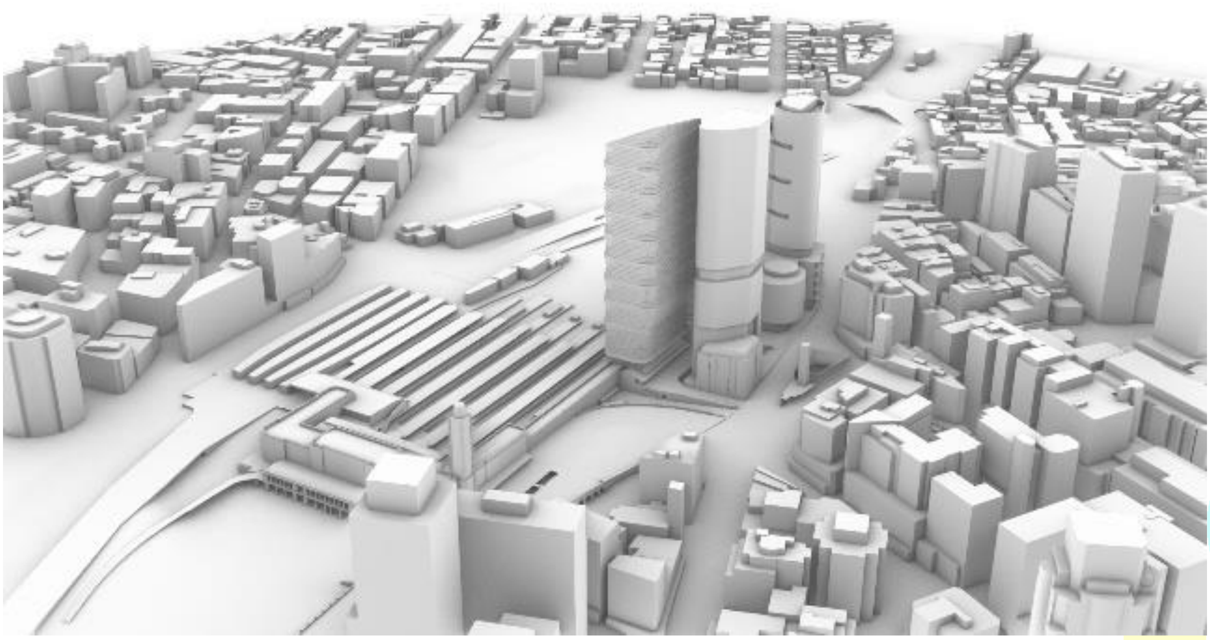

Figure 106: North View of Proposed Iteration 6 – Without Deck

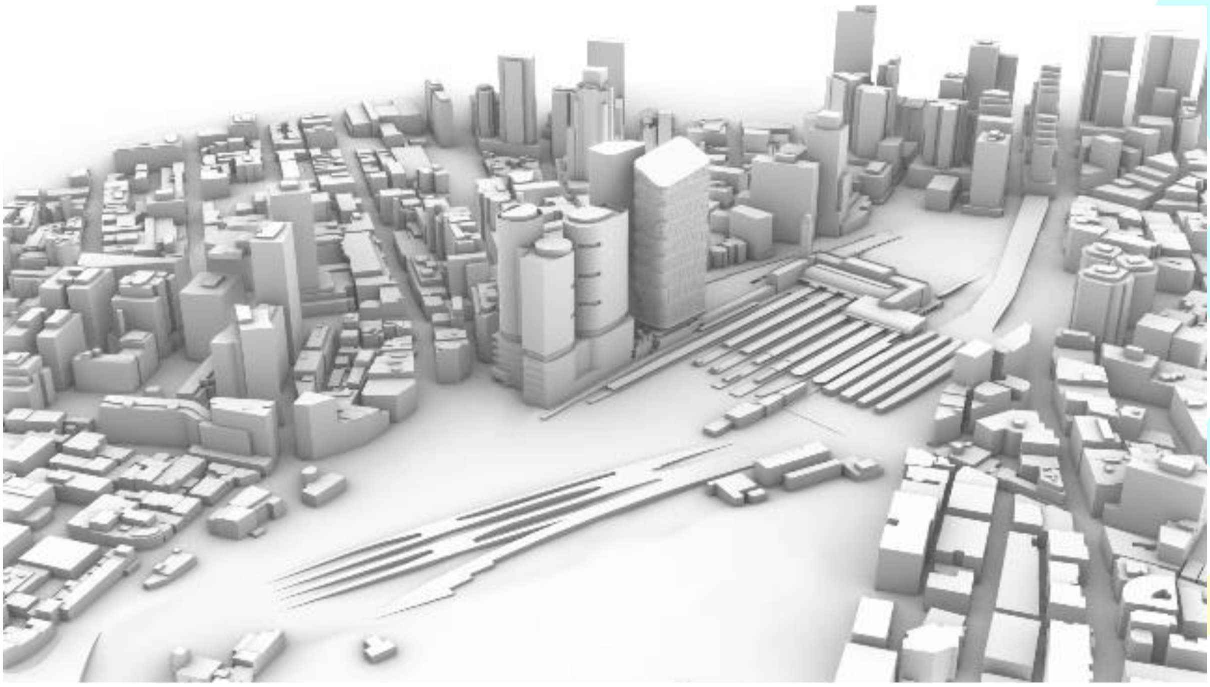

Figure 107: South View of Proposed Iteration 6 – Without Deck

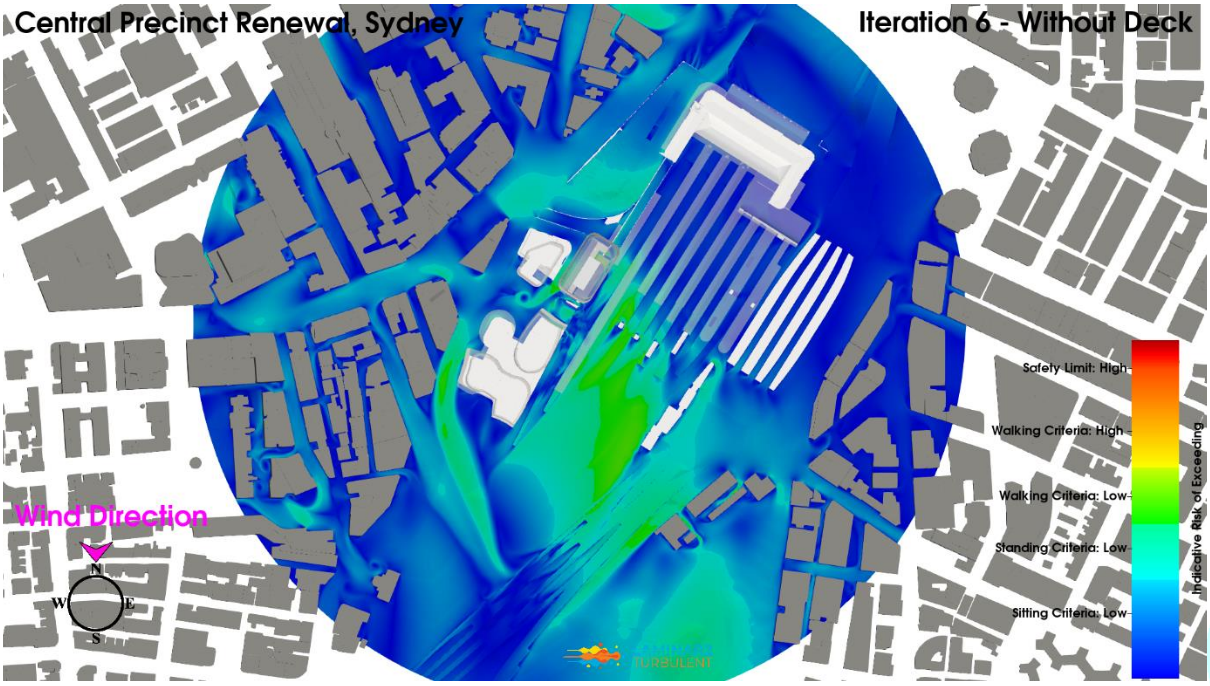

Figure 108: Iteration 6 – Without Deck Configuration, North Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

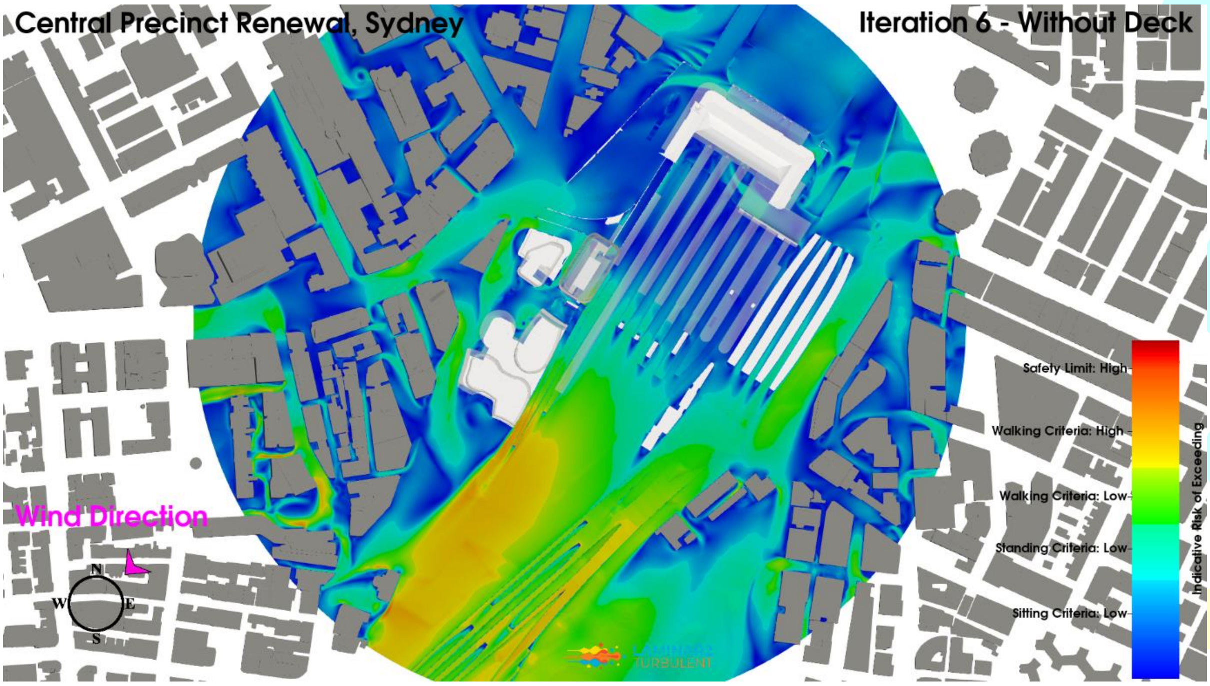

Figure 109: Iteration 6 – Without Deck Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

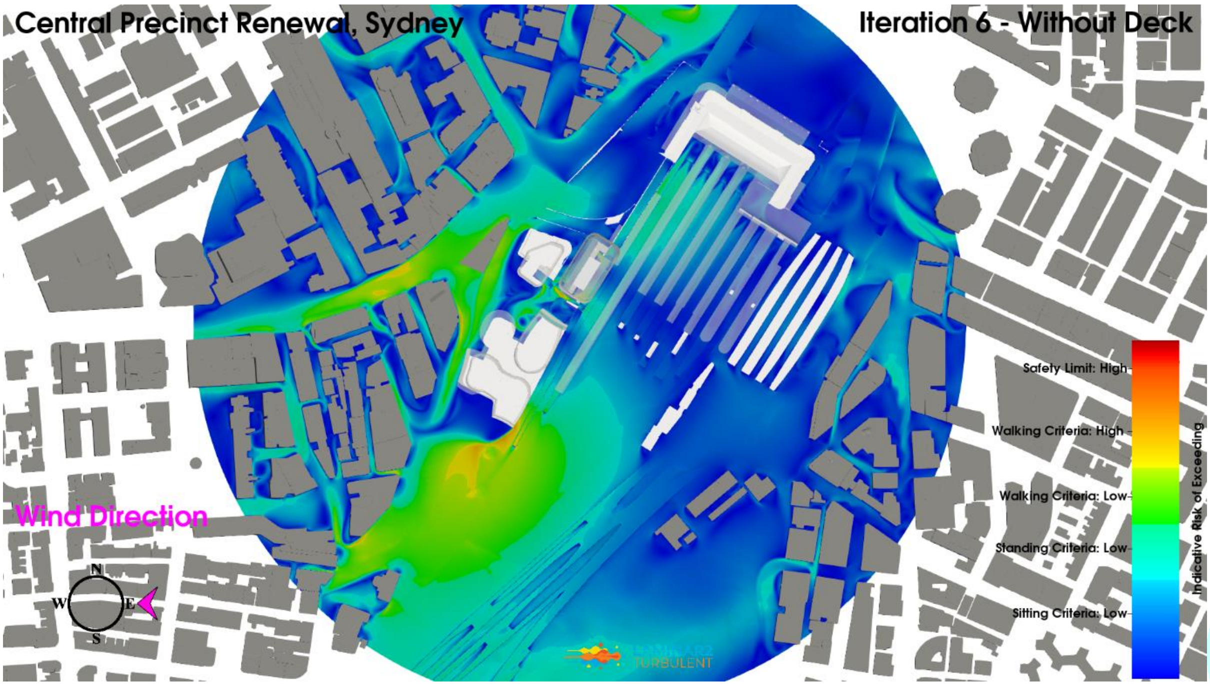

Figure 110: Iteration 6 – Without Deck Configuration, East Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

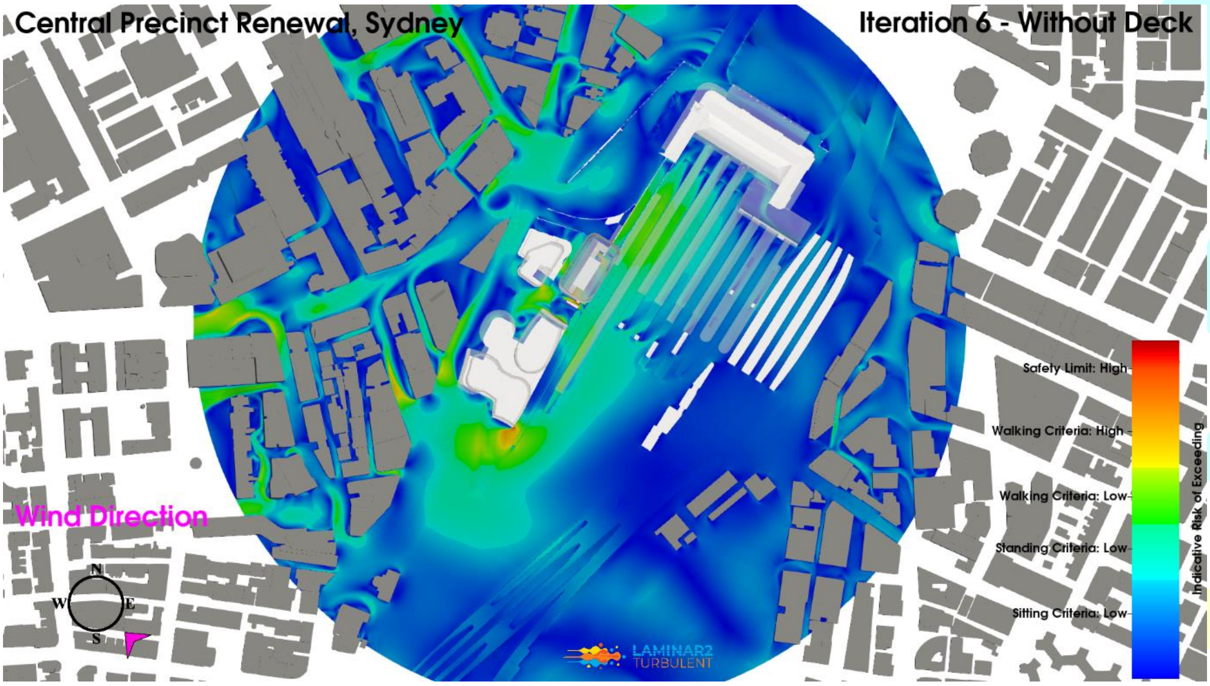

Figure 111: Iteration 6 – Without Deck Configuration, Southeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

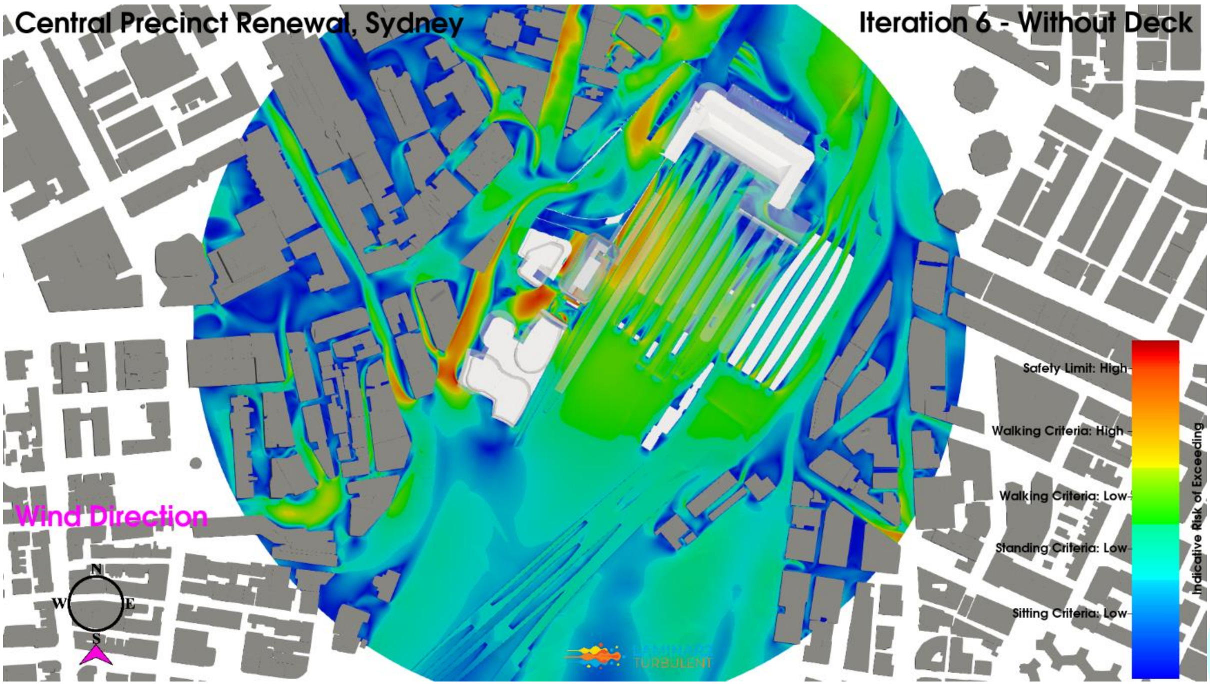

Figure 112: Iteration 6 – Without Deck Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

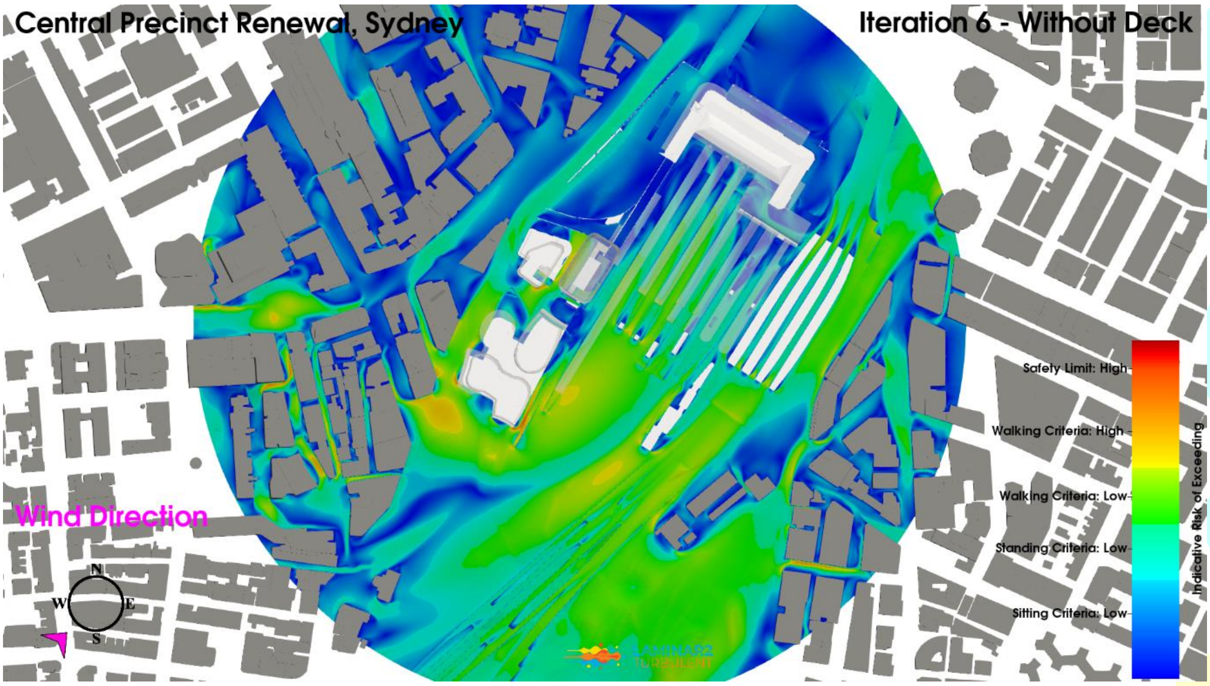

Figure 113: Iteration 6 – Without Deck Configuration, Southwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

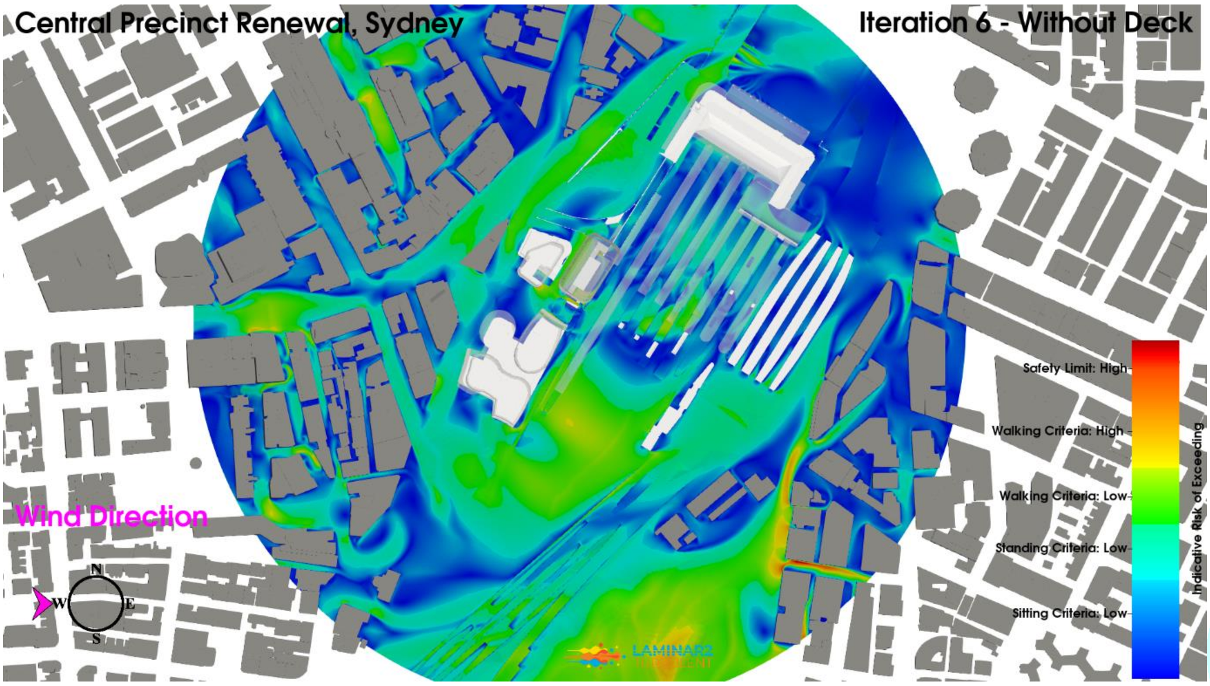

Figure 114: Iteration 6 – Without Deck Configuration, West Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

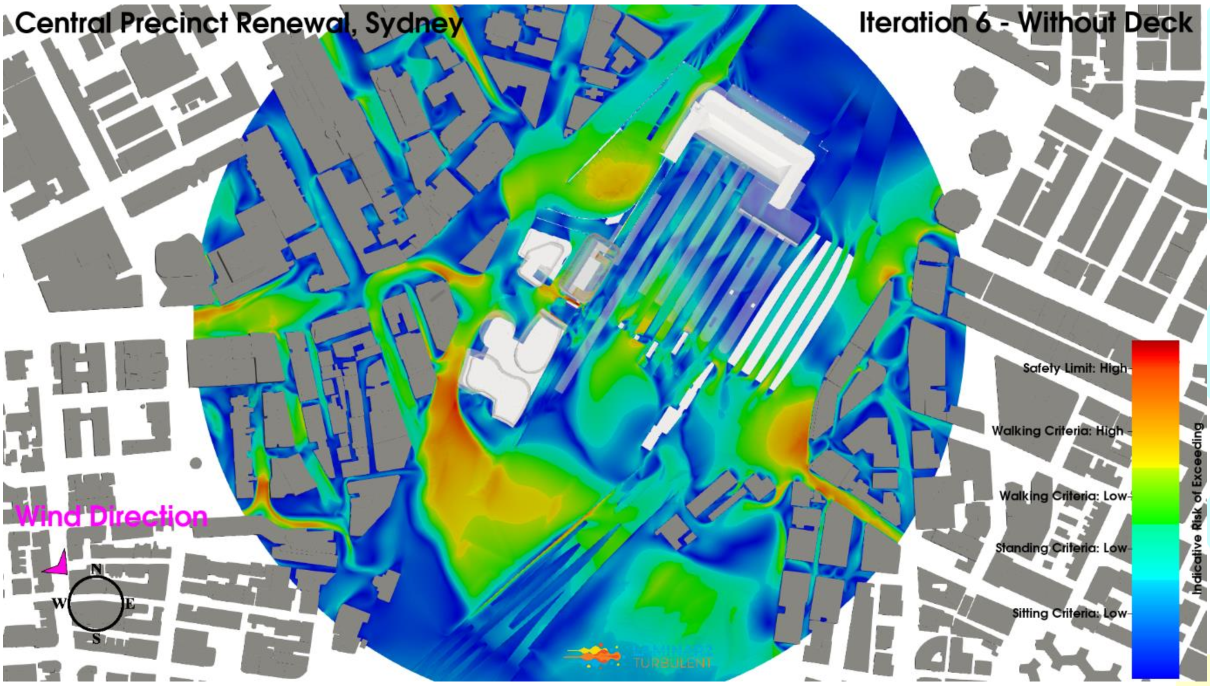

Figure 115: Iteration 6 – Without Deck Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

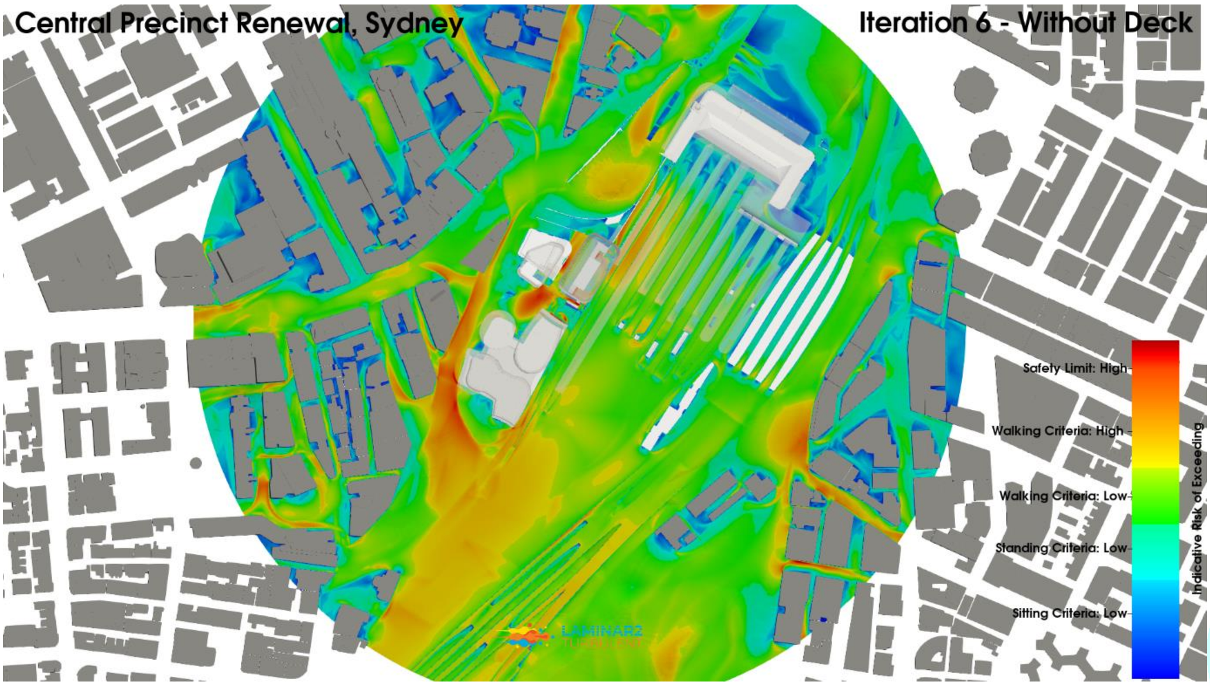

Figure 116: Iteration 6 – Baseline Without Deck Configuration, Combined Wind Directions, Planview, Maximum Pedestrian Level Environmental Wind Risk Contour Plot

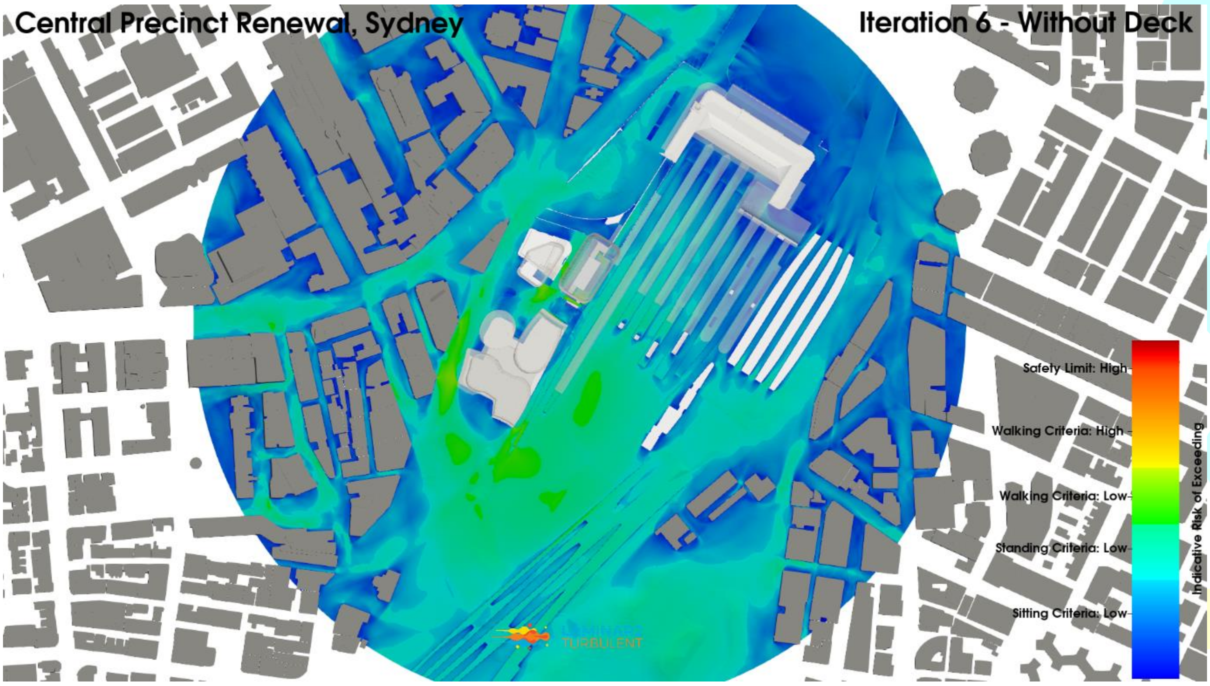

Figure 117: Iteration 6 – Baseline Without Deck Configuration, Combined Wind Directions, Planview, Average Pedestrian Level Environmental Wind Risk Contour Plot

8.17 ITERATION 6 – REVISED PREFERRED MASSING

Figure 118: North View of Proposed Iteration 6 – Revised Preferred Massing

Figure 119: South View of Proposed Iteration 6 – Revised Preferred Massing

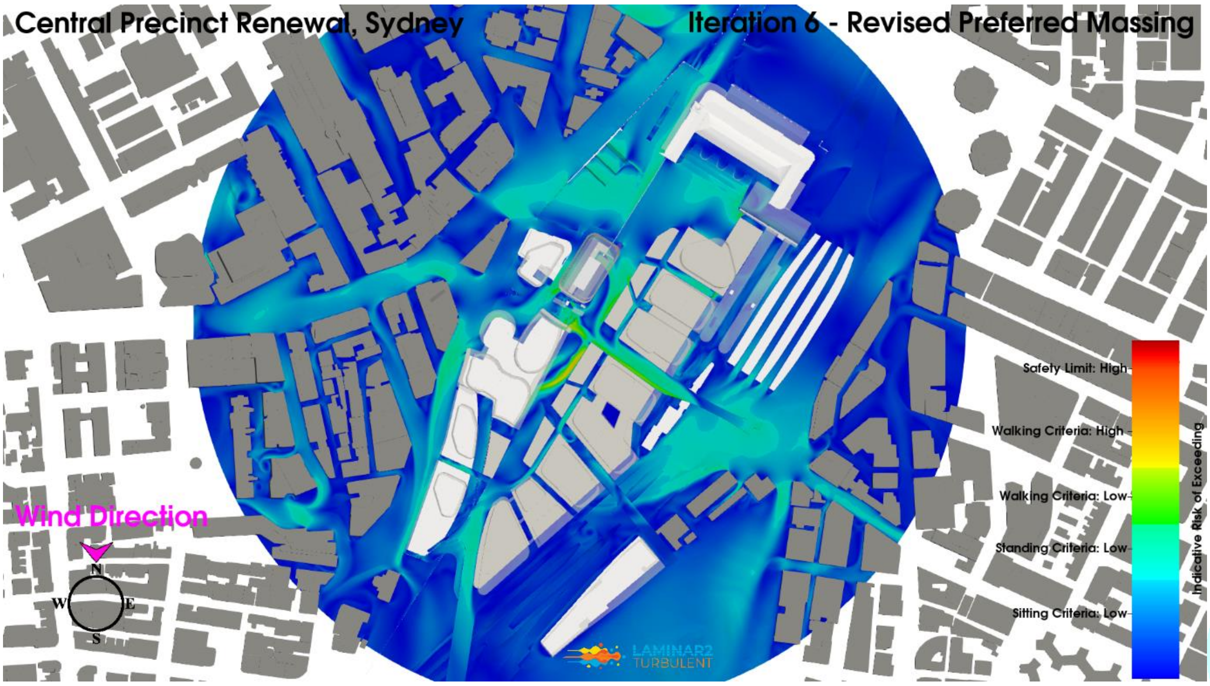

Figure 120: Iteration 6 – Revised Preferred Massing Configuration, North Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

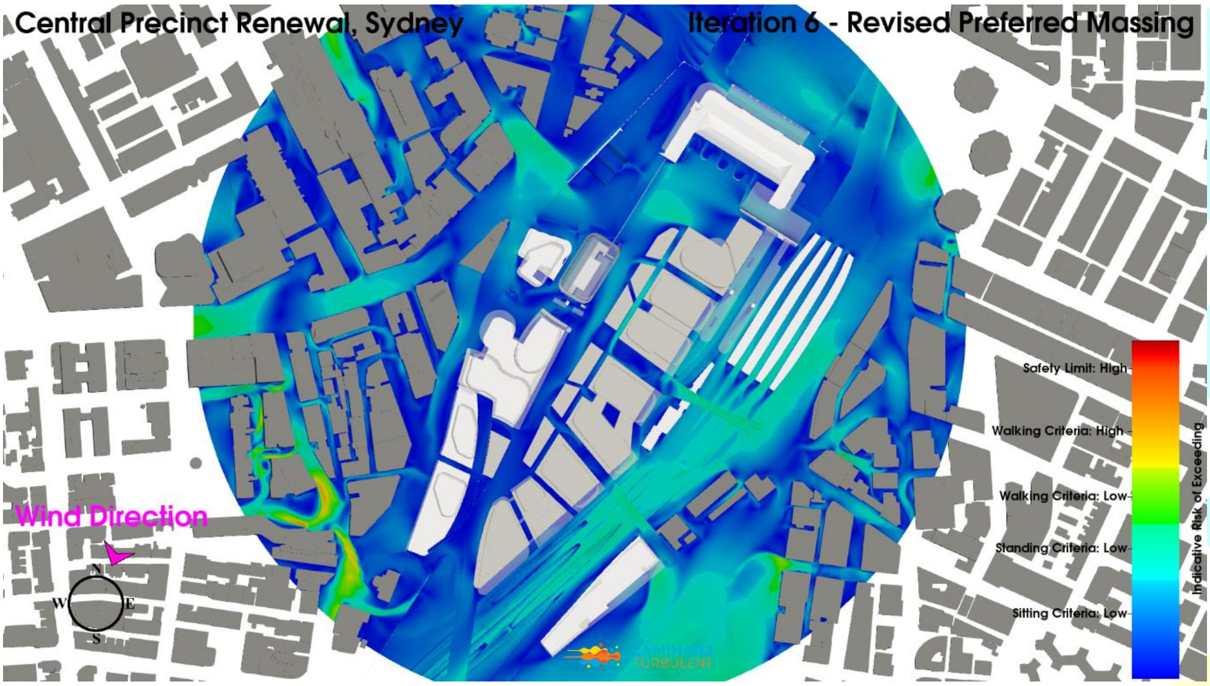

Figure 121: Iteration 6 – Revised Preferred Massing Configuration, North-northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

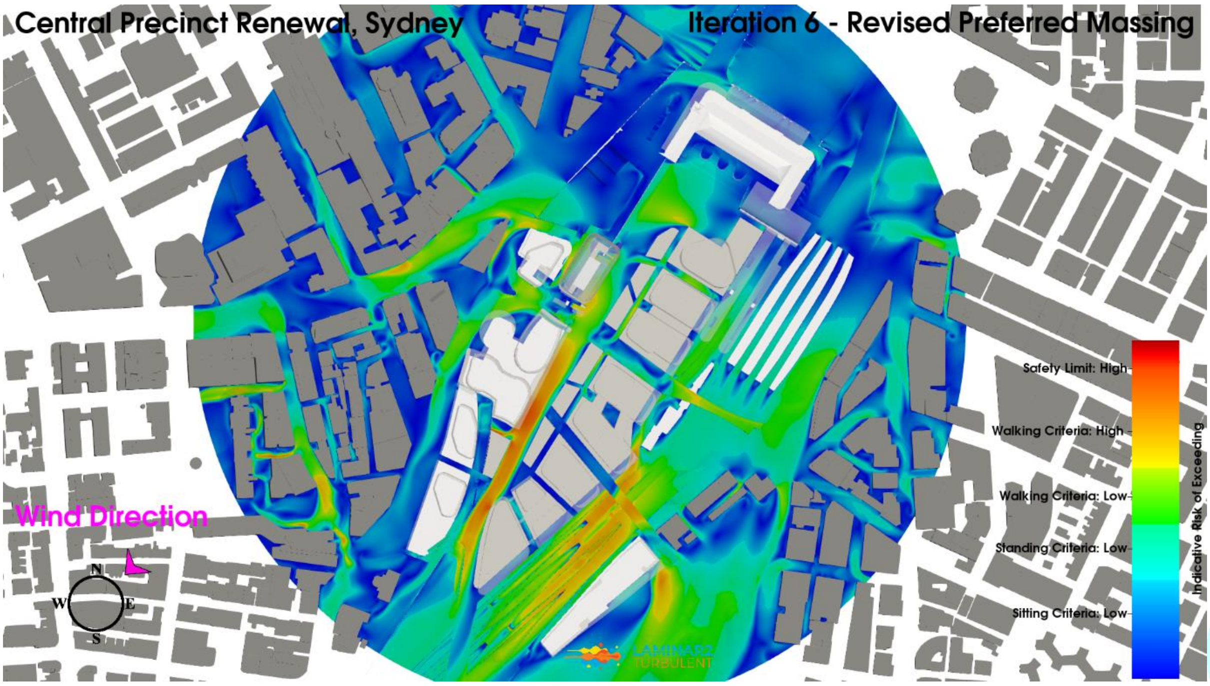

Figure 122: Iteration 6 – Revised Preferred Massing Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

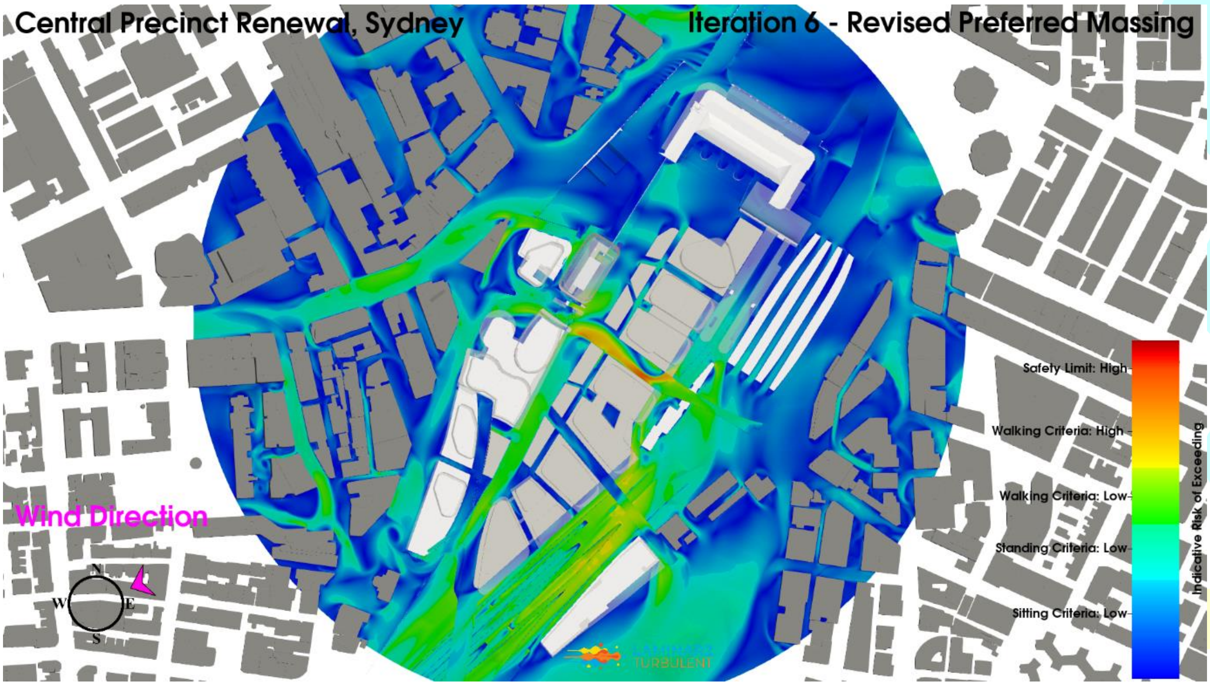

Figure 123: Iteration 6 – Revised Preferred Massing Configuration, East-northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

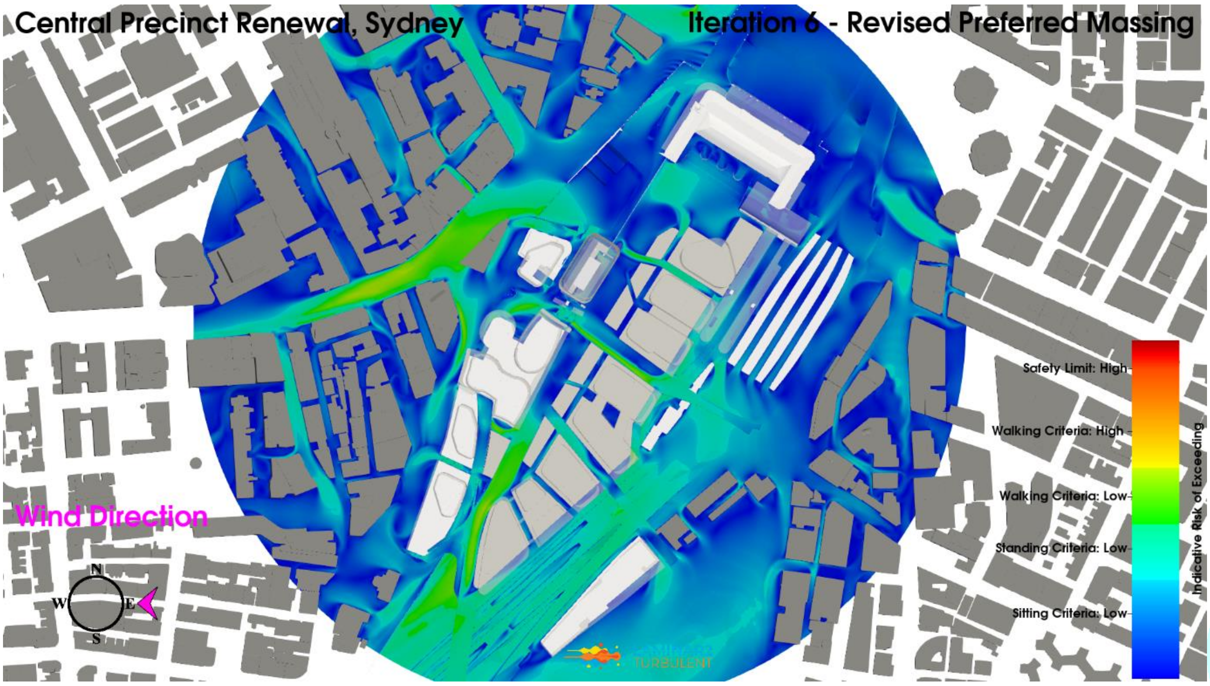

Figure 124: Iteration 6 – Revised Preferred Massing Configuration, East Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

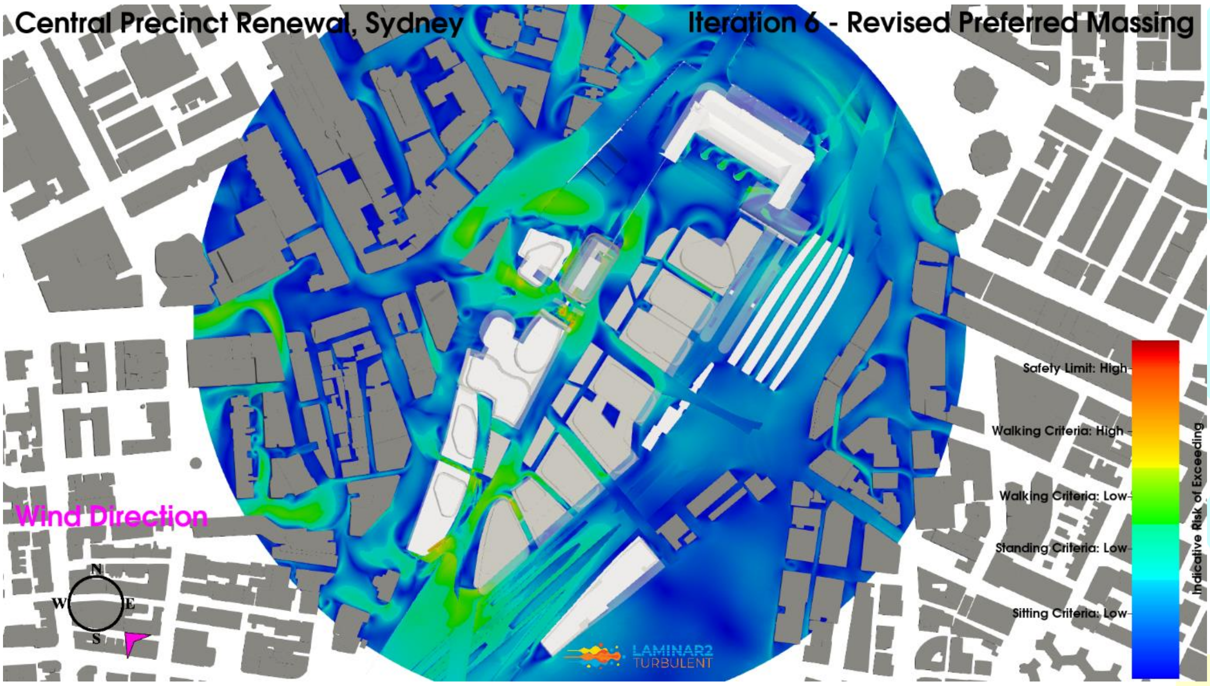

Figure 125: Iteration 6 – Revised Preferred Massing Configuration, Southeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

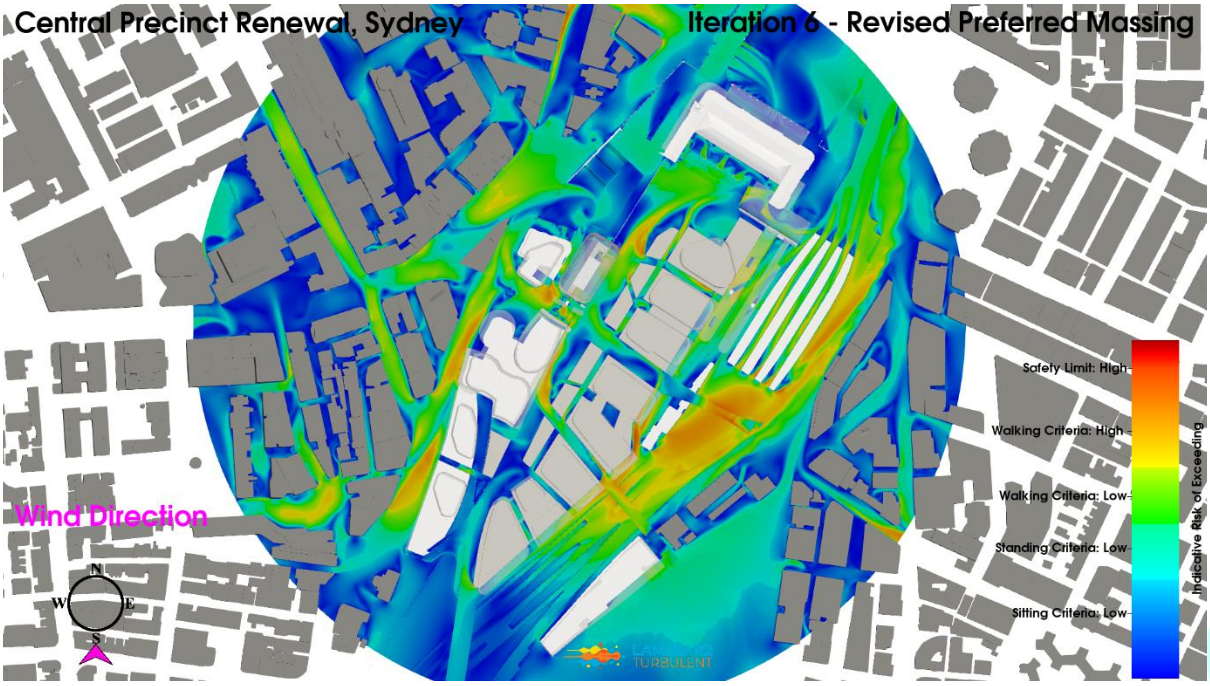

Figure 126: Iteration 6 – Revised Preferred Massing Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

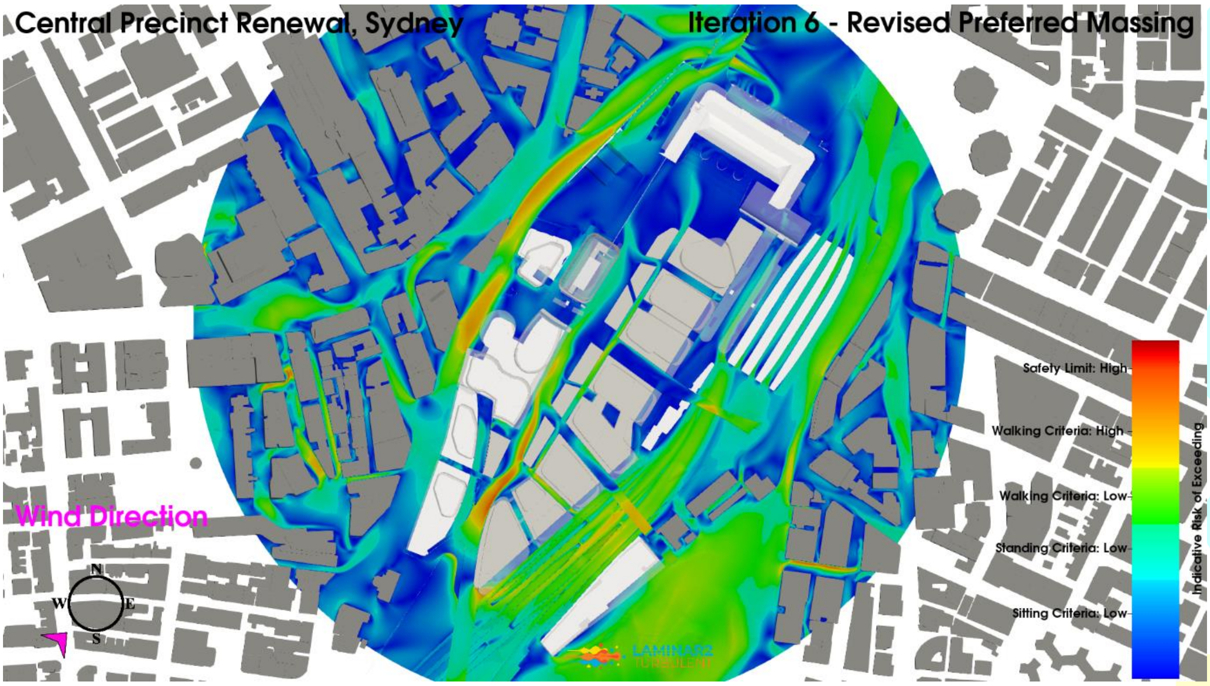

Figure 127: Iteration 6 – Revised Preferred Massing Configuration, Southwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

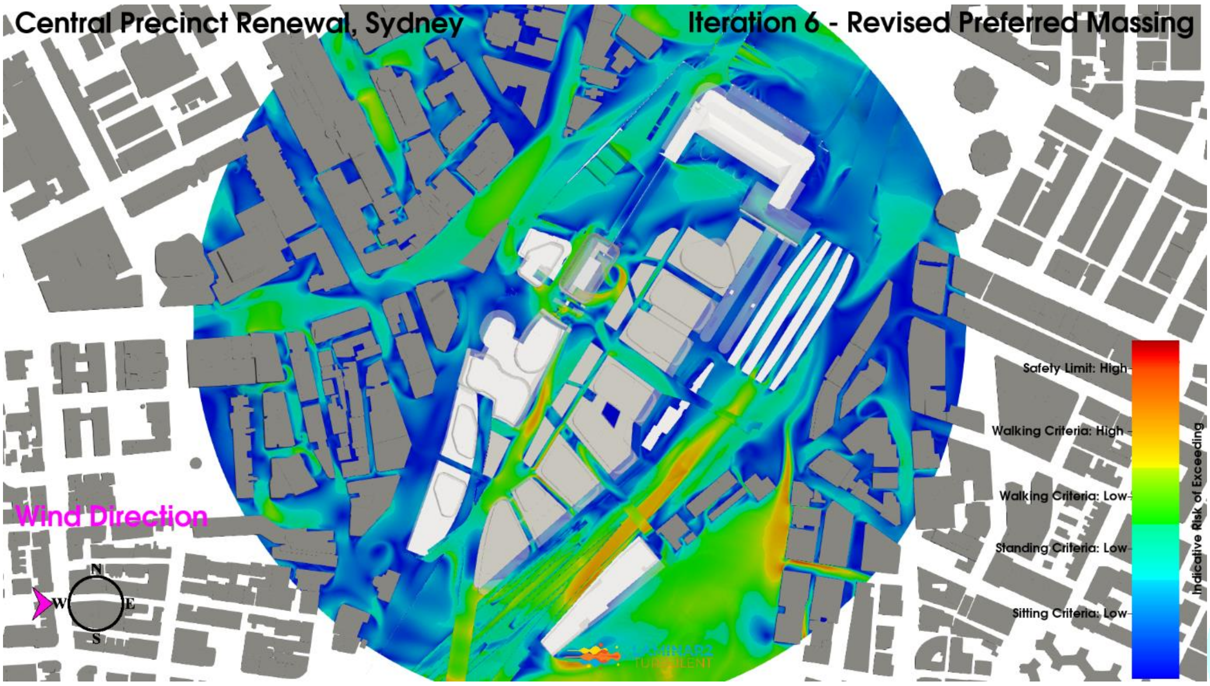

Figure 128: Iteration 6 – Revised Preferred Massing Configuration, West Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

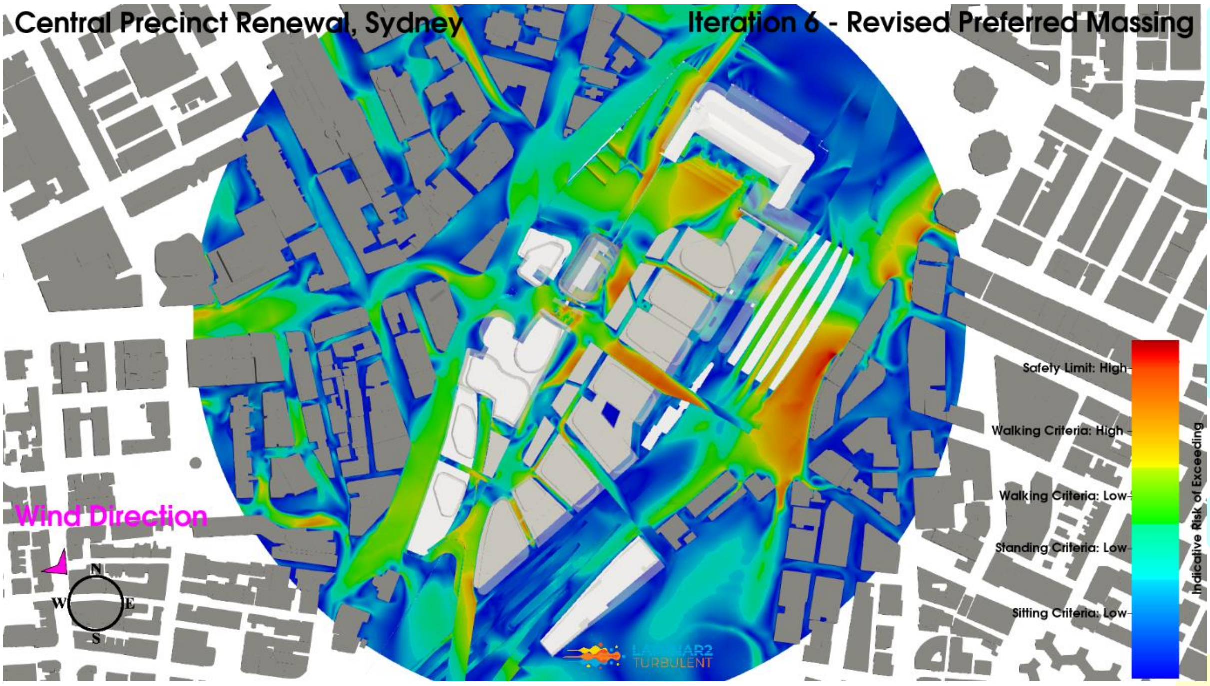

Figure 129: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

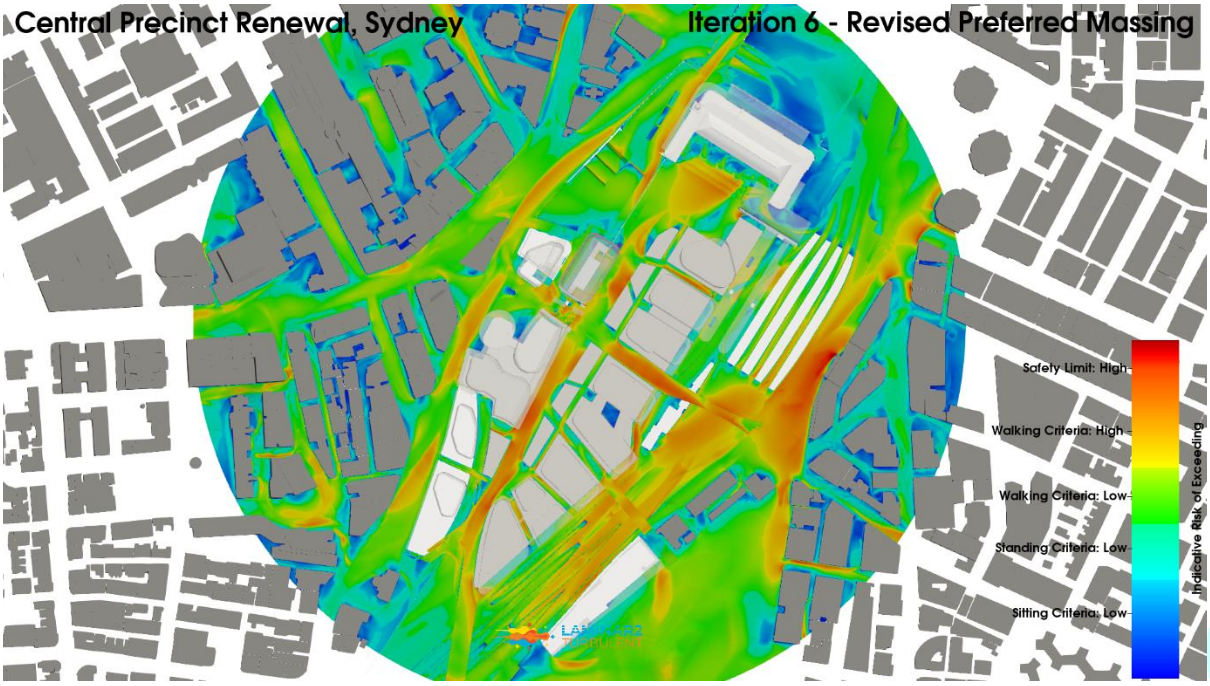

Figure 130: Iteration 6 – Revised Preferred Massing Configuration, Combined Wind Directions, Planview, Maximum Pedestrian Level Environmental Wind Risk Contour Plot

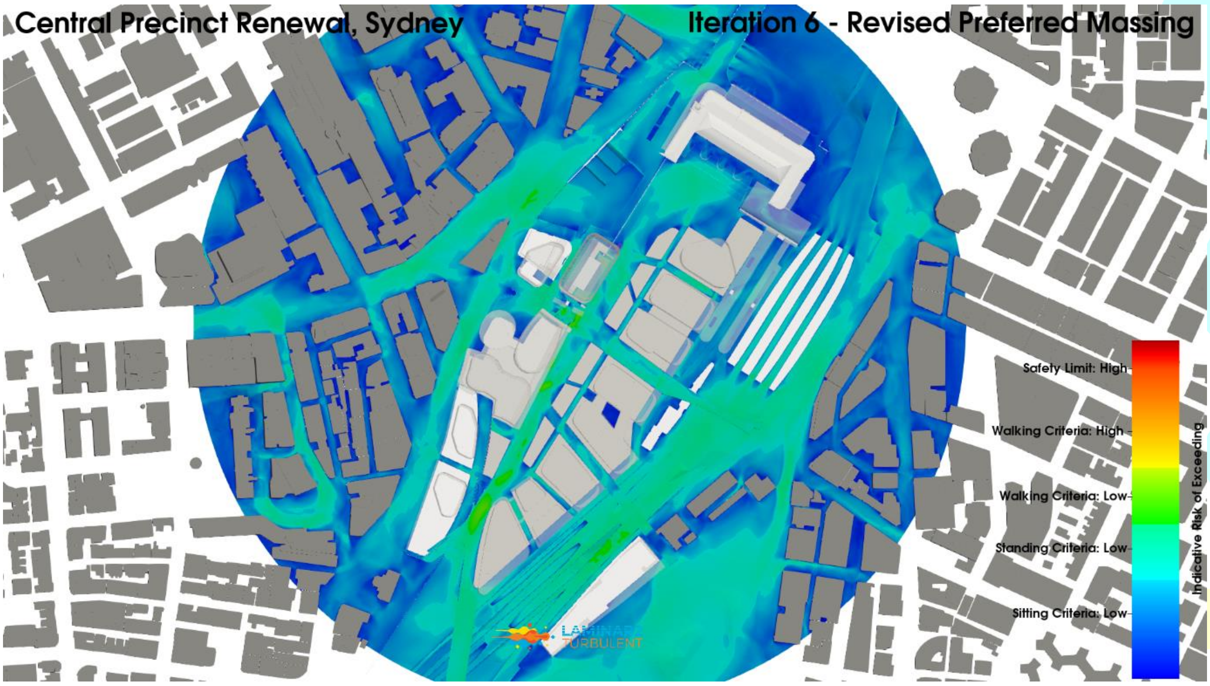

Figure 131: Iteration 6 – Revised Preferred Massing Configuration, Combined Wind Directions, Planview, Average Pedestrian Level Environmental Wind Risk Contour Plot

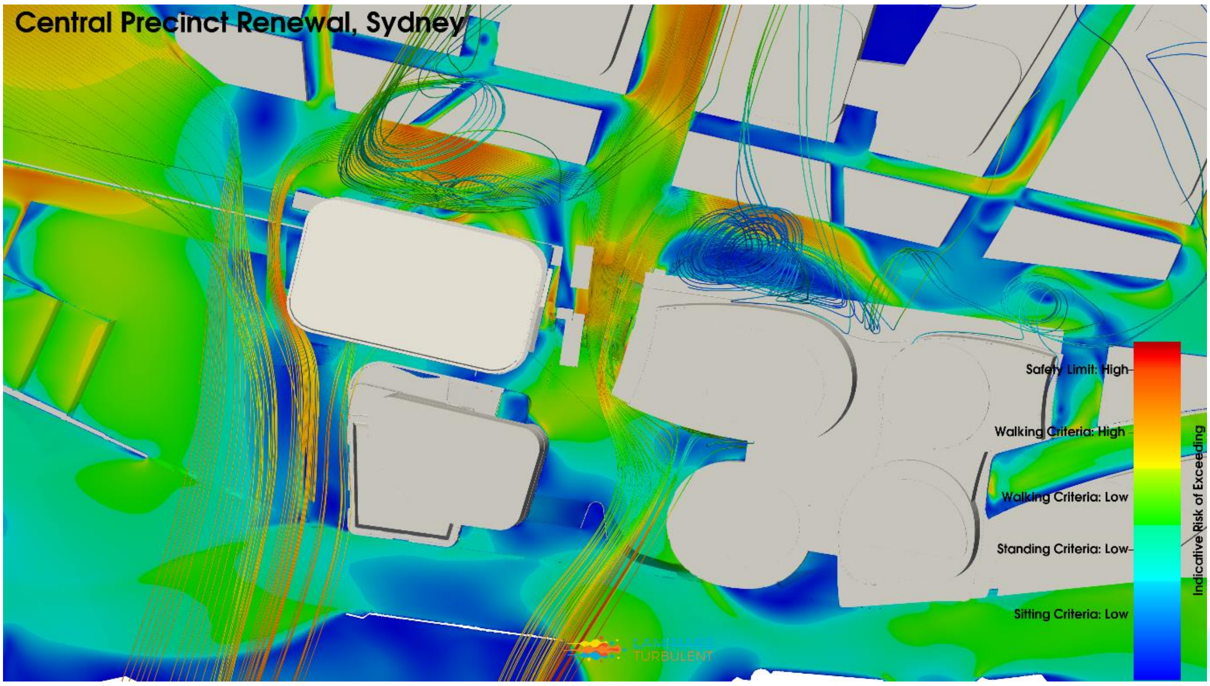

Figure 132: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

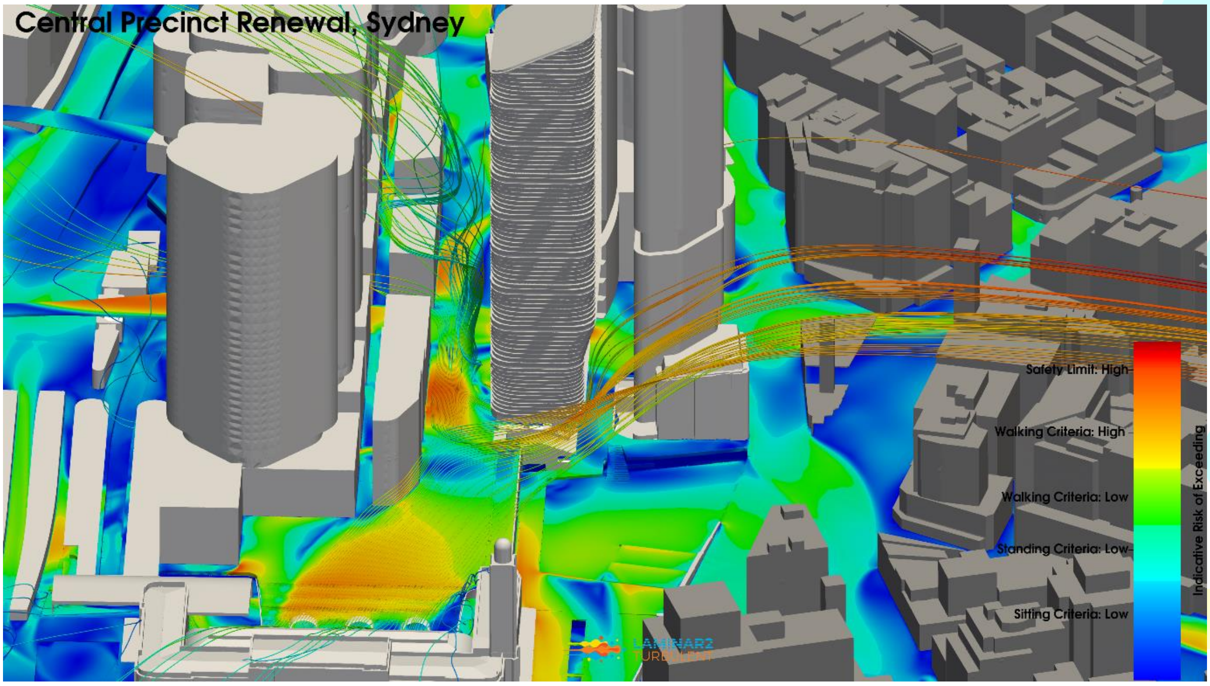

Figure 133: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

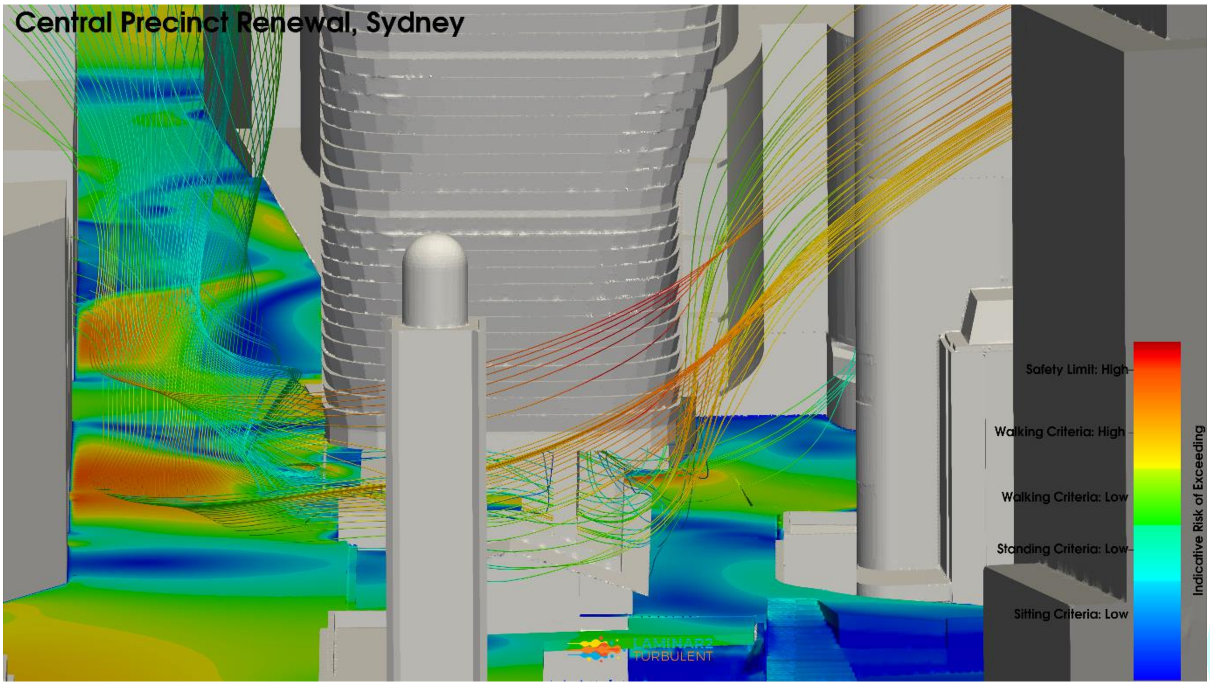

Figure 134: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

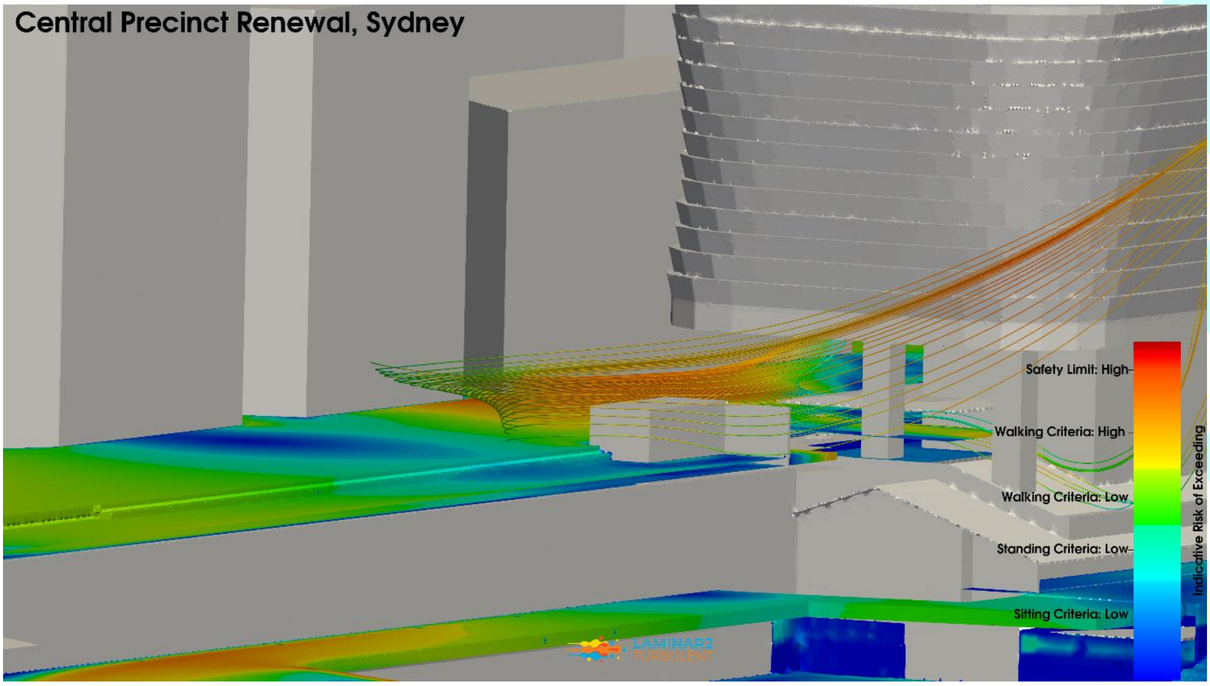

Figure 135: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

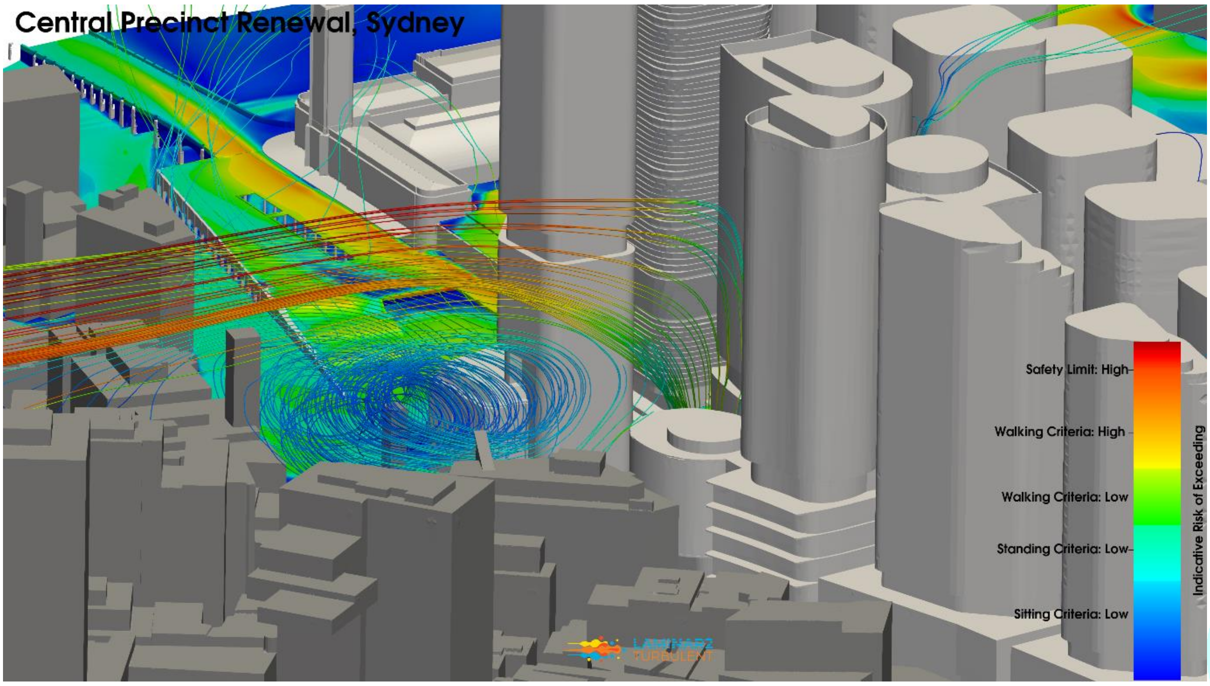

Figure 136: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

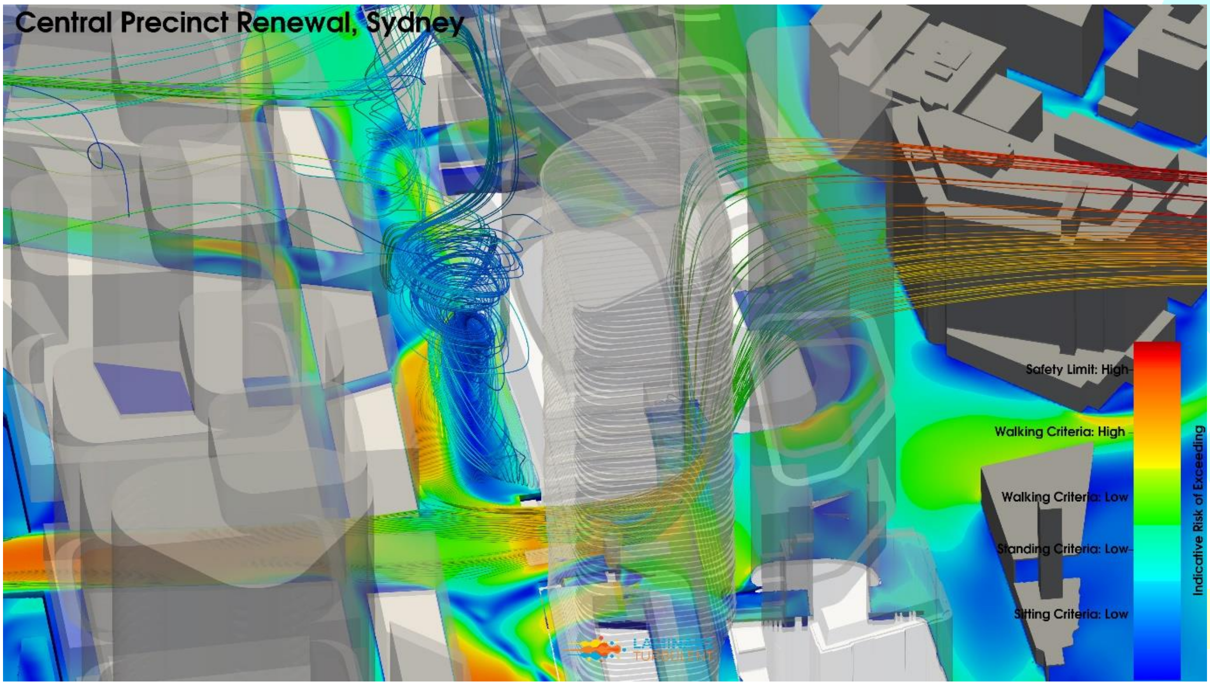

Figure 137: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

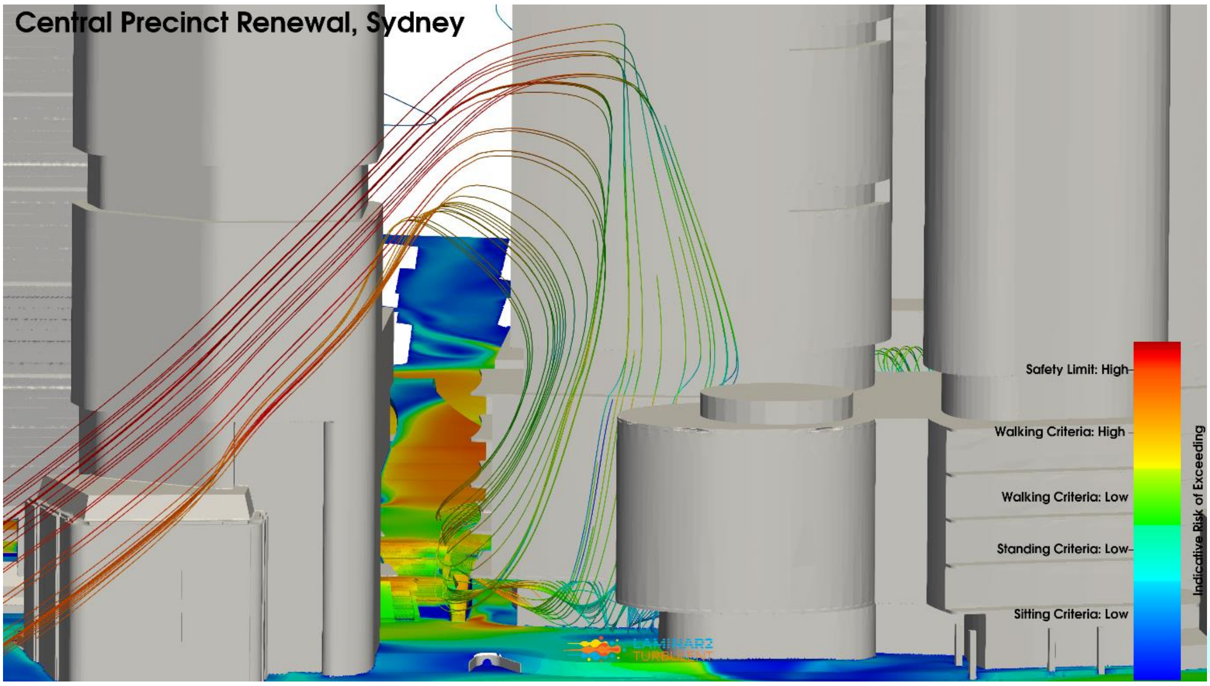

Figure 138: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

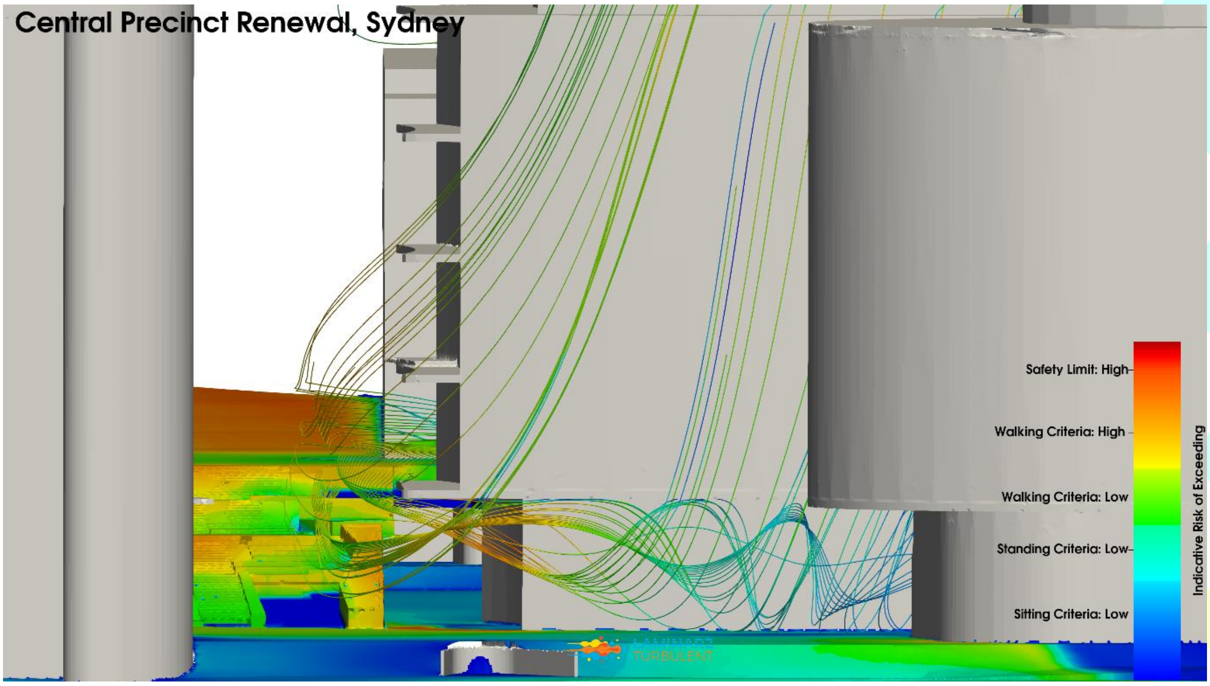

Figure 139: Iteration 6 – Revised Preferred Massing Configuration, Northwest Wind Direction, Streamlines & Pedestrian Level Environmental Wind Risk Contour Plot

8.18 ITERATION 6 – 8M SETBACK

Figure 140: North View of Proposed Iteration 6 – 8m Setback

Figure 141: South View of Proposed Iteration 6 – 8m Setback

Figure 142: Iteration 6 – Revised Preferred Massing (white) and Iteration 6 – 8m Setback (blue) Comparison

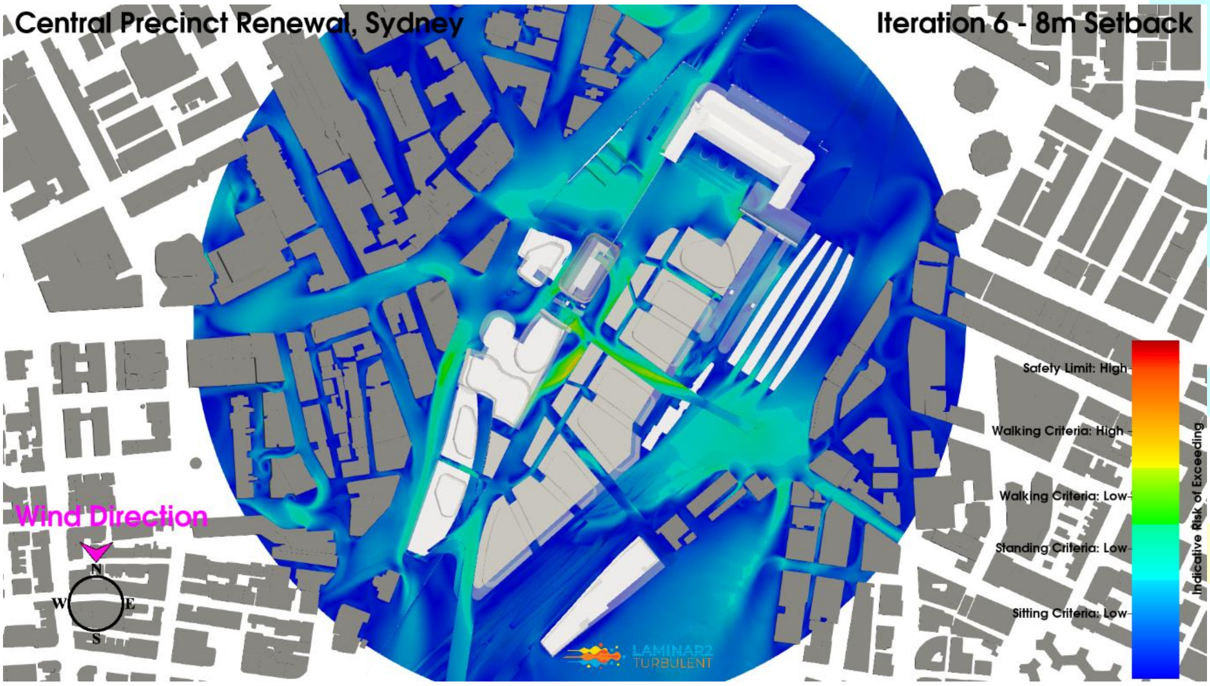

Figure 143: Iteration 6 – 8m Setback Configuration, North Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

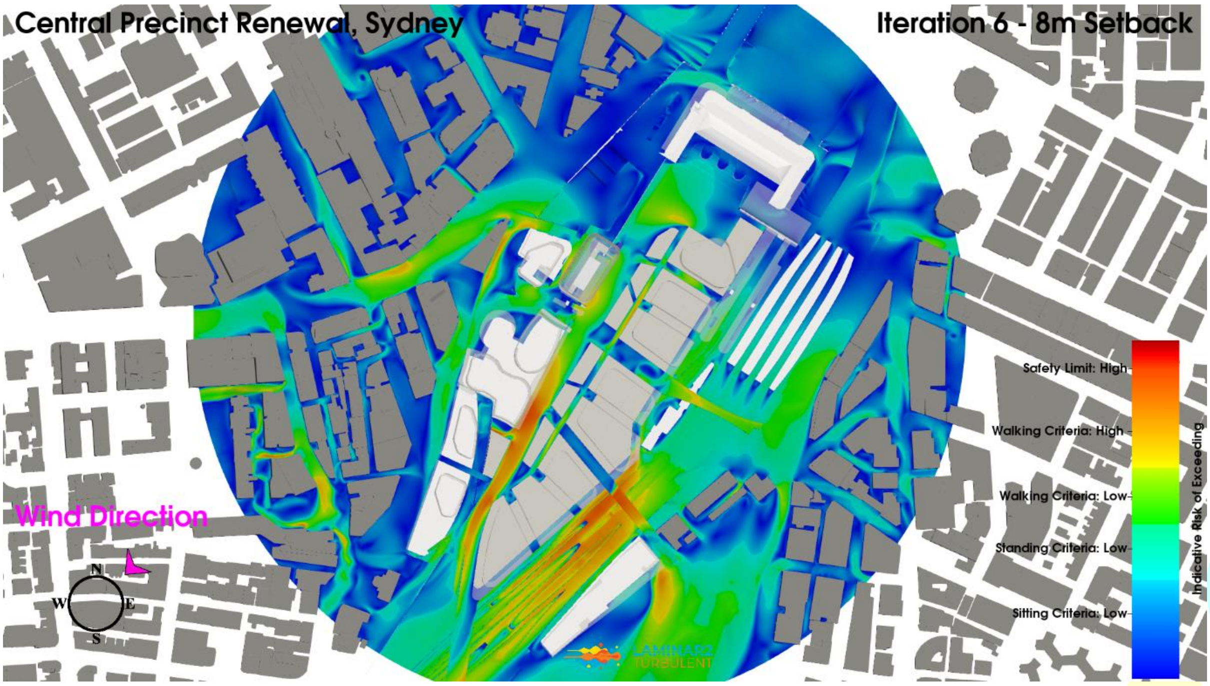

Figure 144: Iteration 6 – 8m Setback Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

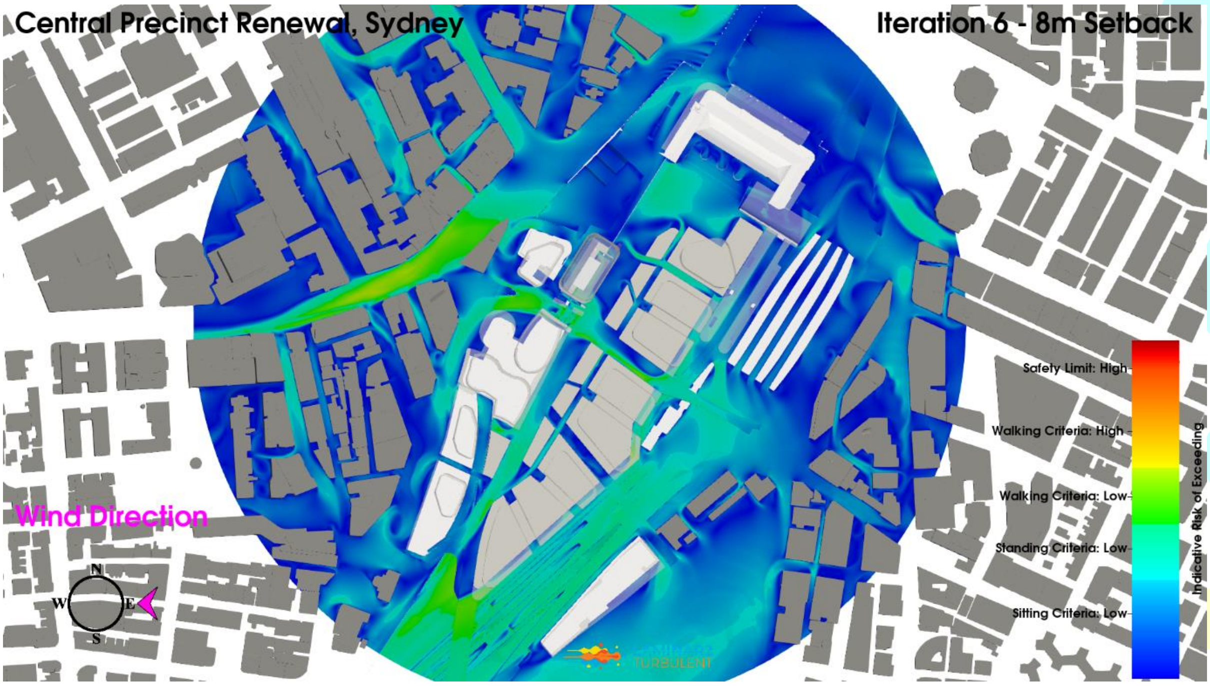

Figure 145: Iteration 6 – 8m Setback Configuration, East Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

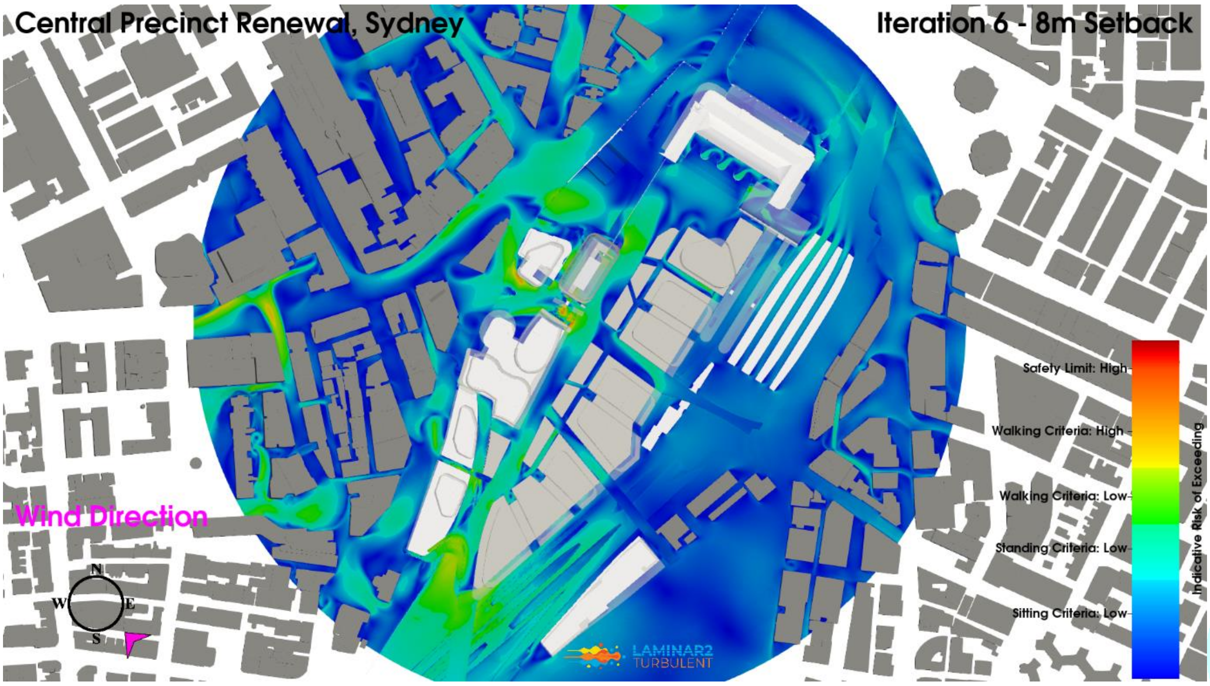

Figure 146: Iteration 6 – 8m Setback Configuration, Southeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

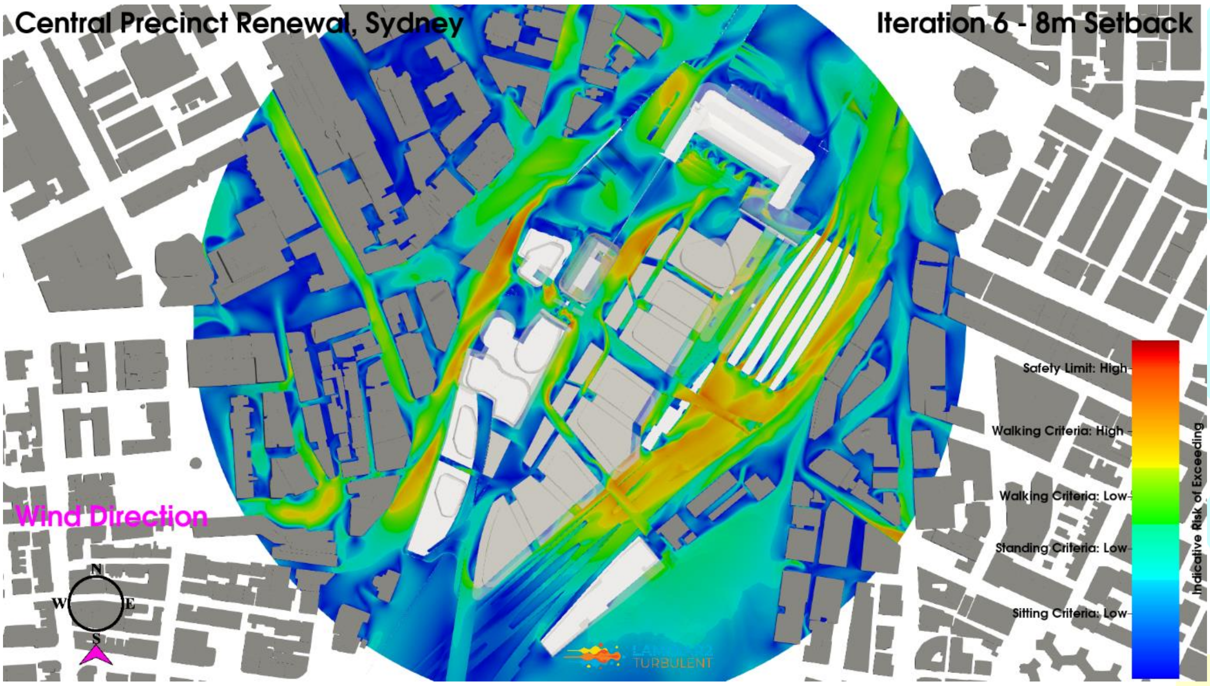

Figure 147: Iteration 6 – 8m Setback Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

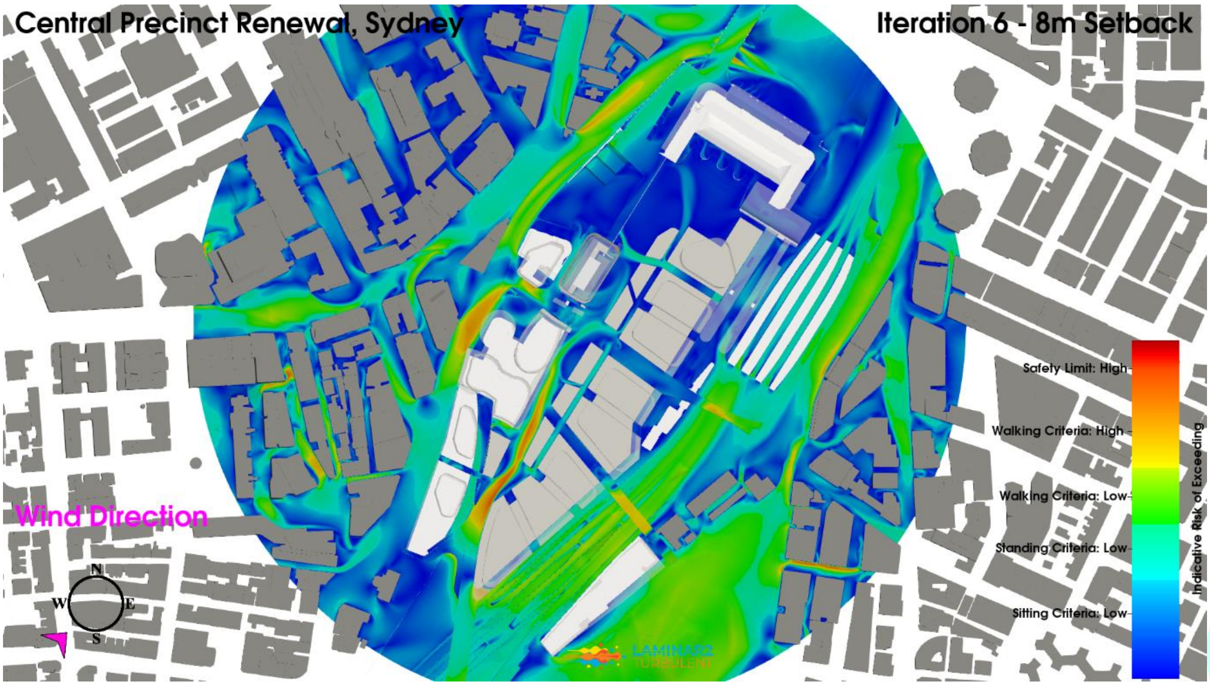

Figure 148: Iteration 6 – 8m Setback Configuration, Southwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

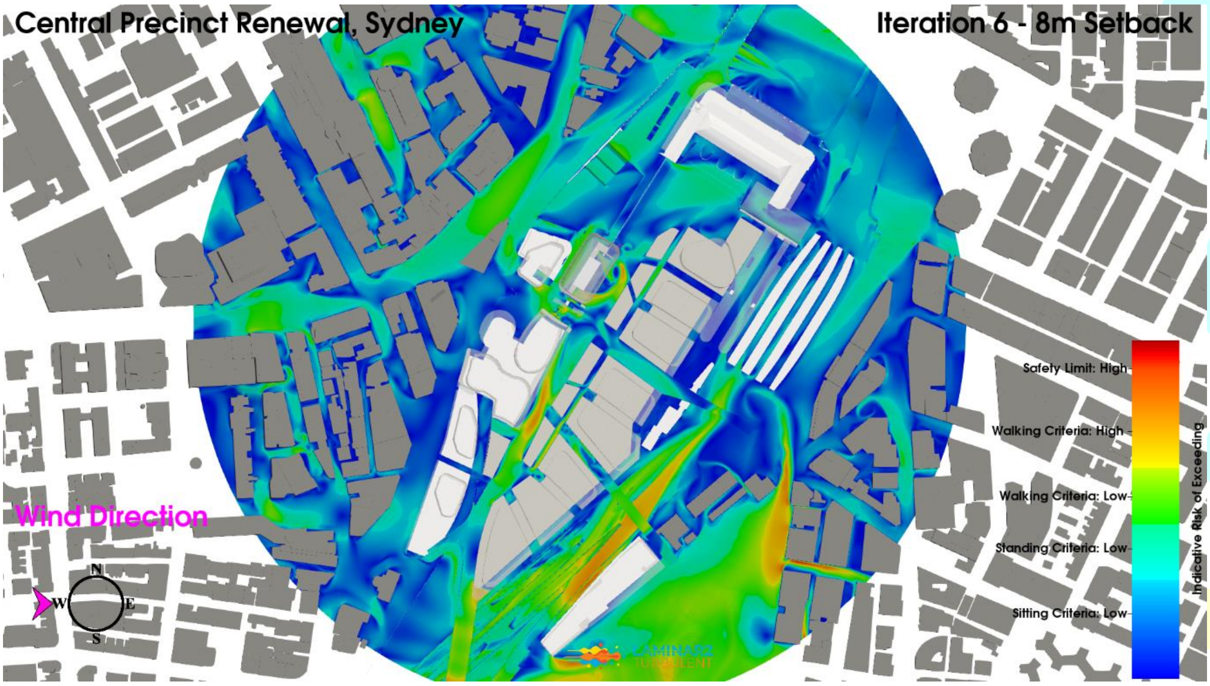

Figure 149: Iteration 6 – 8m Setback Configuration, West Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

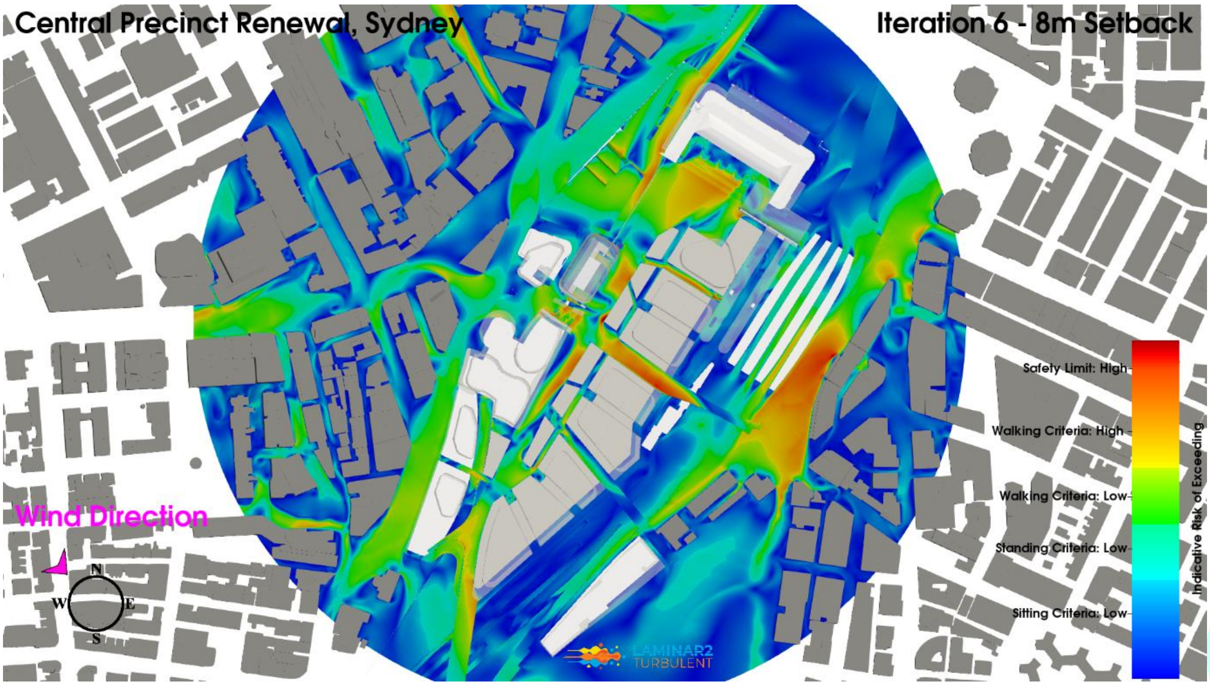

Figure 150: Iteration 6 – 8m Setback Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

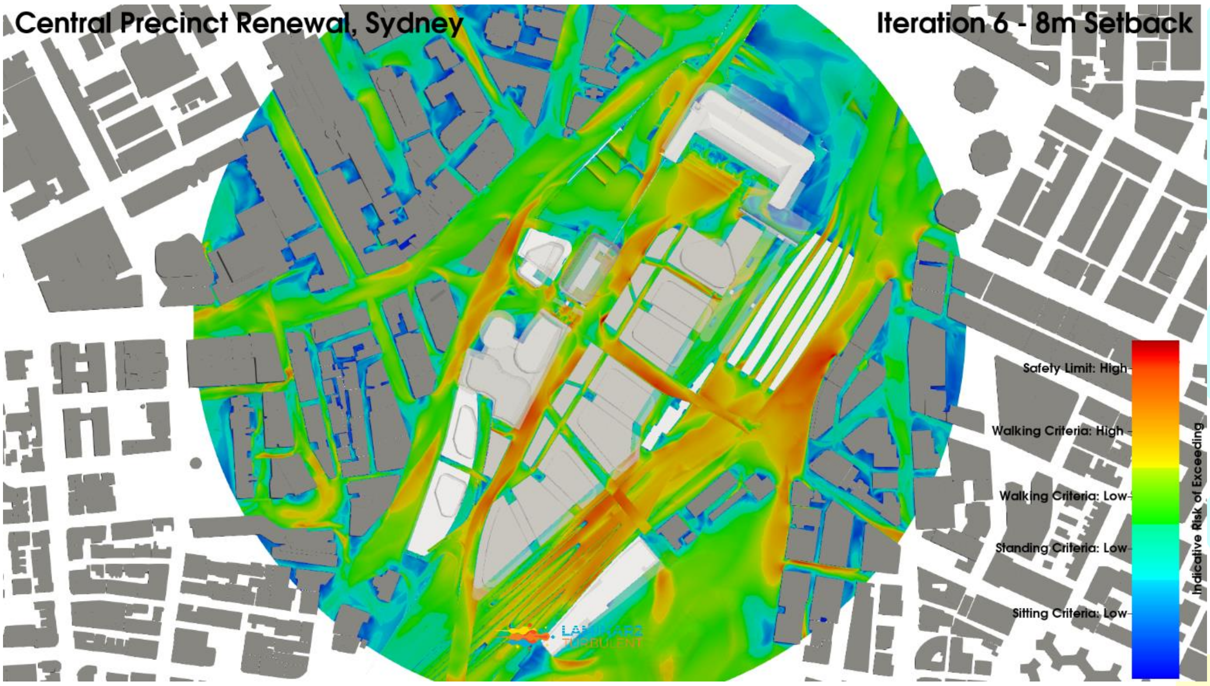

Figure 151: Iteration 6 – 8m Setback Configuration, Combined Wind Directions, Planview, Maximum Pedestrian Level Environmental Wind Risk Contour Plot

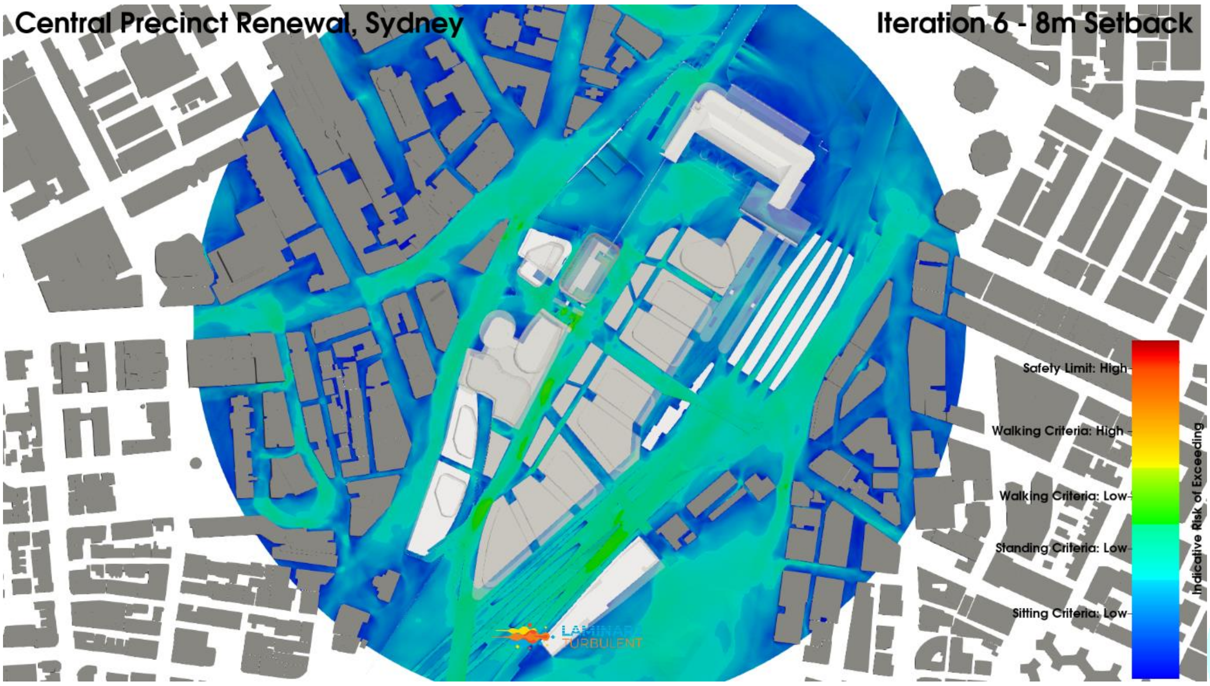

Figure 152: Iteration 6 – 8m Setback Configuration, Combined Wind Directions, Planview, Average Pedestrian Level Environmental Wind Risk Contour Plot

8.19 ITERATION 6 – 8M SETBACK ALTERNATIVE

Figure 153: North View of Proposed Iteration 6 – 8m Setback Alternative Massing

Figure 154: South View of Proposed Iteration 6 – 8m Setback Alternative Massing

Figure 155: Iteration 6 – Revised Preferred Massing (white) and Iteration 6 – 8m Setback Alternative (blue) Comparison

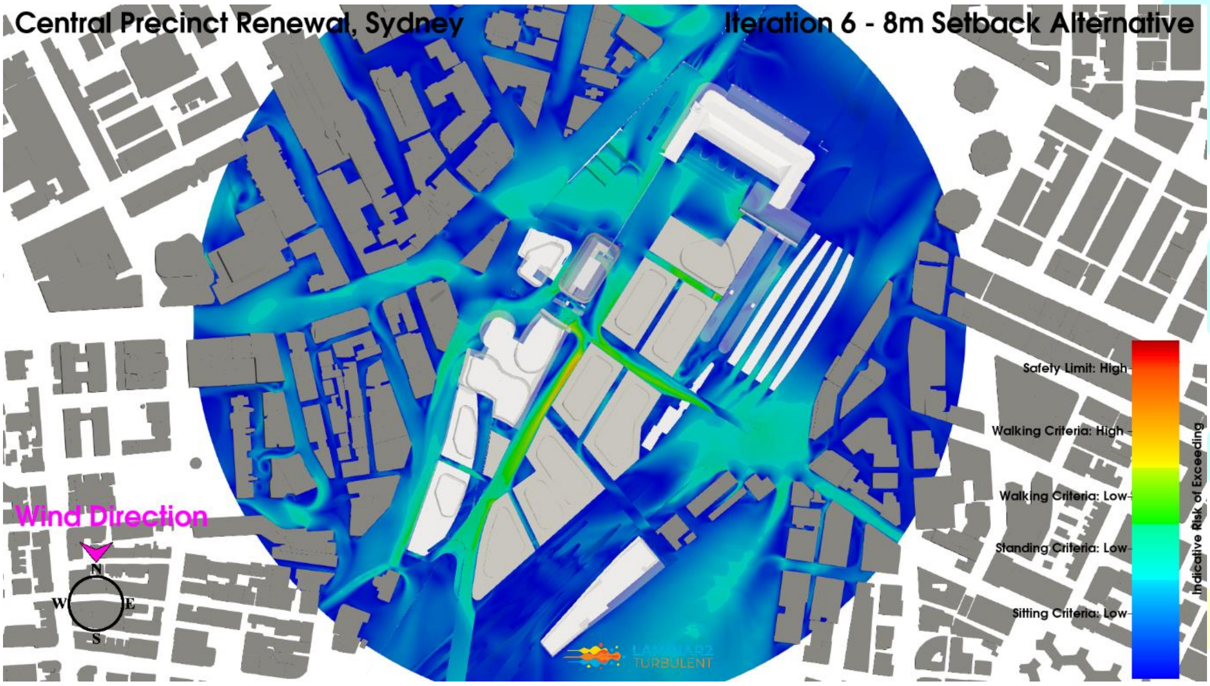

Figure 156: Iteration 6 – 8m Setback Alternative Configuration, North Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

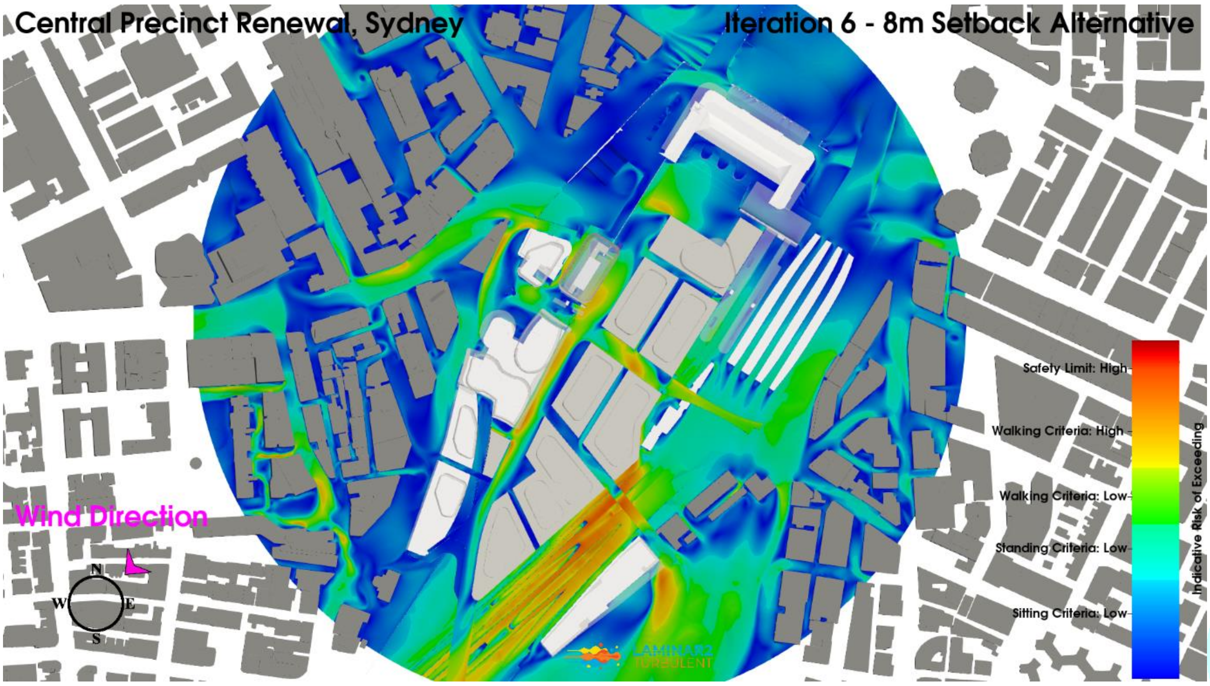

Figure 157: Iteration 6 – 8m Setback Alternative Configuration, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

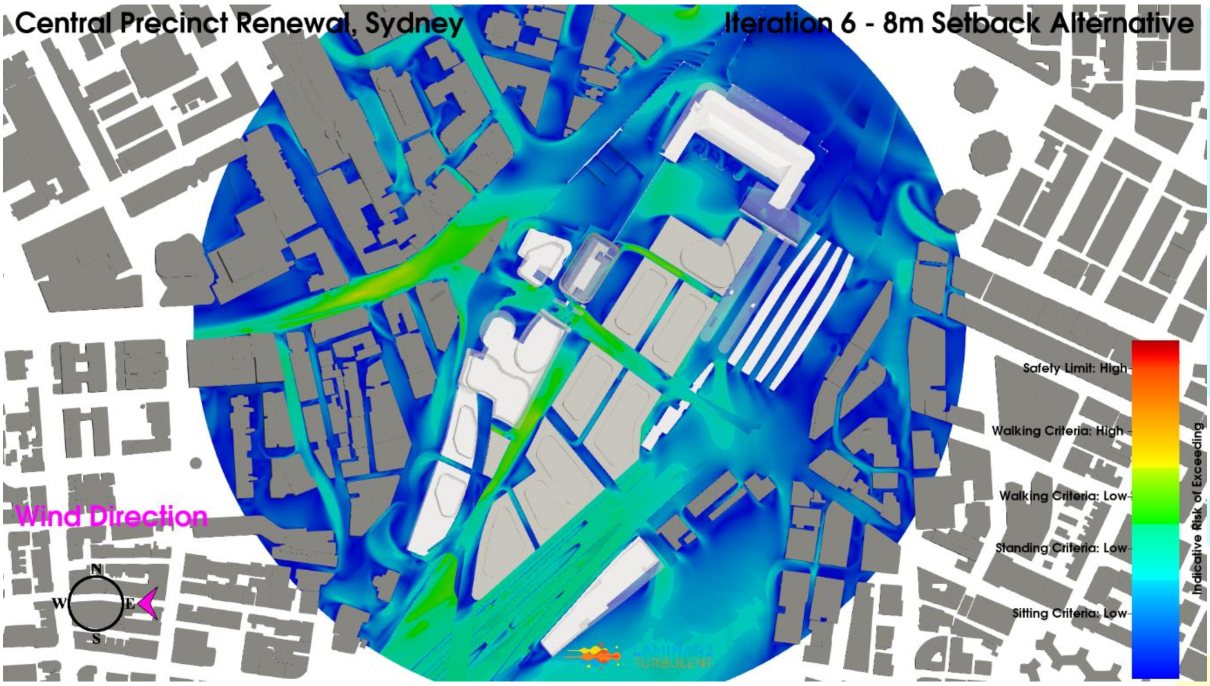

Figure 158: Iteration 6 – 8m Setback Alternative Configuration, East Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

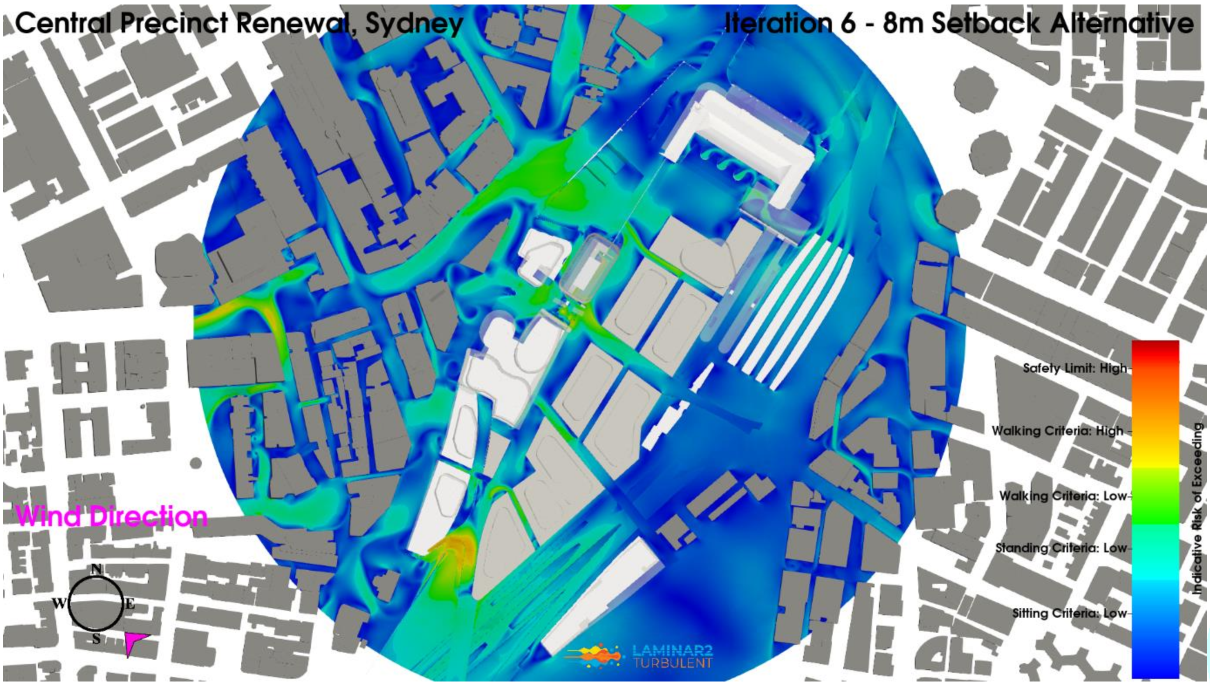

Figure 159: Iteration 6 – 8m Setback Alternative Configuration, Southeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

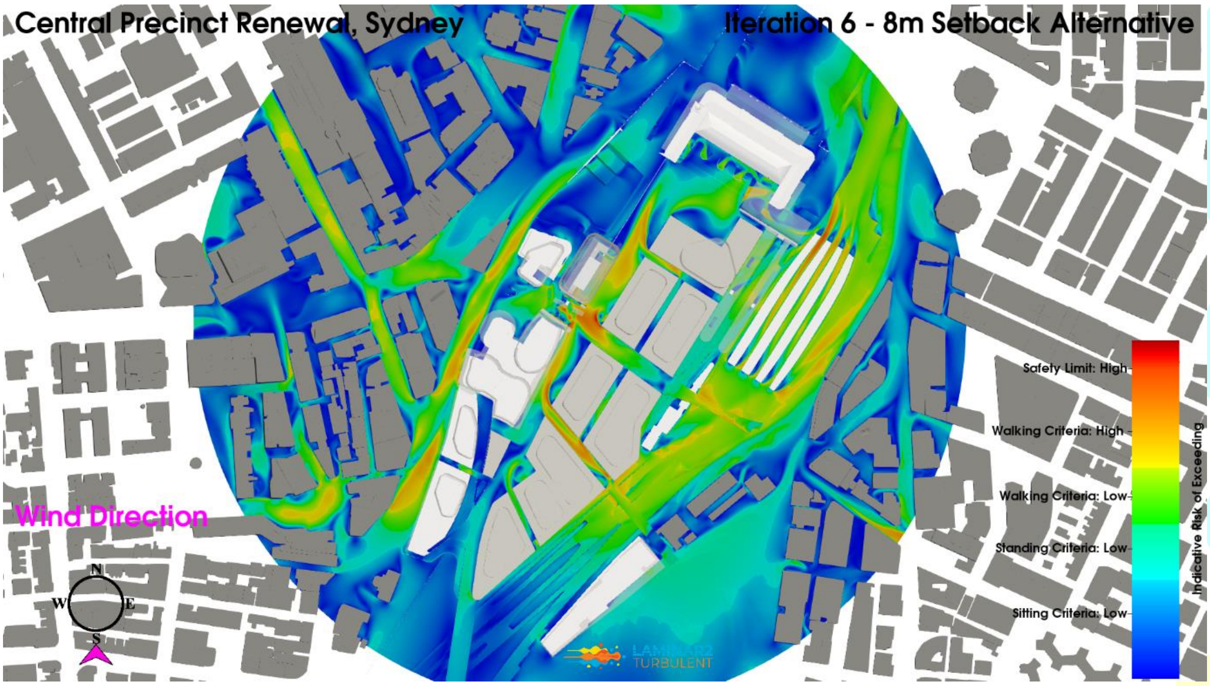

Figure 160: Iteration 6 – 8m Setback Alternative Configuration, South Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

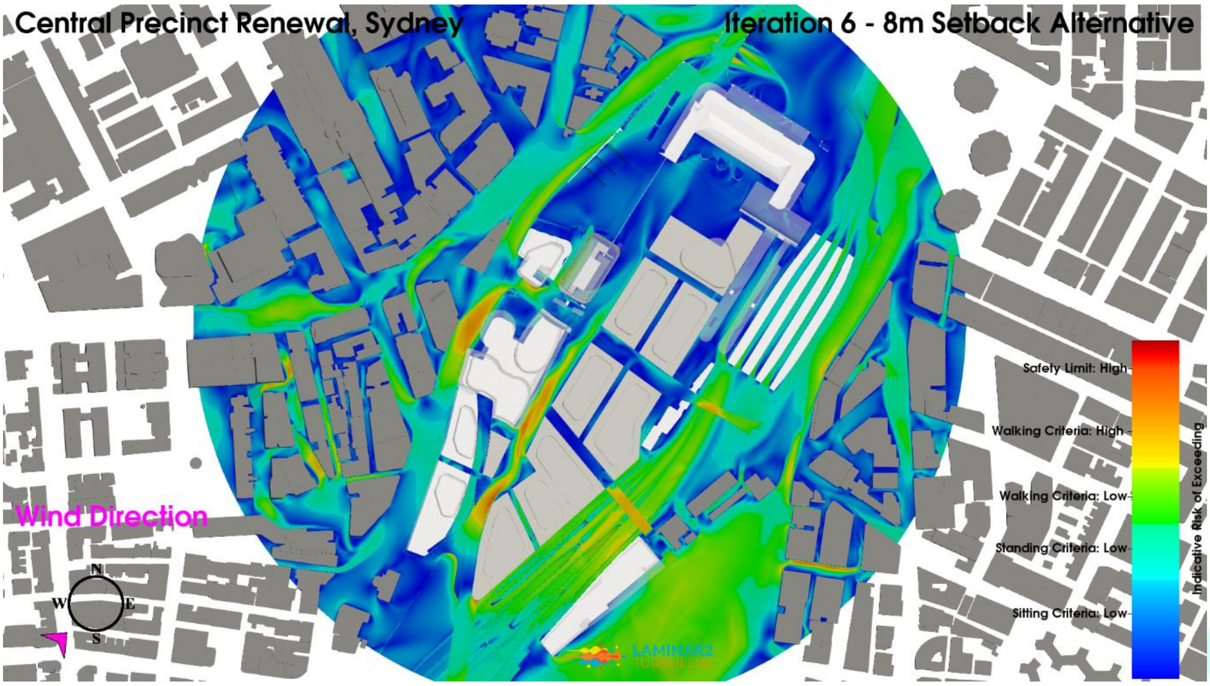

Figure 161: Iteration 6 – 8m Setback Alternative Configuration, Southwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

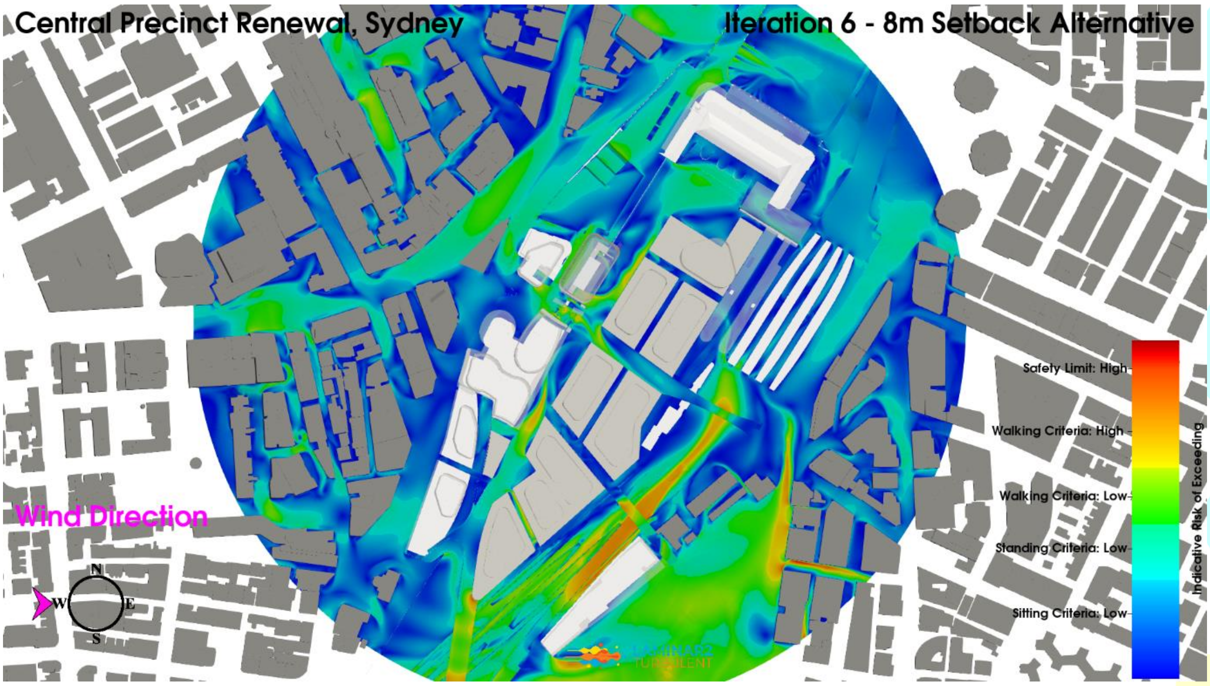

Figure 162: Iteration 6 – 8m Setback Alternative Configuration, West Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

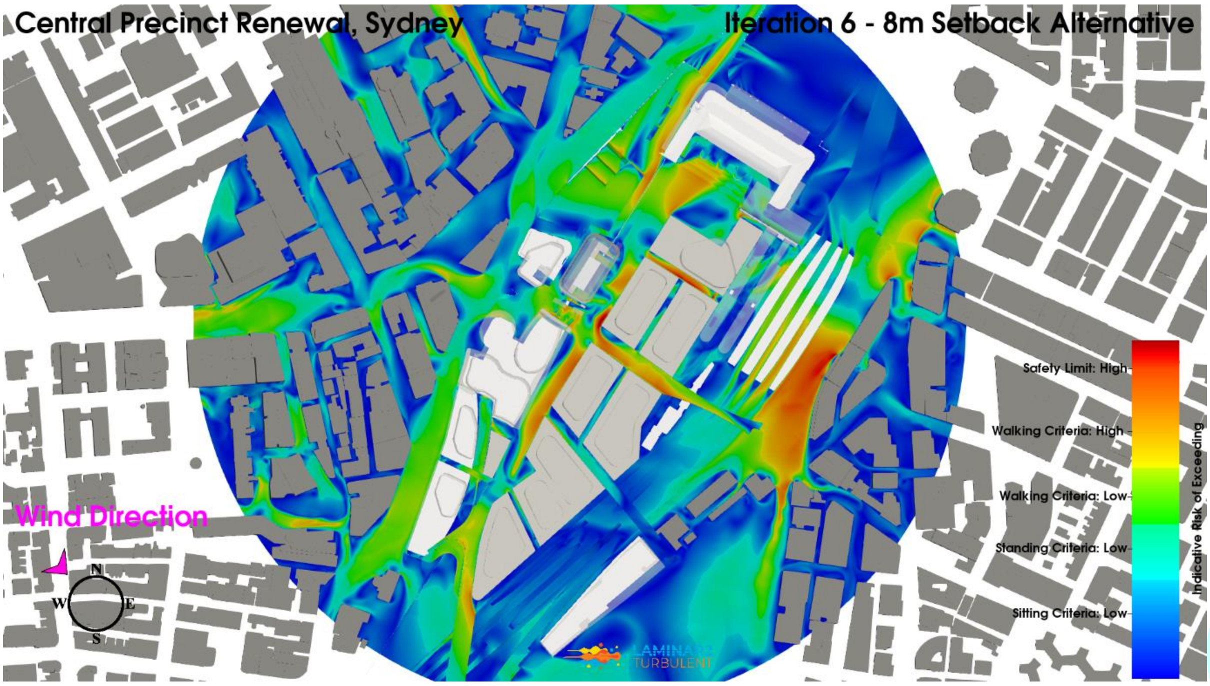

Figure 163: Iteration 6 – 8m Setback Alternative Configuration, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

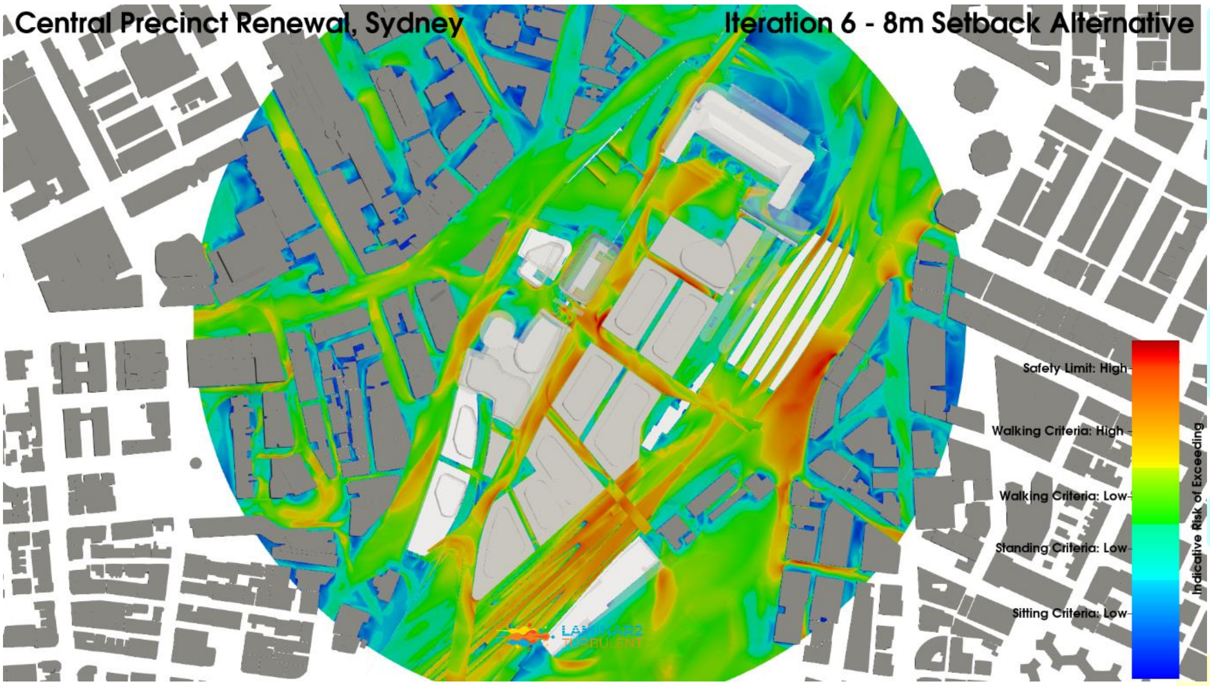

Figure 164: Iteration 6 – 8m Setback Alternative Configuration, Combined Wind Directions, Planview, Maximum Pedestrian Level Environmental Wind Risk Contour Plot

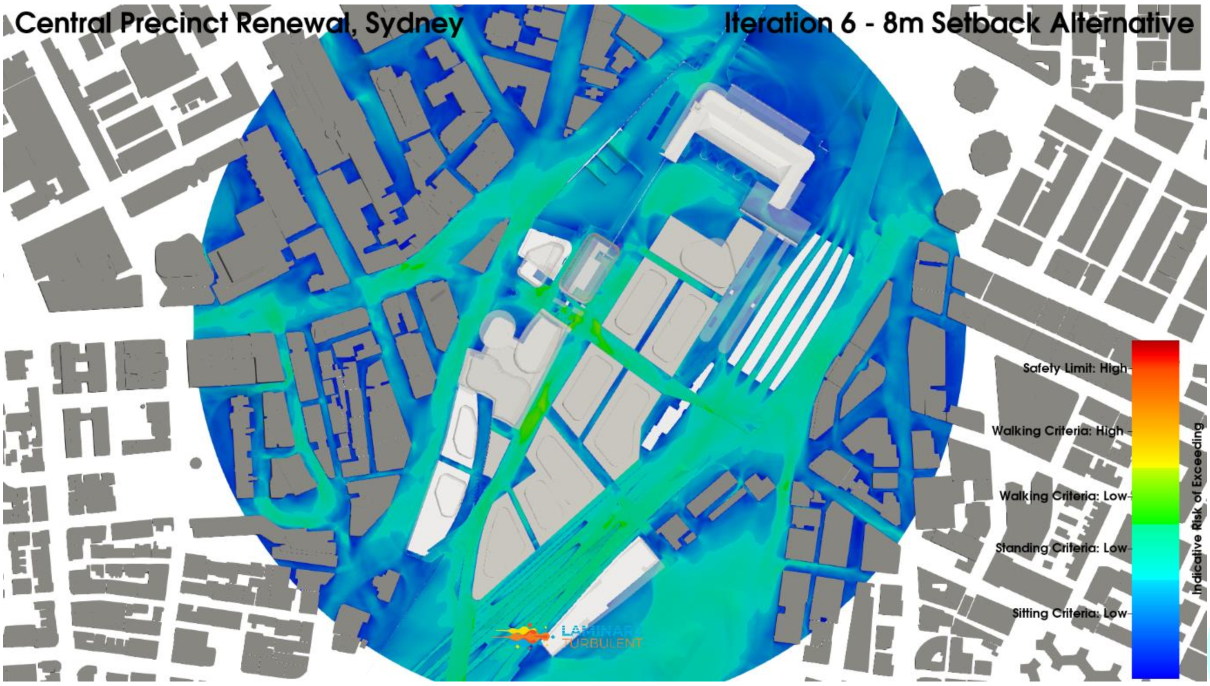

Figure 165: Iteration 6 – 8m Setback Alternative Configuration, Combined Wind Directions, Planview, Average Pedestrian Level Environmental Wind Risk Contour Plot

8.20 ITERATION 6 – COMPARISONS

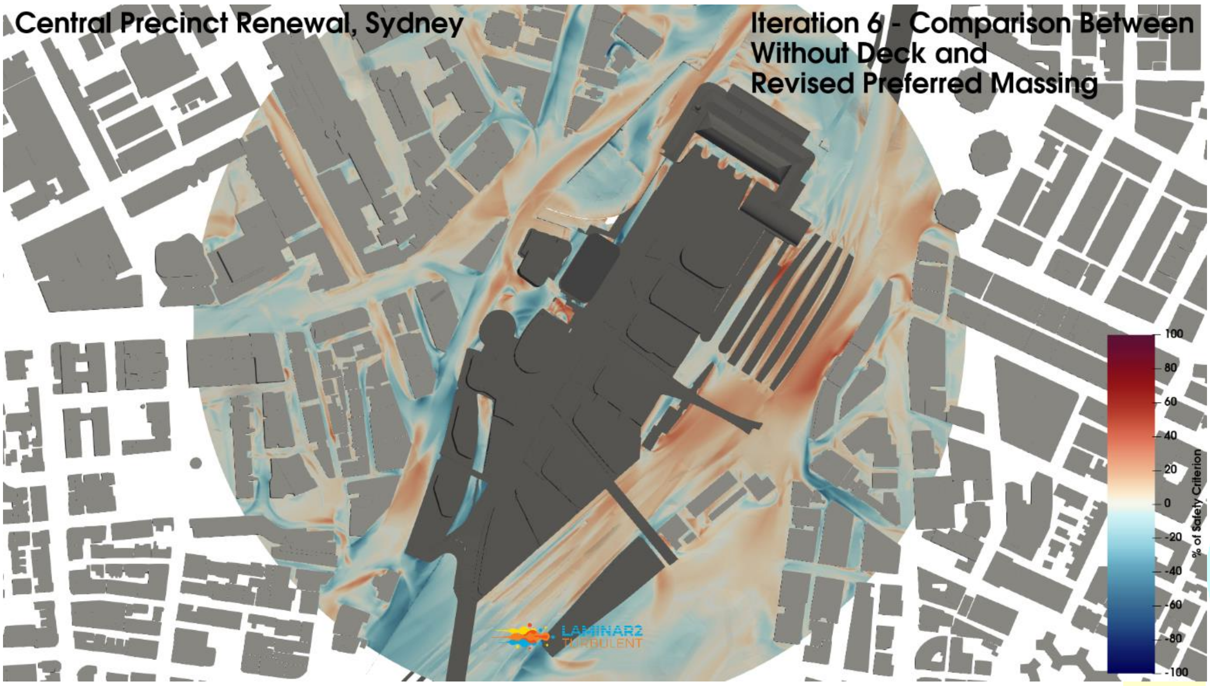

Figure 166: Comparison of Maximum Pedestrian Level Environmental Wind Risk between Iteration 6 – Baseline Without Deck and Iteration 6 – Revised Preferred Massing, Planview.

Figure 167: Comparison of Maximum Pedestrian Level Environmental Wind Risk between Iteration 6 – Revised Preferred Massing and Iteration 6 – 8m Setback, Planview.

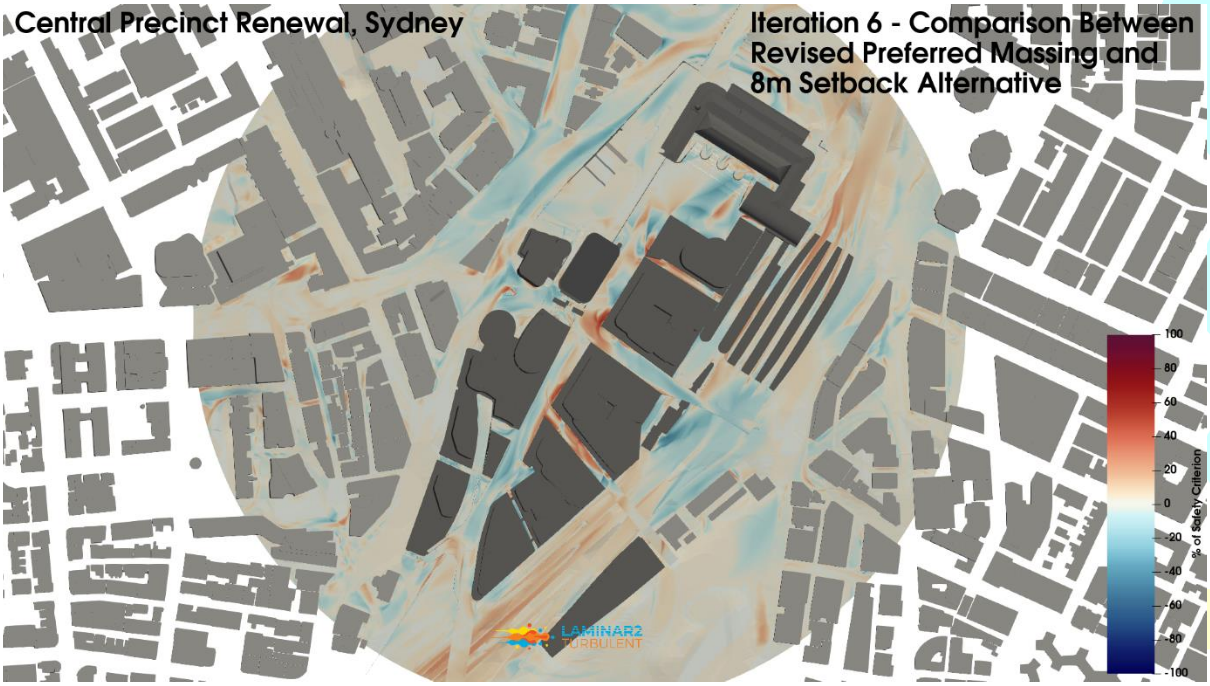

Figure 168: Comparison of Maximum Pedestrian Level Environmental Wind Risk between Iteration 6 – Baseline Without Deck and Iteration 6 – 8m Setback Alternative, Planview.

9 APPENDIX A: ITERATION 7 AND 8

To mitigate high wind speeds identified in isolated regions around the development during wind tunnel testing, porous screening and trees were added to the computational model and the wind impacts assessed at the critical wind northwest and northeast wind direction. Three configurations were initially tested: *Iteration 7 – Option 1* (Figure 169 to Figure 171); *Iteration 7 - Option 2* (Figure 172 to Figure 174); and *Iteration 7 - Option 2 With Trees* (Figure 175 and Figure 176). Detail included in all three configurations is shown in Figure 177 to Figure 180. Small changes to building massing were also made in Iteration 7. Subsequently, a fourth configuration (*Iteration 8 – Option 1*) was tested with additional screening along the Central Avenue (Figure 181). Orange regions in Figure 169 to Figure 181 were modelled with 50% porosity. The green regions in Figure 175 and Figure 176 represented the client specified a combination of Water Gums, Melaleuca Quinquenervia, and Zelkova Serrata. A representative Coefficient of Drag and Leaf Area Index was determined based on published experimental data for trees with similar leaf type and density. From these parameters, a pressure drop per metre depth of foliage was determined. The client provided CAD of tree trunks and canopies, it was assumed that the tree foliage covered the entire volume of the modelled tree canopies. No simulation of deciduous trees without foliage was conducted.

The outcomes of this analysis are as follows:

- *Iteration 7 – Option 1* CFD results show local wind speed reductions along The Avenue close to the Dexus-Fraser building for the northwest wind direction. Local wind speed reduction is also observed on the rail track overpasses and generally around the development site due to the introduction of 50% porous balustrading for both the northwest and northwest wind directions.

- *7 – Option 1* and *Iteration 7 - Option 2* provide comparable improvements in wind conditions when compared to *Iteration 6 - Revised Preferred Massing*, *Iteration* with no local wind mitigation measures.
- The CFD results show the addition of trees in the north of the development, Central Plaza, significantly improves local wind conditions for the northwest and northeast wind directions.

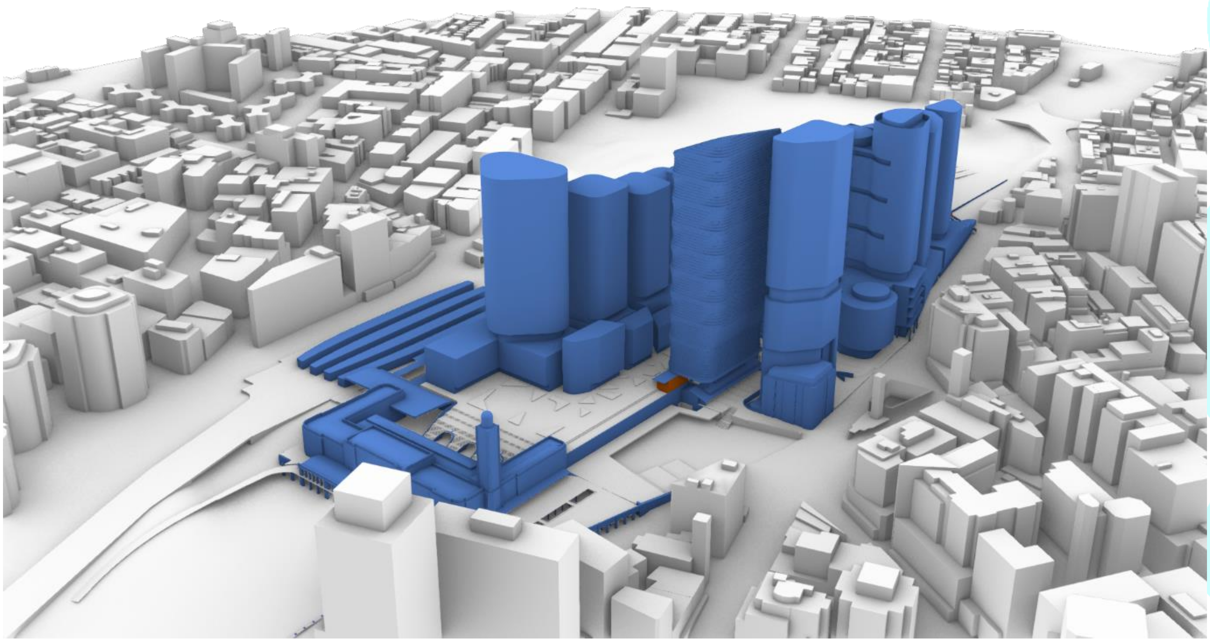

Figure 169: North View of Option 1 Iteration 7.

Figure 170: South View of Option 1 Iteration 7.

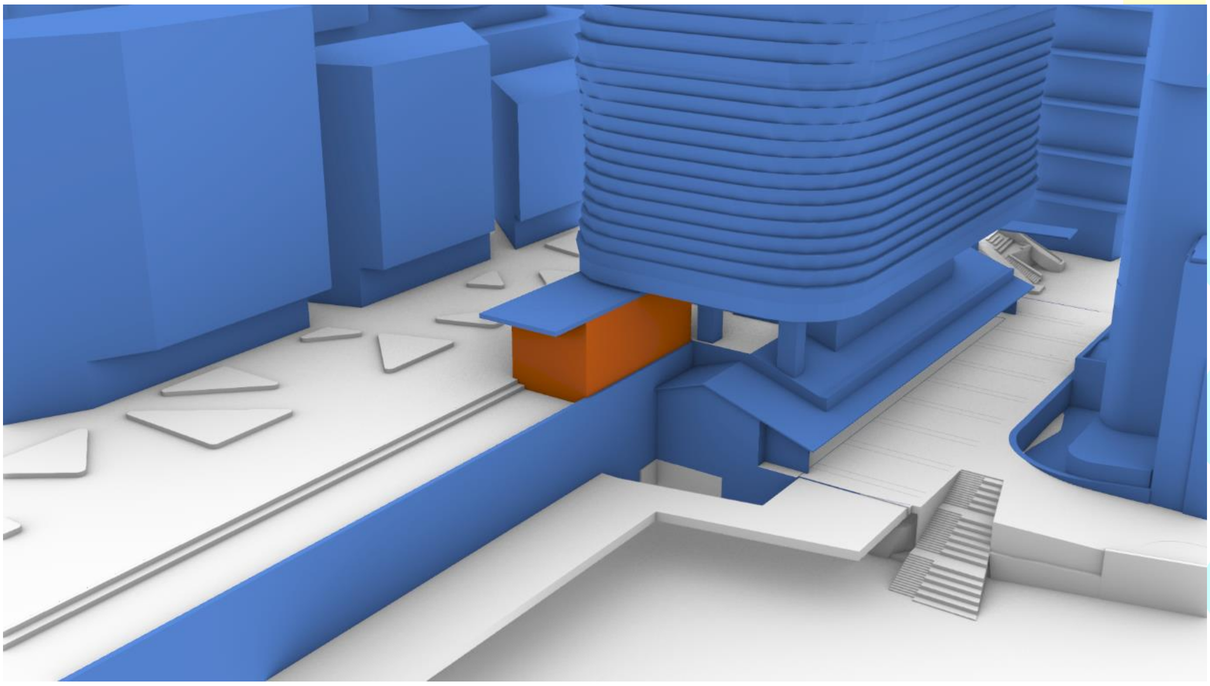

Figure 171: Close-Up North View of Option 1 Iteration 7.

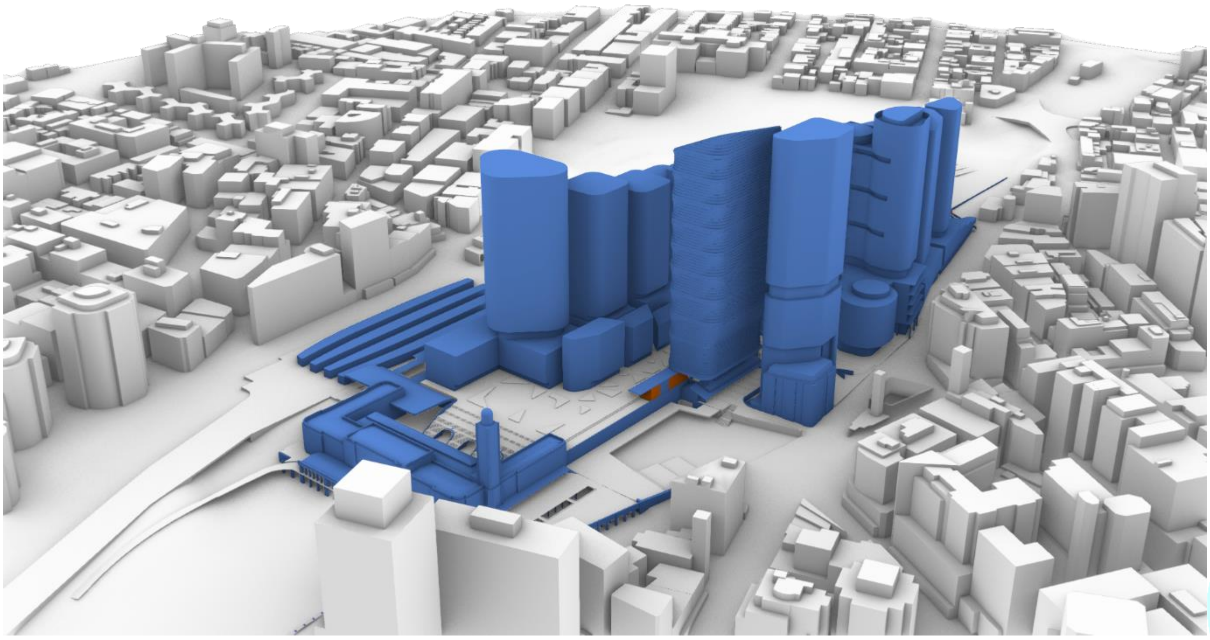

Figure 172: North View of Option 2 Iteration 7.

Figure 173: South View of Option 2 Iteration 7.

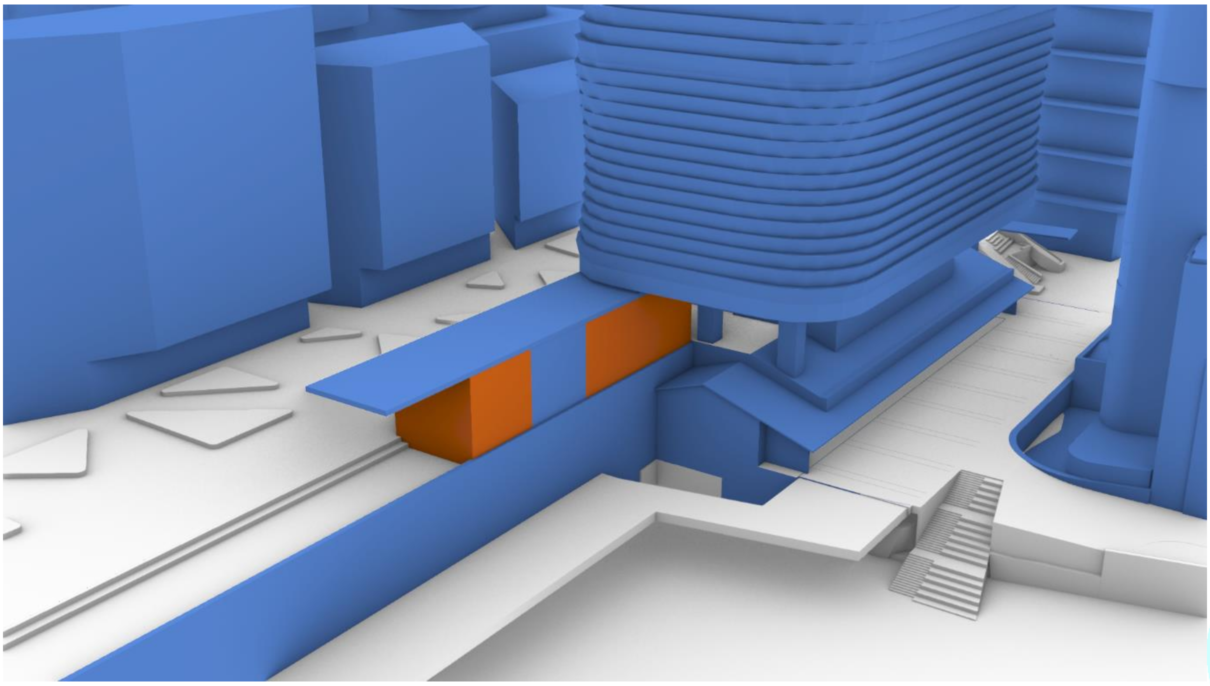

Figure 174: Close-Up North View of Option 2 Iteration 7.

Figure 175: North View of Option 2 Iteration 7 With Trees.

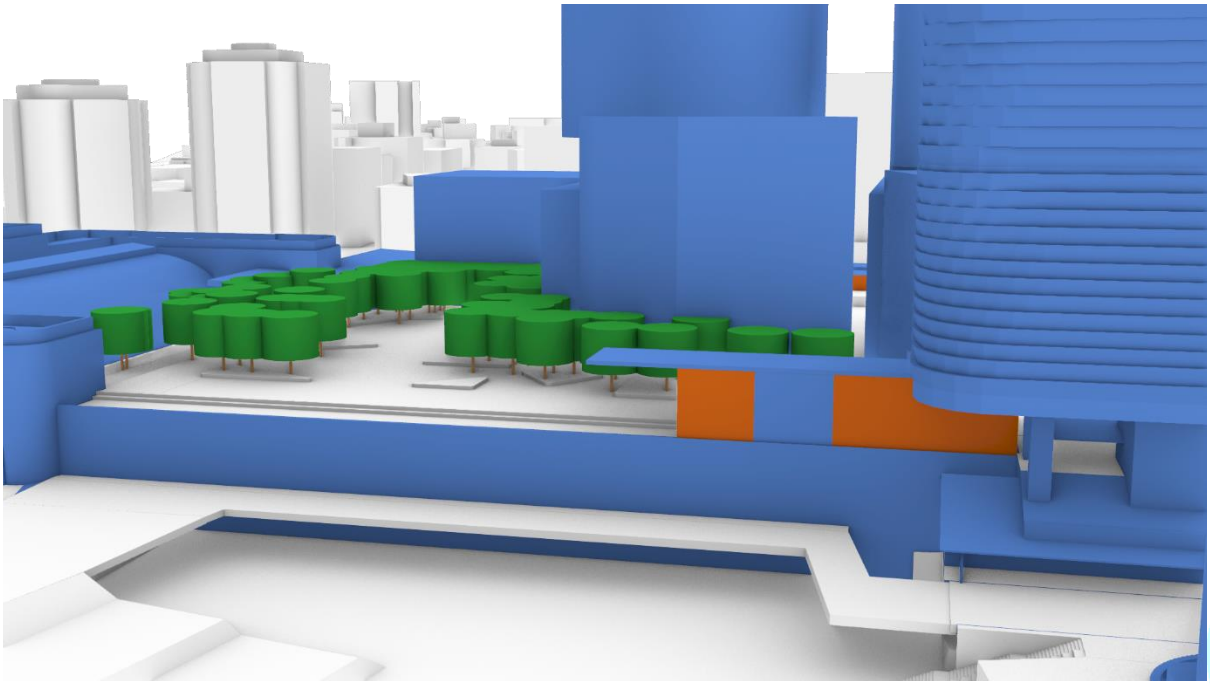

Figure 176: Close-Up Southwest View of Option 2 Iteration 7 With Trees.

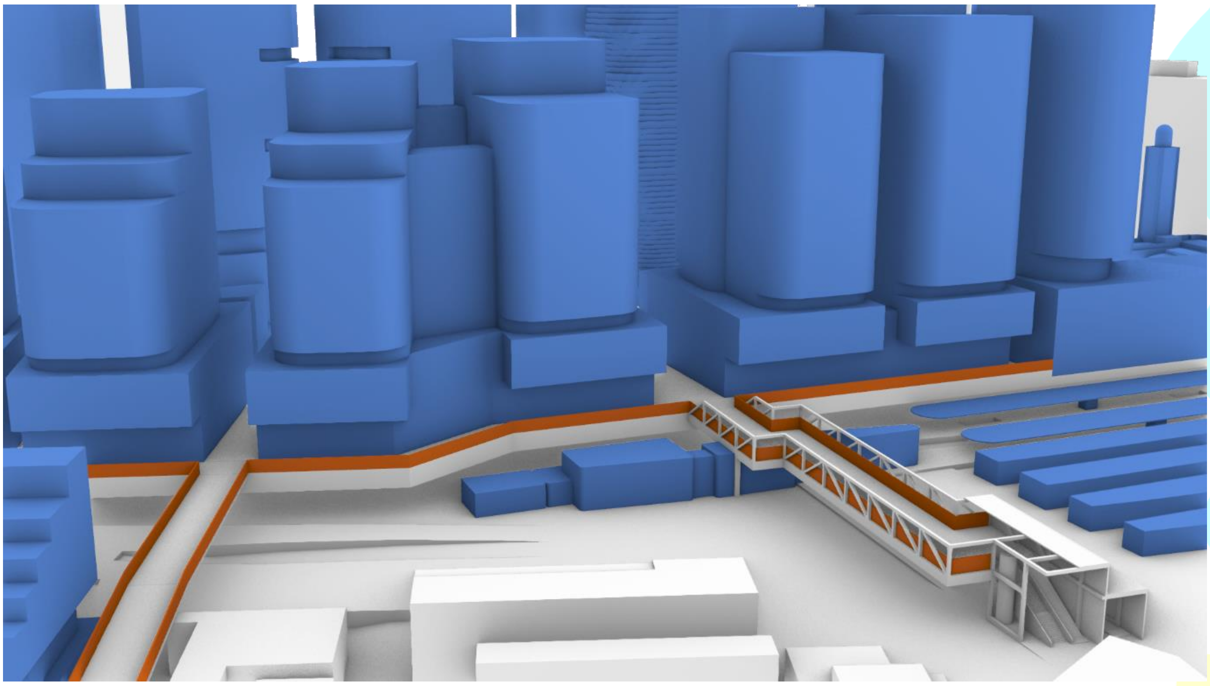

Figure 177: Close-Up East View Showing Detail for All Iteration 7 Options.

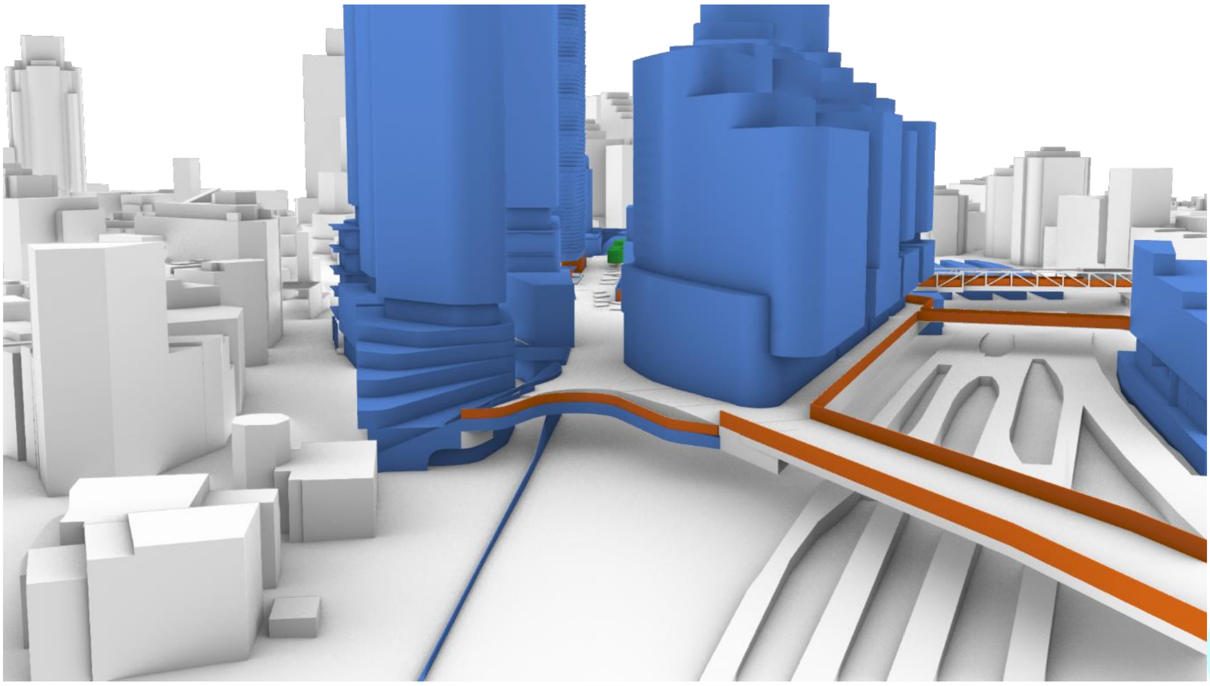

Figure 178: Close-Up Southwest View Showing Detail for All Iteration 7 Options.

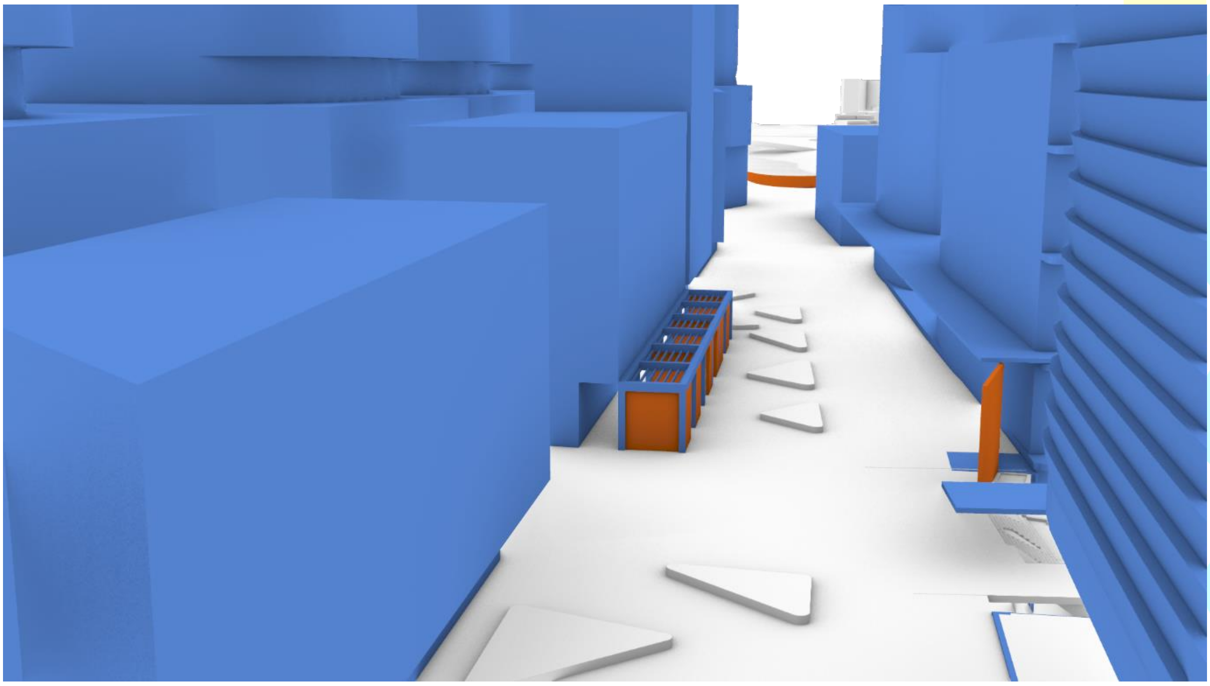

Figure 179: Northeast View of Detail for All Iteration 7 Options.

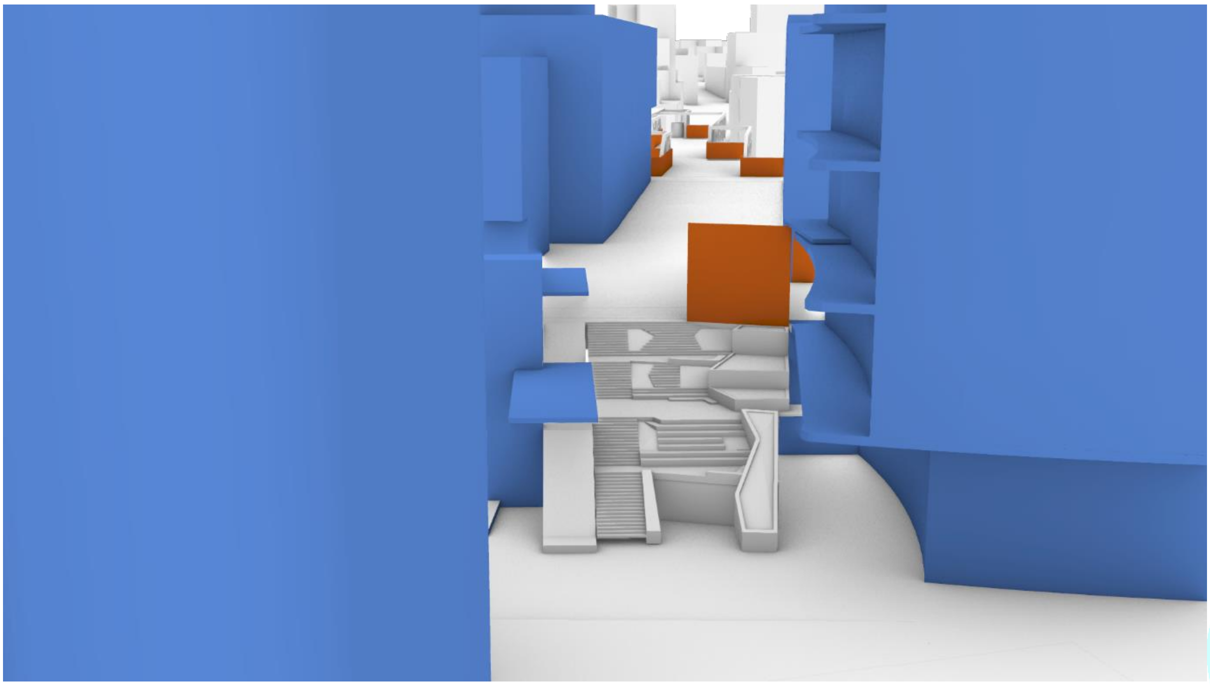

Figure 180: Close-Up Northwest View of Detail for All Iteration 7 Options.

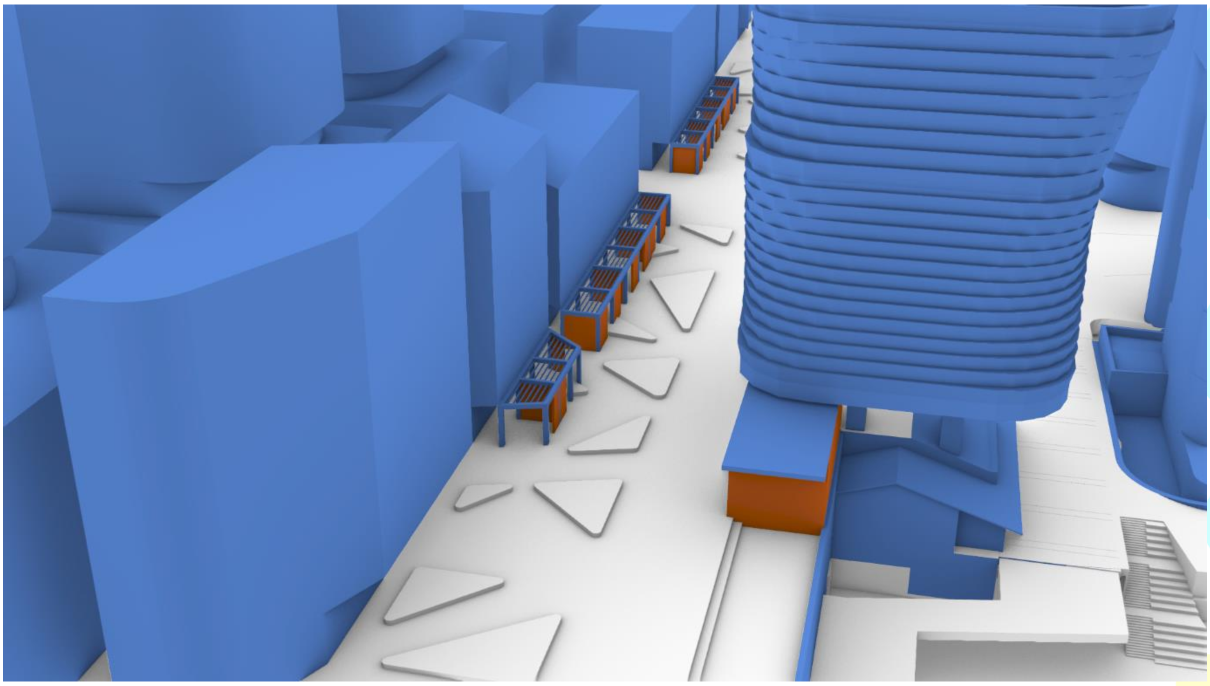

Figure 181: Additional Screening Along the Central Avenue for Option 1 Iteration 8.

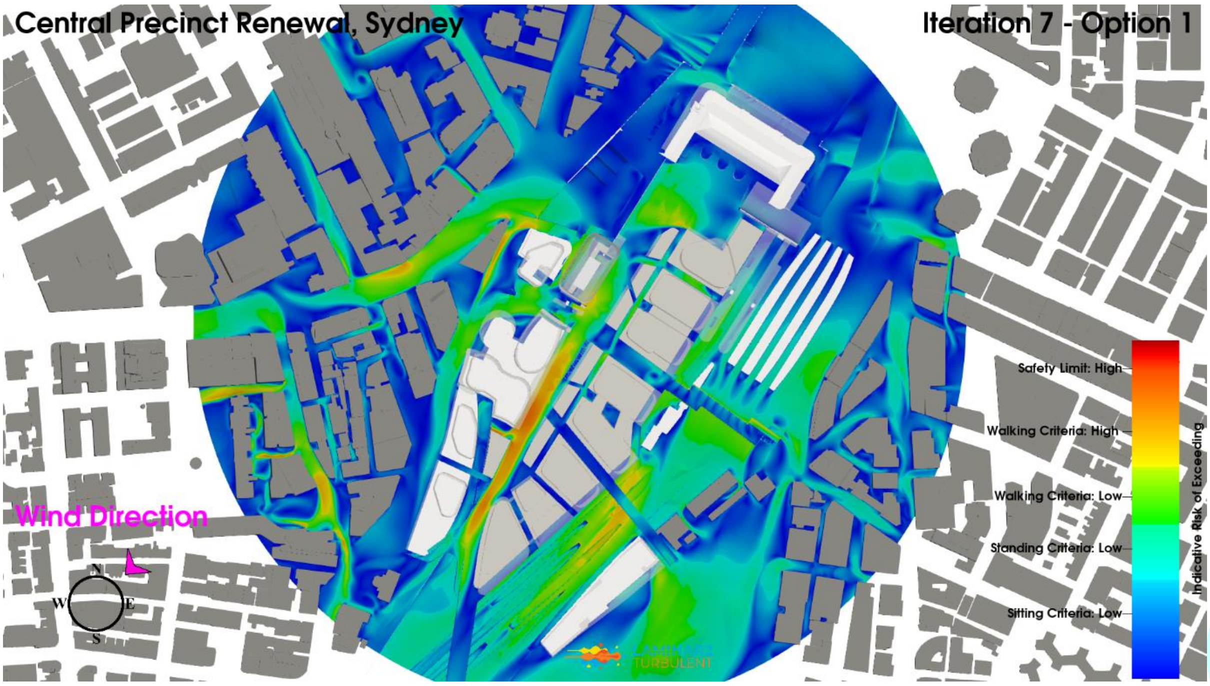

Figure 182: Iteration 7 Option 1, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

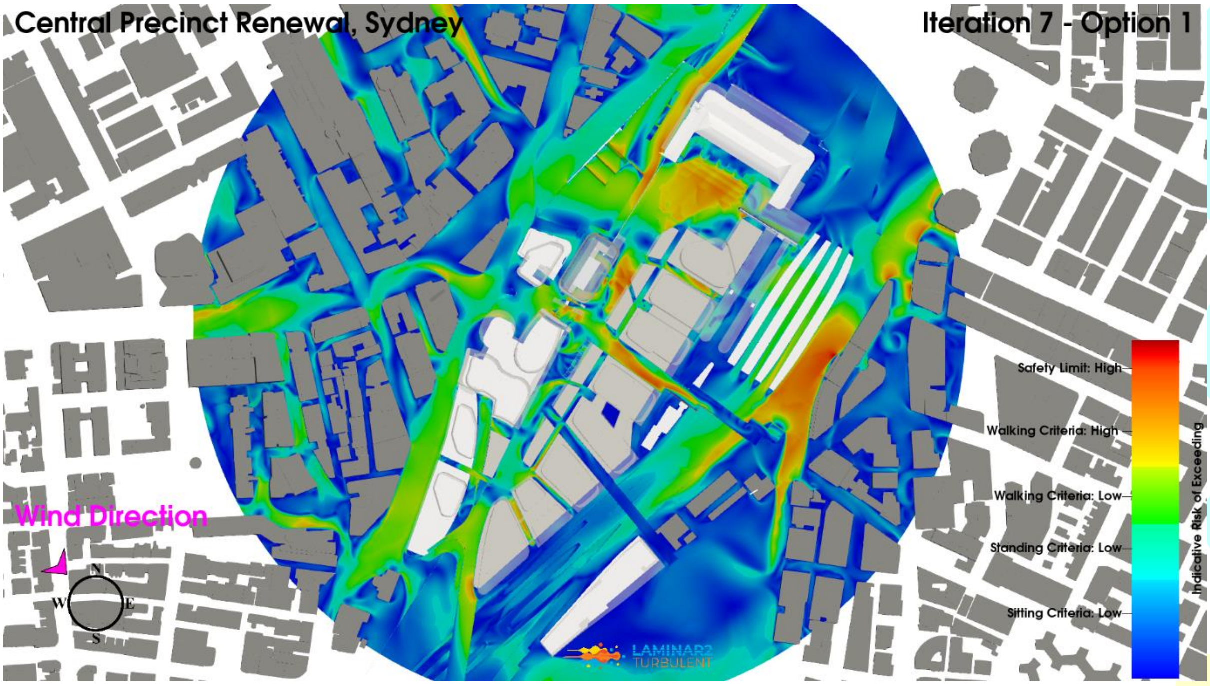

Figure 183: Iteration 7 Option 1, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

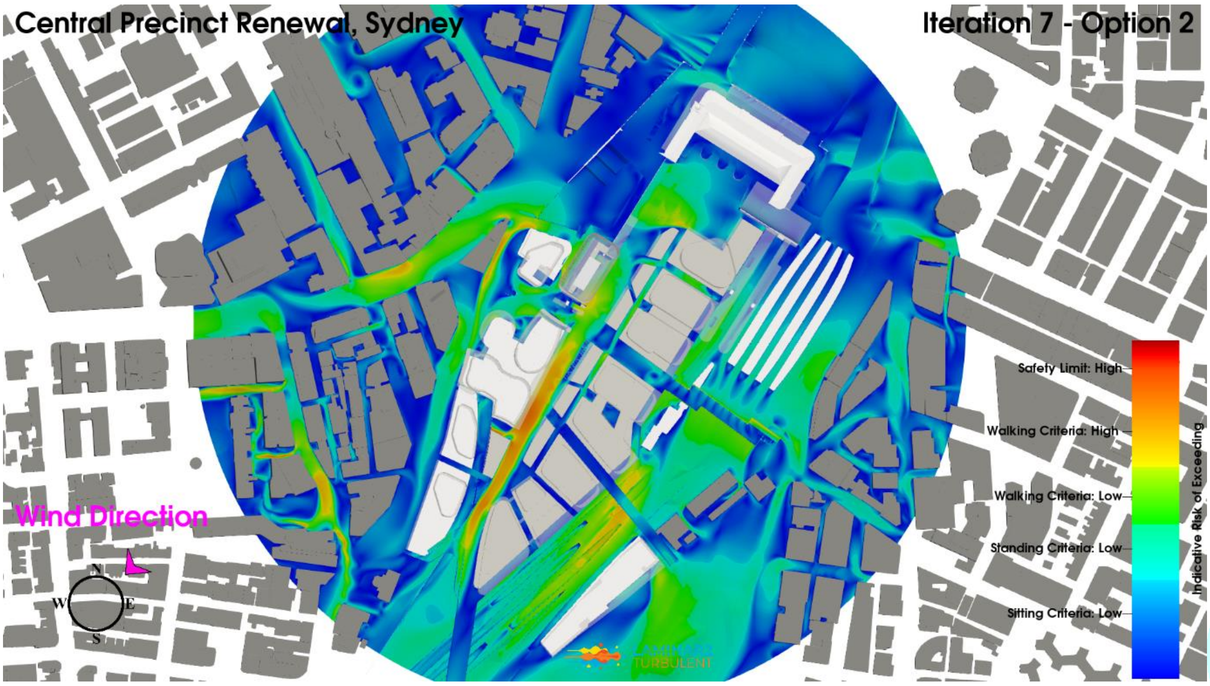

Figure 184: Iteration 7 Option 2, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

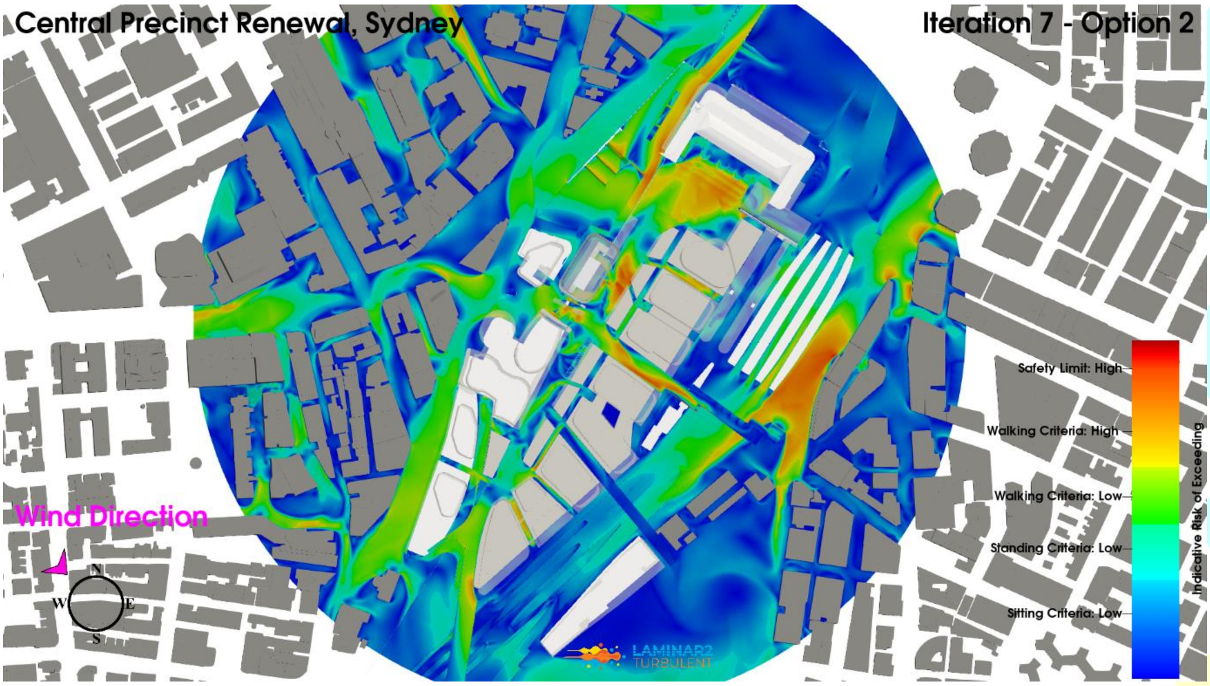

Figure 185: Iteration 7 Option 2, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

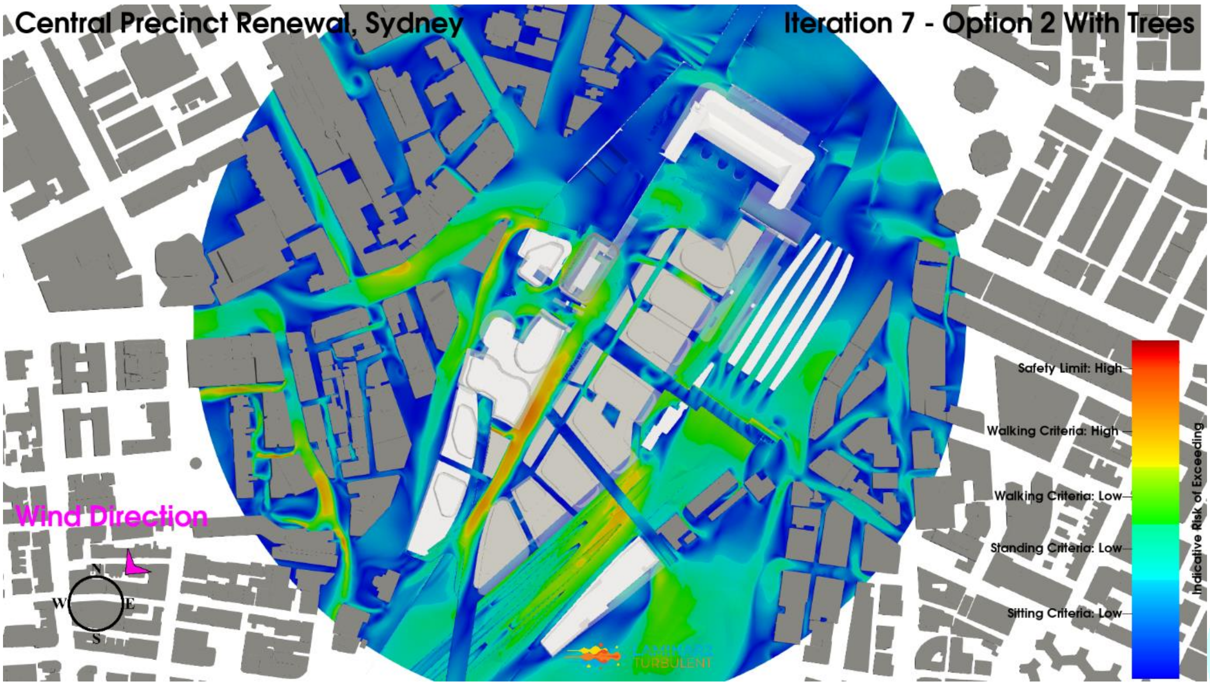

Figure 186: Iteration 7 Option 2 With Trees, Northeast Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

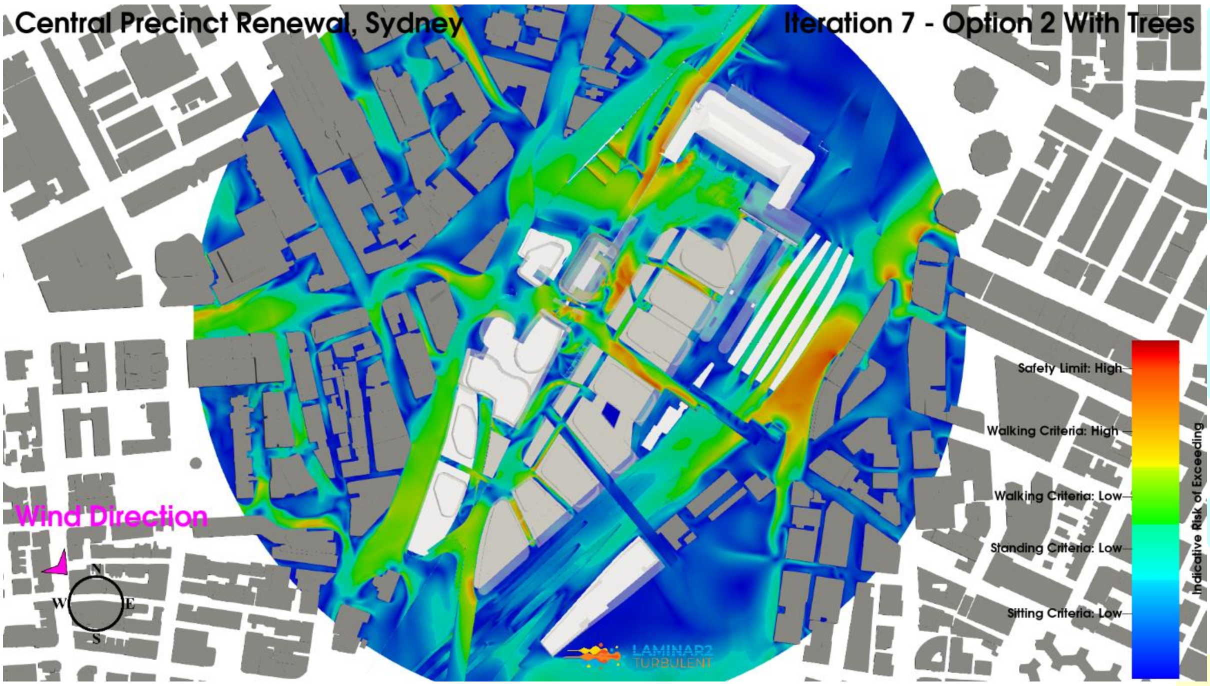

Figure 187: Iteration 7 Option 2 With Trees, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot

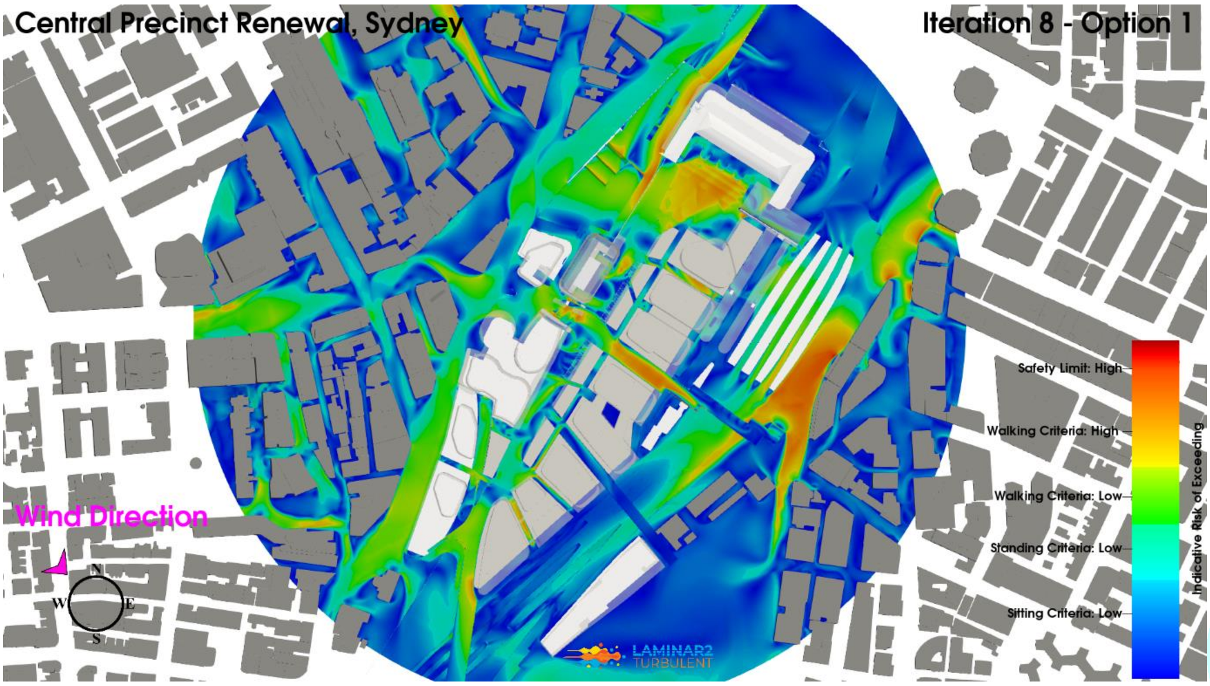

Figure 188: Iteration 8 Option 1, Northwest Wind Direction, Planview, Pedestrian Level Environmental Wind Risk Contour Plot