NSW Health Infrastructure

Royal Prince Alfred Hospital Redevelopment

SSDA Pedestrian Wind Environment Assessment Report

Reference: RPA-WIN-ARP-RPT-SSDA-000

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Executive Summary

Arup have been commissioned to prepare a quantitative pedestrian wind environmental wind impact assessment report for the proposed redevelopment or Royal Price Alfred (RPA) Hospital, Sydney on the pedestrian level wind conditions for comfort and safety in and around the site. This report details the numerical analysis and results quantifying the wind conditions in and around the site.

The proposed redevelopment is larger in size than the surrounding buildings and will therefore have an impact on the local wind conditions. The site is located on the northern edge of a relatively well-developed area. The wind conditions in this medium density area are known to be relatively windy, with the prevailing winds being channelled between the larger buildings.

From a comfort perspective, the wind conditions at the majority of locations in and around the site are classified as suitable for pedestrian standing or walking. These conditions are appropriate for the intended use of the space.

From a safety perspective, there are two small areas in the undercrofts that have a marginal exceedance of the pedestrian safety criterion. These undercroft areas are through the loading dock area and are primarily for maintenance access, and not intended for general pedestrian. The exceedance in the eastern overland flow path section is not accessible to pedestrians as the head height is too low. The minor exceedance area in the northern undercroft occurs to the east of Lambie Dew Drive encompassing the pavement. The changes to building form subsequent to the wind modelling are expected to slightly improve conditions, but require quantification. If the changes are insufficient, there are additional minor changes to the building form that could be explored to mitigate the issue. As the exceedance is minor and the area is mainly used for maintenance access, simple wayfinding to discourage pedestrians passing through the loading bay, and/or installing strong wind warning signage in this area could be adopted. Additional modelling of the final geometry is recommended.

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1. Introduction

1.1 Site description

The Royal Prince Alfred (RPA) Hospital campus is located in Sydney's inner west suburb of Camperdown, within the City of Sydney Local Government Area. The campus is situated between the University of Sydney to the east and the residential area of Camperdown to the west. A north-south arterial road (Missenden Road) divides the campus into two distinct portions, known as the East and West Campuses. The northern boundary of the campus is defined by the Queen Elizabeth II Rehabilitation Centre and the southern extent of the campus is defined by Carillon Avenue.

The works are proposed to both the East and West Campuses, as well as some off-site works occurring within the University of Sydney.

The site comprises the following land titles:

- East campus:
  - Lot 1000 DP 1159799 (12 Missenden Road, Camperdown, 2050).
- West campus:
  - Lot 11 DP 809663 (114 Church Street, Camperdown, 2050); and
  - Lot 101 DP 1179349 (68-81 Missenden Road, Camperdown 2050).

Off-site works are proposed on University of Sydney land, known as Lot 1 DP 1171804 (3 Parramatta Road, Camperdown, 2050) and Lot 1001 DP 1159799 (12A Missenden Road, Camperdown, 2050).

1.2 Project background

In March 2019, the NSW Government announced a significant $750 million investment for the redevelopment and refurbishment of the RPA Hospital campus. The Project will include the development of clinical and non-clinical services infrastructure to expand, integrate, transform and optimise current capacity within the hospital to provide contemporary patient centred care, including expanded and enhanced facilities.

The last major redevelopment of RPA Hospital was undertaken from 1998 to 2004 projected to 2006 service needs. Since then, significant growth has been experienced in the volume and complexity of patients, requiring significant investment to address projected shortfalls in capacity and to update existing services to align with leading models of care.

The redevelopment of RPA Hospital has been the top priority for the Sydney Local Health District since 2017 through the Asset Strategic Planning process, to achieve NSW Health strategic direction to develop a future focused, adaptive, resilient and sustainable health system.

1.3 Description of development

Development consent is sought for:

- Alterations and additions to the RPA Hospital East Campus, comprising:
  - Eastern wing: A new fifteen (15) storey building with clinical space for Inpatient Units (IPU's), Medical Imaging, Delivery, Neonatal and Women's Health Services, connecting to the existing hospital building and a rooftop helicopter landing site (HLS);
  - Eastern extension: A three (3) storey extension to the east the existing clinical services building to accommodate new operating theatres and associated plant areas;
  - Northern expansion: A two (2) storey vertical expansion over RPA Building 89 accommodating a new Intensive Care Unit and connected with the Eastern Wing;
  - internal refurbishment: Major internal refurbishment to existing services including Emergency Department and Imaging, circulation and support spaces;
  - enhanced Northern Entry/ Arrival including improved pedestrian access and public amenity;
  - demolition of affected buildings, structures and trees;
  - changes to internal road alignments and paving treatments; and

    - landscaping works, including tree removal, tree pruning, and compensatory tree planting including off-site on University of Sydney land.
    -
- Ancillary works to the RPA Hospital West Campus, comprising:
    - temporary helicopter landing site above existing multi storey carpark;
    - re-routing of existing services; and
    - associated tree removal along Grose Street.

1.4 Purpose of Report

NSW Health Infrastructure (HI) has engaged Arup to provide a quantitative environmental wind assessment for the proposed RPA Hospital redevelopment. This report outlines the assessment and recommendations relating to the pedestrian wind comfort and safety on the ground level in and around the site.

The purpose of this Report is to support the State Significant Development Application (SSDA), reference number SSD-47662959, for the redevelopment of the RPA Hospital (the project). This report addresses the Planning Secretary's Environmental Assessment Requirements (SEARs) issued on 29 August 2022 as detailed in Table 1.

Table 1. Applicable SEARs

SEARs	Comment / Reference
5. Environmental Amenity: *Assess amenity impacts on the surrounding locality, including lighting impacts, solar access, visual privacy, visual amenity, view loss and view sharing, overshadowing, and wind impacts (including the preparation of a wind assessment where the concept development has a height above four storeys). A high level of environmental amenity for any surrounding residential or other sensitive land uses must be demonstrated.*	This report addresses the Pedestrian Level wind assessment providing a quantitative wind impact assessment prepared by a suitable qualified person. Quantification has been conducted using numerical modelling using Computational Fluid Dynamics (CFD)
7. Public Space *Demonstrate how the development:* • *maximises the amenity of public spaces in line with their intended use, such as through adequate facilities, solar access, shade and wind protection.*	

2. Wind assessment

2.1 Local wind climate

The wind frequency and direction information measured by the Bureau of Meteorology anemometer at a standard height of 10 m at Sydney Airport from 1995 to 2022, between hours of 6 am and 10 pm when the hospital will be more trafficked and the winds are stronger, have been used in this analysis, Figure 1. The Sydney Airport anemometer is located about 8 km to the south of the site. The arms of the wind rose point in the direction from where the wind is coming from. The directional wind speeds measured here are considered representative of the wind conditions at the site.

It is evident from Figure 1 that strong prevailing winds are organised into three main groups centred about the north-east, south, and west directions.

Strong summer winds occur mainly from the north-east and south quadrant. Winds from the south are associated with large synoptic frontal systems and generally provide the strongest gusts during summer. North-east winds often improve thermal comfort on hot summer days.

Winter and early spring strong winds typically occur from the west quadrants. West quadrant winds provide the strongest winds affecting the area throughout the year and tend to be associated with large scale synoptic events that can be hot or cold depending on inland conditions.

The measured mean wind speed is about 5 m/s, and the 5% exceedance mean wind speed is 9.5 m/s.

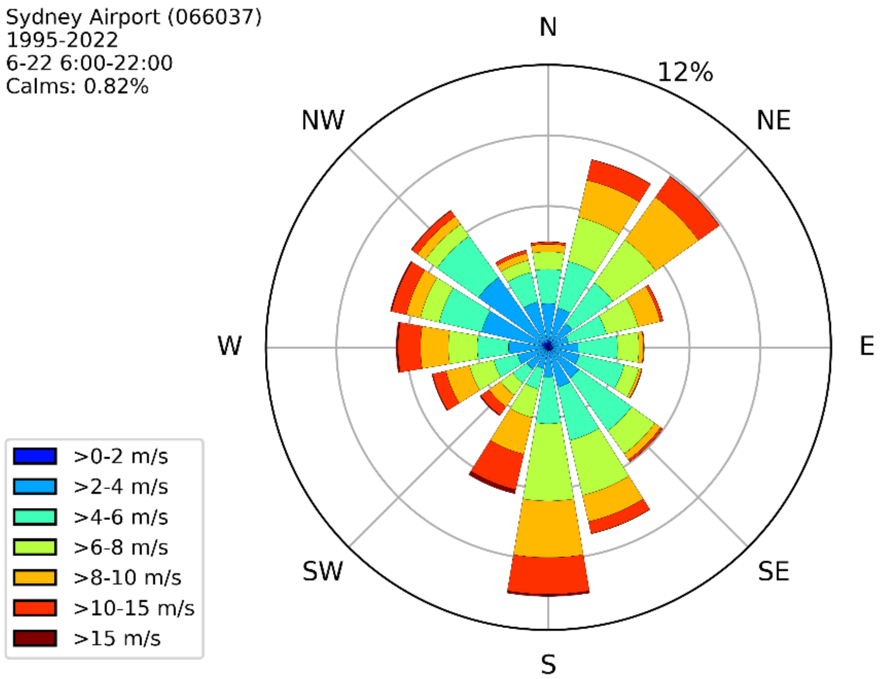


Figure 1: Wind rose showing probability of time of wind direction and speed

A general description on flow patterns around buildings is given in Appendix B.

2.2 Specific wind controls

Wind comfort is generally measured in terms of wind speed and rate of change of wind speed, where higher wind speeds and gradients are considered less comfortable. Air speed has a large impact on thermal comfort and are generally welcome during hot summer conditions. This assessment is focused on wind speed in terms of mechanical comfort.

There have been many wind comfort criteria proposed, and a general discussion is presented in Appendix C.

There are no known wind speed criteria for the redevelopment. The wind speed criteria used in this assessment are based on the work of Lawson (1990) amended to daylight usage as described in Table 2. As the wind conditions overnight are calmer than during the day, the assessment conducted herein is slightly conservative.

Table 2 Pedestrian comfort criteria for various activities

Comfort (max. of mean or GEM wind speed exceeded 5% of the time)	
<2 m/s	Dining
2-4 m/s	Sitting
4-6 m/s	Standing
6-8 m/s	Walking
8-10 m/s	Objective walking or cycling
>10 m/s	Uncomfortable
Safety (max. of mean or GEM wind speed exceeded 2 hours per annum during 6 am to 10 pm; 0.017% of the time)	
<15 m/s	General access
<20 m/s	Able-bodied people (less mobile or cyclists not expected)

Converting the wind climate to the site location, the mean wind speed exceeded 5% of the time would be approximately 6 m/s at pedestrian level. This would be classified between pedestrian standing and walking, which is considered appropriate for the site.

Site description

The RPA hospital redevelopment site is located to the north of the RPA site in inner west Sydney. The site is surrounded by low- to medium-rise buildings and open spaces, Figure 2. Topography within the site is complex between the buildings, generally rising to the west. Remote from the immediate site the topography is essentially flat from a wind perspective.

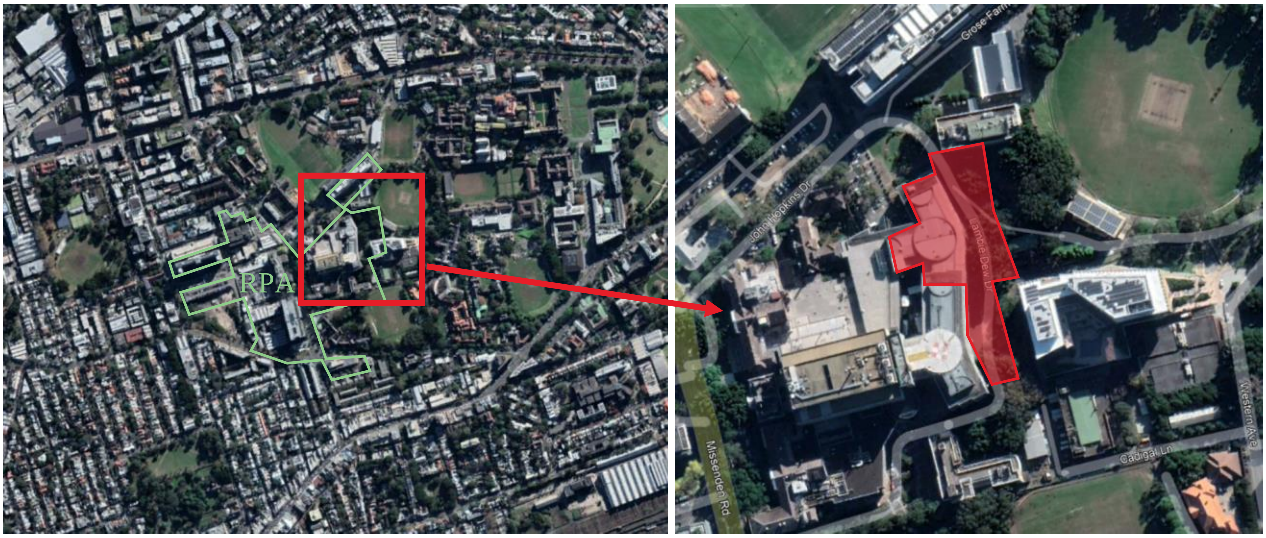


Figure 2: Site location (source Google Maps, 2022)

The proposed redevelopment includes three buildings, as shown in Figure 3. To the north, the Vertical Extension and New East are approximately 18 m and 39 m higher than the existing building. The East Extension is low-rise extending over Lambie Dew Drive, Figure 4.

The wind conditions in the area surrounding the site would be impacted by the increased massing, location, and orientation of the proposed redevelopment, increasing the wind speed for certain wind directions and improving it for others. Due to flow acceleration, the proposed undercrofts, Figure 3, are an area of interest. The wind assessment has been performed for the proposed development.

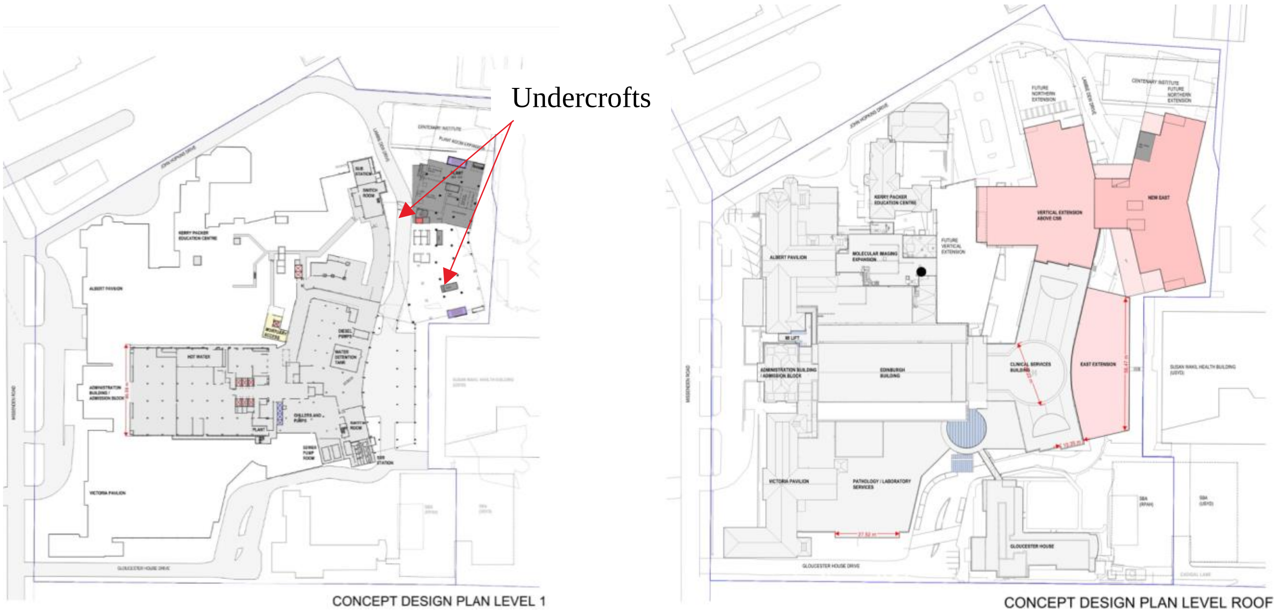
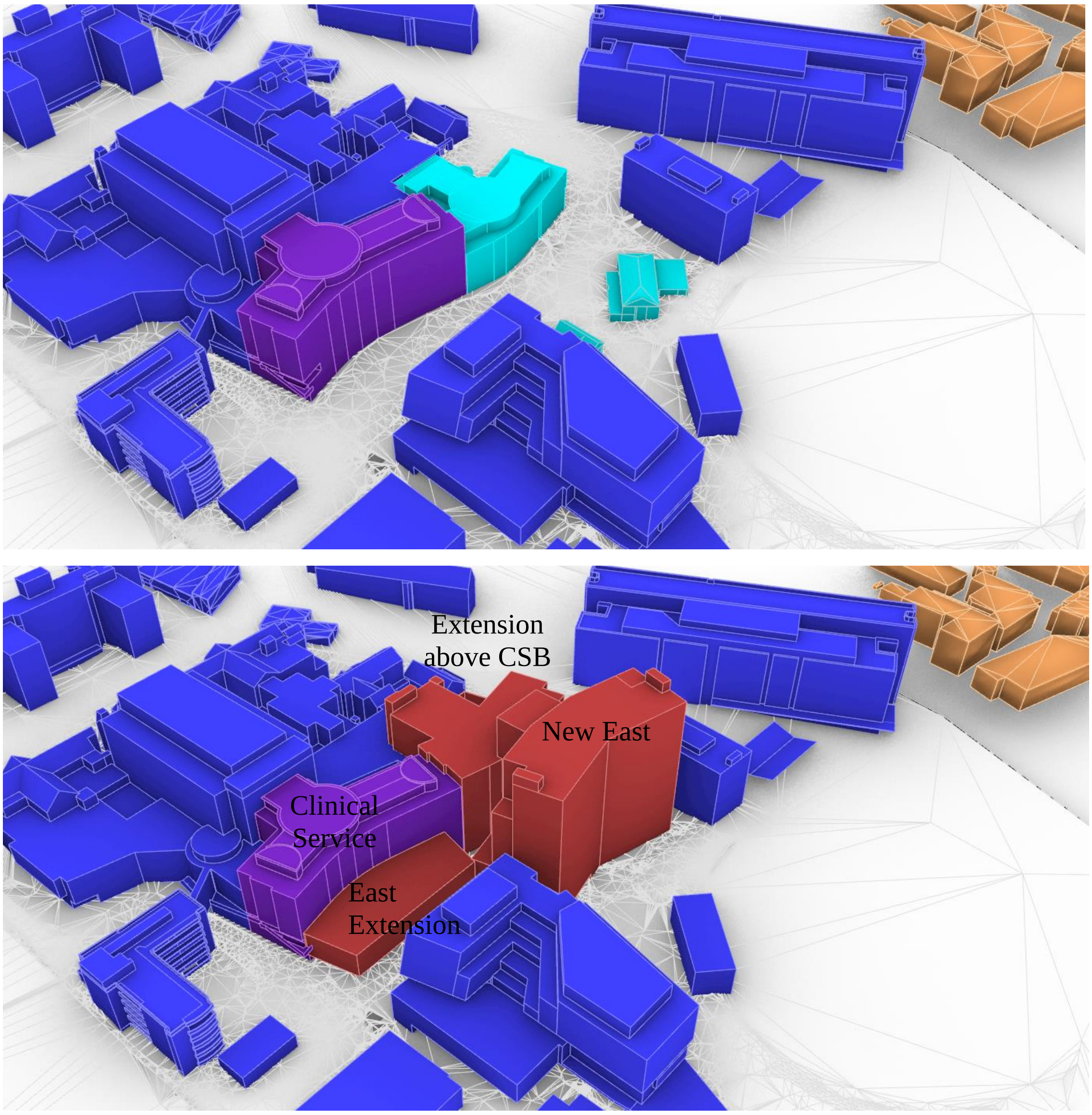


Figure 3: Plans of proposed development at time of modelling



(a)

(b)

Figure 4: 3d model of the (a) Existing and (b) proposed redevelopment

3. Computational Fluid Dynamics (CFD) assessment

3.1 Methodology and modelling

The numerical CFD simulations were conducted for the proposed development using steady-state Reynolds-Averaged Navier-Stokes (RANS) method. The target building (Clinical Service Building) and the proposed development (extension above the CSB, new east, and east extension) are modelled in detail, as shown in Figure 4(b). The urban context including surrounding buildings within a radius of 500 m around the site was explicitly modelled and topography surrounding the site is included in the model, Figure 5. The context is placed in a much larger domain based on best practice guideline for the CFD simulation of flows in urban environment, Figure 6.

A computational mesh was constructed comprising of approximately 39 million hexahedral elements, Figure 7. The grid resolution is finest around the proposed building where greater resolution is required. The computational mesh size increases with distance from the regions of most interest. Other mesh sizing controls including varying the level of mesh refinement were used to capture the effects of important surrounding buildings more accurately from an aerodynamic perspective. Mesh sensitivity study was conducted to reduce the effect of mesh size on the solution.

The effect of terrain outside the 1 km diameter urban context was implicitly modelled using rough wall functions reproducing the roughness characteristics corresponding to suburban, Terrain Category 3 (TC3) as defined in Standards Australia (2021). The wind speed and turbulence profiles corresponding to TC3 were employed at the inlet boundary. Simulations were conducted for 16 wind directions at 22.5° increments.

The CFD setup followed the best practices and guidelines for simulating flow in urban environments (Franke, 2011). Probes at different locations around the site and parameter residuals were used to monitor the convergence of the results and ensure the solution reached a steady state solution.

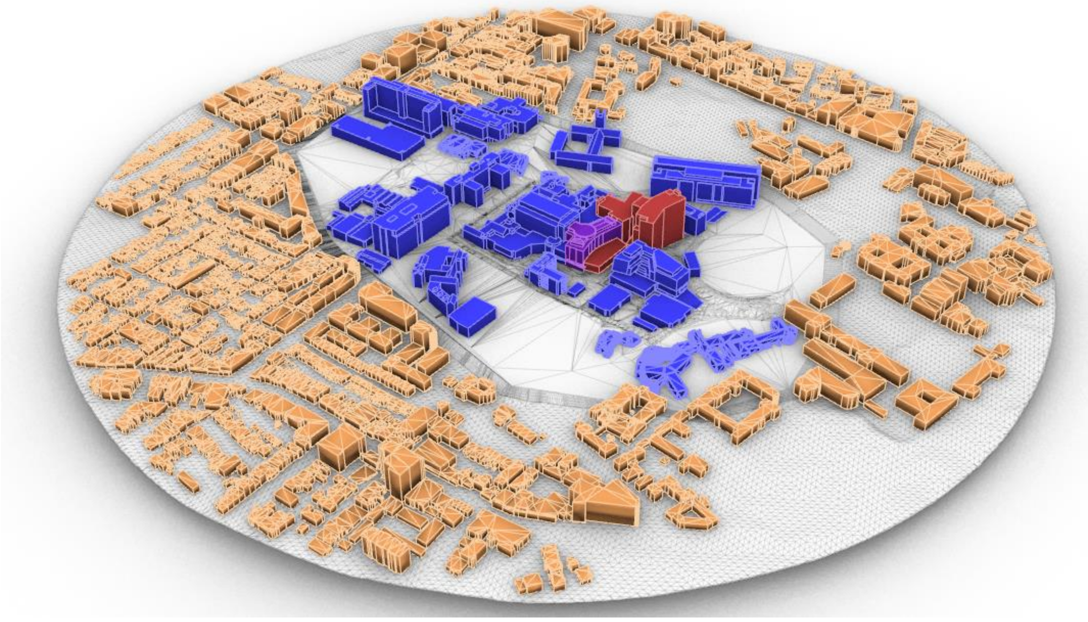


Figure 5: Urban context including and the surrounding buildings and topography

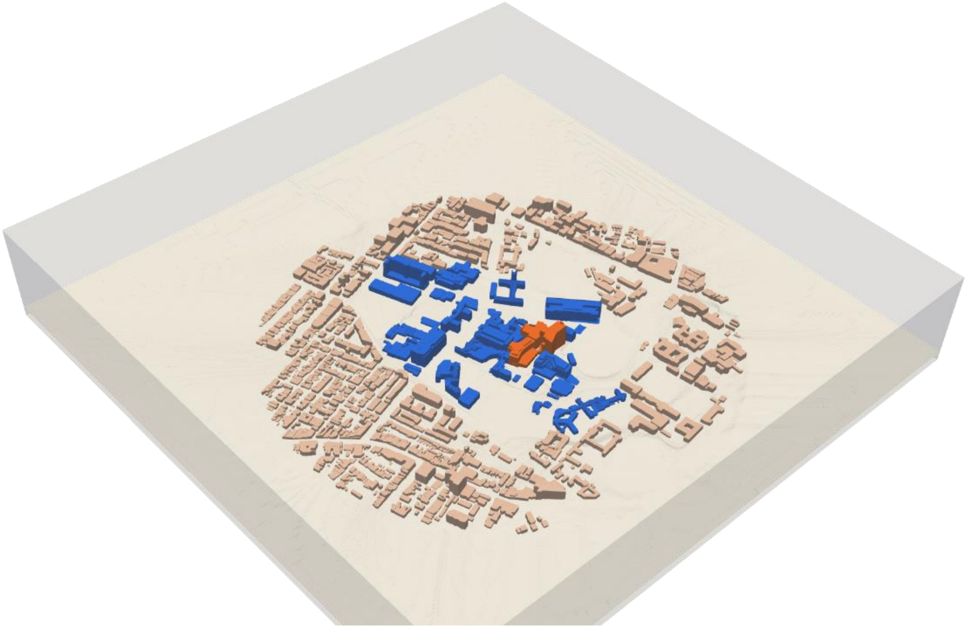


Figure 6. Simulation domain based on the dimension of the tallest building modelled.

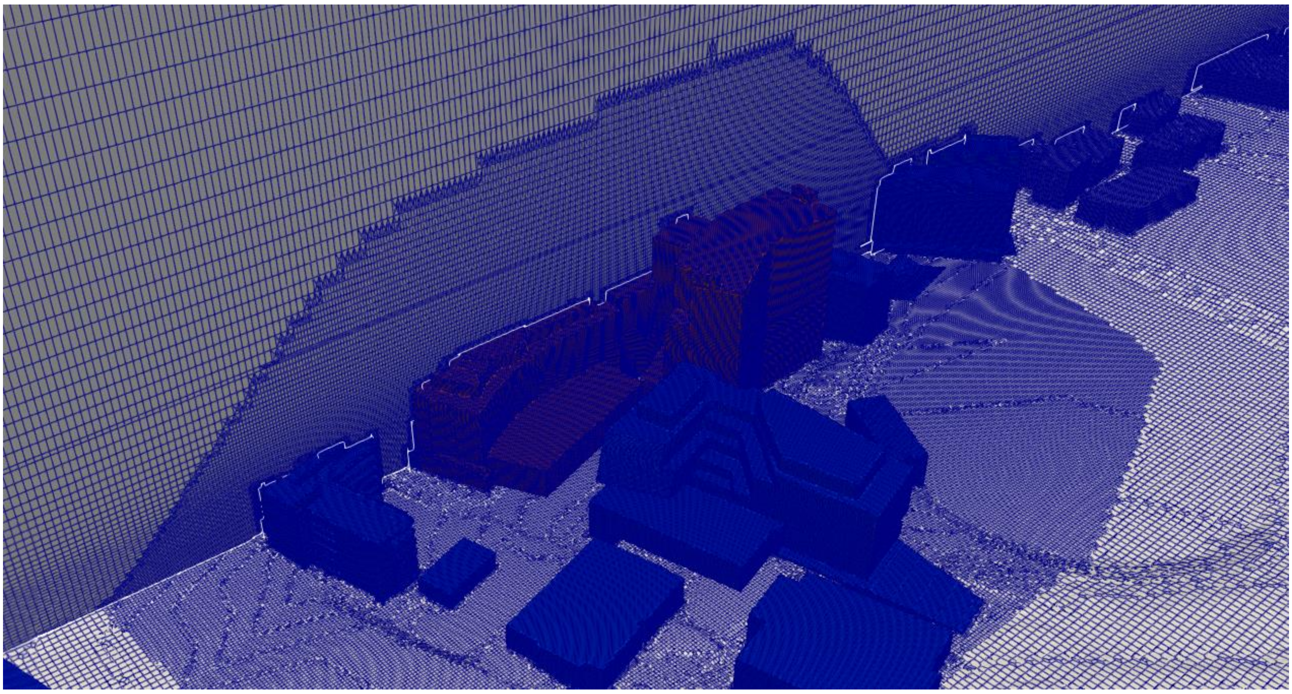


Figure 7: Mesh refinement strategy

3.2 Wind conditions on ground level

Contour maps of wind speed ratio at pedestrian level at pedestrian height of 1.5 m above the local ground level for 16 wind directions are presented in Appendix A. The extension of the assessed area around the site is aligned with guidelines for pedestrian wind effects criteria, AWES (2014). The wind speeds over the entire surface are integrated with the local wind climate data presented in Section 2.1 for assessment against the Lawson criteria for pedestrian comfort and safety. For assessment against the criteria, the Gust Equivalent Mean (GEM) is calculated based on measured turbulent kinetic energy. Considering isotropic turbulence, standard deviation of wind speed can be calculated using:

$$\sigma = (2/3k)^{0.5}$$

where k is turbulent kinetic energy. Using mean wind speed and standard deviation, GEM can be determined based the equation in Appendix C. The maximum of GEM and mean wind speed is statistically analysed to provide the comfort classification based on 5% of the time exceedance and indicative safety rating based on 0.022% of time in accordance with the Lawson wind criteria. Contour maps showing the directionally integrated safety and comfort classifications are presented in Figure 8 and Figure 14 respectively.

It is evident from Figure 8 that pedestrian safety at all locations passes the safety criterion except minor exceedances in some small areas remote from the proposed building, and beneath the undercrofts of the proposed buildings. At the remote location, the incident wind directions causing the exceedances indicate that these are existing conditions and not a consequence of the proposed building. The flow pattern in the undercroft areas is pressure-driven, induced by the overall massing of the buildings, resulting in relatively steady flow with little turbulence. The steady flow allows people to better prepare for the strong wind conditions. The maximum wind speed is less than 10% above the criterion level. The exceedance in the undercroft to the east is entirely located in the building sub-floor for overland flood flow with reduced ceiling height, and is inaccessible to pedestrians. The undercroft to the north is in an area primarily used for maintenance access with limited pedestrian usage.

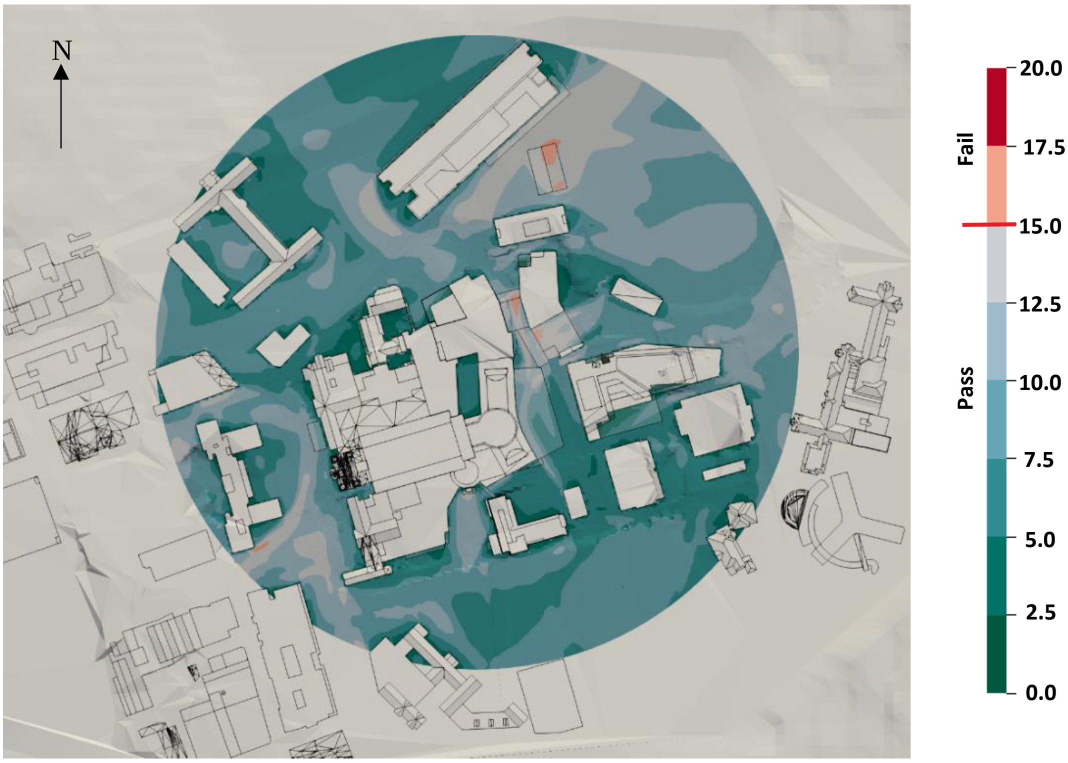


Figure 8. Safety map

The northern exceedance is caused by winds from the north-west accelerating around the Charles Perkins Centre and stagnating in the L-shaped tower section to the north-west of the New East Building inducing an area of high pressure (low wind speed). The pressure at the southern opening to the undercroft in the lee of the New East Building experiences negative pressure. The pressure difference between the openings induces accelerated flow through the undercroft, Figure 9; where the streamline colour indicates the speed of the flow with red fast. It is evident that upwind of the opening the wind speed is slow and accelerates into the undercroft.

Northern safety exceedance

The local areas exceeding the safety criterion are superimposed on the latest drawings for the site, Figure 10, showing the north zone encroaches on the eastern pavement near the maintenance access stairs to the north of the Level 2 lifts. Subsequent to the CFD modelling, the building geometry has been developed as illustrated in Figure 11 and Figure 12. Positive changes in geometry for the wind conditions are:

- reduction in massing and rounding of the western link above the roof of the existing building,
- greater articulation of the podium above the north end of the undercroft, and

- additional porosity in the north-west corner of the New East building.

Negative aspect of the changes are:

- reduction in tower setback from the northern edge of Level 6, and
- change in angle of the northern façade of the western link.

The geometric changes would be expected to have a nett beneficial impact on the wind conditions through the undercroft. It would be recommended to test the final geometry.

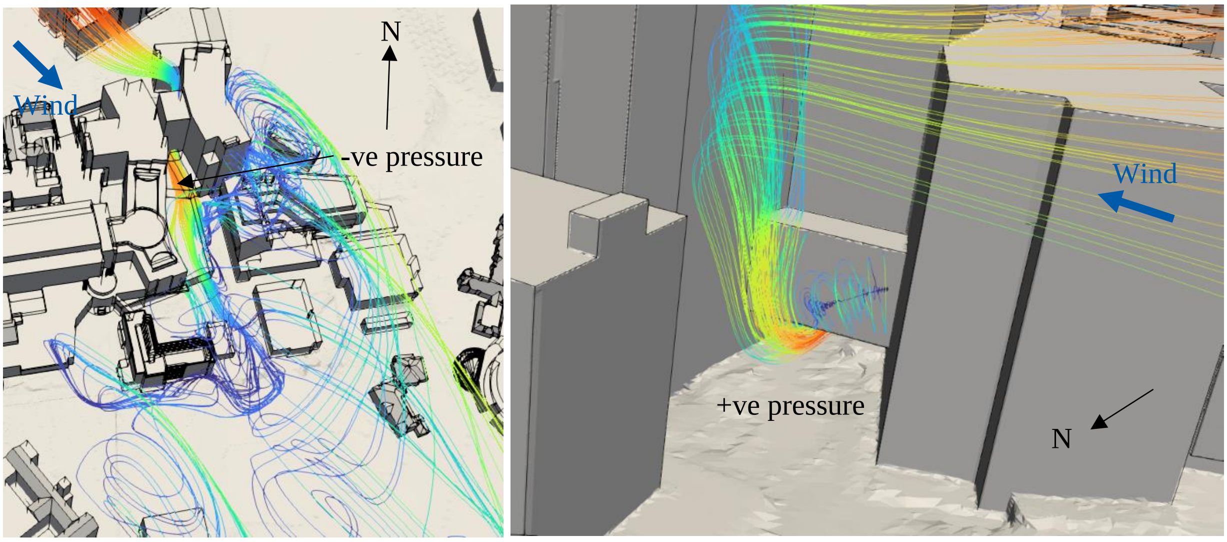


Figure 9: Flow pattern through north undercroft (blue slow, red fast)

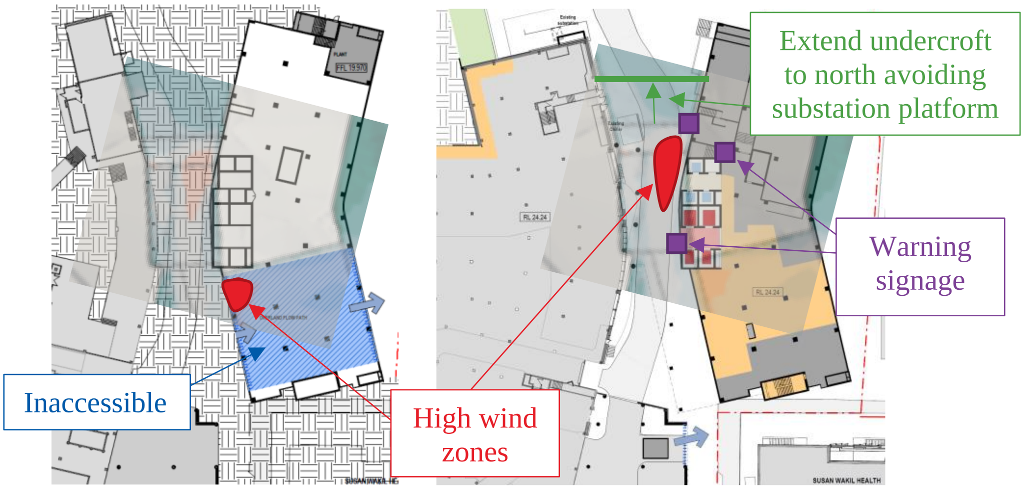


Figure 10: Floor plans for Level 1 (L) and Level 2 (R)

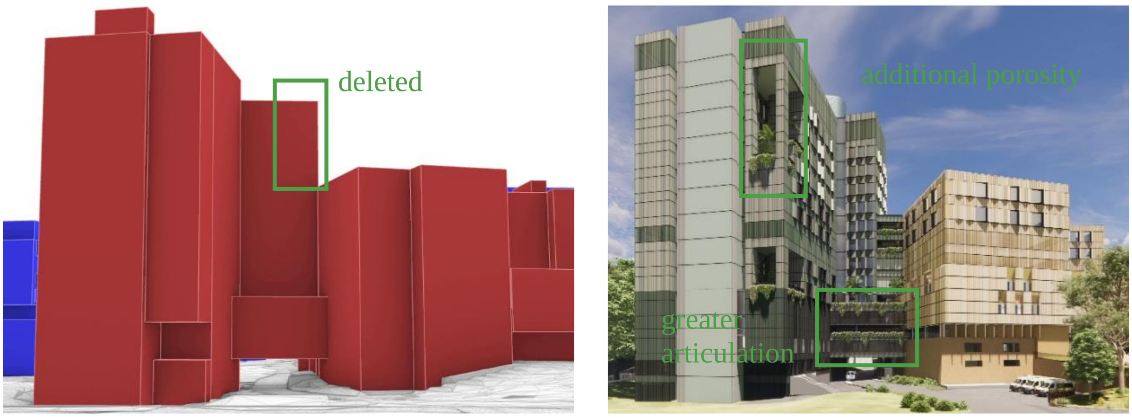


Figure 11: View from north of model geometry (L), current architectural model (R)

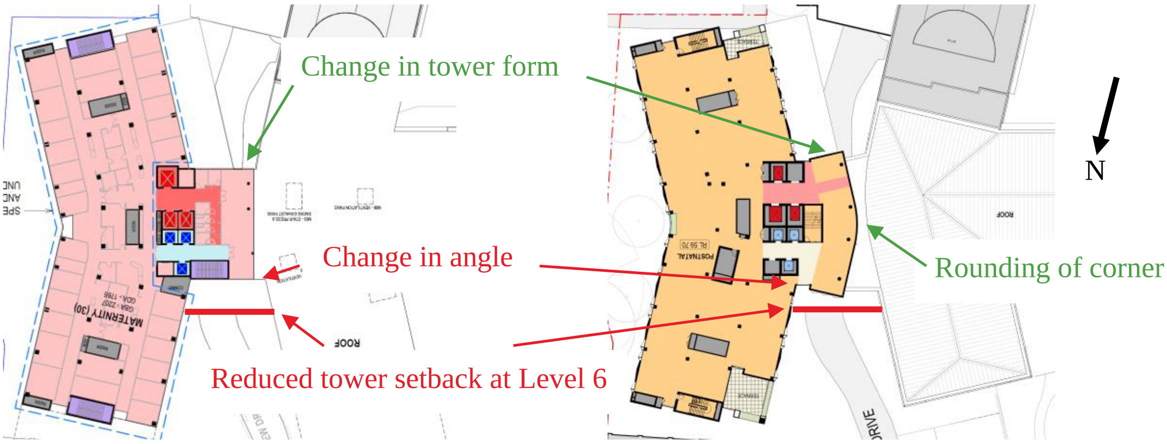


Figure 12: Level 11 plan

If the final geometry does not meet the safety criterion, further design refinements could be investigated to improve conditions in the undercroft including:

- amend the geometry of the western link above the existing roof height,
- extend the undercroft, or include a horizontal canopy to the north,
- increasing the height of the undercroft
- rounding the northern soffit to the undercroft, and/or
- introduce wayfinding to discourage pedestrians passing through the loading dock area, and
- strong wind warning signage near the undercroft pertain access points, Figure 10.

Eastern safety exceedance

The safety exceedance in the eastern undercroft is caused by winds from the south-south-west. The mechanism is similar to that for the northern undercroft and caused by the building massing. Winds from the south-south-west blow into the elbow of the New East Building above inducing a large positive pressure. The eastern side of the building experiences negative pressure for winds from this direction. The high wind speed through the undercroft is caused by the pressure differential between the openings. The flow pattern for this wind direction is presented in Figure 13. As the eastern undercroft is inaccessible to pedestrians, the exceedance of the safety criterion is not considered an issue.

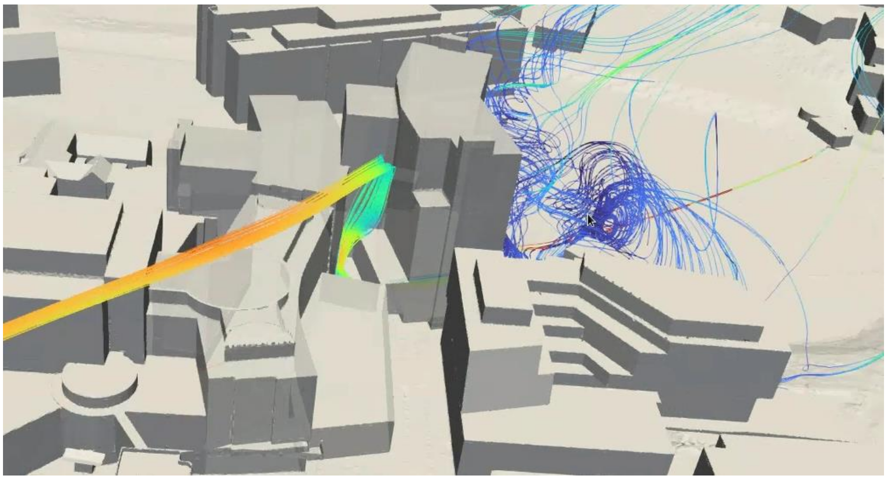


Figure 13: Streamlines for winds from the south-south-west through eastern undercroft

Pedestrian comfort

In terms of pedestrian comfort, the majority of the site is classified as suitable for pedestrian standing type activities with localised areas of pedestrian walking primarily through the undercrofts and in open spaces unaffected by the proposed development, Figure 14. The heavily articulated building and recessed main entrances maximise the amenity of the external public spaces at ground level in and around the development. These wind conditions are considered acceptable for the intended use of pedestrian access in and around the site. The wind conditions in local outdoor areas could be further improved with additional local screening and landscaping.

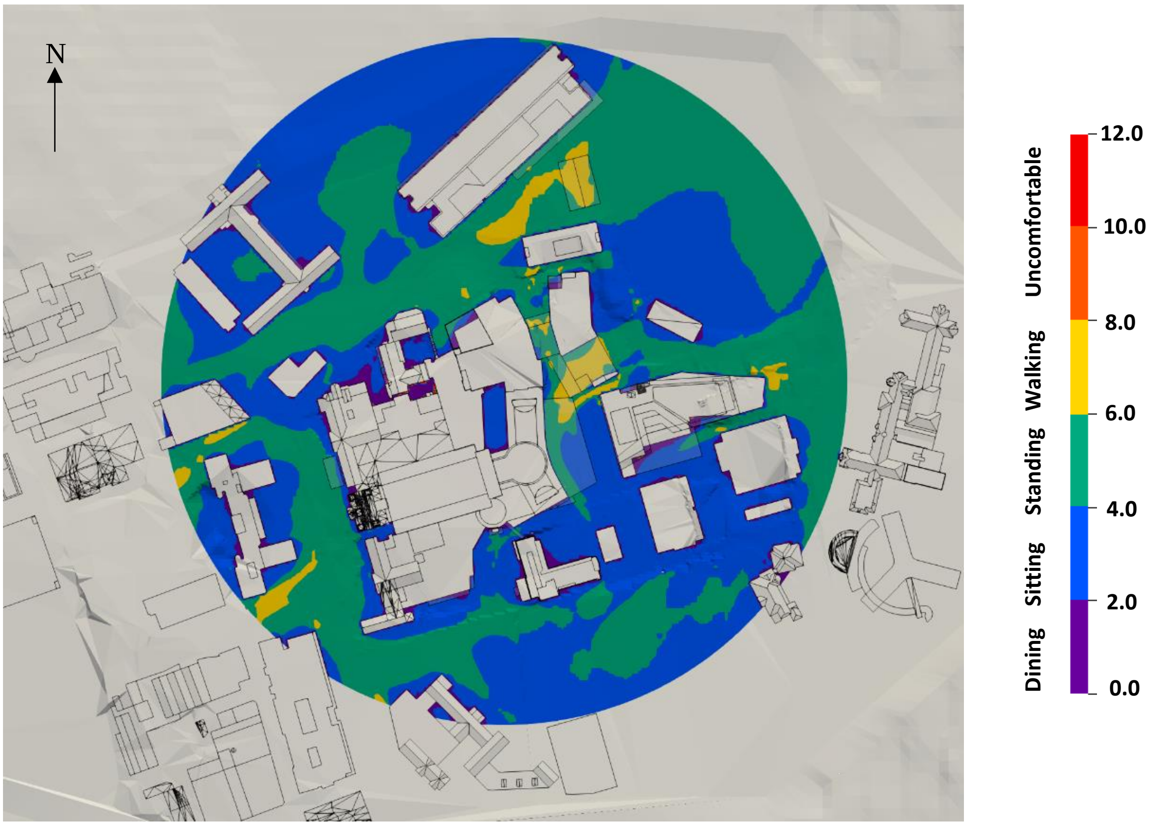
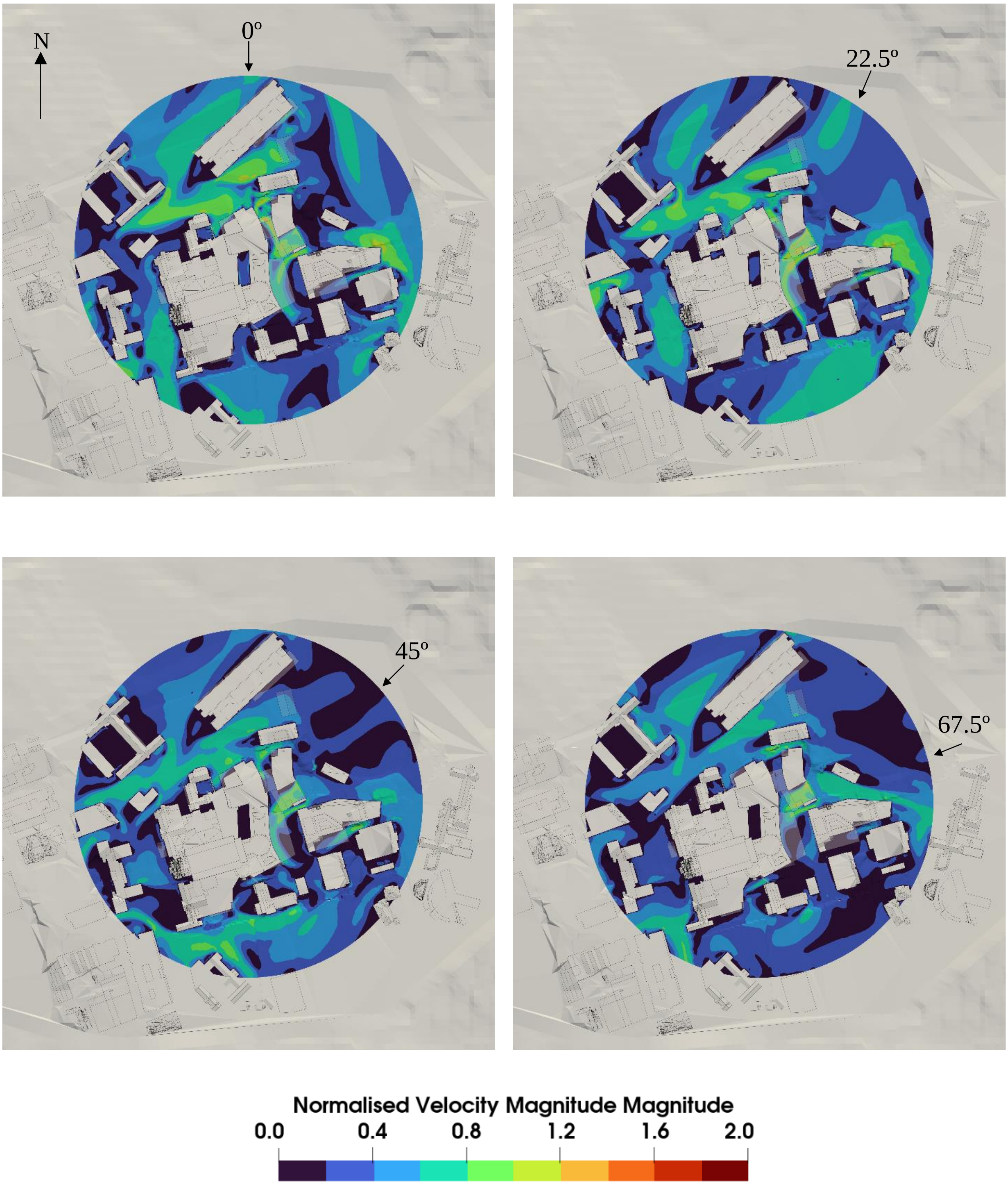
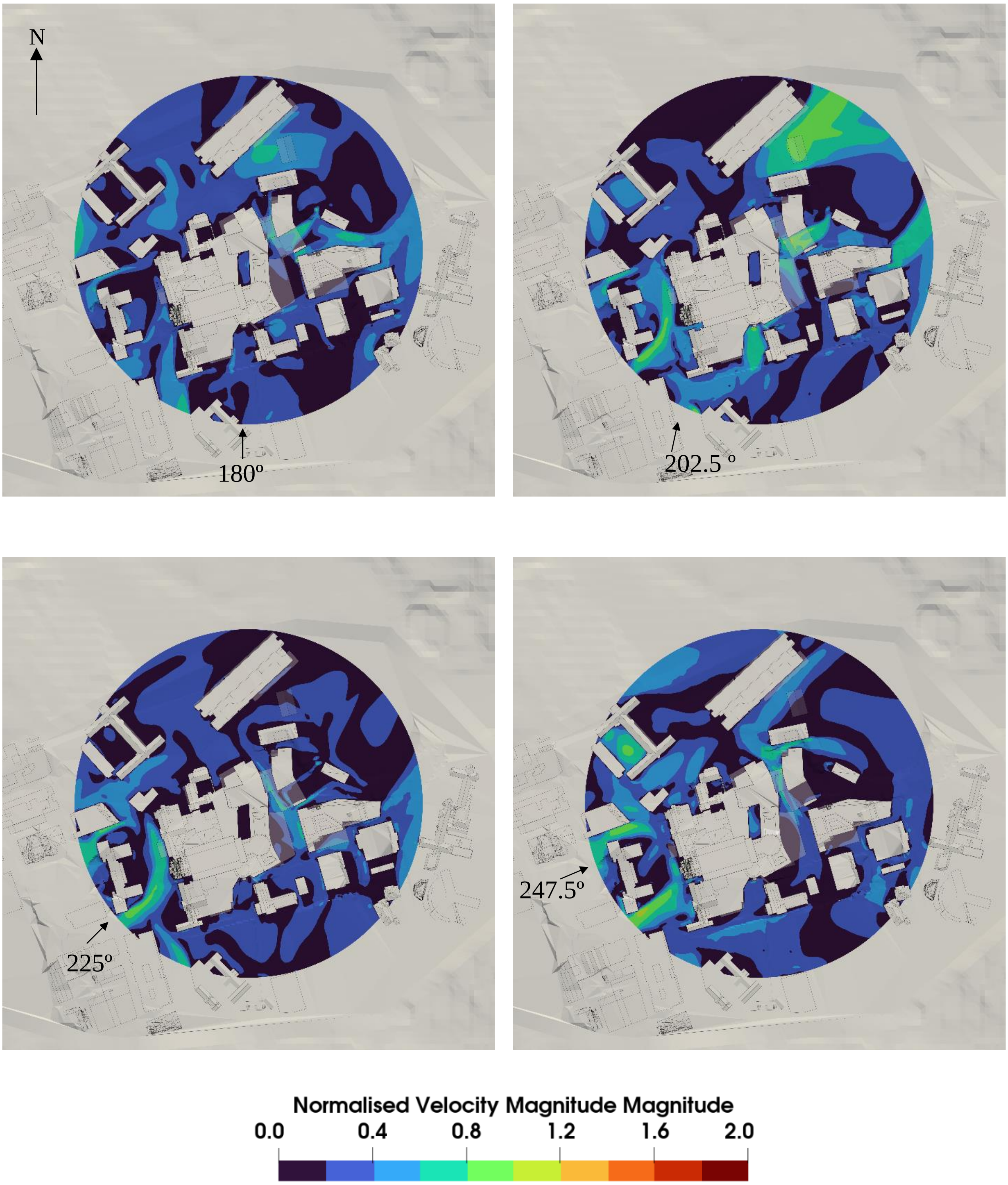


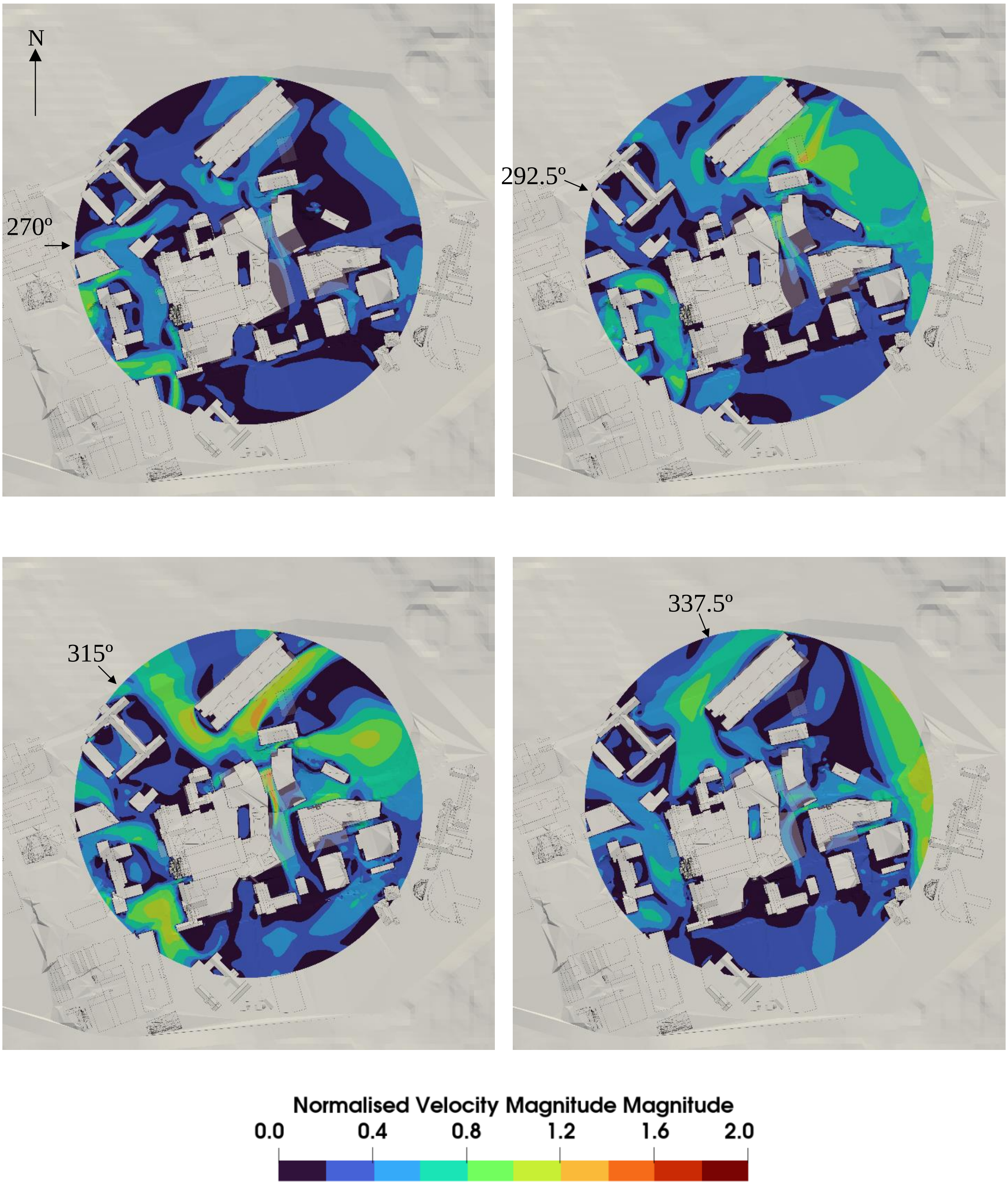
Figure 14: Comfort map

Appendix A Directional results at pedestrian level




N
90º
112.5º
135º
167.5º
Normalised Velocity Magnitude Magnitude
0.0
0.4
0.8
1.2
1.6
2.0


N
180°
202.5 °
225°
247.5°
Normalised Velocity Magnitude Magnitude
0.0
0.4
0.8
1.2
1.6
2.0



N
270º
292.5º
315º
337.5º
Normalised Velocity Magnitude Magnitude
0.0
0.4
0.8
1.2
1.6
2.0

Appendix B Wind flow mechanisms

An urban environment generates a complex wind flow pattern around closely spaced structures, hence it is exceptionally difficult to generalise the flow mechanisms and impact of specific buildings as the flow is generated by the entire surrounds. However, it is best to start with an understanding of the basic flow mechanisms around an isolated structure.

Isolated building

When the wind hits an isolated building, the wind is decelerated on the windward face generating an area of high pressure, Figure 15, with the highest pressure at the stagnation point at about two thirds of the height of the building. The higher-pressure bubble extends a distance from the building face of about half the building height or width, whichever is lower. The flow is then accelerated down and around the windward corners to areas of lower pressure, Figure 15. This flow mechanism is called **downwash** and causes the windiest conditions at ground level on the windward corners and along the sides of the building.

Rounding the building corners or chamfering the edges reduces downwash by encouraging the flow to go around the building at higher levels. However, concave curving of the windward face can increase the amount of downwash. Depending on the orientation and isolation of the building, uncomfortable downwash can be experienced on buildings of greater than about 6 storeys.

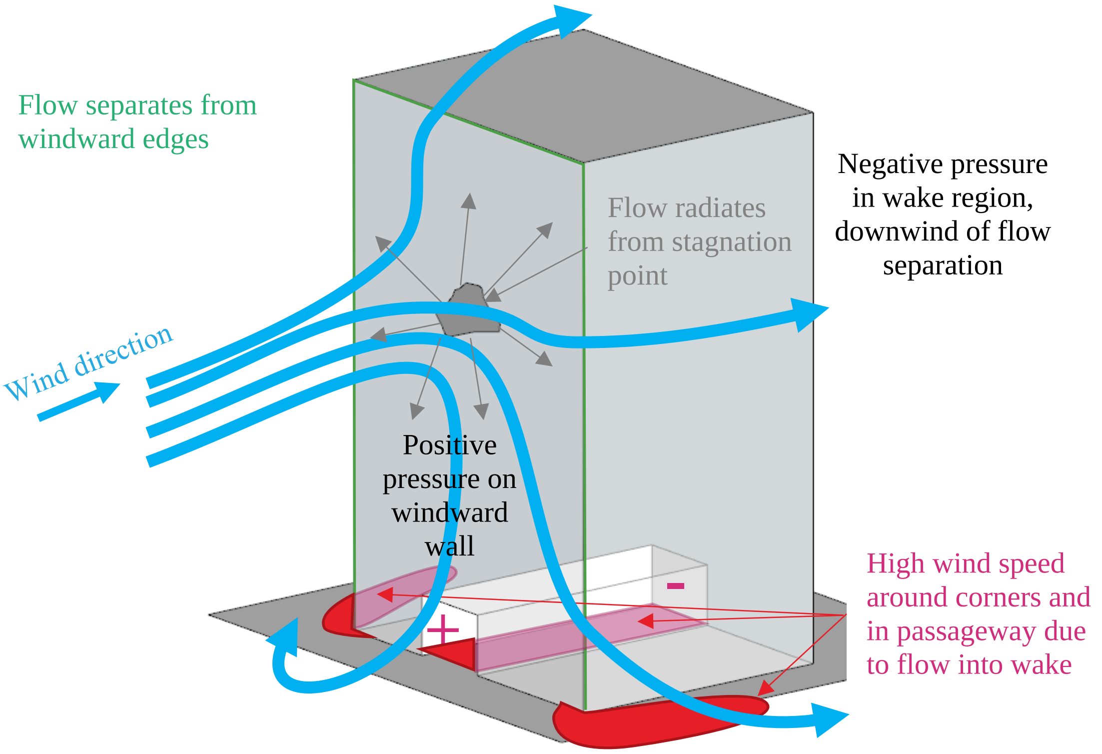


Figure 15: Schematic wind flow around tall, isolated building

Techniques to mitigate the effects of downwash winds at ground level include the provision of horizontal elements, the most effective being a podium to divert the downward flow away from pavements and building entrances, but this will generate windy conditions on the podium roof, Figure 16. Generally, the lower the podium roof and deeper the setback from the podium edge to the tower improves the ground level wind conditions. The provision of an 8 m setback on an isolated building is generally sufficient to improve ground level conditions, but is highly dependent on the building isolation, orientation to prevailing wind directions, shape and width of the building, and any plan form changes at higher level.

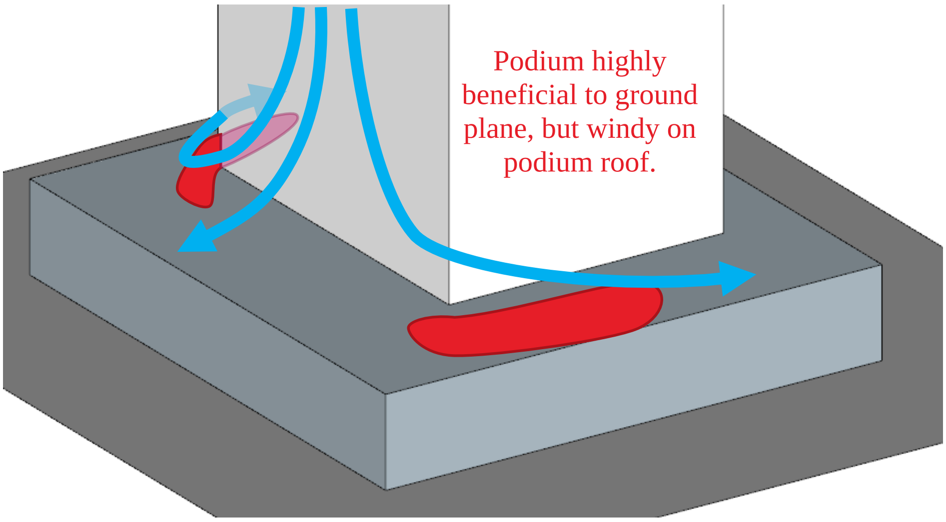


Figure 16: Schematic flow pattern around building with podium

Awnings along street frontages perform a similar function as a podium, and generally the larger the horizontal projection from the façade, the more effective it will be in diverting downwash flow, Figure 17. Awnings become less effective if they are not continuous along the entire façade, or on wide buildings as the positive pressure bubble extends beyond the awning resulting in horizontal flow under the awning.

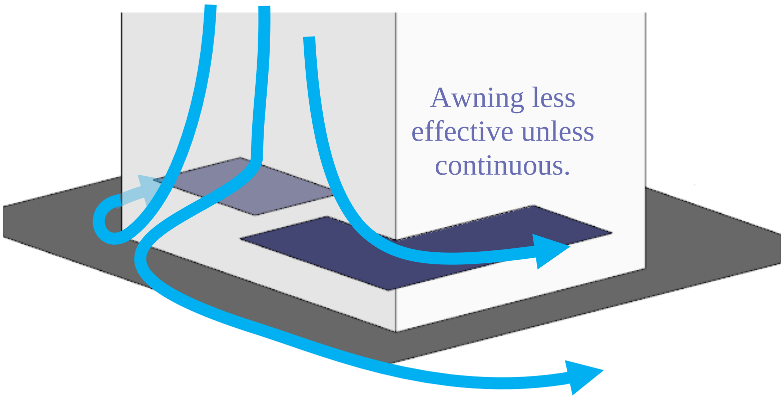


Figure 17: Schematic flow pattern around building with podium

It should be noted that colonnades at the base of a building with no podium generally create augmented windy conditions at the corners due to an increase in the pressure differential, Figure 18. Similarly, open through-site links through a building cause wind issues as the pressure tries to equilibrate between the entrances to the link causing strong flow, Figure 15. If the link is blocked, wind conditions will be relatively calm, Figure 19. This area is in a region of high pressure and therefore there is the potential for internal flow issues. A ground level recessed corner has a similar effect as an undercroft, resulting in windier conditions, Figure 19.

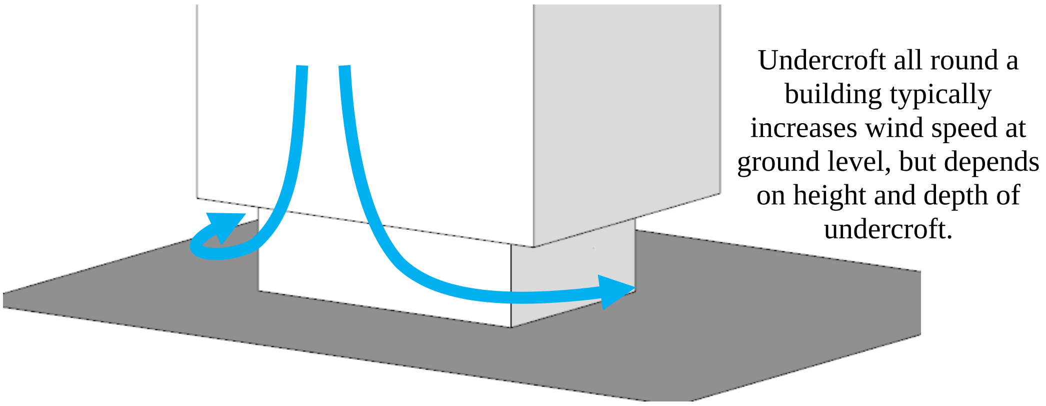


Figure 18: Schematic of flow patterns around isolated building with undercroft

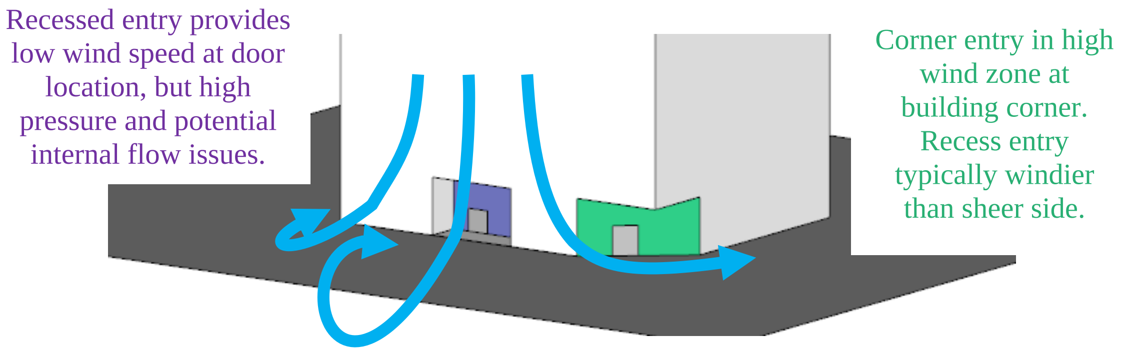


Figure 19: Schematic of flow patterns around isolated building with ground articulation

Multiple buildings

When a building is located in a city environment, depending on upwind buildings, the interference effects may be positive or negative, Figure 20. If the building is taller, more of the wind impacting on the exposed section of the building is likely to be drawn to ground level by the increase in height of the stagnation point, and the additional negative pressure induced at the base. If the upwind buildings are of similar height then the pressure around the building will be more uniform hence downwash is typically reduced with the flow passing over the buildings.

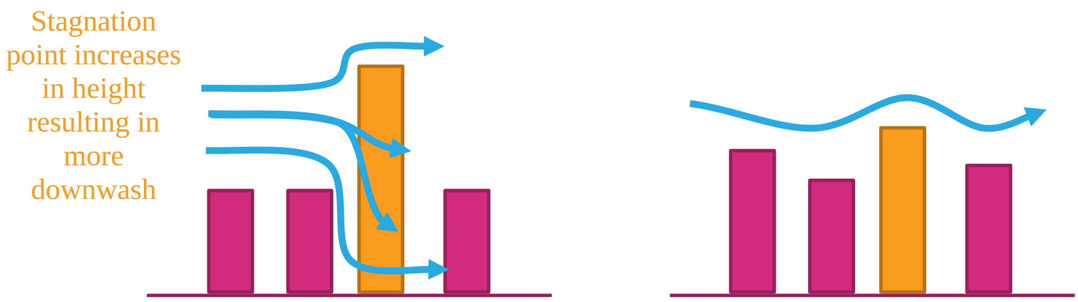


Figure 20: Schematic of flow pattern interference from surrounding buildings

The above discussion becomes more complex when three-dimensional effects are considered, both with orientation and staggering of buildings, and incident wind direction, Figure 21.

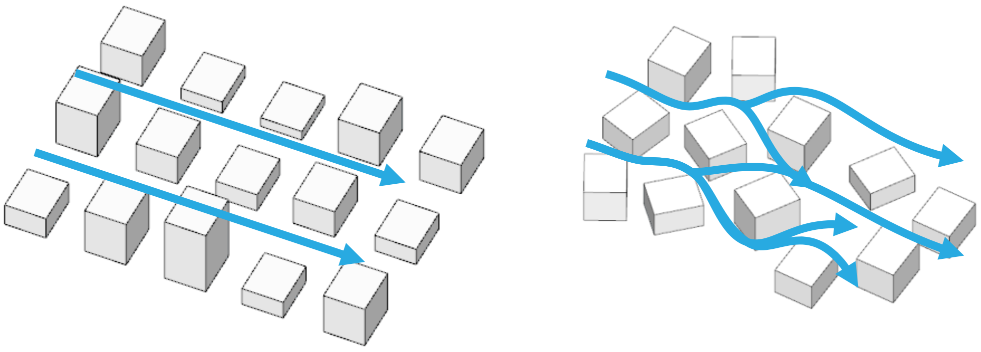


Figure 21: Schematic of flow patterns through a grid and random street layout

On the fringe of a city, the compound shape of neighbouring buildings instigates the flow pattern through the city. The overall massing causes an obstruction to the flow causing a slowing of the incident flow and increasing the windward pressure. Pressure driven flow is produced between the buildings, Figure 22. The vertical component in pressure driven flow is lower than downwash flow.

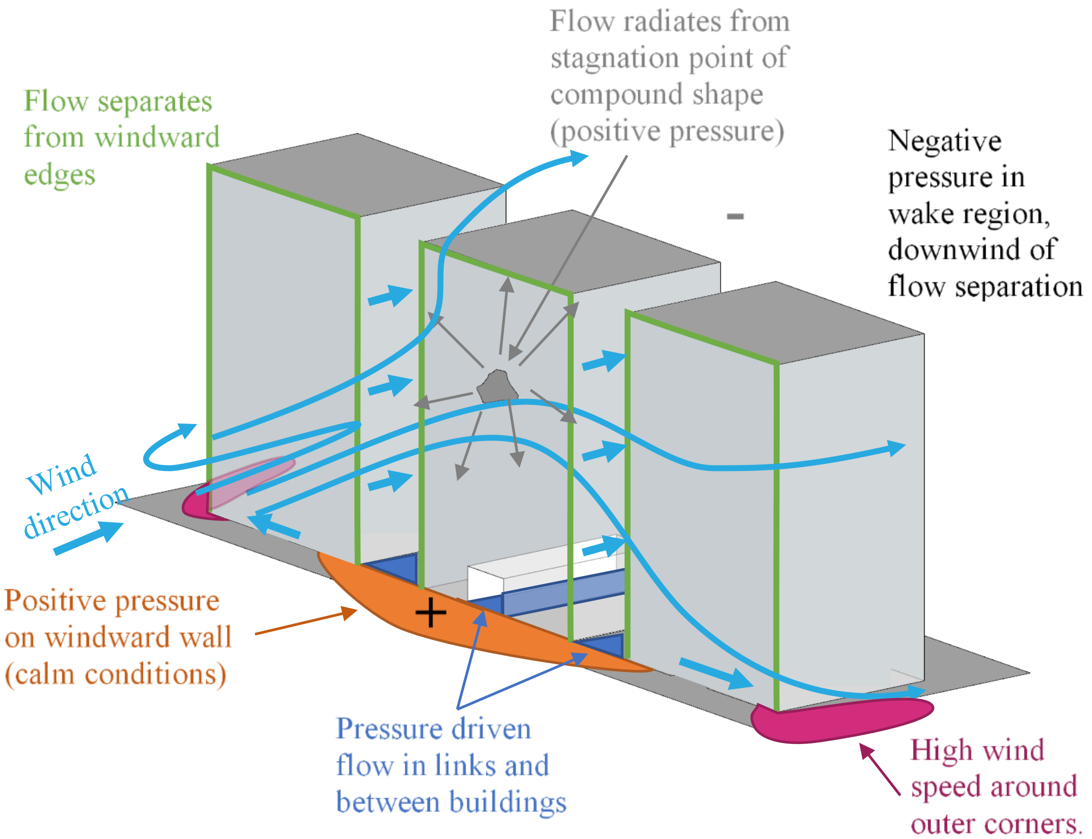


Figure 22: General flow pattern around multiple buildings

Channelling is instigated when pressure driven flow accelerates between two buildings, and continues along straight streets with buildings on either side, Figure 21(L). This occurs on the edge of large built-up areas where the approaching flow is diverted around the overall massing and channelled along the fringe by a relatively continuous wall of building facades. This is generally the primary mechanism producing strong wind conditions on the perimeter of a built-up area, particularly on corners, which can be exposed to multiple prevailing wind directions. The perimeter edge zone in a built-up area is typically about two blocks deep. Downwash is more important flow mechanism for the edge zone of a built-up area with buildings of similar height.

As the city expands, the central section of the city typically becomes calmer, particularly if the grid pattern of the streets is discontinued, Figure 21(R). When buildings are located on the corner of a central city block, the geometry becomes slightly more important with respect to the local wind environment.

Single barriers and screens

The wind flow pattern over a vertical barrier is illustrated in Figure 23, showing there will be recirculation zones near the windward wall and in the immediate lee of the barrier. The typical extent of these recirculation zones relative to the height of the barrier, h, is illustrated in Figure 23. These regions are not fixed but fluctuate in time. The mean wind speed in the wake areas drops significantly compared with the incident flow. With increasing distance from the barrier, the flow pattern will resort to the undisturbed state. Typically, the mean velocity and turbulence intensity at barrier height would be expected to be within 10% of the free stream conditions at 10 times the height of the structure downwind from the barrier.

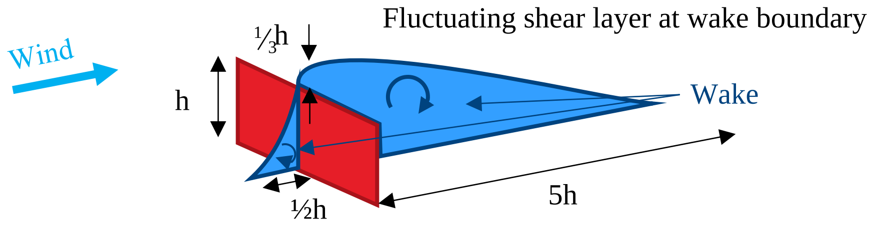


Figure 23: Sketch of the flow pattern over an isolated structure

Appendix C Wind speed criteria

General discussion

Primary controls that are used in the assessment of how wind affects pedestrians are the wind speed, and rate of change of wind speed. A description of the effect of a specific wind speed on pedestrians is provided in Table 3. It should be noted that the turbulence, or rate of change of wind speed, will affect human response to wind and the descriptions are more associated with response to mean wind speed.

Table 3: Summary of wind effects on pedestrians

Description	Speed (m/s)	Effects
Calm, light air	0–2	Human perception to wind speed at about 0.2 m/s. Napkins blown away and newspapers flutter at about 1 m/s.
Light breeze	2–3	Wind felt on face. Light clothing disturbed. Cappuccino froth blown off at about 2.5 m/s.
Gentle breeze	3–5	Wind extends light flag. Hair is disturbed. Clothing flaps.
Moderate breeze	5–8	Raises dust, dry soil. Hair disarranged. Sand on beach saltates at about 5 m/s. Full paper coffee cup blown over at about 5.5 m/s.
Fresh breeze	8–11	Force felt on body. Limit of agreeable wind on land. Umbrellas used with difficulty. Wind sock fully extended at about 8 m/s.
Strong breeze	11–14	Hair blown straight. Difficult to walk steadily. Wind noise on ears unpleasant. Windborne snow above head height (blizzard).
Near gale	14–17	Inconvenience felt when walking.
Gale	17–21	Generally impedes progress. Difficulty with balance in gusts.
Strong gale	21–24	People blown over by gusts.

Local wind effects can be assessed with respect to a number of environmental wind speed criteria established by various researchers. These have all generally been developed around a 3 s gust, or 1 hour mean wind speed. During strong events, a pedestrian would react to a significantly shorter duration gust than a 3 s, and historic weather data is normally presented as a 10 minute mean.

Despite the apparent differences in numerical values and assumptions made in their development, it has been found that when these are compared on a probabilistic basis, there is some agreement between the various criteria. However, a number of studies have shown that over a wider range of flow conditions, such as smooth flow across water bodies, to turbulent flow in city centres, there is less general agreement among. The downside of these criteria is that they have seldom been benchmarked, or confirmed through long-term measurements in the field, particularly for comfort conditions. The wind criteria were all developed in temperate climates and are unfortunately not the only environmental factor that affects pedestrian comfort.

For assessing the effects of wind on pedestrians, neither the random peak gust wind speed (3 s or otherwise), nor the mean wind speed in isolation are adequate. The gust wind speed gives a measure of the extreme nature of the wind, but the mean wind speed indicates the longer duration impact on pedestrians. The extreme gust wind speed is considered to be suitable for safety considerations, but not necessarily for serviceability comfort issues such as outdoor dining. This is because the instantaneous gust velocity does not always correlate well with mean wind speed, and is not necessarily representative of the parent distribution.

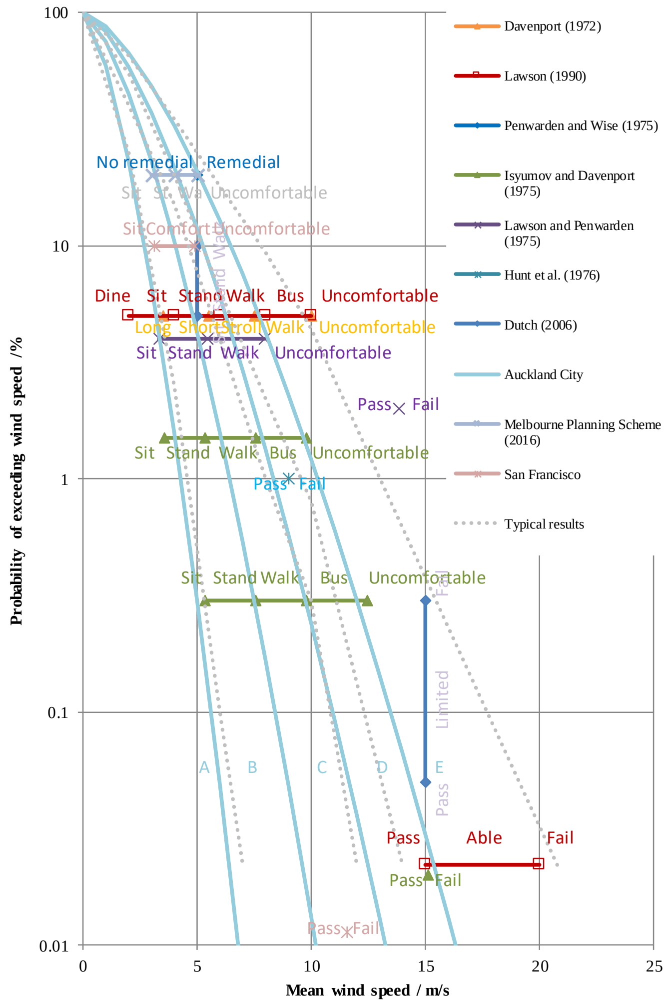
Hence, the perceived 'windiness' of a location can either be dictated by strong steady flows, or gusty turbulent flow with a smaller mean wind speed.

To measure the effect of turbulent wind conditions on pedestrians, a statistical procedure is required to combine the effects of both mean and gust. This has been conducted by various researchers to develop an equivalent mean wind speed to represent the perceived effect of a gust event. This is called the 'gust equivalent mean' or 'effective wind speed' and the relationship between the mean and 3 s gust wind speed is defined within the criteria, but two typical conversions are:

$$U_{GEM} = \frac{(U_{1\,hour\,mean} + 3 \cdot \sigma_u)}{1.85} \text{ and } U_{GEM} = \frac{1.3 \cdot (U_{1\,hour\,mean} + 2 \cdot \sigma_u)}{1.85}$$

It is evident that a standard description of the relationship between the mean and impact of the gust would vary considerably depending on the approach turbulence, and use of the space.

A comparison between the mean and 3 s gust wind speed criteria from a probabilistic basis are presented in Figure 24 and Figure 25. The grey lines are typical results from modelling and show how the various criteria would classify a single location. City of Auckland has control mechanisms for accessing usability of spaces from a wind perspective as illustrated in Figure 24 with definitions of the intended use of the space categories included in this Figure.



Auckland Utility Plan (2016) wind categories

Category A	Areas of pedestrian use or adjacent dwellings containing significant formal elements and features intended to encourage longer term recreational or relaxation use i.e. public open space and adjacent outdoor living space
Category B	Areas of pedestrian use or adjacent dwellings containing minor elements and features intended to encourage short term recreation or relaxation, including adjacent private residential properties
Category C	Areas of formed footpath or open space pedestrian linkages, used primarily for pedestrian transit and devoid of significant or repeated recreational or relaxational features, such as footpaths not covered in categories A or B above
Category D	Areas of road, carriage way, or vehicular routes, used primarily for vehicular transit and open storage, such as roads generally where devoid of any features or form which would include the spaces in categories A - C above.
Category E	Category E represents conditions which are dangerous to the elderly and infants and of considerable cumulative discomfort to others, including residents in adjacent sites. Category E

Figure 24: Probabilistic comparison between wind criteria based on mean wind speed

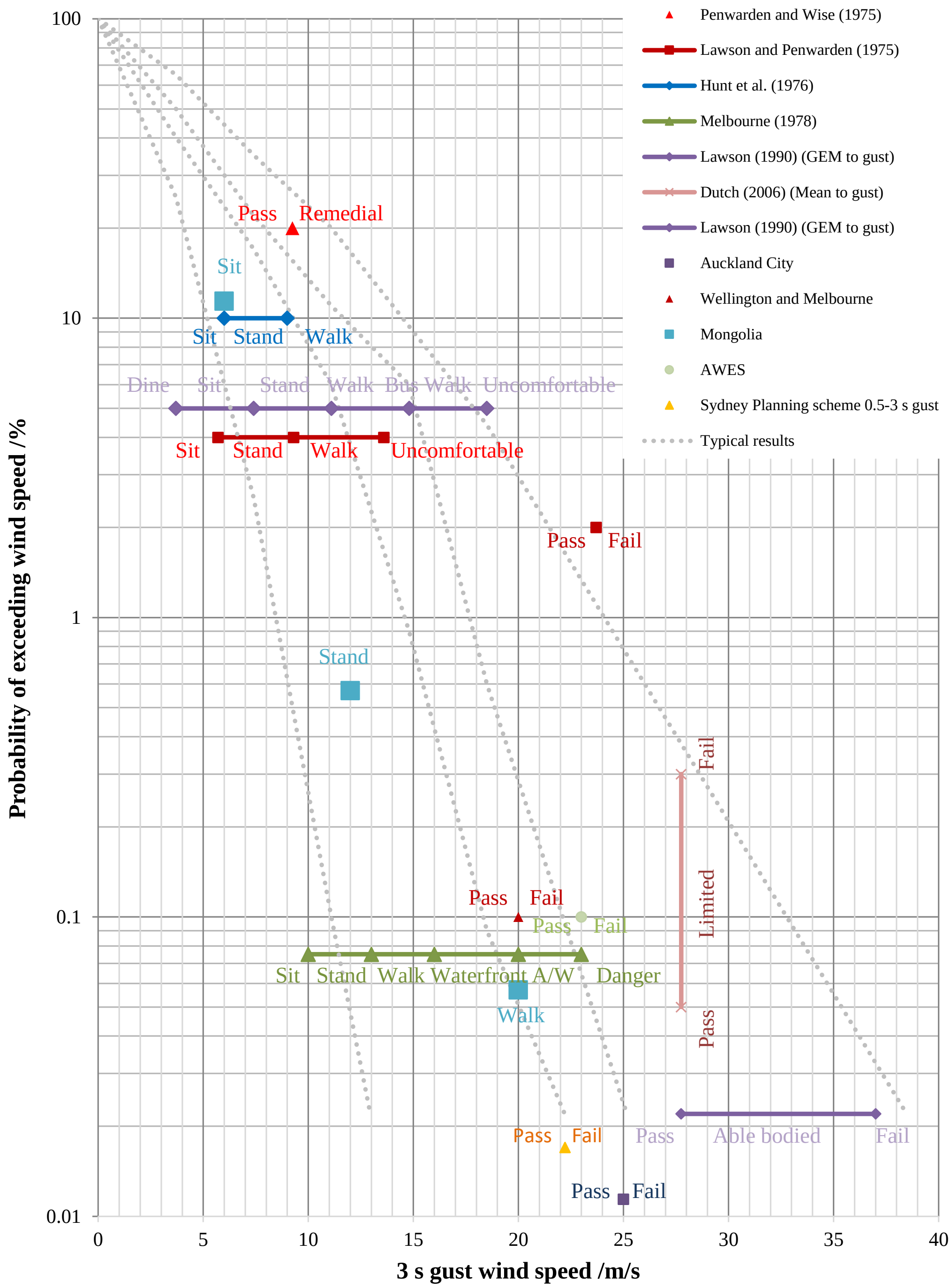


Figure 25: Probabilistic comparison between wind criteria based on 3 s gust wind speed

Appendix D Reference documents

In preparing the assessment, the following documents have been referenced to understand the building massing and features. The proposed building model and the topography were being updated via communications with Jacobs and TTW.

- RPA-ARC-BSA-DRG-MW-DA0001(A).pdf
- RPA-ARC-BSA-DRG-MW-DA0104(A).pdf
- RPA-ARC-BSA-DRG-MW-DA0301(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0302(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0303(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0304(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0305(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0306(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0307(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0308(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0309(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0310(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0311(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0312(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0313(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0314(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0315(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0316(B).pdf
- RPA-ARC-BSA-DRG-MW-DA0317(A).pdf
- RPA-ARC-BSA-DRG-MW-DA0318(A).pdf
- RPA-ARC-BSA-DRG-MW-DA0901(A).pdf
- RPA-ARC-BSA-DRG-MW-DA0902(A).pdf
- RPA-ARC-BSA-DRG-MW-DA1001(A).pdf
- RPA-ARC-BSA-DRG-MW-DA1002(A).pdf

- IA021700-SITE(35)
- IA251300-BLD12(28)
- IA251300-CAD(27)
- IA251300-FACADE (16)
- IA251300-FFE1(25)
- IA251300-FFE2(26)
- IA251300-MAIN(28)
- IA251300-NEWB-FFE(27)
- IA251300-NEWB-MAIN(46)