Appendix Q
Environmental Wind Assessment

Create NSW

Powerhouse Ultimo Renewal

Environmental Wind Assessment

Wind

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Executive summary

Arup have been commissioned by The Department of Enterprise, Investment and Trade (Create NSW) to provide an experienced-based impact assessment of the proposed renewal of the Powerhouse, Ultimo on the pedestrian level wind conditions for comfort and safety in and around the site.

The assessment has considered both the maximum building massing envelope and an indicative reference design prepared by JWA. For the maximum building massing envelope design, it is considered that the development would have a slight impact on the wind conditions in and around the site causing windier conditions around the southern corners. The indicative reference design would have minimal impact on the existing wind conditions.

Qualitatively, integrating the expected directional wind conditions around the site with the wind climate, it is considered that wind conditions at the majority of locations around the site would be classified as suitable for pedestrian standing with windier conditions around the building corners being classified as suitable for pedestrian walking. These are similar to the existing wind conditions around the site.

All locations around both the envelope and reference designs would be expected to pass the safety criterion.

To quantify the qualitative advice provided in this report, numerical or physical modelling of the development would be required, which is best conducted once the geometry has been finalised during detailed design.

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Disclaimer

This assessment of the site environmental wind conditions is presented based on engineering judgement. In addition, experience from more detailed simulations have been used to refine recommendations. No detailed simulation, physical or computational study has been made to develop the recommendations presented in this report.

1 Introduction

This report has been prepared on behalf of the Department of Enterprise, Investment and Trade (Create NSW) to support a State Significant Development (SSD) Development Application (DA) for alterations and additions to Powerhouse Ultimo at 500 Harris Street, Ultimo.

The Powerhouse Ultimo Renewal project comprises a transformative $480-$500 million investment by the NSW Government to establish a world-class museum that will significantly contribute to an important and developing part of Sydney. The renewal will see Powerhouse Ultimo deliver a programming focus on design and fashion, presenting exhibitions that showcase the Powerhouse Collection, international exclusive exhibitions, and programs that support the design and fashion industries.

1.1 Process

The Powerhouse Ultimo Renewal project is for the purposes of an 'information and education facility' with a capital investment value of more than $30 million, and such is classified as State Significant Development (SSD) pursuant to Section 13(1) of Schedule 1 of *State Environmental Planning Policy (Planning Systems) 2021*.

The delivery of the new Creative Industries Precinct for Powerhouse Ultimo will occur in stages, comprising the following:

- **Stage 1** – Concept DA establishing the planning, design, and assessment framework for the Powerhouse Ultimo Renewal Project including the indicative land uses, maximum building envelopes, general parameters for the future layout of the site, and strategies to guide the subsequent detailed design phases of the project including Urban Design Guidelines and Design Excellence Strategy.
- **Architectural Design Competition** – A competitive design process to critically analyse and provide design alternatives for the Powerhouse Ultimo Renewal project in accordance with the planning and development framework established for the site under the Concept DA. A winning design will be selected by a jury of experts and will inform the subsequent detailed design and assessment phase (Stage 2) of the project.
- **Stage 2** – A Detailed DA confirming the ultimate architectural design and operation of Powerhouse Ultimo and assessing any associated planning and environmental impacts. This Detailed DA will seek consent for the detailed design, construction and operation of the proposed development and follows the same planning assessment and determination process as the Concept DA (Stage 1).

1.2 Site Description

Powerhouse Ultimo is situated upon the lands of the Gadigal people of the Eora Nation. It is located within the City of Sydney Local Government Area and its primary address is 500 Harris Street, Ultimo.

The site contains two heritage-listed buildings, being the ‘Ultimo Power House’ (c.1899-1905) and the ‘Former Ultimo Post Office including interior’ (c.1901), both of which are listed on the State Heritage Register under the *Heritage Act 1997*, Figure 1. Other buildings within the site include the former tram shed (Harwood Building), and the 1988 museum building fronting Harris Street (Wran Building). A café building has been constructed immediately to the south of the Power House at the northern end of the Ultimo Goods Line. Located at the corner of Harris Street and Macarthur Street is a forecourt that acts as the main public entrance to the site, but provides limited activation and is disconnected from higher-quality urban spaces including the Ultimo Goods Line.

The primary focus of the Powerhouse Ultimo Renewal project is the museum to the north of Macarthur Street and bounded by Harris Street, Pier Street and the light rail corridor. However, some enabling and minor decoupling works will occur within the broader Powerhouse Ultimo precinct.

No substantive works or changes in use are proposed to the Harwood Building located between Macarthur Street and Mary Ann Street.

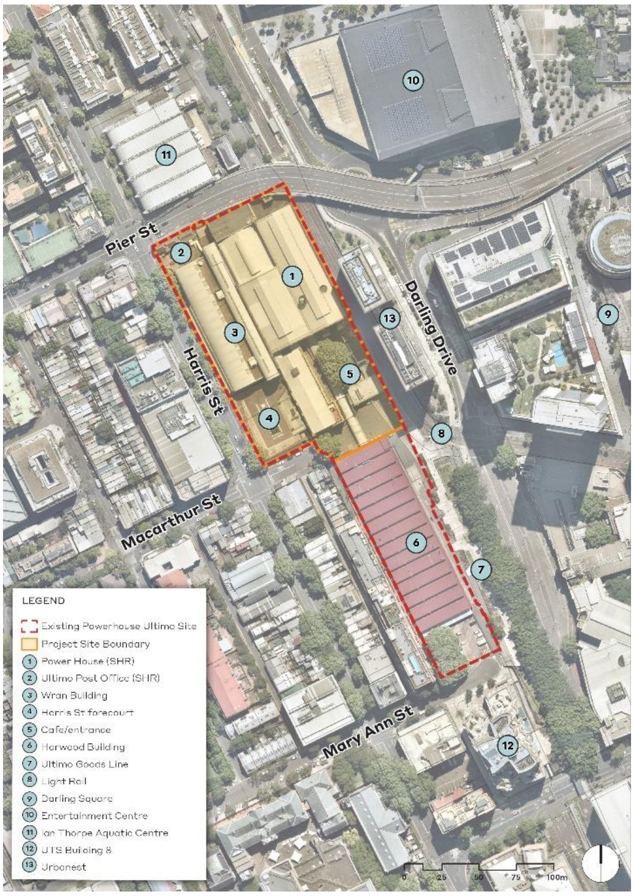

Figure 1: Site plan

1.3 Overview of Proposed Development

This Concept DA sets the vision for the renewal of Powerhouse Ultimo and the creation of the Powerhouse Creative Industries Precinct, with the detailed design, construction, and operation of the project to be sought at a separate and future stage (Stage 2).

Concept approval is sought for the following:

- A maximum building envelope for any new buildings and alterations and additions to existing buildings retained on the site.
- Use of the new spaces and built form as an ‘information and education facility’ including exhibition, education, and back of house spaces, and a range of related and ancillary uses to contribute to the operation of Powerhouse Ultimo.
- Endorsement of Urban Design Guidelines and a Design Excellence Strategy to guide the detailed design of the future building, internal spaces, and public domain areas that will be the subject of a competitive design process and a separate and future DA (Stage 2).
- An updated Conservation Management Plan to ensure that future development occurs in a manner that is compatible with, and facilitates the conservation of, the heritage values of the site.
- General functional parameters for the future design, construction, and operation of buildings and uses on the site including the principles and strategies for the management of transport and access, flooding, sustainability, heritage and the like.

1.4 Assessment Requirements

The Department of Planning and Environment (DPE) has issued Secretary’s Environmental Assessment Requirements (SEARs) to the applicant for the preparation of an Environmental Impact Statement (EIS) for the proposed development. This wind assessment report has been prepared with regard to the SEARs as noted in Table 1.

Table 1: Details of SEARs

Environmental Assessment Requirement	Where addressed in this report
5. Assess amenity impacts on the surrounding locality, including lighting impacts, reflectivity, solar access, visual privacy, visual amenity, view loss and view sharing, overshadowing and wind impacts. A high level of environmental amenity for any surrounding residential or other sensitive land uses must be demonstrated.	The entire document is the wind assessment report, in particular Section 3.

2 Site orientation and design

The Powerhouse Ultimo Renewal site is located on the block bounded by the light rail corridor to the east, and MacArthur, Harris, and William Henry Streets, Figure 2. The site is surround by low- to medium-rise buildings in all directions, except to the east where there are high-rise buildings. Topography surrounding the site drops to the east and rises to the crest of Pyrmont ridge to the west that runs south-south-east to north-north-west, Figure 2.

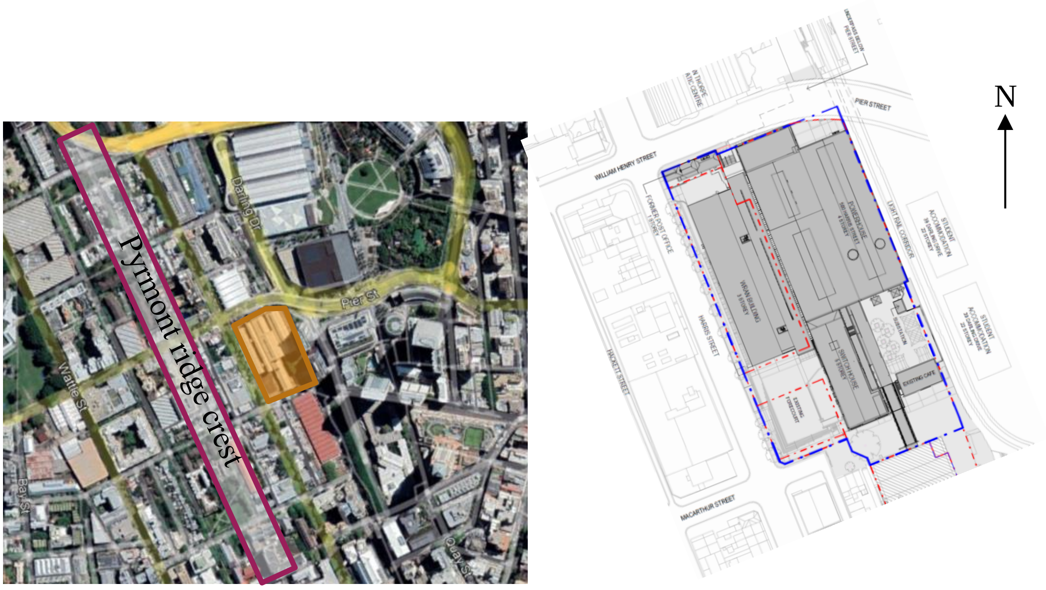

Figure 2 Site location (L Google Earth 2021) and existing site plan (R)

This wind assessment considers the overall envelope massing, Figure 3 as well as the initial reference design for the site, Figure 4. The overall envelope massing rises to about 30 m above local ground level with the design excellence 10% height bonus. From a wind perspective the main differences between the existing and reference scheme are the inclusion of a building in the south-west corner of the site, and the removal of the existing café building in the south-east corner of the site to open the pedestrian entrance from the Goods Line.

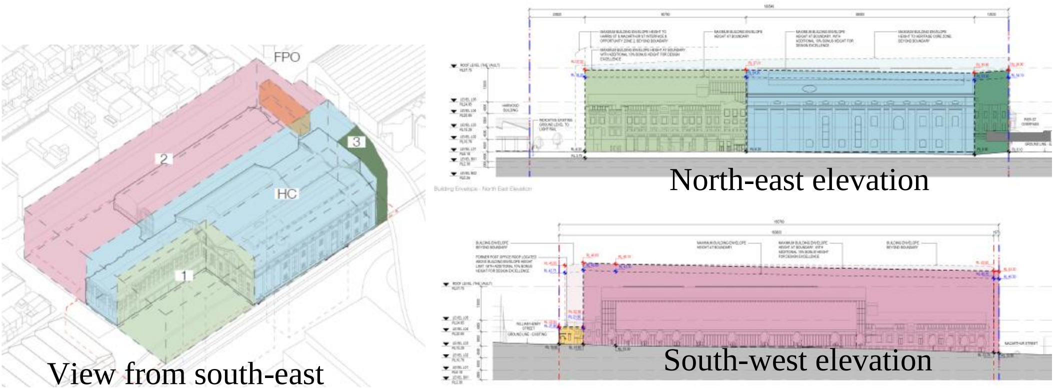

Figure 3: Envelope massing

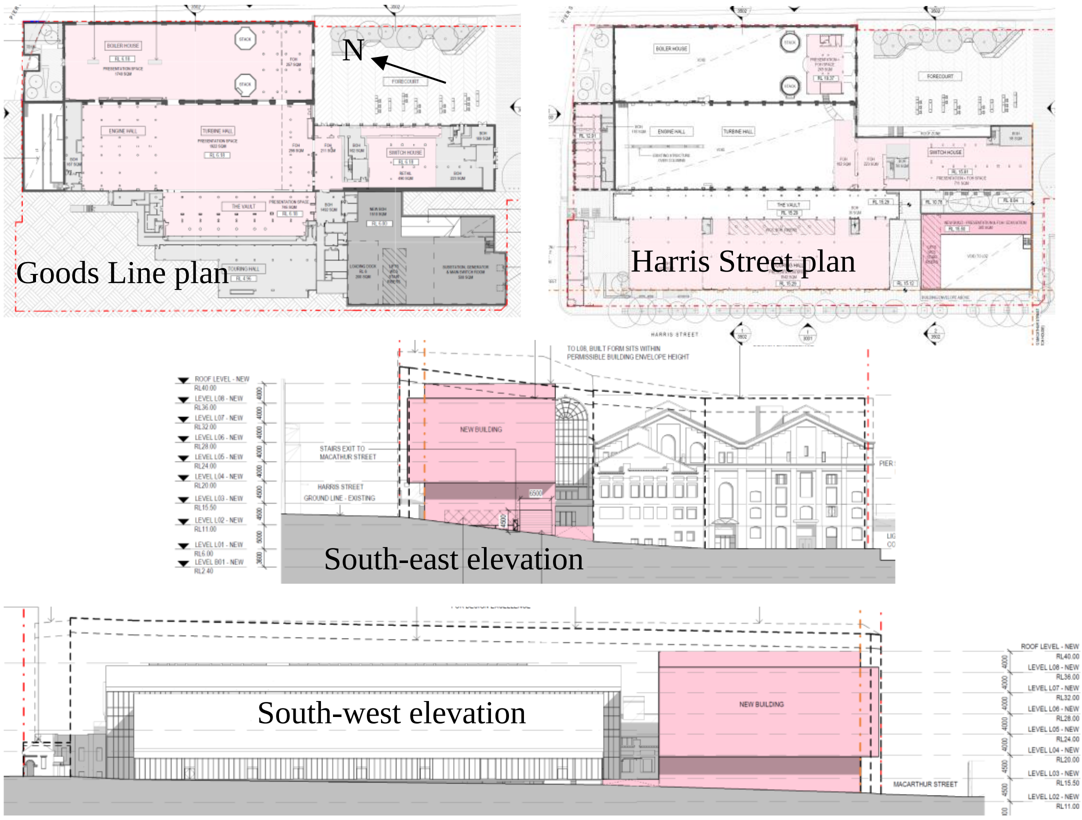

Figure 4: Reference design

3 Wind assessment

3.1 Local wind climate

Weather data recorded at Sydney Airport by the Bureau of Meteorology has been analysed for this project. The anemometer is located about 9 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 incident wind conditions at the site, due to the proximity to the site and distance from the coast.

It is evident from Figure 5 that the prevailing wind directions are from north-east, south, and west quadrants. The measured mean wind speed is about 4.5 m/s, and the 5% exceedance mean wind speed is 10 m/s.

A general description on flow patterns around buildings is given in Appendix 1

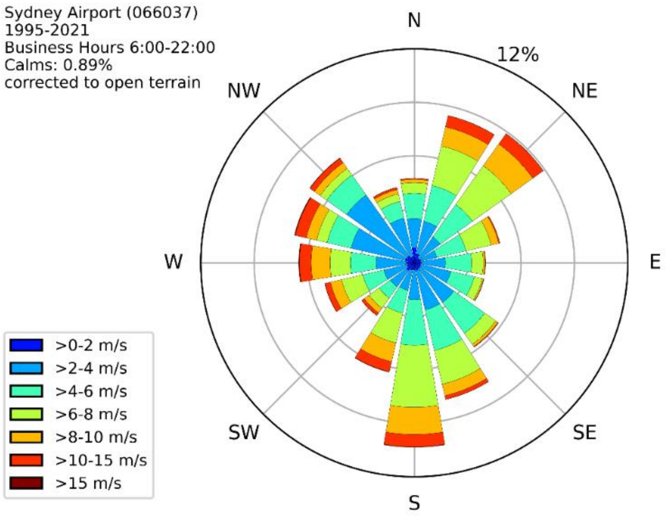

Figure 5. Wind rose showing probability of time of wind direction and speed during business hours 6 am to 10 pm

3.2 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 2.

The wind controls used in this wind assessment are the current Central Sydney Planning Strategy 2016-2036 wind controls, described in Figure 22 and Table 2. These comfort controls are based on the work of Lawson (1990). The safety criterion in Table 2 is based on a 0.5 s gust wind speed of 24 m/s occurring once per annum during daylight hours. The comfort criterion are based on a 5% of the time exceedance during daylight hours. With reference to the wind climate, transferring the measured 5% of the time wind speed to the site would result in a general wind speed of about 6 m/s, which would be on the classification boundary between pedestrian standing and walking. With knowledge of the site, this is considered an appropriate comfort classification.

Table 2 Pedestrian comfort criteria for various activities

Comfort (max. of mean or GEM wind speed exceeded 5% of the time from 6 am to 10 pm)	
<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 (peak 0.5 s gust wind speed in an hour of 24 m/s exceeded once per annum from 6 am to 10 pm (0.0171%))	

3.3 Predicted wind conditions on ground plane

This section of the report outlines the predicted wind conditions in and around the site based on the local climate, topography, and proposed building form. Redevelopment to the entire envelope massing could not be achieved due to other design guidelines hence generic design advice and potential impacts are provided for this case. Specific comments are provided for the reference scheme.

Compared with the massing of the surrounding buildings, the massing of the proposed redevelopment ranges from minor to significant depending on what spaces are activated in the envelope and will therefore have an impact on the local wind conditions.

Winds from the north-east

Winds from the north-east are ameliorated by the CBD before reaching the site and would impinge on the north-east face of the building, Figure 6. Pedestrian access to the north-east corner of the site is limited by the Light Rail corridor and access under Pier Street. The existing building is approaching the envelope height hence increasing the building height to the envelope would have a minimal impact on the ground-level wind conditions. The proximity of the elevated Pier Street and rising topography to the west offers additional protection to the local ground plane by encouraging flow over and around the building rather than down to ground level, Figure 7. The redirection of the incident flow along the Light Rail corridor is dictated by the taller buildings along Darling Drive.

The articulation of the north-west façade of the building in the reference scheme is beneficial in reducing the flow along Pier Street and around the corner with Harris Street. The lower height of the Post Office building in the west corner of the site is beneficial to improve the wind conditions at ground level.

The wind across the Forecourt in the south-east corner of the site is ameliorated by the existing café structure. Removal of this obstruction as per the reference design would be expected to adversely affect the wind conditions across the space with wind passing through the space, Figure 7. Any landscaping along the east boundary of the courtyard would reduce impact, Figure 8. The taller and denser the landscaping, the greater the reduction in wind speed. Similar mitigation could be achieved with landscaping along the south boundary, which could be investigated during detailed design.

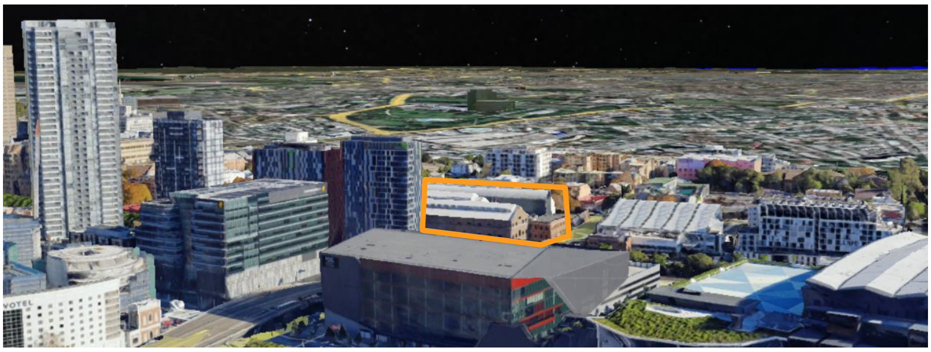

Figure 6: View for the site from the north-east (Google Earth, 2021)

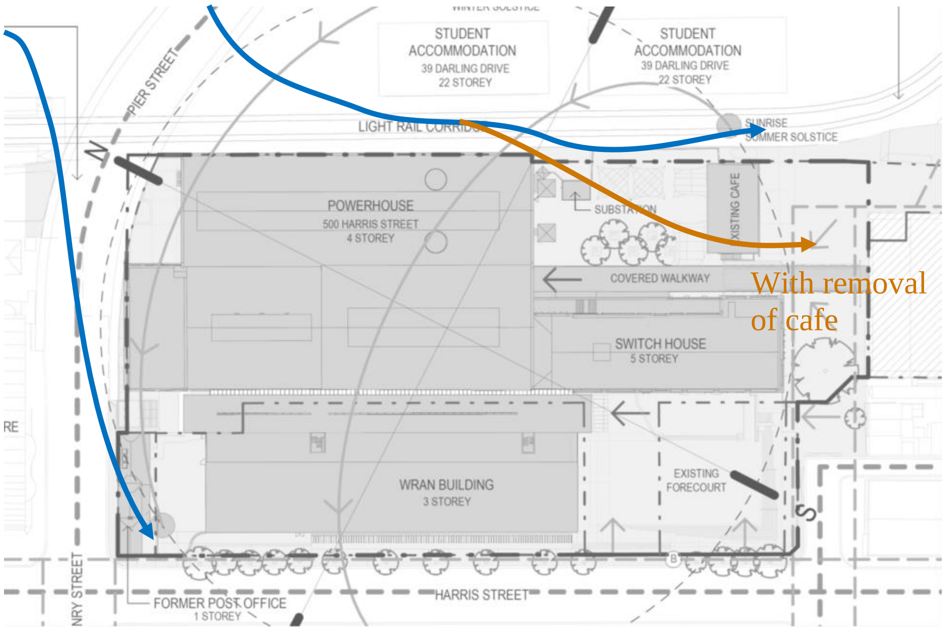

Figure 7: Sketch of flow pattern around building for winds from the north-east

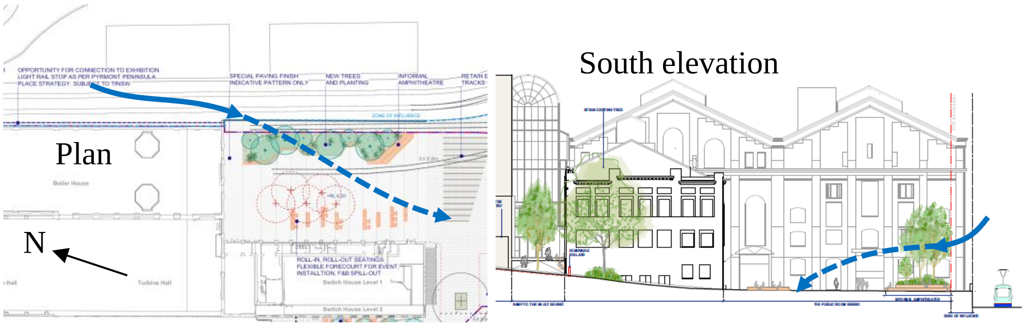

Figure 8: Proposed landscaping providing local amelioration

Winds from the south

Winds from the south are relatively undisturbed on reaching the site and redirected to the west by the overall massing of the city, Figure 9. On reaching the site, the flow at ground level has already been channelled along Harris Street and Ultimo Goods Line. Increasing the size of the south-east façade would induce more flow around the outer corners of the building, Figure 10. Even if extended to the envelope, this would not be expected to cause an issue from a safety perspective, but would impact the comfort level in these areas. The drop in topography to the east and the existing large mature tree in the middle of MacArthur Street are beneficial to reduce the wind flow at ground level to the east of the site by encouraging flow over the roof of the building, Figure 11.

A benefit of the reference design is the vertical articulation of building height to the east thereby encouraging flow over the top of the building rather than down to ground level, Figure 11. There will be some flow down MacArthur Street and across the forecourt. The removal of the café is slightly detrimental to the wind conditions in this open area and it would be recommended to include some form of landscaping barrier to the south of this area to improve the local wind conditions.

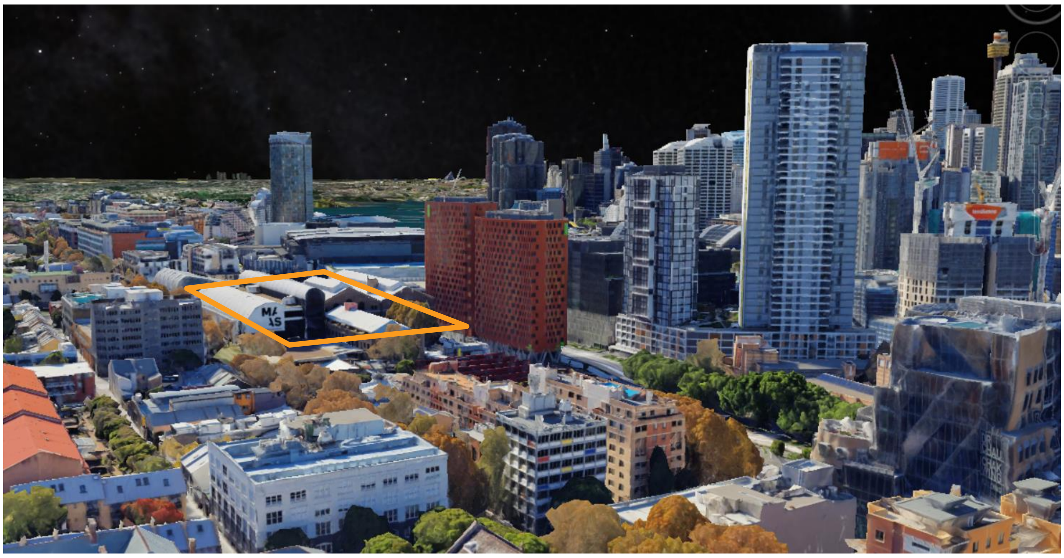

Figure 9: View from the south (Google Earth, 2021)

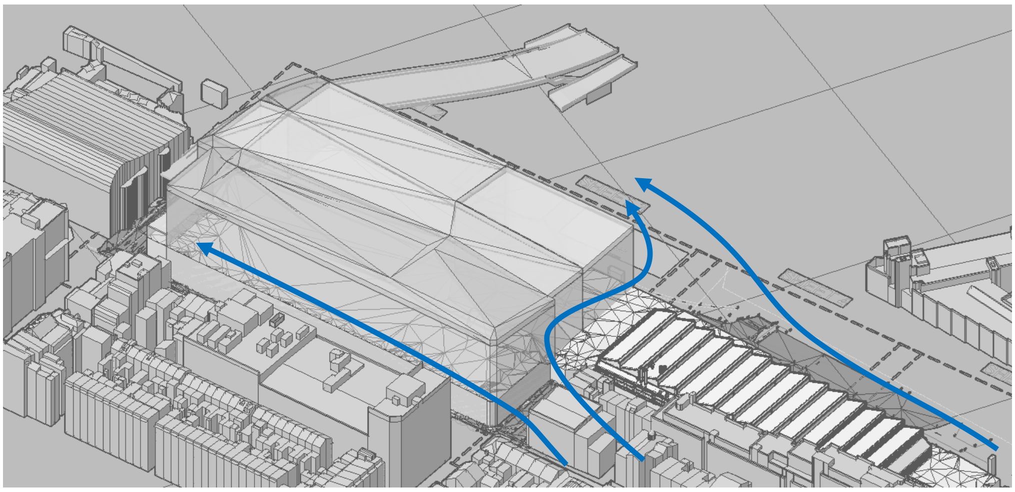

Figure 10: Sketch of flow patterns around envelope massing for winds from the south

Figure 11: Sketch of flow patterns around reference design for winds from the south

Winds from the west

The Powerhouse site is protected by the upstream buildings and topography for winds from the west. The wind conditions to the east of the site are governed by the neighbouring high-rise buildings. Any increase in building massing to the proposed envelope would be expected to have minimal impact on the pedestrian-level wind conditions in and around the site.

The additional large building in the south-west corner of the reference design, Figure 4, would marginally increase the wind speed on the corner of Harris and Macarthur Street.

Figure 12: View of the site from the west (Google Earth, 2021)

Discussion

Qualitatively, integrating the expected directional wind conditions around the entire envelope scheme with the wind climate, it is considered that wind conditions at the majority of locations around the site would be classified as suitable for pedestrian standing with faster conditions around the building corners where classification of pedestrian walking would be expected. These conditions would be slightly windier that around the existing articulated building.

Being smaller than the envelope massing, the reference design would have less of an impact on the wind conditions in and around the site.

4 Additional advice

The serviceability wind conditions around the precinct are important for the success of the facility. This is particularly true for spaces relying on outdoor activation throughout the year or for weather-dependent scheduled events. The Powerhouse currently has two known serviceability internal flow issues driven by the pressure differential around the building: at the main entry and through the café, Figure 13. Both of these issues occur for winds from the south quadrant. The former impacts the ticketing desk when the main door is open, whereas the latter impacts the internal space in the café while the outdoor courtyard space remains calm.

From a wind perspective, the current Powerhouse Museum is leaky with lots of external openings and gaps in the façade. When there is a dominant opening there is flow through the building. This is always an issue for buildings with a large internal volume with numerous external openings on different surfaces of the building. Care has to be taken during detail design to ensure that the internal flow conditions cause minimum impact to staff and operations as retro-fitting solutions is always awkward.

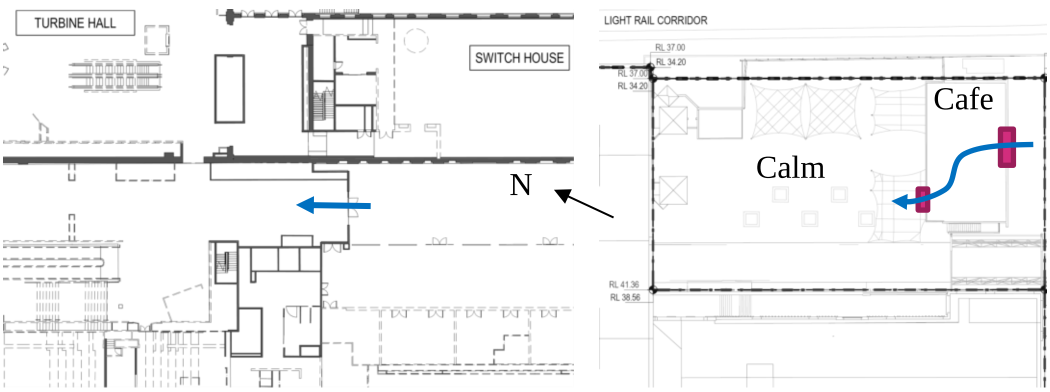

Figure 13: Internal flow patterns with existing building

The wind conditions in an outdoor area are best when more enclosed, with a ranking from best to worst:

1. Open central courtyard enclosed on all sides gives protection in all wind conditions. Depending on the height of the space, these can be airless with

any circulation requiring vertical movement of air or large entrances providing some flow across the space.

2. Courtyard enclosed on three sides. This configuration provides good protection for all wind directions as there is no flow path across the space. The open face allows for more circulation of flow than a fully enclosed space. This is the case for the current café courtyard area.
3. Corner courtyard enclosed on two orthogonal sides forming an L-shape. The wind conditions in the elbow of the L are generally good for all wind directions, with windier conditions experienced further from the building.
4. A space enclosed with two parallel walls, or a through-site link suffers from channelled flow for the majority of wind directions.

In the Sydney wind climate, local amelioration is typically required for any outdoor café areas. These are best designed into the building architecture.

5 References

City of Auckland, (2016), Auckland Unitary Plan Operative.

City of Sydney (2016), Central Sydney Planning Strategy 2016-2036.

City of Melbourne (2017), Melbourne Planning Scheme.

Hunt, J.C.R., Poulton, E.C., and Mumford, J.C., (1976), The effects of wind on people; new criteria based on wind tunnel experiments, Building and Environment, Vol.11.

Isyumov, N. and Davenport, A.G., (1975), The ground level wind environment in built-up areas, Proc. 4th Int. Conf. on Wind Effects on Buildings, Cambridge University Press, U.K.

Lawson, T.V., and Penwarden, A.D., (1975), The effects of wind on people in the vicinity of buildings, Proc. 4th Int. Conf. on Wind Effects on Buildings, Cambridge University Press, U.K.

Lawson, T.V., (1990), The Determination of the wind environment of a building complex before construction, Department of Aerospace Engineering, University of Bristol, Report Number TVL 9025.

Melbourne, W.H., (1978), Criteria for environmental wind conditions, J. Wind Engineering and Industrial Aerodynamics, Vol.3, No.2-3, pp.241-249.

Netherlands Standardization Institute, NEN, (2006). Wind comfort and wind danger in the built environment, NEN 8100 (in Dutch) Dutch Standard.

Penwarden, A.D. and Wise, A.F.E. (1975), Wind environment around buildings, Building Research Establishment Report, HMSO.

San Francisco Planning Department, (2015) San Francisco Planning Code Section 148.

Appendix 1: 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 14, 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 14. 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.

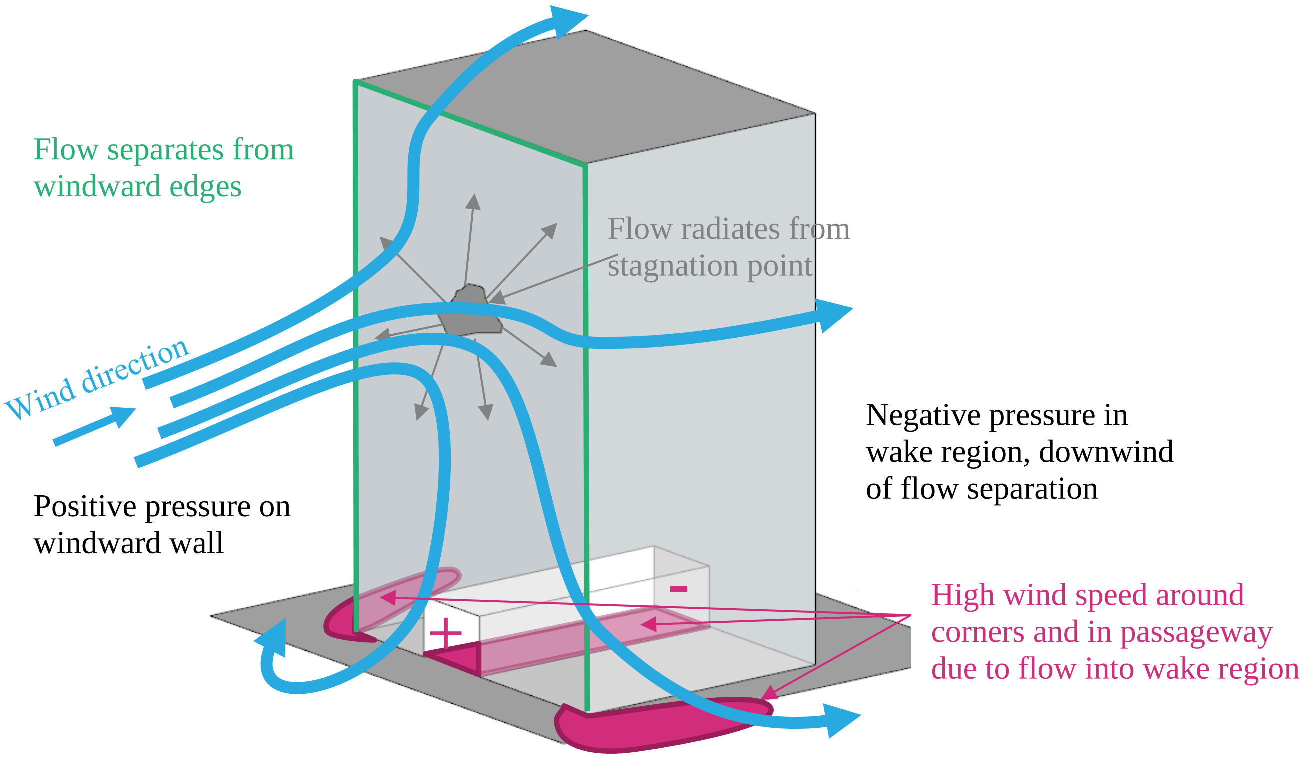

Figure 14 Schematic wind flow around tall isolated building

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 11. 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.

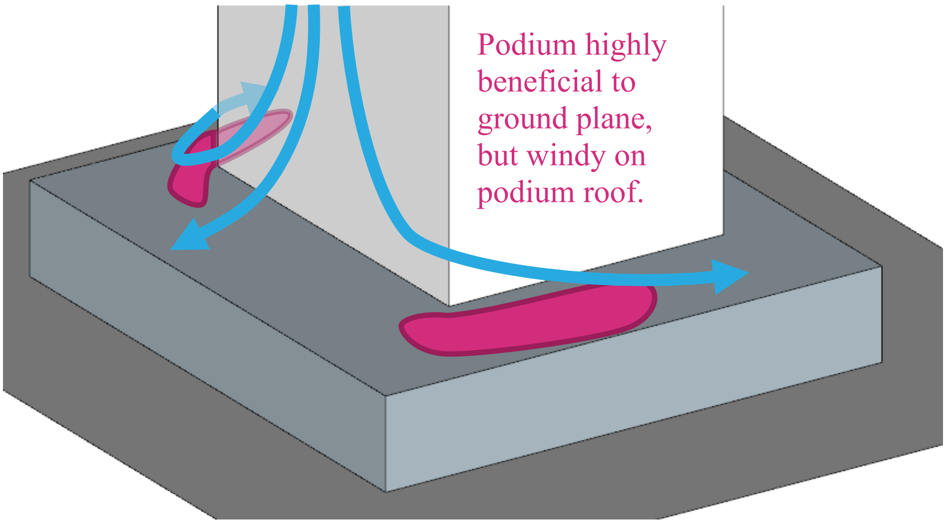

Figure 15 Schematic flow pattern around building with podium

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 16. 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.

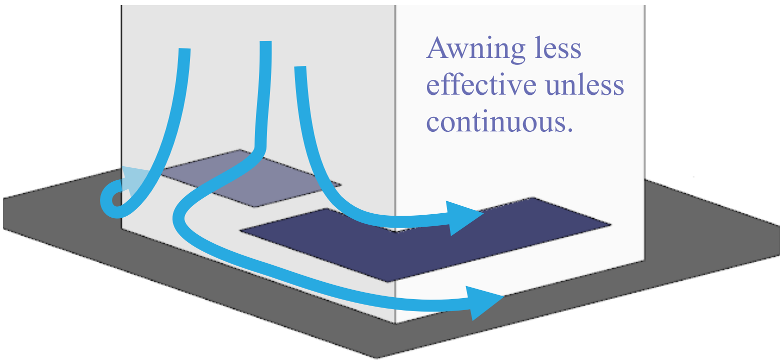

Figure 16 Schematic flow pattern around building with awning

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 17. Similarly, open through-site links through a building cause wind issues as the environment tries to equilibrate the pressure generated at the entrances to the link, Figure 14. If the link is blocked, wind conditions will be calm unless there is a flow path through the building, Figure 18. This area is in a region of high pressure and therefore the is the potential for internal flow issues. A ground level recessed corner has a similar effect as an undercroft, resulting in windier conditions, Figure 18.

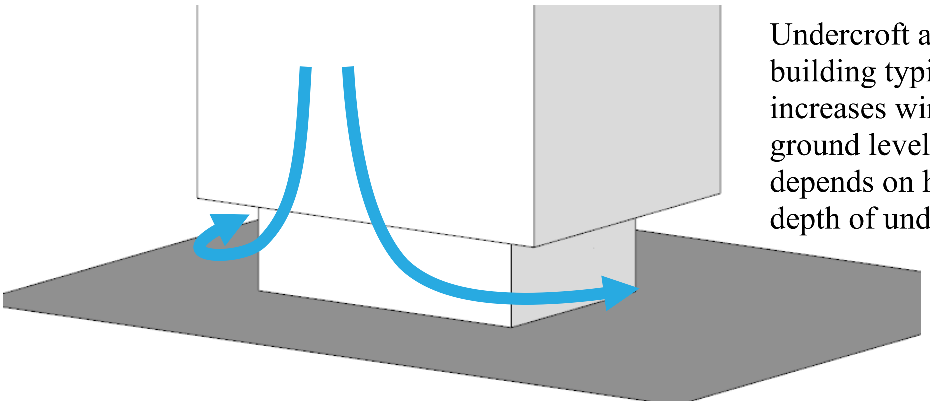

Figure 17 Schematic of flow patterns around isolated building with undercroft

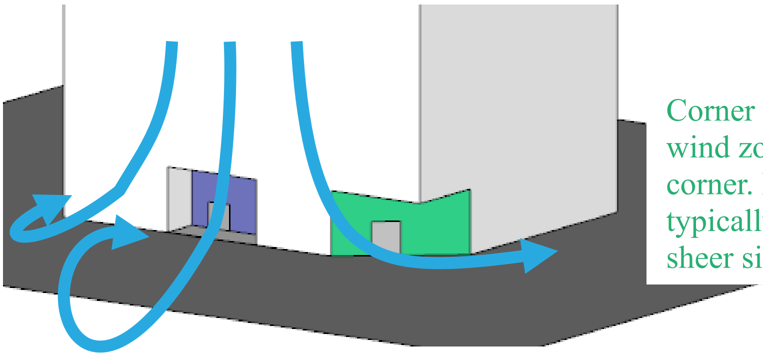

Figure 18 Schematic of flow patterns around isolated building with ground articulation

Multiple buildings

When a building is located in a city environment, depending on upwind buildings, the interference effects may be positive or negative, Figure 19. 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.

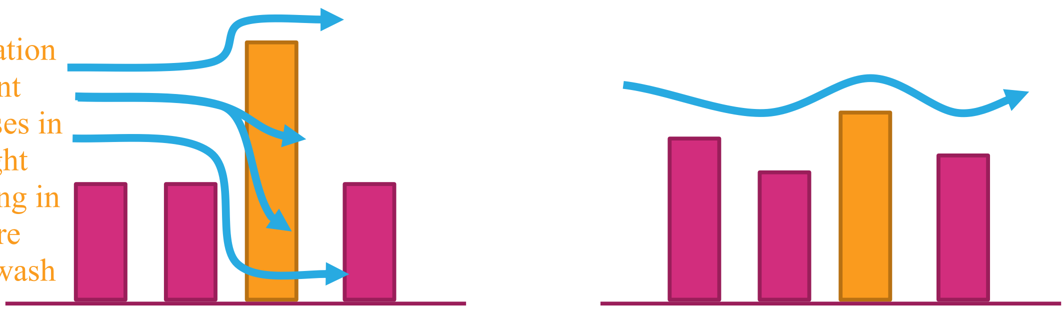

Figure 19 Schematic of flow pattern interference from surrounding buildings

The above discussion becomes more complex when three-dimensional effects are considered, both with orientation and staggering of buildings, and incident wind direction, Figure 20.

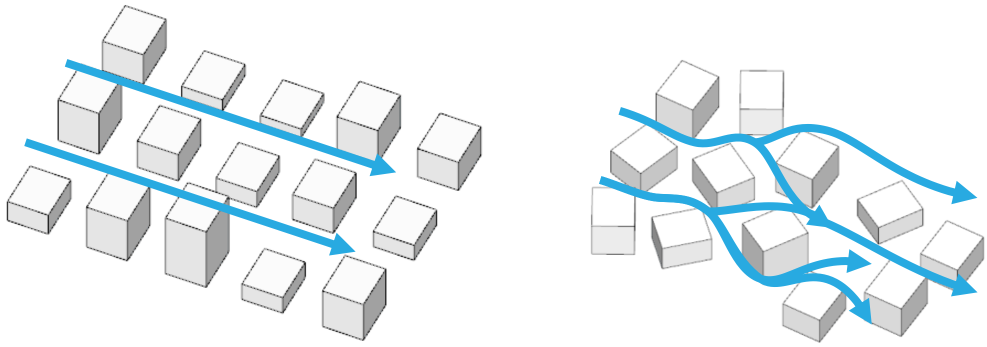

Figure 20 Schematic of flow patterns through a grid and random street layout

Channelling occurs when the wind is accelerated between two buildings, or along straight streets with buildings on either side, Figure 20(L), particularly on the edge of built-up areas where the approaching flow is diverted around the city massing and channelled along the fringe by a relatively continuous wall of building facades. This is generally the primary mechanism driving the wind conditions for this perimeter of a built-up area, particularly on corners, which are exposed to multiple 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 20(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 21, 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 21. 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.

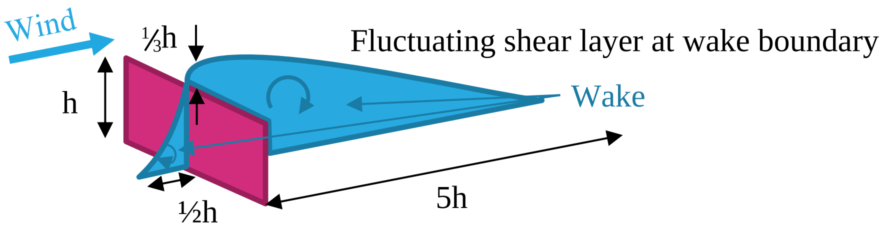

Figure 21: Sketch of the flow pattern over an isolated structure

Appendix 2: 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:

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

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 22 and Figure 24. 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 22 with definitions of the intended use of the space categories defined in Figure 23.

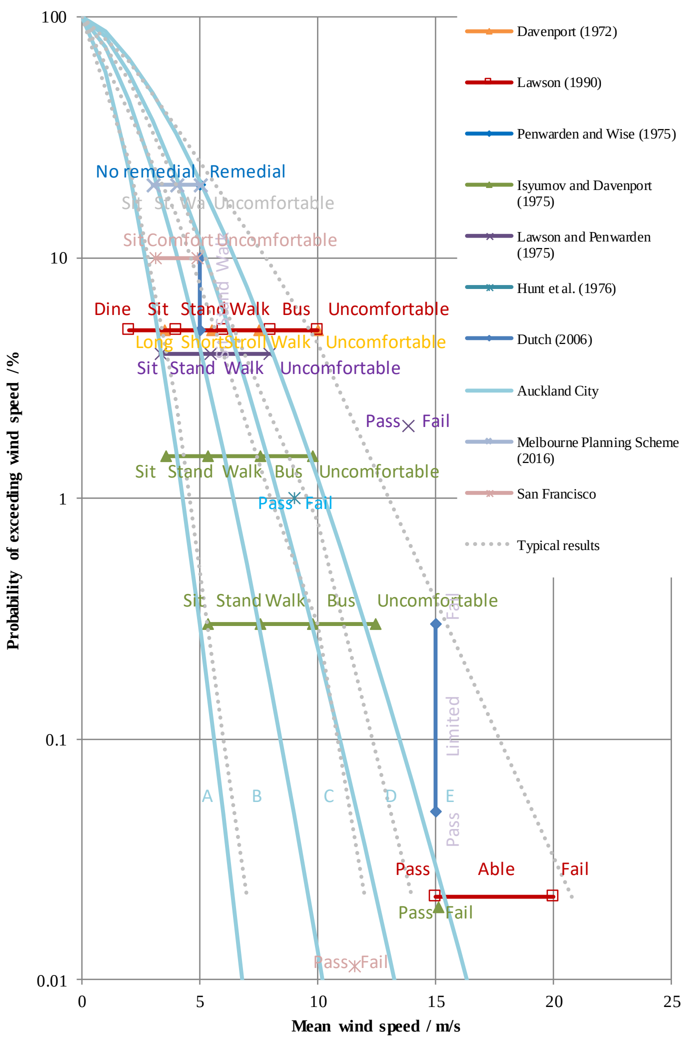

Figure 22 Probabilistic comparison between wind criteria based on mean wind speed

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 23: Auckland Utility Plan (2016) wind categories

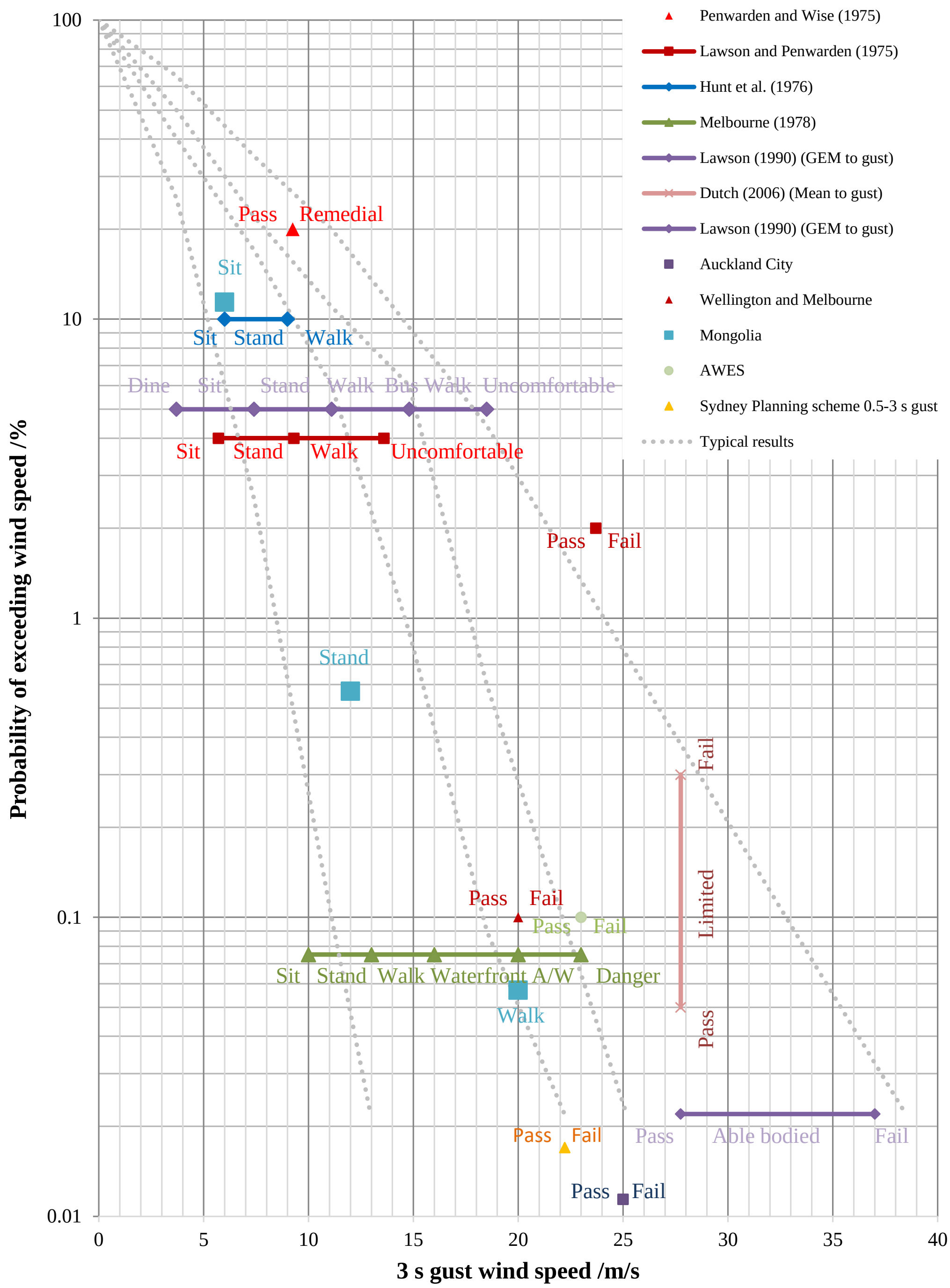

Figure 24 Probabilistic comparison between wind criteria based on 3 s gust wind speed

Appendix 3: Reference documents

In preparing the assessment, the following documents have been referenced to understand the building massing and features.

AR-0000_1.pdf
AR-0400_6.pdf
AR-0401_6.pdf
AR-0500_6.pdf
AR-0700_6.pdf
AR-0701_6.pdf
AR-0800_7.pdf
AR-0900_4.pdf
AR-0901_5.pdf
AR-0902_6.pdf
AR-0903_3.pdf
AR-0904_3.pdf
AR-0905_3.pdf
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AR-1004_7.pdf
AR-1005_6.pdf
AR-1006_6.pdf
AR-1007_4.pdf
AR-1008_4.pdf
AR-1009_4.pdf
AR-1010_6.pdf
AR-3000_6.pdf
AR-3001_6.pdf
AR-3500_6.pdf
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AR-9005_3.pdf
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Landscape drawings

LA-001 A
LA-51 A
LA-100 A
LA-101 A
LA-200 A
LA-201 A
LA-500 A
LA-501 A