Ethos Urban

Bon Marche and Science Precinct University of Technology Sydney

Environmental Wind Assessment

Wind

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Job number 259272-51

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Executive summary

Arup have been commissioned by Ethos Urban on behalf of the University of Technology Sydney (UTS) to provide an experienced-based impact assessment of the proposed UTS Bon Marche and Science Precinct developmenton the pedestrian level wind conditions for comfort and safety in and around the site. The wind conditions on the podium terrace has been discussed.

It is considered that the proposed development would have a minimal impact on the wind conditions in and around the site and the resulting wind conditions would be similar to existing conditions with the majority of locations being classified as suitable for pedestrian standing type activities. All locations would be expected to meet the safety criterion.

Benefits of the design include the orientation of the building to the prevailing wind directions, and the significant setback from Thomas Street and Broadway.

To quantify the wind conditions, numerical or physical modelling would be required. At this stage of the design process, this testing would be best conducted on the final geometry. For a development of this size, location relative to larger buildings, and orientation relative to prevailing wind directions it would not be expected to conclude any safety issues with the design.

Contents

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

Arup have been commissioned by Ethos Urban on behalf of UTS to provide a qualitative environmental wind assessment for the proposed Bon Marche and Science Precinct development. This report outlines the assessment and subsequent recommendations for wind engineering services related to pedestrian wind comfort and safety on the ground level and elevated terraces.

This report supports a Section 75W modification application submitted to the Minister for Planning pursuant to the Environmental Planning and Assessment Act 1979 (EP&A Act) and more specifically, Schedule 2 of the Environmental Planning and Assessment (Savings, Transitional and Other Provisions) Regulation 2017.

The Application relates to the Concept Plan Approval for the University of Technology Sydney (UTS) City Campus Broadway Precinct, which was approved in December 2009 (MP08_0116).

More specifically the modification application relates to the Bon Marche and Science Precinct (Buildings 3, 4, 9, and 18) and includes establishing new building envelopes with corresponding height and Gross Floor Area (GFA).

To quantify the qualitative advice provided in this report, numerical or physical modelling would be required.

2 Client provided text

2.1 Overview of Proposed Modifications

The s75W Application seeks the following key modifications to the approved Concept Plan:

- conceptual demolition of existing Building 4, and rear section of Building 3;
- conceptual modification to heritage items, Buildings 3, 9, and 18;
- creation of a new building envelope for Building 4, Building 3 (part) and Building 9 (cantilevering over only), resulting in a maximum height of RL 86.55, an increase of approximately 45 m above existing Building 4 and approximately 50 m above existing Building 3;
- corresponding increase in GFA for Building 4 and Building 3, comprising an additional increase of up to 36,500 m^2;
- consequential amendments to the Urban Design Quality Controls/Principles to guide the future development of the Bon Marche and Science Precinct; and
- indicative landscape and public domain concept for the precinct.

The proposed new envelope for the Bon Marche and Science Precinct will accommodate a future building that will have an effective maximum height of 15/16 storeys above Harris Street and six (6) storeys above Thomas Street (i.e. excluding basement levels and plant). The resulting total GFA for the Bon Marche and Science Precinct (new building envelope and existing buildings) is 73,103 m^2.

No physical works are proposed as part of this s75W modification application, with detailed application(s) to follow any approval granted.

2.2 Background

2.2.1 Evolution of UTS

UTS was formed in 1988 from the former NSW Institute of Technology, and was restructured in 1990 with the merger of the Kuring-gai College of Advanced Education, the School of Design, and the Institute of Technical and Adult Teacher Education to form the current UTS. This change in profile, combined with the University's predominantly CBD location in Sydney, created a new identity. During its early evolution, student numbers increased at UTS without any significant increase in student facilities.

UTS recognised the need to upgrade the City Campus back in 2000, and undertook a number of visioning and master planning projects culminating in the City Campus Masterplan 2020 (BVN, 2008) which provided a framework for refurbishments and new building works across the campus (comprising the Broadway Precinct and other sites in the Sydney CBD) in order to provide improved facilities and to accommodate future expected student and staff growth.

On 23 December 2009 a critical step in realising UTS's vision and identity for the Broadway Precinct was realised, with approval of the UTS City Campus Broadway Precinct Concept Plan (BPCP).

Since approval of the Concept Plan in 2009 UTS has secured the necessary detailed planning approvals and delivered a number of state of the art and iconic learning, research and social facilities across the Broadway Precinct, Figure 1, including:

- Faculty of Engineering and IT Building, designed by Denton Corker Marshall Architects.
- Multi-Purpose Sports Hall, designed by PTW Architects.
- Alumni Green, designed by ASPECT Studios Landscape Architects.
- Faculty of Science and Graduate School of Health Building, designed by Durbach Block Jaggers in association with BVN Architecture.
- Library Retrieval System, designed by Hassell Architects.
- Great Hall and Balcony Room Upgrade, Designed by DRAW Architects in association with Kann Finch Architects.
- Student Housing Building, designed by nettletontribe.

The UTS Central Project (designed by fjmt in collaboration with Lacoste + Stevenson in association with Darryl Jackson Robin Dyke Architects) represents the latest project being delivered by UTS to meet the needs of staff and students. The first phase of the UTS Central Project, which required a modification to the Concept Plan (MOD 5), is expected to be completed in 2019. The second phase of this project will include an extension to the podium of Building 1 addressing Broadway.

UTS currently has less than 2% of space across campus unallocated which is insufficient to accommodate forecast continued growth in student and staff numbers in the future. The educational facilities within the existing Bon Marche Building 3 are outdated and inadequate to meet the needs of contemporary teaching and learning environments.

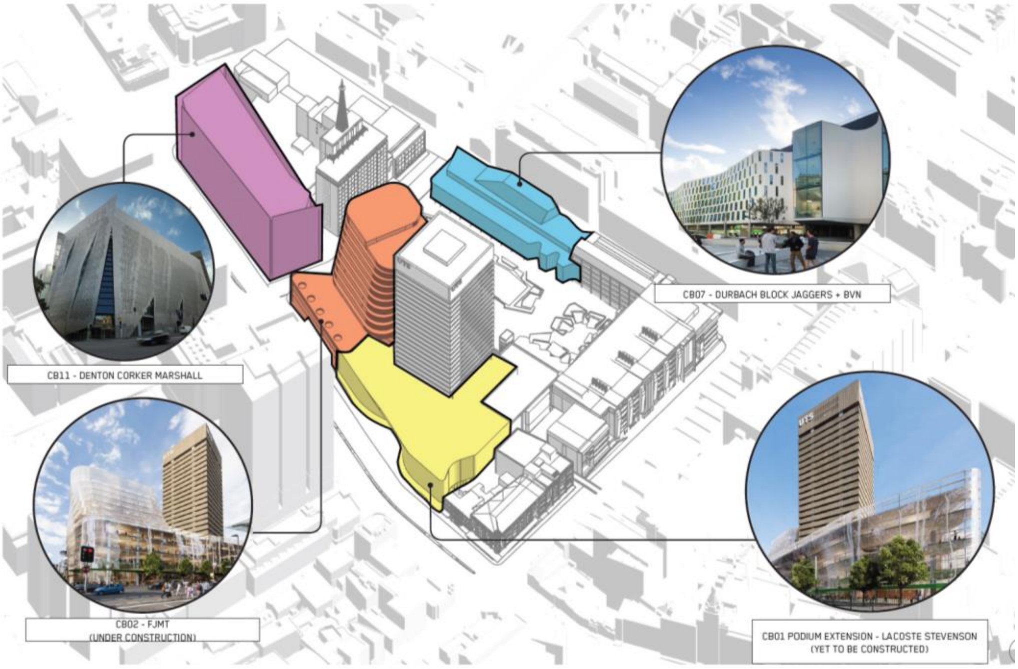

Figure 1: Key UTS projects approved/delivered under the Concept Plan (BVN)

The existing Science buildings (Building 4) are nearing the end of their lifecycle, which together with the continued growing demands from students locally and abroad and growth in both Science and Design, Architectural and Building (DAB) faculties presents an opportunity for UTS to progress with plans to support additional and much needed teaching and research space.

UTS plays an important role in the success of Sydney and NSW, with the Greater Sydney Commission's recently released Sydney Regional and District plans acknowledging this importance and identifying the need to protect and support the growth of education activity within the Harbour CBD Innovation Corridor.

2.2.2 Evolution of concept plan

The UTS City Campus Broadway Precinct Concept Plan (BPCP, as illustrated in Figure 2) was approved by the then Minister for Planning on 23 December 2009 (MP08_0116). The Concept Plan initially included:

- new Broadway Building and Thomas Street Building with a combined gross floor area (GFA) of 44,650 m^2;
- expansion of Buildings 1 and 2 with a combined additional GFA of 10,800 m^2;
- expansion of Building 6 for the provisions of student housing with an additional 25,250 m^2 GFA;
- modifications to Buildings 3, 4, and 10;
- modifications to Alumni Green with a new Multi Purpose Sports Hall and book vault beneath; and
- public domain improvements to Broadway and Thomas, Harris, Wattle, and Jones Streets.

The Minister also granted Project Approval for the following works:

- Construction of a new underground Multi Purpose Sports Hall; and
- Demolition of Buildings 11, 12 and 13.

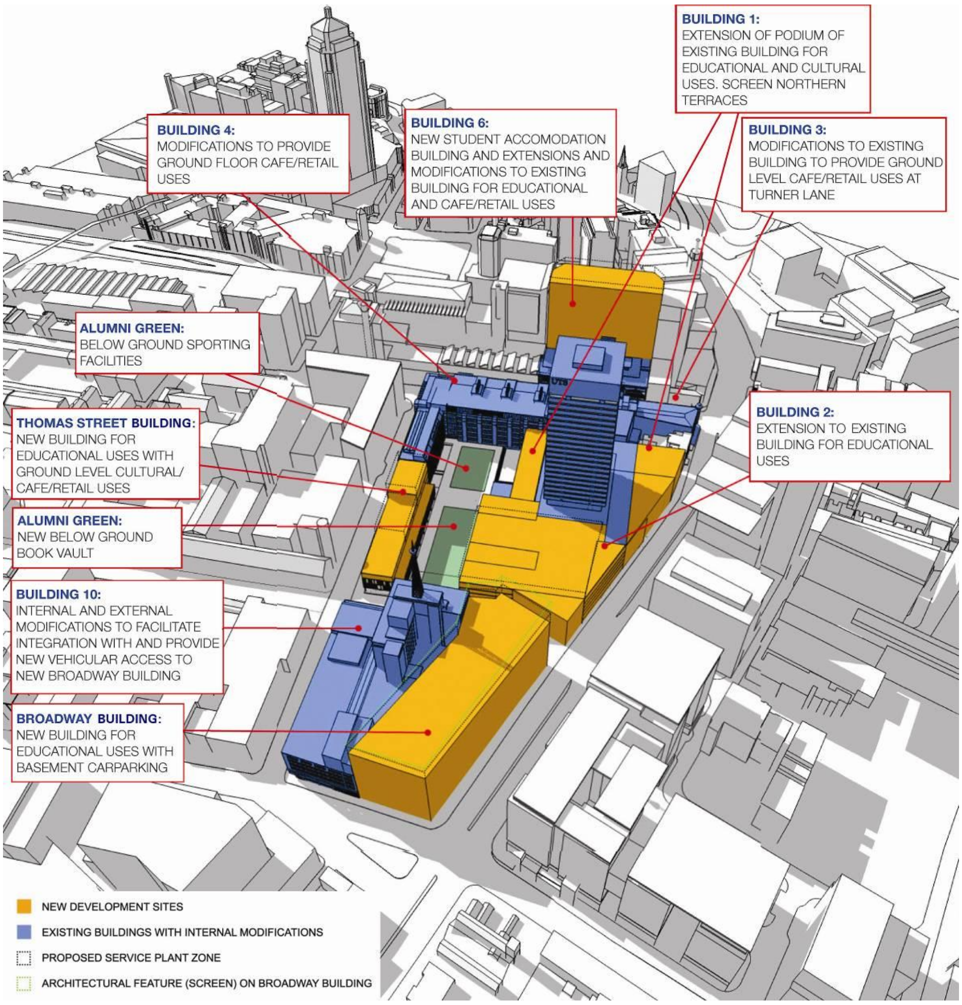

Figure 2: 3D Model of approved concept plan (Source: BVN, DCM and JBA)

The Concept Plan did not set new maximum heights and GFA for the Bon Marche and Science Precinct as demand for growth or redevelopment of these buildings was not identified at the time. The Concept Plan (2009) was informed by UTS's Growth Plan at the time to 2020, which had not foreseen that additional floor area and significant modifications and upgrades to existing buildings was required in the Bon Marche and Science Precinct. The 2009 Concept Plan also did not take into account the lifecycle status of Building 4, which was recently investigated and reported to be nearing end of life in 2026.

Since the Concept Plan was approved, five (5) subsequent modifications have been approved.

- Modification No 1 (MP 08_0116 Mod 1), approved in March 2011, sought to include bulk excavation works for the Broadway Building as part of the Project Approval works granted under the Concept Plan approval (enabling these works to be undertaken ahead of the Project Application for the building).

- Modification No 2 (MP 08_0116 Mod 2), approved in March 2011, related to an administration amendment to Concept Plan condition B2.
- Modification No 3 (MP 08_0116 Mod 3), approved in July 2011, sought to include the excavation, construction and operation of the Library Retrieval System (LRS) and Storage Building together with bulk excavation works for the Thomas Street Building as part of the Project Approval works granted under the Concept Plan approval (enabling these works to be undertaken without any further environmental assessment).
  The modification also included a revised breakdown of GFA across the UTS Broadway site, with the Environmental Assessment submitted in support of the S75W identifying an increased GFA for the Thomas Street building of 12,150 m^2 (corresponding with a decreased GFA for the Broadway Building of 34,650 m^2).
- Modification No 4 (MP 08_0116 Mod 4), approved in March 2012, related to an administration amendment to Concept Plan condition E3 (approved truck route plan for excavation of Thomas Street building and the library retrieval system).
- Modification No 5 (MP 08_0116 MOD 5) was approved by the then Minister for Planning in March 2016 and facilitated an expanded Building 2 envelope (maximum RL of 79.5) and corresponding increase in GFA for a new Building 2 and the Building 1 podium extension (resulting in a total maximum of 60,357 m^2). The modification provided the planning framework for the UTS Central project currently under construction.

This report has been prepared in support of proposed Modification No 6 (MP 08_0116 Mod 6) to the Concept Plan.

2.3 SEARs

Secretary's Environmental Assessment Requirements (SEARs) were issued by the Department of Planning and Environment (DP&E) on 1 February 2018. Specifically, this report responds to SEARs requirements 5 addressing the impact of the proposed development on the local wind amenity.

2.4 The site

The Broadway Precinct of the UTS City Campus is located on the southern edge of the Sydney Central Business District (CBD). The UTS City Campus is located entirely within the Sydney Local Government Area.

The Campus has frontages to Broadway, Thomas, Wattle and Harris Streets, and the Goods Line [change text in diagram as no longer known as the UPN] and is less than 700 m from Central Railway Station. Jones Street runs through the Precinct. The area covered by the Concept Plan (MP 08_0116) is shown in Figure 3.

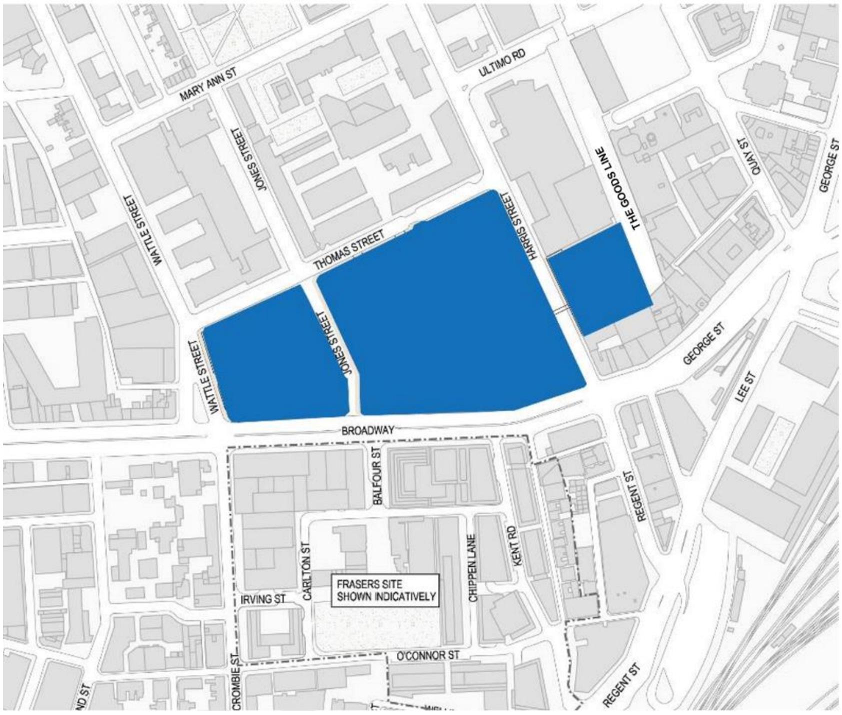

Figure 3: Site context (BVN)

More specifically, the Bon Marche and Science Precinct is located within the eastern part of the Broadway campus between Thomas Street and Broadway with frontage to Harris Street. It incorporates Buildings 3, 4, 9, and 18. Buildings 3, 9, and 18 are identified as heritage items under the *Sydney Local Environmental Plan 2012* (SLEP 2012). Refer to Figure 4 and Figure 5 for the location of the Bon Marche and Science Precinct.

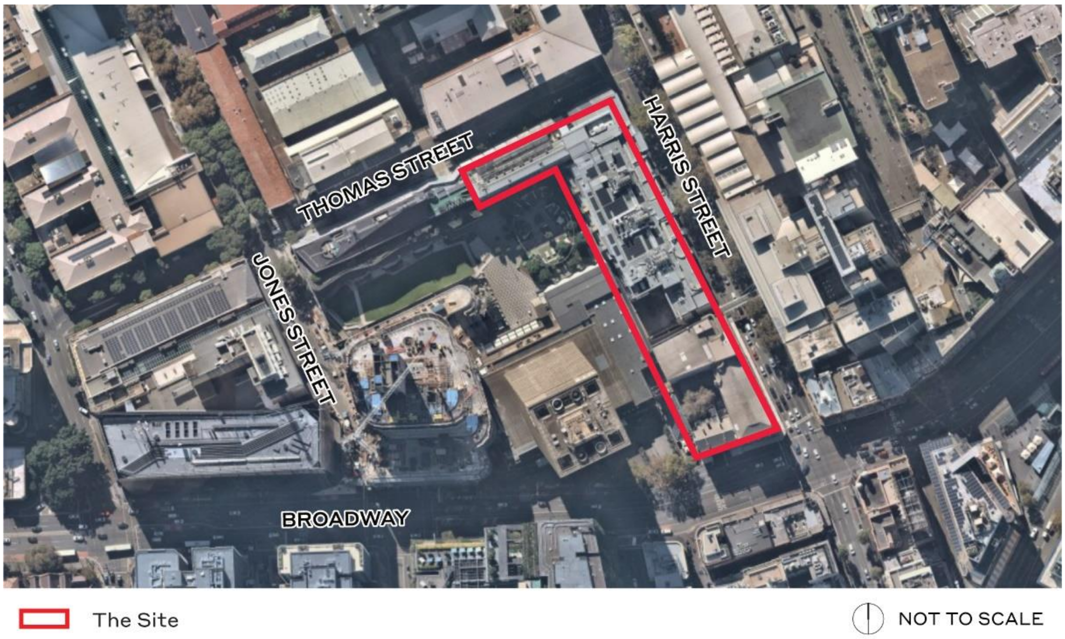

Figure 4: Aerial image of Bon Marche and Science Precinct (outlined in red) – May 2018

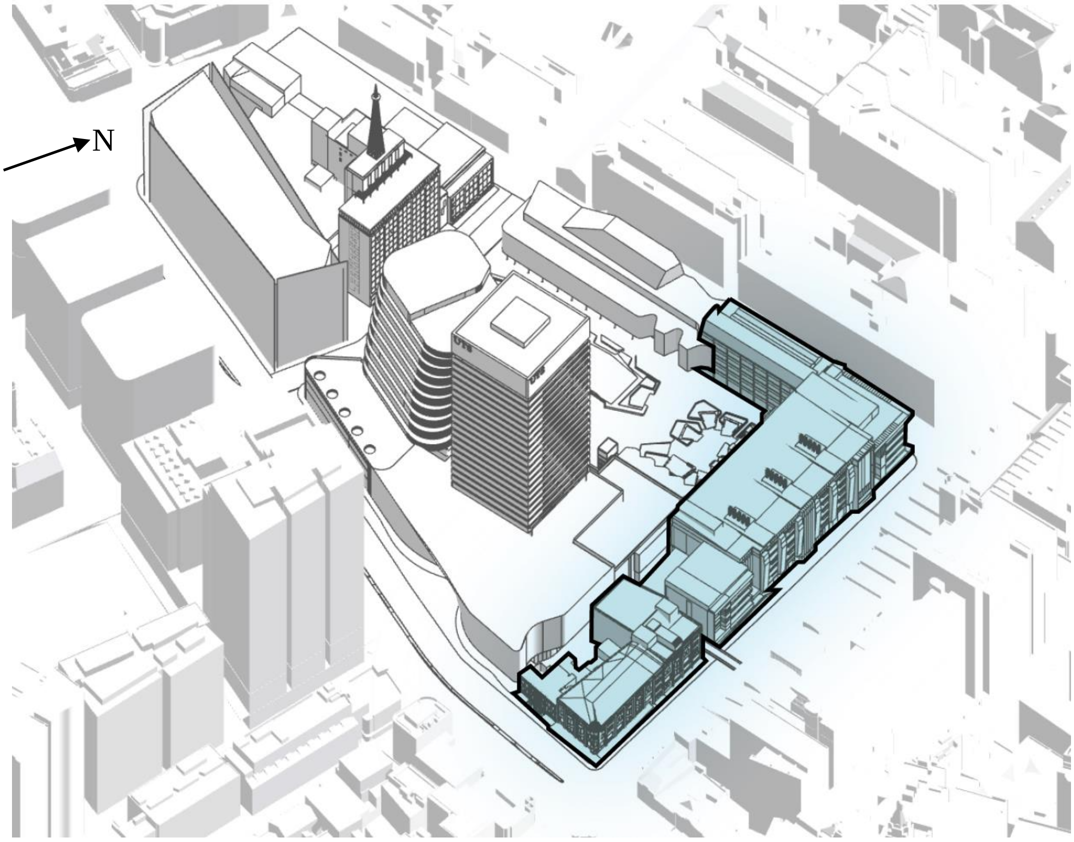

Figure 5: 3D perspective of the existing Bon Marche and Science Precinct (BVN)

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 analysis is summarised in Appendix 1. Strong prevailing winds for the site are from the north-east, south, and west quadrants. This wind assessment is based on these wind directions.

A general description on flow patterns around buildings is given in Appendix 2.

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 3.

The current draft Central Sydney Planning Strategy 2016-2036 wind controls are based on the work of Lawson (1990), described in Figure 17 and Table 1. The safety criterion 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.

3.3 Site description

The proposed Bon Marche and Science Precinct site is located on the block bounded by Broadway, and Jones, Thomas, and Harris Streets, Figure 3 and Figure 4. The site is surrounded by a range of medium- to high-rise buildings that offer some shielding to prevailing winds. From a wind perspective, topography surrounding the site is relatively flat, dropping slightly to the north-west along Harris Street, and rising slightly along Regent Street to the south-east.

The proposed development envelope consists of a lower rise podium across the entire site with maximum height of 6 storeys above ground level. Above the podium level along the south side of Harris Street, Figure 6 and Figure 7, there are an additional 10-storeys above podium level. The maximum height of the development is about 77 m above ground level.

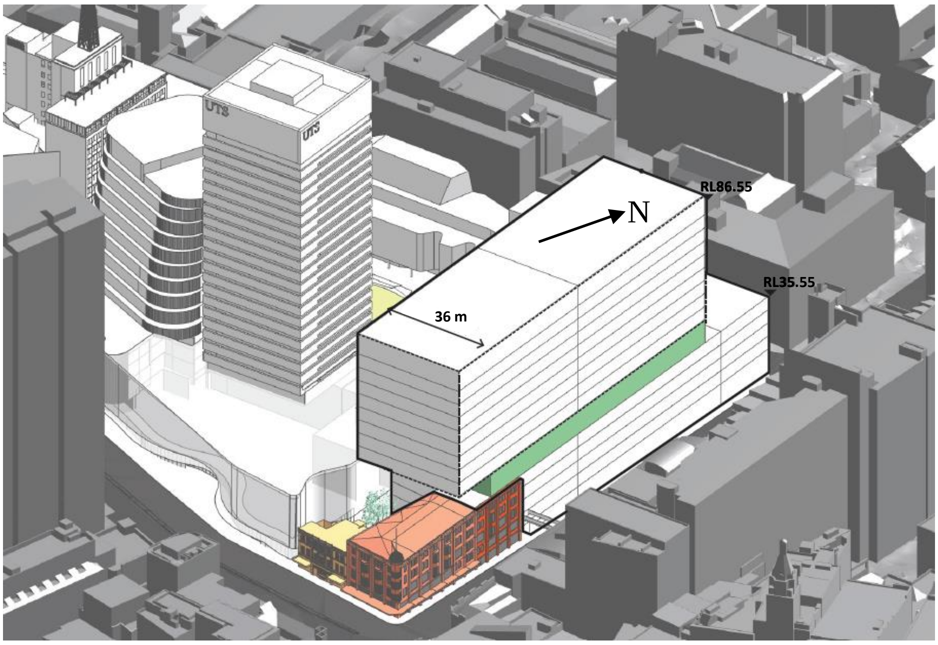

Figure 6: 3D perspective of the proposed Bon Marche and Science Precinct (BVN)

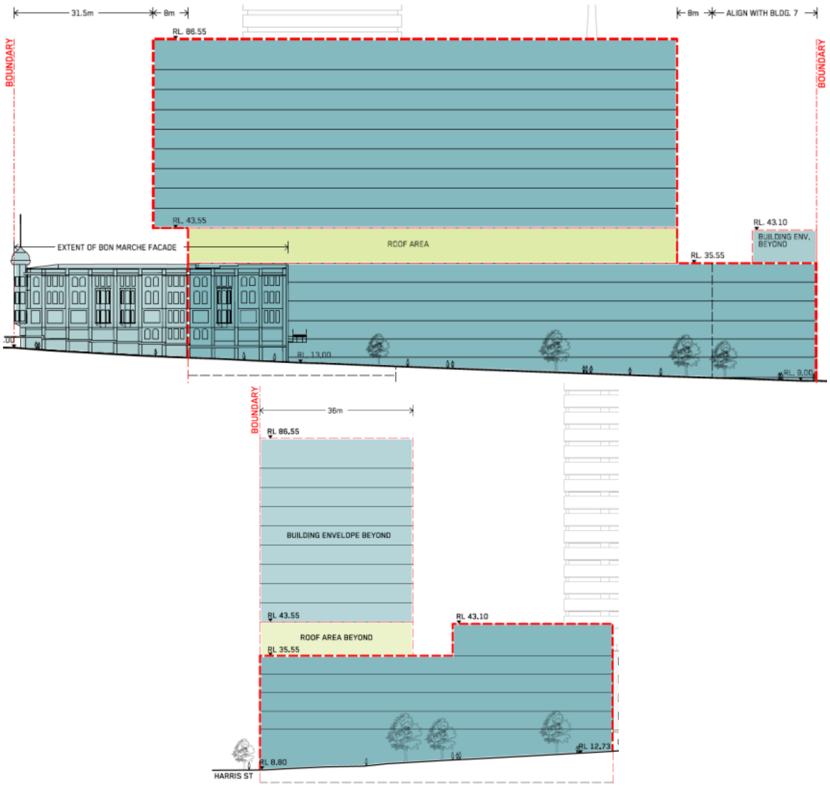

Figure 7: East elevation (top) and north elevation (bottom) of proposed development envelope

3.4 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 wind climate, topography, and building form.

The massing of the proposed redevelopment is significant compared with the massing of the surrounding buildings, however due to the orientation relative to the wind climate, it is expected to have a relatively minor impact on the local wind conditions.

Winds from the north-east

Winds from the north-east are relatively shielded by the overall massing of Sydney CBD and the similar sized buildings in Haymarket. On reaching the site, the flow would impinge on the Thomas and Harris Street corner of the building, encouraging flow to pass horizontally around the building rather than induce downwash. The proposed height of the development on this corner is similar to the existing building and therefore the wind conditions would be similar near this location.

The height of the taller section is setback from Thomas Street and flow impinging on this corner would be directed across the podium roof and Alumni Green, or horizontally along Harris Street. The long Harris Street frontage, would accelerate the flow up the topography rising to the south. The wind conditions on the corner of Harris Street and Broadway would be expected to get slightly windier by increasing the amount of channelled flow, however the fact that the taller building stops short of both north and south corners, and Harris Street has mature trees along the length, any increase is wind speed is expected to be minor.

Winds from the south

The massing of the proposed building is relatively narrow in the east-west direction and therefore prevailing winds from the south would pass around the building rather than descending to ground level. The overhanging to the south would further reduce the impact along Harris Street. The wind conditions would be expected to get marginally windier on the east side of Harris Street. The existing podium roof of the taller UTS tower to the west, and the existing building along the south side of Thomas Street would encourage the flow to stay high and not descent into Alumni Green.

Winds from the west

Winds from the west are currently channelled along Broadway. The curve of Broadway to the north from Kensington Street encourages flow to the south side of the street resulting in calmer conditions on the northern corners of Harris Street and Broadway. The irregular street pattern in the area to the west of the site discourages channelled flow with a large portion of the wind going over the top of buildings rather than at ground level.

The UTS tower (Building 1) offers significant interference to the approach flow and the southern section of the proposed building would be located in the wake region of the larger upstream building. Winds from the west would impinge on the northern section of the wide west face of the proposed building. The setback from the north of the site is beneficial in allowing the flow to discharge over the roofs of the buildings to the east of the site rather than be directed to ground level.

The proposed building and the buildings to the north and south of Alumni Green would constrain the flow resulting in calmer conditions across this open area, slightly windier conditions around the Jones Street corners, with the majority of the flow discharging over the lower roof to the north of the proposed buildings.

Summary

Qualitatively, integrating the expected directional wind conditions around the site with the wind climate, it is considered that wind conditions would be similar to existing conditions with the majority of locations classified as suitable for pedestrian standing activities. Slightly windier locations are expected on the corner of Broadway and Harris Street where wind conditions may exceed the standing level and be classified as suitable for pedestrian walking. Other regions within Alumni Green and close to the façade along Harris Street would be expected to meet the pedestrian sitting classification. All locations would be expected to meet the safety criterion.

3.5 General observations

The final design of the ground plane and the outdoor podium roof accessible area will dictate the wind conditions in these areas. An indicative scheme proposed by BVN is presented in Figure 8, showing multiple passageways from Harris Street through to Alumni Green, and a relatively open podium roof.

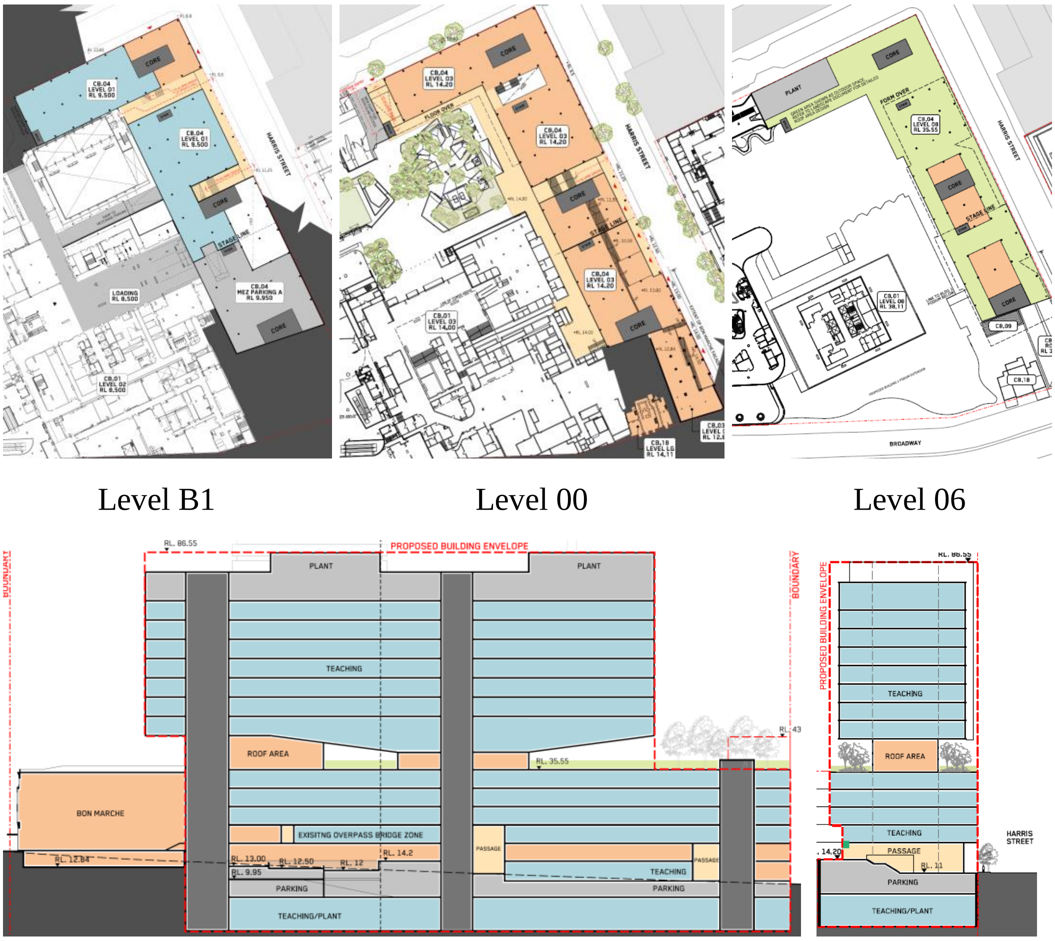

Figure 8: Indicative scheme: Plan levels (Top), north-south section looking west (BL), east-west section looking north (BR)

The flow though the ground floor passageways is generated by the overall massing of the development developing a pressure distribution at the various entrances to the pedestrian links. The pressure difference between the entrances induces the internal flow. This pressure driven flow, will be felt the narrowest section along the flow path. It is considered best to have a single narrow section along the passage, rather than a passageway of constant cross-sectional area as it isolates the windiness. In Figure 8(BL), the entire through-site link section with the low ceiling height to the west would experience windier conditions than the higher roof section to the east. The windy locations could be further isolated with the inclusion of the vertical screen above the west entry. Increasing the size of the opening does not markedly change the wind speed felt in the passage, as it is based on the pressure differential between either end of the passage.

An open podium roof level would be expected to experience relatively windy conditions for winds from all directions. The flow would be accelerated by the pressure differential on either side of the building inducing wind speeds faster than in the incident flow. The intended use of this space would dictate the architectural design to combat the wind issues of this level. If the space is to be used for scheduled events, it would be recommended to have a central access spine to the outdoor areas that would protect either side. Alternatively, if the space is only to be access when environmental conditions allow, local vertical screening can be used to create calmer conditions suitable for stationary activities.

4 Summary

Arup have provided qualitative advice for the impact of the proposed development on pedestrian wind comfort.

It is Arup's opinion that all locations within the proposed development would meet the safety criterion. From a wind comfort perspective, the surrounding areas are expected to meet the requirements for the intended use of the space as suitable for pedestrian walking type activities.

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

5 References

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Appendix 1: 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 2017 have been used in this analysis, Figure 9. The arms of the wind rose point in the direction from where the wind is coming from. The anemometer is located about 9 km to the south of the site. The directional wind speeds measured here are considered representative of the wind conditions at the site.

It is evident from Figure 9 that strong prevailing winds are organised into three main groups which centre at about the north-east, south, and west quadrants.

Strong summer winds occur mainly from the south quadrant and the north-east. Winds from the south are associated with large synoptic frontal systems and generally provide the strongest gusts during summer. Moderate intensity winds from the north-east tend to bring cooling relief on hot summer afternoons typically lasting from noon to dusk. These are small-scale temperature driven effects; the larger the temperature differential between land and sea, the stronger the wind.

Winter and early spring strong winds typically occur from the south-west, and 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.

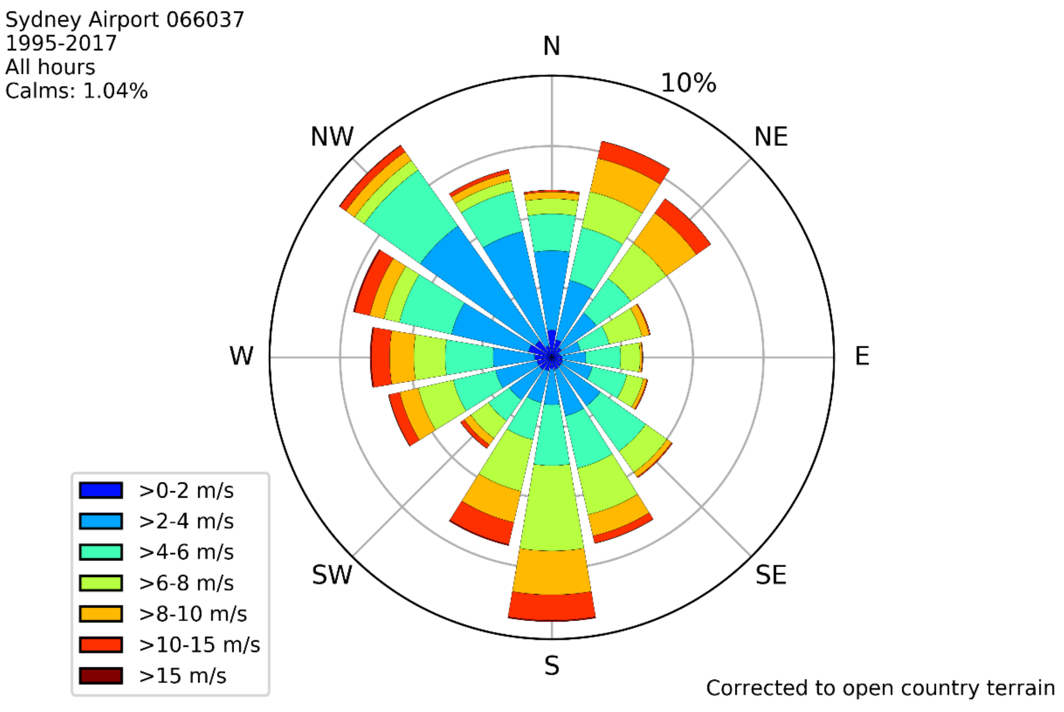

Figure 9 Wind rose showing probability of time of wind direction and speed

Appendix 2: 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 10, 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 10. 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.

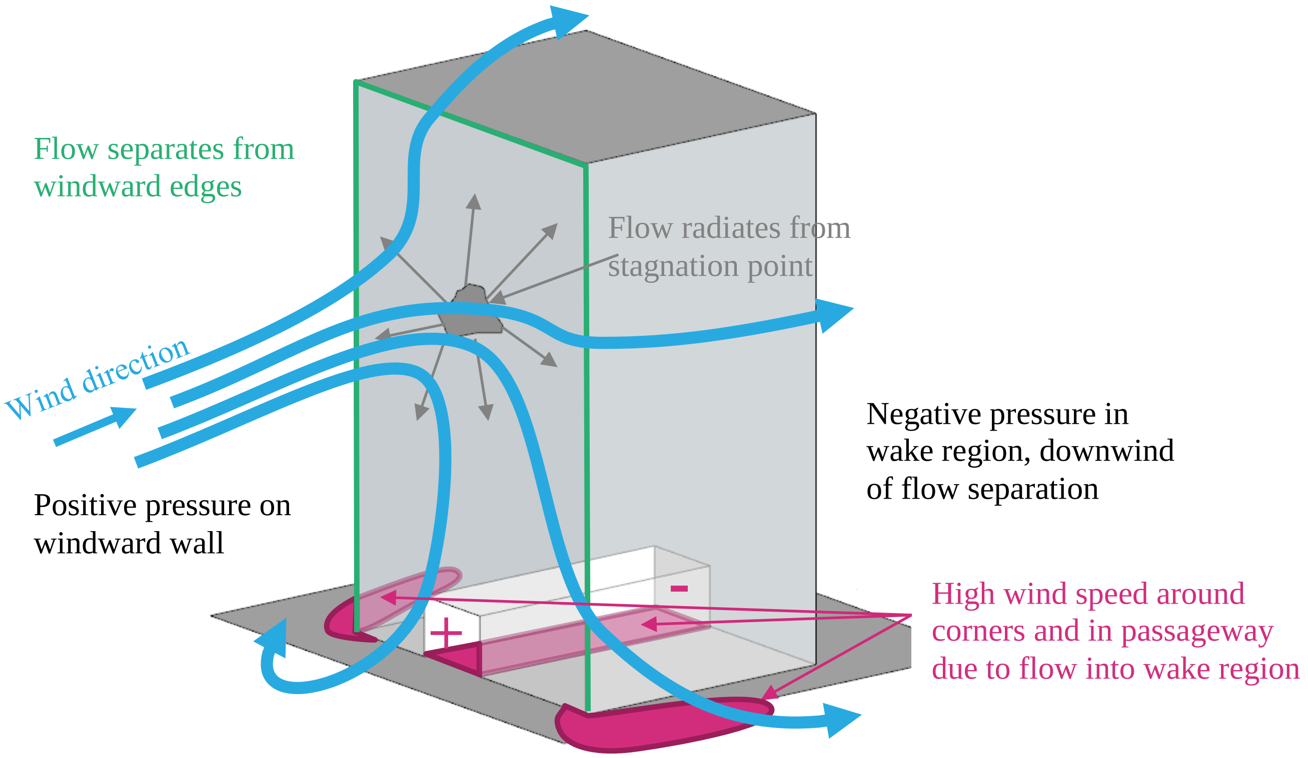

Figure 10 Schematic wind flow around tall isolated building

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.

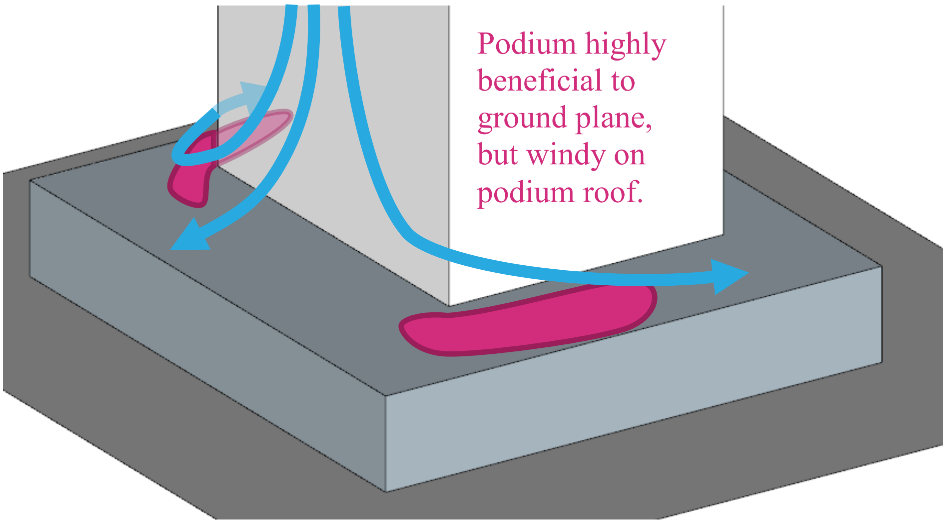

Figure 11 Schematic flow pattern around building with podium

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 12. 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.

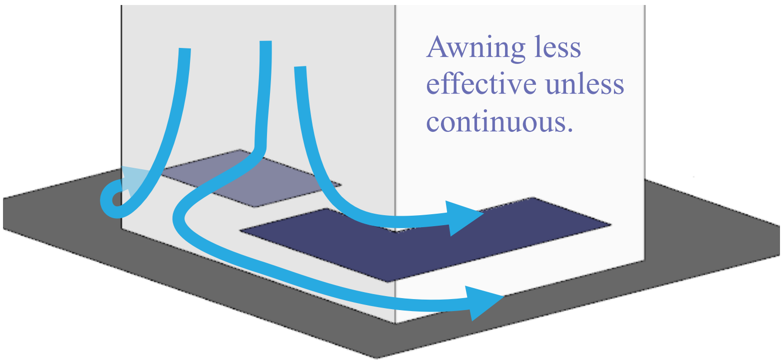

Figure 12 Schematic flow pattern around building with awning

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 13. 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 10. If the link is blocked, wind conditions will be calm unless there is a flow path through the building, Figure 14. 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 14.

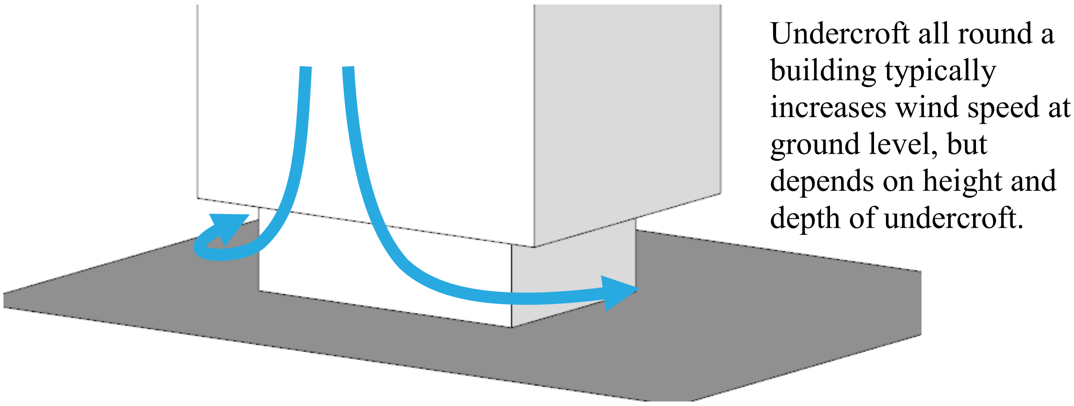

Figure 13 Schematic of flow patterns around isolated building with undercroft

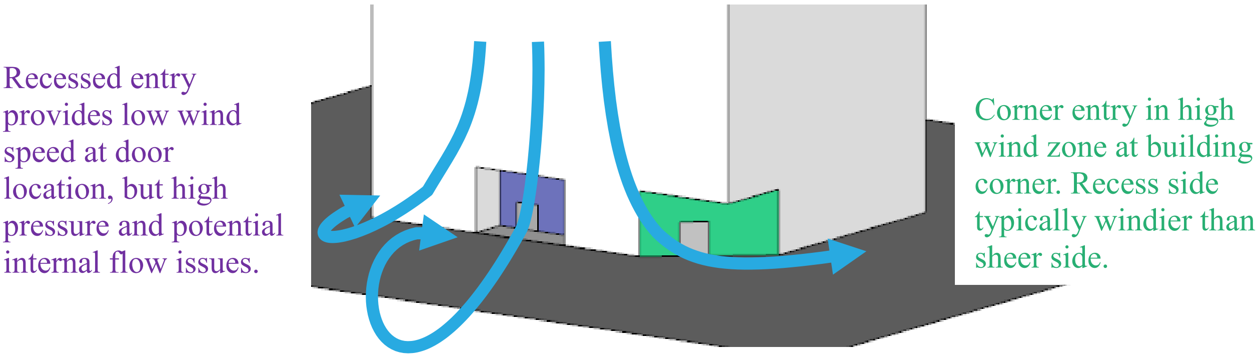

Figure 14 Schematic of flow patterns around isolated building with ground articulation

Multiple buildings

When a building is located in a city environment, depending on upwind buildings, the interference effects may be positive or negative, Figure 15. 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.

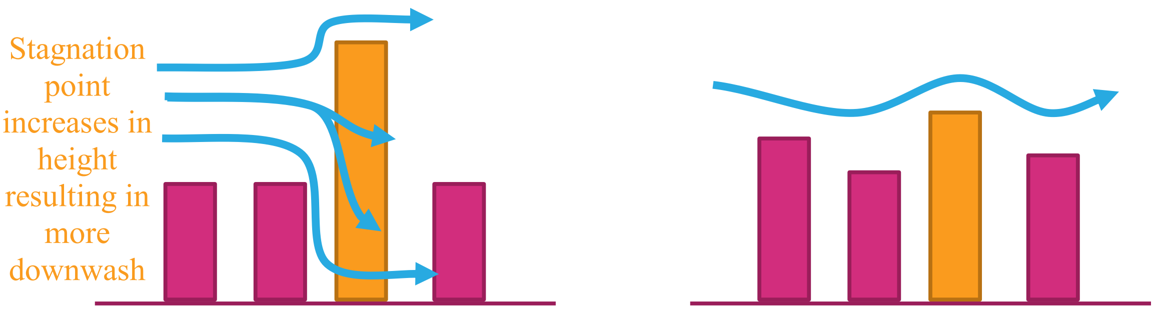

Figure 15 Schematic of flow pattern interference from surrounding buildings

The above discussion becomes more complex when three-dimensional effects are considered, both with orientation and staggering of buildings, and incident wind direction, Figure 16.

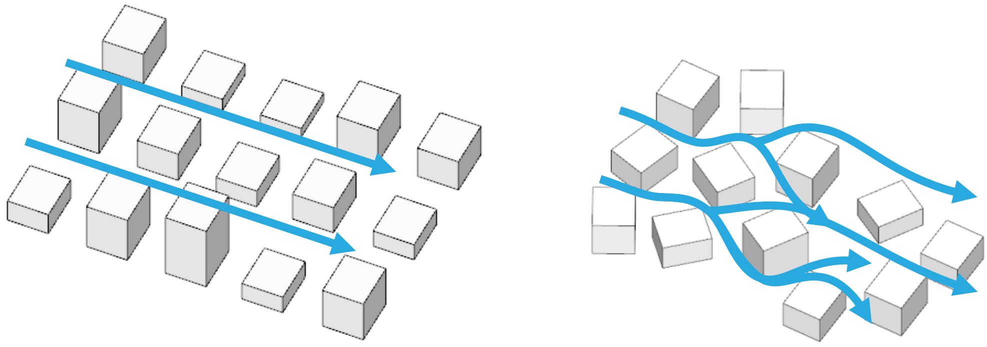

Figure 16 Schematic of flow patterns through a grid and random street layout

Channelling occurs when the wind is accelerated between two buildings, or along straight streets with buildings on either side, Figure 16(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 16(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.

Appendix 3: 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 2. 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 2 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:

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

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 17 and Figure 19. 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 17 with definitions of the intended use of the space categories defined in Figure 18.

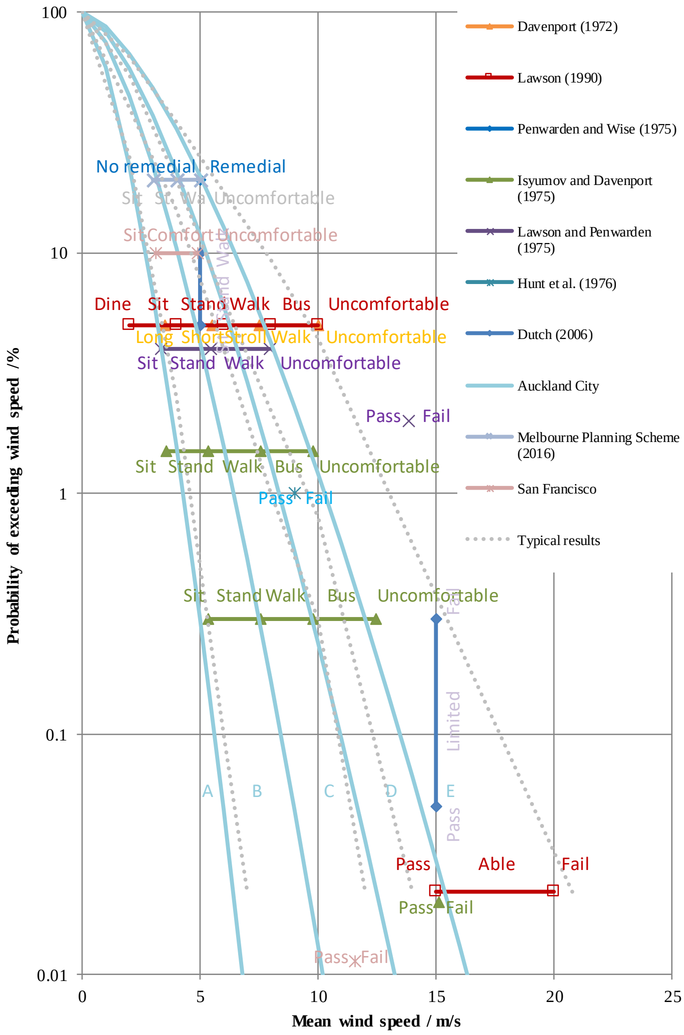

Figure 17 Probabilistic comparison between wind criteria based on mean wind speed

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 18: Auckland Utility Plan (2016) wind categories

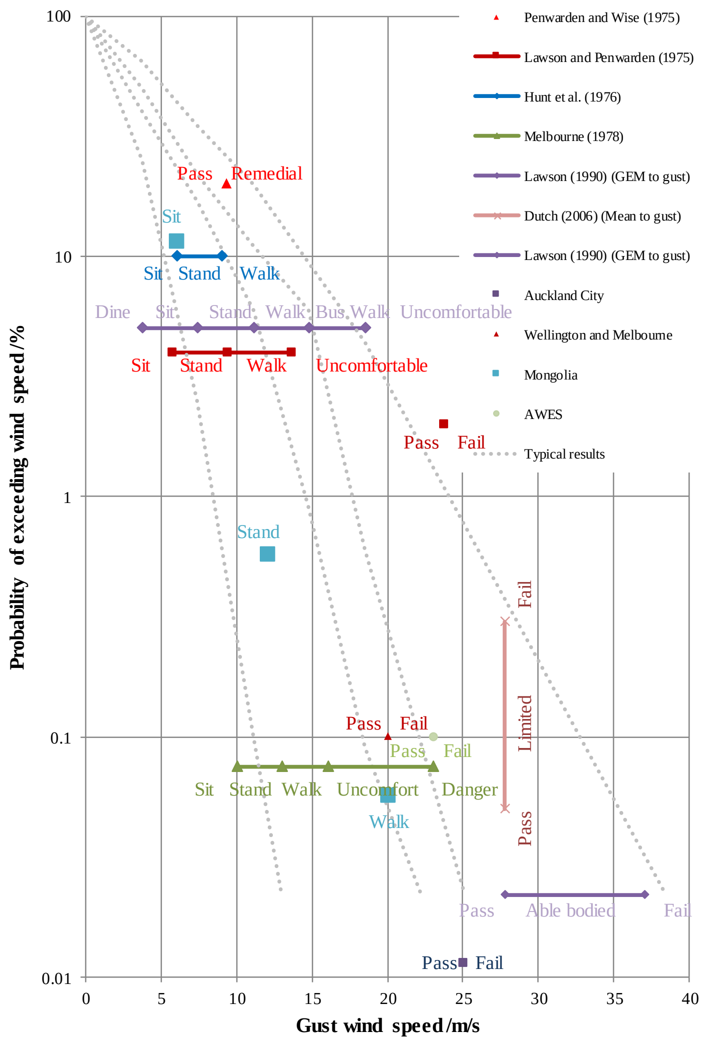

Figure 19 Probabilistic comparison between wind criteria based on 3 s gust wind speed

Appendix 4: Reference documents

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

- EN-EL-EE-01.pdf
- EN-EL-NE-01.pdf
- EN-EL-SE-01.pdf
- EN-FP-TY-BA.pdf
- EN-FP-TY-LO.pdf
- EN-FP-TY-UP.pdf
- EN-SS-EW-01.pdf
- EN-SS-EW-02.pdf
- EN-SS-EW-03.pdf
- EN-SS-NS-01.pdf
- EX-EL-EE-01.pdf
- EX-EL-NE-01.pdf
- EX-EL-SE-01.pdf
- EX-SP-RF-01.pdf
- ID-EL-EE-01.pdf
- ID-FP-CL-00.pdf
- ID-FP-CL-01.pdf
- ID-FP-CL-02.pdf
- ID-FP-CL-05.pdf
- ID-FP-CL-06.pdf
- ID-FP-CL-B1.pdf
- ID-FP-CL-B2_M.pdf
- ID-FP-CL-B3.pdf
- ID-SS-EW-01.pdf
- ID-SS-EW-02.pdf
- ID-SS-EW-03.pdf
- ID-SS-EW-04.pdf
- ID-SS-NS-01.pdf
- ID-SS-NS-02.pdf