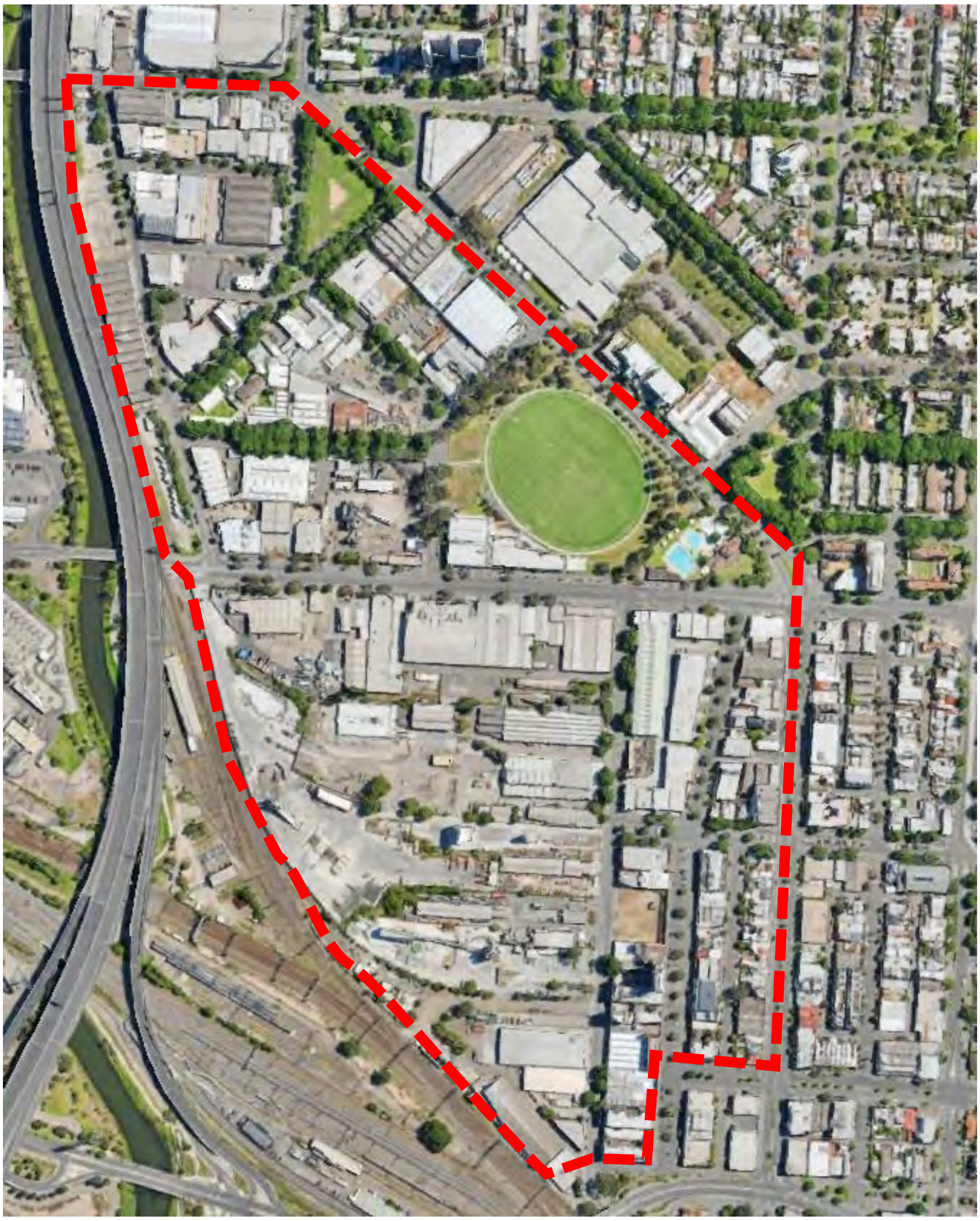
Victorian Planning Authority (VPA)

Arden Urban Renewal Precinct, North Melbourne

Wind Assessment



GWTS

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0	Draft Report
1	Review
2	Review
3	Final Issue

EXECUTIVE SUMMARY

Global Wind Technology Services Pty Ltd (GWTS) was commissioned by the **Victorian Planning Authority (VPA)** to perform a wind assessment on the proposed Arden Precinct redevelopment in North Melbourne, Melbourne**.**

The assessment utilised information provided by the client, as well as climate data for North Melbourne obtained from the Bureau of Meteorology. A detailed Computational Wind Engineering (CWE) simulation was also carried out as part of this assessment. The assessment objective is to evaluate the wind climate in the proposed Arden Precinct and assist in understanding the wind environment.

Following the initial version of this report, the Draft Structure Plan was updated, and the sub precinct boundaries changed to reflect what is seen in Sections 1.1, 3.1, 3.2, 3.6 and 3.7. The configuration displayed in the CWE Analysis – Section 4 – has not been updated. This update has no effect on the analysis.

The summary of the study and the main points for considerations are as follows:

- **Climate:** The wind climate of Melbourne was assessed using three Bureau of Meteorology Stations: Melbourne Airport (Station 08686282), Essendon Airport (Station 08686038) and Fawkner Beacon (Station 08686376). The North wind is the dominant wind direction. This wind direction is the most frequent as well as the strongest.
- **Wind Speed thresholds:** The threshold wind speed criteria is shown below.

The safety criterion is based on gust wind speeds of infrequent occurrence (once a year) while the comfort criteria is based on frequently occurring winds (winds that occur 80% of the time). Sets of annual maximum peak 3-second gust velocities, mean wind velocities (hourly mean wind speed) and the Gust Equivalent Mean velocities (GEM), calculated from 3-second gust divided by 1.85, were derived from meteorological data for the geographical location under consideration, for 16 wind directions.

Table 1: Wind Comfort and Safety Gust Criteria for Melbourne Central City	
SAFETY CRITERIA	
Annual maximum 3 second gust speed with an annual probability of exceedance of 0.01%	**Result on perceived pedestrian comfort**
>20m/s	Unsafe (frail pedestrians knocked over)
COMFORT CRITERIA	
Maximum of: 1. Hourly mean wind speed 2. Gust equivalent mean speed (3 second gust wind speed divided by 1.85), for winds occurring 80% of the time.	**Result on perceived pedestrian comfort**
<5 m/s	Acceptable for walking (steady steps for most pedestrians)
<4 m/s	Acceptable for standing (window shopping, vehicle drop off, queuing)
<3 m/s	Acceptable for sitting (outdoor cafés, pool area, gardens)

Table 2: Recommended application of criteria

Area	**Recommended Criteria**
Public Footpaths	Recommended to meet the criterion for walking
Building Entrances	Recommended to meet the criterion for standing
Balconies, Podium roof, Roof Terraces	Recommended to meet the criterion for walking (refer to the discussion below)

- **<u>CWE Analysis:</u>**

The CWE analysis conducted, yielded results showing that the north wind direction has the most severe impact on the proposed development due to its dominance in the local wind climate in both frequency and strength. The simulation domain was discretised with around 20 million cells, with inflow boundary condition specified with the wind profile for Terrain Category 3, turbulence intensity and dissipation rate.

The north wind directions is shown to be dominant throughout the year. The south wind direction is shown to become the prominent wind direction during the summer months allowing for the passive cooling of the precinct. The analysis has shown that the sub precinct with the highest potential to improve conditions across the entire precinct is Arden North. It is also the most sensitive due to its northern location and presence of large open areas. Thus, wind control mechanisms were made more stringent for this sub precinct.

The design scheme of the precinct allows for the north, south and west winds to penetrate far into the development allowing for cooling and proper ventilation. However, corner acceleration and channelling events are prone to occur and thus, the wind control mechanisms presented in this study must be followed.

Building separation must be considered carefully and the objective for the separation distance: whether the street is set to become an air path or not for example. The general guideline for building separation is to allow a minimum distance between buildings to be equal to the widest dimension of the tower floor plate. However, this is not usually the case in densely packed urban areas. Many parameters influence the appropriate separation distance between adjacent buildings, including the position of these, their size and orientation, shape, overshadowing, pedestrian level wind and relative height among others. A strong limitation for the separation distance in this case, is that the streets are already present. Therefore, utilising the tools and guidelines provided will help towards an appropriate design, and careful assessment of the development will yield their effectiveness.

The inclusion of air paths to the precinct design will improve ventilation and cooling of these areas, ultimately decreasing the average temperature of the precinct during the summer months. The north to south orientation will affect the cooling capacity, and the east to west orientation will affect the ventilation capacity of the precinct. Using the equation shown in Section 3.1, will yield an approximation of the effective width for the creation of an air path. The air path width changes throughout the precinct at different locations, this calculation will help guide the effective street widths for the creation of air paths. This method was derived for the Hong Kong climate which has a main objective to promote wind flow, whereas the Melbourne climate leans more towards shielding.

Sources of error can be introduced in three forms into the simulation: through the accuracy and resolution of geometrical models, numerical errors and appropriateness of the boundary conditions initially defined.

The precinct 3D model provided to GWTS by the client came in two sets, one contained all the buildings within the proposed Arden Precinct, as well as its immediate surroundings. The second set contained the model of the topography of the precinct. GWTS combined both models, ensuring that all the buildings rested on the terrain and that all developments were sealed to run the simulation correctly.

CWE is capable of capturing the overall wind flow pattern and locate areas of high and low wind speeds, to allow for appropriate recommendations for further analysis where deemed necessary. The assumptions outlined in Section 4.1 mean that the results yielded by the CWE simulation are expected to be significantly higher than those expected at the actual site, but wind tunnel testing is likely to confirm some of the detrimental conditions predicted by the CWE.

Lastly, the software simulates all wind directions with the same probability of occurrence. The climate study shows that the east wind direction is almost negligible in Melbourne, while the north wind direction is dominant. Thus, the results for the east wind results do not carry equal weight as the north wind results and are analysed with different degrees of scrutiny.

The wind control mechanisms outlined in this report are accepted by the 'Better Apartments' design guidelines and its 2021 update. All wind control mechanisms proposed have been considered and have been determined whether they are required or recommended to be incorporated to the design.

<table>
<tr><th>Sub-precinct</th><th>Wind Control Requirements</th><th>Individual Cases</th></tr>
<tr><td rowspan="6">Arden North</td><td>Wind tunnel testing is required for any development ≥ 20 m in height.</td><td rowspan="2">• Detailed CWE analysis of Fogarty Street, Henderson Street and Boundary Road.</td></tr>
<tr><td>Developments above 20 m required to be designed with articulated facades. Buildings less than 20 m in height, with smooth façade will require wind tunnel testing.</td></tr>
<tr><td>Developments are required to be designed with podiums with a minimum 6 m setback.</td><td rowspan="4">• Building C2 will require wind tunnel testing.</td></tr>
<tr><td>The design must include vegetation at street level. Evergreen trees are recommended. Young trees may need protection until fully grown in windy areas.</td></tr>
<tr><td>Building entrances are recommended not to face the North or West.</td></tr>
<tr><td>It is recommended to conduct a Wind Impacts Assessment on remaining buildings not prescribed by the above, nor the AS/NZS 1170.2 and Better Apartments standards.</td></tr>
<tr><td rowspan="6">Arden Central</td><td rowspan="2">Wind tunnel testing is required for any development ≥ 30 m in height.</td><td>• Group D buildings will require wind tunnel testing.</td></tr>
<tr><td>• Central Open Areas will require detailed CWE assessment and wind tunnel testing.</td></tr>
<tr><td>Developments above 30 m tall are required to be designed with articulated facades Buildings less than 30 m in height with smooth façade, will require wind tunnel testing.</td><td>• Arden Station, building G4, will require detailed CWE analysis.</td></tr>
<tr><td rowspan="2">Developments are required to be designed with podiums with a minimum 6 m setback. (All developments in this sub-precinct are assumed to be designed with podiums).</td><td>• Building G5 will require detailed CWE analysis and wind tunnel testing.</td></tr>
<tr><td>• Detailed CWE analysis of corridor between G1 and G2, and through G5.</td></tr>
<tr><td>The design must include vegetation at street level. Evergreen trees are recommended. Young trees may need protection until fully grown in windy areas.</td><td>• Building E1 will require wind tunnel testing.</td></tr>
</table>

	Building entrances are recommended not to face the North or West. It is recommended to conduct a Wind Impacts Assessment on remaining buildings not prescribed by the above, nor the AS/NZS 1170.2 and Better Apartments standards.	
Laurens Street	Wind tunnel testing is required for any development ≥ 40 m in height. (As defined in the AS/NZS 1170.2) Developments above 40 m tall are required to be designed with articulated facades. Buildings with smooth façade less than 40 m in height, will require wind tunnel testing. The design must include vegetation at street level. Evergreen trees are recommended. Young trees may need protection until fully grown in windy areas. Building entrances are recommended not to face the North or West. It is recommended to conduct a Wind Impacts Assessment on remaining buildings not prescribed by the above, nor the AS/NZS 1170.2 and Better Apartments standards.	• Building H1 will require wind tunnel testing.

TABLE OF CONTENTS

1. INTRODUCTION

Global Wind Technology Services (GWTS) has been commissioned by VPA to conduct a microclimate study of the proposed Arden Urban Renewal Precinct, North Melbourne, Victoria. This section of the study presents the general considerations on the design of the Arden Urban Renewal Precinct design.

1.1 Proposed Site, Development & Surroundings

The Arden Precinct is located 2 km, northwest of Melbourne CBD. The site topography is characterised by an elevation difference from the Moonee Ponds Creek on the western border increasing towards the east by up to 25 m. The site is highlighted in Figure 1 and the site context is provided in Figure 2.

The proposed Arden Urban Renewal Precinct concept designs and site context are shown in Figure 3 and Figure 4. The surroundings of the proposed development site are characterised by a mix of low rise; 1- to 3-storey industrial and residential buildings. North of the project site there are some high-rise residential building blocks up to 21-storeys.

North of the proposed site, the topography follows the same configuration rising from west to east by up to a 40m elevation. Less than 1 km north of the project site there is a large open park; Royal Park. To the south, there is a cluster of train lines and motorways set on flat land. To the west, on the other side of Moonee Ponds Creek, there is an elevation of 20m from east to west and the area is generally comprised of 1- to 2-storey industrial developments.

Figure 1: Overall view of the site surroundings

Figure 2: Site location within the Melbourne metropolitan area

The proposed development consists of three sub-precincts:

- **<u>Arden North</u>**
  - Rail hub
  - Small-scale industry
  - Arts, cultural and community hub
  - Commercial
  - Warehousing
  - Open-space and recreation: North Melbourne Recreation Reserve, North Melbourne Recreation Centre and Pool and the Clayton Reserve.
  - Figure 3 illustrates the division within the precinct of the development plan. As it can be appreciated, groups A, B and C form Arden North.
  - Low-, mid- and high-rise, mixed-use residential buildings on podiums are found in Arden North.
  - The orientation of the towers varies from a north-south configuration to east-west for clusters A and B; except for B1, western building in group B parallel to Langford and between Gracie and Straker Streets.
  - The podiums of the group C buildings area parallel to Henderson Street; they have been turned by 45 degrees compared to groups A and B. The towers on the group

C podiums are orientated northeast to southwest, with the taller buildings to the north.

- **Arden Central – Innovation and Mixed-Use**
    - Arden Central is split into two with the innovation hub to the north side and the Mixed-Use hub to the south side of Arden Central.
    - Rail Main Precinct Hub – Arden Station
    - Civic and Commercial offices
    - Health or institutional services
    - Upper level residential
    - Government School
    - As seen in Figure 3, Arden Central – Innovation includes buildings groups D, E, F, G, and part of J. Arden Central Mixed-Use includes the remaining J buildings, K and N.
    - Group D buildings are mid-rise, podium towers with a north-south orientation. They are mixed-use innovation developments boasting of a community facility to the east.
    - Group E is characterised by mid- and high-rise towers sitting on podiums following a north to south orientation, with the tallest on the northern boundary.
    - Group F buildings have a staggered height decreasing from north to south down to a low-rise innovation building on its southern end, adjacent to the Capital City open space.
    - Group G is comprised of four mid-rise mixed-use innovation towers, with the Arden Precinct Metro Station and the Capital City Open Space on the south-west corner of the group area.
    - Groups J and N are residential areas and contain the tallest developments across the whole precinct. These buildings mainly follow a north to south orientation, except on the southwest precinct boundary where they follow the train tracks' street orientation: northwest to southeast.
    - Group K is comprised of three mixed-use innovation buildings on the southern end and a government school on the north: along with two community facilities on the south-east corner of the group area. On the north-western corner, there will be a new green open space directly opposite the Capital City open space.
- **Laurens Street**
    - Residential
    - Industrial
    - Retail
    - Retail Services
    - As seen in Figure 3 it includes building groups H, I, L, M
    - Groups H and L contain the tallest buildings in the Laurens Street sub-precinct. Within these two groups, the taller developments are found to the north of group H, with the building height decreasing in the southern direction. In group L the

taller developments are on the northern end and low-rise developments are found on the southern end.

- Groups I and M are primarily low-rise and some mid-rise mixed-use developments with an orientation perpendicular to the north to south street configuration.

Figure 3: Arden Precinct development plan

Figure 4: South-eastern view of the proposed site

2. CLIMATE

The purpose of the climate analysis is to understand the local climate and thus, ensure that the proposed building design and layout appropriately responds and adapts to it.

The local climate analysis considers local weather data and wind analysis (speed, direction and frequency), to identify the most frequent wind directions and their strength. This analysis considers the locations of building entrances and both the orientation and distribution of buildings for natural ventilation among other features.

The site wind climate was evaluated based on three Bureau of Meteorology stations. The three stations being: Melbourne Airport, located 18 km northwest of the proposed development, Essendon Airport, located 9 km northwest and Fawkner Beacon, located 12 km south. The three stations were selected due to the considerations described in the paragraph below.

Melbourne Airport (Station # 086282) is located on the northwest as shown in Figure 5. This station has unbiased data of the most frequent wind from the north. Thus, despite the station being the furthest from the development, it still provided reliable wind climate data and 17 years of 1-minute wind data was used to analyse the wind from this station.

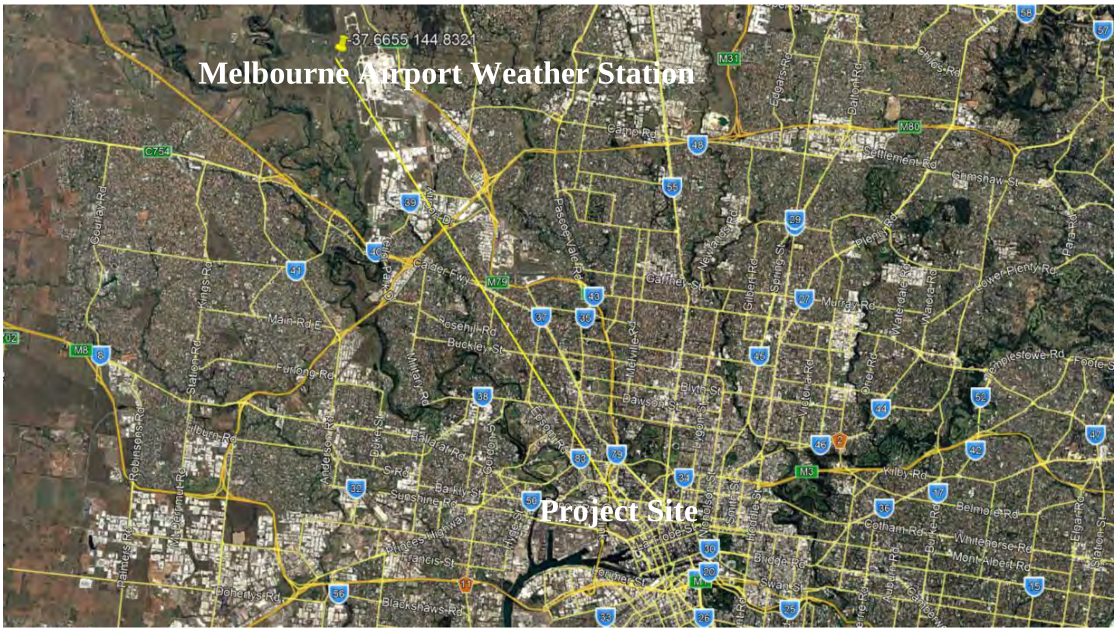


Figure 5: Melbourne Airport Weather Station 18 km from the site

Essendon Airport (Station # 086038) is located on the northwest as shown in Figure 6. This station is 9 km from the project site. The station is surrounded by suburban terrain. The data from this station was not frequently used due to the terrain bias introduced in the data. However, this station is the closest to the development and showed changes from the Melbourne Airport data.

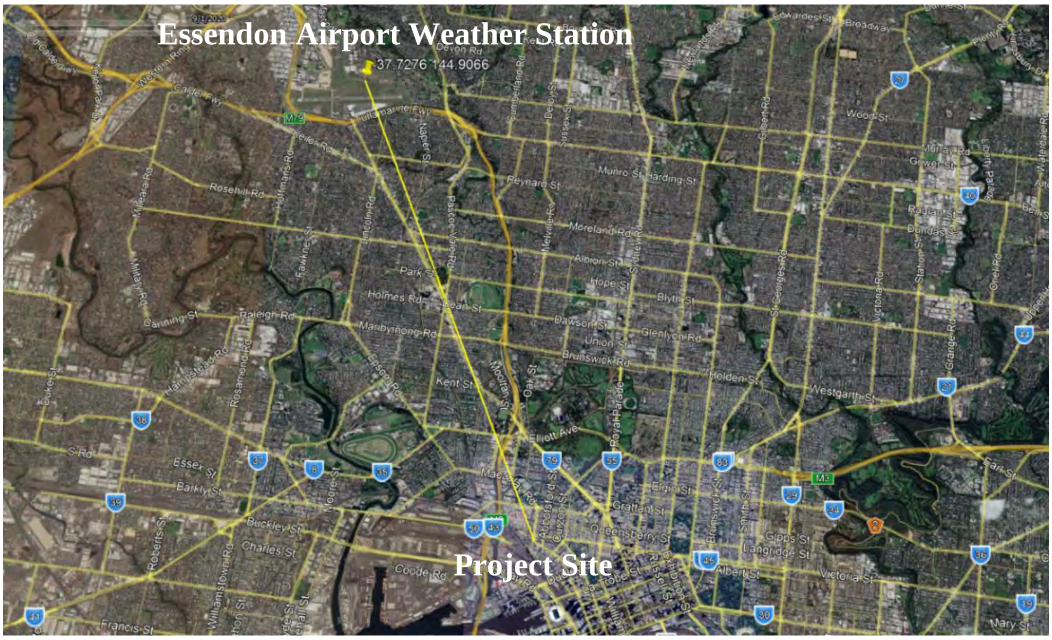


Figure 6: Essendon Airport Weather Station 9 km from the site

Fawkner Beacon (Station # 086376) is located on the south as shown in Figure 7. This station is 12 km from the project site. The station is surrounded by water and it provides unbiased data for the south direction. The data for the north and remaining directions, from this station, are influenced by the city and the surrounding suburbs. Data from this station was evaluated and presented here for the south direction wind which is responsible for the sea breeze.

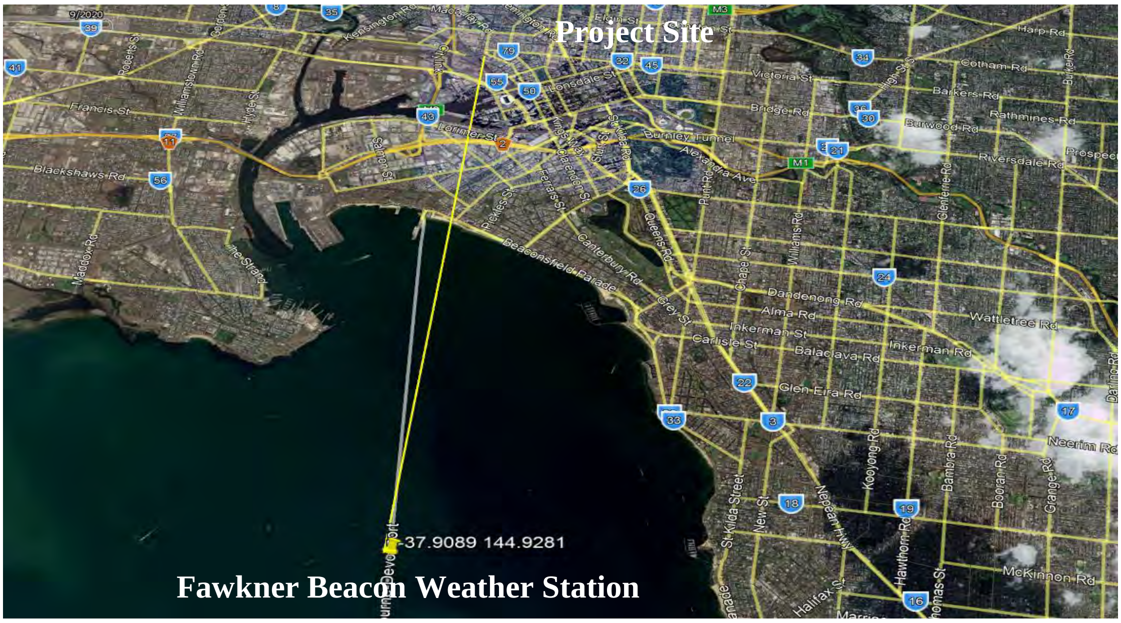


Figure 7: Fawkner Beacon Weather Station 12 km form the site

Wind data of 19, 15 and 19 years was evaluated from the Melbourne Airport, Essendon Airport and Fawkner Beacon stations, respectively. This data was analysed for the wind frequency and strength. The north wind was the dominant wind direction in all three stations. Understanding the overall frequency and strength of the winds, as well as their monthly variation is important for managing the wind environment and design accordingly. Thus, polar plots from the Melbourne Airport Station are shown for the overall wind speed and frequency, and for each month, in Figure 8 through to Figure 20. The polar plots for all three stations can be found in Appendix A.

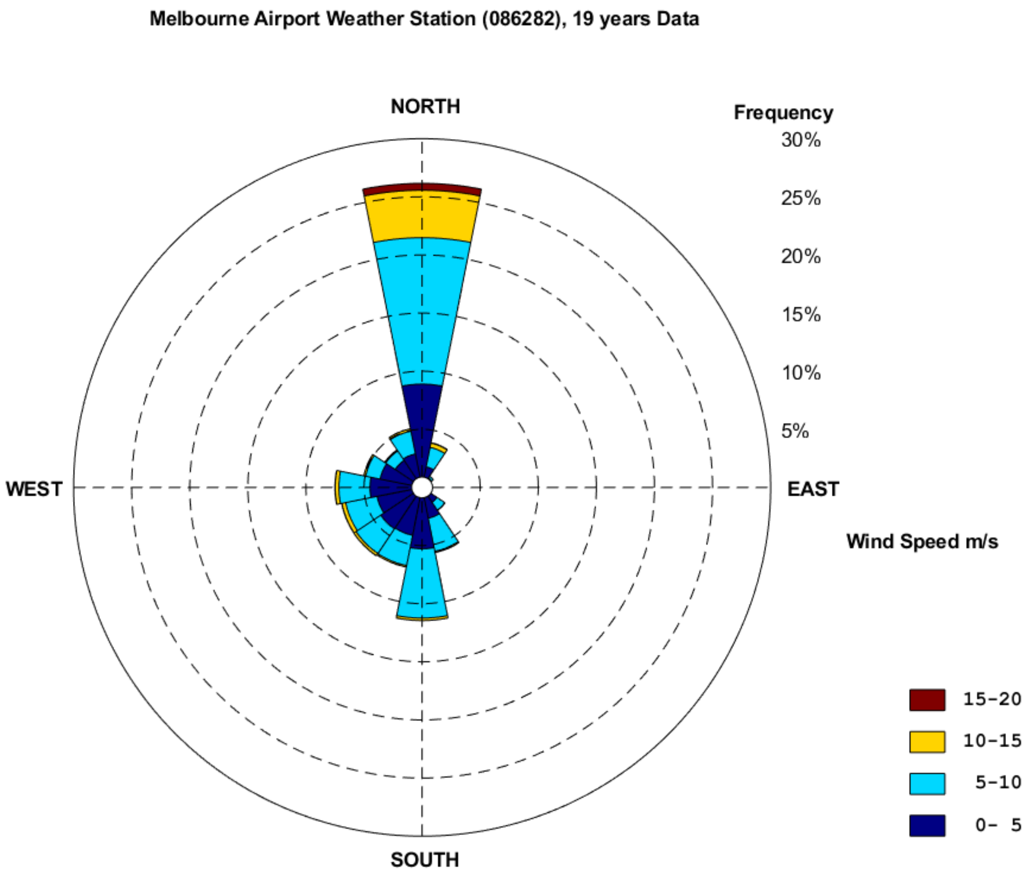


Figure 8: The overall frequency and strength of wind, Melbourne Airport

Figure 8 shows the overall variation of wind at Melbourne Airport. It can be observed that the north wind is the dominant wind with more than 25% frequency, as well as being the strongest wind direction. The south direction is the second most frequent and is dominated by the sea breeze. The east wind is the weakest and the least frequent direction. Thus, semi-enclosed spaces, closed to the north, south and west will likely have increased pollution concentration due to poor ventilation.

The summer wind pattern is shown by the polar plots of December, January and February in Figure 9, Figure 10 and Figure 11 respectively. In December, the frequency of north and south winds is the same, with each slightly above 15%. In January, the frequency of the south wind increases above 20% while the north decreases below 15%. The trend continues in February with a similar frequency as in January. To promote the sea breeze in streets and parks, opening to the south direction will help to increase ventilation and cooling during the summer months.

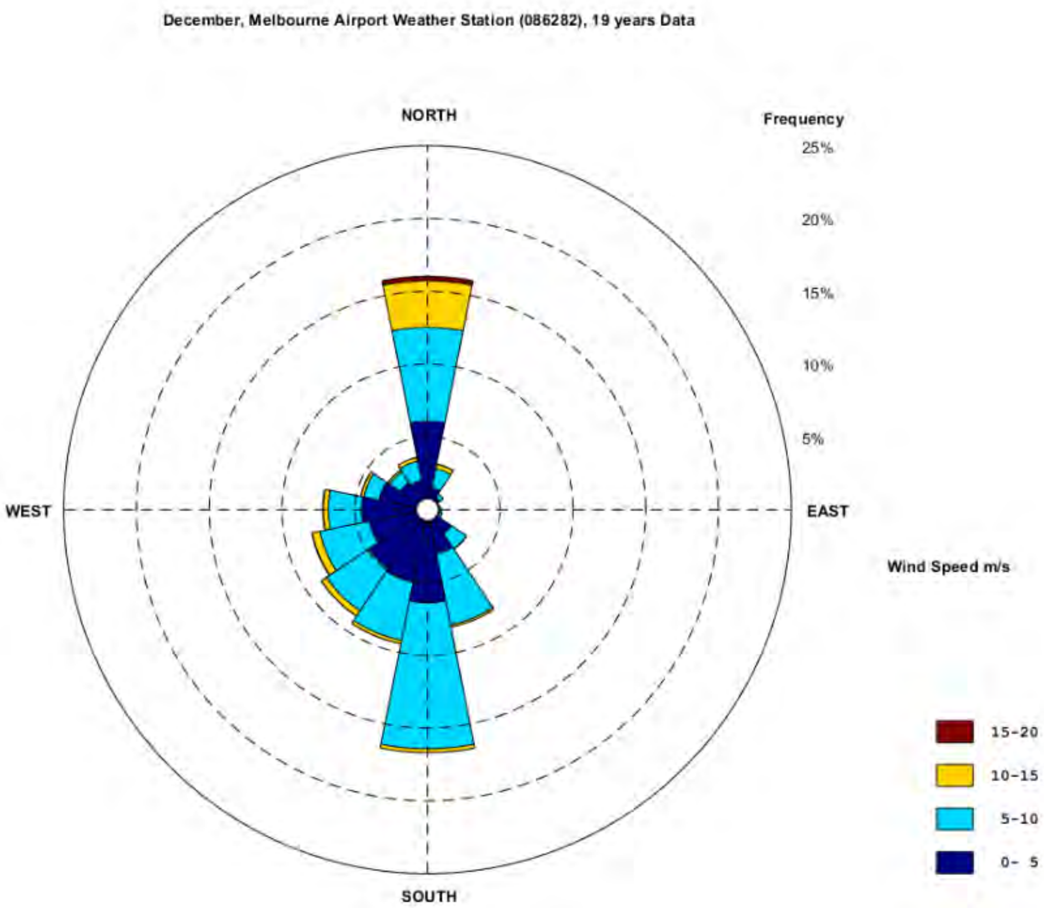


Figure 9: December frequency and strength of wind, Melbourne Airport

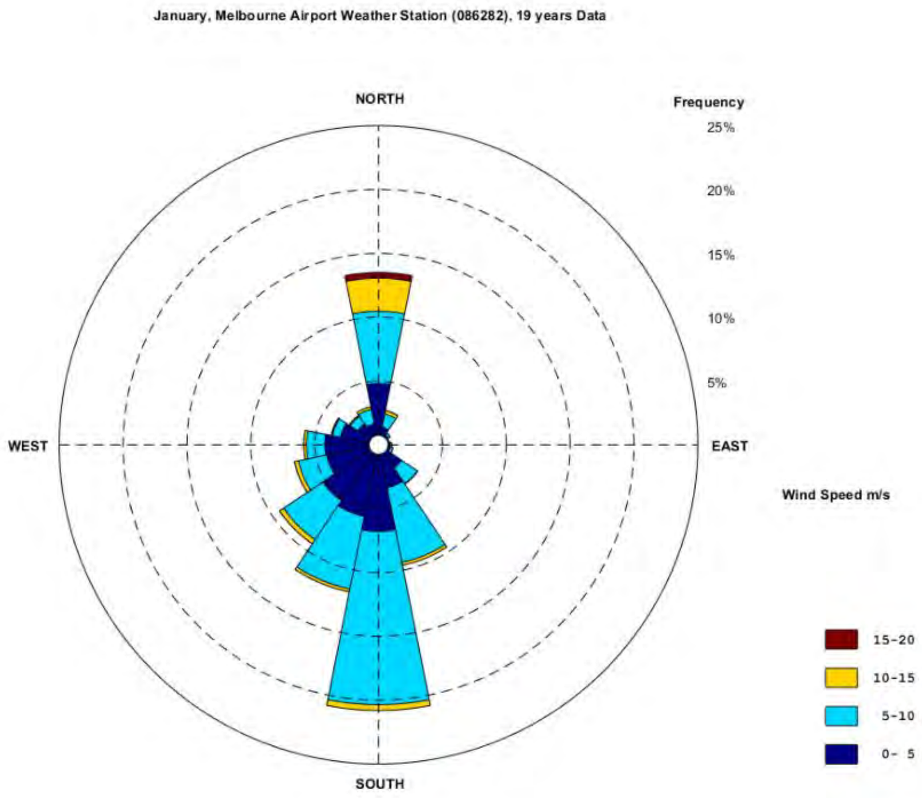


Figure 10: January frequency and strength of wind, Melbourne Airport

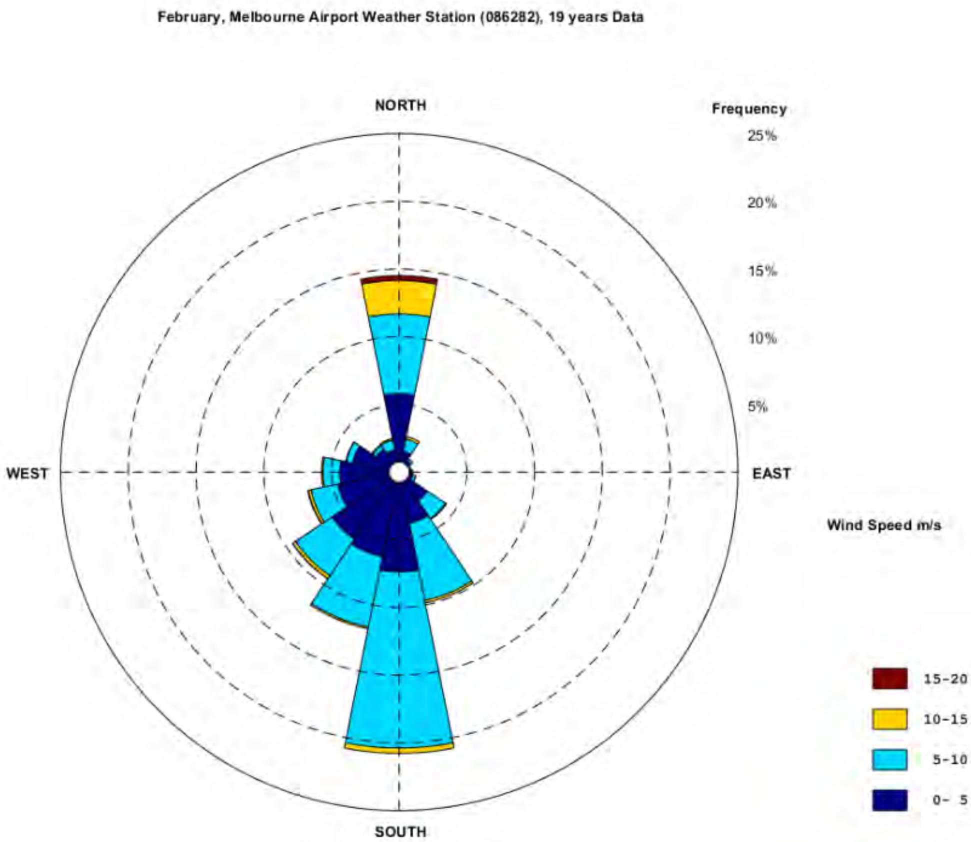


Figure 11: February frequency and strength of wind, Melbourne Airport

The wind climate in autumn months are shown in Figure 12 to Figure 14 for the following months: March, April and May, respectively. The sea breeze starts reducing in March – to less than 10%. The north wind becomes less than 20% but increases from 15% in February. In April, the north wind is dominant with more than 25%, while the south wind becomes less than 10%. The trend of increasing frequency of the north wind continues in May, with the frequency growing to 35%, whilst the west wind is the second most frequent wind with 10%.

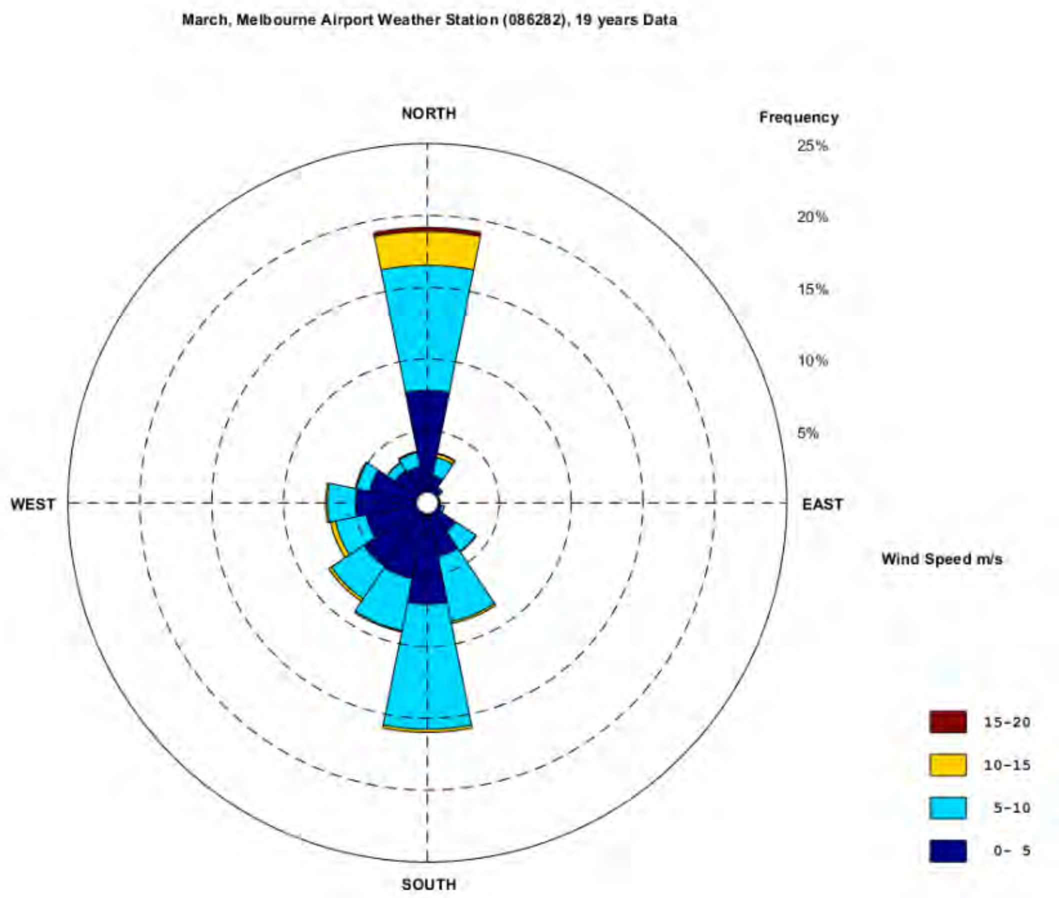


Figure 12: March frequency and strength of wind, Melbourne Airport

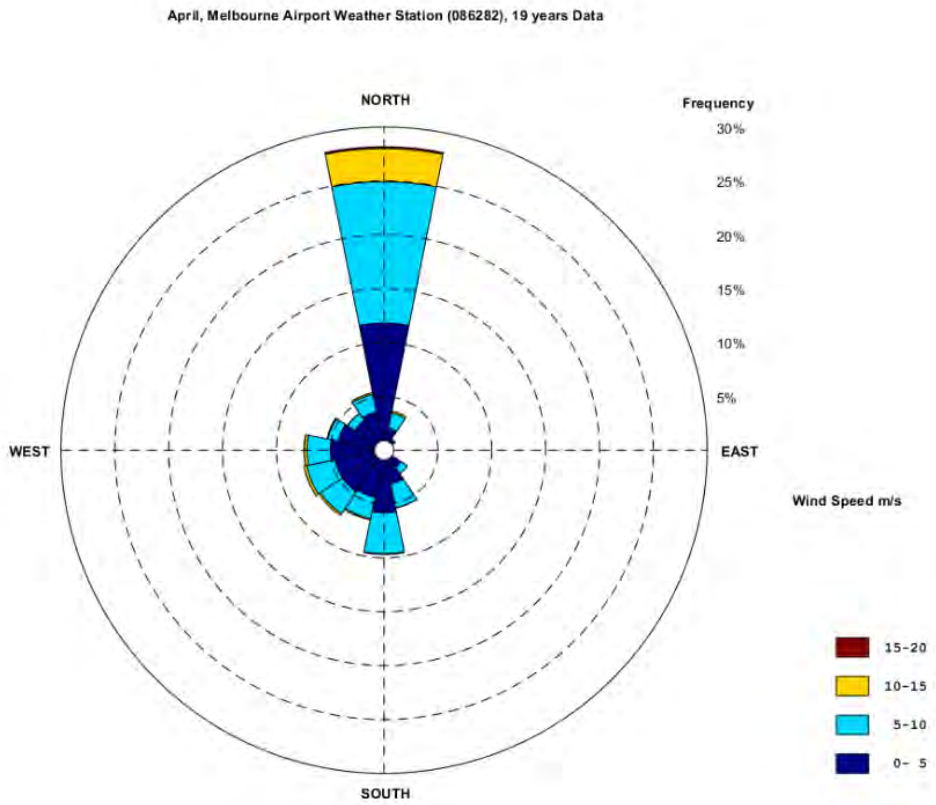


Figure 13: April frequency and strength of wind, Melbourne Airport

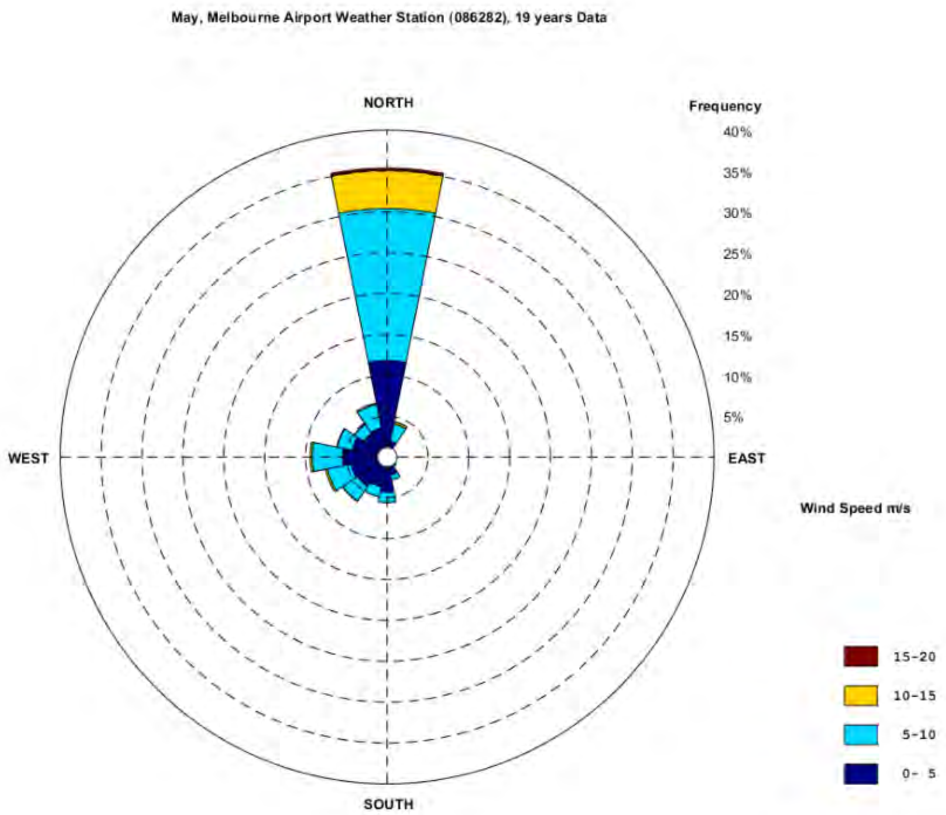


Figure 14: May frequency and strength of wind, Melbourne Airport

The winter months: June, July and August, are dominated by the north wind as shown in Figure 15, Figure 16 and Figure 17 respectively. The frequency of the north wind in June is above 35% and increases to more than 40% in July. However, it starts to drop down in August. The west wind is the second most frequent wind direction for this period.

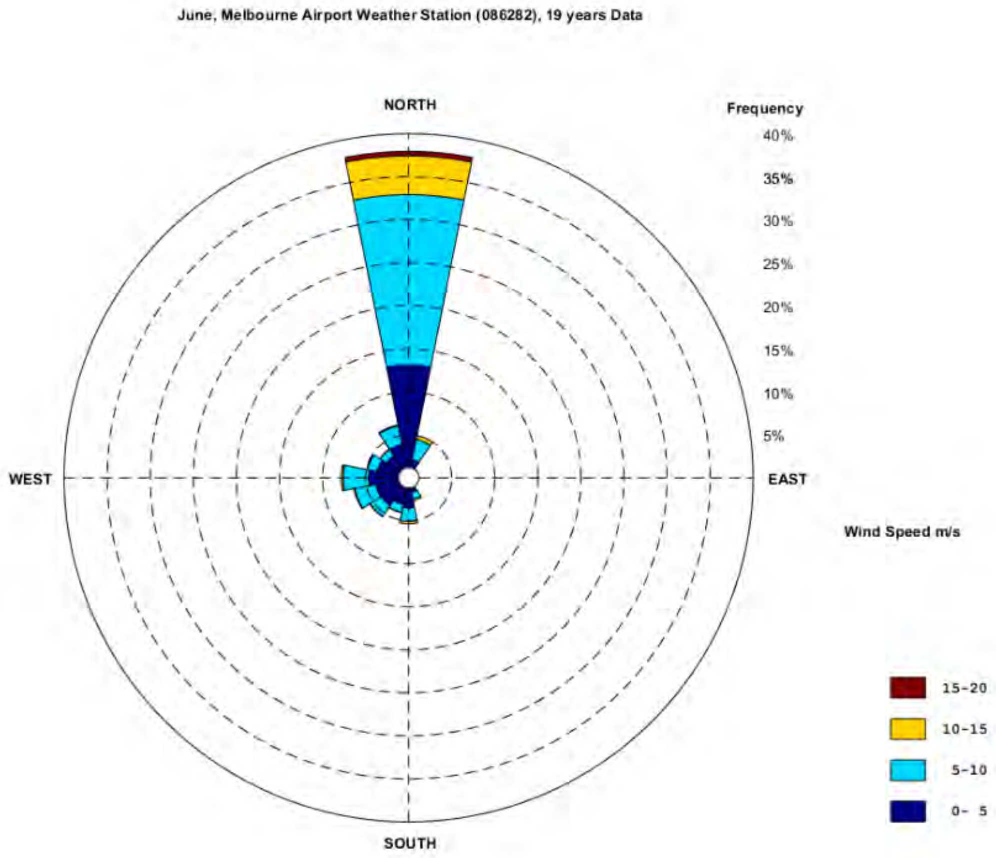


Figure 15: June frequency and strength of wind, Melbourne Airport

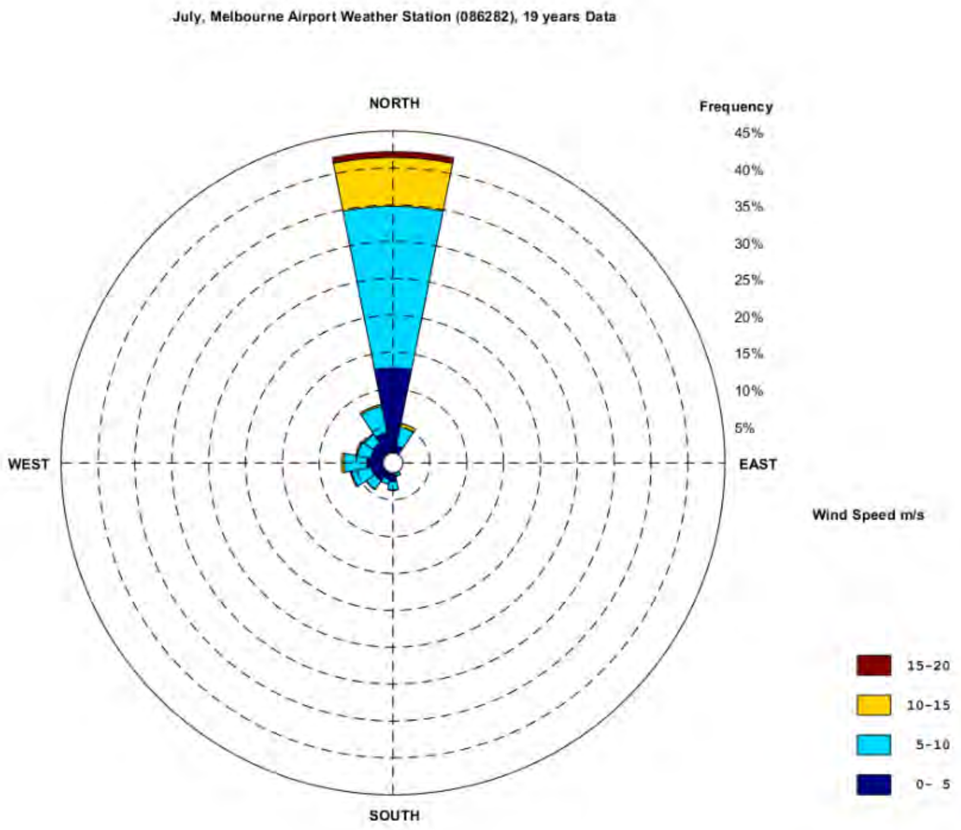


Figure 16: July frequency and strength of wind, Melbourne Airport

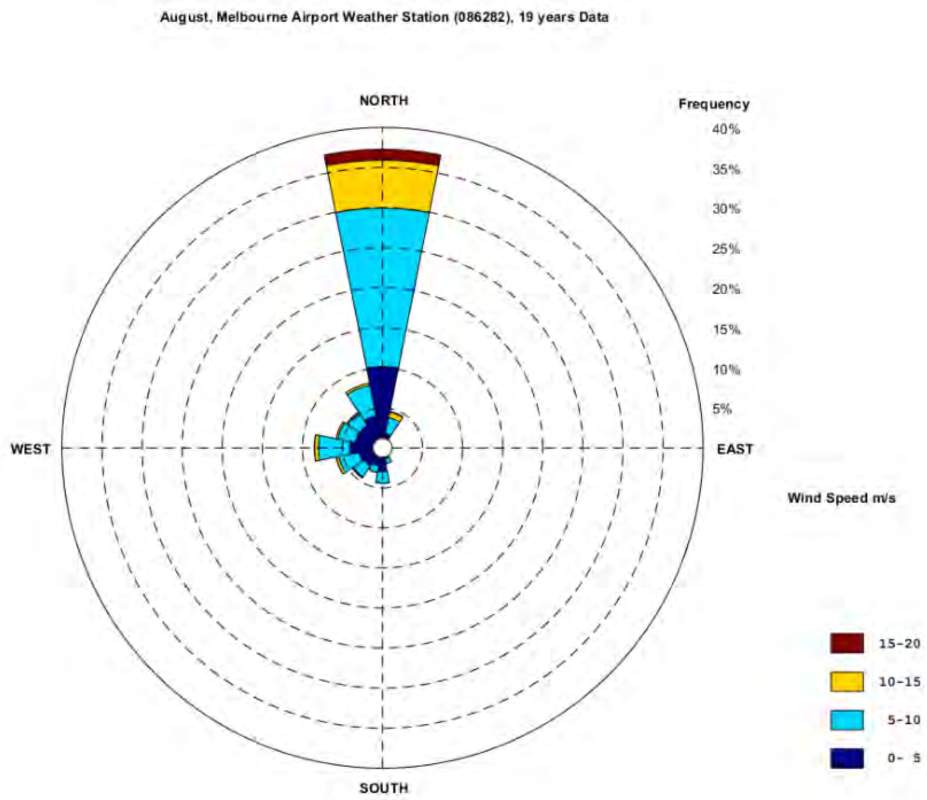


Figure 17: August frequency and strength of wind, Melbourne Airport

The spring wind climate: September, October and November; the temperatures begin to increase, accompanied by a change in the dominant wind direction from north to south as seen from Figure 18 to Figure 20. Thus, in November the wind from the south becomes more frequent than the north wind as shown in Figure 20.

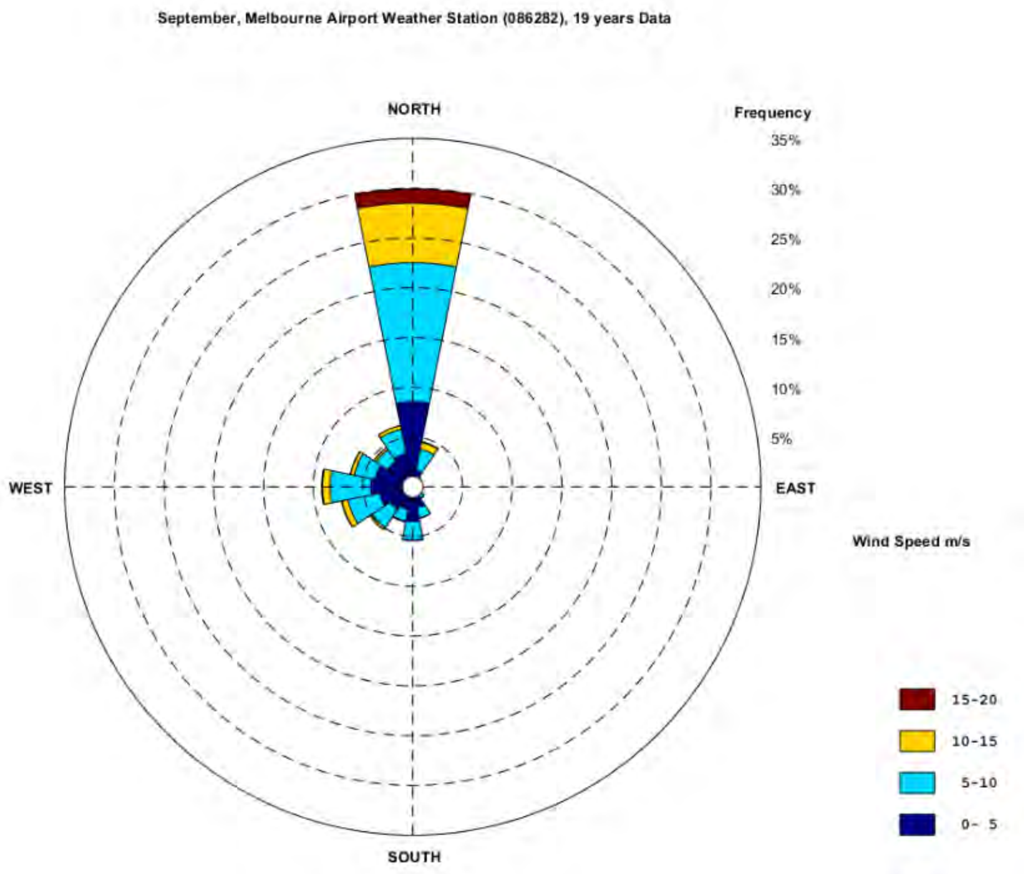


Figure 18: September frequency and strength of wind, Melbourne Airport

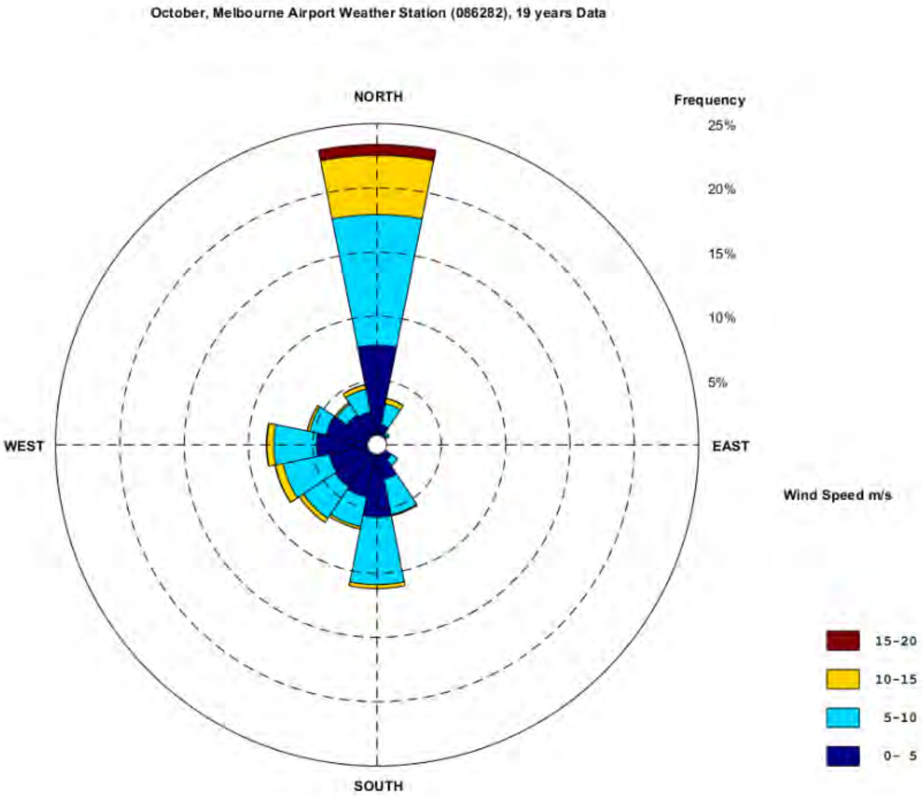


Figure 19: October frequency and strength of wind, Melbourne Airport

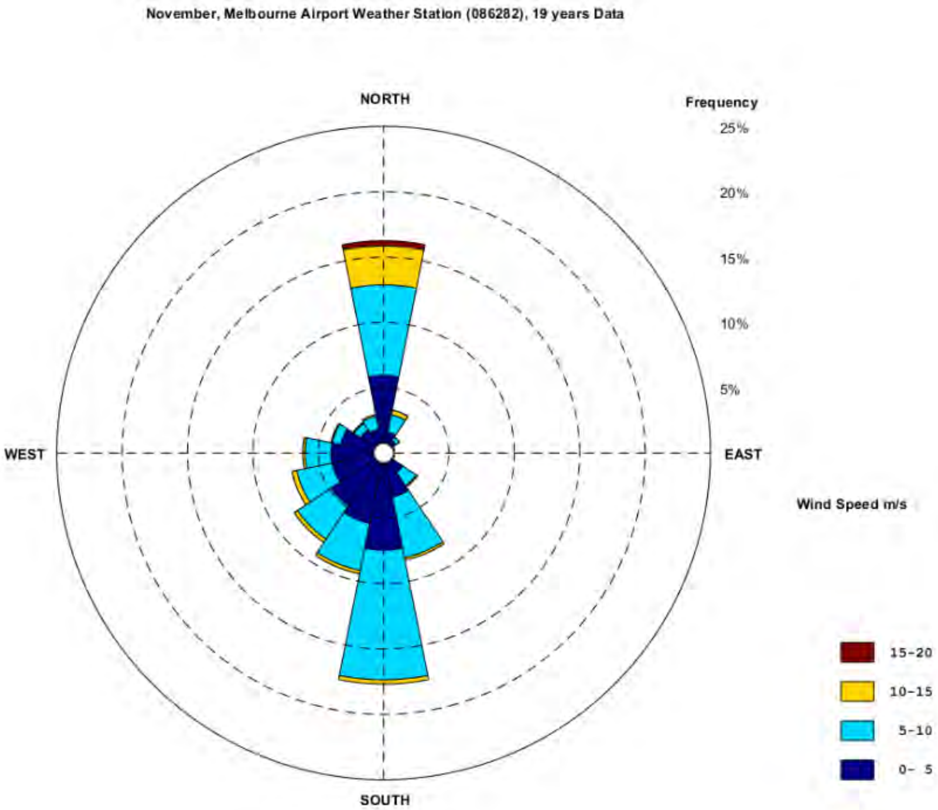


Figure 20: November frequency and strength of wind, Melbourne Airport

3. Wind Design Guide

The following section presents practices for the design of new urban areas in relation to the wind.

3.1 Street Width and Orientation

For designing suitable high-density urban areas, the following parameters are of paramount importance for achieving acceptable wind conditions at street level.

- Air paths

A general guide for street width is to have a building height to street width ratio less than 0.7. However, in high-density urban areas, the building height is much greater than the street width. Therefore, to improve wind penetration, air paths are the method of choice for high-density urban areas.

Figure 21 below illustrates the view from the north of the proposed development. The following calculation is carried out to show the method of calculating the air path street width. The width of the air path changes throughout the precinct for different locations, and this calculation will help guide the effective street widths for the creation of air paths. The width of the highlighted buildings at either side of the opening is:

1. $w_A = 43\ m\ (width\ of\ podium);\ \&\ w'_A = 29\ m\ (width\ of\ tower)$;
   $l_A = 63\ m$; $h_A = 62\ m$ (incl. tower as P = 25m)
2. $w_B = 25\ m$; $l_B = 64\ m$; $h_B = 59\ m$ (incl. tower as P = 25m)

$$W_{AIR} = 50\%\ of\ (W_A + W_B)$$

$$W_{AIR} = \frac{1}{2}(29 + 25) = 27m$$

where $w = width\ of\ podium\ (m)$
$w' = width\ of\ tower\ (m)$
$l = length\ of\ development\ (m)$
$h = total\ height\ of\ building\ (m)$ – *including podium*
$W_{AIR} = width\ of\ air\ path$ – *distance between A and B (m)*
$(refer\ to\ \mathbf{Figure\ 21}\ and\ \mathbf{Figure\ 23}\ below)$

Given this calculation, for the buildings at each side of the street, the width of the street should roughly equal 27 m. However, given that the current width in the design is 8 m, no air paths can be developed within this street. This does not mean that channelling and other environmental wind effects may not occur at this location.

Southern Fogarty Street on the other hand, has a suitable ratio to allow an air path to develop, resulting in a calculated $W_{AIR} = 24\ m$ and measured separation of $W_{AIR} = 26\ m$. This means that Fogarty Street will become an effective air path for the north direction to improve the cooling and ventilation of this precinct area. However, the area will need careful study to determine if environmental wind effects such as channelling are prone to occur, thereby reducing the effectiveness of the air path.

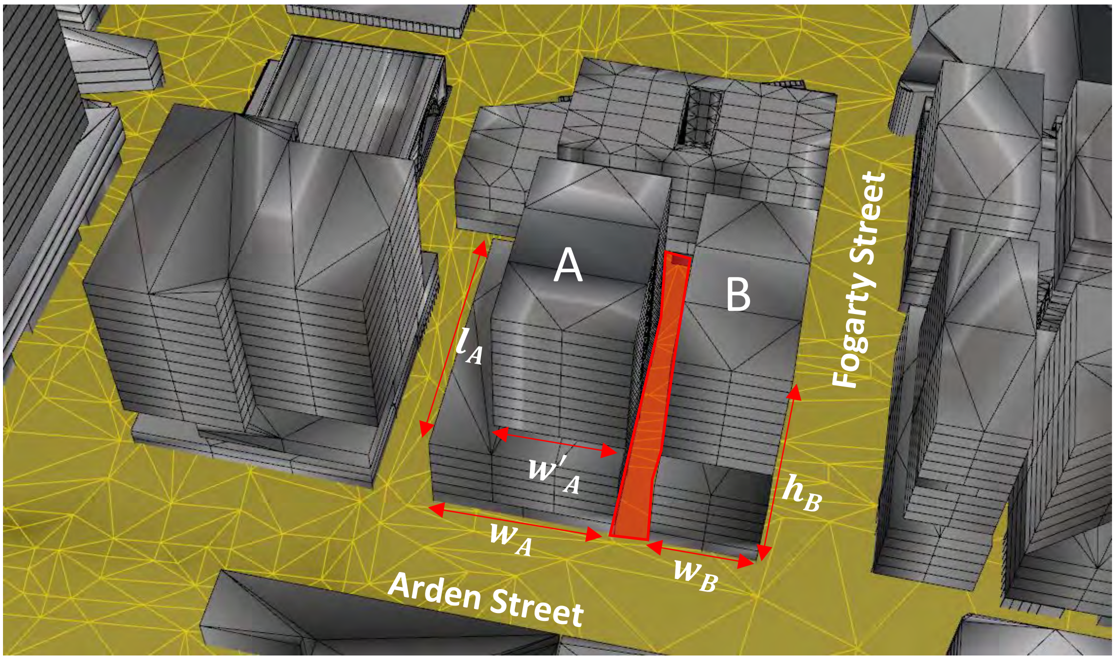


Figure 21: Air path determination between buildings G1 and G2

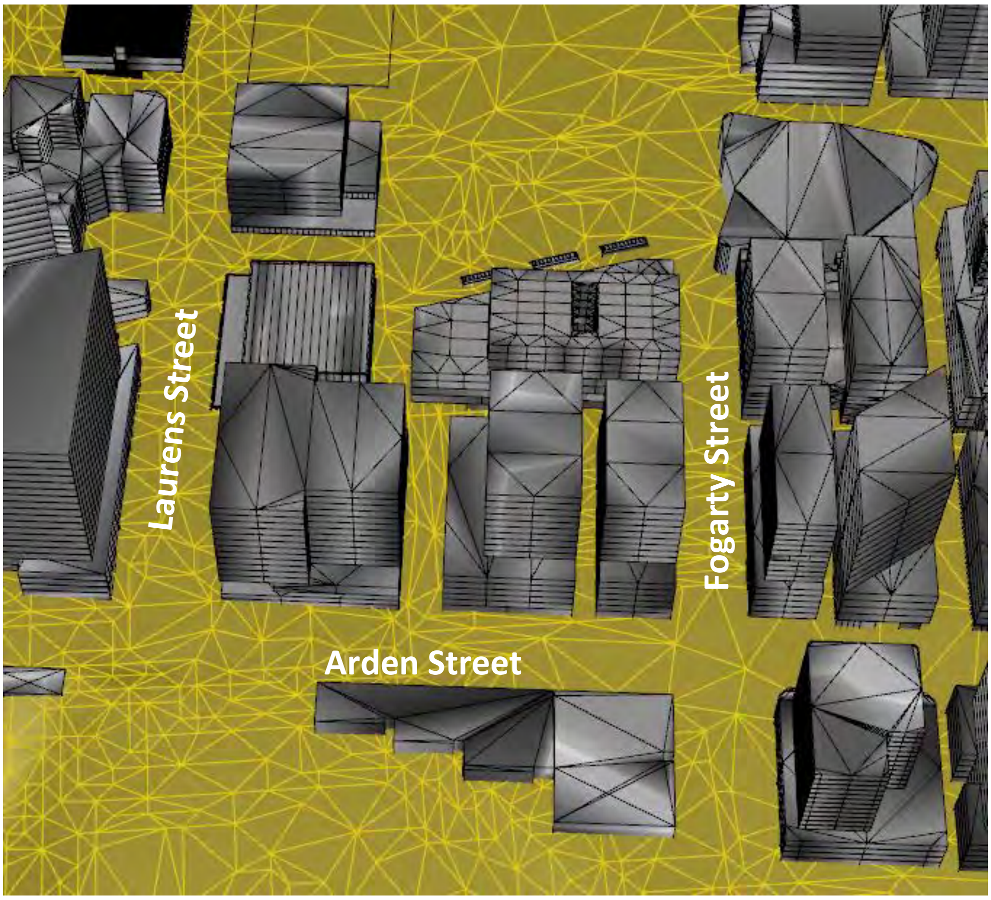


Figure 22: Building Group G in Arden Central site context

For Laurens Street, the calculated air path width is $W_{AIR} = 58\ m$ compared to the measured value which is $W_{AIR} = 63\ m$. This then means that Laurens Street will retain the potential to create an air path through the development. However, it is also greatly exposed to the northern winds with the North Melbourne Recreation Reserve across Arden Street.

Previous studies [6] propose a design principle as illustrated in Figure 23 below. For air paths to be effective, the width of the air path at the windward side should be at least, and on average, 50% of the total widths of the buildings at either side. The length of the air path must also be considered.

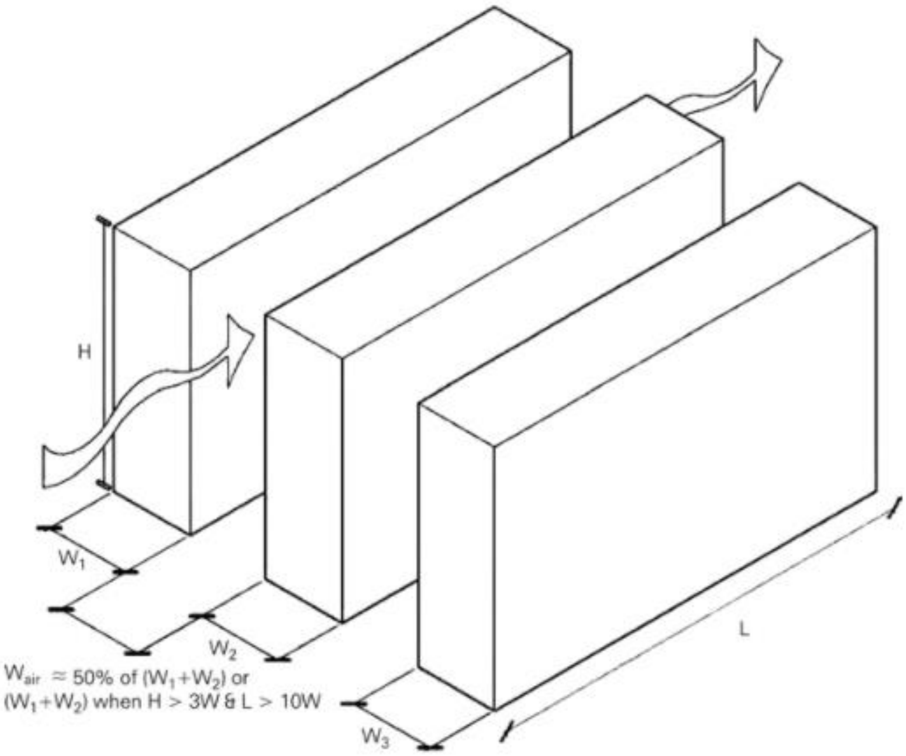


Figure 23: Air path and building geometry relationship [6]

It must be noted that this principle was mainly derived for buildings in Hong Kong, where the wind environment is very different to Melbourne. Hong Kong has a very low average wind velocity whereas Melbourne has a much higher average wind velocity and frequency. Thus, whilst the criteria can be applied to the Melbourne urban design, the focus must be tailored for the situation. Hong Kong looks to promote wind flow and increase circulation whilst Melbourne requires concentration on shielding and redistribution.

As cities grow, the mean height of buildings increases while the street width generally remains unchanged. Therefore, achieving suitable penetration of the wind to reach the ground floor, and thus promote ventilation is of the utmost importance.

The orientation of the streets determines the wind interaction between buildings and along the streets as well as the strength of the wind, and ventilation of public spaces. The street orientation of the proposed development is shown in Figure 24. The north wind is the most frequent wind for North Melbourne as per the climate study above. This direction is the most frequent all-year-round except in summer. In summer, the sea breeze from the south is dominant.

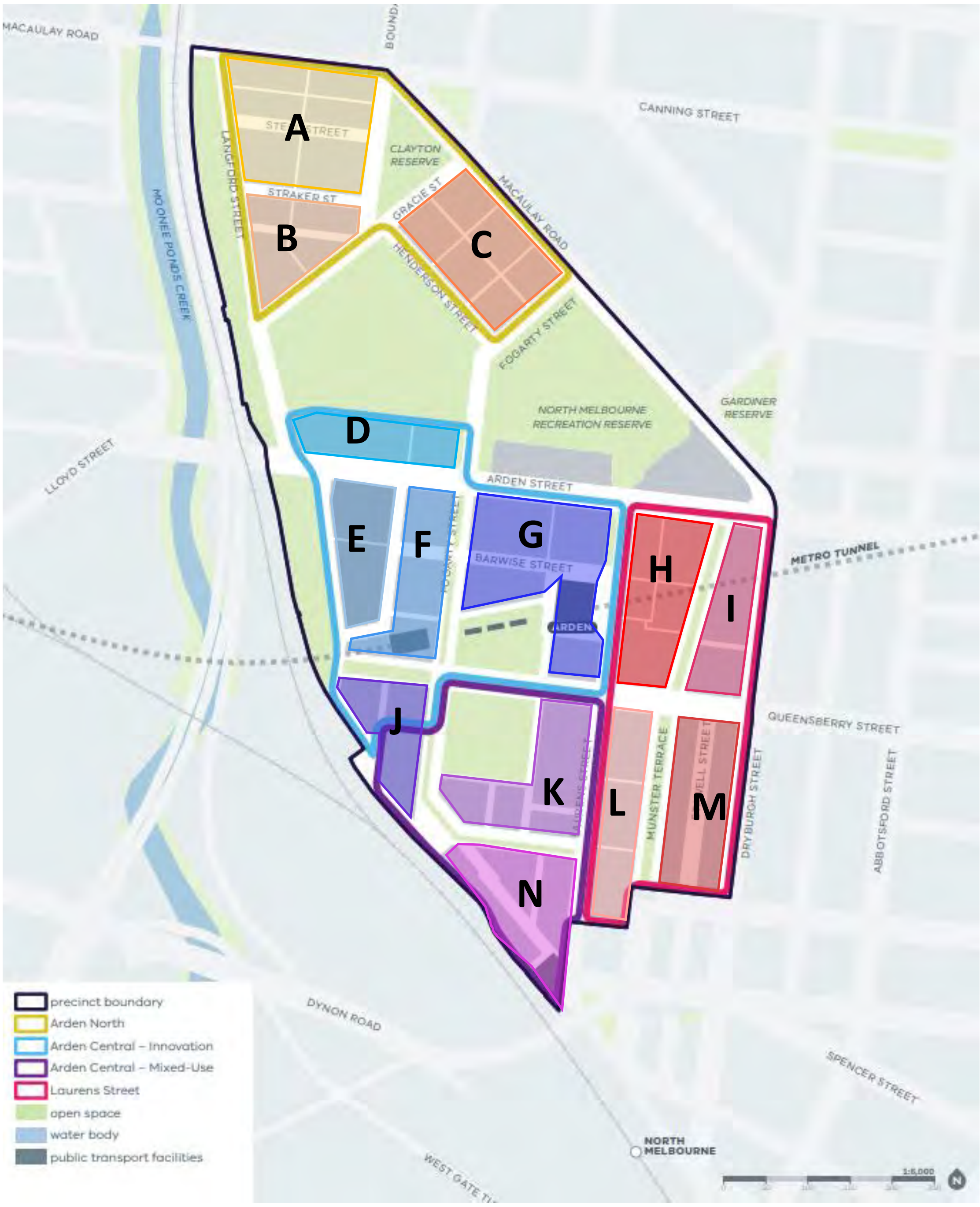


Figure 24: Street Orientation of the Proposed Development

The street orientation of the Arden Urban Renewal Precinct runs north to south and east to west with a 6.5° clockwise rotation. This street orientation has the potential to create a channelling flow of the undesired north wind. However, it also helps the sea breeze from the south penetrate further into the development. Pedestrian walkways parallel to the north direction should be known as potential areas for adverse conditions. All design strategies for wind control need to be considered in these areas.

3.2 Building Orientation (Comfort and Safety)

The building orientation and the location of the main entrances to buildings will affect pedestrian comfort and safety. Thus, the following methods are proven in creating a pedestrian-friendly wind environment.

- Building entrances not face the dominant wind directions. This will avoid downwash effects of a strong wind at building entrances.
- Buildings with an articulated façade – this will breakdown the wind and thus, less wind will reach the street level.
- Buildings with podiums and canopies reduce the downwash effect and decelerate the pedestrian level winds.

The proposed Arden Urban Renewal Precinct building orientation is shown in Figure 25. The orientation of most buildings is north–south. This orientation will increase the precinct's ventilation, but it will also require careful consideration of the position of building entrances; which are recommended to be on the east face; on the leeward face of the buildings.

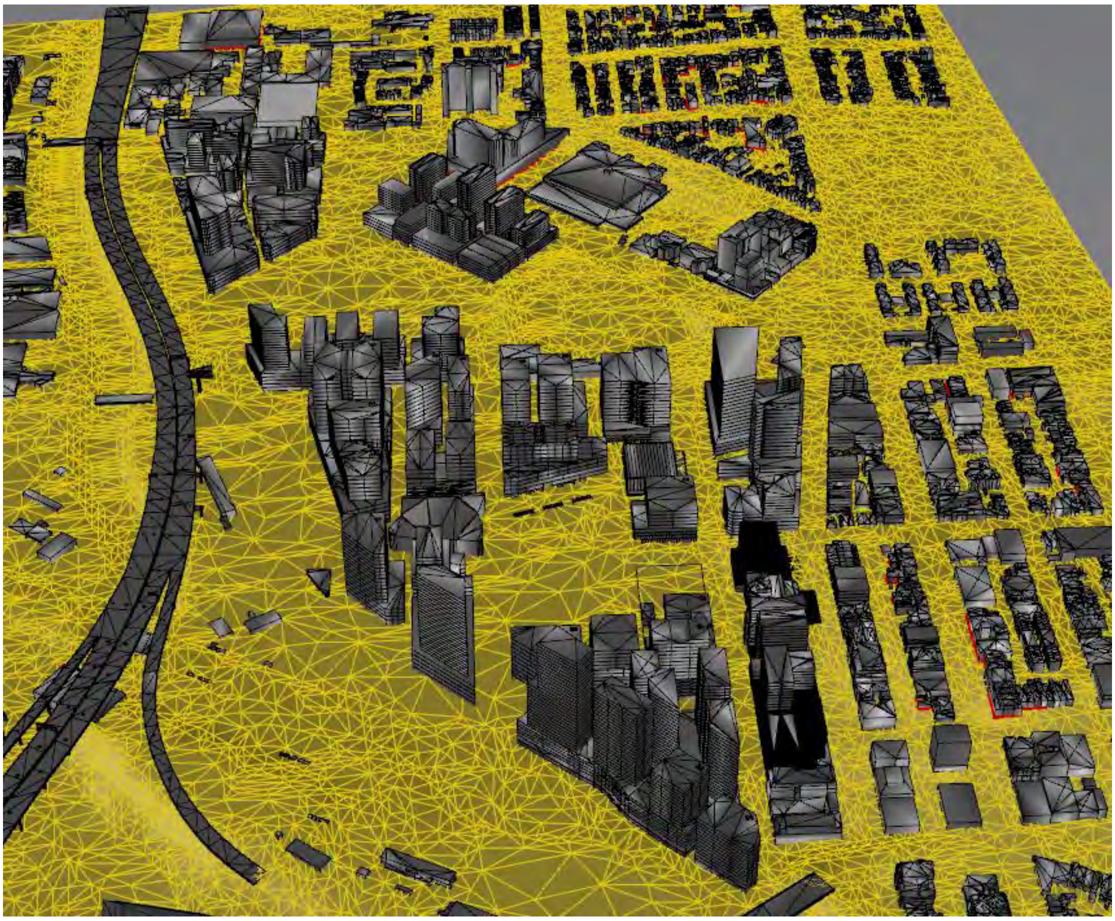


Figure 25: Building Orientation of the Proposed Development and surroundings

As discussed in earlier sections, the orientation of the buildings is not uniform across the entire development and some sub-precincts contain buildings which vary from the general scheme. This aspect is determined by the position of these buildings, which are found mainly at the precinct boundaries.

To the north of Arden Street, buildings in groups A, B and D are orientated equitably north to south and west to east. Group C resemble the street configuration of Macaulay Road and thus, their orientation is northeast to southwest and along Henderson Street it becomes northwest to southeast.

Building B1 is the tallest in Arden North and has an orientation of northwest to southeast parallel to Langford Street. Building A1, found in the northwest corner of Arden North, its western face shows the same configuration, as do all the podiums of both groups which face to Langford Street. Figure 26 illustrates a close-up view of Arden North including the reference grouping and naming of the buildings.

The orientation of the buildings in cluster D will help create air paths to allow for ventilation of the western half of both Arden Central sub-precincts for the incoming northern wind. Building D1, on the west, shows the same orientation as the buildings and podiums along Langford Street in groups A and B; and groups E, F and G opposite Arden Street to the south of them.

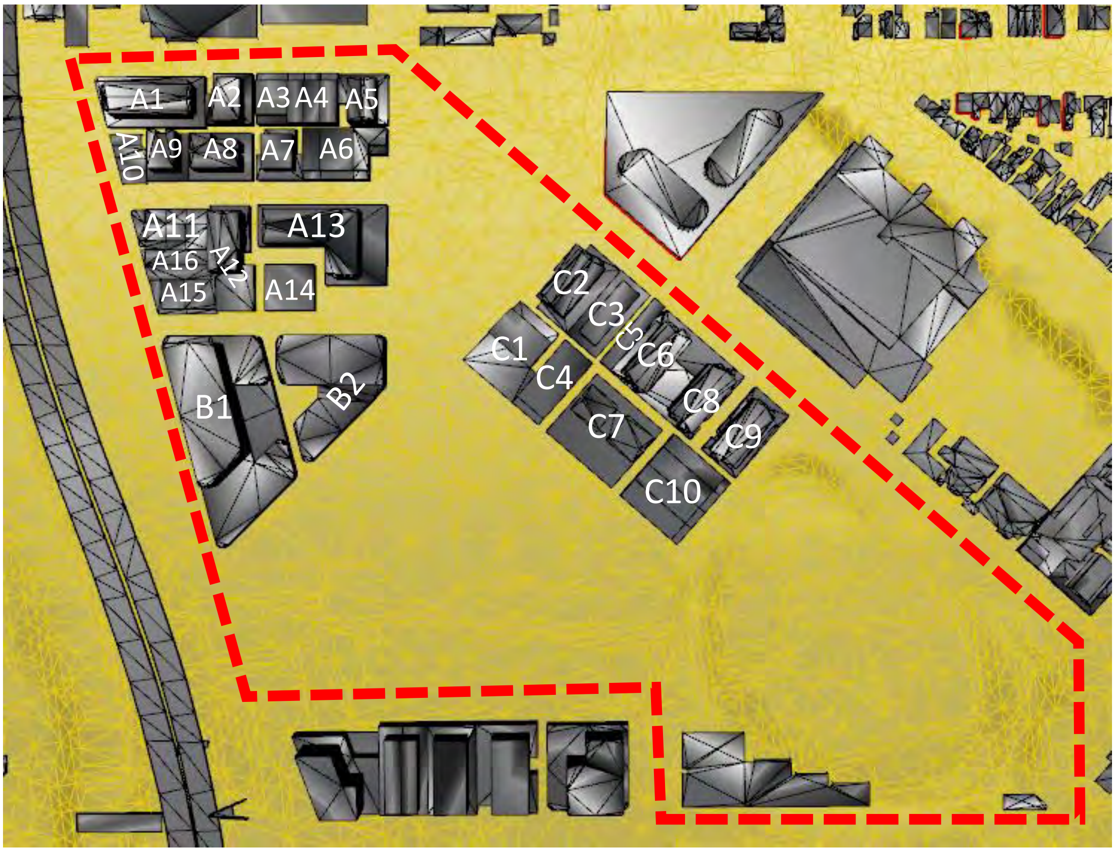


Figure 26: Arden North close-up individual building denomination

Both Arden Central sub-precincts display a similar scheme to Arden North in the north half of the sub-precinct; buildings in clusters D, E, F, G and K generally follow the same north to south and west to east orientation. Their distribution maximises the interlocking of buildings to avoid channelling in this area and promote ventilation in perpendicular streets to the north direction, while leaving room for potential air paths to develop. Figure 27 and Figure 28 shows a close-up view of both Arden Central sub-precincts design schemes, including the reference grouping and naming of the buildings.

Figure 27: Arden Central - Innovation sub-precinct close-up individual building denomination

Figure 28: Arden Central – Mixed-Use sub-precinct close-up individual building denomination

As shown above, developments E1 and E2 display a less sharp angle on their western faces as in Arden North, with a north-northwest to south-southeast orientation. The podiums and towers of developments J1, J4, N1, N2 and N3 all have the same pitch on their southwestern faces, resembling the street configuration. The developments in cluster K include: K1 as a low-rise government school building with north to south orientation, K2 and K4 have a west to east orientation, and K3 displays a north to south orientation. Building K4's south-western edge is diagonally parallel to the street, with a similar pitch as cluster N buildings. Figure 29 shows a specific area of interest and the shape and distribution of buildings J3 and J4, in relation to the orientation and shape of buildings in group N. This area will require careful study to determine if channelling will develop, especially for northerly winds.

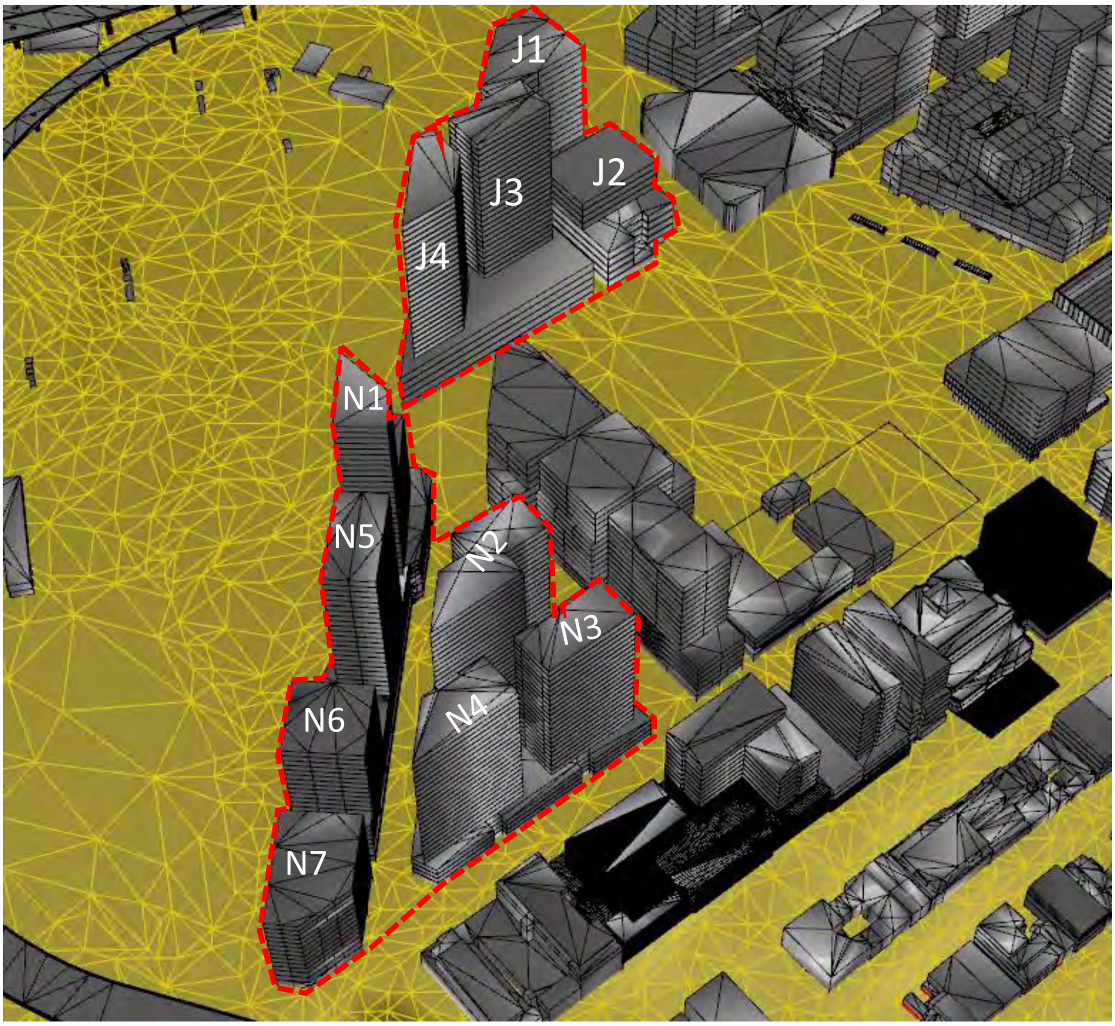


Figure 29: Close-up of building groups J and N

Laurens Street sub-precinct concentrates the tallest buildings in cluster H to the north. Buildings H1, H2 and H6 are orientated north to south. Meanwhile, H3 and H4 are orientated W to E and H5 resembles a reflected L-shape located on the corner of Munster Terrace and Queensberry Street. Group L buildings are mainly orientated W to E, except for L5 which has an L shape rotated by 90 degrees anti-clockwise and the longest side orientated north to south. Buildings in groups I and m are primarily low-rise buildings; with I1 to I4 designed as mid-rise developments, all display an orientation west to east. The orientation of buildings in the Laurens Street sub-precinct is shown in Figure 30 below.

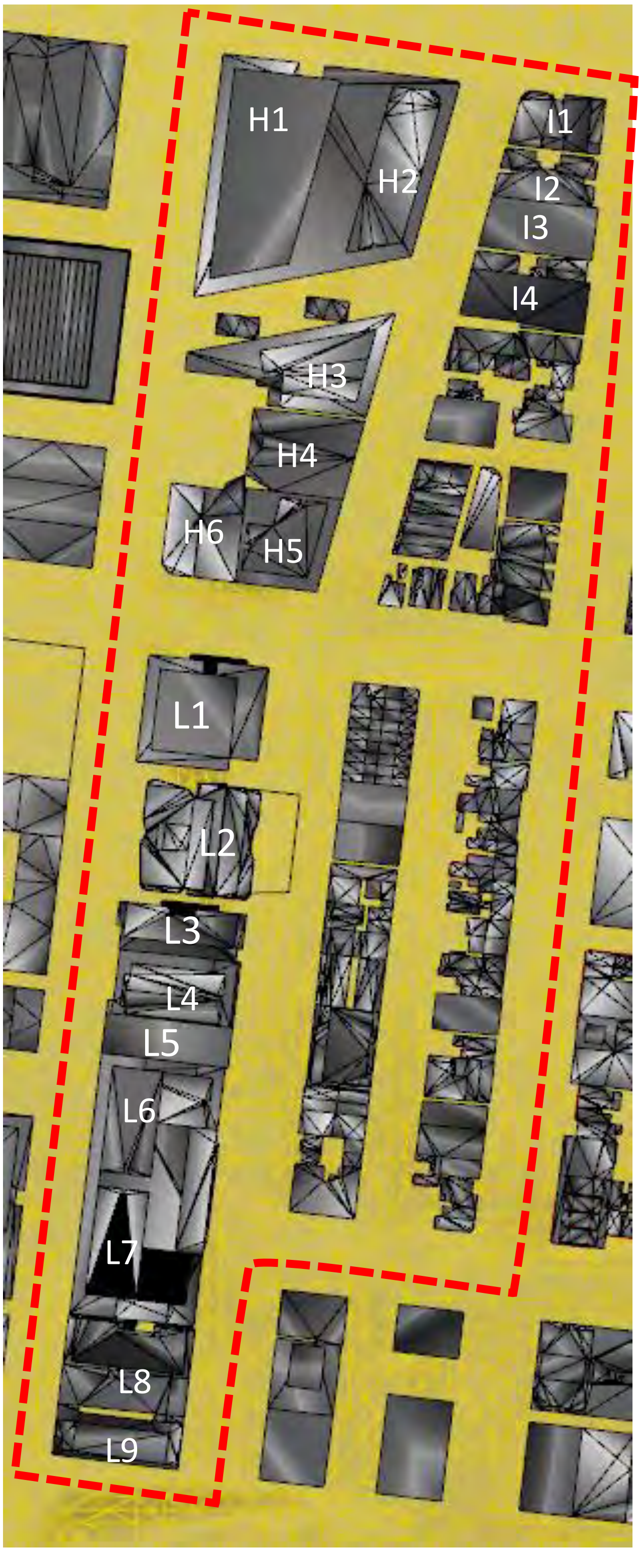


Figure 30: Laurens Street close-up individual building denomination

3.3 Building Orientation (natural ventilation)

The building orientation is responsible for promoting or hindering natural ventilation. If a building is orientated so that the windows are facing the most frequent wind direction for the desired wind, natural ventilation will be considerably more effective. Thus, windows used for the inlet of natural ventilation are required to be oriented to face the south direction for access to the southern sea breeze. The topography of the site increases from west to east, as shown in Figure 31. Buildings that are orientated west to east can expect increased wind speed on the western face.

To effectively design for natural ventilation, the height of the buildings should increase from south to north and from west to east. This will allow for winds to penetrate further into the development and ensure that ventilation occurs in the entire precinct. Detailed positioning of windows for natural ventilation of buildings is not covered in this study and will require a detailed study.

Figure 31: Precinct topography

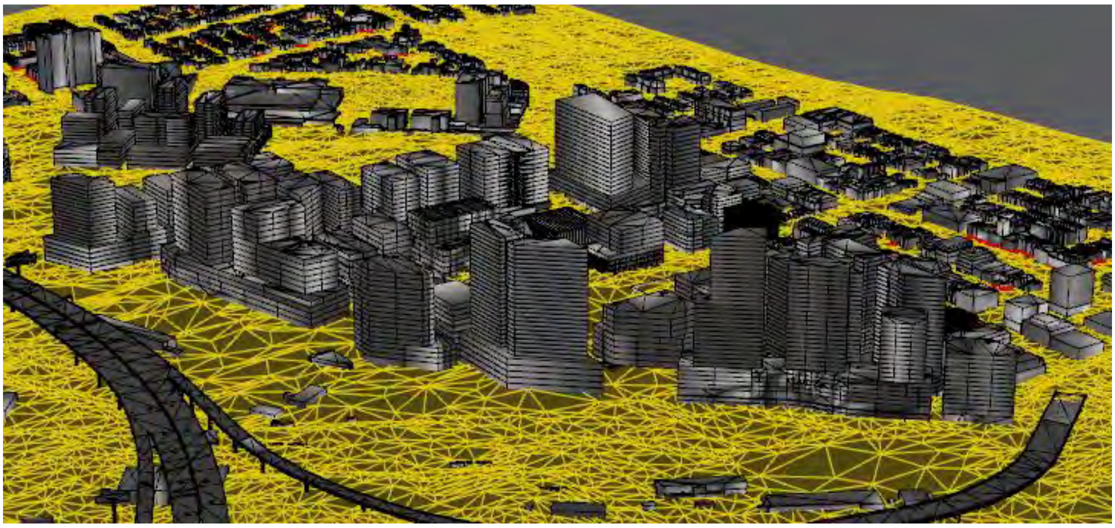


Figure 32: Building Orientation

3.4 Building Relative height difference

Building height difference will contribute to the nature and the magnitude of the wind distribution. Relative height difference; as can be appreciated in Figure 33, can be as effective in the z-direction as the x- or y-directions. Downwash is the characteristic environmental effect of this scenario. It takes place on the windward and leeward faces of the buildings; thus, spiralling vortexes towards the ground. As a result, a pressure differential is induced with positive and negative pressures on the two sides of a slab-like building, encouraging the wind to move parallel to the building facades along the street, and thus urban ventilation. Table 1 shows the relationship between the height difference and the air changes per hour, as a measure for suitable ventilation.

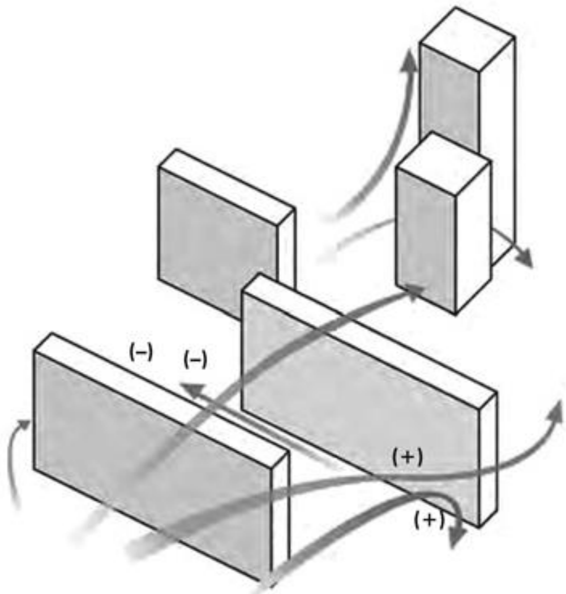


Figure 33: Effects of variable building heights [6]

Table 1: Effect of relative height difference in air changes per hour [6]

Height contrast	Height difference Max:Min	Air changes per hour
0	4:4	10.5
3	3:6	10.8
4	3:7	11.9
6	2:8	13.8
7	2:9	11.2
8	1:9	13.3
10	1:11	13.4
10	0:10	17.9
14	0:14	17.0

A taller building at the south edge will block the wind and less wind will be available at the centre for ventilation and pollution dispersion. Thus, it is recommended that the taller buildings be to the north, while the shorter buildings be situated to the southwest. The extent of blockage should be determined in a detailed study, as the wind penetration through the gaps can be enough in some cases. Figure 34 shows how the progressive massing affects, and builds on, the wind flow pattern. Figure 35 shows the buildings that may experience insufficient sea breeze in summer. A general design guideline would be to have at least one third of the building stand taller than the shorter building.

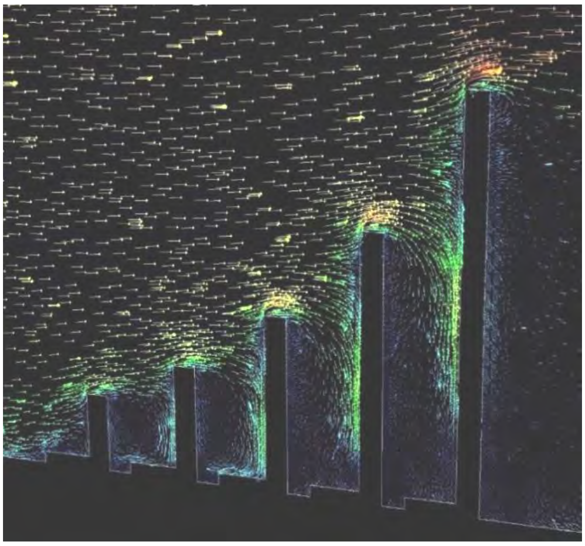


Figure 34: Wind flow pattern and progressive massing

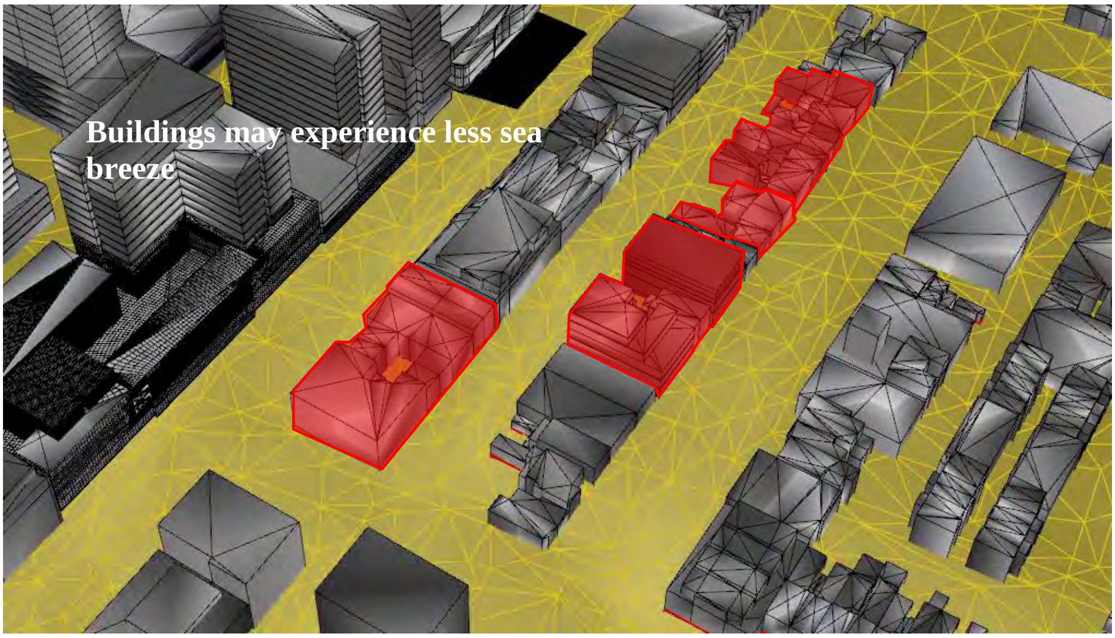


Figure 35: Buildings and courtyards in group M with potentially low ventilation and cooling from the southern cooling breeze

3.5 Space between Buildings

Buildings with very close spacing will have low air circulation but it will prove advantageous in retaining heat in during cold weather. Buildings far apart will have the wind distribution of isolated buildings and will be subjected to strong wind movement around their base. However, buildings spaced at a reasonable distance apart will help to achieve a comfortable wind circulation. Buildings spaced less than their height are considered closely spaced buildings. This is mostly applicable for low-rise developments. Figure 36 shows the wind pattern in three different cases. The first is an isolated flow, where there is less interaction between the flow structure of one building with the other. In the second case, the wake interference flow partially interacts between both building's flow structure, however, one structure does not fully shield the other. The last case, skimming flow, is when the flow progresses over the building and there is less flow in between buildings – less dispersion in this case.

Minimising the negative impacts of buildings on the public realm is paramount. Some of the most important considerations include the following: overshadowing, pedestrian level wind, daylight access and privacy of building occupants. A separation of minimum 25 m is often a viable distance but it does not take into account the building shape, height or exposure. The more appropriate guideline to follow would be: the minimum separation distance should equal the widest dimension of the tower floor plate.

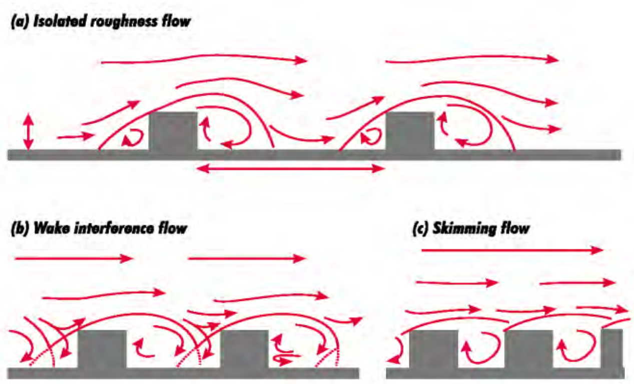


Figure 36: Flow structure and building spacing

Within the Arden Precinct there are areas in which the spacing between buildings and their positioning is too small and thus, volumes with low air circulation and higher levels of pollution concentration are created as a result.

Beyond design guidelines for appropriate street width and building separation, the following parameter is also of paramount importance:

- Deep Street Canyons

According to previous studies [6], the Height to Width (H/W) of deep street canyons for the creation of a suitably ventilated environment, must be at least 1:2. However, in densely built-up areas, much higher ratios are commonplace. If the height is much larger than the width, the vortexes that detach from the urban canopy boundary layer will not reach the ground.

For the Laurens Street northern end, the H/W of the buildings; including the relative height difference, demonstrates a ratio of approximately $h: W_1: H_1 = 1: 3: 3$ – refer to Figure 37. According to this calculated ratio, the air in this location will also boast of high circulation with western winds; elevating pollution dispersion and the cooling effect, as described in Figure 38. Although there are advantageous conditions created by the massing and distribution of these developments, there is a higher potential for downwash taking place and flowing down onto Laurens Street. In addition to having the Arden Central Train Station forecourt entry, this area will require careful study to ascertain if the building is setback far enough and whether conditions will remain comfortable in this particularly important area.

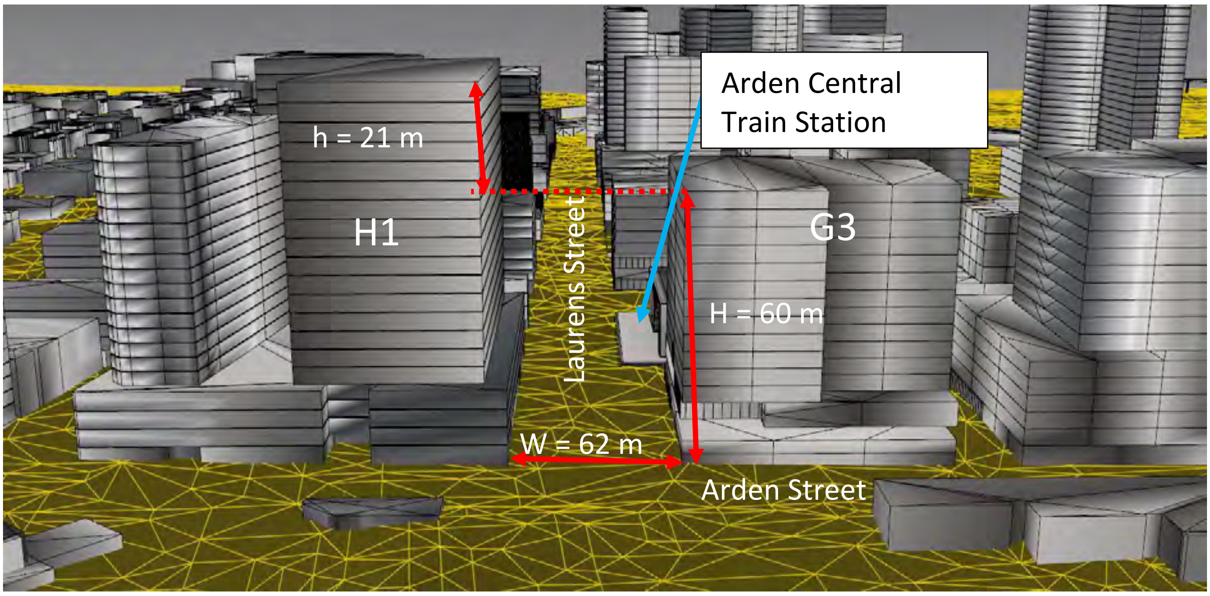


Figure 37: Building dimensions for H/W ratio calculation

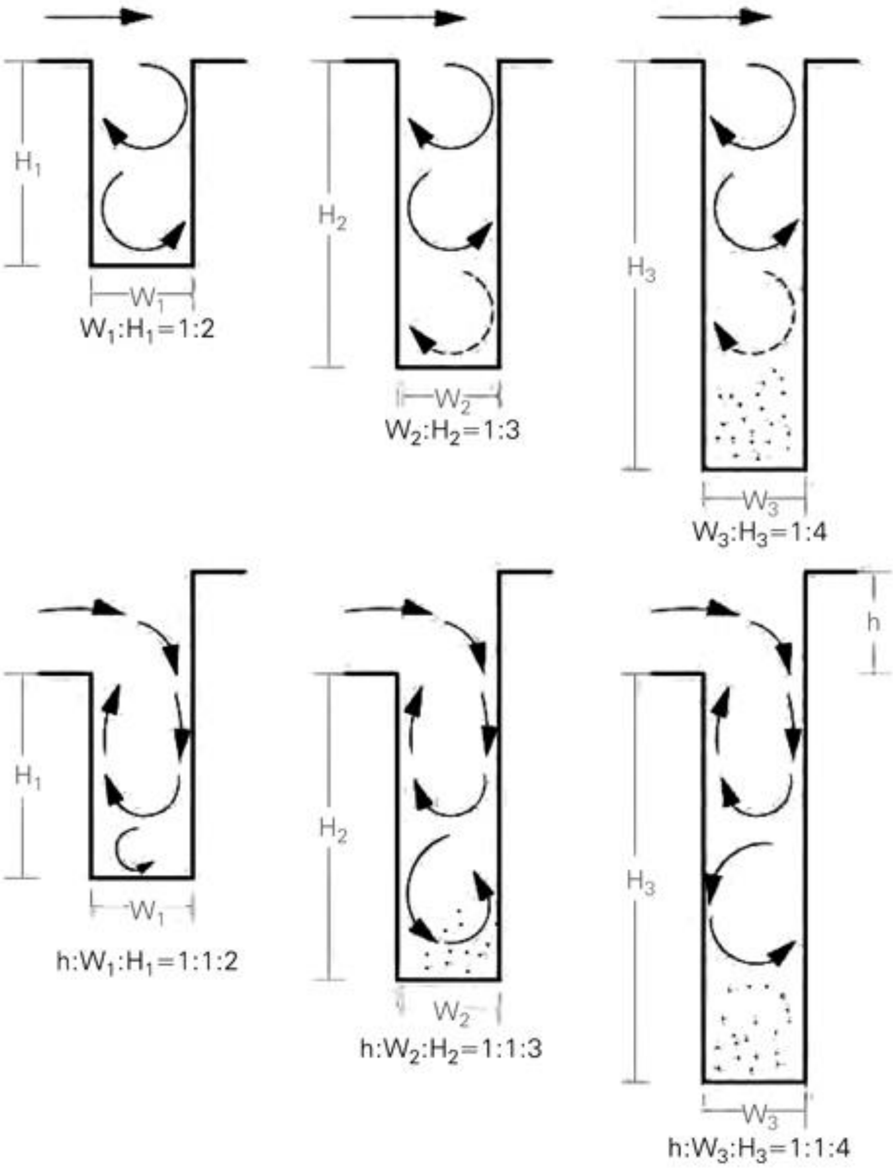


Figure 38: Street canyons and air circulation vortexes [6]

These criteria were developed for Hong Kong [6], which has a very low-wind environment and is vastly populated by tall high-rise towers. In a densely built-up city, creating effective air paths is essential to its liveability. However, in the case of Melbourne, the high-wind environment means that the focus is shifted to create shielding rather than promoting. Hence, despite the importance of air paths to the success of the project, they must be strategically placed to satisfy comfort and safety within the wind conditions required of the project.

Locations of special interest have been highlighted from Figure 39 to Figure 44 below and a higher level of scrutiny was applied in these areas to ensure acceptable conditions. The areas of high interest are the following:

- Arden Central Train Station Forecourt entrance
- Arden Street adjacent to Fogarty/Little Fogarty Street intersection.
- High-capacity public transport and cycling corridors: Fogarty Street (between Macaulay Road and Fogarty Street South), Henderson Street, Boundary Road, Laurens Street, Barwise Street.
- Further testing of the created central open space in Arden North, where dangerous wind conditions were identified at the Green and Fogarty Street intersection.
- Linear parks: Munster Terrace (western side of Munster Terrace), Queensberry (south side between Laurens Street and Langford Streets).

Arden Central Station is shown in Figure 39. Due to the orientation of Laurens Street, parallel to the north wind direction, and the high level of exposure provided by the open expanse of the North Melbourne Recreation Reserve, Laurens Street suffers from high channelling potential. The forecourt entrance will experience particularly high wind speeds from channelling. The location of the station on the northern end of Laurens Street means that the channelling flow will retain its high energy by the time it reaches the station and will render conditions unsuitable.

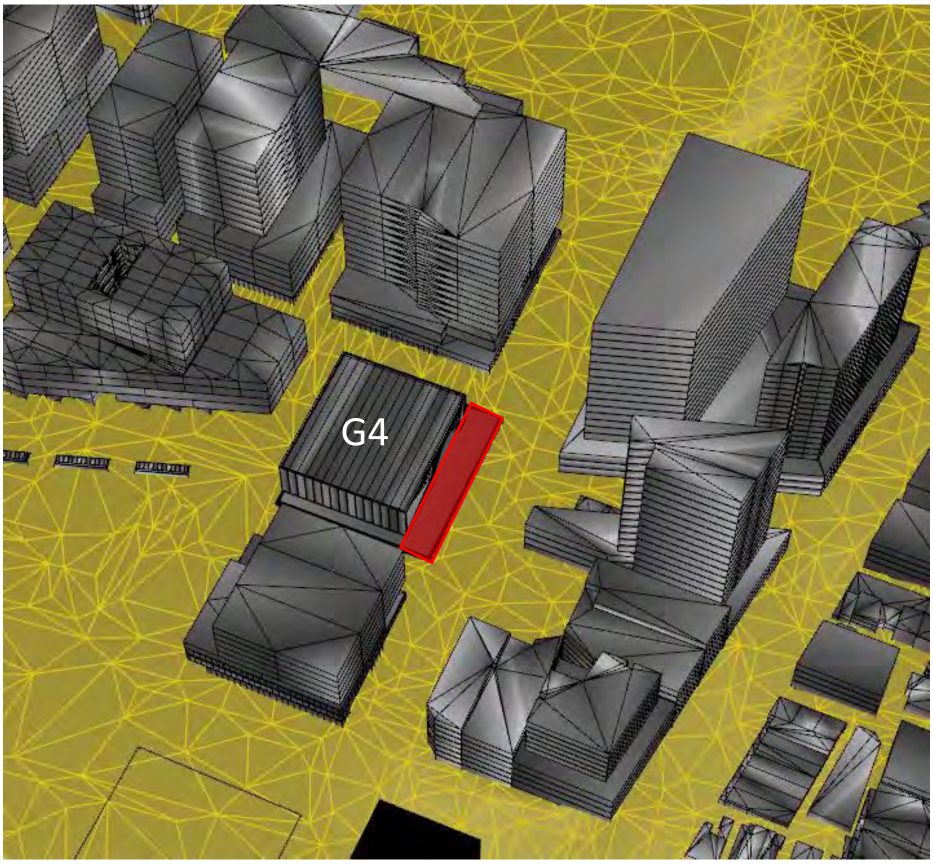


Figure 39: Arden Central Station (G4) forecourt entrance

The corridor between buildings F3, F4 and F5, as shown below in Figure 40, has been depicted as a potential area for a 'dead zone'. A dead zone is an area with low air circulation in which the air largely remains stagnant and pollution accumulates and cooling during the summer months does not take place. The flow will perform skimming and will not be redirected to the ground level, as shown in Figure 36. This is due to the width of the corridor highlighted and the height difference between the podium of F3 and F4 and the building height of F5.

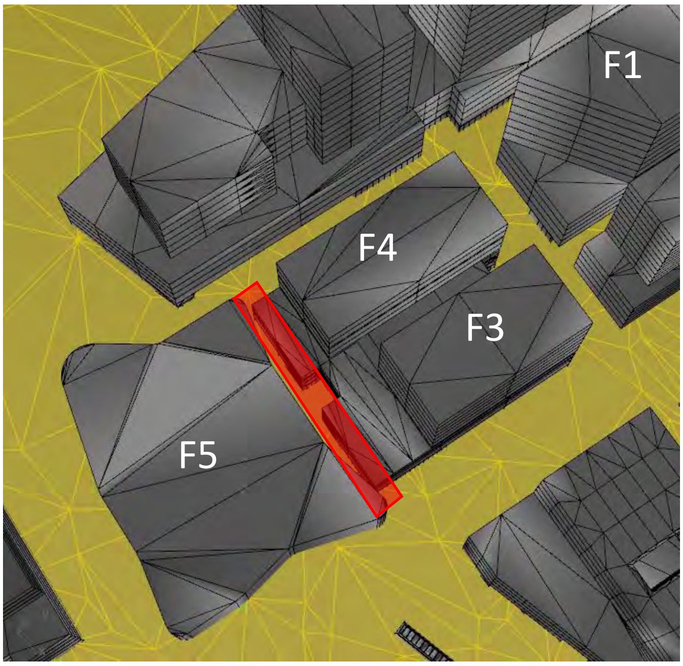


Figure 40: Group F potential dead zone

The area highlighted in Figure 41 is predicted to experience channelling from the northern wind direction. The reduced building separation and relative height difference and, most importantly, the pedestrian walkway under building G5 connecting Barwise Street to the Capital City Open Space increase this potential.

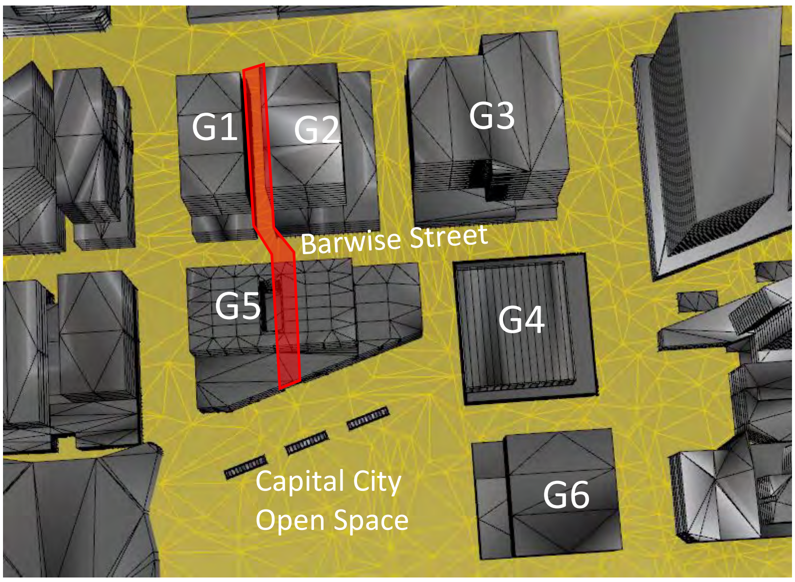


Figure 41: Group G potential channelling area

As discussed previously, Barwise Street is defined as a 'high-capacity public transport and cycling corridor', which incurs that the wind criteria of this street will require careful consideration to satisfy the intended main activity of this area.

The green open space in Arden North illustrated below in Figure 42, bounded by Gracie and Henderson Streets to the north, Fogarty to the east and Langford Street to the west is largely exposed to the northern wind direction. The buildings at the intersection of Gracie and Henderson Streets create funnel-like shape promoting channelling flow. Therefore, this area will require thorough scrutiny and the activities for the area must be taken into consideration when defining the wind conditions.

Furthermore, the north strip of Fogarty Street; Henderson Street, and Boundary Road are also defined as 'high-capacity public transport and cycling corridor' locations and thus will also require a higher level of scrutiny when defining the wind conditions for these areas.

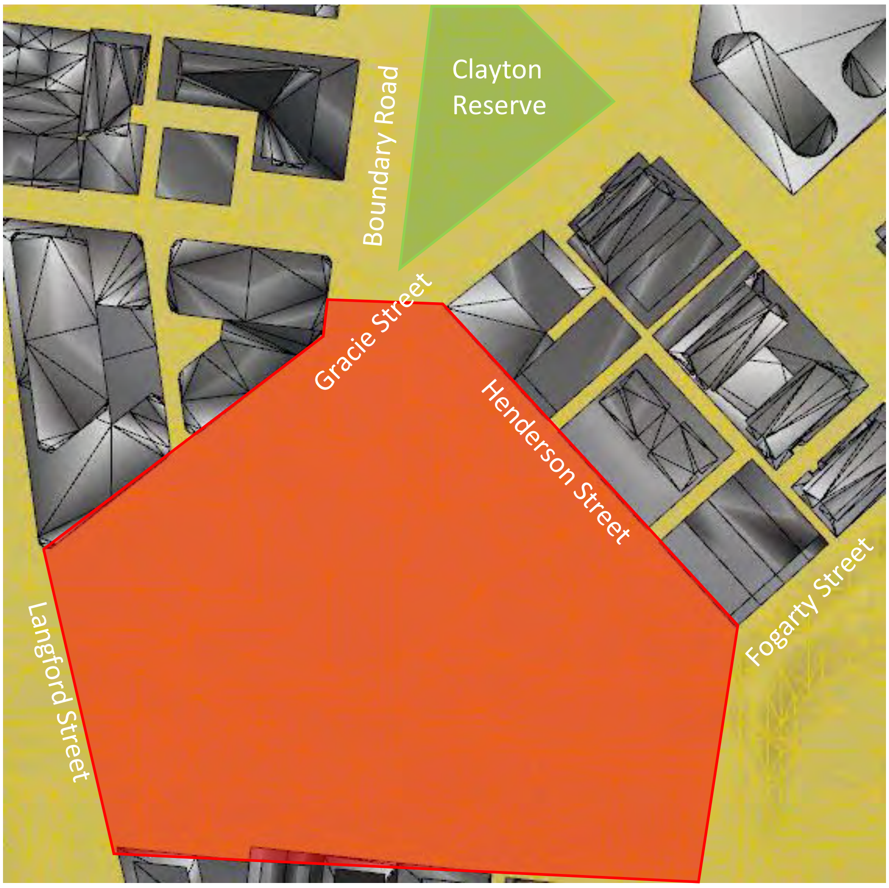


Figure 42: Location of the Arden Reserve open space

In Figure 43 below, the buildings in group J are shown. The taller building J1 being on the precinct boundary will provide shelter to Arden Central from detrimental western winds. However, the street in between J1 and J2 will experience very low wind flow due to its width and the relative height difference between J1 and J2.

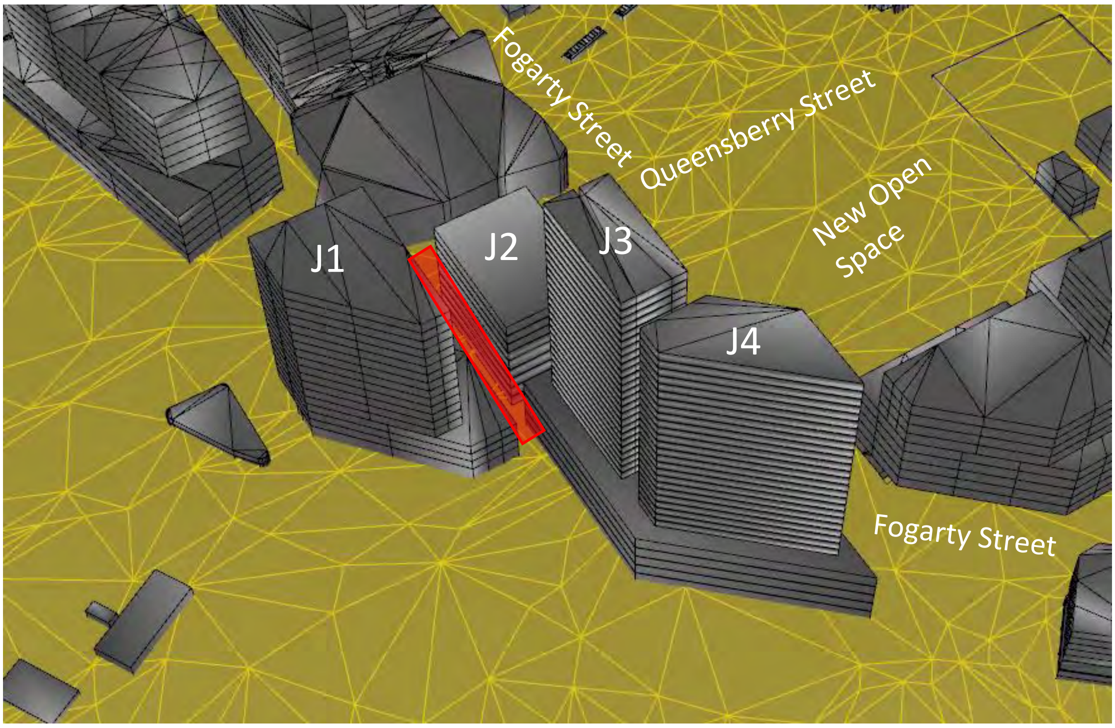


Figure 43: Group J potential dead zone

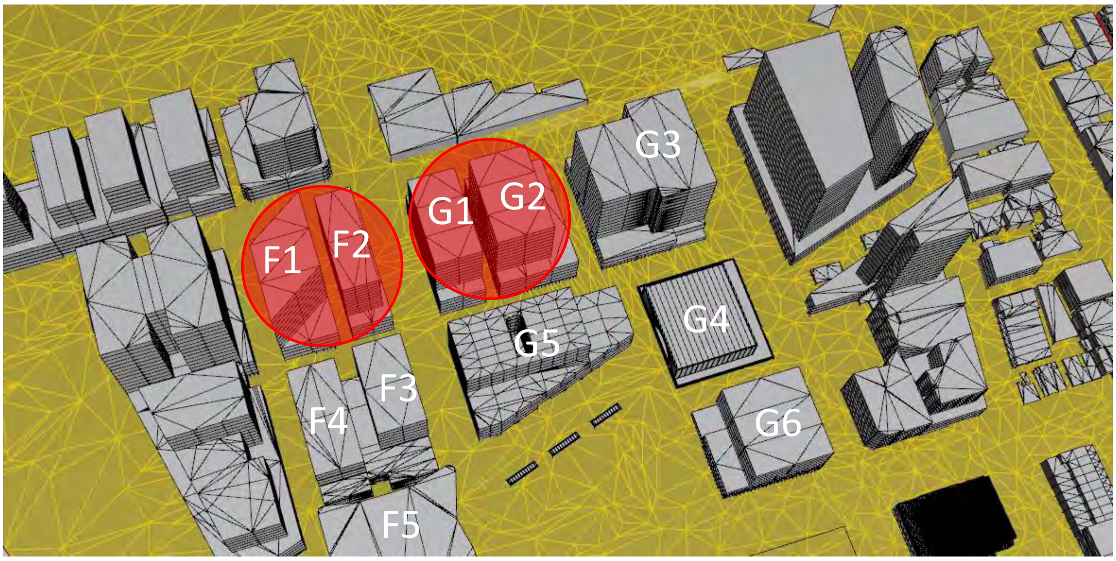


Figure 44: Building Separation

3.6 Location of Public spaces

There are several public spaces dispersed around each sub-precinct. Figure 46 highlights the locations of the public areas. As it can be appreciated, these areas have been designed for different purposes. The civic spines on the western side of Langford Street and the open space bounded by Gracie, Henderson and Langford Streets are defined as integrated stormwater management open spaces as their main function.

Figure 45: Public spaces highlighted in red

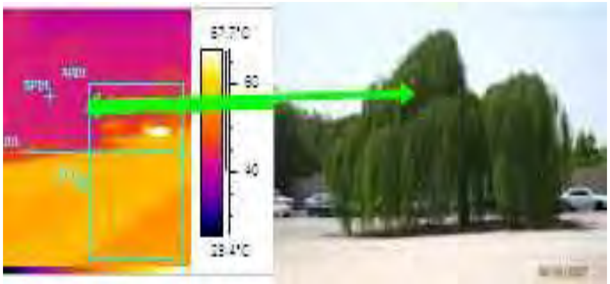
The location of public spaces needs further consideration for ventilation, shadow and nearby structures. The area shown in Figure 45 is the public space considered for this evaluation. This area is open to the wind from the north and west. These wind directions are frequent and undesirable. Thus, having trees on the west and north side to reduce the elevated wind speed is recommended.

Figure 46 below presents the design scheme for the integrated stormwater management open space. The funnel-shape at the intersection of Gracie and Henderson Streets will create a channelling effect onto the new open space proposed on the south. The channelling flow will be led to the open green space and beyond that to the group D buildings.

Figure 46: Plan view of proposed integrated stormwater management open space in Arden North

3.7 Layout of plantation

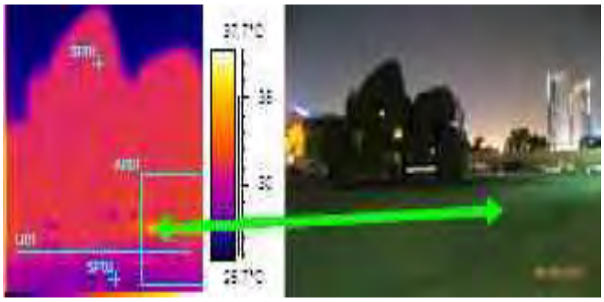
Plantation helps to reduce the heat island effect by absorbing heat during the day; during high intensity and releasing the heat at night time. Figure 47 shows the comparison between the day and night time heat exchange of trees and pavement. In GWTS's several microclimate studies, it has shown that plantation is a crucial aspect to be considered in the external environmental design.



Day time

Tree: low temperature

Pavement: high temperature



Night time

Tree: high temperature

Pavement: low temperature

Figure 47: Heat exchange between tree and pavement

Figure 45 above, displays the layout of the green open spaces proposed for the entire precinct and Figure 46 shows the intended design for the new integrated stormwater management open space with the vegetation distribution proposed for the site. The large density of trees along Henderson and Gracie Streets as shown in Figure 48, will aid in reducing the channelling effect that may take place at the intersection.

Figure 48: Proposed tree distribution along Gracie and Henderson Streets

Figure 49 below illustrates the existing configuration at the site of the proposed integrated stormwater management open space, Clayton Reserve to the north and the north-east corner of the North Melbourne Recreation Reserve. As it can be appreciated, the area is highly populated by large trees that will improve the albedo of the precinct and reduce the average temperature significantly – on top of the wind mitigation provided by the tree cover. Therefore, evergreen trees are the choice of preference for these purposes.

Figure 49: Existing tree distribution along Gracie and Henderson Streets

The dissemination of plants helps increase the absorption of the sun's heat energy and keep these areas cooler. Therefore, this practice will increase the precinct's capacity to maintain a more stable and comfortable environment for people. Plantation embedded in the road layout will initiate the thermal exchange throughout the development, contributing to a reduced heat exchange keeping the temperature as close to the ambient temperature as possible – especially in areas of high sun exposure.

Lastly, the proposed sites for the Civic Spines are shown below in Figure 50. The open spaces include trees with a 20m separation distance and a canopy diameter of 10-15m (*as informed by the client*). Separation distance between trees, from approximately their centre is shown by the orange line in Figure 51. With this approach, conditions on the streets where these civic spines have been proposed will be improved with a decreased average wind speed at pedestrian level and higher heat absorption thus, lowering the average temperatures of these areas.

Figure 50: Location of the civic spines within the proposed development

Figure 51: Existing tree separation distance on Munster Terrace

The civic spines as depicted above, are found along Fogarty and Queensberry Streets in Arden Central and Munster Terrace in Laurens Street sub-precinct. Due to the orientation and exposure to the North and West winds of Fogarty and Munster Terrace; and Queensberry Street respectively, there is a high potential for channelling to develop and the tree-populated Civic Spines will help disrupt the flow and hence, improve conditions at these locations.

4. Computational Wind Engineering (CWE) Analysis

The CWE modelling was carried out for the Arden Precinct and is discussed in this section. The simulation utilises the climate analysis carried out in Section 2.0 of this report. The wind environment study is based on a CWE modelling to obtain the wind pattern as a result of the development. Following the initial version of this report, the Draft Structure Plan was updated, and the sub precinct boundaries changed to reflect what is seen in Sections 1.1, 3.1, 3.2, 3.6 and 3.7. The configuration displayed in the following analysis has not been updated and is shown in Figure 54 below.

The wind environment is described for the three main sub-precincts: Arden North, Arden Central and Laurens Street. The simulation results are shown as velocity contour and velocity vector plots.

The CWE analysis was conducted based on the 3D model provided by VPA. The geometry was simplified, and the previously-agreed-upon areas of interest for the CWE simulation were studied with a higher level of scrutiny. However, the limitation of CWE is taken into consideration in the objective of its application in the present study. Thus, the main objective of the CWE modelling in the present study is to understand the general wind flow pattern in Arden Precinct under the proposed development layout and screen out regions which require further study with refined development design using highly developed CWE and wind tunnel study.

When preparing the simulation, several parameters required careful consideration: the proposed site's wind climate, the importance of the different areas for the development, computational time and required mesh resolution.

To simulate the wind climate in the development, 8 wind directions were selected: North, North-East, East, South-East, South, South-West, West and North-West. The north wind is the strongest and most frequent. Thus, it was selected as the main direction for the CWE simulation. Please note that the software simulates the initial output does not integrate the wind directional probability distribution. Based on the climate analysis, the East wind direction rarely takes place. Therefore, the effects of the eastern winds are not as important to take into consideration as the northern wind.

For each plot there are two different criteria to which each wind direction is subjected to, the Gust Wind Speed and the Gust Equivalent Mean (GEM). The Gust Wind Speeds are constructed based on mean wind speed, turbulence intensity and gust factor. The gust wind speed criterion defines the safety conditions for the precinct with a threshold of up to 20 m/s wind speeds. The GEM on the other hand, defines the comfort conditions with a threshold of up to 5 m/s wind speeds.

The domain and the mesh of the CWE model are shown in Figure 52 and Figure 53 respectively. The domain is discretised with around 20 million cells. The inflow boundary condition is specified with a wind profile of Terrain Category 3, turbulence intensity and dissipation rate. Figure 55 shows the gust wind speed velocity contour plot for Arden Precinct for the northern wind direction.

4.1 Limitations & Assumptions of CWE Analysis

There are several sources of error in CWE modelling and simulations. Some of the sources of error are:

- Geometrical Models: The accuracy of the geometrical model and its resolutions determines the outcome of the CWE simulations.
- Numerical Errors: these errors can be due to mesh resolutions, round-off errors, discretization (truncation errors), turbulence model.
- Boundary Conditions: the accuracy of the solution is determined by the initial boundary profile used and how this profile propagates through the domain.

For large scale simulations, the accuracy of the CWE simulations is determined by the available computing power and timing available. The higher the resolution – the greater the number of cells there are in the domain – the longer the simulation time and the higher computing power required for it to converge.

The quality of the mesh used for the simulation is dependent on the expertise and experience of the analyst. If the mesh is not fine enough, then numerical errors will be introduced into the results due to inaccurate interpolation between cells i.e. truncation errors.

There are a number of guides for CWE quality assurance and best practices. The simulations in this project take into consideration the available advice in the quality control, and the objective of the simulations to arrive at an acceptable outcome.

All the buildings in the domain were modelled to have smooth facades. Furthermore, the model did not contain any vegetation. Both these conditions have a significant impact on the results as the wind speeds at pedestrian level, predicted by the simulation, will be considerably higher. However, the general wind flow pattern and location of high and low wind speeds, are captured to allow for recommendations for further analysis.

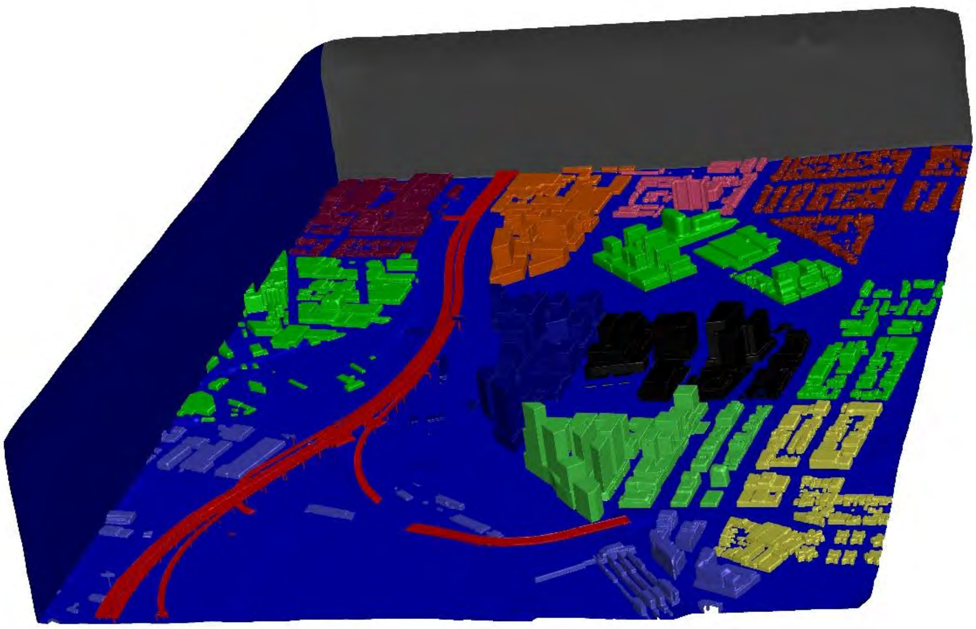


Figure 52: Domain for CWE

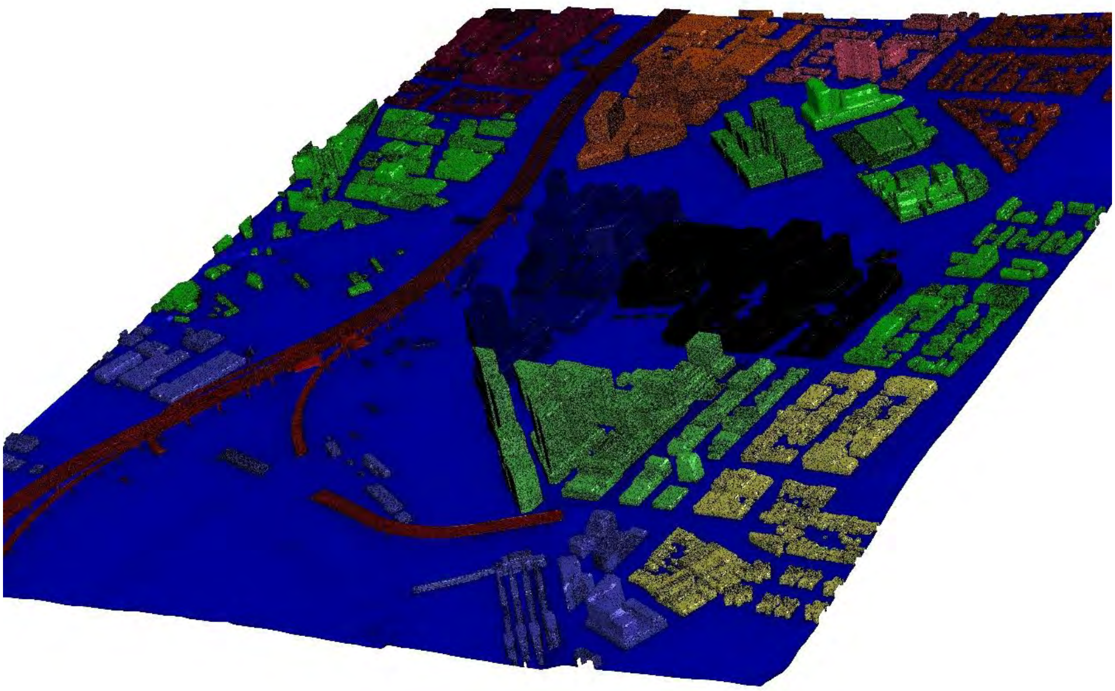


Figure 53: Mesh of Arden Precinct

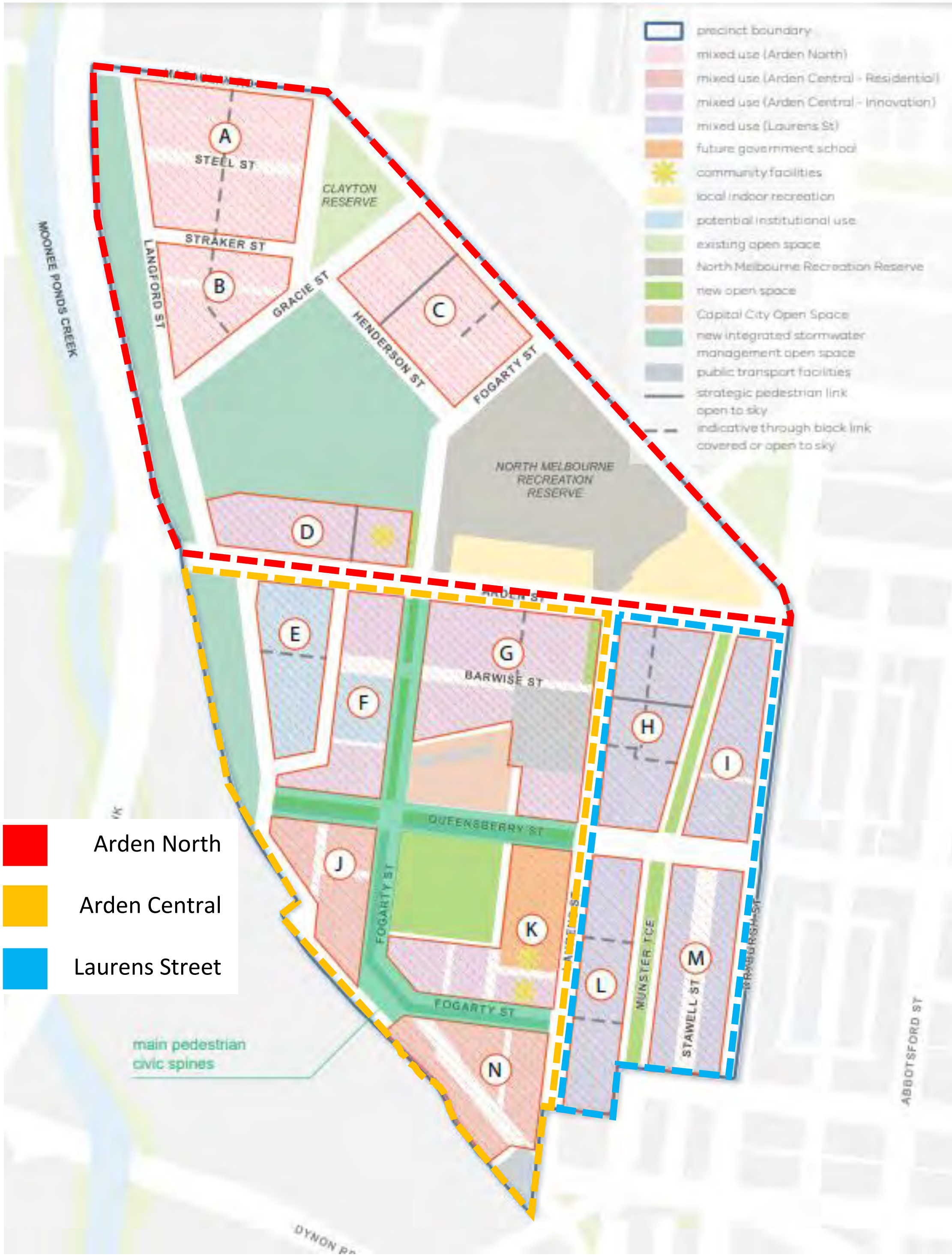


Figure 54: Arden Precinct previous sub precinct boundary configuration

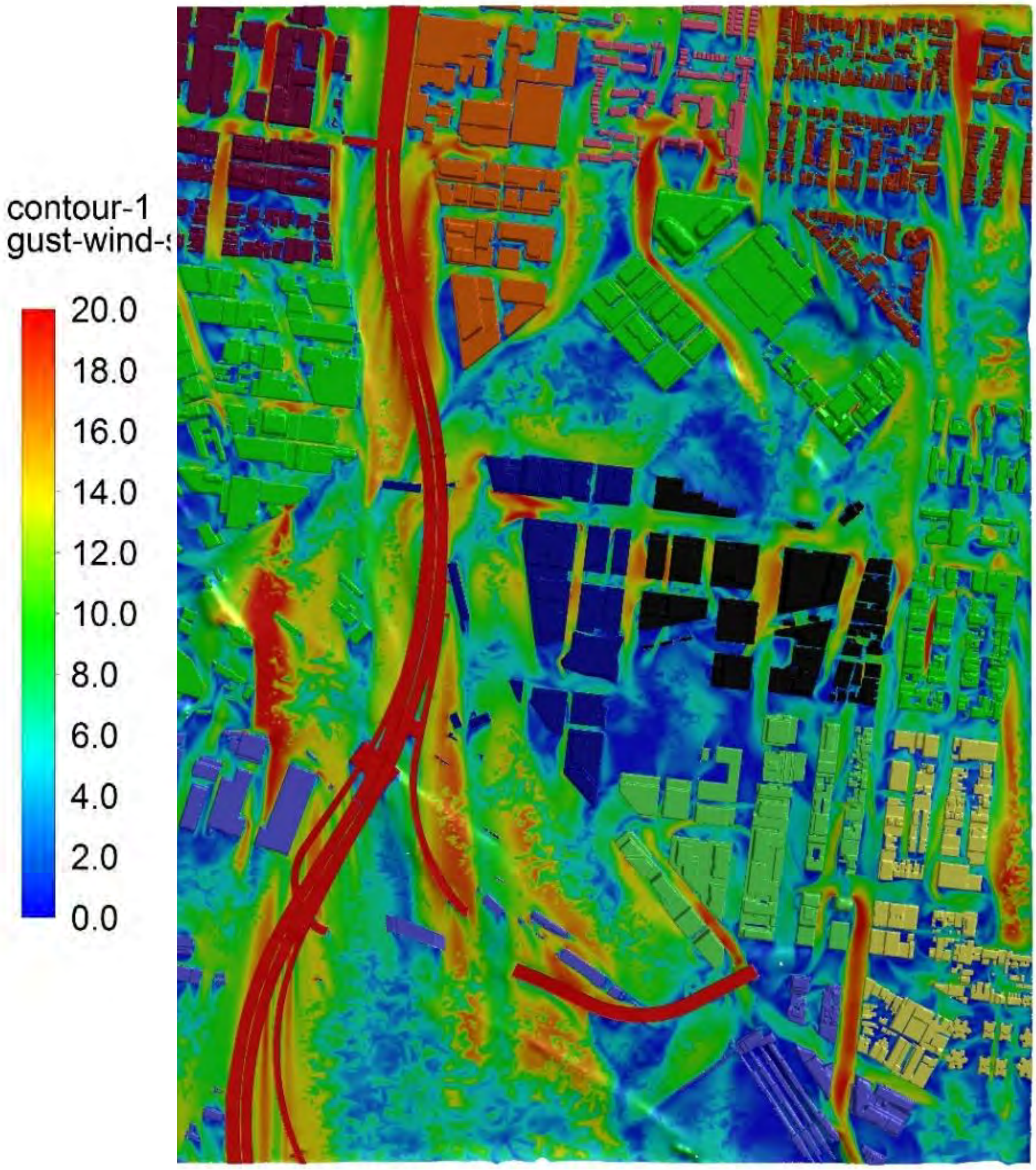


Figure 55: Velocity contour plot of gust wind speed for the entire precinct and surroundings for the north wind direction

4.2 Arden North

Arden North is subdivided into four building groups: A, B, C and D; this area is shown in Figure 56 below. The wind flow in different areas of Arden North is shown in the velocity contour and vector plots below for each group described above from Figure 57 to Figure 65.

Figure 56: Arden North

North Wind:

Figure 57 below displays the wind behaviour in Arden North for the North wind direction. As it can be appreciated, there are areas with detrimental conditions due to environmental wind effects taking place with varying degrees of influence.

Group A; bounded by Macaulay Road to the north, Boundary Road to the east, Straker Street to the south and Langford Street to the west, located on the north-west corner of the precinct, experiences high wind velocity along Langford Street due to the corner acceleration taking place on the corner of building A1. Furthermore, on the corner of Macaulay Road and Langford Street there is also downwash taking place off the northern face of the A1 building upwards of 18 m/s. There is also corner acceleration taking place on building A5 on the corner of Macaulay and Boundary Roads, with maximum wind speeds around 16 m/s. This accelerated wind flows southward and is again accelerated at the south eastern corner of the B2 building along Gracie Street.

Along Langford Street, the accelerated wind flows in a southern direction detaching from the edge of the buildings fronting Langford Street between Macaulay Road and Gracie Street. Thus, conditions along the western façade of building B1 remain acceptable.

The wind conditions predicted for the group of buildings between Macaulay Road, Henderson Street, and Gracie and Fogarty Streets, exceed the safety criteria. The elevated wind flow that is appreciated develops north of the proposed site from corner accelerations on the western edge of the development (refer to Figure 55 above). It then flows south and hits the C2 and C3 buildings and is directed down Macaulay Road with a velocity of 20 m/s or higher, until it reaches the North Melbourne Recreating Reserve, and it dissipates in the open space.

Lastly, Figure 61, Figure 64 and Figure 65 show the results of the simulation for the open areas and buildings north of Arden Street, between Langford and Fogarty Streets. As can be appreciated, wind speeds increase on the south of the Arden Reserve due to downwash taking place on the north face. Figure 64 and Figure 65 show the direction of the wind as well as the magnitude. There is also corner acceleration taking place on the north-western corner of D1.

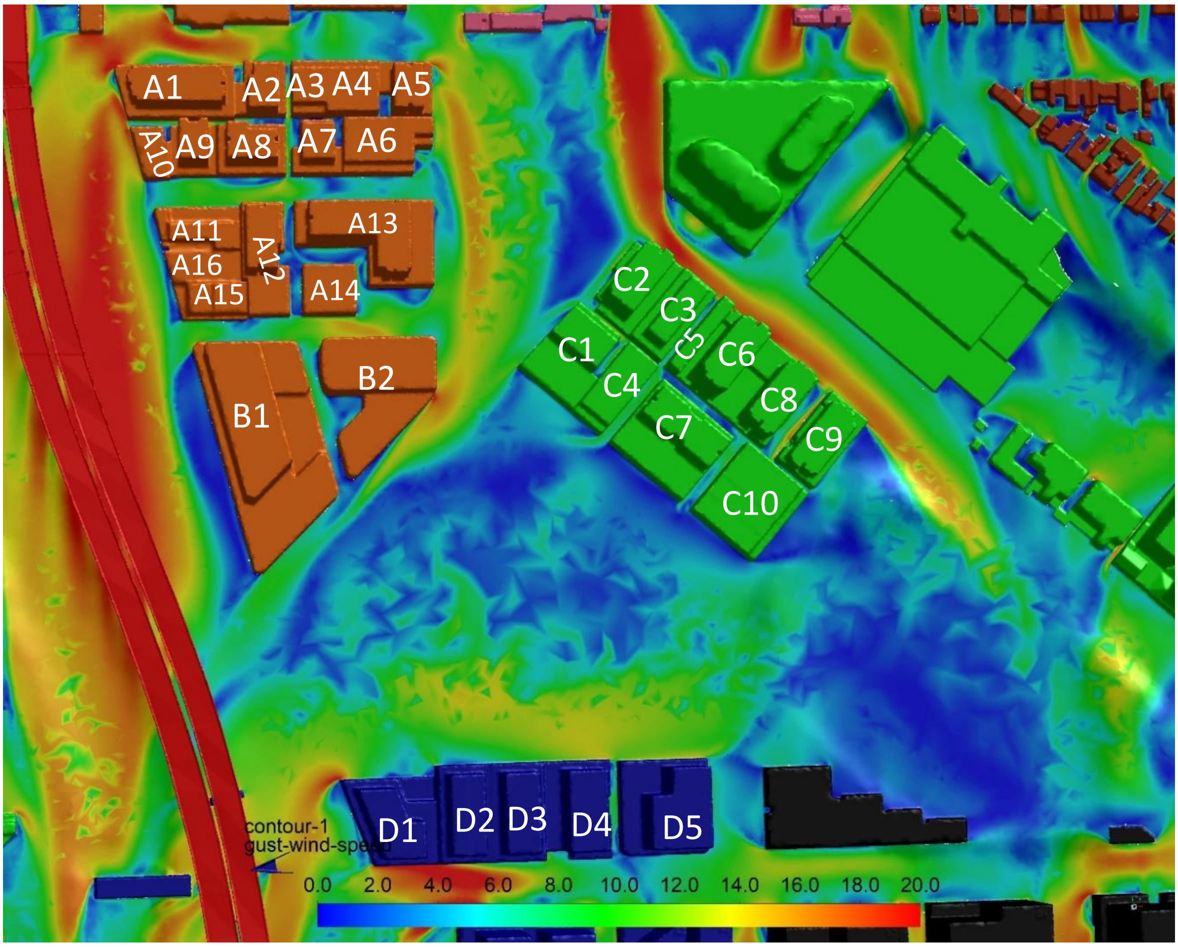


Figure 57: Gust wind velocity contour plot of Arden North; North wind

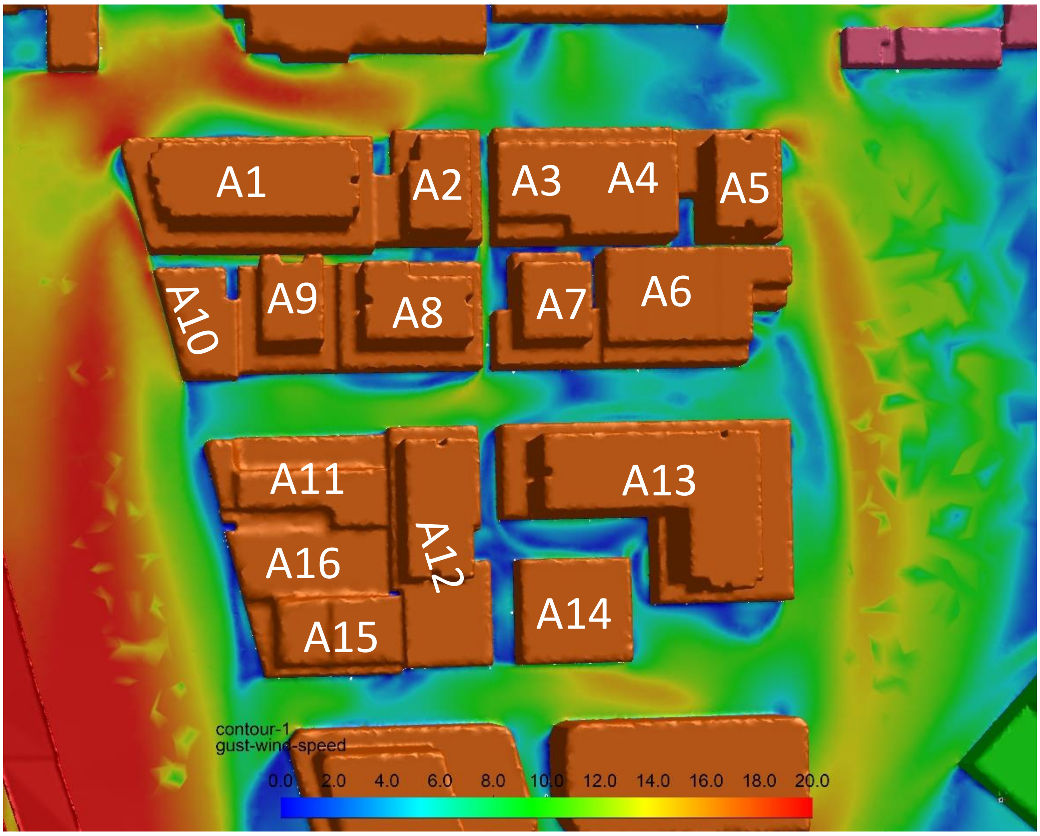


Figure 58: Gust wind velocity contour plot of Group A; North wind

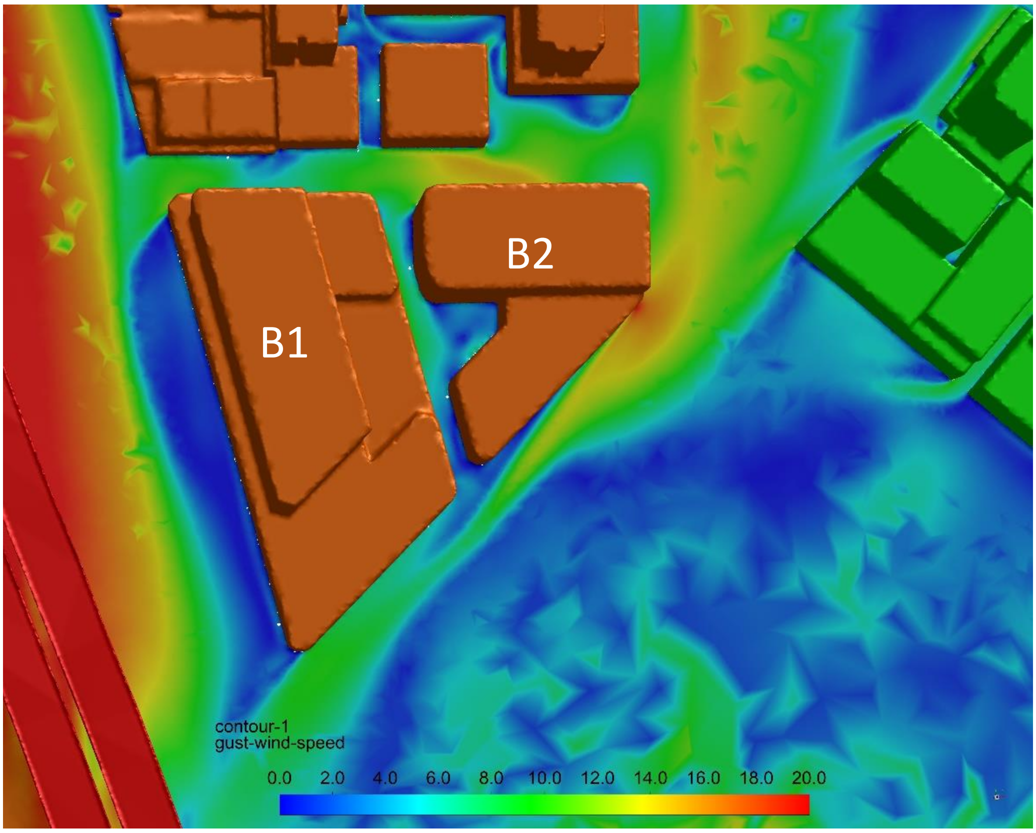


Figure 59: Gust wind velocity contour plot of Group B; North wind

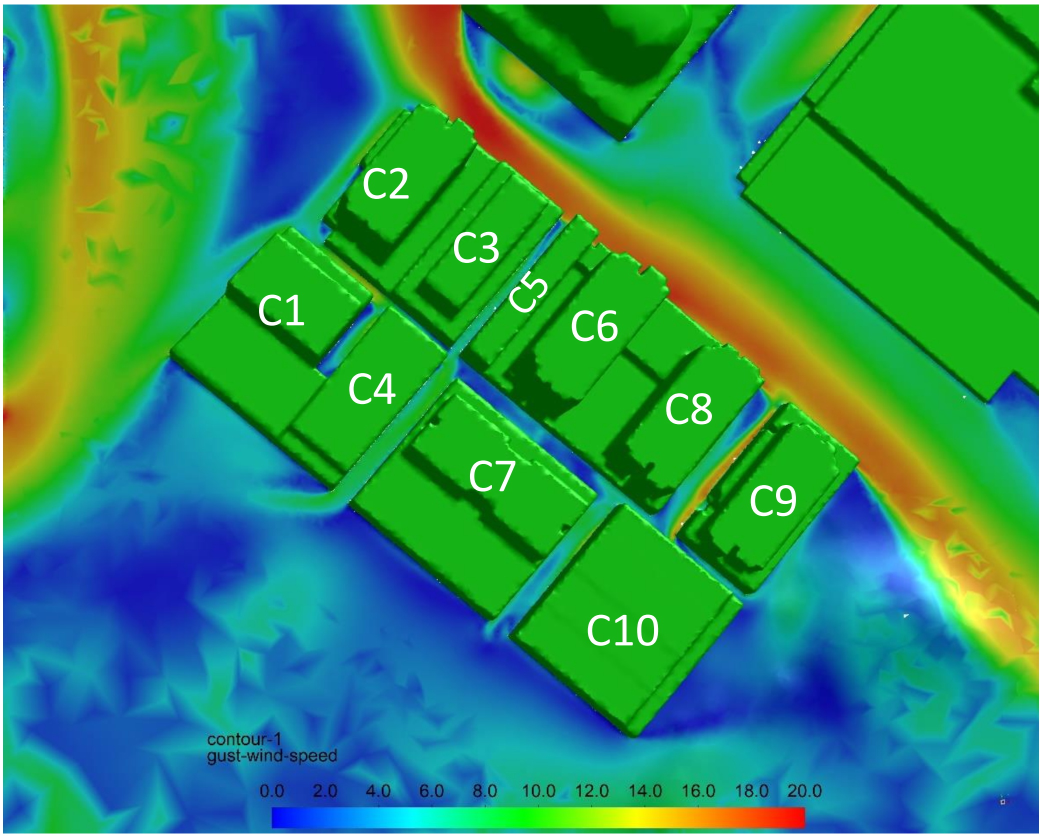


Figure 60: Gust wind velocity contour plot of Group C; North wind

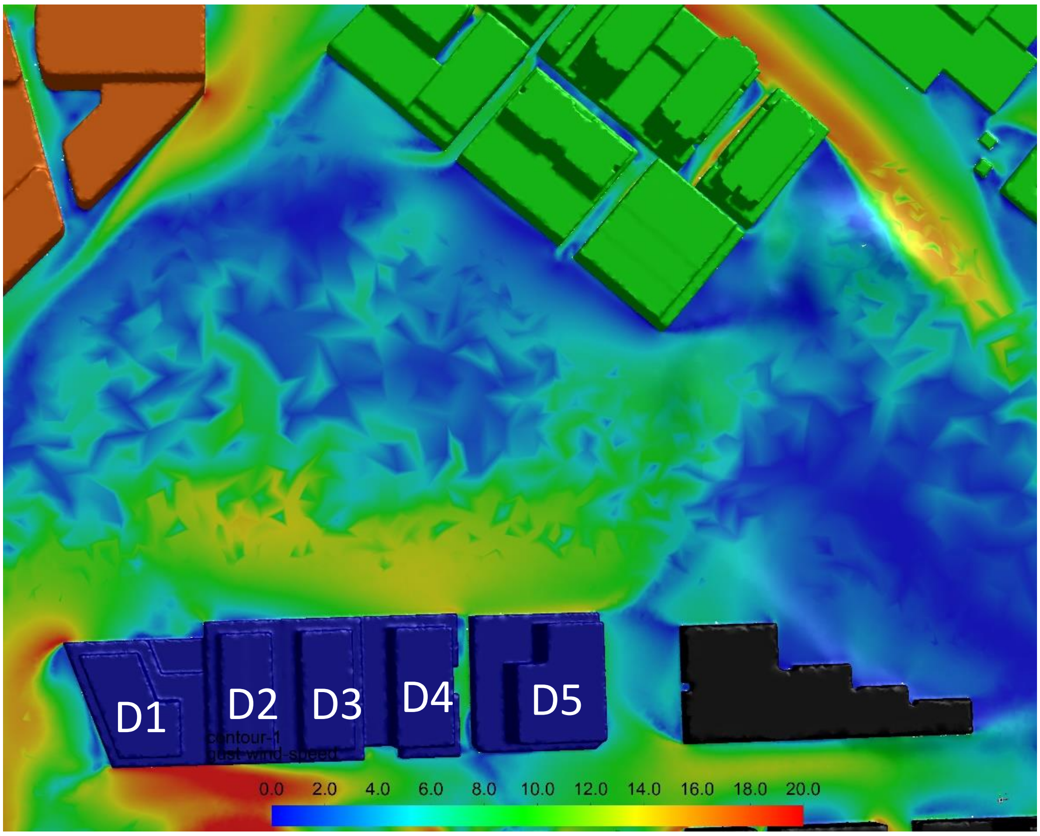


Figure 61: Gust wind velocity contour plot of Group D; North wind

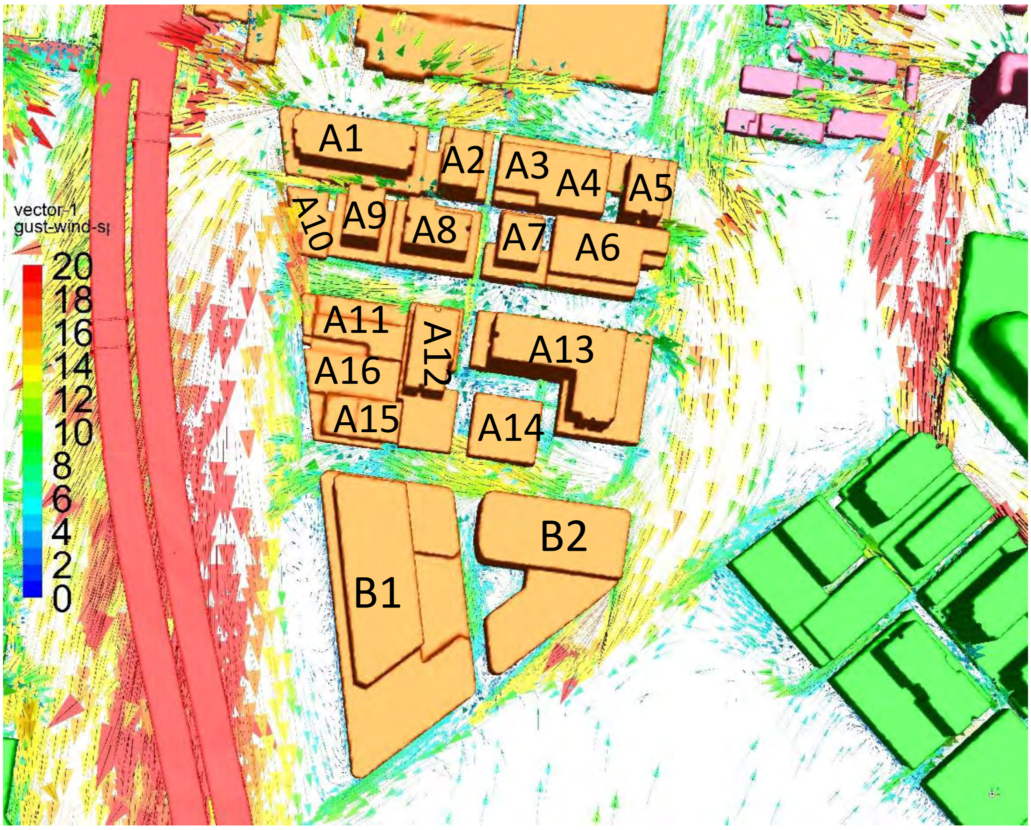


Figure 62: Gust wind velocity vector plot of Groups A & B; North wind

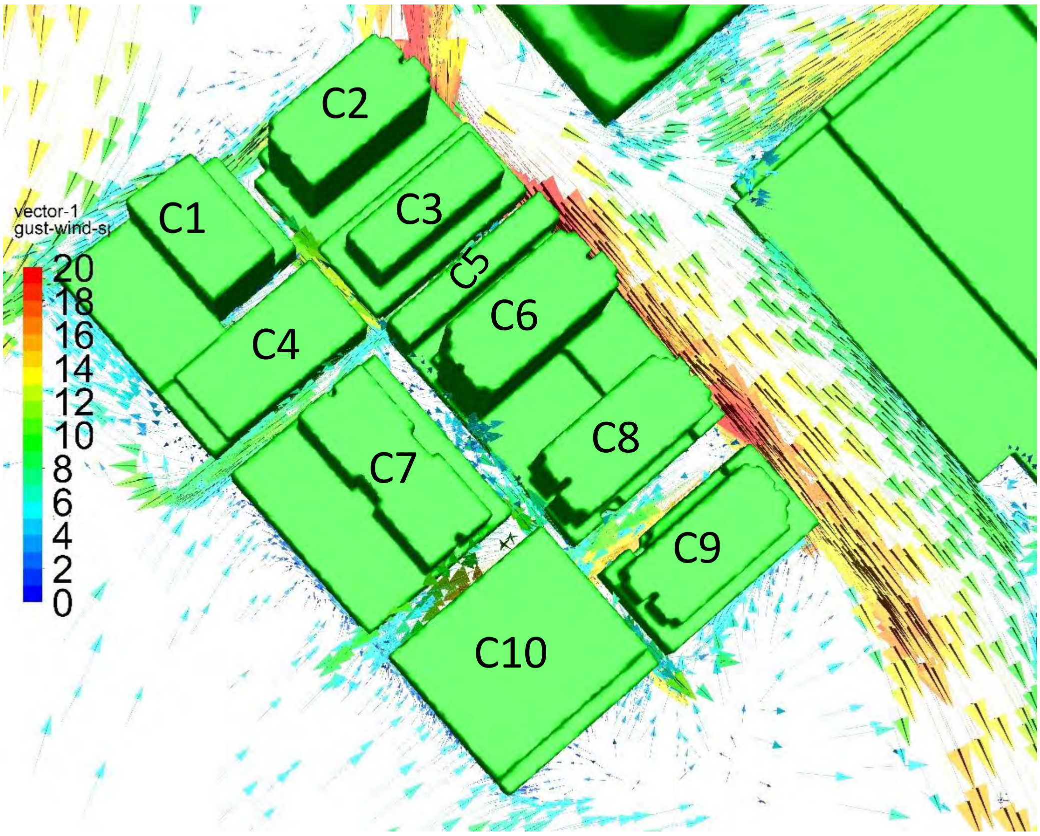


Figure 63: Gust wind velocity vector plot of Group D; North wind

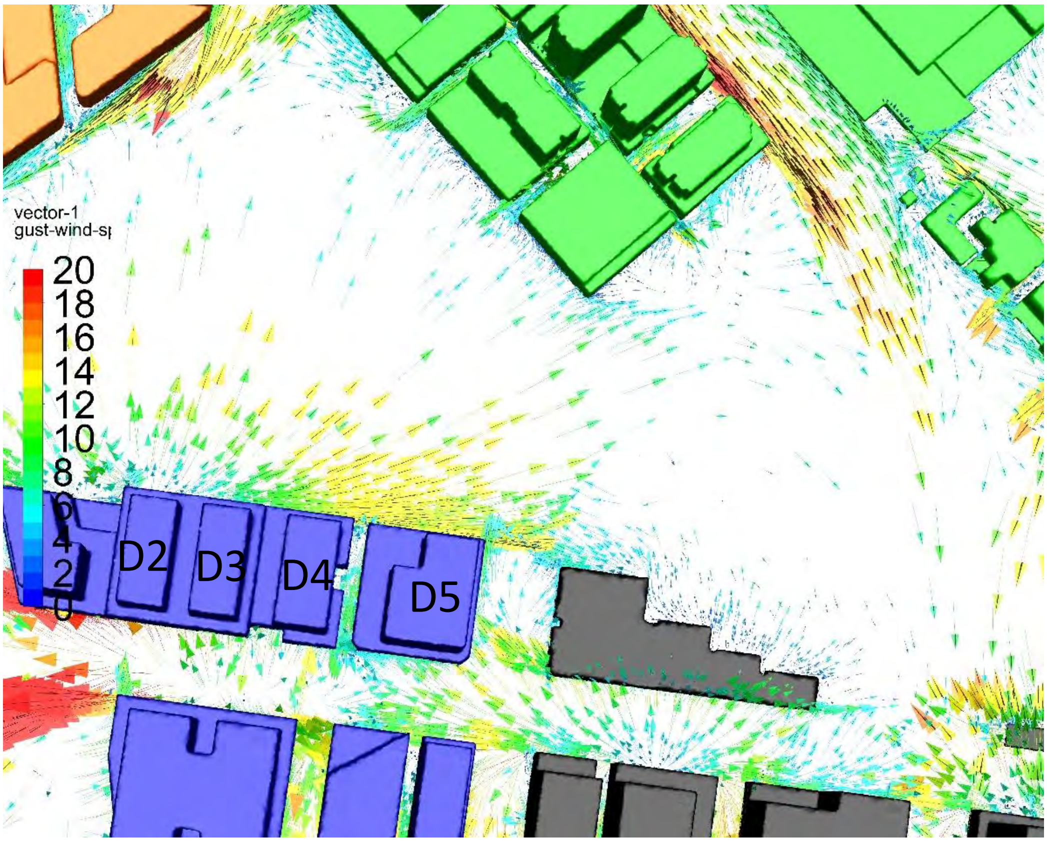


Figure 64: Gust wind velocity vector plot of Open Spaces and Group D; North wind

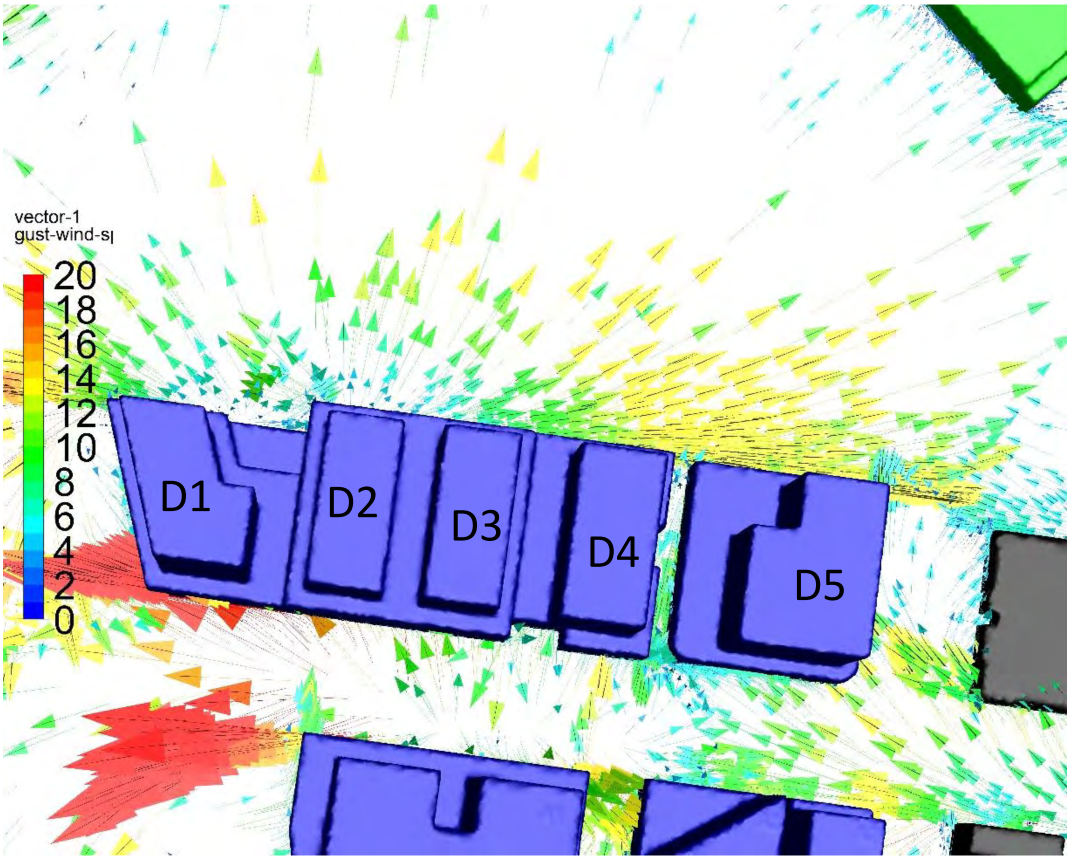


Figure 65: Gust wind velocity vector plot of Group D; North wind

South Wind

From the climate study performed in Section 2.0, the southern wind is dominant during the summer months and provides a cooling effect across the development. However, as illustrated in Figure 66, there are several areas with elevated wind speeds.

Figure 66 and Figure 67 illustrate how the southern wind behaves within Arden North. As it can be appreciated, wind conditions on the eastern and western ends of the sub-precinct experience high wind speeds exceeding the safety criteria of 20 m/s. Clusters D, B and A; experience exceedingly high wind velocities on their western faces and thus, renders Langford Street unsafe. These detrimental conditions arise from corner accelerations taking place off the southwestern corner of D1 building. Conditions between Macaulay Road and Straker Street, and Langford Street and Boundary Road are found to be acceptable, and no major issues can be identified for this wind direction except for Langford Street.

Buildings between Straker and Gracie Streets experience some relatively minor corner accelerations, as compared to those on the north side of Arden Street, on the south-eastern corner of B1 and B2 and increasing wind speeds along Boundary Road of up to 14 m/s due to channelling taking place through the intersection of Gracie and Henderson Streets.

Wind conditions in the Arden Reserve improve from those propagated by the north wind. The elevated wind speeds in the southern half of the open space – up to around 10 m/s – is due to the high wind speeds that develops on the western end of Arden Street. These are a cause of corner accelerations taking place south of cluster D developments, which then directs the flow towards the southern faces of group D buildings. Most of the wind experiences downwash onto Arden Street with an eastern trajectory and eventually flows north along Fogarty Street and then along the northern façade of cluster D buildings. This phenomenon is shown in Figure 67.

The North Melbourne Recreation Reserve experiences vastly different conditions between its eastern and western halves. The eastern half of the open area is subjected to the wake region of the channelling flow taking place at the end of Laurens Street. The wind speeds in this area approach, or exceed, 20 m/s and hence, defining the area as unsafe. On the western half however, conditions are more tamed with wind speeds between 2 m/s and 7 m/s.

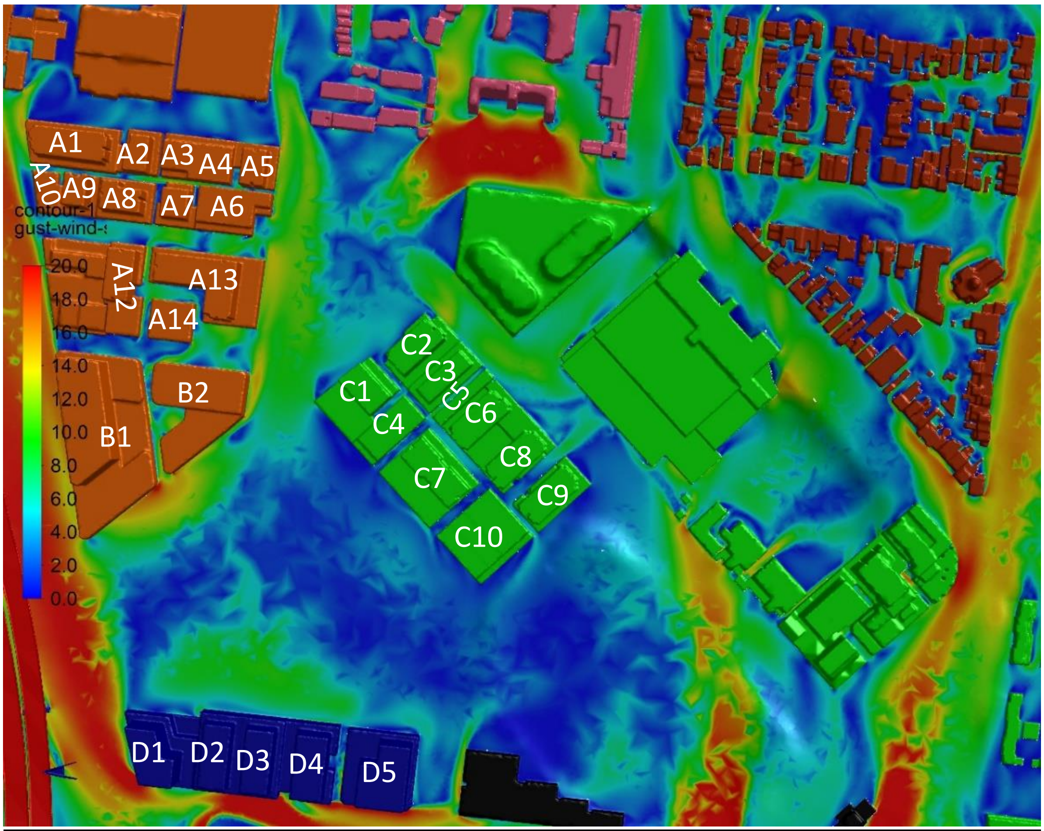


Figure 66: Gust wind velocity contour plot of Groups A, B, C & D; South wind

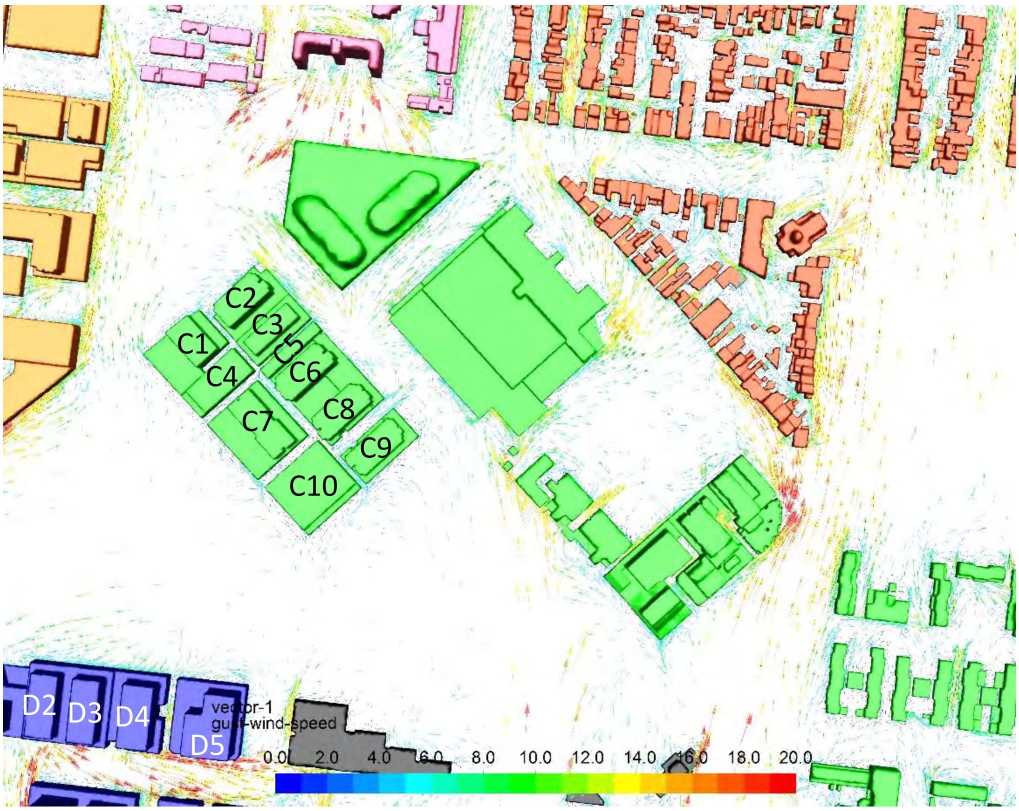


Figure 67: Gust wind velocity vector plot of Groups A, B, C & D; South wind

West Wind:

Figure 68 and Figure 69 present the results of the simulation of the West wind flowing through the proposed development. There are many areas of very high wind velocities in Arden North created primarily by corner acceleration and channelling. Moreover, the western wind is naturally accelerated the further it penetrates the development due to the increasing elevation of the topography from west to east; up to 20m difference between Moonee Ponds Creek and Dryburgh Street.

Building clusters found along Langford Street suffer the worst conditions in Arden North as is appreciated. Macaulay Road is heavily negatively impacted by both corner acceleration taking place off building A1 and channelling, with speeds exceeding the safety criteria of 20 m/s. Conditions along Steel and Straker Streets are also severely impacted by western winds from the same environmental wind effects: corner accelerations and channelling. Figure 69 shows the magnitude and the direction of the wind within the sub-precinct and it helps discern the phenomena taking place at these unfavourable locations.

Langford Street remains subjected to mostly acceptable conditions along towards its north end. Although there is some downwash taking place off B1’s western façade. Detrimental corner accelerations on the south west edge of B1 lead to a large wake region in the northern half of the Arden Reserve. These phenomena can be appreciated in Figure 68; showing wind speeds upwards of 18 m/s. These accelerated wind speeds develop further through the open space and hit the facades of buildings along Henderson Street which accelerates the flow again and diverts it in parallel directions to the street.

Group D buildings experience and create the worst conditions in the sub-precinct. Corner accelerations off the western edge of D1. This accelerated flow attaches to group D creating detrimental conditions along their northern facades with unsafe conditions. The flow begins to dissipate and slightly decelerate through the North Melbourne Recreation Reserve before it is joined by streams coming from Arden Central and Laurens Street sub-precincts and leaves the proposed site at elevated speeds.

Arden Street also suffers from adverse conditions from corner accelerations off building E1 and D2, which is then channelled through, reaching speeds up to or exceeding 20 m/s. The conditions on Fogarty Street are mostly unfavourable, especially between Henderson and Arden Streets. At both locations, high-velocity wind is being led into the street.

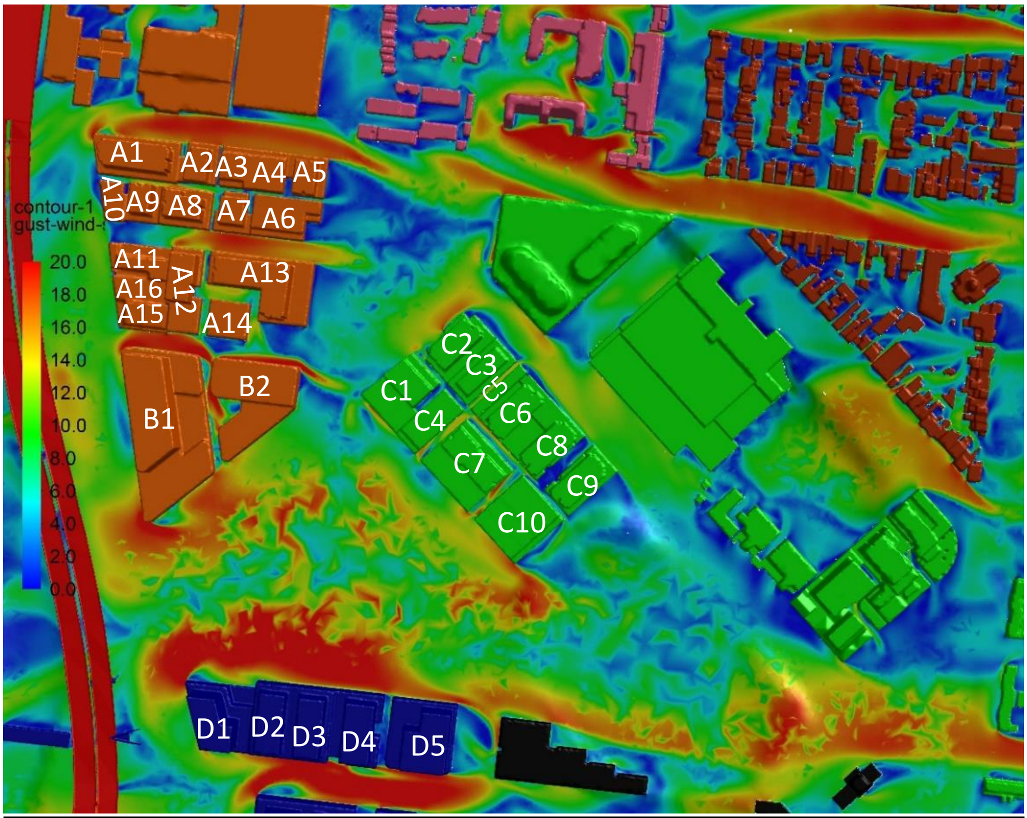


Figure 68: Gust wind velocity contour plot of Groups A, B, C & D; West wind

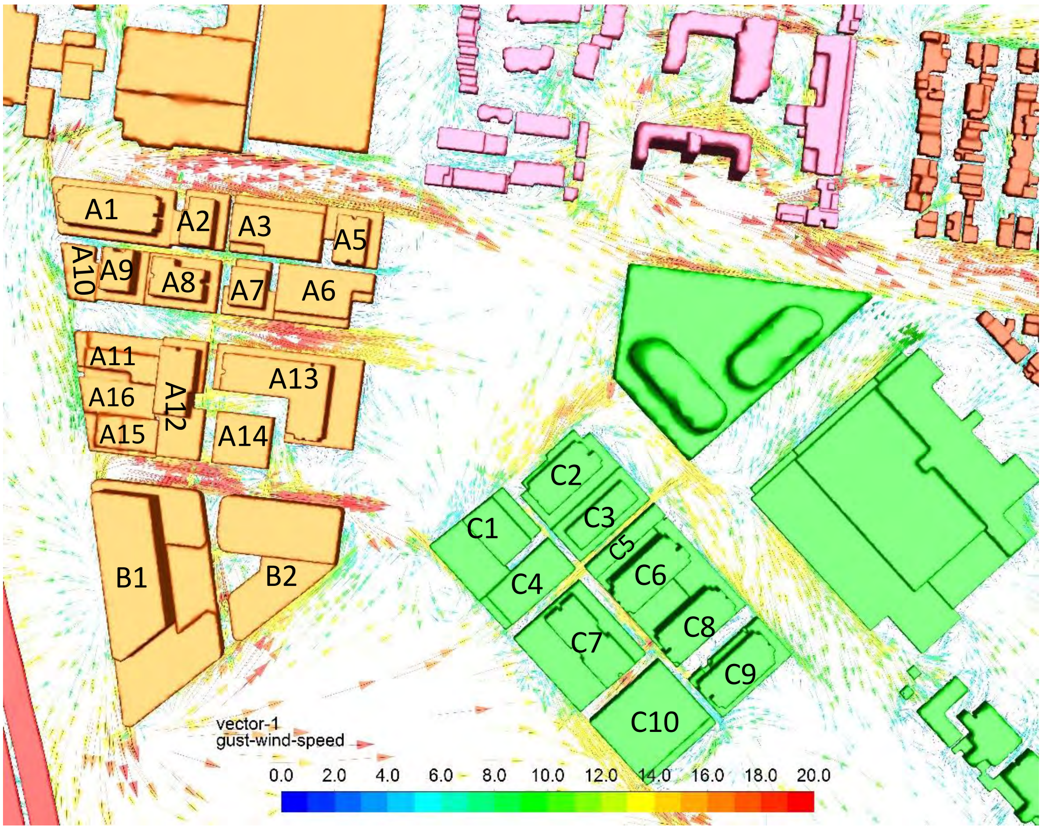


Figure 69: Gust wind velocity vector plot of Groups A, B, C & D; West wind

The following can be observed from the simulation results:

- **Street Orientation**:

The north to south and east to west configuration of the streets allows for ventilation and penetration of the wind into the development. The angled orientation of Gracie and Henderson Streets allows for appropriate ventilation while not encouraging channelling. The orientation of the streets in Arden North overall ensures that the conditions are the best possible. As it is previously discussed, Arden North suffers from some of the worst wind conditions as it is the furthest upstream of the development.

Lastly, the slight orientation of Langford Street is beneficial as the corner acceleration from A1's podium travels directly south and quickly detaches from the buildings. Only the northern end of the street suffers detrimental conditions, although the stormwater management open spaces will take the full force of the incoming accelerated wind.

- **Building Orientation:**

The orientation of these buildings is of paramount importance to ensure acceptable conditions throughout the rest of the development as it is located upstream of the north wind which is the dominant and strongest. Therefore, the main objective of the buildings to the north is to shield and disrupt the north wind.

The northernmost buildings in group A; A1 to A4, are separated into 3 different podiums. The heights of these buildings are 35.2m for A1 and A2, A3 is 22.5m and A4 is 33.8m. The podium heights for A1, A2 are 13m, for A3 is 15.5m and A4 is 11.4m. The setback between the tower and the podium is 5m for A1, A2, and A3. A4 has a podium setback of 6m. The vector plot shows that there is some downwash taking place at this location around A1 for the north wind, with wind speeds reaching around 20 m/s. However, the main issue is the addition of corner accelerations off the building across Macaulay Road from A1.

Building B1 suffers elevated wind speeds due to its narrow setback podium and the lack of a setback on building B2. This leads the accelerated flow to Langford Street where conditions are unsafe because of corner accelerations off the podium A1. The total height of B1 is 61.5m with a podium height of 21.5m. The setback of the development is 5m on its northern and western faces and up to 40m on its south face. Figure 62 and Figure 69 show that Straker Street displays elevated wind speeds for the northern wind and adverse conditions in the west wind. Increasing the setback of B1 would improve the wind climate as well as on the northern façade of B2, thus, measures have been outlined for wind control mechanisms.

Building cluster C is orientated parallel to Henderson Street. Incoming accelerated corner flow from an existing building upstream hits the C2 podium wall. The results show that the orientation of these buildings does not cause any additional detrimental conditions to arise.

Buildings on the north side of Arden Street suffer from much downwash from the north wind as appreciated previously in Figure 65. The shortest length of the building faces the north and the wind hitting it is driven down to the Arden Reserve at elevated speeds. The total height of these buildings are as follows: D1 is 69m, D2 is 49m, D3 is 53m, D4 is 53m and D5 is 55m. The podium heights for each are: D1 is 21m, D2 and D3 is 25m; D4 is 21m and D5 is 17m. The setback between the towers and the podiums is 5m and after studying the results, this distance is not enough for acceptable wind conditions at the base for the exposure and location of these buildings.

- **Building Orientation (Natural Ventilation):**

The nature of the wind environment and location of Arden North imposes that careful consideration is given to building orientation. For natural ventilation purposes, it is appreciated that the orientation is fitting as the northern wind will have the greatest presence and the southern will provide cooling during the summer months. Therefore, it is advisable to orientate buildings with ventilation inlets on the southern facades to take advantage of the summer's southern sea breeze.

- **Building Relative Height Differences:**

It is of paramount importance to have a significant building height difference, especially for buildings across from each other along narrow perpendicular streets to the prevailing wind directions: north and south. Therefore, as presented in Figure 38, calculating the ratios for deep street canyon at particularly important locations is crucial.

Between buildings A12 and A13, for the western wind direction, the ratio h:W:H is 1:1:4. This meaning that the secondary and tertiary air circulation vortexes are not predicted to reach the ground and thus, defining the air in this area to be stagnant i.e. a dead zone. This is due to the increased height of both buildings, a width less than the height difference and a height difference that is too small for the height of the buildings. Thus, the air flow expected in the area will resemble the air circulation shown in Figure 37 for the ratio 1:1:4.

- **Spacing between Buildings:**

The spacing between buildings will allow for proper ventilation and cooling to take place all-year-round. Thus, having suitable separation with the main focus on the northern and southern wind will improve the environment within the precinct. To achieve suitable ventilation in perpendicular streets such as that between A1-A5 and A6-10, the deep street canyon effect must be considered. Given the height of buildings A4 and A6 being 22.5 m, the ratio would be about 1:7 (W:H) which according to Figure 38, the height is too large compared to the separation.

The width of Steel Street is measured to be about 15 m between A8 and A12. Following the calculation for the deep street canyon ratio for suitable ventilation (refer to Figure 38), the result for Steel Street between A8 and A12 is around 1:2.5. Therefore, as appreciated in the illustration, as the ratio is smaller than 1:3, the air circulation vortexes will reach the ground and allow for suitable ventilation and cooling for this area during the prevailing North winds.

The separation distance between C3 and C5 is 3 m (refer to Figure 23). To create a street wide enough to divert the elevated north wind the following air path calculation was carried out:

$$W_{air} \approx \frac{1}{2}(W_3 + W_5) = 0.5(24 + 9)$$

$$W_{air} \approx 17\ m$$

The result shows that the distance between C3 and C5 is not enough to create an air path. By allocating a wider spacing between these 2 buildings, it would increase the amount of accelerated flow diverted from incoming wind from the north. This would then decrease the overall speed of the accelerated flow appreciated along the north face along Macaulay Road and thus, lowering the wind speed and improving the safety conditions.

The spacing between buildings D4 and D5 is measured as 6 m. and following the same procedure as for C3 and C5, the ideal width to create an effective air path would be:

$$W_{air} \approx \frac{1}{2}(W_4 + W_5) = 0.5(37 + 50)$$

$$W_{air} \approx 44\ m$$

However, the potential for channelling occurring through this space and into Arden Central must be carefully considered as the location and exposure of this group of buildings is shown to already experience high wind speeds.

- **Public Space:**

  Civic spines on Langford Street suffer detrimental conditions for both the northern and southern wind directions as illustrated in Figure 57 and Figure 66. Corner accelerations off buildings A1 and D1 propagate elevated wind velocities developing over these green spaces.

  The North Melbourne Recreation Reserve is affected by an accelerated flow caused by a building to the north of the proposed precinct site (refer to Figure 55). This flow is then deflected towards the south-east by group C buildings along Macaulay Road and is finally redirected south, after passing building C9, and onto the open area with increased wind speeds of around 16 m/s.

  Furthermore, results for the northern and southern wind directions show that conditions at the Clayton Reserve, Arden Reserve and the North Melbourne Recreation Centre are greatly affected by these winds. This is due to the location and the exposure of these areas. The careful layout of vegetation in these areas will significantly improve the conditions found at these locations. As per the proposed design scheme in Figure 46, the position of the trees to the north of the site will decrease wind speeds of the northern wind penetrating the open space through the Gracie and Henderson Streets intersection.

- **Layout of Plantation:**

Tree location along the Civic Spines on Langford Street can be assumed to be 20 m apart, with a canopy diameter of 10-25 m: as given by the client. The CWE model did not consider the presence of trees therefore, results show the unabated wind environment. The wind speed is expected to decrease with the introduction of trees and vegetation increasing the obstructions for the wind. Figure 46 shows the proposed design for Arden Reserve.

Improving the wind environment of Arden North especially for the north wind, will have a significant positive impact across the entire development.

4.3 Arden Central

Arden Central is subdivided into 6 building groups: E, F, G, J, K and N; the area is shown in Figure 70. The wind flow in different areas of Arden Central is shown below using velocity contour and vector plots from Figure 71 to Figure 93.

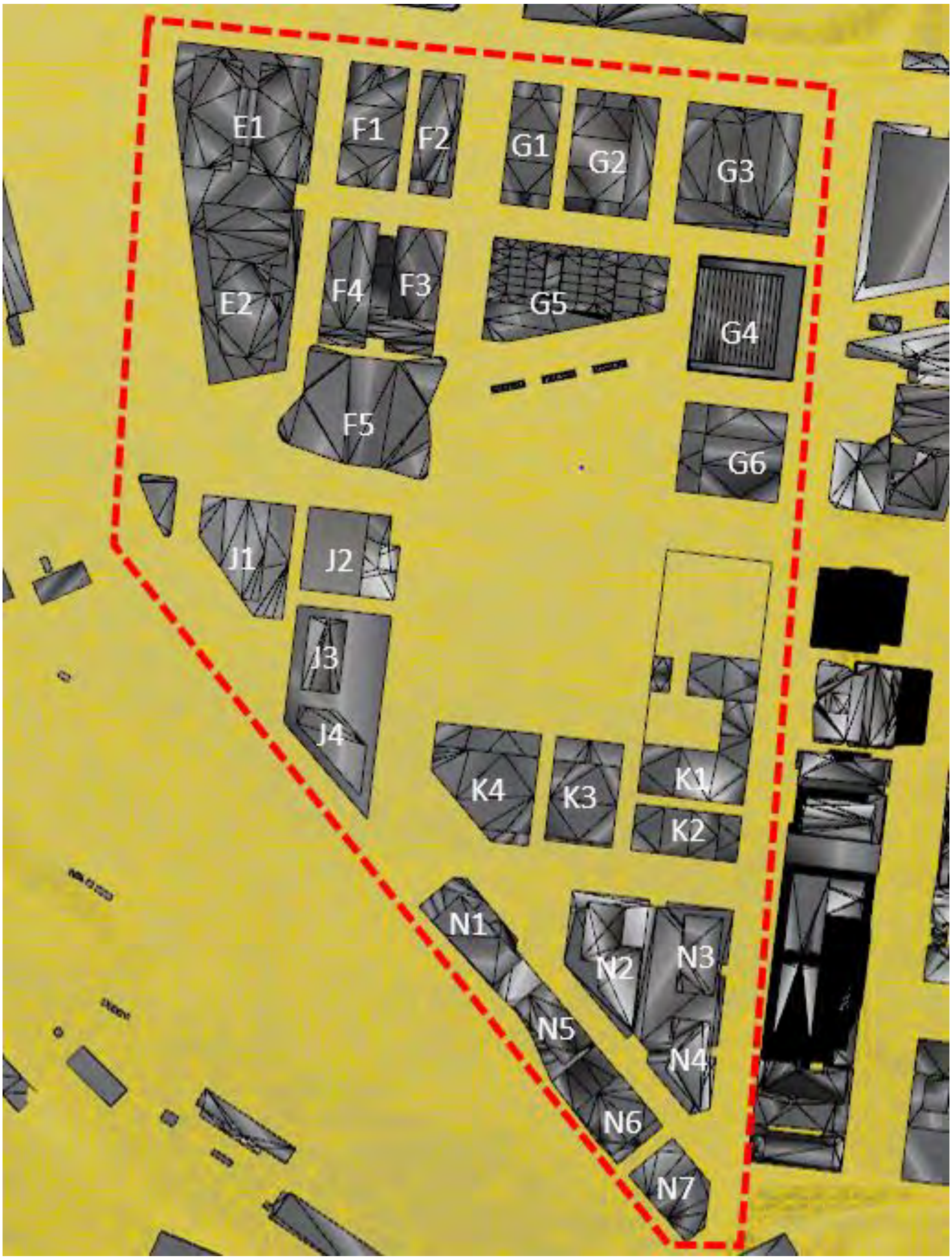


Figure 70: Arden Central

North Wind:

The wind environment in Arden Central is shown below in Figure 71 to Figure 85. Streets perpendicular to the wind direction display acceptable conditions in most areas. Figure 71, shows that there are detrimental conditions arising at the western end of Arden Street due to corner accelerations and downwash, as appreciated in Figure 80 from the direction of the wind, from buildings E1 and D1.

The streets parallel to the wind direction suffer the most severe wind conditions with wind speeds around 16 m/s. Between groups E and F; F and G; G and I; corner accelerations take place significantly increasing the velocity of the flow; which together with slight channelling taking place, raises the average wind speeds in these areas rendering them unfavourable.

As it is presented in Figure 72, Fogarty and Laurens Streets suffer the worst winds mostly due to their orientation. The conditions around Arden Station are adverse with increased wind speeds up to 18 m/s. On Laurens Street, the accelerated winds are led into the large eastern opening of the station, which is open to the open area on the other side of the station. This may cause channelling through the station's large openings, deteriorating conditions even further.

Furthermore, the laneway between building G1 and G2 creates channelling due to a reduced building separation of less than 8 m. This reaches upwards of 18 m/s and flows onto Barwise Street and the pedestrian underpass through building G5. The underpass further increases the channelling effect of the incoming wind as it flows through the corridor and leads it onto the civic open area. The mouth of the corridor of building G5 will experience adverse conditions from this channelling effect.

Group J and K experience acceptable wind conditions for the northern wind direction as it is displayed in Figure 73. The accelerated winds along Fogarty and Laurens Street are dissipated and diverted as they reach the open areas and thus conditions remain satisfactory.

Group N, as it is shown in Figure 74, experiences strong winds from corner accelerations, downwash and channelling. Buildings N1, N5, N6 and N7 display corner acceleration taking place off the podium and tower edges of building N1, as well as significant downwash onto the street due to the increased building heights and the reduced podium setback. On the northern face of these four buildings, several environmental effects are combined creating severe wind conditions along this diagonal street. These wind effects are corner acceleration taking place off the podium edge of building N2, channelling of the wind flowing through the street and downwash along the northern façade of building N6. The northern wind flows in between buildings N2, and N3 and N4; which then exhibits downwash and is added to the accelerated flow increasing the wind speed upwards of 20 m/s.

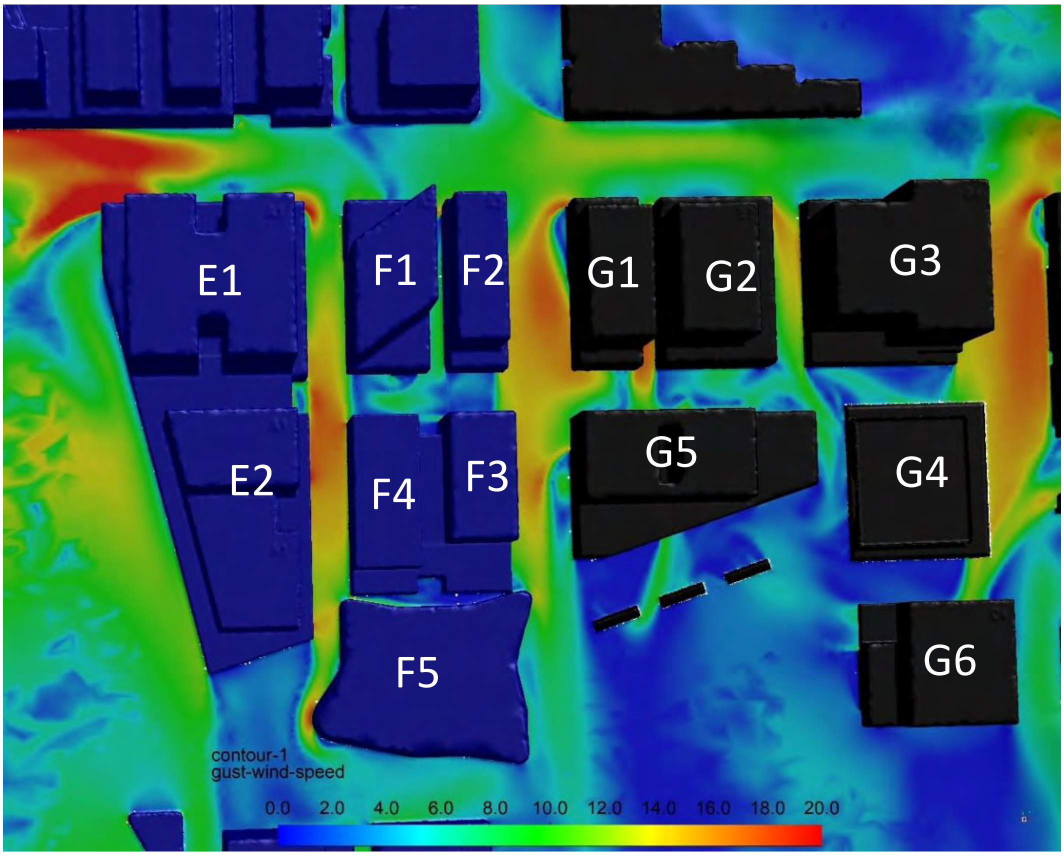


Figure 71: Gust wind velocity contour plot of Groups E, F & G; North wind

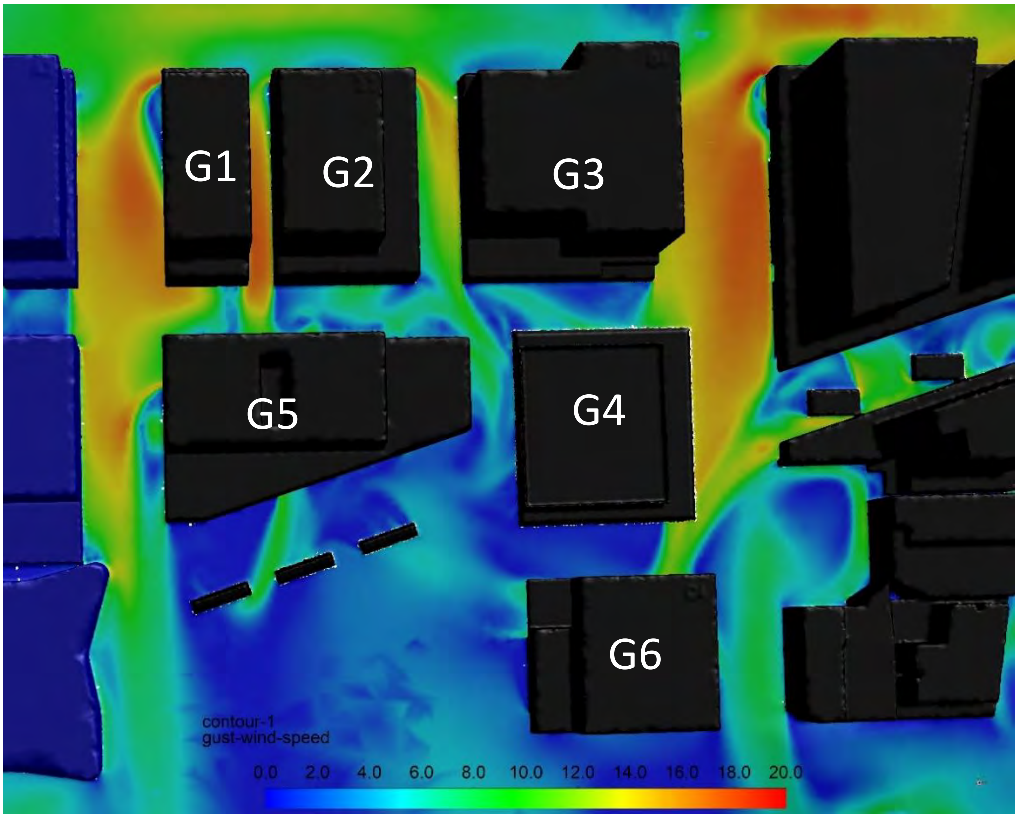


Figure 72: Gust wind velocity contour plot of Group G; North wind

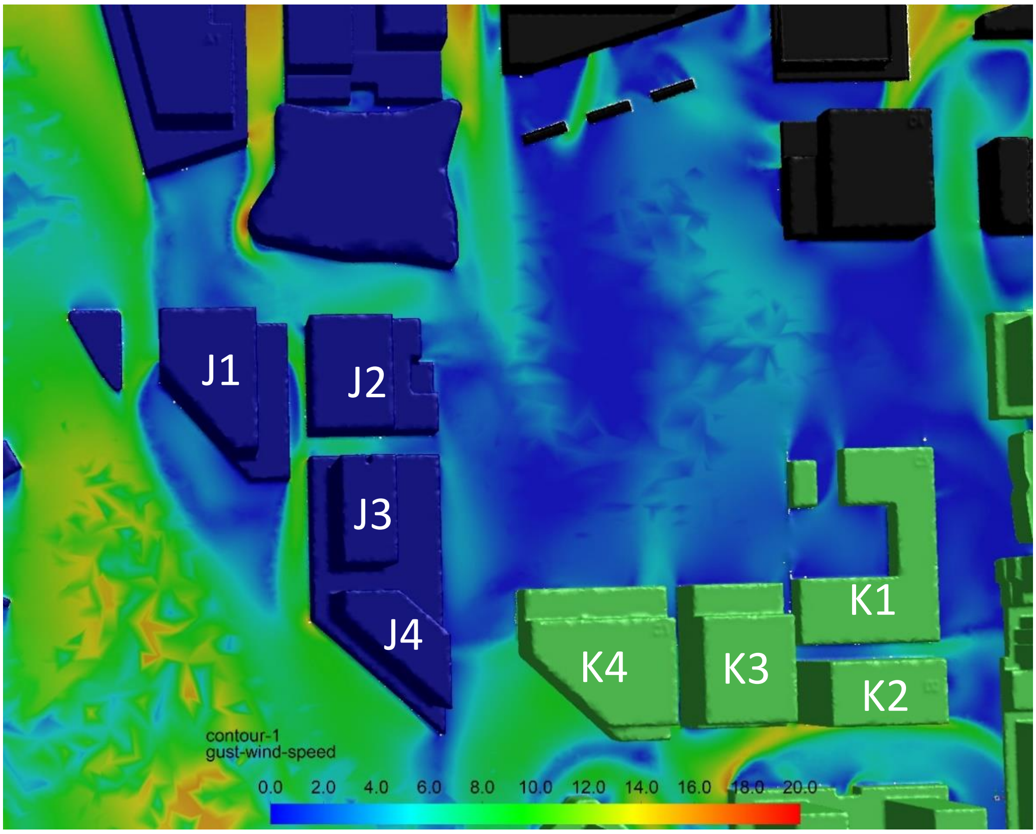


Figure 73: Gust wind velocity contour plot of Groups J & K; North wind

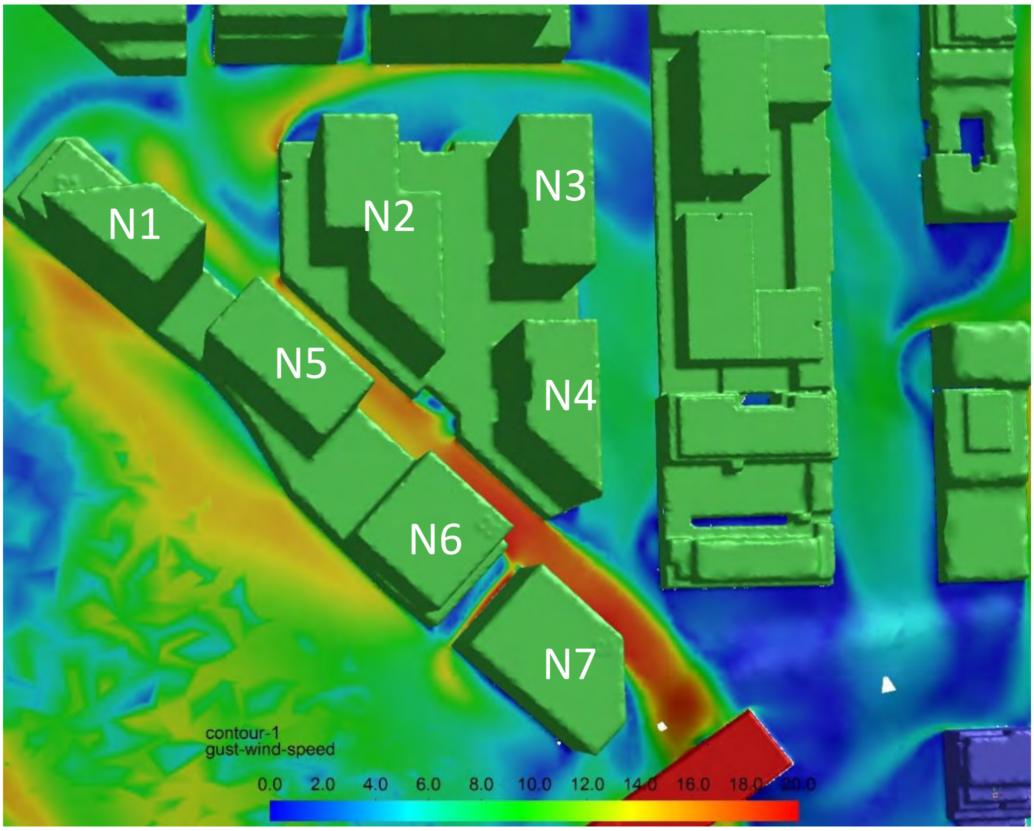


Figure 74: Gust wind velocity contour plot of Group N; North wind

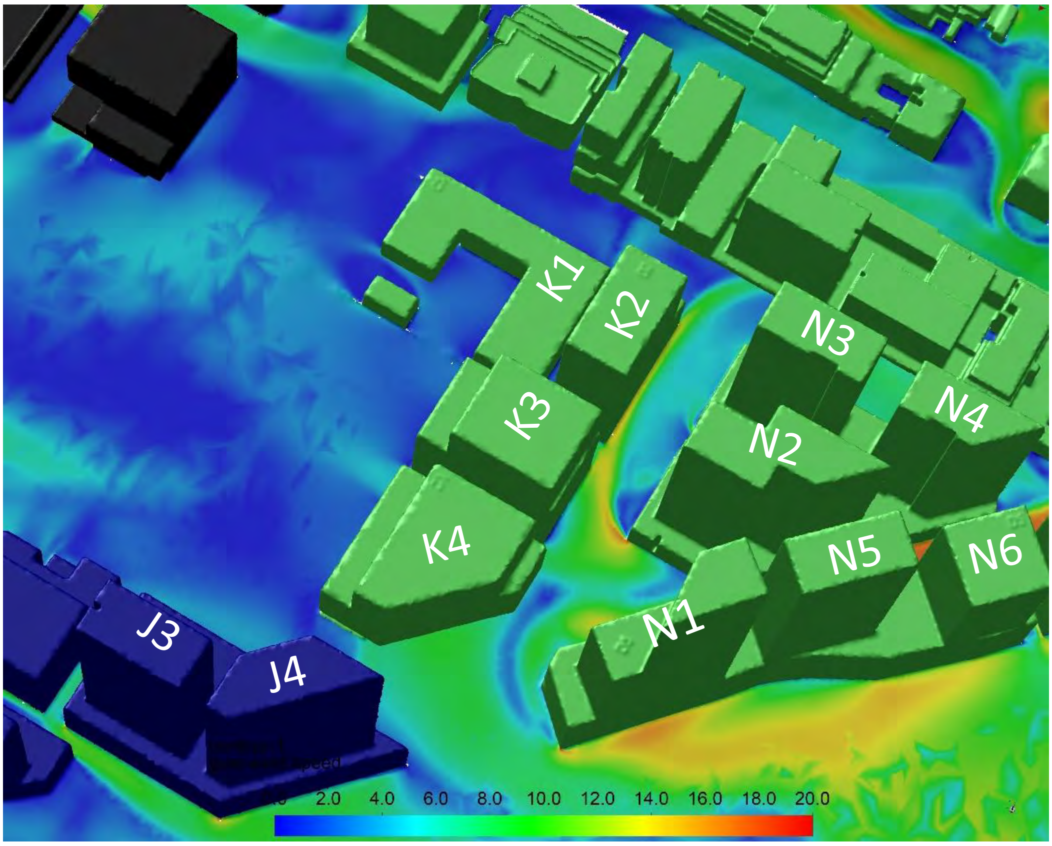


Figure 75: Gust wind velocity contour plot of Groups K & N; North wind

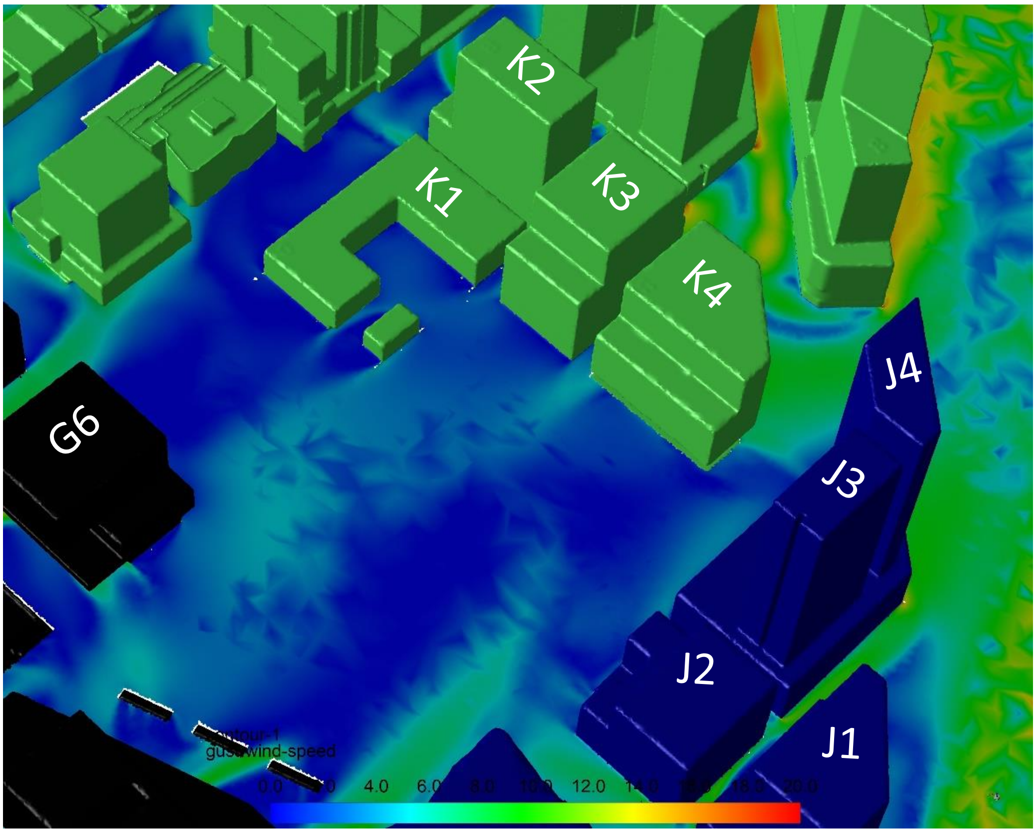


Figure 76: Gust wind velocity contour plot of the Capital City Open Space; North wind

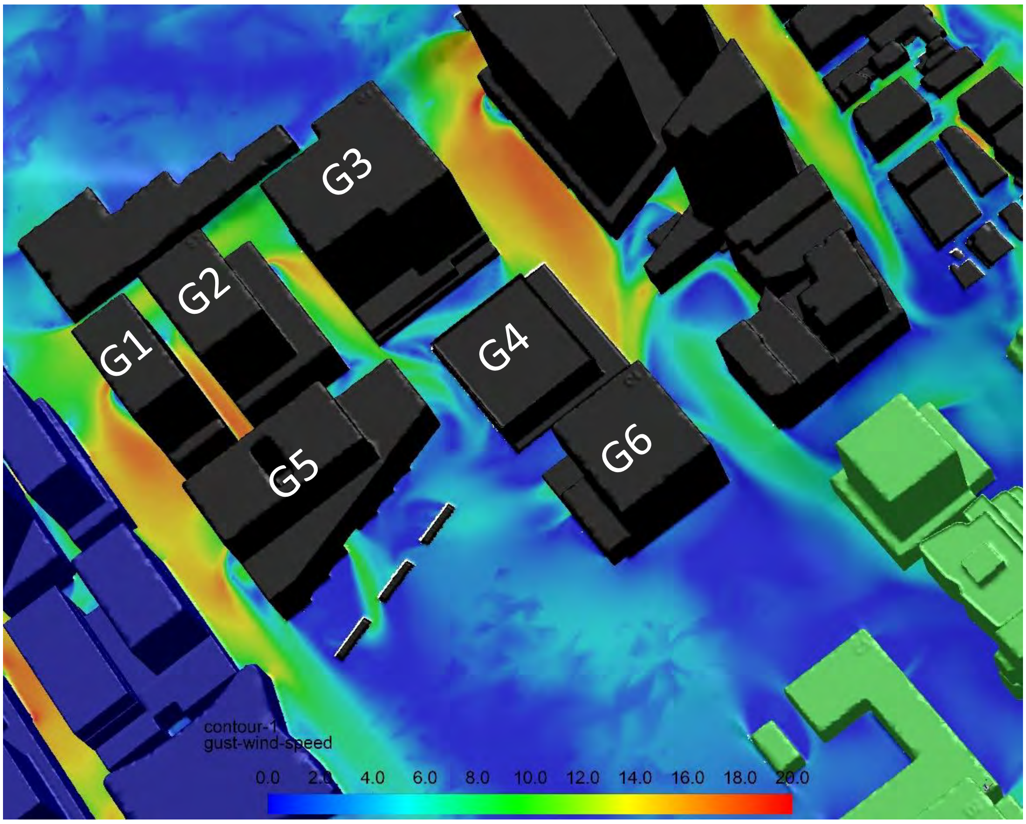


Figure 77: Gust wind velocity contour plot of Arden Central Station; North wind

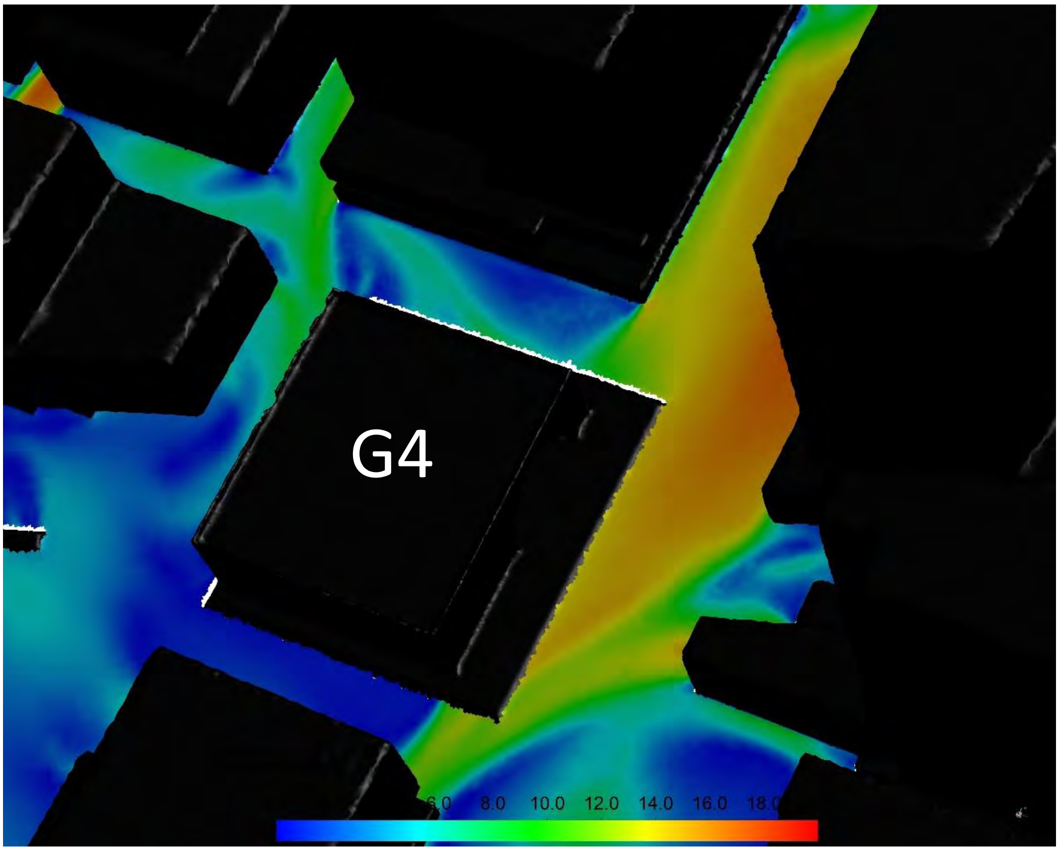


Figure 78: Gust wind velocity contour plot of Arden Central Station Forecourt Entry (view from Laurens Street); North wind

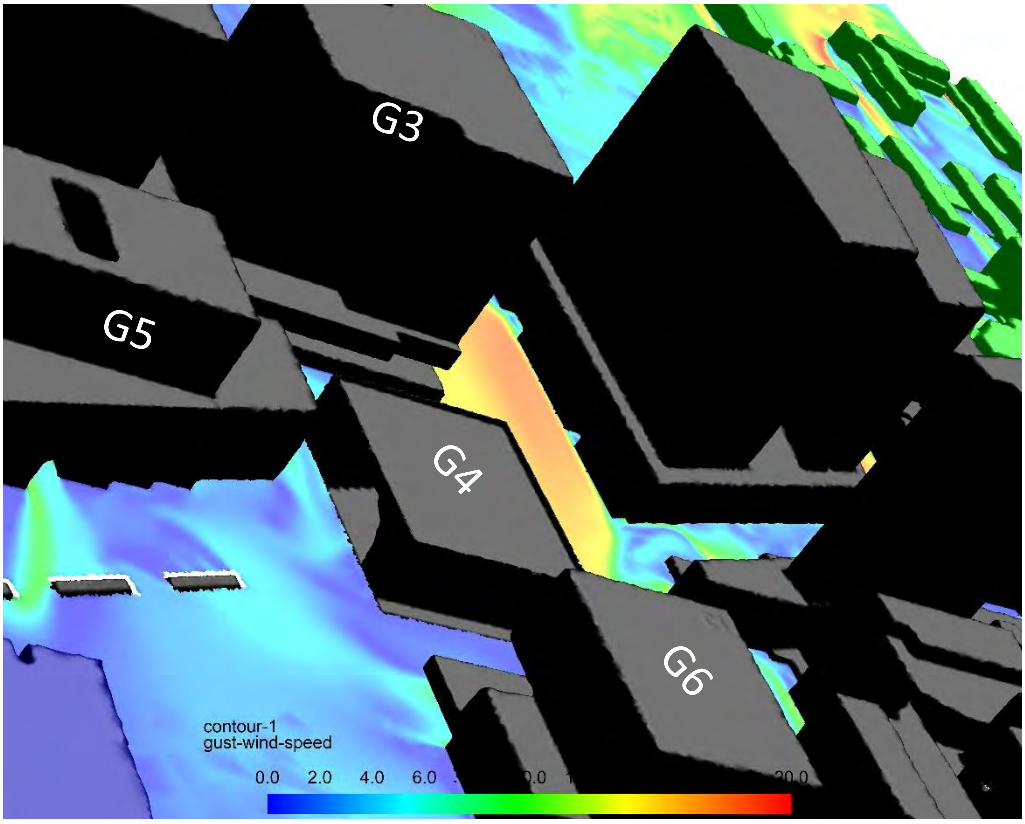


Figure 79: Gust wind velocity contour plot of Arden Central Station Forecourt Entry (view from Capital City Open Space); North wind

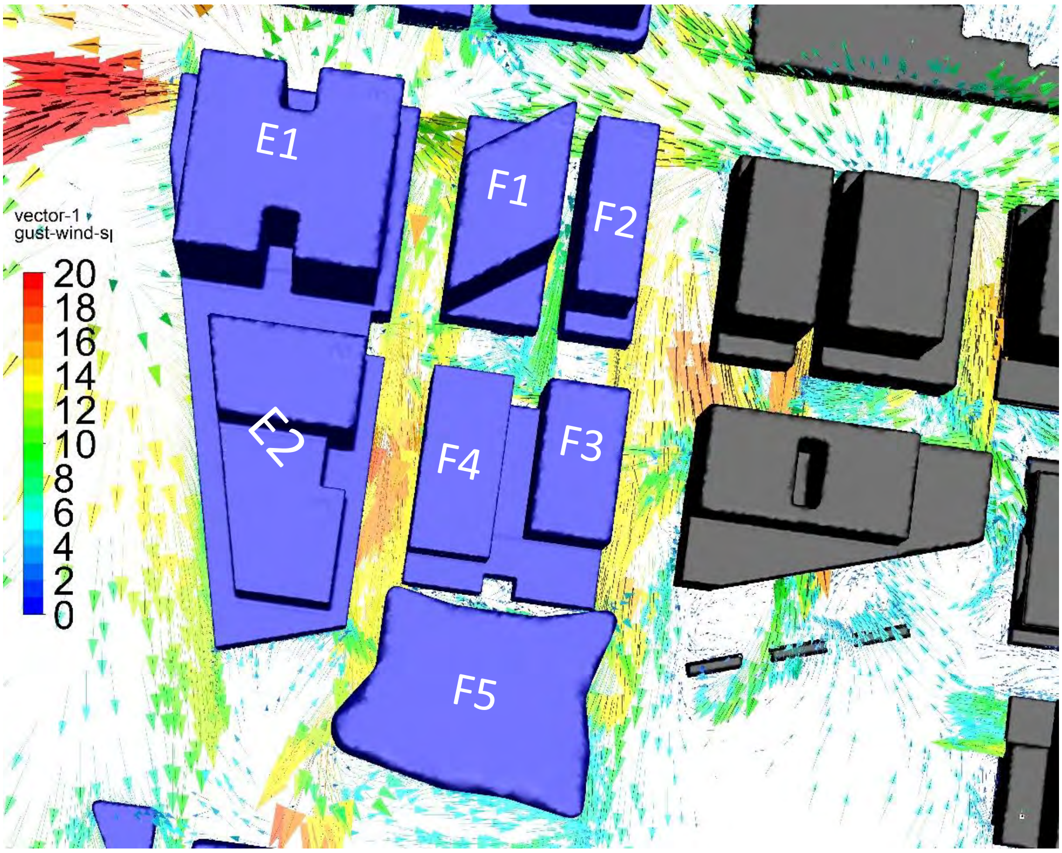


Figure 80: Gust wind velocity vector plot of Groups E & F; North wind

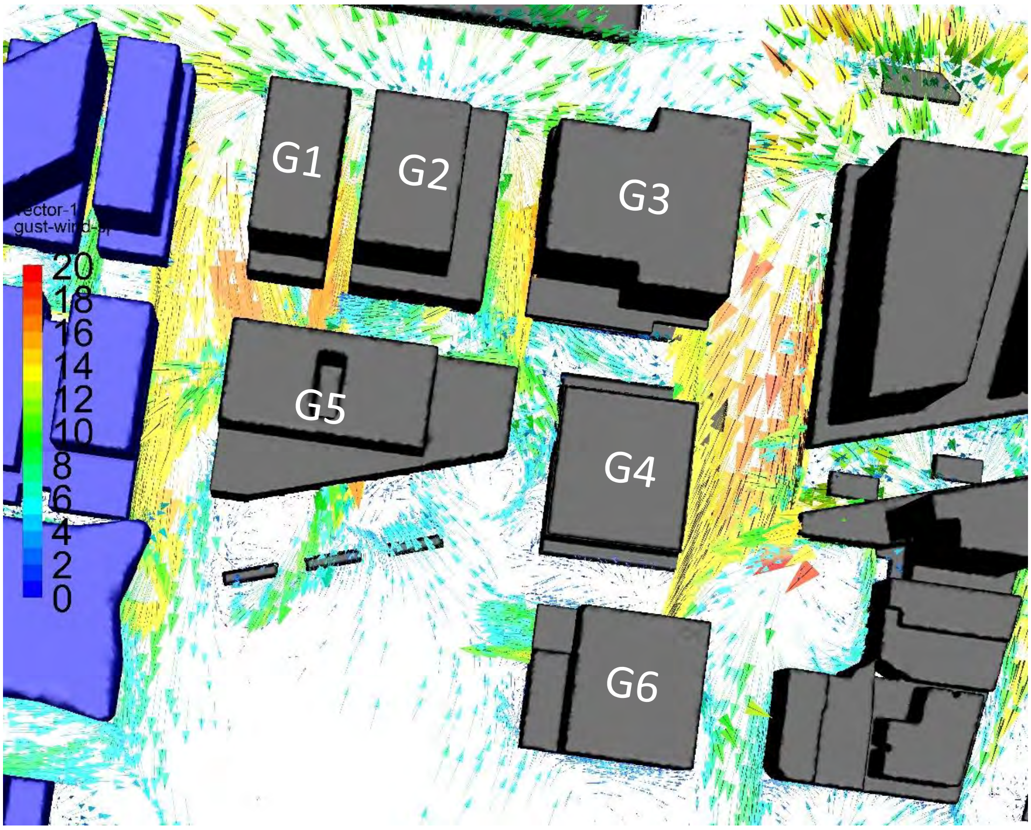


Figure 81: Gust wind velocity vector plot of Group G; North wind

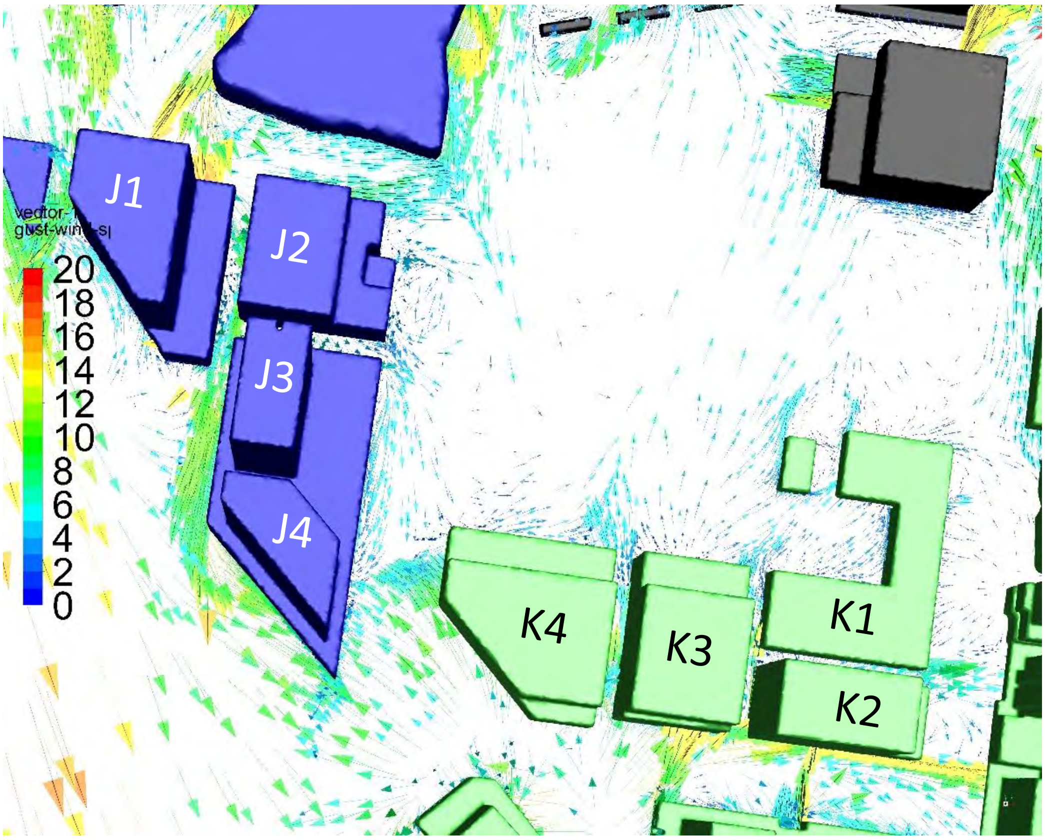


Figure 82: Gust wind velocity vector plot of Groups J, K & Central Open Space; North wind

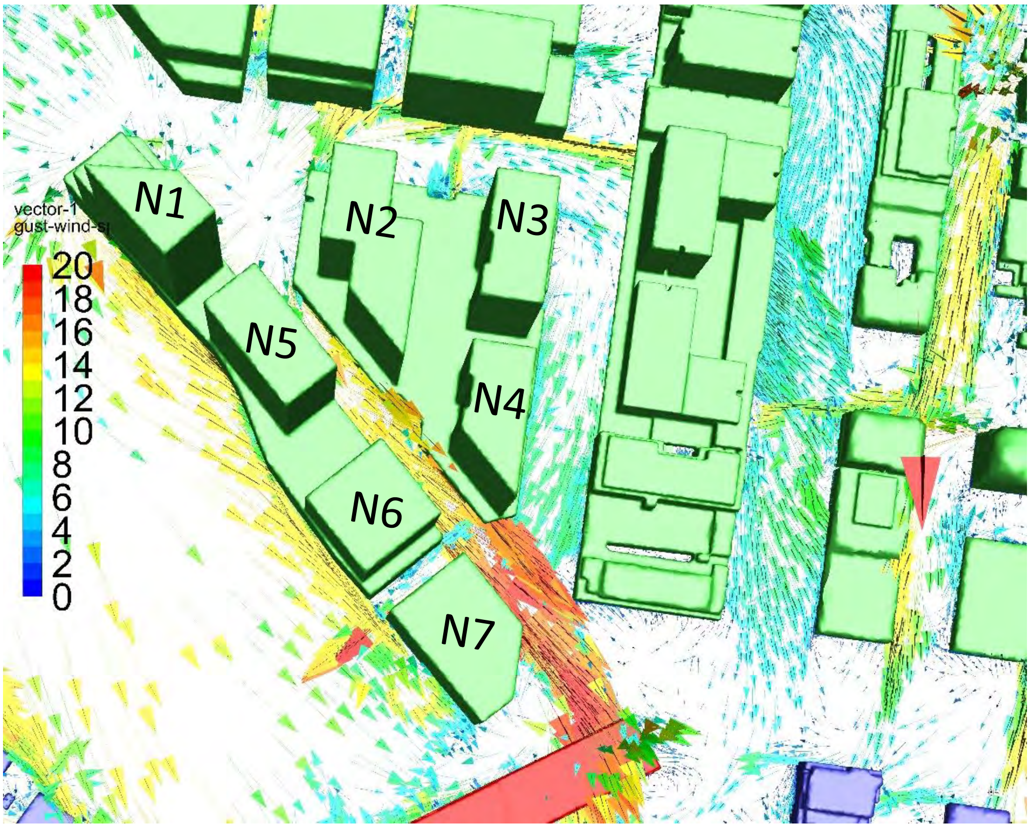


Figure 83: Gust wind velocity vector plot of Group N; North wind

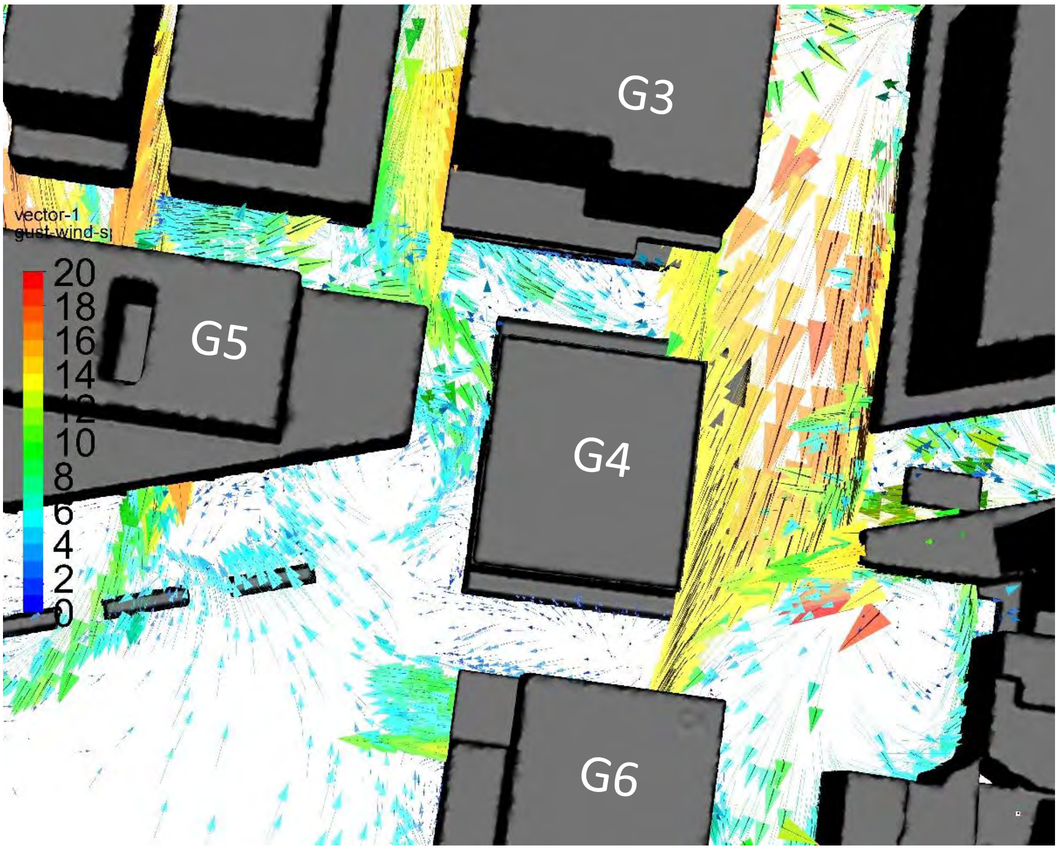


Figure 84: Gust wind velocity vector plot of Arden Central Station; North wind

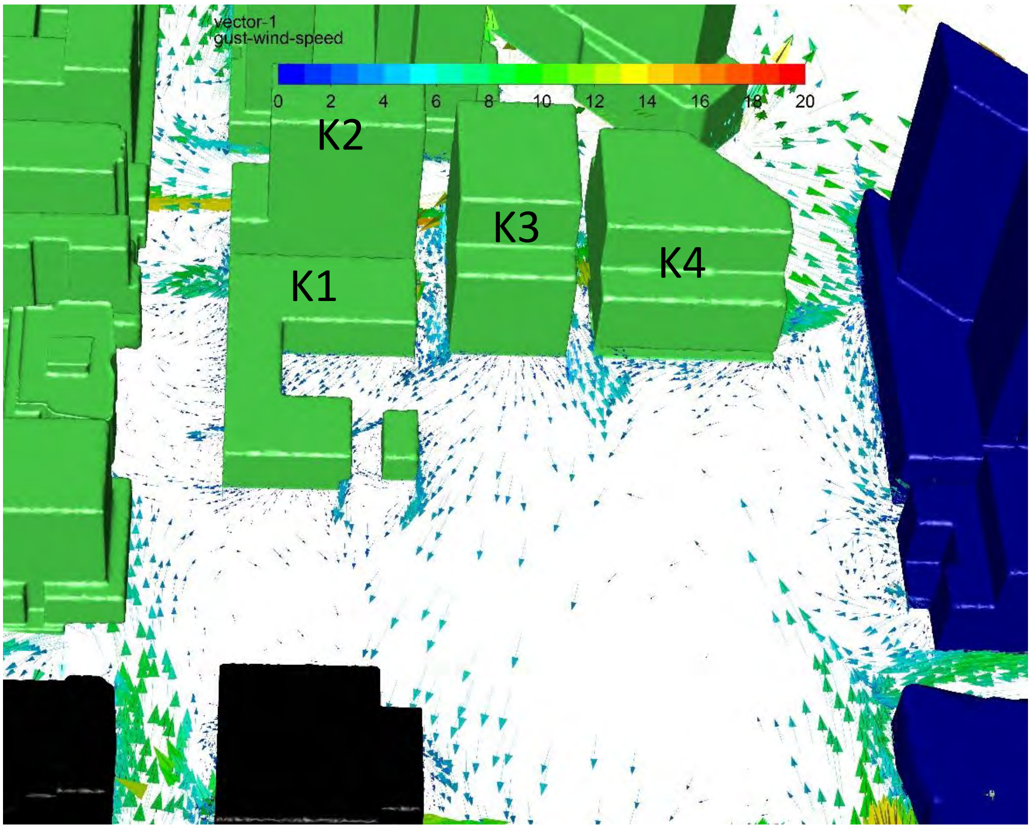


Figure 85: Gust wind velocity vector plot of Group K and Central Open Space; North wind

South Wind:

The degree of penetration of the southern wind is incredibly important, as it will provide cooling across the precinct during the hot summer months. Therefore, creating air paths for the southern wind to flow through the development will ensure that this phenomenon occurs.

Figure 86 to Figure 89 present the predicted conditions within Arden Central and it highlights areas of potential risk. The direct exposure of group N buildings to the south wind, introduces unfavourable environmental effects for Laurens and Fogarty Streets. Furthermore, due to the orientation of buildings N1, N5, N6 and N7 the southern wind is directed towards the north-west; parallel to the street orientation, suffering from accelerated wind flow which propagates to cluster J and Fogarty Street.

The diagonal street in cluster N also suffers elevated wind velocities from several environmental wind effects: flow separation, channelling and downwash on the southern faces of buildings N2 and N4.

While Laurens Street also displays high wind speeds on its southern end, conditions are not as severe as in Munster Terrace. Building N7 experiences corner acceleration on its south eastern edge which leads into Laurens Street. The accelerated wind speeds reach around 18 m/s around group K and then is directed towards the central open areas. This significantly increases the wind speed at the Capital City Open Space to a maximum of around 16 m/s.

The southern face of building H6 receives the strong winds that develop along Munster Terrace and suffers from corner acceleration and downwash. Corner acceleration develops off building H6's south-western podium edge. The accelerated wind flow is redirected into

Laurens Street and then into the opening of Arden Train Station. Wind speeds around the station entrance reach around 18 m/s, classifying this area as unfavourable for its intended use. The wind flow develops further up Laurens Street and experiences channelling before Arden Street and hence, dissipating on to North Melbourne Recreation Reserve.

Conditions at Barwise Street satisfy the safety criteria. However, the pedestrian link through building G5 to the laneway between G1 and G2, experiences elevated wind velocities due to channelling. At the intersection of the laneway with Arden Street, the wind speed reaches around 16 m/s.

Cluster J suffers high wind speeds above 16 m/s on its western and eastern faces due to the accelerated wind flow incoming from cluster N. As the wind flow from cluster N reaches the podium corner of J4, it experiences corner acceleration up Fogarty street east-side and on the western edge of the group too.

The accelerated flow along Fogarty Street hits the south-eastern corner of building F5 redirecting the flow west through the perpendicular Queensberry Street. Severe corner acceleration takes place on the north-west corner of building E1 which then hits group D's southern facades. This creates downwash onto the street by group D and results in wind speeds approaching, and exceeding, 20 m/s on the western end of Arden Street.

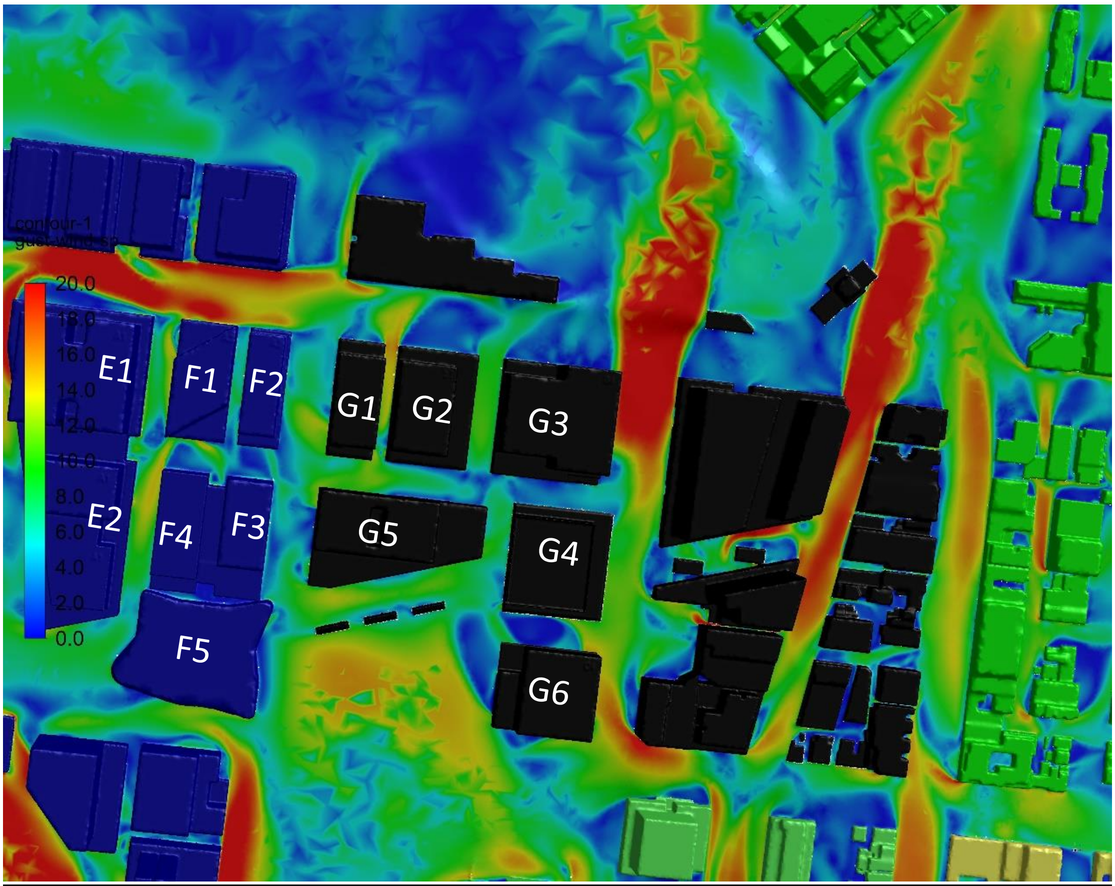


Figure 86: Gust wind velocity contour plot of Groups E, F, G & Capital City Open Space; South wind

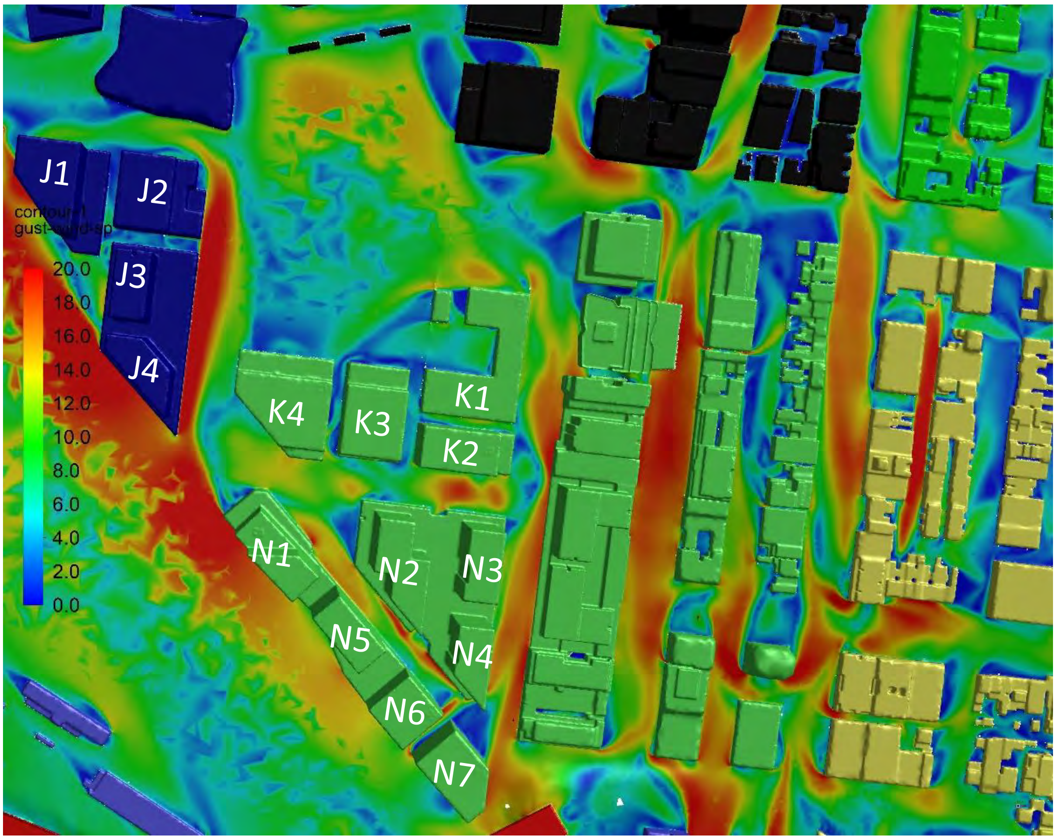


Figure 87: Gust wind velocity contour plot of Groups J, K, N & Open Spaces; South wind

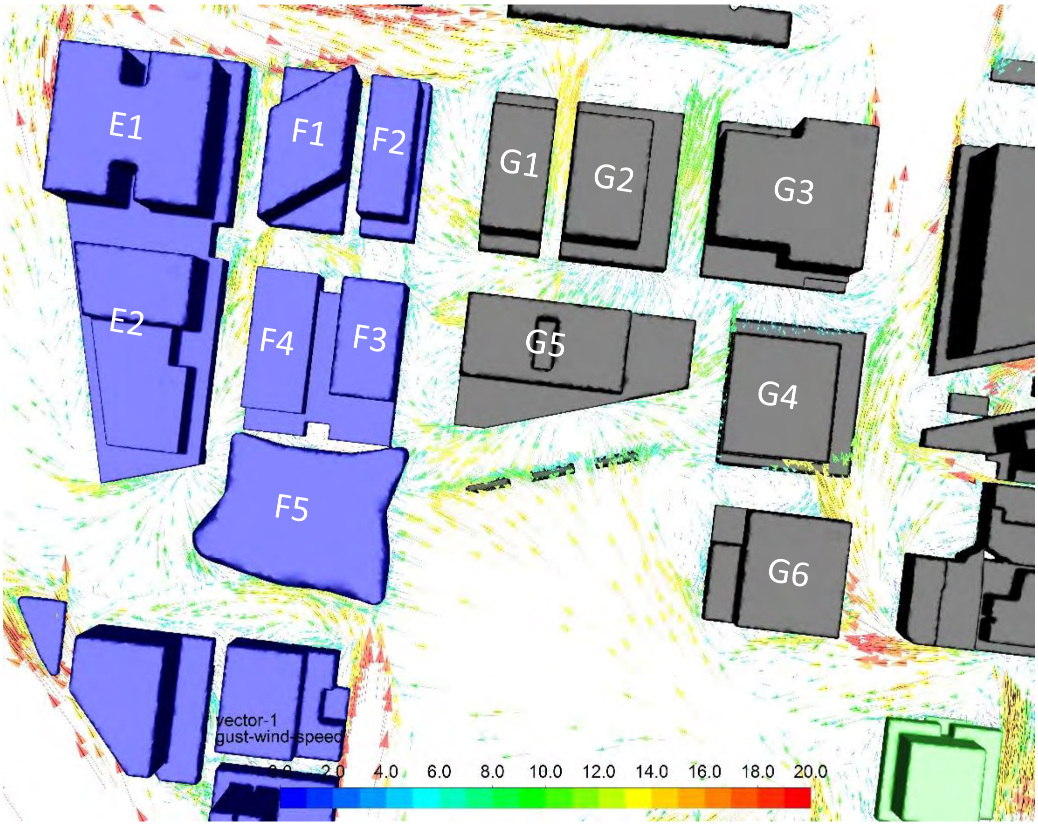


Figure 88: Gust wind velocity vector plot of Groups E, F, G & Capital City Open Space; South wind

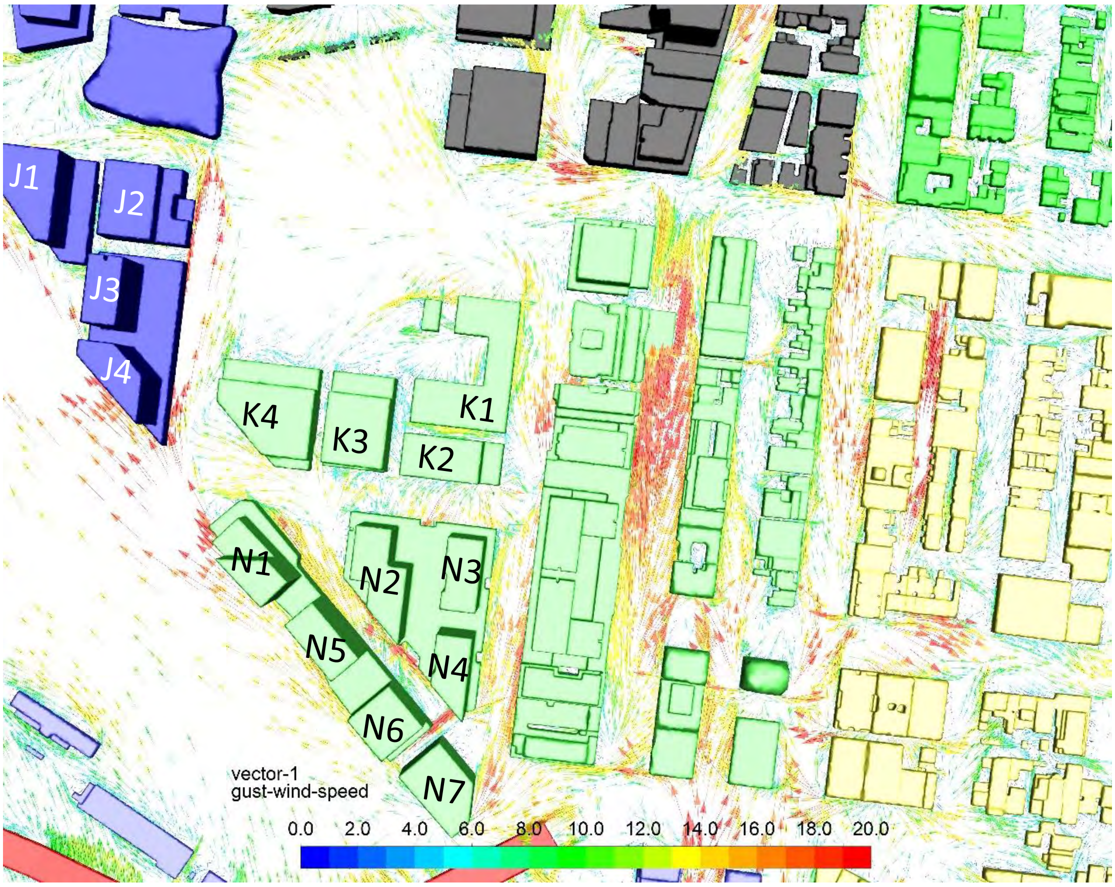


Figure 89: Gust wind velocity vector plot of Groups J, K, N & Open Spaces; South wind

West Wind:

As previously discussed, due to the configuration of the street, the western winds will penetrate through the development, with detrimental conditions arising at the western end of the site in parallel locations.

Arden Street, the southern continuation of Langford Street, Queensberry Street and Fogarty Street all suffer the most severe winds as appreciated in Figure 90 to Figure 93. Building E1 experiences corner acceleration on its northern end, which, coupled with channelling flow further down the building face and corner acceleration from D1 and D4's podium corner, classifies this strip of the street as unsafe. Between E1 and G1, Arden Street experiences speeds of 20 m/s and above.

Downwash on the western façade of building E2, along with corner acceleration at the podium's south-west edge increase winds speeds upwards of 18 m/s. The accelerated wind flow is then directed at F5 which separates the flow between Queensberry Street and the street in between groups E and F, with increased wind speeds at both locations rendering the areas unsafe.

The laneway between J1 and J2 is also predicted to experience unsafe wind conditions due to downwash wind on the façade of J3 and J4 being redirected towards it. Once inside the laneway, the wind is further accelerated by channelling due to the reduced building separation between J1 and J2. Between J2 and J3, this laneway also experiences elevated wind speeds due to channelling and corner accelerations from the podiums of each building.

The high-speed winds are led into the central open areas adjacent to Arden Station displaying wind speeds of around 15 m/s in the Capital City Open Space and further increasing due to corner acceleration on the south-west corner of G6 building to 18 m/s. Conditions around the station display wind speeds of around 10 m/s and increasing up to around 16 m/s on its north-west corner.

The southern half of Arden Central displays elevated wind speeds as appreciated in Figure 91. Fogarty Street between groups J and K and K and N show the worst conditions. The shape of the N1 podium and the south-western face of K4, resemble a funnel and thus, creates channelling flow; in conjunction with the corner accelerations taking place off building J4. Downwash also takes place on the south-west face of K4 which is then separated between the two perpendicular directions at the elbow of Fogarty Street.

Group N buildings suffer severe wind conditions on all sides. The diagonal street shown in Figure 91 shows that the elevated high-speed wind flow in Fogarty Street is also fed into it; along with downwash off the tower and corner acceleration from the N2 podium. On the southern face of buildings N1, N5, N6 and N7, high wind velocities are also found due to downwash on all four buildings. Part of this accelerated wind flow is then lead through the partition between N6 and N7, accelerated by both building’s outer corners and driven into Laurens Street.

Figure 90 and Figure 92 depicts the predicted conditions found at the intersection of Fogarty and Laurens Streets. The wind environment at the intersection is classified as unsafe with winds upwards of 20 m/s which then goes on to hit the group L buildings. This incoming wind onto the L cluster experiences downwash back onto Laurens with high wind speeds at perpendicular directions. The remaining incoming wind flows between the L cluster buildings undergo acceleration due to channelling and corner accelerations. This wind stream then flows perpendicularly onto Munster Terrace at different points on the street.

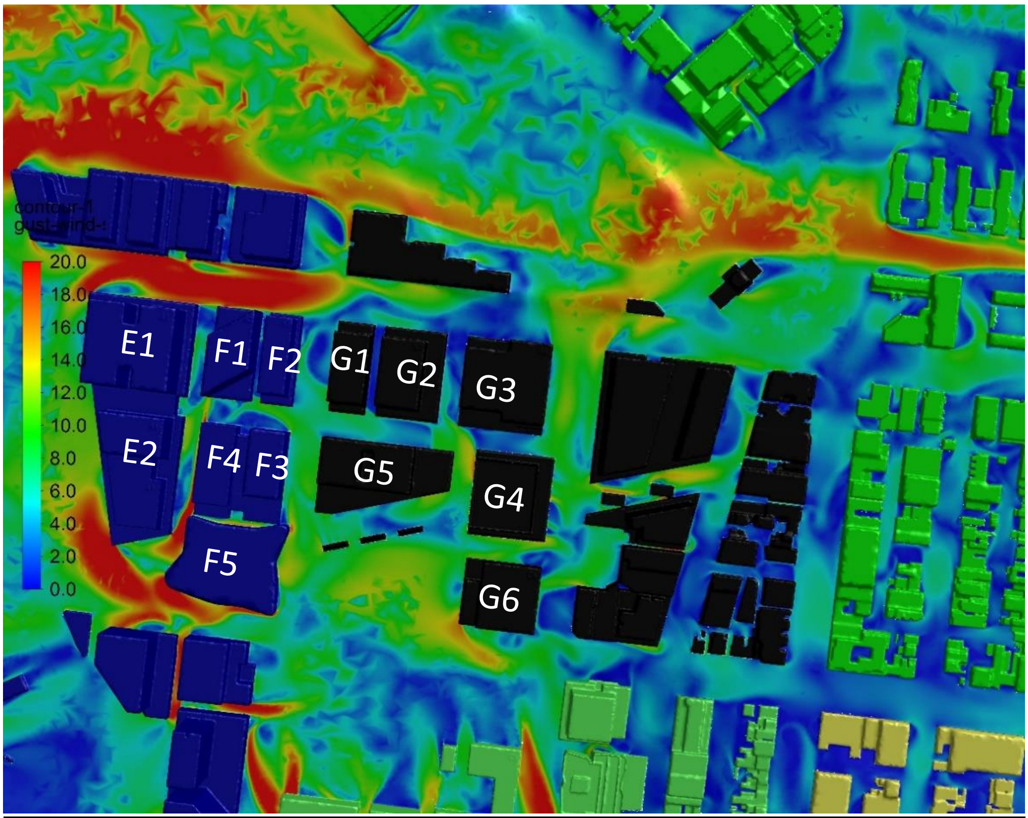


Figure 90: Gust wind velocity contour plot of Groups E, F, G & Capital City Open Space; West wind

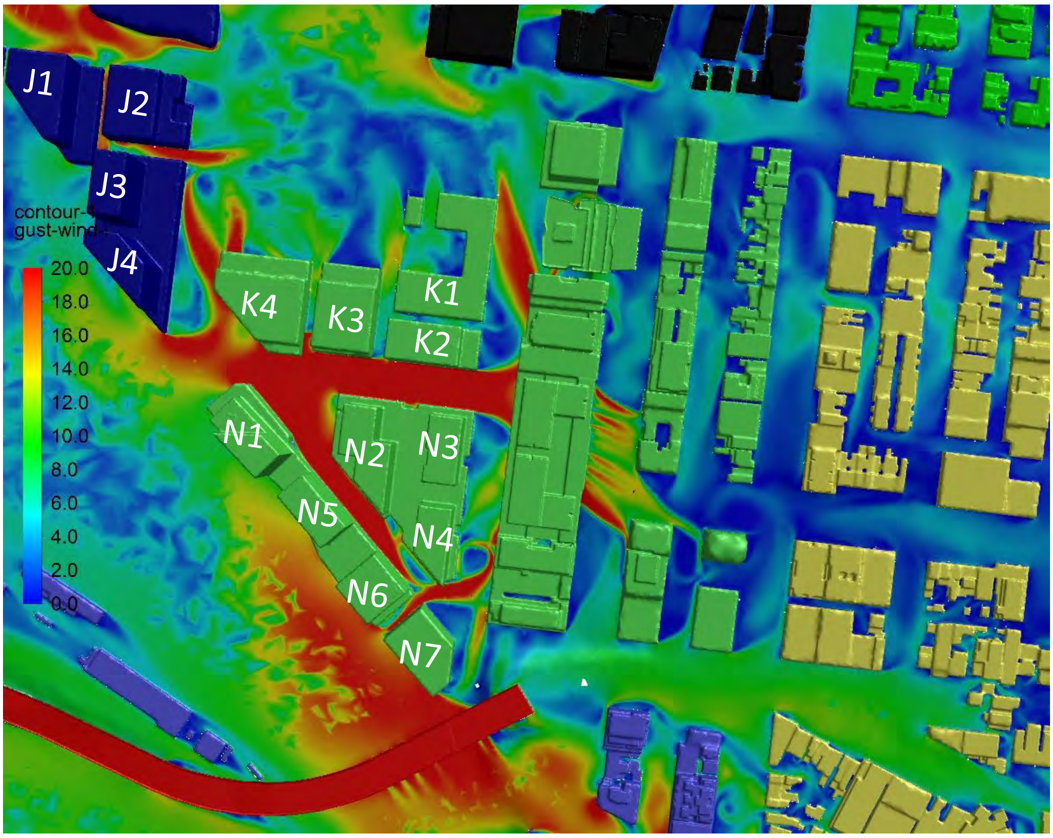


Figure 91: Gust wind velocity contour plot of Groups J, K, N & Open Spaces; West wind

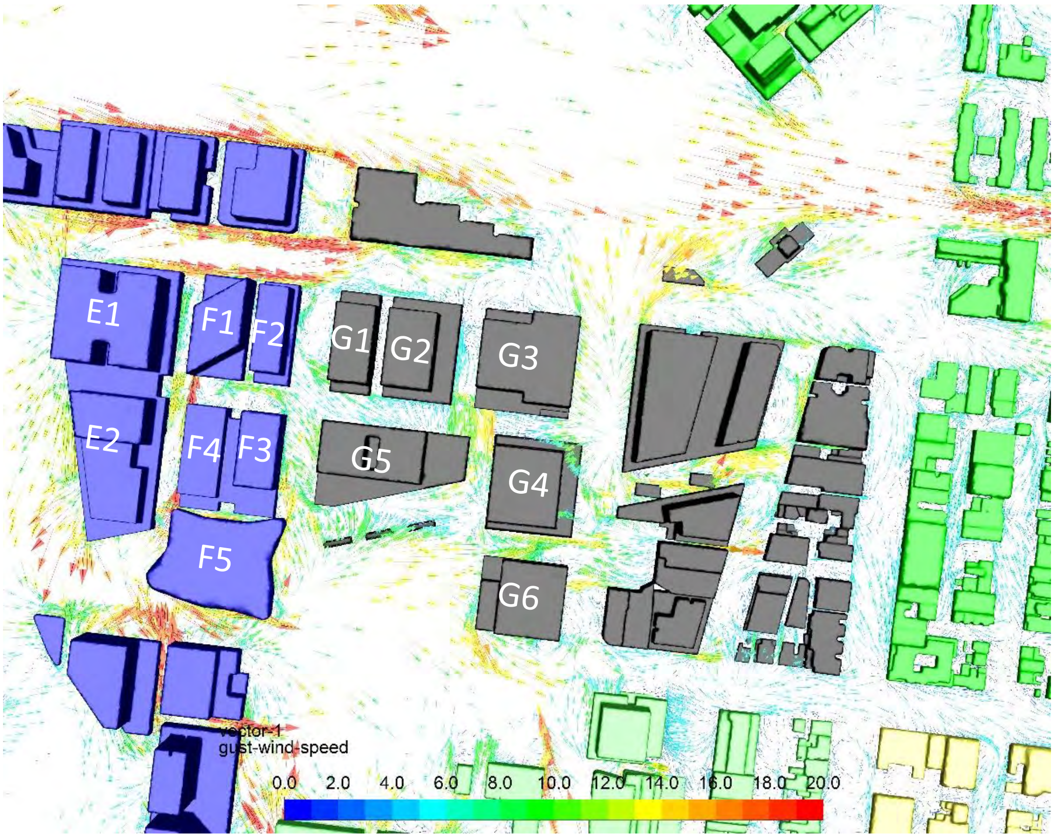


Figure 92: Gust wind velocity vector plot of Groups E, F, G & Capital City Open Space; West wind

Figure 93: Gust wind velocity vector plot of Groups J, K, N & Open Spaces; West wind

The following can be observed in Arden Central from the velocity contour and vector plots above:

- **Street Orientation**:

This sub-precinct follows the same street configuration as Arden North with streets orientated north to south and east to west, except for the continuation of Langford Street and the remaining streets on the western boundary. Streets to the west of groups E, J and N are diagonal to the general street configuration of the precinct.

As appreciated in the results for the northern wind direction, the western border of Arden Central experiences fitting wind conditions for the activities proposed for this area. The corner accelerations taking place off podium D1 and E1 are directed westward and are not driven south along the boundary thus, providing acceptable conditions. On the west side, higher wind speeds can be appreciated up to around 14 m/s due to downwash and the reduced setback of E1 and E2.

Around group J buildings, conditions are milder than around E; reaching around 10 m/s, and therefore remain satisfactory. However, conditions around group N are much more adverse, with wind speeds up to 20 m/s along the end of the street between N7 and N4.

The parallel orientation of Laurens Street, Fogarty Street to the north and south wind directions and Arden Street and Queensberry Street to the west wind direction, means that elevated wind speeds are prone to develop as the wind is accelerated due to corner accelerations and channelling. The simulation results show that Arden Train Station suffers detrimental conditions, particularly on its eastern façade, for almost all wind directions (refer to Appendix C) except for the western wind direction. The north wind direction creates the worst wind conditions around the eastern station entrance. The southern direction leads to channelling taking place at the northern end of Laurens Street onto the North Melbourne Recreation Reserve, with wind conditions around the station entrance being around 10 m/s.

The south wind direction creates severe wind speeds to be found northward along group N and J buildings due to the unobstructed corner accelerations taking place and reduced setback. This then allows for downwash to take place all the way to the ground and contribute to the already high wind speeds at ground level (refer to Figure 87). Fogarty also suffers from elevated wind speeds south of its intersection with Queensberry Street due to this stream which is divided by the corner of J4.

Figure 90 and Figure 91 also display severe wind conditions for the western wind direction on Arden and Fogarty Street (east-west orientation), with speeds reaching and exceeding 20 m/s.

- **Building Orientation:**

Buildings in this sub-precinct are also mostly orientated north to south, with some exceptions primarily found on the western border of the proposed development site: groups E, J and N. The orientation of the buildings in these three groups differs with the position, diagonally orientated buildings are found to the west and towards the centre of the development, the orientation follows the same general north to south orientation.

All of the developments in Arden Central are proposed to be built as podium towers except for the Arden Station building, innovation mixed-use building F5, government school K1 and public transport facility building N7.

Building E1 experiences a slight downwash effect on its northern façade for the north wind direction, which adds to the significantly higher acceleration seen on the north-west corner of its podium in Figure 71. The total tower height of E1 is 82 m and its podium is 24m, with a setback of 6 m. The effects of downwash are minimal and thus this is an effective setback distance for this building and its location. Figure 88 presents the conditions predicted for the south wind direction. It is appreciated that the wind environment is milder than that of the north wind direction. Corner acceleration takes place off the north-western corner of E1 which then hits the group D southern facades, is downwash onto ground level and dissipates eastward along Arden Street with speeds exceeding 20 m/s.

Group G displays a much more agreeable wind environment for the south wind direction except at the intersection of Laurens Street and Arden Street where channelling takes place. Conditions around Barwise Street and the narrow pedestrian links between G1 and G2, and G2 and G3 display much more suitable conditions. Figure 71 and Figure 72 shows that the detrimental conditions suffered around building groups E, F and G are mostly due to corner accelerations taking place from the podium corners of their respective buildings.

The south wind direction causes severe wind conditions to arise along the southern façade of groups N and J buildings. The main originators for the elevated wind conditions are corner accelerations off the podium corner of N1 and further downstream J4, and downwash off the l=southern facades of the large N1, N5 and N6 buildings. The total tower heights for these buildings are N1 is 121 m, N5 is 102 m and N6 is 70 m; including a shared podium height of 28 m. The setbacks for each tower are: less than 1 m for N1, from 1 m at the north-west corner to 9.5 m at the south-west corner of N5, and less than 1 m again for N6. The 1 m setbacks are shown not to disrupt the wind significantly for the height of these buildings and thus cause elevated wind conditions for both the south and west wind directions, thus it is recommended to increase the set back at these locations accordingly.

Buildings N2, N3 and N4 display much more appropriate setback distances. The sharpness of their corners to the south causes elevated corner accelerations for the south and west wind directions in particular.

Furthermore, building K4 on the south-west corner shows an angled façade, which in conjunction with N1 resembles a funnel-like shape from the west wind direction. This will encourage the wind to create a channelling flow through the parallel Fogarty Street, which will further increased in speed by corner accelerations taking place off the podium corners of N1, and the corner accelerations on the south-west corner of K4, as well as unobstructed downwash due to the lack of setback (refer to Figure 89).

- **Building Orientation (Natural Ventilation):**

The orientation of the buildings in this sub-precinct allows for agreeable ventilation to take place. The north half of Arden Central displays an increasing building height from south to north which will allow for the summer breeze to maximise its cooling potential. The southern half of Arden Central contains the tallest towers in the whole development. In regards to the natural ventilation, the spacing between the towers in group N is large enough so that their position does not compromise significantly the ventilation potential of the precinct.

- **Building Relative Height Differences:**

The average height in this sub-precinct is considerably higher than the rest of the development. The general arrangement follows a decreasing building height from west to east and towards the centre of the sub-precinct.

In group N, buildings N3 and N4 have the same height and thus, as Figure 36 presents, skimming flow will occur over the roof of these two towers. Therefore, in order to ensure suitable ventilation to take place, building N4 must be shorter than N3.

Furthermore, building K2 lacks a podium setback on its northern façade. The position of K2 can suppose detrimental conditions to arise at ground level between K2 and K1; the government school. Also, the exposure of the face to the dominant detrimental wind conditions, and its proximity to a school, contribute to the assessment of the measures presented for the wind control mechanisms.

- **Space between Buildings:**

Figure 81 shows that the pedestrian link between G1 and G2 experiences elevated wind speeds from the north wind direction. This is an undesirable effect as this accelerated wind flow is then led into Barwise Street and then through the almost-parallel block link in G5. The accelerated wind flow due to channelling leads out onto the Capital City Open Space behind the Arden Train Station, deteriorating the wind environment in the area directly adjacent to the southern façade of G5. The reduced building separation is responsible for this phenomenon occurring at this location. G1 and G2 are 59 m and 62 m high, respectively. The separation between both buildings is 8 m, and with the lack of a setback on the northern façade of G5, the accelerated wind downwashes onto Barwise Street and through the pedestrian block link at very high wind speeds exceeding 20 m/s.

The building separation between E1 and F1 is about 15 m for buildings of 82 m and 64 m heights, respectively. Figure 80 shows that the conditions in this street are adverse for the north with an increasing gradient from around 8 m/s to about 17 m/s midway at E2. Therefore, increasing the building separation between F5, and F3 and F4, will allow for some of the accelerated wind flow to be discharged through this corridor and provide it with increased ventilation. Figure 80 shows that there almost no air flow taking place at this location as the difference in height between the F3 and F4 podium and F5, is less than 1 m and the separation is minimal, rendering this as a dead zone.

The corridor between F2 and F3 for the south wind direction receives is presented by Figure 86 and Figure 88. As described in Figure 38, the ratio between both buildings was calculated to be 1:1:2 (h:W:H), which resembles the prediction of the flow with the same ratio expecting the air at ground level to be subject to suitable circulation and allowing for proper dispersion of pollutants in the area and cooling in summer.

Fogarty has a width of 26 m. Due to the orientation and exposure of the street, the potential for the creation of an air path along it is very high. Therefore, the following calculation as put forth by *Edward Ng* [6] is as follows:

- Fogarty Street

$$W_{air} \approx \frac{1}{2}(W_{F2} + W_{G1}) = 0.5(22 + 25)$$

$$W_{air} \approx 24\, m$$

Comparing the measured width of 26 m of Fogarty Street, to the estimated width for the allowance of air paths of 24 m, it shows that it has the potential to be an effective air path through Arden Central for the northern wind direction.

The spacing between building N2 and N5 directly across the street is 21 m. Given the large funnel-like shape created between N1 and N2, and K4 wind coming from the west will experience channelling that will be separated into two flows, one along the parallel section of Fogarty Street and the other down the south-eastern street crossing in the middle of group N buildings. Building N2 is proposed with a podium setback of 8 m for a total tower height of 77 m including a 14 m podium height. Figure 73 shows the phenomena taking place around this group of buildings which is mainly characterised by corner accelerations as seen on the south-west podium corner of N2 and downwash on several northern facades in cluster N. Buildings N5 and N6 display no podium setback on the northern face and this will contribute to the acceleration of the wind flow through this street.

- **Public Space:**

There are two main open areas in this sub-precinct found in the centre of the development. The conditions in these areas are found to be suitable for the activities proposed for these areas, although the sitting area will have to be carefully placed so to avoid the strongest currents. The Capital City Open Space to the north shows marginally higher wind speeds than the new open space directly to the south. The western entrance of the Arden Station leads to the Capital City Open Space and conditions are slightly elevated with a maximum speed of around 10 m/s for the north wind, as seen in Figure 81.

The north wind direction around the open area next to group K can be appreciated in Figure 82. The conditions around K4 and K3 are shown to be below 8 m/s which is due to the location and especially with a large setback of 12 m. There will also be pedestrian civic spines along the southern continuation of Langford Street, Fogarty and Queensberry Streets.

- **Layout of Plantation:**

The CWE model did not take into account the existence of the civic spines along Fogarty and Queensberry Streets. These green areas will contain 10 to 15 m canopy trees at roughly 20 m which will disrupt the wind at pedestrian level and thus, improving the wind environment.

4.4 Laurens Street

Laurens Street is subdivided into four building groups: H, I, L and M; the area shown in Figure 94. The wind flow in different areas of Laurens Street is shown below using velocity contour and vector plots from Figure 95 to Figure 107.

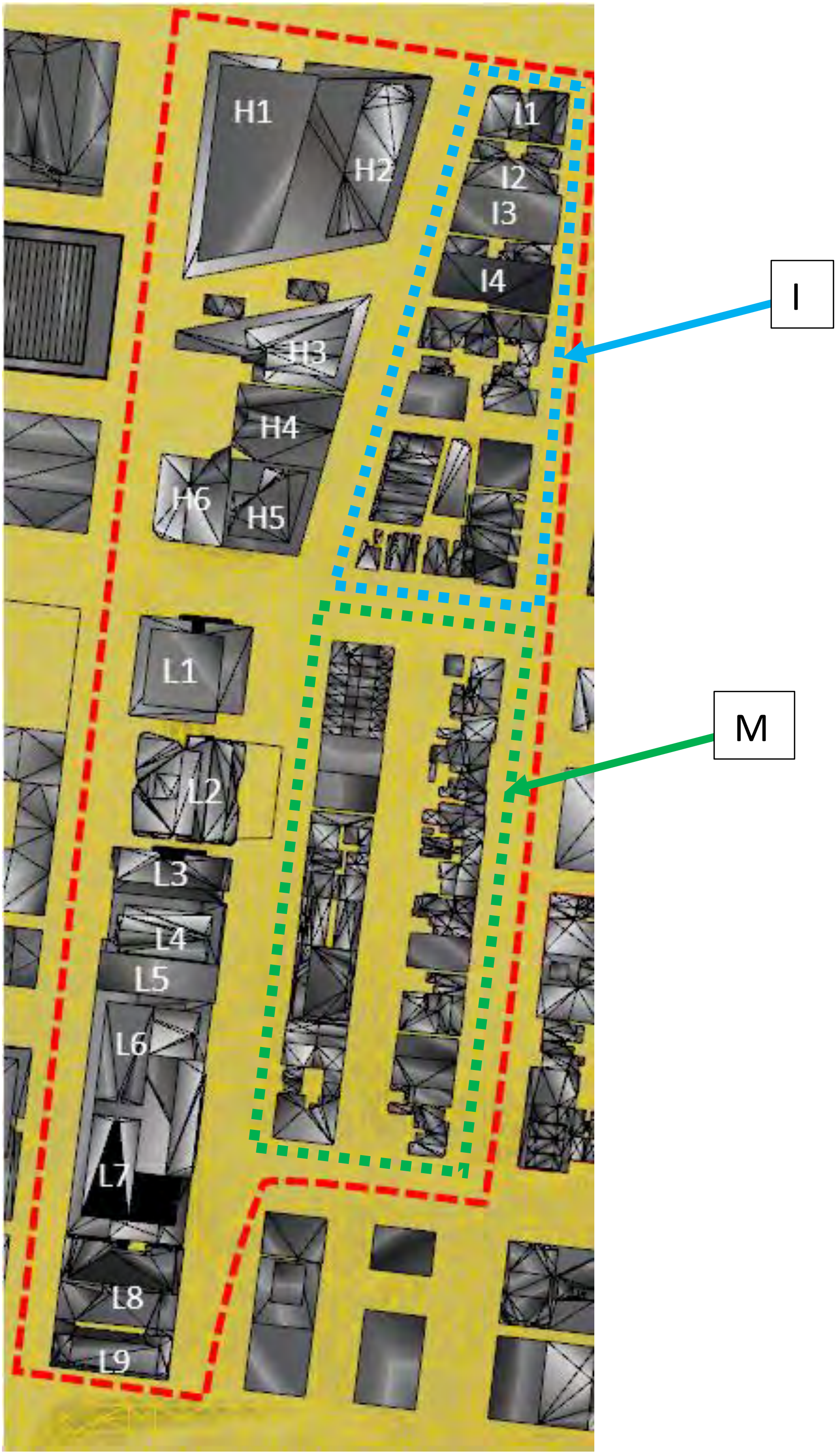


Figure 94: Laurens Street

North Wind:

The north end of Laurens Street is gravely exposed to the adverse northern wind characteristic of the Melbourne region. The North Melbourne Recreation Reserve is located directly north of Laurens Street, Munster Terrace and Dryburgh Street. Thus, there are few obstructions to break up the incoming wind before it reaches groups H and I.

The wind conditions born along the north end of Laurens and Dryburgh Streets and Munster Terrace are presented in Figure 95 and Figure 98. Both illustrations show that the frontage of buildings H1 and H2 suffer from downwash and the accelerated flow is redirected onto Arden Street. In addition, corner accelerations take place on the shared podium at the north-east and north-west corners, leading into Munster Terrace and Laurens Street, respectively. Conditions along both these streets are unfavourable, experiencing wind speeds of up to 20 m/s in some locations.

Building I1 also encounters corner acceleration on its north-east podium corner driving the accelerated flow down Dryburgh Street, rendering conditions unsafe in this northern end of the street.

The wind conditions on the northern half of Munster Terrace are mostly predicted to remain suitable with localised areas of higher wind speeds. The higher wind speeds are mainly due to corner acceleration. The accelerated flows are quickly dissipated, with the highest predicted wind speeds to be around 14 m/s, but the majority of these streets will experience an average wind speed of around 6 m/s.

Figure 96 to Figure 100 show the conditions predicted for building groups L and M. As it can be appreciated, the wind environment remains a suitable one for pedestrians in this area, except for slightly higher wind speeds taking place, due to corner accelerations, off the middle of Stawell Street. The accelerated wind increases up to a maximum of around 15 m/s and then quickly decelerates before reaching the intersection with Victoria Street.

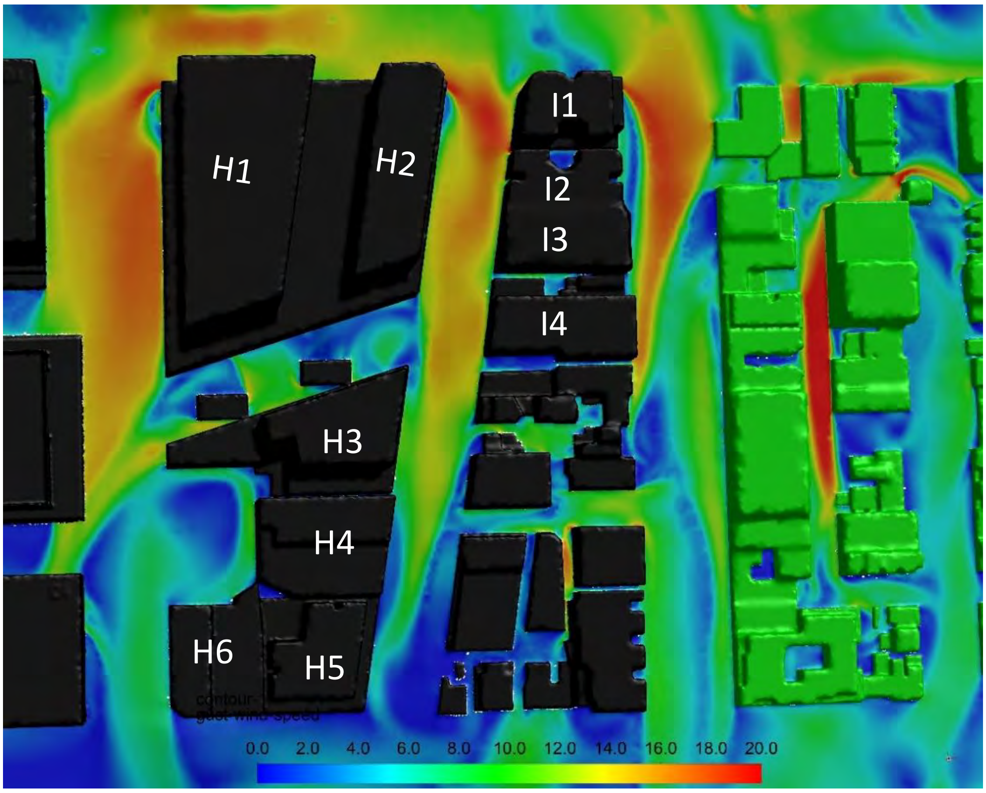


Figure 95: Gust wind velocity contour plot of Groups H & I; North wind

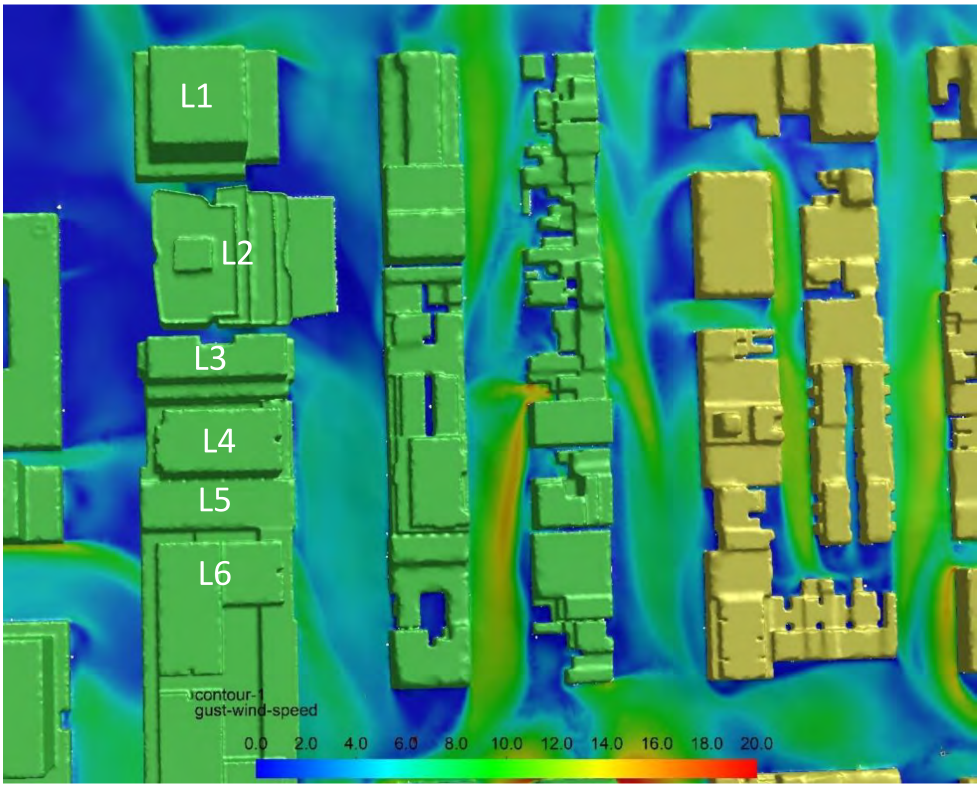


Figure 96: Gust wind velocity contour plot of Groups L & M; North wind

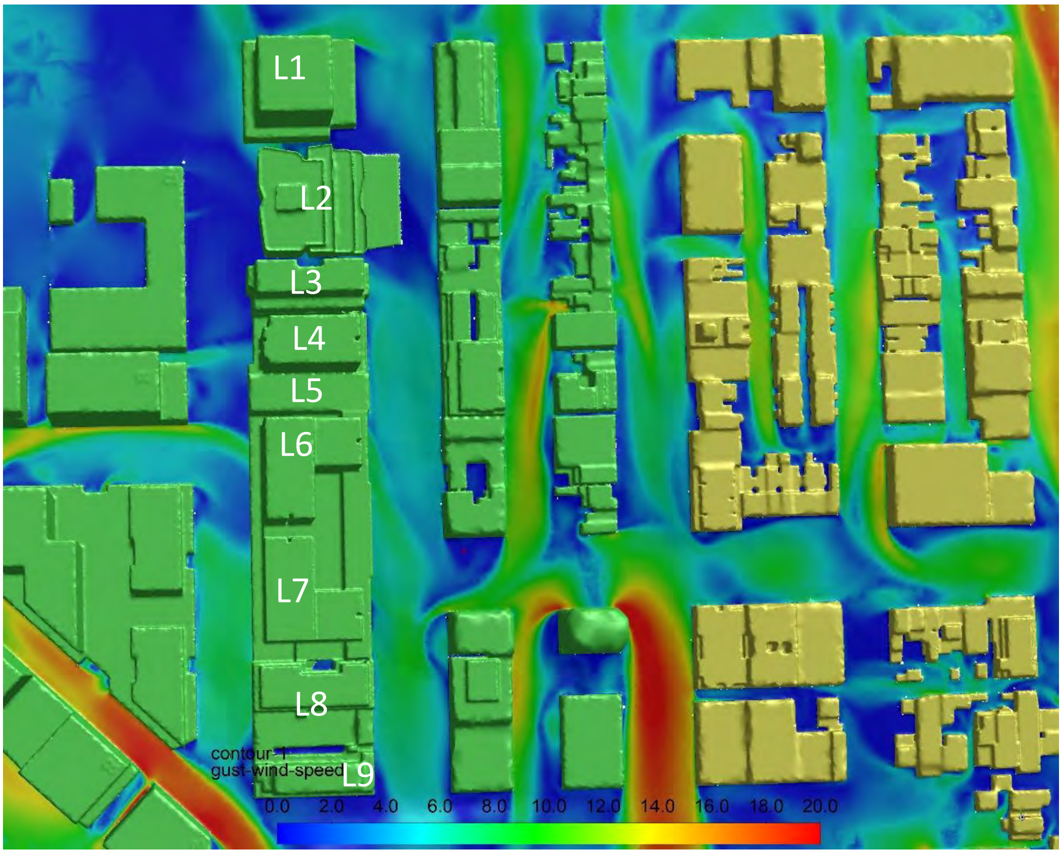


Figure 97: Gust wind velocity contour plot of Groups L & M; North wind

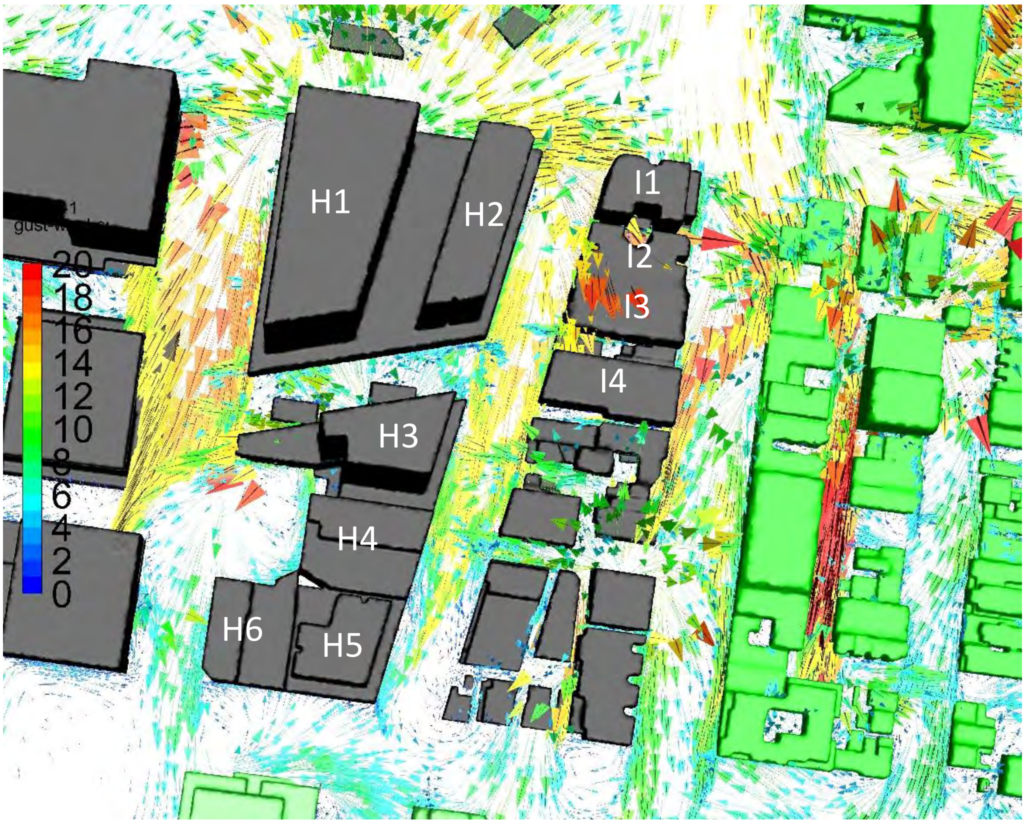


Figure 98: Gust wind velocity vector plot of Groups H & I; North wind

Figure 99: Gust wind velocity vector plot of Groups L & M; North wind

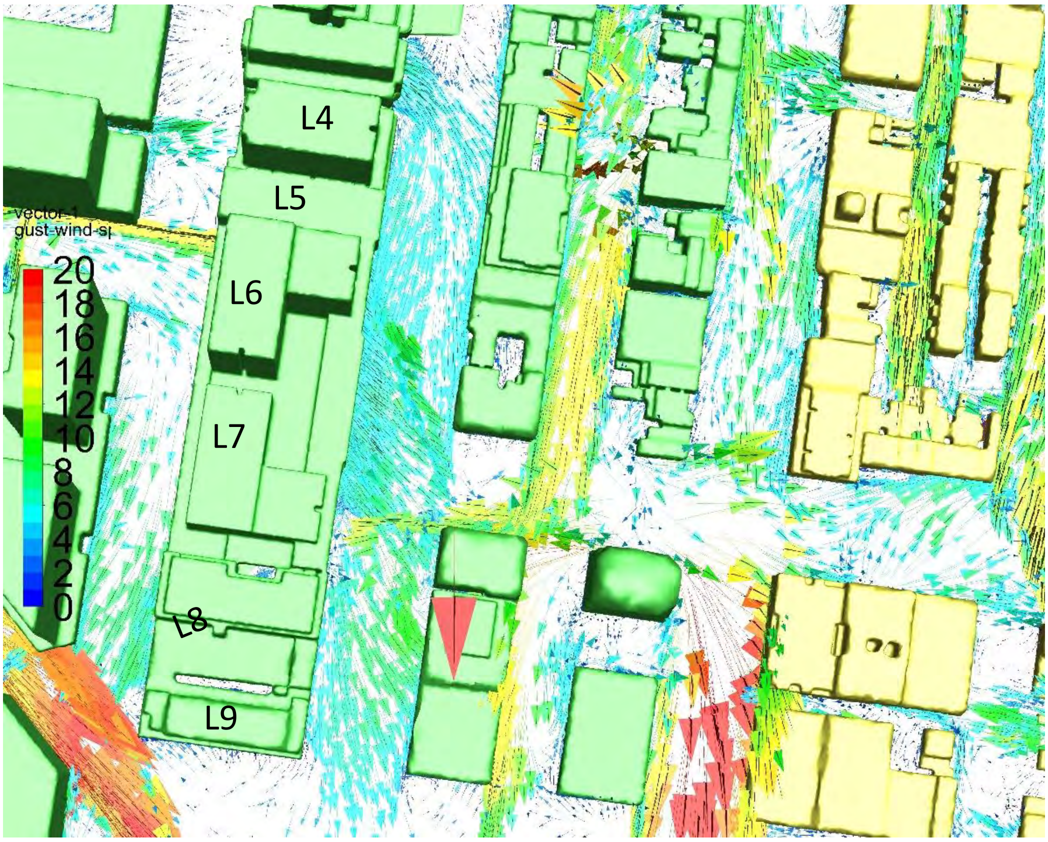


Figure 100: Gust wind velocity vector plot of Groups L & M; North wind

South Wind:

The worst affected locations are Munster Terrace and Dryburgh Streets, as there is a high level of channelling taking place which is further increased by lesser, and yet strong, corner accelerations taking place off buildings at the southern edges from groups L and M; refer to Figure 101. The mid-section of group L; buildings L6, L5 and L4 on Munster Terrace, display the highest wind speeds exceeding 20 m/s. The flow decreases in speed as it reaches the intersection with Queensberry Street and accelerates again before reaching Arden Street, dissipating onto North Melbourne Recreation Reserve.

Laurens Street is subjected to strong winds too, although the conditions are more favourable than Munster Terrace or Dryburgh Street. Figure 103 shows that corner acceleration off the south-east corner of building N7 is driven into Laurens Street, hitting the podium of the buildings on the southern end. Furthermore, accelerated wind flowing through N6 and N7 is further accelerated on the southern corner of N4. This flow is then diverted into two; one is directed towards the eastern side of Laurens Street and joining the high-speed flow, and the other experiences further acceleration and develops on the western side of Laurens Street.

The wind speed on Laurens Street lessens around the intersection with Fogarty Street, before they increase again immediately after due to corner acceleration off the podium corner of building L5; directly opposite Fogarty Street.

Stawell Street remains largely suitable with wind speeds of around 6 m/s and localised corner accelerations taking place. As seen in Figure 101, this phenomenon takes place on the buildings across Victoria Street from group M and dissipates quickly after the intersection. On Dryburgh Street however, this acceleration is later influenced by corner accelerations happening on the eastern side of the street which render the environment between Victoria Street and Queensberry Street, as unfavourable.

At the northern end of Laurens Street and Munster Terrace, conditions worsen with mainly two phenomena combining: channelling and corner accelerations. Figure 102 illustrates the unsafe conditions predicted to arise at these locations and how the wake of the detrimental flows bleeds out onto The North Melbourne Recreation Reserve open area, Macaulay Road and the Gardiner Reserve.

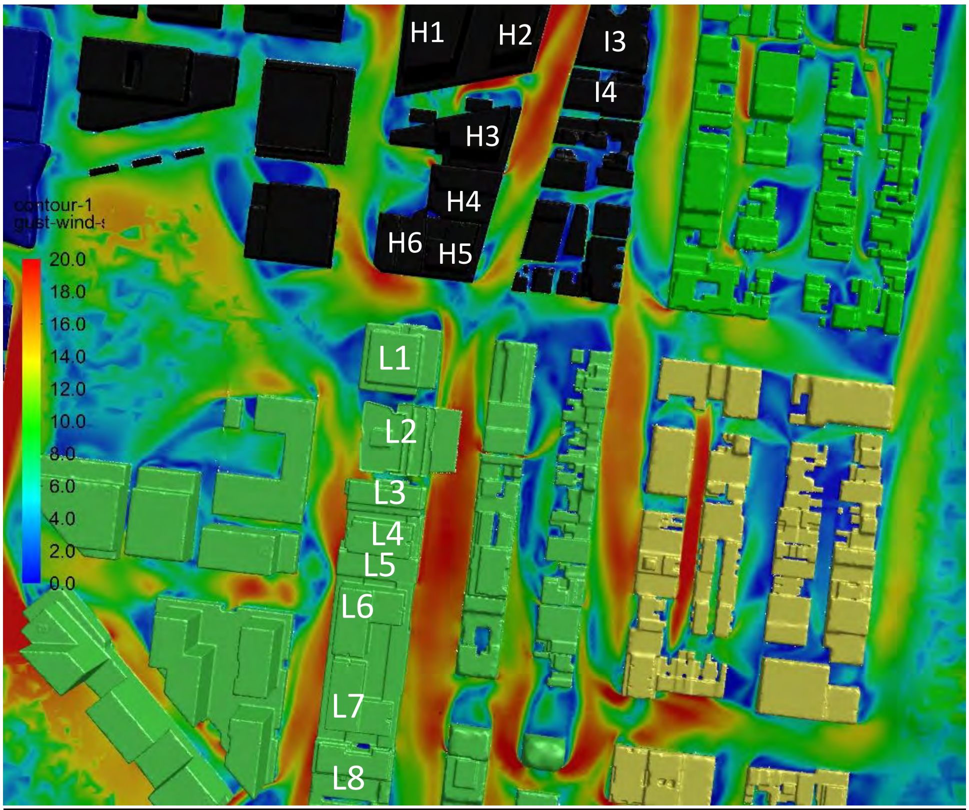


Figure 101: Gust wind velocity contour plot of Groups H, I, L & M; South wind

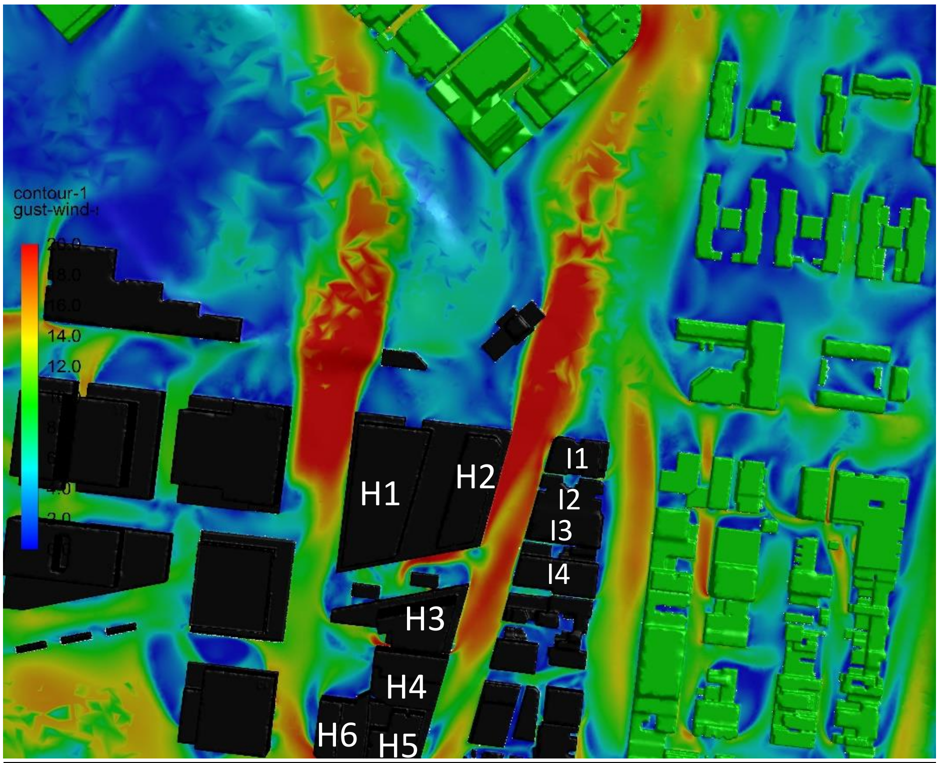


Figure 102: Gust wind velocity contour plot of Groups H, & I; South wind

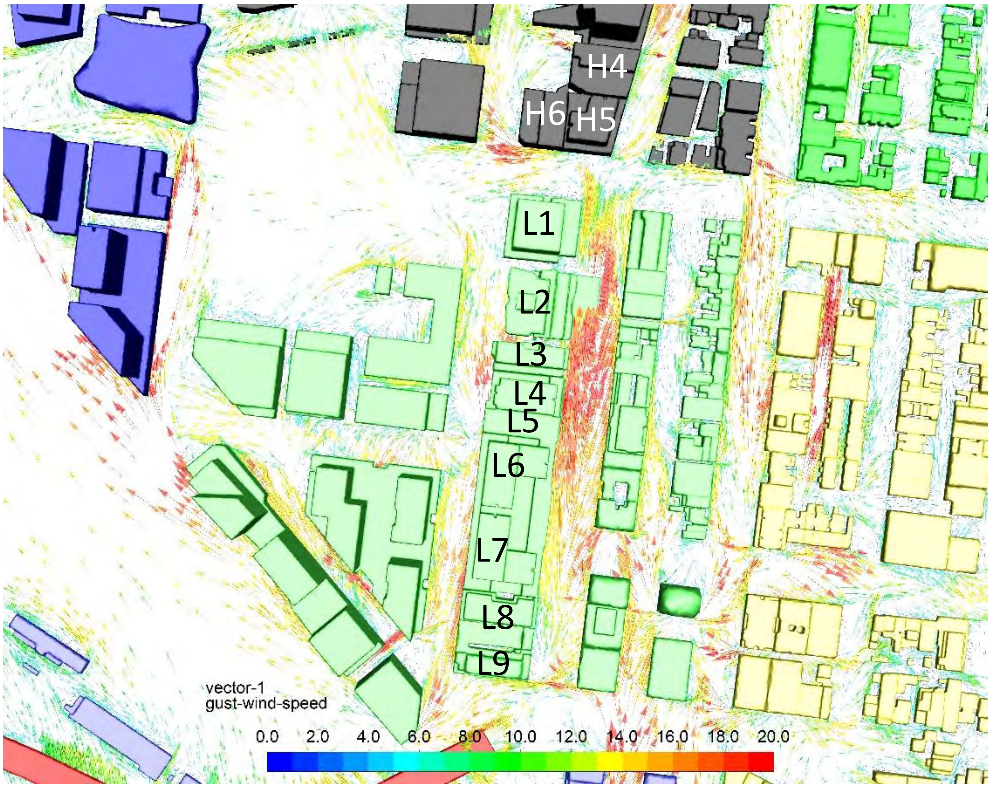


Figure 103: Gust wind velocity vector plot of Groups H, I, L & M; South wind

<u>West Wind:</u>

This wind direction is the third most frequent wind direction in the region, with less than 10% yearly probability of occurrence (refer to Figure 8). Building groups L and M suffer the most severe wind conditions as a result of the flow that develops along Fogarty Street - parallel to the wind direction.

Laurens Street experiences the worst conditions at the intersection with Fogarty Street. The high-speed wind flow of over 20 m/s, is encouraged onto the buildings L6 and L5. The wind then experiences flow separation and retains much of its velocity as it seeps through the spaces between the towers L7, L6, L5 and L4. On Munster Terrace, the accelerated wind flows between L buildings does not coalesce back into one and thus, quickly loses energy as it hits the facades of the buildings fronting Munster Terrace and dissipating onto Victoria Street.

Buildings L3 and L4 create downwash on the incoming high-velocity wind redirected northward from Fogarty Street and is launched against the government school; building K1. The accelerated wind flow quickly decreases speed after K1 and has little effect on the wind environment on the school grounds north of the actual building.

The wind conditions predicted for groups H and I as presented in Figure 105 and Figure 107, show that they are not as susceptible to generating adverse conditions for the western wind as they for the north and south. At the intersections of Laurens Street, Munster Terrace and Dryburgh Street with Arden Street, conditions remain largely adequate with slight corner accelerations taking place at each corner on the Laurens Street side of the podium of tower H1. Group I also displays satisfying conditions for the west wind direction, as appreciated in Figure 105.

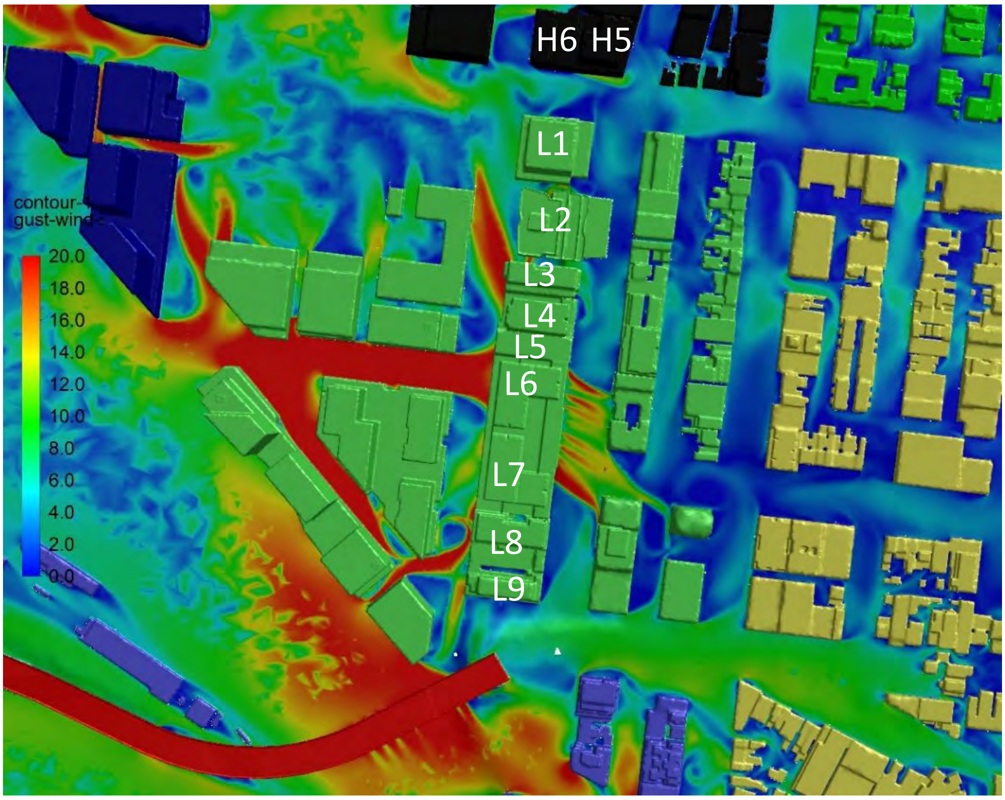


Figure 104: Gust wind velocity contour plot of Groups L & M; West wind

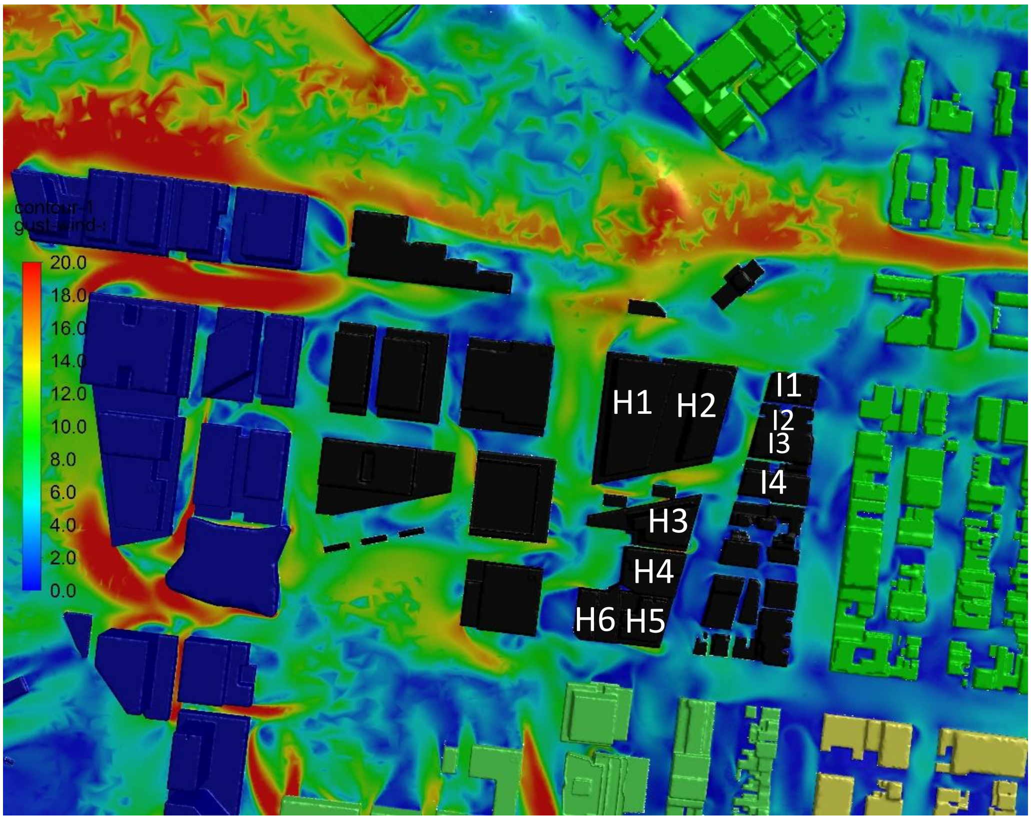


Figure 105: Gust wind velocity contour plot of Groups H & I; West wind

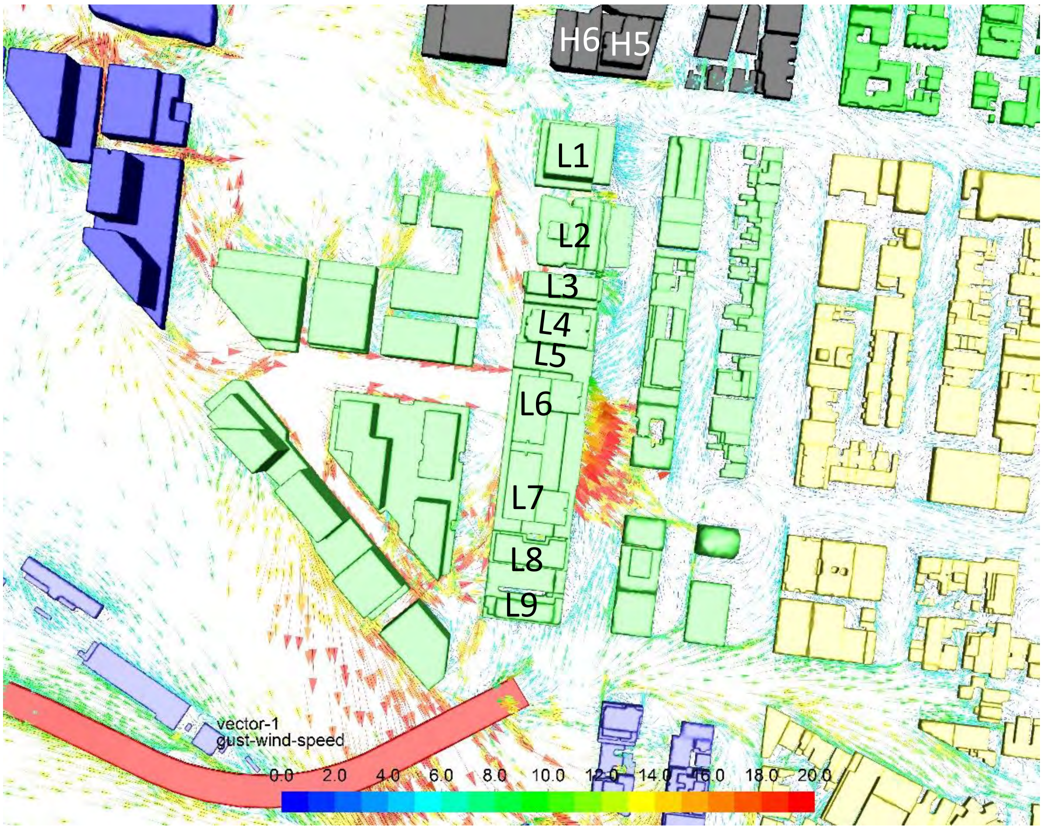


Figure 106: Gust wind velocity vector plot of Groups L & M; West wind

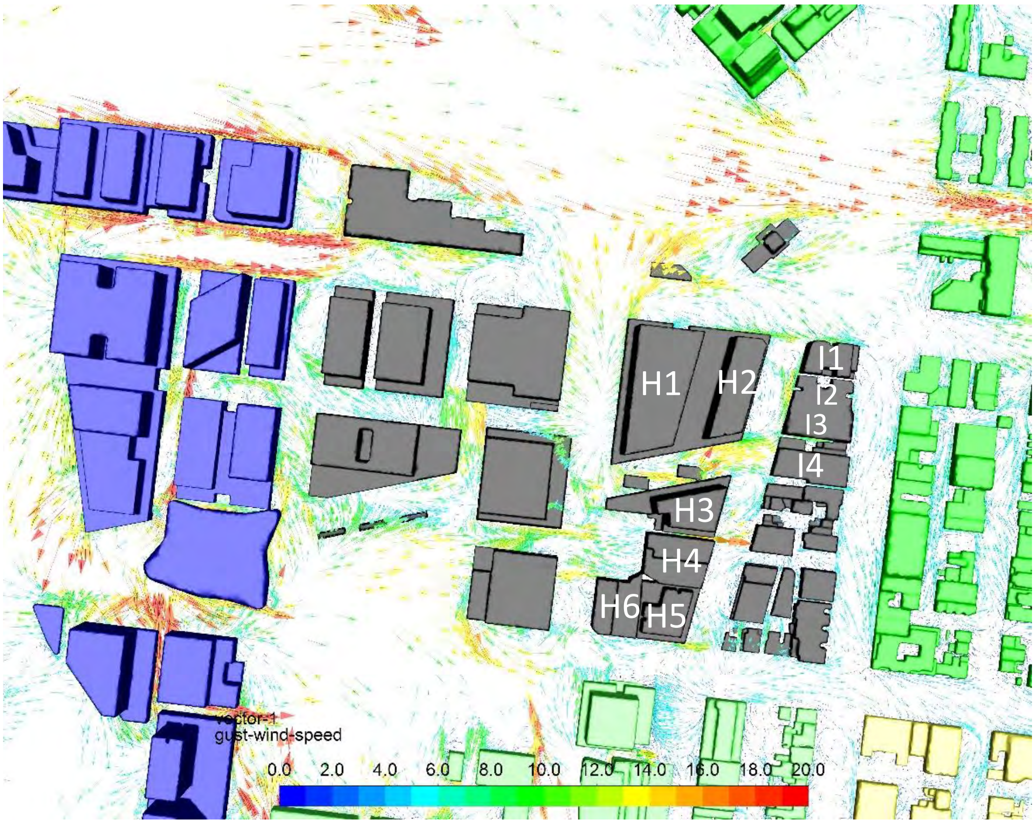


Figure 107: Gust wind velocity vector plot of Groups H & I; West wind

The following can be observed on Laurens Street from the velocity contour and vector plots above:

- **Street Orientation**:

The street orientation in this sub-precinct clearly follows a north to south configuration as displayed by Laurens, Stawell and Dryburgh Streets, and Munster Terrace which its northern end is slightly at an angle towards north-northeast.

The north wind direction generates corner accelerations to take place off H1 and H2 onto Laurens Street and Munster Terrace, and off I1 onto Dryburgh Street with a maximum wind speed of around 18 m/s, as depicted in Figure 95.

Munster Terrace and Laurens Street suffer the most from southerly winds as seen in Figure 102. The initial accelerated flow is a result of corner acceleration at the southern end of these streets, which then develops into channelling flow prior to reaching the intersection with Queensberry Street. Before leaving the sub-precinct, the flow experiences channelling at the northern end, with corner acceleration contributing to increasing the speeds to exceeding 20 m/s. Figure 101 to Figure 103 shows the results predicted for the conditions at this location.

The orientation of the streets within the sub-precinct allows for the southern wind to penetrate the sub-precinct unobstructed up to Queensberry Street. This will ensure proper ventilation and cooling of the area during the summer months, but as appreciated in Figure 103, detrimental conditions are prone to arise along Munster Terrace. However, the simulation did not account for the green civic spines along Munster Terrace which are expected to improve conditions significantly. Stawell Street displays suitable conditions for all wind directions, with only corner acceleration taking place off the building across Victoria Street from group M, which quickly dissipates as it reaches Stawell Street.

For the west wind direction, Munster Terrace experiences elevated wind speeds around buildings L7 to L5. The accelerated wind flow is accelerated through Arden Central and then hits the western façade of L group buildings, seeping through the structures and onto Munster Terrace. Figure 104 and Figure 106 presents the predicted conditions at this location. Figure 105 and Figure 107 shows that conditions remain suitable at all other locations within the sub-precinct.

- **Building Orientation:**

Groups L and M follow a north to south and east to west orientation. Groups H and I display a similar trend except for H2, H3, and H5 which are slightly at an angle compared to the rest of the buildings in the sub-precinct.

- **Building Orientation (Natural Ventilation):**

The orientation of the buildings is well-suited to promote natural ventilation. This is a result of the progressive height increase from south to north.