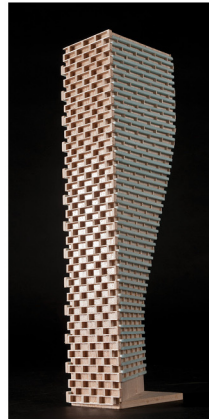# GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

1357 Baseline Road
Ottawa, Ontario

Report: 19-141-PLW

November 21, 2019

PREPARED FOR

Selection Group International Inc.
2400 Boulevard Daniel-Johnson
Laval, QC H7T 3A4

PREPARED BY

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy site plan control application requirements for a proposed development located at 1357 Baseline Road in Ottawa, Ontario (hereinafter referred to as "subject site"). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where necessary.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings provided by ACDF Architecture in November 2019, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery via Google Earth Pro and the Copernicus Open Access Hub.

A complete summary of the predicted wind comfort and safety conditions at grade level and within the amenity terraces is provided in Section 5 of this report and illustrated in Figures 3A-6B, and Figures 7A-7D (following the main text). The results and recommendations are summarized as follows:

1) Wind comfort conditions within and surrounding the subject site at grade level are predicted to be mostly calm and acceptable for all anticipated uses throughout the year. Of importance, primary building entrances are predicted to be suitable for standing or better throughout the year. Additionally, while wind channelling is predicted to impact the laneway along the north side of the subject site, conditions are predicted to be suitable for strolling, or better, throughout the year. The noted conditions are considered acceptable for the anticipated uses of the areas.

2) Regarding the amenity terraces, wind conditions are predicted to be mostly calm and acceptable during the typical use period of late spring through early autumn, as described in Section 5.

3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas surrounding the subject site at grade level were found to experience conditions that are classified as uncomfortable or dangerous.

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TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Selection Group International Inc. to undertake a pedestrian level wind (PLW) study to satisfy site plan control application requirements for a proposed development located at 1357 Baseline Road in Ottawa, Ontario (hereinafter referred to as "subject site"). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where necessary.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings provided by ACDF Architecture in November 2019, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery via Google Earth Pro and the Copernicus Open Access Hub.

2. TERMS OF REFERENCE

The subject site is located at 1357 Baseline Road in Ottawa, Ontario and is situated on the north corner at the intersection of Baseline Road and Clyde Avenue. The proposed development comprises two 15-storey buildings. On the west side of the development, the Fridom Residence building rises approximately 52 meters (m) to the top of its mechanical penthouse, while on the east side the Signature Senior Residence building rises 49 m to the top of its mechanical penthouse. The buildings are connected by a stepped podium of one-storey on the south side and five storeys on the north side.

The development includes parking at grade and on three levels below grade. The ground floor plan of the development includes retail, lobby, and office spaces, as well as an indoor amenity space that leads to an outdoor amenity area on the west side of the Fridom Residence building. Level 2 of the Signature Senior Residence building comprises various indoor amenities. The remaining floors contain residential space. The floorplate steps back on the south side at Level 2 to create a horseshoe building planform and an outdoor amenity area on the roof of the 1-storey podium. The two buildings share a 5-storey podium at the north end and rise independently from Levels 6-15.
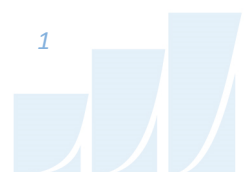
Public spaces are included at grade level around the full perimeter of the subject site with amenity terraces on the west side and southwest corner of the site. The lower podium includes a large public outdoor terrace, which is mostly situated between the two buildings but also extends around the south side of the Signature Senior Residence building. The main entrances to the Fridom Residence building, Health Centre, and Signature Senior Residence building are situated on the north side, while retail entrances are located on the south side fronting Baseline Road.

Regarding wind exposures, the near-field surroundings of the subject site (defined as an area falling within a 500-m radius of the site) will experience urban wind exposures from the west clockwise to the northwest of the site due to the presence of the High-Rise Manor complex, a mix of open and suburban wind exposures from the north clockwise to the south, and predominantly suburban exposures for the remaining compass directions. The far-field surroundings (defined as the area beyond the near field and within a five kilometer (km) radius) are characterized by a mix of open and suburban wind exposures. From the northwest clockwise to north, the terrain is primarily suburban, while the presence of isolated tall buildings (1205-1305 Baseline Road) produce an urban exposure that acts to decrease the mean wind, while the presence of the Ottawa River produces an open exposure within this area that acts to increase the mean wind while decreasing turbulence intensity. From the northeast clockwise to east, the terrain is predominantly suburban, although the presence of Dow's Lake and the Ottawa Experimental Farm contribute an open exposure within this quadrant, resulting in a mixed open-suburban exposure. The remaining compass directions produce suburban exposures, with isolated open areas that increase the mean wind. Figure 1 illustrates the subject site and surrounding context, while Figures 2A-2D illustrate the computational model used to conduct the study.

3.   OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind comfort and safety conditions at key areas within and surrounding the subject site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the subject site is based on CFD simulations of wind speeds across the subject site and its surroundings within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with City of Ottawa wind comfort and safety criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

4.1   Computer-Based Context Modelling

A computer-based PLW study was performed to determine the influence of the wind environment on pedestrian comfort over the proposed development site. Pedestrian comfort predictions, based on the mechanical effects of wind, were determined by combining measured wind speed data from CFD simulations with statistical weather data obtained for Ottawa Macdonald-Cartier International Airport.

The general concept and approach to CFD modelling is to represent building and topographic details in the immediate vicinity of the study site on the surrounding model, and to create suitable atmospheric wind profiles at the model boundary. The wind profiles are designed to have similar mean and turbulent wind properties consistent with actual site exposures.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative (i.e., windier) wind speed values.

4.2   Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 1,040 m.

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[1] City of Ottawa Terms of References: Wind Analysis
https://documents.ottawa.ca/sites/default/files/torwindanalysis_en.pdf

Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade, and 1.5 m above the various amenity terraces, were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. The gradient height represents the theoretical depth of the boundary layer of the earth's atmosphere, above which the mean wind speed remains constant. Appendices A and B provide greater detail of the theory behind wind speed measurements.

4.3 Meteorological Data Analysis

A statistical model for winds in Ottawa was developed from approximately 40 years of hourly meteorological wind data recorded at Ottawa Macdonald-Cartier International Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were analyzed for each month of the year in order to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns. Based on this portion of analysis, the four seasons are represented by grouping data from consecutive months based on similarity of weather patterns, and not according to the traditional calendar method. Summer is defined as June-September, autumn as October and November, winter as December-March, and spring as April and May.

The statistical model of the Ottawa area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate the seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Ottawa, the most common winds occur for westerly wind directions, followed by those from the east, while the most common wind speeds are below 36 km/h. The directional preference and relative magnitude of wind speed changes somewhat from season to season.
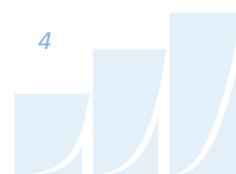
SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS DIRECTIONS
OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT
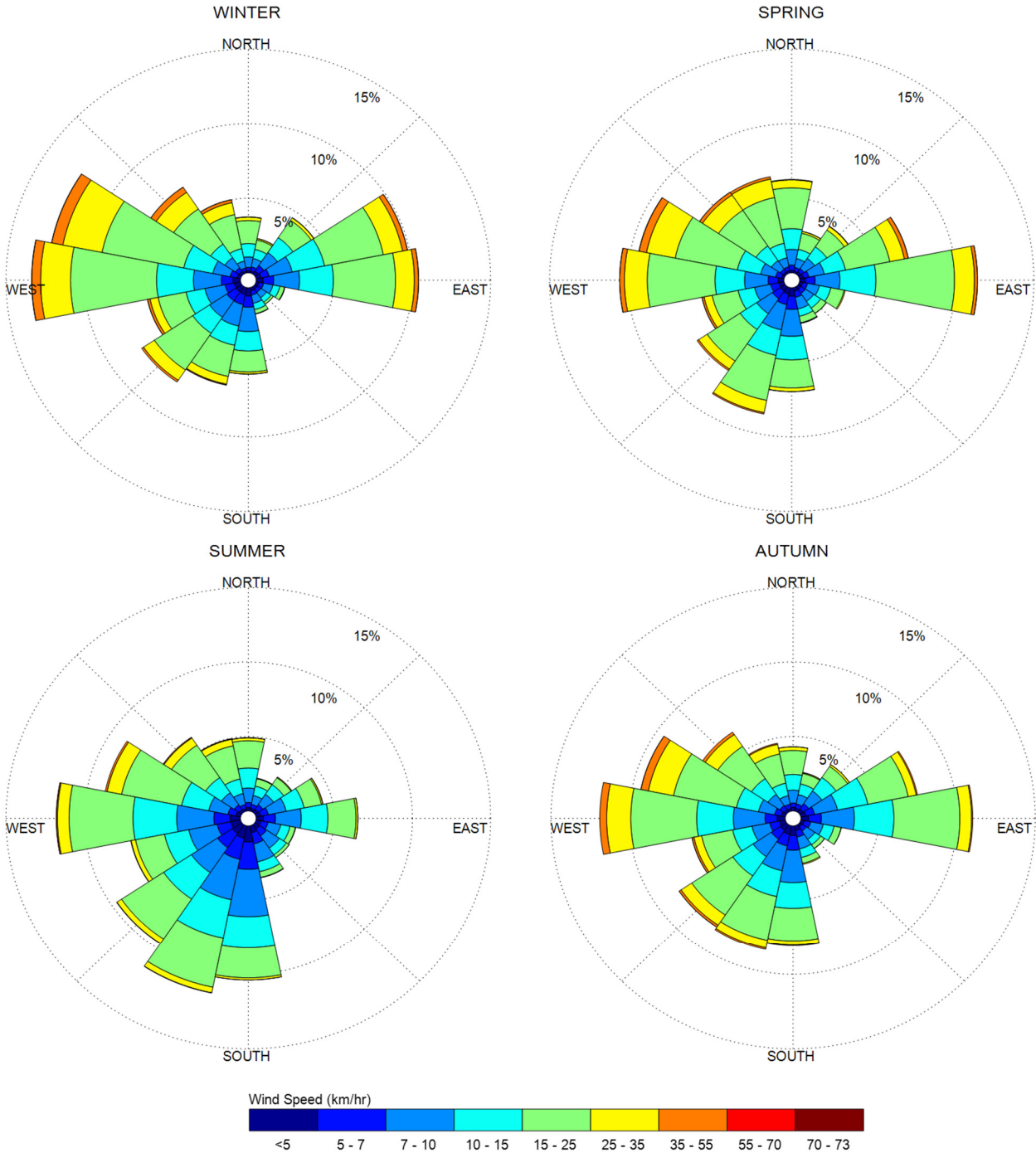
Notes:
1. Radial distances indicate percentage of time of wind events.
2. Wind speeds are mean hourly in km/h, measured at 10 m above the ground.

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1357 BASELINE ROAD, OTTAWA: PEDESTRIAN LEVEL WIND STUDY

4.4   Pedestrian Comfort and Safety Criteria – City of Ottawa

Pedestrian comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 80% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

1)   **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 16 km/h.

2)   **Standing:** Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 22 km/h.

3)   **Strolling:** Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 27 km/h.

4)   **Walking:** Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 32 km/h.

5)   **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

The pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. The gust speeds, and equivalent mean speeds, are selected based on 'The Beaufort Scale', presented on the following page, which describes the effects of forces produced by varying wind speed levels on objects. Gust speeds are included because pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians. The mean gust speed ranges are selected based on 'The Beaufort Scale', which describes the effect of forces produced by varying wind speeds on levels on objects.

THE BEAUFORT SCALE

Number	Description	Wind Speed (km/h)	Description
2	Light Breeze	6-11	Wind felt on faces
3	Gentle Breeze	12-19	Leaves and small twigs in constant motion; Wind extends light flags
4	Moderate Breeze	20-28	Wind raises dust and loose paper; Small branches are moved
5	Fresh Breeze	29-38	Small trees in leaf begin to sway
6	Strong Breeze	39-49	Large branches in motion; Whistling heard in electrical wires; Umbrellas used with difficulty
7	Moderate Gale	50-61	Whole trees in motion; Inconvenient walking against wind
8	Gale	62-74	Breaks twigs off trees; Generally impedes progress

Experience and research on people's perception of mechanical wind effects has shown that if the wind speed levels are exceeded for more than 80% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if a mean wind speed of 10 km/h (gust equivalent mean wind speed of 16 km/h) was exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if mean wind speed of 20 km/h (gust equivalent mean wind speed of 32 km/h) at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established at tested locations, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type represented by the sensor (i.e., a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Major Building Entrances	Standing
Secondary Building Access Points	Walking
Primary Public Sidewalks	Strolling
Secondary Public Sidewalks / Bicycle Paths	Walking
Outdoor Amenity Spaces	Sitting / Standing / Strolling
Cafés / Patios / Benches / Gardens	Sitting
Transit Shelters	Standing
Public Parks / Plazas	Standing / Strolling
Garage / Service Entrances	Walking
Parking Lots	Strolling / Walking
Vehicular Drop-Off Zones	Standing / Strolling / Walking

5.   RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-6B (following the main text) illustrating the seasonal wind conditions at grade level and within the common amenity terraces at grade level and Level 2. The colour contours indicate various comfort classes predicted for certain regions. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, and conditions suitable for walking are represented by blue. The colour magenta represents wind conditions considered uncomfortable for walking. In addition to the standard wind comfort class results, Figures 7A-7D illustrate the percentage of time the amenity terraces will be suitable for sitting on a seasonal basis. Pedestrian wind comfort is summarized below for each seasonal period.

5.1   Wind Comfort Conditions – Grade level

Following the introduction of the subject site, wind conditions at grade level within and surrounding the site are predicted to be moderately calm during the summer season and moderately windy throughout the remaining colder seasons.

- Spring Season: Wind conditions are predicted to be suitable for a mix of sitting and standing around most of the site. Conditions to the north of the site are predicted to be suitable for a mix of standing and strolling (Figure 3A).

- Summer Season   Wind conditions are predicted to be suitable for sitting over most areas, while conditions to the north of the site are predicted to be mostly suitable for standing (Figure 4A).

- Autumn Season   Conditions are similar to those predicted during the spring season, but somewhat calmer (Figure 5A).

- Winter Season   Conditions are similar to those predicted during the spring season, but moderately windier (Figure 6A).

Wind speeds are predicted to satisfy the strolling comfort class, or better, over all pedestrian areas, which is acceptable. Primary building entrances are predicted to be suitable for standing or better throughout the year. While wind channelling is predicted to impact the laneway area along the north side of the subject site, pedestrian wind comfort is predicted to be suitable for strolling, or better, throughout the year, which is acceptable.

5.2   Wind Comfort Conditions – West Grade Level Amenity Terrace

Wind conditions within the amenity terrace situated on the west side of the study site at grade level are predicted to be calm and acceptable for sitting during the spring, summer, and autumn seasons. During the winter season, conditions are predicted to be mostly suitable for sitting with the southwest corner of the terrace becoming suitable for standing (Figure 6B). Figure 7D indicates that this terrace will be suitable for sitting for at least 75% of the time during the winter season without mitigation.

## 5.3 Wind Comfort Conditions – Southwest Grade Level Amenity Terrace

The following discussion is focused on wind conditions within the terrace situated on the southwest corner of the study site; pedestrian wind comfort is summarized below for each seasonal period.

- Spring Season: Conditions are predicted to be mostly suitable for sitting, with isolated regions suitable for standing near the west side and southwest corner of the terrace (3B). Additionally, Figure 7A indicates that the entire terrace will be suitable for sitting for at least 70% of the time during the spring season without mitigation.

- Summer Season Conditions are predicted to be suitable for sitting (Figure 4B).

- Autumn Season Conditions are predicted to be suitable for sitting (Figure 5B).

- Winter Season Conditions are similar to those predicted during the spring season (Figure 6B). Additionally, Figure 7D indicates that the entire terrace will be suitable for sitting for at least 70% of the time during the winter season without mitigation.

Conditions within the southwest amenity terrace are suitable for the anticipated uses during the typical use period of late spring through early autumn without mitigation.

5.4   Wind Comfort Conditions – Level 2 Amenity Terrace

The following discussion is focused on wind conditions within the Level 2 amenity terrace; pedestrian wind comfort is summarized below for each seasonal period. Based on the architectural drawings provided at the time of the study, perimeter guardrails were not modelled. The introduction of guardrails along the exposed perimeter of the terrace would result in calmer wind conditions within the main roof area.

- Spring Season: Conditions are predicted to be mostly suitable for sitting, with a region suitable for standing on the south side of the terrace. The main roof area between the two buildings is suitable for sitting (Figure 3B). Figure 7A indicates this terrace is suitable for sitting for at least 70% of the time, with isolated regions suitable for sitting for at least 60% of the time near the south and southeast corners of the terrace during the spring season.

- Summer Season   Conditions are predicted to be suitable for sitting (Figure 4B).

- Autumn Season   Conditions are similar to those predicted during the spring season, but moderately calmer (Figure 5B). Figure 7C indicates that most of this terrace will be suitable for sitting for at least 75% of the time.

- Winter Season   Conditions are similar to those predicted during the spring season, as illustrated in Figure 6B. Figure 7D indicates that most of the terrace will also be suitable for sitting for at least 70% of the time.

Conditions within the Level 2 amenity terrace are suitable for the anticipated uses during the typical use period of late spring through early autumn without mitigation. The introduction of standard-height guardrails along the exposed perimeter is expected to further improve wind conditions, particularly within the windier areas near the southern edge of the terrace.
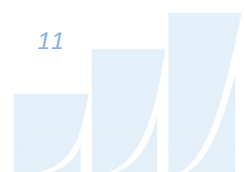
5.5   Wind Comfort Conditions – Surrounding Area Beyond the Subject Site

Wind conditions over surrounding sidewalks beyond the development site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the study site. Future changes (i.e., construction or demolition) of these surroundings may cause changes to the wind effects in two ways, namely: (i) changes beyond the immediate vicinity of the site would alter the wind profile approaching the site; and (ii) development in proximity to the site would cause changes to local flow patterns. More specifically, development in urban centers generally creates reduction in the mean wind and localized increases in the gustiness of the wind.

6.   SUMMARY

A complete summary of the predicted wind comfort and safety conditions at grade level and within the amenity terraces is provided in Section 5 of this report and illustrated in Figures 3A-6B, and Figures 7A-7D (following the main text). Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with similar developments in Ottawa, we conclude the following:

4)   Wind comfort conditions within and surrounding the subject site at grade level are predicted to be mostly calm and acceptable for all anticipated uses throughout the year. Of importance, primary building entrances are predicted to be suitable for standing or better throughout the year. Additionally, while wind channelling is predicted to impact the laneway along the north side of the subject site, conditions are predicted to be suitable for strolling, or better, throughout the year. The noted conditions are considered acceptable for the anticipated uses of the areas.

5)   Regarding the amenity terraces, wind conditions are predicted to be mostly calm and acceptable during the typical use period of late spring through early autumn, as described in Section 5.

6)   Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas surrounding the subject site at grade level were found to experience conditions that are classified as uncomfortable or dangerous.
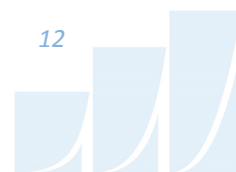
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This concludes our pedestrian level wind study and report. Please advise the undersigned of any questions or comments.

Sincerely,

Gradient Wind Engineering Inc.
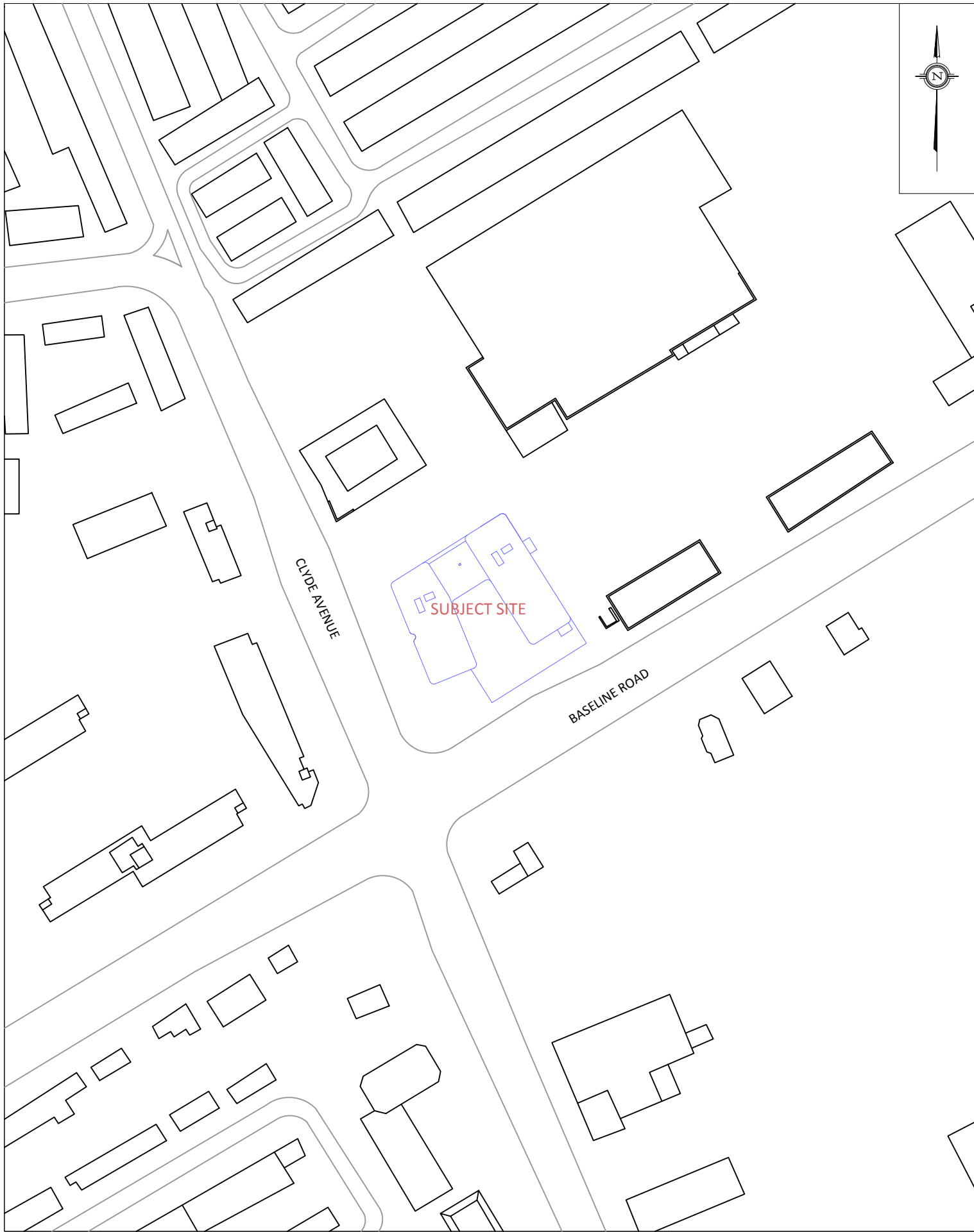
Edward Urbanski, M.Eng.
Junior Wind Scientist

Justin Ferraro, P.Eng.
Principal

Sacha Ruzzante, MASc.
Junior Wind Scientist

Gradient Wind File #19-141

CLYDE AVENUE

SUBJECT SITE

BASELINE ROAD

N

PROJECT	1357 BASELINE ROAD, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION	
SCALE	1:2500 (APPROX.)	DRAWING NO. 19-141-1		FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
DATE	NOVEMBER 21, 2019	DRAWN BY R.R.		
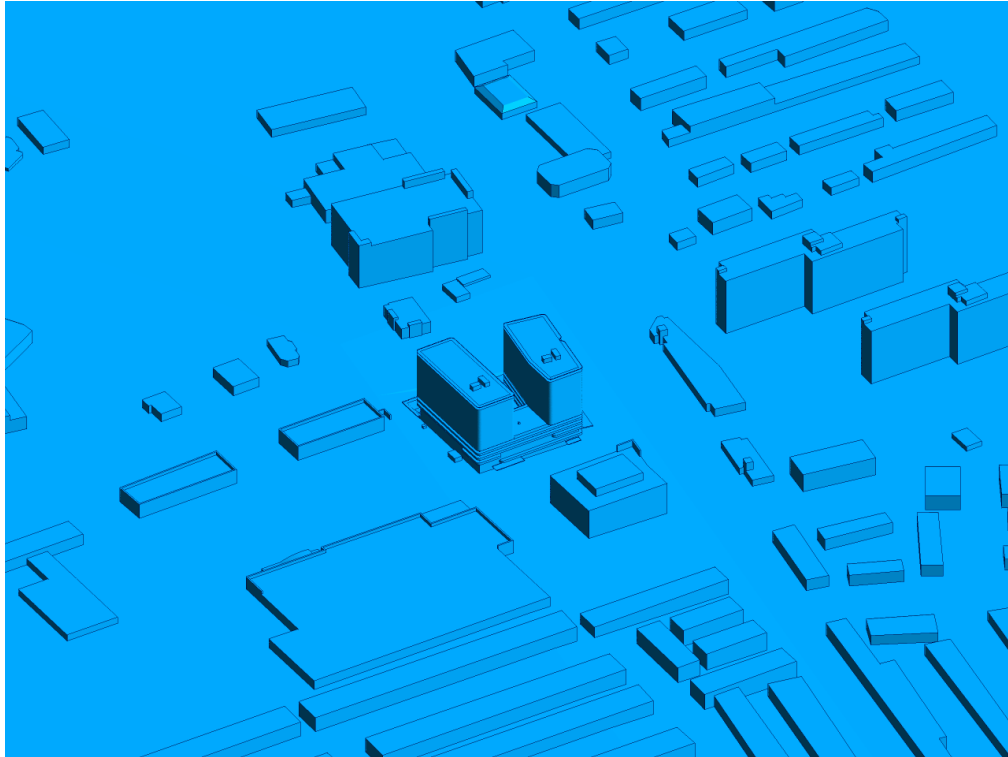
FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

FRIDOM
RESIDENCE

SIGNATURE
SENIOR
RESIDENCE
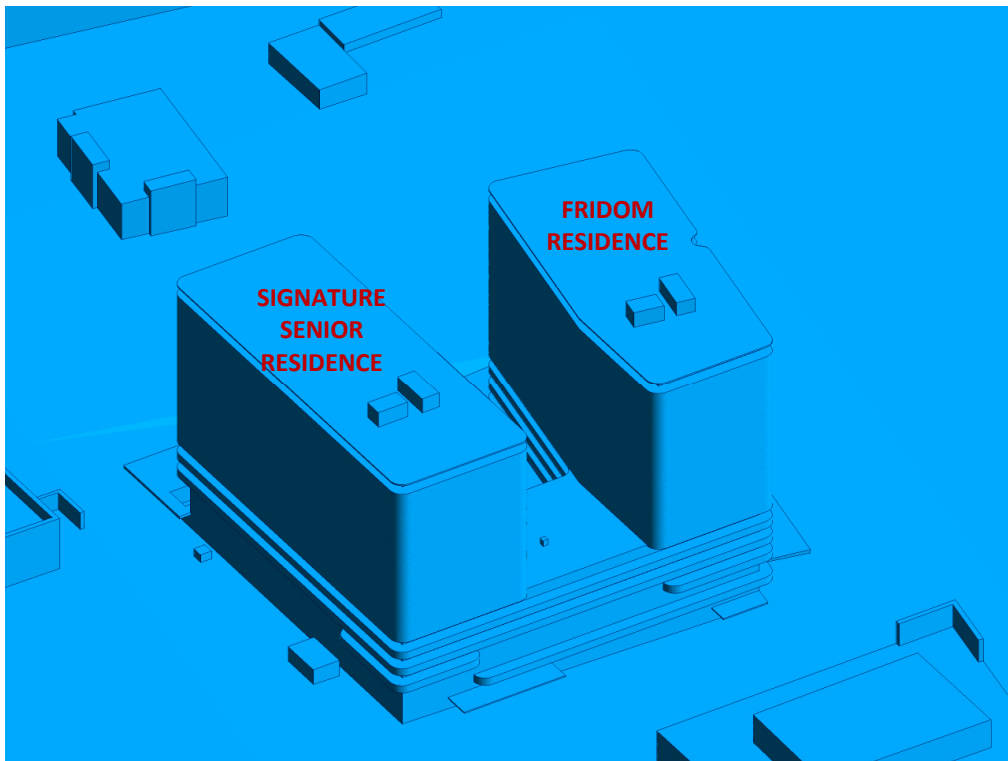
FIGURE 2B: CLOSE UP OF FIGURE 2A
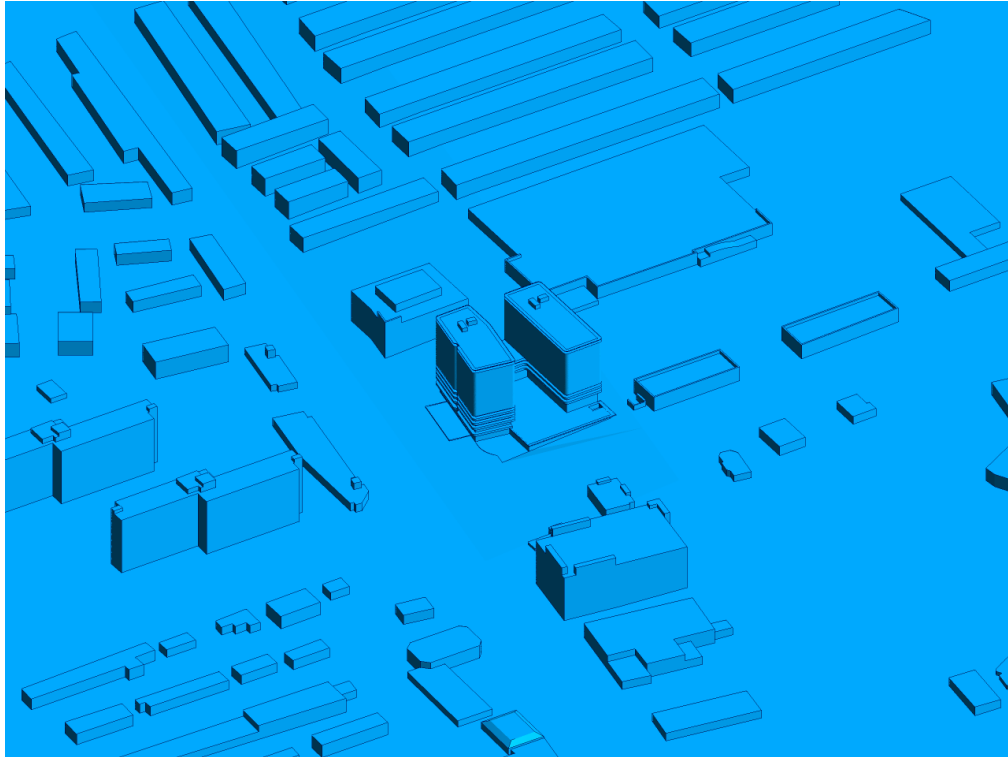
FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

SIGNATURE
SENIOR
RESIDENCE

FRIDOM
RESIDENCE
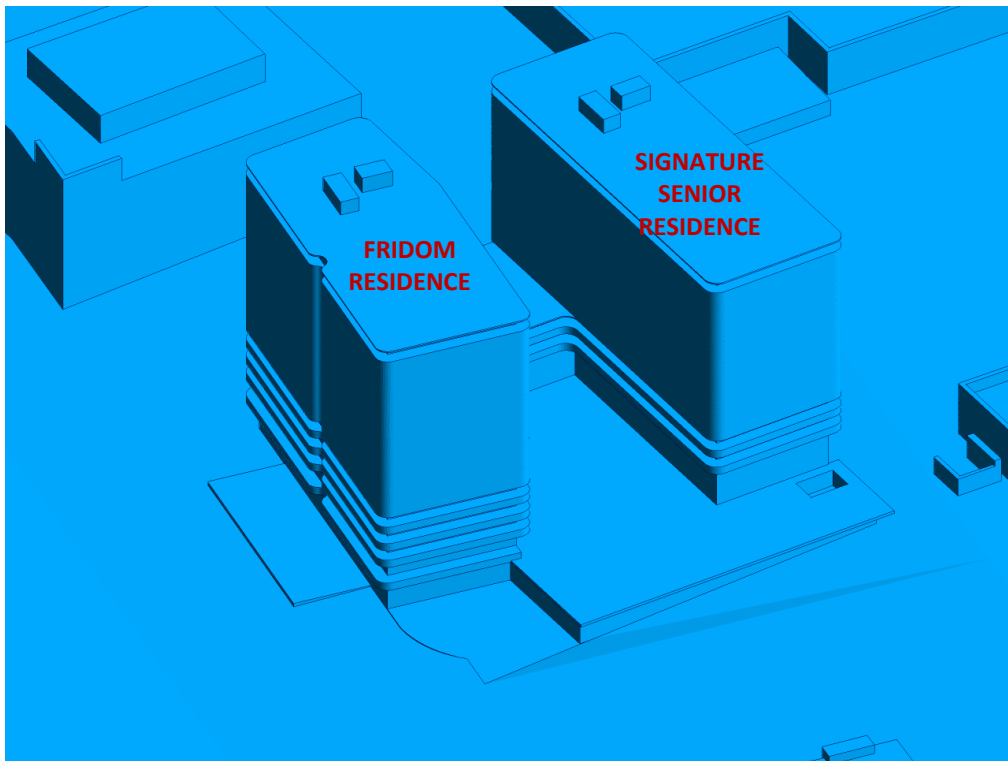
FIGURE 2D: CLOSE UP OF FIGURE 2C

GREEN – SITTING
YELLOW – STANDING
ORANGE – STROLLING
BLUE – WALKING
MAGENTA – UNCOMFORTABLE
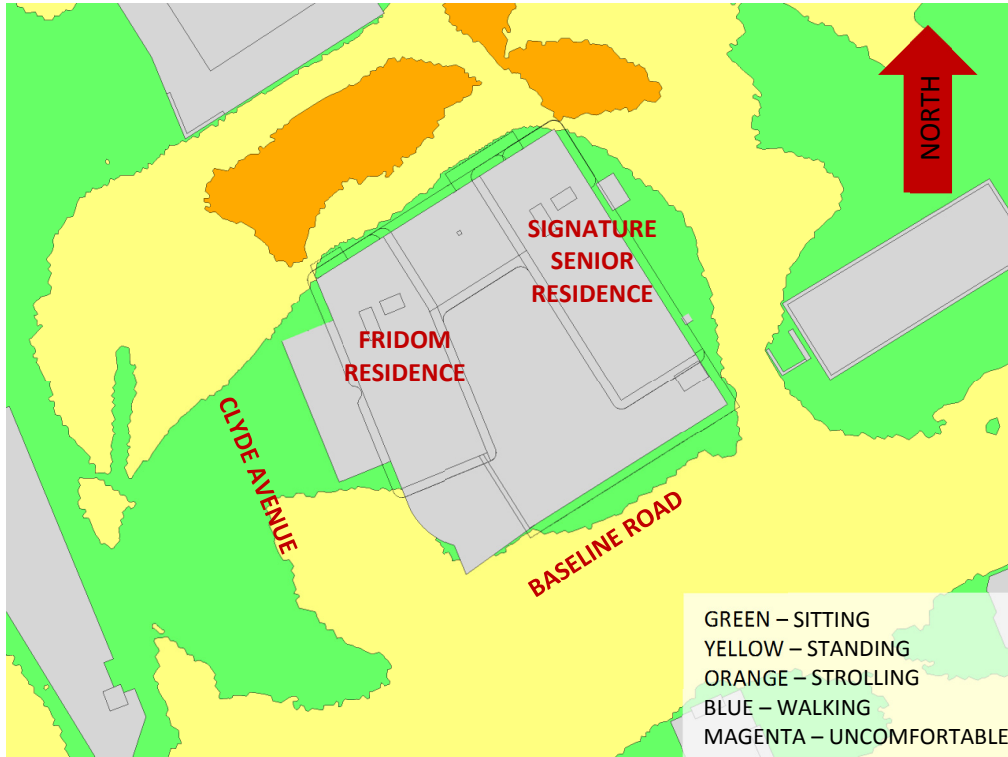
FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

GREEN – SITTING
YELLOW – STANDING
ORANGE – STROLLING
BLUE – WALKING
MAGENTA – UNCOMFORTABLE
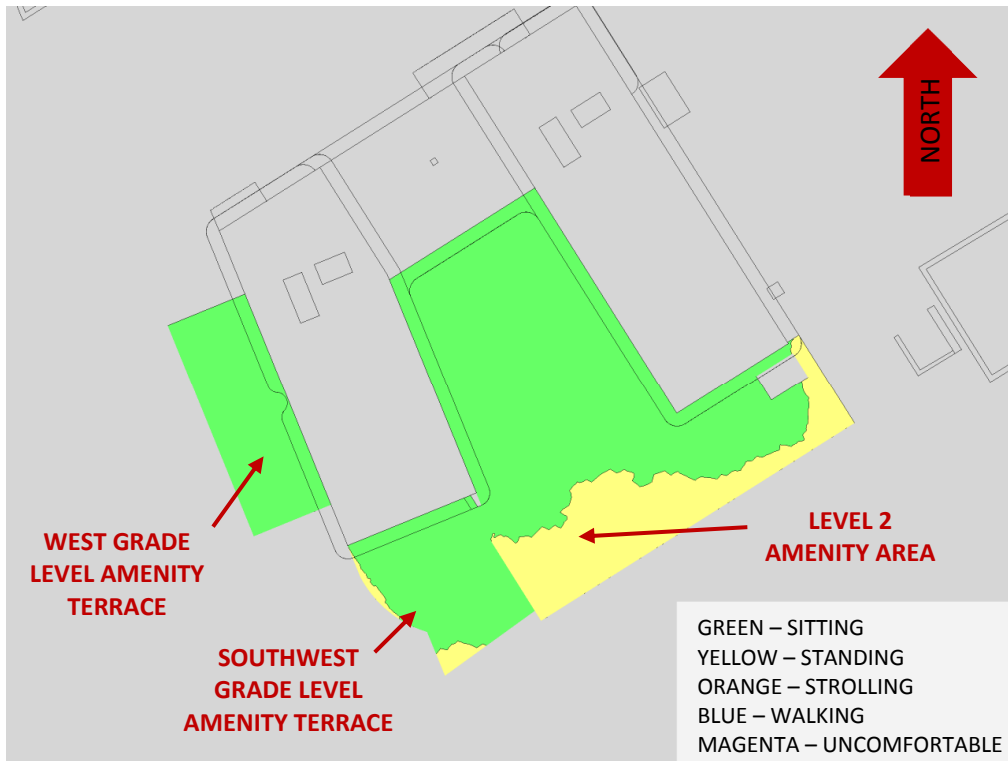
FIGURE 3B: SPRING – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES
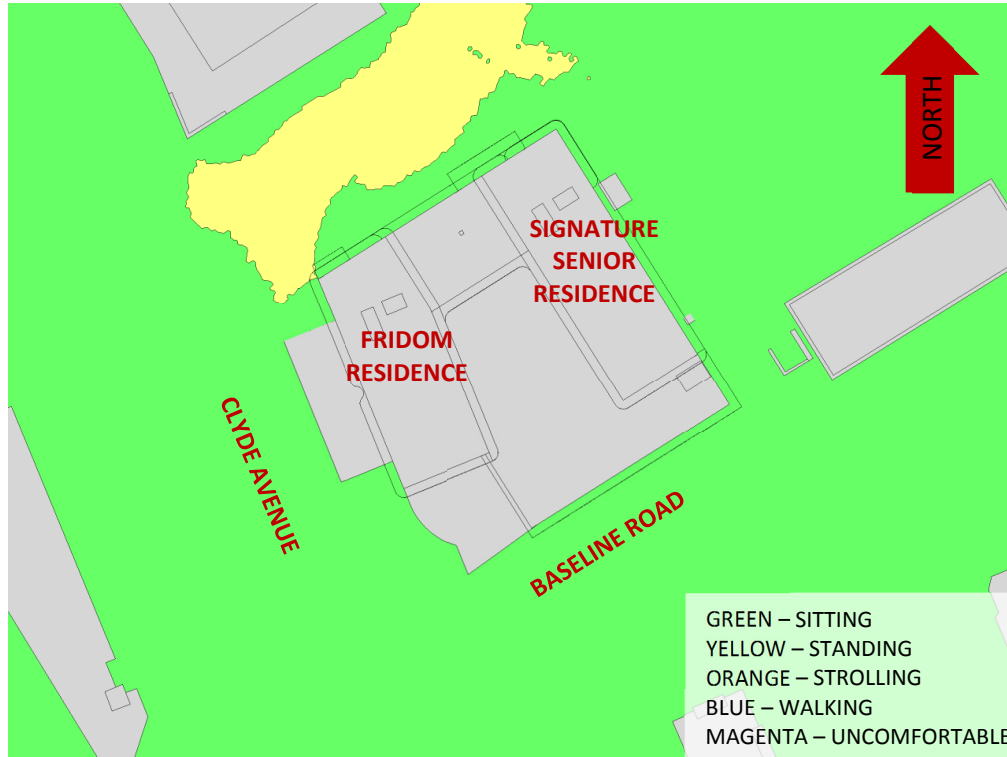
FIGURE 4A: SUMMER – WIND CONDITIONS AT GRADE LEVEL

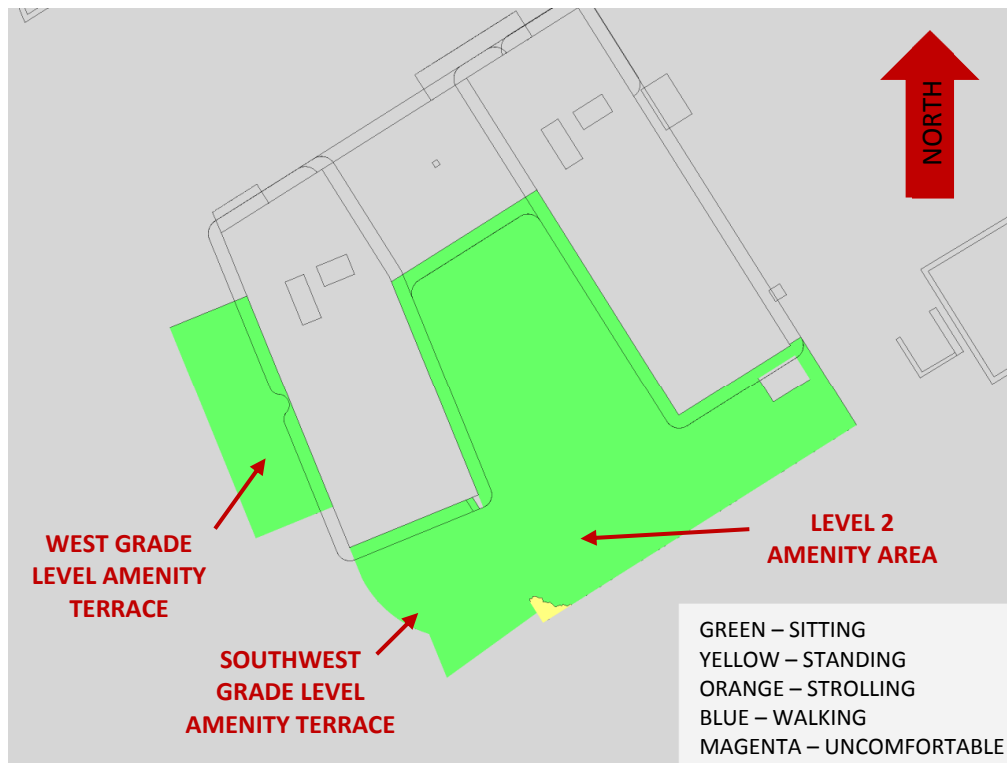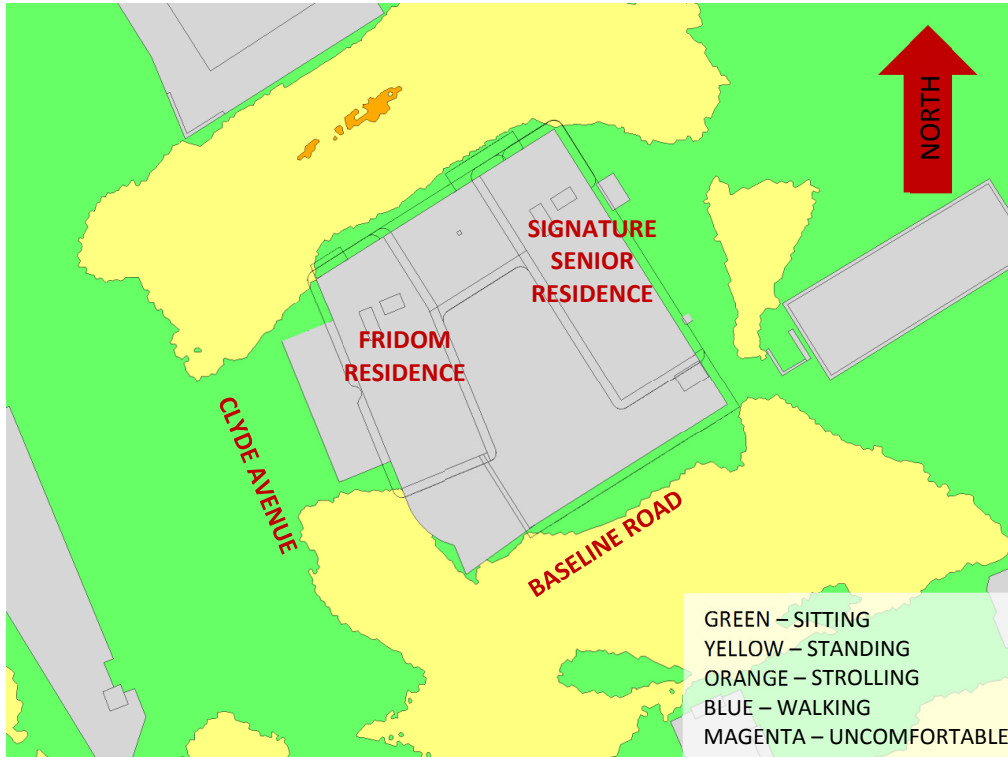**FIGURE 4B: SUMMER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES**

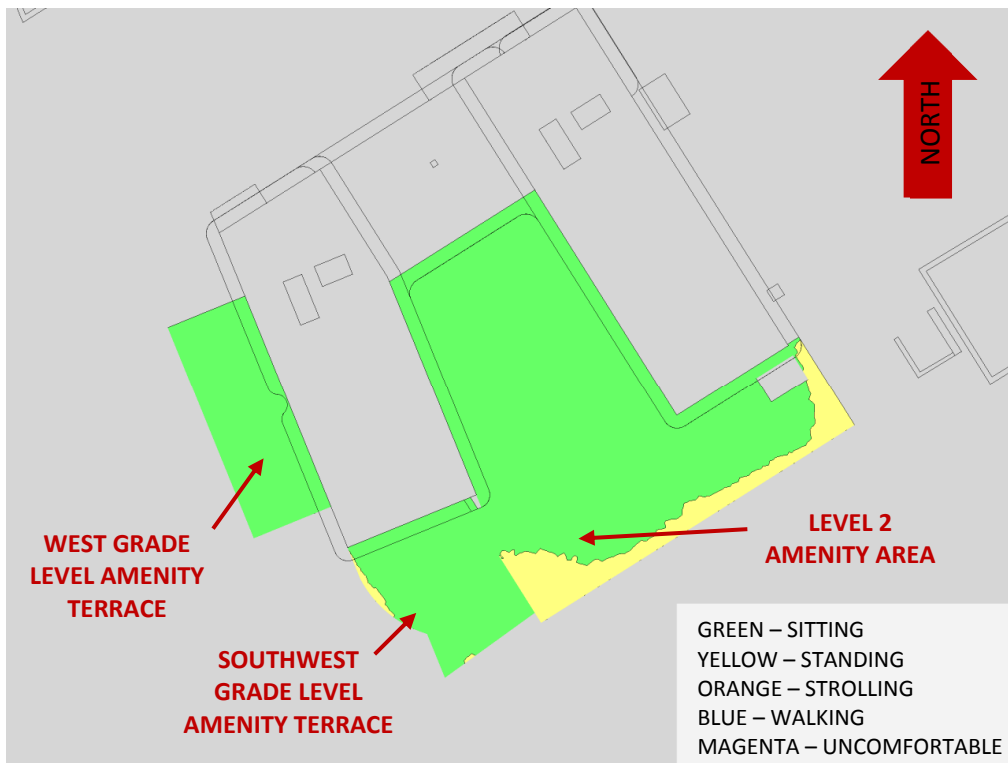**FIGURE 5A: AUTUMN – WIND CONDITIONS AT GRADE LEVEL**

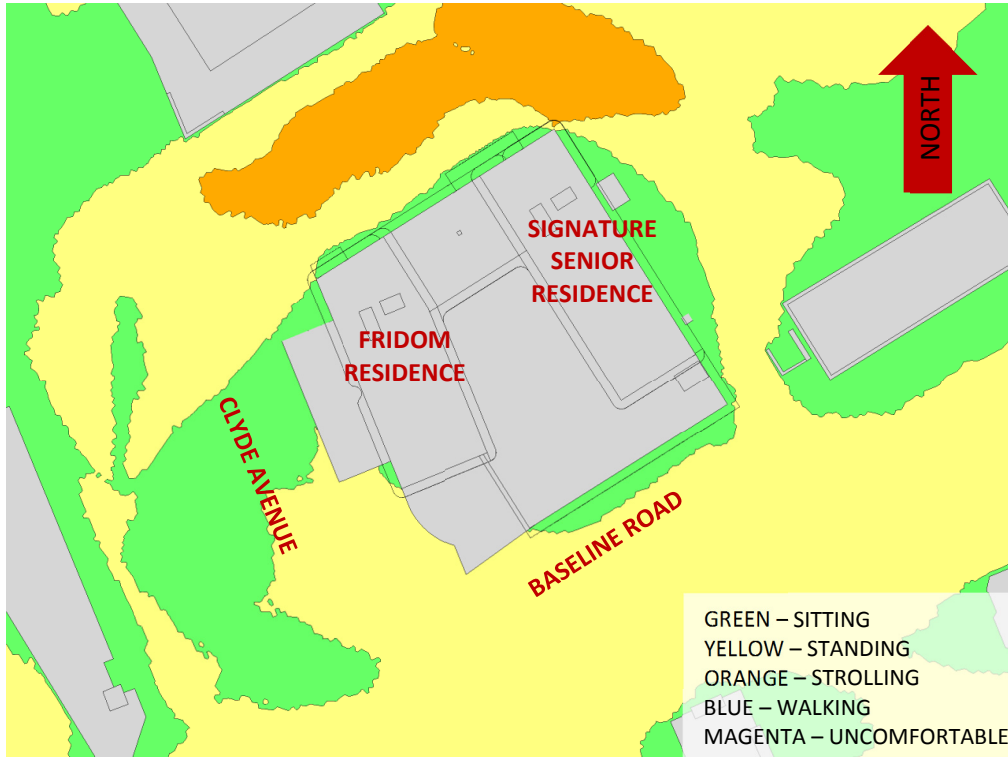**FIGURE 5B: AUTUMN – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES**

NORTH

SIGNATURE SENIOR RESIDENCE

FRIDOM RESIDENCE

CLYDE AVENUE

BASELINE ROAD

GREEN – SITTING
YELLOW – STANDING
ORANGE – STROLLING
BLUE – WALKING
MAGENTA – UNCOMFORTABLE

FIGURE 6A: WINTER – WIND CONDITIONS AT GRADE LEVEL

NORTH

WEST GRADE LEVEL AMENITY TERRACE

SOUTHWEST GRADE LEVEL AMENITY TERRACE

LEVEL 2 AMENITY AREA

GREEN – SITTING
YELLOW – STANDING
ORANGE – STROLLING
BLUE – WALKING
MAGENTA – UNCOMFORTABLE

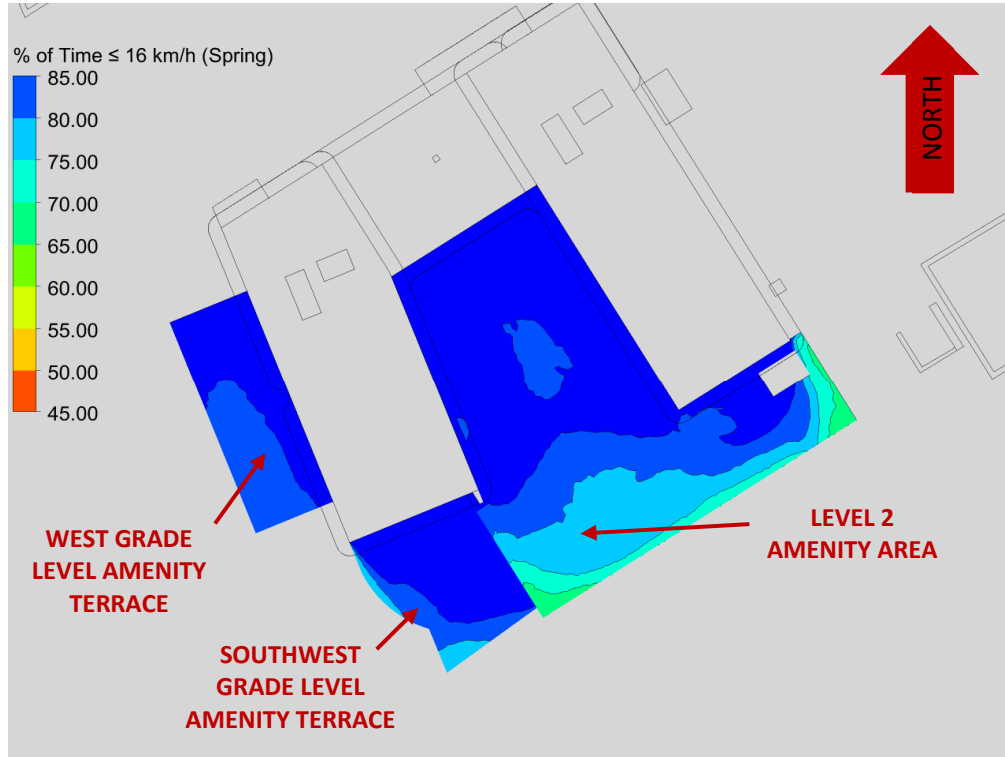**FIGURE 6B: WINTER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES**

FIGURE 7A: SPRING – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)
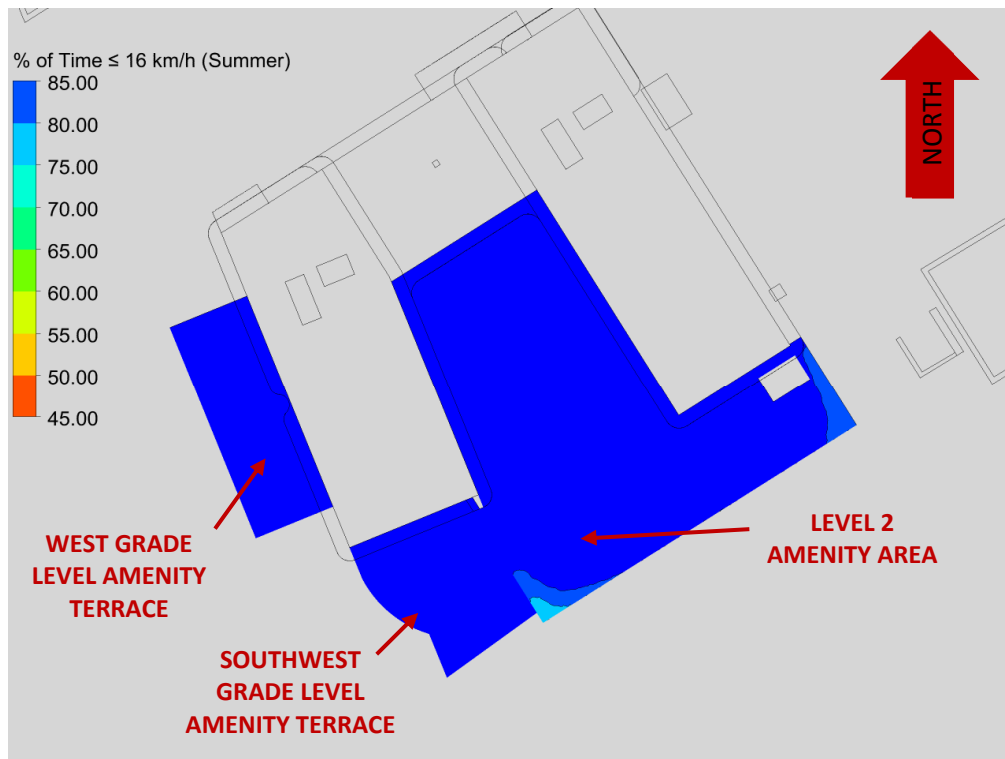

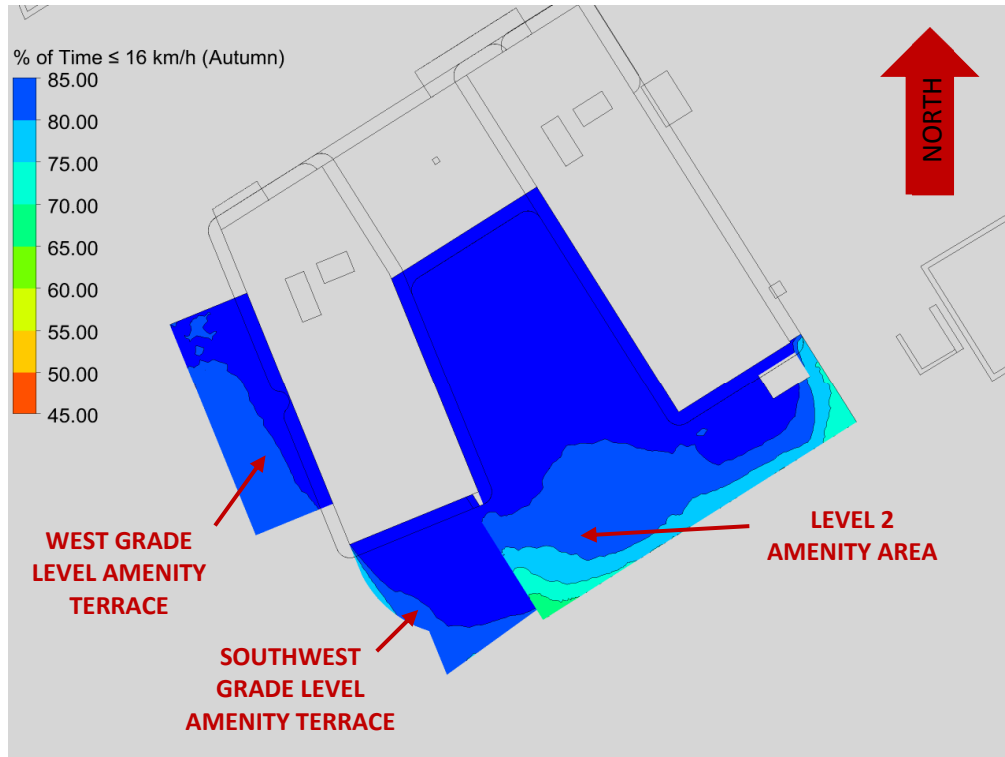**FIGURE 7B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)**

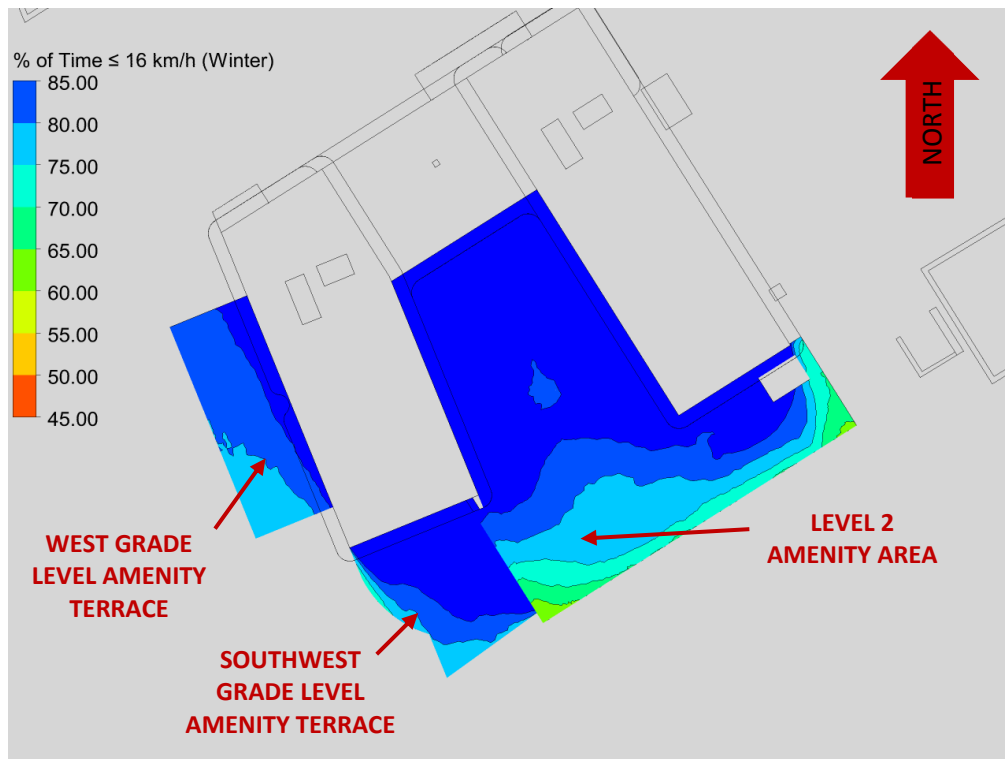**FIGURE 7C: AUTUMN – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)**
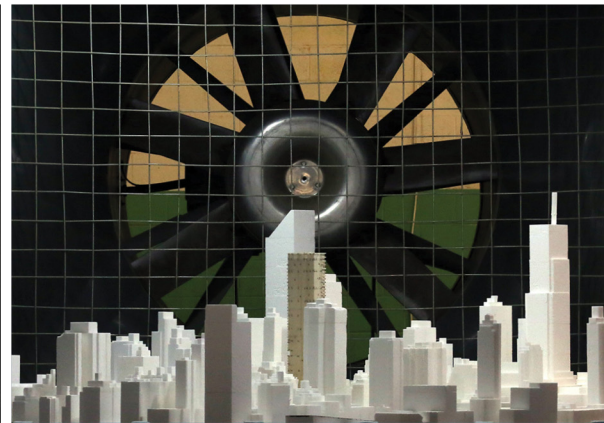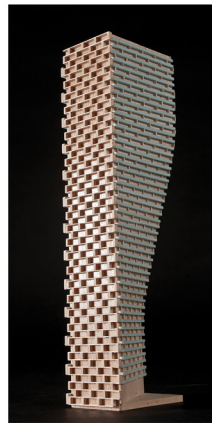

FIGURE 7D: WINTER – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)

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APPENDIX A

SIMULATION OF THE NATURAL WIND

The information contained within this appendix is offered to provide a greater understanding of the

relationship between the physical wind tunnel testing method and

virtual computer-based simulations

SIMULATION OF THE NATURAL WIND

Wind flowing over the surface of the earth develops a boundary layer due to the drag produced by surface features such as vegetation and man-made structures. Within this boundary layer, the mean wind speed varies from zero at the surface to the gradient wind speed at the top of the layer. The height of the top of the boundary layer is referred to as the gradient height, above which the velocity remains more-or-less constant for a given synoptic weather system. The mean wind speed is taken to be the average value over one hour. Superimposed on the mean wind speed are fluctuating (or turbulent) components in the longitudinal (i.e. along wind), vertical and lateral directions. Although turbulence varies according to the roughness of the surface, the turbulence level generally increases from nearly zero (smooth flow) at gradient height to maximum values near the ground. While for a calm ocean the maximum could be 20%, the maximum for a very rough surface such as the center of a city could be 100%, or equal to the local mean wind speed. The height of the boundary layer varies in time and over different terrain roughness within the range of 400 metres (m) to 600 m.

Simulating real wind behaviour in a wind tunnel, or by computational simulations (CFD), requires simulating the variation of mean wind speed with height, simulating the turbulence intensity, and matching the typical length scales of turbulence. It is the ratio between wind tunnel turbulence length scales and turbulence scales in the atmosphere that determines the geometric scales that models can assume in a wind tunnel. Hence, when a 1:200 scale model is quoted, this implies that the turbulence scales in the wind tunnel and the atmosphere have the same ratios. Some flexibility in this requirement has been shown to produce reasonable wind tunnel predictions compared to full scale. In model scale the mean and turbulence characteristics of the wind are obtained with the use of spires at one end of the tunnel and roughness elements along the floor of the tunnel. The fan is located at the model end and wind is pulled over the spires, roughness elements and model. It has been found that, to a good approximation, the mean wind profile can be represented by a power law relation, shown below, giving height above ground versus wind speed.

$$U = U_g \left(\frac{Z}{Z_g} \right)^\alpha$$

Where; U = mean wind speed, U_g = gradient wind speed, Z = height above ground, Z_g = depth of the boundary layer (gradient height) and α is the power law exponent.

Figure A1 on the following page plots three velocity profiles for open country, and suburban and urban exposures. The exponent α varies according to the type of upwind terrain; α ranges from 0.14 for open country to 0.33 for an urban exposure. Figure A2 illustrates the theoretical variation of turbulence for open country, suburban and urban exposures.

The integral length scale of turbulence can be thought of as an average size of gust in the atmosphere. Although it varies with height and ground roughness, it has been found to generally be in the range of 100 m to 200 m in the upper half of the boundary layer. Thus, for a 1:300 scale, the model value should be between 1/3 and 2/3 of a metre. Integral length scales are derived from power spectra, which describe the energy content of wind as a function of frequency. There are several ways of determining integral length scales of turbulence. One way is by comparison of a measured power spectrum in model scale to a non-dimensional theoretical spectrum such as the Davenport spectrum of longitudinal turbulence. Using the Davenport spectrum, which agrees well with full-scale spectra, one can estimate the integral scale by plotting the theoretical spectrum with varying L until it matches as closely as possible the measured spectrum:

$$f \times S(f) = \frac{\dfrac{4(Lf)^2}{U_{10}^{\,2}}}{\left[1 + \dfrac{4(Lf)^2}{U_{10}^{\,2}}\right]^{\frac{4}{3}}}$$

Where, f is frequency, S(f) is the spectrum value at frequency f, U10 is the wind speed 10 m above ground level, and L is the characteristic length of turbulence.

Once the wind simulation is correct, the model, constructed to a suitable scale, is installed at the centre of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel center-line axis.
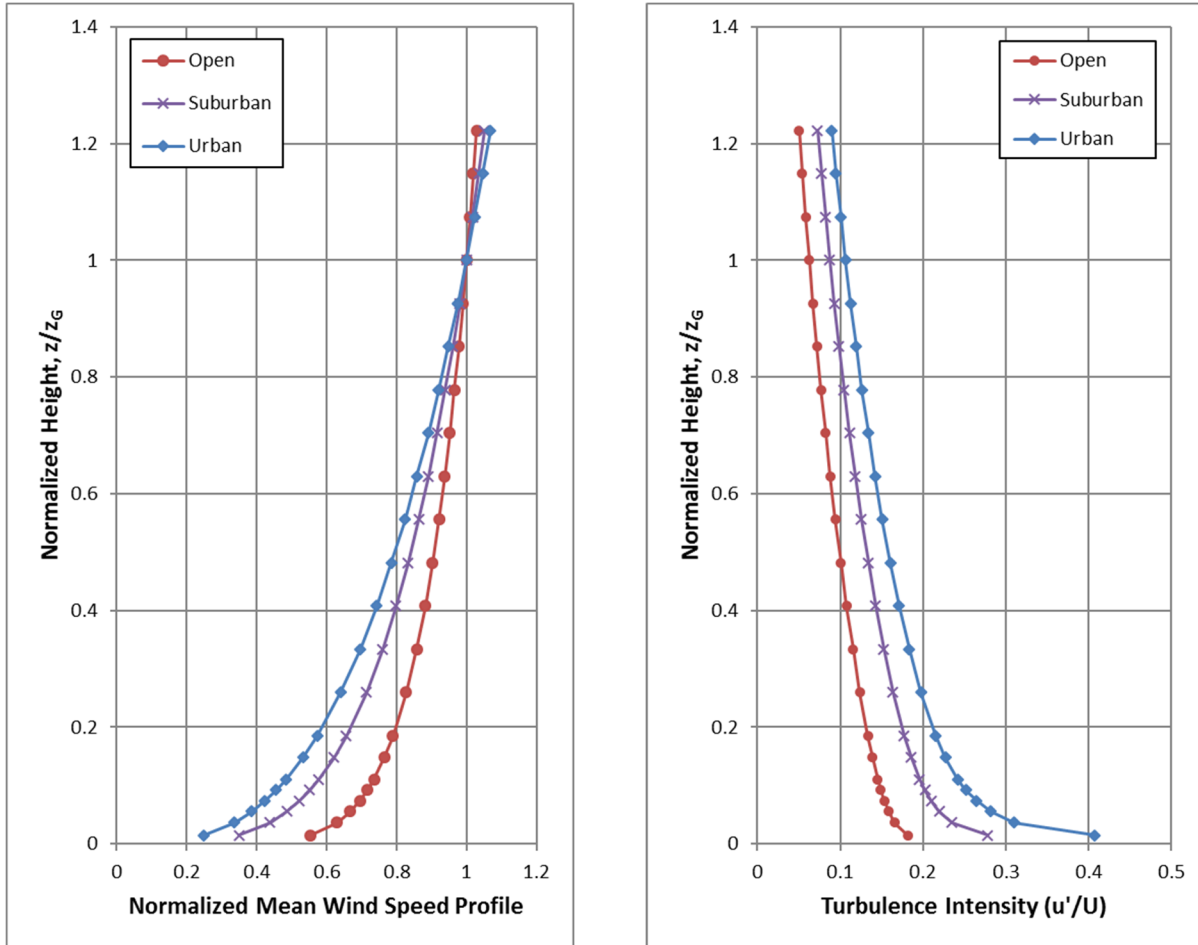
FIGURE A1 (LEFT): MEAN WIND SPEED PROFILES
FIGURE A2 (RIGHT): TURBULENCE INTENSITY PROFILES

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2. Flay, R.G., Stevenson, D.C., 'Integral Length Scales in an Atmospheric Boundary Layer near the Ground', 9th Australian Fluid Mechanics Conference, Auckland, Dec. 1966

3. ESDU, 'Characteristics of Atmospheric Turbulence Near the Ground', 74030

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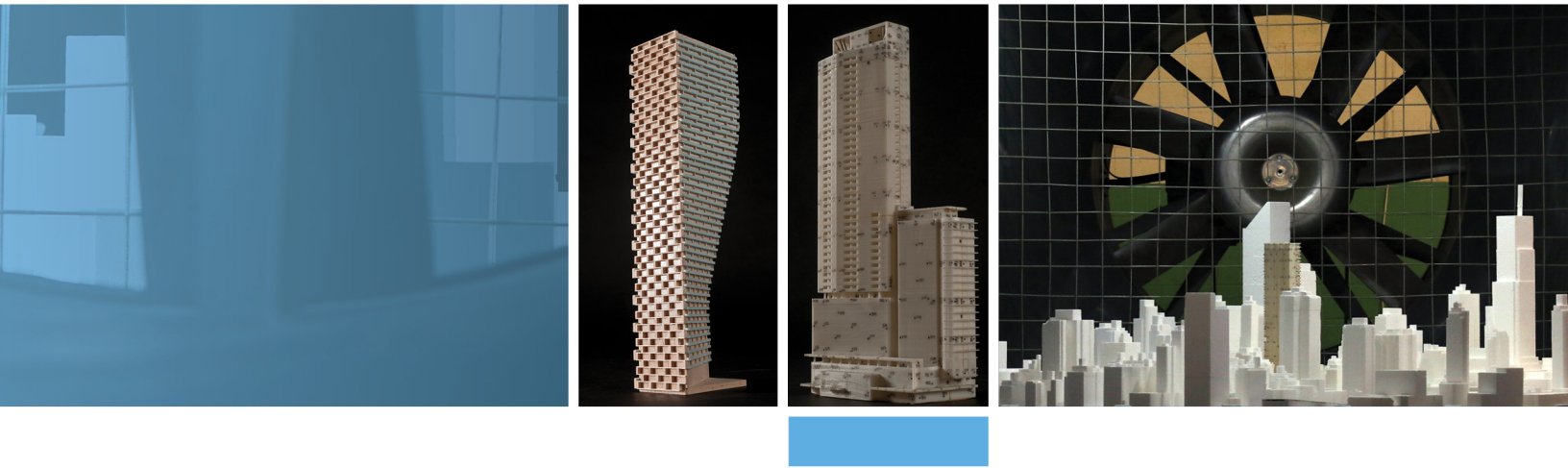
APPENDIX B

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

The information contained within this appendix is offered to provide a greater understanding of the

relationship between the physical wind tunnel testing method and

virtual computer-based simulations

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

Pedestrian level wind studies are performed in a wind tunnel on a physical model of the study buildings at a suitable scale. Instantaneous wind speed measurements are recorded at a model height corresponding to 1.5 m full scale using either a hot wire anemometer or a pressure-based transducer. Measurements are performed at any number of locations on the model and usually for 36 wind directions. For each wind direction, the roughness of the upwind terrain is matched in the wind tunnel to generate the correct mean and turbulent wind profiles approaching the model.

The hot wire anemometer is an instrument consisting of a thin metallic wire conducting an electric current. It is an omni-directional device equally sensitive to wind approaching from any direction in the horizontal plane. By compensating for the cooling effect of wind flowing over the wire, the associated electronics produce an analog voltage signal that can be calibrated against velocity of the air stream. For all measurements, the wire is oriented vertically so as to be sensitive to wind approaching from all directions in a horizontal plane.

The pressure sensor is a small cylindrical device that measures instantaneous pressure differences over a small area. The sensor is connected via tubing to a transducer that translates the pressure to a voltage signal that is recorded by computer. With appropriately designed tubing, the sensor is sensitive to a suitable range of fluctuating velocities.

For a given wind direction and location on the model, a time history of the wind speed is recorded for a period of time equal to one hour in full-scale. The analog signal produced by the hot wire or pressure sensor is digitized at a rate of 400 samples per second. A sample recording for several seconds is illustrated in Figure B1. This data is analyzed to extract the mean, root-mean-square (rms) and the peak of the signal. The peak value, or gust wind speed, is formed by averaging a number of peaks obtained from sub-intervals of the sampling period. The mean and gust speeds are then normalized by the wind tunnel gradient wind speed, which is the speed at the top of the model boundary layer, to obtain mean and gust ratios. At each location, the measurements are repeated for 36 wind directions to produce normalized polar plots, which will be provided upon request.

In order to determine the duration of various wind speeds at full scale for a given measurement location the gust ratios are combined with a statistical (mathematical) model of the wind climate for the project site. This mathematical model is based on hourly wind data obtained from one or more meteorological stations (usually airports) close to the project location. The probability model used to represent the data is the Weibull distribution expressed as:

$$P\left(>U_g\right) = A_\theta \bullet \exp\left[\left(-\frac{U_g}{C_\theta}\right)^{K\theta}\right]$$

Where,

$P\ (>U_g)$ is the probability, fraction of time, that the gradient wind speed U_g is exceeded; θ is the wind direction measured clockwise from true north, A, C, K are the Weibull coefficients, (Units: A - dimensionless, C - wind speed units [km/h] for instance, K - dimensionless). A_θ is the fraction of time wind blows from a $10°$ sector centered on θ.

Analysis of the hourly wind data recorded for a length of time, on the order of 10 to 30 years, yields the A_θ, C_θ and K_θ values. The probability of exceeding a chosen wind speed level, say 20 km/h, at sensor N is given by the following expression:

$$P_N\left(>20\right) = \Sigma_\theta P\left[\frac{\left(>20\right)}{\left(\frac{U_N}{U_g}\right)}\right]$$

$$P_N\ (>20)\ =\ \Sigma_\theta P\{>20/(U_N/U_g)\}$$

Where, U_N/U_g is the gust velocity ratios, where the summation is taken over all 36 wind directions at 10° intervals.

If there are significant seasonal variations in the weather data, as determined by inspection of the C_θ and K_θ values, then the analysis is performed separately for two or more times corresponding to the groupings of seasonal wind data. Wind speed levels of interest for predicting pedestrian comfort are based on the comfort guidelines chosen to represent various pedestrian activity levels as discussed in the main text.
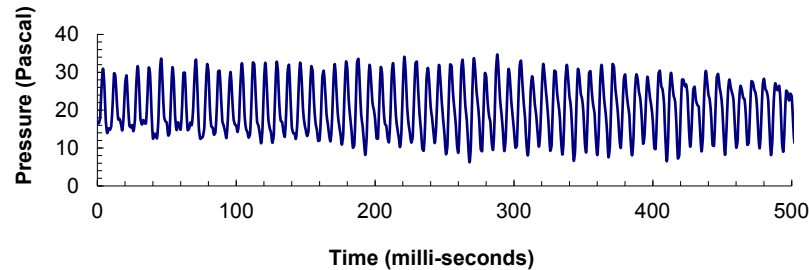

FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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1. Davenport, A.G., '*The Dependence of Wind Loading on Meteorological Parameters*', Proc. of Int. Res. Seminar, Wind Effects on Buildings & Structures, NRC, Ottawa, 1967, University of Toronto Press.

2. Wu, S., Bose, N., 'An *Extended Power Law Model for the Calibration of Hot-wire/Hot-film Constant Temperature Probes*', Int. J. of Heat Mass Transfer, Vol.17, No.3, pp.437-442, Pergamon Press.