Pedestrian Level Wind Study

Westgate Shopping Centre Redevelopment, Phase 1

Ottawa, Ontario

REPORT: GWE15-067-CFDPLW-2018

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EXECUTIVE SUMMARY

This report describes a computer-based pedestrian level wind study in support of site plan application for Phase 1 of the Westgate Shopping Centre redevelopment, a 24-storey building with a four-storey mixed-use podium, located at the northwest corner of the Merivale Road and Carling Avenue intersection in Ottawa, Ontario. The study involves the simulation of wind speeds for selected wind directions in a three-dimensional (3D) computer model using the Computational Fluid Dynamics (CFD) technique, combined with meteorological data integration, to assess pedestrian comfort and safety within and surrounding the development site. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

This study is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by RLA Architecture in October 2018, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

A complete summary of the predicted wind conditions is presented in Section 5 of this report. Based on CFD test results, interpretation and experience with similar developments, we conclude that all grade-level pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses throughout the year. More specifically, all sidewalks, walkways, parking lots, transit stops and building access points within and surrounding the development site will experience acceptable wind conditions throughout the year.

The Level 5 outdoor amenity area will not achieve conditions suitable for sitting throughout the year. To ensure that the area is suitable for sitting during the intended use period of late spring to early autumn, mitigation is recommended in the form of wind barriers and canopies, as described in Section 5. The exact configuration of the terrace wind mitigation will be refined as the design progresses.

Of importance, excluding anomalous localized storm events such as tornadoes and downbursts, no area over the study site are considered uncomfortable for walking, or unsafe.

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by RioCan Holdings Inc. to undertake a computer-based pedestrian level wind (PLW) study for Phase 1 of the Westgate Shopping Centre redevelopment, located at the northwest corner of the Merivale Road and Carling Avenue intersection in Ottawa, Ontario. Our mandate within this study, as outlined in GWE proposal # GWE15-094P R1, dated July 25, 2018, is to investigate pedestrian wind comfort within and surrounding the development 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 CFD simulation and data analysis procedures, architectural drawings provided by RLA Architecture in October 2018, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

2. TERMS OF REFERENCE

The focus of this PLW study is Phase 1 of the Westgate Shopping Centre redevelopment in Ottawa, Ontario. Phase 1 of the redevelopment will introduce a mixed-use building to the southeast corner of the overall study site, which is bounded by the Queensway to the northwest, Merivale Road to the east and Carling Avenue to the south.

The proposed development is a 24-storey building with a stepped four-storey podium, rising approximately 80 metres above grade to the top of the mechanical penthouse. At grade, the podium platform is nearly rectangular with rectangular insets and the long axis oriented along Carling Avenue. Ground floor primarily comprises retail space, with the exception of bicycle storage, loading areas and a ramp to two levels of underground parking at the northeast corner, as well as building support function and indoor amenity spaces near the southeast corner. Various building access points are located on the north, west, and south elevations. The mezzanine above is largely open to below, with additional bicycle storage at the northeast corner. Residential use occupies above floors. At Level 2, the floorplate sets back from the south, east and north sides to create an irregular L-shaped platform open to the north side. At Level 5, the floorplate sets back from the west side to create an outdoor amenity area as well as an articulated rectangular floorplate with rectangular insets. The floorplate sets back again from the east side at Level 21 and from the north, east and south sides of the mechanical penthouse.

The near-field surroundings of the study site primarily comprise the existing Westgate Shopping Centre and adjacent parking lots to the north and west, and a mixture of low-rise commercial and residential buildings in remaining directions as well as one high-rise building to the southwest. The far field (farther than 200 metres and within 2 kilometres of the site) primarily comprises low-rise suburban residences, transitioning to fields of the Experimental Farm in the southeast quadrant and with the addition of low-rise commercial developments southwest along the Queensway. Carling Park is located approximately 1.4 kilometres to the southwest, and Hampton Park approximately 150 metres north across the Queensway. The Ottawa River is located approximately 2.5 kilometres northwest of the site.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks and walkways, parking lots, transit stops and building access points. Pedestrian comfort has also been evaluated over the rooftop outdoor amenity area at the west side of Level 5. Figure 1 illustrates the ground floor plan, while Figures 2A and 2B illustrate the computational model used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to: (i) determine pedestrian level comfort and safety conditions within and surrounding the development site; (ii) identify areas where future 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 site is based on Computational Fluid Dynamics (CFD) simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with industry-accepted guidelines[1]. The following sections describe the analysis procedures, including a discussion of the pedestrian comfort guidelines.

4.1 Computer-Based Context Modelling

A computer-based PLW study is 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, are determined by combining measured wind speed data from CFD

[1] City of Ottawa Terms of References: Wind Analysis

simulations with statistical weather data obtained from Ottawa's 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 wind tunnel model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative 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 buildings, complete with surrounding massing within a diameter of approximately 822 metres.

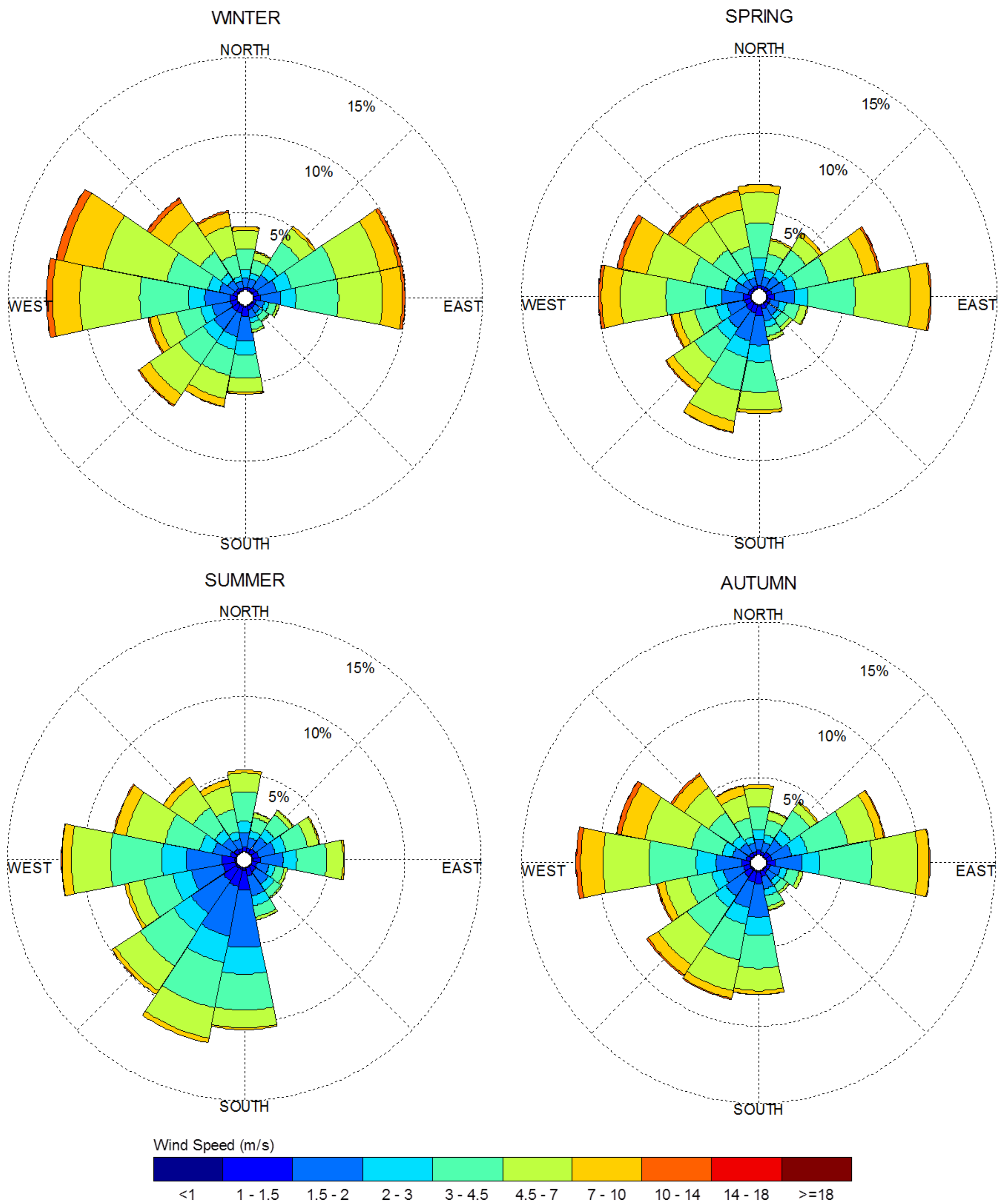
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 metres above local grade were referenced to the wind speed at gradient height to generate 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 Macdonald-Cartier International Airport, and obtained from the local branch of Atmospheric Environment Services of Environment 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 the 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.

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 seasonal distribution of measured wind speeds and directions in 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 10 metres per second (m/s). The directional preference and relative magnitude of wind speed changes somewhat from season to season. By convention in microclimate studies, wind direction refers to the wind origin (e.g., a north wind blows from north to south).

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
MACDONALD-CARTIER INTERNATIONAL AIRPORT, OTTAWA, ONTARIO



Notes:

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds represent mean hourly wind speeds measured at 10 m above the ground.

4.4 Pedestrian Comfort Guidelines

Pedestrian comfort guidelines are based on mechanical wind effects without consideration of other meteorological conditions (i.e. temperature, relative humidity). The guidelines provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort, which include: (i) Sitting; (ii) Standing; (iii) Walking; (iv) Uncomfortable; and (v) Dangerous. More specifically, the comfort classes, associated wind speed ranges, and limiting criteria are summarized as follows:

(i) **Sitting:** Mean wind speeds less than or equal to 10 kilometers per hour (km/h), occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 14 km/h.

(ii) **Standing:** Mean wind speeds less than or equal to 14 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 20 km/h.

(iii) **Strolling:** Mean wind speeds less than or equal to 17 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 25 km/h.

(iv) **Walking:** Mean wind speeds less than or equal to 20 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 30 km/h.

(v) **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 guideline.

(vi) **Dangerous:** Gust equivalent mean wind speeds greater than or equal to 90 km/h, occurring more often than 0.1% of the time, are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall.

Gust speeds are used in the criteria because people 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 cause 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	4-8	Wind felt on faces.
3	Gentle Breeze	8-15	Leaves and small twigs in constant motion; Wind extends light flags.
4	Moderate Breeze	15-22	Wind raises dust and loose paper; Small branches are moved.
5	Fresh Breeze	22-30	Small trees in leaf begin to sway.
6	Strong Breeze	30-40	Large branches in motion; Whistling heard in electrical wires; Umbrellas used with difficulty.
7	Moderate Gale	40-50	Whole trees in motion; Inconvenient walking against wind.
8	Gale	50-60	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 20% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if wind speeds of 14 km/h were exceeded for more than 20% of the time, most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if 30 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 across the study site, 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. 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
Cafés / Patios / Benches / Gardens	Sitting
Transit Shelters	Standing
Public Parks / Plazas	Strolling
Garage / Service Entrances	Walking
Parking Lots	Walking
Vehicular Drop-Off Zones	Walking

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions for the study site is accompanied by Figures 3A through 6B (following the main text) illustrating the seasonal wind conditions at grade level and over the rooftop outdoor amenity area. The colour contours indicate predicted regions of the various comfort classes. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by salmon, and conditions suitable for walking are represented by blue.

Carling Avenue Sidewalk and Adjacent Entrances (Tags A & B): The sidewalk along the south side of the building (Tag A) will be comfortable for standing or better during the summer and strolling or better for the remainder of the year, with the windier conditions occurring at the building corners. All adjacent building entrances (Tag B) will experience conditions suitable for standing or better throughout the year. The noted conditions are acceptable for the intended uses of the spaces.

Merivale Road Sidewalk (Tag C): The sidewalk along the east side of the building will be comfortable for standing or better during the summer and strolling or better for the remainder of the year, which is acceptable.

North Side of Building and Adjacent Building Access Points (Tags D, E & F): The walkway along the north side of the building (Tag D), as well as the vehicular access points for the loading bay and underground parking ramp at the northeast corner (Tag E), will be comfortable for standing or better during the summer and strolling or better for the remainder of the year. The building access points at the north corners of the building (Tag F) will experience conditions suitable for sitting throughout the year due to their inset location. The noted conditions are acceptable for the intended uses of the spaces.

West Side of Building and Adjacent Entrances (Tags G & H): The walkway along the west side of the building (Tag G) will be comfortable for standing or better during the summer and strolling or better for the remainder of the year, with windier conditions occurring at the southwest corner. The adjacent retail entrance (Tag H) will experience conditions suitable for sitting throughout the year due to its inset location within the building façade. The noted conditions are acceptable for the intended uses.

Parking Lots (Tag I): The parking lots to the north and west of the study building will be comfortable for strolling or better throughout the year, which is acceptable.

Pedestrian Walkway and Entrances along the Westgate Shopping Centre (Tag J): The walkway and adjacent entrances serving the south and east sides of the Westgate Shopping Centre will be comfortable for standing or better throughout the year, which is acceptable.

Transit Stops (Tag K): All transit stops surrounding the study site will be suitable for standing or better during the summer, spring and autumn, transitioning to conditions suitable for strolling or better during the winter for the two stops nearest the Merivale Road and Carling Avenue intersection. Although the desired comfort classification of standing is not achieved by all transit stops during the winter, these two windier stops are equipped with three-walled vestibules that will allow pedestrians to take cover during limited periods of windier conditions. Conditions at all transit stops surrounding the development site are therefore acceptable.

Level 5 Outdoor Amenity Area (Tag L): Overall, wind conditions over the Level 5 outdoor amenity area will be comfortable for standing during the summer and largely suitable for strolling or better for the remainder of the year. To ensure conditions are suitable for seating during the intended use period of late spring to early autumn, it is recommended to raise the perimeter guard to 1.8 metres above the walking surface along the full perimeter of the space, as well as to provide targeted wind barriers internal to the space to shield from prominent westerly winds. As well, it is recommended to install a wraparound canopy at the south corner of the building façade to deflect the downwash of high-level winds. The exact configuration of the terrace mitigation can be coordinated with the design team as the terrace plan develops.

Influence of the Proposed Development on Existing Wind Conditions near the Study Site: Wind conditions over surrounding sidewalks and beyond the development site will generally be comfortable for strolling or better throughout the year upon introduction of the proposed redevelopment at the Westgate Shopping Centre.

Wind Safety: Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no grade-level areas over the study site were found to experience wind conditions that are considered uncomfortable for walking or unsafe.

6. SUMMARY AND RECOMMENDATIONS

This document summarizes the results of a pedestrian level wind study undertaken to assess wind comfort for Phase 1 of the Westgate Shopping Centre redevelopment, located at the at the northwest corner of the Merivale Road and Carling Avenue intersection in Ottawa, Ontario. This work is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by RLA Architecture in October 2018, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

Based on CFD test results, interpretation, and experience with similar developments, we conclude that all grade-level pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses throughout the year. More specifically, all sidewalks, walkways, parking lots, transit stops and building access points within and surrounding the development site will experience acceptable wind conditions throughout the year.

The Level 5 outdoor amenity area will not achieve conditions suitable for sitting throughout the year. To ensure that the area is suitable for sitting during the intended use period of late spring to early autumn, mitigation is recommended in the form of wind barriers and canopies, as described in Section 5. The exact configuration of the terrace wind mitigation will be refined as the design progresses.

Of importance, excluding anomalous localized storm events such as tornadoes and downbursts, no area over the study site are considered uncomfortable for walking or unsafe.

This concludes our pedestrian level wind report. Please advise the undersigned of any questions or comments.

Sincerely,

Gradient Wind Engineering Inc.

LICENSED PROFESSIONAL ENGINEER
11/21/18
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Principal

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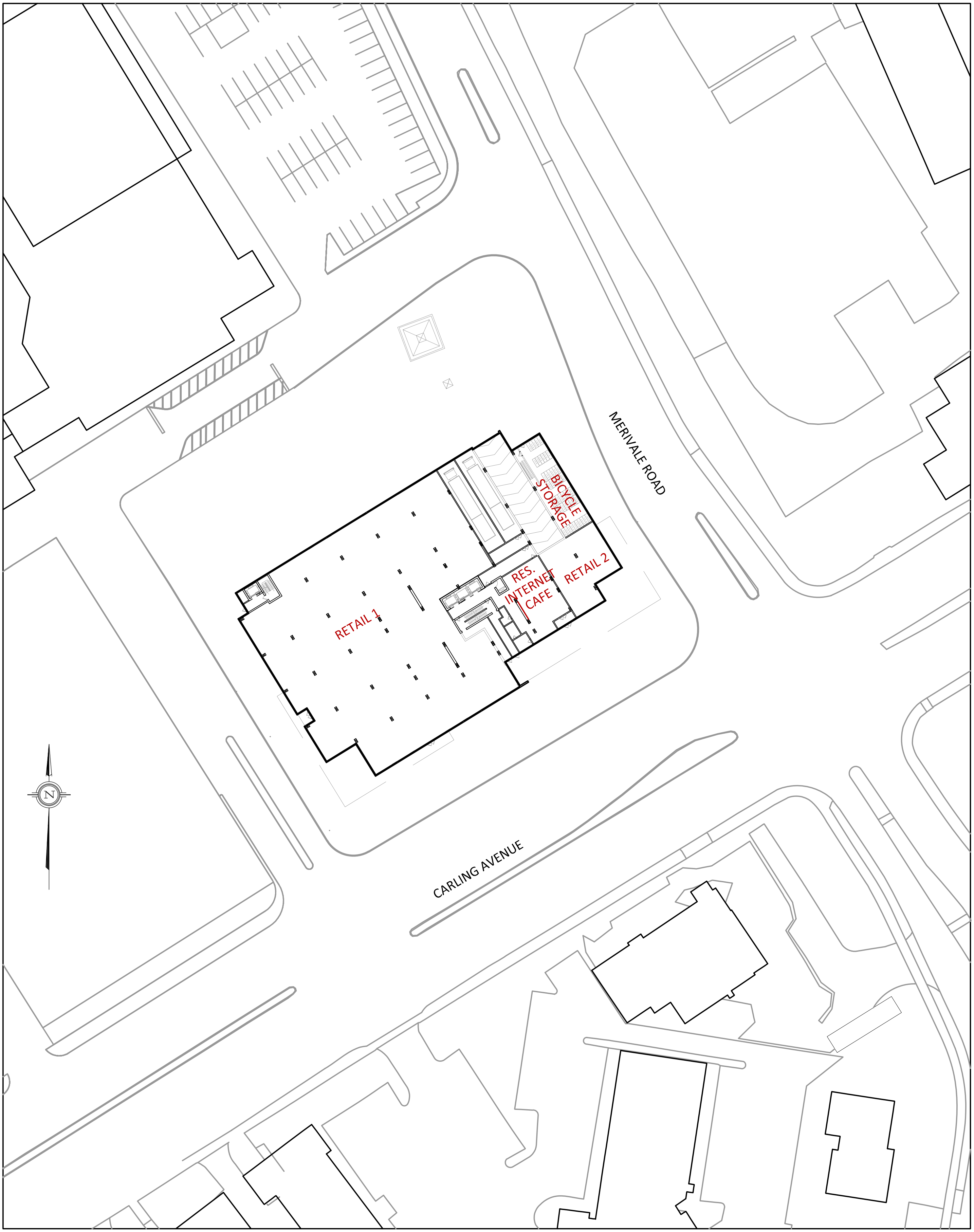

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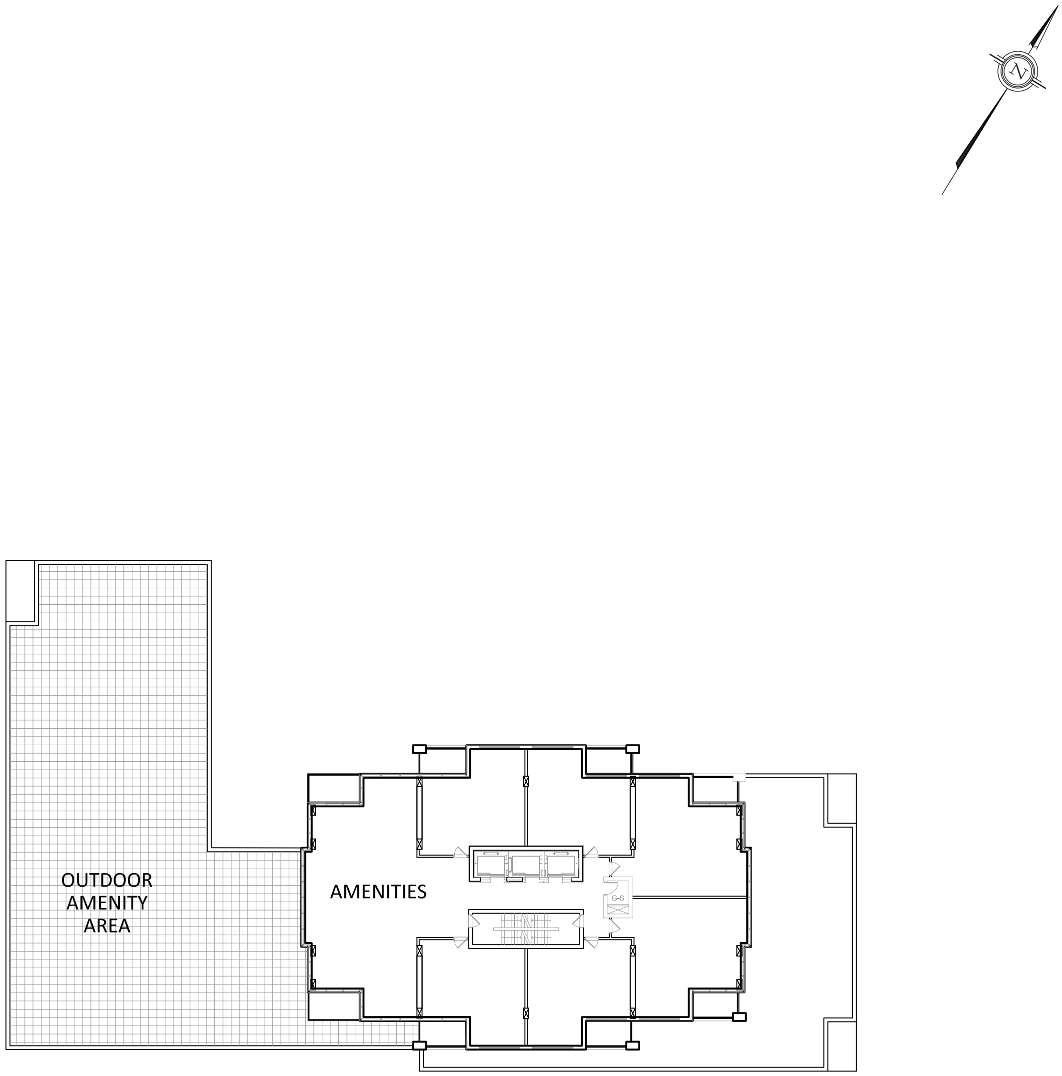
GRADIENT WIND ENGINEERING INC

PROJECT WESTGATE SHOPPING CENTRE REDEVELOPMENT, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION
SCALE 1:1000 (APPROX.)	DRAWING NO. GWE15-067-PLW-2018-1	FIGURE 1A: GROUND FLOOR AND SURROUNDING CONTEXT
DATE NOVEMBER 5, 2018	DRAWN BY K.A.	



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PROJECT WESTGATE SHOPPING CENTRE REDEVELOPMENT, OTTAWA PEDESTRIAN LEVEL WIND STUDY	
SCALE 1:800 (APPROX.)	DRAWING NO. GWE15-067-PLW-2018-2
DATE NOVEMBER 5, 2018	DRAWN BY K.A.

DESCRIPTION

FIGURE 1B:
LEVEL 5 OUTDOOR AMENITY AREA

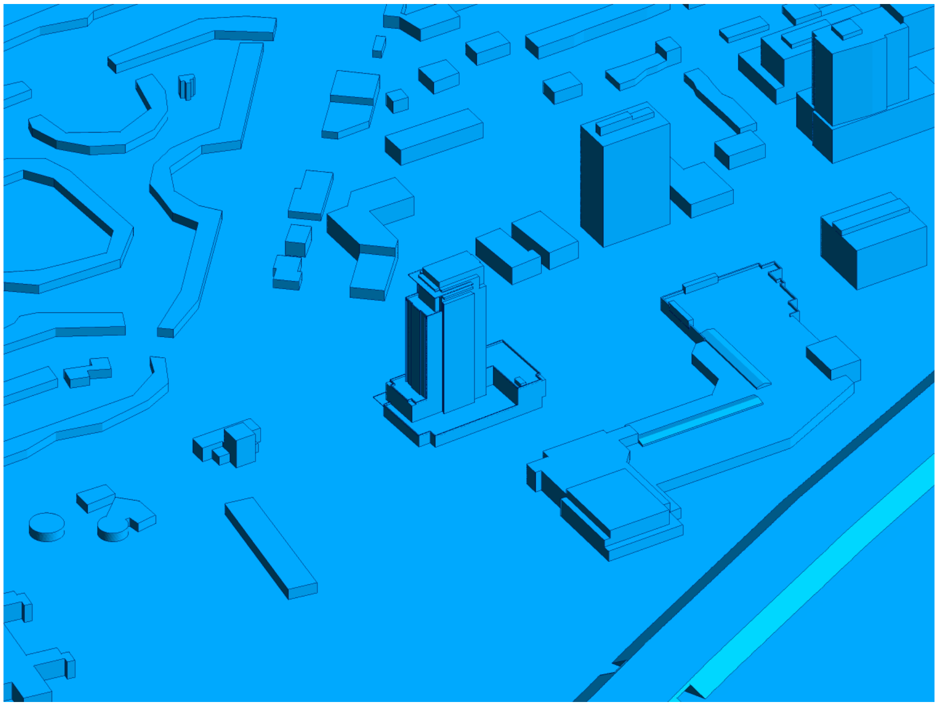


FIGURE 2A: COMPUTATIONAL MODEL, LOOKING SOUTH

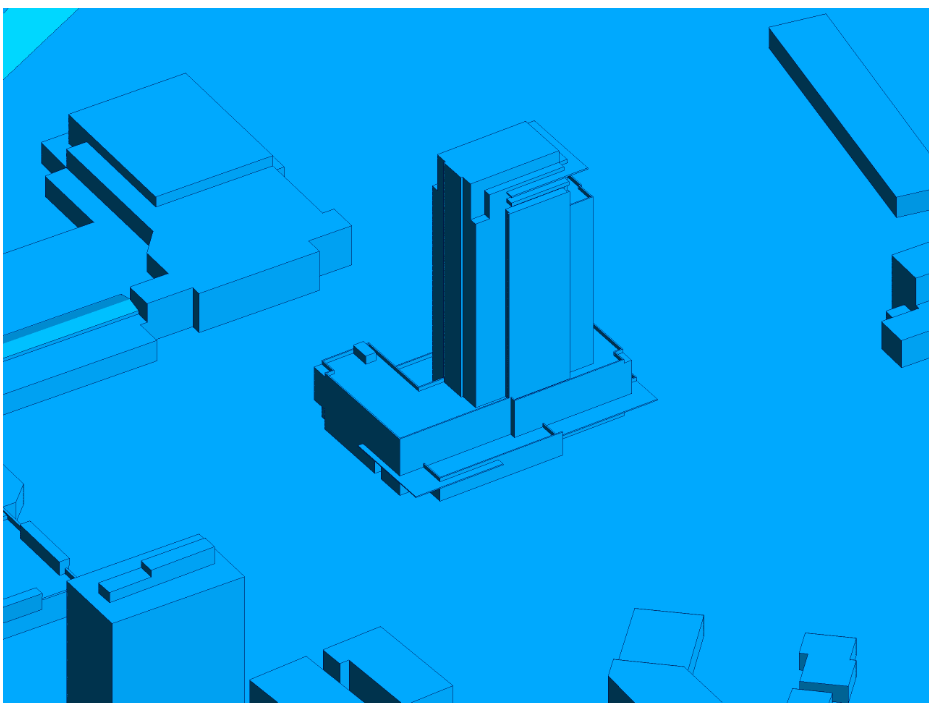


FIGURE 2B: STUDY BUILDING, LOOKING NORTH

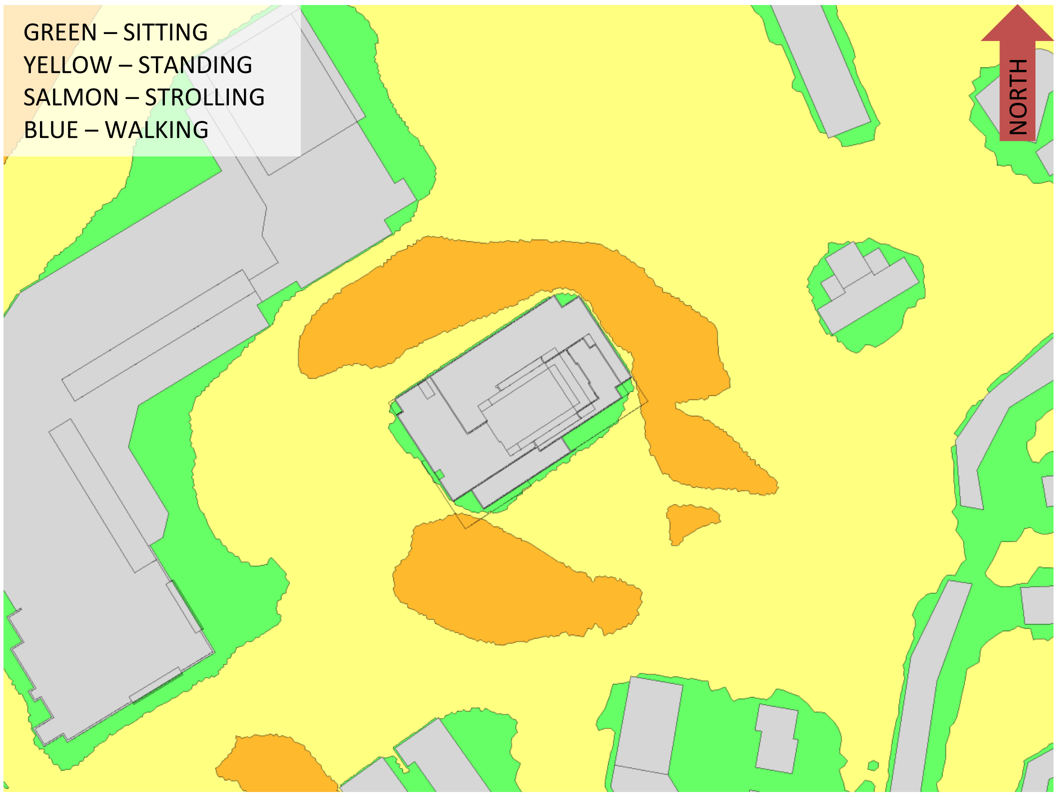
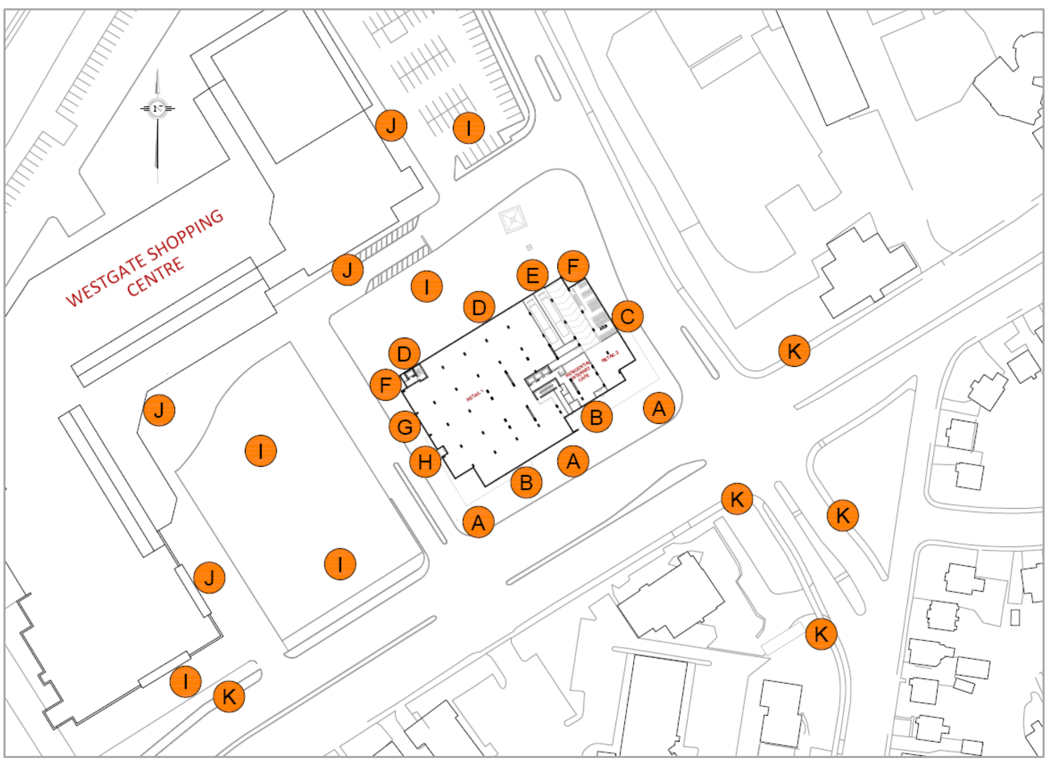


FIGURE 3A: SPRING – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



PHASE 1 WESTGATE REDEVELOPMENT SITE – GRADE LEVEL REFERENCE MARKER LOCATIONS

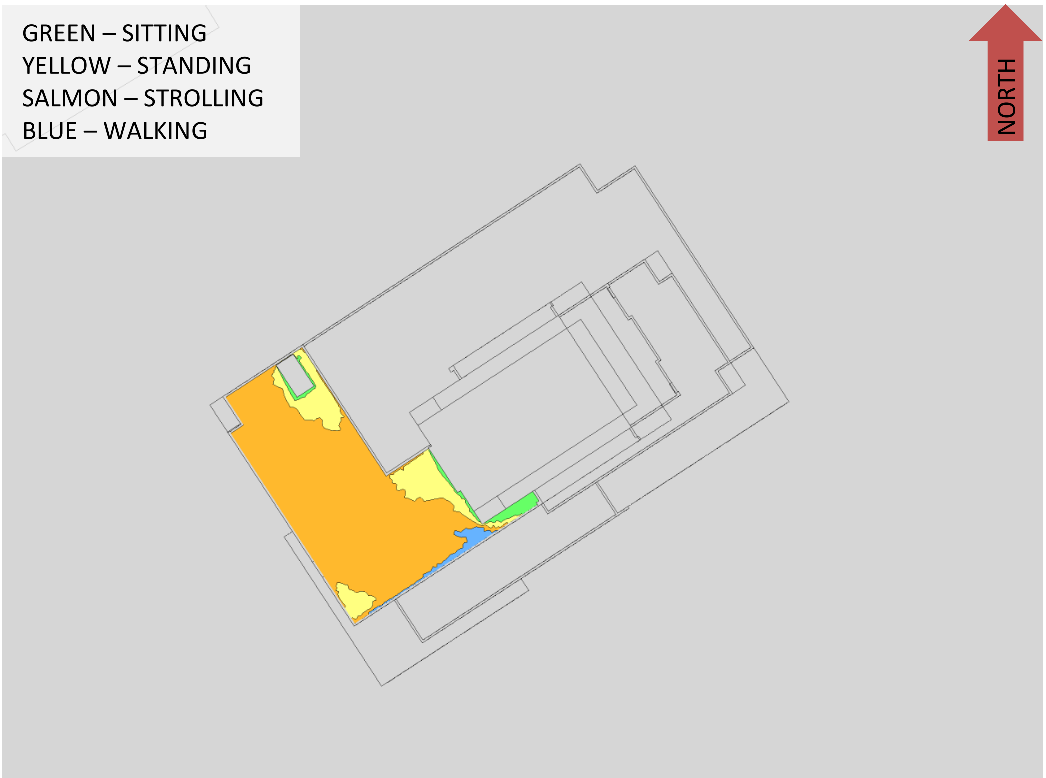
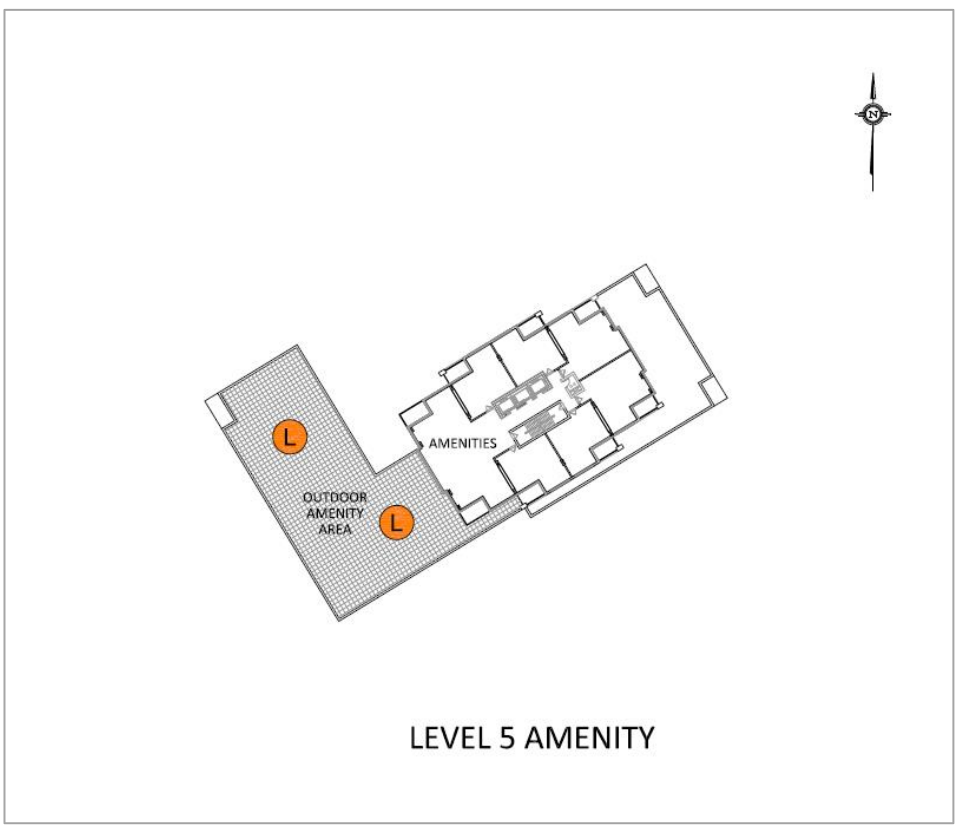


FIGURE 3B: SPRING – PODIUM ROOFTOP TERRACE WIND CONDITIONS



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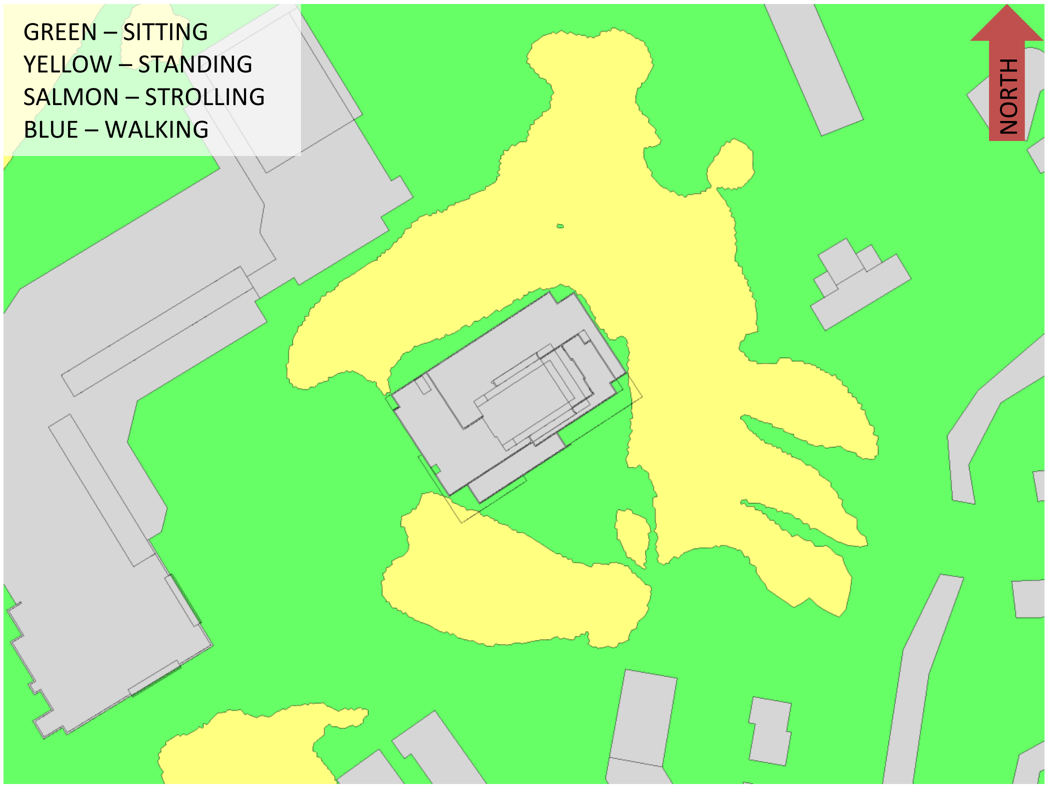
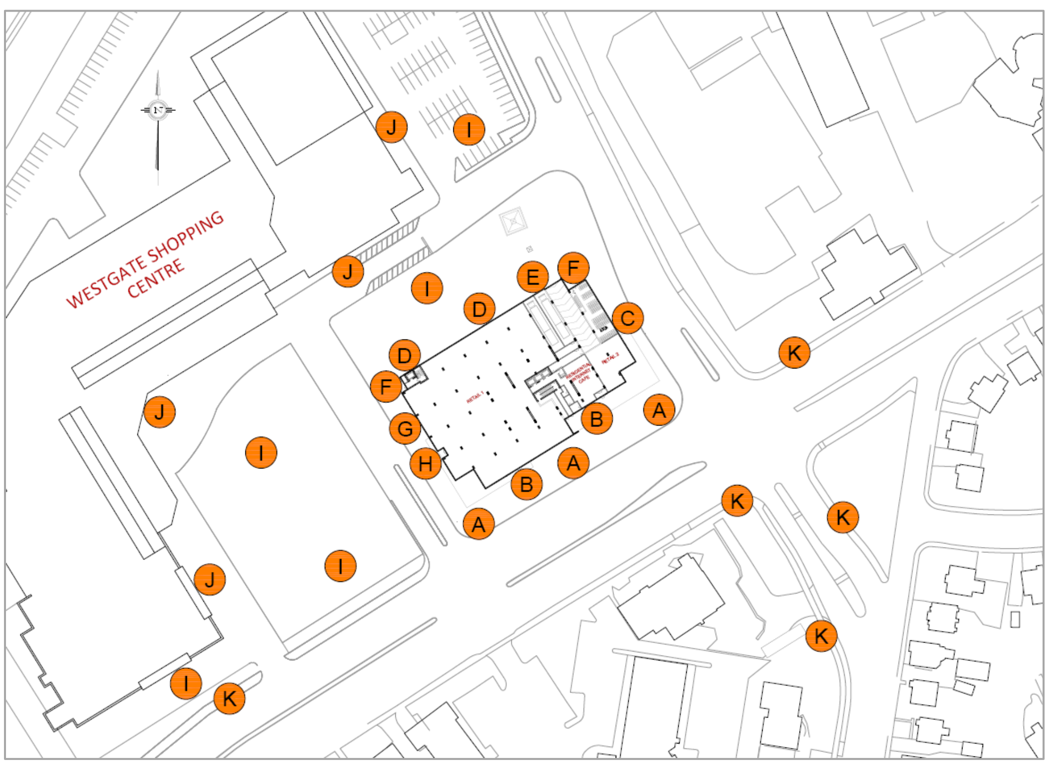


FIGURE 4A: SUMMER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



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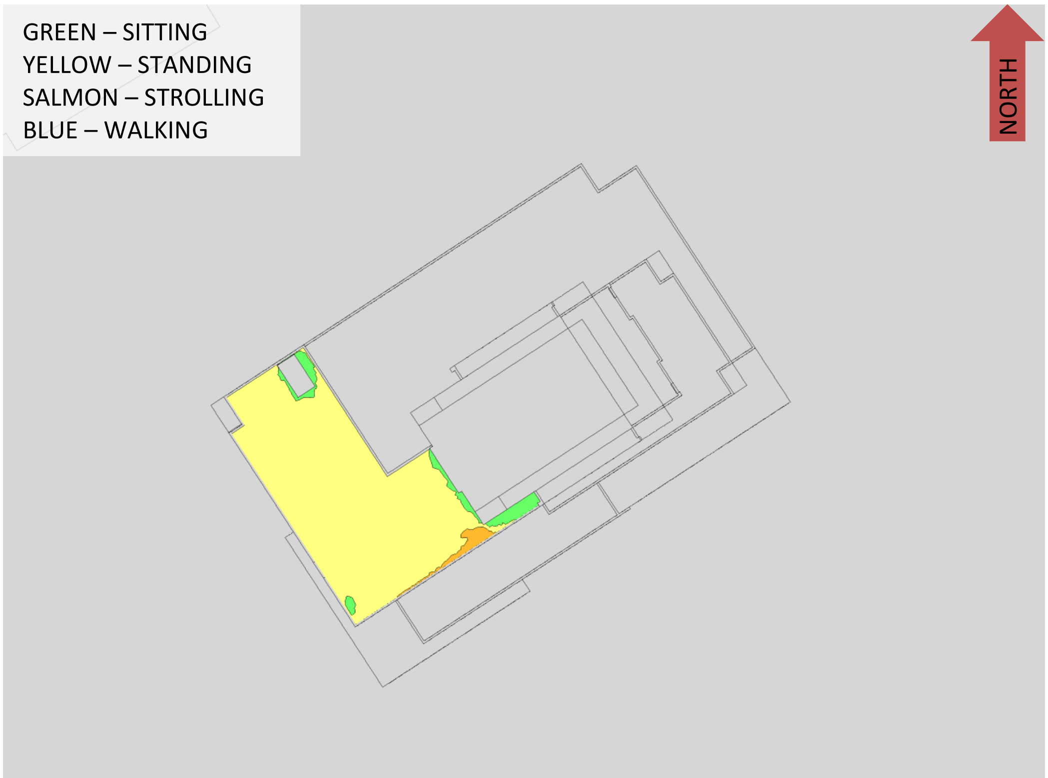
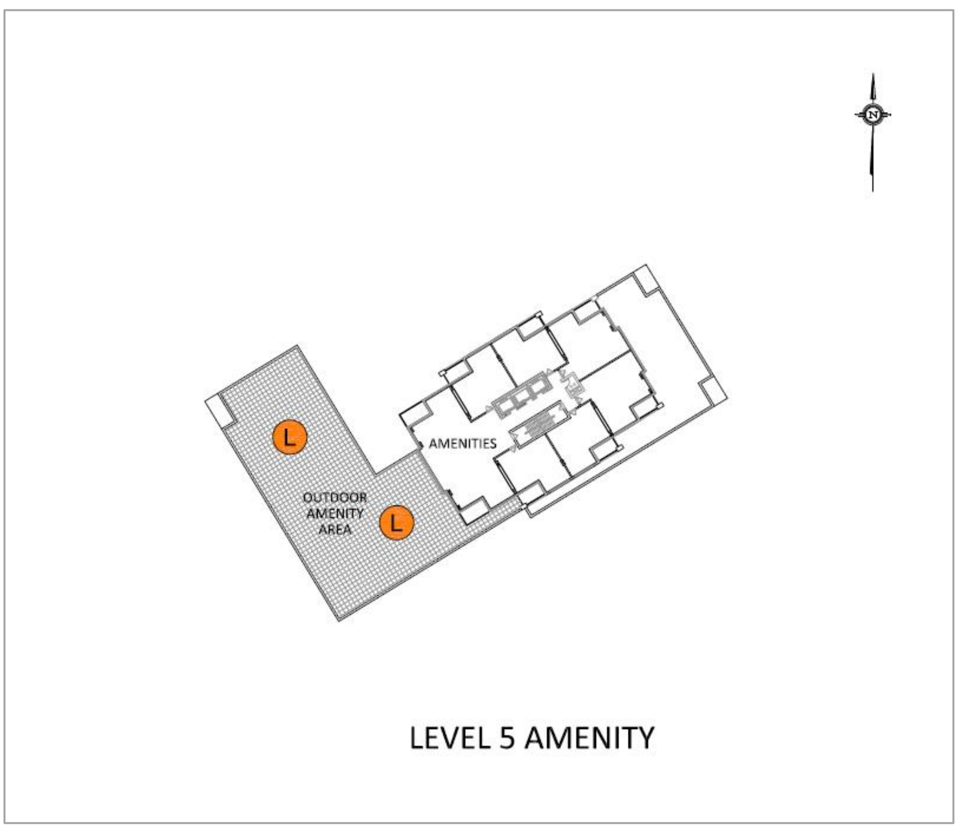
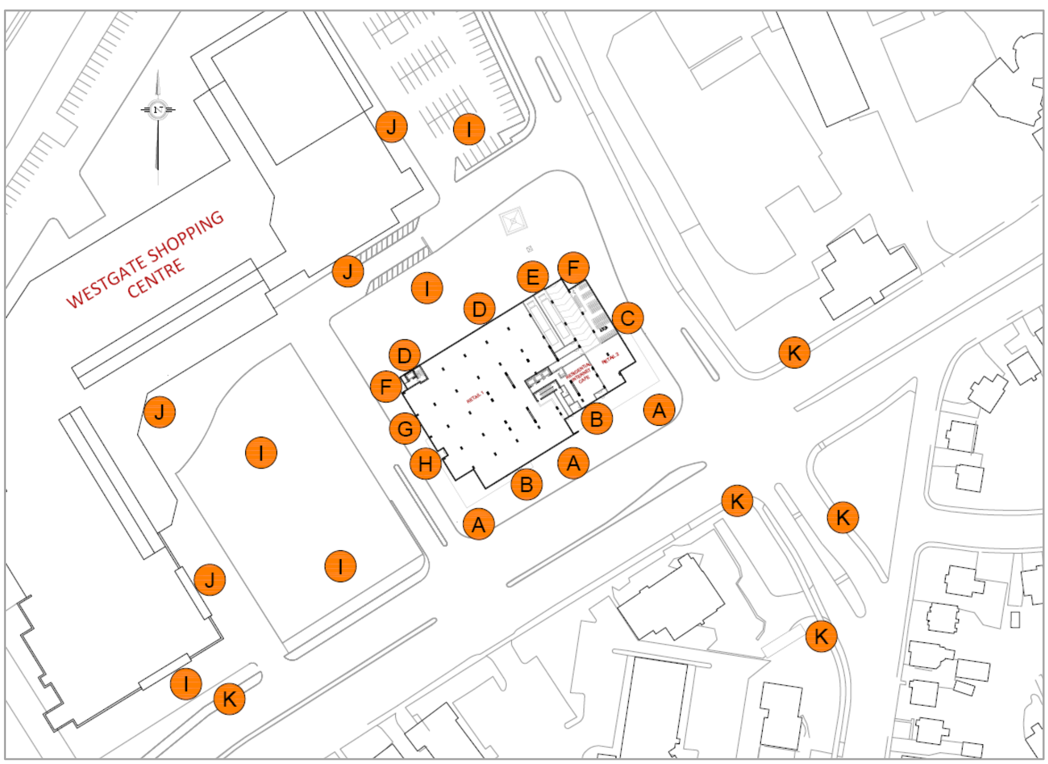


FIGURE 4B: SUMMER – PODIUM ROOFTOP TERRACE WIND CONDITIONS



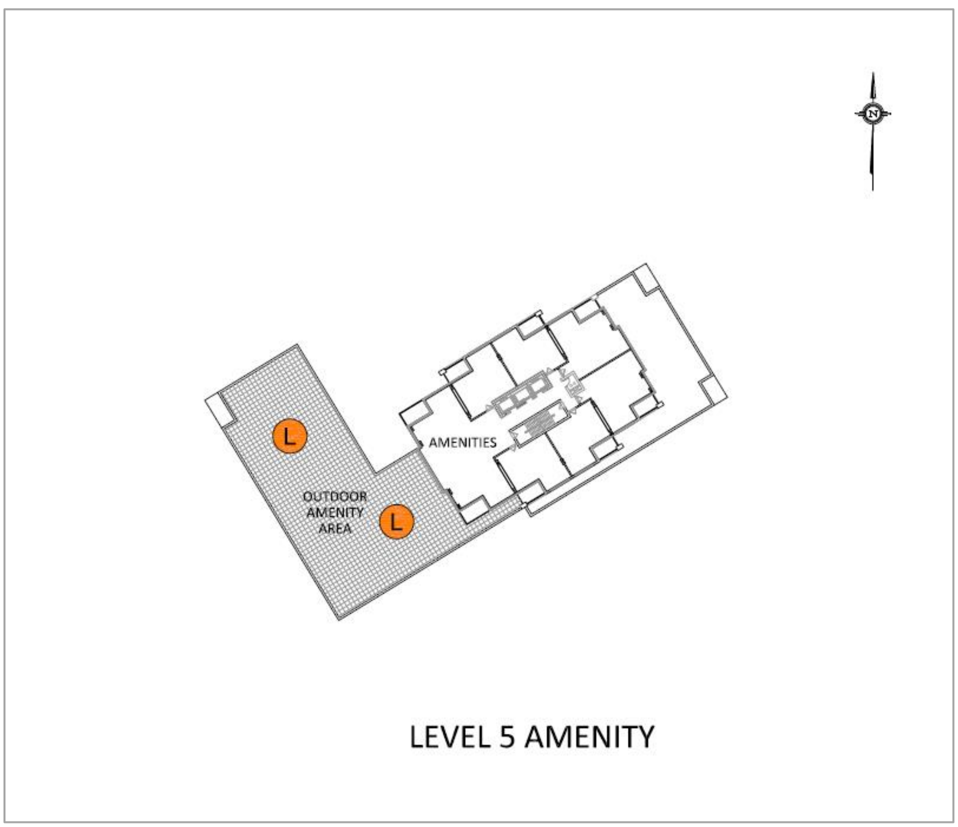
PHASE 1 WESTGATE REDEVELOPMENT SITE – ELEVATED REFERENCE MARKER LOCATIONS

FIGURE 5A: AUTUMN – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



PHASE 1 WESTGATE REDEVELOPMENT SITE – GRADE LEVEL REFERENCE MARKER LOCATIONS

FIGURE 5B: AUTUMN – PODIUM ROOFTOP TERRACE WIND CONDITIONS



PHASE 1 WESTGATE REDEVELOPMENT SITE – ELEVATED REFERENCE MARKER LOCATIONS

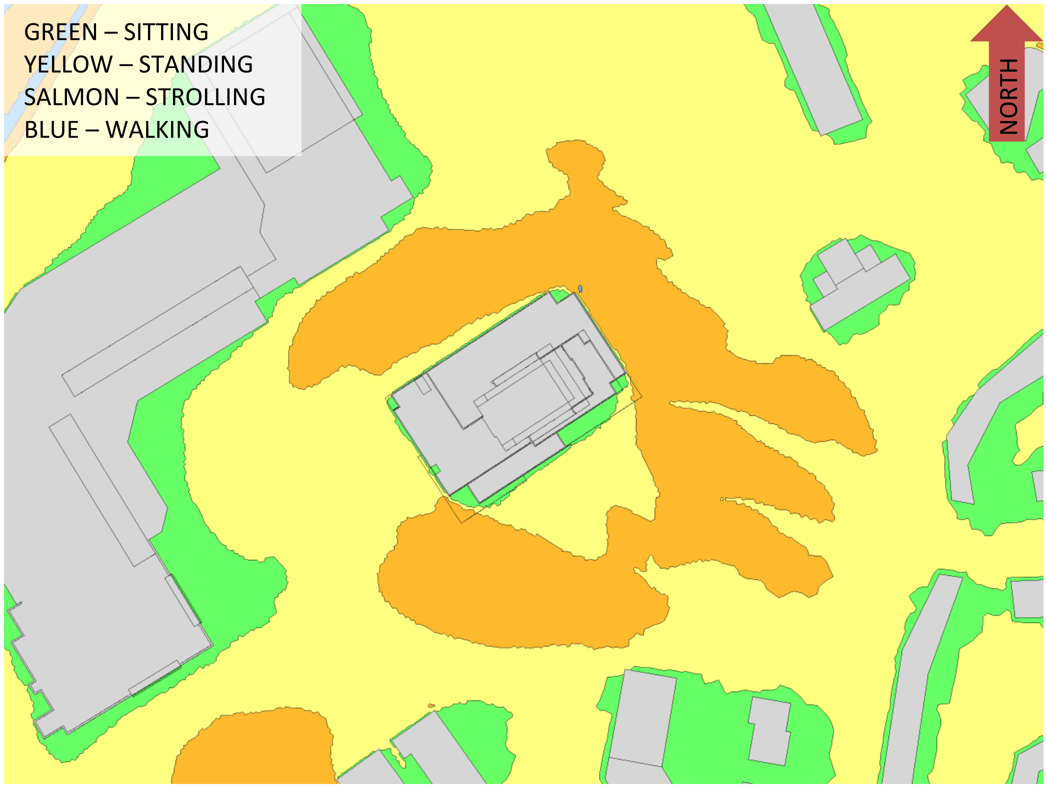
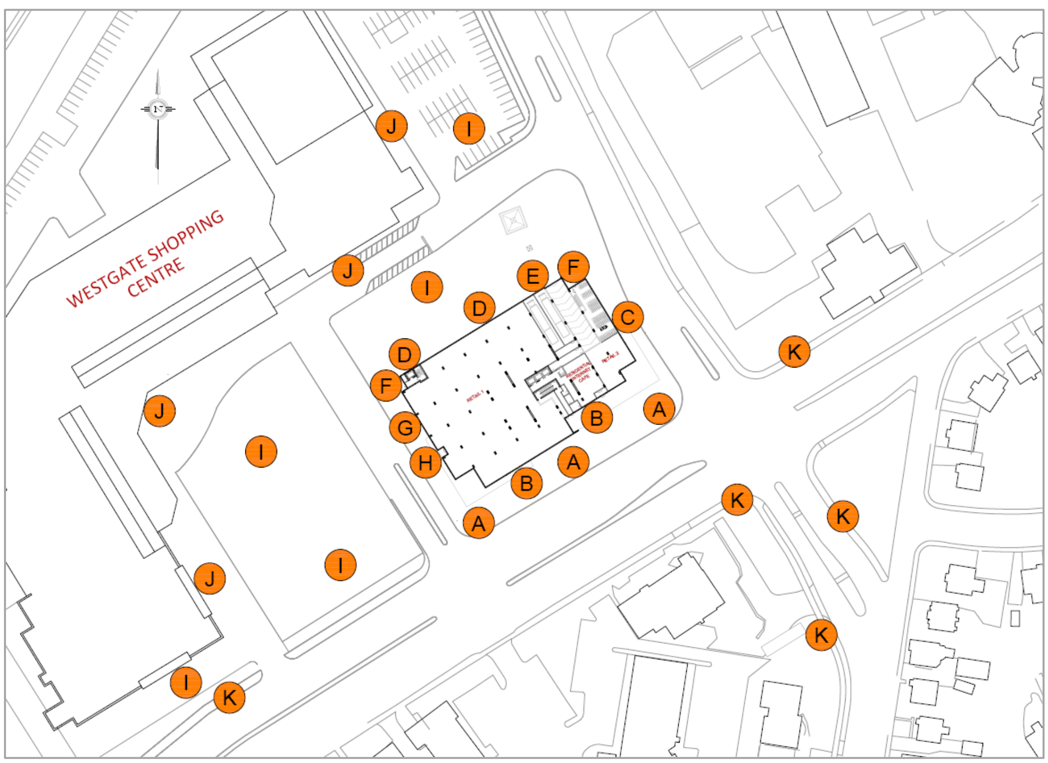
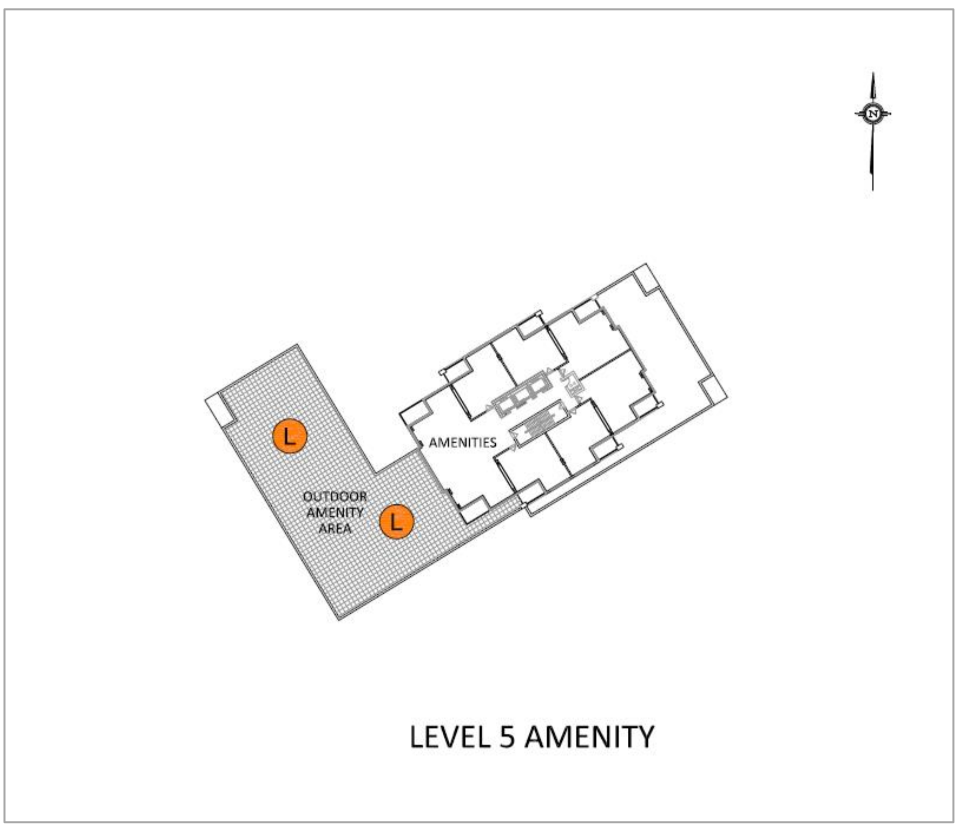


FIGURE 6A: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



PHASE 1 WESTGATE REDEVELOPMENT SITE – GRADE LEVEL REFERENCE MARKER LOCATIONS

FIGURE 6B: WINTER – PODIUM ROOFTOP TERRACE WIND CONDITIONS



PHASE 1 WESTGATE REDEVELOPMENT SITE – ELEVATED REFERENCE MARKER LOCATIONS

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

WIND TUNNEL 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 m to 600 m.

Simulating real wind behaviour in a wind tunnel, or by computer models (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; $\boldsymbol{U}$ = mean wind speed, $\boldsymbol{U_g}$ = gradient wind speed, $\boldsymbol{Z}$ = height above ground, $\boldsymbol{Z_g}$ = depth of the boundary layer (gradient height) and α is the power law exponent.

Figure A1 plots three such profiles for the open country, suburban and urban exposures. The exponent α varies according to the type of terrain; α = 0.14, 0.25 and 0.33 for open country, suburban and urban exposures respectively. Figure A2 illustrates the theoretical variation of turbulence in full scale and some wind tunnel measurement for comparison.

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. For a 1:300 scale, for example, 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, U_{10} 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 center 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.

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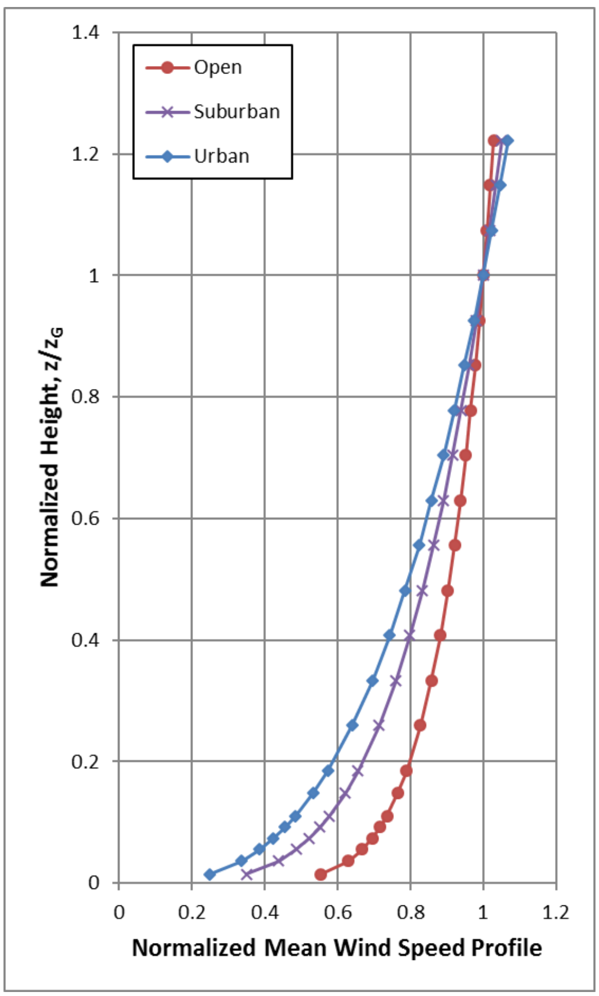


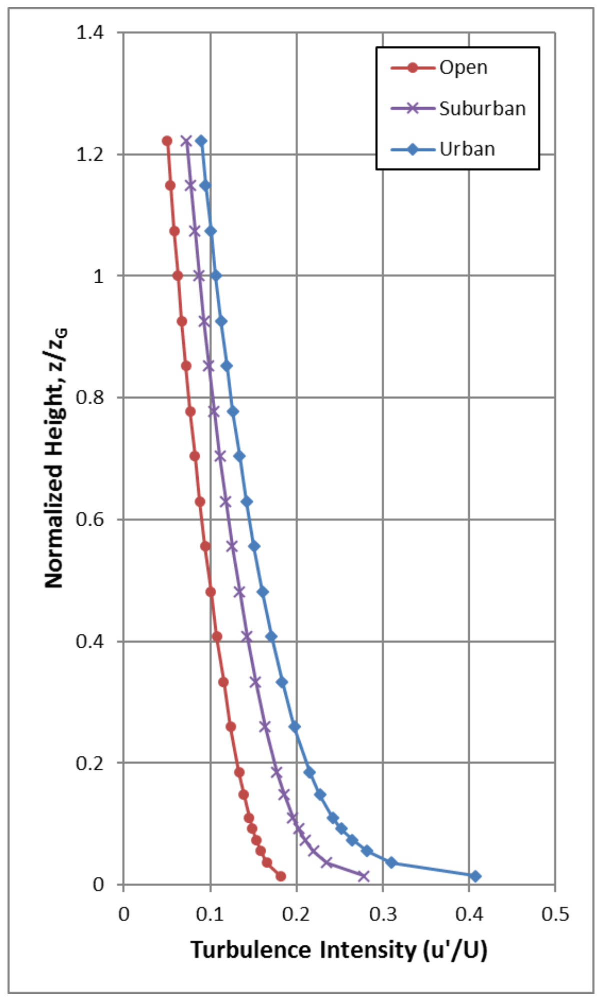


Figure A1: Mean Wind Speed Profiles

Figure A2: Turbulence Intensity Profiles

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 B. 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:

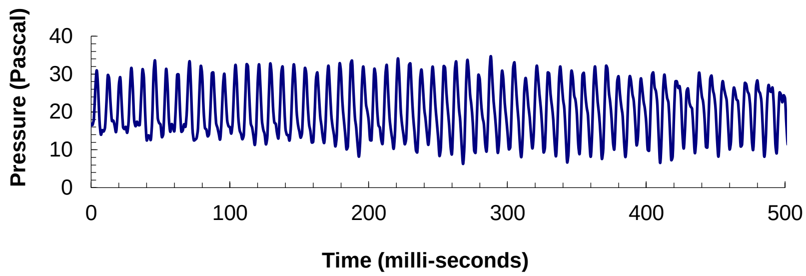
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

$$P_N\,(>20) \quad = \quad \Sigma_\theta\, P\,\{>20/(U_N/Ug)\}$$

Where, ***U_N/U_g*** is the aforementioned normalized 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 B: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR



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