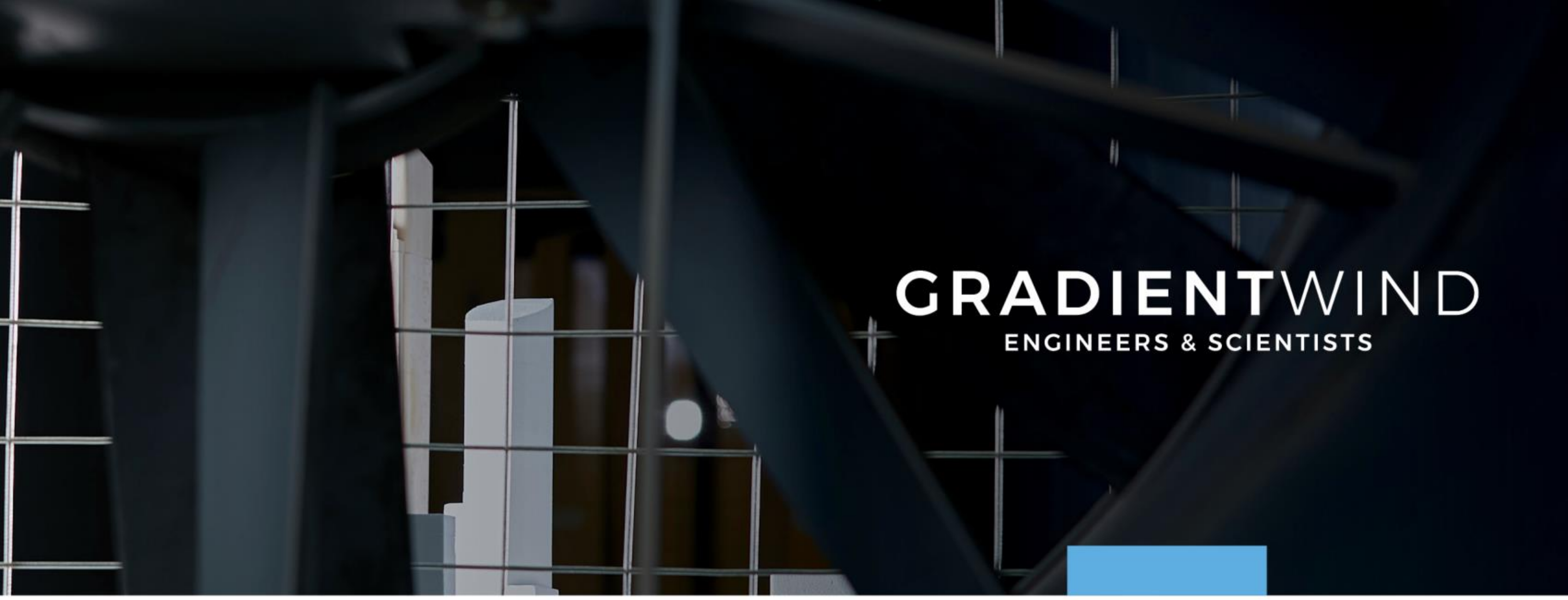
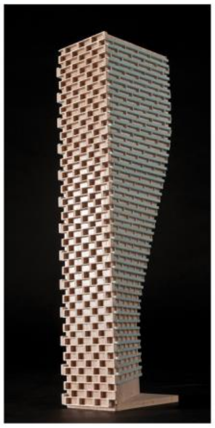
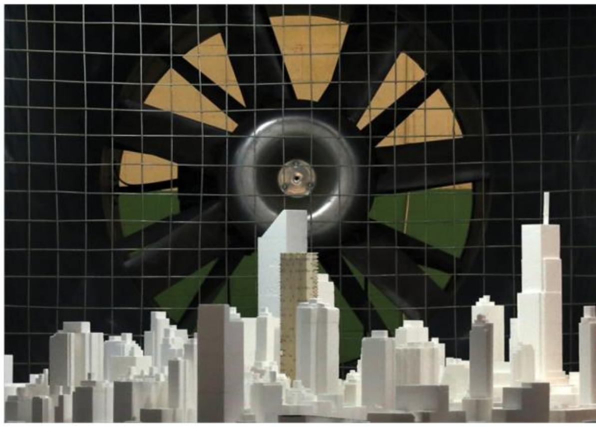


PEDESTRIAN LEVEL WIND STUDY

City Park Redevelopment, Phase 2
Ottawa, Ontario

REPORT: GWE15-068-CFDPLW – PHASE 2





November 12, 2018

PREPARED FOR
Stuart Craig
RioTrin Prop (Gloucester 3) Inc. (RioCan REIT)
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EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind conditions for Phase 2 of the City Park Redevelopment in Ottawa, Ontario. It is noteworthy that the study model for this site incorporated the future proposed massing of Phases 3 through 5, in addition to Phase 2 and the existing Phase 1 massing. The study involves 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.

Our work is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by Hobin Architecture Incorporated 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 provided in Section 5 of this report and illustrated in Figures 3A-6B following the main text. Based on CFD test results, interpretation, and experience with similar developments, as well as reference to City of Ottawa pedestrian wind speed criteria, we conclude that wind conditions over most pedestrian sensitive grade-level locations within and surrounding the study site will be acceptable for the intended uses on a seasonal basis. Exceptions include the Phase 2 podium rooftop amenity area, as well as windier areas of the landscaped spaces and Phase 1 podium rooftop if seating is desired for these locations. The outdoor amenity space at Level 21 will not achieve conditions suitable for sitting without mitigation. To ensure acceptable wind conditions over these areas, mitigation is recommended as described in Section 5.

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to experience conditions too windy for walking, or that could be considered unsafe.

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by RioTrin Prop (Gloucester 3) Inc. (RioCan REIT) to undertake a computer-based pedestrian level wind study for Phase 2 of the proposed City Park Redevelopment in Ottawa, Ontario. Our mandate within this study is to investigate pedestrian wind comfort and safety 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 computer simulations using the Computational Fluid Dynamics (CFD) technique and data analysis procedures, architectural drawings provided by Hobin Architecture Incorporated 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 detailed pedestrian level wind study is Phase 2 of the proposed City Park Redevelopment in Ottawa, Ontario. While the focus of this study is Phase 2, the study model also incorporated the future proposed massing of Phases 3 through 5, in addition to Phase 2 and the existing Phase 1 massing. The study site is located at 2280 City Park Drive, on a parcel of land bounded by City Park Drive to the north, the OC Transpo transitway to the south and east, and green space to the west.

The overall development site comprises Phases 1 through 5, respectively located clockwise on the site beginning with Phase 5 at the southeast corner. Phase 1 is an existing 23-storey building, while Phases 2 through 5 are single-building developments that respectively rise 20, 18, 16 and 18 storeys. All phases feature nearly rectangular building planforms with rectangular corner insets. Additionally, the site includes a proposed two-storey commercial building at the northeast corner, separated from Phase 2 to the south by green space and Phase 4 to the west by Settlement Drive. A roundabout driveway at the centre of the site (also referred to as Settlement Drive) connects the study buildings to City Park Drive, while the centre of the roundabout provides landscaped area and pedestrian walkways.

Phases 1 through 5 feature partially sunken, single-storey podia that collectively wrap around the south and west perimeter of the site. The topography at the interior of the study site slopes up from the roundabout so that the podia rooftops occur at grade-level when accessed from the east and north, while the south and west elevations of the buildings are fully exposed from grade to rooftop level. A driveway wraps around the south and west sides of the building, providing several vehicle and pedestrian access points to covered parking garages within the podia.

Phase 2, the focus of the present study, is a residential building of rectangular planform with the long-axis oriented in the east-west direction. The sunken podium/P1 level comprises indoor parking and building support function rooms. Building entrances are located along the south and west elevations of the P1 Level, in addition to a vehicular access point at the west side. Ground floor comprises indoor amenity space and residential units, with building entrances located along the north and west elevations. The exterior of ground floor features indoor amenity space at the west side of the building, overtop of the sunken podium rooftop. At Level 4, the floorplate variably sets back from all elevations to create cantilevered balconies. At Level 21, the floorplate sets back from the north, east and west, creating an outdoor amenity terrace that wraps around the west and north sides of the mechanical penthouse. The Level 21 terrace is partially covered by a canopy feature extending from the west side of the mechanical penthouse.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-metre radius of the site) are characterized by low-rise commercial buildings and paved space to the north and east, green space followed by low-rise residential buildings to the west, and the Queensway followed by low-rise residential buildings to the south. The far-field surroundings (defined as the area beyond the near field and within a two-kilometer radius), are characterized by low-rise commercial and residential developments from the south clockwise to the northeast, and green space including the Pine View Golf Course to the southeast.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, walkways, surface parking, building access points, landscaped areas, and the grade-level and rooftop outdoor amenity areas. Figure 1A illustrates the study site and surrounding context, while Figure 1B illustrates the rooftop outdoor amenity areas. 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 wind comfort and safety conditions at key areas within and surrounding the development 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 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 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 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 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.

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

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 840 metres.

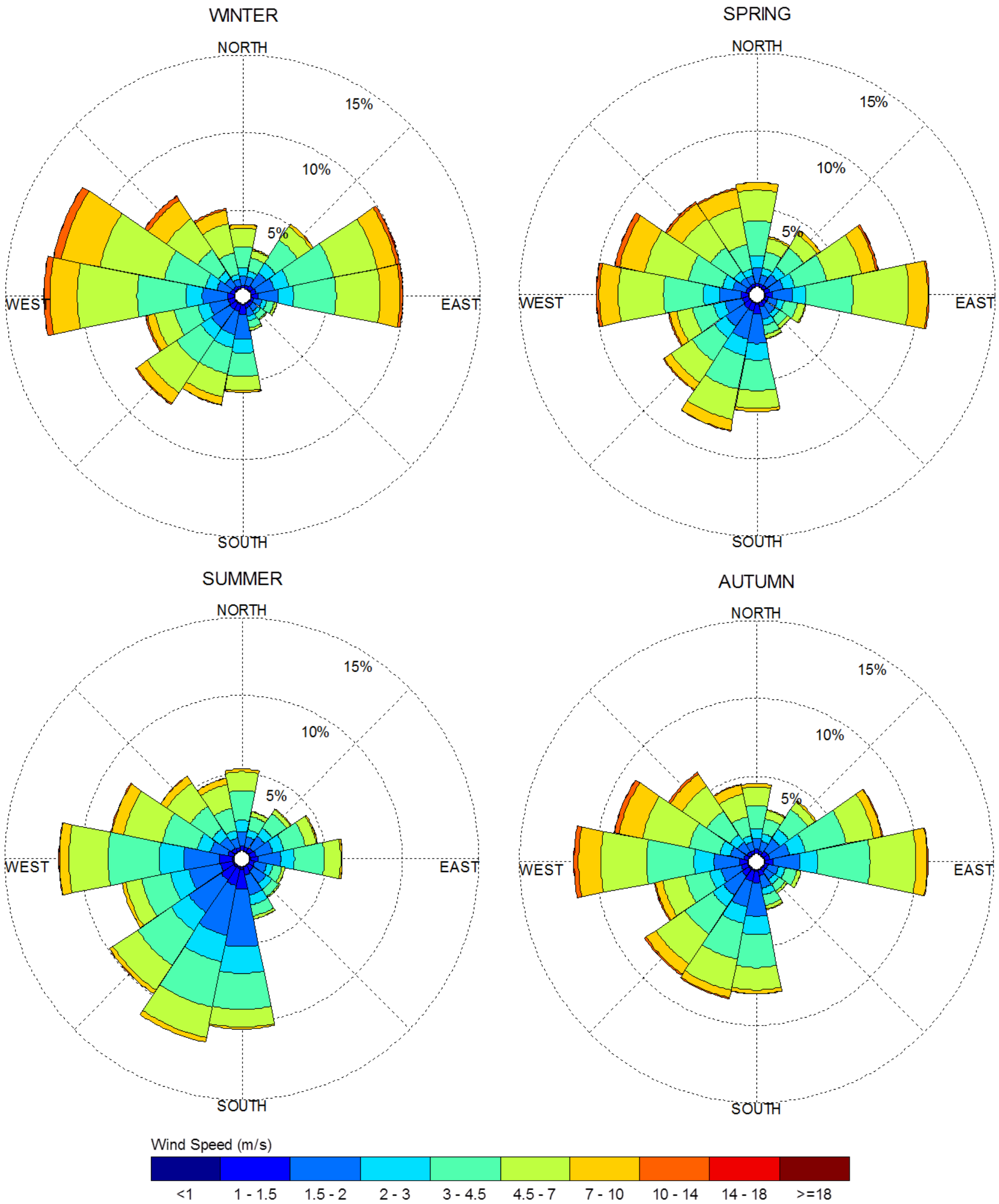
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 metres above local grade were referenced to the wind speed at gradient height to generate 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 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 m/s. 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 are mean hourly in m/s, measured at 10 m above the ground.

4.4 Pedestrian Comfort and Safety Guidelines

Pedestrian comfort and safety guidelines 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 gust wind speed ranges, which include (i) Sitting; (ii) Standing; (iii) Strolling; (iv) Walking; and (v) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

(i) **Sitting:** Mean wind speeds less than or equal to 10 kilometers per hour (km/h).

(ii) **Standing:** Mean wind speeds less than or equal to 14 km/h (i.e. 10-14 km/h).

(iii) **Strolling:** Mean wind speeds less than or equal to 16 km/h (i.e. 14-16 km/h).

(iv) **Walking:** Mean wind speeds less than or equal to 20 km/h (i.e. 16-20 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.

The pedestrian safety wind speed guideline 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 greater than 90 km/h is classified as dangerous.

The gust speed, and equivalent mean speed, ranges 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.

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 80% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if wind speeds of 10 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 20 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
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 is accompanied by Figures 3A through 6B (following the main text) illustrating the seasonal wind conditions at grade level and elevated terraces. 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 salmon and conditions suitable for walking are represented by blue.

Phase 2, Ground Floor Building Access Points, North and West Elevations (Tags A & B): The lobby and leasing office entrances at the north elevation of the Phase 2 building (Tag A) will be suitable for sitting throughout the year, which is acceptable. The secondary amenity entrances along the west elevation of the building will be suitable for sitting or standing during the summer, spring and autumn, transitioning to conditions suitable for strolling during the winter at the two southernmost entrances, which is acceptable.

Phase 2, P1 Level Building Access Points, South Elevation (Tags C): All pedestrian access points to the P1 level along the south elevation will be suitable for sitting or standing throughout the year, which is acceptable.

Phase 2, Grade-Level Outdoor Amenity Area at West Side of Building (Tag D): The outdoor amenity area serving Phase 2 over the podium rooftop is suitable for standing during the summer and walking or better for the remainder of the year, with the windiest conditions occurring at the southeast edge of the podium. To ensure the space is suitable for seating or more sedentary activities during the intended use period of late spring to early autumn, it is recommended to install a 2.0-metre-tall wind barrier along the podium edge between Phases 2 and 3, as well as 2.0-metre-deep canopies along the inward-facing elevations of the Phase 2 and Phase 3 buildings to deflect downwash flows. Additionally, it is recommended to install 1.8-metre-tall localized wind barriers directly northwest of seating areas. The noted barriers may take the form of high-solidity wind barriers, dense coniferous plantings, or a combination thereof. The exact placement and configuration of barriers can be determined at a later date as the landscape plan develops.

All Garage Entrances and Adjacent Surface Parking, West and South Elevations of Podia (Tags E & F): The parking garage entrances serving all phases along the south and west sides of the podium (Tag E) will be suitable for sitting during the summer and sitting or standing for the remainder of the year. The adjacent surface parking areas (Tag F) will be suitable for sitting or standing during the summer and strolling or better for the remainder of the year. These conditions are appropriate for the intended uses.

Settlement Drive Including Adjacent Surface Parking and Sidewalks (Tag G): Settlement Drive, including all adjacent surface parking and sidewalks, will be suitable for sitting or standing during the summer and mostly be suitable for strolling or better throughout the remainder of the year, which is acceptable.

Landscaped Areas Serving the Development Site (Tag H): The landscaped areas serving the development, including the green space at the centre of the Settlement Drive roundabout and the space between Phase 1 and the proposed commercial building, will be suitable for sitting or standing during the summer and mostly suitable for strolling or better for the remainder of the year. These conditions are acceptable, provided seating or more sedentary activities are not desired. If seating is desired in windier locations, it is recommended to install localized 1.8-metre-tall wind barriers directly north and west of seating. The exact placement and configuration of barriers can be determined at a later date as the landscape plan develops.

Potential Podium Rooftop Amenity Areas Serving Phase 1 (Tag I): The podium rooftop serving Phase 1 to the south of the building will be suitable for sitting throughout the year without mitigation, while the west side of the building will be suitable for walking or better throughout the year. If seating is desired over this windier west section of podium, it is recommended to install a 2.0-metre-tall wind barrier along the podium edge between Phases 1 and 2, as well as 2.0-metre-deep canopies along the inward-facing elevations of the Phase 1 and Phase 2 buildings. Additionally, it is recommended to install 1.8-metre-tall localized wind barriers directly northwest of seating areas. The exact placement and configuration of barriers can be determined at a later date as the landscape plan develops.

Wind conditions over the remaining podia rooftops serving Phases 3, 4 and 5 are not likely to be significantly influenced by the Phase 2 development, given the directional probability of winds, orientation of the various massing, and the distance of these phases from the study building. Wind conditions over these areas are therefore not described in the present assessment.

Phase 2 Level 21 Rooftop Terrace (Tag J): The rooftop amenity area at the west and north sides of the mechanical penthouse will largely be suitable for standing during the summer and strolling or standing for the remainder of the year. To ensure the area is suitable for sitting during the intended use period of late spring to early autumn, it is recommended to install 2.0-metre-tall wind barriers along the entire perimeter of the space.

Influence of the Proposed Development on Existing Wind Conditions near the Study Site: Wind conditions over surrounding sidewalks beyond the development site, as well as at nearby building entrances, will be comfortable for their intended pedestrian uses during each seasonal period upon the introduction of the proposed Phase 2 development.

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

6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for Phase 2 of the proposed City Park Redevelopment in Ottawa, Ontario. The study was performed in accordance with industry standard CFD simulation and data analysis procedures.

A complete summary of the predicted wind conditions is provided in Section 5 of this report and illustrated in Figures 3A-6B following the main text. Based on CFD test results, meteorological data analysis of the Ottawa wind climate, and experience with similar developments in Ottawa, we conclude that wind conditions over most pedestrian sensitive grade-level locations within and surrounding the study site will be acceptable for the intended uses on a seasonal basis. Exceptions include the Phase 2 podium rooftop amenity area, as well as windier areas of the landscaped spaces and Phase 1 podium rooftop if seating is desired for these locations. The outdoor amenity space at Level 21 will not achieve conditions suitable for sitting without mitigation. To ensure acceptable wind conditions over these areas, mitigation is recommended as described in Section 5.

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to experience conditions too windy for walking, or that could be considered unsafe.

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

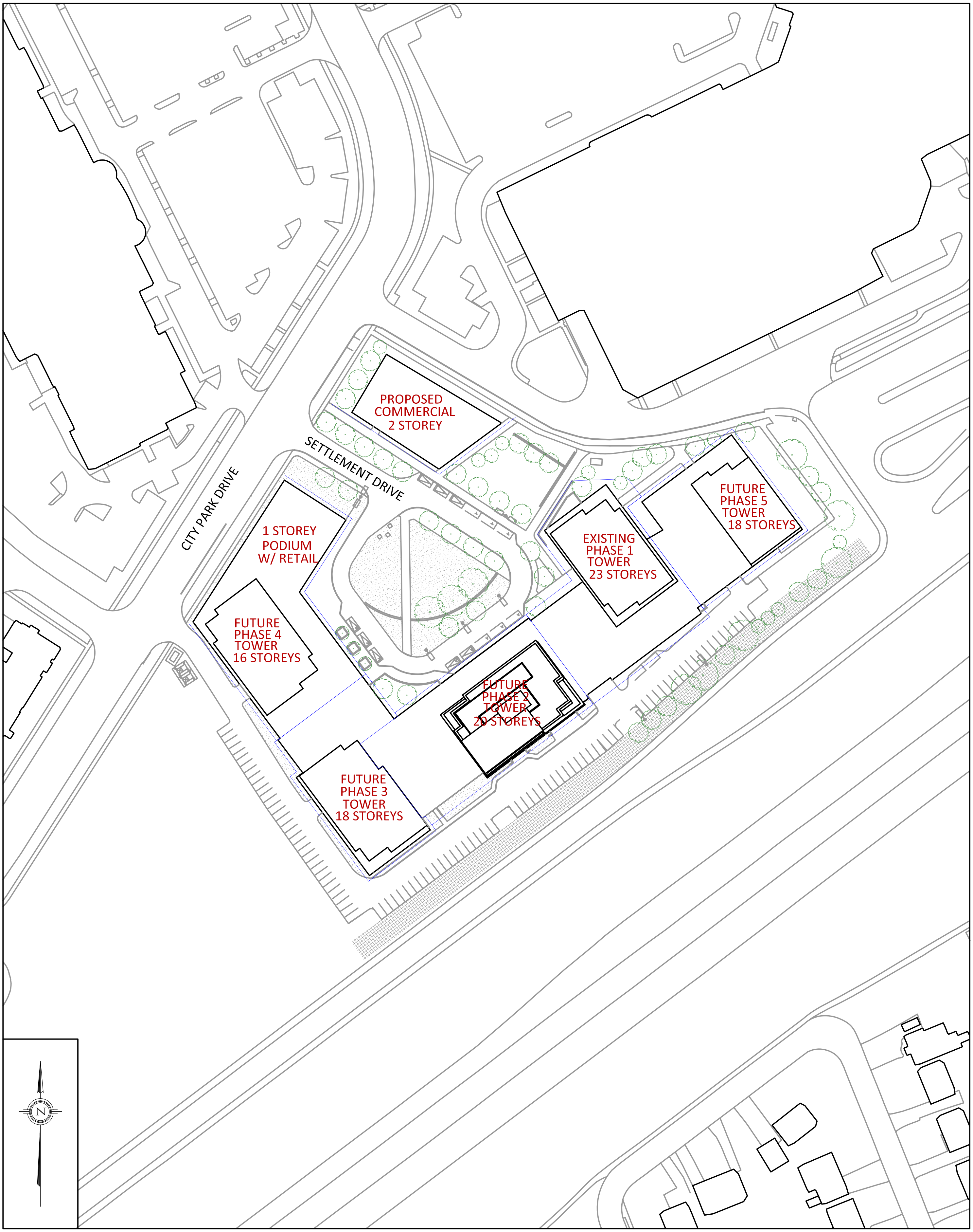
Sincerely,

Gradient Wind Engineering Inc.

Megan Prescott, MESc.,
Project Manager

Andrew Sliasas, M.A.Sc., P.Eng.,
Principal

GWE15-068-CFDPLW – PHASE 2



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PROJECT: CITY PARK REDEVELOPMENT - PHASE 2, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
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DATE: NOVEMBER 12, 2018	DRAWN BY: K.A.	

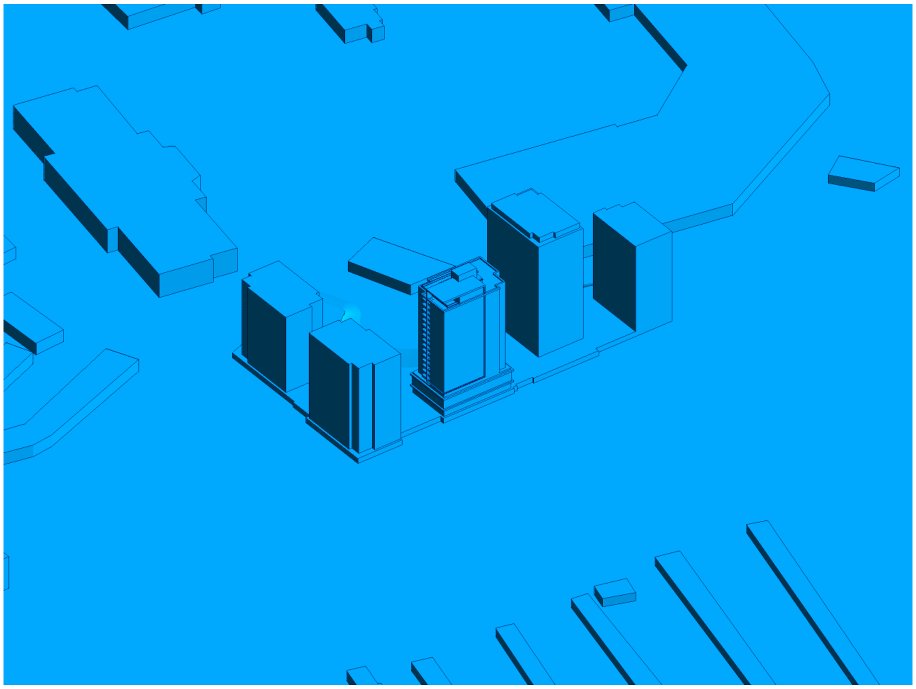


FIGURE 2A: COMPUTATIONAL MODEL, LOOKING NORTH

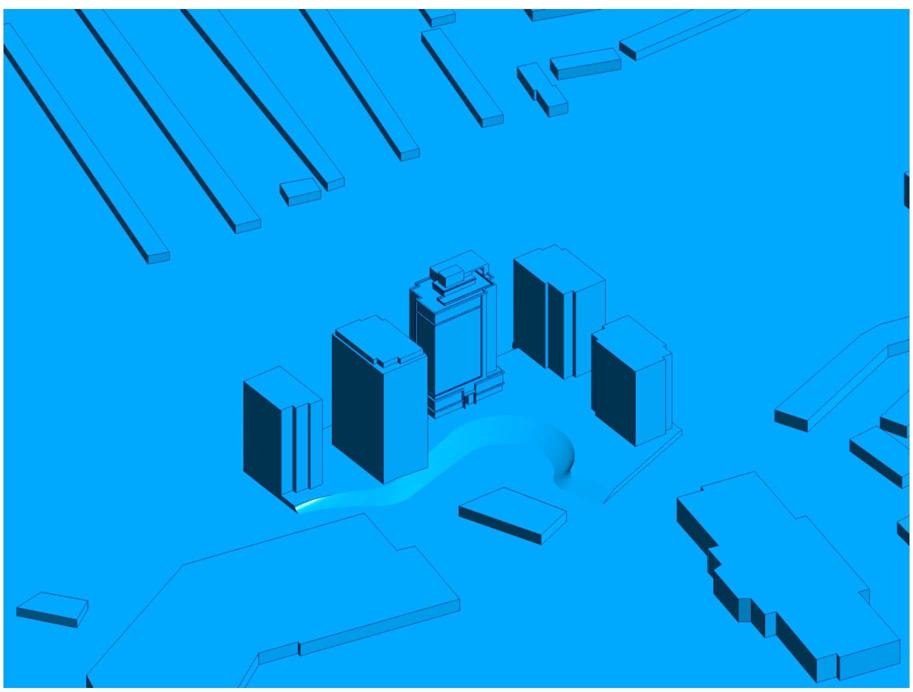


FIGURE 2B: STUDY BUILDING, LOOKING SOUTH

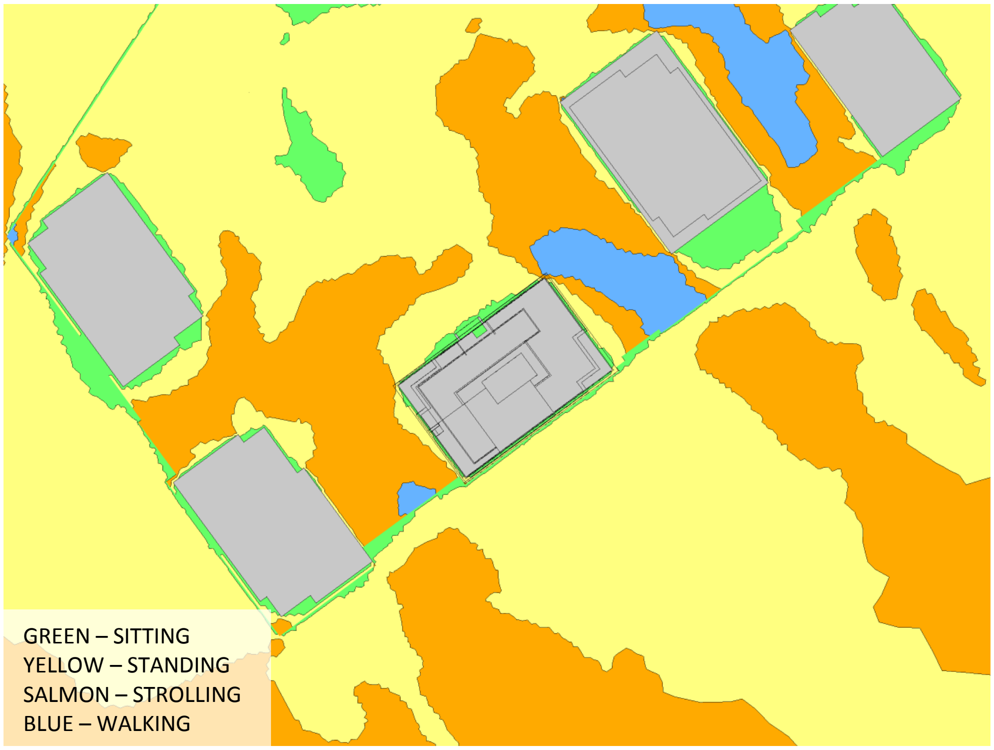
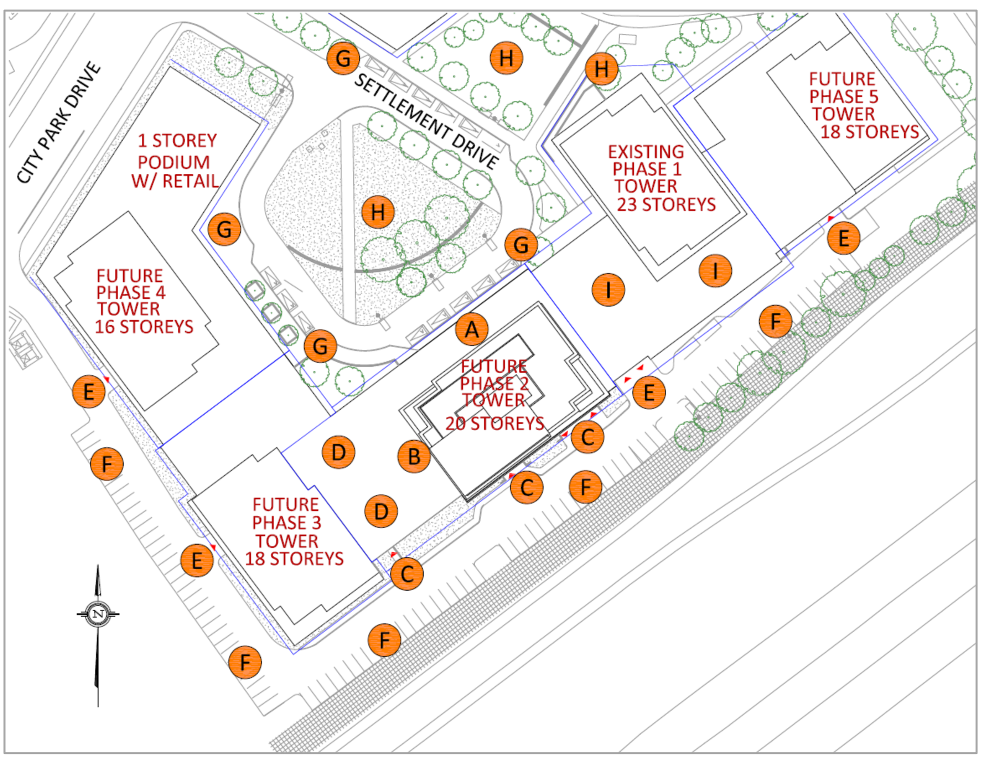


FIGURE 3A: SPRING – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



CITY PARK REDEVELOPMENT, PHASE 2 – GRADE REFERENCE MARKER LOCATION

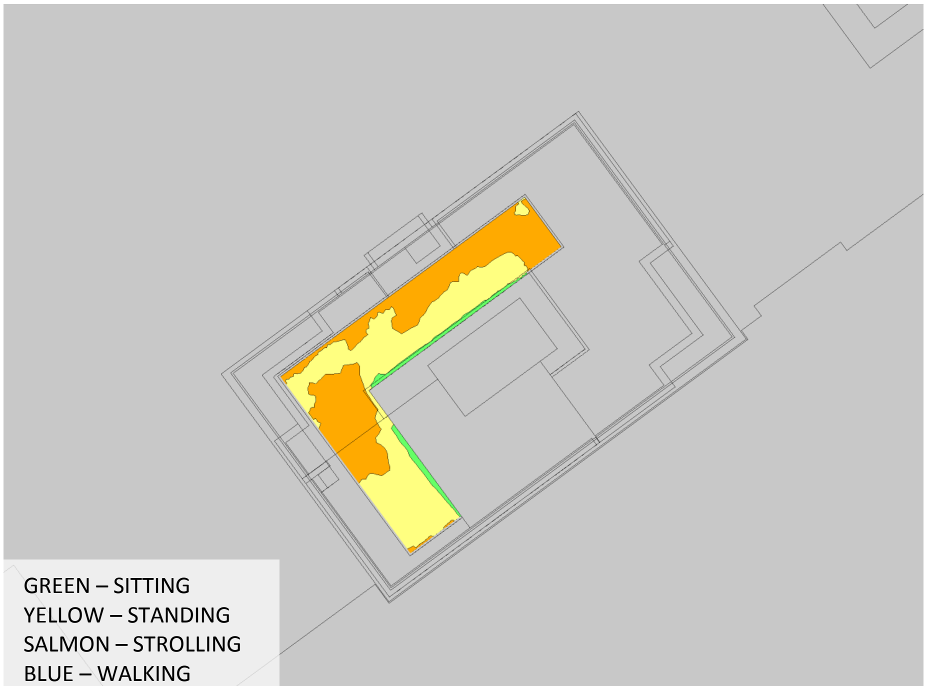
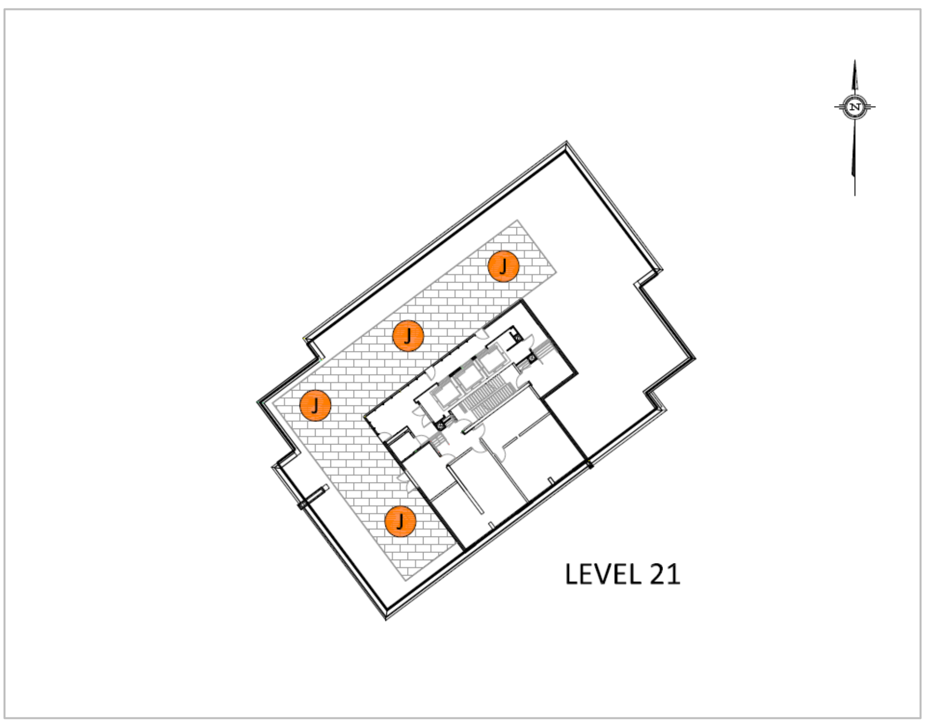
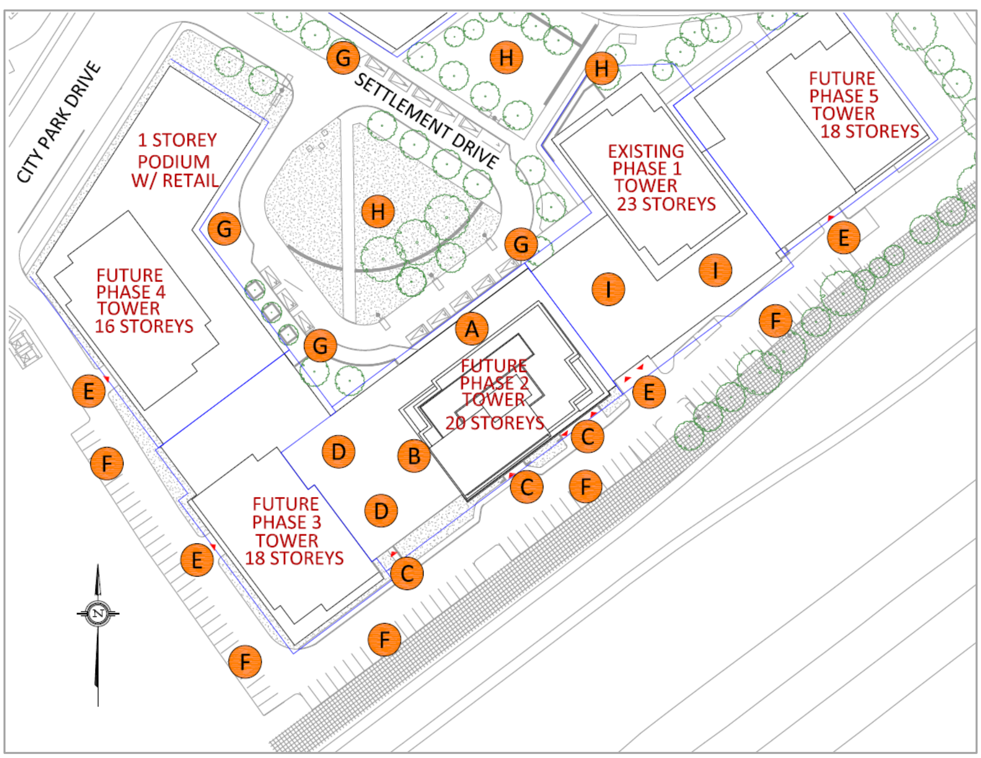


FIGURE 3B: SPRING – OUTDOOR AMENITY AREA WIND CONDITIONS



CITY PARK DEVELOPMENT, PHASE 2 – ELEVATED REFERENCE MARKER LOCATIONS

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



CITY PARK REDEVELOPMENT, PHASE 2 – GRADE REFERENCE MARKER LOCATION

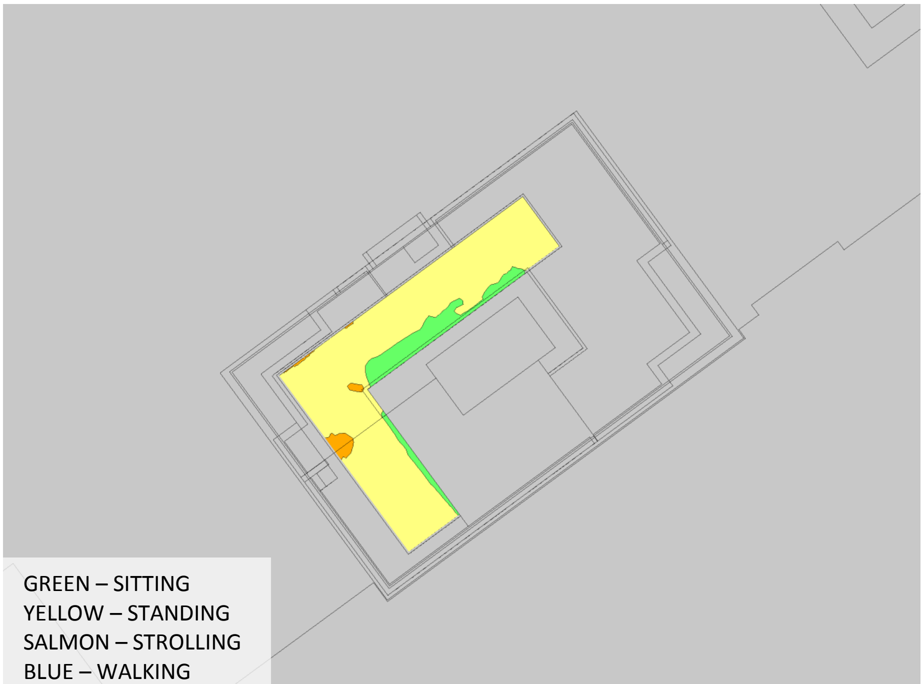
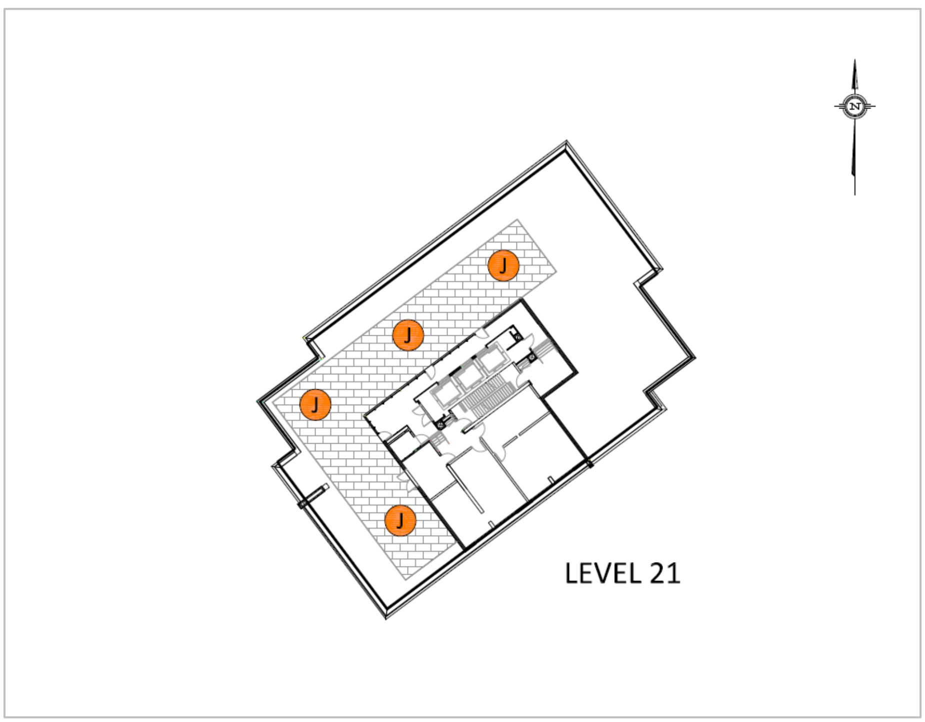


FIGURE 4B: SUMMER – OUTDOOR AMENITY AREA WIND CONDITIONS



CITY PARK DEVELOPMENT, PHASE 2 – ELEVATED REFERENCE MARKER LOCATIONS

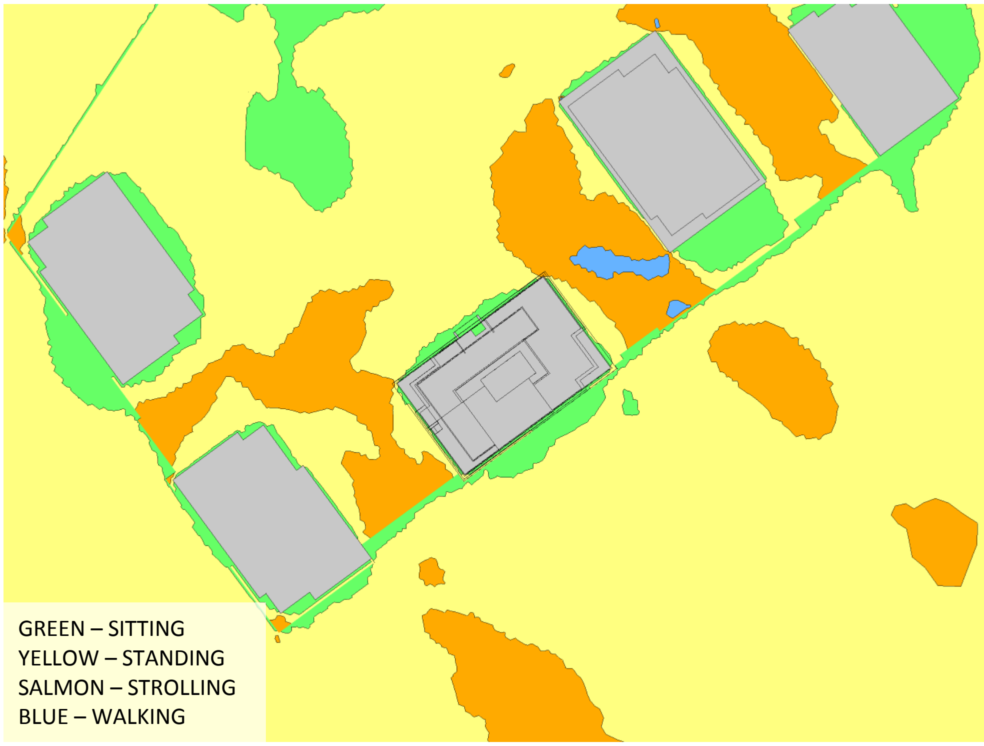
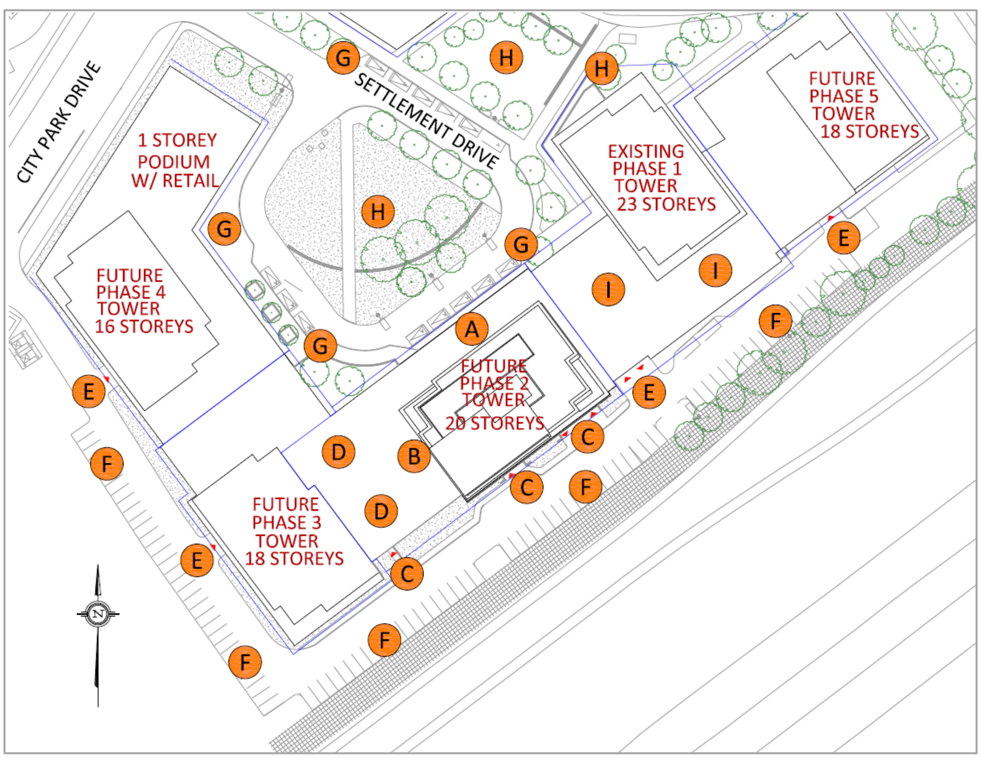


FIGURE 5A: AUTUMN – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



CITY PARK REDEVELOPMENT, PHASE 2 – GRADE REFERENCE MARKER LOCATION

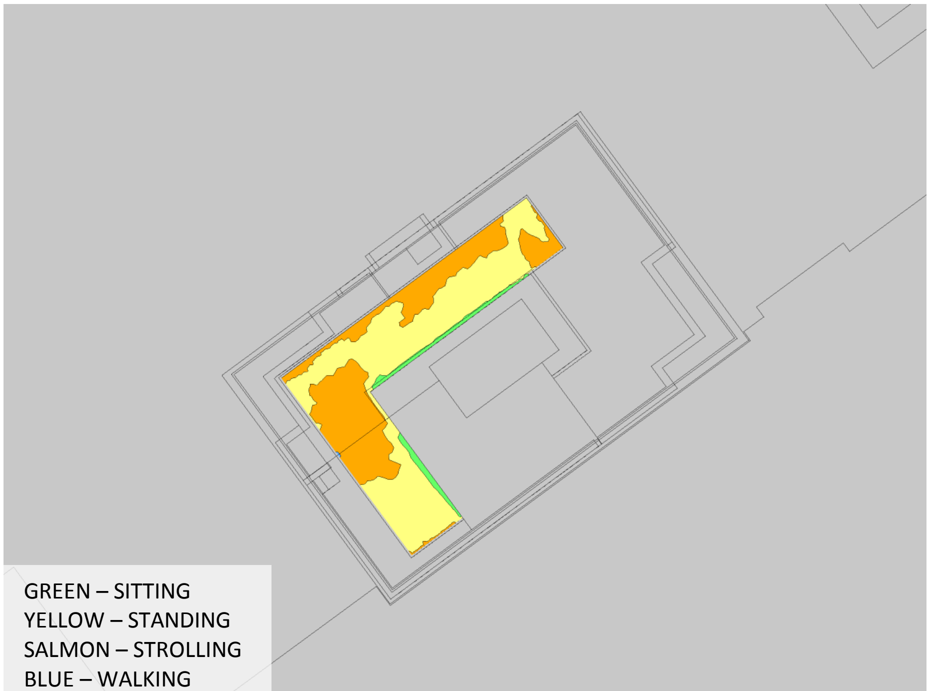
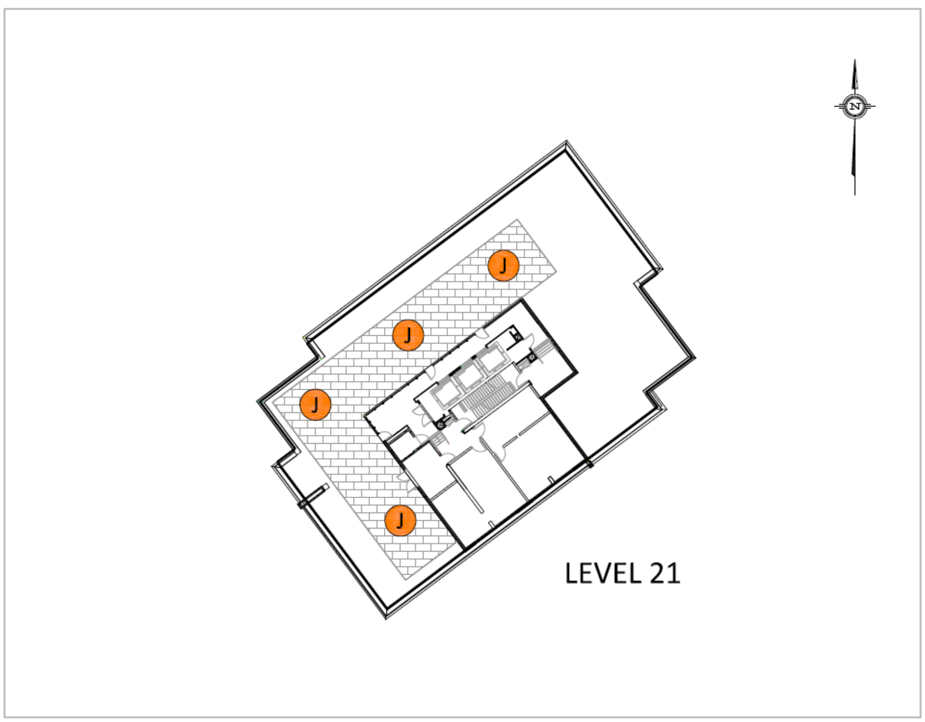


FIGURE 5B: AUTUMN – OUTDOOR AMENITY AREA WIND CONDITIONS



CITY PARK DEVELOPMENT, PHASE 2 – ELEVATED REFERENCE MARKER LOCATIONS

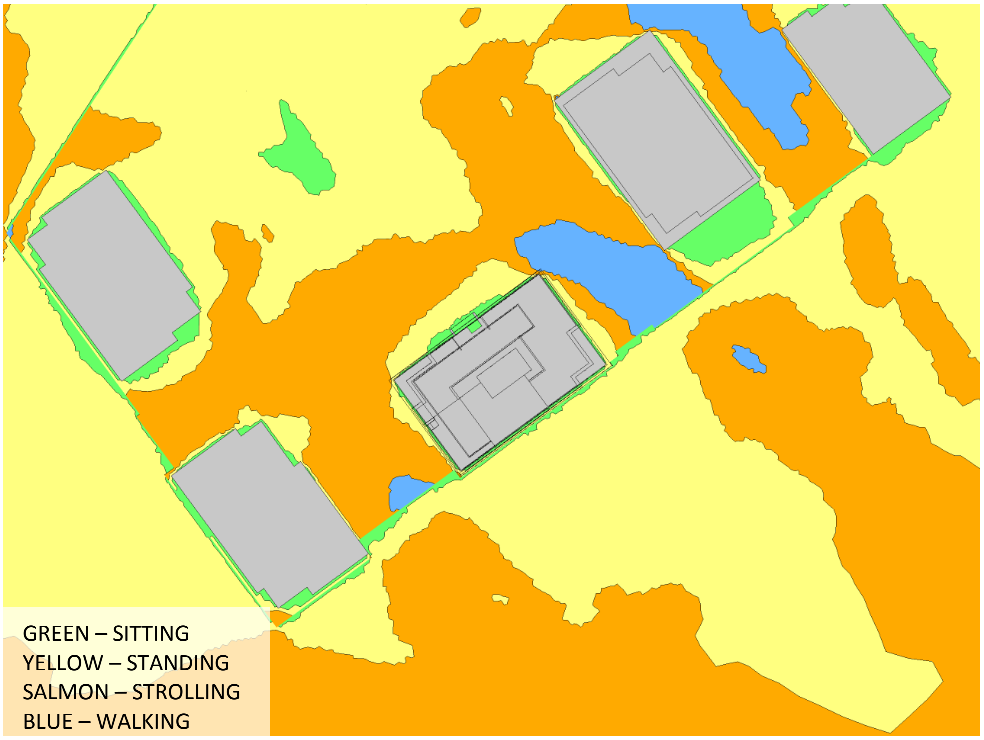
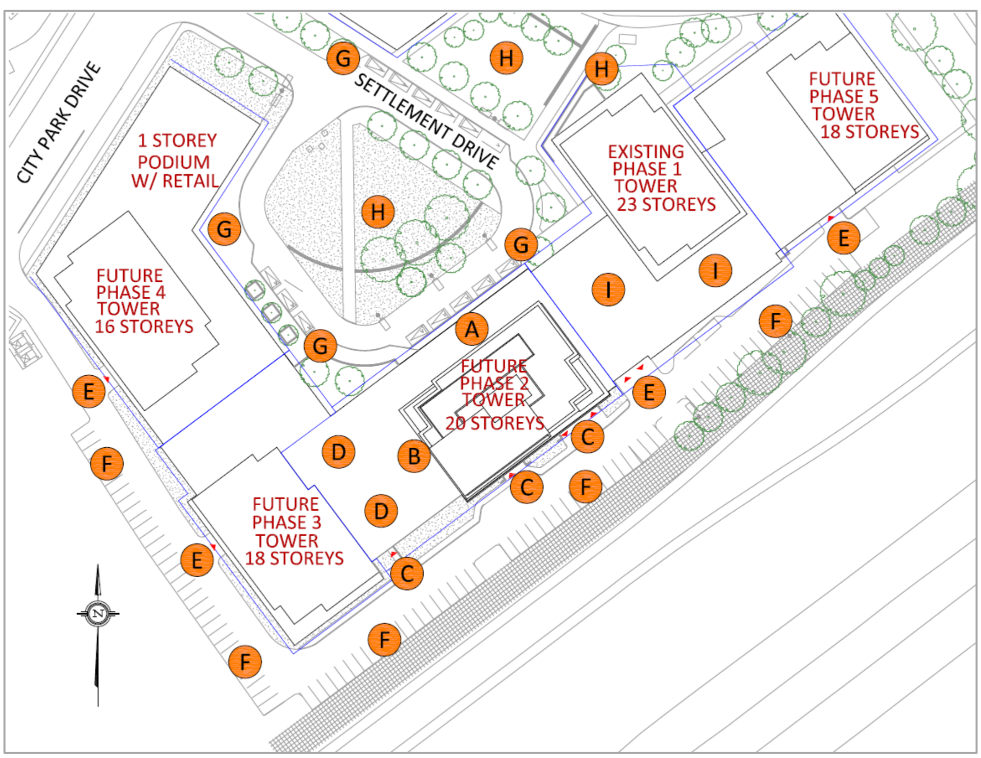


FIGURE 6A: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



CITY PARK REDEVELOPMENT, PHASE 2 – GRADE REFERENCE MARKER LOCATION

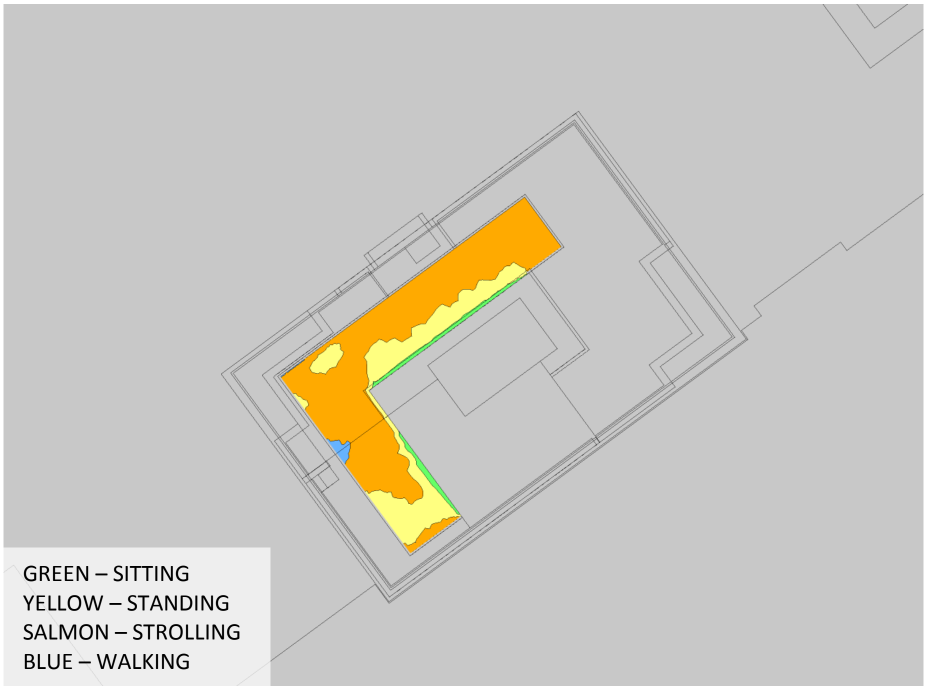
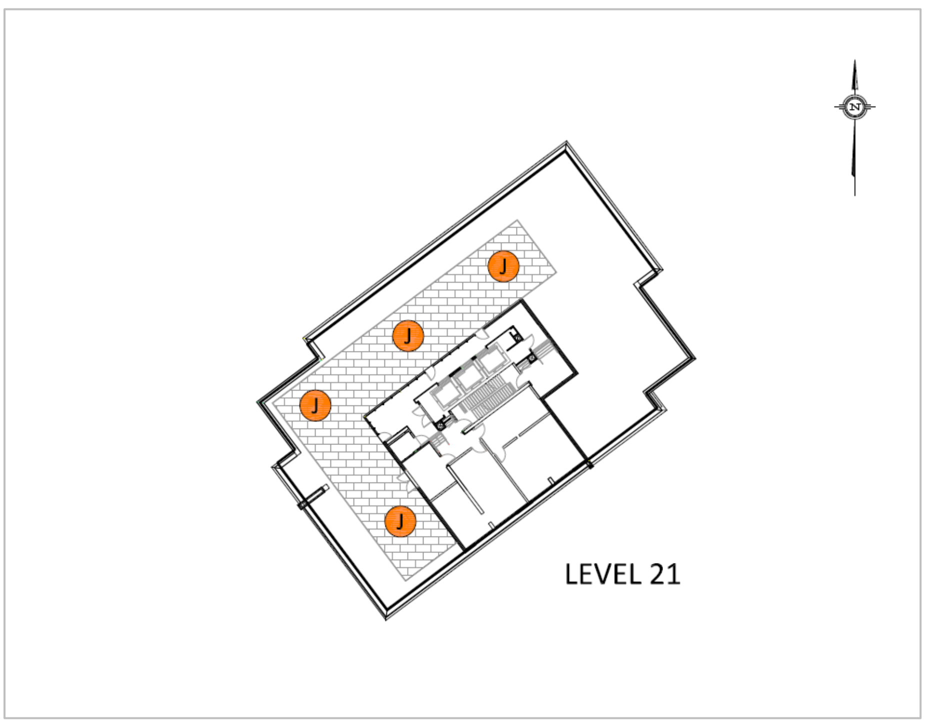
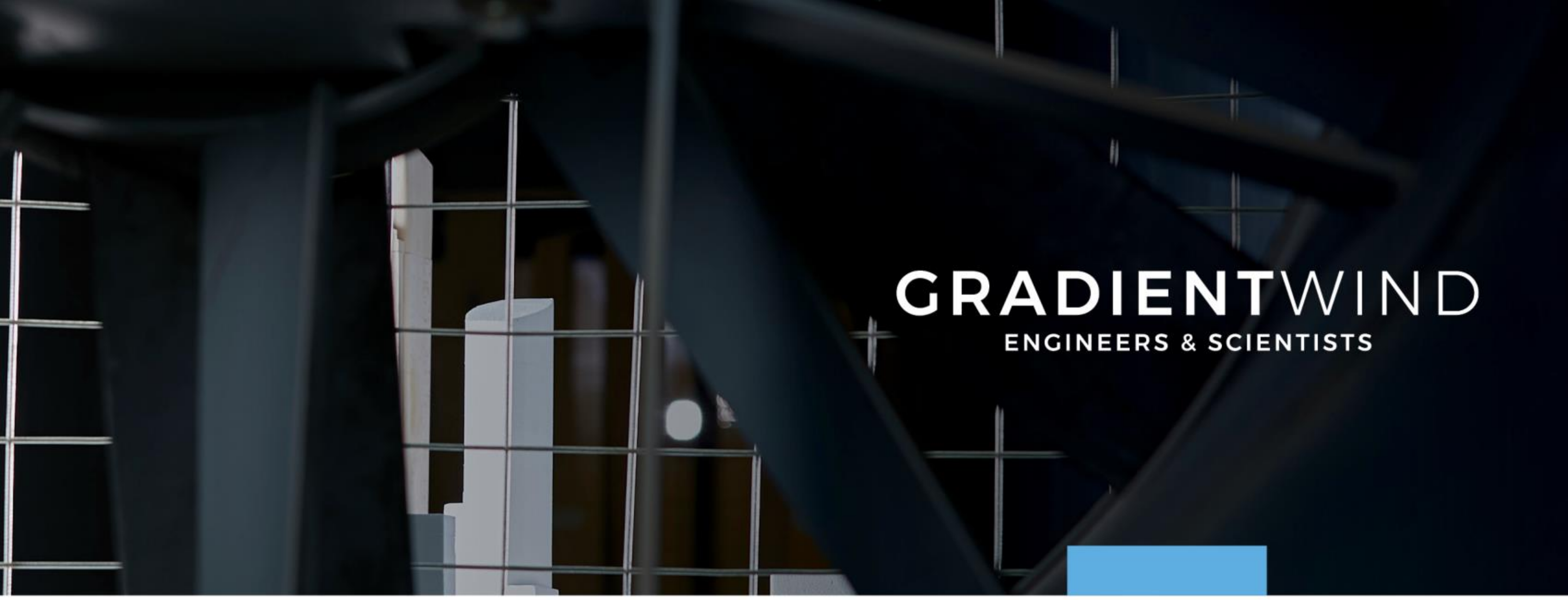


FIGURE 6A: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



CITY PARK DEVELOPMENT, PHASE 2 – ELEVATED REFERENCE MARKER LOCATIONS



APPENDIX A

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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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 metres (m) to 600 m.

Simulating real wind behaviour in a wind tunnel 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 B1 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 B2 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 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.

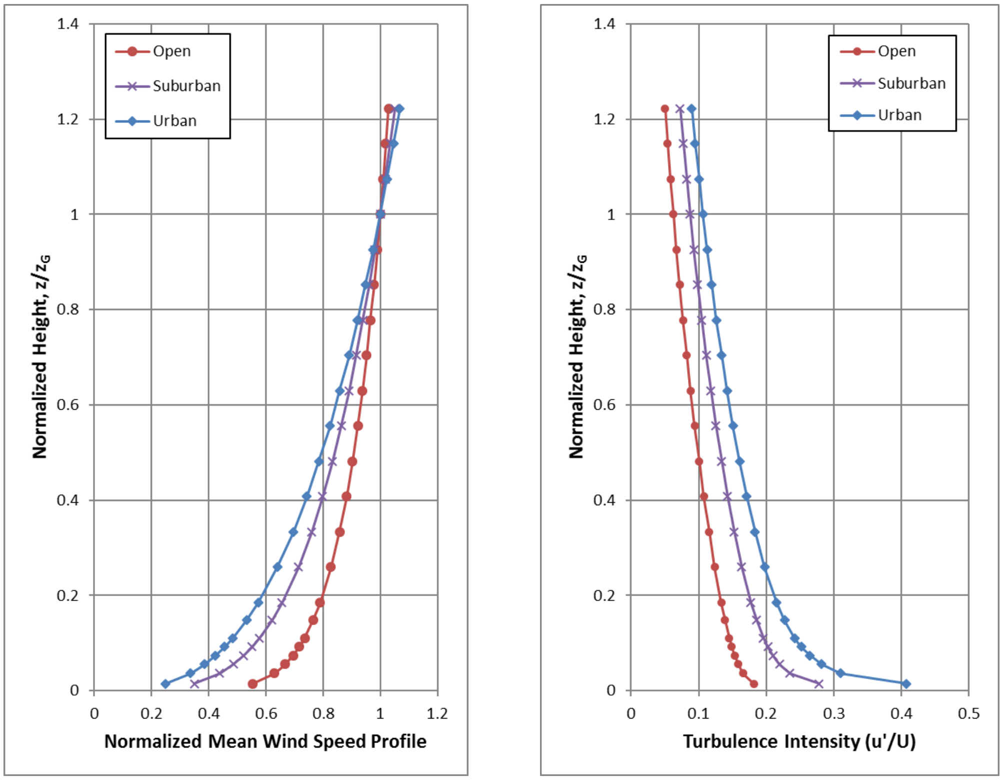

FIGURE A1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE A2 (RIGHT): TURBULENCE INTENSITY PROFILES

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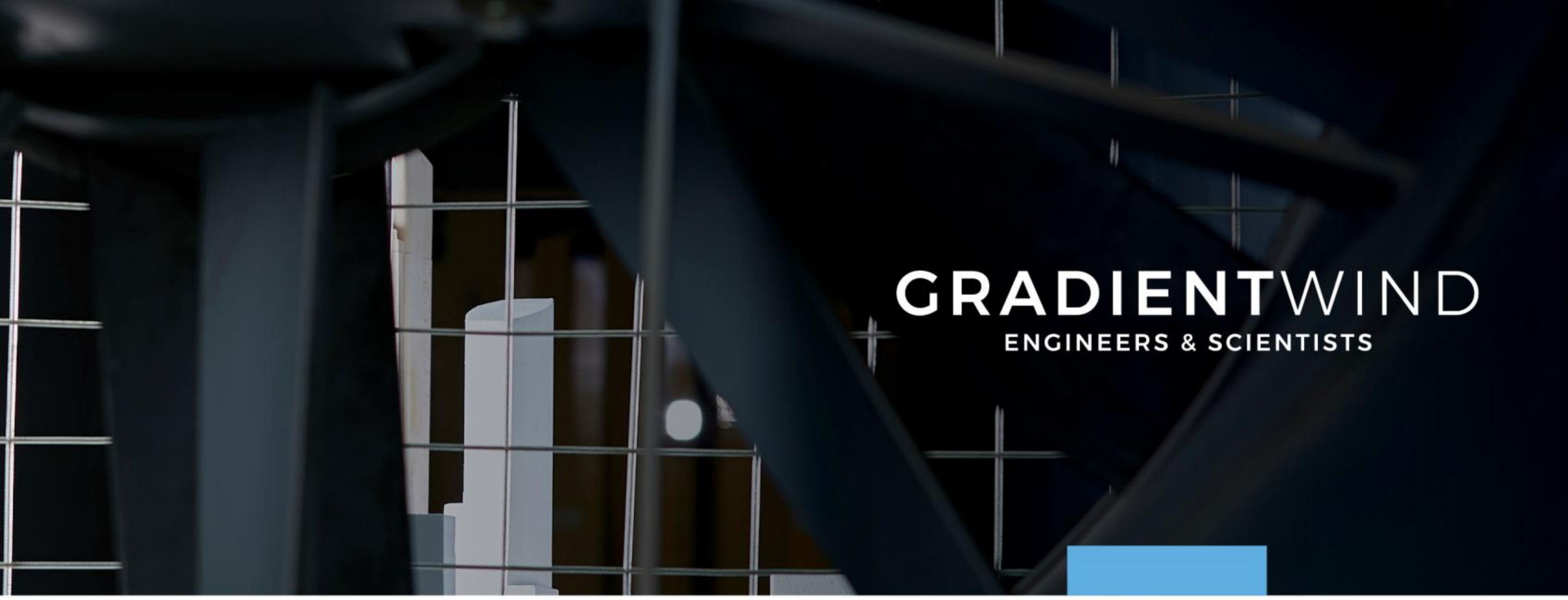

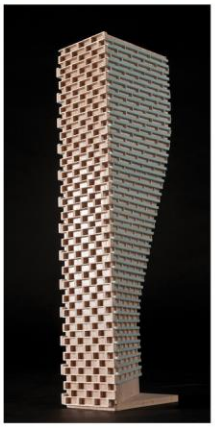

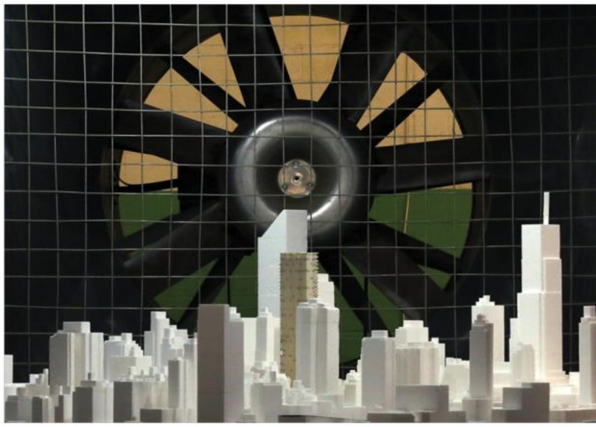

APPENDIX B

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

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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:

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

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

Where, ***U_N/U_g*** is the 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.

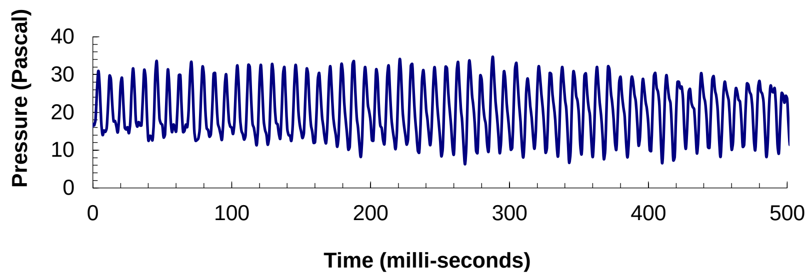

FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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