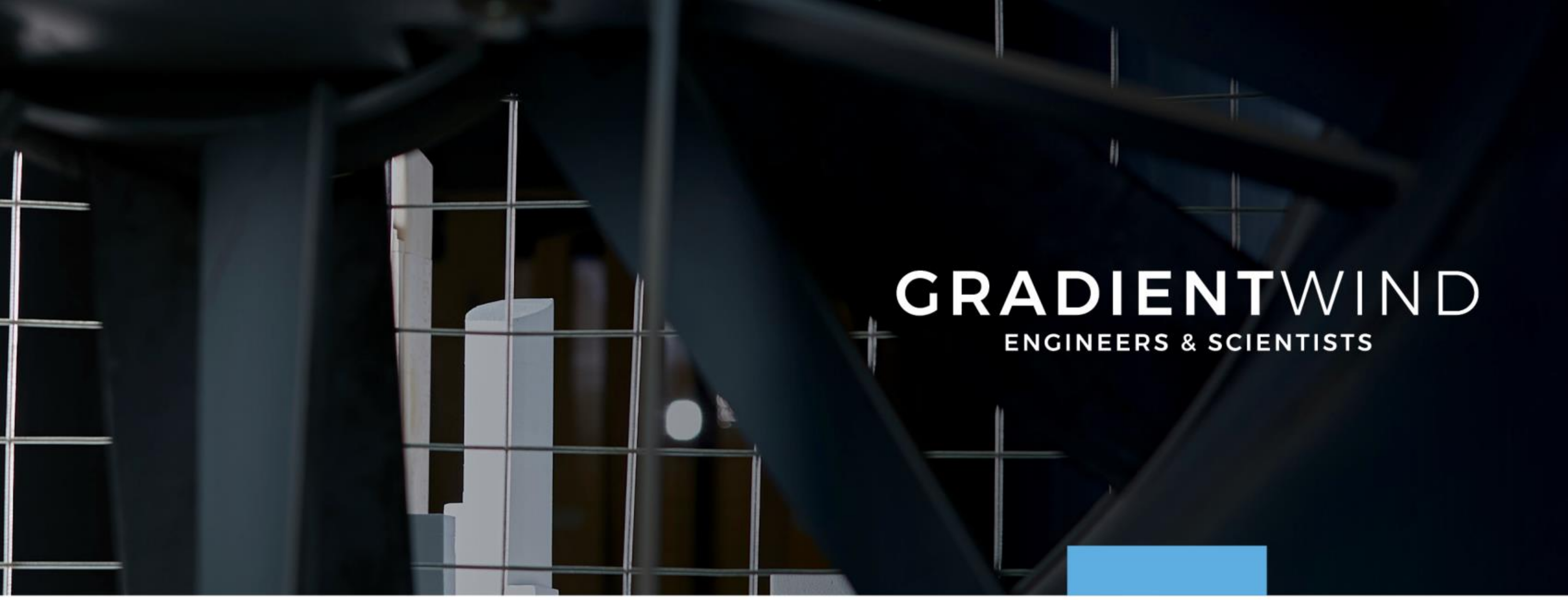
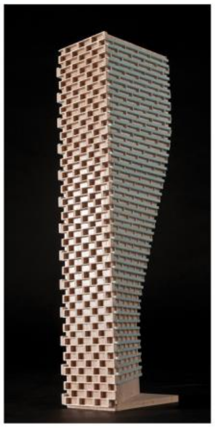
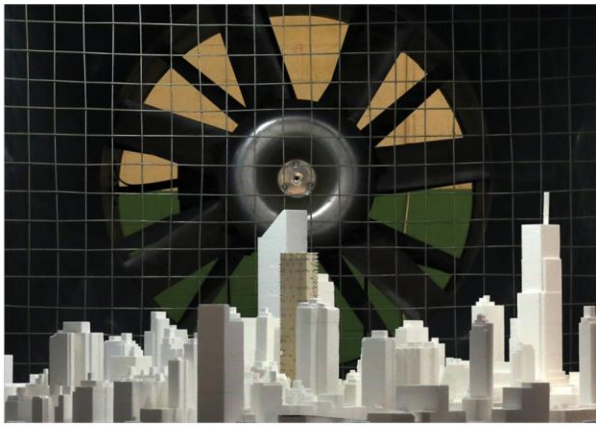


PEDESTRIAN LEVEL WIND STUDY

100 Bayshore Drive
Ottawa, Ontario

Report: 19-225-PLW-R1





April 28, 2021

PREPARED FOR
Bayshore Shopping Centre Limited and KS Bayshore Inc.
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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for a proposed two-building development located at 100 Bayshore Drive 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, as required.

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 wind comfort and safety within and surrounding the subject site according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report, illustrated in Figures 3A-5B, and summarized as follows:

1) With one exception, all areas at grade are predicted to be suitable for their intended uses throughout the year. This includes building access points, nearby sidewalks, landscaped areas, and the Bayshore Transit Station.

    a. The one area at grade that is not expected to meet the wind comfort criteria is the bus stop to the north of the proposed development, on Woodbridge Crescent. Conditions are predicted to exceed the standing comfort class during the three colder seasons. We recommend that a typical bus shelter be installed at this location to ensure pedestrians are provided with an opportunity to seek relief during periods of strong winds.

2) Conditions on the amenity terrace at Level 4 are mostly predicted to be suitable for standing during the typical use period (May to October, inclusive). Mitigation will be required to ensure conditions are comfortable for sitting within designated seating areas. A comprehensive mitigation strategy will be developed in collaboration with the design team. Specifically, in addition to the 1.8-metre-tall wind screen along the perimeter of the roof that was included in the present study, the strategy will include local wind barriers inboard of the perimeter to protect

designated seating areas and may also include canopies extending from the towers. Additional testing will be performed to confirm the efficacy of the preferred mitigation strategy.

3) The Amenity Levels (Levels 28 and 31 of the West and East Towers, respectively) have not yet been designed and may include outdoor amenity spaces. Wind conditions on any terrace that will serve common amenities will be investigated in the future, in conjunction with the mitigation testing for the Level 4 amenity terrace noted above.

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

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Bayshore Shopping Centre Limited and KS Bayshore Inc., at the request of Ivanhoe Cambridge Inc., to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for a proposed two-building development located at 100 Bayshore Drive 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, as required.

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 of the subject site prepared by Hobin Architecture in April 2021, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, recent satellite imagery, and experience with numerous similar developments.

2. TERMS OF REFERENCE

The subject site is located at 100 Bayshore Drive in Ottawa, Ontario and is situated on a parcel of land bordered by Woodridge Crescent to the north, Bayshore Transit Station to the south, Bayshore Shopping Centre to the east, and an existing 12-storey development to the west.

The subject site features two buildings rising 27 storeys and 30 storeys above grade, referred to as "West Tower" and "East Tower", respectively. The buildings rise to heights of approximately 95 meters (m) and 104 m, respectively, to the top of their mechanical penthouses, and share a three-storey L-shaped podium. A 1-storey amenity pavilion is located on top of the 3-storey podium, between the two buildings. Common outdoor amenity space is located to the north of the amenity pavilion, which will include an outdoor kitchen, a community garden, and seating areas. The terrace includes 1.8-m-tall wind barriers along its perimeter.

The buildings include Amenity Levels at Levels 28 and 31 of the West and East Towers, respectively, which have not yet been designed and may include indoor and/or outdoor amenity space. Should outdoor amenities be included, wind conditions for these spaces will be studied at a later date.

A covered pedestrian bridge will connect Level 2 of the building to the existing Bayshore Transit Station and Bayshore Shopping Centre. Primary building entrances are located along the north elevation of the West Tower and on the west elevation of the East Tower.

The near-field surroundings (defined as an area within 500 m of the study site) are composed of a mix of low-rise residential developments and isolated taller buildings from the west clockwise to the north-northeast (Accora Village), Bayshore Shopping Centre to the northeast, Bayshore Transit Station immediately to the south, and mostly open land from the east clockwise to the west, including greenspace and Highway 417. The far-field surroundings contribute primarily open wind exposures from the west-northwest clockwise to north, suburban wind exposures from the northeast clockwise to south-southeast, open wind exposures from the south clockwise to west-southwest, and hybrid open-suburban wind exposures from the west.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, walkways, building access points, nearby transit stops, and the rooftop amenity terraces serving the podium of the subject site. 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 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 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 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 from 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.

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

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 820 m.

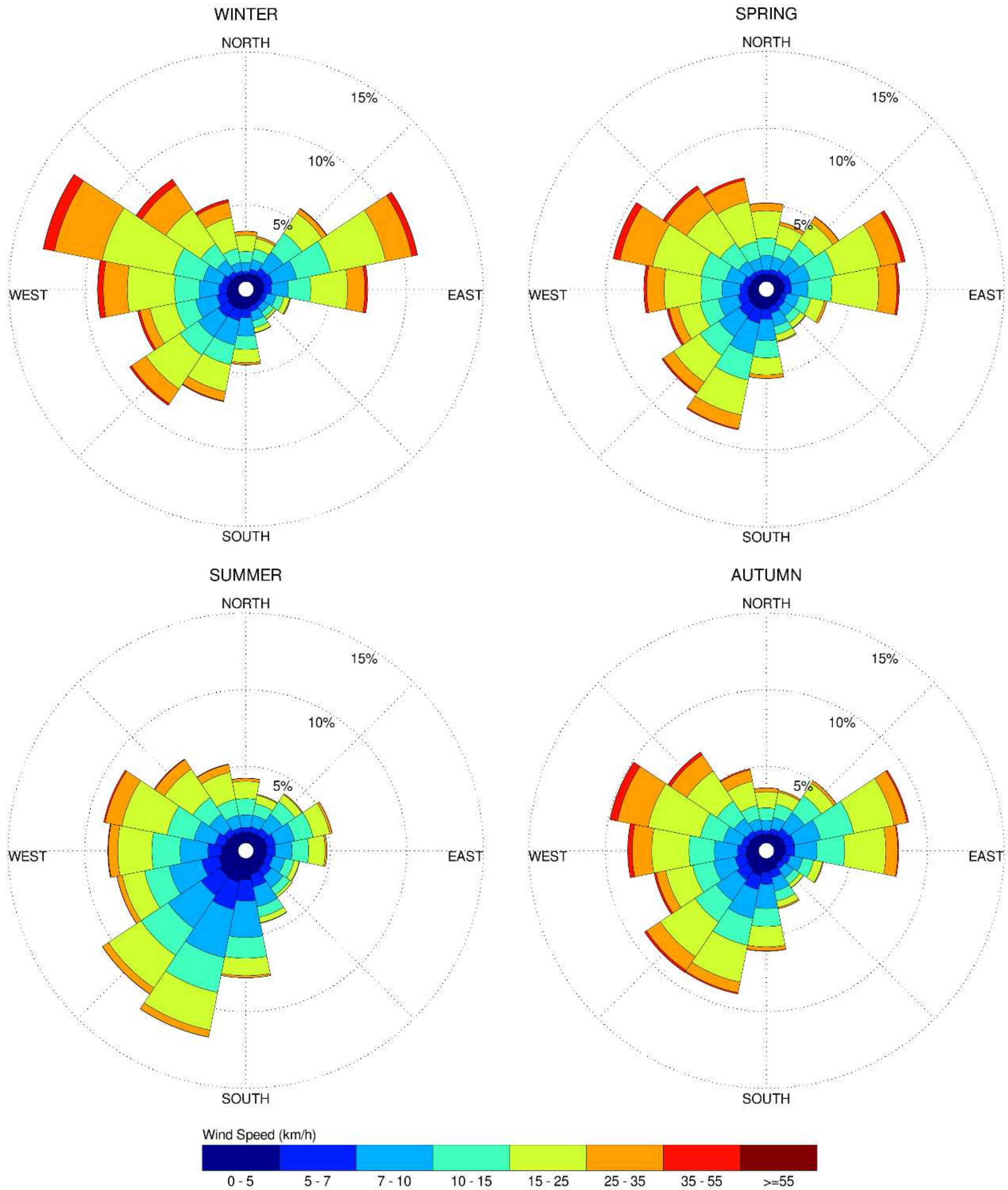
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds on a continuous measurement plane 1.5 m above local grade, and 1.5 m above the elevated amenity terrace 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. Further details of the CFD wind flow simulation technique are presented in Appendix A.

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 to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns.

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 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 WIND
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.

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 criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 20% 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 equivalent gust 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 equivalent gust 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 equivalent gust 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 equivalent gust 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 BEAUFORT SCALE

Number	Description	Wind Speed (km/h)		Description
		Mean	Gust	
2	Light Breeze	6-11	9-17	Wind felt on faces
3	Gentle Breeze	12-19	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	20-28	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	29-38	43-57	Small trees in leaf begin to sway
6	Strong Breeze	39-49	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	50-61	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	62-74	93-111	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 a mean wind speed 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. Similarly, if mean wind speed of 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 throughout the site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the desired comfort classes, which are dictated by the location type for each region (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
Primary Building Entrance	Standing
Secondary Building Access Point	Standing / Strolling / Walking
Primary Public Sidewalk	Strolling / Walking
Secondary Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting / Standing / Strolling
Café / Patio / Bench / Garden	Sitting
Transit Stop	Sitting / Standing
Public Park / Plaza	Standing / Strolling
Garage / Service Entrance	Walking
Parking Lot	Strolling / Walking
Vehicular Drop-Off Zone	Standing / Strolling / Walking

5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-3D and Figures 4A-4D (following the main text), illustrating seasonal wind comfort conditions at grade level and within the Level 4 amenity terrace, respectively. Wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site. The colour contours indicate various comfort classes predicted for certain regions, which correspond to the City of Ottawa wind comfort criteria in Section 4.4. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, walking by blue, while uncomfortable conditions are represented by the colour magenta.

Wind conditions over the Level 4 amenity terrace are also reported for the typical use period, which is defined as May to October, inclusive. Figure 5A illustrates wind comfort conditions during this period, consistent with the comfort classes in Section 4.4, while Figure 5B illustrates contours indicating the percentage of time the roof areas are predicted to be suitable for sitting. Pedestrian comfort is summarized below for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Woodridge Crescent: The sidewalks along Woodridge Crescent are predicted to be suitable for a mix of sitting and standing during the summer, suitable for strolling or better during the autumn, and suitable for walking or better during the spring and winter seasons. The windier conditions are predicted to occur near the northeast corner of the East Tower and the northwest corner of the West Tower. The noted conditions are considered acceptable with respect to the City of Ottawa pedestrian wind comfort criteria.

Transit Station Entrance Drive: The sidewalks along the entrance drive to the Bayshore transit station are predicted to be mostly suitable for standing during the summer, although a region below the elevated walkway that connects the noted station with the shopping centre is predicted to be suitable for strolling. During the remaining colder seasons, the area is predicted to be suitable for walking or better. The noted conditions are considered acceptable with respect to the City of Ottawa pedestrian wind comfort criteria.

Bus Stop: The bus stop to the north of the proposed development, on Woodbridge Crescent, is predicted to be suitable for standing during the summer and suitable for strolling during the remaining three colder seasons. We recommend that a typical bus shelter be installed at this location to ensure pedestrians are provided with an opportunity to seek relief during periods of strong winds.

Bayshore Transit Station: Conditions within the outdoor waiting areas serving the transit station are predicted to be suitable for standing during the three warmer seasons, becoming suitable for a mix of standing and strolling during the winter. While these conditions do not meet the target criterion for transit stops (suitable for standing or better throughout the year), conditions may be considered acceptable as the station is served by an indoor waiting area.

Landscaping Surrounding Proposed Building: Conditions within most of the landscaped areas throughout the subject site are predicted to be suitable for sitting during the summer, suitable for a mix of sitting and standing during the autumn, and suitable for strolling or better during the spring and winter. No areas within the subject site are predicted to exceed the walking comfort class on a seasonal basis. The noted conditions are considered acceptable according to the City of Ottawa wind comfort criteria.

Primary Building Entrances: **C**onditions in the immediate vicinity of the two primary building entrances serving the proposed development are expected to be suitable for sitting throughout the year. These conditions are considered acceptable with respect to the City of Ottawa wind comfort criteria.

5.2 Wind Comfort Conditions – Common Amenity Terrace

Level 4 Amenity Terrace: The common terrace on the roof of the podium, which is located between the East and West Towers and to the north of the Amenity Pavilion, is predicted to be mostly suitable for standing during the summer, suitable for strolling or better during the autumn, and suitable for walking or better during the remaining two colder seasons. In addition, Figure 5A illustrates that the amenity terrace is predicted to be mostly suitable for standing during the typical use period, although the northwest corner of the area is predicted to be suitable for strolling. Figure 5B illustrates that most of the terrace will also be suitable for sitting at least 65% of the time during the typical use period.

Mitigation measures will be required to ensure conditions are suitable for sitting during the typical use period within designated seating areas. In addition to the 1.8-m-tall perimeter guards that were included in the present study, wind barriers will be required inboard of the perimeter to protect seating areas. Canopies on the East and West Towers may also be beneficial. A comprehensive mitigation strategy for the amenity terrace is currently being developed in collaboration with the design team. Additional testing is expected to be required to confirm the efficacy of the preferred mitigation strategy.

Outdoor Amenities, Amenity Levels: The Amenity Levels (Levels 28 and 31 of the West and East Towers, respectively) have not yet been designed and may include outdoor amenity spaces. Wind conditions on any terrace that will serve common amenities will be investigated in the future, in conjunction with the mitigation testing for the Level 4 amenity terrace.

5.3 Wind Safety – Grade Level

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level were found to experience conditions that could be considered dangerous, as defined in Section 4.4.

5.4 Applicability of Results

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. In general, development in urban centers creates reduction in the mean wind speeds and localized increases in the gustiness of the wind.

Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind comfort and safety conditions is provided in Section 5 and illustrated in Figures 3A-5B (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 numerous similar developments, the study concludes the following:

1) With one exception, all areas at grade are predicted to be suitable for their intended uses throughout the year. This includes building access points, nearby sidewalks, landscaped areas, and the Bayshore Transit Station.

    a. The one area at grade that is not expected to meet the wind comfort criteria is the bus stop to the north of the proposed development, on Woodbridge Crescent. Conditions are predicted to exceed the standing comfort class during the three colder seasons. We recommend that a typical bus shelter be installed at this location to ensure pedestrians are provided with an opportunity to seek relief during periods of strong winds.

2) Conditions on the amenity terrace at Level 4 are mostly predicted to be suitable for standing during the typical use period (May to October, inclusive). Mitigation will be required to ensure conditions are comfortable for sitting within designated seating areas. A comprehensive mitigation strategy will be developed in collaboration with the design team. Specifically, in

addition to the 1.8-m-tall wind screen along the perimeter of the roof that was included in the present study, the strategy will include local wind barriers inboard of the perimeter to protect designated seating areas and may also include canopies extending from the towers. Additional testing will be performed to confirm the efficacy of the preferred mitigation strategy.

3) The Amenity Levels (Levels 28 and 31 of the West and East Towers, respectively) have not yet been designed and may include outdoor amenity spaces. Wind conditions on any terrace that will serve common amenities will be investigated in the future, in conjunction with the mitigation testing for the Level 4 amenity terrace noted above.

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

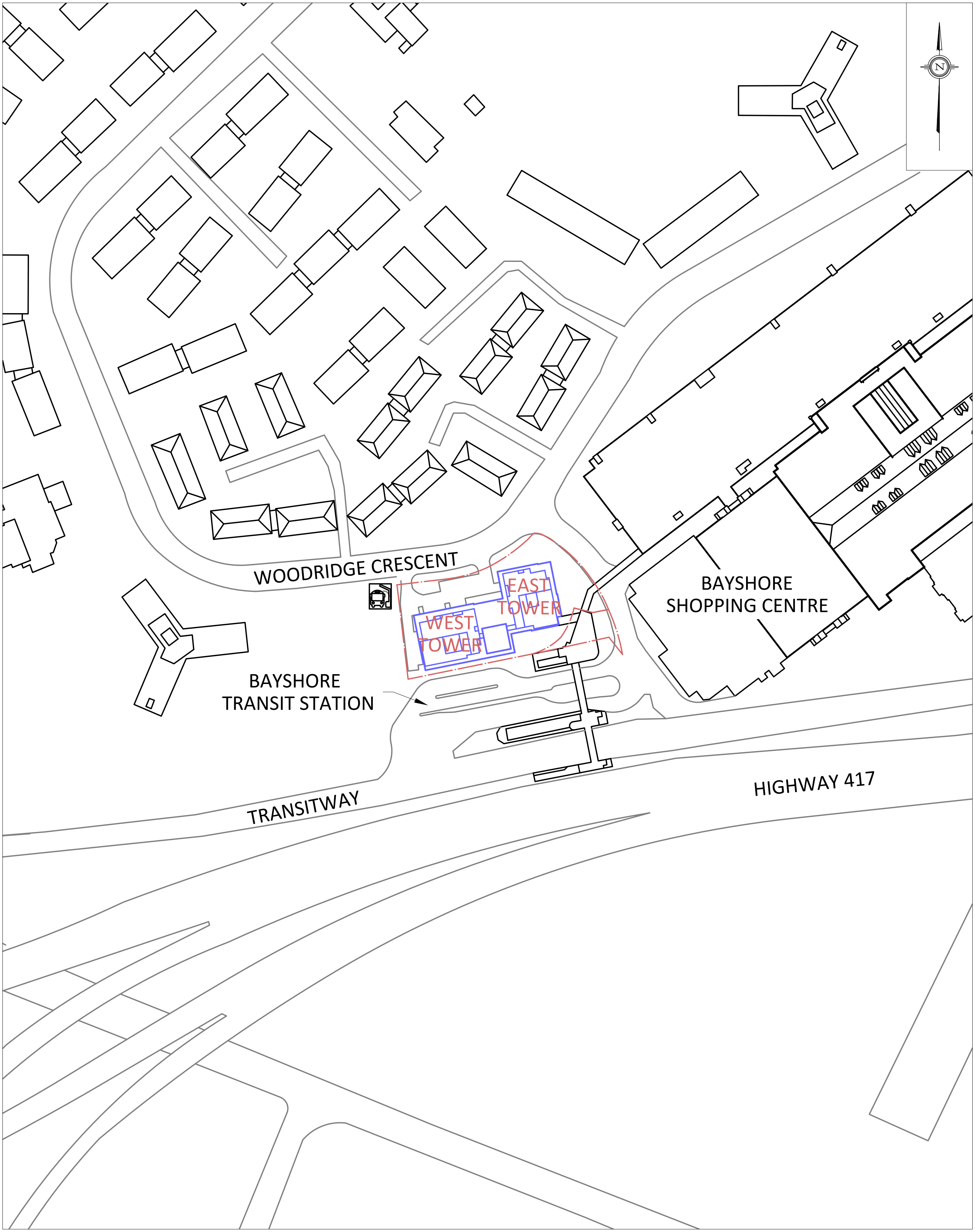
Sincerely,

Gradient Wind Engineering Inc.

Sacha Ruzzante, MASc
Wind Scientist

LICENSED PROFESSIONAL ENGINEER
J. D. FERRARO
100158495
Apr 28, 2021
PROVINCE OF ONTARIO

Justin Ferraro, P.Eng.
Principal



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PROJECT	100 BAYSHORE DRIVE, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:3000	DRAWING NO.	19-225-PLW-1-R1
DATE	APRIL 28, 2021	DRAWN BY	O.R.

DESCRIPTION

FIGURE 1:
SITE PLAN AND SURROUNDING CONTEXT

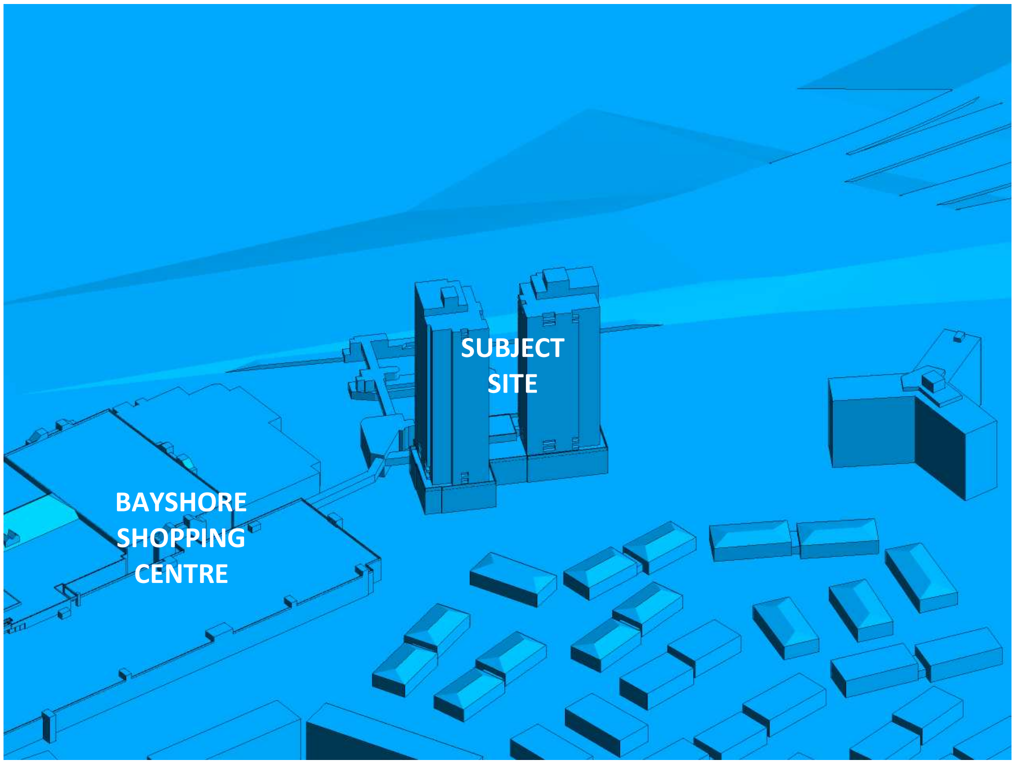

FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

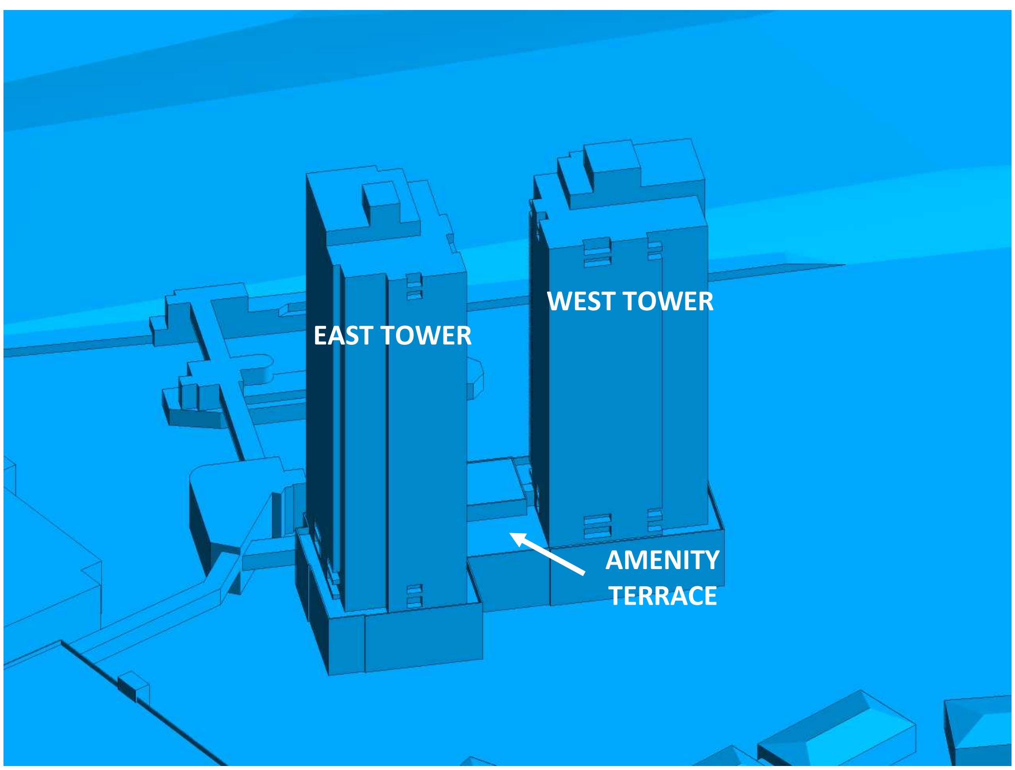

FIGURE 2B: CLOSE UP OF FIGURE 2A

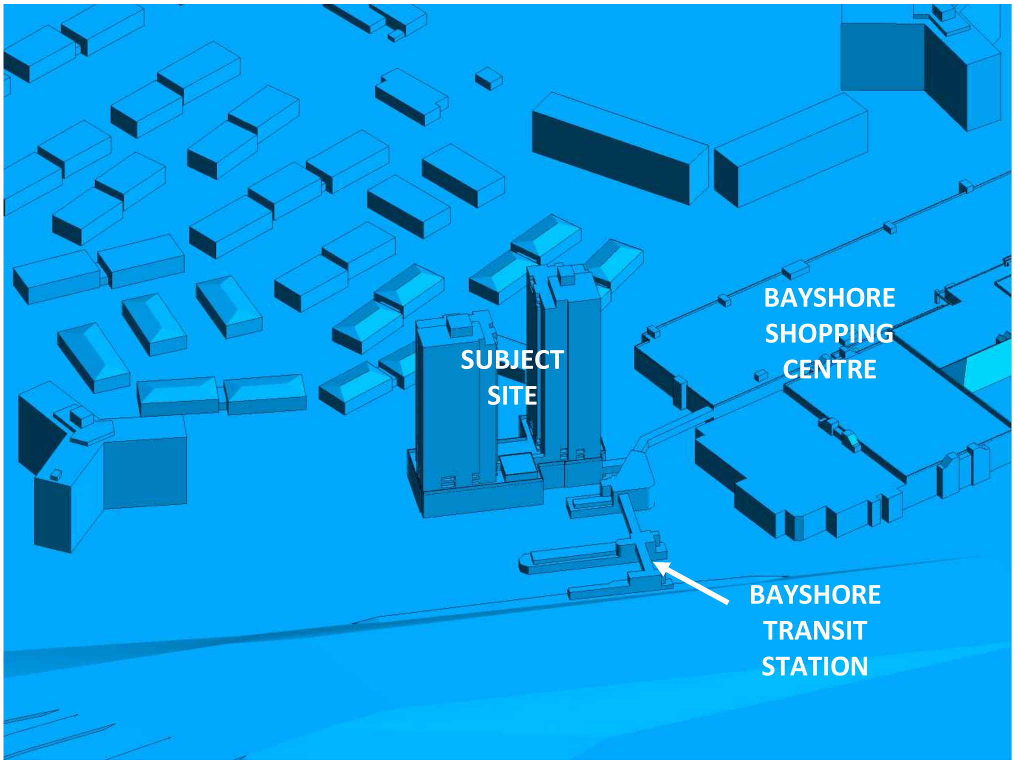

FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

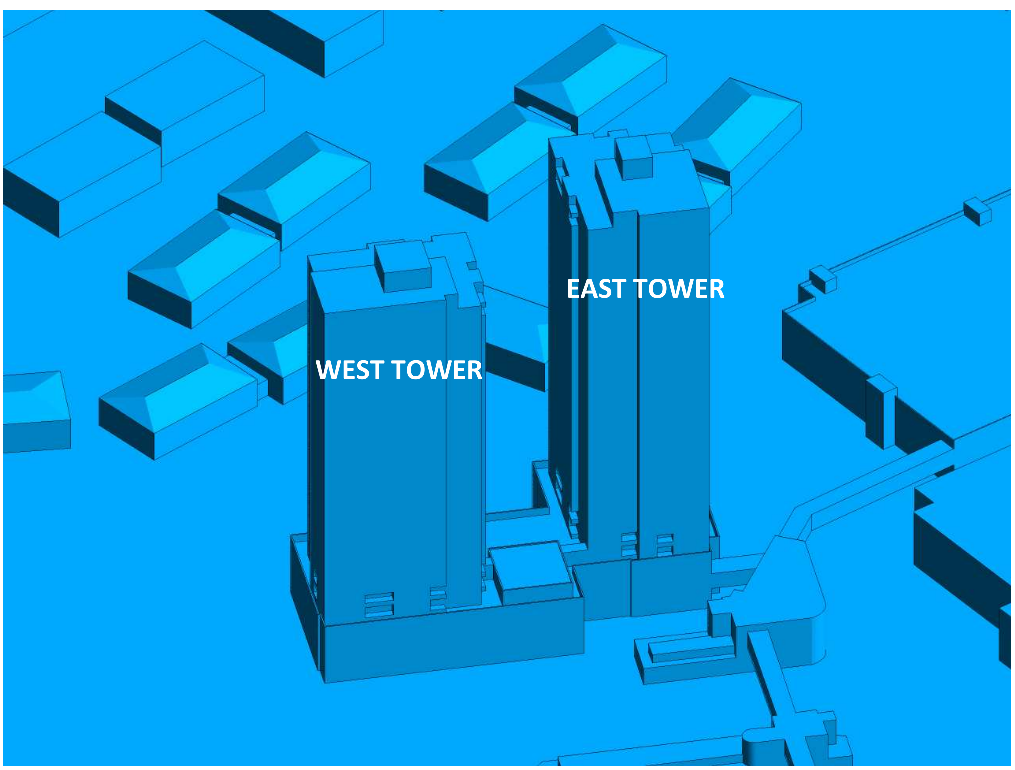

FIGURE 2D: CLOSE UP OF FIGURE 2C

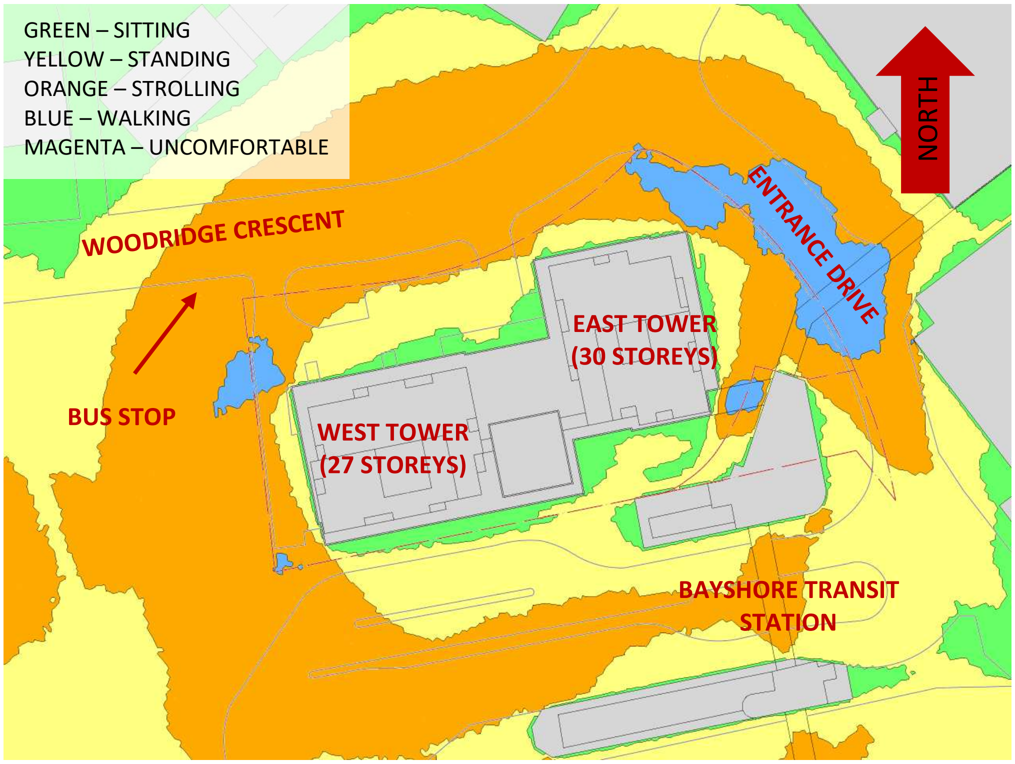

FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

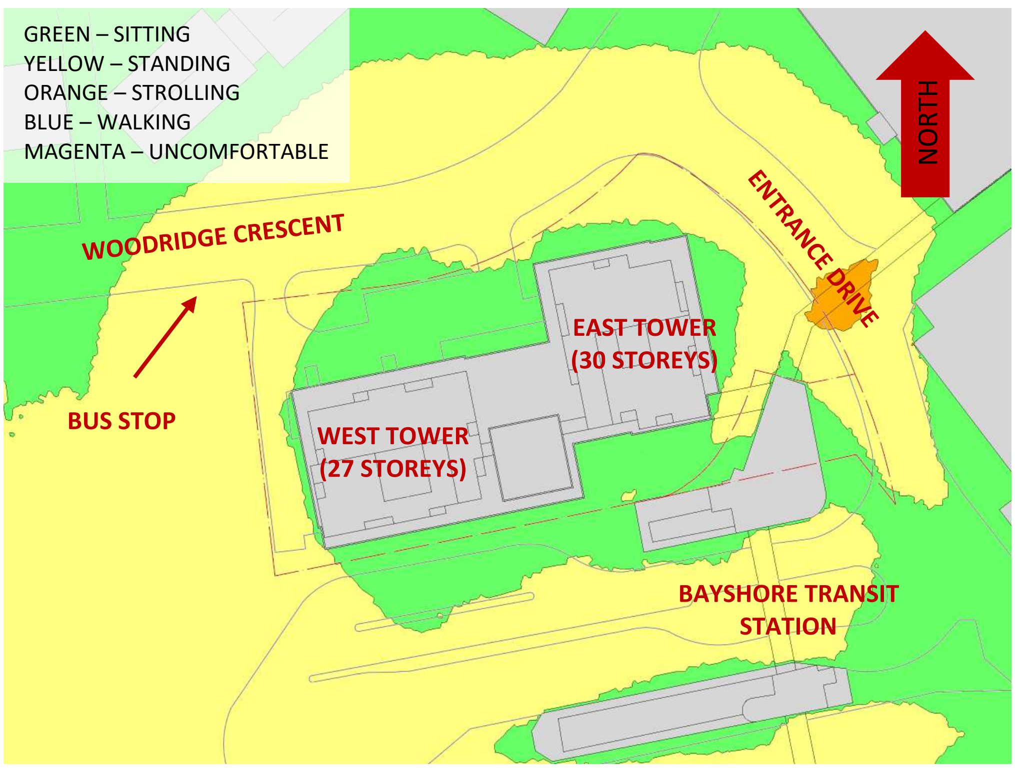

FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL

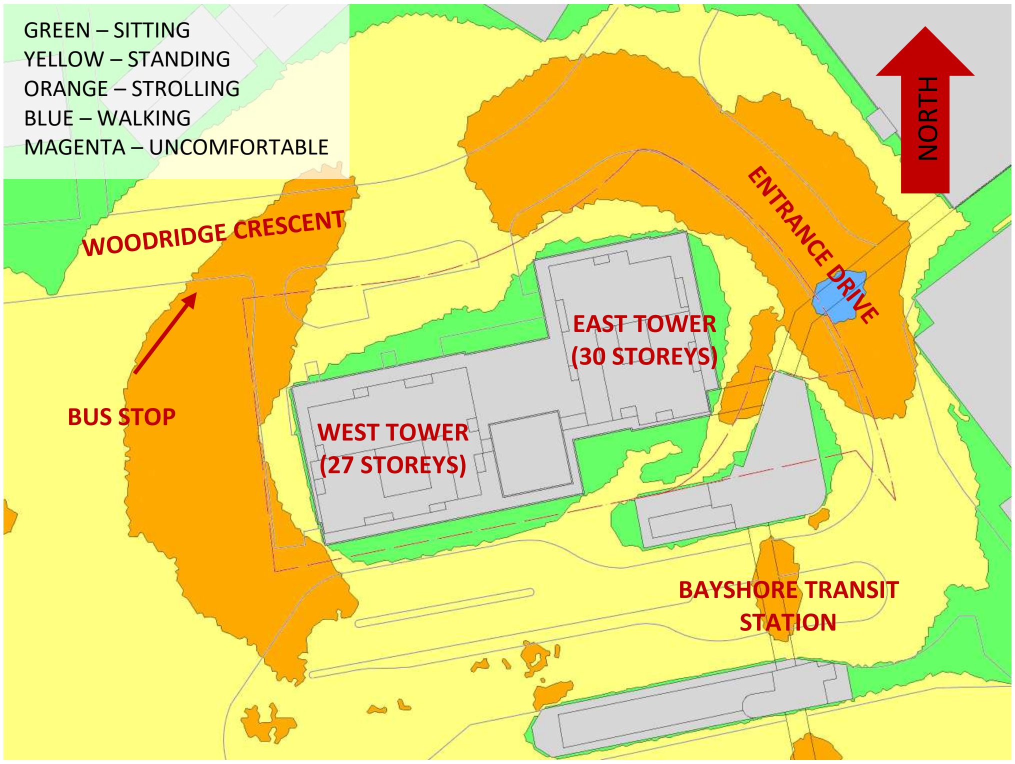

FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

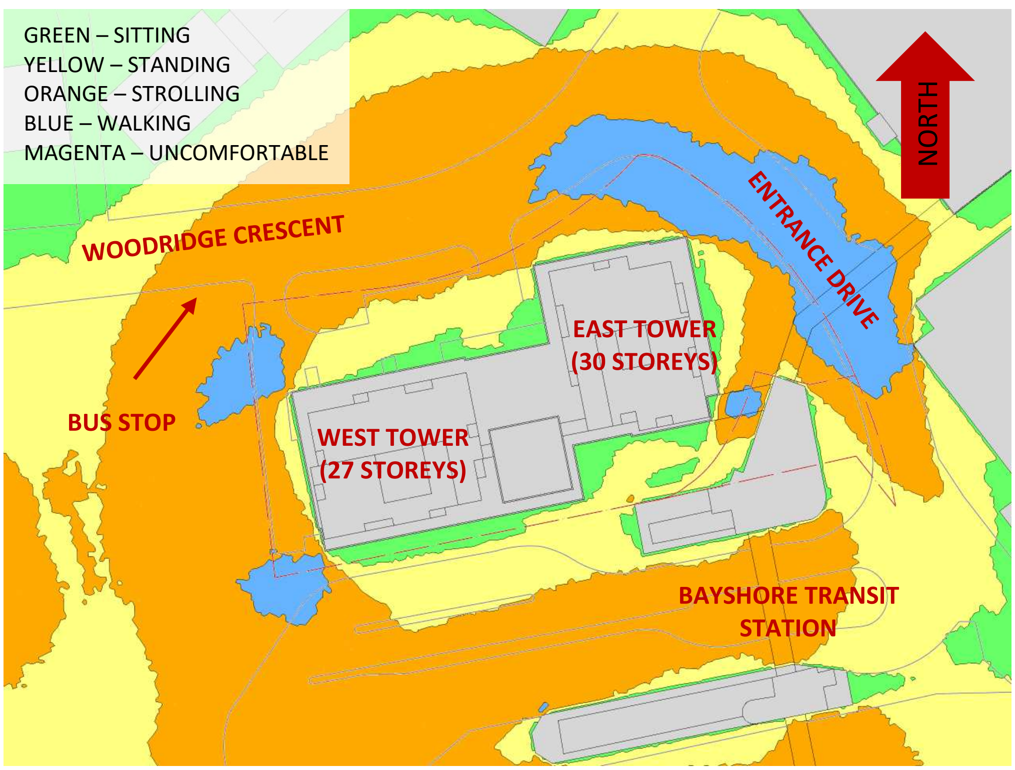

FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL

FIGURE 4A: SPRING – WIND COMFORT CONDITIONS, MPH LEVEL AMENITY TERRACE

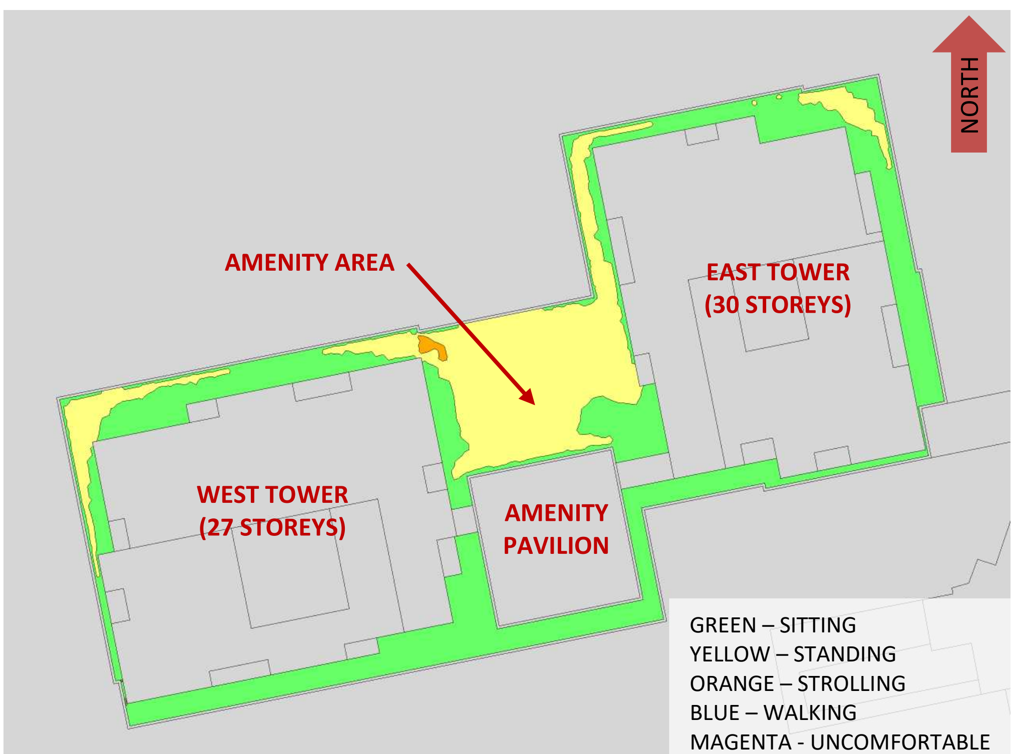

FIGURE 4B: SUMMER – WIND COMFORT CONDITIONS, MPH LEVEL AMENITY TERRACE

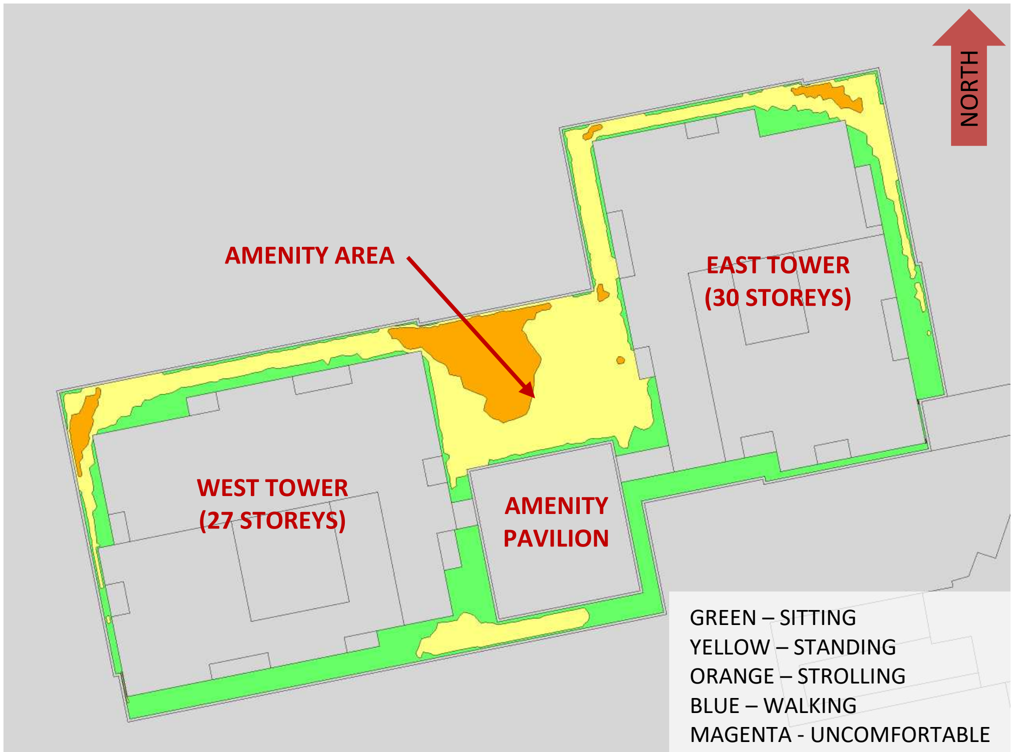

FIGURE 4C: AUTUMN – WIND COMFORT CONDITIONS, MPH LEVEL AMENITY TERRACE

FIGURE 4D: WINTER – WIND COMFORT CONDITIONS, MPH LEVEL AMENITY TERRACE

FIGURE 5A: TYPICAL USE PERIOD (MAY-OCTOBER) – WIND COMFORT, AMENITY TERRACE

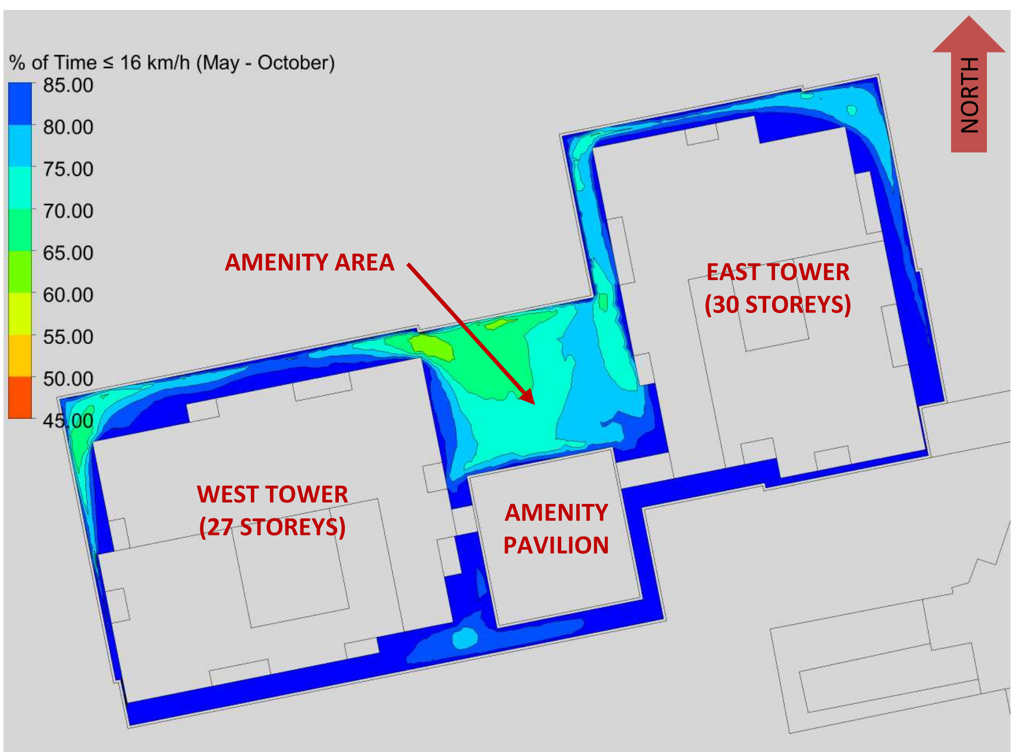

FIGURE 5B: TYPICAL USE PERIOD – % OF TIME SUITABLE FOR SITTING, AMENITY TERRACE

APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

The atmospheric boundary layer (ABL) is defined by the velocity and turbulence profiles according to industry standard practices. The mean wind profile can be represented, to a good approximation, by a power law relation, Equation (1), giving height above ground versus wind speed [1], [2].

$$U = U_g \left(\frac{Z}{Z_g}\right)^{\alpha} \qquad \text{Equation (1)}$$

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.

For the model, U_g is set to 6.5 metres per second (m/s), which approximately corresponds to the 60% mean wind speed for Ottawa based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

Z_g is set to 540 m. The selection of gradient height is relatively unimportant, so long as it exceeds the building heights surrounding the subject site. The value has been selected to correspond to our physical wind tunnel reference value.

α is determined based on the upstream exposure of the far-field surroundings (i.e., the area that it not captured within the simulation model).

Table 1 presents the values of α used in this study, while Table 2 presents several reference values of α. When the upstream exposure of the far-field surroundings is a mixture of multiple types of terrain, the α values are a weighted average with terrain that is closer to the subject site given greater weight.

TABLE 1: UPSTREAM EXPOSURE (ALPHA VALUE) VS TRUE WIND DIRECTION

Wind Direction (Degrees True)	Alpha Value (α)
0	0.23
49	0.22
74	0.22
103	0.23
167	0.23
197	0.23
217	0.22
237	0.22
262	0.23
282	0.23
302	0.23
324	0.23

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

Upstream Exposure Type	Alpha Value (α)
Open Water	0.14-0.15
Open Field	0.16-0.19
Light Suburban	0.21-0.24
Heavy Suburban	0.24-0.27
Light Urban	0.28-0.30
Heavy Urban	0.31-0.33

The turbulence model in the computational fluid dynamics (CFD) simulations is a two-equation shear-stress transport (SST) model, and thus the ABL turbulence profile requires that two parameters be defined at the inlet of the domain. The turbulence profile is defined following the recommendations of the Architectural Institute of Japan for flat terrain [3].

$$I(Z) = \begin{cases} 0.1\left(\dfrac{Z}{Z_g}\right)^{-\alpha-0.05}, & Z > 10\text{ m} \\ 0.1\left(\dfrac{10}{Z_g}\right)^{-\alpha-0.05}, & Z \leq 10\text{ m} \end{cases} \qquad \text{Equation (2)}$$

$$L_t(Z) = \begin{cases} 100\text{ m}\sqrt{\dfrac{Z}{30}}, & Z > 30\text{ m} \\ 100\text{ m}, & Z \leq 30\text{ m} \end{cases} \qquad \text{Equation (3)}$$

where, ***I*** = turbulence intensity, $\boldsymbol{L_t}$ = turbulence length scale, ***Z*** = height above ground, and **α** is the power law exponent used for the velocity profile in Equation (1).

Boundary conditions on all other domain boundaries are defined as follows: the ground is a no-slip surface; the side walls of the domain have a symmetry boundary condition; the top of the domain has a specified shear, which maintains a constant wind speed at gradient height; and the outlet has a static pressure boundary condition.

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