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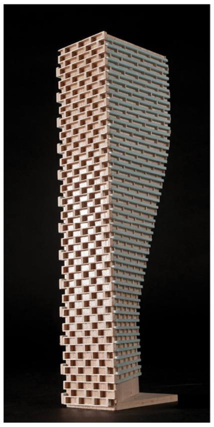
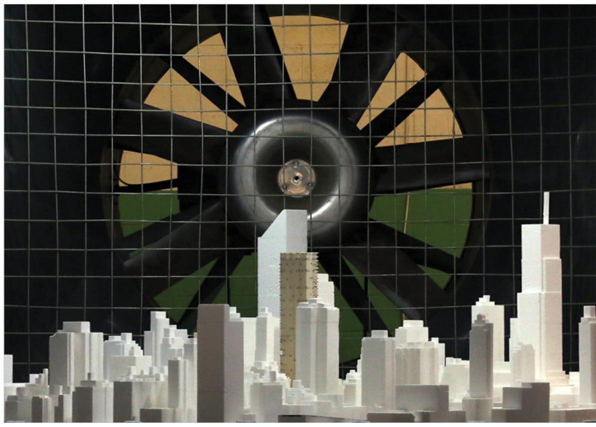
PEDESTRIAN LEVEL WIND STUDY

East Flats
301 Lett Street
Ottawa, Ontario

Report: 17-074-PLW





May 8, 2020

PREPARED FOR
Claridge Homes
2001-210 Gladstone Avenue
Ottawa, ON K2P 0Y6

PREPARED BY
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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 development located at 301 Lett Street in Ottawa, Ontario. 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) All grade-level areas within and surrounding the subject site will be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, outdoor amenity areas, driveways, within Pindigen Park, and within the proposed future park to the south of the subject site, are considered acceptable for the intended pedestrian uses throughout the year.

2) Conditions within the common amenity areas serving Towers 1 and 2 at Level 6 will be suitable for a mix of sitting and standing during the typical use period. Depending on the programing of the terraces, local wind barriers inboard of the perimeter would be expected to create comfortable conditions during the typical use period. Mitigation may take the form of glass architectural wind screens and/or coniferous trees planted in a dense arrangement and positioned to protect designated seating areas. A mitigation strategy for the terrace can be confirmed during detailed design development.

3) 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 or within the common amenity terraces were found to experience conditions that could be considered uncomfortable or dangerous.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Claridge Homes to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a site plan control application submission for a proposed development located at 301 Lett Street 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 provided by EVOQ Architecture in April 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery via Google Earth Pro.

2. TERMS OF REFERENCE

The subject site is situated on a parcel of land bordered by Fleet Street to the north, Lett Street to the east and south, and Lloyd Street the west.

Rendering, Northeast Perspective
(Courtesy of EVOQ Architecture)

The proposed two-building development comprises a 25-storey building (Tower 1) and a 30-storey building (Tower 2). Tower 1 is located at the north end of the subject site, and has a nearly rectangular planform at grade, with the long axis along Fleet Street. The building steps back from the south elevation at Level 2, and from the east elevation at Level 6, creating a large 5-storey podium with a common amenity terrace at Level 6. The building then rises with a uniform planform to Level 24. The mechanical penthouse at the top of the building is set back from the east and south elevations.

Tower 2 has an 'L'-shaped planform at grade with the long axis along the south elevation. Similar to Tower 1, the building steps back from the north elevation at Level 2, and from the west elevation at Level 6, creating a large 5-storey podium with a common amenity terrace at Level 6. The building then rises with a uniform planform to Level 29. At Level 30, the mechanical penthouse at the top of the building is set back from the north and west elevations.

At grade, both buildings include lobby, office, residential unit, and amenity spaces, while Tower 1 also includes a daycare space and Tower 2 a design centre space. The primary daycare entrance is located along the east elevation of Tower 1, fronting Lett Street, while the primary residential entrances are located on the west and east elevations of Tower 1 and 2 fronting Lloyd Street and Lett Street respectively. A grade-level outdoor amenity area including both a walkway and seating areas is located in between the two towers. South of this amenity area there is a driveway for the underground entrance to the parking garage accessed from Lloyd Street. In Tower 2, Level 2 comprises residential units and a design studio space. Level 6 for both buildings includes indoor and outdoor amenity space. All other floors for both towers comprise residential units. Pindigen Park is located north of Tower 1 across Fleet Street and a proposed future park area is located south of Tower 2 across Lett Street.

The near-field surroundings (defined as an area within a radius of 500 metres (m) of the subject site) to the immediate east of the subject site includes four medium-rise residential buildings completed as part of the initial phases of the LeBreton Flats Redevelopment master plan. To the west there are three planned future interconnected high-rise buildings, while the Pimisi LRT station is located to the southwest of the subject site. The far-field surroundings (defined as an area beyond the near-field and within a five kilometer (km) radius of the subject site) contribute primarily open wind exposures from the west clockwise to north, urban exposures from downtown Ottawa from northeast clockwise to the east, and a suburban mix of low-to medium rise developments for the remaining compass directions.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, walkways, building access points, and the amenity terraces at Level 6. 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

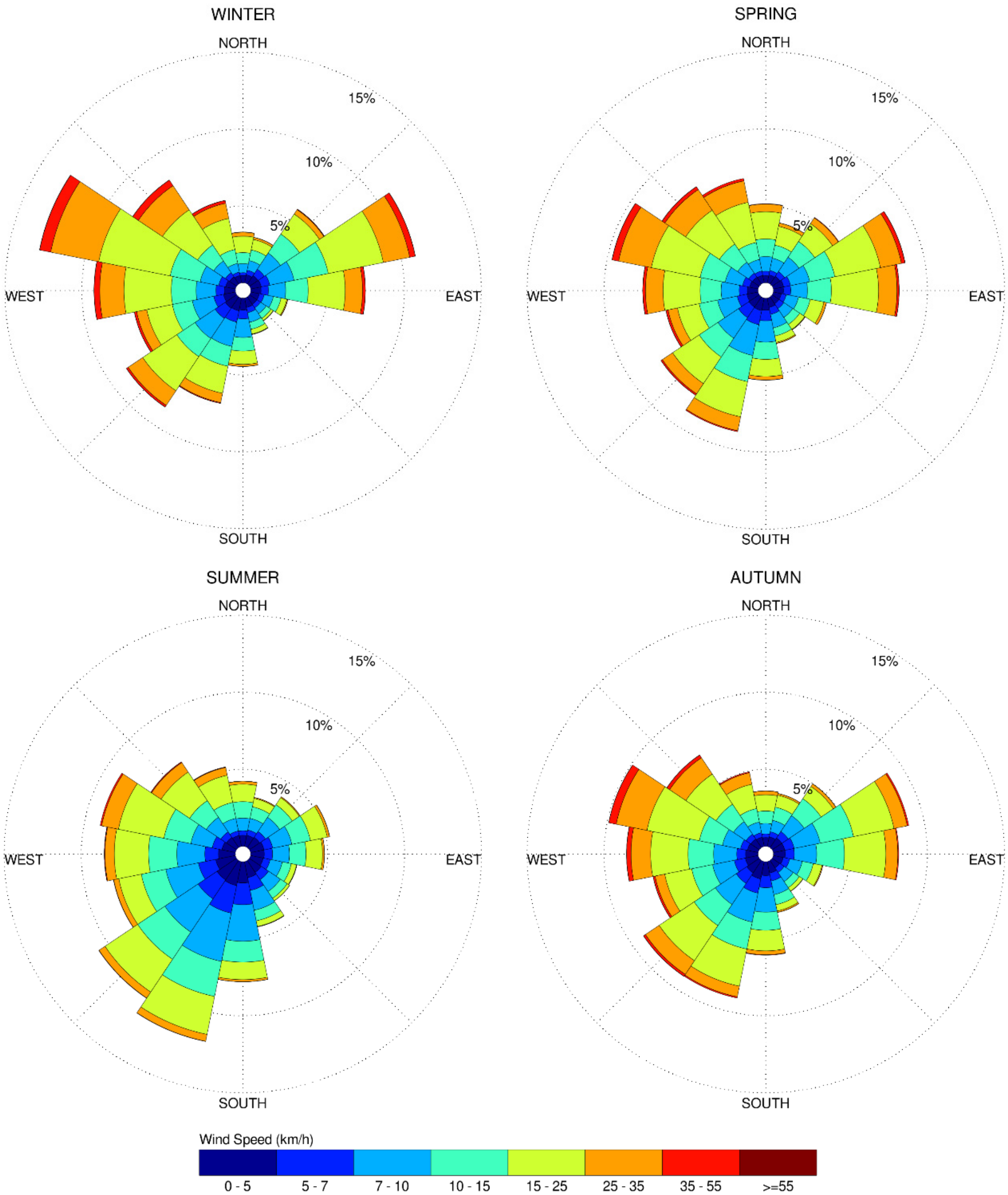
The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 1.2 km. Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the rooftop amenity terraces were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. 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 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 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 winter season is defined as December-March, spring as April-May, summer as June-September, and autumn as October-November.

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 80% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

1) **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The 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 mean gust speed ranges are selected based on 'The Beaufort Scale', which describes the effect of forces produced by varying wind speeds on levels on objects.

THE BEAUFORT SCALE

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

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

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

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	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 (following the main text) illustrating the seasonal wind conditions at grade level, and Figures 4A-4D illustrating the seasonal wind conditions within the common elevated amenity 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 orange, walking by blue, while uncomfortable conditions are represented by the colour magenta. Pedestrian wind comfort is summarized below for each area of interest. In addition, Figures 5A and 5B illustrate the percentage of time the areas at grade and within the elevated amenity terraces, respectively, will be suitable for sitting during the summer season.

5.1 Wind Comfort Conditions – Grade Level

Fleet Street: The sidewalks along Fleet Street are predicted to be suitable for a mix of sitting and standing during the summer season, becoming suitable for a mix of standing and strolling for the remainder of the year. These conditions are considered acceptable for public sidewalks.

Lett Street: The sidewalks along Lett Street will be suitable for a mix of sitting and standing during the summer, becoming suitable for a mix of sitting, standing and strolling for the remainder of the year. These conditions are considered acceptable.

Lloyd Street: The sidewalks along Lloyd Street are predicted to be suitable for a mix of sitting and standing during the summer season, suitable for standing during the autumn season, and suitable for a mix of standing and strolling during spring and winter seasons. These conditions are considered acceptable.

Daycare, Residential & Secondary Building Entrances: All entrances serving Towers 1 and 2 will be suitable for sitting throughout the year, which is acceptable.

Driveway, Walkways, and Grade-Level Amenity Area Between Towers 1 and 2: The area at grade between Towers 1 and 2 will be mostly suitable for sitting during the summer, with some regions within the planned walkway areas suitable for standing. During the autumn, conditions in this area will be suitable outright for standing. During the spring and winter, conditions will be mostly suitable for standing, with some regions within the planned walkway areas suitable for strolling. Figure 5A illustrates that the whole area between Towers 1 and 2 will be suitable for sitting at least 75% of the time during the summer season, which is considered acceptable.

Pindigen Park: The east half of Pindigen Park, north of Tower 1, will be suitable for sitting during the summer, becoming suitable for standing for the remainder of the year. The west half of Pindigen Park will be suitable for a mix of sitting and standing during the summer, becoming suitable for standing during the spring and autumn, and suitable for a mix of standing and strolling during the winter. For those areas that are predicted to be suitable for standing during the colder seasons, sitting conditions are also predicted for at least 75% of time during the summer season, as illustrated in Figure 5A. The noted conditions are considered acceptable.

Proposed Future Park: The proposed future park south of Tower 2 will primarily be suitable for sitting during the summer with an isolated region to the west being suitable for standing. During the spring and autumn, the future park will be suitable for a mix of sitting and standing, and during the winter, conditions are predicted to be suitable for a mix of sitting, standing and strolling. Figure 5A illustrates that the isolated region suitable for standing during the summer will also be suitable for sitting at least 75% of the time during the summer season, which is considered acceptable.

5.2 Wind Comfort Conditions – Common Amenity Terraces

Tower 1, Level 6 Terrace: Wind conditions within the common amenity terrace serving Tower 1 will be suitable for a mix of sitting and standing during the typical use period, defined as late spring through to early autumn. Figure 5B illustrates that during the summer the majority of the terrace will be suitable for sitting at least 75% of the time with an isolated region being suitable for sitting at least 70% of the time near the north corner.

If the programming of the terrace will include more sedentary areas south of the stairwell and more active areas to the north, the noted conditions would be considered acceptable. Otherwise, local wind barriers inboard of the perimeter would be required to create suitable conditions. These may take the form of glass architectural wind screens and/or coniferous trees planted in a dense arrangement and positioned to protect designated seating areas. A mitigation strategy for the terrace can be confirmed during detailed design development.

Tower 2, Level 6 Terrace: Wind conditions within the common amenity terrace serving Tower 2 will be suitable for a mix of sitting and standing during the typical use period. Figure 5B illustrates that during the summer the terrace will mostly be suitable for sitting at least 75% of the time with an isolated region suitable for sitting at least 70% of the time near the southwest corner of the terrace.

If the programming of the terrace will include more sedentary areas northeast of the stairwell and more active areas to the southwest, these conditions would be considered acceptable. If more sedentary areas are desired to serve the southwest portion of the terrace, local wind barriers inboard of the perimeter would be expected to create comfortable conditions during the typical use period. Similar to Tower 1, mitigation may take the form of glass architectural wind screens and/or coniferous trees planted in a dense arrangement and positioned to protect designated seating areas. A mitigation strategy for the terrace can be confirmed during detailed design development.

5.3 Wind Comfort Conditions – Surrounding Area

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

6. SUMMARY OF RESULTS

A complete summary of the predicted wind comfort and safety conditions is provided in Section 5 and illustrated in Figures 3A-5B. Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with similar developments in Ottawa, we conclude the following:

1) All grade-level areas within and surrounding the subject site will be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, outdoor amenity areas, driveways, within Pindigen Park, and within the proposed future park to the south of the subject site, are considered acceptable for the intended pedestrian uses throughout the year.

2) Conditions within the common amenity areas serving Towers 1 and 2 at Level 6 will be suitable for a mix of sitting and standing during the typical use period. Depending on the programing of the terraces, local wind barriers inboard of the perimeter would be expected to create comfortable conditions during the typical use period. Mitigation may take the form of glass architectural wind screens and/or coniferous trees planted in a dense arrangement and positioned to protect designated seating areas. A mitigation strategy for the terrace can be confirmed during detailed design development.

3) 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 or within the common amenity terraces were found to experience conditions that could be considered uncomfortable or dangerous.

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

Sincerely,

Gradient Wind Engineering Inc.

Edward Urbanski, M.Eng.
Junior Wind Scientist

LICENSED PROFESSIONAL ENGINEER
J. D. FERRARO
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May 8, 2020
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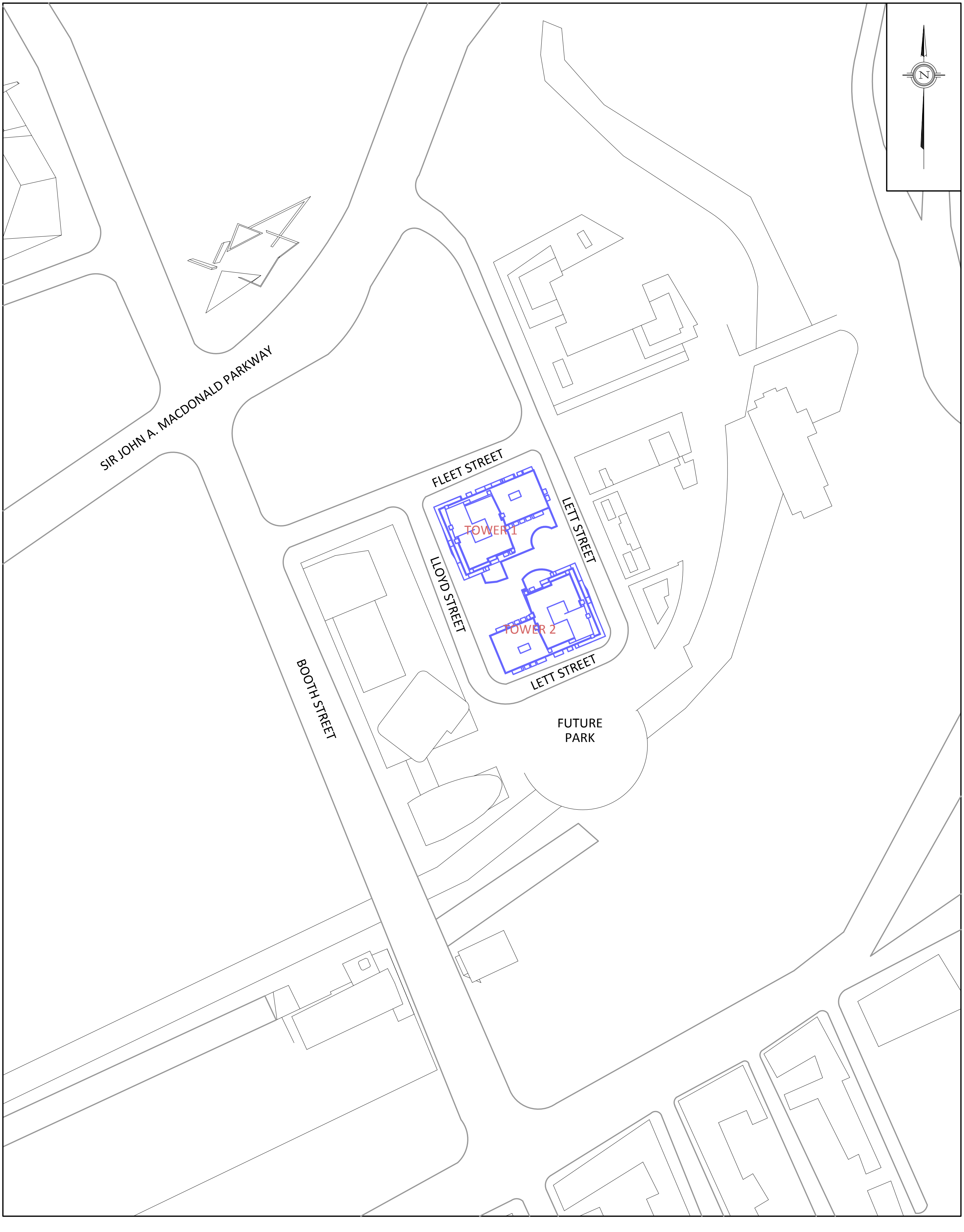

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PROJECT	301 LETT STREET EAST FLATS, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:2500	DRAWING NO.	17-074-PLW-1
DATE	MAY 7, 2020	DRAWN BY	E.U.

DESCRIPTION

FIGURE 1:
SITE PLAN AND SURROUNDING CONTEXT

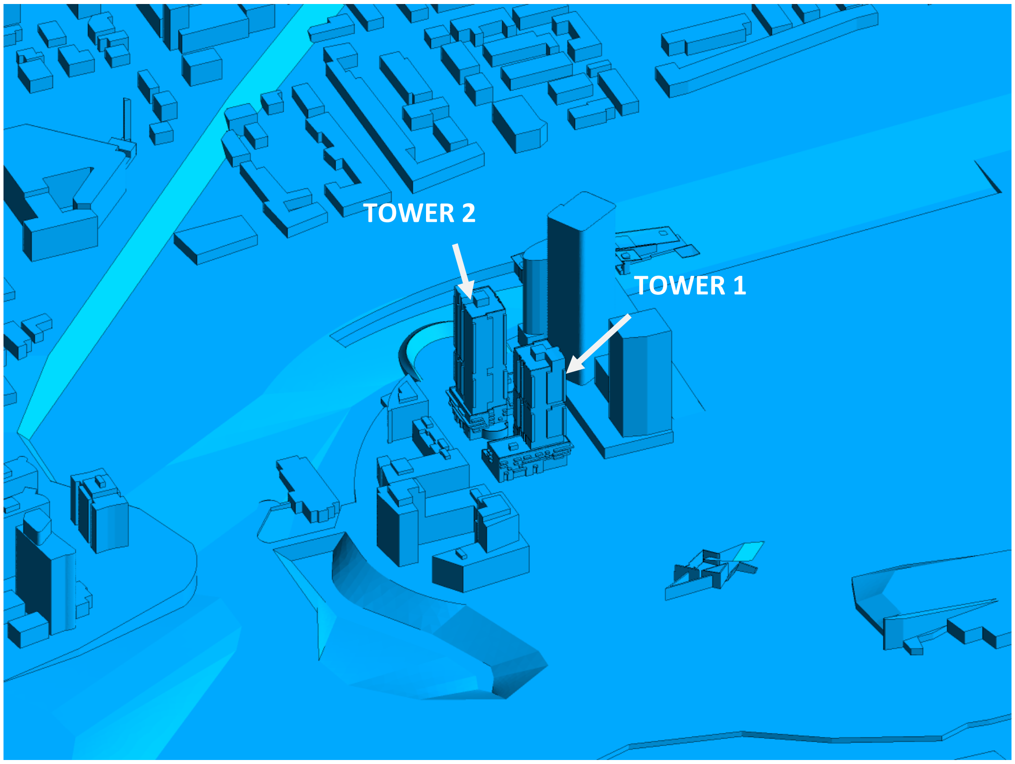

FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

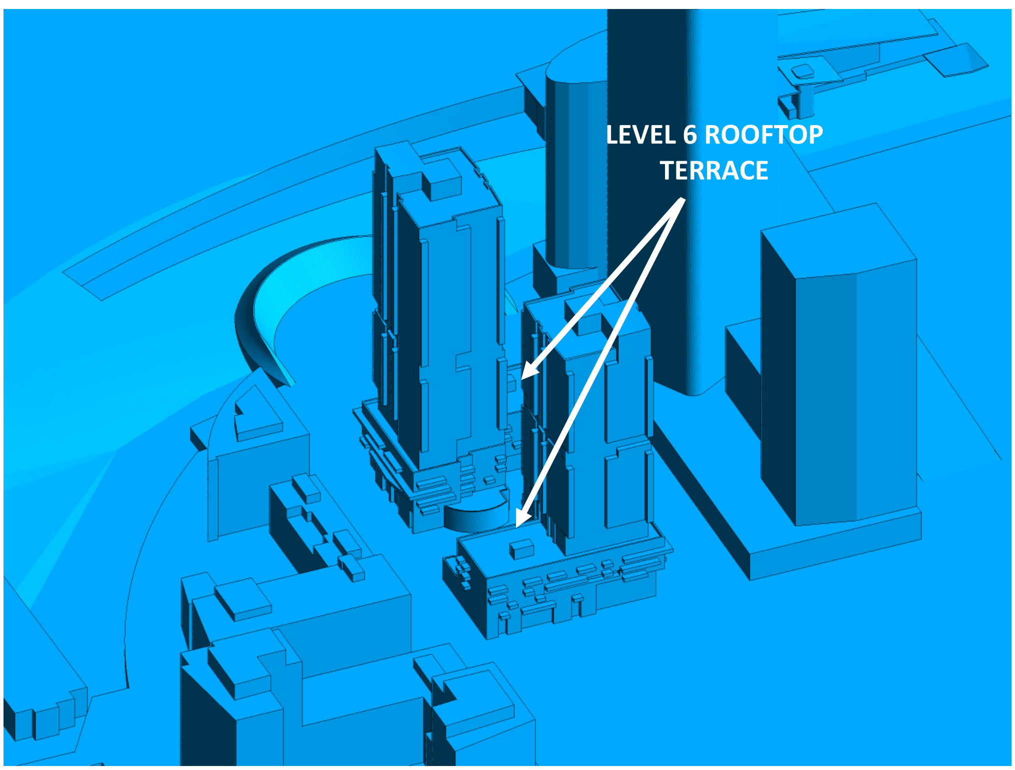

FIGURE 2B: CLOSE UP OF FIGURE 2A

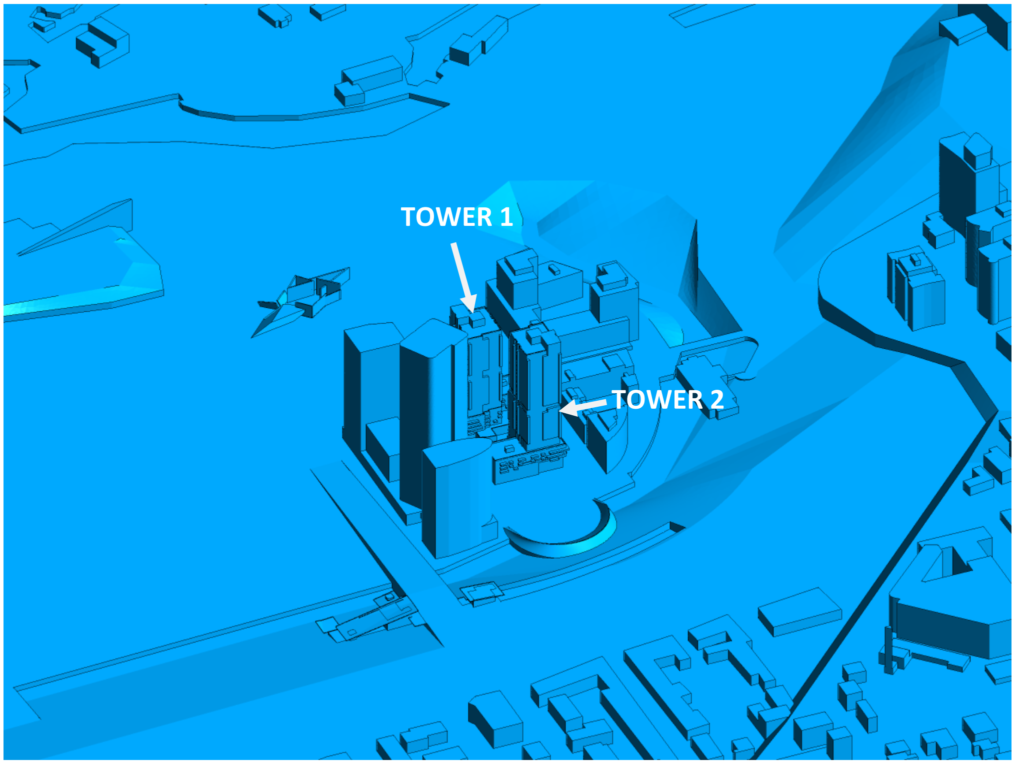

FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

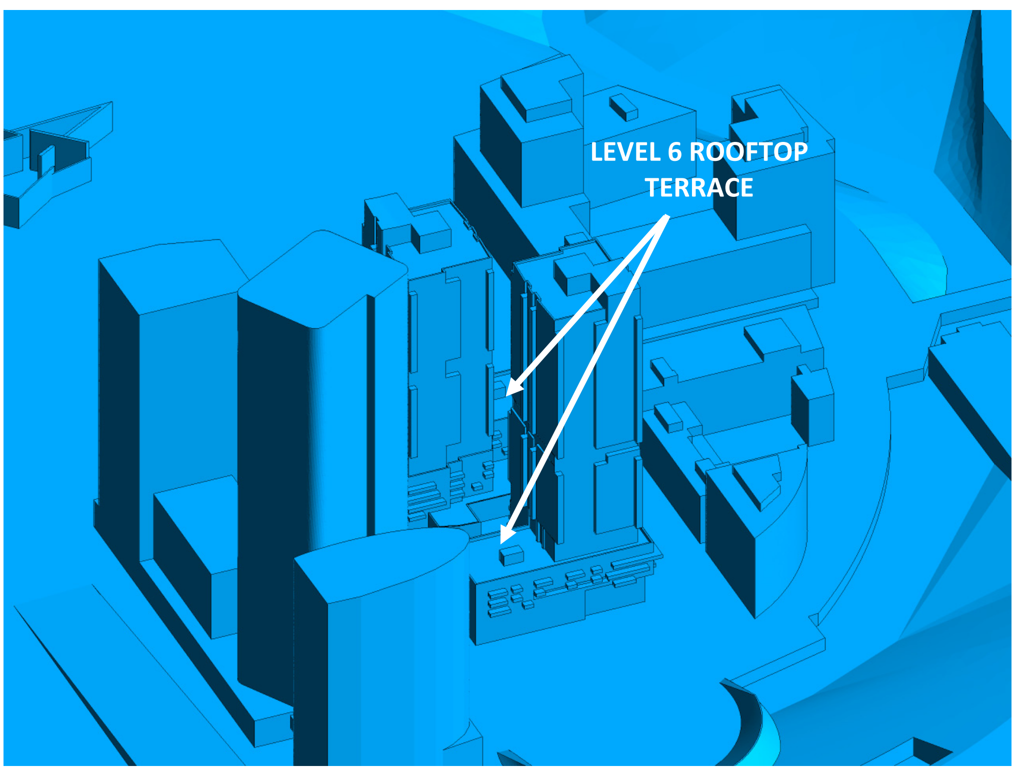

FIGURE 2D: CLOSE UP OF FIGURE 2C

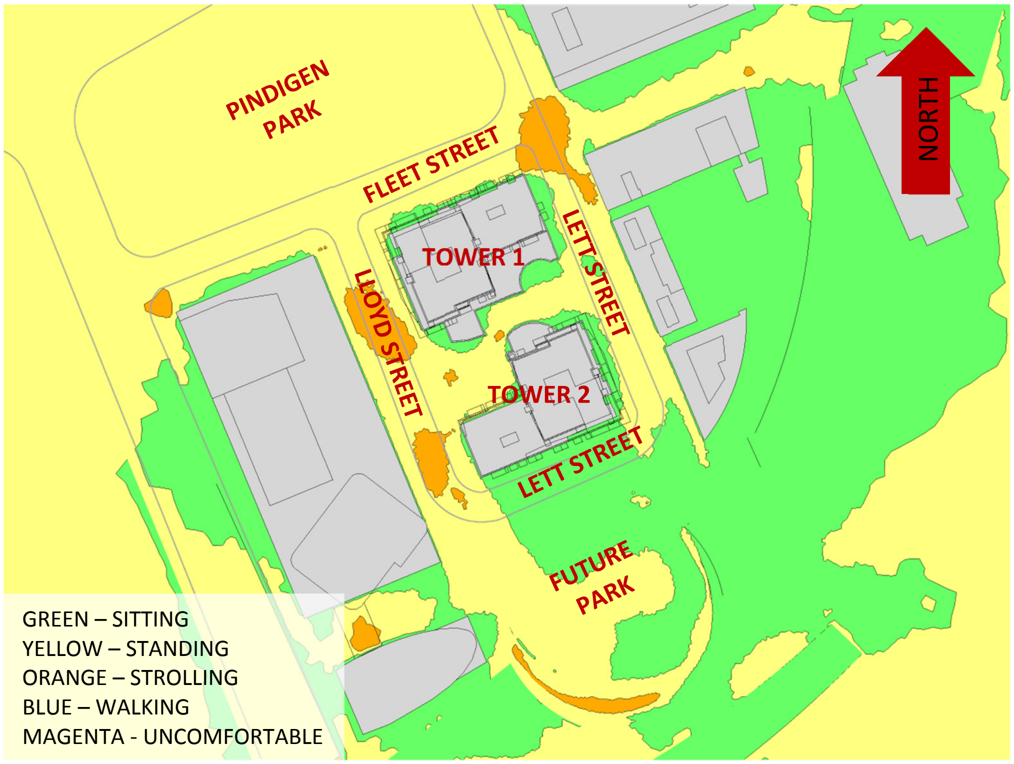

FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

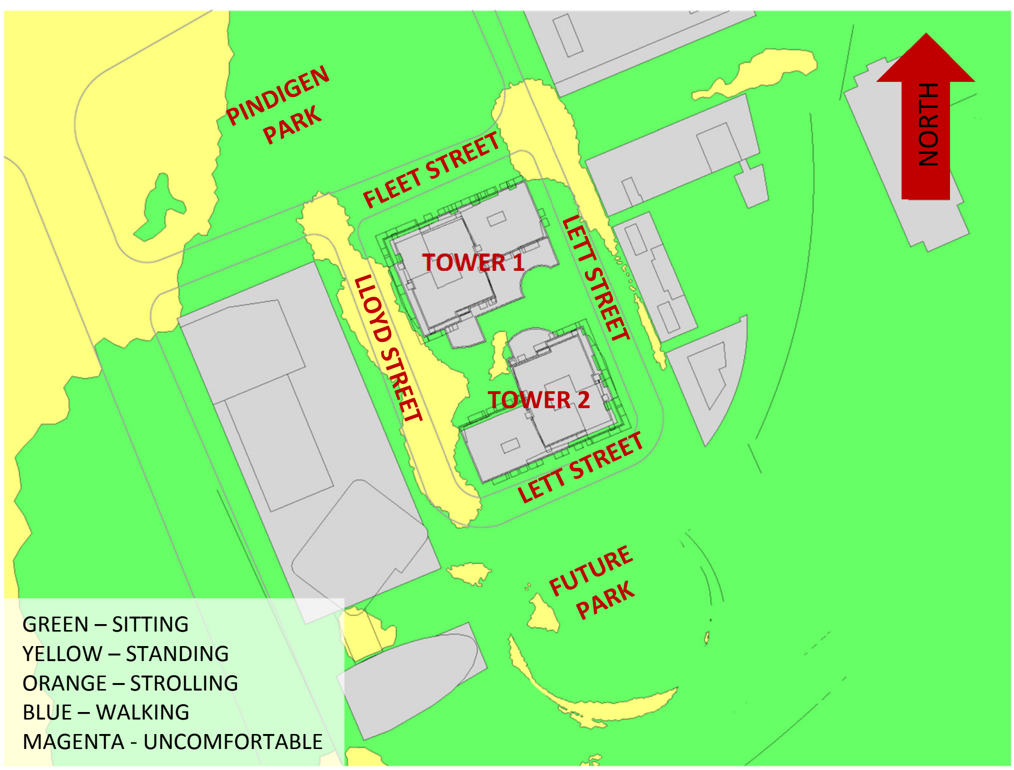

FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL

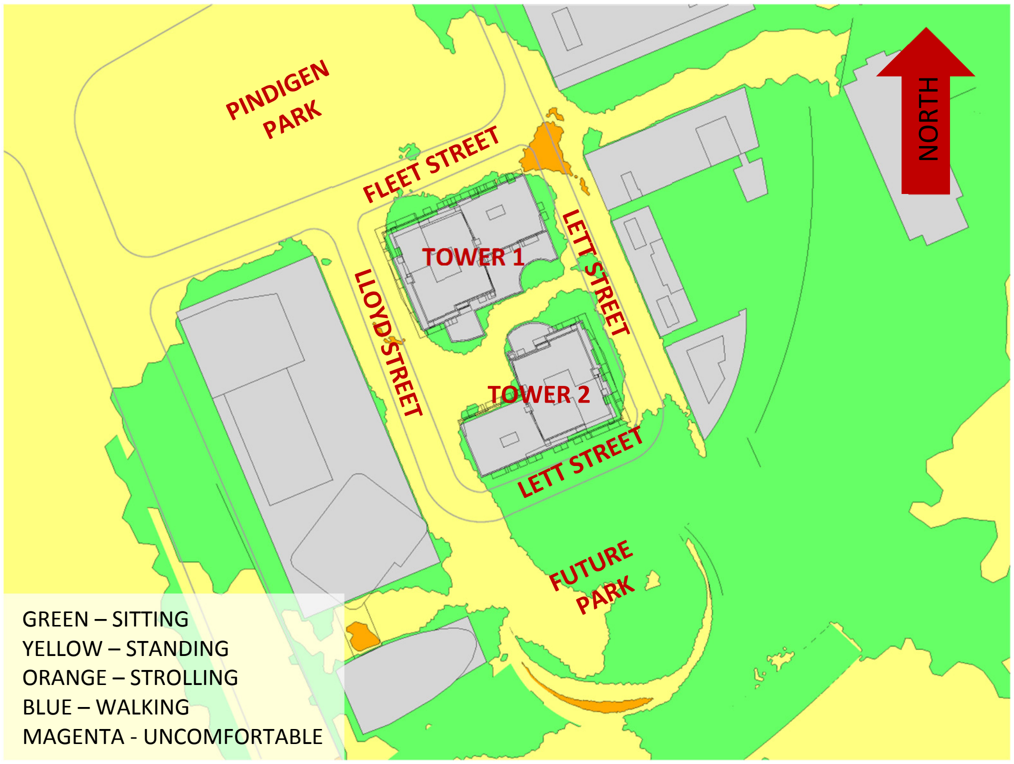

FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

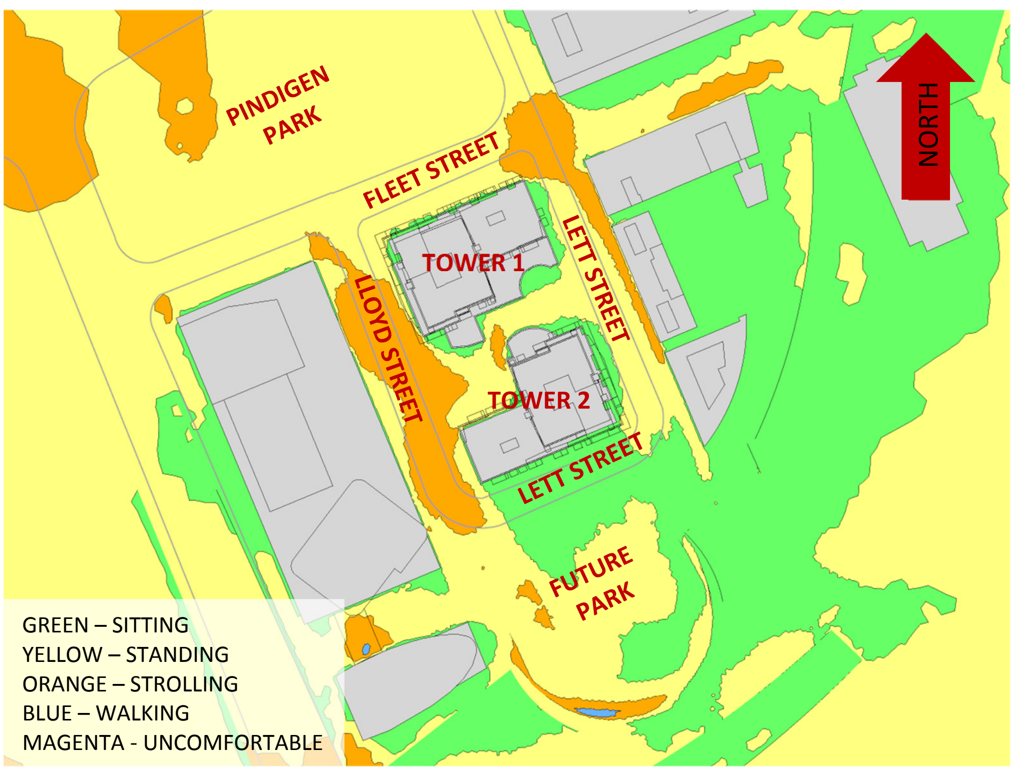

FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL

FIGURE 4A: SPRING – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

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

FIGURE 4C: AUTUMN – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

FIGURE 4D: WINTER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

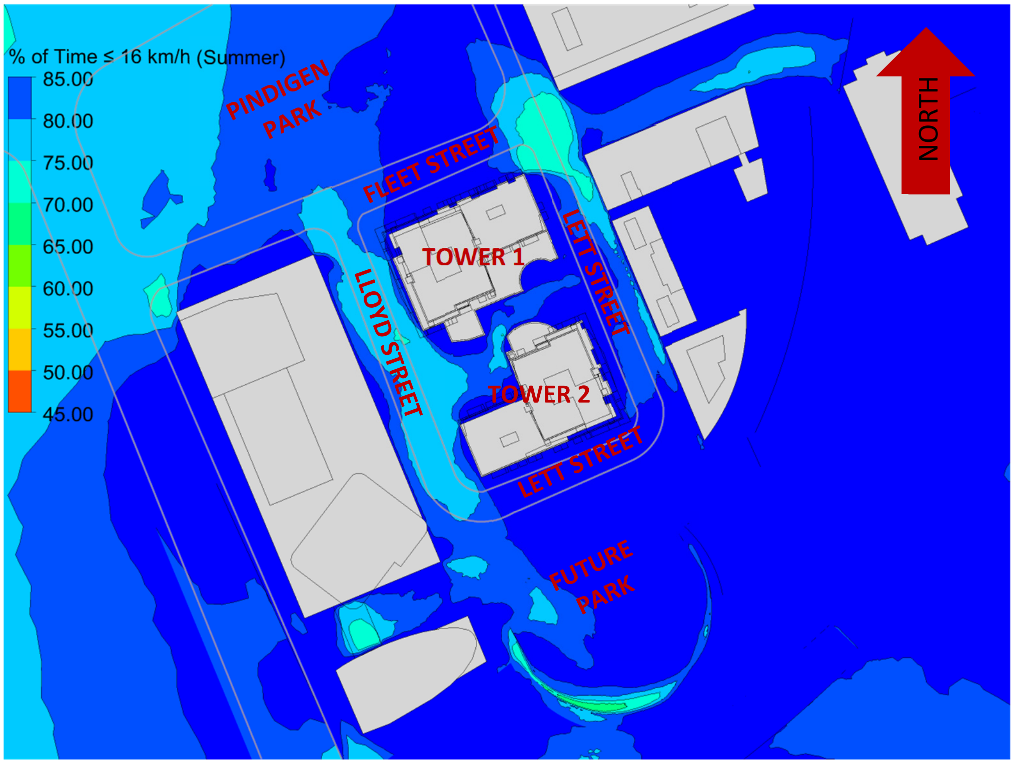

FIGURE 5A: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING (GRADE)

FIGURE 5B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)

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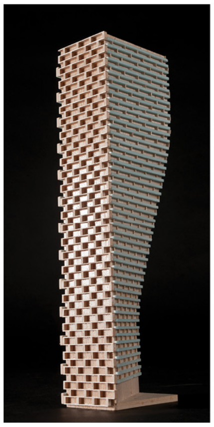

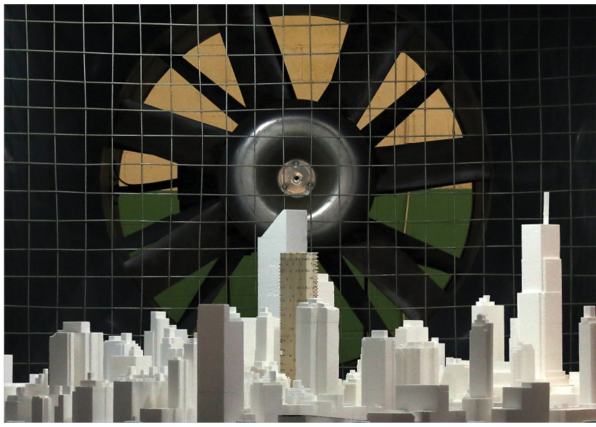

APPENDIX A

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 (° True)	Alpha (α) Value
0	0.26
49	0.25
74	0.29
103	0.25
167	0.25
197	0.25
217	0.25
237	0.23
262	0.20
282	0.21
302	0.23
324	0.25

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

Upstream Exposure Type	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].

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

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

where, I = turbulence intensity, 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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