

**PEDESTRIAN LEVEL
WIND STUDY**

211 Centrum Boulevard
Ottawa, Ontario

Report: 20-070-PLW R1



November 20, 2020

PREPARED FOR

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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 (SPA) submission for a proposed multi-building retirement residence located at 211 Centrum Boulevard 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-3D, 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, driveways, the grade-level outdoor amenity areas, and the bus stop in the immediate vicinity of the subject site are considered acceptable for the intended pedestrian uses throughout the year.
- 2) The area between the subject site and the existing Holiday Inn Express (500 Brisebois Crescent), which is situated to the north-northeast of North Block, is predicted to receive accelerated wind flow from most wind directions, including all statistically prominent directions for Ottawa. While wind comfort is predicted to be acceptable, as noted Section 5.1, the general area may also be uncomfortable during periods of strong wind activity. Of importance, the affected area resides mostly within the property line of the proposed development.
- 3) 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.



- 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.

Following the completion of the PLW study, we understand the architectural drawings for the subject site have been updated (ref. Hobin Architecture Incorporated 'Le Groupe Maurice Centrum Retirement – Issued for SPC & Zoning', dated November 20, 2020). The following is a list of changes to the subject site relevant to pedestrian wind comfort and safety:

- The 1-storey extension at the west side of the 4-storey podium serving the North and South Blocks has been relocated to the east side of the podium.
- The grade-level outdoor dining terrace at the east side of the podium has been removed.
- The small 1-storey extension at the southeast corner of the 4-storey podium, jointly serving the North and South Blocks, near the main entrance, has been removed.
- At grade, the landscaped courtyard at the west side has been slightly reduced in size.
- The underground parking level has been extended to the north of the North Block; the local topography creates an elevated surface in the general.



*Architectural Rendering of the Updated Design, Southeast Perspective
(Courtesy of Hobin Architecture Incorporated)*

Since the general massing of the updated design is similar to the previous design, which was referenced for the detailed wind comfort and safety study, the results contained within this report are representative of the updated design. Additional wind simulations are not required.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. TERMS OF REFERENCE 1

3. OBJECTIVES 2

4. METHODOLOGY..... 3

4.1 Computer-Based Context Modelling3

4.2 Wind Speed Measurements.....4

4.3 Meteorological Data Analysis4

4.4 Pedestrian Comfort and Safety Criteria – City of Ottawa6

5. RESULTS AND DISCUSSION..... 8

5.1 Wind Comfort Conditions – Grade Level.....8

5.2 Wind Comfort Conditions – Elevated Amenity Terraces10

5.3 Wind Safety10

5.4 Applicability of Results10

6. CONCLUSIONS AND RECOMMENDATIONS 11

FIGURES

APPENDICES

Appendix A – Simulation of the Atmospheric Boundary Layer



1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Le Group Maurice to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control submission for a proposed multi-building retirement residence located at 211 Centrum Boulevard 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 areas where 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 Incorporated in August 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery.

2. TERMS OF REFERENCE

The subject site is located at 211 Centrum Boulevard in Ottawa on an irregular parcel of land bounded by the Queensway to the north, Brisebois Crescent to the east, Centrum Boulevard to the south, and Place D’Orléans Drive to the west.



*Architectural Rendering, Southeast Perspective
(Courtesy of Hobin Architecture Incorporated)*

The subject site comprises two buildings with rectangular planforms at grade connected by a 4-storey podium. The North Block, of 17 storeys, is located at the north of the site, with the long axis oriented along the Queensway. The South Block, of 9 storeys, is located at the west of the site with the long axis oriented along Place D’Orléans Drive. The ground floor comprises residential space and lobby and amenity space. Levels 2 and above comprise residential units. The main



building entrance is located west of the drop off area in the subject site, near the centre of the southeast elevation of the 4-storey podium. Pedestrian walkways are located all around the site at grade. Exterior amenity courtyards are provided at grade, near the northwest, northeast and southeast corners of the podium. At the southeast corner of the North Block is an entrance that gives access to the 2 level below grade parking. A bus stop is located at the centre of the south boundary along Centrum Boulevard.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) include the 3-storey Shenkman Arts Centre (245 Centrum Boulevard) and 5-storey Holiday Inn Express (500 Brisebois Crescent) to the north-northeast clockwise to east-northeast, low-rise commercial developments clockwise to south-southeast, surface parking clockwise to south-southwest, Place d'Orléans Shopping Centre (110 Place d'Orléans Drive) clockwise to west-northwest, and Highway 174 for the remaining compass directions. The far-field surroundings (defined as an area beyond the near-field and within a 5-kilometre (km) radius of the subject site) contribute primarily suburban wind exposures from all directions, although the Ottawa River to the north and farmland to the east and west contribute slightly more open exposures.

Key areas under consideration include surrounding sidewalks, walkways, building access points, nearby transit stop, and outdoor amenity areas. 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 criteria¹. 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

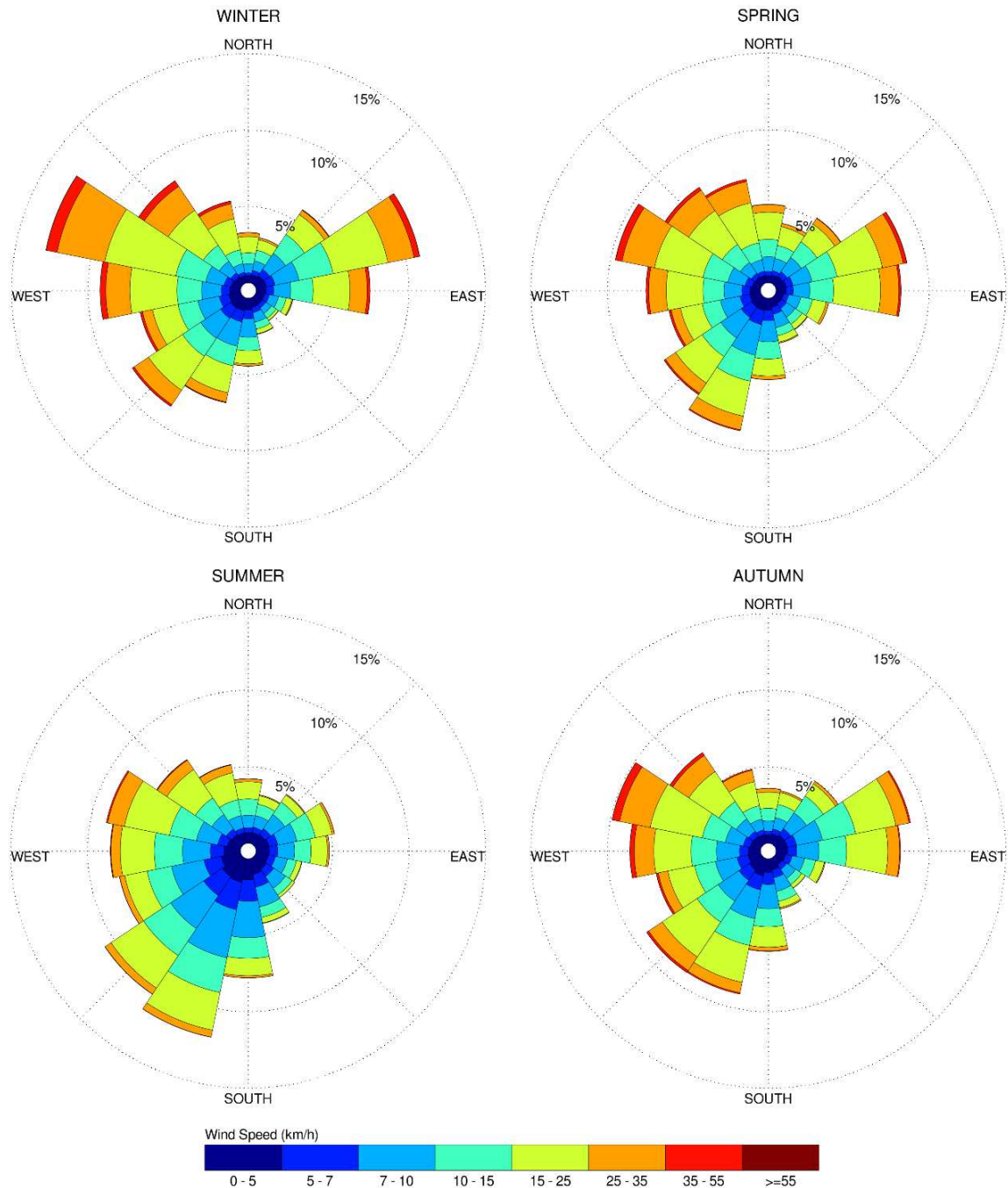
The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 820 m. Mean and peak wind speed data 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 approximately 1.5 m above local grade was 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 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
		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	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 seasonal wind conditions at grade level. 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 comfort is summarized below for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Place D’Orléans Drive: The pedestrian walkways and public sidewalks along Place D’Orléans Drive are predicted to be suitable for sitting during the summer season, transitioning to standing near the northwest corner of North Block. During the remaining three colder seasons, the sidewalks are predicted to be suitable for a mix of sitting and standing, with strolling conditions developing near the northwest and southwest corners of North Block during the coldest months of the year. These conditions are considered acceptable according to the wind comfort criteria in Section 4.4.

Centrum Boulevard: The sidewalks along Centrum Boulevard are predicted to be suitable for sitting during the summer season, becoming mostly suitable for standing during the remaining three colder seasons. These conditions are considered acceptable.

Brisebois Crescent and Holiday Inn Express: Wind conditions along the Brisebois Crescent sidewalks are predicted to be mixed throughout the year; wind speeds within the south half will be calmer than those within the north half. Specifically, the south half will be suitable for sitting during the summer, becoming suitable for standing during the remaining colder seasons. The north half will be suitable for standing during the summer, a mix of standing and strolling during the autumn season, becoming mostly suitable for strolling during the spring and winter seasons. These conditions are considered acceptable for public sidewalks and pedestrian pathways.

The area between the subject site and the existing Holiday Inn Express (500 Brisebois Crescent), which is situated to the north-northeast of North Block, is predicted to receive accelerated wind flow from most wind directions, including all statistically prominent directions for Ottawa. As such, wind conditions are predicted to be suitable for standing during the summer, strolling during the autumn, a mix of strolling and walking during the spring season, and mostly suitable for walking during the winter season. While the noted conditions are considered acceptable according to the wind comfort criteria in Section 4.4, the general area may also be uncomfortable during periods of strong wind activity. Of importance, the affected area resides mostly within the property line of the proposed development.

Drop Off & Driveway Area: The drop off and driveway area will be suitable for a sitting during the summer season, becoming suitable for a mix of sitting and standing during the remaining colder seasons, which are considered acceptable.

Northwest Amenity Area, Grade Level: During the summer season, the northwest amenity area will be suitable for sitting with an isolated region suitable for standing within the northwest corner of the space. During the remaining three colder seasons, the area is predicted to be suitable for a mix of sitting and standing. The noted conditions are considered acceptable without the need for mitigation.

Northeast and Southeast Amenity Areas, Grade Level: The two amenity areas along the east side of the subject site are predicted to be suitable for sitting throughout the year without the need for mitigation, which is acceptable.

Building Access Points and Centrum Boulevard Bus Stop: All primary and secondary access points serving the North and South Blocks, as well as the bus stop on Centrum Boulevard, are predicted to be suitable for standing or better throughout the year, which is acceptable according to the wind comfort criteria.

5.2 Wind Comfort Conditions – Elevated Amenity Terraces

Level 4 Amenity Terrace: The elevated amenity terrace at Level 5 between the North and South Blocks is predicted to be suitable for a mix of sitting and standing during the typical use period of late spring through early autumn. As illustrated in Figure 5B, the terrace will be suitable for sitting at least 75% of the time during the typical use period. It is recommended that these conditions be considered acceptable.

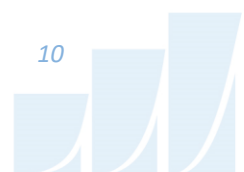
5.3 Wind Safety

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 on the elevated amenity terraces were found to experience conditions that could be considered dangerous, as defined in Section 4.4.

5.4 Applicability of Results

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 generally 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-3D. 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, driveways, the grade-level outdoor amenity areas, and the bus stop in the immediate vicinity of the subject site are considered acceptable for the intended pedestrian uses throughout the year.
- 2) The area between the subject site and the existing Holiday Inn Express, which is situated to the north-northeast of North Block, is predicted to receive accelerated wind flow from most wind directions, including all statistically prominent directions for Ottawa. While wind comfort is predicted to be acceptable, as noted Section 5.1, the general area may also be uncomfortable during periods of strong wind activity. Of importance, the affected area resides mostly within the property line of the proposed 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 were found to experience conditions that could be considered uncomfortable or dangerous.

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

Sincerely,

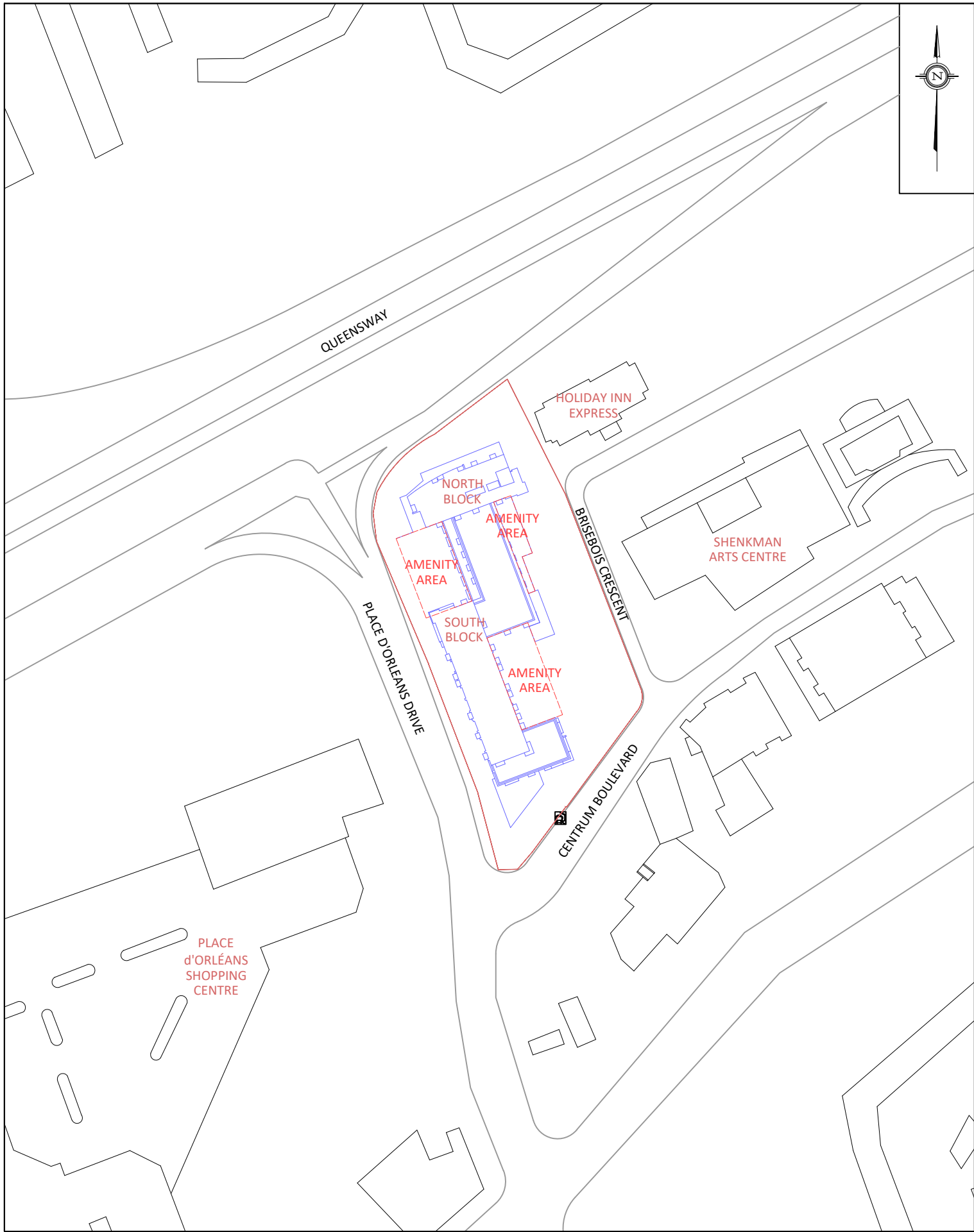
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PROJECT	211 CENTRUM BOULEVARD, OTTAWA PEDESTRIAN LEVEL WIND STUDY	
SCALE	1:2500	DRAWING NO. 20-070-PLW-1
DATE	AUGUST 25, 2020	DRAWN BY C.E.

DESCRIPTION	FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
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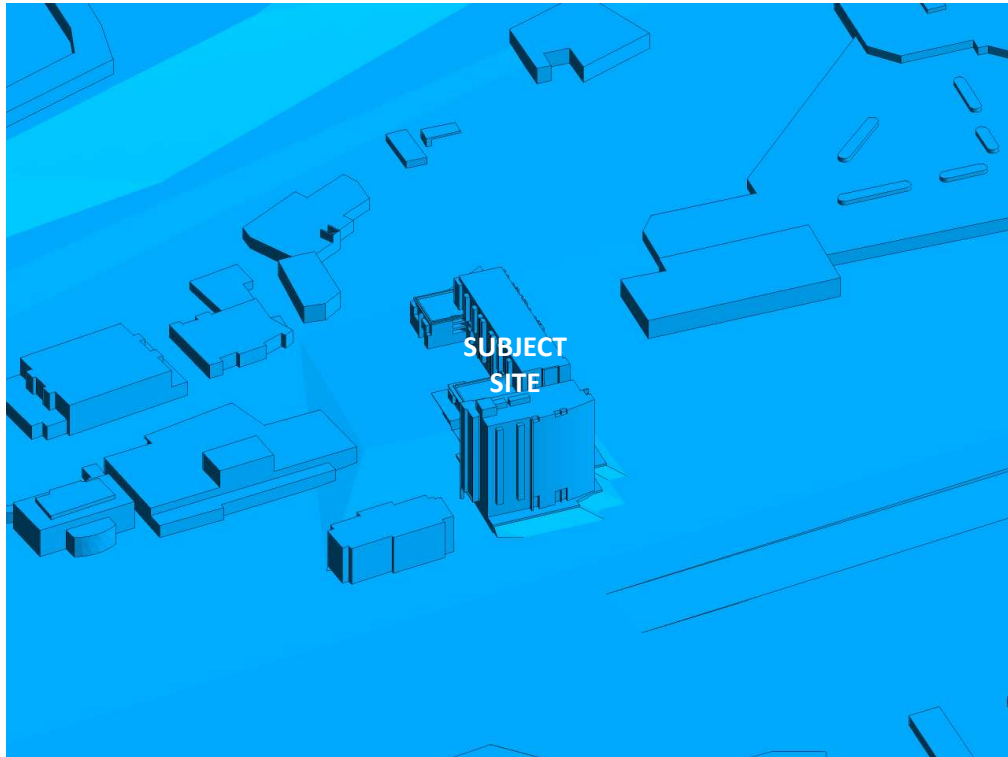


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

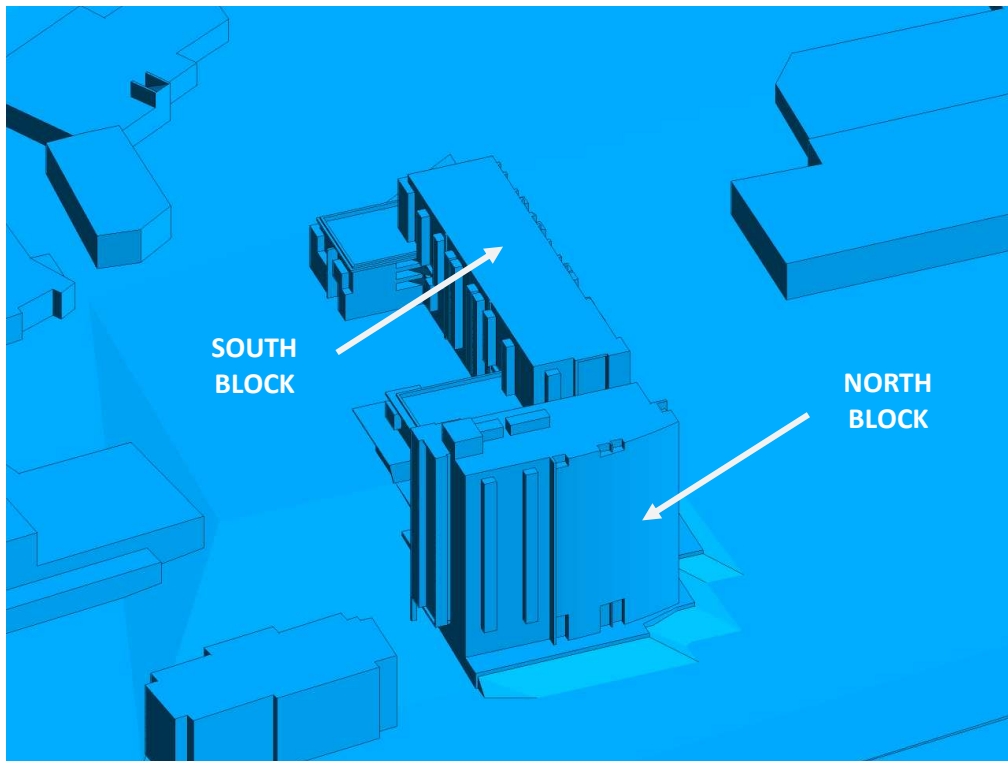


FIGURE 2B: CLOSE UP OF FIGURE 2A

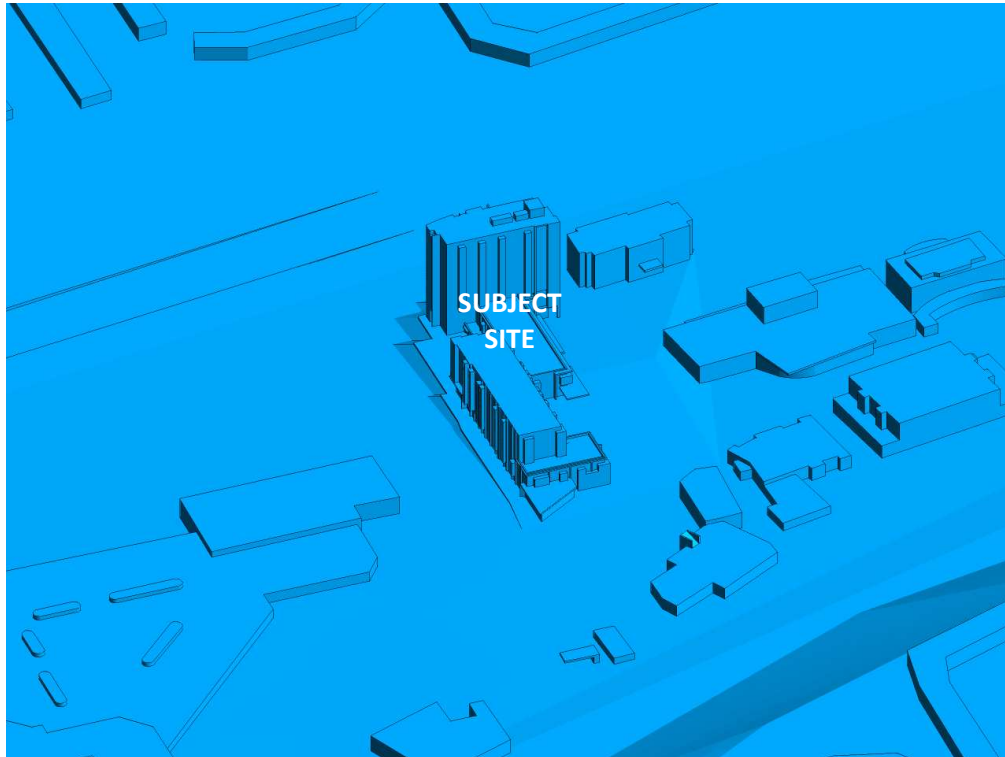


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

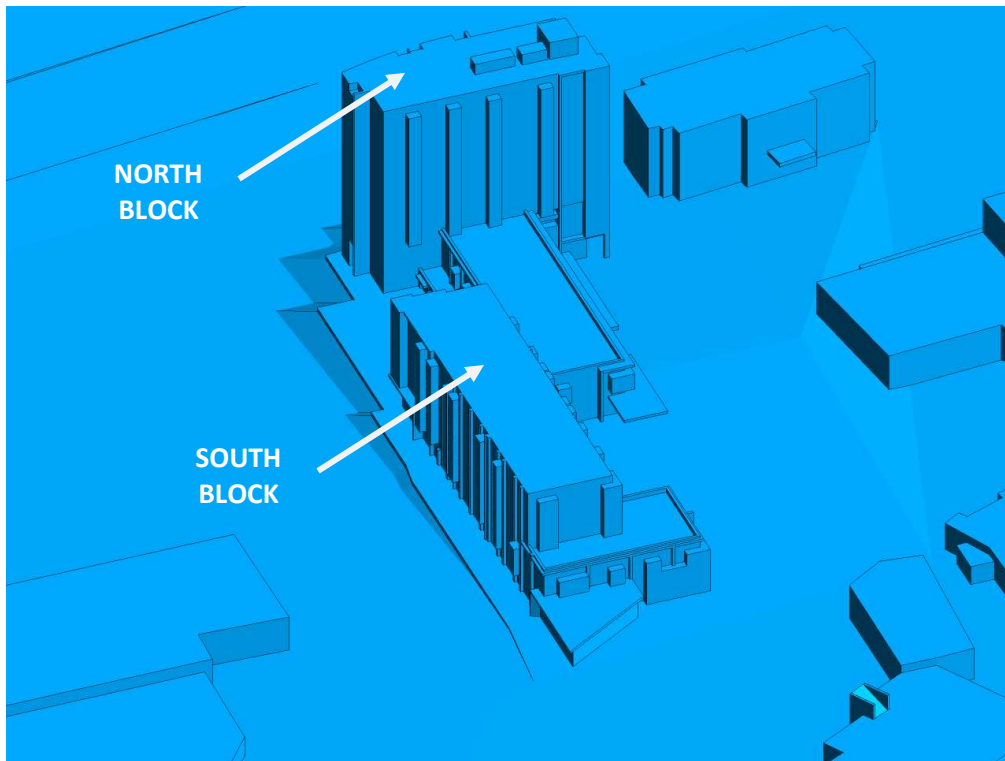


FIGURE 2D: CLOSE UP OF FIGURE 2C



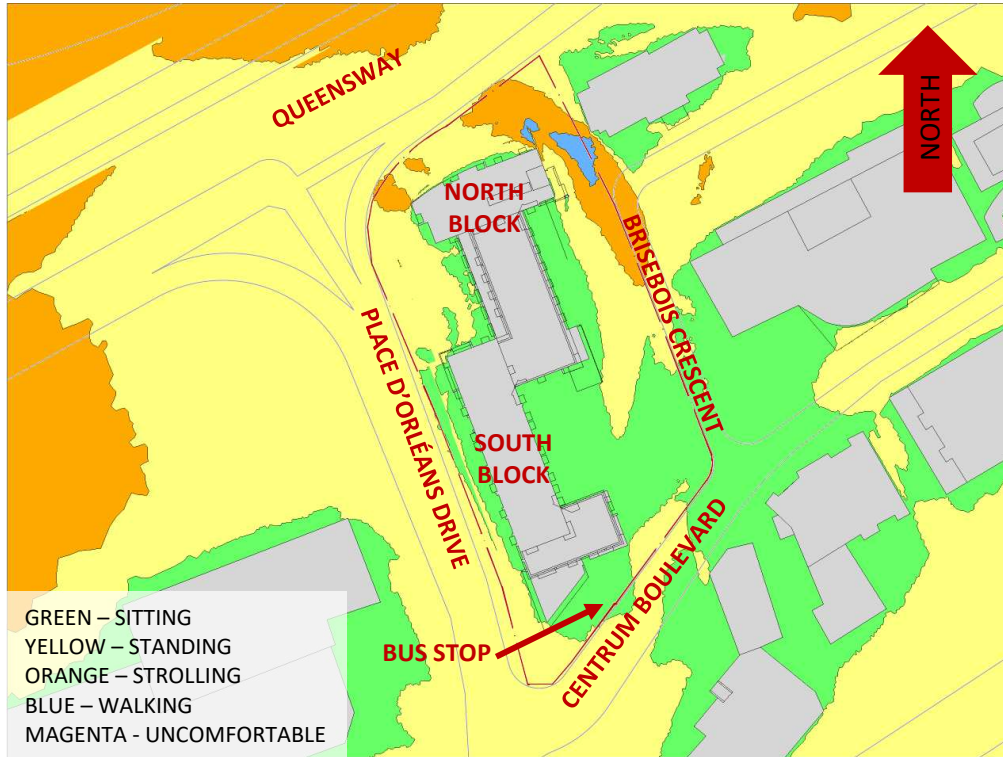


FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

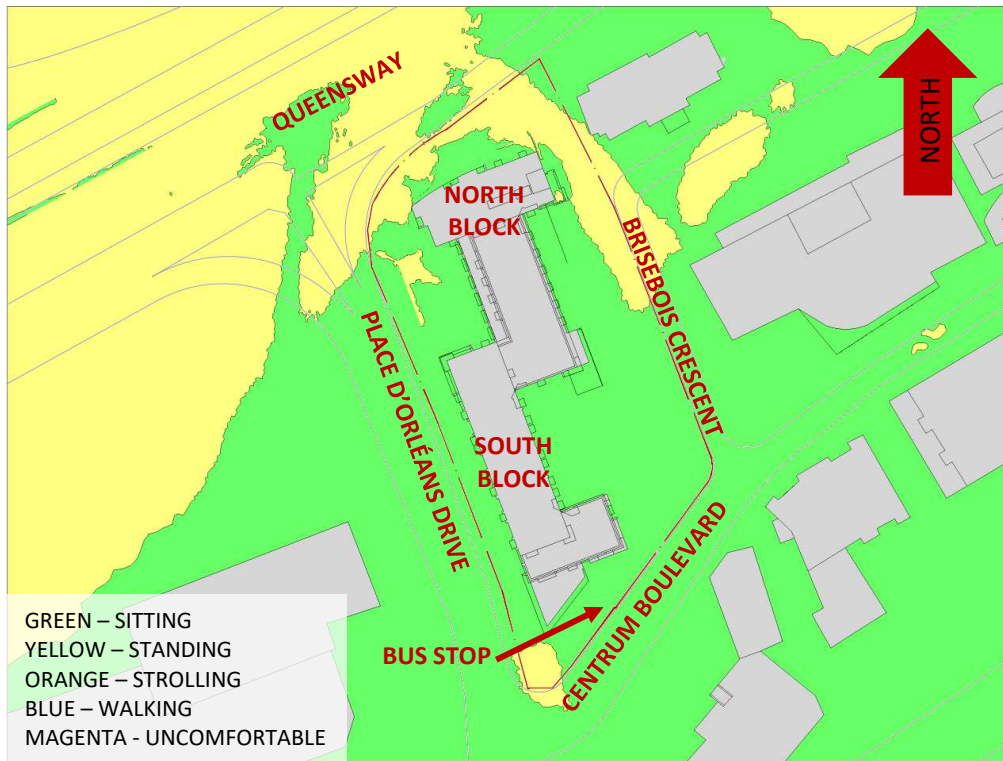


FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL



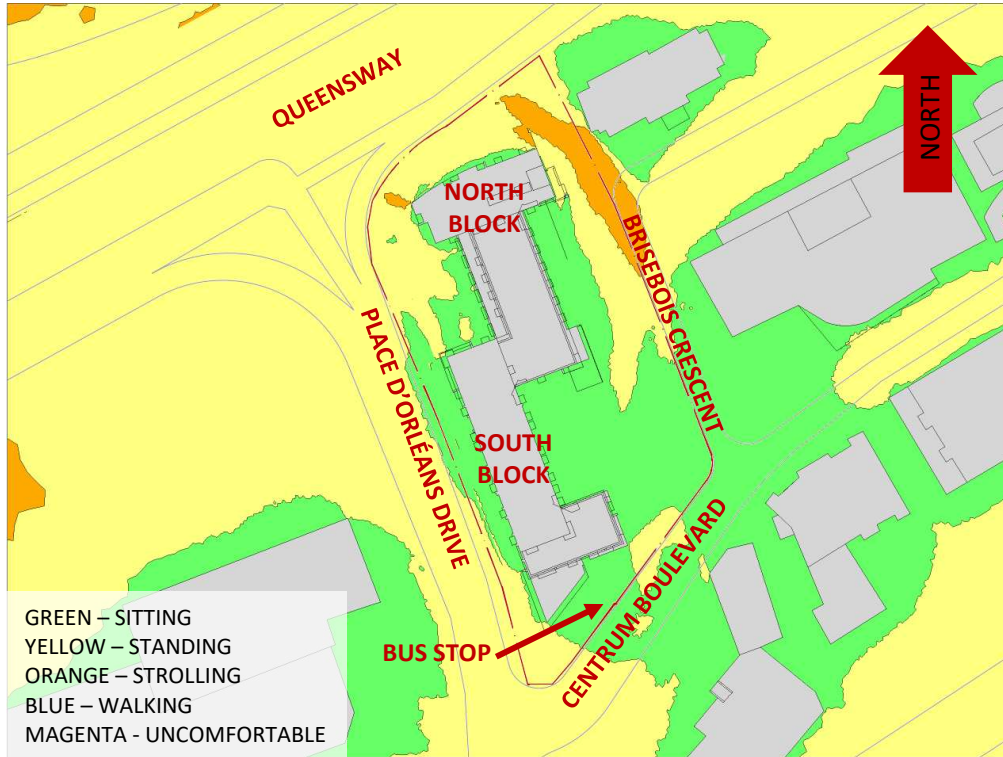


FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

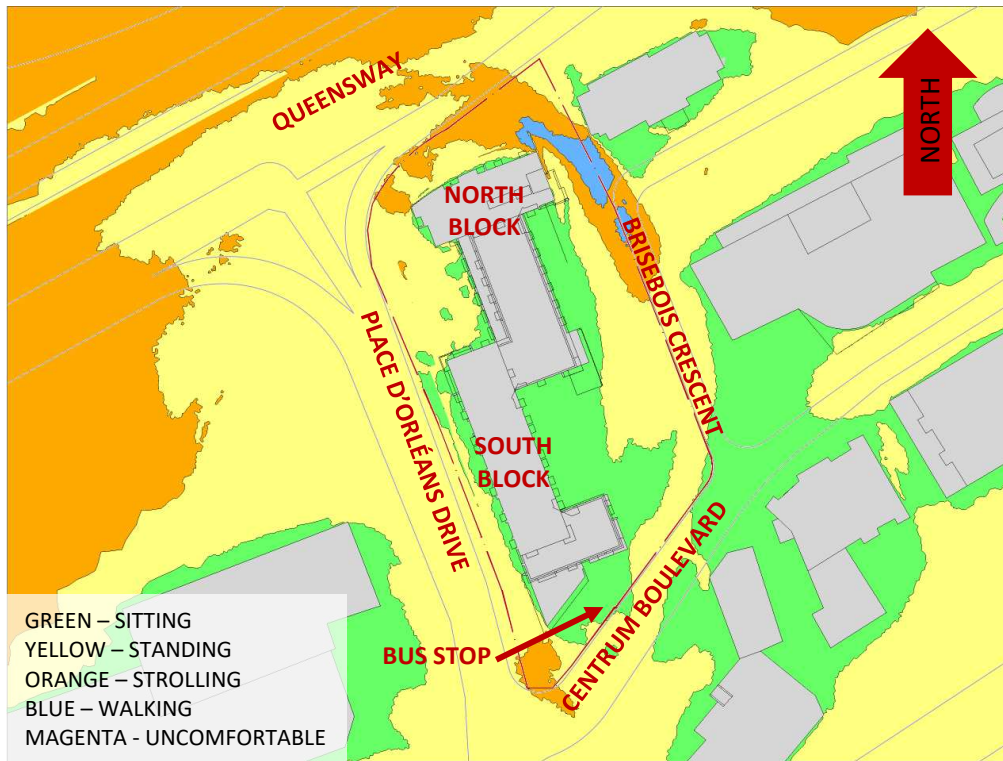


FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL



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APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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].

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

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.

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	0.20
49	0.21
74	0.23
103	0.24
167	0.23
197	0.24
217	0.23
237	0.23
262	0.23
282	0.21
301	0.20

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].

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

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

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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